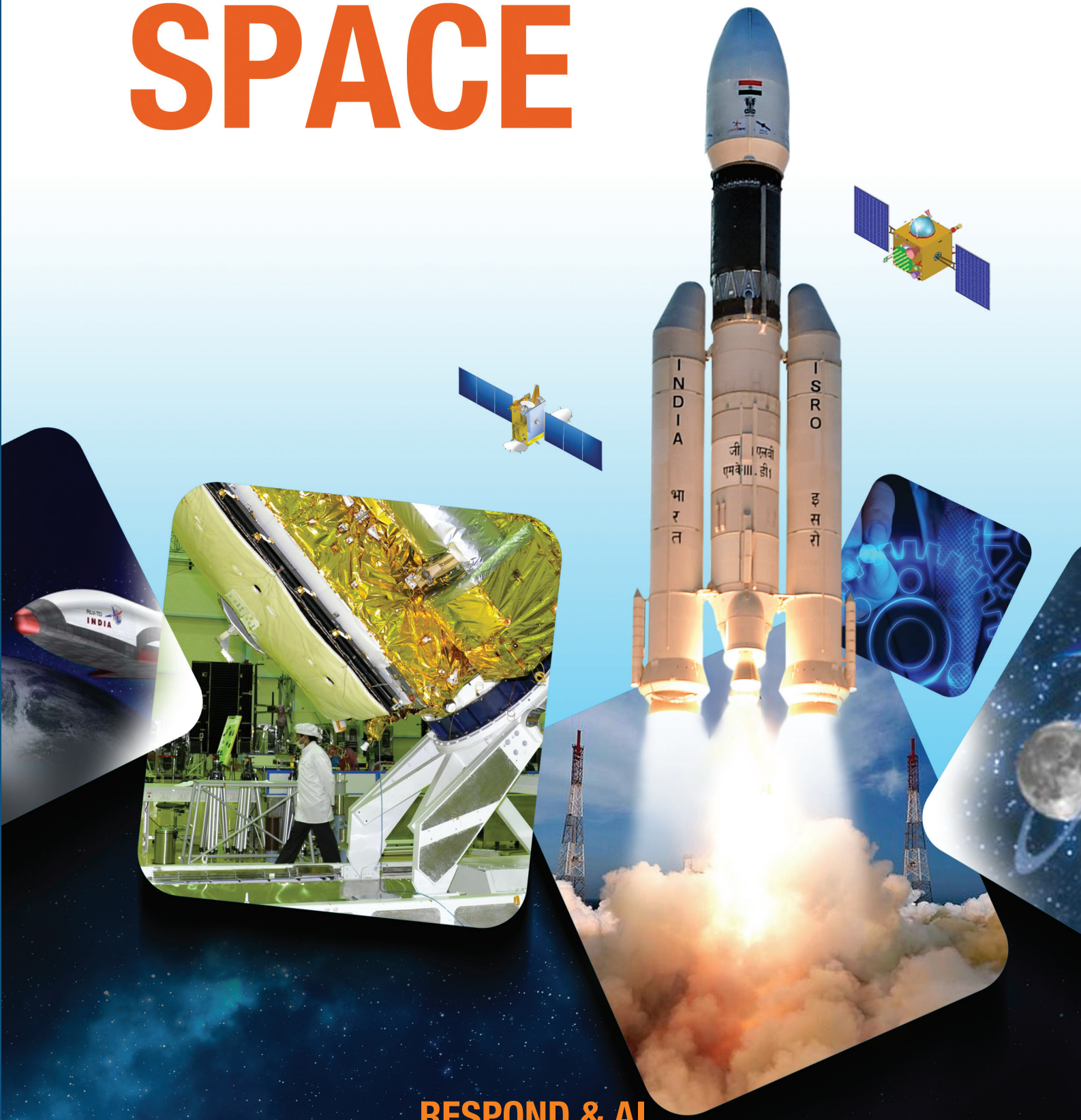
RESEARCH AREAS IN SPACE



RESPOND & AI

Capacity Building Programme Office
ISRO HQ, Bengaluru

RESEARCH AREAS IN SPACE

A Document for
Preparing
Research Project Proposals

RESPOND & AI
Capacity Building Programme Office
ISRO HQ, Bengaluru

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Technical Guidance and compilation

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MESSAGE

Right since the inception, the ISRO-Academia-Industry triad has played pivotal role in the progress of Indian Space Programme. Over the years, ISRO has had a long partnership with academia through the Sponsored Research Programme. This partnership was crucial in meeting the National demand in launch vehicle and satellite services.

Today, ISRO is venturing into new areas like advanced High Throughput Satellites, Navigation Systems, planetary exploration missions, reusable launch vehicles and the recently announced Gaganyaan Programme. In this aspect, it is essential to not only strengthen the existing interface with academia but also expand the footprint of space activities in the country.

In this regard, I am happy to note that RESPOND Office of Capacity Building Programme Office at ISRO Headquarters has brought out a comprehensive document on "Research Areas in Space' which will help the prospective researchers to prepare research proposals of mutual interest.

I hope that this will pave the way for a more fruitful partnership with the academia in the R&D activities of Indian Space Programme in the coming years.

Dated: November 7TH, 2018

(कै. शिवन / **K. Sivan**)

PREFACE

I am extremely delighted to bring out the current edition of the Research Area Document. This comprehensive document is exclusively prepared to highlight the major programmes of ISRO and the current and upcoming Research and Development requirements.

As you may be aware, ISRO is embarking upon many new areas of Science and Technology by taking up challenging technological assignments incessantly. In this important task of National Importance, ISRO is looking for wider participation and contributions from academia in a focused manner for timely accomplishments of its goals. In view of this, the concept of ISRO Academia day is brought out. The main aim behind this is to showcase the emerging research and development areas of ISRO, so that the faculty of the academic institutions can take up the research projects in the area of their specialization and expertise. A “Research Areas In Space” document has been brought out to enable the interested researchers to choose the topics.

The document is split into five major Programmes of ISRO namely Launch Vehicle, Satellite Communications Programme, Earth Observations Programme, Space Science Programme and Meteorology. The document has been compiled and worked out in a precise manner by RESPOND Team, CBPO, ISRO HQs in consultation with the different Centres of ISRO to enable Faculty/ Researchers at Academic Institutions to prepare suitable proposals of relevance to ISRO.

I wish all the best and warmly invite academia to come forward and participate in R & D programme of ISRO.

P V Venkitakrishnan
Director, Capacity Building Programme Office
ISRO Head Quarters, Bengaluru

Introduction

Sponsored Research Programme (RESPOND) under the aegis of Capacity Building Programme Office (CBPO) of ISRO is a unique initiative of the Indian Space Research Organisation to promote Research and Development activities in collaboration with Academia. The main objective of the RESPOND Programme is to establish strong links with academic institutions in the country to carry out research and developmental projects which are of relevance to space programme and hence contribute in various space related activities. Under RESPOND, financial support is provided to Academic Institutions within the country to carry out research projects in a wide range of topics in space technology, space science and space applications.

Presently, there are around 186 projects ongoing under RESPOND scheme. Projects are in the areas like rocket and satellite technology, propulsion system design and optimization, aerodynamics and heat transfer problem related to space vehicles, guidance and control for launch vehicles and spacecraft, propellant technology, ultra-light-weight structure, satellite energy systems, space electronics, space communication systems, orbital mechanics, computer sciences and new material development, remote sensing of the earth's resources: space communication, satellite geodesy image processing, satellite meteorology including weather forecasting, physics of the ionosphere and magnetosphere, meteorology, dynamics of the atmosphere, geophysics, geology, astronomy, cosmology, astrophysics; planetary and interplanetary space physics, climatology etc.

To enable faculty of Universities/Institutes to prepare suitable proposals of relevance to Space programme, a detailed list of R&D areas/sub areas/topics/problems and a brief write up have been provided about major programmes of ISRO and the same has been given in this document " Research Areas in Space". The concerned ISRO/DOS centre to be approached by the faculty/researcher is given in the brackets after areas/sub areas/topics/problems. The faculty/researcher may select a suitable topic/problem and prepare the proposal and submit to the concerned centre/unit for consideration. The proposals may be submitted to the Director of concerned centre as given in **Annexure 1.**

Hope this document highlighting brief outline and possible set of topics for various research themes would help the academia to prepare research proposals under RESPOND programme of ISRO. The proposal submission format and other necessary details are available in the ISRO web site under the link www.isro.gov.in/research-and-academia-interface/submission-of-research-proposal.

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1.0 Launch Vehicle Programme

A	Area	Aerospace Engineering (VSSC)
A1	Sub Area	Aerodynamics and Aero Thermal Engineering (VSSC)
A1.1	**Estimation of gaseous radiation during interplanetary missions (VSSC)** Planetary entry missions involve penetration of its atmosphere at very high entry velocities. The external surface of entry body is exposed to extreme heating rates owing to dissipation of its large kinetic energy. Strong shocks are formed ahead of the entering body increasing the internal energy of entrapped gas. Gas within the shock layer attains very high temperature levels leading to thermochemical non-equilibrium. Gaseous radiation becomes significant in such conditions. Both equilibrium and non-equilibrium air radiation have to be modeled for estimation of radiative heating. Number densities of various chemical species, translational, rotational and vibrational temperatures of heavy particles and electrons are to be evaluated for modeling emission and absorption characteristics of air under these conditions. Available database on radiative properties incorporating spectral absorption and emission behavior of gases at high temperature are to be used. The proposed study should focus on establishing a methodology for evaluation of gas radiation for planetary entries. Comparison of estimated gas radiation levels with available measurements in literature is essential for validation.	
A1.2	**Flow field over a double delta wing configuration (VSSC)** Heat flux data for the double delta configuration is important, especially for regions of shock-shock interaction, leeward region flow, base flow, fuselage wing interaction for accurate distribution of TPS and for mass optimization. It is proposed that experimental heat flux measurements on the above region on ISRO's RLV may be attempted at flow enthalpies of about 2 MJ.kg, M = 6.6, To = 1700 – 1800 K. Diagnostic shall be (a) heat flux (b) liquid crystal thermography/IR thermography (c) Flow visualization. The generated data shall be compared with the predictions, and suggestions for improving the prediction may also be attempted.	
A1.3	**Influence of back pressure fluctuations on the unsteady transonic shock wave boundary layer interaction (VSSC)** A study of shockwave boundary layer interaction in a constant area duct is proposed to understand the effect of back pressure rise on the unstart of typical ramjet/scramjet air intakes. One important factor which affect the large scale motion of the shock and Shock wave/boundary layer interaction (SWBLI) is the downstream pressure perturbations. Hence a proposal is invited to understand the response of shock wave and SWBLI to downstream perturbations to mitigate its ill effects.	
A1.4	**Supersonic retro propulsion (VSSC)** In order to reduce the peak dynamic pressure on the stage during its recovery or to reduce the speed of entry modules during planetary entry, supersonic retro propulsion is an attractive option. This is especially true for entry in planetary atmospheres like that of Mars, which	

	has low-density and does not provide adequate drag to slow down the entry vehicle before touch-down. It has very practical applications in stage recovery where the high dynamic pressure of the recoverable stage is reduced using the impulse provided by propulsion in the supersonic / hypersonic regime of flight. The rocket motor exhaust exhausts into the opposing high speed free stream. The aim of optimal supersonic retro propulsion is to maximize the axial force exploiting the interaction between propulsion and aerodynamics and also to assess the aerodynamic and thermal impact on the parent stage / vehicle. Proposals are solicited for design, analysis and testing of deceleration system with Supersonic Retro Propulsion with single-jet and multi-jets (clustered configurations) to optimize the axial force for stage recovery and planetary entry conditions.
A1.5	**Simulation and studies of soil mechanics for understanding supersonic jet impingement and subsequent dust generation for planetary missions (VSSC)** The search for extra-terrestrial life is being explored on a larger scale. This involves visiting other celestial bodies and exploring for signs of life. Generally, a propulsion system would be used to carry landing on the planed/meteoroids. Understanding the interaction of jet exhaust with the soil during the terminal descent phase is critical for nominal system performance. Proper physics modelling of soil and mechanics of soil-jet interaction, soil particulate formation and dust propagation form major parts of such a study. From this project it is expected that the capabilities would be developed for understanding and modeling of soil erosion and dust particle generation for future interplanetary missions to Moon, Mars, Titan and Venus. This could be in the form of a stand-alone code or be a feature addition to the current framework of PARAS-3D.
A1.6	**Development of an engineering procedure to account for the ground proximity effect on Aerodynamics for the small aspect ratio wing body configuration using CFD database (VSSC)** The aerodynamic characteristic of the wing body configuration is influenced by the ground proximity effect. The ground proximity effect changes the aerodynamic lift, moment and drag coefficients of the wing body configuration. Therefore, it is essential to characteristic the vehicle in the presence of ground and also the associated aerodynamic loads has to be considered for the vehicle design. Ground proximity effect is measurable, when the height is below the one wing span of the vehicle. In general, the ground proximity effect increase the lift-curve slope, decrease the drag due to reduction in the induced drag, and increase or decrease the pitching moment of the wing-body configurations. Nevertheless, the above ground effect is a function of the given configuration and may increase/ or decrease the aerodynamic coefficients. Hence, the ground effect is highly configuration dependent and it has to characterised using wind tunnel testing or CFD simulations with appropriate wall boundary conditions. A CFD based database code has to be developed to account for the ground proximity effect for various angle of attack and height from the ground. The basic coefficients can be given us input. The code has to handle the re-entry type of wing-body configuration with small aspect ratio, blunt swept double delta wing platform and vertical tail.

A2	Sub Area	Aerodynamic Design (VSSC)
A2.1	**Scramjet Experimental Vehicle (SEV) (VSSC)** Towards long duration demonstration of powered hypersonic flight, ISRO is proposing liquid fuel Isrosene (similar to JP-7) powered scramjet flight vehicle accelerating from Mach 6 to Mach 7. This project envisages demonstration of supersonic combustion on a simple model scramjet at an inlet Mach number of 2, with either liquid kerosene droplet injection / vapour injection with the use of struts. Apart from conventional pressure and heat flux measurements, optical diagnostics of H20 and OH are preferable. Also, measurement of Thrust for the model combustor, estimation of skin friction in presence of combustion is also the part of the project.	
A2.2	**Super sonic parachute design (VSSC)** For payload and stage recovery missions, including planetary entry vehicles, providing deceleration in the supersonic and hypersonic regimes is very important. In planets with low density atmospheres, unless adequate deceleration is provided at high speeds, the touch down speeds can not be reduced to desired safe levels. Similarly, stage recovery missions lead to very high dynamic pressures at high Mach numbers, unless deceleration is provided using either a drag device or propulsion. Often, entry modules become dynamically unstable at transonic Mach numbers. Parachutes are efficient drag decelerators because of their low mass and high drag. Also, supersonic parachutes are used to provide static and dynamic stability to modules descenting at high speeds. However, the design of supersonic parachutes is challenging. Proposals are solicited to design, analyse and test supersonic parachutes which can work at transonic, high supersonic, and if possible, hypersonic Mach numbers. The proposals are solicited in the areas of aerodynamic, flight dynamic, structural and thermal Multi-Disciplinary Design Analysis & Optimization design and testing.	
A2.3	**Inflatable aerodynamic decelerator design, analysis fabrication and flight testing (VSSC)** Inflatable Aerodynamic Decelerators (IAD) are promising for payload recovery, planetary entry and other missions. It enables substantial reduction in peak dynamic pressure, heat flux and heat load due to very low ballistic coefficient with minimal structural mass for the aerodynamic decelerator. The design of these decelerators has multiple challenges, namely optimal external configuration design, trailing distance, structural design, flexible thermal protection system design, inflation system design, etc. Analysis challenges include aero-thermo-elastic analysis of highly deformable structures, dynamic stability analysis, multi-body dynamics, etc. Fabrication methodologies as well as testing methodologies of various inflatable aerodynamic decelerator components, including high pressure toroids or multi-chamber inflatable structures, their leak proofing, inflation system design, structural and environment testing, wind tunnel testing etc. also need to be developed. Researchers are encouraged to take up Multi-disciplinary analysis & design optimization and testing studies for IAD.	

A2.4	**Airbags for impact attenuation (VSSC)** During the recovery of space modules and launch vehicle stages on land or on water, it is essential to attenuate the impact. Otherwise, the impact loads will be transferred to the payload, structure, instrumentation or crew in the vehicle. Often Air-bags are used for this purpose. Proposals are invited for design, analysis and testing of air-bags or any other impact attenuation devices for use in ground / water landing recovery missions. Following candidate areas can be addressed in the proposals: structural design, ground impact analysis / testing, water impact simulations / testing, dynamics during and after impact, inflation system design, energy dissipation analysis during impact, packing configuration, etc.
A2.5	**Intake design for Scramjet Experimental Vehicle (SEV) (VSSC)** Intake plays a very important role in capturing the incoming air flow efficiently and directing it towards the combustion chamber. The intake efficiency can be assessed based on pressure recovery, mass capture and kinetic energy efficiency. Intakes are of two types namely outward and inward turning intakes based on the complete external, internal or mixed compressions. Currently, SEV intake is outward turning intake with three ramp system followed by two successive expansion corners. To turn the flow into the engine, a shock generates at the inlet's cowl lip and impinges on the engine floor resulting into separation bubble and total pressure loss. The heat generated due to combustion depends on the quality of the approach flow. The kinetic energy efficiency and the total pressure recovery are two important parameters that dictate the flow quality. During the endothermic reaction process, the energy is drawn from the kinetic and potential energy of the incoming flow to form products and which in turn generate heat during exothermic recombination process. The mass flow rate through the geometric throat of the diffuser is directly proportional to total pressure and inversely proportional to square root of total temperature. So the higher pressure recovery will allow higher mass flow rate through the geometric throat that will result into higher change in momentum as well as thrust after the heat addition. Moreover, when the heat is added to the supersonic flow the Mach number as well as total pressure decrease while the total temperature increases that may result into thermal chocking at the aerodynamic throat in the combustor if excess heat is added. So if the pressure recovery is sufficiently high, the adverse effect of increase in total temperature and decrease in total pressure after heat addition can be reduced to avoid thermal chocking. The intake is mainly designed to provide the flow conditions required for the self-ignition of fuel air mixture. In addition, the intake is also responsible for issuing high quality flow into the combustion for adequate heat production that result in the large increase in static pressure as well as the internal energy of the flow required for generating large kinetic energy and flow velocity through nozzle expansion. This will lead to high thrust owing to large change in momentum. The ignition delay is proportional to temperature. The self ignition temperature of kerosene which is used as fuel is around 600k at STP. The ignition delay at 600k temperature will demand very high combustor length that leads to weight increase. So care should be

	taken through proper intake design to ensure sufficient reduction in ignition delay to reduce the combustor length and hence the weight. The intake cowl configuration design should be carried out in concurrence with the expansion corners. The cowl drooping may be necessary for incorporating two subsequent compression to reduce the shock strength and hence the total pressure losses. The cowl lip angles and expansion corners should be properly arranged to have the cowl shocks impinge on the expansion corners to reduce the adverse effect of shock reflections. An intake can be designed at one particular hypersonic Mach number to have the shocks at the lip to avoid the spillage and divert the maximum possible mass flow in to the engine at a given altitude. If the Mach number varies from Mach 6.0 to 7.0 during the SEV operation and the intake is designed at Mach number 6.5, the intake remains under-critical at Mach 6.0 and super-critical at Mach 7.0. During the under-critical operation the flow spillage results into spillage drag with the reduction in Mass flow entering into the engine, while in the case of super-critical intake, the ramp shocks enter inside the inlet creating a possibility of flow separation due to shock and incoming boundary layer interaction. This will result into severe total pressure loss and higher unsteady pressure levels. The disadvantages in the off design Mach numbers should be addressed in the intake design. The optimal intake design should cater to all these above aspects The constraints: Cowl height varies between 0.5 to 0.6m.
A2.6	**Isolator design (VSSC)** The isolator isolates the combustor and the intake to avoid the upstream influence of the consequences of the heat addition in the combustor. During the exothermic process the heat addition in the combustor results in large pressure rise. The effect of high pressure rise is felt upstream through the boundary layers in all sides. Sometimes this may lead to boundary layer separation which may propagate upstream even up to inlet causing changes in the inlet conditions. To avoid this situation an isolator is provided to separate intake and combustor by sufficient distance such as to avoid the upstream influence on the intake completely. But in that process the isolator length should be optimized to reduce the weight penalty and isolator drag. Selection of isolator length also depends on the shock train spreading along the isolator with the gradual reduction in successive shocks' strength to almost negligible to provide uniform flow at the entrance of the combustor. The additional pressure and temperature rise owing to shock train should be accounted for the combustor entry condition. The isolator length depends on the ratio of combustor pressure and intake's internal pressure. It also depends on boundary layer parameters. Higher the boundary layer thickness in the combustor, higher should be the length of the isolator. The only physical parameter it depends on is combustor height. The proposal should bring out a methodology for isolator length determination which suites to our configuration. The constraints are : combustor height 100mm, pressure rise between 2 to 4 bar, Mach No to combustor entry between 1.75 to 2.0, design parameter is isolator length.

A3	Sub Area	Development of Tools (VSSC)
A3.1	**Development of a flow through balance (VSSC)**	

This project envisages development of a flow through balance towards measurement of six component forces / moments in a supersonic / hypersonic wind tunnel with jet passing through the core. The balance shall allow a clear diameter of 20mm for passing the jets and the outer diameter shall be restricted to 45mm. The balance shall be so designed such that the jet reaction is not passed to the metric portion. For balance design, following loads may be considered.

Outer Diameter of the Balance = 45mm (preferably)
Flow passage = 20mm
No of components = 6
Balance Ranges
Axial Force : 100 kg
Side Force : 200 kg
Normal Force : 100 kg
Rolling Moment : 150 kg-cm
Pitching Moment : 600 kg-cm
Yawing Moment : 450 kg-cm
Medium : Dry air at maximum temperature of 60 deg C
Factor of Safety : >2.0
Dynamic loads : Balance will be used in NAL 4' x 4' tunnel, hence subjected to start / stop loads. Factor for dynamic loads shall be taken as per practice.
Mach No: : 0.8 to 4
Inside air pressure : 150 bar (max)
FS sensitivity : 0.5mV/V to 1mV/V
Excitation : 5 V DC
Accuracy : ±0.25% FS
Interaction : <5% of FS
Natural Frequency : Along with a model of ~15 kg weight, the balance + model first mode in both pitch and yaw plane should be around 25 Hz
Model end fixity : Cylinder (TBD)
Earth end fixity.

A3.2	**Development of two stage light gas gun for simulating hypervelocity impacts (VSSC)**	

Space debris consists of all defunct objects in orbit around earth. These objects are real threat for all space related activities especially in low earth orbit.

Two stage light gas gun is used to simulate the hypervelocity impacts in ground. An analytical tool need to be developed, that can simulate the gas dynamics of a two stage light gas gun for different gas media considering the movement of piston and projectile for estimating the mass and velocity achieved by the projectile for given loading conditions. Development of an analytical tool to simulate the hydrodynamic behavior of solids when subjected to hypervelocity impacts.

A3.3	**Development of high temperature Fiber Bragg grating sensors (VSSC)** During the thermo-structural testing of hot structures, high temperature strain gauges (electronic gauges) are used for strain measurement. Of the late, Fiber Bragg grating (FBG) sensors, an optical based contact type measurement system for strain and temperature is proven to be reliable with specific advantages over electronic strain gauges. FBG sensors that can withstand temperatures up to 800°C need to be developed and characterized for utilization during thermo-structural testing.
A3.4	**Development of robust algorithm for CFD simulation of supersonic and hypersonic flows around complex geometries on unstructured meshes (VSSC)** Supersonic and hypersonic flows around complex geometries of launch vehicles and re-entry vehicles are of interest to VSSC as it forms an important part of characterization of launch vehicles. An unstructured finite volume 3D RANS solver is under development in VSSC. This solver has popular upwind scheme such as AUSM, Roe etc. with SA and SST turbulence models. Explicit as well as implicit time integration schemes are available. Currently, some issues are observed in convergence of supersonic and hypersonic flows while simulating flows at higher altitudes with low pressure and density. As part of this project, a robust algorithm is to be developed to simulate supersonic and hypersonic flows in particular, that can be implemented in the in-house finite volume solver. The algorithm should be demonstrated on an unstructured grid finite volume 3D RANS solver that is either open-source or developed by the Principal Investigator. Convergence of the simulations using this algorithm should be shown on a generic launch vehicle geometry for various free-stream conditions including those with low pressure and density (higher altitudes). The algorithm should be able to work with upwind schemes such as AUSM, Roe etc. and popular turbulence models like SA and SST in both explicit and implicit time integration. Details of the algorithm can range from changing the values of closure coefficients in the turbulence model, update in the flux difference splitting schemes to development of a separate module that modifies the cell updates based on certain criterion. The project can be divided in two parts: 1. Algorithm for supersonic flows $2.0 < M \leq 4.0$ and 2. Algorithm for hypersonic flows $4.0 < M \leq 8.0$. Separate algorithm can be developed for these two or one algorithm can be developed that suites both these regimes.
A3.5	**Adjoint based grid adaptation algorithm (VSSC)** The solution-adaptive mesh refinement feature allows the user to refine and/or coarsen grid based on geometric and numerical solution data. The unstructured data format allows incorporating solution-adaptive refinement for better resolution. The main issue in the design of the refinement algorithm is to minimize the reduction in grid quality of the adapted mesh, since high quality meshes are often desired for numerical reasons. The boundary layer transition prediction methods require well resolved boundary layer profiles including accurate higher order derivatives and inflection points. The properties of the boundary layer are not known before the solution is computed. This makes grid adaptation uniquely suited to ensuring that the first cell height and the outer portions of

	the boundary layer are properly resolved. Using a rigorous mathematical approach to automate the grid resolution required within the boundary layer would have a dramatic impact on complex design and analysis applications. Recent trend is towards adjoint based unstructured grid adaptation. The basic idea of the adjoint-based adaptation method is to construct an adaptive sensor from a more robust and accurate error estimation. It is seen that the adjoint solutions provide a very powerful approach to compute output error estimation as well as to systematically adapt grids to reduce spacial discretization errors. In adjoint-based adaptation there is a significant reduction in unnecessary grid points compared to the feature-based adaptation in both 2D and 3D flows. The focus of the work should be towards a feature/ adjoint based grid refinement algorithm which can operate in all types of flow regime (subsonic, transonic till hypersonic flows). The algorithm should resolve the flow features like shocks, waves and vortices with relative ease and should be automated with minimal human intervention. The grid adaptation logic is to be designed in such a way that the cell quality should not deteriorate beyond the baseline grid.
A3.6	**Lattice-Boltzmann methods (VSSC)** In recent years, the lattice Boltzmann (LB) method has been developed as an alternative method of Computational Fluid Dynamics (CFD). This method originates from kinetic theory and has several advantages in modeling fluid flows in complex geometries and multiphase flows. In addition, the explicit and local interaction makes it amenable for parallel realizations in large scale simulations. The utilization of lattice-Boltzmann has been focused on incompressible flow since the deviations of the many lattice-Boltzmann model are proportional to the square of Mach numbers. The effort to recover the Navier-Stokes equations of compressible flow has become successful for flows with medium Mach numbers near one using the Hermite polynomials as the expansion basis. In the early development the equilibrium distribution function is chosen to be a small-Mach number expansion containing a few coefficients. This approach has achieved great success for the continuity and momentum equations. The effort of recovering the energy equation has met some difficulties due to numerical instability. There are some models that aim to simulate Euler and Navier-Stokes equations and are recovered by the finite difference LB method. The focus of the work would be towards development of a parallel and efficient algorithm for simulating single-phase, multiphase fluid flows for supersonic flows (M > 1.0) with finite Knudson Number.
A3.7	**Laminar to turbulent flow transition- modeling and implementation (VSSC)** Majority of the flows encountered in regular aerospace problems are turbulent in nature. The understanding of how a fluid flow develops 'turbulent' properties is not fully understood. The flow transition from laminar to turbulent on reentry bodies like Reusable Launch Vehicle (RLV), Crew Modules etc. is required for accurate prediction of aerodynamic coefficient as well as heat flux distribution. The aim of this work is to develop the better models to be incorporated in 3D unstructured grid Finite Volume based CFD solver.

A3.8	**Turbulence chemistry interaction studies (VSSC)** The turbulent combustion is an interdisciplinary and broad topic. It combines turbulent flow described by the fluid dynamics equations, and complex chemical kinetics. Turbulence enhances mixing of reactants; on the other hand, the chemical reaction involving temperature rise due to heat addition enhances the turbulence levels of the flow itself. Therefore, aside of mass and heat transfer, the coupling between turbulence and chemistry plays a crucial role in turbulent reacting flows. In order to deal with the problem of turbulent reactive flow, one has to solve the system of closed equation of motion, species transport and energy conservation. The key difficulty in mathematical modeling of turbulent combustion is the source term in the species transport equation. The reaction is based on the Arrhunious law which is highly non-linear, and it is not easy to express it as a function of mean values. Expanding the mean reaction rate as Taylor series of the temperature fluctuation leads to various difficulties and is not commonly used. Therefore existing models are based on physical analysis, comparing chemical and turbulent time scales, and most of them classified as one point statistics, geometrical analysis or turbulence mixing approach. Assumed probability density function, Steady laminar flamelet, Eddy dissipation concept and partially stirred reactor model are being used in RANS to bring out the effect of turbulence chemistry interaction. Assessment of the turbulent chemistry interaction can be made by using commercially available software like Fluent or CFD++. Or separate module can be developed and incorporated in open source CFD softwares like openfoam or SU2 or in house CFD code like PARAS.
A4	**Sub Area**	**Trajectroy Design (VSSC)**
A4.1	**Development of analytical tool for low thrust interplanetary mission trajectories (VSSC)** Spacecraft trajectories are obtained from the integration of the spacecraft's equations of motions, which contain terms for the external forces that are acting on the spacecraft and for the thrust force. The convergence behavior of trajectory optimization methods depends on an adequate initial guess of the solution, which is often hard to find. An efficient analytical tool can provide with good initial approximation which can reduce exhaustive numerical computation.	
A4.2	**Re-entry trajectory design and analysis of two closely following bodies with a possibility of a break ups (VSSC)** Re-entry trajectory design is complex as large amount of heat has to be dissipated and structural integrity of the body has to be ensured. Design becomes challenging when two bodies closely follow each other. This typically occurs in one of the missions where crew module and cryostage enters the Earth's atmosphere and are in close vicinity. In this TDP, possibility of cryostage breakup during the re-entry is to be analysed. Number of pieces during the break-up are to be evaluated based upon detailed structural analysis of the cryo stage components. The survivability of these pieces and the effect of impact of these pieces on the ongoing crew module is to be assessed.	

B	Area	Propulsion (LPSC/ VSSC/ SDSC-SHAR)
B1	Sub Area	Solid Propulsion (VSSC)
B1.1	**Study on interaction of fluid-structure and resulting pressure and thrust oscillations in segmented solid motors (VSSC)** The thrust oscillations resulting from the chamber pressure oscillations in large solid boosters of launch vehicles is a perennial problem. In solid motors there are several reasons for pressure oscillations. The oscillations resulting from the three dimensional and uneven nature of the propellant grain surfaces (paretal oscillations), oscillations due to the burn rate variations and resulting combustion instability, the pressure fluctuations arising from the vortex formation due to the protruding inhibitions between the segments are some of the major reasons. Among them, the third one is the most severe one causing the largest amplitudes in pressure fluctuations. These fluctuations in pressures may be amplified several times in thrust. When the solid motors are used in paired mode (like S200 motors GSLV Mk III) the thrust oscillations pause issues in controllability also. Hence, the study of the pressure oscillations in solid motors become very significant. In segmented solid motors, the segment inhibition made of rocasin or similar material will not burn along with the propellant grain and will remain there for a long time. This will cause formation of eddies and recirculation zones in the vicinity of inhibitions. The periodic shedding of the eddies result in the pressure oscillations. The inhibition material and the propellant grain also will respond to the pressure fluctuation in the port. Hence the phenomenon of pressure and thrust oscillation in segmented solid motor is to be studied in a coupled manner considering the effect of fluid dynamic oscillations and oscillations of inhibitions and propellant grain deformations. The Objective of the proposal would be : i) To bring out the frequency and magnitudes of pressure and thrust oscillations within the solid motor considering the fluid-structure interaction of the port flow gases, protruding inhibitions and deformation of the propellant grain. ii) The problem has to be addressed in a transient, quasi-steady manner considering the grain surface evolution. iii) The validation has to be done with the available test data of subscale tests or flight measured data.	
B2	Sub Area	Slosh Analysis (LPSC)
B2.1	**Ignition modeling of semi cryo engine & comparison of performance with slug igniter & electrical igniter for LOX kerosene combustion (LPSC)** In future, multi start semi cryo engine are required for space transportation missions. Slug igniter is a fuel which is hypergolic with LOX where as electrical igniter is another heating device to generate adequate heat energy to ignite LOX with Kerosene. Modeling of igniter aspects, performance prediction, improvements etc. are some of the areas of research.	

B2.2	**Modeling of two phase flow heat transfer of Liquid Methane in regenerative cooling channels of LOX/Methane rocket engines with Methane film cooling (LPSC)** In future LOX/Methane engines are essentially needed for Mars missions where in fuel refilling is possible. A good thermal model for two phase flow will be of much application for design of LOX/Methane engines.
B2.3	**Study, design & optimization of clearance seals used in high speed turbo machinery operating in cryogenic fluids and vacuum conditions (LPSC)** Clearance seals are used in Liquid Hydrogen/Liquid Oxygen during chilling phase and in vacuum conditions during operation of turbo pumps. The vibration, friction and wear characteristics of the seal/runner combination plays a vital role in the turbopump performance. Detailed study in this area is required to optimize the existing seal designs/ configurations.
B2.4	**Control of combustion instability in liquid engines (LPSC)** Combustion instability is a phenomenon that sometimes occurs in liquid engines and can lead to damage/destruction of the hardware. It can be controlled by passive techniques such as slots, baffles and resonators. To widen the range of operating conditions under which control is effective, active control techniques such as anti-sound and secondary fuel injection can also be used. It is necessary to characterize the performance and stability of passive/active control techniques to evaluate suitability for liquid engines.
B2.5	**Supersonic film cooling of nozzle divergent (LPSC)** The Nozzle divergent of ISRO upper stage engines are cooled by dump cooling. Dump cooling needs double wall construction, which is having higher weight penalty. Moreover overall Isp of the engine is reduced as the dump coolant is expelled at low temperature. The existing dump cooling method can be upgraded by introducing supersonic film cooling, in which coolant will be injected in the nozzle divergent in the form of a thin slit. This method of cooling needs only single wall structure. Also the coolant will expand through main nozzle at high temperature, which will result in higher Isp.
B2.6	**Theoretical modeling of atomisation in cryogenic injectors (LPSC)** Development of the primary atomization model to predict the droplet size as well as to have the secondary droplet formation, vaporization etc. for the complex gas-liquid flow existing in the cryogenic engine injectors of CE20 and CUS, where the engines are operating in supercritical conditions of the propellant. Some common approach could be of generation of spray model by full Lagrangian approach, or the phenomenological approach of the Ω-Y model or the hybrid approach using VOF-Lagrangian coupling. The model generated can be validated through experimental data in actual hardware.
B2.7	**Development of throttleable injector element for liquid engines (LPSC)** Throttlable injectors are necessary for missions requiring soft landing or stage recovery. Various types of swirl configurations as well as pintle type of injectors which will have control over the orifice opening area for flow control and thus control over thrust developed by engine are employed. This could find application in LOX-Methane engine design concept

	which requires soft landing type of operations for future space missions. Modelling and experimental characterization of the injectors for various operating conditions are areas to be studied.
B2.8	**Development of a theoretical model to determine the characteristic frequency of feed line coupled-oscillations in liquid rocket engine (LPSC)** This project is intended to study the vibration response of metallic pipelines conveying propellants to a liquid engine. The pipelines will have the added mass of the fluid inside it. During operation of the engine (Hot firing) it will generate vibrations predominantly in the axial direction. The vibratory response of these lines is to be investigated.
B2.9	**Regenerative cooling analysis with kerosene for semicryogenic thrust chamber to study coking characteristics (LPSC)** For semi-cryogenic engine the coolant used for regenerative cooling is refined version of kerosene (equivalent to RP1). The kerosene is a mixture of many hydrocarbons. During passing through the coolant channels the temperature of kerosene increases. However when kerosene comes in to contact with high temperature walls, it decomposes and leaves behind a sticky rubber like substance called coke. This coke can clogg the injector element holes, which are very small in size (~0.8 mm). Hence the coking characteristics is to be studied thoroughly for different operating conditions.
B2.10	**Prediction model for vibration in turbopumps considering the effects of unbalance, constraints, fluid forces, seals, internal clearances (housing/shaft/bearing) etc. (LPSC)** Turbopumps are highly critical systems due to its high power, high speed operation and hazardous propellents being handled. Condition monitoring of turbopumps is essential for the safe shutdown and preventing catastrophic damage. Vibration assessment is a very effective tool for condition monitoring of turbopumps. A prediction model for vibration in turbopumps can be effectively used for condition monitioning of turbopumps during its operation.
B2.11	**Mathematical modelling of liquid migration under Zero ‘g’ condition and the associated heat transfer with warm tank wall and pressurent gas is essential to predict the rate of pressure build up in LH2 tank (LPSC)** In cryogenic propulsion Stage residual liquid migration in LH2 tank is generally observed after engine shut down. This causes higher tank pressure due to mixing of liquid hydrogen with warm pressurent gas and heat transfer with warm tank wall.
B2.12	**Development of diagnostic tool for measurement of plasma/plume parameters of stationary plasma thruster and pulsed plasma thruster (LPSC)** Plasma parameters like electron temperature, density, energy distribution function and plasma potential are essential parameters to evaluate to understand the performance of plasma thruster. Since near field region of Hall thruster is so hot, measurements cannot be carried in low frequency mode. So that high temporal resolution probes are required to serve the purpose. However, measurement using electric probes like Langmuir probe and Emissive probe is challenging in high frequency range. Hence Langmuir and

	Emissive probes with special measurement circuit is needed to special attention to serve the purpose Deliverables: 1. Langmuir probe and emissive probes compatible to high temperature plasma. 2. Measurement circuit with high frequency measurement compatibility. 3. Programme (code) to analyze and deduct the results from raw data.
B2.13	**Model for the prediction of thrusters' life (LPSC)** Non contact type measurement of thruster anode liner erosion Anode liner is a crucial part, which decides the life of Stationary Plasma Thruster (SPT) also known as Hall thrusters. This liner protects the magnetic circuit from hot plasma and also play role in thruster performance. The high energetic ion beam impregnates the liner material and causes erosion and affects the life. Since the physical presence of probes will disturb the thruster's plasma and also can damage the probe, non-contact type measurements are preferable. On this ground, non-contact measurement of liner erosion and prediction of the thruster's life is very important. Deliverables: 1. Develop and demonstrate a non-contact experimental technique to measure the anode liner erosion. 2. Model for the prediction of thrusters' life.
B2.14	**The complete thermal modelling of the thruster (LPSC)** The monopropellant hydrazine thrusters are used in reaction control system of IRS projects. The monopropellant hydrazine thrusters use the principle of dissociation of hydrazine using catalyst to produce the exhaust gases. These exhaust gases are expanded through the nozzle to produce thrust. The complete hydrazine dissociation model for the monopropellant thruster is required for thruster design and optimization. Based on the dissociation model, the complete thermal modelling of the thruster to be carried out.
B2.15	**Alternate green propellants (LPSC)** The monopropellant hydrazine is highly corrosive, carcinogenic and not environmental friendly. The alternate green propellants such as Amonium Di Nitramide (ADN), Hydroxyl Ammonium Nitride (HAN) based monopropellants are under studies. The green propellant formulation and its detail properties, dissociation phenomenons are essential to replace the existing hydrazine system. Development of suitable catalyst for the green propellant.
B2.16	**Life cycle prediction of thrust chamber for reusable regeneratively cooled liquid engines (LPSC)** This project is to study the cyclic life of double walled regeneratively cooled thrust chambers of liquid rocket engines. Theoretical and experimental investigations are required to study the thermomechanical behavior of different thrust chamber materials in the parent metal and welded forms for this at different temperatures and strain rates. Damage mechanics has to be incorporated in the studies.

B2.17	**Heat transfer characterization of kerosene with aluminium nano particles (LPSC)** Energetic propellant nanosized particle based nanofluid can be used in the regeneratively cooled CRE. The nanofluid will be used as a coolant to the thrust chamber through regeneratively cooled channel and film cooling. Preparation of long term stable nanofluid with respect to any surface, determination of its thermophysical properties and finally heat transfer performance & pressure drop characteristics during regenerative cooling and film cooling is of interest to ISRO.
B2.18	**Liquid film cooling study of thrust chamber with kerosene for LOX/Kerosene semi-cryogenic Engine (LPSC)** The 2000 kN Semi-cryogenic engine is a high thrust engine and generates high thermal load on the thrust chamber wall. Hence the thrust chamber is cooled by film cooling along with regenerative cooling. The film coolant, after injection in to the thrust chamber takes part in combustion, hence film coolant layer depletes gradually. For safe operation of engine, a positive film coolant (without film layer breakage) is an essential requirement. This necessitates detail modelling of film coolant phase change considering proper reaction steps, species, reaction rates through CFD.
B2.19	**Modelling and analysis of throat film cooling for semi cryogenic engine thrust chamber (LPSC)** The throat region of thrust chamber is subjected to maximum heat flux. The conventional film coolant injected near the injector end is not sufficient to keep the throat wall temperature below safe temperature limit. Hence additional film cooling provided near the throat region. Isrosene (fuel used for semicryo engine: equivalent to RP1) is used for both film cooling as well as regenerative cooling in liquid state. For safe operation of engine, a positive film coolant is an essential requirement. Hence detail modelling of phase change of film coolant and participation in combustion is required considering proper reaction steps, species and reaction rates. Based on the CFD results an empirical correlation is also to be formulated for predicting the film coolant thickness in the thrust chamber for varying operating parameters.
B2.20	**Modelling of film cooling / sweat cooling in liquid rocket engines (LPSC)** All high thrust liquid rocket engines employ film cooling along with regenerative cooling to reduce the heat flux at throat. As the film coolant undergoes phase change and gradually takes part in combustion, it is difficult to predict the overall effectiveness in different operating conditions. Also higher film cooling rate reduces engine specific impulse. Hence a detail CFD analysis is required for all ISRO liquid engines to optimise film cooling flow rate.
B2.21	**Combustion modelling & combustion instability modelling of liquid rocket engines (LPSC)** Numerical steady state flow model can be carried out with the consideration of the various species for the cryo/semi-cryo thrust chamber and this can be perturbed to give unsteady results which give signatures of the dominant acoustic modes. The initial guess of the droplet size of the propellant will decide the vaporization, mixing and combustion in the

	chamber, therefore an experimental assessment of the droplet size will help in accurate predictions. Stability assessment can be done for ranges of droplet sizes and the stability boundaries can be defined. Design evaluation of the present cryo/semicryogenic engine with stability enhancing mechanisms can be taken up for studies.
B2.22	**Combustion studies on gel kerosene & gel kerosene with aluminium nano particles (LPSC)** Properties of stable Gel kerosene nanofluid, its flow performance and increase in density impulse.Rheological properties, thermophysical properties and energetic constants. Cold flow as well as combustion performance of these nanofluid at realistic conditions.
B2.23	**Numerical modelling of nonlinear thermo acoustic instability in liquid rocket engine (LPSC)** Numerical modelling of nonlinear thermoacoustic instability is required as instability is inherently noinlinear. Work has already been done in computational modelling using Unsteady Reynolds Averaged Namier Stoke technique (URANS). The use of Large Eddy Simulation (LES) and Direct Numerical Simulation (DNS) techniques is to be investigated to improve accuracy.
B2.24	**Optimization of passive suppression devices for thermo acoustic instability in liquid rocket chambers (LPSC)** Passive suppressin devices for suppressing thermoacoustic instability such as baffles and resonators are being used in rocket motors worlwide. LPSC needs to investigate the damping characteristics of baffles, resonators. etc. for application to our engines, in paticular, semi cryogenic engines.
B2.25	**Two phase flow modeling in cryogenic propellant feed lines (LPSC)** Cryogenic engines make use of propellants such as liquid hydrogen and liquid oxygen at very low temperatures in order to obtain a high specific impulse and controllable thrust. The feed lines are to be chilled to cryogenic temperature prior to the start of engine operation to avoid undesirable flow oscillation. The flow of cryogenic fluids through a feed line is complex due to two phase flow, heat in leak in the feed line and boils off at the source. The flow of cryogenic fluids is complicated because surface tension makes all the dynamics nonlinear. Moreover, the density of the two phases differs considerably and compressibility becomes important due to the large change in density. Flow induced pressure drop can lead to further change of phase. In addition various types of instabilities may develop. Methods are available for modeling of two phase flow using numerical techniques such as volume of fluid method, level set method, front tracking and the Lattice-Boltzmann methods. However, modeling of two phase cryogenic flow incorporating properly phase change and heat transfer as well as fluid dynamics is still a developing field. Specialised models for cryogenic engines will have to be developed considering the actual fluids and operating conditions. New methodologies may have to be investigated to accurately capture the flow behavior.

B2.26	**Conjugate heat transfer analysis in cryogenic engine systems (LPSC)** 1. Development of liquid film cooling model for cryo and non-cryo engines. Detailed model for helical chemical regenerative cooling in LOX-LH2 propellant along with film cooling 2. Ablative throat charring analysis in conjugate model.
B2.27	**Experimental evaluation and constitutive modelling to simulate structural behaviour and failure criteria for dissimilar weld joints (LPSC)** This study plans to address the structural behavior and failure of dissimilar material weld joints commonly encountered in liquid rocket engine combustion chambers. Material combinations such as SS- Copper, Copper-Nickel, SS- Nickel have to be addressed. Different thicknesses have to be accounted for. FEA based simulations have to be done to predict the failure of such joints.
B2.28	**Spray interaction effects in a multi-element injector head of a liquid rocket engine (LPSC)** Multi-element swirl injectors are used in high thrust liquid rocket engines. The intra-element characteristics of the swirl injector is mainly influenced by geometrical and flow parameters. The injector elements are arranged in a specific pattern based on the thrust per injector element of the rocket engine. In addition, the conical spray from an injector element interacts with the spray formed in its neighbouring elements. The performance and stability of liquid rocket engine is influenced by both intra-element and inter-element spray characteristics. Spray interaction in multi-element injector head depends on both the intra-element spray characteristics as well as combustion chamber operating conditions. For simulating the spray interaction in a multi-element injector, experiments and analyses need to be carried out at different operating conditions.
B2.29	**Studies on deflagration to detonation transition (LPSC)** Combustion can be classified into deflagration and detonation based on whether the flame is travelling at subsonic or supersonic speeds respectively with respect to the unburned medium. Deflagration is associated with low overpressure whereas detonation is explosive in nature having high overpressure associated with a shock wave. In conventional liquid rocket engines, deflagration occurs whereas in scramjets and pulse detonation rocket engines, detonation can occur. Dynamics of deflagration and detonation waves have been investigated extensively. However, under certain conditions a deflagration wave may accelerate and transform into a detonation wave. This mechanics of this transition are not well understood. It is necessary to obtain a deeper understanding of the deflagration to detonation transition in scramjets and detonation based rocket engines using numerical and experimental techniques. The data would be required for design and optimization of these systems.
B2.30	**Modeling of atomization of coaxial injectors, impinging jet injectors (LPSC)** Coaxial injectors are mainly selected for gas-liquid propellant combinations in both the cryo and semicryo engines. The impinging injector finds application in the earth storable engines where the injectors are operating in liquid-liquid mode.Flow modeling of

	atomization of coaxial or impinging jets and parameters affecting the atomization, mixing, vaporization of the propellant is to be studied. Theoretical studies with experimental correlation can be carried out.
B2.31	**Effect of acoustics on spray characteristics of swirl coaxial injectors (LPSC)** Combustion instability is characterized by large pressure perturbations with attendant large thermal stresses and is one of the most important challenges for liquid rocket engine design. Low and medium frequency combustion instability is believed to be caused by the dynamic processes in supply system or combustion. Dynamic processes with specific reference to atomization is to be studied & modelled as it plays important role.
B2.32	**Finite element simulation of non-linear, high strain forming processes of metals like deep drawing, flaring etc (LPSC)** This study is for evaluating the state of stress and strain in sheet metal work undergoing high plastic starins as in deep drawing and flaring. FEA based simulations and tests are required to assess the structural integrity of the work piece so as to optimize the process parameters.
B2.33	**Transient chill down analysis of regeneratievely cooled thrust chambers (LPSC)** The Thrust chambers of cryo engines are preconditioned by low and high flow rate chill down before engine firing. This is a highly transient phenomena involving conjugate heat transfer, radiation and phase change. A proper flow analysis is essentially required to optimise the coolant flow rate during the chill down as this coolant is drawn from the fuel tank during flight. Optimising chill down flow rate can significantly improve the payload carrying capability as it will reduce the fuel loading from the upper stage engine.
B2.34	**Film cooling breakage studies under unstable combustion conditions (Boundary Layer breakage) (LPSC)** During combustion, instability can lead to multiple high pressure zones inside the thrust chamber. This in turn break the film coolant layer near the boundary layer. As a result the heat transfer to chamber wall can increase significantly, which may lead to catastrophic failure of thrust chamber. Hence a proper study of effect of various modes of combustion instabilities on film coolant layer is to be carried out.
B2.35	**Evaluation of damange cretiria for AA2219 welds under bi-axial stress field from experiments and simulation (LPSC)** This project plans to address the damage modelling and failure prediction of AA2219 GTA welds and parent metal under biaxial state of stress. Both tests and simulations based on FEA are required for this. Different biaxial stress rates have to be addressed. Tests have to be conducted for different specimen thickness commonly encountered in liquid propellant tanks.
B2.36	**Prediction of anode liner erosion of hall effect thruster (LPSC)** Anode liner is a crucial part, which decides the life of Stationary Plasma Thruster (SPT) also known as Hall thrusters. This liner protects the magnetic circuit from hot plasma and

	also play role in thrusters performance. The high energetic ion beam impregnates the liner material and causes erosion and affects the life. Since the life of the SPTs is of the order of 1000s of hours, it is not practical to measure the erosion pattern on full scale. Hence we need a technique to estimate the erosion rate and life of the thrusters based on suitable modelling. Deliverables: 1. Model to predict the anode liner erosion of Hall thrusters. 2. Estimation of Hall thruster's life.
B2.37	**Design of packaging / interfaces for MEMS based fabricated valves & actuators (LPSC)** Development and testing of a MEMS based Piezo valve is successfully demonstrated. However the next challenge in development is to integrate the microsystem (valve) to the mechanical fluid system . Interfacing of the silicon wafer etched micro valve to the stainless steel tubing with proper interface sealing is yet to be developed.
B2.38	**Development of a mathematical model for characterizing the dynamic behavior of a check valve under different operating conditions (LPSC)** Check valves sometimes exhibit chattering under flow conditions which is not desirable. For double poppet check valves which are two check valves in a series mode this phenomenon is complex and hence needs to be studied. Modelling of double poppet check valves preferably using specialized software tools like AmeSIM to 1. Characterize check valve chattering under different input conditions for the given Design and 2. Characterize and optimize the valve design parameters for eliminating chattering. Check valve chattering.
B2.39	**Design & development of solenoid coils for liquid helium applications (LPSC)** Liquid helium storage under pressurized condition and on-board isolation will call for a fast response electromagnetically actuated solenoid valve. At these temperatures because of the low viscosity of liquid helium sealing is a concern. The valve envisages the usage of superconducting winding wires wherein the current carrying capacity is amplified many times due to a drastic drop in coil resistance accompanied by minimal increase in power at around liquid helium temperatures. The valve design can make use of magnetostrictive actuator. Development of valve with super conducting coil and achieving leak tightness for Liquid Helium application is a challenge.
B2.40	**Estimation of torque co-efficient and load distribution in threaded joints (LPSC)** This project is to study the mechanical behaviour of bolted joints at cryo, ambient and elevated temperatures under the combined action of bolt pre-torque, internal pressure and axial loads. Experimental and numerical studies have to be carried out considering different nut factors and bolts/flange materials.

B2.41	**Development of a mathematical model for propellant tank pressurization system chain for cryogenic application (LPSC)** Complex thermodynamic processes occur in the ullage Propellant volume of cryogenic tank during pressurisation process and propellant outflow from tank. Hence analysis of cryogenic tank pressurisation system requires development of a mathematical model for the pressurisation process of cryogenic tank addressing heat transfer between cold tank wall and warm ullage gas, heat transfer between liquid free surface and ullage gas, enthalpy of pressurant gas supplied for tank pressurisation, tank geometry, propellant outflow rate during engine operation etc. This thermal model computes temperature gradient in tank wall and ullage gas column with respect to liquid expulsion time and thereby predicting mass flow rate variation of pressurant gas with liquid expulsion time. This input is necessary for designing the pressurisation system including the gas bottle for pressurant gas storage.
B2.42	**Modelling of magneto plasma dynamic thruster (LPSC)** Magneto Plasma Dynamic Thrutser (MPD) is a plasma thruster where the ions accelerated with magnetic force. MPDs are mainly operates at very high power in the range of 10 kW to one MW. Though it is possible to realize MPD's less than 10kW range, the performance of the thruster will not be as good as Gridded Ion thruster or Stationary Plasma thruster. Pulsed Plasma thruster, VASMIR are the examples of MPD. There are mainly two types of MPD thruster. 1. Self induced MPD 2. External magnet MPD. In the self induced MPDs, the magnetic field generated by the high current plasma within the thruster accelerated the ions by Lorenz force. The classical example is Pulsed Plasma Thruster (PPT). In PPT a very high current plasma discharge between the cathode and anode induces the magnetic field and accelerates the ions produced. The thrust generated by PPT is of the order of 500 micro newtons and there are no precise thrust measurement system available. Considering this modelling of the plasma in terms of plasma generation, the magnitude of ion current, magnitude of magnetic field generated, and thrust production mechanism etc. needs to be modeled. MPDs with external magnets are the devices where strong magnetic field is generated which compliments the induced magnetic field. In this type of thruster also the thrust production mechanism is being the same, modelling of the magnetic field generated and applied magnetic field along with the modelling of plasma and its acceleration is important for the design of the thruster and understanding the thruster behavior. Last but not the least, to understand the the main technical challenge associated with MPD i.e erosion of cathode a very good model of MPD is essential.

C	Area	Propellants, Polymers & Chemicals (VSSC/SDSC-SHAR)
C1	Sub Area	Propellants (VSSC)
C1.1	**Development of software for modeling/simulation of mechanical/ballistic properties of solid rocket propellants (VSSC)** Objective is to develop a code/software to accurately predict the mechanical properties and burn rate of HTPB-Al-AP based composite solid propellant. This may be effected in two phases:- Phase I: In this phase, the concept and general framework of a modelling/simulation code for the propellant should be established. Phase II: In this phase a working code containing a full Graphical User Interface (GUI) and capable of running on a multi-processor platform should be provided. The code should predict the mechanical properties of the propellant and burn rate at a given pressure with a minimum of empirical correlations.	
C1.2	**Ultra-fast reaction monitoring of energetic materials (VSSC)** The basic understanding of decomposition kinetics and dynamics of energetic materials in the ultrafast time regime (femto, 10-15/pico, 10-12 seconds). Theoretical understanding of the reaction mechanism using computational tools. Elucidation of the ignition behaviour, reaction pathways, complex combustion phenomenon, measurement of species and flame structure profile etc of solid, liquid (storable and cryogenic) propellants.	
C1.3	**Development of a process for morphological tailoring of energetic materials for controlled particle size and shapes (VSSC)** The size/shape and the density of the energetic crystals govern the performance of energetic formulations. Such performance properties include burn rate, internal ballistics, combustion phenomena, pressure during combustion etc. For each size/shape of the particles, the bulk density, mechanical strength, sensitivity, storage, and handling can be very different. The phase behaviour that controls the purity and the kinetics that defines size distribution are critical in the design of the energetic particles. The project shall aim to selectively achieve a defined morphology of energetic materials through different crystallization methods viz., solution crystallization, co-precipitation, forced precipitation, melt crystallization, emulsion crystallization, prilling etc. The process conditions shall be tailored to generate specific crystal shape and size distributions (with D50: 50-90 microns and D50:150-250 microns). Studies may be attempted using Ammonium Nitrate (AN).	
C2	Sub Area	Liquid Propellant Storage and Service (SDSC-SHAR)
C2.1	**Stress-strain analysis of pressure vessels during hydrostatic testing (SDSC-SHAR)** All the pressure vessels are subjected to hydro test as a part of qualification for further usage. During hydro test the tank is subjected to 3 dimensional stress and strain (Von Mises Theory). The stress and strain are to be pre-determined for safe hydro/ pneumatic testing.	

C2.2	**Performance evaluation of spiral plate heat exchanger (SDSC-SHAR)** Spiral plate heat exchanger is being used in earth storable propellant system for propellant chilling operations. The performance characteristics of the heat exchanger are to be studied for better maintenance and operation. Based on analysis any improvement as a outcome can be suitably adopted.	
C2.3	**Pressure vessels qualification by advanced NDT technique (SDSC-SHAR)** An alternative method for hydrostatic qualification testing of Pressure vessel to be invented.	
C2.4	**Upgradation of existing Inline propellant filter, compatible to propellant (SDSC-SHAR)** The existing propellant filter are of 30 micron, pleated, cylindrical mesh type (SS 304L/316L) elements.In single filter housing, three or four elements will be available. Improvement has to be worked out to enhance the number of pleats in the filter element, increasing the dimensions of the filter, exploring different type of meshes, so that the filtration area can be improved	
C2.5	**Enhancing the existing method UH-25, MMH, N2O4 & MON3 effluent treatment (SDSC-SHAR)** Currently the effluent treatment of the propellant effluents is being carried out in batch process mode using reaction tank. Instead of batch process, continuous method of treatment with improved chemical method is being looked for.	
C2.6	**Numerical analysis and effectiveness validation of propellant cooling system (SDSC-SHAR)** Currently spiral type heat exchangers are being used in chilling of earth storable propellants.Even though their performance is satisfactory, improvements is being looked for in terms of increasing the effective heat transfer co-efficient, fouling factor, increasing the mach number of flow, efficiency estimation at different coolant flow rates.A detailed mathematical model and numerical analysis is required for the same.	
C3	**Sub Area**	**Solid Propellant Plant (SDSC-SHAR)**
C3.1	**Detection of toxic isocyanate vapors in solid propellant plant by a simple inexpensive sampling instrument (SDSC-SHAR)** Monitoring of isocyanate levels to check exposure limit is required to forewarn the people working in this area. Available monitoring systems provide significant statistical differences and interference problems, especially from humidity in the air. Hence a detector that detects TDI pollution in PPB levels using chemi-resistor sensor has to be developed. Chemical sensors transform the concentrations of analytes to other detectable physical signals, such as currents, absorbance, mass or acoustic variables. Organic semi conducting polymers will be selected because they are mechanically robust and work well in high humidity conditions for the synthesis of chemiresistor.	

C4	Sub Area	Polymers (VSSC)
C4.1	**Development of fluoro oil for use in liquid engines (VSSC)** Fluoro Oils are being used in the liquid engines of ISRO's Launch Vehicles. It requires the development of two different grades of fluoro oils with varying density and viscosity characteristics. Grade 1 fluoro with a density of 1.80 g/cc and absolute viscosity of 17 cps and Grade 2 with 1.87g/cc and 140cps.	
C4.2	**Solvent free coating of moisture sensitive oxidizer materials for propellant application (VSSC)** Majority of oxidizers used in propellant formulations are sensitive to moisture and humidity. In order to circumvent this issue, hydrophobic coating/encapsulation with suitable material over the oxidizer particles are warranted. Many coating techniques are available today for this purpose. Proper selection of coating material and coating technique will provide effective and efficient coating without compromising its energetic properties. Most film coatings using fluid bed coating technique are applied as organic based polymeric solutions. This organic solvent based coating has its own disadvantages such as toxicity, health hazards, flammability, long processing time, high energy consumption and compatibility issues with base oxidizer material. In order to overcome these drawbacks solvent free supercritical fluid based coating is essential. Solvent less coating will reduce the processing time and suitable for temperature sensitive oxidizer material. Coating methodology to be evolved for particle size ranges of (D50: 50-90 microns and 150-250 microns). Coating weight <1.0% by weight of precursor.	
C4.3	**Development of single-part, space-grade silicone adhesives (VSSC)** Development of low out-gassing, single-part silicone adhesive for satellite applications. The conventional space grade silicone adhesives are available as two-part systems which require weighing and mixing of part A and part B components at the time of application. The proposed single-part adhesive should be made available in ready-to-use squeeze tubes and should be able to cure by following addition-cure chemistry, once it is exposed to ambient conditions of temperature and humidity. The chemistry followed should not be condensation cure chemistry which would increase the out-gassing characteristics beyond acceptance level.	
C4.4	**Development of thermoplastic liners for helium gas bottle (VSSC)** At present, liners of helium gas bottles are fabricated using titanium alloy. Titanium alloy based liners attract large production delay, high cost and fabrication difficulties. In order to save time and cost in realizing such liners, it is proposed that the liners can be fabricated using suitable thermoplastic materials. Two important criteria for selecting the thermoplastic polymer for such applications are the helium gas barrier property and linear elasticity in the range of 10-20%. The thermoplastic polymers of choice are high density polyethylene, polyetherether ketone, nylon etc. In order two increase the gas barrier properties, the polymer needs to be reinforced with platelet type fillers (nanoclay, graphene etc) in such a way that the helium leak rate of 10 E-8 mbar lit/sec/cm2 or better is achieved. The processing of layered material incorporated thermpolastic liners can	

	be optimized using twin screw extrusion followed by injection molding of the two halves to get spherical liners. The plastic welding process also needs to be optimized so that there is no leakage of helium gas through the weld area and only maximum 5% drop in strength due to welding.
C4.5	**Mechanically strong, flexible polyimide aerogels (VSSC)** Aerogels are attractive material for potential space applications which can perform as a structural component with minimal density that plays the role of the thermal and vibration insulator, thereby increasing the mission capability. The challenge is to develop a low density, flexible aerogels based on polyimides, having good structural integrity and better thermally insulating properties. Polyimide aerogels with three-dimensional cross-linked structure can be prepared from polyamic acid solutions, cross-linked with the multifunctional amines, followed by chemically imidization and drying using supercritical CO2 extraction. The mechanical integrity, flexibility, thermal stability and very low density needs to be demonstrated.
C4.6	**Atomic oxygen resistant polymers for re-entry missions (VSSC)** Development of polymers with excellent atomic oxygen resistance, which finds potential applications in the re-entry missions of ISRO. Polymeric materials, in particular polyimide and other polymers, are ubiquitous on spacecrafts. These polymers are rapidly degraded in the highly oxidative environment of low earth orbit (LEO). The primary mechanism for eroding organic hydrocarbon polymers is oxidation by atomic oxygen (AO), which can seriously reduce the service life of polymers and shorten the lifetime of the spacecrafts. Hence, the development of soft and AO resistant polymeric coatings with self-healing capabilities is desired. Present proposal envisages the preparation of space durable and AO resistant polymers by following the methods such as (i) blending with organic/ inorganic polymers or fillers, (2) by applying protective metallic/non-metallic coating over the desired polymers or (3) by the chemical incorporation of functionalized organic/ inorganic moieties to the backbone of polymer.
C5	**Sub Area** — **Energy Systems for Satellite & Launch Vehicles (VSSC)**	
C5.1	**Analysis of different gas-water separation techniques for oxygen and hydrogen gases with regard to space applications of fuel cells (VSSC)** The requirement is analysis of different techniques for separation of liquid water from exhaust hydrogen and oxygen gases at variable flow rate in microgravity environment.
C5.2	**Development of high energy electrode materials (VSSC)** Power requirements of satellite and launch vehicle programs of ISRO calls for the development of efficient battery technology, especially advanced Lithium-ion cell technology. Thus, to improve the energy density of present-day Li-ion cells (150 Wh/kg) to >400 Wh/kg, realization of newer electrode materials with light weight and high energy storage capacity is essential. Suitable anode materials like nano-sized silicon, reduced grapheme oxide encapsulated silicon, lithium alloys of Silicon and/or tin, etc. and suitable cathode materials such as sulphur, carbon-sulphur composites, fluorophosphates,

	LiNix or yCoxMnxO2 –NMC 111, NMC811 etc. need to be developed, characterized and evaluated.
C5.3	**Development of high voltage electrolyte (VSSC)** As a part of realizing high energy Li-ion systems, it is essential to develop electrolytes that can perform satisfactorily with chemical and electrochemical stability under a wide electrochemical window from 0 – 5 V, like sulfones, sulfoxides, fluorinated carbonates, etc.
C5.4	**Development of durable and smart catalyst layer structures of LT PEM Fuel Cell (VSSC)** Envisages to develop high durable ORR catalyst layers capable of greater than 400 mW/cm2 within 0.6 V for air cathode with 0.1 mg /cm2 loading at fuel cell MEA level.
C5.5	**Development of efficient OER catalyst for LT PEM water electrolysers (VSSC)** Establishing a synthesis route for high durable catalyst and realizing OER catalyst layer to achieve electrode level performance of 1A/cm2 or greater within 1.70 V for Low temperature (<80 °C) PEM water electrolyser.
C5.6	**Development of catalyst for electrochemical reduction of carbon dioxide gas to methane in Proton Exchange Membrane (PEM) cells (VSSC)** Energy efficient conversion of CO2 gas to methane is highly relevant in manned space missions as well as mars missions. It also assumes significance in terms of carbon sequestration and recycle. PEM cell based electrolytic conversion of CO2 gas to methane using water and electricity forms a potentially attractive solution in this regard. It is envisaged to develop efficient electro-catalyst for selective reduction CO2 to methane in PEM electrolytic cells.
C5.7	**Development of solid electrolytes (VSSC)** Solid state lithium batteries that make use of solid electrolytes rather than a liquid electrolyte can provide higher energy density cells and can eliminate the safety issues of present-day cells. Hence, Lithium ion conducting solid electrolytes with ionic conductivity of the order of 10-3 S/cm at room temperature need to be developed. This development shall lead to realization of thin, flexible batteries and thus pave the way for processing versatility of cells.
C5.8	**Materials for advanced supercapacitors for space applications (VSSC)** Towards improving the power density and energy density of supercapacitors, development of high surface area materials such as activated carbon, carbon aerogels, carbide derived carbon, pyrolytic graphite, etc., need to developed.
C5.9	**Development of electrolytes/ionic liquids (VSSC)** In line with improving the energy and power density of present day supercapacitors, hybrid ion capacitors are advancing by invoking the principles of battery as well as supercapacitors. Suitable electrolytes/ionic liquids shall be developed with high voltage and conductivity capabilities for implementation in device level applications.

C5.10	**Development of Sodium – sulphur battery based on solid electrolyte (VSSC)** Solid-state batteries provide a promising choice to the next generation of devices because of their enhanced safety and high-energy and high-power densities. Sodium has low reduction potential and is cheap and abundant and is an ideal candidate for cheap high energy batteries. Sodium batteries generally comprise four components: cathode, anode, electrolyte, and separator materials, while in the case of solid state sodium batteries, solid electrolytes serve the purpose of electrolyte and separator simultaneously. Solid electrolyte provides improved safety compared to conventional liquid electrolytes. Sulphur is a high capacity cathode material and is cheap and abundant. Therefore, sodium-sulphur batteries with solid electrolyte will provide high energy density and improved safety at a lower cost.	
C6	**Sub Area**	**Ceramics (VSSC/LPSC)**
C6.1	**Modelling of polymer derived nano-ceramics (VSSC)** Most of the inorganic materials synthesized from polymer thermolysis retain amorphous structure upto 2000°C. Structural characterization of these materials at atomic level is required to achieve better understanding of their properties. Using structural modeling and computational studies details of atomic structure can be obtained which will further enable meaningful interpretation of experimental data. Generally Continuous random networks with well-defined local coordination of all atoms are considered for molecular dynamics simulations to locate the minimum energy structures. These structures are further subjected to optimization and annealing scheme using DFT methods as implemented in Vienna ab initio Package (VASP) to get improved structural features.	
C6.2	**Development of ceramic material with higher electrical insulation at high temperature (LPSC)** Ceramic materials with high electric insulation at high temperature of 1800 °C are required for Hollow cathode. Hollow cathodes serve as electron source for discharge as well as beam neutralization on electric propulsion thrusters. To get the desired emission currents, emitter material in the cathode has to be heated for high temperatures. An insulation material at 1800 °C is needed for the purpose. Presently, these ceramic materials have mostly imported. Based on the overwhelming demand of electric propulsion thrusters in the near future, the indigenous material development is essential. Deliverables: 1. Ceramic materials with high electric insulation at 1800 °C.	
C6.3	**Development of ceramic coating to prevent metal burning in high temperature and oxygen rich environment (LPSC)** Metal burning in hot oxygen enviorment is an important issue which is not yet solved. Ceramic coating containing oxides is one of the solutuion for preventing metal burning. Adhesion of the coating to the metal substrate is an important aspect. Addition of metal particles to ceramic will help to improve the ductility of the coating so that it will not fracture under tensile loads.	

C6.4	**Development of new thermal barrier coating to reduce heat flux in semi cryogenic engine thrust chamber (LPSC)** Thermal barrier coating (TBC) for semicryogenic thrust chamber is manadatory requirement to bring down the coolant channel temperature below the coking limit of the coolant (fuel). Heat flux to thrust chamber material (copper alloy) can be minimised by TBC . TBC can be any material which has got conductivity less chamber material (copper alloy).	
C6.5	**Development of coating materials used in high temperature environment (LPSC)** For high temperature application, two kinds of coatings are required. One is TBC for superalloys including Co base or Ni base alloys which has got melting point less than 1400°C. Other is oxidation protection coating which is needed for refractory alloys like C103 or Mo/Ta alloys.	
C7	**Sub Area**	**Catalysis (VSSC)**
C7.1	**Development of effective catalysts and reaction kinetic models for carbon dioxide reduction reaction (VSSC)** The Sabatier reaction, also referred to as carbon dioxide methanation, involves reacting carbon dioxide and hydrogen in presence of a catalyst producing water and methane. Number of catalysts have been reported in the literature for the reaction. Development of highly efficient catalyst with high methane selectivity, lower on set temperature and minimum pressure drop is solicited. Towards this objective, bimetallic or tri-metallic catalysts on suitable supports are required to be designed. Either wash-coating on monoliths or support on metal based mesh for enhanced heat transfer properties may be attempted for realization of the catalyst system with the desired efficiency. Further, reaction kinetic studies for the developed catalyst(s) are required to be undertaken based on which kinetic models should be developed / formulated. These kinetic models shall form the basis for designing of the reactor for undertaking carbon dioxide methanation reaction.	
C8	**Sub Area**	**Human in Space Programme and Mars Exploration (VSSC)**
C8.1	**Development of catalysts for splitting of carbon dioxide (VSSC)** Atmosphere of Mars is reported to comprise mainly (95%) of carbon dioxide. It is suggested that oxygen for propulsion (for return flight to Earth) can be produced in Mars by catalytic splitting of carbon dioxide into carbon monoxide and oxygen. Another method is to reduce carbon dioxide using hydrogen (transported from Earth) to produce oxygen and methane. Development of catalysts for these reactions and optimisation of reaction conditions will go a long way in realizing Mars explorations.	

C9	Sub Area	Electro-active Actuators (VSSC)
C9.1	**Development of electro-active actuators for positioning & control of aerospace components (VSSC)** Electro-active actuators are necessary for shaping, tuning and positioning of reflectors/ antennae/ solar panels in aerospace field. Polymers actuatable by current/voltage can lead to shape memory or shape changing polymers. The response is based on the ionic movement or electrical conduction capability of specially designed polymers. The movement of ions/electrons facilitates the actuation of mechanical shape. Compared to common actuation by heat, it is superior in control and accuracy. Also, development of enhanced electro- active polymer material (based on dielectric polymers such as silicone and PVDF) based sensors and actuators with improved adaptability for space-related applications are required.	
C10	**Sub Area**	**Metal Organic Frameworks (MOF) (VSSC)**
C10.1	**Development of metal organic frameworks for the selective adsorption of gases like H2, CO2 and CO (VSSC)** The work involves molecular modelling, synthesis and characterization of the MOF and evaluation performance. Academia should desirably be equipped with processing facilities such as pressure reactors and characterization facilities including BET surface area analyser, Single crystal XRD, FESEM, Electron Paramagnetic Resonance (EPR),129Xe Nuclear Magnetic Resonance.	
C11	**Sub Area**	**Shaped Fillers (VSSC)**
C11.1	**Development of shape controlled inorganic fillers for thermal interface materials (VSSC)** Thermal interface materials are very critical for the miniaturization of electronic components. In order to enhance the thermal conductivity of the interface thermal pad, conductive fillers like alumina and boron nitride are being used. The shape of filler significantly contributes to the thermal conductivity. The objective is to synthesise the platelet and spherical shaped fillers and development of electrically insulated thermal pad.	
C12	**Sub Area**	**Gas Adsorbent and Absorber (VSSC)**
C12.1	**Development of a compact, lightweight regenrable adsorbent for Carbon dioxide capture (VSSC)** Re-generable carbon dioxide capture system is vital for environmental control and life support system in long duration manned space missions. The proposal envisages to identify promising re-generable systems for selectively capturing carbon dioxide from the air. Number of materials namely, solid amines, zeolites, molecular sieves, etc. have been reported for their high efficiency to selectively remove carbon dioxide and chemical contaminants as well as their chemical inertness and non-flammable properties. Furthermore, these sorbent materials can be readily regenerated via either Thermal Swing Adsorption (TSA) or Pressure Swing Adsorption (PSA), and therefore, are reported to be suitable for the removal of carbon dioxide and trace contaminants.	

	These regenerable adsorber systems do not have to be replaced during a space mission, and can be smaller and lighter than the disposable adsorber beds.Currently, packed beds of sorbent pellets are mostly used in the adsorption systems; however, recent studies have shown that these materials can be easily fluidized and/or eroded, due to both thermal cycling and mechanical vibration, and can generate fine particulates that bypass the downstream mesh filters. This results in particulates buildup in downstream pumps, blowers, and other components, and has been problematic in some aerospace applications. Furthermore, these packed beds of pelletscreate a large pressure drop across the adsorption system. In view of the above, it is imperative to develop alternative approaches to packed bed systems, where the suitable adsorbent material should be coated on metal mesh elements (substrate consists of a series of ultra-short-channel-length) or monoliths which can effectively adsorb / capturecarbon dioxide and trace contaminants.The study should aim at developing the regenerable adsorbent material having selective carbon dioxide adsorption efficiency of minimum 8% by weight.
D	**Area** — **Control, Guidance & Simulation (VSSC)**
D1	**Sub Area** — **Control System (VSSC)**
D 1.1	**Development of Control algorithms for autonomous mobile robotic manipulator (VSSC)** The research proposal is for developing advanced control algorithms for an autonomous mobile robotic manipulator which consists of a six degree of freedom (6 DOF), robotic manipulator mounted over a four wheel mobile robot with the wheels having independent drive and steering control. Conventional control and intelligent control shall be hybridized to develop a hierarchical control and vision-based control for robots. The control algorithm provides dynamic coordination of manipulator arm joints and mobile robot wheel drives to execute precision tasks in unstructured environments using multiple sensor feedback. With the development of multilayered control architecture, the robot should be able to automatically compute its motions from the high level description of tasks. The proposed study also needs to develop algorithms for Simultaneous Localization and Mapping for the navigation and locomotion of mobile robot.
D2	**Sub Area** — **Control & Guidance (VSSC)**
D 2.1	**Rendezvous and docking (VSSC)** To achieve docking during the final phase of the mission, the relative position and velocity of the target spacecraft and chaser spacecraft has to be brought to zero. To ensure proper alignment of the docking port, the relative angular orientation needs to be precisely aligned. Moreover, relative angular rate of the target and chaser are to be very close to zero for successful docking. Simultaneous control of the translational and rotational dynamics is required to achieve the docking conditions.

D3	**Sub Area**	**Simulation (VSSC)**
D 3.1	**Multi-body dynamics simulator (VSSC)** Launch vehicle simulations require solving multi-body dynamics for addressing scenarios such as space transportation missions, crew module ejection, stage separation, booster/ strap-on separation, satellite separation etc. All individual bodies having its own inertial systems and are bound to possess independent mass-inertia characteristics, propulsion systems, aerodynamic properties, guidance and control algorithms, control power plants etc. Simultaneous solving of translational and rotational dynamics for each body (during ascent and descent phase) is required with real-time plotting of trajectory parameters and other critical states. Software model can follow modular or component architecture whereby system modules can be plugged in and used as required.	
E	**Area**	**Materials and Metallurgy (VSSC)**
E1	**Sub Area**	**Foundry Technology (VSSC)**
E1.1	**Solidification behavior and grain refinement of cast superalloys (VSSC)** Superalloys are used for making many cast components used at turbine side of the turbo-pumps. Investment casting is the process used for making these components. Grain coarsening happens due to inherent slow cooling involved in the process. Suitable grain refinement techniques are needed to control the grain size for better fatigue and strength properties and weldability. Detailed study is envisaged to understand the solidification behavior, homogenization parameters and ageing characteristics for the Ni-base and Ni-Fe base superalloys.	
E1.2	**Development of Ultrasonic technique for locating casting defects (VSSC)** Many critical components are made through casting route. Complex castings get few unacceptable defects which are to be repaired through welding. It is necessary to locate the defect precisely in the wall of the casting to avoid unnecessary gouging. Ultrasonic technique can be very effective in this regards. But due to cast structure low frequency probes only can be used. Also response of the cast material is not good to Ultrasonic testing. Considering these limitations a suitable technique/procedure is to be developed for defect detection using UT.	
E1.3	**Development of Cast components in high entropy alloys (VSSC)** High entropy alloys are considered as a future material due to exotic combination of properties. Considering the issues in the deformation of these alloys during working, it is required to evaluate these alloys for making cast components. It is required to finalize few alloys and evaluate their properties after casting and heat treatment.	
E1.4	**Effect of processing parameters on cryo impact properties of cast alloys (VSSC)** Many alloys are used in form of castings at cryo temperatures. Under this project proposal, it is envisaged to evaluate cryo-temperature properties, particularly impact properties at cryo temperatures and to study the effect of heat treatment on different phase and cryo-properties. Materials (04X and 08X) shall be provided by VSSC in the form of test bar.	

E1.5	**Optimization of Heat treatment parameters & characterization of super alloys (VSSC)** Various cast superalloys (XH43, IN 718, XH62, and XH67) are being used in our space programme. It is necessary to take up extensive studies on characterization of these superalloy and optimization of heat treatment parameters and compositions for better performance. Material for heat treatment studies shall be provided by VSSC in the form of test bar.
E1.6	**Simulation of SLM (Selective Laser Melting) process for prediction of defects and parametric control in printing of components (VSSC)** Selective Laser Melting is process for making complex shaped components in very less time. Process optimization and modeling is very important for improving reliability of the process. Models should be based on thermal imaging of the melting passes and should be able to predict the effect of parameters on discontinuities in the product.
E1.7	**Design of alloys for powder base additive manufacturing processes (VSSC)** Powder base additive manufacturing processes involves high solidification rates. It can lead to design of new alloys which cannot be processed through conventional processes but can be processed through SLM/LENS process into a component. It can lead to development of component in alloys with exotic properties and significant weight saving. Under this project, few alloys can be selected for light weight, high strength, stiffness for light weight and high temperature capability.
E1.8	**Modeling of solidification for various cast alloys (VSSC)** Cast alloy solidification modeling should aim for prediction of the solidification modes, different phases and shrinkage characteristics for different cooling rates. It shall also aim to get details like effect of various parameters on fluidity of cast alloys.
E2	**Sub Area** — **Welding Technology (VSSC)**
E2.1	**Improving tensile properties and controlling of residual stresses in 2219 and 2014 aluminum alloy FSW weldments by laser shot peening (VSSC)** Friction Stir Welding is considered as potential welding processing to realize aerospace hardware without hot cracking and porosities. The scope of work is to improve the mechanical properties of Al alloys (2219 and 2195) FSW welds by laser shot peening. Data shall be generated on the effect of laser shot peening on tensile properties and residual stresses in weldments. FSW welded plates will be supplied by VSSC.
E2.2	**Brazing of alumina to metals using reactive brazing foils (VSSC)** Generally, a layer of Mo-Mn and Ni coatings are provided on the ceramic (Al2O3) substrate to enhance the wettability. Alternatively, Active Braze Alloys (ABAs) can be used for metal-ceramic brazing easily by eliminating complicated metallization process. These ABAs contain some titanium, which activates or reacts with the surface of the ceramic base material facilitating good wetting. Metals to be bonded are Kovar, copper, and molybdenum. Study involves selection of suitable ABAs and optimization of brazing process. Scope also includes extensive characterization of brazed samples as per AWS guidelines. VSSC can extend vacuum brazing support.

E2.3	**Magnetic Pulse Welding (MPW) of AISI 321 stainless steel to AA2219 Aluminium alloy (VSSC)** Solid state welding processes are widely used to join dissimilar materials like stainless steel and aluminum alloys. MPW, a recent addition to the family of solid-state welding processes has enormous potential over the conventional explosive bonding to produce bimetallic adaptors (AISI 321/AA2219). Scope of the work involves design, analysis, fabrication, and demonstration of suitable magnetic coils and field shapers to realize bimetallic adaptors of various sizes. Realized bimetallic adaptors have to be subjected to extensive pressure and leak test at ambient and LN2 temperatures. The scope of study also includes detailed mechanical and microstructural investigation of the weld joints. Materials (AISI 321, AA2219, Cu alloy for coil) of the trials can be supplied from VSSC. VSSC can also extend support for pressure and leak test.	
E3	**Sub Area**	**Materials Processing (VSSC)**
E3.1	**Development of NDT technique to evaluate bond quality of explosive welded AA2219/SS321 bimetallic joints (VSSC)** Explosive welded SS321 stainless steel and AA2219 aluminum alloy bimetallic joints (pure Al OR pure Cu as interlayer) are being used for cryogenic application. Detailed characterization of joint interface viz. AA 2219+pure Al/Cu and SS321+pure Al/Cu needs to be carried out which includes (i) Establish NDT technique to evaluate the interface quality and validate w.r.t He-leak test (ii) NDT result correlation with mechanical properties, microstructural features.	
E3.2	**Development and characterization of hexagonal phase boron nitride powder through chemical route (VSSC)** Hexagonal phase boron nitride powder is being used as raw material for metal matrix composite seals towards realization for space borne components. The objective of the proposal is to develop a process technology through chemical route and characterization for phase purity, average particle size, particle size distribution etc.	
E4	**Sub Area**	**Materials Characterisation (VSSC/LPSC)**
E4.1	**Secondary electron measurement of BN/Silica composite for electric propulsion application (VSSC)** Secondary electron emission characteristics of the discharge chamber wall material have a significant role in determining the plume characteristics and hence the thruster efficiency of stationary plasma thruster for electric propulsion. Measurements to quantify the secondary electron emission from BN/silica are very important to select the wall material. At present BN/silica composite is being used as wall material for ISRO's electric propulsion system. Understating the variation of secondary electron emission with varying the silica content of the composite will help to select the appropriate composition of the composite material as discharge chamber wall.	

E4.2	**3D atom probe analysis of precipitates in age hardenable aluminium alloys (VSSC)** Three-dimensional atom probe (3DAP) is an established tool for the identification of size, volume fraction and location of specific elements or fine strengthening precipitates in materials. The aim of this project is to study the precipitates in high strength aluminium and aluminium-lithium alloys of aerospace grades. The changes in the sub-microstructure by the effect of thermo-mechanical processing on these materials and role of minor element additions have to be studied. Al alloys will be supplied by VSSC.
E4.3	**Development of space radiation resistant materials (VSSC)** Exposure of critical and vital components of spacecrafts to external radiation leads to degradation of the properties of the structural and electronic materials, thereby jeopardizing the flightworthiness of the spacecrafts. Hence it is critical for the identification of significant property changes induced as a result of the radiation exposure in the aforementioned materials. The purpose of this project is to develop and understand the radiation effects on the physical, mechanical, thermal and optical properties of materials (metallic and composite).
E4.4	**Development of ultrafine grained magnesium alloys by friction stir processing (VSSC)** Magnesium alloys are widely used for light weight applications in satellites and launch vehicles for electronic housings. Friction stir processing is an advanced materials processing technique by which grain refinement can be obtained in both cast and wrought alloys leading to improvements in mechanical strength. The objective of the present project is to develop ultrafine grained magnesium alloys through friction stir processing.
E4.5	**Studies on hydrogen permeation and trapping in high strength steels (VSSC)** The deleterious effect of hydrogen on the mechanical behavior of high strength steels is well known. The hydrogen embrittlement resistance is closely related to the microstructural features such as dislocation density, grain boundary, carbides and inclusions. These features are generally classified as diffusive, reversible and irreversible traps. Understanding the influence of these traps on the HE resistance of steel materials is very important towards improving the microstructure with improved HE resistance. On this aspect, hydrogen permeation and Thermal Desorption Spectroscopy (TDS) are widely used for obtaining quantitative information on the hydrogen effect on steels. The purpose of this is to study the HE resistance using the above techniques.
E4.6	**Development of graphene reinforced zinc rich nano composite coating for the corrosion protection of aluminum alloys (VSSC)** In recent years, graphene and graphene oxide reinforced polymer coatings have attracted several researchers for the fabrication of high performance polymeric coatings with enhanced thermal, mechanical and corrosion properties. There is growing interest in using graphene reinforcement with Zn rich coatings towards obtaining efficient cathodic protection as well as improved barrier properties. Hence it is of interest to develop modified Zn rich coating with graphene reinforcement and to study its corrosion properties using DC and AC electrochemical methods to be used for light alloy structures of aerospace industry.

E4.7	**High temperature oxidation behavior of laser coated NiCrAlY bond coating on Ni-base alloys (VSSC)** Ni based superalloys are being used in the aerospace industry for high temperature structural applications. In order to use them for high temperature applications, a coating system consists of a Bond Coat (BC) and a Thermal Barrier Coating (TBC) is fabricated over the alloy through plasma spray coating or other methods. The overall oxidation resistance of the coating depends on the preferential formation of alumina coating between BC and TBC. Recently, BC fabrication using laser aided manufacturing (LSM) has been reported with improved properties. Hence there is interest towards using the above method of coating and to examine the oxidation resistance and mechanical properties of the coating for Ni base alloys in the aerospace industry.
E4.8	**Quantitative analysis of environmental assisted cracking behavior of high strength steels using direct current potential method (VSSC)** High strength steels are being used in the aerospace industry for the fabrication of pressure vessels and their weldments. The susceptibility of steels and their weldments need to be evaluated through crack growth measurements and threshold stress intensity (K1scc) based on fracture mechanics concept. Although qualitative analysis using constant load and slow strain rate techniques are being used for stress corrosion cracking tests, quantitative information by dynamic methods using Direct Current Potential Drop (DCPD) is needed towards characterizing the alloy resistance to environment cracking behavior in marine environment
E4.9	**Development of environmentally friendly conversion coatings for the corrosion protection of aerospace grade aluminum alloys (VSSC)** Anticorrosion pretreatments such as chromate conversion coatings are widely used for the corrosion protection of aluminum alloys in the aerospace industry. However, the toxicity and carcinogenic nature of hexavalent chromium is strictly prohibited globally. Hence there is growing interest towards developing environment friendly alternate coatings and to explore the corrosion resistance for light alloy structures.
E4.10	**Room and elevated temperature fretting wear behaviour of superalloys (VSSC)** Materials subjected to fretting at room temperature and elevated temperatures are subjected to premature failure than regular fatigue or friction. The brief scope of the study is as follows a) Evaluate the amount of material removal as a function of force, temperature and the amplitude. b) Test temperature can be from RT to at maximum of 600 °C. Temperatures upto 800 °C if possible is also can be considered in this study. c) Evaluate the metallurgical factors that influence the fretting characteristics. d) Research outcome: research outcome is to develop a model as the function of above variables to predict the fretting wear. e) The materials to study are XH42 and XH53 alloys. VSSC will provide the raw material. f) Heat treatment conditions is standard aging cycle and standard brazing cycle, VSSC will facilitate the heat treatment of coupons. g) Specimen fabrication and surface preparation is in the scope of responding agency.

E4.11	**Evaluation of Mixed mode fracture toughness of high strength aerospace materials (VSSC)** Structures commonly experience mixed mode fracture in real engineering applications. Mode I fracture properties are significantly used in engineering calculations since it is worst case scenario. However, knowledge of mixed mode fracture characteristics of materials will enable designers to decide the actual margins in actual engineering applications. The scope of the study is as follows a) Evaluate Mode I and Mode II, Mode I and Mode III stress intensity factors with different ratios. b) Evaluate Pure Mode I, Mode II using novel specimen and fixture technique. If possible, pure Mode III also can be evaluated. c) Study the influence of mixed mode using classical and FEM models and that of the experimentally evaluated. d) Make scientific/Engineering assessment and correct the FEM by appropriate factors based on experimental data (if applicable) e) The material proposed to study are Maraging steel (M250) and ESR15CDV6 both parent and weld. Material and welded coupons for the study will be provided by VSSC. f) Responding agency is requested to use minimum quantity of material as it is scarce. g) Specimen design, fabrication, fixture design and fabrication, testing, data evaluation, metallurgical analyses are in the scope of responding agency.
E4.12	**Material behaviour at hot hydrogen environment (LPSC)** Gaseous Hydrogen embrittlement of metals and alloys are possible at ambient to 200°. In order to avoid this, new alloy design which is compatable with hydrogen is required . Existing alloys shall be given coating which is not permeable for hydrogen.
E4.13	**Fracture behaviour studies of rocket engine materials for cryogenic application (LPSC)** This study plans to address the fracture behavior of aluminium and titanium alloys used in pressure vessel materials in rocket engines. The behavior of this sections containing part through cracks under tensile stresses is to be explored at ambient and cryo temperatures through tests and simulations.
E5	**Sub Area**	**Cryogenic applications (LPSC)**
E5.1	**Physical property measurement at low temperature up to 20K (LPSC)** Physical properties like modulus,thermal, electrical and expansion/contraction measurement are mandatory requirement for all materials used upto 20K.
E5.2	**Development of materials/alloys including coatings for high pressure oxygen environment (LPSC)** New alloys or coatings for existing materials are required handling high pressure oxygen. Coatings can be of nobel metals whose oxides are unstable or ceramic coatings which will be never ignited in high pressure oxygen. New alloys should have very high ignition temperature so that it will ignite in normal operating temperature.

E5.3	**Development of thermal barrier coating with Nano materials (LPSC)** Using Nano materials, TBC can be made with superior mechanical properties as compared to conventional powders. Even with air plasma spraying Nano powdered TBC shows mechanical properties similar EB-PVD.	
E6	**Sub Area**	**Welding (LPSC)**
E6.1	**Development of Vacuum Brazing Technique for joining carbon fiber reinforced Silicon Carbide (C-SiC) to Columbium and C-SiC to Titanium (LPSC)** C/C composite are proposed for an alternative for the existing Columbium chamber for Satellite engines on ground on higher temperature resistance property. The present design of satellite engines, uses titanium alloy injector welded with columbium chamber. When the chamber is replaced by CC composite, to have a joint with titanium alloy, different mechanisms have to be ventured into. Vacuum brazing is one of the route which seems to be feasible. Different braze materials like TiCuSil, Ti Cu Ni etc can be used as filler materials. The development of brazing joint of these dissimilar materials to have a flange free joint is to ventured into. The physical and thermal properties of the joint has to match both the materials to have the safe operation which has to be characterized after joining.	
F	**Area**	**Composites (VSSC)**
F1	**Sub Area**	**Modelling of CC Composites (VSSC)**
F1.1	**Inelastic finite element model of multidirectional carbon-carbon composites to predict the material characteristics and behaviours (VSSC)** Multidirectional C-C composites (3D, 4D) are composite material wherein the reinforcing fibres act as reinforcement at various directions. 4D C-C composites has found successful applications in solid rocket nozzles especially as ITE's. The material behaviour of nD C-C composites are highly anisotropic and shows nonlinear elastic behaviour. Most of the work carried to assess the behaviour of multidirectional C-C composites is evaluated through destructive testing, hence limited data is generated for the mechanical properties. In this limited work has been carried to theoretically predict the mechanical behaviour of the material and corresponding material properties associated with this class of material. Since at VSSC, nD C-C composites are envisaged to have application as SRM throat inserts and also as TPS material for certain applications, it is planned to initiate the micromechanical model studies to theoretically predict the material behaviour vis-a-vis the mechanical properties. Scope of work includes development of an elastoplastic finite element model, including homogenised mono-axial stiffness that can predict the material properties as has been referred in literature and, available tested material properties.	
F1.2	**Process optimization of isothermal CVI process (VSSC)** One of the most promising and common methods of fabrication of thinner Carbon-Carbon & Carbon-Silicon Carbide Composites is through vapor phase densification of porous structure of carbon fibers acting as reinforcement. During CVI process, the hydrocarbon	

	gases or vapors of silanes decomposes to produce the desired carbon /Silicon carbide matrix within the pores of the preform and thereby increases the density. The density aimed after the final densification is based on the targeted mechanical and thermal properties required for the specific use of application of the product. Practically, the major hindrance of realisation of C-C/ C-SiC products through CVI process is the long processing duration required to achieve the desired density. Furthermore the process must be intermediately interrupted to permit surface machining or heat treatment at high temperature in order to open the pores for further densification. Scope of work includes development of a comprehensive numerical modelling to simulate and optimise the processing parameters to achieve the required density and also to reduce the long process duration
F2	**Sub Area** — **Composite Materials / Process Development (VSSC)**
F2.1	**Development of C-SiC composite through CVI using Mono-Methyl-Silane (VSSC)** Carbon-Silicon Carbide is considered as an ideal material for future Thermo-Structural applications, considering the various advantages offered by the material. SiC matrix is derived presently using Methyl-Trichlo-Silane, having drawbacks in due to high corrosive nature of the chemical and by-products of chlorides which are formed during the process. To meet the future requirements of C-SiC composites and also to provide SiC coating over Carbon-Carbon Composite products for various space applications, it is envisaged to use Mono Methyl Silane (MMS) as precursor for Chemical Vapour Infiltration/Deposition method. MMS is considered to be advantageous compared to other MTCS and Silane precursors, considering the chemical nature (Low Molecular Weight), processing under low temperature (~800 0C) and being less hazardous, non corrosive and non toxic. The scope of work in this program includes the following: • Development of process Technology to provide SiC coating on C-C product through CVD using MMS as a process precursor. • Development of process technology to densify Carbon preform with SiC matrix through CVD using MMS as a process precursor. • Evolve details of storage, handling and usage of MMS for CVI and CVD processes.
F2.2	**Noble metal coating over Carbon-Carbon composite (VSSC)** Carbon-Carbon Composite materials are coated with SiC to protect from oxidation when the applications temperature is higher than 4000C. However due to numerous applications of the material above 17000C, development program to coat Carbon-Carbon Composite with Noble Metals is initiated. Also during thermostructural applications which demands leak tightness of C-C products like C-C combustion chamber, coating of Iridium on C-C composite is considered to be an ideal solution. Iridium (Ir) is considered as promising candidate for oxidation resistant materials at elevated temperature due to its high melting point (2430 0C), good chemical stability, low oxygen permeability, impermeability to gases, good chemical compatibility and low carbon solubility below the eutectic temperature of 2100–2300 0C. Considering the various merits offered by electrodeposition (ED) method for coating, it is proposed to develop the coating of Iridium (Ir) on Carbon Carbon (C-C) Composite through ED. Also to overcome the problem of CTE mismatch between C-C and Ir, interlayer coating of Rhenium shall be provided through the same methodology.

	Scope of Work: • Development of Coating Methdology of Iridium on Carbon-Carbon Composite Samples through electro deposition. • Development of Interlayer Coating of Rhenium through electro deposition. • Microstructural & Compositional Characterisation of Coating. • Demonstration of the process on various geometries (Conical & rectangular).
F2.3	**Out of autoclave processing of prepreg based fibres reinforced composites (VSSC)** Conventionally composite products for satellite structure applications are realised by Autoclave curing Processes. The prepreg layup is completed on a tool/mould under room temperature conditions. The curing is completed under higher temperatures of the order of 1750C.The inherent disadvantage of this process is the likely curing stresses induced in the composite part. Scope of work includes development of prepregs which can cure under UV light OR using conventional prepregs but curing outside autoclaves using more energy efficient methods.
F3	**Sub Area** — **Composite Process Modeling (VSSC)**
F3.1	**Composite process modelling – to capture warpage, shrinkage,spring back, and other moisture/curing induced deformations of Autoclave Cured - Prepreg based Fibre Reinforced Composites (VSSC)** Composite products for satellite structure applications are mostly realised by Autoclave curing Processes. The prepreg lay up is completed on a tool/mould under room temperature conditions. The curing is completed under higher temperatures of the order of 1750C.The product is cooled to room temperature before extraction. The high temperature curing and the cool down back to room temperature induces curing stresses in the composite part. After extraction from the tooling these stresses along with the inherent anisotropy of the composite manifest itself in the form of warpage/shrinkage ,spring back and other deformations of the composite part. A detailed model need to be worked out to capture and predict such behaviour - especially for regular geometries like Flat , Conical, Paraboloid , C shaped , L shaped & Tubular sections (round/square/ rectangular cross sections)- considering anisotorpy of the composite as well.
F3.2	**Hydroclave cure modelling of phenolic composites (VSSC)** Carbon-Phenolic and Silica-Phenolic composites are widely used for ablative thermal protection of rocket nozzles and re-entry bodies. Condensation cured Phenol-Formaldehyde resin used in these composites because of its higher char yield. The prepreg is cut into tapes and wound on mandrels to get the required geometry. Typically, the thickness of these ablative composites are considerably higher which requires curing in Hydroclave at pressures in the range 30 to 70 bar to get defect-free products. Also, long curing cycles are employed to keep thermal gradients lower. A detailed cure model is essential to optimize the curing cycle. The scope of the proposed research work is to develop a thermal-chemical pressure model for the curing of Phenolic composites in Hydroclave to get defectfree products.

	The model should provide optimum temperature and pressure cycles for the given cure setup, with a user friendly interface. Evaluation of the required material properties for the resin/reinforcement being used by VSSC is also part of the scope of work.
F3.3	**Modelling of resin transfer molding of benzoxazine resin in carbon perform (VSSC)** Benzoxazine resin is a potential candidate for ablative application, which is also amenable for Resin Transfer Molding (RTM). RTM process has established itself as a cost effective method for producing good quality composite parts. Prediction of flow patterns of the resin in the preform is essential to identify the locations for placement of injection and vent ports. The scope of this research work is to develop mathematical model for RTM of Benzoxazine resin in Carbon preform. The preform will be either stack of bidirectional woven fabric, needled felt of a multi-directional preform. The evaluation of required material properties is part of the scope of work. The developed model should provide inputs for the placement of injection and vent ports for complete filling of the cavity and pressures required for getting defect-free products.
F4	**Sub Area** — **Structural Health Monitoring (VSSC)**
F4.1	**Structural health monitoring of composite structures using optical fibres with bragg grating sensors (VSSC)** Optical fibres with Bragg Grating sensors are the leading candidate technology for Structural Health Monitoring (SHM) since they have minimal mass penalty for extremely large numbers of sensors. There are many advantages like compatibility with the composites, low Electro Magnetic Interference (EMI), multiple sensing capabilities with a single fibre etc. This sensor technology will be useful in present as well as our future launch vehicle applications. Scope: Supply of optical fibres with Fibre Bragg Grating (FBG) sensors inscribed, at required locations. Support for embedment/surface bonding of sensors for subsurface/surface strain monitoring of composite components. Demonstration of strain and temperature sensing with data recording in a computer on specimen and component levels. Development of interrogation techniques for multiple Fibre Bragg Grating sensors embedded in a single fibre.
F5	**Sub Area** — **Piezoelectric Actuators (VSSC)**
F5.1	**Piezoelectric actuators for position/shape control applications (VSSC)** Piezoelectric materials produce voltage when stress is applied. This effect is also reversible in manner, i.e. a voltage across the sample will produce stress within the sample. Because of this reversible property, piezoelectric materials can act both as sensor as well as actuator. Piezoelectric actuation can be used in precision (small strain, fast response time) applications. One application envisaged is the precision position control of mirrors used in optical structures of satellites. Scope of work is development and demonstration of closed loop control algorithm for precise position control of an object mounted over a tubular composite tripod structure.

F6	Sub Area	Modelling and Study of Large Antenna (VSSC)
F6.1	**Geometric, kinematic and finite element modelling of large deployable/ inflatable/ unfurlable structures in space (VSSC)** Large antenna reflectors and other structures are being used in increasing numbers for satellite applications. The sizes range from dia.5.0m and upwards to 20.0m.During Launch phase these reflectors will be stowed so that launch envelope interfaces requirements are not violated. In space these structures get deployed by suitable mechanism of energy release like inflatables, Unfurlable ,Unfoldables etc. Scope of work includes development of a suitable model need (a) To capture Geometry of these structures in space (0g condition) and in ground (1g condition) (b) To capture and model the kinematics of the members /linkages involved and (c)Finite element modeling of the structure to capture its dynamic, Static and Thermal distortion behaviour under space conditions.	
F7	**Sub Area**	**Assessment of Composite Structures (VSSC)**
F7.1	**Nano meter level measurement and assessment of space composite structures (VSSC)** An increasing demand for high-quality, low cost Earth imagery has led to the requirement for improved structural stability of the satellite instruments providing the imagery. This translates into camera structures capable of maintaining very high levels of dimensional stability order of few micron (<10μ) for a length of 1m over their lifetime. CFRP is one of the materials for dimensionally stable space structures. The “theoretical” zero CTE is only approximated as well as the manufacturing precision allows. So in ultra stable structure where micron level dimensional stability is required, there is an need for quantitative assessment of the magnitude of change in dimensions. Scope of work includes nano meter level measurement setup with all associated analytical software and hardware fully integrated, meant for specimen level as well as assembly level evaluation of the payload and camera structure.	
F8	**Sub Area**	**Shape Memory Composites (VSSC)**
F8.1	**Development of shape memory composite reflector antenna (VSSC)** Shape Memory Composites (SMC) are a sub set of the broad class of Smart Materials namely shape memory materials. Shape memory effect in materials is essentially the capacity to recover a “ memorized” strain rate upon application of external stimuli like heat, light, moisture ,magnetic ,electric field etc. Shape Memory Polymers (SMP) are a group of polymeric materials which are capable of recovering the memorized shape when triggered by an external stimulus. Unreinforced SMPs have much lower stiffness and recovery potential ,however in combination with a reinforcement (fibers,fabrics,and mats made of Carbon,Glass and Kevlar) the mechanical properties of SMPs remarkably increase. Composites of SMPs with high performance reinforcing fibers find use in self deployable structures for spacecraft applications. SMPCs used for such applications are also called Elastic Memory composites.	

	These composites can be compacted on earth, stored in a compact shape ,and then self-deploy in space. Applications include support structures for telecommunication subsystems. Scope of work includes development and demonstration of SMP Composite for a paraboloid reflector of 1m diameter with a stowage volume of ~25%.
F9	**Sub Area** — **Composites 3D Printing (VSSC)**
F9.1	**Development of automation head for 3D printing of continuous fibre composites (VSSC)** Fibers used as reinforcement in high strength/high-performance Composites application are primarily long fibres. Their one-dimensional nature make them amenable for automation methods such as filament winding and fiber placement. However, the use of thermoset resin warrant a mandrel or support structure during processing. With recent developments in 3D printing using thermoplastic resins, time is ripe to jive the high-strength long fibers with thermoplastic or similar resin system, to 3-D print Composite products. Attempts of infusing short fiber as chopped strands in the existing 3D print filaments, marginally improves the resin capability but nowhere near the continuous fiber based composite products. R& D efforts are already on by many groups (ex. Owens-corning with Kuka) towards the long fiber based print process. Scope of work is to realize a winding head that can be mounted to a robotic system or similar mechanism, that can dispense long fibers (carbon, glass or aramid), impregnated with thermoplastic resin, for free-form (without mandrel) material deposition. Alternate resin system shall also be explored, but with capability to be in-situ cured instantaneously to facilitate uninterrupted 3D printing.
G	**Area** — **Tranducers and Sensors (LPSC)**
G1	**Fibre optic sensors (LPSC)** Fiber optic technology based sensors need to be developed for sensing of pressure, temperature, level, flow rate etc. for the propulsion systems of launch vehicle. Distributed sensing of strain and temperature over structures using Fiber Bragg Gratings (FBGs) need to be realized. Cost effective interrogator units are required to be developed with lesser weight. Multiplexing of sensors using fiber technology is another area of importance.
G2	**O2 & CO2 gas sensors and development of graphene based sensors (LPSC)** Graphene is one of the potential materials which can be used for sensing applications. There is a need for measuring different gases like O2, CO2 etc. for human space flight where the environment of the crew module has to be carefully monitored and controlled. Development of gas sensors based on graphene need to be explored for this purpose as they have lesser weight, faster response, low power consumption etc.
G3	**Development of nanotechnology based pressure & strain sensors (LPSC)** Various nano material and nano structures like ZnO, MoS2, Carbon Nano Tube (CNT), graphene etc. can be used for strain/pressure sensing. Selection of suitable substrate,

	nano material/structure synthesis, characterization etc. are envisaged. Sensors based on nano technology is to be developed for measuring pressure of propellant and gases in the range 1 bar to 1000 bar.
G4	**Development of nano technology based gas sensor (both presence & % quantity) (LPSC)** Gas sensors need to be employed in various facilities and space systems to monitor either presence or leak of gases. Monitoring of gases like H2, CO, CO2, NO2, O2 etc. (both presence and quantity) is mandatory in various space systems. Development of Nanostructures of various metal oxides for gas sensing need to be attempted. Feasibility of an array of multiple element gas sensors on a single substrate using nano fabrication technique may be attempted.
H	**Area** — **Structures and Fabrication (VSSC/LPSC)**
H1	**Sub Area** — **Structures and Fabrication (LPSC)**
H1.1	**Experimental evaluation of damping in fluid conveying pipelines immersed in fluid environment (Both theoretical empirical relation & Experiments) (LPSC)** Most of the pipelines carrying fluids are immersed in fluid environment. To design these properties, the damping is very important parameter. In order to evaluate the effect of added mass on frequency viscosity on damping, it is envisaged to design a vibration test setup to carry out experiments. By doing experiments it is proposed to evaluate dynamic behaviour of pipelines immersed in fluid.
H1.2	**Crack growth studies in propellant tanks through experiments & theoretical modelling (LPSC)** This study plans to address the fracture behavior of aluminium and titanium alloys used in pressure vessel materials in rocket engines. The behavior of this sections containing part through cracks under tensile stresses is to be explored at ambient and cryo temperatures through tests and simulations.
H1.3	**Electrical Discharge Machining/ Die Sinking (EDM) (LPSC)** Optimization of machining parameters for machining of following super alloys: Titanium Ti6Al4V, Inconel 600 / 718, Hynes-25, Molybdenum, Columbium 103.
H2	**Sub Area** — **Experimental Mechanics (VSSC)**
H2.1	**Identification of type of failure from global Acoustic Emission (AE) data using ANN/ clustering approach (VSSC)** AE monitoring is being used for the integrity evaluation of various flight hardware during their proof pressure test for example Titanium alloy Gas Bottles, Aluminium alloy Prop Tanks, Maraging steel and 15 CDV6 chambers etc. Implementation of an automated AE analysis on the stored data with ANN/Neural Network for the integrity evaluation of the hardware helps in reducing the total dependence on human expertise and speed up analysis. The AE corresponding to different failure types have to be segregated using

	ANN. This is to be compared with AE from the test results of similar hardware tested with PAC AE DAQ system which can be made use of in training the algorithm.
H2.2	**Background noise elimination from global acoustic emission data to segregate genuine Acoustic Emission (AE) signature corresponding to defects using Spectral content analysis or any other advanced technique (VSSC)** In online AE monitoring, differentiating the genuine AE signals from pneumatic pressurisation noises is a big problem for the real time AE evaluation of flight propellant tanks during pressure tests. This is especially troublesome in case of pneumatic pressurisation. Due to the noise, the initiation of any defects like crack, yield etc. is difficult to be identified during the pressurisation / loading phases. Since some of the noise signals are similar to genuine AE signals, identifying these noise signals in real time is a tedious job. Implementing a criterion for online filtering of these noises using Spectral content analysis or any other advanced technique making use of previous test data is the need of the hour. This can help in monitoring the health of the hardware during pressurization time and help in averting failures.
H2.3	**Development of online Acoustic Emission (AE) instrumentation for proof pressure test of titanium alloy gas bottles at cryo and elevated temperature (VSSC)** Presently AE monitoring is being used for the integrity evaluation of Ti alloy Gas Bottles during their Room Temp proof pressure test. Implementation of AE instrumentation suitable for CRYO Temp/ elevated Temperature of Ti alloy Gas Bottles is expected to help the integrity evaluation of the Ti-alloy gas bottles using AE for flight use.
H2.4	**Through thickness measurement of non-uniform residual stresses in metallic components with sufficient resolution for aerospace applications (VSSC)** The current technique of incremental hole drilling technique measures the residual stress to a depth of 2mm only. The development envisaged is the implementation of an accurate method for measuring residual stress through thickness for metallic materials for thickness more than 5 mm to 10 mm with a resolution better than 10 MPa. Use of a combination of different techniques also can be pursued.
H2.5	**Development of an algorithm and codes for measurement of non-uniform residual stresses in composite components using the method of incremental hole drilling (VSSC)** The current technique of incremental hole drilling technique measures the residual stress to a depth of 2mm only in metallic materials. With analysis methods like integral method the results are available for a depth of less than 1 mm only. The development envisaged is the implementation of an accurate algorithm including codes for measuring residual stress in composite materials for thickness up to 2 mm with a resolution better than 20 MPa.
H2.6	**Theoretical studies on the prediction of failure incorporating measured residual stress data to service loads in aerospace components (VSSC)** Residual stresses on parent material /weld in components can be measured through various techniques like hole drilling technique. Theoretical study on the effect of such residual stresses on the structural behaviour under service loads to predict the failure.

H2.7	**Implementation of post processing of FBG sensor data using ANN / suitable algorithms to detect failure signature (VSSC)** Strain / displ Strain / displacement / acceleration data from a network of FBG sensors mounted on a structure need to be analysed to ascertain its health. An analysis methodology has to be developed through structural models with and without defects along with algorithms to predict the life of structure through ANN like approaches.	
H3	**Sub Area**	**Structural Analysis (VSSC)**
H3.1	**Active noise control for composite payload fairings (VSSC)** Acoustic loads are one of the important environments for launch vehicles. The acoustic load transmission into the vehicle, particularly inside the heat shield needs to be attenuated for the proper functioning of satellite. The magnitude of acoustic loads transmitted to the payload is a function of external environment as well as design of payload fairing and its sound absorbing treatments. At present, passive acoustic blanket is used to reduce the internal acoustic field. The use of composite payload fairing has the advantage of reducing mass, but it has detrimental effect on acoustic levels inside the payload fairing especially at low frequencies. Passive approaches for acoustic attenuation are limited at low frequency because of sound absorption is limited in low frequencies. Active control offers an attractive approach for low frequency acoustic noise attenuation inside payload fairing.	
H3.2	**Dynamic modelling and analysis of human body exposed to vibration environment during space flight (VSSC)** In manned mission, human body may be exposed to various severe environments for a long time. This may be detrimental to life or may cause illness/fatigue to the body. One of the major environments is vibration. Therefore, it is essential to study the influence of vibration on human body and necessary to find solutions to prevent such environment. To understand the effect of vibration on human body, it is required to generate three-dimensional dynamic model of the human body and carryout dynamic analysis for human biomechanical responses. The human body shall be idealized using beam, spring and mass elements to represent the various dynamics of the body. The model needs to be validated with the available literature / test results.	
H4	**Sub Area**	**Structural Modelling / Design (VSSC)**
H4.1	**Analytical procedure for dynamic load factors of a free standing launch vehicle against gusty winds (VSSC)** During the pre-launch operation, launch vehicle standing on the launch pad confronts either steady or gusty wind. To estimate the dynamic loads due to gusty wind, generalized analytical procedure applicable to the uniform wind or power law profile wind speed varying from 5 m/s to 30 m/s with wind plane direction of 0^{o} to 360^{o} shall be developed for any configuration of vehicle in the presence of umbilical tower. The dynamic load factors for a free standing launch vehicle in the presence of gusty wind has to be generated. Wind tunnel study should be performed to validate the procedure.	

H4.2	**Health monitoring of structures using vibration data (VSSC)** Monitoring the health of a structure subjected to severe dynamic load condition is essential particularly for assessing the reusability of the structure. Health monitoring is a process aimed at providing accurate information concerning the structural condition and performance. It consists of continuous or periodic recording of representative parameters like vibration measurements over short or long duration. The measured responses can be used for assessing the damage of the structure, if any. Damage can be defined as changes introduced in the system that adversely affects its current or future performance. The damage will alter the stiffness, mass or energy dissipation properties of a system, which in turn alter the measured dynamic response of the system. From these vibration measurements, the health of the system can be assessed. Damage detection and health monitoring scheme have to be developed for aero- space structures using vibration data. The scheme includes data acquisition, feature extraction and information condensation and statistical discrimination of features for health monitoring of structures.
H4.3	**Development of analytical techniques for the design of impact resistant structures (VSSC)** In the future missions of ISRO like reusable launch vehicles, human space flight, etc., the structural components will be subjected to impact loads during orbital and landing operations. These structures should be designed with highest probability of human, package and critical component survival. Design and analysis methodologies including structural, material and environment modelling needs to be established for effective design of impact resistant structures. Analytical methodologies to assess response of human body and critical packages to impact load needs to be developed.
H4.4	**Development of advanced element types (VSSC)** VSSC/ISRO is developing indegeneous finite element software. The software has to be further enhanced in terms of various finite element types. This project is proposed for the formulation and implementation of cable element, damper element, elements for modelling joints, pipe element and elements for delamination studies. The source code can be in Matlab or C++ programming language.
H4.5	**Development of adaptive finite element method (VSSC)** VSSC/ISRO is developing indegeneous finite element software. The software has to be further enhanced with adaptive finite element method. This project is proposed for the formulation and implementation of adaptive mesh modification schemes and error estimation methods. The source code can be in Matlab or C++ programming language.
H4.6	**Prediction of structural response due to Pyro-shock (VSSC)** Establishment of numerical approach/methodology for predicting pyroshock induced response on the launch vehicle and package locations. The approach shall be capable of simulating the elastic wave propagation phenomena in 1D, 2D and 3D environments

	accounting for the attenuation due to material and structural discontinuities, joints, lumped masses, shock absorbers, etc. The method shall be capable of modelling isotropic, honeycomb and composite materials. Different numerical approaches are to be considered to predict the near, mid and far field shock environment to cover the entire frequency range considered for package qualification. This is required to predict the response at critical locations on the launch vehicle and packages due to various separation induced shocks.
H4.7	**Development of Isogeometric elements (VSSC)** Isogeometric Analysis (IGA) uses Non-Uniform Rational B-Splines (NURBS) applied extensively in computer aided design (CAD). Adopting IGA will reduce the time taken from design to analysis phase. IGA technique involves change of basis functions of an element currently followed in a finite element software. A project proposal is invited for developing elements based on IGA for enhancing indigenous finite element software.
H4.8	**Development of fast and efficient iterative linear/eigen solvers for large order sparse systems on parallel computing platforms (VSSC)** The solver should be compatible for Finite element system matrices for computing deformations and extracting eigen values efficiently. The computing platform should be a distributed parallel systems suitable for HPC cluster. The program should be developed in C++ and use threading and multiprocessing for job distribution.
H5	**Sub Area** — **Structural Testing (VSSC)**
H5.1	**Development of a noise-canceling headphone using active noise control (VSSC)** Noise cancelling headphones reduce unwanted ambient sound or acoustic noise using Active Noise Control (ANC). This involves using a microphone placed near the ear, a signal processing circuitry which generates an 'antinoise' so that the noise within the enclosed volume is cancelled. This is useful for an operator working in noisy environment such as vibration test facility, machine floor etc. The cancellation may be achieved using filtered X-LMS algorithm using some DSP processor. The minimum requirement of sampling is 12KHz with cut-off frequency of 5KHz. The required reduction is 40dB in the band of 100Hz to 2000Hz. The system should operate in battery and the electronics should be miniaturized and kept inside the headphone.
H5.2	**Control algorithm for multi axial vibration testing (VSSC)** Vibration testing is done to ensure that the flight structures and system will work satisfactorily in its service environment. In conventional vibration testing the vibration in each axis is separately simulated using single axis shakers using vibration controllers. But to simulate the actual vibration condition in flight, techniques to be developed to excite the structure in all the three axes simultaneously using three shakers in mutually perpendicular axes. For this a special vibration controller to control all the three shakers is required. The proposed work is to develop the control algorithms for sine and random multi shaker vibration testing. All the required algorithms have to be developed, implemented with suitable DSPs (Digital Signal Processor) and tested.

H5.3	**Data compression technique for vibration signals (VSSC)** The measured vibration signals from launch vehicle flights contain high frequency signals upto 2000 Hz. In order to telemeter these signals to ground during flight high bit rate is required. Typically for a measurement with 8 bit data resolution with a sampling rate of 6000 samples /second, it works out as 48 kbits/second per channel. In a typical launch vehicle flight around 10 channels of vibration measurements are made which requires a telemetry bit rate of 480 kbits /second. The bit rate for the typical launch vehicle is only 1 megabit/second. Hence suitable data compression techniques are required to reduce the telemetry bit rate.	
H6	**Sub Area**	**Structural Design & Analysis (VSSC)**
H6.1	**Development of mathematical model to study the effect of residual stresses on fatigue crack growth and life estimation (VSSC)** Residual stresses are generated at weld joints during welding and local weld repairs. They significantly influence the fatigue and fracture behavior of the material. A mathematical model becomes important to study the effect of residual stresses on fatigue crack growth and life estimation. An analysis methodology to be developed for simulation of crack propagation in the presence of residual stresses. Specimen level tests shall be carried out to validate the analytical model.	
H6.2	**Damage tolerant analysis of viewport glass material (VSSC)** Viewports are very essential for viewing the surroundings in space or underwater exploration modules. Based on the kind of load acting, viewport shall be designed as flat, conical or spherical in shape. Wide range of materials are commercially used for viewport construction such as Acrylic, poly carbonate etc. which are brittle in nature. In the case of a glass viewport being sealed to a metal flange, direct contact between the glass and a mating metallic flange may produce stresses in the glass that can lead to failure during operating condition. Based on the kind of operating conditions viewport material shall be subjected to tensile or compressive stress fields. The verification of all such potential fracture critical glass components, shall include an analysis of crack growth under conditions of the stresses and the environments encountered during their service life. Both sustained stress as well as fatigue crack growth data are to be generated for these materials and fracture based design criteria established for structural components Combination of experimental and numerical methods shall be used for the extensive fracture characterization of viewport glass materials.	
H6.3	**Optimal shaping of cutout corners in non-linear range (VSSC)** Launch vehicle structures are optimized for the mass and hence are highly stressed. In this kind of highly stressed structures, rectangular cut outs are commonly used. Hence very high stress concentrations are observed in the cutout corner which is very much local in nature. If not attended properly, this zone can be cause failure initiation and further propagate to a catastrophic failure of launch vehicle. Normally designers overcome this stress concentration problem by giving liberal fillet. Useful size of fillet to overcome the stress concentration blocks the free entry of large object and defeat the purpose for which	

	the cutout is intended. There is no quantification of allowable or safe stress in this type of zones. There is a need to shape the cutout including fillet considering the stress in the non-linear range and nature of the stress field at the cutout corner. Theoretical determination and experimental validation is expected. The study is expected to arrive at a parametric definition of minimum fillet radius based on geometry of cutout like r/w etc for using it in all sizes of cutouts of different width-w.
H6.4	**An assessment of knock down factors for cylindrical shells used in launch vehicles based on energy barrier approach (VSSC)** The current design of launch vehicle structure which are compressively loaded is based on the knock down factors and subsequent qualification tests. However, due to the improvement of computation methods, better estimates of collapse load are now possible and the knock down factors applied on theoretical computations are believed to be conservative. Some estimates show that the current design under-predict the buckling load carrying capacity by about 20%. The lack of reliability (lack of repeatability and the non-availability of a non- destructive testing technique) of cylindrical shell buckling experiments is a major contributing factor for this under estimation. The need for high-fidelity estimates of the buckling loads of shell structures is of critical importance for reliance or to increase payload capability. Methods based on energy barrier can be used as a non-destructive and non-invasive technique for determining the shock sensitivity and stability of thin-walled structures. Energy barrier method for shell buckling problems is a new approach for estimating the stability characteristics of cylindrical shells. This method has promising applications in the space industry for predicting the buckling load carrying capacity and the robustness of a cylindrical shell subjected to external undulations. Information about a structure's stiffness and robustness against buckling in terms of energy and other force parameters can be arrived using this technique. In simple terms, the energy barrier is the energy that needs to be supplied to drive the shell over buckling. And the determination of this energy barrier in a way helps us to find the buckling load carrying capacity and the shock sensitivity of the structure. The energy barrier of a structure can be determined from simple experiments or numerical procedures by introducing transverse perturbation to cylindrical shell preloaded by axially compressive force.
H6.5	**Design / analysis of membrane structures like parachute canopy for different loading conditions (VSSC)** In present time, use of membrane structures is widely increased in field of science and aerospace technology. Parachutes form one of the major part of recovery subsystems in field of Human Space Missions, whereas hot air balloons are widely used for atmospheric studies and navigation. The mentioned membrane structures come in the category of tensile structures where stresses in the structures determine the shape as fabrics used in the design have no appreciable stiffness out of the plane it lies in and no appreciable bending stiffness. Design of such structures is sensitive to its geometry, material properties and patterning (fabrication) direction. The mechanical behavior of fabrics used in realization of such structures is nonlinear and time dependent, with assumed or highly simplified material properties commonly used for analysis. The scope of the proposed

	project is to emphasize on the design criteria for membrane structures such as parachute canopy, to develop an analysis methodology for estimation of canopy stresses and loads in the canopy reinforcement using available / independent analysis tools.
H6.6	**Residual stresses estimation on additive manufacturing (VSSC)** Additive manufacturing is being widely used to fabricate functional metal parts in automobile, aerospace, energy and medical device industries due to its flexible process capacity including complex geometry, functionally graded materials, and free usage of tool. Additive manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. Additive manufacturing builds up components layer by layer using materials which are available in fine powder form. A range of different metals, plastics and composite materials may be used. Additive manufacturing can be used in launch vehicle program especially in the upper stages. This will reduce the number of components in the assembly and hence the time and cost of realization of hardware. Residual stresses which get induced in a realised component due to thermal loads generated during deposition of layers during additive manufacturing puts restrictions in the usage of it especially for launch vehicle structures. Minimizing the residual stress build-up in metal-based additive manufacturing plays a pivotal role in selecting a particular material and technique for making a component. An accurate estimation of residual stresses and distortion is necessary to achieve dimensional accuracy and prevent premature fatigue failure, delamination and buckling of components. Since many process variables affect the amount of residual stress getting induced during additive manufacturing and experimental measurement of residual stresses and distortion are time consuming and expensive, development of numerical thermo-mechanical models for their estimation is highly essential.
H6.7	**Damage tolerant designs for laminated composite structures used in aerospace structures (VSSC)** The initiation and propagation of manufacturing induced or service induced damage in the structural design of laminated composites are of primary concern for aerospace structures. The laminated composite wing and fuselage structure with low transverse strength, low inter-laminar shear strength and no plastic deformation are more susceptible to damage growth. A stress based criterion can determine the locations of potential damages followed by fracture analysis to predict the initiation of delamination. Based on suitable failure criterion, the failure is predicted. A thorough understanding is required to predict the multiple complex failure mechanisms in composite structures which are used especially in aerospace industry such as the wing structure. Virtual Crack Closure Technique (VCCT), Cohesive Zone Modeling (CZM) and Progressive Failure Analysis (PFA) are the techniques to predict the failure followed by the experiments to validate the criterion. A series of aerospace materials ranging from the metals to composites has to be tested and predictions through analytical and numerical method have to be carried out for the better understanding for future requirements.

H6.8	**Thermo-mechanical response of polymer matrix composites under high heating rates (VSSC)** Thermo setting polymer matrix composites are used in the aerospace industry as thermal insulation liners for nozzles system as well as heat shields for re-entry vehicles. These composite materials experience rapid heating during operational time, ie. they are exposed to very high temperature in short duration. The polymer resin constituent undergoes thermochemical decomposition (charring). During this endothermic charring process, the polymer chain is broken down and decomposed into water vapour, pyrolysis gases and a solid carbon residue. Development of mathematical model to predict the thermo-mechanical response of ablation of polymeric materials during thermo chemical decomposition is planned in this proposal. Ablation analysis should capture simultaneously thermo-chemical and thermo-mechanical response of the Silica-Phenolic / carbon – Phenolic ablative systems.
H6.9	**Development of nano composites for aero space application (VSSC)** To formulate and develop software for finite element analysis of nano composite structures, which includes geometric nonlinearity and effect of size in constitutive behavior. The continuum damage mechanics model which includes the different mode of failure observed in the composite structures such as fiber failure, matrix failure, inter laminar and trans laminar failure. Validation of the present study can be through fabrication of small nano composite plate and subject the same to different loading conditions and correlating the results with the theoretical study.
H6.10	**Fracture studies on textile composites (VSSC)** Textile Composites are being used in the aerospace industries, specifically in the areas of impact resistant structures and hot structures. The increased use of these materials calls for the proper understanding of their fatigue behaviour. To ascertain the endurance of structural components made of Textile composites, fatigue and fracture studies on materials and structures are essential. A suitable method to perform the progressive fiber/matrix failure analysis has to be established in the presence/absence of defects useful for life estimation.
H6.11	**Structural health monitoring through classification of strain patterns using artificial neural network (VSSC)** Structural health monitoring technology has become an important approach to increase the safety and reduce the maintenance costs of high performance composite structures used in aircraft and re-entry vehicles. There is a requirement to develop the tools to detect damages such as fiber failure, matrix cracking, de-laminations, skin-stiffener de-bonds in composite structures. Neural network is one of the tools. Tool will be used to classify sensor malfunctioning and structural failure(s) based on the observed static strain patterns of the healthy and unhealthy structures. Analytical and experimental studies have to be made to validate the adopted methodology.

H6.12	**Visco-elastic structural analysis of solid propellant grains in the presence of voids (VSSC)** Solid rocket systems are used extensively in situations where the total impulse is known in advance and restart is not required. Structurally, a rocket motor consists of the solid propellant grain, liner, insulation, motor case and the igniter. Solid propellant grains are strained / stressed due to thermal, gravitational, flight acceleration and ignition pressure loads. The structural response of the propellant grain in the presence of voids / porosity disrupt the stress/strain field. It is essential to examine the criticality of voids in solid propellant motor grains based on structural as well as ballistic and thermal considerations. A detailed viscoelastic solid propellant grain analysis in the presence of different void shapes and sizes is to be carried out for storage, thermal and ignition pressurization loading conditions for the development of an acceptance criterion. A methodology has to be established to model the void and examine its deformation criticality through finite element analysis.
H6.13	**Biaxial testing of visco elastic material (VSSC)** Solid rocket systems are used in launch vehicle. Solid propellant grains are strained / stressed due to thermal, gravitational, flight acceleration and ignition pressure loads. Behaviour of the solid propellant is visco elastic in nature. Study of biaxial behaviour of this visco elastic material under biaxial testing is proposed.
H6.14	**Development of design/analysis criterion for aerospace structures subjected to shock loads of varying intensities and duration (VSSC)** Usually in aerospace structural engineering, the structures need to be designed to withstand transient dynamic loads and shock excitation loads. Sometimes the health of the designed hardware need to be assessed by finite element analysis for specific transient dynamic / shock loads, before the clearance of hardware for launch. Tests on AA 2014 alloy plates has shown plastic yielding in metallic plates. Hence a clear understanding on the dynamic stress response of structures for varying time duration of shocks and intensities and its relation with the structural health is required for an optimum structural design. The Objectives of the study is to develop a methodology for design of aerospace structures subjected to varying shock loads and to develop an analysis methodology for health assessment of structures subjected to shock loads of varying peaks and time duration.
H7	**Sub Area** — **Honeycomb Structures (VSSC)**
H7.1	**Semi-analytical approach for the evaluation of acoustic performance of Aluminium/ CFRP skinned sandwich panel (VSSC)** Acoustic performance of metallic honeycomb sandwich panels under low frequency were obtained through test using reverberation chamber. Honeycomb cells were embedded with semi-flexible PUF. Comparisons were made for the acoustic attenuation in terms of insertion loss for the rectangular panels with and without PUF. Based on say, LS DYANA obtain a semi analytical approach for the prediction of attenuation of sandwich panel for variables like skin thickness, core height, density of PUF etc.

H7.2	**Inter laminar shear stress evaluation of bonded structures (VSSC)** To estimate accurately the stresses in the sandwich structures, in particular in the bond between the skin (metallic or FRP laminate skin) and honeycomb core higher order shear deformation theory is followed. Provide the software code that will be useful for studies in related areas.	
H7.3	**Evaluation of acoustic characteristics of Polyimide foam for sandwich application (VSSC)** Honeycomb sandwich panels embedded with Polyimide foam inside the honeycomb cells have been tested for insertion loss (dB) over a range up to 1200 Hz. using reverberation chamber and air pulse tube. For analytical model for a theoretical prediction for insertion loss of the honeycomb sandwich panel, it is necessary to evaluate properties like porosity, sound flow resistivity etc. as per the standards.	
H7.4	**Development of sandwich structures with negative poisson's ratio honeycomb core (VSSC)** The core with negative Poisson's ratio improves the shear strength and resistance to piercing for the core and keeps inserts more intact in sandwich structures. The geometry of core and skin material/processing provides negative Poisson's effect for the sandwich structures as reported in literature. This will help to increase the load carrying capacity of the sandwich structure.	
H7.5	**Crashworthiness studies of metallic honeycomb sandwich structures (VSSC)** Honey comb core has a constant crush curve and hence is capable of taking load even after initial crush. Aluminium honeycomb has good crashworthy properties and evaluation of these properties analytically is proposed to be done. This can be done for different types of damages and structural integrity to be assessed.	
H7.6	**Non destructive evaluation of weak bond in honeycomb structures (VSSC)** Honeycomb structures are bonded structures wherein the strength of the structure is contributed by adhesion and cohesion. NDE methods are available for evaluating the cohesive strength. Adhesion strength is controlled by process parameters. Development of an NDE method to evaluate adhesion strength of adhesive will help in a great way in assessing the structural health.	
I	**Area**	**Avionics (VSSC)**
I1	**Sub Area**	**Motors (VSSC)**
I1.1	**Space vector PWM control for PMSM motor (VSSC)** Space vector PWM technology is being widely used in industrial application owing to the inherent advantages of better DC utilization and improved harmonic performance. As part of optimizing the systems for aerospace applications improving the efficiency by reducing the losses is the prime focus. On this background the usage of SVPWM technique for PMSM drives can offer significant advantage.	

I1.2	**Fault tolerance of five phase BLDC/PMSM motor (VSSC)** The motor industry is witnessing the migration of machines from three phases to increased number of phases on account of decreasing the current per phase thereby bring down the losses and the inherent fault tolerance. The inherent fault tolerant capability of a five phase BLDC/PMSM motor has to be established through simulations and experimental validations for the technology to be adapted to the aerospace industry. A comprehensive study of the failure modes, performance assessment, reconfiguration if required etc. are to be part of the study.
I1.3	**Design and development of 25kW quadruplex BLDC motor with quadruplex hallsensor sets (VSSC)** 25kW quadruplex BLDC motor with quadruplex hallsensor sets is planned as a driver for linear electro-mechanical actuators generating high actuation forces. The scope includes Design of motor and controller for the input requirements. Modeling and analysis using finite element analysis software to validate the motor performance. Generation of fabrication drawings and PCB layout. Procurement of components needed for the motor and controller. Realisation, assembly and testing of motor and controller.
I1.4	**Design and development of dual redundant 22.50 stepper motor for the rotary actuator (VSSC)** The scope includes Design of motor for the input requirements. Modeling and analysis using finite element analysis software to validate the motor performance. Generation of fabrication drawings. Procurement of components. Realisation, assembly and testing of motor.
I2	**Sub Area** — **Actuators (VSSC)**
I2.1	**Magnetic levitation based linear actuators (VSSC)** For the present day electromechanical actuation systems, the weakest element in the system is the rotary to linear conversion mechanism. The disadvantage offered by the rotor inertia being reflected in the engine also offer challenges as majority of the power in the system is utilized in overcoming the self inertia of the system. On this back ground the feasibility of developing a magnetically levitated linear electromechanical actuator of 4T force capability. The detailed simulation study bringing out the configuration and performance assessment is to be carried out. A proto model to be developed and demonstrated.

I2.2	**Design and analysis (static & dynamic) of a planetary roller screw (VSSC)** Planetary rollerscrews having double nut configuration are used in high power electromechanical actuators for converting the rotary motion to linear. The scope of project includes: Mechanical design of the roller screw based on input requirement which includes detailed specification and outer dimensions of Rollerscrew. Generation of 3D CAD model. Kinematic analysis and estimation of slip. Static analysis (Finite Element Analysis), stiffness and efficiency. Dynamic analysis (Using solvers like ADAMS). Fabrication drawing of all components.	
I2.3	**Design and analysis of harmonic drive (VSSC)** Harmonic drive replaces the conventional gear train of the rotary actuator. The scope includes: Mechanical design of the harmonic drive for the input requirements. Modeling and quasi-static analysis using finite element analysis for the tooth mesh conditions [for stress, strain and stiffness]. Kinematic and kinetic analyses using ADAMS like software. Tooth profile optimization for maximizing performance. Generation of fabrication drawings. Procurement of components (like elliptical bearings, circlip, etc, needed for the assembly) Realisation, assembly and testing.	
I3	**Sub Area**	**ASIC/FPGA (VSSC)**
I3.1	**Custom ASIC design of asynchronous RISC processor (VSSC)** As the ASIC technology scaling continues, the effect of leakage and dynamic power consumption of the CMOS gets more consideration. Moreover the clock requirement for the new designs goes on increasing although the majority of the internal logic does not clock in the same speed. In such scenarios, the use of asynchronous circuit design gains importance. Indigenous FPGA: As a part of import substitution efforts, it is required to design an Indigenous anti fuse FPGA in-house for the future ISRO missions. The design involves the following steps. Universal logic cell design Creating synthesis library Programmable interconnect design Modeling programmable interconnect Place and route software tool development FPGA fabrication FPGA programmer hardware and software development	

I4	Sub Area	Onboard Computers (VSSC)
I4.1	**Software modeling of on-board computer hardware (VSSC)** VIKRAM1601 is a 16-bit microprocessor based on-board computer indigenously developed by ISRO. A suitable software model, that would accurately simulate all the features of the system, is required to be developed. This is required for plugging into checkout systems for doing software validation of integrated flight software. This eliminates the requirement of hardware packages during software testing.	
I4.2	**Formal methods for flight software specification and verification (VSSC)** Formal methods for software specification and verification are based on mathematical methods and offer a more rigorous approach for software development and verification. In order to ensure consistency of requirements and provide proof of correctness, formal methods are to be used to supplement the traditional techniques followed for specification and verification of flight software for launch vehicles.	
I4.3	**Model-based software development for safety-critical systems (VSSC)** Model-based approach to Software Development involves a mathematical and visual method of addressing problems associated with designing complex systems. It provides a common design environment for all development agencies, facilitates rapid proto-typing and early detection of errors as well as design re-use. One of the safety-critical elements of flight software is to be developed using the model-based software development paradigm, as a pilot project.	
I5	**Sub Area**	**Power System (VSSC)**
I5.1	**Integrated on chip multi output DC-DC converter with soft switching topology (VSSC)** The scope of the project includes the modelling, analysis, design and development of miniaturised multiple output isolated DC-DC converter with soft switching topology for aerospace applications. These converters should have efficiency greater than 85%. The scope of the project includes the design of on chip PWM controller for the proposed control algorithm.The proposed scheme shall be verified by simulation and hardware implementation.	
I5.2	**Wireless power transfer (VSSC)** The project aims at the design and development of wireless power transfer technique to transfer power from battery to various subsystems for aerospace applications. The project aims at the study of existing technologies of wireless power transmission and to arrive at a suitable technique to transfer power in the following cases 1) Low power at a distance of few centimeters (charging of batteries etc) 2) Medium power at a distance of few meters. The proposed scheme has to be verified by hardware implementation.	

I6	Sub Area	Robotics (VSSC)
I6.1	**Modeling, simulation, analysis and design of a controller for a robotic manipulator having five degree of freedom for lunar mission (VSSC)** Modeling, simulation, analysis and design of a controller for a robotic manipulator having five degree of freedom for lunar mission. Robotic manipulator having five degree of freedom forms part of a lunar exploration rover. The scope of project includes, Generation of a mathematical model and its analysis which includes forward and inverse kinematics, work space analysis, trajectory planning, static and dynamic analysis. Design of a controller and simulation of certain predefined tasks. Hardware realization of the controller (control electronics to drive the manipulator). Experimental demonstration of the predefined tasks (Robotic manipulator will be provided for this purpose). Design, analysis and experimental verification of a force and slip controller for the object grasp by an underactuated three fingered robotic hand. Design of force and slip controller (including selection and procurement of appropriate sensor / sensors). Simulation of grasp (Spherical, Cylindrical & Planar) with objects of various sizes and shapes. Experimental demonstration of grasp (Spherical, Cylindrical & Planar) with objects of various sizes and shapes (Underactuated robotic hand will be provided for this purpose)	
I6.2	**Determination of space debris, its shape and orientation and distance using image processing through stereo camera (VSSC)** Image processing through stereo camera to determine the shape and dimensions of space debris in orbit. Estimation of altitude, angular velocity and tumbling axis of the debris. Machine learning could be used to achieve the goal. Date update frequency should be more than 25Hz. Camera configuration, Processor and algorithm should be define accordingly. Algorithm should be platform independent so that it can be exported to the controllers having different architecture	
I7	Sub Area	Sensors & Instrumentation (VSSC)
I7.1	**Sensors based on RF transduction principles for Remote Wireless Sensing (VSSC)** This project aims at realizing sensors using RF techniques such as resonance and propagation phase shift. Development of such techniques allows non-invasive measurement of a variety of parameters. The project involves design and development of such sensing systems and the associated electronics so as to enable wireless remote sensing of parameters for aerospace and industrial applications.	

I7.2	**Integration of sensors and electronics - analog, digital, RF & antenna on flex substrate for complete wireless sensing system (VSSC)** This project aims at realizing integrated sensors on flexible substrate. This involves design and development of a process flow that will allow Sensing elements, Analog, Digital, RF and Antenna elements to be implemented on the same flexible substrate base. Suitable placement, routing and fabrication techniques to be developed that will allow all these elements of diverse domains to work with minimal interference effects such as cross-talk and noise pickup that can affect the signal integrity in individual domains. The end goal is to develop technologies required for design and fabrication of smart, conformal wireless sensing systems for applications such as aerospace, industrial IOT and structural health monitoring.
I7.3	**Sensors based on nanotechnology principles (VSSC)** The focus of this project is to design and develop sensors based on Nanotechnology principles. This will involve identification of suitable materials, process flow for fabrication and optimization of device characteristics. Characterization of sensors thus developed for performance parameters like linearity and sensitivity will also be part of the project. The sensors thus developed need to be of low volume, mass, power consumption and cost for them to be useful for future applications in ISRO missions.
I7.4	**Design, fabrication, testing and realization of a Nanomaterial (CNT/Graphene) based gas sensor (VSSC)** The project aims to develop nanomaterial based gas sensors with high sensitivity and selectivity. As nanomaterial sensors are reliable, accurate and fast to respond, they are preferred. The output of the sensors can be either as electrical resistance variation or current, depending upon the exposure of the corresponding gas. The various gas sensors that is required for monitoring the Crew module environment are the following H2 N2 CO2 CO These are to be monitored for estimating and regulating the module environment. The sensing elements are to be developed for detection and estimation of the above gases.
I7.5	**Design, fabrication, testing and realization of Erbium Doped Fiber (EDF) edge filter (VSSC)** The Erbium Doped Fiber (EDF) Edge filteris to be developed. The component is for interrogating (Fiber Bragg Grating grating) FBG sensors. EDF will be used to convert the Bragg wavelength shift to optical intensity variation. The Edge filter band width coverage : 1525 to 1565nm or more The EDF response should be temperature independent Variation of power over wavelength : 1dB/nm

I7.6	**Algorithms for structural health monitoring of launch vehicles (VSSC)** This project encompasses the development of techniques required for evaluating the Health of Launch Vehicle Structures suitable for an Integrated Vehicle Health Management (IVHM) system. This consists of identifying the instrumentation requirements, development of suitable data analysis techniques in various domains such as time and frequency and study of relevant algorithms based on Dynamic System theory (such as State Estimation – Kalman filter), Statistical techniques (like Regression methods), Decision Making techniques (such as Dempster-Shafer) and those based on Neural Networks and Fuzzy Logic. The developed algorithms have to be demonstrated on flight data as well as test data with faults injected and their efficacy established.	
I8	**Sub Area**	**Analog Phase Modulator (VSSC)**
I8.1	**Miniaturized wideband analog phase modulator using phase locked loop (PLL) (VSSC)** The project aims at the implementation of wideband continuous analog phase modulator capable of handling 2 Mbps data rate using PLL technique. Phase modulation (PCM/PM) is presently being employed for ISRO launch vehicle telemetry applications. The modulator subsystem is the major contributor in the size and mass of the telemetry transmitter. The objective of this research is to miniaturize the present telemetry transmitter system by developing a new method of modulation inside the PLL. The major advantages of implementing such a system will be a significant reduction of size, mass and cost of the transmitter. The present system employs PLL based frequency synthesizer for carrier generation in S band (2.2-2.3 GHz). The present proposal is for the state-of-art in the field which is the implementation of modulation within the carrier generation loop itself using fractional-N frequency synthesizer chip with integrated VCO.	
J	**Area**	**Launch Vehicle Inertal Systems Area (IISU)**
J1	**Sub Area**	**Atom Interferometer (AI) based sensor technology development for Precision Inertial (IISU)**
J1.1	**Design and development of Gravity Gradiometer using atom interferometry techniques in a double MOT set up with laser cooled Rb atoms (IISU)** Development of cold atom interferometer based inertial sensors to measure gravity gradient tensor, angular rates and linear accelerations. The accuracy aimed using such sensors are : Gyro : < 10-7 deg/hr, Accelerometer : < 10-10 g, Gradiometer : < 10-11 g/m and Navigation accuracy : < 5 m/hr class.	
J2	**Sub Area**	**Miniature High Frequency Hybrid Micro Circuit DC-DC Converter (IISU)**
J2.1	DC-DC Converters are widely used in Launch Vehicle and Spacecraft applications. Currently, ISRO Launch vehicle packages use Single and Dual Surface Mount Technology (SMT) DC-DC converters with power density of 2.4 W/in3. In complex systems which need many (up to eight) output voltages like Inertial Systems, space & mass constraints	

	impose the use of high power density and Triple Output imported Hybrid Micro Circuit (HMC) DC-DC Converters. Specifically, for systems like DRINS for HSP, where more sensors are used for higher level of failure tolerance, use of conventional SMT DC-DCs will result in a heavy power module for INS. The objective of the TDP is to indigenously design and develop miniature (10 W/in3 or higher), Low Profile (less than 17mm), High Frequency (500 kHz or above) Single, Dual and Triple Output HMC DC-DC Converters with miniature magnetics.	
J3	**Sub Area**	**Videometer based Navigation System for Autonomous Rendezvous and Docking (IISU)**
J3.1	Development of a fully autonomous vision navigation system for doing relative navigation. A set of retro reflectors mounted on the target at specified coordinates form a three dimensional target pattern which will be imaged using camera kept at the chaser vehicle. The camera detects the reflected signal. The onboard processor in the chaser process the detector output and the image processing algorithms resident in the processor analyzes the imagery to identify the corner reflectors and to derive the current state vector. The relative navigation and attitude state variables are estimated using a state observer and suitable filtering algorithms. Develop relative navigation concept for use in future missions like landing missions, in final docking phase (<500m range) of autonomous rendezvous docking process, in stage recovery experiment, etc. Identify the technologies involved and define suitable configuration of sensors, reflector pattern, camera and various elements of the system. Design of image processing algorithms, state observer and filter algorithms to estimate the relative state vectors (position, velocity, attitude and angular rates). Development and realization of the system elements and integration of the system. Develop the test methodology and test system required to demonstrate performance. Performance demonstration & qualification of the developed system.	
K	**Area**	**Advanced Inertial Systems Area (IISU)**
K1	**Development of atomic magnetometer and quantum technologies (IISU)** Design and Development of the technologies for the atomic magnetometer (design and characterization of vapor cell, magnetic shielding, Heating and Electronics Design etc) for a sensitivity of nT/OHz. Atomic magnetometer can be used for the measurement of nano Tesla level magnetic fields.	
K2	**Development of optical correlator based sensors (IISU)** An optical correlator is a high speed image cross correlator which can update camera based aiding sensor output within a few milliseconds. This is proposed to improve the performance of integrated navigation using aiding sensors. Development of optical correlator and demonstration of Integrated navigation for obstacle avoidance and proximity operations.	

K3	**Development of Ultrasonic Motors (USM) for special applications (IISU)** USM has advantage of high torque density at low speed, direct drive without speed reduction gears, quick response, better electromagnetic compatibility, high holding torque while power off. To be used for low torque applications and fine control of movement.
K4	**Development of fiber optic sensors for launch vehicles applications (IISU)** TDP is about developing and demonstrating Fiber optic sensors, tensile sensors (pressure/ strain and temperature) for LV applications . Such sensors are immune to EMI and light weight.
K5	**Disc Resonator Gyroscope (DRG) (IISU)** Design and Realization of a Vacuum packaged Silicon Disc Resonator Gyroscope (DRG) with a bias stability less than 10 deg/hr and with discrete electronics for rate and tactical applications.
K6	**Mixed signal ASIC electronics development for vibrating gyros (IISU)** A micro machined silicon ring resonator based rate gyroscope is under development at IISU. It is a closed loop rate sensor working on the Coriolis effect in a vibrating ring structure. This sensor requires two loops on the drive side to track the resonant frequency and to keep constant amplitude of vibration. Two loops are required on the output or sense side to null the real and quadrature vibration terms. The amplitude of the nulling signal is taken as the readout for the rate. The loops are presently being developed in the analog domain as it is intuitive and also easy to modify/tune to the sensing elements. However the analog circuit has many components, leading to difficulty in miniaturizing and also leading to higher power. Development of a state of the art rate sensor requires realizing a smart device where the electronics is co packaged with the sensing unit and gives a direct digital output. This requires implementing the control loop in digital domain and realizing the same as an ASIC. Essential glue electronics have also to be developed. All electronics have to operate from a single low voltage supply. The electronics have to be packaged together with the sensing unit with a DC-IN Digital-OUT format.
L	**Area**	**Mechanical Design and Production Group (IISU)**
L1	**Sub Area**	**Active Vibration Control (IISU)**
	It is proposed to develop a platform to provide six degrees of freedom vibration isolated platform using negative stiffness mechanisms. This would thus form a platform which could be used for attenuating very low frequency vibration noise. This platform could be used for carrying out experiments which require very stringent vibration attenuations. Also such platforms are mandatory for the new and advanced inertial sensors like cold atoms inertial sensors where very low frequency vibrations have to be controlled.	

M	Area	Launch Vehicle Tracking System, Range Operation and Safety Engineering (SDSC- SHAR)
M1	Sub Area	Ground Safety (SDSC-SHAR)
M1.1	**Study on radiant heat flux from propellant fires and its effects (SDSC-SHAR)** Estimation of Heat flux around the propellant burning areas through experimental setup will help us to validate our theoretical estimation, thereby it helps us to provide input for ensuring the adequacy of protection to our personnel our systems.	
M1.2	**Design of fire alarm and detection system for high bays based on smoke modeling (SDSC-SHAR)** To design optimal and effective Fire Alarm detection systems for High rise and high bay based on smoke modeling. It helps us to optimize the location of the sensors and detection mechanisms for a faster detection.	
M1.3	**Risk analysis for liquid propellant storage facilities (SDSC-SHAR)** The Siting of Liquid propellant storage facilities are based on the quantity distance criteria, fire ball diameter calculations etc., considering the worst case scenario. Risk analysis studies help us to estimate the risk levels of the liquid propellant storage and handling in bulk as well as the adequacy of safety system and its protection levels.	
M1.4	**Smoke extractor system for solid motors exhaust gas during testing (SDSC-SHAR)** As a part of qualification trials for the solid motor testing of Agni motors have increased manifolds. As the solid motors exhaust gases contain traces of toxic Products like HCl gas, Al2O3 and CO. In order to protect the environment and persons from these exposures an attempt is planned for a smoke extractor system for safe collection of exhaust gases for disposal.	
M1.5	**Experimental studies on dispersion of solid rocket motor exhaust gases (SDSC-SHAR)** The Exhaust gases dispersion studies will help us to understand the behavior of gas dispersion. Based on which static testing of solid motors safety criteria's can be evolved with aim to prevent the dispersion of exhaust gases towards land mass. It helps us to protect the public /operational personnel from toxic gases as well as to protect the flora and fauna of our Sriharikota.	
M1.6	**Experimental studies on oxygen deficiency environments due to accidental spillage or release of gases (SDSC-SHAR)** The Box model sub- scale gases dispersion studies will help us to understand the behavior of gas dispersion. It will help us to estimate the concentration levels at various elevations and distances etc. It helps us to optimize the location of the sensors and detection mechanisms for a faster detection.	

M1.7	**Experimental studies on liquid propellant dispersion due to accidental release or spillages (SDSC-SHAR)** The Exhaust gases dispersion studies will help us to understand the behavior of gas dispersion. Based on which safety criteria's can be evolved with aim to estimate the toxic corridors and pollution levels form the source of leak. It also helps us to optimize the location of the sensors for a faster response and for initiating the safing actions at a faster detection.	
M2	**Sub Area**	**Multi Object Tracking Radar (SDSC-SHAR)**
M2.1	**Coherent integration for space objects tracking (SDSC-SHAR)** Detection of low RCS targets with high speed and complex motions has been receiving a growing attention and significant research efforts in the modern radar field especially in space debris tracking.Real-time implementation long term coherent integration by compensating phase fluctuation among different sampling pulses for High Performance Embedded computing platforms which involves searching the velocity fold factor, estimating acceleration, jerk values and performing CLEAN algorithm for integrating multiple targets has to be developed.	
M2.2	**Target identification using machine learning algorithms from MOTR radar data (SDSC-SHAR)** Radar data consists of Range, Azimuth, Elevation and Signal to Noise Ratio (SNR). From Range and SNR correlation target size can be classified. From SNR variation alone in a single track duration, target nature can be established. Using Machine Learning algorithms, a model should be trained on radar tracked data (Range, Azimuth, Elevation and SNR). The trained model should identify a target nature (controlled or uncontrolled) and size. Using standard libraries in Python Machine Learning Algorithms have become realizable models.	
M2.3	**Real time JPDA & MHT based data association in dense multi target tracking environment (SDSC-SHAR)** MOTR has implemented Linear Kalman Filter (LKF) and Extended Kalman Filter (EKF) for tracking multiple targets simultaneously and Simple Nearest Neighborhood (SNN) based data association algorithm to associate target returns with the target being tracked. SNN data association algorithm gives a better result in tracking multiple targets when the targets being tracked are spatially separated. When multiple targets are very closer SNN algorithm gives poor result. It also fails in situation like targets cross over and co traveling of two targets. To overcome this situation Probability based Data Association (PDA) methods like Joint Probability Data Association (JPDA) and Multiple Hypothesis Tracking (MHT) algorithms are used. Since these algorithms uses probability based algorithms these are complex incorporated to SNN. Hence these algorithms are mostly used in offline analysis.	

M2.4	**Space debris RCS estimation and dynamics characterisation from MOTR Space debris tracked data (SDSC-SHAR)** Studying the received signal from the target gives us the information of the target like its dynamics spin, its size and RCS. These characteristics of the debris need to be catalogued, to compute its drag coefficient, and its life time assessment.	
M3	**Sub Area**	**Solid Motor Performance & Enviornmental Test Facility (SDSC-SHAR)**
M3.1	**Flow visualization of ignition overpressure wave from blast generator (SDSC-SHAR)** During the startup of the solid rocket motor, a weak blast wave or shock front is generated. This overpressure pulse interact with the launch vehicle and launch complex system. Hence its is required to capture the overpressure wave propagation in a launchpad environment using a suitable simulation using a blast generator.	
M3.2	**Study on effect of high intensity pressure waves in the near field of rocket exhaust jet and Ignition Overpressure (IOP) wave on typical launch vehicle structures (SDSC-SHAR)** The angle of incidence (grazing and impinging) of shock fronts and acoustic impedance of the interacting surface with the shock fronts are having influence on its structural response. Present study proposes to develop transfer functions for different overpressure interaction with launch vehicle structure.	
M3.3	**Ignition Overpressure mitigation studies in scale model using active and passive suppression techniques for LVM3 (SDSC-SHAR)** The blast wave amplitude is crucial in the design of launch vehicle structure. Hence, suppressing the overpressure amplitude through different techniques is the objective here.	
M3.4	**Acoustic suppression system for TLP configuration JDD (SDSC-SHAR)** The lift-off aeroacoustics is the generate peak vibro-acoustic stress for a launch vehicle and its mitigation is a major research topic. Objective of the present work is to bring forth innovative sound suppression schemes for the future launchpad.	
M3.5	**Design and development of STED for 100AR nozzle through numerical and experimental studies (SDSC-SHAR)** Higher area ratio nozzle testing in vacuum is a major hurdle in the nozzle development. This project aims to develop a STED system for 100AR nozzle.	
M3.6	**Realization of post fire quenching system with halon alternates in large scale solid rocket motors using ethylene gylcol, gleserol and water mixtures (SDSC-SHAR)** Post fire quenching inside a solid rocket motor after static test is a major requirement. Due to the ban of Halon as quenching medium, it is required to develop an equivalent medium which is having same or better capabilities compared to Halon.	

M3.7	**Development of an algorithm for prediction of acoustic suppression using water injection for a free jet case (SDSC-SHAR)** The existing rocket noise prediction with empirical scheme based on NASA SP8072 is only for exhaust jet without water injection. The objective is to modify the empirical scheme to accommodate the effect of water injection suppression system on the aeroacoustics of liftoff jets.
M3.8	**Multi-objective design optimisation strategy for launch pad configuration to reduce the impingement pressure, sound pressure on payload bay and launch pad construction and refurbishment cost from experimental data with surrogate gas simulation studies (SDSC-SHAR)** The final jet deflector configuration is based on minimum construction cost and acoustic loading on the launch vehicle. The parameters governing these two requirements are derived from a series of experiments and numerical methods. The objective is to employ optimization techniques like GA for finding the optimized configuration of Jet Deflector Duct (JDD).
M3.9	**Developing a jet noise source localisation technique using a microphone array with appropriate beam forming algorithms (SDSC-SHAR)** Locating the jet noise sources in the lift-off scenario of a launch vehicle will benefit highly in the suppression of the noise sources. Present method proposes to use an array of microphones and employ suitable algorithm and develop a code to locate the noise sources.
M3.10	**Flow diagnostics at nozzle exit in vacuum condition using vacuum chamber and laser flow diagnostic setup (PIV) (SDSC-SHAR)** The flow structure of a jet at very low vacuum is highly important with respect to engines performing in the space. The objective is to study the exhaust jet in a vacuum chamber using PIV setup.
M3.11	**Fatigue life estimation of structural members under random vibrations through strain gauge measurements (SDSC-SHAR)** The launch complex structures are huge and undergo random vibration loading. Present objective is to estimate the fatigue life through strain gauge measurements.
M3.12	**Modelling and evaluation of damping in threaded joints of load cells and its impact on measuring dynamic force components (SDSC-SHAR)** During static test, the thrust load transfer is through threaded joints. The thread damping is important with respect to the dynamic thrust measurement. Here the objective is to model and experimentally evaluate the threaded joint damping for unsteady load transfer.
M3.13	**Development of low cost MEMS based vibration sensors for health monitoring (SDSC-SHAR)** Launch complex structures are huge in size and its health monitoring with respect to each launch is very important. Present work proposes to develop a low cost accelerometer for outdoor application. These developed accelerometers will be mounted on structures for health monitoring, especially during launch.

M3.14	**Effect of jet aeroacoustic environment on the vibrations of different panels with typical application in launch vehicles (SDSC-SHAR)** The transfer function and prediction of vibration levels for a particular jet noise spectrum on the launch vehicle subassembly decks is a major research. Present work proposes to validate the Statistical Energy Analysis (SEA) in the actual environment of a solid rocket motor exhaust. Typical subassembly deck will be mounted in the near and far field of the rocket exhaust jet. The acoustic interaction and vibration levels will be measured on the structure.
M3.15	**Development of MEMS based miniature unsteady pressure sensors for overpressure measurement (SDSC-SHAR)** Overpressure measurement during the rocket motor startup is very important. The existing sensors are imported and costly. The sensors are usually sacrificial in nature and the present work proposes to develop an unsteady pressure sensor indigenously.
M3.16	**Numerical simulation of pressure oscillation inside large segmented solid rocket motor. Also to simulate the Flow Structure Interaction (FSI) inside the rocket motor for the subsonic flow over the inhibition tip (SDSC-SHAR)** Finding the pressure oscillation inside the large segmented solid rocket motor is very crucial. The objective is to numerically simulate the subsonic flow inside the solid rocket motor and find out the flow structure interaction.
N	**Area** — **Project and Programme Management (SAC)**
N1	**Framework for strategic research management in government R&D organizations (SAC)** With key emphasis on the Indian Scenario of Research in Government R&D organization, it is imperative that the R&D should be strategically managed in view of the goals of the organization and those of the Nation at large. The goals must be SMART (Specific, Measurable, Attainable, Relevant and Timely) and hence will drive R&D in the right direction. Research may be undertaken in this broad are to see how Strategic Management can be carried out in Government Organizations for an effective output.
N2	**Research quality assessment and evaluation techniques (SAC)** Today Research is coming out in large quantum and is varied in nature in terms of its inputs, deliverables and utilization. It is important for organizations to assess the quality of research over quantity and evaluate it on parameters that give an effective rating to the researches carried out. Techniques may be developed to assess research quality.
N3	**Role of Intrapreneurship in government R&D organizations (SAC)** Entrepreneurship has become more than relevant today changing the landscape of traditional businesses. Corporates have adopted the same through Intrapreneurship in order to stay innovative and competitive. Developing this culture in Government R&D Organizations in Indian Scenario, giving individuals the space for Intrapreneurship seems a thoughtful approach. Case based research may be undertaken to see if such practices are being carried out and their impact on the organization.

N4	**Other topics (SAC)** Work flow design/ management Benefits and Challenges for outsourcing Space projects Monitoring & Evaluating Projects: Contemporary Methods Projects Management and Monitoring: Measuring Performance: Earned Value Analysis Studies of Budgeting Methods for Indian Space Program Cost Management approach for Science, technology & Engineering Projects Cost Benefit Analysis of Communication payload projects Technology valuation and management Technology R&D and Knowledge management Technology Forecasting with respect to State of the Art Technologies Mentoring & Incubating Space Industry for creating the sustainable supply chain Demand assessment for future communication services Demand assessment for future earth observation requirements Organisational communication Information dissemination methods Learning & Development Development of Competency Framework for different categories of people Profiling New Generation S&T people Employee Engagement Organisational Commitment Innovative Organisation - building culture of Innovation – SAC case study Impact analysis of SAC/ISRO's space programs (RS,SATCOM, SATNAV) in Rural and Urban India Space Technology – Need and expectation of society and present scenario study Need of ground and space based sensors to meet India's requirements Research on Planning and development strategies Enterprise Resource Planning in Govt. R & D organization Exploring Techno-management areas of association between Govt. – Academic institutions and Industry – Market research
N5	**Work flow design/ management (SAC)** Under this, researcher should study work flow of the various electronics & Mechanical Fabrication and suggest the improvements. Also designing of the web-based tracking mechanism for the effective management.
N6	**Benefits and challenges for outsourcing space projects (SAC)** Comprehensive study of the current practices along with a case study of the Make or Buy Decisions.

N7	**Monitoring & evaluating projects: contemporary methods (SAC)** Projects Management and Monitoring; Measuring Performance; Earned Value Analysis Methods and other methods like trend analysis etc.
N8	**Cost management approach for science, technology & engineering projects (SAC)** Development of Model for the various cost attribution to the activities and refining the costing approach for overall payload costing.
N9	**Cost benefit analysis of communication payload projects (SAC)** Benchmarking of Indian Payloads with worldwide Space industry in terms of Cost and Mass. Establishing the business case for Indian satellite solution with Indigenous launch.
N10	**Human resources development (SAC)** An organisation is responsible for ensuring that its employees have the appropriate competencies to fulfil the organization's strategic and operational objectives. Training and Development (T&D) strategy aims to develop competencies of employees. National Training Policy (NTP, 2012) have also emphasized competency framework in Training & Development. The possible research work may include design and development online course content on various themes with implementation on suitable LMS and development of competency framework for various categories of people. The other research areas in Human Resource Development includes organizational commitment, employee engagement, profiling new generation S&T personnel with suitable instruments and also linking these data with Training & Development.
N11	**Social impact assessment of SATCOM and remote sensing (SAC)** There is no dispute over the fact that technology brings far reaching and fundamental changes in our social set up and brings economic progress. Today there is no aspect of human life that has not been influenced by technology and it is very important factor of social change. Technological changes have both direct as well as indirect effects. Space technology is no exception and it can be a great enabler for development. Innovative Space Applications can foster social development to great extent. Many applications of SAC are being effectively used by government departments in the areas of Rural Livelihoods, Agriculture, Food Security, Natural Resources Management, Forest Management, Urban Planning, Information Access to Remote and Inaccessible areas and Disaster Management. A detailed proposal can be designed on understanding the social as well as economic impact of space applications.
O	**Area** — **Testing of Liquid Propulsion Systems (IPRC)**
O1	**Development of data management system for effective monitoring of various systems of large liquid rocket engine test facility (IPRC)** A liquid rocket engine test facility consists of various fluid systems such as propellant fill, feed, drain systems, and Service fluid systems. All such system composed of various piping systems with flow components, pressure vessels, heat transfer equipments, safety equipments, instruments & gauges etc. Each fluid system has numerous numbers

	of flow components with specification for each component. For the test facility to be ready for testing and in serviceable condition all the above need to be maintained, tested and calibrated within the periodicity specified for the equipment/components concerned. Safety & ISO norms also insist this. Considering voluminous data to be maintained & periodically updated and higher no. of equipments/ components at ICET, a user friendly "Data management System" for maintenance of records and for periodic updating of records is essential. This system shall have provision for data entry, edit, update, store, retrieve, presenting in the form report, print etc. Also, it shall have flexibility to add other test facility systems with similar features.
O2	**Establishment of polytrophic index for expansion of gas (GH2 & GN2) in storage cylinders during expulsion at high flow rate (IPRC)** Pressurant gases such as GN2 & GH2 (Gaseous Nitrogen and Gaseous Hydrogen) stored under high pressure in gas cylinders are withdrawn at various flow rates to pressurize the facility tanks. The pressurant flow rates vary depending upon the rate and duration of propellant expelled from the tank for the test at various phases of test operations. The expansion of gases in cylinders during these phases is neither isothermal nor isentropic and the index of expansion is to be established for understanding the expansion phenomena and for deriving the pressurant flow rates required for expulsion.
O3	**Modeling, analysis and development of double walled jacketed type flame deflector for a liquid rocket test facility (IPRC)** Lame deflector is an important element of a rocket engine test facility to protect the test facility structure and equipments from the high momentum and high temperature engine exhaust plume. Many types of flame deflectors are in use worldwide. In ISRO conventional dry plate heat sink deflector with external water spray is used. An attempt was taken to guide the flame through a water spray duct, which shows a better result. Based on literature survey, it is found that Double walled Jacketed type flame deflector will be more efficient, compact and cost saving. The constructional feature of this type of flame deflector is that it is of 'J' shape and the flame is made to hit at an appropriate angle vertical to the deflector. An annular space as jacket is formed between two mild steel plates. The entire deflector shall be made into many segments. Water enters into the jacket of each segment of the deflector at its bottom through pipes. At the top surface holes of appropriate size are drilled and distributed to ensure proper cooling of the deflector plate so that it will not distort during testing. During testing water will be supplied into the deflector and injected into the flame as fine spry through the minute holes. By doing this water is converted into super heated steam and act as a thermal barrier between the deflector and flame. The objective of this proposal is to finalize a deflector with suitable configuration, modeling and analysis for a given rocket engine parameters. The result of analysis shall include optimum impingement depth of jet, deflector size, segment size, total water flow rate, size of hole, total number of holes, hole distribution, water flow rate per hole, distribution pattern, temperature of plate without water cooling & with water cooling, annular space, thickness of top & bottom plates etc. A modular thermo structural analysis and proto type deflector testing with actual rocket exhaust shall be needed for implementation.

O4	**Design and development of dynamic pressure sensor (IPRC)** Dynamic pressure measurements are essential to find and analyze the dynamic response of the propellant combustion under the operating condition of the Rocket/ Spacecraft engines. The investigated results are correlated to combustion stability and engine efficiency. Presently, piezoelectric/piezo resistive water cooled dynamic pressure sensors are being used. These sensors are imported from the manufactures viz. PCB, kulite, keller etc. Cooling of these sensors are mandatory during the measurements as the pressure port is in direct contact with the thrust chamber. Also, the piezoelectric type sensor gives only the dynamic pressure response, making it difficult to clear for the test as there is no ambient available. The advanced technical approaches using fibre Optic, MEMS and nano technologies may be attempted to design suitable dynamic pressure sensors for our requirements. A better prediction of the level of combustion instability can be achieved with these types of sensors which can withstand higher temperatures also. A parametric study of the theoretical results as well as the comparison with the existing experimental data shall be carried out to qualify the designed sensor.
O5	**Detection of hazardous environment and its mitigation using wireless sensor networks (IPRC)** Earth storable hypergolic propellants are used for propelling the rocket and satellite engines at IPRC facilities. These propellants are highly toxic and hazardous. Hence, monitoring leakage of these propellants during the storage, transportation, filling and draining operations at the test stands and during the hot test activities is very much essential. As the remote storage facilities and test stands are not continuously manned, 24x7 monitoring is essential to correctly detect the leakages if any, and to mitigate the effects (fire, explosion etc), in the quickest possible time. Wireless sensor networks supported by data fusion techniques can be employed to precisely determine the exact location and severity & the hazard without fear of any false alarm possibility. GIS (Geographical Information System) aids this scheme to identify the exact location of the incident and helps to alert the concerned personnel with the aid of GSM/GPRS message in real time. The mitigation activities depend on the severity of the incident and the facilities available/planned for the mitigation.
O6	**Design and development of stirling cryogenic cooler (IPRC)** IPRC uses Liquid Nitrogen for pre cooling and Gaseous Nitrogen for inertization, media substitution and ejector operations. Liquid Nitrogen is stored in LIN storage Tank/Tankers of capacity 10 KL to 75 KL. The Boil off vapour in storage tank or in the Air Separation Units can be liquefied by incorporation of Stirling Cryogenic Cooler. Initially it is proposed to develop a cooler with cooling capacity of 500 W at 77K.
O7	**Rocket engine test article measurements of low varying parameters using wireless sensor networks (IPRC)** Rocket motors use liquid fuel, Solid fuel, cryogenic and semi-cryogenic propellants depending upon the mission requirements and are designed for specific applications. Different instrumentation sensors used are pressure transducers strain gauges,

	thermocouple, RTDs, flow meters, accelerometers and micro phones. As per the requirement the sensors are selected and mounted on the rocket engine at specific locations. Right now these sensor's' data are transmitted to the control centre with a aid of hard-wired cables and lot of problem are faced in maintaining these cables to get error free data at the control centre. The requirement of this project is to get rid of these cables which amount to hundreds of kilometers in length altogether. These measurement data is to be acquired with the aid of wireless sensors and the new data/processed data only need to be transmitted to the control centre using wireless Ethernet, zig-bee or GSM technologies. We expect moderate data relates upto 2000 samples/parameter to get meaningful representation of the measured parameters suitable software to be developed to acquire, format out transmit test data, receive and strip the test data, process and analyze the test data etc.
O8	**Data processing and analyzing of earth storable liquid propulsion rocket engine test data using data mining techniques (IPRC)** The performance of rocket engine can be examined through the processing of acquired test data, and the buildup of different parameter models. IPRC have a good collection of Earth Storable Liquid propulsion rocket engine static test data. Data mining techniques can be adopted to analyze the test data. The technique may involve de-noising the parameter values without losing the useful information. Mathematical and statistical analysis to be carried out and the advantages of frequency domain and wavelet transformation to be exploited to arrive at a conclusion about the health and performance of the rocket engines in comparison with the similar hardware tested earlier.
O9	**Design and development of ANFIS controller for optimized control in cryogenic high altitude test facility of IPRC (IPRC)** Cryogenic HAT facility in IPRC is comprised of Vacuum System, Diffuser System, Cooling System and Ejector System along with Propellant Filling / Feed Circuits, Structural Components, Safety Systems and Instrumentation systems for the Static testing and Qualification of Cryogenic Engines. The major components of the Vacuum System are the Vacuum Chamber inside which the test specimen is mounted and the Ejector for chamber evacuation. This ejector has a clustered nozzle configuration for admitting constant GN2 into the chamber through the Pneumatic lines, Field Elements (Electro pneumatic valves and Control valves) and Sensing devices for process parameter monitoring. A single input based Closed-loop Proportional Integral Derivative (PID) controller is deployed for the control valve in order to attain the required flow rate with theoretically estimated static set point. The Proportional, Integral and Derivative coefficients are determined offline. PID is an error based control approach without direct knowledge of the process and is suitable for well defined and static process. Also overshoots, oscillations and noise amplification are associated with the PID based control approach. An ANFIS (Adaptive Neuro based Fuzzy Inference System) is an integrated Neuro-Fuzzy system with a knowledge based approach for a Process control. Artificial Neural Networks

	(ANN) are adaptive systems that can be trained and tuned from a set of trials whereas Fuzzy Inference Systems (FIS) have the ability to represent and execute reasoning using fuzzy rules. ANFIS controllers can cater to the process needs with decisions based on more than one process parameter and can handle dynamic or changing process conditions. Hence it is proposed to design, develop and deploy ANFIS controller. The neural network can be implemented with the available process data and the necessary algorithms for control has to be developed and deployed on an independent controller that can be interfaced to existing data repositories using standard interface protocols for real time decision and control.
O10	**Development of high entropy alloy thermal barrier and wear resistance coatings for rocket engines (IPRC)** High-entropy alloys (HEAs) are presently of great research interest in materials science and engineering. Unlike conventional alloys, which contain one and rarely two base elements, HEAs comprise multiple principal elements, with the possible number of HEA compositions extending considerably more than conventional alloys. The concept of high entropy introduces a new path of developing advanced materials with unique properties, which cannot be achieved by the conventional micro-alloying approach based on only one dominant element. Up to date, many HEAs with promising properties have been reported, e.g., high wear-resistant HEAs, Co1.5CrFeNi1.5Ti and Al0.2Co1.5CrFeNi1.5Ti alloys; high-strength body-centered-cubic (BCC) AlCoCrFeNi HEAs at room temperature, and NbMoTaV HEA at elevated temperatures. Furthermore, the general corrosion resistance of the Cu0.5NiAlCoCrFeSi HEA is much better than that of the conventional 304-stainless steel. In addition, HEAs have excellent specific strength, superior mechanical performance at high temperatures, exceptional ductility and fracture toughness at cryogenic temperatures, superparamagnetism, and superconductivity. Due to their considerable structural and functional potential as well as richness of design, HEAs are promising candidates for coating applications, which warrants further studies. Thermal-spray (TS) technology to fabricate coatings of the NixCo0.6Fe0.2-CrySizAlTi0.2 HEAs was developed. These sprayed particles are accumulated on the substrate by cooling and building up one by one into a cohesive structure. Thus, coatings are formed. The results also indicate that the hardness of the HEAs prepared by the TS in combination with annealing at 1100°C/10 h is significantly increased to that of the as-cast state (1045 HV). These samples exhibited excellent coarsening resistance, resulting from the Cr3Si and several unidentified phases. NixCo0.6Fe0.2CrySizAlTi0.2 alloy system does precipitate during casting, which is quite different from many other HEAs. The literature survey confirmed that phase formation and final microstructure of HEAs are strongly dependant on the processing conditions. A low-cost HEA coating with a nominal composition of 6FeNiCoCrAlTiSi was prepared by laser cladding. This technique normally results in a metallurgical bond that has the superior bond strength over TS. The resultant coating is dense with no voids or porosity. One of the advantages of the laser-cladding process is the laser beam which can be focused and concentrated to a very small area and keeps the heat-affected zone of the

	substrate very shallow. This feature minimizes the chance of cracking, distorting, or changing the metallurgy of the substrate. Additionally, the lower total heat minimizes the dilution of the coating with materials from the substrate. The coating prepared by laser cladding has a simple BCC solid solution with high micro-hardness, high resistance to softening, and large electrical resistivity. After being annealed at T < 750°C, the coating shows high thermal stability, and its resistivity slightly decreases, but the micro-hardness almost remains unchanged. After annealing at T > 750°C, the micro-hardness of the coating slowly decreases with increasing the decomposition rate of the BCC solid solutions. A suitable high entropy alloy system and coating process need to be developed for the rocket engines to make the HEAs coating more uniform and with high cohesion with substrates.
O11	**Enhancement of fracture toughness of nickel based super alloy weld metal through addition of nano fibres (IPRC)** Possible solid material, known as nanomaterial, and its introduction in welding production has improved the weld strength properties and overcome unstable microstructures in the weld. This study critically reviews the methods of introducing nanomaterial to the superalloy weldments and the characteristics of the welds produced by GMA (gas metal arc) and GTA (gas tungsten arc) welding processes. The study mainly focuses on changes in the microstructural formation and strength properties on the superalloy welded joint (Inconel 718) and also discusses the factors influencing such improvements due to the addition of nanomaterials. The literature review shows that the effect of nanomaterial addition in the welding process modifies the physics of the joint region, thereby resulting insignificant improvement in the strength properties, with a stable microstructure in the weld. In general, the factors that have a major influence on joint strength are the dispersion, characteristics, quantity and selection of nanomaterials. The nanomaterials addition does not affect the fundamental properties and characteristics of the base metals and the filler metal. However, in some cases, the addition of nanomaterials leads to the deterioration of the joint properties by unstable microstructural formations. Research is still being conducted to achieve high weld properties in various materials through different welding processes and on other factors that influence joint strength.
O12	**Development of new filler metal for super alloys with inoculants (IPRC)** The microstructure of a weld metal can be altered by controlling the fluid flow during solidification. Such control produces drastically different results depending on whether a solute addition acts as an inoculating agent (involving a low proportion of a nucleating second phase) or if it is mostly soluble and forms a second phase only as a result of microsegregation. This differentiation, previously shown for Al and some of its alloys, is repeated with magnesium containing zirconium, which is a known inoculant for MS. Copper is then tested as an addition to lead. Its action allows the production of very curious macroscopic grain structures which will be shown to be characteristic of an inoculant. Subsequent tests support the validity of applying fluid flow structure-control as a method for identifying inoculants. Suitable inoculants for nickel based superalloy (Alloy 718, Alloy 706 and Rene 41) need to be selected and prepared. One probable set of inoculants composed of two ternary

	intermetallic compounds shall be Co3FeNb2 and CrFeNb. Their effects on the structures of superalloy need to be investigated. The influence of mixed inoculants consisting of Co3FeNb2 and CrFeNb to the melt on the refinement of grains of the γ matrix of superalloy and the effect of proportion of equiaxed grains need to be theoretically analyzed and experimentally demonstrated. In addition, experimental evidence to be demonstrated for the trace addition of inoculants to the melt neither introduces inclusions nor changes the phase constituent of the alloy.
O13	**Investigation on the influence of curing conditions, hydration reaction, rheological properties, environmental parameters and chemical composition on refractory cement and mechanism on the formation of defects (IPRC)** The objective of this work is to evaluate simultaneous mass loss, thermal and fluid dynamic changes in a refractory castables, hydration kinetics, rheological properties and curing conditions at different water to cement ratio. Tests need to be performed with high-alumina refractory castables with different type of hydraulic binders, and included evaluation of permeability changes due to thermal expansion effects. Removal of physical (moisture) and chemical (hydrates) water at different heating rates is also to be evaluated for refractory castables based on calcium aluminate cement (CAC) and hydratable alumina binders (HAB). A method to be proposed for understanding how variables such as the curing environment and the type of binder agent or permeability-aid additives influence the occurrence of voids and crack formation, thereby helping to define the best castable composition and plan safe curing schedules.
O14	**Development of bimetallic cylinders (Austenitic Stainless Steel AISI321+AA2219, AISI321+Ti-6Al-4V and AISI304L+Ti-6Al-4V) through friction welding route with suitable inter layers (IPRC)** The family of friction welding processes includes several methods, such as rotary friction welding (RFW), linear friction welding (LFW), and the newest one, friction stir welding (FSW). However, the main principle is always the same—to obtain the joint it is necessary to heat the materials to the plastic-state and with the use of “upsetting force” plastically displace the materials and create the weld. The heat is generated by the friction between two welded components (RFW and LFW) or between components and specially designed tool (FSW). Welding processes are classified as solid-state joining methods because the melting of joined materials does not occur these processes. A big attractiveness of these joining methods results from many technical and economic advantages, such as high efficiency and stability of the process or better conditions of occupational safety and health than in the case of traditional welding technologies. However, recently, the most important seems to be the possibility of joining materials with different properties. Due to the fact that in the fusion zone between the two different materials the intermetallic compounds are formed and the joining process of dissimilar materials is often very difficult. To obtain high-quality joint it is necessary to know and analyze phase diagram of the two welded materials. Furthermore, the microstructure and different properties of is also necessary in the case of joining dissimilar materials. The proposed project deals about the friction welding of aluminium and titanium alloys with different types of steel.

	The demand for increased launch requirements means that rocket-engines are growing in thrust, temperature, and size. To withstand the higher temperatures, critical aerospace components are being made with materials such as superalloy, bimetallic, stainless steel and aluminum. These materials, which can be difficult and many times impossible to weld with conventional methods, can be joined with the friction welding process. These higher-temperature materials, along with the large component size, require large amounts of weld energy and load. In order to meet this increasing demand, higher diameter (>125mm) transition joints in Welding process need to be developed.
O15	**Processing and properties of high-entropy ultra-high temperature carbides (IPRC)** Ultra-High Temperature Ceramics (UHTC's) are a limited and select set of carbides, nitrides and borides of the group IV and V transition metals, which are typically defined as having melting temperatures more than 3300 K; with HfC exhibiting the highest known melting point of all materials (4232 ± 84 K)1. UHTC's also display high hardness, elastic modulus and resistance to thermal shock and chemical attack. These materials represent the only suitable class of materials available to make or protect components that are placed under the most extreme of operating environments. As these developing technologies become more advanced and more demanding, UHTC's are coming under increasing pressure to perform under more diverse operating conditions. A greater selection of UHTC's that exhibit a much broader range and combination of physical, chemical and mechanical properties are therefore required to meet these demands. Bulk equiatomic (Hf-Ta-Zr-Ti)C and (Hf-Ta-Zr-Nb)C high entropy Ultra-High Temperature Ceramic (UHTC) carbide compositions shall be processed through optimized route for the (Hf-Ta-Zr-Nb)C composition to produce a high purity, single phase, homogeneous, bulk high entropy material (99% density); revealing a vast new compositional space for the exploration of new UHTCs. Mono/binary carbides need to be developed with hardness (36.1 ± 1.6 GPa,) compared to the hardest monocarbide (HfC, 31.5 ± 1.3 GPa) and the binary (Hf-Ta)C (32.9 ± 1.8 GPa).
O16	**Multi-material additive manufacturing of metamaterials with giant, tailor able Negative Poisson's Ratios (IPRC)** Materials with designed three-dimensional micro-architectures offer multiple beneficial properties such as low weight, high stiffness and strength, negative poisson ratio and energy absorptions and can open up a myriad of material by design applications from flexible armor, responsive materials to bio-mimetic materials. Ultimately, one would like to 3D print functional device or components that incorporate multiple material constituents without the requirement of excessive assembling procedures such as gluing, aligning, fitting, and welding. Apart from enhancing spatial resolution and printing speed, achieving this goal requires the ability to incorporate an array of different material properties within a manufacturing platform. In analogy to typical 2D color printers that can integrate multiple colors from mixing a few colors (magenta, cyan, yellow), a three-dimensional fabrication platform should not only be able to integrate multiple colors, but also be capable of spatially integrating encoded material properties and compositions from mixing only a limited number of feedstock materials.

	A strategy to achieve unusual mechanical properties through coupling variable elastic moduli from a few GPa to below KPa within a single tissue to be evolved. The ability to produce multi-material, three-dimensional (3D) micro-architectures with high fidelity incorporating dissimilar components has been a major challenge in man-made materials. The multi-modulus metamaterials whose architectural element is comprised of encoded elasticity ranging from rigid to soft. In contrast to ordinary architected materials whose negative Poisson's ratio is dictated by their geometry, these types of metamaterials are capable of displaying Poisson's ratios from extreme negative to zero, independent of their 3D micro-architecture. The resulting low density metamaterials is capable of achieving functionally graded, distributed strain amplification capabilities within the metamaterial with uniform micro-architectures. Simultaneous tuning of Poisson's ratio and moduli within the 3D multi-materials could open up a broad array of material by design applications ranging from flexible armor, artificial muscles, to actuators and bio-mimetic materials.
O17	**Thermodynamic and micro structural study of Ti2AlNb oxides at 800 °C for coating applications (IPRC)** Ti2AlNb-based alloy, sometimes referred to as orthorhombic alloy, is a class of highly promising lightweight high-temperature materials. This type of alloy is considered to partially substitute the high-density (ρ = 8~8.5 g/cm3) Ni-based superalloys in the aerospace industry due to its low density, high strength, superior plasticity, high fracture toughness and excellent creep resistance at elevated temperatures. In such applications, the operating temperatures could go beyond 600–650 °C, leading to severe oxidation of the alloy surface. There are three potential approaches to improve high-temperature oxidation resistance: alloying, pre-oxidation and coating. A two-step voltage-controlled microarc oxidation (MAO) method can be used to produce ceramic coatings on a Ti2AlNb-based alloy. However, after a prolonged exposure to air at elevated temperatures, intermetallics exhibit oxygen-induced embrittlement characteristics such as low ductility and brittle fracture. Thus, an understanding of high-temperature oxidation mechanisms is essential for improving the oxidation resistance of materials. A Ti2AlNb-based alloy is observed to exhibit fairly good oxidation resistance below 750 °C. After reaching 800 °C, the oxidation resistance decreased dramatically. Thus, the oxidation behavior and mechanisms are to be investigated at a higher temperature of 800 °C and above.
O18	**Super-strong materials for temperatures exceeding 2000 °C (IPRC)** Ceramics based on group IV-V transition metal borides and carbides possess melting points above 3000 °C, are ablation resistant and are, therefore, candidates for the design of components of next generation space vehicles, rocket nozzle inserts, and nose cones or leading edges for hypersonic aerospace vehicles. As such, they will have to bear high thermo-mechanical loads, which makes strength at high temperature of great importance. While testing of these materials above 2000 °C is necessary to prove their capabilities at anticipated operating temperatures, literature reports are quite limited. Reported strength values for zirconium diboride (ZrB2) ceramics can exceed 1 GPa at room temperature, but these values rapidly decrease, with all previously reported strengths being less than 340 MPa at 1500 °C or above. The strength of ZrB2 ceramics was increased to more than

	800 MPa at temperatures in the range of 1500–2100 °C. These exceptional strengths are due to a core-shell microstructure, which leads to in-situ toughening and sub-grain refinement at elevated temperatures. The development of such materials those are super-strong at ultra-high temperatures are proposed.
O19	**The effect of reduced gravity on cryogenic nitrogen boiling and pipe chill down (IPRC)** Manned deep space exploration will require cryogenic in-space propulsion. Yet, accurate prediction of cryogenic pipe flow boiling heat transfer is lacking, due to the absence of a cohesive reduced gravity data set covering the expected flow and thermodynamic parameter ranges needed to validate cryogenic two-phase heat transfer models. The proposed work provides a wide range of cryogenic chilldown data aboard an aircraft flying parabolic trajectories to simulate reduced gravity. Liquid nitrogen is used to quench a 1.27 cm diameter tube from room temperature. The pressure, temperature, flow rate, and inlet conditions are reported from 10 tests covering liquid Reynolds number from 2,000 to 80,000 and pressures from 80 to 810 kPa. Corresponding terrestrial gravity tests were performed in upward, downward, and horizontal flow configurations to identify gravity and flow direction effects on chilldown. Film boiling heat transfer was lessened by up to 25% in reduced gravity, resulting in longer time and more liquid to quench the pipe to liquid temperatures. Heat transfer was enhanced by increasing the flow rate, and differences between reduced and terrestrial gravity diminished at high flow rates. The new data set will enable the development of accurate and robust heat transfer models of cryogenic pipe chilldown in reduced gravity.
O20	**Super elasticity and cryogenic linear shape memory effects of CaFe2As2 (IPRC)** Shape memory materials have the ability to recover their original shape after a significant amount of deformation when they are subjected to certain stimuli, for instance, heat or magnetic fields. However, their performance is often limited by the energetics and geometry of the martensitic-austenitic phase transformation. An unique shape memory behavior in CaFe2As2, which exhibits superelasticity with over 13% recoverable strain, over 3 GPa yield strength, repeatable stress–strain response even at the micrometer scale, and cryogenic linear shape memory effects near 50 K. These properties are achieved through a reversible uni-axial phase transformation mechanism, the tetragonal/orthorhombic-to-collapsed-tetragonal phase transformation. The proposed work is for developing cryogenic linear actuation technologies with a high precision and high actuation power per unit volume for deep space exploration, and more broadly, suggest a mechanistic path to a class of shape memory materials, ThCr2Si2-structured intermetallic compounds.
O21	**Development of mechanical meta materials at the theoretical limit of isotropic elastic stiffness (IPRC)** A wide variety of high-performance applications require materials for which shape control is maintained under substantial stress, and that have minimal density. Bio-inspired hexagonal and square honeycomb structures and lattice materials based on repeating unit cells composed of webs or trusses, when made from materials of high elastic stiffness and low density, represent some of the lightest, stiffest and strongest materials

	available today. Recent advances in 3D printing and automated assembly have enabled such complicated material geometries to be fabricated at low (and declining) cost. These mechanical metamaterials have properties that are a function of their mesoscale geometry as well as their constituents, leading to combinations of properties that are unobtainable in solid materials; however, a material geometry that achieves the theoretical upper bounds for isotropic elasticity and strain energy storage (the Hashin–Shtrikman upper bounds) has yet to be identified. Here we need to evaluate the manner in which strain energy distributes under load in a representative selection of material geometries, to identify the morphological features associated with high elastic performance. Using finite-element models, supported by analytical methods, and a heuristic optimization scheme, material geometry shall be identified that achieves the Hashin–Shtrikman upper bounds on isotropic elastic stiffness. The advantageous properties of low-density mechanical metamaterials are: their mesoscale geometry can facilitate large crushing strains with high energy absorption, optical bandgaps and mechanically tunable acoustic bandgaps, high thermal insulation, buoyancy, and fluid storage and transport.
O22	**Study on microgravity testing of a phase-change (IPRC)** Orbital sensors to monitor global climate change during the next decade require low-drift rates for onboard thermometry, which is currently unattainable without on-orbit recalibration. Phase-change materials (PCMs), such as those that make up the ITS-90 standard, are seen as the most reliable references on the ground and could be good candidates for orbital recalibration. Development on miniaturized phase-change references capable of deployment on an orbital blackbody is mandatory. The objective of the proposed work is on the improvement of orbital temperature measurements for long duration earth observing and remote sensing. This proposal needs certain microgravity research either in space or in a lab level is required to determine whether and how microgravity will affect the phase transitions. There will be a need for orbital temperature knowledge to support infrared radiance measurements with 0.1K uncertainty over a period of at least 10 years. As temperature uncertainty is only one of the contributors to the desired 0.1K uncertainty, the goal for on-orbit temperature knowledge must be smaller (in the range of 0.01 K) to leave margin for other uncertainties in the calibration chain. Onboard references utilizing phase transitions have been identified as the most likely means for realizing International System of Units (SI) traceability for temperature measurements in orbit. The ITS-90 identifies several phase-change materials (PCMs) with reliable fixed points that can be reproduced and used as references with submilli-kelvin absolute uncertainties for ground-based calibrations. Three PCMs with fixed points in the range required to calibrate Earth-observing sensors are Gallium (Ga), water, and mercury with melt points of 302.9146K, 273.16K, and 234.3156 K, respectively. However, the ITS-90 description of procedures and apparatuses does not translate easily into a design for an automated orbital implementation. ITS-90 describes fixed-point cells that use fragile materials such as plastic or glass to contain PCMs and require sensors to be placed in reentrant wells within relatively large volumes of 250 ml or more of the PCM. The described procedures do not apply directly to in situ sensor calibrations such as those that will be required on an orbital blackbody.

	In early 2006, the suitability of Ga and its various binary eutectics were investigated at the All Russian Institute for Opto-Physical Measurements (VNIIOFI) in Moscow, Russia under a subcontract with Space Dynamics Laboratory (SDL) in Logan, UT, USA. The purpose of these studies is to significantly reduce the size and volume of qualified containers and identify PCMs within the range of 273K–303 K that could be used as calibration standards aboard Earth-observing satellites. This study will be characterizing several suitable eutectics to fill the gap in the ITS-90 temperature scale between the triple point of water and the melting point
O23	**Numerical study on the porous injector concept for throttling of liquid rocket engine (IPRC)** In liquid rocket engines, the injector design has influence on the combustion stability, combustion chamber durability, overall all engine performance and greatly on the throttling capabilities of the engine. Presently co-axial injectors are used in LOX/H2 or LOX/CH4 liquid propellant rocket engines. Advanced injector design which is insensitive to the varying injection conditions is required for applications specifically for throttling capability. One of the promising candidates for the development of throttleable injector shall be the porous injector for the cryogenic rocket engines. For example, in order to increase in the contact surface between fuel and oxidizer, the oxidizer (Liquid Oxygen, LOX) injected through many small tubes in a parallel showerhead configuration and the fuel in this case, hydrogen/methane shall be injected through a porous faceplate. The main advantage is that of throttling the engine by reducing the propellant mass flow, which in this case has minor influence on the atomization and mixing characteristics. In addition, very low combustion roughness can be achieved even at very low pressure drops across the injector. Another advantage are the potentially lower manufacturing costs based on the simple design. Expected deliverables: Numerical modeling of flow through porous media and atomization characteristics of the porous injector. Parametric studies to understand the impact of the operating conditions and the porous geometry on the performance of the injectors. A model, incorporating numerical and analytical approaches to predict the mixing efficiency and throttling capabilities of porous injectors in cryogenic engines Experimental validations of the numerical study through cold flow spray characterization and hot-fire tests
O24	**Modeling and simulation of micro-channel reactor for Sabatier reaction for methane synthesis from carbon-dioxide (IPRC)** In the view of Mars exploration missions and human space missions, Sabatier reaction plays a vital role in order to convert the carbon-dioxide into the useful products. Sabatier reaction involves the methanation reaction of CO2 using hydrogen to produce methane and water. For human spacecraft, CO2 removal from the crew-cabin is accomplished by engaging the catalytic reactor. In the same way, CO2 from the Mars atmosphere shall be converted to the propellant - methane (CH4) as a concept of in-situ resource utilization.

	In the view of space qualified product development, it requires a compact and light weight catalytic reactor to convert the CO2 into the useful methane and water. One of the viable options shall be the micro-channeled reactor and in order to configure the light weight & compact system which needs a fundamental research on the modeling and simulation of micro reactor for efficient operation of the methanation process. Expected deliverables: CFD modeling of the micro reactor with reaction kinetics to design the reactor for the maximum conversion. Process dynamics and simulation of process parameters to optimize the process intensification. Experimental validation of micro-reactor for Sabatier reaction. Uncertainty analysis of designed reactor for different operating conditions. Process model which includes the reactor, Heat Exchanger, recycle loop for further design of a full-scale process
O25	**Solar photo voltaic based sensing (IPRC)** Heat flux is measured based on the Thermopile technology which involves and multi metal junctions integrated in the sensing element. Also, the solar cells convert the irradiated energy into electrical energy. This work is towards converting the solar/photovoltaic cell for Heat flux sensing and measurement. The solar cells provide the output voltage/ current proportional to the irradiated light energy. It is possible to correlate the irradiated energy spectrum vs heat flux. Hence the solar cell/Photovoltaic can be converted for measurement of Heat flux. Explorative experimental investigations are essential for the development of photovoltaic based heat flux sensing. In this process the IV Generation of solar cells i.e. Pervoskite solar cells are to be studied for conversion efficiency on Visible, IR, UV and Dark energy conversion etc to tune the photovoltaic cells for Heat sensing applications. The work is to be extended towards the efficiency improvement of the photovoltaic cells. And to, enhance the dark current generation in photovoltaic generators. This finds application as power generators in deep space missions where the space probes are engulfed in the e.m. waves. The major work involves theoretical estimate of the e.m. energy spectrum. Hence this work involves a) fabrication of Solar Cells (I, II, III or IV) generation solar cells b) study the conversion efficiency c) theoretical study on the sensing linked to Heat flux d) fabrication of proto version of solar cell/Photovoltaic based heat flux sensor.
O26	**Numerical modeling of vapor liquid interaction in cryogenic systems (IPRC)** In cryogenic systems, pressure measurement is carried out using pressure sensors which are designed to work at ambient temperature. To avoid the low temperature exposure of the sensing elements of these pressure sensors, lengthy canalisation tubes are used for warming up the cryogenic fluid. Because of this arrangement a large thermal gradient along the length of a vapour filled column which is closed at the warm end creates oscillations in pressure measurement. Those typical cryogenic oscillations include the thermal acoustic oscillations, the “Geyser” oscillations, gasification oscillations, and those oscillations under the periodic heat load from the wall of bare (Non-insulated) canalisation lines.

	The thermal acoustic oscillations occur when cryogenic liquid and vapour. interacts each other. The warm gas in the column contracts due to the thermal interaction between the vapour liquid interactions. The gas expands at the other end due to the thermal interaction between the ambient through the canalisation walls. The inertia of the gas moving away from the warm section creates a low pressure in the warm section. This is aggravated by the high density and therefore high mass of the gas in the cold section which is being pushed away from the warm section. At low temperatures, the viscosity of the gas decreases; therefore there is a slug of high density gas, with low viscosity acting like a mass attached to a spring. In the two-phase fluid interactions subject to pressure variation in the cryogenic liquid flow, the compressibility of the vapour bubbles act as a spring with an asymmetric non-linear characteristic. The volume of the vapour bubbles increases or decreases differently if the pressure fluctuations are compressing or expanding. These studies are complements to the characterization of thermal acoustic effects on pressure measurement. Aim of this work is to develop numerical model to simulate the pressure oscillations focus on the effect of diameter, wall thickness, length and material of the canalisation line on the formation of pressure oscillations and to develop the methodology to bias or eliminate the effects of pressure oscillation.
O27	**Solid cryogenic green propulsion system (IPRC)** Cryogenic propellants offers the highest energy efficiency for rocket engines because of the low molar mass of their combustion products, high combustion temperature hence maximum specific impulse can be obtained. The complex feed system required either with turbo-pumps and regenerative cooling is disadvantaging the cryogenic propulsion systems. Solid propellant rocket motors are simple because they do not have the complex feed system and solid propellant insulates the combustion chamber walls from the hot gases so there is no need of cooling. The performance of solid rocket motors (in terms of Isp) is substantially lower than that of cryogenic liquid engines and the mass of the combustion chamber is substantially higher than the mass of the liquid propellant tanks. The advantage is that the demonstrated reliability of solid rocket motors is higher than that of liquid engines and the cost of a solid motor is only a meagre portion of a liquid engine for the same total impulse. Present solid rockets propellants are not the eco friendly chemicals. The advantages of solid and cryogenic liquid propulsion systems shall be combined to develop an eco friendly solid cryogenic green system is an extremely attractive solution for heavy thrust rocket boosters. The theoretical feasibility and lab level experimental study to demonstrate the prospects of using solid cryogenic green rocket engines, which could lead to substantial improvement in efficiency, eco friendly and reduction in launch costs in addition to improving the launch reliability.

2.0 Satellite Communications Programme

A	Area	SATCOM Applications (NESAC)
A1	Sub Area	SATCOM Applications (NESAC)
A1.1	**Local TEC model for NER through IRNSS + GPS + GAGAN Receiver (NESAC)** Using current DF IRNSS + GPS + GAGAN Receivers, generation of local TEC model and characterization of Ionospheric Anomalies. This will provide reliable delay calculation which may lead to better positional accuracy. Earthquake induced TEC anomaly will be also tried to study so that any usable earthquake precursor may be identified and used for earthquake early warning.	
A1.2	**ZIGBEE based wireless sensor network for landslide (NESAC)** A multi column landslide sensor may be implemented for real time forecasting of landslides and dissemination of alerts in a wireless sensor network for centralized mitigation.	
A1.3	**Wireless communication channel noise characterization for hilly urban areas like shillong (NESAC)** A study of the various noise effects impairing wireless communication in a hilly urban environment like Shillong is to be modeled and characterized. This may help in mobile tower location optimization and transmit power and modulation scheme optimization.	
B	**Area**	**Electronics Support Services (SAC)**
B1	Sub Area	Microelectronics (SAC)
B1.1	**Design, fabrication and test of RF subsystems using packaging technologies like MCM, LTCC System in Package (SiP), advanced System-on-Chip (SoC) &Wafer Level Packaging for both space and ground applications (SAC)**	
B1.2	**Research area also include fabrication technologies like fabrication and assembly of HMIC based subsystems, fabrication process development like thin film processes, optical and electron beam lithography, wet/dry pattern generation techniques, LTCC processes, device assembly and hermetic sealing of microwave packages (SAC)**	
B1.3	**Each of these advanced technology areas pose challenges in every field - design, simulation, optimization, CAD tool development, modelling of devices and fabrication processes (SAC)**	
B1.4	**Semiconductor device (GaAs PHEMT, MHEMT, InP & GaN based) modeling (linear, non-linear, noise) including statistical process variation and temperature dependence (SAC)** Very few MMIC foundries give complete device models, which are required for simulation and design of MMICs, especially in non-linear simulations like frequency converter, frequency multiplier, gain control amplifier, voltage controlled oscillators. In most of the	

	cases limited models are available from foundry. Scalable models including linear, noise, non-linear, statistical process dependence and temperature dependence needs to be developed which can be integrated with EDA software.
B1.5	**Development of temperature dependent models of PHEMTs, MHEMTs and InPHEMTs, their validity at cryogenic temperatures and application in design of LNAs for DSN in S, X and Ka-band (SAC)** Presently limited data and models are available for simulation of active microwave circuits over temperature range including cryogenic temperatures. Circuits are designed at ambient and their response is studied practically at these temperatures. If proper models of basic devices are available over temperature and frequency of operation, it will be helpful in designing circuits optimized for cryogenic temperatures.
B1.6	**Non-linear stability analysis of multi-transistor MMIC (SAC)** Though nonlinear stability is an established field, presently no microwave CAD software is available which can easily predict the stability of a nonlinear circuit and they do in linear case. For multi-transistor MMIC, presently few alternative methods like, convergence of harmonic balance simulator, S11 at all the active device points etc. are used, which are time consuming and empirical in nature. CAD software to easily predict nonlinear stability is desirable.
B1.7	**Simulation, process development & characterization of GaN/AlGaN heterostructures usable for GaN High Electron Mobility Transistor (HEMT) application (SAC)** GaN is very promising material for high power and high frequency devices due to wide band gap (WBG), high thermal stability and high breakdown voltage. Gallium Nitride semiconductors and heterostructure devices are prime contenders for advanced electronics systems including space hardware due to their outstanding material properties especially with reference to speed, power, efficiency, linearity. GaN based high-power, high frequency devices found special place in communication area due to their distinct advantages. However, at the same time the fabrication technology offers challenges due to involvement of high growth temperature and other intrinsic factors. The aim of the proposed project is to develop the GaN/AlGaN heterostructure on SiC wafer using MBE or MOCVD process for GaN HEMT RF applications. These shall include Generation of working Physics based models of AlGaN/GaN Heterostructure on SiC substrate (using suitable modelling software). The models will include the extraction of electron transport properties, mobility, breakdown voltage, 2D electron gas density with respect to the variation in composition and thickness of active layer in heterostructure. Process development & optimization for GaN Heterostructure. Demonstration the properties of fabricated GaN Heterostructure in terms of 2D electron gas density, mobility, spectral response, defect density, composition and thickness uniformity, etc.

B1.8	**Simulation, process development & characterization of compound semiconductor heterostructures usable for terahertz (THz) detector application (SAC)** Compound semiconductor (GaAs, GaN, InP etc.) and its heterostructure are very promising materials for photonics application. Compound semiconductors and its heterostructure devices are prime contenders for advanced photonics systems including space hardware due to their outstanding material properties especially with reference to speed, power, efficiency, linearity. Compound semiconductor based Terahertz sources and detector devices found special place in Space application area due to their distinct advantages. However, at the same time the Physics based model generation and fabrication technology for THz application offers challenges. The aim of the proposed project is to develop the Compound semiconductor (GaAs, GaN, InP etc.) and its heterostructures using MBE or MOCVD process for Terahertz Detector applications. These shall include: Generation of working Physics based models of compound semiconductor Heterostructure (using suitable modelling software). The models will include the extraction of electron transport properties, detectivity, dark current, responsivity, Noise equivalent power (NEP) with respect to the variation in composition and thickness of active layer in compound semiconductor heterostructure. Process development & optimization for Compound semiconductor Heterostructure. Demonstration the properties of fabricated compound semiconductor Heterostructure in terms of 2D electron gas density, spectral response, defect density, composition and thickness uniformity, etc.
B1.9	**Development of via hole on silicon carbide types of hard materials by using UV laser (355nm) and study of failure modes and analysis (SAC)** Space Applications Centre, Ahmedabad, ISRO is engaged in the development and realization of various satellite payloads as well as R&D activities for ground & space hardware. It involves developing new nano electronics facility. Here we are going to study and develop GaN HEMT based device fabrication. In this development of via hole of 100 microns on SiC, Si, etc. types of hard material are required. This hole can be drilled by using UV (355nm) laser. This holes are to be metallized for grounding and other purpose so it is required that holes are burr free, crack free. Also study of aspect ratio, mechanical stress and shape of the hole during the drilling process.
B1.10	**Non cyanide, neutral gold electro plating bath chemistry to deposit 5-7 micron thickness on patterned seed layer coated alumina substrate (SAC)** Cyanide base gold electroplating solution in not compatible for patterned substrate by liquid photo resist and the conventional method for fabrication of microwave circuits is producing more effluent having gold and its increases the wastage of gold. So it is generating the environment problem. The disposal of cyanide bath is also generating the water pollution. To overcome technical as well environmental issues, it is preferable to use non cyanide electro plating bath which gives good edge finish by additive process. It is also preferable to use this non cyanide chemistry in other applications as well other

	industries as an indigenous development.Summary: For the first time, an exhaustive linear and nonlinear stability analysis of multitransistors monolithic-microwave integrated-circuit (MMIC) circuits is presented. A key point of the proposed stability analysis lies in that it can be easily implement. Summary: Exploration of the Solar System with automated spacecraft that are more than ten astronomical units from Earth requires very large antennae employing extremely sensitive receivers. A key figure of merit in the specification of the spacecraft-to-earth.
B1.11	**Application of exact synthesis methods in design of microwave and millimeter wave non- linear circuits (SAC)** Design of microwave circuits and components uses both non-synthesis and exact synthesis methods. Exact synthesis methods are generally used in filter and matching circuit designs. This design method is extended to linear active microwave circuit design where input and output of the active device is approximated by simple equivalent circuit. There is a need to extend this powerful exact synthesis method to non-linear microwave circuit design, like mixer, modulator, frequency multiplier etc., which will lead to best optimized designs requiring less time for computer optimization. Use of non-uniform transmission lines in synthesis method may also lead to interesting solution.
B1.12	**Wafer level packaging technology (SAC)** Ka-band receiver MMIC SoC containing GaAs MEMS, as well as other MMIC and MEMS based devices (designed and developed by SAC) need wafer level packaging for maintaining performance and size advantage of chip. Heterogeneous integration and packaging at the MMIC wafer level is an attractive and enabling technology.
B1.13	**InP based Schottky Barrier Diode, antiparallel diodes for sub millimetre wave applications (SAC)** For applications in sub millimetre wave &Terahertz, InP based Schottky barrier diode finds many applications due to low turn on voltage in comparison to GaAs. THz detectors with zero biased operation and improved noise property can be designed. In application of sub millimetre wave mixers and multipliers a low turn on voltage help in achieving low losses. There is a need to develop InP Schottky barrier diode, antiparallel diodes for sub millimetre wave and terahertz applications targeting 300GHz or beyond.
B1.14	**Film bulk acoustic resonator based RF filters (SAC)** Film Bulk Acoustic Resonator (FBAR) is used in high frequency RF filters because of its very high Q factor and low temperature coefficient. The scope of the research will include fabrication & modelling of FBAR and design of filter using FBAR. S-band filters are required for both space and ground application.
B1.15	**RF SAW filters (SAC)** Leaky Surface Acoustic Wave (LSAW) Resonator based RF filters offer several performance advantages in a compact size in the frequency range of 800 MHz to 3 GHz. One-port resonators acting as Impedance Elements are connected in ladder/ lattice configuration to obtain filtering characteristics. The scope of the work shall include

	modeling and design of SAW resonators and RF filters based on these resonators. The deliverables shall include CAD tool for the synthesis and design of these filters. SAC, Ahmedabad shall extend fabrication support for these devices.
B1.16	**Development of algorithm for accurate determination of material constants of piezoelectric crystals (SAC)** Space Applications Centre, Ahmedabad, ISRO is engaged with the development and realization of various satellite payloads as well as R&D activities for ground hardware. To support these activities variety of SAW filters have been used. For precise SAW filter design, an accurate and complete characterization of piezoelectric substrates is necessary. Piezoelectric substrates used for SAW devices are characterized by their linear elastic, piezoelectric and dielectric material constants. To achieve diffraction modelling direct measurement of SAW velocities in a suitable angular range around the direction of propagation is necessary. However, simulations of other second order effects, e.g. spurious excitation and transmission of BAWs, need the linear elastic, piezoelectric and dielectric material constants to characterize the substrate, because these models start with the basic linear equations for piezoelectric materials. So the current proposal is for extraction of aforementioned constants with following deliverables: Algorithm for accurate determination of following acoustical physical constants of piezoelectric crystals (e.g. 42degY-X Lithium Tantalate, X-112degY Lithium Tantalate): Elastic Constants Piezoelectric Constants Dielectric Constants Density Error bound/ accuracy should be computed for each material constant. Validation of algorithm with measured data.
B1.17	**SAW based sensors (SAC)** The operation of Surface Acoustic Wave (SAW) based sensors has been widely demonstrated in many different application fields for the detection of both physical and chemical quantities. SAW based temperature, pressure, humidity and gas sensors are known for their high sensitivity and robustness to environmental stresses. These sensors work on the principle of change in the propagation properties of surface waves induced by a change in the ambient level of the measurand. The scope of the work shall include conception, design and development of such sensors, including associated electronics, packaging and calibration for the detection of physical parameters such as temperature and pressure, humidity and partial pressure of gaseous species such as Oxygen, Carbon Dioxide and Carbon Monoxide.
B1.18	**Extraction of COM parameter for SAW devices (SAC)** In a SAW (Surface Acoustic Wave) device, COM (Coupling of Mode) parameters are velocity, transduction coefficient, propagation constant & capacitance. These COM parameters needs to be extracted for simulation and optimal design of a low loss and mid

	loss SAW filter. The extracted COM parameters are important inputs in the design of various SAW topologies viz. Electrode Width Control (EWC), Distributed Acoustic Reflection Transducers (DART) type Single Phase Unidirectional Transducers (SPUDT) structure etc.
B1.19	**Development of nano structured magnetostrictive thin films for surface acoustic wave device applications (SAC)** Surface Acoustic Wave (SAW) devices are widely used in communications such as filters, delay line etc. Conventional SAW devices consist of metallic IDT on top of a piezoelectric film or substrates. Research involves the development of high quality thin films of giant magnetostrictive materials (e.g. Fe-Si) which exhibit high magnetostriction coefficient suitable for low insertion loss SAW devices.
B1.20	**Sintering process in LTCC (Low Temperature Co-fired Ceramics) (SAC)** Low Temperature Co-fired Ceramics (LTCC) is having inherent advantages like multilayer integration, embedded passives, localized hermetic sealing dominates MCM technologies for up to mm-wave frequencies. It provides increased electrical performance and miniaturization of electronics packaging for space use. Sintering process is the most important and crucial step in the LTCC process flow considering its effect on final product quality, shrinkage value and reliability which is also important for RF performance. There are mainly three types of sintering processes: Free Sintering/unconstrained sintering in which the sample shrinks in all the three directions (X, Y & Z directions); Pressure Less Assisted Sintering (PLAS) in which a limited force is applied during the sintering process and shrinkage is limited to Z direction. The last one is constrained sintering/Pressure Assisted Sintering (PAS), where the uncontrolled shrinkage in X & Y direction is translated in to Z direction and it provides nearly zero shrinkage along X & Y directions. It has been reported and also observed that free sintering is best for maintaining the integrity of cavity structure. But, Pressure Assisted Sintering (PAS) needs to be experimented in order to utilize the process accordingly. The scope of the work shall include the study and optimisation of PAS process in LTCC. Also exploration of other LTCC materials suitable for zero shrinkage may also be included in the research work.
B1.21	**Development of electron beam / LASER Beam sensitive glass (SAC)** This requires development of types of glasses that are sensitive to electron beam/ LASER Beam and upon exposure to these change their optical density (OD) or transmittance. The development will be useful in the development of optical elements like sinusoidal calibration targets for optical payload calibration, gratings, Fresnel lenses etc., using grey scale electron beam or LASER lithography.
B2	**Sub Area** — **PCB Fabrication, Wiring and Assembly (SAC)**
B2.1	**Defects analysis of solder joints in electronics fabrication for space use & algorithm development (SAC)** Fabrication data collection, compilation and methods can be developed to understand the cause of defect, quantification in various categories, impact of reviewed/reworked defects in solder joints under various environment conditions, impact on life span long

	term space missions as well as on interplanetary missions, co-relation of that data in various orbits by preparing the samples, measuring relevant parameters. Subsequently, Algorithms development, Monitoring and improving PCB assembly quality by statistical optimization of processes and materials.
B2.2	**Lead free soldering and surface finish (SAC)** Solder materials used in assemblies pervade many forms of electronic platforms used by Space. Therefore, any change in soldering technology will have major implications for space operations. Lead-free soldering is fast becoming the norm for commercial applications. Before long, there will be a push for a similar switch to lead-free solder for high-reliability electronics, as is seen in Space applications. While lead-free solders are purported to reduce environmental and health risks, these solders present certain technical risks. Of concern, the reliability of most lead-free solders is not well known for high-reliability applications and the adverse environments of space. Identify, develop and qualify lead-free PCBs & solders to replace conventional tin-lead solders used in circuit card assemblies, connectors, and other electronics etc. Identify and develop lead free dummy components. Identify, develop and qualify environmentally acceptable replacements to surface finishes and RTV/conformal coatings currently used in circuit card manufacturing meeting out gassing requirements. Finally, ensure the reliability issues surrounding lead-free electronics in high reliability applications. Objective is to generate comprehensive test data (including inspection requirements) on the reliability of circuit cards newly manufactured with lead-free solder and subjected to simulated high-reliability environmental conditions.
B2.3	**3D packaging (SAC)** For space borne system, electronic packaging plays an important role for deciding about the weight & volume of the overall electronic system/sub-system. Discrete component design moved on to integrated circuits which in turm moved to programmable devices. Even packaging graduated from DIP type to SMD to BGA/CCGA to flip chip to direct die attachment on printed boards. Printed circuit board technology also graduated from single side PCB to double side and in turn to multi layer boards. Interconnection within PCB graduated from non plated through holes to plated through hole, blind via / buried via connectivity and to laser drilled micro vias. These still form the packing or interconnectivity in multiple boards as through conventional wired or though rigid flex boards. This needs a relook into packaging technology. These different assembled boards can be moulded all together and the interconnection can be through patterning on these 3D structures. This will enable compactness of the packages and more electronics can be accommodated in the same volume or in the first volume is reduced, which will reduce overall size of the package. Following may be explored meeting the space usage requirements, Epoxy material suitable for such packaging High aspect ratio hole drilling 3D writing/structuring on moulded structure

B2.4	**Advanced thermal management solutions on PCBs for high power (SAC)** With increasing power loss of electrical components, thermal performance of an assembled device becomes one of the most important quality factors in electronic packaging. Due to the rapid advances in semiconductor technology, particularly in the regime of high-power components, the temperature dependence of the long-term reliability is a critical parameter. Two main drivers in the space technology are miniaturization and reliability. Whereas there is a continuous improvement concerning miniaturization of conductor tracks (continuous reduction in lines/spaces), miniaturization of the circuit carrier itself has mostly been limited to decreased layer-counts and base material thicknesses. This can lead to significant component temperature and therewith to accelerated system degradation. Thus, enhancement of the system reliability is directly connected to an efficient thermal management on the PCB-level. Development of base materials with advanced thermal performance and use of innovative build-up concepts.
B2.5	**Low temperature soldering (SAC)** Soldering of electronic components on printed boards generally takes place at temperatures of between 240°C and 250°C. During soldering, the components and printed boards are exposed to thermal shock that affects their long-term. A reduction in the soldering temperature to about 180°C using low melting point solders is expected to for specific temperature sensitive components to reduce risk of components failure. Development of number of possible low temperature solders in combination with suitable low temperature flux without sacrificing reliability of solder joint.
B2.6	**Electroless gold plating for space applications (SAC)** Gold is used extensively in the electronics industry, particularly because of its exceptional electrical properties. Electroless gold plating process is a promising candidate for deposition of gold on high frequency circuits leading to the miniaturisation. Autocatalytic electroless gold deposition process is preferred as it ensures minimum 2 micron gold for wire bonding and solder ball joint applications for mounting ICs on soft substrates without any undercoat. A technology need to be developed to deposit minimum 2 micron of soft gold on a patterned circuits on various high frequency laminates having 4 mil line and spacing. Deposited gold should be non porous and ductile, should withstand environmental tests prescribed for space applications and ensure long term reliability.
B3	**Sub Area** — **Surface Treatment Process Technology (SAC)**
B3.1	**Process development to realize electroforming process for aluminum components (SAC)** Electroforming is a technique used in fabrication of complex contoured components with high dimensional tolerances which are difficult to fabricate using conventional machining methodology. At present, electroforming process of copper components on Aluminum mandrels has been successfully realized at SAC. Copper has disadvantage of high density of 8.9 grams/cc.

	Hence, efforts are invited to carry out in depth feasibility study to realize electroforming process of Aluminum components and develop detailed process & setup for the same. This process can be used for mm-wave components.	
B3.2	**Non-cyanide based electroless silver plating process development (SAC)** Silver plated components are widely used in RF systems of satellites. With miniaturization of mechanical assemblies and usage of higher frequency bands like K-band & Ka-band, dimensions have decreased to around 4 mm & lower. Also long waveguides of the length of 1.2 meters are being used with twists and turns in various planes, making it extremely difficult to silver plate inside surface of the cavity using the conventional electrolytic silver plating methodology. Hence, proposals are invited in the area of non-cyanide based Electroless silver plating chemistry for plating aluminum 6061T6 alloy components with plating thickness of ≥2 microns of silver inside complex multi planar wave guides.	
B3.3	**Development of electroless gold plating process (SAC)** Gold plating on aluminium 6061T6 boxes and Kovar carrier plates is being carried out for EMI/EMC requirements, corrosion protection, solder ability etc. Hence, efforts are invited in the area of Electro less gold plating process using either cyanide based or non-cyanide based chemistry for plating aluminium 6061T6 alloy components/Kovar substrates with plating thickness of ≥2 microns of gold. Once developed, this process will be used for all ISRO projects as per requirements.	
B4	**Sub Area**	**Environmental Test Technology (SAC)**
B4.1	**Study and analysis of various forms of contaminations like surface & airborne particulates, surface and airborne molecular contaminants in and around thermo-vacuum chambers. Carryout in-depth measurement of such contaminants using APC, PFO, RGA, TQCM and CQCM available and carry out detailed process study as well as make recommendations in this regard for implementation (SAC)**	
B4.2	**Study and analysis of Liquid Nitrogen consumption in Thermo-vacuum test facility with respect to different type of tests being carried out in different LN2 based thermo-vacuum chambers. Study and analyze transfer, static and flash losses taking place in various system elements during thermo-vacuum tests and carry out detailed process study as well as make recommendations in this regard for implementation (SAC)**	
C	**Area**	**Antenna (SAC)**
C1	**Sub Area**	**Antenna (SAC)**
C1.1	**Electromagnetic analysis of 3D geometries (SAC)** This work includes the development of codes using suitable CEM techniques like FEM, FDTD, High frequency asymptotic techniques of PO/PTD, GO/GTD and hybrid techniques like FEM/BEM, GTD/MoM etc for analyzing the scattering and radiation parameters of	

	antennas and its components. The developed codes should have also the capability to analyze the scattering properties of the 3D arbitrary objects by estimating RCS. The development of algorithm and computer codes for mesh generation for arbitrary boundary of 3D geometry with details of data-structure for co-ordinates of each node with respect to local and global coordinate system is the pre-requisite for the development of Electromagnetic codes. The computer code should be capable of generation of adaptive meshing depending on the geometry and field values at different parts of the geometry depending on the electromagnetic boundary conditions and electromagnetic computation based on the above cited CEM techniques.
C1.2	**Barium strontium titanate based phased array antenna (SAC)** Barium Strontium Titanate (BST) based tunable components falls under a category of Ferroelectric materials, possessing nonlinear dielectric constant which can be altered by application of external electric field, material composition ratio or with the changes in the ambient temperature. The tuning dielectric constant with bias voltage of BST find many applications such as antennas, varactors, phase shifters, non volatile memory etc. Due to its lesser impact time, high power handling capabilities, low losses at microwave frequencies BST is the most preferred choice in antenna reconfigurability. These phase tunable micro strip lines can be used at the inputs of the individual Patch Antenna elements in a Phased Array Antenna so as to electronically steer the radiation pattern in a desired direction. The study needs to be carried out for variation in RF properties due to change in material composition.
C1.3	**Characterization of dielectric materials at high frequency (SAC)** Ferroelectric thin film can be used at its maximum potential for phased array antenna only when its material properties like dielectric constant, loss tangent, tunability are accurately characterized as a function of frequency, bias voltage applied, temperature at higher frequency setup. This requires the antenna material characterization for its dielectric properties and suitable techniques needs to be developed for the characterization.
C1.4	**Broadband conjugate matched feed horn for offset reflector geometry (SAC)** In radiometric applications or satellite communication, generally offset parabolic reflector antennas are preferred due to their inherent advantages of reduced aperture blockage, isolation between the reflector and the feed, lesser spurious radiation and suppressed side-lobes. But the performance of offset reflectors is satisfactory in terms of cross-polarisation components only when the larger F/D is selected. Space constraints limit the selection of large F/D. The concept of conjugate matched feed provides the solution forthis contradicting requirement where low cross polarization can be achieved with smaller F/D. There is a need to design conjugate matched feed for 20 % bandwidth with cross polar performance better than -35 dB. SAC has already achieved 8 % bandwidth for the design of conjugate matched feed.
C1.5	**FEM/BI method for finite frequency selective surface(FSS) analysis (SAC)** There is a requirement of analyzing finite FSS based on hybrid Finite element method (FEM) and Boundary Integral (BI) method. FEM used to solve the electric fields inside

	and on the boundaries of FSS (metal or dielectric based) by discretizing the FSS into finite number of tetrahedral elements. The source used to excite the FSS can be corrugated feed horn or Gaussian source. The BI method is used to solve the radiation characteristics of the FSS i.e. transmission and reflected radiation pattern by using the boundary fields solved by FEM
C1.6	**High frequency Substrate Integrated Waveguide (SIW) antenna technology (SAC)** Generally coplanar corporate feeder networks distributes the transmit/receive signal to the individual elements for less phase dispersion. At higher frequencies ohmic and dielectric losses of the connecting microstrip line dominates and results into undesired radiation. Among all transmission line hollow metallic waveguide feature extremely low losses up to very high frequencies but it is very bulky. Substrate integrated waveguide (SIW) technology provides a solution with ease of manufacturing and low cost of micro strip line and with the performance of the waveguide. LTCC, micromachining technique can be used for fabrication of SIW. The feeding mechanism needs to be developed using SIW technology for different antennas like planar cavity backed antenna, slot array antenna, Vivaldi antenna, horn antenna ,reflector antenna and planar micro strip antenna can be replaced by SIW. The system on chip and antenna on package may be studied in connection with this technology.
C1.7	**Antenna measurement using time domain method to mitigate multipath reflections (SAC)** The research problem involves the use of time domain method employed for radiation pattern measurements and applying algorithms to mitigate multipath reflections. This technique is essentially required to carry out measurements at low frequencies viz. UHF so that it can avoid the need of large size absorbers at such low frequencies.
C1.8	**Accurate prediction of far field pattern using different topologies of near field data (SAC)** This research problem involves the conversion of near field data, acquired using various scan geometries, into far field pattern. The objective of the study is to find out accurate and efficient near field to far-field conversion using various acquisition geometries as well as transformation scheme. Suitable interpolation techniques e.g. Optimal Sampling Algorithm, Bivariate Lagrange Interpolation etc. can be developed to convert the polar/ spiral and other formatted data to rectangular grid using various interpolation schemes. Direct transformation techniques e.g. Jacobi-Bessel can also be explored to achieve accurate performance.
C1.9	**Analysis of radomes on radar antenna performance (SAC)** The efficient operation of delicate microwave antennas in the presence of adverse weather conditions requires in many circumstances the covering of the antenna by a radome. Radome is a protective cover for the antenna and is used extensively on terrestrial, weather radar systems, air traffic control, telemetry, satellite communications, satcom uplink and receive-only terminals. Radome structure is a framework structure (metal or dielectric) of interconnected columns (beams/seams). Foam and honeycomb cores are

	often added between inner and outer skins of the radome to function as low dielectric constant spacer material (reduced reflections) providing structural strength and rigidity. Investigations may be carried out for electromagnetic modeling of radome structure and the analysis to estimate the effects of radome on the antenna radiation characteristics may be carried out using suitable analysis techniques.
C1.10	**High efficiency dual polarized wideband slotted waveguide array antenna (SAC)** Waveguide slotted array antenna finds its application for its inherent advantages of good phase stability, low losses, high power handling capability and rugged structure. Open literature is available for narrow band waveguide slotted array like longitudinal shunt slot, series inclined slot and compound coupling and radiating slots. This investigation and design of slotted waveguide array intended at X & Ku band frequencies for technique to provide wide band width around 14-15 % with common antenna operating for dual linear polarization. The radiating aperture needs to be analyzed along with coupling slot feed array.
C1.11	**Electronic band-gap antenna (SAC)** Design and analysis of high efficiency/compact printed antenna array using electronic band gap structure such as mushroom type, fork type, unipolar type structure to improve the mutual coupling and making it suitable for wide angle scanning active phased array antenna. These structure can be integrated with microstrip antenna, waveguide slotted array antenna and horn array antenna to study the change in radiation properties. The electronic band gap structures integrated on intercostal structures has to be simulated for its RF transparency to improve the gain performance of the DGR antenna.
C1.12	**Quasi-optical techniques for millimeter-wave antenna (SAC)** This type of antenna system are of paramount use in millimeter wave (30-300 GHz) and Sub-millimeter wave (>300GHz) frequency bands. This type of antenna system has a reflector-antenna that transforms the wide received signal-beams into beams of intermediate width (intermediate gain) that pass through a train of reflectors or lenses before being focused into the low-gain feed-horns of the receivers. The research problem includes the formulation using different techniques like long Fourier optics, Physical optics and Geometric theory of diffraction to design the train of the reflectors so as to optimize the overall gain of the antenna.
C1.13	**Multiband high efficiency feed antennas (SAC)** Design, simulation and full wave analysis of multiband antenna structure such as sierpinski, appollian packaging monopole and koch geometry is required to estimate various antenna parameters like return loss, gain variation over frequency. These multiband geometries are being used for ground terminals for MSS type D, navigation satellite. Multifrequency operation of antenna feed can also be achieved by developing the common aperture feed catering dual/triple frequency and technique has to be developed so as to suppress the generation of higher order mode. Analysis and design of high efficiency antenna feed and its Orthomode Transducer, polarizer, diplexer etc are required for multiple beam antenna. Various types of feed horn catering different applications such as Trifurcated

	feed horn, Quasi integrated horn for high frequency application, horn with high power handling capability, Single aperture feed at C/Ku/Ka band for ground segment, profiled compact horn etc are to be designed. The navigational satellites will be radiating a composite signal covering the three bands simultaneously. There is a requirement to receive these three bands using a single compact ground terminal antenna covering L1, L% & S band. The common aperture antenna needs to be designed with single feed and it has to provide good axial ratio over large coverage angular extent up to 60-70 degree. The main objective is to study and demonstrate an optimum design for these requirements.
C1.14	**Feed array for reflector antennas (SAC)** Feed array or multiple feeds illuminating reflector is required for multiple frequency or multiple polarization applications .Effect of mutual coupling between focal array feeds and its effect on the antenna performance parameters like cross polarization, gain, beam width have to be studied. Beam shaping as well as the phase errors correction due to surface deformation may be accomplished by using cluster of feeds with proper beam forming network at the focal plane of the reflector. Investigation is needed to calculate the array excitation coefficients through the derivation of focal region fields for a shaped pattern or a reflector with deformed surface.
C1.15	**Flexible coverage antenna (SAC)** Various reconfigurable antenna systems for flexible coverage on the antenna need to be studied and designed. This requires design & study of multiple beam antenna, computation of excitation distribution to get the required beam shape and position. Development of various beam-forming algorithms and its implementation required to be explored.
C1.16	**Antennas based on Micro-machined/Wafer- borne substrates (SAC)** At mm-wave frequency ranges, antennas & feed may be realized on thin substrates and / or wafer-construction. The scope is to study various techniques and propose optimum fabrication methodology for such antenna systems for future linkage.
C1.17	**Medium- or High-Gain UHF antennas for satellites (SAC)** In recent times, the need for satellite-borne UHF antennas has emerged. Configurations for antennas with medium- or high-gain that may be mounted on satellites need to be studied and evolved. The investigator should undertake this study and propose optimum antennas for this requirement. Prototype demonstration may be included in the scope.
C1.18	**Conformal antennas for omni-directional coverage patterns (SAC)** Due to upcoming space-science and inter-planetary missions, satellites need to carry antennas that are conformal to the cylindrical / arbitrarily-shaped satellite body. Also, pointing mechanisms may be expensive / unviable on such missions. Hence, investigators should develop antenna configurations that provide omni-coverage including the effect of the satellite body on the radiation pattern.

C1.19	**Ultra wideband antenna at VHF band (SAC)** Design and development of suitable compact antenna element at 10-50MHz with 150-200% band-width with the constraints of mass & volume for interplanetary mission of ISRO.
C1.20	**Soft computing techniques for shaped reflector antenna design (SAC)** Different evolutionary techniques like back propagation algorithm, radial basis function and quantum/binary particle swarm optimization technique may be developed for shaped parabolic hyperbolic and elliptical reflectors to generate required secondary pattern and scattered pattern of sub- reflector at both. These techniques may also be studied for optimization of antenna performance parameter.
C1.21	**Un-furlable/Inflatable antenna (SAC)** Emerging requirement of achieving higher EIRP and G/T with achievable edge of coverage gain gives the birth for ultra-light reflector technology. There is the requiremefnt of simulation of large size unfurlable/inflatable antenna. The simulation has to include the cryosphere. The number of segment needed so that radiation pattern performance is close to true parabola. It can also include the optimization of number of facets and buttons needed, the material and gas to inflate the reflector. It also includes the study of RF feed through and compact size antenna with active element for required beam steering.
C1.22	**Antennas based on nano technology (SAC)** Emerging trends in Nano Technology are to be investigated for the applications of satellite communications for space borne and ground based applications. The advantages of nano technology to be exploited for the miniaturizing the antennas. The current analysis tools do not support the design and analysis of nano technology, hence research proposals are invited to carry out theoretical work in this field.
D	**Area** — **Mission Development Area (URSC)**
D1	**Sub Area** — **Mission (URSC)**
D1.1	**New tools and techniques for automation of multi satellite operations (URSC)** With the ever-increasing assets of ISRO in space in terms of remote sensing/ communication/scientific satellite, automation of on-orbit operations of spacecrafts are very essential. ISRO has already established certain softwares and systems to facilitate this automation to a certain extent. Efforts are on within ISRO to extend the automation to different areas. Academic/research institutions can contribute towards design and development of tools encompassing automatic decision making utilizing vast amount of spacecraft Knowledge and also latest IT technologies for building systems for automation.
D1.2	**Attitude determinations using filtering techniques (URSC)** In-house attitude determination is by concentrating around discrete determinations using star sensor data and earth sensor data. Using filtering techniques, one can improve the attitude determinations to a good extent like enhanced Kalman filtering techniques by using star sensor data and Gyro Data.

D1.3	**Filtering techniques for onboard applications (URSC)** For many on-board applications steady state filters with limited state parameters are being tried in our missions. The effect of such implications are not giving enough observability with respect to many parameters. Full-fledged filters development with continuous time tracking with appropriate gain tuning shall be studied for onboard applications.
D1.4	**Earth's terrain mapping – development of models (URSC)** Using Cartosat-1, we might have already collected the country's imagery with 2.5 m resolution many a time. Obtaining digital elevation model for the total country by making using of Cartosat-1 data and the model update with required resolutions and with respect to time are also required to understand the tectonic motions. When high-resolution imageries are collected at the required terrain, the height information & the shape of the surfaces also need to be uplinked.
D1.5	**The spacecraft attitude profiles for landmarks tracings (URSC)** Spacecraft needs to compute its attitude as a function of its position w.r.t static or dynamic objects. Academic / research institutions can support with development of certain algorithms to do the above. It may be augmented with design of control systems for the optimal tracking of above with optimization of maneuvering / time.
D1.6	**Secure transfer and access to mission data (URSC)** On-orbit operations of satellite in space are conducted through ground segment spanning different networks. There are issues currently with respect to providing access to the archived satellite data as well as real-time data anytime/ anywhere to any users viz. satellite designers, ground segment developers etc. This requirement will be important in future. Issues related to data security are primarily dictating these restrictions. Academic/ research institutions can help in terms of robust IT technologies to establish connectivity among various nodes and also design of mechanisms/tools for providing secure access to valuable data with encryption related to different missions.
D1.7	**In-Orbit satellite data utilization from academia (URSC)** Spacecraft provide very voluminous data with respect to external environment. The data-information, modeling on the environment, usage of the payload data sets can happen in a big way with the participation of academic data sets, performance modeling evaluations on a non-operational spacecraft.
D1.8	**Software package development with GUI and animation for the following applications (URSC)** Mission design and analysis Orbit determination Orbit propagation Interplanetary trajectory On-bound Image analysis in lieu of stringent pointing accuracies (<0.01deg.) and drift specifications

D2	Sub Area	Navigation (URSC)
D2.1	Determination of Spacecraft orbit for Inter – Planetary Mission through Optical Navigation (LEOS) The Spacecraft will navigate autonomously by using optical data taken by on-board camera to determine its orbit and use this information to predict its future trajectory and make necessary corrections. The objective of the study is to develop a methodology to determine the spacecraft's position and velocity for intermediate cruise and target encounter phase. Intermediate cruise phase navigation is based on image celestial bodies (called beacons) through Line of Sight (LOS) measurements in the background of stars whose Helio Centric Positions are known in order to estimate the Spacecraft Position and Velocity. Target encounter phase where the object (beacon) LOS measurements are made through image processing techniques either by computing Center of Mass (COM) for known image types, Centre of Brightness (COB) for unknown image types and limb measurement for the images than do not fit fully in FOV and estimate the Spacecraft Position and Velocity. The study involves systems design, Framing Camera Specifications, Image Processing, Navigation and Guidance and Software implementation.	
D2.2	**Navigation satellite autonomous maintenance (URSC)** Algorithm development of Inter-satellite ranging and onboard orbit estimation and satellite clock bias computation, onboard broadcast navigation parameter generation.	
D2.3	**Broadcast signal Anti-Spoofing techniques (URSC)** Design of Long PRN code (like GPS P(Y)) for secured application Design of different types of PRN codes for GNSS signals (Gold code, kasami) Message Authentication	
D2.4	**Big data processing** System architecture – storage and computation Compressed and multiple Image formats handling Signal Processing methodologies FFT, Wavelets etc. Video Processing Big data Analytics CBIR, Robust Classifiers, Object Detections etc.	
D3	**Sub Area**	**Flight Dynamics (URSC)**
D3.1	**EO satellite orbit determination (URSC)** Parameter estimation methods, including least squares and Kalman filtering. Attention should be paid to statistical aspects and data processing.	
D3.2	**Orbit determination (URSC)** Parameter estimation methods, including least squares and Kalman filtering. Attention should be paid to statistical aspects and data processing.	

D3.3	**Formation flying (URSC)** Orbital dynamics of formation satellites including Rendezvous and Docking experiments.
D3.4	**Orbital motion (URSC)** Models for orbital motion about irregular shaped bodies such as Comets, asteroids etc.
D3.5	**3-body dynamics (URSC)** Orbits in Libration points and their stability and station keeping.
D3.6	**Interplanetary trajectory design and maneuver strategy analysis for exploratory missions to celestial bodies in the solar system, employing gravity assist and Lagrangian points (URSC)** Development of generalized trajectory design s/w to plan missions to any specified planet in the solar system. Interplanetary trajectory design involves generation of optimum departure opportunities for Venus, Mars, Mercury, Saturn & Jupiter. Manoeuvre strategy analysis involves Design of orbit insertion with aero-braking capabilities & Generation of optimum flyby opportunities for Mercury, Saturn and Jupiter.
D3.7	**Design of navigation and guidance schemes for lunar soft landing and for entry, descent and landing with atmosphere (URSC)** On the moon, soft landing of the lander-craft is achieved via powered descent phase which comprises three Stages-Rough Braking, Attitude Hold and Precision Braking. This multiphase Lunar landing problem is solved in a single optimal control framework. Further development is required for Lunar Lander mission
D3.8	**Design of navigation and guidance schemes for terminal rendezvous (URSC)** Rendezvous and docking is an important technology required for missions involving: In-orbit assembly of large units; re-supply of orbital stations; exchange of crew in orbital stations; repair of spacecraft in orbit; retrieval of spacecraft; re-joining an orbital vehicle using a lander - in case of lunar/planetary return missions. This technology is required to be used for the Spacecraft docking experiment (SPADEX) project.
D3.9	**Attitude determination based on imaging payloads (URSC)** Optics based methods are widely used for POSE(Relative Position and Attitude Estimation) estimation in space missions. This technology is required for missions such as the Space Docking Experiment Mission (SPADEX).
D3.10	**Development of methods for applying satellite data in modeling the gravity of celestial bodies (URSC)** Mathematical modeling of the gravitational potential of a planet accounting perturbation effects arising due to non-spherical geometry of planets, non-uniform mass distribution of a planet & non-uniform gravitational potential and supported by sensor data from satellites, needs incorporation.

E	Area	Communication and Power (URSC)
E1	Sub Area	Communication (URSC)
E1.1	**PN ranging receivers (URSC)** Development and integration of regenerative PN ranging functionality feature into S-band Coherent receiver for improved ranging accuracy in deep space missions.	
E1.2	**Optical data communication (URSC)** Increase demand for high bandwidth communication and precision ranging will make optical systems ideal for space applications. Optical data communication can provide sub-meter accuracies in deep space communication.	
E1.3	**Ka-band phased array antenna system (URSC)** Ka-band is at present allotted for deep space and GEO orbits. Development of Phased Array Antenna systems at Ka-band for data transmission.	
E1.4	**Active micro strip arrays (URSC)** Microstrip Arrays for On-orbit Telemetry & Tele Command applications.	
E1.5	**GPS based radio occultation receivers /attitude determination receivers (URSC)** To develop a new technology for a radio receiver to receive a signal without prior knowledge about its defining characteristics, its ability to reconfigure the features with respect to an incoming signal and to respond intelligently without pre-configuration or re-programming.	
E1.6	**Shaped beam antenna systems (URSC)** Shaped beam antenna systems for S, X-band for data transmission applications.	
E1.7	**Radio navigation receivers for space applications (URSC)** Radio Navigation Receivers using GNSS (Global Navigation Satellite Systems) signals are capable of providing a wide array of services through space -borne platforms.	
E1.8	**FPGA based re-configurable digital modulator (URSC)** Advances in FPGA technology to be utilized for realizing high speed digital modulators. Provision to choose different modulation schemes-QPSK, 8PSK, QAM etc. Re-configurable pre -modulation filters to limit out-of-band emissions	
E2	Sub Area	Power (URSC)
E2.1	**Regenerative fuel cell technology development with an energy density of 420Wh/Kg (URSC)** Regenerative Fuel Cell (RFC) technology, in either solid oxide or proton exchange membrane chemistry, offers large-scale energy storage at specific energy levels well beyond that is possible with chemical batteries. RFC produces power and water from electrolysis of oxygen and hydrogen and electrolyze stored water into hydrogen and oxygen by drawing power. These cells are useful for manned missions as they provide potable water as by-product.	

E2.2	**Radio isotope thermo-electric generator (URSC)** Radioisotopes decay provide continuous source of energy independent of orientation and hence are very useful for long deep space missions. Radioisotope thermoelectric generator (RTG, ~100 W) based on plutonium-238 have been used in space since 1961, with typical performance of 3-5 W /kg, 6 % efficiency and over a 30-year demonstrated life. These are static in operation providing very high reliability and long life.
E2.3	**Zero-point energy power modules (URSC)** This will provide the energy needed for long range space flights by taping the Zero-point energy / vacuum / cosmic / ambient energy fields.
E2.4	**Lithium ion cell balancing electronics (HMC Version) (URSC)** The main function of the cell balancing electronics is to maintain all the cells in a battery at their maximum state of charge, so that the voltage difference between the cells of a battery are in a window of 50 mv when the battery is fully charged.
E2.5	**Development of pouch type lithium ion cell (URSC)** Design of batteries using pouch type lithium polymer cells which give the advantage of better packing of cells for future space usage such as human rated space flight, interplanetary missions etc.
E2.6	**Zero voltage transition bi-directional converter (URSC)** Bi-directional converters can do the functions of both charging the battery as well as regulating the bus. This configuration will reduce the mass of power electronics.
E2.7	**Modeling of lithium ion cell and battery for BOL and EOL conditions (URSC)** Lithium-ion batteries designed and developed using Commercially-off-the-shelf (COTS) cells with capacity range of up to 2.8Ah are packed in required series-parallel configuration have been successfully flown in many LEO missions.
E2.8	**Design & development of lightweight metal matrix composite for batteries (URSC)** Metal-matrix composites are such class of materials which are playing a significant role in the development of future space components. They are particularly interesting for space structures applications because of their excellent weight specific mechanical properties, high thermal and electrical conductivity, low coefficient of thermal expansion and the absence of out-gasing. Use of light weight new composite materials to replace the metal alloy parts. The battery with proposed material will have low weight with equivalent thermal and mechanical properties as that of metallic parts.

F	Area	Integration and Checkout (URSC)
F1	Sub Area	Integration (URSC)
F1.1	**Development of system capable of measuring the 3D co-ordinates of markers / 3D objects (URSC)** The system should be capable of measuring the 3D co-ordinates of the markers on the object to be measured.	
F1.2	**Design and development of cable coupling analysis program (URSC)** Satellite is made up of a large amount of harness carrying various types of signals, frequencies and power levels. The harness design should achieve Electro Magnetic Compatibility between the various functions and facilitate the functioning of the satellite system. As a first step in this direction it becomes incumbent to quantify the coupled signals. Once this is done measures can be taken to reduce the coupling. Software needs to be developed to quantify the quantum of coupling.	
F1.3	**Automation of integration testing (URSC)** Scope exists to automate satellite testing. Though the monitoring points are spread out, there exists scope to electronically switch, monitor and record the measured readings, wave forms etc. This is the subject matter of development. As a spin off, the data archiving, retrieval, data tagging follow. As a next step auto control of test equipment can be tried out.	
F1.4	**Design and development of test equipment (URSC)** In addition to standard test equipment available in the market, a good number of dedicated test equipments get developed. Scope exists for universities or organizations to contribute to design and development of test equipment.	
F1.5	**Mechanical ground support equipment (URSC)** A large number of mechanical ground support equipment (viz., Satellite handling systems, panel handling systems, Satellite transportation containers, physical parameter measurement machines etc.,) connected with physically measured parameters like Centre of Gravity, moment of Inertia. Measurement of Misalignments of sensors, actuators and payloads and applying corrections to meet the specifications is another area where scope for design and development exists.	
F2	Sub Area	Checkout (URSC)
F2.1	**EMI/EMC compliance for the checkout equipment / systems (URSC)** Comprehensive guidelines Design aspects a PCB level, equipment level and total system level Testing the equipment and system for compliance	
F2.2	**Design and realization of high data rate payload data reception system (URSC)** The requirement is to come out of single vendor dependency. Design of RF sections and high bit rate digital circuits are involved.	

G	Area	Mechanical Systems (URSC)
G1	Sub Area	Thermal (URSC)
G1.1	**Novel thermal bus systems which can collect transport and provide heat for components (URSC)** Loop Heat Pipe, Miniature Heat Pipes, Two-phase MPFL with micro channel evaporator are presently used in thermal control of Indian satellites. In Future, Micro -channel pumped flow, Micro Heat Pipe, PCM Coupled Heat Pipe, Flexible Heat Pipes, Liquid Droplet and Sheet, Radiators Expandable Radiators are required. Miniature LHPs, LHP on flight experiments, Cryogenic LHPs and High temperature LHPs are further needed.	
G1.2	**Phase change materials / studies (URSC)** When spacecraft heat loads are transient in nature and of shorter duration, temperature swings and peaks are noticeable. An efficient heat storage and heat transport system, like PCM (Phase Change Material) coupled heat pipe is required to control such swings in temperature. The PCM acts as a thermal capacitor storing heat during transient peaks and releasing heat during the off peak load conditions to the radiator through the heat pipe. Selection of a suitable PCM is important. Such applications are to be used in future high power radar based missions. Technological challenges like Containerisation of PCM, Phase change operation of PCM under micro gravity conditions, position of PCM canister w.r.t. heat pipe and heat source exist.	
G1.3	**Thermo electric devices (URSC)** A radioisotope thermoelectric generator (RTG, RITEG) is an electrical generator that uses an array of thermocouples to convert the heat released by the decay of a suitable radioactive material into electricity by the Seebeck effect. They are most attractive in deep space applications where the solar flux is too low, or for extended planetary applications such as that on Mars where the day/night cycle, settling of dust,and long -life requirements limit the usefulness of photo-voltaics. TED generates electricity for very long periods of time to sustain harsh environments. They however, have Low power conversion efficiency of about 7% (advanced sterling converters have up to 30%). Low specific power of about 5 W/kg and material availability. TEDs are used in deep space missions of NASA and Mars rover. Essential for Indian deep space missions, landers and in rovers.	
G1.4	**Development of super insulating material (URSC)** Aerogel is a synthetic porous ultra light material derived from a gel, in which the liquid component of the gel has been removed or replaced with a gas. The result is a solid with extremely low density(< 0.1 g/cm3); and low thermal conductivity - 0.01W/mk (of MLI being 0.05 W/m2k); with High Solar Transmission: > 95% and High compressive strength. It has potential applications (a) as a porous micro-structure for stopping/capturing like high velocity particles (HVPC) (b) as a highly efficient thermal barrier (insulator) (c) insulation in Gaseous environment of Planets Mars, Venus, Jupiter etc.	

G1.5	**Development of thin film gas sensor, actuators and micro-heater (URSC)** Thin film based micro -heater with chosen pattern on the metallic / non-metallic foils and Thin Film based Gas Sensor have potential application in sensing the gas leakage in spacecraft propulsion / rocket propulsion while thin Film based Actuator has potential application as Pressure sensors, micro valves and pumps louvers.
G1.6	**Development of high emittance surfaces (URSC)** Ultra high absorber super black spray coatings for thermal control application methods - that enhance the flexibility of applying super -black coatings (CNT based) by spraying are required. A black coating with a reflectance of typically 0.2% in the visible spectrum(@700nm) to be achieved by Spraying techniques that allow to produce super -black coatings on almost any stable material surface such as polymers, as well as to large and complex shapes. The application process needs to be much more flexible than producing CNT coating applied in a vacuum chamber using chemical vapour deposition (CVD) technique. This project has linkage to all current and future projects.
G1.7	**Development of alternate radiative surface (URSC)** To provide more radiating window during phases with Sun illumination or higher dissipation or to reduce the heat losses during cold phases.Development of bimetallic spring actuated Louvers system with actuation based on panel temperature and shutter operated by an electric motor. System should be light -weight and with simple mechanisms, with greater reliability Configurable for mission requirements.
G1.8	**Technology to minimize the heat transfer between electronic package and radiator when dissipation is zero or minimum (URSC)** Development of commandable heat switches to make and break connections as a thermally conductive path between source (electronic package) and sink (radiator). Alternate transparent conductive coating (other than ITO) 1.Graphene/Graphene Oxide The problems with using ITO are three fold, viz:(a) Indium is expensive and scarce (b) ITO possess poor mechanical property (i.e., brittle) and (c) keeping stoichiometry / phase purity is difficult. Graphene offers several potential advantages over ITO including weight,robustness, flexibility, chemical stability and cost. 2.Transparent and conductive nano dispersion coatings: Currently ITO is coated on Kapton to bleed static charges. In this study, efforts to be made to develop alternate Transparent and conductive coatings using nano dispersions. This project has linkage to all current and future projects.
G1.9	**CNT based efficient thermal conductors (URSC)** Development of Carbon nanotube based or carbon fiber based materials offer ultrahigh thermal conductivity with mass saving. Development of carbon nanotube based or carbon fiber based ultra high conductivity materials instead of materials like Cu,Al etc. to transfer heat very efficiently with mass saving. Technology to embed these fibers in

	laminated composite structures.Can be used in laminated composites like PCBs, Carton nano tubes, diffusion of heat from high heat flux zones 1. Thermal Interface Materials Development of compliant thermal interface materials with high conductance, ease of application and long life. Study additives such as graphene, graphene petals. Study of its characterization over a wide range of temperatures. 2. Vertically aligned Multi walled CNT (MWCNT) coating has been proved to be the darkest material (ultra high absorptance flat absorber). These coatings are extremely useful to improve the absorptance of thermal detectors and to suppress the unwanted reflections or scattered light in optical systems.Studies on MWCNTs growth on various substrates,viz,anodic alumina, Titanium. Invar, magnesium,polymers. FESEM, TEM, Raman spectroscopy techniques employed applied for characterization studies.Studies to get stable optical properties.
G1.10	**Thermo chromic and electrochromic materials (URSC)** Electro-chromic devices operate on the principle that electrochromic material changes its reflectance in infrared wavelength as acceptor or donor of ions or electrons. By applying a small biased voltage, the charged ions are either collected or removed from electro-chromic layer of the device resulting in a change in the infrared reflectance of the device. Electrochromic Layers: WO3 or MoO3,CO203, V205 etc. (Anodic) & NiO (Cathodic) can be used. Development of such multilayered materials are required.
G1.11	**Continuous roll coating facility for thin film deposition on thin flexible polymeric sheets (URSC)** The present silicon based solar cell technology introduces anti-reflective layer along with transparent conductive coatings (TCC) to upsurge light harvesting.Various oxides and nitrides e.g., SiO2, TiO2, A1203, Si3N4 etc. are used as anti-reflection coating with single, double or multi -layer architectures. Single layer thermo-chromic, multifunctional and smart, crystalline, nano-porous and nano-textured pulsed RF magnetron sputtered vanadium -molybdenum oxide (VO-MO) thin film are required to be developed using thin film deposition on thin flexible polymeric sheets.
G1.12	**Functional ceramic coating and carbon based films by PVD, CVD and plasma based techniques (URSC)** Carbon based films can combine the properties of solid lubricating graphite structure and hard diamond crystal structure, i.e., high hardness, chemical inertness, high thermal conductivity and optical transparency without the crystalline structure of diamond. Issues of fundamental importance associated with nanocarbon coatings are reducing stress, improving adhesion and compatibility with substrates. In this work new nanocomposite coatings with improved toughness based in nanocrystalline phases of metals and ceramics embedded in amorphous carbon matrix to be developed within the frame of a research project. Thermal spray / plasma spray (PS) for coating: Future HVOF Process where in molten particles are sprayed onto a substrate to form splats, which rapidly solidify,eventually

	depositing a coating onto the substrate. Plasmas sprayed ceramic coatings are widely used for corrosion, wear and heat protection of hot components in gas and steam turbines. For, Space Launch Vehicles application, mullite powder (2A1203.Si02)is coated by PS technique with Flat absorber (high a and e) and Atomic Oxygen resistant properties. AO resistant thermal control A1203 coating is applied for Microsatellite application Boron carbide (B4C), strong neutron absorption ability, thus good space -ionizing radiation protection coating material for spacecraft is coated with PS technique.
G1.13	**Thermal control of microelectronics (at board and chip level) (URSC)** Development of high thermal conductivity thermal diffusers for high heat flux applications. Materials:carbon-based materials, e.g.,graphene, grafoil, K13D2U/TC41O Micro channels (single and two phase) Micro heat pipes and loop heat pipes (transport capacities can be in the range 1W to 100W).
G1.14	**Development of an advanced solver for coupled fluid flow and heat transfer with conduction, radiation (participative and non-participative) and convection (URSC)** Spacecraft use various optical devices that consist of mirrors, lenses, prism, etc. New devices under design are often exposed to high intensity irradiation viz.-mirrors in Coronagraph payload, corner-cube in spacecraft, Earth sensor, Mars payloads (during transfer orbit), etc.to accurately estimate the temperature of various optical elements radiative energy transport in participating medium needs to be established.
G1.15	**Degradation of spacecraft thermal properties (including contamination films) by high energy particles, atomic oxygen and UV (URSC)** Its effects on the following may be studied: (a) SiO2 based Thin Film Coating (b) SiO2 film is deposited on FOSR and Kapton (c) CNT-POSS polyimide nano -composite film.
G1.16	**Development of light weight stirling / brayton engines for spacecraft application to generate power using waste heat (URSC)** Development of high efficiency engines for space power generation using waste heat or nuclear sources Energy cycles. Study candidates: (a) thermodynamic cycles such as Stirling, Brayton, Rankine, etc. (b) Thermo -fluid modeling of these systems (c) Development and characterization of the working fluids (d) Study suitable engine designs.
G1.17	**Enhancement of heat transfer in fluids using electric / magnetic fields (URSC)** 1.Liquid Droplet Radiator (LDR) utilizes electric or magnetic fields to control droplet trajectories of fluids such as liquid metals (Na/K) and silicon oils (FC75/DC705) for heat removal from electronics. Heat is absorbed from the heat source by the working fluid. The hot liquid then enters into a droplet generator that generates fine liquid droplets (size -200-300pm). These droplets reject heat to space and the cooled droplets are collected by a droplet collector. The collected liquid is circulated back using a pump. The concept of Liquid Sheet Radiator (LSR) is same as that of LDR, except that LSR uses thin liquid sheet (-100pm) as radiating surface (thru narrow slits). These can handle heat loading in kW.

	Application:S/C level thermal management. Demonstration studies/ Micro -gravity experiments by NASA and Japanese drop shaft experiments.(MG LAB and JAMIC). 2. Magnetic cooling (Adiabatic Demagnetization Refrigeration system) combined with super conducting thermal switch produces a continuous operating magnetic refrigerator for operations below 1K. This has application in TCS at low temperatures.
G1.18	**Variable emissivity coatings near unity emissivity with the ability to reduce emissivity by at least a factor of ten (URSC)** Small spacecraft have low thermal capacitance thus subjecting them to large temperature swings when either the heat generation rate or the thermal sink temperature changes. This needs modulating the heat rejection rate. Variable emittance thermal control coatings change the effective infra-red emissivity of a thermal control surface to allow the radiative heat transfer rate to be modulated (adaptive or "smart' thermal control of spacecraft). These are useful thermal control coatings, whenever fluctuating heat loads are experienced. They acts like a mechanical louver system without any moving parts. Variable emitting materials-Thermochromic (Based on temperature/heat) and Pervoskite materials: Thin film / Solgel based coating and Temperature sensitive paints-Electrochromic (Based on electrical micro voltage) may be studied.
G1.19	**Suitable materials / surface engineering against atomic oxygen environment (URSC)** SiO2 based Thin Film Coating : SiO2 film deposited on FOSR and Kapton with Preliminary studies after environmental tests that show no degradation of thermo-optical properties of SiO2 on FOSR and Kapton. Silylation of paints & polymers for space and application Paints and polymer -based materials are extensively used in spacecraft applications due to their properties and performances.A new method of surface modification of paints and polymers -based materials, based on a "Silylation process", is to be studied CNT-POSS polyimide nano-composite film: Polyimide based nanocomposite films that show both AO durability and ESD protection by incorporating polyhedraloligomeric silsesquioxane (POSS) and carbon nanotube (CNT) additives. The stability of the films to thermal cycling and ionizing radiation are to be demonstrated. It needs to act as flat absorber surface with high a and high e properties.
G1.20	**Passive thermal control techniques for Martian atmosphere (URSC)** Thermal protection systems for long term interplanetary orbiter and lander missions. Understanding atmospheric conditions of various candidate planets/moons Modeling of heat transfer under these conditions Materials development and testing (including effects such as corrosion, etc.) Combined active/passive thermal control systems.
G1.21	**Advanced composite materials having higher stiffness, higher strength and better hygroscopic properties (URSC)** Carbon fibre reinforced plastics is widely used in spacecraft structure. Though the structural properties of the fibres are excellent, the properties in the resin dominated directions are poorer. Metal matrix reinforced by fibres can provide better structural

	properties in matrix dominated direction too. The work envisages development of such composites having very high structural properties with a lower value of density.
G1.22	**SMART materials like piezo elastic, electrostrictive and magnetostrictive materials (URSC)** There are several applications in which the vibrations to be reduced. Development of active isolator is one of the aims. In some applications large actuating force needs to be applied. There are cases where the shape control need to be achieved. These can be achieved by employing the above materials in suitable manner. The collaboration is in working with such materials.
G1.23	**Large sized composite panels with metallic embedments (URSC)** Metallic embedment is often used in composite panels. Due to the differences in the coefficient of thermal expansion, stresses are developed in the composites. The work involves determination of these stresses, their mathematical modelling, experimental verification and ways to reduce them. Some amount of work is already carried out, some specific development is looked up on.
G1.24	**Inflated structure for airship application (URSC)** Inflatable structures find newer applications. Its mathematical modelling is a challenge with inter-disciplinary work and non-linear material behaviour. The models are required even for maintaining the required shape. Look for collaboration in this field.
G1.25	**Development theoretical models for prediction of response to acoustic excitation (BEM, SEA) (URSC)** Estimation of responses to acoustic excitation at low frequencies are carried out using Boundary Element Method (BEM). For estimating the responses at higher order modes, Statistical energy Analysis (SEA) is used. Significant amount of work in this direction is already carried out. But there are still some differences between such predicted responses and the experimentally seen responses. Need to fill this gap.
G1.26	**Image processing techniques (ultrasonics, thermography, speckle interferrometry) (URSC)** Composite and honeycomb sandwich panels are widely used in spacecraft. The quality is assessed through NDT techniques such as ultrasonics, thermography, speckle interferometry. They are image based techniques. Some of the images need further processing to reveal the defects. The work is to develop image processing techniques / algorithms such that the defects are revealed.
G1.27	**Use of Ultrasonic inspection of heat pipe embedded honeycomb panels (URSC)** Honeycomb sandwich panels with embedded heat pipes are widely used in spacecraft. Ultrasonic waves are used for inspection of panels. These waves get modified as they encounter embedment. Characteristics of such phenomena have to be investigated. A methodology to assess the quality of the panel to be established. Some part amount of this work is already carried out. Some specific development is looked up on.

G1.28	**Estimation of micro-vibration and its mitigation techniques (URSC)** Micro-vibrations are generated in the spacecraft while in orbit. Estimation of these disturbances is essential. Development of mathematical models to realistically estimate these disturbances are being investigated. Techniques other than finite element based are looked up on. Once the models are reliable ways to mitigate, passive or active, also need to be addressed.	
G1.29	**Development of theoretical models for prediction of response to high frequency shock (spectral element, wave propagation techniques, Statistical energy analysis) (URSC)** The high frequency shock responses can be estimated using spectral elements / wave propagation techniques / Statistical Energy Analysis. Some amount of work in this direction are already carried out. Several spectral elements including for honeycomb sandwich construction are developed. Responses are determined using wave propagation techniques. But still there are unresolved issues. Looking for collaboration in these works.	
G1.30	**Unconventional manufacturing technique for composites (URSC)** Autoclave processing is normally done. Needs large autoclaves and is costly. VARTM is also being used for specific applications. Looking for other techniques for specific applications that will benefit compared to autoclave processing.	
G1.31	**Curing induced deformation and stress in composites (URSC)** Curing process used for the manufacturing of composite structures results in built-in stresses. This results in shape deformations. The work involves understanding of curing stresses, their mathematical modelling, experimental verification and ways to reduce them. Some amount of work is already carried out, some specific development is looked up on.	
G2	**Sub Area**	**Mechanical System Design (URSC-LEOS)**
G2.1	**Space qualified surface treatment on different base metals to absorb stray light for optical imaging systems (URSC-LEOS)** Development of Stray light absorbing Baffle for star sensor optics is essential requirement. The suitable surface treatment on Aluminum alloy, Stainless Steel, Titanium etc to absorb 99.9% incident light in the visible spectrum from 400 to 900 nm. The surface treatment shall sustain stringent set of space environment. High precision lens mount to survive space environment: A lens mount which can retain the optical element or multi elements closer to the specified optical axis needs to be developed. The developed system shall survive satellite launch and operational environments.	
G3	**Sub Area**	**Mechanisms (URSC)**
G3.1	**Humanoid mechanism development (URSC)** The compact mechanism / actuation required for a humanoid (2 legged system) to accomplish movements in a stable manner is to be developed.	

G3.2	**Gripper for end reflector (URSC)** Grippers for micro Robots to handle problem related to handling / operating different tools etc. to be developed.
G3.3	**Analysis of large deployable membrane structure (URSC)** This involves non-linear FEM methods and required for large unfurlable / inflatable antennas which are mass efficient.
G3.4	**Wheel soil interaction study (URSC)** The different parameters required for the wheel soil interactions during the Rover movement are to be obtained and analytical modeling of the same to be developed for wheel with different type etc.
G3.5	**Compliant mechanisms development (URSC)** These are mechanisms where the joints are replaced with flexures to eliminate friction and backlash - useful for precision mechanisms.
G3.6	**Mobility system for all terrains (URSC)** A planetary mobility system for unstructured environment which can provide a stable platform for movement in the presence of slopes, obstacles, pits etc.
G3.7	**Static forward and inverse Kinematics (URSC)** This study is required for synthesis of membranes surfaces and hardware realization for inflatable/Unfurlable Space Antennas.
G3.8	**Kinematics, dynamics and fatigue complaint mechanisms (URSC)** Useful for mechanisms with repeatable operations.
G3.9	**Kinematics and dynamics of quadrupeds and hexapeds (URSC)** Quadrupeds and Hexapeds walking machines could be a reality for exploration of interplanetary surfaces. Kinematics and Dynamics of such machines are essential for synthesis and analytical studies.
G3.10	**Reversible hold down and release devices (URSC)** Reversible hold down and release devices enable complete testability on ground before being used in space.
G3.11	**Shock absorbing devices like inflatable air bags (URSC)** For landing on interplanetary surfaces, shock absorption is an essential feature. Inflatable air bags are one of the strong contenders for such missions.
G3.12	**Kinematics and dynamic behavior of snap like devices (URSC)** Useful for hold down and release mechanisms with the advantage of a testability and reusability before flight.
G3.13	**Exploratory studies in the area of nano mechanisms (URSC)** Identification of Nano Mechanisms and their specifications for possible usage in Space application.

G3.14	**Detailed studies pertaining to statics (URSC)** Useful for pointing / high pay-load capacity manipulators with high accuracy. Detailed studies pertaining to statics, kinematics, dynamics and workspace for parallel mechanisms like Six-Degree of freedom generic Stewart Platform type mechanisms with compliant legs and joints.	
G3.15	**Smart mechanism (URSC)** For sensing, actuation and measurement, using piezoelectric, SMA and other materials. Shape Control can be useful to overcome the effects of thermal distortion in space structures using membranes.	
G3.16	**Development of stepper motors & brushless DC motors for space applications (URSC)** Spacecraft mechanisms require many types of electro-mechanical (EM) drives where continuous, intermittent, forward and reverse motion is needed for multiple operations. These EM drives are typically used for the steering and pointing of Antenna, deployment and rotation of various appendages like reflectors, Cameras, Solar panels etc. These drives invariably use Motors as the driving element. The commonly used motors for space application are Stepper motors and Brushless DC (BLDC) motors. The work envisages design and development of Stepper and Brushless DC motors, first in Frameless configuration (Rotor and Stator separate) and later in Housed configuration (by including Housing/Shaft and Bearings) which would be useful for future EM drives. Torque ranges from 20 mN m to less than1 Nm.	
H	**Area**	**Controls and Digital (URSC)**
H1	**Sub Area**	**Control Dynamics (URSC)**
H1.1	**Control algorithms for high pointing and stability for advanced remote sensing satellites (URSC)** This involves 2 stages:- Multi-level Cascaded control architecture for fixed pointing involving coarse and fine controls ; Highly robust control incorporating active disturbance rejection, damping of solar arrays to provide quick settling and Isolation of structural and rotating elements are needed	
H1.2	**Development of control algorithms for autonomous station keeping single/ multiple satellites (URSC)** The autonomous station keeping / Orbit Manoeuvring is proposed for LEO satellites using GPS, accelerometer, star sensor and gyro as sensor and thrusters/electric propulsion as actuation. This is applicable for single satellite autonomous station keeping, formation control with two satellites and Rendezvous and docking where autonomous stringent orbit corrections are required. Constellation/Formation Control of multiple satellites signal delays, Communication failure and FDIR for formation to be developed.	

H1.3	**Modelling & simulation of multibody systems (URSC)** A complete and high reliable model with vibration, flexibility, non-inertial influences, external environment disturbances etc., to be developed.
H1.4	**Structural flexible mode control (URSC)** Large Structural Flexible Mode control (active /passive) using Adaptive Filters for large appendages vibrations.
H1.5	**Smooth trajectory planning for time-bound (track to track) reorientation of agile spacecraft (URSC)** Present Guidance algorithm used in on-board Carto series is iteration based and changeover between maneuver and imaging is not smooth resulting in settling time requirement (Wait Phase) post reorientation. With development of non-iterative guidance, this problem can be avoided. The term Track to Track means both initial and final rates are non-zero.
H1.6	**Guidance and control algorithms for rendezvous & docking/formation flying etc (URSC)** Interface development for driving the simulator from dynamics computer. Study and implementation of various sensor interfaces and their stimuli simulators.
H1.7	**Study of CASE tools for automatic generation of onboard software codes (URSC)** Identification of CASE tools for space qualified space software / protocol development and study on the efficiency / optimization of automatically generated software code with that of Non-auto generated software.
H1.8	**Development of statistical based algorithms for providing fault detection isolation and reconfiguration using Unscented Kalman Filter (UKF) (URSC)** Model based fault diagnosis techniques have been applied in recent years. Kalman, EKF and UKF filters are the main workhorse for stochastic fault diagnosis.
H1.9	**Fault tolerant techniques (URSC)** Fault Tolerant by Multi Processing (FTMP) and Fault Tolerant by Parallel Processing (FTPP) etc. for onboard computers.
H1.10	**Development of robust control system using Linear Matrix Inequality (LMI) concept for single / multiple satellites (URSC)** 1. System development to meet high pointing requirements with minimal ground loop delays. 2. Building autonomy in HILS testing.
H1.11	**Networking of space resources (URSC)** Net-centric architecture for space resources using appropriate networking protocols to interoperate with other networks. The approach could be routable or demand access routable architecture instead of manually configurable point to point network at present. The DTN (Delay Tolerant Networking) model or subscribe / publish message transfer model or any similar new concept may be considered for interplanetary / deep space exploration type of networking application.

H2	Sub Area	Control & Digital Electronics (URSC)
H2.1	**System on chip and mixed signal processing (URSC)** Study and Implementation of System on Chip (SoC) as well as Mixed Signal ASICs development for analog data processing and data acquisition.	
H2.2	**Quad redundant fault tolerant system studies (URSC)** Study on systems, algorithms, fault tolerant logics for Quad redundant platforms.	
H2.3	**Active microvibration control (URSC)** Studies related to measurement and control of micro-vibrations on Imaging sensors. Active Micro-vibration control for High Bandwidth sensing and actuation.	
H2.4	**Reconfigurable hardware (URSC)** Studies related to Reliable, evolutionary reconfigurable hardware systems that can be applicable to long drawn missions.	
H2.5	**Anti-jamming using spread spectrum technique for telecommand links (URSC)** The objective of the work should be design of spread spectrum system with anti-jam capability for the uplink of telecommands in CCSDS format. The system design should ensure to have minimal impact on the CCSDS tele-command system.	
H2.6	**Low on resistance MOSFET for ASIP development (URSC)** Development of MOSFETs with low ON resistance for minimizing the power dissipation in a device when used in ASIP (Application Specific Integrated Package) type of application in large numbers.	
H2.7	**Fault tolerant computer architecture (URSC)** Study and comparison of available fault tolerant computer architectures comprising hardware, software and network solution for achieving Ultra-High reliability. (Complete system that is suitable to meet ultra-reliable onboard requirement with realistic estimate of achievable reliability).	
H2.8	**Safety critical buses for space usage (URSC)** Study and comparison of different safety critical buses for satellites / space vehicles / manned vehicles. Reinforcement of terrestrial protocols (like Ethernet, etc at MAC layer, IP etc at Network layer) for its usage in space environment.	
H2.9	**Quad redundant fault tolerant system studies (URSC)** Study on systems, algorithms, fault tolerant logics for Quad redundant platforms.	
H2.10	**Machine learning and AI (URSC)** Application of machine learning for fault detection or prediction in telemetry.	
H2.11	**Study of reconfigurable hardware design and ai concepts in embedded systems (URSC)** Studies related to Reliable, reconfigurable hardware systems.	

H3	Sub Area	Digital Systems (URSC)
H3.1	**1) New generation still image compression algorithm (lossy / lossless) for space application / Advanced Audio / Video coding, beyond the CCSDS wavelet image compression & H264 coding.** **2) Advanced channel coding/decoding techniques beyond the LDPC & TCM techniques** **3) Onboard image processing techniques for feature extraction, change detection etc. (URSC)**	
H3.2	**Advanced audio / video coding (URSC)** Advanced audio / video coding like MPEG 4 for satellite communications that may be extended for manned missions.	
H3.3	**Encryption / decryption (URSC)** Development of advanced encryption methodology.	
H3.4	**Image compression (URSC)** Research and development of an efficient image compression algorithm (lossy/lossless) for space applications. The objective is to develop a new data compression algorithm to meet the high speed implementation requirements with less power and having high performances.	
H3.5	**Onboard data processing (URSC)** Reduce data by volume, smart acquisition, capture only ROI requested by users, engage with captured data for achieving best compression, discarding unwanted data at onboard level.	
I	**Area**	**Reliability and Components (URSC)**
I1	**Sub Area**	**Indigenization and Components (URSC)**
I1.1	**System-In package (SIP) (URSC)** Today the trend is towards system in package (SIP) development for which the following enabling technologies have good potential for advanced R & D. Multichip Modules (MCMs). (With vertical stacking, embedded passives, Co-fired ceramic technology, Chip-on-board technology, Chip-first technology and Flip Chip Technology etc.) MMIC based modules for high frequency applications with efficient fabrication, assembly and packaging techniques, fine line pattern generation and Controlled interconnection techniques, improved Reliability considerations like usage of Hydrogen Getter etc.,	
I2	**Sub Area**	**Reliability (URSC)**
I2.1	**Contamination modeling and kinetics studies (URSC)** Contamination of spacecraft and instruments can cause performance degradation and even limit the useful life. Spacecraft sensitive surfaces like thermal control surfaces,	

	sensor, optics, lenses, etc are particularly vulnerable. Polymeric materials like adhesives, paints, potting compounds, coatings etc that are used on the spacecraft, outgass under Space environment. The outgassed material can deposit on a surface and thus alter the absorptance, transmittance, reflectance and emittance and/ or intercept the field of view of a sensor or experiment and either scatter, emit or absorb electromagnetic radiation. Besides outgassing, in-orbit contamination can also occur due to plume impingement and photo enhanced deposition.
I2.2	**Thermal control paints for spacecraft application (URSC)** Coatings like white paint and black paints are used on spacecraft as thermal control materials. The problems that are usually associated with these paints are their poor electrical conductivity and radiation resistance. Poor electrical conductivity leads to ESD (Electro Static Discharge) problems in GEO missions. Besides, radiation (UV and particulate) and Atomic Oxygen (ATOX) can degrade the paint functionally, as a result of which it can cease to function as a thermal control material. In view of this it would be useful, if such paints could be developed that would be electrically conducting as well as withstand degradation due to radiation and ATOX. The major areas of interest would be to develop a white and black paint which would be electrically conducting and capable of withstanding the degradation due to radiation and ATOX.
I2.3	**Trends and techniques in electronic packaging area (URSC)** Electronic packaging is a major discipline within the field of electronic engineering which includes a wide variety of technologies right from materials to interconnecting and packaging techniques. It refers to enclosures and protective features built in to the equipment itself including the packaging techniques of devices used in the realization of equipment. Miniaturization, low operating voltage and power consumption with increase in speed/ frequency requirements has driven the electronic packaging industry to the development of device packaging styles having large I/O pin count. In order to meet the increased demands for miniaturization and increased performance, research is needed in the area of Materials, Design Approaches, Methods, and Techniques used in device packaging and assembly techniques interconnect design and manufacturing to realize the Hi-Rel Electronic hardware.
I2.4	**High Density Interconnect (HDI) PCB qualification and testing (URSC)** High Density Interconnect PCBs are used for the realization of miniaturized electronic assemblies. There are several construction methods for the realization of HDI PCBs. Hence detailed study is needed to identify the failure mechanisms, accelerated testing techniques in the HDI PCBs and to bring out a process qualification and acceptance testing method to use HDI PCBs in the electronic assemblies.
I2.5	**Response prediction for spacecraft and sub-systems due to shock loads (URSC)** Spacecraft experiences various types of loads during its launch such as vibration, acoustic and shock loads. The main source of shock loads is stage separation, heat

	shield separation and clamp band release. For larger and heavier launch vehicles, the shock loads produced are higher. In order to assess the qualification of the spacecraft and sub-systems for shock loads, accurate prediction of response due to shock loads is required.	
J	**Area**	**Systems Production (URSC)**
J1	**Sub Area**	**Systems Engineering (URSC)**
J1.1	**Automation in test systems for various space conditions (URSC)** Spacecraft electronic packages (simulation, Analysis) and data logging	
J1.2	**Development of new materials for lubrication as an alternative to MOS2 (URSC)** MoS2 is sensitive to moisture. New materials with similar characteristics but having no sensitivity to moistures as an advantage.	
J2	**Sub Area**	**PCB Design & Fabrication (URSC)**
J2.1	**Development of System on Chip (SoC), Analog and Mixed Signal ASICs, and Multi-million gate ASICs comply with DFT, Low Power, High Performance, IR Drop, EM analysis and RAD Hard requirements to develop miniaturized electronic sub-systems (URSC)**	
J2.2	**ECAD Layout designs (highly complex) with fine vias, fine line complying with Signal Integrity, Power Integrity, EMI/EMC, and Thermal Integrity checks (URSC)**	
K	**Area**	**VLSI Design (SCL)**
K1	**Sub Area**	**ASIC Design (SCL)**
K1.1	**Charge pump PLL frequency synthesizer design (SCL)** Description: Design of low phase noise differential CMOS VCO Differential change pump with CMFB(Common Mode Feed Back) Basic specs: 5MHz to 65MHz PLL output frequency required: input frequency*(28)	
K1.2	**Design of instrumentation amplifier (SCL)** The brief specifications are: Low noise:0.3μV p-p at 0.1 Hz to 10 Hz Low nonlinearity 0.003%(G-1) High CMRR: 120dB (G=1000) Low offset voltage: 50μV Low offset voltage drift: 0.5μV/OC GBW product: 25 MHz	

K1.3	**Design of a current feedback amplifier (SCL)** The brief specifications are: High speed: 1650 Mhz (G = +1) Low voltage offset : 0.7 mV Low input bias current : 7μA High O/p drive : 100 mA
K1.4	**Design of low noise amplifier (SCL)** The brief specifications are; To operate from 1.8V power supply To give flat gain from 3 to 5 GHz To deliver 21 dB power gain with only -15dB variation Average noise figure to be 5.4 dB Input and output reflection coefficients to be -13.3 and -19.5 dB
K1.5	**Design of 12 bit, 200/250 MHz, Low Power (<200mW) Pipeline ADC, 3.3V supply, 0.18μm SCL technology (SCL)** The pipeline analog-to-digital converter (ADC) architecture is the most popular topology for video processing, telecommunications, digital imaging etc. designs because its speed is comparable to the parallel or flash architecture, whereas the implementation area and power dissipation are significantly smaller. Both advantages stem from the concurrent operation of the stages, that is, at any time; the first stage operates on the most recent sample while all other stages operate on residues from previous samples. Once the pipeline is primed, converted digital data are always available at every clock cycle. This design of ADC should cater imaging as well as communication applications with these features in Junction temperature range -40 °C to +125 °C SNDR >66 dBFS at 200 Msps SFDR >80 dBc at 200 Msps DNL <±0.5LSB INL <±0.5LSB No missing Code Gain Error<±0.5LSB Offset Error<±0.5LSB Output data format in LVDS or CMOS
K1.6	**Design of SAR ADC 14/16 bit, 10/20 Mbps, low power (<300mW), 3.3V supply, 0.18nm SCL technology (SCL)** The successive-approximation ADC is by far the most popular architecture for data-acquisition applications. Successive-approximation ADCs comprise four main sub circuits: the sample-and-hold amplifier (SHA), analog comparator, reference digital-to-analog converter (DAC), and successive-approximation register (SAR). Because the

	SAR controls the converter's operation, successive-approximation converters are often called SAR ADCs. This SAR ADC should cater test and Measurement, Imaging and high-Precision, high-Speed data acquisition applications with these features in Junction temperature range -40 °C to +125 °C SNDR >72 dBFS at 10 Msps SFDR >80 dBc at 10 Msps DNL <±0.5LSB INL <±0.5LSB No missing Code Gain Error<±0.5LSB Offset Error<±0.5LSB Output data format in LVDS or CMOS
K1.7	**Design of DAC 12/14 bit, 1Gbps, power (<450mW), 3.3V supply, 0.18nm SCL technology (SCL)** Digital to Analog Converter (DAC) is a device that transforms digital data into an analog signal. The digital data may be produced from a microprocessor, Application Specific Integrated Circuit (ASIC), or Field Programmable Gate Array (FPGA), but ultimately the data requires the conversion to an analog signal in order to interact with the real world. This DAC should cater test and Measurement, Imaging and high-Precision, high-Speed data acquisition applications with these features in Junction temperature range -40 °C to +125 °C SNDR >72 dBFS at 10 Msps SFDR >80 dBc at 10 Msps DNL <±0.5LSB INL <±0.5LSB Gain Error<±0.5LSB Offset Error<±0.5LSB
K1.8	**Design of programmable gain amplifier in 180nm SCL technology (SCL)** PGA is an essential block in the majority of communication systems in order to optimize the dynamic range of the system. PGA gain is controlled by a digital circuit. So the gain is discrete. This design of PGA should cater these features in Junction temperature range -40 °C to +125 °C Gain Range 0.1 to 100 Gain Error: ±0.1% (max.) Gain Drift :5ppm/ºC PSRR>94dB CMRR>80dB

K1.9	**Design of high slew rate amplifier in 180nm SCL technology (SCL)** The operational amplifier (op-amp) is a critical component in analog and mixed signal design applications. Among all parameters of op-amp slew rate is a critical parameter in the design. The output of an operational amplifier should follow the input irrespective of any conditions, but this does not happen at high frequency. The slew rate of an op-amp is very less at high frequency. The design of High Slew Rate Amplifier should cater these features in Junction temperature range -40 °C to +125 °C: Slew rate >1200V/µsec, UGB >200MHz, Input offset<100µV
K1.10	**Design of low offset and low drift OPAMP in 180nm SCL technology (SCL)** Open Loop gain> 80dB UGB > 100MHz Offset 75µV Max Low Drift 1.3µV/ºC
K1.11	**Design of PLL with VCO, 25MHz -3000MHz, Ultra Low Phase Noise -110dBc/Hz, Very Low RMS jiiter<180fs (SCL) in 180nm SCL technology (SCL)** The Phase-Locked Loop (PLL) is a closed-loop frequency-control system that compares the phase difference between the input signal and the output signal of a voltage-controlled oscillator (VCO). The negative feedback loop of the system forces the PLL to be phase-locked. PLLs are widely used in telecommunications, computers, and other electronic applications. PLL can use to generate stable frequencies, recover signals from a noisy communication channel, or distribute clock signals throughout design. Design a PLL with these features in Junction temperature range -40 °C to +125 °C VCO output frequency = 40MHz -1000MHz Phase Noise -110dBc/Hz RMS jiiter <180fs
K1.12	**Design of DSP processor (180nm) (SCL)** A digital signal processor (DSP) is a specialized microprocessor, with its architecture optimized for the operational needs of digital signal processing.
L	**Area** — **CMOS Process Technology (SCL)**
L1	**Development of 1.8/5V I / O circuits (SCL)** Development of 1.8/5V I / O circuits (Analog and Digital Pad Circuits with ESD) in 180 nm CMOS process is required. Process integration for 5V-MOSFETs in the baseline process has been done.

L2	**Development of accurate frequency dependant SPICE models for both active transistors and passive elements (SCL)** The minimum-channel length MOSFETs SCL process (180nm CMOS technology) has Unity Current Gain frequency, Ft ~55 GHz. The existing device models supported by the technology are however valid up to baseband frequencies (one tenth of Ft of transistors) only. Development of accurate frequency dependant SPICE models for both active transistors and passive elements (Inductors & capacitors) in gigahertz range is required for RF-circuit designs capability in the existing process.
L3	**Modelling of HV (10, 20, 40, 50/60V) devices (n and PMOS) (SCL)** Process development work at SCL is in progress for the process integration of LDMOS (10, 20, 40, 50/60V) devices (n and PMOS) in standard 180nm baseline process. The SPICE device models are required for the above LDMOS devices for circuit design implementation. The developed models should be accurately predicting both DC and AC performance of the devices over a range of voltage and temperatures (-55°C to 125°C).
L4	**Development of I/O pads with ESD and latch-up protection for HV process (SCL)** Robust I/O pads for 1.8/5V CMOS process developed at SCL with respect to Latch-up and ESD tolerance (2KV HBM) as well as power/speed requirements is required.
L5	**Modeling of bipolar devices and development of I/O pads (SCL)** CMOS Process integration of Bipolar transistors for applications in the design of analog and RF circuits in SCL 180nm baseline process is in progress. The SPICE device models are required for the above BJT devices (conventional and double poly self-aligned Bipolar Transistors) to enable circuit design. The developed models should be accurately predicting both DC and AC performance of the devices over a range of voltage, temperatures (-55°C to 125°C) and frequencies.
L6	**Modelling of devices in SOI-CMOS process (SCL)** SOI-CMOS process development, i.e. development and optimization of Partially-depleted SOI-MOSFETs is being carried out at SCL for Radhard, low-power high-speed and RF-applications. The SPICE device models are required for the above PD-SOI MOSFETs to enable circuit design. The developed models should be scalable models and accurately predicting both DC and AC performance of the devices over a range of voltage (1.8V, temperatures (-55°C to 125°C) and frequencies.
L7	**Enablement of PDK for HV, biploar and SOI CMOS process (SCL)** Process design Kit compatible to standard EDA is required for all the standard device elements being developed in 180nm CMOS process.
L8	**Studies on epitaxial growth and characterization of lattice matched InAlN/GaN heterostructures on silicon for high power applications (SCL)** GaN-based wide band gap semiconductors are suitable for light emitting diodes, solar cells and ultraviolet photodiodes applications. They are also of use for wireless network base stations and satellite communication systems etc. where GaN-based devices can

	multiply the efficiency of amplifiers. However, improvements in GaN-based High Electron Mobility Transistors (HEMTs) are limited by the fundamental parameters of established AlGaN / GaN heterostructures. The objective is to explore new heterostructures using InAlN/GaN alloys and enhance the potential power density of HEMTs. InAlN alloys are attractive due to their wide bandgap (0.6 to 6.2 eV) and lattice matching capability with GaN. Extremely high electron gas density coupled with polarisation fields in the heterojunction offers power densities of 30W/mm at 2 to 12 GHz. Focus should be on optimizing the growth of InAlN/GaN HEMT layers on Si using metalorganic vapour deposition (MOCVD) techniques to demonstrate high performance HEMT devices.
L9	**To develop high electron mobility transistor structures for high power rf devices using gallium nitride based wide bandgap semiconductors on silicon (SCL)** Epitaxial growth Metal Organic CVD (MOCVD) of novel GaN-based hetero structures on silicon as low cost solution for high speed and high power RF devices. Novel stress mitigation techniques to grow crack-free layers. Advanced electrical (Hall, I-V, C-V) surface (AFM), structural (XRD, TEM) and optical (Photoluminescence, Raman) characterizations to assess the quality of layer structures. Submicron HEMT device fabrication and DC and RF characterization.
L10	**Development of gallium nitride -based ultraviolet (UV) photodetectors on silicon (SCL)** Conventional silicon-based UV detectors have some major intrinsic limitations such as aging due to exposure to radiation of much higher energy than the Si bandgap, reduced quantum efficiency in the deep-UV range, significant loss of effective area due to the need to use filters and cooling if low dark current is required. On the other hand, Group III Nitrides offer advantages over Si for UV detection. It is proposed to develop GaN-based ultraviolet (UV) detectors on Si with high performance. GaN and AlGaN layer structures of appropriate composition are required to be grown on Si substrates using MOCVD. Structural, electrical and optical characterizations need to be carried out to optimize the quality, composition and thickness of the layers suitable for photodetector applications. The (Al)GaN MSM (metal-semiconductor-metal) UV detectors (<280 nm) need to be designed and fabricated. The fabricated GaN/Si UV detectors will be aimed to exhibit high performance such as low dark current and high responsivity. Further studies may include addressing the dark current issues using insulating layers such as ZrO2 and HfO2.
L11	**Development of process technology for Germanium –via heterogeneous integration with silicon (SCL)** It is required to develop a growth method of Ge on Si integration using Chemical Vapour Deposition (CVD) with an aim to achieve reasonable quality for electronic and photonic applications. Once the Ge/Si hetrostructure with the desired properties is obtained, it is required that their electrical and optical properties need to be studied by fabricating active devices. The proposed development work should cover materials study, growth/ fabrication and device characterization.

L12	**Development of dry etch technology for aluminium free InGaP/GaAs/InGaAs epitaxial films for laser diodes (SCL)** Aluminium free InGaP/GaAs/InGaAs laser diodes are receiving a great deal of attention because of their superior performance and reliability in comparison to more conventional AlGaAs/GaAs/InGaAs laser diodes. Interest in these devices is driven by their compatibility with the epitaxy-on-electronics (EoE) monolithic optoelectronic integration technology. In particular, high quality aluminium-free laser diodes can be grown at temperature below 475°C, which are compatible with EoE technology whereas laser diodes with aluminium in or near their active regions cannot be grown at such low temperatures. An important challenge with aluminium-free hetrostructures is dry etching vertical end mirror facets and angled deflector structures because of the very different chemical makeup of the layers. In particular, the wider bandgap InGaAsP layers contain significant amounts of In and P and relatively little or no As, whereas the narrow gap GaAs and InGaAs layers contain roughly 50% As no P, and relatively little or no In. Conventional chlorine based and methane based dry etch techniques do not work well with the Aluminium free hetrostructures. Literature suggest that ion bean assisted chlorine etching of InGaP is very slow at room temperature; at elevated temperature where InGaP etch satisfactorily, GaAs layer are etched without ion beam and several lateral etching occurs, i.e the etch is not directional and anisotropic. The solution to this problem lies in changing the etchant from chlorine to bromine because the vapour pressures of the relevant bromides are much more similar than are those of corresponding chlorides. Consequently, it is possible to find etch conditions for which the etch rates of InGAP and GaAs are sufficiently similar that vertical mirror facets can be successfully etched. Therefore, it is proposed to develop an etch chemistry for the aforesaid application.
L13	**Si-on-GaAs: monolithic heterogenous integration of Si-CMOS with GaAs optoelectronic devices using EoE technology (SCL)** As electronic technology becomes faster and denser, electrical interconnects (wires) have begun to limit the performance of the systems that depends on them. In order to alleviate this problem, optical interconnects are being considered as an alternative. Some of the benefits of optical interconnects include higher speeds of operation with low drive requirements and minimal power dissipation, reduced size weight and cost, freedom from electromagnetic interference, crosstalk and ease of layout and routing. In order to implement optical interconnects, optoelectronic integrated circuits (OEICs) which integrate both electrical devices (transistors) with optical devices (optical detectors and emitters) must be created using electronic integrated circuits. However, due to intrinsic structure of silicon, this material is not capable of emitting light efficiently. Compound semiconductors such as GaAs on the other hand can be used to make LEDs and Lasers. Efforts are on without much success to develop technology that would support the monolithic integration of these two types of semiconductors. Therefore, it is proposed to develop a new technology which can combine silicon and GaAs substrates by wafer bonding or Epitaxy on Electronics (EoE).

L14	**Modeling of buried channel MOSFET (SCL)** The existing CCD process development at SCL is based on buried channel technology to cater the need of high Charge Transfer Efficiency with high SNR. The output stage of CCD comprises of multiple stage source follower amplifier connected with sense node to produce voltage equivalent of collected charge with greater sensitivity. To design CCD output amplifier, modeling of n-buried channel MOSFET is required using SPICE.
M	**Area** **MEMS Design & Process Technology (SCL/URSC-LEOS)**
M1	**Micro Fluidics: simulations to capture following behaviours (SCL)** Movement of ionic fluid (EMI-BF4) in a micro-capillary under the influence of electric field. Formation of Taylor's Cone at the capillary tip under the influence of electric field. Spray formation & droplet movement under the influence of electric field.
M2	**Design & development of MEMS based THz devices for space applications (SCL)** It will be used to develop the devices for satellite communications.
M3	**Design & development of SiC based pressure sensors for harsh environment applications (SCL)** These are basically intended to the pressure sensors for very high temperatures/extreme conditions.
M4	**Design & development of MEMS flow sensor for low flow rate measurements (SCL)** These flow sensors are required for the low flow rate measurements in micro propulsion systems as well as miniaturized liquid thrusts.
M5	**Design and development of a miniaturized atomic frequency standard (URSC-LEOS)** High accuracy frequency standards are the heart of many advanced space applications. Some typical examples include satellite navigation systems and precision clocks for high speed communication networks. In addition, many scientific missions also need high accuracy timing that is not possible using conventional crystal oscillators, present day atomic frequency standards for space applications comprise of complex gas filled cells and discharge lamps. Presently used atomic frequency standards are based on 'opitcal pumping' technique that involve the use of a microwave cavity where the frequency of the microwave signal is locked to selected ground state hyperfine level via feedback through an resonant optical absorption. The atomic system is that of an alkali metal vapor form (Rb87 or CS 133). The conventional atomic frequency standards cannot be miniaturized beyond a limit due to the minimum size constraint of microwave cavity. In recent years, frequency standards based on the Coherent Population Trapping (CPT) resonance technique has been demonstrated. One of the key components of the frequency standards or clock is the vapor cell that holds the alkali vapor in a gaseous state. MEMS based technologies are now being used to develop miniaturized vapor cells. Vapor cell development Areas of collaboration with academic partners:

	Development of experimental techniques to characterize the miniature alkali vapor cells developed in LEOS using absorption spectroscopy and CPT spectroscopy. Design and development of methods of integrating optical sources, thermal control and detectors to the vapor cells to develop a miniaturized "physics package" capable of being used as an atomic frequency standard. It is expected that the project will result in establishment of experimental techniques, designs, methods of modeling and systematic documentation that will pave the way towards the development of miniaturized atomic frequency standards for space applications.
M6	**Development of a micro heat pipe for electronics cooling (URSC-LEOS)** Heat pipe is one of the efficient examples of thermal management systems. It operates by taking the advantage of phase change. Conventional heat pipes are larger in size and not suitable for transferring heat from localised hot spots in electronics. MEMS based heat pipes have the advantage of fabricating channels and structures down to few microns' dimensions. Embedded directly on the hot spots in electronic circuits, micro heat pipes can act as a passive heat transferring thermal management system which has wide range applications in space based systems as they are compact and lighter. From the operational perspective, the heat pipe is a closed cycle where within an evacuated closed tubular chamber fluid evaporates at the hot end and condenses at the cooler end, thus enabling heat transfer. Work done in LEOS so far includes designing and fabrication of micro heat pipes, charging them appropriately, sealing and testing them to study its heat transferring properties. Photolithographic masks were designed with respect to the ideas obtained from literature and Silicon based Micro heat pipes were fabricated and tested with in house MEMS fabrication facility and testing facility. There is a further scope to improve upon design and testing methodology to have better understanding on these promising devices to make them suitable for space application. Areas of collaboration with academic partners: Design of Micro heat pipe, addressing specifically evaporator condenser and reservoir and developing analytical models or carrying out simulations for the same. Development of suitable methods to correctly meter the fluid charge and characterization of micro heat pipe for various heat inputs based upon different fluids and fluid charges. Packaging to minimize joints and providing leak tight interface to suite to end applications.
N	**Area** — **SATCOM & Navigation Payload (SAC)**	
N1	**Sub Area** — **SATCOM and Navigation Payload (SAC)**	
N1.1	**Hexagonal nano-ferrite circulator on silicon CMOS substrate (SAC)** Active quasi circulators fabricated in commercial CMOS processes were designed for microwave and millimetre wave frequency range. However, a ferrite based passive circulator has lower power consumption and high power handling ability. To achieve

	a passive circulator in a CMOS integrated circuit platform, micro and nano-size hexaferrites are optimal. Hexagonal ferrites have very strong anisotropic magnetic field and remnant magnetism. By employing these properties, magnetic devices can work in the tens of GHz frequency range without strong external magnetic field and a compact & high performance circulator is reported using standard CMOS process. The CMOS circulator provides a suitable solution to be integrated with other circuit components. RF & microwave front end circuits such as power amplifiers (PA) and low noise amplifiers (LNA) can be implemented by the same CMOS process along with the circulator.	
N2	**Sub Area**	**System Engineering (SAC)**
N2.1	As the demand for High Throughput and higher data rates is ever increasing, free space optical communications gives a promising solution. Present satellite communication systems are based on Microwave frequencies which are limited in bandwidth and suffer from higher energy losses due to wave propagation characteristics. Since lasers can be focused to beams with a low divergence, they can transfer signalling power to the receiver with less energy loss than microwaves can. Therefore, optical free-space communication systems can work with less power consumption than microwave based systems, while offering higher data rates at the same time. The research areas in this field include Development of Antenna Tracking and Pointing (ATP) module along with ATP algorithm, to maintain narrower beam-width line of sight between transmitter and receiver stations irrespective of disturbances created due to satellite platform and atmosphere. As the atmosphere greatly affects the optical link, studies on cloud free field of view to supplement cloud free line of sight (CFLOS) Cover for Free-space optical link over Indian region is required. System studies related to different Modulation Schemes like PPM, PSK, etc. for efficient transmission and development of optical modulators with these modulation schemes. Development of High Power Laser transmitter to support interplanetary links.	
N2.2	**Software defined radio based satellite architectures for future satcom systems (SAC)** In present scenario, low cost small satellites (Micro or Nano Satellites) are being launched or planned for launch on LEO orbit to provide communication services over the Globe. Small satellites provide an efficient and cost effective solution to different communication services as compared to bigger satellite platforms targeted for GEO orbit. Due to their low mass, power and volume envelope, the payload also has to be designed considering these constraints. Software Defined Radio (SDR) based payload architectures can provide solution for compact/miniaturized design which requires low mass, low DC power consumption & less volume. Present SDR systems can receive/transmit signals directly at RF level up to S band. This will eliminate the requirements of the complex frontend hardware which in turn provides savings in mass, volume and DC power consumption. Scope of research proposal:	

	SDR based communication payload architecture is well suitable for Indian Nano Satellite Bus (INS) and Indian Micro Satellite Bus (IMS). SDRs will also be useful for future communication payloads for GEO satellites. Common RF transceiver (compact single board) having RF front end and Digital subsystems (direct sampling based ADC and DAC modules) to operate from UHF to S band frequencies. Studies and implementation of different signal processing algorithms for regenerative processing and flexibility in terms of channelization and bandwidth. Development of integrated wideband RF front end with LNA, Band pass Filters & PLL on RF Transceiver module Development of Direct Sampling based ADC and DAC modules which can be integrated with wide band RF front end.
N2.3	**Hybrid satellite/terrestrial networks and their compatibility with 5G cellular system (SAC)** As the spectrum resources are becoming limited and trend is towards delivering high speed data rates in both satellite and terrestrial mobile communication. Hybrid network of terrestrial and satellite systems complementing each other shall be developed for ubiquitous coverage, seamless connectivity and high data rates. Scope of research proposal Research areas in this direction are: Studies on Satellite – Terrestrial system architecture compatible with 5G Networks Protocol level integration of satellite and terrestrial system. Channel modelling considering both land-mobile and earth-to-space channels Investigations on satellite platforms (LEO/MEO/GEO/HEO) complementing 5G networks.
N2.4	**Development of advanced signal processing algorithms for multi giga hertz signal analysis (SAC)** With the advancement in signal processing capabilities, trend in research community is towards analysis of wideband signals covering gigahertz bandwidth. Using conventional approach, it demands significant amount of processing requirements. Compressed Sensing / Sparse Signal Analysis based algorithms can be applied for signal detection, analysis, feature detection (like modulation, coding, data rate etc.) and reconstruction of signals. Scope of research proposal Research areas in this direction are: Development of signal analysis algorithms for wideband signals (Multi-gigahertz bandwidth). Sparse Signal Analysis/Compressed Sensing based algorithms can be targeted. Signal Analysis algorithms for signal detection, signal structure and feature extraction for identification purposes. Satellite system design and architecture for Multi-Giga Hertz signal processing payload.

N2.5	**System studies and design of aeronautical mobile satellite systems (SAC)** In order to cater in-flight passenger communication services and to improve air traffic control, safety services, airline management, there is a huge demand for reliable communication link between the aircrafts and the ground control stations. Also from a user perspective, a wireless access solution for multimedia and personal communications services through users' own equipment (laptop, phones etc.) is required. The high data rate connectivity in airplanes may be made through satellite links. Due to global and continuous coverage requirement, satellites play an important role in this field. The communication link between the aircrafts and ground via satellite is known as Aeronautical Mobile Satellite Services (AMSS). A single satellite may be utilized for aeronautical, terrestrial and maritime mobile communication services. Scope of research proposal Research areas in this direction are: System configuration studies and design for satellite systems for AMSS applications in Indian region. System studies and analysis of various impairments in AMSS like multipath, Doppler etc. and developing algorithms to mitigate these impairments and developing techniques to mitigate these impairments. Development of light weight and miniaturized RF terminals for aircrafts and other aeronautical platforms.
N2.6	**Studies on advanced navigation systems (SAC)** Satellite navigation has become a key infrastructure element worldwide, enabling numerous applications along with great economic activity. These systems have been conceived as cornerstone of the national security and playing that role effectively. The significance of these systems is evident from the fact that currently there are six global navigation satellite systems (GNSS) which are either operational, under deployment or modernization. The system capability is evolving in both civil and defence domains. Indian Regional Navigation Satellite System(IRNSS) system is now a full-fledged operational system which is providing navigation services over Indian region. Scope of research proposal The evolving user requirements and global scenario will certainly require continuous research and development to acquire and utilize newer technology in this field. Few such potential areas are enlisted below: Use of IRNSS signals for navigation with "signals of opportunity" of terrestrial networks. Systems studies for autonomous satellite navigation. Applicability of bandwidth efficient modulation schemes such as GMSK, APSK, etc. for satellite navigation systems. Utilisation of Code Shift Keying (CSK) for enhancing navigation data rates and associated receiver processing techniques. Development of simulation tools for situation awareness for navigation end users supporting their mission planning. Such tools will consider the complete navigation

	systems and provide the information about the system accuracy, availability, integrity and reliability for any operational situation. Studies on impact of LMS channel and required error control schemes. Research on security features of navigation signals such as anti-spoof and message authentication. Studies on navigation signal generation and multiplexing schemes. Research in utilizing space service volume capability of GNSS signals. Integration of IRNSS signals with existing GNSS signals at the receiver level to demonstrate the inter-operability.
N3	**Sub Area** — **Atomic Clock-Navigation related Technology (SAC)**
N3.1	Atomic frequency standards are the back-bone of the satellite navigation technology. SAC is pursuing the R&D of indigenous atomic clocks for India's navigation programme – IRNSS (NavIC). The key concepts of atomic clocks involve atomic spectroscopy; RF & microwave electronics; microwave cavities; optics; low noise detection schemes and digital electronics. In view of supporting the in-house R&D activities, further detailed theoretical modelling can aid the practical work. Herewith, the following proposed research on theoretical and experimental studies can enhance the activities towards the realization of atomic clocks.
N3.2	**Rubidium atomic clock modelling and theoretical studies on fundamental limitations in detection schemes and stabilities of atomic frequency standards (SAC)** A detailed analytical modelling of rubidium atomic clock is to be performed. This should include the modelling of atomic signal and its features and the locking of crystal oscillator using the atomic signal. The signal-to-noise ratio in an atomic clock depends on the detection noise present in the system. Low noise detectors and low noise electronics have to be employed in order to reach better clock stabilities. Thorough studies on the best possible detection schemes are needed to employ the efficient methodology in compact space clocks.
N3.3	**Coherent population trapping based schemes for atomic clocks (SAC)** In the Coherent Population Trapping scheme, the use of microwave cavities can be avoided to build atomic clocks. This can, in principle, bring down the size to a considerable extent. The recent advances in chip-scale atomic clocks have been possible due to CPT methods. Initial theoretical and experimental studies on this can be helpful for us to take it forward towards the space based atomic clocks.
N3.4	**Studies on light-shift effects in atomic clocks and analyses of on-board clock jumps (SAC)** Rubidium atomic clocks are the widely used clocks in GNSS for space based navigation. These Rb clocks are prone to on board frequency jumps, which results in the error on the navigation signals. It is of utmost importance to understand the source of the jumps in the Rb clocks. The prima-facie understanding has brought to notice that light-shift effect

	is the main cause of these jumps. However, a detailed study is needed to quantitatively understand the physics behind these jumps. Moreover, in this study the other potential parameters such as the radiation effect, magnetic effects etc. need to be addressed which may result in giving rise to clock frequency jumps.
N4	**Sub Area** — **Digital Technology (SAC)**
N4.1	**Design & simulation of on-board ephemeris and clock parameters prediction model (SAC)** The two most important parameters used by user receivers to compute accurate position are ephemeris or satellite orbit parameters and clock correction parameters for pseudo range computation. Currently these data are uplinked to NSGU from ground station and NSGU use this data for navigation frame generation, to be used by user receivers. A prediction model can be designed which provides autonomous navigation facility. The model can predicate the satellite ephemeris and clock parameters on-board and can work for many days without receiving any uplink from ground station.
N4.2	**Study of On-board navigation service reliability (SAC)** Reliability is also major concern for navigation services. Break/anomaly in service could lead to collateral damage to the user. User may be using the system for driving assistance etc. Anomaly reporting system to the user should be as fast as possible. Currently on board anomaly reporting to the user is through alert flag in navigation sub-frame. But it is update through ground tele command. This could take few minutes in some scenarios. On-board reliability monitoring should be implemented which can report the anomaly to the user with maximum one frame time. i.e. 12 seconds.
N4.3	**Design and analysis of new modulation scheme of navigation signals (SAC)** The modulation schemes for the navigation purposes such as BOC modulation are the few state of the art modulation schemes, which can be considered for ISRO's future navigation program. The Alternative BOC modulation (AltBOC) is conceptually very similar to the BOC modulation but with an important difference, since contrary to BOC, AltBOC provides high spectral isolation between the two upper main lobes and the two lower main lobes (considering the I and Q phases separately). This is accomplished by using different codes for each main lobe.
N4.4	**Strong encryption and different navigation data for SPS and RS services (SAC)** Strong Encryption standard should be implemented for RS service in lieu of open AES standard. Navigation data for RS service should be different than SPS service so that critical data like encryption keys and other encryption related messages can be transmitted to authorized users only. Also time-tagged periodic messages to strategic users can be transmitted. As both data and code is encrypted.
N4.5	**Optimized low power algorithm design and performance analysis of digital narrow band channelization and digital beam former (SAC)** This next generation of satellite communication systems for asks for requirements such as very high throughput digital processors, with enhanced flexibility in terms of channel

	bandwidth and connectivity, and processing of high number of user beams. An efficient exploitation of available limited spectrum resources requires the implementation of large frequency re-use among the user beams and the flexibility in bandwidth, beam shaping and power transmission associated to each channel. Advanced analysis is required in frequency planning, physical layer, access method. The payload requirements in terms of processed bandwidth, connectivity, flexibility in channel sizing, beam forming and power allocation. Also different signal processing algorithms of the processors have to be developed for channel de-multiplexing, switching, beam forming and power control. Complexity of the different processor architectures are to be traded off, taking also into account their flexibility and scalability.
N4.6	**Digital filter for efficient use of bandwidth (SAC)** In conventional single beam coverage fixed spectrum is assigned to the given satellite and it is not possible to reassign spectrum to other satellites on requirement basis as the channelization filter bandwidth is fixed at design stage prior to satellite launch. Second issue is that, with RF channelization, additional spectrum in the guard band is wasted to meet the stringent in-band response and out of band rejection requirements. The solution for these problems will be served by an on board Digital Flexible Bandwidth Filter, which can help in efficient utilization of spectrum by cutting down the guard band requirements, on-demand flexible assignment of spectrum to different satellites either prior or post satellite launch and circumventing interference related issues. Types of filter:There are two distinct types of digital filters presently we are in need. Digital Flexible Bandwidth Filter Digital Bandwidth Efficient Filter There is a research component in efficient algorithms development, which will reduce the real estate requirement of Gate array fabric, handling high data rate, lower power consumption and handling SEU issues. However, in future an attempt should be made towards realization of ASIC.
N5	**Sub Area** — **Optical Communication Technology (SAC)**
N5.1	**Photonic analog-to-digital conversion (SAC)** The use of optical technologies to achieve high speed analog-to-digital conversion and broad bandwidth is now of great interest to the technological breakthrough in pulsed laser sources, which can produce ultra-narrow and high repetition rate optical sampling pulses.A multi-channel OADC can be realized using multiple Electro-optic Mach-Zehnder modulators which are biased such that the transfer functions of the Mach-Zehnder modulators are laterally shifted, which leads to the generation of a linear binary code to represent the analog input signal
N5.2	**Ultra low noise optical amplifiers (SAC)** Optical amplifiers are used to enhance optical power either at transmitting end or to boost the power at the receiving end. The photonic devices used for detection have sensitivity of typically -24dBm. In this case a very low noise amplifier will be required which can detect the feeble signal and increase the sensitivity of system to a level of -60 dBm or less.

N5.3	**Photonic true-time delay beam forming (SAC)** Traditionally, feed networks and phase shifters for phased array antennas were realized using electronic components. With the advancement of technology, severe limitations were observed in electrical devices. For example, copper wires display high losses at high frequencies resulting in a limited bandwidth for the feed signals. Furthermore, electrical beam forming networks have a relatively high weight, thus limiting their use in airborne systems. The wavelengths from a multi-wavelength source are modulated. Each wavelength feeds one array element. The modulated wavelengths are optically amplified by an Erbium-Doped Fibre Amplifier (EDFA). By independently adjusting the temperature of each FBG, phase and amplitude of the signal on each wavelength can be controlled separately.
N5.4	**MEMS optical switch (SAC)** MEMS use tiny reflective surfaces to redirect the light beams to a desired port by either ricocheting the light off of neighbouring reflective surfaces to a port or by steering the light beam directly to a port. In 2-D MEMS, the switches are digital, since the mirror position is bi-stable (ON or OFF), which makes driving the switch very straightforward.
N5.5	**Data recorder and streaming system up to 10 Gbps for optical links (SAC)** Optical links are being envisaged for high speed (up to 10 GBPS) data transfer using inter satellite links. Optical links can support very high data rate transfer of imagery data of earth observation satellite to GEO satellite or to the ground station. The high resolution imagery data need to be stored and streamed via to the 10 Gbps optical link. Solid state recorders up to 1 Gbps are invariably attempted for this purpose. Since the optical link can support multi Gbps data rate the data recording and streaming system puts a limitation on the maximum data rate available through the link. Research is required for the design of recorder and streaming circuits for that capability.
N5.6	**Forward Error Control (FEC) schemes for high data rate optical communications (SAC)** An accurate optical wireless communication system design considers and analyses all factors like components and techniques such as wavelength, modulation, detection, channel modelling, types of mitigation techniques on atmospheric turbulence etc. The performance can be improved by introducing Forward Error Correction (FEC) schemes like Low Density Parity Check (LDPC) codes, Reed-Solomon (RS) codes, Turbo codes, convolutional codes, trellis-coded modulation (TCM) etc. One can combat fading induced by atmospheric turbulence. The net coding gain offered by these schemes could be in the range of 3 to 6 dB with hard decision decoding of the component codes for an output bit-error rate (BER) of 10-9 for the data rates of up to 1 Gbps. Further improvement in coding gain can be achieved by soft decision decoding. The area of research includes simulation of these FEC schemes to provide sufficient coding gain and to validate the outcomes by implementation on hardware for the data rates of up to 1 Gbps and the BER of 10-9.

N6	Sub Area	Electronic Power Conditioners (EPC) (SAC)
N6.1	**Theoretical analysis for FPGA controlled switching GaN based electronic power conditioners (EPC) (SAC)** Devices like FPGA and GaNFETs are going to play a major role in new generation space power electronics. FPGA bring in advanced control methods along with built-in re-configurability feature to the power systems whereas usage of GaN based switching power devices offer low loss at higher switching frequency operation (500KHz-2MHz) compare to its counterpart Si devices. Both the above features implemented on advanced ZVS conversion topologies can pave the way for developing state of art efficient, compact and reconfigurable power modules required for future high density- Flexible payloads. Scope of research proposal Theoretical analysis of FPGA/ASIC controlled GaN Based EPC modelling and simulation involves several challenges viz. Modelling of GaN devices for high frequency transient, small signal behavioural Modelling of Advanced soft-switching conversion topologies Modelling of Digital control loop using discrete time models to assess its start-up, steady state and transient behaviour. HDL level simulations and Co-simulations for existing DPWM, DPFM & DPSPWM, DPID algorithms, and for Advanced Algorithm developments. Overall simulation of EPC with digital controller hardware in loop The above activities will be explored in two EPC designs FPGA Controlled GaN based Medium power (40-60W) EPC FPGA Controlled GaN based High Power(400-650W) EPC.	
N6.2	**Theoretical analysis of High Voltage Electronic Power Conditioners (HV-EPC) for Traveling Wave Tube (TWT) applications (SAC)** High efficient, compact high voltages EPCs are having potential for energizing TWT for space applications. There is also spin off to this activity for on-board Thruster applications. FPGA and GaNFETs are going to play a major role in new generation HV EPCs for the same. Advanced HV conversion topologies, digital control methods & theoretical study, simulation analysis are potential areas to explore to assess the robustness of the existing designs and upcoming designs. Scope of research proposal Theoretical Analysis of Advanced Resonant HV EPCs using digital control, GaN switching devices involves several challenges viz. Modelling of HV Conversion topologies using GaN devices and its simulation Modelling and simulation with Digital controllers in the loop simulation. HDL level simulations/Co-simulations for Algorithms for DPWM, DPFM & DPSPWM, DPIDs Overall simulation of HV EPC for Start-up, Steady-state, transient, frequency domain behaviours.	

	The above analyses will be explored on designs Advanced Digitally Controlled 6KV 300-500W HV EPC Advanced Digitally Controlled 2KV @ 1500W HV EPC.
N6.3	**Theoretical analysis on HMC & LTCC EPC packaging technologies (SAC)** Packaging technologies like HMC, LTCC, Planar-Integrated Magnetics (PIM) has high potential for new generation space power electronic systems. They bring in modularity, miniaturization and pave the way for high density payload realization. Scope of research proposal Theoretical studies on HMC, LTCC, Planar-Integrated Magnetics (PIM) for Low and Medium power EPCs Electrical circuit Modelling, simulation (EPC circuits for HMC, LTCC, PIM) Magnetic Modelling, simulation (PIM) Thermal Modelling, simulation (HMC, LTCC, PIM) Structural Modelling, simulation (HMC, LTCC, PIM) The above analysis will be performed on two designs 5-20W Low power EPC 40-60W Medium power EPC.
N7	**Sub Area** — **Filters (SAC)**
N7.1	**Artificial Neural Network based generalized parameter extraction software for microwave filters (SAC)** A typical communication satellite contains large number of microwave filters. The recent trend of multi-beam satellites with increasing frequency reuse, requires large numbers of filters with complex transfer functions. Such microwave filters are required to undergo extensive tuning after fabrication to compensate for mechanical deviations. This tuning process is expensive and cumbersome and, depending on the complexity of the filter and skill set of the manpower, this process may take up to several hours. Hence, a generalized parameter extraction software is required reduce the time taken for tuning. The software, once installed on Network Analyzer, provides the real time equivalent circuit parameters from the measured S-parameters. Based upon the extracted parameters, even a semi-skilled manpower can also decide the tuning direction and the filter can be tuned within minimal time. Although, various software techniques such as Cauchy Approximation, Vector fitting and sequential non-linear optimization have been explored in the past with some limitations, recent research is focused around incorporating Artificial Neural Network (ANN) learning methods into the software. The software utilizes multidimensional approximation of ANN to map characteristics of the filter in real time. The software can also be used in sequential characterization of the filter coupling values. Moreover, the algorithm should be adaptable to any number of poles and transmission zeros in filter transfer function for any frequency band.

N7.2 Development of ferrite material for space use (SAC)

Microwave circulators and isolators are used in communication payloads to improve impedance matching and to avoid multiple reflections. Ferrite material is used in the waveguide junctions because of its nonreciprocal properties. Presence of the ferrite inside the waveguide junction would result in circulation when it is magnetized.

Understanding the structure of the ferrite material requires knowledge of chemistry, theory of magnetism in ferromagnetic materials as the operation of microwave ferrite devices is determined mainly by the strength of magnetic field in the ferrite material, the nonreciprocal characteristic of ferrite junction at microwave frequencies due to gyromagnetic effect which involves the physics and advanced mathematics.

Magnetization: This property is based on the alignment of the spins of electrons parallel to applied magnetic field H.

Gyromagnetic resonance: The gyromagnetic resonance and so the non-reciprocal effect is created in ferrite devices under a static magnetic field H. In case of saturation of the ferrite Ms and in case of wave propagating parallel to Z axis the microwave field h is in xy plane perpendicular to z axis and rotating at a frequency f magnetization M discloses a precession motion about the field H at the frequency f. There is a resonance for H=Hr given by:

Hr=f/γ, where γ is the gyromagnetic ratio.

Effective line width ΔHeff: The magnetic losses in the ferrites affect the insertion loss of the device. It is related to the imaginary part of permeability of the positive polarization which increases with the gyromagnetic line width ΔH.

APPLICATIONS	REQUIREMENTS	EFFECT ON CHOICE OF MATERIAL
Low level power circulator	Low insertion loss High directivity Compactness Widest possible frequency band Wide temperature range	ΔH_{eff} minimum ΔH minimum ϵ' maximum M_S adjusted to frequency α as low as possible
High level power circulator	Power behavior Low insertion loss Temperature stable M_S	ΔH_k high ΔH_{eff} and ΔH as low as possible compatible with ΔH_k
Isolator below resonant frequency circulator	Low insertion loss Narrow frequency band	ΔH_{eff} minimum M_S and ΔM_S function of frequency ΔH according to the required band

N7.3 Dynamically Tunable Microwave Filter in Optical Range (SAC)

The current range of Ku/Ka band satellites operate in multi-beam scenario. These satellites are designed with a mission life of 15 years. It is often difficult to predict the future channel capacity of these individual beams/channels in the prevailing data communication capabilities. Therefore, it is highly preferable to have dynamic allocation of bandwidth in the various channels/beams of the satellite. In order to achieve this, we need to have dynamically tunable filters in the payload segment of the spacecraft. This is currently achieved by:

Switchable filter banks

Tunable filters by varying the center frequency and bandwidth of the filter.

	Down convert the signal to digital domain and have digital flexible filters and then up-convert the signal back to the actual range of operation. While each of these approaches has its own limitations in terms of either mass, space or life of tuning mechanism, we want to explore a way to develop dynamically tunable filter by translating the microwave signal to photonic range by using suitable optical modulators and then performing the frequency and bandwidth variations in the optical domain using variable optical filter, and then converting the optical signal back to microwave range using photodiodes.
N8	**Sub Area** — **Amplifier Technology (SAC)**
N8.1	The next generation satellite communication systems require high output power, small size, low weight, high efficiency and high reliability amplifiers. At the lower end of frequency spectrum, at UHF to C band, availability of GaN technology is offering newer breakthroughs in realizing power amplifiers which may even be replacing TWTA in future satellites. The Indian Regional Navigational Satellite system or IRNSS provides regional satellite system using a combination of GEO and GSO spacecrafts over the Indian region. GaN based Solid State Power Amplifier (SSPA) are emerging as a viable alternative to TWT amplifiers especially at L and S band used in these navigation satellites. Scope of work exists in the area of design, simulation of compact SSPA within the similar size as TWTA. To have higher power, low loss combining techniques and development of planar compact dividers and combiners is required. ISRO is also working on future transponders up to Q and V band. There is a requirement of wideband, high power MMIC power amplifier designs up to V band. There is also research scope in development of thermal modelling and thermal measurement techniques for power amplifier MMIC. Areas of research are: Wideband, high power SSPA and channel amplifiers modules in L, S, C,Ku & Ka-bands. GaN based High power compact SSPA at L and S band Q and V band SSPA, multiport amplifiers and associated technologies High Power MMIC Designs Compact Microwave Power Modules & Combiner High Efficiency CW SSPAs (MOS/GaAs FET, GaN HEMT/HBT) with associated thermal & power management. Thermal modelling and simulation of MMIC power amplifiers.

N9	Sub Area	Receivers & Oscillator Technologies (SAC)

N9.1 Design and development of space grade integer-N PLL IC, up to 5GHz operation (SAC)

Design Specification:

Parameters	Specification
Process Technology	90nm /180nm CMOS
Reference Frequency(Fref)	Up to 200 MHz
I/P Reference Signal Power	-5dBm to +5dBm
Comparison Frequency (Fcomp)	10-50 MHz Min
Input RF Frequency (Fin)	5GHz min
Input RF Power	-5dBm to +5dBm
Normalized Phase Noise Floor	−210 dBc/Hz
Frequency resolution	Better then 10Hz
Supply Voltage	3V Max
Radiation Hardness TID	100KRads min

Main blocks of PLL frequency synthesizer:

Phase frequency detector

Programmable Reference R divider

Programmable Fractional N I/P Frequency M divider with pre-scaler & delta sigma modulator

Control Logic for Divide value selection (Hardwire/Serial Data Controls)

Usage: After successful development of Fractional/Integer-N PLL IC, it will be used for local oscillator design in future GEOSAT & Navigation payloads.

O	Area	SATCOM and SATNAV Applications and Associated Technologies (SAC)
O1	Sub Area	SATCOM and SATNAV Applications and Associated Technologies (SAC)

O1.1 GNSS receiver development (SAC)

Along with regional NAVIC there are GNSS like GPS, GLONASS, GALILEO, COMPASS, which are of importance to the GNSS users. The following algorithm development/ Receiver development activities may be taken up considering these GNSS.

Acquisition & Tracking of GLONASS Signals & Position Solution (Receiver)

Acquisition & Tracking of Galileo Signals & Position Solution (Receiver)

Acquisition Tracking of Beidou (COMPASS) Signals & Position Solution (Receiver)

SDR based GNSS Receiver

O1.2	**Navigation signal processing (SAC)** For GNSS to succeed as a state of the art technology GNSS signal processing techniques need to be worked on. Following are some of the areas of Research in this domain. MBOC(6,1,1/11) signal acquisition and tracking For new signal identification in L1 Band, MBOC (6,1,1/11) modulation is one of the candidate for IRNSS SPS signal. Its acquisition, tracking and performance in multi-path and interference scenario can be simulated and analysed. n-PSK BOCCOS(12,2) signal acquisition and tracking for IRNSS signal n-PSK BOCCOS (12,2) is totally new modulation scheme for GNSS scenario. Its acquisition, tracking performance and demodulation schemes are to be studied and simulated. Whether this type of modulation gives any advantage in multi-path and interference environment that has to be also seen. Some of the other Research and Development topics in the field of Navigation Signal Processing are: Simulation of Space-Borne GNSS Receiver GNSS Spoofing –Detection and Mitigation GNSS Jamming –detection and mitigation Low cost low power Multi GNSS RF Front End development.
O1.3	**Navigation simulation (SAC)** The design and development of GNSS Receivers is highly dependent on the signals provided by GNSS Simulators right from conceptualization to product development cycle. Following are important research area in Navigation Signal Simulation: Interference Simulator for GNSS bands Low cost Navigation Educational Kit.
O1.4	**Different types of GNSS receiver development (SAC)** Irrespective of the GNSS constellation to be used there are different class of GNSS Receivers developed for specified applications and differ in the methodology of technical realization. Following are some research areas of the different types of GNSS Receivers to be developed for specified applications. IRNSS receiver with Mapping service integration IRNSS receiver provides PVT and this should be integrated with other Google/NOKIA/ Apple map services based on this PVT solution in Android/IOS/Windows8 environment. More services like showing best routes from one place to other places, tracking the fleet using IRNSS receiver kind of services are to be explored. Other topics in the field of GNSS Receiver Development are: High Sensitivity receiver development NavIC receiver for Orbit Determination GAGAN receiver for Avionics NavIC Receiver for Marine Applications NavIC Receiver for Radio occultation.

O1.5	**Encryption (SAC)** Encryption plays a very important role in GNSS as it is highly used for strategic users. Following are some important research areas in Encryption. Key Exchange algorithm for RS Receiver IRNSS RS service involves encryption and to improve security, encryption keys are changed regularly to avoid brute force attack and cryptanalysis from unauthorized users. IRNSS RS receivers deployed in field will have to be communicated with changed keys. ECC offers highest security and almost impossible to break the algorithm. Public Key exchange mechanism based on Elliptic Key Cryptography is to be developed for IRNSS RS service. Design, development and implementation of Lightweight authentication algorithm Development of lightweight authentication protocols can be taken up as an activity which would be useful in IRNSS where authentication of some sort can provide security against spoofing kind of attacks. However, any kind of authentication mechanism should not incur too much overhead on IRNSS receiver for which it is must that the authentication algorithm should be resource efficient. Moreover, the implementation should be such that it is safeguarded against side channel kind of attacks. Tamper Proof Hardware Technology IRNSS RS Receiver design and development is taken up at SAC. RS receiver is to be protected for the secret key and code inbuilt to the receiver in case of RS receiver is compromised by opening the unit. Tamper proof hardware technology will provide this protection to RS receiver. Other than the above mentioned, following is also topic of interest in Encryption: Authentication Techniques for GNSS.
O1.6	**SatNav technology (SAC)** The heart of the success of GNSS lies in the design and development of various Satellite Navigation Technology, Algorithms and Techniques which ultimately provides the performance improvement in the GNSS Receivers developed. Following are important topics of research in this domain. Study and Performance estimation of a Multi Carrier –Code Division Multiple Access System Today, in parallel with multi-carrier transmission, the field of multi-carrier spread spectrum communications is considered to be an independent and important research topic. Multi-carrier spread spectrum is considered a potential candidate to fulfil the requirements of next-generation (4G) high speed wireless multimedia communications systems, where spectral efficiency and flexibility are considered as the most important criteria for the choice of the air interface. The MC-CDMA technique is based on a serial concatenation of direct Sequence (DS) spreading with multi-carrier modulation technique. It offers the advantage of both the proven technologies. The DS-CDMA system is a multiple access technique that relies on spreading the data stream using an assigned spreading code for each user in the time domain. The capability of is given by the cross-correlation properties of the spreading codes helps in minimizing

	multiple access interference. Whereas the auto-correlation properties of the spreading codes provide the capability of distinguishing one component from others in the composite received signal in the case of severe multi-path propagation in mobile communications. However, the performance of a DS-CDMA system strongly depends on the number of active users, the channel characteristics, and the number of arms employed in the rake- receiver. The system capacity is limited by self interference and multiple access interference, which results from the imperfect auto- and cross-correlation properties of spreading codes. The basic principle of multi-carrier modulation relies on the transmission of data by dividing a high-rate data stream into several low rate sub-streams. These sub-streams are modulated on different sub-carriers by using a large number of sub-carriers, a high immunity against multi-path dispersion can be provided since the useful symbol duration Ts on each sub-stream is much larger than the channel time dispersion. Hence, the effects of ISI are minimized. The main advantages of multi-carrier transmission are its robustness in frequency selective fading channels and, in particular, the reduced signal processing complexity by equalization in the frequency domain. OFDM, a multi carrier dulation system offers high spectral efficiency and effectively combats the problems with multipath propagation in mobile communications. Thus the advantages of multi-carrier modulation on the one hand and the flexibility offered by the spread spectrum technique on the other hand have motivated for the Multi carrier –CDMA systems design. Two different technologies called MC-CDMA (OFDM- CDMA) and MC-DS-CDMA have emerged as a combination of these two independent technologies. Thus the study and performance estimation of a MC-CDMA system in a multipath fading channel can be a very interesting and useful topic of research which can help in designing of an optimum MC-CDMA system for a fading channel.
O1.7	**Scintillation resistant receivers (SAC)** The equatorial region is very prone to scintillation, which takes place predominantly during the equinoctial months over Indian region. This results in abrupt very rapid and random variation in received power which leads to loss of lock to weaker signals leading to deterioration of accuracy or even unavailability of the systems. A scintillation resistant receiver may be developed that may (i) Predict the onset of scintillation (ii) Effectively track and use intelligent techniques to use scintillating signal for positioning, thus avoid sacrificing DOP (iii) Use scintillation effects on the signal to estimate Ionospheric irregularity parameters. Some of the other topics in the field of SATNAV Technologies are: GNSS Anti Spoofing Algorithms GNSS Anti-Jamming Techniques TTFF improvement in Navigation Receiver Ionospheric delay processing Techniques in GNSS receiver Carrier Phase based Positioning Algorithms Multipath Mitigation Techniques in GNSS Receivers Differential NavIC Algorithm and technique.

	Performance Analysis of Pseudolite Based Navigation System Development of Techniques to Mitigate Near Far Problem in Pseudolite based Navigation System GNSS Receiver Algorithm development for Weak Signal for In House Applications GNSS Receiver Algorithm development to support very High Dynamics typically seen in Launch Vehicles Algorithms for GNSS Timing Receivers Algorithms for Geodetic Receivers withReal Time Kinematics (RTK) Algorithms for GNSS Interference Mitigation Advanced Receiver Autonomous Integrity Monitoring (ARAIM) Algorithms Ground Testing of Rubidium Atomic Clocks Navigation Solution with Multi-Constellation Ground Characterization of On-board Atomic Clock performance Effect of Wi-Fi, 3G/4G on NavIC Signals Design of Global Indian Navigation constellation.
O1.8	**Integration of GNSS with other technologies (SAC)** For better accuracy and reliability of Navigation Receivers GNSS technology may be integrated with other positioning techniques to develop Hybrid Receivers. Following are some important areas of Research in this domain. Integration of GSM with Navigation Receiver Integration of Inertial navigation system with Satellite navigation receiver.
O1.9	**SatNav applications (SAC)** Following are some of the important areas of research for providing GNSS based Applications. Analysis and Simulation of Reverse Fountain Effect Currently, there is an increased interest in deriving Space Weather effects on equatorial ionosphere. The GAGAN and NAVIC data may be used to obtain the temporal variations in the Vertical Total Electron Content (VTEC) of the Ionosphere from which post sunset events like 'Reverse Fountain Effect' may be derived. Its occurrence in relation to the solar activities and wind characters are of prime concern. The Reverse Fountain Effect may be studied from the data variations and simulated. Other areas in the field of SATNAV Applications are: GAGAN Applications Innovative NAVIC Applications GNSS Reflectometry Precision Agriculture application using NavIC Low Cost Surveying and Land Record Mapping using NavIC & GAGAN Receivers Aero-plane tracking system NavIC Networks

	Geo-tagging known/unknown Important Tourist Spots GNSS for Smart city NavIC based Vehicle parking system Person Tracking system GNSS Applications using Space Borne Receivers IRNSS applications on Mobile Phones Applications of GNSS Reflectometry.	
O2	**Sub Area**	**Satellite Communication (SAC)**
O2.1	**Design, simulation and development of AIS Receiver with improved probability of ship detection for space (Satellite) based AIS (Automatic Identification System) network** ISRO is coming up with its own satellite to support Space Based AIS detection. So far all the ground network across globe provides only probabilistic guarantee for signal detection of space based AIS network. Within this proposal, it is expected from researchers to address issues and algorithm for improved probability of detection of ships while implementing AIS over satellite using LEO constellation of satellites in VHF band with all practical implementation considerations.	
O2.2	**Wideband spectrum sensing and interference cancellation techniques in compressive sensing domain for next generation broadband satellite communication (SAC)** Compressive sensing has been a promising area to solve the problems like sensing, detection and filtering in wideband communication. It helps to overcome the hardware or device boundaries to solve problems of wideband communication. Within this proposal it is expected from researchers to design, simulate and propose implementation plan using available devices for compressive sensing based framework to solve problems of wideband spectrum sensing, interference detection etc.	
O2.3	**Adaptation of GMR (Geo Mobile Radio) or similar standard & technologies for seamless communication between terrestrial & ISRO MSS network (SAC)** GEO-Mobile Radio Interface (GEO stands for Geostationary Earth Orbit), better known as GMR, is an ETSI standard for satellite phones. GMR standard is derived from the 3GPP-family terrestrial digital cellular standards and supports access to GSM/UMTS core networks. It is used by ACeS, ICO, Inmarsat, SkyTerra, TerreStar and Thuraya for high speed internet as well as audio and video services. Since ISRO is coming up with its next generation of MSS satellite with 12m antenna in space, it would be worthwhile to look at the standards that are similar to GMR or GMR itself for seamless communication between GSM and ISRO's MSSnetworks. It is expected from researchers to analyze the channel models and "propose, develop & implement" efficient protocol stack for effective MSS applications.	

O2.4	**Design, simulation and implementation of single frequency network with suitable waveform (like OFDM) to support broadcast services to handheld or miniaturized devices on the move & everywhere (SAC)** DVB-SH is a published standard from ETSI for broadcast services to handheld devices using satellites to handheld devices. Under this topic, it is expected from researchers to come up with a proposal which is simpler and effective for implementation in single frequency and single waveform (preferably OFDM) network.
O2.5	**Fast acquisition burst demodulator or preamble-less demodulation (PN Sequence based) (SAC)** ISRO is working towards development of its own protocol and network for ground systems. Burst demodulation becomes very important for implementation of any TDMA network and sensor data reporting or position reporting applications. PN Based fast carrier acquisition and burst demodulation for satellite communications is very popular. Within this framework, it is expected from researchers to come up with innovative proposals on development of burst demodulation techniques with minimal preamble and burst to burst gap duration. It should be contemporary and suitable for implementation of efficient MF-TDMA networks.
O2.6	**Design, simulation and development of high data rate PSK Modems for LEO to GEO communication like for upcoming indian data relay satellite system, joint source and channel coding for high data rate transfer from LEO platform (SAC)** ISRO is working on development of its own data relay satellite system. It is expected from researchers to submit a proposal on design, simulation and implementation of high doppler compensated PSK MODEM for communication from a LEO platform to GEO platform with higher order coding. Researchers may also propose schemes like joint source and channel coding for effective high data rate transfer from LEO platforms.
O2.7	**Design and development of advanced pulse shaping techniques with lower roll off for efficient spectrum utilization (SAC)** Spectrum is a scares resource. In MSS & FSS services, in order to optimize the resources and to cater to large user based within limited bandwidth, ISRO invites suitable research proposal on pulse shaping techniques may be coupled with suitable power efficient modulation and demodulation schemes for its SATCOM networks. The proposal should include design, simulation and development of techniques with low roll off filters
O2.8	**Development of waveform and signal processing techniques to utilize low cost and efficient power amplifiers in MSS communication (SAC)** MSS communication utilizes personal battery operated gadgets. In order to improve the efficiency of the terminals, ISRO invites research proposals on development of suitable waveform with signal processing techniques for utilization of low cost power efficient amplifiers in its ground terminal.

O2.9	**Design and Simulation of digital beam-forming / electronic beam steering techniques for high frequency COTM (Communication On The Move) applications. (SAC)** ISRO has been allocated S-band for Mobile Satellite Service. In order to make the terminal efficient and support COTM, electron beam steering technology is used. Research proposal is invited on design and development of efficient electronic beam steering system with interference protection features for better & effective MSS applications. Other topics of interest in the field of Baseband Algorithm and Technology Development are: Design of algorithm for Short Term Attenuation Prediction modules with lightweight implementation for Ka-band or higher frequency band communication terminals Design and Development of Low-bit rate Speech Codecs for MSS applications Development of protocols for efficient TDM/MF-TDMA network and techniques for effective time synchronization. Design and Development of Header Compression. QoS Mechanism for IP data communication services over satellite network Design and Development of Seamless Mobility Management Techniques (Soft handover mechanism) for multi-beam MSS network. Low complexity video encoder based on Wyner-Ziv principles and corresponding video decoder with motion compensation with quality approaching to H.264.	
O3	**Sub Area**	**ASIC & HardwareTechnology Development (SAC)**
O3.1	**Design and Development of miniaturized, multiband (S, L, UHF band) / S-band Low power wideband transceiver mixed signal ASIC for SATCOM terminal (SAC)** This proposal should address the development of low power, low cost custom RF wideband transceiver ASIC in S-band to support communication using miniaturized handheld and battery operated satcom terminals.	
O3.2	**Design & development of RF-MEMS based monoscan converter for single-channel monopulse tracking system (SAC)** Monopulse tracking is used for precise pointing of on-board as well as ground station antennae. It is used in three configurations: Single-Channel, Two-Channel and Three- Channel. Single and two-channel configurations are commonly used in practice. Since single-channel configuration has advantage in terms of weight, size, power and phase-optimization, it is a preferred choice for most applications. But, the simplicity results in increased complexity at feed end, where three RF signals (Ka / Ku Band for example) need to be combined into one RF-signal using monoscan converter. It is also called autotrack modulator/combiner. The proposal could aim for developing RF-MEMS based (Ka / Ku Band) monoscan convertor technology, which should have potential to meet reliability requirements of onboard applications.	
O3.3	**Development multi-mode miniaturized mobile terminal (SAC)** Multimode smart phone is going to be future trend. The same phone will operate in different radio technologies and there is requirement of seamless transition between the	

	networks. Media Independent Handover (IEEE 802.21) has been standardized for the seamless communication between different radio technologies. The proposal should aim for network design and mobile terminal development.
O3.4	**Design of miniaturized low cost S-band antenna with near omnidirectional coverage for mobile hand held terminals (SAC)** The requirement is to develop transmit only, receive only and transmit-receive antenna for different MSS (S-band) terminals & applications. Since MSS terminals are primarily personalized gadgets and manufactured for mass deployment, it is expected to be a low cost, light weight design suitable for small gadgets. It should be a reproducible design including radome. Someother topics of interest in the field of Satellite Communication are: Development of Miniaturized, low cost QHF/DRA/Patch S-band antenna for personal communication gadgets and mass deployment Design and Development of RF-ASIC to support implementation of low-power, cost effective electronic beam steering capabilities for satellite mobile communication ASIC development for IDU of DVB-RCS2. Development of IDU and HUB baseband compatible with or similar to DVB-RCS2 standard. Baseband ASIC development for DVB-S2x Receiver for VSAT network Development of miniaturized S-band transceiver terminals with Class-F amplifiers Development of low loss, light weight duplexer for MSS Applications Development of GPS based auto pointing/ Satellite acquisition system for VSAT In this proposal, researchers can propose a low cost hardware solution for auto-pointing of VSAT antenna of 1.2m, 1.8m size in field for C, Ext-C, Ku and Ka band communication.
O4	**Sub Area** — **Application & Tools Development (SAC)**
O4.1	**Hybrid terrestrial-satellite DVB/IP infrastructure for triple-play services (SAC)** With the advent of Digital Video Broadcasting (DVB) technology and its exploitation over terrestrial links (DVB-T) along with its inherent characteristic to combine heterogeneous traffic into the same data stream (i.e., MPEG-2 and IP data), presents the possibility for the creation of a converged DVB/IP networking infrastructure, which is able to provide triple-play services within the broadcasting footprint. Other than above, few topics of interest are: Design & Development of low cost tool-kit for Satellite visibility analysis (LEO, GEO, MEO etc.) communication link analysis and communication channel condition analysis for Space to Ground and Space to Space communication. Development of Hybrid Network for Real-time Person or Asset Tracking using Machine to Machine Communication Technology and Indian Navigation System. Development of Spectrum and Waveform Analysis tool using low cost SDR platforms.

P	Area	Mechanical Engineering Systems (SAC)
P1	**Design, fabrication and testing of computer generated hologram for testing of aspheric reflective optics (SAC)** Computer generated holograms (CGH) are now widely used in the testing of aspheric optical elements and it is expected that this technique will eliminate need of null corrector. CGHs also have potential to use it in testing free form optics. CGH is a binary representation of the interferogram, or hologram that is recorded if we were to interfere the aspheric wavefront coming from a perfect aspheric surface with the reference beam. The procedure for making the CGH is to first ray trace the interferometer to determine the position of the fringes in the theoretical interferogram that would be obtained if the mirror under test were perfect. A plotter, such as a laser beam recorder or an e-beam recorder, is then used to draw lines along the calculated fringe positions. Aspheric wave front can be generated by illuminating CGH with reference beam. Typical optical setup is shown below for testing of aspheric surface using CGH. Scope of research proposal Proposal shall include detailed methodology for design, fabrication and testing of computer generated hologram for testing of aspheric optics (Convex/concave).Principle investigator shall have experience /publication in the field of design and development of computer generated hologram.	
P2	**Design and development of deformable mirror for correction of wave front in space based optical instrument (SAC)** Space-borne telescopes are subjected to orbital loads like temperature excursion,absence of gravity, moisture desorption of metering structure etc., which leads to misalignment of optical system and loss of the optical performance. Future space based large telescope will be made from number of smaller mirrors, which are aligned together to create a larger segmented mirror & continuous mirror. Due to time varying orbital loads, misalignment will occur in these smaller mirrors supported by large structures and intern this will introduce aberrations in imaging. Hence, there is a need of wavefront correction using deformable mirror. Scope of research proposal: It shall include study on various options for deformable mirrors. Detail design and development of best suitable option of deformable mirror.	
P3	**Smart reconfigurable spacecraft antennas using intelligent materials (SAC)** Smart reconfigurable antenna technology can re-establish the antenna radiation characteristics and have immense potential to improve data communication quality by increasing channel capacity, spectrum efficiency and coverage range of communication channel. Scope of research proposal Research proposes to develop a 1.0m diameter and 2.0m diameter shaped reflectors using intelligent materials.	

P4	**Deployment mechanisms for 12m diameter spacecraft antennas (SAC)** The study deals with the mechanics of deployment of 12 meter diameter spacecraft antennas. The objectives are as follows: a) Design and analysis of stable configuration for 12m deployable antenna reflector for space application meeting with all space environmental test load specifications. b) Design and Development of Knitted RF reflective mesh made of gold plated Molybdenum mesh for deployable reflectors of size 12m diameter. Scope of research proposal Research proposes to develop a 12.0m diameter parabolic spacecraft reflector using gold plated molybdenum mesh. Scope of work is elaborated as: Configuration design study of deployable mechanism for mesh reflector. The work also includes Mechanical & Structural designs including Finite Element modeling and experimental investigations. Design and optimization of ring structure for deployable Mesh antenna reflector of size 12m diameter which will include dimensional configuration of Links, mass, interconnection and hinges. Configuration design study of knitting methodology for realization of RF reflective mesh. This study would also extend to exploration of material substitute for RF reflective mesh. Actuation, Control and sensing methodology The scope also includes space qualification of verification model upto space qualification levels. Development of the DVM. Dynamic evaluation of DVM by vibration testing upto qualification levels. Check for thermal stability of DVM by thermal cycling in space environment as per Environmental test level specifications.
P5	**Ultra-light weight structures using advanced high strength materials like P.E.E.K, C.N.T, Graphene, frozen smoke& chain link materials including aluminium metallization for high frequency RF signals (SAC)** The study deals with the development and manufacturing of Ultra Lightweight (ULW) materials for future aerospace vehicles and structures. Replacing the traditional materials with the Ultra lightweight materials will reduce significantly the mass of payload. Scope of research proposal The ULW materials such as P.E.E.K, CNT, Graphene, frozen smoke will be used to develop payload brackets, feed horns, spacecraft panels and MFDs etc. Payload brackets, Feed horns, spacecraft panels, MFDs, etc.
P6	**True stress - strain curves development for non-linear materials like indium for atomic clock development at SAC (SAC)** A true stress-true stain curve gives the stress required to cause the material to flow plastically to certain stress. The research area deals with the stress- strain curve development for nonlinear materials such as Indium for development of atomic clock at SAC.

	Scope of research proposal The area of research included True stress-strain curve development for Spherical and Cylindrical bulb options of atomic clock with indium fixtures.
P7	**Accurate shock response analysis of structures using implicit / explicit approaches (SAC)** Accurate Shock Response Analysis of Structures using Implicit / Explicit Approaches(SAC) Shock analysis makes it possible to directly compute the response of specific structures resulting from well-defined actual transient forces. The SR analysis method can be used for steady state vibration applications as well as transient. Scope of research proposal The study deals with the accurate shock response analysis on camera structures / spacecraft payloads using implicit and explicit approaches.
Q	**Area** **Systems Reliability (SAC)**
Q1	**To develop epoxy based radiation shielding material, to possibly replace Ta-sheet and Pb- tape (SAC)** Objective To develop epoxy based Radiation Shielding material. This can replace Ta and Pb currently being used for providing Radiation shielding to Electronic components. Scope Target is finalizing the chemical composition of material to achieve radiation shielding in least possible thickness by optimizing absorption co-efficient. Material composition will be finalized and chemical process will be optimized. It is also for development of mouldable material which can be formed in required shape of component package, which can be applied directly on the component. Linkage Electronic systems for all payloads.
Q2	**Development of microwave absorber (carbonyl iron filled silicon rubber sheets) over the frequency band of 1 to 8 GHz (SAC)** Goal: To develop high loss microwave absorbers that attenuate electromagnetic interference. Objective Development of Microwave Absorber (Carbonyl Iron Filled Silicon Rubber Sheets) in 1 to 8 GHz range. To design, fabricate, characterize and test silicon rubber based microwave absorbing materials in sheet form operating in 1 to 8 GHz. Linkage MW absorber material will be used in all GEOSAT & MW Remote sensing programs for improving the EMI/EMC compliance (RF pick up / leakages) of the RF package of various payloads.

	Salient Features: - Microwave absorbing materials based on carbonyl iron loaded silicon rubber sheets. Frequency range: 1 to 8 GHz. Reflectivity: ≤ -20dB. Layers: Single layer, dual layer, tri-layer and multi layered. Space qualified material.
R	**Area** **Material Characterisation (SAC)**
R1	**Guided wave based non-contact NDT of composites using air coupled ultrasonic signals (SAC)** Goal: Design and development of non-contact NDT of Composites using air coupled Ultrasonics. Objective Development of non-contact type transducer to assess the integrity of composite structures without contaminating or affecting the physical properties of composite raw materials Fast and Accurate Very useful for complex, integrate and large dimension objects Linkage All upcoming payload systems.
R2	**Assessment of NDE capability for material & process characterization for complex additive manufacturing & analyse physics of failure mechanism in aerospace components (SAC)** Background Additive Manufacturing (AM) is a revolutionary technology which produces components directly from 3D data, layer-by-layer. It is possible to manufacture parts with geometries which are difficult to produce by other conventional technologies. While AM is beginning to revolutionise the aerospace manufacturing industry, one of the largest barriers to broader adoption of AM for producing aerospace parts is the lack of a “Standardized Qualification Process” that includes fully characterized process definition, developing in-situ process monitoring, sensing and quantifying of the drivers of manufacturing variability in AM production parts. In-situ process monitoring sensors enable one to “certify as you build”. NDE is a technique for Inspection, testing or evaluation of materials, component or assemblies for discontinuity or difference in characteristics without destroying serviceability of the part or component. NDE methods like, Ultrasonic, Radiography, Computed tomography etc.have to be adopted for real time in-process monitoring to insure proper Quality Assurance and Control activities for defect free space component. Moreover, such techniques are required to understand the physics of failure of Electro-mechanical assemblies.Currently there are no universally accepted or commercially available IQIs for industrial NDE.

	Scope Develop a set of tools to assess NDE system performance to measure & defect detection for bluntness, resolution or contrast sensitivity. Identify materials and design internal features useful for assessing inspection capabilities. Model development for AM Fabricated Image Quality Indicators (IQIs) to simulate defects andparts features. Analyse IQI volume data to assess NDE detectability limits, contrast sensitivity and resolution. Development of in-situ QA methodologies for qualification of AM process leading to development of parts. This is for total understanding of materials and processes correlations, process capability, variability aspects as applicable to failure modes. Generation of defects library & documents of cause and effects of defects. Detection of failure mechanism with its co-relation to physics of failure, through layer by layer detection of discontinuities, thermal environment simulation to measure the performancedegradation and break down in internal circuitry of electronic components. NDE methods tocheck the integrity of component and their functionality and performance. Reverse approach by using advanced NDE techniques to ascertain Additive Manufacturing materialbuild defects and limitations. Anticipated Benefits Provide a multi-use standard for the assessment of NDE performance as well as AM build quality. High Resolution measurement of internal construction measurement. Metrology verification AM Manufacturability AM Repeatability
R3	**Realization of Shape Memory Alloys (SMA) (SAC)** Different mechanisms will be required to be developed for payload operations. Development of shape memory alloy based mechanism will make simplified and reliable payloads. Special type of shape and programming technique is to be developed. With the increase emphasis on both reliability & multi-functionalities in aerospace industry active materials [Shape Memory Alloys-(SMA) are playing vital and important role for design and development of space components and mechanism.
R4	**Smart/Intelligent materials (SAC)** Smart or intelligent materials/adaptive materials are those structural elements, which have the capability to adapt to the external load or stimuli. External stimulus can be in the form of vibration load, thermal load, pressure load etc. Using smart materials and structural systems a Design Validation Model (DVM) of a typical Spacecraft Reconfigurable reflector has been envisaged to be developed which is able to change the shape and curvature of the reflecting surface using Smart material. An innovative concept of smart backup beams will be developed for testing the re-configurability of the reflecting surface for satellite applications.

	Challenging aspect is realization of the reconfigurable reflector mechanically, structurally & electrically and the research element of the research problem is finalizing the most optimum configuration / geometric topology of the SMA Stiffeners after iterative process of analysis, to meet the Satellite specifications.
S	**Area** **Semiconductor (SAC)**
S1	Background GaN semiconductors offer distinct advantages in terms of: Higher voltage of operation Better efficiency resulting in higher output power Higher bandwidth GaN has become a technology of choice for fabrication of various functional structures viz. diodes, transistors and also MMICs, for possible application in satellite payload elements. Building Hi-Rel semi-conductor structure needs evaluation from various reliability aspects. A comprehensive study of GaN semi-conductor is proposed addressing following aspects Aspects for study: Study and evaluation of bulk GaN semiconductor defects: trapping, dislocation and diffusion mechanisms. Impact of Purity, doping concentration, and Above defects on basic performance parameters of mobility, saturation velocity. Substrate materials for GaN semiconductor and their effects on functionality & performance,addressing fabrication process. Semi-conductor process technologies, its suitability for different device structure/ functionality(discrete semi-conductors, microcircuit etc.), dominant failure modes & mechanismsand deriving activation energies for each mechanism. Semi-conductor process design and process parameter variability, its degradation mechanisms with respect to Device geometry (gate length), metallization schemes, Ohmic and Schottky contacts; Systematic studies for the determination of their activation energies. Physical Effect of electrical stresses on device structures under different application conditions, like: a) DC conditions (pulsed and CW) b) RF conditions (pulsed and CW) c) Combination of (a) and (b) Material and Device performance under typical application conditions (over - O/P power, Operating point, temperature, vacuum, space radiation) Device effects under controlled and uncontrolled environmental and handling conditions.

T	Area	Spacecraft Inertial Systems Area (IISU)
T1	Sub Area	Advanced Electromagnetic Sensors and Actuators (IISU)
T1.1	**Digital slipring, magnetic encoder, anti helmholtz coil (IISU)** Digital Slipring – Magnetic sliprings are self-contained units that enables the signal processing of information signal to be done in the rotor of machines and later transfer it to the stator through rotory transformers. • Magnetic Encoder – Development of magnetic encoders that are compact, mechanically robust and reliable and cost effective. • Anti Helmholtz Coil – It helps to establish a uniform gradient magnetic field in the region between the coils. It is an integral part of Magneto Optical Traps used in Atom interferometers.	
T2	Sub Area	Maglev controller and motor drive (IISU)
T2.1	**Magnetically levitated motor and drive electronics (IISU)** It is aimed to develop a system controller and miniature motor drive for IIIrd generation magnetically levitated motor. It involves development of • Miniature speed control electronics for BLDC motor • Control electronics for two axis actively controlled magnetic bearing	
T3	Sub Area	High speed Self-Bearing Actuators (IISU)
T3.1	Momentum/ Reaction wheels are the standard solution for attitude control in a spacecraft. At present these actuators mainly use ball bearings, whose mechanical wear is a significant life limiting factor. In order to maintain a longer life time, ball bearings are usually operated at speeds below 6,000 rev/min. If we go for ultra-high speed operation of wheels in the range of 1 lakh rpm, considerable reduction of wheel size is possible. The main challenges in the design of high speed motor are high iron loss, high speed rotor construction, selection of compact and high frequency power electronics topology, and high speed sensing and control circuit. A slot-less self-bearing motor based on Lorentz force can take care of high frequency losses to a good extend and it also helps in the rotor construction for high-speed operation. However, the maximum bearing forces achievable are small for Lorentz force based machines compared to reluctance-force-based machines.	
T4	Sub Area	Autonomously Navigating Robot for Space Mission (IISU)
T4.1	A half Vyomnoid with Sensing and perception of surroundings with 3D vision and Dexterous manipulative abilities to carry out defined crew functions in an unmanned mission or assist crew in manned missions. Design & Realization of FULL Vyomnoid with features that include full autonomy with 3D vision, dynamically controlled movement in zero ‘g’, Artificial Intelligence / Machine Learning enabled real time decision making with vision optimization and path planning algorithms.	

	Develop state-of-the-art technologies for 1. sensing & perception 2. Dexterous manipulation 3. Hierarchical Control system 4. Artificial Intelligence enabled algorithms	
T5	**Sub Area**	**Multi-DOF Actuators/Reaction Sphere (IISU)**
T5.1	Spherical Motor – Precursor of advanced actuators for satellite applications. Spherical motor with accurate position control can replace complex mechanism that uses multiple motors for multi degree of freedom actuation. The same motor with speed and torque control drives can act as a preliminary design model towards reaction sphere.	
T6	**Sub Area**	**High Precision Servo System (PMSM, FOC, Angle Sensor and Processing Electronics) (IISU)**
T6.1	The typical three-phase motor drive consists of a Drive motor, power stage with a three-phase full-bridge scheme and a controller that should provide three-phase PWM signals based on an encoder or a resolver for the position feedback. Permanent Magnet Synchronous Motor There are two types of permanent magnet brushless dc motors, which depend on their back-EMF waveforms. The one with sinusoidal back-EMF is called PMSM. PMSM provides nearly zero torque ripples, which gives higher efficiency. The airgap flux density and winding patter will be sinusoidal in PMSM. Field Oriented Control The FOC is suitable for the high-end application due to its complex design and higher processing requirements. It commutates the motor by calculating voltage and current vectors based on motor current feedback. It maintains high efficiency over a wide operating range and allows for precise dynamic control of speed and torque. Angle Sensor and its Processing Electronics PMSM along with FOC need phase current sensing and continuous rotor position sensing. Resistive based (GMR) or Inductive based (Resolver) sensor will be used along with its processing electronics.	
T7	**Sub Area**	**High Accuracy Rotary Transducer (IISU)**
T7.1	Rotary Transducers are precision scale elements used for extremely accurate measurement of angular displacement. Non-contacting coupled elements of the rotary transducer can be directly attached to the fixed and movable members of rotary machine tools, navigational systems and other precision mechanisms. Electrical output signals can drive readout displays, generate computer input data and provide servo feedback signals. Because of non-contacting elements (zero wear) very high reliability is achieved and original accuracy is maintained indefinitely.Angular accuracies of ± 2-3 arc seconds have been achieved. This TDP aims at making high accuracy rotary transducers of ± 1 arc-sec accuracy.	

T8	**Sub Area**	**ASIC Development for Inertial Sensor Electronics (IISU)**
T8.1	IISU has development various sensors like Dynamically Tuned Gyro(DTG), ISRO Laser Gyro (ILG) and Ceramic Servo Accelerometer (CSA) . Efforts are initiated to miniaturize sensors electronics for these sensors. One of the development route initiated is through ASIC based sensor electronics.	
U	**Area**	**Bearing and Space Tribology (IISU)**
U1	**Sub Area**	**Thin film development for Harmonic Drive (IISU)**
U1.1	The harmonic drive is a special gear-drive speed reduction system whose operation principle is based on the elastic deformation rather than the rigid body motion of general gearing system. It has many advantages, such as high speed reduction ratio, high rotational accuracy, high torque transfer per weight, high efficiency, little backlash and very compact size. The three basic components of the harmonic drive are the circular spline, flexspline and elliptical wave generator. The Wave Generator is a special ballbearing assembly with a rigid elliptical inner race and flexible outer race. The Flexspline is a thin walled, flexible cylindrical cup adorned with small external gear teeth around its rim and the Circular Spline is a rigid ring with internal teeth, engaging the teeth of the Flexspline across the major axis of the Wave Generator.	
U2	**Sub Area**	**Multilayered coatings for high speed ball bearings (IISU)**
U2.1	Ball bearing metal parts- races and balls are coated with multi layered multi-functional films for improving surface properties and wear resistance. Since the combined thickness of these coatings are very less (2-3 μ), this process maintains the bulk properties of bearing steel with the surface properties of the coatings. The coated layer avoids formation of micro-welds during asperity interactions and subsequent elimination of local hot spots thereby reducing the rate of lubricant degradation. These surfaces can yield better stiction performance, low friction and wear during possible ball sliding conditions, reduced lubricant degradation and overall improvement in life of the bearings	

3.0 Earth Observations Programme

A	Area	Mission Development and Remote Sensing Sensor Technology (SAC/URSC-LEOS)
A1	Sub Area	Electro Optical Sensors (SAC)
A1.1	**Super lenses (using meta-materials) (SAC)** 'Diffraction limit' in optics: Whenever an object is imaged by an optical system, such as the lens of a camera, fine features — those smaller than half the wavelength of the light — are permanently lost in the image. The loss of information arises because light emerging from the object's fine features carries components with high spatial frequency — that is, evanescent waves that exponentially decay, resulting in an imperfect image. The 'lost treasures', as the sub-wavelength details could be called, are the fundamental reason for Abbe's diffraction limit, which determines the smallest features that one can see through even the best of lenses. Artificially engineered metamaterials now offer the possibility of building a superlens that overcomes this limit. When a lens made of Negative Index Material is placed close to an object, the near-field evanescent waves can be strongly enhanced across the lens. After emerging from the NIM lens, the evanescent waves decay again until their amplitudes reach their original level at the image plane. On the other hand, the propagating waves pass through the NIM lens with both negative refraction and a reversed phase front, leading to zero phase change at the image plane. By completely recovering both propagating and evanescent waves in phase and amplitude, a perfect image is created Superlenses have great potential in space applications and can be used to develop highly miniaturized optical systems.	
A1.2	**Athermalization of optics using phase plate (SAC)** Phase plate based wavefront coding involves the insertion of an asymmetric refractive mask close to the pupil plane of an imaging system so as to encode the image with a specific point spread function that, when combined with decoding of the recorded image, can enable greatly reduced sensitivity to imaging aberrations. The application of wavefront coding can increase the instantaneous depth of field which can enable the development of simple, low-cost, light-weight lens systems. Wavefront coding can alleviate optical aberrations and extend the depth of field of incoherent imaging systems whilst maintaining diffraction-limited resolution. It is particularly useful in controlling thermally induced defocus aberrations in infrared imaging systems.	
A1.3	**ASIC design and simulation (SAC)** The scope of activity covers Analog, digital and mixed signal ASIC front end design, simulation, verification, Layout, Post layout simulation, RC extraction, optimization. In addition, the design and development of Radiation Hardened (RH) library standard cells and devices. Some design blocks like amplifiers, switches, bandgap references, etc. are most commonly used in various designs of ASIC's. Development of these blocks will help in speed up the design process. Design of ADC with >16-bit digitization, > 5Msps through put with high ENOB, low power and low size will be extremely useful.	

	Similarly, Digital ASICs combining Compression/Decompression, Packetization cum Formatter with SERDES interface will find wide application across all EO payloads.
A1.4	**Modelling of silicon based optical sensor (SAC)** Modelling of Silicon based optical imaging sensor (front and back illuminated buried channel Charge Coupled Devices): device and process modelling for simulation of channel potential, 3D potential profile of MOS capacitor and photodiode, charge transfer, Quantum efficiency, and amplifier. Novel structures for performance (MTF, responsivity) improvement. Modelling of Anti-reflection coating (specific to UV, NIR, wide bands). Surface treatment approaches for photodiode Quantum Efficiency improvement (NIR to Blue and/ or selected wavelength regions). Graded antireflection coating for minimization of reflection as a function of wavelength, in area array Si CCD. Surface treatment for dark current minimization. Modelling of Pinned photodiode structure. Impact on EO performance due to irradiation of Proton, Gamma, and Heavy ions.
A1.5	**Modelling of electro-optical sensors (SAC)** Development of Mathematical Models for an Electro-Optical System and Software to simulate the final image, with sensitivity to design parameter/system environment/on-board processing/viewing geometry. The software should have interface with COTS design software systems or simulation tools in Optical/Mechanical/Electrical domain. It can be extended to simulate images of a conceived sensor by transforming images acquired from other sensors.
A2	**Sub Area** — **Electronics for EO Sensors (SAC)**
	Speed of operation of on-board electronic circuits has a direct bearing on the geometric resolution of a camera and also on the number of colours in which a camera captures a feature. As the resolution improves, the circuit operation becomes faster. Compaction calls for miniaturization of electronics and development of specialized multi-function, ultra-low power circuits. Following are the areas of research for electronics.
A2.1	**Analog front-end device for detector signal processing (SAC)** Ultra-low power, High-speed and high resolution analog front-end devices for processing of detector signals along with high driving capability to efficiently drive the detector video signal while maintaining signal integrity.
A2.2	**ASICs and ROIC (SAC)** Miniaturization of electronics in the form of low power ASICS and Read Out Integrated Circuits (ROIC) with objective of integrating multiple functionality of electronics in the single devices with lower power and size. The scope of activity covers Analog, digital and mixed signal ASIC front end design, simulation, verification, Layout, Post layout simulation, RC extraction, optimization, tape out and fabrication. In addition, the design and development of Radiation Hardened (RH) library standard cells and devices. Some design blocks like amplifiers, switches, bandgap references, etc. are most commonly used in various designs of ASIC's. Development of these blocks will help in speed up the design process.

A2.3	**On-board data processing & data transfer (SAC)** On board data processing, loss-less data compression and generating theme based data output using radiometric, spatial and spectral compression techniques . On-board high speed data transfer, interfacing and networking. Design of optical fibre based high speed data transfer interfaces for on-board use.
A2.4	**Advance PCB design/technology (SAC)** Advanced PCB technology for miniaturization of high speed and high power front-end electronics including its thermal management., it includes PCB design with large number of layers (>10), Micro-via Technology, High Density Interconnects, solder ball pin technology, design of flexi PCB's, etc.
A2.5	**Very low signal extraction (SAC)** Extraction of very low signal from noise – Techniques (SAC). The target application is to sense very low true video signal from CCD and CMOS type of detectors. The other very important application is temperature sensing from very low analog signal travelling through noisy environment.
A2.6	**High power drive and control electronics (SAC)** Study / Development of Drive and Control Electronics for Auto-focusing Mechanisms for On-board Use. It involves the high accuracy (<100nm) actuating mechanism which further requires very high voltage drive and control electronics. Development of miniaturized and adaptive cooler drive electronics for Cryogenic temperatures. Study and demonstration of the adaptive cooler drive algorithms. Algorithm to minimize jitter at cold tip of pulse tube cooler or sterling cycle cooler using close loop active vibration control. Development of algorithm or MATLAB model to estimate/optimize PID coefficient for optimum response based on overall close loop transfer function or any industry defined PID tuning method. Also, development of cooler transfer function based on empirical data or close loop response measurement. Thermal, EMI/EMC management of high power drive electronics. Development of miniaturized high power thermal control electronics near focal plane. High power capacitance/inductance drivers with multilevel voltages.
A2.7	**Modeling of special devices – techniques (SAC)** Modelling of special devices – Techniques: Modelling of various state of the art mixed signal devices, detectors, interfaces etc. In addition, modelling of devices for Cryogenic temperature operation which involves the modelling of NMOS, PMOS and other devices for the cryogenic temperature to enable the design and development of full ASIC which can work on cryogenic temperature.
A2.8	**Mitigation techniques for space environment (SAC)** Mitigation techniques for radiation environment in space (TID/SEL/SEU etc) - Device level, System level Rad hard fabrication process is required for space grade ASIC fabrication. SOI process, Thin epi over heavily doped substrate, Trench isolation/P+ guard rings around NMOS transistors are some of mitigation techniques used at wafer level. At layout level Rad Hard libraries, Redundancy and feedback at transistor level are some mitigation techniques.

A2.9	**Topologies for high speed design and digitization (SAC)** The high speed and high resolution in ADC's are conflicting requirements which require selection of proper topology while keeping the target application in mind. The various type of digitizers required in Payload chain like 16bit-5msps, 14bit12msps, 12bit-24msps, etc. with high ENOB, low power and low size depending on the application. Very small video buffers with high driving capability to efficiently drive the detector video signal while maintaining signal integrity.
A2.10	**High speed ADC (SAC)** Design of >16 bit, >5Msps Digitizer with high ENOB, low power and low size
A2.11	**EMI susceptibility analysis (SAC)** EMI susceptibility analysis for co-existence of low noise, high speed, high power analog/ digital circuits.
A2.12	**DSP based signal analysis and image processing (SAC)** DSP based real /near real time data processing for signal analysis and image processing with emphasis on frequency and spatial domain. Tentative applications are Hardware and/or software with Image Based attitude determination electronics. Spacecraft docking system electronics Real Time decision making for Landing System Near real time camera for 3D map of terrain Navigation requires information of terrain over which the vehicle moves. Along with distance, size information of the targets is also required for activities like obstacle detection, landing site and optimizing the travel time. A 3D camera can provide such information.
A2.13	**Electronics for on-board computing (SAC)** On-board computer electronic system (including volatile, non-volatile mass memories, processors, standard interfaces, RTOS etc.) for space environment supporting soft computing of complex algorithms and real time applications.
A2.14	**Hardware for near real time decompression for CCSDS standard (SAC)** Near real time compression is planned for future high data volume payloads based on CCSDS methods. The decompression is software based which had long processing time. A hardware based decompression will reduce the processing to near real time for quick browsing.
A2.15	**Vector processor for video signal processing (SAC)** Reconfigurable vector processor can be utilized for future remote sensing satellite for implementation of the on-board image processing algorithm. Vector processor architecture shall support various primitive operation facilitating implementation of various image processing and compression algorithm. Development shall also incorporate required compiler for the development of different program on proposed architecture.

A2.16	**Very low noise, high efficiency power supplies for space (SAC)** Remote sensing and Meteorological Imaging Payload electronics redefine requirements in terms of processing speeds, resolutions, modularity, reliability and miniaturization which in turn requires very low noise, efficient and customized regulated supply lines to various camera electronics sub-systems. Camera electronics will have functional blocks like analog processing, mixed design, digital hardware, high voltage bias requirements, very high load/current requirements. Based on present and future missions, power supply requirements are anticipated and categorized as below: Very Low noise (≤1mV), Low power (<10W), highly efficient (>80%) complying with EMI 461E standard, space grade isolated power supply /module. Multi-output (3 to 4 voltage lines in range 3.3V to 24V), high efficiency (>80%), Medium Power (25W – 100W), Low noise (≤10mV) complying with EMI 461E standard isolated space grade power supply High output voltage (150V to 250V) with low output current (<50 mA) having 28-42V unregulated supply input Very high output current (up to 18A), low output voltage (0.8 V to 3.3V), >90% efficiency, wide input supply range (3V to 9V), very low quiescent power, space grade miniaturized Point of Load (POL) converter.
A3	**Sub Area** **Optics for EO Sensors (SAC)**
	Hyper spectral Systems are replacing multi-spectral type instruments. Finer resolution implies larger and bulkier optics. There is a great scope in this area for compaction, innovative focusing, alignment techniques and swath improvement. Multi-purpose large area array detectors are replacing the present day linear detectors. Mathematical modelling and optical domain processing are envisaged to be implemented. Following is the list of research areas where academic institution can contribute either in terms of study, algorithm development or prototype development.
A3.1	**Adaptive optical elements (SAC)** Adaptive Optics (AO) is a technology used to improve the performance of optical systems by reducing the effect of wave front distortions: it aims at correcting the deformations of an incoming wave front by deforming a mirror in order to compensate for the distortion. Adaptive optics works by measuring the distortions in a wave front and compensating for them with a device that corrects those errors such as a deformable mirror or a liquid crystal array.
A3.2	**Development of extremely thin and deformable mirrors (SAC)** Deformable Mirrors (DM) are mirrors whose surface can be deformed, in order to achieve wave front control and correction of optical aberrations. Deformable mirrors are used in combination with wavefront sensors and real-time control systems in adaptive optics. The shape of a DM can be controlled with a speed that is appropriate for compensation of dynamic aberrations present in the optical system.

	Origami Lenses Taking advantage of both refractive and reflective optics, light is folded multiple number of times in a crystal. Light enters through an obscured annular aperture located at the periphery of the lens and gets reflected multiple times inside the crystal with the help of concentric zone reflectors on both the surfaces of the lens. Folding the light beam helps to reduce the overall track length of the lens without compromising on the optical performance. Additionally, it also helps to increase the angular resolution by improving the lens magnification. Hence by reducing the number of folds, one can achieve a higher Field-Of-View (FOV) at the expense of the overall focal length of the lens. The overall diameter of the annular folded optics is scaled proportionately to collect the same power as an unobscured conventional refractive optical system.
A 3.3	**Metal mirror optics for VIS / NIR imaging (SAC)** Metals have been used as mirrors for many terrestrial applications due to their machinability, and cost. Aluminium has been used extensively due to its ease of machining and polishing and because it is highly reflective and does not need to be coated to yield high broadband reflectivity. Aluminium has a higher specific stiffness than glass, which makes it a potential low cost alternative. Creating a composite of aluminium or beryllium and carbon fibres would allow CTE to be tailored while retaining low density and high stiffness.
A3.4	**Sparse aperture optical systems (SAC)** The quest for finer angular resolution in astronomy inevitably leads to larger apertures. For the traditional telescope with single aperture, the angular resolution of diffraction-limited is basically given by 1.22λ/D, where λ is the wavelength and D the diameter of the aperture. Unfortunately, the primary mirror diameter of telescope is limited by the current glass-making technology, and the cost of monolithic optics increases faster than diameter squared 2. In order to overcome this limit, the technique of optical synthetic aperture can be utilized. The optical synthetic aperture consists of several telescope apertures that phased together to generate an equivalent resolution of large single aperture telescope.
A3.5	**Segmented mirrors (SAC)** A segmented mirror is an array of smaller mirrors designed to act as segments of a single large curved mirror. The segments can be either spherical or asymmetric (if they are part of a larger parabolic reflector. They are used as objectives for large reflecting telescopes. To function, all the mirror segments have to be polished to a precise shape and actively aligned by a computer-controlled active optics system using actuators built into the mirror support cell.
A3.6	**Use of hybrid optical systems in TIR (SAC)** The usage of hybrid optical elements (combination of refractive & diffractive optical elements) are being used to design compact and light weight, high performance imaging lens assemblies in TIR and MIR wavelength range. The ray path in a conventional refractive optical element is governed by the Snell law while in a diffractive optical element it is governed by grating equation. The spherical

	refractive lens has a continuous phase profile. If this phase profile is converted into a mod 2π discrete phase zones, then same focusing action can be achieved as in refractive case. In hybrid lenses the refractive lens is combined with diffractive optical element. For example, a Plano convex lens where basic lens power is provided by spherical surface and the spherical aberration is corrected by fabricating a diffractive phase profile on the other surface. The diffractive optical elements are highly dispersive. The focal length of a diffractive lens is inversely proportional to wavelength and the Abbe no.of diffractive optical element is always negative and very small, while the Abbe no. of refractive lens is positive. This dispersion behaviour of DOE can be used to correct the chromatic aberration of a refractive lens. By aspherising one surface of spherical refractive lens one can correct the spherical aberration and superposition of a diffractive phase profile on the aspheric phase, chromatic aberration can be corrected. Thus the use of the refractive/diffractive combination one can design low weight, compact and the high image quality broadband lens. The diffractive optical elements can be fabricated using photolithography and diamond turning techniques. one can realize hybrid optical component in 10-12□m range using diamond turning fabrication techniques as the required no. of zones for Ge lens is very small.
A3.7	**Foveated optics (SAC)** Foveated imaging can deliver two different resolutions on a single focal plane, which can inexpensively allow more capability for space systems. The development of compact imaging systems capable of covering a wide Field-Of-View (FOV) while transmitting high-resolution images in real-time is critical in a variety of applications. Foveated imaging is a data compression technique to speed up transmission and processing of high-resolution digital video frames by reducing the resolution of the image with the exception of a region of interest (ROI), which can be dynamically repositioned anywhere within the FOV. This multiresolution video compression method is ideal for applications where images from a wide FOV have to be transmitted and processed in real-time, yet high-resolution is required at the ROI. Foveated imaging can be achieved at the software level, by applying foveation algorithms to full-resolution digital video frames from a conventional imaging system, or it can be achieved at the hardware level, by combining images from several sensors or by using sensor arrays with variable resolution.
A4	**Sub Area** — **Electro-Optical Systems (SAC)**
A4.1	**Miniaturization of EO sensors/imagers through use of MOEMS (SAC)** Photonic circuits, in which beams of light redirect the flow of other beams of light, are a long-standing goal for developing highly integrated optical communication components. Micro-optical components, such as diffractive and refractive microlenses, have recently received considerable attention for the development of optical systems. The technology combines micro-optics, microelectronics, and micromechanics creates a new and broader class of Micro-Opto-Electro-Mechanical (MOEM) devices, which may attract additional industrial demonstrations of commercial devices. A few examples are lasers, fiber gratings, Fabry-Perot etalons, optical shutters, switches, interconnections,

	reflectors. Integrated devices can form free-space integrated optics and consequently push technology to the development of a micro-optical bench on a chip. The biggest advantage is the miniaturization that this technology offers, as this can be incorporated in many optical devices to make the whole optical system ultra-compact and light weight.
A4.2	**Space LIDAR/LADAR (SAC)** Lidar (also called LIDAR, LiDAR, and LADAR) measures distance to a target by illuminating that target with a laser light. A narrow laser-beam can map physical features with very high resolutions. Typically, light is reflected via backscattering. Different types of scattering are used for different lidar applications: most commonly Rayleigh scattering, Mie scattering, Raman scattering, and fluorescence. Based on different kinds of backscattering, the lidar can be accordingly called Rayleigh Lidar, Mie Lidar, Raman Lidar, Na/Fe/K Fluorescence Lidar, and so on. Suitable combinations of wavelengths can allow for remote mapping of atmospheric contents by identifying wavelength dependent changes in the intensity of the returned signal. LIDAR is used to make high-resolution maps, with applications in geodesy, geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, atmospheric physics, laser guidance, Airborne Laser Swath Mapping (ALSM), and laser altimetry.
A4.3	**Formation flying EO systems (SAC)** The quest for finer angular resolution in astronomy inevitably leads to larger apertures. For the traditional telescope with single aperture, the angular resolution of diffraction-limited is basically given by 1.22λ/D, where λ is the wavelength and D the diameter of the aperture. Unfortunately, the primary mirror diameter of telescope is limited by the current glass-making technology, and the cost of monolithic optics increases faster than diameter squared 2. In order to overcome this limit, the technique of optical synthetic aperture can be utilized. The optical synthetic aperture consists of several telescope apertures that phased together to generate an equivalent resolution of large single aperture telescope.
A5	**Sub Area** — **Micro Fabrication for Optics (URSC-LEOS)**
A5.1	**Deformable mirror by micro fabrication for phase correction in adaptive optics (URSC-LEOS)** Deformable Mirror (DM) is an important sub system of adaptive optical instrumentation which helps in improving the optical performance of an imaging system by actively correcting the measured wave font errors. The surface figure of a deformable mirror is actively controlled and modified such that it cancels out the measured surface error of system. It is made up a flexible Si wafer with thin film piezoelectric actuators fabricated on the back side using micro lithography techniques. This technology has multiple applications in improving imaging performance, optical communicated and ophthalmology.
A5.1	**Micro mirror array for wave front phase sensor (URSC-LEOS)** Micro mirror array is an important optical device with multiple applications. Realizing the fabrication technology of this device will be a significant step in the development of more complex instruments such as Shack Hartman Sensor etc.

A6	Sub Area	Spectroscopy Instrumentation and Application (URSC-LEOS)
A6.1	**Optical design and development of compact spectrograph for spectroscopy (URSC-LEOS)** Aberration corrected spherical surface gratings for specific spectroscopy application can be designed and the groove pattern can be realized using direct-write electron beam lithography. It is possible to fabricated analog depth diffractive optics in thin films of polymethyl methacrylate. Diffractive optic fabrication on non-flat (to date convex spherical) substrates can be fabricated utilizing the large depth of filed inherent in E-beam lithography. Realization of this technology will help in realizing compact, high performance spectrograph with minimum number of optical components.	
A6.2	**Raman spectroscopy application in earth and planetary atmosphere studies (URSC-LEOS)** The gaseous composition of earth and planetary atmospheres are required to be studied and analyzed on a regular basis to understand the climatic changes that are happening. LIDAR instrument based on Raman spectroscopy can give us valuable information on gaseous distribution along the attitude. Laboratory simulated atmosphere studies of gaseous planets and also experimental Raman LIDAR spectroscopy studies of earth atmosphere are of interest.	
A6.3	**Raman spectroscopy based studies on optical materials and minerals (URSC-LEOS)** It is now well established that most of the covalently bonded optical materials and minerals have their characteristic Raman spectrum which can be used to identify the compound. Proposal to do mineralogical study using Raman spectroscopy are useful to collect sufficient data and develop techniques to analyze and identify mineral compositions of any unknown minerals. These results and experience will help in future moon / mars mineralogy using Raman instrument.	
A7	**Sub Area**	**Electronic, Software & Support Systems For Imaging (SAC)**
A7.1	**3-Axis stabilized platforms for airborne imaging (SAC)** 3-axis precisely controlled mounts for distortion free imaging in aircraft/UAV platform. The typical payload mass range may be 1 to 30 Kg. The controlled angular resolution may be of the order of 0.001 deg., necessitating FOG/RLG based IMU as platform attitude sensor, and closed loop fast acting Servo actuators working up to 200 Hz.	
A7.2	**Very high speed data acquisition (SAC)** Very high speed Data acquisition of the order of minimum 20Gbps (up to 40Gbps) sustained for about 1 TB volume using multiple Serializer-Deserializer data interfaces, synchronized data acquisition using PCI express DAQ modules and GP-GPU based real time image display. GP-GPU may be used to Compress/Decompress acquired payload data, generate statistical parameters from the image data and provide real time visualization.	

A7.3	**CCSDS prescribed baseband data reception (SAC)** Firmware for reception and real time processing of CCSDS formatted data streams. This may include Viterbi Decoding/RS Decoding/De-compression and Decrypting. The data received from satellite, in addition to standard markers and randomization may have any or all of forward chain implementations for above blocks. A reception system nominally should have the capability to carry out all the processing required to extract useful data in Real time. With the availability of capable FPGA/Microcontroller based hardware in the market, it is possible to design and develop firmware meeting all the requirements. The data rate expected to support such implementation will be of the order of 100 Mbps.
A7.4	**System (Hardware & Software) for optimized for NRT EO data processing (SAC)** Algorithm/software to create a super straddle of workstations and associated hardware towards effective utilization of computing resources, particularly optimized and tuned for electro-optical payload development environment. Based on the specific requirements of an imaging sensor development, the work will comprise of choice of appropriate hardware, optimizing/developing algorithms to suit the underlying architecture and assigning tasks to the system on the fly based on requirement/complexity.
A7.5	**Image source and algorithms for characterization of imaging sensors (SAC)** Development of systems and algorithms/software to generate images that can be used to characterize Imaging Sensor. With use of DMD and Digital Light Processing, it is possible to generate Multi-spectral and Hyper spectral images as targets. It will also involve simulation of synthetic images with features that can be used to estimate the performance of the sensor, development of algorithms to compute the sensor quality metrics from the images.
A7.6	**Super resolution in spectral domain (SAC)** Extraction of finer spectral resolution information from Hyper-spectral Imagery, given a large number of relatively coarser resolution images with overlapping spectrums. Similar to super-resolution imagery, if data is collected with a given spectral bandwidth, but spectral sampling is much finer compared to the bandwidth, then it should be possible to generate images having narrower spectral bandwidth.
A7.7	**High-speed FO link commensurate with Thermo-vacuum requirements (SAC)** The future high resolution EO cameras will generate very high speed data at a rate of more than 20Gbps. The camera needs to undergo various phases of integrated testing and evaluation, including under thermo-vacuum conditions. To acquire such a data from systems located in Thermovac chamber, long length FO based high speed data link can be a solution. The digital data from multiple ports of camera needs to be suitably formatted, for transmission through FO link. The formatter and FO transceiver part has to sustain Thermovac conditions (up to 10-5torrpressure at -10°Ctemperature). Formatting may call for usage of high speed SERDES ICs, high speed FPGAs,with formatted data transmission through Active Optical Cables.

A8	Sub Area	Integration and Testing of EO Sensors (SAC)
	Assembly, integration and testing of space-borne EO imaging systems is a multidisciplinary task and requires state of the art test and evaluation setups and methodologies. In a complex EO system environment, system performance needs to be optimized to achieve goals. Technology trends coupled with growing user demands has propelled the development of very small size systems to very large size EO systems. Integration and testing of these systems are very challenging and requires custom development. During various phases of testing, large amount of ground test data is generated, which is used for system performance characterization. Integration and testing of space-borne imaging systems requires development of test setups, system performance estimation models, performance optimization and characterization methodologies, in-orbit performance prediction models, data analysis and interpretation, troubleshooting etc. Following areas of research is of interest in the field of Assembly, integration and testing of EO imaging systems.	
A8.1	**Automation of imaging system test setup (SAC)** Integrated payload test setups are developed for payload testing during various phases of testing. These test setups are used for tele command, telemetry and data acquisition. Research can be taken up in this field to develop completely automatic test setup for improved performance.	
A8.2	**Precision test setups (SAC)** Payload performance is measured / characterized by the test setups. These test setups need to be one order better than the payload to better characterization. Research in development of precision test setups can significantly improve the payload performance.	
A8.3	**Development of innovative techniques/methodologies for integration and testing (SAC)** Integration being multidisciplinary activities, and every time different genre of payloads are to be integrated and tested. It is required to develop innovative techniques for integration and testing to cater to technological advances adopted in payloads.	
A8.4	**Development of imaging system performance optimization and characterization techniques (SAC)** This is another field where research can significantly help in delivering high standard payloads. better characterization of payload avoids post launch problems and also helps in deriving better performance from the payload.	
A8.5	**Development of In-orbit performance prediction models and performance evaluation techniques (SAC)** Based on ground test results, methods to be developed to predict in-orbit performance so that any optimization required on the ground can be carried out.	

A8.6	**Development of methodologies and fast algorithms for analysis of large amount of test data (SAC)** During the testing large amount of data is acquired and various statistical analysis is carried out often limited to few samples. Various techniques for development of fast algorithms for evaluating such large volume data can significantly help in identifying and problems.	
A8.7	**Assembly, integration and testing of IR payloads (SAC)** Integration, characterization and calibration of low IR background large aperture cooled optics Payloads. The major challenges are to minimize the IR Background, IR signal drift correction, IDCA heat removal in lab and IR calibration.	
A8.8	**Development of In-orbit calibration sources (SAC)** Research in the development of On-board calibration sources e.g. Blackbody for IR calibration, Perforated plate or diffuser plate for VIS/NIR calibration can significantly help the payloads.	
A8.9	**High speed communication (SAC)** Space qualified hardware using optical communication for Telemetry, Telecommand and Video data transfer can be developed leading to standardization of the interfaces catering to different interface speed requirements.	
A9	**Sub Area**	**Sensor Electronics (URSC-LEOS)**
A9.1	**On Orbit mounting estimation of star sensor (URSC-LEOS)** Star Sensor Mounting Estimation using on orbit / in-situ measurements The star sensor provides attitude accurate to 10'' in measurement axes and 40" in bore-sight axis, leading the spacecraft pointing and control of 36" in body frame at about 4/8Hz update rate. The mounting / mechanical stability contributes to about 4-6'' uncertainty. Also due to various factors like thermal, effects of structural stability etc., the SS mounting varies by small amount cyclically in orbit/season. Towards providing further improved attitude accuracy of about 10" (in all three axes in body frame), it is proposed for research studies the problem of estimating the star sensor mounting on orbit/in-situ, using star sensor measurements, so that mounting updated at every attitude solution cycle, can be delivered along with estimated attitude solution to AOCS for significantly improving the pointing control accuracies of spacecraft & location accuracies of imageries.	
A10	**Sub Area**	**System Study & Analysis (SAC)**
A10.1	**Long-term analysis of Scatsat-1 data with a goal of demonstrating climate-quality (SAC)** For analysing systematic biases in spatial and time scales.	
A10.2	**Characterization of spectral signature of astronomical molecules in 200-300 GHz regime (SAC)** Preparation of list of astronomical molecules having 200-300 GHz spectral signatures. Simulation of emission/absorption spectra of all such molecules based upon the temperature and pressure environments of their sources	

	Radiative Transfer Simulation for such molecular signatures from their parent sources to an observatory in space. Determination of line-centres, spectral-width and intensity. Preparing a catalogue of observable targets with their distances and requisite angular resolution for all sky survey, specifically for the molecules of interest.	
A11	**Sub Area**	**RF / Microwave / Sub-millimetre wave (SAC)**
A11.1	**Study, design & development of THz range Schottky diodes (SAC)** Physics & Feasibility study using GAETEC Foundry. Modelling, Design, Development and Characterization.	
A11.2	**Design & development of 300 GHz & 600 GHz mixers (SAC)** Study and design using MMIC / Disctere devices. Development of Waveguide based modules.	
A11.3	**Design of millimetre wave fractional frequency synthesizer (SAC)** Feasibility study and design of synthesizers of 60 GHz, 120 GHz and 150 GHz.	
A11.4	**Design & development of Ku/X-Band front end ferrite switch matrix (SAC)** Design & Development of Ku/X-Band Ferrite Switch. Design & Development of Switch Matrix based on developed Ferrite Switches.	
A11.5	**Silicon micromachined sub-millimetre wave waveguide components (SAC)** Process feasibility study & process establishment. Design & development of Waveguide modules based on developed process.	
A11.6	**Design & development of sub-millimetre wave circuits on thin quartz substrate (SAC)** Process feasibility study & process establishment. Design & Development of thin Etching and Patterning of Quartz substrate.	
A11.7	**Design & development of millimeter wave RF MEMS based switches (SAC)** Process feasibility study & process establishment. Design & Development of thin Etching and Patterning of Quartz substrate.	
A12	**Sub Area**	**Digital Controls, Data Acquisition and Processing (SAC)**
A12.1	**Rad-Hard by Design (RHBD) Memories for 180 nm CMOS process of SCL (SAC)** Design & Characterisation of RHBD memories for 180nm CMOS process of SCL, Chandigarh.	
A12.2	**Real Time Operating System (RTOS) optimisation for on board Payload Controller (PLC) (SAC)** Customize standard RTOS for PLC applications in terms of optimization for resources with Fault Tolerant (FT).	

A12.3	**Adaptive On board SAR data compression algorithms (SAC)** A generic BAQ algorithm to compress the SAR data independent (or adapt) of the input signal distribution resulting in better SNR.
A12.4	**ONFI Controller with EDAC IP development for FPGA for solid state recorder (SAC)** Error correction and detection algorithms to maintain data integrity and reliable operation of solid state recorders.
A12.5	**Power optimisation techniques and protocol efficiency studies for wireless temperature sensors (SAC)** Design and develop a PMU, which takes power from solar cell and provide enough energy to operate sensor, microcontroller and RF. PMU will store energy in capacitor and it will be used by microcontroller to read the temperature from sensor and send it through RF link. Once capacitor is discharged PMU will again charge it with required voltage. PMU should be designed, simulated and fabricated on SCL 180nm fab.
A13	**Sub Area** — **Power Electronics (SAC)**
A13.1	Digitally Controlled Ultra-fast Energy Efficient Multi-Output DC-DC converter Digital control algorithm for fast transient response Secondary side of the converter implementation using SIMO (Single Input Multi-output) buck converters. Energy efficient power management solutions for dynamic load requirements.
A14	**Sub Area** — **Optical Thin Films (URSC-LEOS)**
A14.1	**Studies on transition metal oxide thin film coatings (URSC-LEOS)** Transition metal oxide coatings are potential candidates for their applications as infrared detector sensing elements, switching devices, radio-frequency transparent thermal control coatings, etc. Studies on optical, electrical and thermal properties of the thin films will lead to development of devices for space applications.
A14.2	**Laser damage threshold studies on optical thin film coatings (URSC-LEOS)** The optical coatings such reflector coatings, antireflection coatings, interference filter coatings, etc have their applications in laser based instruments for ground as well as space applications. Based on the energy of the laser the coatings may be damaged. The studies on laser damage threshold of optical coatings give an insight into the durability aspects of the coatings for laser applications
A14.3	**Studies on hydrophobic/ dust repellent coatings (URSC-LEOS)** Optical thin film coatings are essential for space based reflective / refractive electro-optics systems. The front optical elements being exposed to space environment, they need to be protected from dust and condensable vapours which seldom detrimental

	to the performance of payloads. These coatings will also be useful in interplanetary missions during landing the instrument over the surface of the planet. Hence the study of hydrophobic/ dust repellent coatings find space applications.
A14.4	**Infrared optical coating technologies for filters, anti reflectance coatings etc for IR optics (URSC-LEOS)** Space qualified optical coating technologies to produce filters and ARCs in different spectral bands in the near IR, SWIR and far IR for the imaging and spectroscopy instruments that are being envisaged in the future space programs are required to be developed.
A14.5	**Thin film solar cells and thin film batteries for satellite power requirement (URSC-LEOS)** It is already recognized that Thin film solar cells based Cu-In-Ga-S (CIGS) materials coatings are highly advantageous for space power application as these panels have high specific power (Watts / Kg) and are highly radiation resistant. Development of this technology for space usage will help in significantly reducing the weight contribution due to solar power requirements.
A14.6	**Nano technology based optical / gas sensors (URSC-LEOS)** Nano technology based rechargeable Thin film batteries which can be charged and store the power generated by solar cells are under development for space application. With this combination failures due to lack of power can be significantly reduced.
A14.7	**Optical material, coatings and components for NIR or Visible LASER development (URSC-LEOS)** Indigenous development of LASER for space application in an ongoing process at LEOS which requires lasing materials, damage resistant coatings and Thin film based laser diodes etc., research and development in realizing these technologies can be very useful.
A14.8	**Ultra narrow band pass and notch filters for a single wavelength of a laser line (URSC-LEOS)** These filters are required for Raman Spectroscopy Instrumentation where the incoming laser should be spectrally stable with a very narrow band width and without any side lobes. This can be possible only with a very narrow band pass filters placed in front of the laser. Similarly the Rayleigh scattered radiation from a laser illuminated sample has the same wavelength as the laser. In order to observe the Raman Spectrum, this component needs to be filtered out completely using a very narrow band notch filter centered at the laser wavelength. Development of these filters will help in indigenous realization of Raman instrument for space application.
A14.9	**Glancing angle deposited optical films with unique optical properties and their applications (URSC-LEOS)** Porous nano-engineered thin films fabricated using GLAD have a wide variety of optical applications. Helical films exhibit intriguing chiral optical properties, including circular Bragg effects and optical activity. GLAD films with grade index can be used for wide-

	band antireflection coatings exhibiting transmittance in excess of 99.7% over a 460 nm wavelength range, rugate filters with wide stopbands, spectral hole filters with narrow passbands, and even optical humidity sensors with superior performance response time and sensitivity to many commercial available sensors. The square spiral chiral film can be used to produce photonic crystals with a complete, three dimensional bandgap.	
A15	**Sub Area**	**Fusion Algorithm for computation of Spacecraft Attitude with Multiple – Head Star Trackers (URSC-LEOS)**
A15.1	**Development of optimized fusion algorithms and techniques to combine the images obtained from multiple heads, compensate for thermo-elastic distortions between heads and compute spacecraft attitude (URSC-LEOS)** Higher attitude measurement accuracy is obtained by using the star image captured from multiple star tracker heads that are mounted with different relative orientations. The accuracy is improved with the availability of more number of stars from multiple heads and different orientations of star tracker heads that offset bore-sight errors. The difficulty in multiple heads configuration is the results may be affected by thermo - elastic distortions between the heads.	
A16	**Sub Area**	**Micro Aircraft for Mars-2 (URSC-LEOS)**
A16.1	**Development of Unmanned Aerial Vehicle (UAV) which can fly using solar power (URSC-LEOS)** It will have imaging payload and an RF link with the orbiter spacecraft. It should have adjustable propellers to fly forward as well as for hovering. It should be built with non-corrosive and light weight material. The Mars is having lot of attention from the researchers for its exploration, related to existence of life. Typically the exploration is carried out in two phases. A spacecraft orbiting over Mars and taking images with very high resolution images, which are bulky to fine the area of interest. But this has limitations. The dust and clouds make a thick layer and make the visibility poorer for the attitude of a spacecraft. After finding the region of interest a rover is made to land on the surface and the rover does the soil study in very limited area. There can be one intermediate stage to find out area of interest on Mars surface by a low attitude Arial survey. Since Mars is having atmosphere an Aeroplane can fly over here. This plane should be solar powered, built with light weight non corrosive materials and carries small camera for surveillance and RF link with the satellite should have Mars upto 3 kg. It's propellers should be adjustable to front direction fly as well as for hovering. The Aero plane is deployed from the satellite into the Mars atmosphere and the plane performs high resolution survey on a wide area with miniature cameras. In case the area is found to be unsuitable the plane can be made to hover at a different area. This makes the search very economical for the desired landing spot for a rover, since the higher resolution images can be obtained with a much smaller payload when a low attitude survey is carried out.	

A17	**Sub Area**	**Vision System (URSC-LEOS)**
A17.1	**Three dimensional geometry and pose estimation using computer vision based techniques (URSC-LEOS)** Vision System has become integral sensor for future robotic missions as it provide important information to function automatically in unstructured environment. Computer Vision based techniques can be used to generate three dimensional geometry (relative rotation and translation) from image processing based techniques and algorithms. This algorithm can be implemented on stereo/ multi view camera or using depth camera or fusing of depth camera and stereo camera. This technique will be helpful to navigate and perform specific task by robotic systems, hazard avoidance, optimal path planning, autonomous rover or lander movement in unknown terrain for interplanetary mission within an autonomous process. Development of robust algorithm to generate relative pose of the objects in a scene with respect to camera in an automated manner and it should be processed in hardware in real time.	
B	**Area**	**Remote Sensing, Signal and Image Processing and Software Development (SAC/NRSC/IIRS/ NESAC)**
B1	**Sub Area**	**Image Processing (IIRS/ NESAC)**
B1.1	**Automatic extraction of 3D city models using LIDAR/ Satellite data (IIRS/ NESAC)** Extraction of buildings in undulating terrain is a more challenging task in comparison to plain region. The proposed research would be useful for preparing smart city planning in all hilly cities.	
B1.2	**3D surface modelling and features capturing of UAV/UAS data (NESAC)** A user friendly and robust UAV/UAS data processing software/model would help in using the UAV data more efficiently and more diversified field. In-flight geometric calibration & processing of UAV data will help in reducing the total output generation time significantly.	
B1.3	**Automatic Feature Extraction with advanced image processing algorithms (IIRS)** Automatic extraction and labelling of urban features like roads and buildings from high resolution satellite images has been an important research topic. Accurate and up-to-date road network information and buildings is essential for urban planning. Most of the traditional processing algorithms fail when the resolution increases significantly and have limited automation. Recently CNN has become a very popular tool for image classification which can automatically extract features, learn and classify them. It is a common belief that CNN can always perform better than other well-known classifiers. Hence there is a need to study and evaluate advance algorithms for automatic extraction of objects.	

B1.4	**Synergetic utilization of multi-sensor data for urban features extraction & modelling (IIRS)** Urban features extraction (such as 2D & 3D building parameters, individual trees, tree plantations, parks, play grounds, built-up area, etc.) is important for various planning, management and decision making at various levels. Availability of multi-sensor/ temporal data coupled with advanced algorithms are useful for features extraction in an urban area. Most of the traditional processing algorithms fail when the resolution increases significantly. For instance, conventional statistical learning becomes intractable with hyperspectral data due to the data dimensionality. Similarly, it is easier to classify urban versus non-urban areas with medium resolution data, very high resolution data enable the accurate classification at the building scale, but the use of such data requires completely re-designing the whole processing chain.
B1.5	**3D Modelling of urban areas/ 3D city modelling (IIRS)** The 3D models of urban areas assist in better visualization of urban areas as well can be useful for building typologies, landscape morphological characteristics, urban climate studies and many more applications for urban planners. This involves review and development of algorithms for automatic extraction of buildings, reconstruction of building planes and construction of 3D model using LiDAR and high-resolution stereo pair data. Currently, emphasis is given to develop methods for generating the 3D models using high-resolution stereo satellite data and Laser scanner based data.
B2	**Sub Area** — **Development of Image Processing Algorithms (NRSC/ NESAC/IIRS)**
B2.1	**Automatic image registration (NRSC)** This should cater to multi-temporal, multi-resolution and multi-spectral imagery registration with a specified accuracy for each category with a sub-pixel accuracy.
B2.2	**Hyper spectral image analysis (NRSC/ NESAC)** Development of techniques of hyper spectral analysis for EO and planetary applications.
B2.3	**Bundle block adjustment of aerial/satellite imagery (NRSC)** A technique development for operational bundle adjustment of large number of satellite imagery. This should cater to the multi-resolution and multi-resolution satellite imagery. Should make use of a distributed processing environment including the state of the art computer architecture.
B2.4	**Advanced models for satellite data pre-processing methods (NRSC)** Innovative high resolution image processing algorithms like image restoration, noise elimination, blur reduction and other quality improvements including advanced geometric correction models for satellite imagery.
B2.5	**Development of techniques of hyper spectral analysis for EO and planetary applications (NRSC)** Hyperspectral sensing is a method of extracting information about an object or scene in narrow spectral bands using imaging spectroscopy. Since the object or scene is imaged

	in narrow bands of wavelengths the neighboring pixel values are highly correlated. Further, the imaging conditions play a vital role in extracting end members for specific applications such as crop classification, mineral mapping, and urban scene analysis. A range of hyperspectral sensors are flown by ISRO namely Hyper spectral imaging camera of ISRO (HySI - ISRO) is flown on IMS-1, and Chandrayan-1 having a spectral range from 0.4 to 0.95 micro meter at 10nm spectral resolution, Chandrayan 2 mission Imaging Infra-Red Spectrometer for studying mineral mapping on moon. The present challenges facing the hyperspectral imagery processing and analysis being (i) data fusion, (ii) spectral unmixing, (iii) Data reduction, (iv) fast computing, and (v) data mining. We welcome proposals providing solutions in any of the above areas of our interests.	
B3	**Sub Area**	**Data Simulation (SAC)**
B3.1	**High resolution data simulation for future Cartosat series and HYSI mission (SAC)** There is a need of data simulation towards understanding the TDI devices in terms optical butting (used to make swath larger), high bit depth (radiometric resolution) and spatial resolution (0.5 m or higher). Therefore TDI sensor data simulation will be taken up in near future by using the other TDI devices data already flown globally like IKONOS/Quick Bird etc. This simulation will help in calibration, and testing the data processing and data compression s/w of Cartosat-2C and 3. Data simulation is also required for HYSI sensors for testing of data processing algorithms, simulation of agile platform effects as well as testing of data compression algorithms.	
B3.2	**Simulations for microwave sensors (SAC)** There is a need of data simulation for testing effect of various sensor parameters like chirp bandwidth, slice bandwidth and resolution, SNR etc. on performance of pencil beam scatterometer. Simulations of wave-forms are required for deciding on optimum sensor parameters and tracking algorithms for spaceborne altimeter system. Simulations are required to develop robust phase unwrapping algorithms for SAR Interferometry techniques. Simulations to understand concept of SweepSAR for acquiring data over large area with better geometric resolution. Data simulation will also help in testing of data processing algorithms.	
B4	**Sub Area**	**Data Visualisation (SAC)**
B4.1	**An immersive satellite image navigator with human gesture recognition (SAC)** This research may brandish a complete suite to visualize the image data with gesture recognition features. This kind of navigation will enable swift display and browsing of satellite image data with the help of no contact, gesture driven device (like Wii). Also, it can be used in discussion panels, exhibitions and presentations which intend to use this type of visualization as an approach for technology demonstration.	
B4.2	**Development of image fusion techniques (SAC)** This research is aimed towards development of image fusion techniques by spatial and frequency domain methods for merging HR PAN & MX data as well as optical and microwave data. The scope includes	

	Development of Image fusion method to generate merged product of Cartosat-2C. Study & implementation of suitable algorithm and in-house software development from the existing approaches for HR data and Development of Image fusion methods to generate merged products from various optical bands and microwave multi-polarised data acquired at different look angles. Initially testing can be done by existing Cartosat-1, IRS-P6 and RISAT-1 data sets.
B4.3	**Image matching for DEM generation (SAC)** One of the most important components of DEM generation from stereo/ multi-view imagery is the generation of high density match points and their structuring. Current version of CartoDEM based on Cartosat-1 stereo pair is based on advances in template matching to produce high density match points and structuring by TIN. Further research areas taken up in this include feature-based matching, better shadow and outlier detection, and improved DEM regularization/ conditioning for end-use. Another area of research in this field is development of robust algorithm for triplet matching, which will be enhancing the current version of Lunar DEM generated from Chandrayaan-1 TMC as well as for future Chandrayaan-2 TMC. R&D efforts are required to generate very high quality DEM from Aerial TMC stereo/triplet data sets by extending the above methods in terms of improvements in techniques/algorithms.
B4.4	**Image quality improvement (SAC)** The image component of Data products are a result of correction for systematic errors/ variations in Radiometry and Geometry. Development of techniques for restoration (MTF correction) of high spatial resolution imagery (e.g. Carto-2 series), de-striping of narrow-band sensors like OCM, and spectral de-convolution of Hyper-spectral imagery are areas of research in this category. Currently operational MTF restoration for Cartosat series are based on techniques developed here.
B4.5	**Quality indices for quantifying data quality (SAC)** The area of research deals with the delivery & maintenance of operational system for DQE (Data Quality Evaluation) for all ISRO sensors being the primary responsibility of IAQD of SPDCG.There is continuous R&D in terms of identifying suitable quality parameters for each sensor, development of algorithms for evaluating the parameters from data, and quantifying uncertainties in the process.
B4.6	**Generation of quality flags for INSAT-3D products (INSAT-3D, INSAT-3DR) (SAC)** A study on identification of quality flags for data products of Imager and Sounder is planned to be initiated. Quality flags will be formulated to capture end-to-end quality related to sensor performance, data processing approach and calibration quality, keeping in view quality requirements of climate quality data. Some of proposed scene-wise quality flags for Level-1 products are a) Radiometric quality – visual, calibration accuracy, sensor noise and b) Geometric accuracy - navigation accuracy, channel mis-registration. Additional flags as per requirement may be identified. Effect of above quality flags on usability of geo-physical products (eg. SST, OLR, UTH, Atmospheric winds) on identified sites will be studied. Validation exercise with references/ in-situ measurements to be carried out.

B4.7	**Identification of quality parameters for hyper spectral data (SAC)** Quality parameters to quantify Geometric, Radiometric and Spectral quality of Hyper-spectral data are required to be identified. Quality aspects specific to Planetary or Land applications such as spectral signature identification for mineral mapping can be explored. Effect of basic data quality on usability and accuracy of higher level products generated for applications can be analysed. Study area can be identified with available hyper-spectral data (Hyperion/AHYSI sensors), where sensor performance and data quality can be studied and validated with ground observations.
B4.8	**Integrated work bench for quality analysis of remote sensing images (SAC)** A work bench for quality analysis is proposed to be developed that would support data visualization and quality evaluation of remote sensing images. The software should support visualization of different types of satellite images (Medium to High resolution, Multi/Hyper spectral, Optical/SAR) and geo-physical data products (SST/UTH/WV etc). It should have capability of overlaying Vector Layers (District/State boundaries), Ground Control Points (GCPS), Google-Maps available in public domain on images. Use of Open source libraries/ GIS packages can be explored for implementation. Domain specific techniques for semi-automatic quality evaluation will be integrated with the proposed software.
B4.9	**Post-launch calibration of space-borne sensors (SAC)** This is carried out for medium resolution optical land-imaging sensors' radiometry based on natural calibration sites, for narrow-band Ocean Colour sensors based on Moon-imaging, for high resolution sensor MTF based on artificial targets, and for SAR sensor geometry using corner reflectors and radiometry from natural sites. Development of suitable models for ground radiometry assimilation, Top-of-Atmosphere radiance generation, Moon-image irradiance modeling, target design and modeling for MTF evaluation, and for modeling of calibration parameter determination for SAR targets are areas of research in this category. In each aspect operational methods are based on R&D carried out here. SAR radiometric calibration is one of the important aspect to characterize and maintain image quality throughout the mission and to provide stable, quantifiable image products to the users. This exercise is carried out throughout the mission in different manners. For SAR sensors, continuous monitoring of gamma naught and sigma naught on non-variant calibration sites like Amazon rainforest, Boreal forest is done to observe antenna pattern and consistency in gamma0. Radiometric parameters like sigma0, speckle index and radiometric resolution are observed from other distributed targets for the data sets with same instrumental parameters (beam, polarization). This exercise is used to estimate noise equivalent sigma0 to ensure the data quality. Scalloping and banding are the distortions needs to be quantified for ScanSAR mode Corner reflector based calibration is done to compute the impulse response parameters. A regular and systematic analysis helps to estimate the radiometric accuracy and stability using corner reflector based data Monitoring of SAR instrument subsystem components is used to study gain variations or linearity.

	A novel approach for Data quality evaluation of Scatterometers (OceanSat or upcoming mission ScatSat-1) is being worked out where one can relate the parameters available at different levels of product to geophysical parameters. In Scatterometer the vector wind is retrieved by combining several backscatter observations made from multiple viewing geometries. From Level 0, Leve1 and Level 2 data products, behavior of each sensor parameter is studied and suitable flags are generated if any deviation is observed. Pre-requisite of this exercise is first to have proper understanding of the instrument and algorithm characteristics which gives an insight into the factors controlling data quality. This monitoring and stringent flagging of required parameters at each level ease the traceability in order to relate the end product with Level 0 or intermediate level of products Scatterometer calibration includes the monitoring of onboard calibration data to keep a check on transmitted power. Invariant sites like Amazon rainforest, Sahara Desert, Antarctic snow are required to be monitored regularly and time series of backscattered or brightness temperature can be generated to check the system behavior. Regular such feedbacks help data processing to fine tune the DP system in order to generate high accuracy data products..
B5	**Sub Area** **Geometry Modelling (SAC/IIRS)**
B5.1	**Geometry modelling (SAC)** Advanced technique and algorithm development for in-flight Geometrical Calibration and its Standardization for Optical Remote Sensing payloads In-flight geometric calibration exercises are carried out usually during initial phase of the mission and necessary algorithms and corresponding s/w are developed for each mission separately. Special efforts are put for conducting a large number of exercises and analysis of results. This makes the in-flight experiments purely mission dependent calling for s/w changes for any new mission. Further, different modelling approaches are availabl. So a need for generalized s/w is felt based on the current experiences while giving scope for flexibility to extend the approach for new sensors like TDI and other high-resolution imaging modes. A scheme for standardization/generalisation of this activity is being evolved in terms of the following viz. Establishing necessary set of pre-identified test bed areas where adequate number of accurate control points are available, for use by any mission Development of mission independent techniques/algorithms and necessary s/w to work with or without control. Provision to incorporate new techniques, various modelling options to work with/without control points, options for single sensor, stereo sensors, triple sensors, multi-strips, multi-bands, TDI sensor, imaging modes etc. Identifying a set of common in-flight geometric parameters for adjustment for any mission as well as mission specific features. Approach should be able to characterize interior and exterior orientation of the sensors. Standardization of definition, convention for in-flight geometric parameters and their use

	Estimation and separation of attitude biases from spacecraft alignment and payload alignment angles etc. Attitude profiles analysis and validation techniques Standardization of Input/output file formats and contents Scope for adding any additional, new features pertaining to in-flight procedures. Scope of research proposal This research aims at development of new procedures (both technology development as well as R&D work for development of algorithms and s/w) and standardization/ generalization of the approaches for in-flight geometric calibration of the sensors on-board remote sensing satellites, which will result in high accurate data product realization at system level, apart from improving registration and mosaicking accuracies across missions for handling heterogeneous data sets. This can also give a future direction to the calibration procedures in terms of the requirements of some of the hardware on-board so that they can be useful in the current and future remote sensors (CARTOSAT-2C/2D, CARTOSAT-3, CARTOSAT-1A/1B, Chandrayaan-2 etc.) of different configuration. Modelling for Multiple Satellite/Sensor/Strip/View data in block adjustment sense The aim of this research is to develop approaches/techniques (both parametric and non-parametric) to model simultaneously data from multiple satellite/sensor/strips/Views from CARTOSAT-1/2/2A/2B and future missions to generate terrain corrected products with high accuracy. Scope of research proposal The scope of the proposal includes development of techniques for generation of Digital Elevation Models and Ortho-images without using the control points to meet the Global requirements. This can be achieved by increasing the redundancy in the datasets. Both Physical and RPC models will be built in block adjustment such a way, it can be easily adopted for planetary missions Chandrayaan-1 and Chandrayaan-2. It is planned to make use of this approach with global missions like Quickbird, IKONOS, and Worldview for available data sets. The proposed research will be able to handle and model full pass duration with limited control or no control and pave way for realising highly accurate DEMs and good quality data products especially for future HR missions like CARTOSAT-2C/2D, CARTOSAT-3 & other upcoming CARTO series of satellites & other High resolution missions.
B5.2	**Sensor web enablement (IIRS)** Open Geospatial Consortium (OGC) has taken a major initiative towards the development of OGC SWE specification. The OGC's Sensor Web Enablement (SWE) standards enable developers to make all types of sensors, transducers and sensor data repositories discoverable, accessible and useable via the Web. Some of the key areas of SWE research are on Sensor Web Data Visualization, Sensor Web Data Uncertainty Management, Sensor Web Data Management (e.g., Indexing, Caching, Query & Processing), Sensor Web Data Discovery and Search and SWE Deployment for Real-world Applications. Also few areas like Convergence of GeoWeb, Sensor Web and Social Web and Interoperable Middleware Architectures for heterogeneous Sensor Networks/ Sensor Web are in developmental stages.

B6	Sub Area	Earth Observation Data Processing (SAC/ NRSC/ IIRS/ NESAC)
B6.1	**Data processing for smart satellites (SAC)**	Carry out the Technology demonstration of complete Data processing on-board and disseminating products/Information.
B6.2	**Cloud avoidance scheduling (NRSC)**	Payload programming makes the optimum use of satellite resources to satisfy User requirements. The various capabilities of the IRS satellites and its resources call for a meticulous planning. Payload programming is successful only when it results in acquisition which cater to user requirements in terms of data quality, correct area of coverage (targeting accuracy), timeliness (within the period of interest) and cloud free acquisition. Cloud cover is one of the major problems in the acquisition of optical satellite remote sensing data and has a negative impact on the efficiency of data scheduling. The necessary global cloud information (on a daily / hourly basis) derived from meteorological satellites has to be incorporated in the planning system to improve the planning efficiency.
B6.3	**Time series data processing (SAC)**	Re-Processing all IRS, land and ocean data for generation of Atmospherically corrected ortho-rectified (water leaving radiance and ground reflectance) products, which can be used for Time Series analysis and generation of climate quality products.
B6.4	**Algorithms for time series analysis of satellite data (NRSC)**	National Remote Sensing Centre has been archiving all remote sensing data right from IRS 1A mission of ISRO till date. The datasets has all the characteristics that may constitute a time series and hence is a good resource for long term studies related to climate change and change detection etc. One of the possible applications of a time series data is to build models for forecasting. Statistical Methods such as ARIMA and GARCH are popular in predicting time series but they are far from satisfactory in terms of precision. Recent developments in machine learning algorithms and its use in regression and classification problems have paved a way for their use in forecasting time series. We invite proposals that incorporate the state-of-the-art algorithms for remote sensing applications, characterization of sensors and reconstruction of data.
B6.5	**Linking urban air quality with built-form using geospatial techniques (IIRS)**	Air pollutants occur both, outdoor and indoor, and can be natural or man-made. The major indicators of air pollution are SO2, CO, NO2, O3, NH3, H2S, particulate matters (PM2.5 and PM10), etc. The major sources of air pollution in urban areas are vehicular emission, solid waste burning, domestic fuels, power station, industries, etc. With the increasing tren d of air pollution in urban areas, its analysis is required for understanding causative factors, better planning and for general awareness using geospatial tools.

B6.6	**Solar potential assessment in urban areas (IIRS)** The world's energy problem and the huge scarcity of sources producing energy, drifts our attention towards renewable energy sources. It is important to identify areas that receive maximum solar radiation, and to prevent losses in solar gain due to obstructions from surrounding buildings and topographic features. Recent research has shown that net-zero energy buildings are achievable if site analysis and various climatological factors are taken into consideration while designing a building, house or a community.	
B6.7	**Semi-empirical modelling for forest biophysical characterization using PolSAR data (NESAC)** Influence of slope in forest biophysical characteristic of hilly regions needs to be understood properly.	
B6.8	**Tool and techniques for improving the quality of SAR images by post processing including removal of various artefacts like scalloping, banding, streaking, Terrain normalization using DEM, multi resolution, multi resolution SAR image and optical image fusion, time series analysis (SAC)**	
B7	**Sub Area**	**Image Processing and Pattern Recognition (IIRS)**
B7.1	**Machine leaning algorithms for earth observation data processing (IIRS)** Artificial Neural networks (ANN) is a generic name for a large class of machine learning algorithms, most of them are trained with an algorithm called back propagation. In the late eighties, early to mid-nineties, dominating algorithm in neural nets was fully connected neural networks. These types of networks have a large number of parameters, and so do not scale well. But convolutional neural networks (CNN) are not considered to be fully connected neural nets. CNNs have convolution and pooling layers, whereas ANN have only fully connected layers, which is a key difference. Moreover, there are many other parameters which can make difference like number of layers, kernel size, learning rate etc. While applying Possibilistic c-Means (PCM) fuzzy based classifier homogeneity within class was less while observing learning based classifiers homogeneity was found more. Best class identification with respect to homogeneity within class was found in CNN output. With this it gives a path to explore various deep leaning algorithms in various applications of earth observation data like; self-learning based classification, prediction, multi-sensor temporal data in crop/forest species identification, remote sensing time series data analysis.	
B7.2	**Super resolution approaches for hyperspectral remote sensing images (IIRS)** To enhance spatial resolution of the hyperspectral data, it needs to be fused with other sensor data of high spatial resolution. This results in enhanced spatial information but with loss of information. To obtain enhanced spatial information in hyperspectral data without using external data super resolution technique can be applied. The technique could be single frame super resolution technique, which converts hyperspectral data from low resolution to high resolution and can be utilized for detailed land cover analysis.	

B7.3	**Subpixel target detection using spectral unmixing of hyperspectral data (IIRS)** Hyperspectral sensors are able to provide unprecedented spectral and radiometric excellence in the data sets. These datasets are very important for identifying features and discriminating various materials. Issues related to hyperspectral data processing include endmember extraction and subpixel analysis, which are essential for land cover information extraction. There are various automatic and semiautomatic techniques developed to extract endmembers and some of them relies on the existence of relatively pure pixels. Purest endmember can be extracted from the data collected by airborne hyperspectral sensors. Spectral unmixing in each pixel of hyperspectral data deals with the fact of decomposition of spectra present into its corresponding constituent components. Linear and nonlinear techniques of spectral unmixing allows proper subpixel analysis of the earth surface utilizing hyperspectral data.
B7.4	**Enhanced land cover information extraction from high resolution hyperspectral data using object based technique (IIRS)** Satellite image classification for land-cover information extraction using high spectral and spatial resolution data is challenging task for traditional pixel based classification approaches. The pixel based classification approach only utilizes spectral information of the pixels to classify the image. Normally different physical objects have different spectral information and it is easy to differentiate using pixel based classification. The ability of the approach is limited when objects have similar spectral information. Under this circumstances the image are not classified correctly. To separate the objects with similar spectral information object based image analysis can be used which uses spatial as well as textural information. This approach segments the pixels into objects according to the homogeneity of the image and classify the image by treating objects as a whole.
B7.5	**Advanced sensor models for optical & microwave data Geo-referencing (NRSC)** Georeferencing is the process of assigning spatial location to each pixel of an image using sensor models or GCPs. Precise georeferencing is a major issue especially in high resolution optical and microwave imagery. Presently, rigorous sensor models and rational function models are widely in used in optical imagery geo referencing. For microwave sensors the range Doppler method is generally employed for assigning precise geo location. This method corrects the imagery for foreshortening and layover effects by utilizing the topology, orbit and velocity measurements from satellite and assigns a geolocation to each pixel. We welcome proposals that defines new methods/models and implementation of any of the above algorithms both for optical and microwave imagery.
B7.6	**Atmospheric correction procedures implementation for Visible & NIR & HySI (NRSC)** Atmospheric correction is key image processing step to retrieve surface reflectance values from spectra recorded by remote sensing space borne sensors. This further helps in standardizing physical variables, thus facilitating comparisons across time series of such variables. Presently, Atmospheric correction of all bands of Resourcesat-2 AWIFS and LISS III sensors is being carried out utilizing water vapor, ozone data products

	from MODIS, Aerosol optical depth from INSAT satellites using 6S RTF algorithm. The atmospheric correction has improved our estimation of normalized difference vegetation index by a factor of 50% with respect to TOA. There are possibilities of improving these estimations further by modeling the Bidirectorial reflectance distribution functions, using reflectance references from Drones or physics based models. We invite proposals in any of these areas that aim to minimize the influence of atmospheric effects in estimation of physical variables.	
B8	**Sub Area**	**Visualization, Cloud Computing & Software Architecture (SAC/IIRS)**
B8.1	**A private cloud infrastructure for Image processing and highly compute intensive applications so as enable designers/developers to dynamically use computing and storage resources in HPC environment (SAC)**	
B8.2	**Cloud infrastructure in HPC environment (IIRS)** A private cloud infrastructure for Image processing and highly compute intensive applications so as enable designers/developers to dynamically use computing and storage resources in HPC environment.	
B8.3	**Virtual Internal Network analysis and configurability (IIRS)** Virtualisation of internal Network, desktop and OS is utilized for effective resource management and reduce risk. This provides exploration of network behaviour in certain external or internal anomaly. Better Hardware utilization is another aspect while improving availability and disaster recovery. Auto Configurability and response are Current objectives.	
B8.4	**Parallel processing over HPC environment (IIRS)** Parallel Processing approaches for real time data processing and re-processing in HPC environment and using GPGPU platforms as well as accelerators like Intel-5.	
B9	**Sub Area**	**Image Map Generation Using Remote Sensing Satellite Data (SAC/NESAC)**
B9.1	Remote sensing satellites have provided continuous images with improving resolution since 1985. Currently, CartoDEM and Carto-ortho images are available for Indian region. Intention is to generate image map of cities and other area of interest using the available data sets as mentioned above. Cartosat series (images) data panchromatic (PAN) and multispectral (MX) can to used. Image captured by means of remote sensing are a very important source of geospatial information. Image map is defined as a special map portraying geographic space in a particular cartographical projection and map scale where its content consists of two basic components- image and symbol components. Image component is represented by remote sensing image(s), while symbol component is represented by cartographic symbols. As it is well known that SOI topographic maps are old surveyed and so very less information is available specially in the maps of Indian cities. Satellite data provides latest information	

	which can be encashed for various applications. By means of image map generation user can get better, latest and additional information from the image map. Topographic maps contain the representation of ground features in symbol form but in case of image map beside latest features, one can study and analyse the ground terrain effect also. Image maps can be generated at following scales 1:50000, b) 1:25000 and c) 1:10000 Specifications Positional accuracy: Aim of this proposal is to generate Image map for Indian cities. As per the scale, image map accuracy will be different. But with same input satellite data sets, goal can be targeted <10m accuracy specifications. Map projection & Datum: The Image maps are planned to be generated in World Geodetic System (WGS-84) Datum and will be projected in UTM Map Projection. Radiometric resolution of resultant images will be 10 bit. Methodology Open map series concept to be adopted in image map generation for map sheet numbering. Map grid tile generation with image map number is required. For a particular map grid no. first select the corner coordinates and collect respective area CartoDEM and orthoimages. a) Generate DEM mosaic and orthoimage mosaic. b) In ERDAS s/w, using “map composing tool” generate image map. Image maps can be archived in a database and as per the requirement hardcopy can be printed.
B10	**Sub Area** — **Data Registration (NRSC)**
B10.1	**Techniques for multi-date data registration and mosaics (NRSC)** Image-registration can be defined as ‘the process of overlaying images (two or more) of the same scene taken at different times, from different viewpoints, and/or by different sensors’. It plays an essential role in remote sensing as it is a prerequisite for the analysis of multi-date image sequences. Image co-registration issues might seriously influence the final quality of the remote sensing analysis and products because small misalignments in the input data could give large errors in the final outputs. e.g. for change detection applications. Image-to-image methods have two important advantages. The first one concerns the analyzed data: many applications require the comparison of multi-temporal and multisource data that should be precisely aligned. The relative co-registration of different images is therefore more important than their absolute geo-referencing. Secondly, image-to-image co-registration methods are based on the analysis of dataset of the same type. This leads to a general simplification of the co-registration process especially in the case automatic co-registration techniques are used. The co-registration essentially required for Bhuvan portal, where the multiple images has to match each other previous layer. It includes free download of AWIFS and LISS-3 orthorectified products and High Resolution satellite of multiple years, which are being used for feature extraction. The co-registered product enables automatic updation of newly identified features in latest images.

C	Area	Satellite Data Reception and Ground Station (NRSC)
C1	Sub Area	Design and Development of Antenna for data reception (NRSC)
C1.1	**Very high data rate (up to 2GBPS) demodulator & Bitsynchronizer systems with programmability for multiple modulation & encoding schemes (NRSC)** Design & development of Demodulator using Parallelism techniques for handling High data rate(2GBPS) Proposed FPGA demodulator is based on the Advanced High speed Design Methodology using the Parallelism techniques. Based on Hard limited Costas Loop development for Carrier and Clock Recovery. Simultaneous Demodulation and Bit-synchronization Continuous programmability of data rates, Modulation Schemes decoding and adaptable base band filtering.	
C1.2	**Three axis azimuth-elevation-train (variable tilt axis) axis tracking pedestal for antenna system (NRSC)** IMGEOS facility consists of four 7.5 mtr antenna systems for multi-mission data reception. Out of the 4 Antenna systems, 2 have tilted pedestals and 2 have un-tilted pedestals. Tilted pedestals have the capability to avoid the Zenith /overhead passes and can track the high elevation passes without any difficulty. The limitation/drawback of fixed tilt mechanism is that, if the satellite trajectory is in the opposite direction of tilt direction, then the line of sight at horizon/low elevation gets reduced and cannot avoid the zenith/overhead zone.By providing a programmable tilt to the pedestal up to 7 degree tilt, a distinct advantage of adjustment of Tilt in any direction (unlike fixed tilt) as per the satellite trajectory is achieved and totally eliminates cone of silence/ dead zone of Elevation over Azimuth Mounts. This programmable tilted pedestal is also called as Train axis/3-axis mount (Az, El and Train axis) and is essential for tracking the future missions like Cartosat – 3/3A/3B which will transmit the data in Ka band frequency (25.5 – 27.0 GHz).	
C1.3	**Adaptive servo control systems for Ka-Band data reception antennas (NRSC)** Adaptive Servo control System design is based on LQG controller, which is a Linear Quadratic Gaussian controller. It is an optimal and model based controller. Antenna Control servo system (ACSS) is used to control the motion of antenna. Present ACSS is based on PID (Proportional, Integral, Derivative) controller. This LQG controller overcomes the limitations of PID controller in terms of configurability of certain design parameters like rise time, settling time, Overshoot, servo error and disturbance rejection properties. Present PID based controller is not sufficient to meet the Ka and Ku band tracking requirements in view of its narrow beam width.	

C1.4	**FPGA implementation of CCSDS standard DWT-based image decompression (NRSC)** DWT based image compression technique is a compression standard used onboard satellites to improve transmission efficiency and for reducing storage requirements. This technique is very efficient to preserve the original image quality. On ground, the reverse process has to be done to retrieve the original data ie. DWT based decompression. This project work is VLSI Design of DWT based image decompression so that the design can be implemented in FPGA hardware. This hardware implementation will improve the ground data processing speed and hence the Turn around Time.	
C2	**Sub Area**	**Satellite Image Data Compression & Decompression (NRSC)**
C2.1	**Development of high speed CCSDS image compression / decompression technique (NRSC)** The CCSDS has established a recommended standard for a data compression/ decompression algorithm applied to two-dimensional digital spatial image data from payload instruments and to specify how this compressed data shall be formatted into segments to enable decompression at the receiving end. The steps followed can be briefed as: performing an image de-correlating operation (DWT) and then encoding the coefficients in various stages in order to obtain the compressed image. The compressed image has to be decoded with the knowledge of the segment header. Rate regulation needs to be done in order to adjust the compression rate. The decoded coefficients are correlated back (inverse DWT) to get the reconstructed satellite image All the future Cartosat missions follow the CCSDS image compression/decompression technique and there is a need for the high speed implementation of the same. The requirement is the implementation of all the compression and decompression steps using General Purpose Graphics Processing Unit (GPGPU) and CUDA software.	
C3	**Sub Area**	**Error Correction Coding (NRSC)**
C3.1	**Reed Solomon decoding software development for satellite data (NRSC)** Satellite communication channels are subject to channel noise, and thus errors may be introduced during transmission from the source to a receiver. Error detection techniques allow detecting such errors, while error correction enables reconstruction of the original data. Reed Solomon decoding algorithm is one of the error correcting algorithms to correct the received data with errors. Different formats of RS decoding standard algorithms are available like (247,255), (223,255). These things work in two modes one in CCSDS format and the other in traditional standard mode. Because of huge volume of satellite data and large mathematical computation it is time consuming to decode the data by using the traditional methods of Reed Solomon decoding algorithm. Hence there is a need for the high speed implementation of the same. The requirement is the parallelism of the Reed Solomon algorithm in General Purpose Graphics Processing Unit (GPGPU) and by parallel approach in Central Processing Unit (CPU).	

C4	Sub Area	Distributed Workflow Management (NRSC)
C4.1	**Autonomous multi agent job scheduling algorithms for distributed systems (NRSC)** Large scale processing and knowledge extraction from data requires execution of complex workflows in a distributed environment. A generic framework needs to be evolved for collaborative computing among the resources to obtain maximum throughputs from the systems Development of (i) multi-agent system architecture for processing data in a distributed network environment (ii) models for a multi agent communication (iii) schemes for automatic configuration of agents based on the dynamics of the real time job scheduling and (iv) Resource optimization algorithms to improve the processing timelines.	
C5	**Sub Area**	**Data Mining (NRSC/ NESAC)**
C5.1	**Algorithms for knowledge extraction from big data (NRSC /NESAC)** Large volumes of data that cannot be stored in normal relational databases are being generated every day from the remote sensing satellites. Many software elements extract information from the raw data generating information in unstructured form such as images, log files, user orders in pdf, word etc. There is a need for developing efficient data mining algorithms to tag the data sets for facilitating efficient build up of archival and retrieval. In general data mining algorithms work on data sets that are of reasonable size and cannot handle BIG data. Develop Parallel Algorithms for mining the classification rules to facilitate data archival in an optimal manner Develop mining algorithms that are Incremental and can learn and unlearn from the continuous satellite data acquisitions Develop algorithms for extracting meaningful trends in the customer ordering, build customer satisfaction index, predict the future sales or potential sensors or popular products etc.	
C6	**Sub Area**	**Software Engineering (NRSC/SAC)**
	Software is an integral part of all major systems of ISRO and plays a vital role in all its critical activities. Many functions which were done manually hitherto are being automated through software. It is very much important that software life cycle activities from inception to retirement are carried out systematically to ensure high quality in software.	
C6.1	**Software reliability modelling and metrics (NRSC)** There is a need to develop automated tools to extract different metrics from various software packages developed by ISRO to estimate their reliability and predict if possible the failure rates from the version history. Develop customized metrics for different types of software packages including real time, near real time, post processing, workflow software and distributed software Develop algorithms for estimating the software reliability numbers and predictive models for forecasting the failure conditions.	

C6.2	**Predicting reliability & optimal release time of various categories of software (SAC)** Objective To develop new SW Reliability Growth Models considering current trends in software reliability engineering & new challenges of software development process in order to accurately measure and prediction of software reliability. To find out the optimal release time of software. Develop a configurable SW for the same. New SRGM/SRTDM considers factors: specific application, patch-policy, upgrade strategy, testing-effort, testing coverage, testing environment, imperfect debugging, fault reduction factor, fault compression factor, fault removal efficiency. Scope This will cover the various categories of software development projects (mission critical or non-critical applications also, irrespective of its severity level), which are under development/ operations/ maintenance.
C6.3	**Techniques for acceleration of digital design verification (SAC)** Goal: Acceleration of functional simulation of large VLSI designs using hardware (reconfigurable FPGA /ASICs) devices. Functional simulation of large VLSI design carried out at workstations runs at very slow speed. In order to overcome the limitation of enormous time taken for functional simulations of large digital designs (RTL/Gate level netlist), it is required to place resource hungry modules of the VLSI design on the separate FPGA board. System is having such capabilities which can provide combine benefits of HDL simulation (signal visibility) and emulation (speed). Moreover, this acceleration will re-use simulation test benches without compromising their functionality or verification methodology. Linkage This system will be used for the Verification & Validation of all on-board and ground, compatible FPGA and ASIC designs.
C6.4	**Use of multi-processor parallel processing for timing & functional simulation of VLSI designs (SAC)** Goal: To achieve high speed timing & functional simulation of VLSI designs at RTL and GATE level, using multi core processor based EDA simulators. General EDA simulators run on a single core processor of the workstations. Use of only single core for processing, limits the simulation speed and become worse in case of timing (post lay out) simulations. With use of multi core parallel processing based simulator will enhance the simulation speed by a significant factor (10-20X). Linkage This system will be used for the timing and functional simulations of all on-board and ground VLSI designs.

D	Area	Earth, Ocean and Applications (SAC/ NRSC/ IIRS/ NESAC)
	EPSA is responsible for activities related to understanding Earth System, its components, processes and interactions using earth observation data, and its applications towards societal benefits. It aims at identifying Earth Observational (EO) requirements, development of techniques to analyse data to address the science issues and applications related to land, ocean, atmospheric and planetary sciences. The research pertains to operational retrieval of biophysical and geophysical parameters from space borne sensors, sensitivity analysis, calibration and validation of the sensor and retrieved parameters, assimilation of remote sensing derived parameters, in-process modelling pertaining to interactions within the geosphere-biosphere system and atmosphere. EPSA as a world-class multi-disciplinary scientific team has the following major research themes: Sensor system studies towards development of state-of-the art EO Sensors Development of operational retrieval techniques of bio-physical parameters from Indian Earth Observation as well as Planetary missions Advance R & D on retrieval of Geophysical and Biophysical products Synergetic use of space borne data to derive value added bio-geophysical parameters Development of procedures and advanced techniques for inventory and monitoring of natural resources using geo-informatics. Modeling of dynamic physical processes for improved weather and ocean state prediction. Development of assimilation techniques for improved predictions Assessment of environmental impact and associated climate change over different ecosystems. Utilization of data from Indian Satellite Missions including SCATSAT-1, RISAT-1, INSAT-3D/3DR, Oceansat-2, Cartosat-1/2, Resourcesat-2, SARAL AltiKa and Megha-Tropiques. Planetary Sciences Designing, generation and updating of resource database ranging from local to national scale. Capacity building of scientists at national and international level for developing and implementing EO application programs. Facilitating infrastructure design and development at national and international level to support earth observation applications for collaborating agencies Archival, Dissemination of the Meteorological & Oceanographic Satellite data, Experimental forecasts and value added products Archival, Dissemination of the Earth & Planetary Science Data Providing platform to students, academicians & researchers for the analysis of Satellite data.	

D1	Sub Area	Physical Oceanography (Development of Blue Economy) (SAC)
D1.1	**Assimilation of satellite/in situ data in numerical ocean prediction models: Observation System Studies Experiment (OSSE) (SAC)** Advance research is being carried out for assimilation of satellite derived parameters (salinity, temperature, sea level, wave height, ocean color) in ocean prediction models. This involves development of various assimilation techniques for improving the initial condition in the models. Apart from satellite data, lot of in situ measurements (glider, HF Radar, wave rider buoys etc.) are also being taken in the present. It will require intensive modelling and testing optimization techniques towards performing OSSE to ascertain the importance of satellite-based and in situ-based observations.	
D1.2	**High resolution oceanography (SAC)** In the view of high resolution (temporal and spatial) satellite observations from synthetic aperture radar, forthcoming swath altimetry, radiometer-based sea surface temperature and optical imageries, high resolution oceanography is fast becoming a reality. Synergistic use of these information will be key to understanding many unresolved processes at sub-mesoscale level, which can help in better ocean estimation.	
D1.2	**Air Sea interaction studies (SAC)** To understand some of the atmospheric and oceanic processes near ocean surface, air sea interaction study is very important. It is important to assess the validity of existing exchange algorithms (bulk formulations) for different regions of the oceans. Because of scarcity of observed data over the ocean, it is important to understand these processes with the help of satellite data. However, in situ data will form an important data set for validation. This involves diagnostic studies of the processes with the satellite data and numerical model outputs.	
D1.3	**Study on coastal dynamics using satellite and high resolution numerical models (SAC)** Coastal dynamics are extremely important to understand as it has significant implications on coastal population. Coastal processes such as, storm surge, rip currents, extreme waves, oil-spill trajectory forcecastetc need to be studied systematically with the help of high resolution data and numerical modeling.	
D1.4	**Seasonal ocean prediction with coupled atmosphere-ocean models (SAC)** Forecast of anomalous oceanic conditions (Dipole/El Nino) at least one season in advance is of high importance as it has direct influence on the Indian Summer Monsoon. These seasonal to long term forecasts are required to be done by making synergistic use of satellite observations and couple Ocean-Atmosphere models. Effect of satellite data assimilation on the skills of these forecasts are also required to be assessed.	

D2	Sub Area	Geophysical Parameter Retrievals (SAC)
D2.1	**Retrieval of geophysical parameters from satellite data (SAC)**	ISRO has planned for launching a number of meteorological and oceanographic satellites in near future. It has already, Megha-Tropiques, INSAT-3D/3DR and SCATSAT satellites in the orbit. In near future it has plan to launch GISAT and Oceansat-III. It is a challenging work to retrieve geophysical parameters from the sensor data of these satellites. This involves Radiative Transfer modelling and the Inverse modeling techniques.
D2.2	**Retrieval from proposed advanced sensors (SAC)**	ISRO has planned to include advanced sensors such as Microwave Temperature Sounding Unit (TSU) and Humidity Sounding Unit (HSU) in future missions. There is also possibility of inclusion of an advanced microwave radiometer similar to GPM Microwave Imager (GMI) in future missions. The retrieval of geophysical parameters from these sensors is a challenging task that can be taken up by research and academic institutions in the country.
D2.3	**IRNSS/GNSS applications (SAC)**	IRNSS/GNSS offers unique opportunity to retrieve atmospheric geophysical parameters such as TPW. ISRO may also develop satellite-borne receivers for IRNSS/GNSS reflectometry, which has potential to provide various surface parameters including sea surface height, intense sea surface wind speed and direction under severe weather conditions, soil moisture, ice and snow thickness, etc. Theoretical modelling and simulations of the reflectometry observations is desired for the retrieval of the parameters. Until IRNSS receivers are not available, International missions such as TDS-1 and CYGNSS can be used to validate the simulation studies and retrieval algorithms.
D2.4	**Merged data products (SAC)**	Develop data fusion methods to derive most optimized products using a synergy of observations. The examples are (a) Optimized temperature/humidity profiles using IR and microwave sounders (b) Optimized SST and rainfall products from IR and Microwave imagers.
D2.5	**Advanced system study for new sensor definition (SAC)**	For new measurements of atmospheric and Oceanic parameters, new advance sensors have to be defined for future satellites. System study is being done with the help of Radiative transfer models to define the appropriate frequency and bandwidth of new sensors.
D2.6	**Other research areas related to parameter retrieval (SAC)**	Cloud/Rain type classification using INSAT/Kalpana observations. Study of cloud micro physics using 157 GHz of MADRAS and INSAT data Combination of INSAT-3D Imager and Sounder products to improve the quality of a few critical atmospheric products, such as atmospheric stability, total water vapour contents, SST etc.

	INSAT-3D/3DR 3.9 µm channel provides a cleaner atmospheric window compared TIR channel for superior low-level cloud detection at night. However, due to its susceptibility to reflected sunlight from cirrus and especially low-level cumulus clouds limits its usefulness at night-time applications only. Question is to investigate by retrieving 3.9 µm winds at day-time, how much the accuracy is affected, with respect to low-level winds retrieved using TIR channels? Whether this can be useful for any other applications which can't be resolved by the winds from TIR or VIS channels?
D3	**Sub Area** **Geosciences (SAC/ NRSC)**
D3.1	**Geo-Hazards (SAC)** Research leading to development of early warning systems to geo-hazards. Crustal deformation studies using InSAR and GPS. Interseismic deformation modelling along active plate boundaries for earthquake hazard assessment. Volcanic deformation studies. Understanding land subsidence due to groundwater/coal exploitation. Active fault detection and monitoring using InSAR. Developing methods for coastal vulnerability assessment due to natural and man-made hazards. Desertification and Land Degradation Vulnerability assessment Development of techniques to retrieve gravity/geoid using satellite altimetry over marine regions Modeling gravity/geoid data for understanding lithospheric structure and geodynamic processes. Integrated geophysical study of Indian continental margins to understand its geological evolution with specific utility to off-shore oil exploration. Geophysical investigations of the Andaman-Sumatra subduction zone to understand geodynamics and seismo-genesis.
D3.2	**Mineral exploration (SAC)** Develop methods to analyse/evaluate potentials of various space borne /airborne missions (Hyperspectral, RADAR, Thermal,DEM,gravity,magnetic in particular) for mineral exploration Develop GIS based models to identify mineral prognostic zones by integrating geological, geophysical and geochemical data. Develop methods for environmental impact assessment of existing/proposed mining areas using RS and GIS.
D3.3	**Geo-Archaeology (SAC)** Develop methods/ approach to explore archaeological sites using multisensor satellite data (Radar and high resolution multispectral data in particular) in conjunction with geospatial database of known archaeological sites Understand impact of neo-tectonic activities and palaeo-climatic changes on evolution of ancient civilisations.

D4	Sub Area	Cryosphere Science (SAC/NESAC)
D4.1	**Mass balance of Himalayan and other mountain glaciers (SAC)** Mass balance of Himalayan and other Mountain glaciers using DEM differencing approach. Mass balance of Mountain valley glaciers is a direct indicator of effect of climatic variations on glaciers. There are many approaches to compute this parameter. One of the approaches is based on finding of differences in the elevation of glaciers over a period of time using time different DEMs.	
D4.2	**Digital techniques of change detection of area of glaciers and geomorphology around glaciers (SAC)** Change in area of glaciers is a direct indicator of long term increase or decrease in mass of glaciers. Satellite data of medium resolution can be used for this change detection. Methods need to be developed based on digital techniques to extract the changes from satellite images.	
D4.3	**Glacier ice velocity (SAC)** Glacier velocity can be extracted from satellite images using image correlation techniques. Research is required to know the causes of spatial and temporal variations in ice velocity in the Himalayan terrain.	
D4.4	**Ice sheet mass balance, calving and motion (SAC)** Continental ice sheets are very important constituents of earth's system. Research is required to be done in estimating accurately the change in mass balance of ice sheets, rates of calving and motion rates of motion of ice using satellite images.	
D4.5	**Effect of annual variations of sea ice (SAC)** Research is required to be done on the annual variations in growth and decay of different types of sea ice and its effect on global heat circulation.	
D4.6	**Impact of climate change on Himalayan snow & glaciers (NESAC)** Understanding the influence of climate change in snow melt and runoff factors for incorporating in flood forecasting model.	
D5	**Sub Area**	**Environmental Sciences (SAC)**
D5.1	**Estimation of forest biomass (SAC)** SAC is engaged in development of physical and semi-empirical models based on polarimetric SAR data for estimation of forest above-ground biomass and recently, SAC has generated forest above-ground biomass of selected forests in India using SAR data. New research is required for development of PolarimetricInterferometric SAR (PolInSAR) based advanced models for generation of forest tomography and more accurate estimation of forest biomass.	

D6	Sub Area	Advance Techniques Development (SAC)
D6.1	**Development of Polarimetric Interferometric SAR (PolInSAR) based tools/ techniques for airborne/spaceborne SAR (SAC)** PolInSAR is an evolving technique that has enormous potential in geoscience applications especially applications related to vegetation. Future Space borne Synthetic Aperture Radar (SAR) systems such as NASA-ISRO L&S band SAR would provide data suitable for short-baseline PolInSAR applications. SAC is engaged in development of tools and algorithms for PolInSAR analysis.	
D6.2	**Development of models and algorithms for parallel processing of massive Microwave / SAR signal data streams from satellites (SAC)** Modelling SAR / Microwave signal data processing on a parallel stream processing architecture. Development of Algorithms on the chosen Big Data Architecture for processing of SAR / Microwave data from Satellite. Implementation of the developed algorithms on Hadoop based Stream processing architecture.	
D7	**Sub Area**	**Marine Biology and Ecosystem (SAC)**
D7.1	**Bio-optical parameter retrieval for Case-2 and optically complex marine waters (SAC)** Development of bio-optical algorithms for optically complex and case-2 marine waters, especially around the Indian region. Accurate estimation of optically active constituents such as chlorophyll–a concentration, coloured dissolved organic matter (CDOM) absorption and total suspended sediments with error budget. Atmospheric correction models for turbid and optically shallow waters and retrieval of water leaving radiances. Hyperspectral information for accurate estimates of bio-optical parameters.	
D7.2	**Biogeochemical dynamics in oceans (SAC)** Study of various components of the carbon Nitrogen cycle, nutrient dynamics in estuarine coastal and oceanic regions and the effect of density, salinity and temperature on nutrient dynamics, primary production and new production modelling.	
D7.3	**Marine living resource management (SAC)** Modelling of fish habitats, GIS based mapping of fishery resources, environmental impact assessment of fishery resources and conservation for endangered marine organism using geospatial information.	
D7.4	**Micro and microalgae studies (SAC)** Microalgae taxonomic, structural and functional groups using microscopic, optical and chromatographic and remote sensing techniques, biodiversity studies of micro and microalgae of Indian marine waters, environmental impacts on bio-diversity, studies on harmful algal blooms, studies on biofuels, bioactive components using micro/macroalgae.	

D8	Sub Area	Geology, Structure and Geomorphology (NRSC/ IIRS/ NESAC)
D8.1	**Sub-surface geo / archaeological features using GPR data sets (NRSC)** With the Indus Valley civilization and several subsequent empires and kingdoms, India is one of the world's archaeological gems. Be it ancient forts or some of the world's oldest universities, India has more than a thousand known/ excavated archaeological sites over diverse geological provinces. Many of the sites with its extent are yet to be excavated and or mapped. Synergetic usage of Earth Observation (EO) satellite data and ground geophysical observation (Ground Penetrating Radar) has proven to be an effective tool for detection, delineation and mapping of shallow sub surface geo-archaeology and ancient cultural sites with its extent. Proposed study will help in building up scientific understanding and to correlate EO data and GPR signatures of geo-archeological features in known archeological sites (in fluvial Aeolian and coastal regions) to detect, delineate and map the extent of the buried cultural heritage sites.	
D8.2	**Spectral library generation of rocks & archiving from various geological terrain in visible and thermal region (NRSC/IIRS/NESAC)** In this research domain, research is to be carried out to understand the role of mineralogy in shaping diagnostic absorption features imprinted on the reflectance/ emittance spectra of rocks and how mineral spectra of dominant to minor minerals contribute in shaping absorption, kinks in the mineral spectra. Research also should assess the role of linear or non-linear mixing arising due to textural change and how these hamper/influence the diagnostic absorption feature. Research attempt can also be made to prove/assess the utility of spectrometric parameters of absorption/emissivity features in estimating grade of the ore bearing samples.	
D8.3	**Development of an automatic technique using satellite data and DEM for identification of landforms in different geomorphic provinces of India (NRSC)** Understanding the landforms present in different geological provinces like Fluvial, Glacial, Coastal, Denudational, Aeolian etc based on terrain analysis and classification of precise DEM using various satellite and aerial data sets. Exploring the semi-automatic and automatic techniques like Machine based methods, Artificial Neural Network, Object Based classification, Fuzzy logics etc. for automatic classification of the landforms by reducing the manual delineation efforts and time as well as to support the modeling of processes as hydrological modeling, geomorphic modeling etc.	
D8.4	**Numerical modelling for crustal deformation using GPS vectors (NRSC/IIRS/ NESAC)** NRSC operated Continuously Operated Reference stations in 6 locations within the HP and Uttarakhand Himalayas. Differential movement as recorded by GPS observations indicate towards active convergence in the region. Further, as a resultant of such differential movement, it may be possible, that there is significant strain accumulation in	

	the region, pervasively or localized to certain areas. These areas are then prone to future earthquakes. To understand the state of strain in the area, estimation and modeling of the same is important. For this, numerical models (Finite Element) are to be created to ingest the GPS vector data, the fault geometries with the crustal rheological properties and simulate the strain accumulation in the region.
D8.5	**Spectral library generation of minerals and rocks in VNIR, SWIR and TIR Regions (IIRS)** Spectroscopy has emerged as one of the key non-destructive methods to characterize rocks and its constituent minerals. The representative spectra provides an idea about mineral chemistry in a quick and cost effective way. Hence the role of spectral signature is becoming important in mineral exploration day by day. It is a known fact that the USGS library always cannot be used as a standard for minerals occurring in Indian region because of different modes of petrogenesis. Hence, there is strong requirement of indigenous development of important rock forming, ore and other minerals, especially for Indian rocks and minerals. For better and accurate characterization, spectral response of minerals/rocks in infrared spectra of electromagnetic energy is to be considered, in addition to Visible-NIR region. It is also envisaged in this project to take cues from petrographic and geochemical analysis of the minerals to validate and build a complete spectral library.
D8.6	**Active fault mapping and validation using spaceborne and surface (shallow) geophysical investigation (IIRS)** Active fault maps are not available for many parts of India although the Indian plate is very dynamic and both inter and intra plate region active faults are prevalent and are very important features to study for proper seismic risk assessment. There is an urgent need for compilation and preparation of database on active faults using various modern tools and assess their impact on hazards associated with them. For hazard assessment a comprehensive global literature survey would be very helpful. Methodology should be developed to map and monitor such features using advanced tools like HR images, DEM, UAV and GNSS (for knowing present rate of movement). Geophysical techniques should include GPR, IPR and trenching and dating wherever possible.
D8.7	**GNSS data processing for geodynamics study (IIRS)** The overall aim is to shed light on the tectonics and kinematics of the Himalayan region by investigating crustal deformations and to delineate the crustal strain pattern of the region using GNSS measurements and geophysical methods. The project will use advanced earth observation resources for characterization of vulnerable earthquake zones by modelling of GNSS data to find out the stress/strain in the Northwest Himalaya. Successful modelling of stress/strain using numerical simulation has a direct linkage with seismicity of the area. The aim of the study is to monitor crustal deformation, seasonal strain, correlation with hydrological loading and to constrain strain accumulation as a measure of condition that facilitates fault movement and resultant earthquake.

D8.8	**Differential Interferometric SAR technique for groundwater depletion and mining induced land subsidence analysis (IIRS)** Groundwater depletion and mining are two important anthropogenic causes responsible for land subsidence at various places of the country. Differential interferometric SAR is a proven spaceborne technique, which can be successfully used for detection and monitoring of land subsidence much before the damage. Spaceborne DInSAR based analysis needs to be supplemented with ground-based measurements and in-situ observations for validation and characterization of land subsidence. Time series analysis and predictive modelling based on the causative factors would be beneficial to understand the nature of the deformation and scenario analysis.
D8.9	**Study of glacier change in Himalayas and its climatic implications using remote sensing (IIRS)** The direct and indirect impact of glacier response to climate change affect society and mankind and hence makes it important to assess the changes of Himalayan glaciers to climate change. Assessment of glacier changes to climate change is necessary for preparation of countermeasures for glacier variation and related impacts. Despite the importance of the study, very few report are available on the vulnerability of Himalayan glaciers. Under rising temperature and changing precipitation scenario, rapidly retreating glaciers are giving rise to glacial lakes and accelerating the growth of existing glacial lakes. Sudden discharge of water associated with loose debris from these lakes known as the Glacial Lake Outburst Flood (GLOF) causes catastrophe in the downstream. Every country in the Himalayan region is affected by GLOF events. Further, the ice, snow, rock avalanche and mass movement from glaciers pose serious threat to people living in the high mountain region. It is therefore important to study and address the problem in totality using Remote Sensing, GIS and allied space technology.
D8.10	**Development of Methodology for Landslide Microzonation (LMZ) or Largescale Landslide Hazard Zonation (LHZ) and monitoring using high resolution remotely sensed images (IIRS)** Methodologies are available for mesoscale LHZ (1:25,000), however, the same are not available preparing site specific hazard map using data from high resolution satellites, UAV and terrestrial laser scanner or distant photography. There is an urgent need for compilation and preparation of database using various modern tools and make models that identify landslide hazardous areas on large scale (<5000 scale). Secondly, methods should be developed to monitor landslides using advanced tools like TLS, UAV and videography (using data mining and AI approach). The envisaged projects will deal with compilation of data from diverse source (in mainly public domain) for preparation of landslide hazard zonation at large scale and development of monitoring mechanism that would aid in early detection and early warning. The project is to be developed at a potential site, that can be handed over to stake holder after the completion of the project for continuity. The study should also prescribe Research Continuity Plan (RCP) for implementation and follow up.

D8.11	**Land surface deformation monitoring by microwave SAR data analysis in the coal mines of Chhattisgarh (IIRS)** Typically, coalmine subsidence occurs due to extraction of coal by underground mining. Besides, land surface deformation occurs in and around opencast mines and overburden dump areas, which lead to severe mass wasting and slope failure. The common traditional techniques for measuring land surface deformation by ground-based measurement techniques using precise levelling, total station and global navigation satellite system (GNSS), can yield point-based measurements. Spaceborne SAR (Synthetic Aperture radar) interferometric technique provides spatially continuous measurement of land surface deformation over a large area at centimetre to sub-centimetre level precision. This research will focus on spaceborne differential interferometric SAR (DInSAR) data analysis for monitoring land surface deformation due to extraction of coal by underground and opencast mining techniques and their impact assessment.
D8.12	**Predictive modelling and characterization of land subsidence due to groundwater and petroleum extraction in and around Mehsana, Gujarat (IIRS)** It is of ongoing concern that continuous on-shore oil and gas extraction as well as groundwater mining in the area, may contribute to the subsidence of the Mehsana Block of North Cambay basin. Our project will investigate land subsidence in the exploration oilfields due to hydrocarbon extraction in the Mehsana Block of ONGC and land subsidence in the Mehsana basin due to groundwater withdrawal in the region. Land subsidence will be investigated using DInSAR time series to map the land subsidence and to confirm the deformation source. Modelling of land subsidence in relation to groundwater withdrawal and petroleum extraction and consequent mass deficit will help to simulate future land subsidence scenario and to recommend preventive measures.
D8.13	**Derivation of innovative sub-pixel mapping algorithms to identify rarely occurring class indicating mineralisation (NRSC)** Under this research domain, focus should be on the derivation of the effective sub-pixel mapping method which may help to identify the spectrally diagnostic target which occupies 20 to 30 percent of the pixel but. Algorithms should be effective for processing both hyperspectral and multispectral data. These algorithms should also account to characterize complex (stochastic) character of background.
D8.14	**Implementation of algorithms to derive spectrometric parameters of each pixel of hyperspectral data (NRSC)** In this research domain, we require develop image processing tools(in IDL language preferably) which can be used to derive different image products for different spectrometric parameters like absorption depth, width and asymmetry(pixel by pixel basis) from any hyperspectral data once spectral range and wavelength minima of the absorption features are specified. These spectrometric parameter enhancing products would be ideal for geological target detection like alteration zone etc.

D8.15	**Development of regional landslide early warning system based on rainfall threshold (NRSC/NESAC)** Landslides are mainly triggered by rainfall. Daily as well as antecedent (cumulative) rainfalls are responsible for saturation of soil and subsequent landslide in hilly areas. Therefore, a rainfall intensity-duration relationship was developed by NRSC for experimental landslide early warning. Bhuvan platform is currently used to disseminate daily landslide early warning for selected road corridors in the Himalayas. Daily 72 hrs rainfall forecast received from IMD or SAC (MOSDAC) is used as an input to the landslide early warning model. Then the available landslide susceptibility map is integrated with rainfall probability to generate landslide early warning in Bhuvan. Early warning in four categories (Warn, watch, advisory and no warning) are issued regularly through Bhuvan. Currently the landslide earlywarning system is operational experimentally in selected routes of Himachal Pradesh, Uttarakhand, Meghalaya, Assam and Mizoram. Further development of rainfall intensity-duration relationship is required specific to different landslide prone areas of India.
D8.16	**Automatic identification of earthquake and landslide induced terrain changes from high resolution satellite data (NRSC)** Earthquake cause subsidence or upliftment of land in the seismic prone areas. Similarly, landslides, particularly the creeps (slow moving landslides) cause persistent damage to raod and buildings in hilly areas. Object-based change detection technique was used to identify new landslides using Resourcesat-2/2A LISS-IV Mx satellite data. CartoDEM (10 m) was additionally used to eliminate several false positives using slope criteria. Characterisation and identification of terrain changes due to earthquakes and creeps can be done effectively by differential SAR interferometric techniques. The outputs of the same in the terms of displacement maps and velocity fields with are used to model the prediction of debris flow path in the case of complete slope failure. Advanced processing methods like PsINSAR or STamPS will be attempted to overcome problem related to coherence loss or atmospheric interferences.
D8.17	**Correlation of landforms with mineral composition on planetary surfaces (NRSC)** It is widely recognised that understanding of Mars must begin by using the Earth as a reference. Therefore terrestrial analogues, places on Earth that approximate the geological and environmental conditions on Mars; hold the key for understanding the evolution of Martian geology. Off late, detection of water or aqueous environments in Mars is of primary interest for researchers across the world. Therefore, the study will primarily focus on detection of key minerals indicating hydrous past of Mars and establishing it suitable analogues on earth with respect to mineral composition and landform distribution. Further, certain minerals are associated with distinctive landforms, thus indicating the occurrence of that mineral. The study also aims at demarcating such landforms so that first pass mineral deposit identification can be done.

D8.18	**Vulnerability profiling of capital cities of NER (NESAC)** Urban areas are susceptible to disasters (man-made or natural). It is the need of the hour to make a rapid vulnerability assessment of urban areas in order to understand what is required for building disaster resilience community. The potential impact of different parameters on urban services arising from the geographical setting of a city; the nature, size and density of its settlements; and the existing coping capacity of its society and governance system can be studied to create vulnerable profile of urban areas.
D9	**Sub Area** — **Agriculture and Land-ecosystem studies (SAC/IIRS)**
D9.1	**Improved crop discrimination and statistics (SAC)** Development of advanced algorithms for discrimination of multiple crops in a given agricultural patch, minor and scattered field crops, horticultural crops, medicinal and aromatic plants using high resolution time series optical (multi-spectral, hyperspectral) and synthetic aperture radar (SAR) data.
D9.2	**Modelling abiotic and biotic stresses (SAC)** Modelling crop evapotranspiration, its partitioning, water use, light use efficiency, nutrient budgeting, disease, surface energy balance and crop thermal stress detection, using multi-spectral, thermal and hyperspectral data.
D9.3	**Crop Yield modeling (SAC)** Development of satellite data assimilation techniques to crop growth simulation and agro-hydrological models, modelling crop phenology, canopy radiative transfer modelling for retrieving crop biophysical parameters, above-ground crop biomass estimation.
D9.4	**Climate change and terrestrial ecosystem (SAC)** Development of climate change indicators for ecosystem health of mangroves/forest, coral reefs, wetlands, grasslands, climate change impact on hydrological cycle at multi-scales, urban heat island (UHI); Estimation of forest fuel and fire risk potential, automated forest type detection, modelling long-term change in forest phenology, carbon sequestration, nutrient budgeting, growing stock, risk quantification and vulnerability in agro-ecosystem.
D9.5	**Climate resilience and terrestrial environment (SAC)** Development of climate change indicators for ecosystem health of mangroves/forest, coral reefs, wetlands, grasslands, climate change impact on hydrological cycle at multi-scales, urban heat island (UHI); Estimation of forest fuel and fire risk potential, automated forest type detection, modelling long-term change in forest phenology, carbon sequestration, nutrient budgeting, growing stock, risk quantification and vulnerability in agro-ecosystem.
D9.6	**Retrieval of land surface parameters (SAC)** Land surface temperature and emissivity separation, thermal anisotropy,Black-sky and white-sky albedo, photosynthetically absorbed radiation (PAR) in clear and cloudy-sky conditions, retrieval of canopy biochemical parameters and water content, development of passive-active merged algorithm for high-repeat high-resolution soil moisture.

D9.7	**Carbon flux and primary productivity estimation over Agro-ecosystem (IIRS)** Croplands are man-made ecosystems that have high net primary productivity during the growing season of crops, thus impacting carbon and other exchanges with the atmosphere. These exchanges play a major role in nutrient cycling and climate change related issues. Agroecosystems are also considered as important sink of CO2 in recent years owing to increased crop yields, cropping intensity, irrigation and fertilizer inputs. Carbon flux monitoring usually done through remote sensing derived vegetation indices, LUE modeling, eddy flux tower measurements, ecosystem models, climate model, climatic parameters and field measurements. Quantitative extrapolations and scaling-up of flux-tower measurements are now urgently needed for carbon cycle research.
D9.8	**Satellite derived land surface parameters and agro-meteorological variables for agromet-advisory services (IIRS)** Space-borne earth observation from IRS-AWIFS, Terra/MODIS and INSAT-VHRR/ CCD instruments, can, however provide regular information on agrometeorological and hydrological conditions of the land surface for vast areas. Information on evapotranspiration, crop water demand, water use, soil moisture and plant biomass at different phonological stages of crop can nowadays be retrieved from satellite data. Satellite remote sensing models have been developed during the last 25 years to derive spatially discrete values of crop growth, crop yield and seasonal evapotranspiration or consumptive use. These models are most often based on biomass production proportional to absorbed Photosynstheically active radiation (Monteith, 1972) and Surface Energy Balance Algorithm (Bastiaanssen et al., 1998). Aiming at decision making support to the farming community, adoption of space technology aided farming may be the need of hour to increase water use efficiency and thereby increase in the income of farmers.
D9.9	**Remote Sensing for improved crop forecasting (IIRS)** Crop forecasting at various spatial scale, district, state and national level assume key importance in timely decision making and policy formulation. In this regard, accurate crop production forecasts are required for effective decision making on the issues related to export / import of food commodities, pricing, public distribution system and market intervention operations, etc Remote sensing is capable of monitoring information on photosynthesis, crop growth, development and biomass in more spatially explicit manner for agricultural crops. Similarly, agrometeorological observations play an important role in determining the crop growth and yield. It is therefore essential to use both remote sensing and agrometeorological variables with process based crop models that enables early assessment of crop biomass and subsequently economical yield.
D9.10	**Soil nutrient management for precision agriculture using hyper spectral data (IIRS)** Hyperspectral remote sensing data helps in assessing various soil properties especially nutrients, mainly due to the information contained in large number of contiguous bands with a narrow spectral bandwidth. Differences in nutrient concentrations cause spectral response variations, which can be captured and modelled using different multivariate statistical techniques. These techniques help us in spatial mapping of various nutrients and thus aid us in delineation of different management zones as part of precision agriculture.

D9.11	**Soil carbon modelling for monitoring and assessment (IIRS)** Soil organic carbon (SOC), is widely considered as a key indicator of soil quality as the presence of SOC has been found to be beneficial for nutrient retention/recycling, soil productivity, water holding capacity, carbon sequestration. Quantifying and estimating spatial distribution of SOC is vital for evaluating various soil functions and aids in understanding different soil carbon sequestration processes. Studying soil organic carbon on a regional or watershed scale invites special attention these days as it is considered a key parameter, playing central roles in various environmental issues such as climate regulation, food and water security.
D9.12	**Modeling soil erosion and surface runoff for nutrient loss at watershed scale (IIRS)** Soil erosion is the major threats to agricultural productivity and environmental quality especially water and soil quality in the Himalayan region. A comprehensive field-scale and watershed scale studies on soil erosion processes and nutrient loss and its impact on crop yield and soil quality of hilly farming system are limited. Understanding of process based models and simulation of this model for soil erosion, nutrient loss and crop productivity are required for better understanding of land degradation processes and its impact on the Himalayan mountain ecosystem.
D9.13	**Soil ecosystem processes and services at watershed scale (IIRS)** Soil ecosystem services are vital components to all aspects. Ecosystem service-support tools simulate biophysical processes (e.g. soil loss, hydrology, pollution etc.) to quantify relationships between management decisions, ecosystem processes and ecosystem services. Increasingly, researchers use decision-focused ecosystem service-support tools (e.g. InVEST, ARIES) to simplify data collection and analysis, and to simultaneously quantify trade-offs among ecosystem services.
D9.14	**Soil quality and productivity assessment (IIRS)** Soil quality concepts are mainly used for evaluation of sustainable land management in agro ecosystem. Soil quality is used as the sensitivity risk for environment, process of land use planning, which regard as erosion resistance along with water availability. Precise soil quality assessment is a critical task for designating policies for sustainable agriculture, restoring degraded soil, carbon modeling, and improvement of environmental quality.
D9.15	**Digital soil nutrients mapping (IIRS)** Knowledge regarding the soil nutrients/properties and their spatial distribution is extremely important for adequate soil management programs aimed at increased food production efficiency and environmental sustainability. The use of remote sensing and other geospatial techniques provides us with a wide range of environmental covariates corresponding to different soil forming factors at varying spatial as well as temporal resolutions. Various digital soil mapping techniques using these covariates help us in spatial prediction and mapping of soil nutrients/properties and thus generation of raster based soil maps and improving the quality of existing polygon based soil maps.

D9.16	**Agricultural applications using microwave remote sensing data: Crop biophysical parameters monitoring (IIRS)** In the monsoon season availability of the optical data is a critical issue and coincides with the fast growth so multitemporal dual-polarised/ fully polarimetric data of moderate swath and resolution seems viable. Use of various frequency SAR data for different crops has been utilised. Condition assessment in paddy, cotton and jute and some winter crops has been demonstrated. But the high biomass crops need to be addressed with higher wavelength facilitating better penetration. As the crop advances, the radar response increases due to volume scattering. These details in structural dimension will be captured by the various frequency SAR. X- and C band report saturation beyond 5 kg/m2 of fresh biomass and entails difficulty in discrimination and biophysical parameter retreival. Therefore, it is proposed for utilization of lower frequency satellite data (C/S/and L band) and evaluation of its response to crop biophysical parameter monitoring.	
D10	**Sub Area**	**Land Hydrology and Modelling (SAC)**
D10.1	**Development of satellite based hydrological models (SAC)** Hydrological modelling for surface and ground water using satellites based hydro-meteorological parameters is required for assessment of water balance at River basins and National scales. There is need to develop the semi-distributed and distributed hydrological models integrating remote sensing derived inputs such as DEM, rainfall, crop growth parameters (Leaf area index), land use land cover, wetlands, soil moisture, snow cover area, vegetation indices, river network, cross sections, river water level fluctuations etc. to address various water balance components such as interception, runoff, soil moisture, evaporation, transpiration groundwater recharge etc.	
D10.2	**Development of satellite based techniques for the retrievals of hydrological variables (SAC)** Development and refinement of algorithm to retrieve water level precisely from synergy of Altimetry data (SARAL-Altika), Scatterometer data (SCATSAT-1) and Passive Radiometer data over different river basins in India. Develop scheme to assess the water spread during flooded season using observed water levels in different flood prone locations in India. Other river characteristics includes river width, turbulent and calm flows, river cross sections etc.	
D10.3	**Flood simulations (SAC)** Setting up of various hydraulic models such as HEC-RAS, MIKE-11, MIKE FLOOD through integration of remotely sensed hydraulic information for flood inundation modelling and hazard assessment in the flood prone areas of India.	
D10.4	**Satellite based drought monitoring (SAC)** Hydraulic variables such as river/reservoir water levels fluctuations from satellite platforms are being used for the monitoring of hydrological drought conditions in various regions of India.	

D10.5	**Eco-hydrological studies (SAC)** Systematic observations and modelling of role of forest structure and functions in influencing the hydrological budget component over a large region using satellite and ground based measurements.	
D10.6	**Hydrological impacts of climate change (SAC)** Long term variability and trends of surface runoff, river water levels, occurrence of drought, groundwater fluctuations and surface water availability in river basins etc. is an area of important research towards understanding climate change.	
D10.7	**Water quality assessement using satellite data (SAC)** Water quality measurements are important for addressing the issues of rivers which are polluted with increasing population pressure and industrialization. There is need to develop retrieval algorithms to quantify various water quality parameters (suspended sediment concentration, turbidity etc.) usinghyperspectral data	
D11	**Sub Area**	**Calibration and Validation (SAC)**
D11.1	Optimisation of disdrometer/ raingauges distribution and number for addressing beam filling problem in validation of satellite derived rainfall estimates. Microwave leakage through perforated corner reflectors for C, L and S band SAR systems Generic software for estimation of calibration parameters using SAR images and orbital parameters over synchronized satellite pass with various Corner reflectors. Intercomparison of rainfall estimates measurements made by various ground based instruments like Microrain Radar, Disdrometer and raingauges over a validation site. Physical or empirical relationship of various meteorological parameters using long-term time series of measurements over a validation site	
D12	**Sub Area**	**Visualization of Earth Data & Archival System (VEDAS) (SAC)**
	To meet the user expectations of fast access to EO derived product for societal applications, there is a need to develop newer applications for better visualization and understanding of cause / effect of various co-varying features. For that to happen, advanced tools and technologies have to be used in conjunction with improved algorithms and efficient analytics. Research and analysis of the following thrust areas by independent and expert researchers and academia will strengthen the impact of the work. It is expected that with such a handshake between data generators and potential analysts, newer and innovative ways will emerge which will meaningfully bring about transformation in decision making for benefit of population of our country.(SAC)	
D12.1	**Algorithms / procedures for time series visualization (SAC)** VEDAS is responsible for archival and dissemination of thematic data and data products available within SAC. Large amount of spatial time series data is collected over time and visualization of available spatio-temporal data is essential for exploring and understanding	

	structures and patterns, and to identify unusual observations or hidden patterns. However, the volume of data available and number of concurrent users that may be accessing the data challenges current time series map visualisation. The start and end time of episodic events or span of intensive observations may also dynamic. So algorithms are required to be developed and modern techniques are required to be used for visualization of large spatio-temporal (ST) datasets ordered in time for animated mapping. This will be further used for exploring or monitoring unusual observations in large datasets like NDVI, snow, temperature, solar insolation etc.
D12.2	**Data analytics and knowledge discovery (SAC)** To understand and appreciate a natural phenomenon and attach cause and effects to an evolution, there is a growing demand of rendering "on the fly" multi-layer information. There may be concurrent users accessing same set of data. So there is motivation to parallelize computation to improve turn around time of a service. The following research initiatives will be useful steps towards achieving this goal. Design & Development of parallelizable algorithms for interactive geospatial data analysis with high temporal resolution. Design & Development of parallel execution frameworks and/or distributed computing libraries for geospatial data processing operations. Design and Development of scalable general purpose systems/algorithms for removing noise from spatio-temporal datasets. Design and Development of scalable general purpose systems/algorithms for predictive analytics from spatio-temporal datasets. Design and Development of data-mining algorithms for spatial-temporal datasets. Design and Development of scalable techniques for semantic segmentation of orthoimagery.
D12.3	**Super resolution image generation (SAC)** Super Resolution is an Image Processing technique which is used to enhance the image resolution of scene from a number of lower resolution images of same area by reducing effects of noise in the reconstructed image. In case of satellite images, this can be seen as a powerful tool of getting high resolution multi-spectral images (spatial) from low resolution panchromatic images. This will facilitate improved (in spatial scale) Land cover for better natural resource management.
D12.4	**Web enabled sensor system for efficient resource management (SAC)** There is need to develop a prototype and demonstrate the applicability of wealth of information that can be gathered by set of remotely located instruments. Instruments can measure the meteorological conditions as well as ambient conditions and transmit the data to a central hub. Air quality monitoring of a region is a one such example where measurements of PM2.5 and PM10, concentrations of target gases (NOx and SOx – for example), their dispersal (based on wind direction and speed), temperature and humidity are all required by administrators and managers to issue advisory and / or take pro-active preventive measures.

D13	Sub Area	Earth Ecosystems (SAC)
	Following section gives broad spectrum of topics for consideration of research. The problems need to be addressed using predominantly Indian sensor data and products such as RISAT (RADAR Imaging Satellite), AWiFS (Advanced Wide Field Sensors), LISS (Linear Imaging and Self Scanning), Hyper Spectral and INSAT and Other Indian sensor data available. If such Indian sensors are not available other data sets will be used. The technique development and modeling are expected from the candidates.	
D13.1	**The study on applications for forest and agriculture status changes (SAC)** The study on Applications for Forest and Agriculture status changes using remote sensing sensors. The change detection will be carried out using advanced change detection techniques using Multispectral data. The forest and agriculture state change study using red edge shift can also be attempted.	
D13.2	**Calibration and validation of satellites (SAC)** The post-launch vicarious calibration using high reflectance target sites as a reference and accurate measurements of spectral reflectance and atmospheric advancements and popularity of remote sensing and an ever increasing need for the development of a variety of new and complex satellite sensors, it has become even more essential to continually upgrade the ability to provide absolute calibration of sensors. All Indian sensors targeted for vicarious calibration of reflective channels. Satellite derived geo-physical products plays an important role in making effective use of satellite data. We propose to validate the satellite derived geophysical products, namely Relative Humidity, Temperature, Rain, insolation etc.	
D13.3	**Horticulture inventory, site suitability, post-harvest infrastructure (SAC)** Horticulture Inventory and Assessment (technique development for crops like mango, banana, citrus, potato, onion, tomato, chilli in selected districts). To Design, create and organize an integrated inventory database (spatial as well as non-spatial) at 1:50000 scale for horticulture crops. Horticulture Crop Site Suitability using Geo-spatial database, Criteria based GIS analysis for site selection / site suitability and Identification of suitable sites. Post-Harvest Infrastructure (to assess the need and find the optimum locations for infrastructures such as cold chains, markets etc.) The site Suitability/selection comprised two phases viz. I). Search for a suitable area based on physical characteristics and terrain. The physical suitability search phase refers to finding areas that match the physical, environmental or geographic conditions. II) A conditional search, the conditional search phase identifies a set of preferred conditions that are applied to the composite geospatial database will be used for horticulture development are applied to the composite geospatial database.	
D13.4	**Orchard rejuvenation (SAC)** The Orchard rejuvenation can be attempted using Geospatial database derived layers from Horticulture studies. The suitable sites identified for orchard rejuvenation based on RS & field data. The crops and area like Apples in Himachal Pradesh, Mango in Gujarat, Orange in Darjeeling etc.	

D14	Sub Area	Urban Studies (SAC)
D14.1	**Urban feature extraction: Road network delineation (SAC)** Transportation networks such as roads and railway lines are important for several urban applications including disaster management, urban planning, impervious surface extraction, urban growth modelling etc. The automatic methods such as template matching, object-based classifiers and machine learning methods such as neural networks, support vector machines, deep learning etc. can be used to efficiently extract road network from very high-resolution optical and SAR images acquired by Indian Remote Sensing satellites.	
D14.2	**Urban feature extraction: Impervious surface / urban area mapping (SAC)** The mapping of urban land cover remains a challenging task owing to the high spectral and spatial heterogeneity of urban environment. The accuracy of urban area extraction can be improved by combining multi-temporal, multi-resolution and multi-sensor optical and SAR earth observation data.	
D14.3	**Urban feature extraction: 3D building reconstruction (SAC)** The 2D and 3D information of buildings and other urban structures are needed not only for impressive visualisation of urban areas, but also as an input in several urban applications like population estimation, roof-top solar energy potential assessment, visibility studies etc. Building extraction from high-resolution satellite images in urban areas is an intricate problem. Techniques are to be developed for automatic extraction of buildings from Very High Resolution optical data. The availability of very high-resolution imagery from Cartosat series data necessitates development of techniques and algorithms for 3D building reconstruction.	
D14.4	**Urban heat island: Spatial and temporal distribution of urban heat islands on land surface and near surface atmosphere (SAC)** Development of models for deriving day-time and night-time air temperature from satellite-derived land surface temperature and vegetation indices can assist in identification and analysis of spatial and temporal distribution of urban heat islands.	
D14.5	**Urban heat island: Impact of land cover types on urban heat islands (SAC)** The changes in land use - land cover pattern and declining vegetation cover in cities are predominant factors influencing the growth of urban heat islands in the cities. Satellite data derived land use land cover information can be compared with the temperature profiles to assess the impact of land cover on urban heat islands.	
D15	**Sub Area**	**Geospatial Data and Information Science (SAC)**
D15.1	**Advanced data and computing architecture (SAC)** Optimized Data Cubes for multi-dimensional aggregation of satellite images and their spatio-temporal analysis. Techniques for forecasting and in-painting in Data Cubes High Performance Computing of satellite images on Cloud.	

D15.2	**Data visualisation and web processing (SAC)** Advanced data rendering and fast visualization techniques of 2D and 3D satellite data. Fast Tiling and caching techniques for visualization of satellite Images Development of techniques for automatic on-demand web mashup generation. Cloud and Semantic enabling of Web Processing Services.
D15.3	**Data security and information dissemination (SAC)** Data encryption and compression techniques for multicasting of satellite data Customization and optimization of multi-cast protocol using critical distance of client nodes to cater to requirements of real-time data dissemination. Content based data multicasting Information and Data security models for small devices Location aware satellite data dissemination for mobile devices.
D15.4	**Data mining and web analytics (SAC)** Real time analytics for Big Earth Data Pattern recognition based techniques for Event detection Geospatial feature extraction using deep learning techniques Automated event tracking (Cyclone, dust storm, etc.) using machine learning techniques Region growing algorithms for identification and tracking of meteorological and oceanographic events (Fog, bloom, convective initiation, etc.
D15.5	**Data and information lifecycle management (SAC)** Automated algorithms for value evaluation of data and information Techniques for automatic Quality checking of data Techniques for Persistent identifier management Techniques for generation of Linked data Faceted search and Browsing of satellite images semantic annotation and labelling of satellite images.
D15.6	**IoT and sensor network (SAC)** IoT enabled sensor network for acquisition of weather data Smart weather data acquisition systems RTOS based Data acquisition system Virtual Sensors for Weather data acquisition Optimal data capture and processing in Sensor Network.
D15.7	**Virtualization and cloud computing (SAC/NRSC)** 1. High Performance Cloud for Satellite Image Processing Network Virtualization and Software Defined Network Software Defined Storage.

	2. Integrated Multi Mission Ground-segment for earth observation satellites (IMGEOS) integrates data acquisition, processing and dissemination systems (of Satellite Data Reception and Ingest Systems Area as well as Data Processing, Products, Archival and Web Applications Area) and is configured with scalable 3-tier storage system to meet current and near future Earth Observation missions. The main objective of the IMGEOS is to minimize human interaction by automating the activities. The services hosted at IMGEOS are traditionally carried out on dedicated servers. The requirements in this domain are dynamically varying with respect to the IT infrastructure resources. The dynamic provisioning of the IT infrastructure is possible by virtualizing and orchestrating the IT infrastructure resources. This method of dynamic provisioning is cloud computing. Under the Cloud platform, it is envisaged to provide the following services. a) Platform as a service (Virtualized Linux, Windows Servers) b) Data as a service (User Data Products) c) Software as a Service d) Bandwidth as a Service The following are some of the requirements for implementation of IMGEOS private and public Cloud Solutions : a. Data Product generation b. Data Products Regeneration c. Workflow Management d. ISRO Centers Users e. Global user services f. FTP Services g. Web Services h. Data products for free download i. Disaster Management Support Requirements Demonstrated proof of concept for Open Data Access services and FTP services delivery from IMGEOS. Installed and configured 50 TB storage system in internet domain to be used Open Data Access services viz. Bhoonidhi in internet domain using 4 server. The FTP service for delivery of user products is reconfigured using new server and required storage with upgraded Operating System. Implementation of NRSC Public Cloud was completed and implementation of NRSC IMGEOS Private Cloud is in progress.	
D16	**Sub Area**	**Technique Development for the Assimilation of High Spatial Resolution Indian Satellite Data in to NWP Models (SAC)**
D16.1	**Development of observation system simulation experiments (SAC)** In the present data assimilation methods used in various operational meteorological agencies data-thinning techniques are applied to reduce correlations amongst them. This reduces the amount of data ingested in NWP models thus reducing the advantage of high resolution data. To use (satellite) observations to their full extent we have to take	

	these correlations into account. Since these correlations are specific for each data type application - area tailored solutions should be developed using and extending already existing techniques. Exploration of various non-linear data assimilation methods to infer the impact of high spatial resolution observations on the evolution of the nonlinear system under study. While we do have efficient methods to do this for linear systems and linear data-assimilation methods based on regression analysis, methods are lacking for nonlinear systems and nonlinear data-assimilation methods. Hence development of non-linear data assimilation techniques is one of the thrust areas of research. It has already been shown by various researchers, by making use of the impact measures from information theory, like relative entropy and mutual information that the linear measures could be significantly in error, even pointing to impact of the wrong sign. While successful, these measures are computationally expensive and we need more efficient methods to be able to infer observation impact in real Earth system models. An important part of this thrust area is the development of Observation System Simulation Experiments (OSSE's) that will allow us to infer the usefulness of future satellite observations.	
D17	**Sub Area**	**Development of New Forecasting Techniques for Thunderstorm Prediction over the Indian Region Using Satellite Data with a special reference to SHAR region (SAC)**
D17.1	Thunderstorms can generate severe weather situations like intense rain, strong winds, hails and floods which can cause serious threat to life and property. They can also cause hazardous situations to aviation and satellite launch vehicles. During satellite launch activities they can affect and cause damage to fuel, ignition, avionics and other control systems of the launch vehicle. Therefore, thunderstorm forecasting is a very important and desired activity during satellite launch campaigns and in general for the benefit of the society which can help in the decision making process and disaster mitigation. Deep convection by interacting with large scale circulation may play a critically important role in transport of water vapour and other chemical substances across tropopause which has implications for global climate change and health related matters, i.e., increasing trend in stratospheric water vapour (Oltmans& Hofmann 2002) can increase global greenhouse forcing and decreasing trend in stratospheric ozone (Zhou & Zhang 2005) can result in an increasing trend in skin related diseases. A statistical forecasting method using radiosonde data has been developed previously and forecast of deep convection over SHAR region has been provided during satellite launch campaigns (Danish and Kishtawal., 2012). Besides this, WRF model is routinely integrated at SAC and forecasts are provided to SHAR to support launch operations. ISRO's satellite data are routinely assimilated in to the data assimilation system.	
D17.2	**Development of new thunder forecasting techniques (SAC)** To further improve the skills of thunderstorm forecasting, new techniques will be developed. One of the potential approach is decision tree based forecasting using ISRO's satellite data and NWP model forecast.	

	Environmental, thermodynamic and stability parameters will be considered while developing the decision tree approach. Stability indices like Lifted Index, CAPE, CINE, K-Index, Total-Total Index, etc. derived from temperature and humidity profiles of Indian satellites may be used in this approach. Environmental parameters like vertical wind shear, vertical velocity, mid-tropospheric stability etc. can be derived using NWP models. After proper validation of the decision tree method, forecast maps of thunderstorm activity shall be generated. Besides decision tree based approach, other new techniques will also be tried for thunderstorm forecasting.	
D18	**Sub Area**	**Better Understanding of the Monsoon and its Variability using High Resolution Indian Satellite Data (SAC)**
D18.1	India receives about 80% of the annual rain during the summer monsoon season alone. Indian summer monsoon is a large scale process, with monsoon semi-permanent systems prominently seen from southern hemisphere to northern hemisphere. Satellites provide a helping hand in understanding the monsoon process over the data sparse oceanic regions of the southern hemisphere and Equatorial Indian ocean region. Intra-seasonal time scale variability in the summer monsoon activity causes active and break monsoon conditions which have profound impact on agricultural and other related sectors the Indian economy. Similarly, year-to-year variability of the Indian monsoon causes drought and excess monsoon conditions. Global scale atmospheric and oceanic tele-connections are one of the major causes the year-to-year monsoon variability. Mechanisms of intra-seasonal and inter-annual variabilities is not fully understood. ISRO has launched many dedicated meteorological and oceanography satellites (INSAT series, Kalpana-1, Ocaeansat-1 &2, Megha-Tropiques, Saral-Altika, ScatSat-1, etc.) aimed at better understanding of the meteorological processes of the Indian region and its neighbourhood. These data are extensively used to understand the meteorological and oceanographical processes that govern the Indian summer monsoon and its variability. These satellite data are routinely assimilated operationally in India and abroad for predicting monsoon and its variability. Routine short-range, medium range and extended range weather forecasts are provided during monsoon season by SAC using numerical weather prediction models.	
D18.2	**Improved understanding of the monsoon processes (SAC)** Better understanding of the monsoon processes that are not resolved by NWP models and reanalysis data using high-resolution satellite data. Better understanding of the Indian summer monsoon clouds (low and upper levels) and their radiative forcing. Understand the role of stratiform clouds/rains in summer monsoon performance and its variability.	

D19	Sub Area	Soil Resource Characterization, Land Use Planning and Watershed Management (NESAC)
D19.1	**Understanding shifting cultivation as a driver of LULC change (NESAC)** Shifting cultivation of northeast India is assumed to be major factor of LULC changes. However, a comprehensive study including the spatial changes, climatic and socio-economic aspects will give more inside to the actual process and its mitigations.	
D20	Sub Area	Forest and Environment (SAC/NRSC/ IIRS/ NESAC)
D20.1	**Forestry and ecology- biophysical parameters (NRSC/NESAC)** Sub pixel tree cover estimates using multi sensor IRS imagery . Observations on ecophysiological factors for tropical forests and parameterization of biome models for Indian forests. Feature recognition of tree and canopy objects in IRS pan and multi spectral imagery. Automated methods for estimation of tree allometry fine scale biomass and stand structure using laser measurements (SAC)	
D20.2	**Mapping at 1:10K or higher and identification of Eco-sensitive zones areas for conservation and management (NESAC)** As per MoEF&CC, the study is important for all National Park & Wildlife sanctuaries to conserve, protect and maintain its surrounding areas with some definite objectives.	
D20.3	**Wildlife habitat evaluation for different endangered and endemic species (NESAC)** Endangered species habitat modelling like Golden Languor, Hoolock gibbon, Feral Horses etc needs to be studied for insitu conservation and preservation	
D20.4	**Mapping of forest composition and structure at large scale using UAV (NESAC)** High resolution images from UAV expected to give more inside on the forest composition and structure. Research required on optimum identification of understory and ground flora in a mixed forest type.	
D20.5	**In-situ conservation of timber species for climate resilience and sustainable management using space based & UAV remote sensing (NESAC)** Understanding the forest fragmentation, patchiness, segmentation process of Indian forest and site suitability study for conservation of local species for climate resilience.	
D20.6	**Forest phenology and transition of forest type vis-à-vis climate change in NER (NESAC)** To understand the process of forest transition and phenology due to long term and short term weather parameters.	
D20.7	**Large scale bamboo resource monitoring and assessment (NESAC)** North East of India contains 60% of India's total bamboo but very less exercise has been done to make reasonably accurate estimation of total bamboo growing in the region.	

D20.8	**Protected areas Management and conservation strategies (NESAC)** A holistic approach is utmost required make assessment of current status of the protected areas, their inter-connectivity and specific habitat requirement for the important local wildlife species.
D20.9	**Annual forest biomass stock and carbon sequestration (NESAC)** The study is expected to come out a total estimate of biomass and carbon stock in NER and a model for annual/biannual change detection.
D 20.10	**Remote Sensing-based estimation of carbon stock of bamboo resources of Northeast India using machine learning algorithms (IIRS)** Bamboo is an important non-timber forest product (NTFP) of subsistence and meets several commercial, social, environmental and economical perspectives. In spite of bamboo's importance, the statistics on its spatiotemporal distribution and carbon stock is rather scarce and inconsistent. Bamboo forests play an important role in the global carbon sink due to their colossal carbon stock. Using the field inventory based methods, it is difficult to map the spatial distribution of carbon stocks of bamboo resources over a large area. Remote sensing, which enables spatial and temporal assessment of land and vegetation, can effectively address this issue. By integrating satellite and field inventory data, the carbon stock of the bamboo forests can be effectively estimated. The spectral and texture variables, derived from satellite data can be related to the field measured carbon using machine learning algorithms for carbon stock estimation.
D 20.11	**Forest 3D modelling using terrestrial laser scanning for generating tree volume equations (IIRS)** Assessment of three-dimensional (3D) forest structure is very crucial as it impacts the microclimate and regulates several physical and biological processes. LiDAR (light detection and ranging), operating from spaceborne, airborne or terrestrial platforms, can be used to model forest structure. Terrestrial laser scanning (TLS), also known as terrestrial LiDAR, has limited spatial coverage compared to spaceborne and airborne LiDAR, but has the potential to reduce uncertainty of field-based measurements. It is a non-destructive ground-based method that can retrieve the 3D vegetation structure at plot level with high accuracy. The 3D point clouds generated from TLS have the potential to give direct estimates of tree volume, consequently aboveground biomass and forest carbon stock. The generation of volume equations of trees may prove to be indispensable of those tree species whose volume equations are not available.
D 20.12	**Biomass assessment of trees outside forests using very high resolution satellite data (IIRS)** Trees Outside Forests (TOFs) are an important resource that contributes substantially to the biomass and carbon stocks and the livelihood of people. TOF is a dynamic resource and its assessment over large areas, in a relatively shorter period, necessitates use of Remote Sensing (RS) and Geographic Information System (GIS). The needs for reporting carbon stocks and stock changes under the Kyoto Protocol have placed additional demands for accurate surveying methods that are verifiable, specific in time and space,

	and that cover large areas at acceptable cost. In this regard, RS especially very high spatial resolution satellite imagery has opened effective way to estimate TOF biomass and carbon content. Carbon can be mapped at individual tree level using these images. Object-based image classification can be adopted to delineate the canopy projection area (CPA) of trees. By establishing a relationship between CPA and diameter at breast height of trees, the carbon content of the tree can be estimated using species-specific volumetric equations.
D 20.13	**Assessment, monitoring and management of wetlands ecosystems (IIRS)** Wetlands are the most productive ecosystems of the world. Wetlands provide numerous products and services to humanity. The inland wetlands are replenished through different sources of water and nutrients such as rivers, streams, surface flow and flooding, mainly during the monsoon. The monitoring of hydrodynamics of inlands wetlands during monsoon season using optical remote sensing however gets hampered due to cloud cover. Further, wetland ecosystems require precise information on land and water boundary distinction, coverage of floating biomass, nature of substrate beneath the aquatic vegetation, quantities of phytomass along with their temporal dynamics. Microwave remote sensing owing to its all-weather capability and ability to sense moisture and wetness variation, vegetation structural components and penetrate in the vegetation volume, is considered very effective for wetland assessment and monitoring. Furthermore, recent advances in SAR polarimetry offers added sensitivity to wetlands targets and thereby scope for better characterization of inland wetlands and surroundings.
D 20.14	**Forest meteorology and ecosystem modeling (SAC/NESAC)** Forest plays an important role in governing the energy and mass exchange over a region. Quantification of energy fluxes helps in modeling regional climate. SAC is involved in development of 24 Micrometeorological station network in India which are taking continuous measurements in agriculture and natural vegetation system. There is need to develop land surface process models to quantify the fluxes with reference to surface and atmospheric forcing. Most of the biogeochemical modeling depends on phenological understanding of different vegetation types. There is need to carry out ground experimentation as well as satellite modeling to estimate the phenological matrices of different vegetation types. Such efforts would lead to develop the forest growth simulation models. Modeling NPP using satellite measurements such as INSAT-CCD is an important future thrust area. There is need to develop process based model to quantify the net primary productivity and ecosystem level productivity. Network of annual biomass measurements are needed to validate the NPP products. It is known that biomass modeling is limited with optical measurements due to saturation of optical light in denser canopy. Radar based approaches provide improved assessment. It is proposed to develop LIDAR based modeling to account the height of the forest in the estimation of forest biomass. Detection of forest fire and development of fire alarm system based on bioclimatic indices is an important research area which will be carried out using INSAT-3D satellite data.

D 20.15	**Wetland Ecosystem (SAC/NESAC)** Wetlands mapping has been carried out by SAC at 1:50,000 scale for India. There need to develop scheme to map the wetlands using improved and integrated approach involving microwave and optical data. Wetland eutrophication needs to be studied using temporal high resolution optical sensors. Efforts on modeling Methane Emission from Wetlands is an important future thrust area.	
D 20.16	**Developing a Plant functional types based approach for use in biodiversity monitoring using earth observation data (NRSC)** Biodiversity is commonly measured by 'species richness', which is the number of species in a site or habitat, other measures include the structural and functional attributes. Measuring or characterizing biodiversity is needed for understanding and monitoring the temporal and spatial patterns and changes. A definitive understanding is required for state-of-the-art key 'biodiversity metrics' from space based observation for developing biodiversity monitoring strategies. Since species are not always readily identifiable in remotely sensed data, it useful to have a level of abstraction, plant functional types (PFTs) that can be used with RS data sets. It is necessary to identify parameters and develop a PFT characterization for India's forest vegetation. Satellite derived descriptions on the spatial distribution of plant functional types along with spatial descriptions of vegetation structure and function are likely to be a set of variables that are useful to understand the compositional, structural and functional aspects of biodiversity and its monitoring.	
D 20.17	**3D point cloud processing and analysis for towards forestry applications (NRSC)** Background: Point clouds from photogrammetric methods, or active and Terrestrial LiDAR system (TLS) provides a fast and precise description of the area in three dimensions. In forestry, point cloud analysis from these sources can be used to for several applications: TLS derived point clouds could be used to detect and delineate trees, or to extract inventory parameters (such DBH, tree heights and crown shape parameters) at individual tree level; the recognition of individual trees from a combination of nadir looking and oblique point clouds is an interesting possibility; biophysical parameters such as Leaf Area Index, non-destructive tree volume estimates can also be realized. The processing methods of point clouds are still in developmental phase and are challenging research topics. Development of algorithms and open source tools for point cloud analysis for forestry applications is a priority area.	
D21	**Sub Area**	**Water Resources (IIRS/NESAC)**
D21.1	**Future climate data downscaling and hydrological modelling (IIRS)** Assessment of response from land system, especially hydrological, is essential for planning and management of resources. However, major limiting factor in utilizing future climatic forecast in land surface or hydrological models is the spatial scale mismatch.	

	The present project aims at utilizing different (statistical and/or dynamic) downscaling techniques for improving spatial resolution of climatic inputs and use them in distributed hydrological models for assessment of impact of climate change on water resources. Special focus will be given to Himalayan region.
D21.2	**Space based precipitation estimation (IIRS)** Precipitation is the most important element of the local and regional hydrologic cycle. Accurate estimation of precipitation helps in managing the supply and demand of sustainable water resources. Precipitation is also a critical input variable for hydrologic modeling and climate studies which are common tools to assess water-related risks, such as floods/droughts and monitor water resources. Therefore, availability and accurate estimation of precipitation is crucial for demand management, flood forecasting and drought preparedness. A number of different algorithms can be used to estimate precipitation amounts from remote sensing data. Research in the fields of quantitative precipitation forecasting is still in progress (for better understanding of the spatial and temporal distribution of precipitation which is critical to climatic, hydrologic, and ecological applications).
D21.3	**Estimation of river discharge using remote sensing and GIS (IIRS)** Observed discharge in the streams is an essential inputs for all the hydrological studies and water management activities. However, due to limitations (financial, technical, etc.) number of ground observation points are limited in Indian river basins. Advancements in remote sensing and data analysis techniques have enabled the estimation of water level and river discharge using satellite observations. This project aims at utilizing satellite based multi-sensor observations (Altimeter, Microwave, etc.) for water level and discharge estimation. The focus will be on development and testing of methodology/ algorithms for estimation of water level and discharge using multi-sensor approach.
D21.4	**Reservoir sedimentation assessment using remote sensing and GIS (IIRS)** Reservoirs are generally constructed with multiple objectives e.g. water supply, irrigation, discharge regulation, power generation and flood control. However, every year reservoirs lose considerable amount of its storage capacity due to sedimentation. Assessment of this loss of capacity must be quantified at regular interval to update the water distribution/ utilization plans and flood management/response guidelines. This study aims at assessment of reservoir sedimentation using remote sensing data, further the area-elevation-capacity curves will be updated and optimal water utilization planes will be suggested for each reservoir operations. The focus will be on minimizing the dependence on ground observations by utilizing multi-sensor approach (optical, SAR, Altimeter, etc.)
D21.5	**Development of hillslope hydrological model for Northwestern Himalaya Ecosystem (IIRS)** It is a well-known fact that hydrological response of hilly watershed is completely different than agricultural watersheds. Most of the popular models used in the field of water resources are originally meant for agricultural watersheds & temperate region, their accuracy degrades drastically in the hilly regions due to non-availability of techniques

	to simulate the dominant hydrological process occurring in the hilly watershed. The present study aims at development of dedicated hillslope hydrological model that can accommodate the hillslope processes viz. subsurface storm flow, saturation excess flow, overland flow, return flow and pipe storage. Special emphasis will be given on development and testing the model for Northwestern Himalayan region and development of experimental plots, watershed for observations.
D21.6	**Hydrological parameters retrieval using remote sensing (IIRS)** Each of the hydrological parameter plays an important role in our planet's water and energy balance system. Traditional techniques of measuring these parameters lacks in spatial and/or temporal coverage. Remote sensing has proven its capability in retrieval of many terrestrial and atmospheric parameters with high spatial and temporal resolution. Hence, this project aims towards development of algorithms and techniques for operational retrieval of hydrological parameter (viz. Evapotranspiration, Soil Moisture, Surface Runoff, change in Terrestrial Water Storage, snow depth, snow density, snow water equivalent, etc.) using remote sensing data. The calibration of these algorithms will be done using ground observed data and validated methodology will be made operational for continuous retrieval of these parameters. The focus will be towards utilizing Indian remote sensing data.
D21.7	**Improving mapping and monitoring of surface water body, snow, glaciers, sea ice and ice sheets using RS-GIS (IIRS)** The inland surface water consist of lakes/reservoirs, rivers and wetlands, and frozen part of water consists of seasonal snow cover, river ice and sea-ice, glaciers, polar ice sheets. The inland water is crucial for sustenance of mankind and overall health of environment, whereas inland snow and glaciers provides significant melt water during lean period for catchments, and polar sea-ice and ice sheet provides an important feedback to Planet Earth's climate and energy cycles. The regular mapping, monitoring and quantification of these water features can be at different spatio-temporal scales using remote sensing. This project will address the dynamics of water bodies (in terms of quantity and extent), snow (snow cover and water equivalent), glaciers (extent and velocity) sea-ice (extent and thickness) and ice sheets (extent and velocity) using existing and new Earth Observations (EO) sensors and retrieval algorithms.
D21.8	**Ensemble based hydrologic prediction and data assimilation of remote sensing based hydrological parameters in hydrological models (IIRS)** The large variability in physical and climate characteristics of Indian river basins cannot be tackled by use of single RS data or single hydrological model with fixed mathematical representation of these hydrological processes (e.g., the prime hydrological processes governing river flow in Himalayan watershed with snow and glacier will be different than those found in arid watershed of Western India or rainforest dominated watersheds of Western Ghats). Similarly, the large amount of RS data and hydro data products (soil moisture, snow cover, water level etc.) which are generated at daily to monthly time scales, are not used in the hydrological models, which mostly uses only RS abased land use land cover (LULC), soil and elevation. Therefore, this project aims to develop

	ensemble of hydrological models, which can be used in integrated manner to address the major variations in hydrological variables at the watershed/basin scale, as well as develop suitable data assimilation techniques which will utilize in near real time, the RS based land surface and hydrological data products.
D21.9	**Watershed characterization and planning using RS-GIS (IIRS)** Watershed characteristics govern the hydrological response of the watershed. In the absence of detailed observed hydrological data characteristics help hydrologist in modeling watershed processes to estimate runoff, soil loss, etc. Traditionally topographical maps provided by Survey of India were used for delineation of watersheds and mapping of its resources, however the watershed resources change with time (e.g. land used land cover) their-by changing hydrological response of the watershed and the scale of top-maps govern the accuracy of watershed delineation & characterization. This projects aims at utilizing remote sensing data and products (multi-spectral images, high resolution images, DEM's) for characterization of watersheds and its inventory mapping. The project also aims at assessment of DEM accuracy using field based DGPS survey, assessment of DEM scale impact on characterization of watersheds, development of guidelines for deciding stream generation threshold for different terrains and prioritization of ungauged watersheds based on RS&GIS derived characteristics.
D 21.10	**Microwave remote sensing for water resources studies (IIRS)** (SAR, altimeters, radiometer and scatterometer for snow/glacier physical properties, ice sheet & sea ice dynamics, soil moisture, water level and river flow estimation). The microwave remote sensing (MW-RS) which operates in microwave region of electromagnetic spectrum from 1cm to 1m wavelengths, offers an unique opportunity to quantify various bio-geo physical parameters of Earth surface/sub-surface with variety of MW sensors such as synthetic aperture radar's, SAR, altimeters, radiometers and scatterometer's working in various MW frequencies and polarizations. This project aims to improve existing methods and develop new operational algorithms to retrieve hydrology and water related parameters using MW-RS such as top surface soil moisture, snow physical parameters (snow wetness, depth, density and SWE), glacier/ice sheet velocity and elevation, water level and discharge and sea ice thickness. The derived hydro-parameters will serve as important input for hydrological modelers and water resources managers.
D 21.11	**Hyperspectral remote sensing application in water resources (IIRS)** Application of image spectroscopy in mapping and retrieval of water resources parameters e.g. snow grain size, type of snow (wet, dry), type of debris on the glacier, glacier facies, water quality, soil moisture and water stress are evolving research areas. ISRO has planned to launch space based Hyperspectral sensors of varying spatial and spectral resolution. This project aims at developing techniques for mapping and retrieval of water resources parameters using space based and aerial Hyperspectral data. Special emphasis will be given on generation of spectral library of various water resources parameters using field and laboratory observations.

D 21.12	**Hydrological and hydraulic modeling and RS data based hydrological parameters assimilation (IIRS)** The large spatial (cm to km) and temporal (few minutes to days) variation in watershed/ basin scale hydrological parameters and river scale hydraulic parameters cannot be addressed fully by RS based data and data products. Therefore, many academic users and water professional uses hydrological and hydraulic models to simulate watershed/ basin scale hydrological and hydraulic process, and derives, multi-layer soil moisture, snowpack properties, river discharge and flood inundation as output from these models. This project indents to improve parameterization of these hydro models by using latest RS based hydro data in GIS environment, and also develop data assimilation tools which will utilize RS hydro data products in near real time, so as to improve overall simulation accuracy of hydrological/hydraulic models.
D 21.13	**Soil erosion and sediment yield modeling using geospatial tools (IIRS)** Accelerated rate of soil erosion is one side creating problem of loss of nutrient rich, productive top soil from the watershed and on the other the water bodies and reservoirs are losing their capacity and operation life due to sediment yield from the watershed. The present study aims at developing tools and their implementation for distributed soil erosion and sediment yield modeling at varying using geospatial inputs (remote sensing and GIS). The spatially distributed soil erosion and sediment yield maps will be used watershed prioritization and selection of suitable conservation measures. The associated nutrient lose from the watershed will also be modeled. Spatial emphasis will be given towards developing models and techniques for ungauged catchments.
D 21.14	**Irrigation water management using geospatial tools (IIRS)** Irrigated agricultural gets the major share of fresh water (around 82%) annually. However, its overall operational efficiency is as low as 35%. The future sustainability of water sector hinges on increase of water use efficiency by irrigation sector up to 50-65% by 2050. Remote sensing hold tremendous in assisting irrigation section to bring this improvement. Present project aims at utilizing remote sensing data irrigation water management, which include infrastructure mapping and monitoring, IP assessment, spatial estimation of crop water requirement, performance evaluation of irrigation projects, water distribution assessment, conjunctive and deficit water use modeling, etc. Special emphasis will be given on developing standard method which can be replicated at other irrigation projects.
D 21.15	**Site suitability analysis and Environmental Impact Assessment (EIA) for Water resources projects (IIRS)** Selection of best suitable sites for any water resources (WR) project (ranging from water harvesting structures in small watersheds to larger dams for irrigation & hydro-power) is a complex process. Many ecosystem variables play vital role in successful implementation of water resources projects. Hence, consideration of these ecosystem variables during selection of suitable sites for water resources projects (soil & water harvesting structures, river valley, flood control, irrigation, river interlinking and hydro-power projects) are essential. The present project aims at integrating RS & GIS based inputs for pre-feasibility analysis and selecting suitable sites for WR projects. The detailed EIA analysis of these projects will be carried out using geospatial and modeling based inputs.

D 21.16	**Urban water distribution modelling (IIRS)** In India, many cities do not get assured 24 hour piped water supply, mainly due supply, demand, leakage, poor infrastructure and variable water use. The very high resolution RS data combined with GIS and hydraulic models offers a unique solution to address some of these problems. The advanced water network modelling combined with Supervisory Control and Data Acquisition (SCADA) enables a real-time operational management system in urban areas. The benefit of this system enables proactive online operation, pressure management, reducing leakage, access to critical information and key performance indicators (KPIs) and contingency management, i.e. incident and risk reduction.
D 21.17	**Ground water modelling and assessment (IIRS)** Ground water is the primary source of fresh water. Traditionally numerical method based ground water models have been used to solve ground water assessment and development issues. These models use three dimensional ground water flow equations to simulate ground water flow under different hydrological stress scenarios and can be valuable predictive tools for management of ground water resources. Major applications of ground water modelling includes surface water-ground water interaction, sub-surface waterlogging assessment, seawater intrusion in coastal aquifers, prediction of ground water dynamics and impacts of sand mining on ground water. Integration of geospatial tools and ground water modeling tools in an upcoming topic. The present study aims at development of methodology to integrate geospatial inputs in groundwater modelling framework. The regional ground water availability will be assessed using modeling approach as well as remote sensing based analysis (satellite based gravity observations; GRACE-FO).
D 21.18	**Climate and LULC change impact assessment on water resources (IIRS)** India has seen vast expansion of agricultural and industrial activities since 1990s. This expansion has happened in Climate change is likely to increase water demand while shrinking water supplies. The response of catchments towards This shifting balance would challenge water managers to simultaneously meet the needs of growing communities, sensitive ecosystems, farmers, ranchers, energy producers, and manufacturers. In some areas, water shortages will be less of a problem than increases in runoff, flooding, or sea level rise. These effects can reduce the quality of water and can damage the infrastructure that we use to transport and deliver water.
D 21.19	**Planetary water ice and hydrological cycle studies (IIRS)** The first planetary mission of India, Chandrayaan-1 confirmed the presence of water ice at polar and other regions of Earth's Moon. In the last 50 years many space based probes and RS missions have explored planets, moons and asteroid of our solar system, along with space telescopes based search for Earth like planetary systems. In all these mission, the presence of water-ice, liquid water or historical or present sign of hydro-geological cycle are of great scientific interest, as this water can be used as fuel and basic life sustaining resources for any future manned space exploration or colonization missions to these extra-terrestrial space objects. This project aims to develop RS (using

	optical, hyperspectral, MW and LIDARs/GPRs etc.) and modeling based techniques for identification, quantification of water/ice on planetary surface/sub-surfaces and use process based and customized hydrological models to simulate historical and present water cycle components.	
D22	**Sub Area**	**Oceanic Sciences and Climate (SAC/NRSC/IIRS/NESAC)**
D22.1	**Retrieval of IPAR & PAR flam OCM-2 irregular basis and validation with measurements for different regions of tropical, sub tropical and Polar areas (NRSC)** Ocean colour remote sensing is a useful tool and it provides quantitative information of seawater constituents on synoptic scale. ISRO's ocean colour missions namely OCEANSAT-1 and OCEANSAT-2 OCM have been extensively used for various societal and scientific applications like Potential Fishing Zone identification, ocean primary productivity estimation, algal bloom detection and studying the coastal processes etc. Photosynthetically available radiation (PAR) is one of the key parameter along with spatially invariant and uniform aerosol optical depth under clear sky condition has been used for estimating the ocean primary productivity models using OCM data. Thus, modeling PAR from OCM under variable aerosol loading and cloud conditions is a desirable input parameter to estimate ocean primary production from OCM more accurately. The Instantaneous Photosynthetically Available Radiation (IPAR) is used as one of the input for estimating the PAR (400-700 nm) in some of the models.	
D22.2	**Retrieval of sea surface salinity from satellite data and validation (NRSC)** Sea Surface salinity (SSS) is an essential climate variable. It is a key component of the water cycle, as a tracer of precipitation and evaporation, river outflow and ice melt/ freeze. It is a key driver of the oceanic circulation through its role on the ocean density. It is also a critical parameter for understanding the variability of the ocean carbon fluxes, providing information on water masses and of their chemical properties. Salinity dominates seawater density and directly affects physical and biochemical processes. Having a reliable retrieval model is essential to provide frequent and accurate sea surface salinity (SSS) data for marine research. Remote-sensing techniques provide alternatives for SSS data retrieval with its advantages of wide area surveys and real-time monitoring. The past, present and the future ocean colour missions of ISRO can be used for addressing some of the key climate change issues like ocean acidification and carbon dynamics along with it's contemporary sensors like SST and altimeters. |Hence, there is a need to develop the new algorithms or to evaluate and fine tune the SSS algorithms to address the above issues. 1. Ocean Surface salinity is one of the Essential Climate Variable (ECV) 2. L-Band Passive Microwave radiometers such as SMOS, Aquarius and SMAP have demonstrated the capability to retrieve salinity from brightness temperature data 3. Development of algorithms for retrieval of salinity using passive microwave radiative transfer models 4. Validation of the retrieved salinity using Moored buoy, RAMA buoy and other in-situ observations.	

D22.3	**Ocean surface characterization using SARAL Altika Data (NRSC)** A regional tidal model is formulated for the Indian coastal domain based on the barotropic mode of the Princeton Ocean Model (POM). The simulated tidal levels are used in combination with tide gauge measurements and global tidal solutions based on FES2012 for assessing tidal corrections associated with SARAL-ALTIKA along-track sea level measurements.The POM in its 3D mode is also implemented for simulating seasonal mean flow pattern in the GK and its surrounding coastal ocean. This modeling study is now extended to use SARAL-ALTIKA along track sea level data in order to constrain the simulation for better understanding coastal ocean processes around India.
D22.4	**Meso-scale ocean eddy scale analysis (NRSC)** The term Eddy refers to rotational motion of water mass. The eddies with space scales of 50-500 km and time scales of 10-100 days are called meso-scale eddies. They play a significant role in transporting water mass, heat and nutrients. Upwelling areas are associated with cold core eddies, on the other hand downwelling is associated with warm core eddies. An Eddy tracking method using satellite measured Sea Level data has been implemented following Chelton et al., 2011. Using this, identification of the eddy type (Cyclonic or Anti-Cyclonic) and their paths of the movement have been established in the Tropical Indian Ocean. The characterization has been done by computing amplitude of eddies, number of Cyclonic and Anti-Cyclonic eddies formed and Vorticity etc.
D22.5	**Ocean wind, wave and current assessment in coastal waters (NRSC)** 1. Satellite Microwave instruments such as Scatterometers, Radiometers and Altimeters provide ocean surface wind, wave and current measurements which needs to be intercompared especially in the coastal regions. 2. Geostrophic and Ekman components of the currents can be estimated from altimeter derived SLA and Scatterometer wind data. 3. Seasonal and interannual variability of satellite derived wind,wave and currents data to understand the major governing processes for their variability. 4. Interaction of wind-wave-current in the coastal region leads to a complex dynamics which need through investigation for their individual contribution.
D22.6	**Satellite altimeter waveform analysis to improve geophysical parameters retrieval (NRSC)** 1. Altimeters are active microwave instruments which provide Sealevel, Wind and significant wave information through the measured waveform characterstics. 2. Altimeter waveforms are nothing but the variation of received power with respect to time. 3. Magnitude of the returned waveform power gives you the information of surface wind speed 4. Slope of the wave form gives the significant wave height information. 5. Waveform shape and characteristics differ for different targets such as ocean, land and Ice for which different models are needed to understand retrieve geophysical parameters from them.

D22.7	**Satellite altimeter data assimilation in ocean models (NRSC)** 1. Assimilation of satellite derived temp, salinity and sealevel is needed to improve the accuracy ocean model simulations of temp, salinity and currents and their vertical profiles. 2. Altimeters routinely provide information regarding sealevel, wind and wave information. 3. Altimeter derived sealevel can be assimilated using variational techniques such as 3D var and 4D var in ocean circulation models such as MOM, ROMS, MITGCM etc. 4. Altimeter derived significant wave height can be assimilated in ocean wave models such as SWAN, WAVEWATCH etc., for improved prediction of waves along the indian coasts
D22.8	**Derivation of Ocean surface currents utilizing data from SARAL AltiKa and OSCAT. Combining geostrophic currents from SSHA (from Altimeters) and wind driven currents from wind velocities (from Scatterometer), the ocean surface currents can be obtained (NRSC)** The scope of the current observations can be seen in the navigation and optimization of shipping routes, dispersion and drift of pollutants, particularly, algal blooms and oil spills, besides their use in tracing mass and heat distribution across the ocean boundaries. The ocean surface currents of the Global Ocean are estimated combining Ekman Surface Current (ESC) and Surface Geostrophic current (SGC). The ESC is derived from the ocean surface wind fields of Oceansat-2 Scatterometer (OSCAT) data products. The pathwise
	observations of OSCAT wind vector are used after removing high frequency variations with Data Interpolating Variational Analysis (DIVA). Similarly, the SGC component of the current is estimated using SARAL AltiKa Sea Surface Height (SSH) products.
D22.9	**Ocean modelling (NRSC)** Investigation of the thermal inertia of the Indian Ocean. Ocean models can be used to investigate the thermodynamics of the oceans with emphasis on long term thermal evolution in the oceans. This would help in estimating the thermal inertia of the ocean, an indicator of effects on climate change.
D 22.10	**Development of bio-optical algorithms in CASE-2 waters (NRSC)** With the availability of OCM-1 and 2 and for the future OCM-3 with more spectral bands a programme has been planned for reprocessing of ocean colour data sets for the development of ECV like chlorophyll-a, PAR and diffusive attenuation coefficient in coastal waters. Using large sets of in-situ underwater radiation measurements and associated bio-physical measurements coastal bio-optical algorithms has to be developed. Using this algorithm reprocessing of OCM data is to be planned.
D 22.11	**Response of coastal system due to climatic change and its long and short term implications (NRSC)** Coastal ecosystems are key ecosystems considering their importance in providing goods and services. In addition to the aesthetic and recreational value provided by the coastal ecosystems, economic benefits provided by them in supporting human livelihood via food and materials, nutrient cycling, waste processing and other essential goods and services are quite important. Efficient monitoring of these ecosystems is critically important by

	utilizing advanced remote sensing and long-term climatic records for assessing climate change impacts and developing adaptation and mitigation strategies for effective restoration and conservation in Indian coastal zone.
D 22.12	**Satellite based retrieval of geo-physical parameters for coastal processes assessment (NRSC)** 1. Coastal processes are more complex due to the interaction of bathymetry, wave, tides and land-sea breeze etc., 2. Satellite sensors such as Altimeter, Scatterometer, Radiometer and SAR etc., provides information regarding geo-physical variables. 3. Algorithms developed using radiative transfer models and statistical methods are needed to retrieve geo-physical parameters from these satellite measurements.
D 22.13	**Eco-system change direction and responses due to coastal change using high resolution IRS-data sets (NRSC)** Understanding how the coastal ecosystems are changing due to changing coast is an area of importance in India due to natural as well as anthropogenic activities in coastal areas. Remote sensing can take an important role in quantifying and monitoring these changes at local to regional scale. The new high resolution remote sensing datasets from IRS series of satellites can take an important role in studying the changes happening in coastal ecosystems in India.
D 22.14	**In-situ studies of phytoplankton cultures to understand changes in the absorption spectrum in response to different environment variables for developing methodologies for satellite retrieval (NRSC)** Retrieval of spectrum information of dominant phytoplankton groups from satellite ocean colour data especially for case 2 waters is complex and requires good amount of in situ studies from pure cultures to understand how this varies due to age of the culture, between different groups and also with nutrient manipulations. In recent years several methodologies have been developed to extract spectrum information from satellite ocean colour data however this requires important validation to make such techniques operational in the era of OCM.
D 22.15	**Study of relationships between oxygen and C13 based primary productivity for Indian coastal waters to evaluate photosynthesis quotient for developing satellite based primary productivity model (NRSC)** Changes in oxygen concentrations over time can be used to estimate the rates of photosynthesis and therefore primary productivity. Carbon assimilation rates based on oxygen evolution often assumes a ratio of one moles of O2 produced for every moles of CO2 assimilation however this number is highly variable in the environment. Studies can be undertaken to compare this classical techniques with modern C13 based primary productivity to understand the variability which can be used to develop satellite based PP model.

D 22.16	**Measurement of particulate organic and particulate inorganic carbon in coastal and open ocean waters of northern Indian Ocean for development of satellite based algorithm (NRSC)** Particulate organic and inorganic (comprised of mainly cocolithophores) are important component of any oceanic system which influence the marine carbon cycle. Remote sensing measurements are now being used to characterise these component in basin scale due to its large spatial coverage however lack proper validation due less in-situ measurement. Both beam attenuation and in situ POC/PIC have been used to develop empirical relationship as early as 1988. Latest research suggests good relationship between oceanic POC concentrations vs. Rrs (443)/ Rrs (555). Opportunities are available for measuring POC/PIC by chemical or physical method (CTD, Beam Attenuation) for development and validation of satellite algorithm for Northern Indian Ocean.
D 22.17	**Development of methodologies (statistical and numerical methods) for the generation of time series/ long period data base from the OCM sensors (Chl, PAR and AOT) over the Northern Indian Ocean in association with NRSC (NRSC)** ISRO had launched OCM-1 & OCM-2 and going to launch OCM-3 in near future for studying ocean color properties of Northern Indian Ocean such as Chlorophyll. To effectively use this data to study ocean color and climate change It is required to make long time series data combining OCM-1 and OCM-2 data and in future OCM-3. To effectively do this we need to reprocess data from these two sensors to bring them on a common platform to make them inter comparable and compatible. Work already initiated in this direction by developing methodologies for effectively inter comparing data from these satellites with that of SeaWiFS & MODIS (Two of NASA's Ocean color sensors with stable data and accuracy).
D 22.18	**Development of methodologies for generation of near real time ocean surface currents using satellite derived winds, Sea Surface heights/ anomaly, SST and salinity for the Indian ocean (NRSC)** 1 At present there is no satellite technology which can provide ocean surface currents in real time. 2. Satellite Altimeters only provide the information regarding the geostrophic currents. 3. Ekman component of the currents can be derived from scatterometer measurements. 4. Development of improved methodologies is needed to synergistically use different satellite derived parameters such as SST, Salinity, Sealevel and Winds to generate ocean surface currents in realtime such as OSCAR, GlobCurrent products.
D 22.19	**Development of bio-optical algorithms in CASE-II waters using Inherent optical parameters and propagation to the top of atmosphere using appropriate radiative transfer models (NRSC)** ISRO had launched OCM-1 & OCM-2 to study chlorophyll and bio optical properties of North Indian Ocean, and going to launch OCM-3 soon. It is very important to have accurate algorithm to retrieve Geophysical products to effective utilization of satellites. Retrieving Ocean color properties from Case II waters (coastal waters) is very complex as these

	waters are highly influenced by coastal discharges and human influence etc... We are measuring Inherent & Apparent optical properties of coastal water column around India and developing these algorithms using the field data and radiative transfer modelling.
D 22.20	**Use of satellite observation in ocean general circulation model for understanding regional circulation and heat budget in the Indian Ocean (NRSC)** 1. Assimilation of satellite derived temp, salinity and sealevel is needed to improve the accuracy ocean model simulations of temp, salinity and currents and their vertical profiles. 2. Altimeters routinely provide information regarding sealevel, wind and wave information. 3. IR and Microwave radiometers provide SST information which can be assimilated in ocean circulation model for understanding regional circulation and heat budget in the Indian Ocean. 4. Altimeter derived sealevel can be assimilated using variational techniques such as 3D var and 4D var in ocean circulation models such as MOM, ROMS, MITGCM etc. 5. Altimeter derived significant wave height can be assimilated in ocean wave models such as SWAN, WAVEWATCH etc., for improved prediction of waves along the indian coasts.
D 22.21	**Development of eddy-resolving meso scale ocean model and potential fishing zone predictability (NRSC)** Ocean eddies are important features, which play a dominant role in ocean dynamics, nutrient transportation and modification of circulation patterns. The satellite observations have revealed their distribution and temporal variability. Modelling such eddies is underway using a Regional Ocean Modelling System (ROMS). The model has been set up and integrated with Winds, Temperature, Salinity and Surface heat fluxes data for simulation of eddies and regional circulation in the Indian Ocean.
D 22.22	**Assimilation of satellite observation in Ocean general circulation model to reconstruct ocean state parameters (NRSC)** 1. Assimilation of satellite derived temp, salinity and sealevel is needed to improve the accuracy ocean model simulations of temp, salinity and currents and their vertical profiles. 2. Altimeters routinely provide information regarding sealevel, wind and wave information. 3. Altimeter derived sealevel can be assimilated using variational techniques such as 3D var and 4D var in ocean circulation models such as MOM, ROMS, MITGCM etc. 4. Altimeter derived significant wave height can be assimilated in ocean wave models such as SWAN, WAVEWATCH etc., for improved prediction of waves along the indian coasts.
D 22.23	**Development of real time coastal ocean analysis system through ocean general circulation model coupled with ocean Biogeochemical flux model (NRSC)** Tide and current interaction are very significant in the coastal ocean regions which are being neglected in most of the coastal circulation model studies. Indian has vast Exclusive Economic Zone (EEZ) with tremendous influence by anthropogenic activities including industrial and navigation activities. Coastal ecosystem is under stress. It is

	essential to monitor and maintain the health of the marine flora and fauna. In this regard, satellite observations combining with ocean general circulation model to be used for understanding regional circulation and ecosystem dynamics. 1. Establishing regional coastal circulation model driven by global ocean climate model analysis at the open boundaries along with tides and atmospheric forcing. 2. Establishment of Ocean Ecosystem Model and satellite data integration for monitoring health of the marine ecosystem in Indian EEZ. 3. Latest Ocean Circulation Models such as MOM5 have capabilities to simulate Ocean Circulation parameters including biogeochemical models available in their native configuration. 4. Biogeochemical Flux Model can simulate the biogeochemical processes for improved understanding of marine ecosystem variability.
D 22.24	**Use of satellite observation for modeling and assessing regional carbon cycle for the Indian region (NRSC)** Carbon dioxide is a major greenhouse gas and various scientific investigations have revealed that increase in the concentration of CO2 is an important contributor to climate change. Understanding the carbon (C) sink or source potential of ecosystems and their variability in relation to climatic drivers are critical to elucidate and quantify climate-carbon feedbacks. Using satellite data inputs of NDVI, land-use-land-cover, CASA Terrestrial ecosystem model was used to simulate the terrestrial carbon budget over India for the period 1981-2016. GEOS-Chem Model was implemented to understand the atmospheric CO2 variability over India.
D 22.25	**Atmospheric aerosol research (SAC/ NESAC)** Algorithms for atmospheric aerosols using satellite over plain & hilly land and oceans, Aerosol transportation and climate studies.
D 22.26	**Simulation of methane distribution and visualization in Mars atmosphere (NRSC)** Indian Mars mission will be carrying MSM (Methane Sensor for Mars) to map the methane sources and deriving concentration in Mars atmosphere by ppb accuracy. Simulations are planned using other Mars orbiter data like MGS etc. considering the specification of Indian MSM for visualization and understanding the data. This simulation is to be carried jointly with the help of Principal Investigator of MSM.
E	**Area** — **Aerial Remote Sensing (NRSC/ NESAC/IIRS)**	
E1	**Sub Area** — **Automatic feature extraction from aerial images (NRSC)**	
E1.1	**Automatic feature extraction from aerial images (NRSC)** The objective of this study would be to explore the possibilities of automatic feature extraction through the fusion of high resolution aerial digital camera images and DSM either from Lidar technology or from photogrammetry. As per the literature, the fusion of DSM from Lidar scanners and image data from digital cameras showed promising results. The data from these two sources is complementary to each other and hence make a great combination.

E2	Sub Area	Segmentation of Aerial / satellite data (NRSC)
E2.1	Segmentation becomes more important with increasing spatial resolution of imagery. Texture in high-resolution aerial and high resolution satellite images requires substantial amendment in the conventional segmentation algorithms. The potential applications of this segmentation process are (1) Automatic 3D model generation (2) automatic DEM generation from DSM (3) Automation in Quality Checking of vector maps and many more.	
E3	**Sub Area**	**Aerial Data Compression (NRSC)**
E3.1	**Development and incorporation of lossless compression algorithm(s)/ technique(s) (NRSC)** Development and incorporation of lossless compression algorithm(s)/ technique(s) for better handling, archival, effective usage and time critical data processing of aerial analog and digital data. The compression algorithm must meet the requirement of aerial compression system for storage and operation time. The compression techniques must reduce operation memory, and accelerate the processing speed without any data loss.	
E4	**Sub Area**	**Radiometric Calibration LiDAR Waveform (NRSC)**
E4.1	**Radiometric calibration (NRSC)** Radiometric calibration refers to the statistical process of deriving physically well-defined radiometric quantities from the sensor's raw measurements. Waveform LiDAR system provides detail information about the backscattering properties of the observed targets by recording complete return signal. Even though waveform measurements have high content of information, data acquired during different flight campaigns cannot be directly compared without a proper radiometric calibration. Model waveform Radiometric calibration requires formulation of LiDAR equation. This model may be useful for the retrieval of higher level data products.	
E5	**Sub Area**	**Photogrammetry (IIRS)**
E5.1	**DEM fusion (IIRS)** Advance spaceborne remote sensing and geodetic techniques are currently available for generation of high resolution DEMs resulting in the advancement of earth's topographic modelling. DEM assimilation or fusion is one of the technique, which can be utilized effectively to overcome the limitations of individual DEMs generated from different techniques (such as photogrammetry, LiDAR, InSAR) and are available commercially or through open source platforms.	
E6	**Sub Area**	**Aerial Remote Sensing using UAV (NESAC)**
E6.1	**Development of long range communication system for UAVs (NESAC)** Most of the commercial UAVs available today come with a communication range of 5-10 kms in clear line of sight. However for some applications like medicine delivery in remote/ disaster areas, river mapping/monitoring applications require long communication range 40-50 kms for real time transfer of telemetry and data. A low cost, low weight and range communication system will improve the capabilities of existing UAV systems.	

E6.2	**Improvements in battery capacity used in UAVs (NESAC)** Lithium Polymer batteries are being used as source of electric power in the present UAV systems which gives a maximum flight endurance up to 1 hr with different combinations. It is required to develop low weight high capacity batteries to further improve upon the flight endurance of UAVs using different materials and techniques.
E6.3	**Development of data processing software for high volume UAV data processing (NESAC)** Processing of UAV data is a unique challenge due to its large volume. Few of the commercial softwares used for generation of complete data products such as DEM/DTM, 3D point cloud, contour maps etc are very costly and require high end systems. There is a need for developing in house data processing software using open source tools with end to end data processing capabilities which do not require very high end computers.
E6.4	**Real time UAV data processing for disaster monitoring applications (NESAC)** Data acquired from UAV surveys are downloaded after the survey and processed in the lab. Due to the high volume of data, the processing takes lot of time and real time quantitative analysis from the data cannot be made. A real time data processing technique where data is downloaded to ground station in real time as the flight progresses and put into software where maps/models are generated simultaneously and automatically will be helpful for quick disaster response and assessment.
F	**Area** — **Earth and Climate Sciences (NRSC/IIRS/NESAC/SAC)**
F1	**Sub Area** — **Atmosphere and Climate Sciences (NRSC/IIRS/NESAC)**
F1.1	**Regional monitoring of Trace and Green house gases (NRSC/NESAC)** Trace and green house gases in earth atmosphere are important as they affect both air quality and radiation balance of the earth atmosphere system. Anthropogenic activities influence abundance of many of these gases in the atmosphere. In view of this, it is necessary to have continuous monitoring of these gases and changes in their concentrations over different regions to understand anthropogenic impacts on global climate change.
F1.2	**Retrieval of green house gases using satellite data (NRSC)** By realizing the impacts of trace and greenhouse gases in air quality and radiation budget, it is necessary to have measurements of these gases with sufficient spatial coverage. Satellite remote sensing enables retrieval of trace and greenhouse gases over large regions to estimate their effects on earth atmosphere and contribution in climate change. Spatial distribution of abundance of these gases can be used to identify their major source regions and also to estimate long term trends in their concentration.
F1.3	**Transport of chemical constituents of atmosphere using WRF chemical transfer modelling (NRSC /NESAC)** Atmospheric dynamics lead to dispersion and transport of chemical constituents in atmosphere from their source regions to distant locations. In order to understand effects

F1.3	of chemical constituents in earth atmosphere, their transport from source regions to other locations has to be examined. Transport of chemical constituents in atmosphere can be investigated in detail using models such as WRF. 1. Identification of trace gases and understanding their chemistry mechanism using available satellite and ground data. 2. Study of trace gases dispersion using WRF model. 3. Study of chemical mechanism between the species using WRF-Chem model. 4. Generate alert mechanism on pollutant concentration and their transport
F1.4	**Study of boundary layer dynamics (NRSC/NESAC)** Atmospheric Boundary Layer (ABL) is the lowest part of troposphere, which is directly influenced by earth surface and responds to surface forcing with a time scale of an hour or less. Structure of ABL and associated dynamics are important to understand weather, climate, pollution dispersion and exchange processes between surface and atmosphere. The lower layer of the atmosphere, the boundary layer, acts as a conduit for exchange of energy and mass between the surface and the atmosphere. Measurements of the vertical profile of meteorological parameters are essential to study temporal variations in the boundary layer, especially in the lower layers. As the boundary layer varies greatly depending upon the surface characteristics, extensive sampling over different regions is required to accurately represent the boundary layer in numerical models. The 32m meteorological tower at NRSC, Shadnagar is an example of a boundary layer measurement system at a semi-arid region.
F1.5	**Aerosol characterization and its impact on solar radiation (NRSC/ NESAC)** Atmospheric aerosols, one of the major climate forcing agents, affect earth atmosphere radiation balance through aerosol radiation interactions and aerosol cloud interactions. Despite the efforts being carried out for past few decades, atmospheric aerosol remains one of the major sources of uncertainty in climate forcing estimates. Better understanding of aerosol impacts on weather and climate demands adequate incorporation of aerosol parameters in climate models, which needs accurate measurements of aerosol characteristics.
F1.6	**Surface energy budgeting using remote sensing (NRSC/NESAC)** Surface energy budgeting assumes importance as the surface energy balance is one of the major factors affecting hydrostatic stability and mixing of atmospheric constituents such as pollutants in lower atmosphere. Remote sensing can be used for surface energy budgeting over large spatial extends to understand changes in surface energy balance and related effects in earth atmospheric boundary layer characteristics and associated processes. An accurate picture of the global energy balance is necessary to detect perturbations in the Earth's climate system. The top-of-atmosphere radiative energy balance has been relatively well determined by satellites, as compared to the surface energy budget where larger uncertainties exist as surface fluxes cannot be directly measured by satellites.

	The spatio-temporal variations in distribution of surface energy components such as radiative fluxes at the surface, the sensible, latent and ground heat fluxes are retrieved and examined using multi-year data records from geostationary and polar orbiting satellites. The algorithms for estimating surface energy balance components are evolved and validated against ground measurements carried out over different regions.
F1.7	**Impact of aerosol on agricultural productivity (NRSC/ NESAC)** Atmospheric aerosols alter energy balance of the earth atmosphere system through scattering and absorption of radiation and also by modifying cloud properties. Through scattering and absorption, atmospheric aerosols reduce surface reaching solar radiation, which in turn affect agricultural production. In addition aerosols affect large scale circulation systems such as Indian summer monsoon and associated rainfall. Changes in rainfall will have significant effect on agricultural production.
F1.8	**Retrieving vertical profile of temperature and humidity using Radio Occultation (RO) data (NRSC/ NESAC)** Vertical profiles of atmospheric temperature and humidity are important parameters in atmospheric research, especially for weather forecast and climate change studies. Radio Occultation technique is an effective method to retrieve these profiles by receiving radio signals from GPS navigation satellites. The method makes use of the fact that degree of refraction of radio waves while passing through the atmosphere depends on gradients in air density which in turn depends on temperature and humidity.
F1.9	**Climate change impact assessment (NRSC/ NESAC)** Anticipated/Ensuing climate change is expected to alter the water resources availability, demand and use patterns. Many uncertainties remain about the extent of these climatic changes, as well as about their societal implications. Assessment of vulnerability and resulting risk to water resources due to climate-change impacts is necessary to work out appropriate adaptation and mitigation strategies.
F1.10	**Polar ice dynamics studies (IIRS)** To study the impact of climate change on polar ice cover, satellite data are used for monitoring the ice cover over the Polar Regions. Research is being done for identifying different type of ice cover using various satellite measured parameters.
F1.11	**Spatio-temporal variability of aerosol columnar and vertical distribution at regional and global scales (IIRS)** Aerosol columnar and vertical distribution at global and regional scales is one of the crucial parameters for climate change assessment. The data acquired by space borne instruments in conjugation with ground based measurements may be crucial to improvise our understanding on aerosol-climatic interactions. Also required is the detailed investigation on changing levels of different aerosol types at global and regional scales. Especially, increasing smoke levels across the globe in the recent years (Mehta et al., 2018) are of concern in the context of rising temperatures accompanied with increasing wildfires throughout the globe.

F1.12	**Urban micro and meso-scale climate modelling and urban canopy parameters estimation (IIRS)** Urban climate refers to climatic conditions in an urban area that differ from neighbouring rural areas, and are attributable to urban development. Temperatures are higher in cities than the surrounding rural areas—which is popularly manifested as Urban Heat Island (UHI). Urban climate is an effective issue on the local and global climates which is influenced by several factors such as urban morphology and density, the properties of urban surfaces and vegetation cover. The urban built-form due to its dense development, high-rise character and increase in impervious, absorptive surfaces is responsible for the trapping of heat and reduction in evaporative cooling due to decrease in vegetated, soft, pervious surfaces in urban areas. The study of urban climate is gaining further importance in the scenario of climate change. Research is ongoing for the generation of 3D urban database, urban parameterization in numerical weather models, urban canopy parameters estimation and understanding the micro and meso scale urban climate phenomenon. Currently, the emphasis is given to development of urban parameterization and micro and meso scale modelling. It will be further extended to the simulation of urban growth vis-à-vis urban climate.
F1.13	**Aerosol optical thickness and atmospheric correction over land (NESAC)** Calibration and radiometric normalization is the key issue in future remote sensing activities related with biophysical parameter retrieval and climate change. Atmospheric correction of the satellite data is a challenge. Most important input for atmospheric correction involved estimation of Aerosol optical thickness (AOT) either from network of ground observations or satellite data. Retrieval of AOT sensors like Resourcesat series is a challenge. There is need to develop simplified correction approach including AOR inputs using dark dense vegetation approach. There is further need to develop instrumentation with capability of polarized measurements and LIDAR sensing.
F1.14	**Aerosol, trace gases asian monsoon and climate change over NER (NESAC)** Aerosol and Trace Gases Characterization, inventory analyses, 4D profiling of Aerosol and Trace Gases are very important for NER of India. In view of rapid industrialization it is required to study the impact of the industrialization on climate change over NER of India. The impact of Aerosol & Trace gases on Asian summer monsoon with special emphasis in North East India is also an important study. Inventory study and quantification of green house gases and particulate matters from the industries of NER of India and study of physical & chemical characteristics. Study and quantification of land use changes due to industrialization and its impact. 4D profiling and characterization of Aerosol & Trace gases over NER Generation of 4D Aerosol and trace gases model Study of the impact of Aerosol & Trace gases in Asian Summer monsoon with special emphasis in North East India. Generation of climate change indices over NER of India. Development of climate change advisory system for NER of India.

F1.15	**WRF-Hybrid data assimilation to simulate Summer Monsoon and heavy rainfall over India (NESAC)** Data assimilation process combines observation data and short range forecast to best estimate the atmospheric state for initialization of an NWP model. Among different data assimilation techniques some of the commonly used methods are 3DVAR, 4DVAR, EnKF etc. Although these methods are different in their formulation but their main objective is to model the error covariance matrices for background and analysis as accurately as possible. In the variational method the background error covariance is considered to be static and isotropic which contradicts the reality as the error varies substantially with the flow of the day. In Ensemble Kalman Filter where multivariate flow dependent background error covariance is computed from ensembles of short range forecasts represent the error of the day. However, it is reported that the use of finite number of ensembles in EnKF may introduce some statistical noise in the covariance field that will result in unsystematic errors in the estimate. This error may be reduced by increasing the number of ensembles, though in practical purpose for use in atmospheric and oceanographic modeling such huge number of ensembles are not affordable. As both these methods have their pros and cons, so another method called HYBRID has been evolved as one of the computationally suitable technique which combines the strength of both variational and EnKF to get the best out of the methods. WRF-HYBRID method with 80 ensemble members is used for simulation of Indian summer Monsoon and heavy rainfall events over different parts of India.	
F2	**Sub Area**	**Agriculture and Agro-ecosystem studies (SAC/NRSC/NESAC)**
F2.1	**Integrated approach (including remote sensing inputs) for multi-crop assessment in sparse cropped regions (NRSC)** Multi-crop assessment is important for holistic development of agricultural recourses and farmers livelihood. In sparse cropped area there is always a possibility to misclassify the crop using satellite imageries. This can only be improved by using extensive ground based observations, development of crop specific spectral signature, multi-temporal hyperspectral images and cutting edge image processing techniques for crop classifications.	
F2.2	**The remote sensing techniques of crop assessment in hilly terrains/ high altitudes (NRSC/NESAC)** Assessment of crop over the hilly is always very tricky as the satellite images are affected by layover and fore shorting (in case of SAR) and hill shadow effect (in case of optical data). Further the agricultural land holdings are small in size and intermixed with forest/other vegetation. The main challenges would be image correction for the above mentioned effect, ortho-rectification and image processing algorithms for improved crop mapping and condition assessment.	

F2.3	**RS based indices/techniques for agro-ecosystems characterization / evaluation (NRSC/NESAC)** Agro-ecosystem characterization involves assessment of cropping system, crop calendar, crop phenology, agro-meteorological parameterization and soil & land. The aim of the proposal should focus on the carbon sequestration, soil conservation, water use and long terms changes/degradation. The proposal should also focus on the suitability of the agro-ecosystem in terms of the prevail soil, land, weather resources.
F2.4	**Ingestion of RS inputs/products in climate change analysis/modelling of agro-ecosystems (NRSC/NESAC)** It involves long term satellite and climate data analysis, indentify the trend and break points of the multi-temporal data. The proposal should involve crop growth simulation model, cropping system model, nutrient transport model. The model should be calibrated in the present condition and simulated under climate change scenarios. Emphasis should provide to use different RS based inputs into the models.
F2.5	**Development of GHG models for agro-ecosystems under different conditions (NRSC)** It involves modeling of exchanges/fluxes of GHG like CO2, H2O, CH4, N2O etc from the agro-ecosystem at diurnal, seasonal and annual time scale using suitable field instrumentation and modeling techniques. It also involves to identify the driving parameters of the GHG fluxes and upscaling it at regional level using remotely sensed proxies.
F2.6	**Parameter retrieval techniques with hyperspectral data (NRSC/NESAC)** It involves analysis of hyperspectral data and development of narrow band indices sensitive to crop vigour and condition. Retrieval of crop bio-physical parameters like LAI, Biomass, chlorophyll content, surface wetness etc using empirical, semi-empirical or radiative transfer models.
F2.7	**Algorithm development for agro-ecosystems product generation from geostationary platform (NRSC)** Geostationary platforms provides the frequent observations of the land features and is very useful for kharif season monitoring to get rid of frequent cloud cover. The proposal should focus on use of geostationary platform especially INSAT series for generation of weather variables like Total incoming solar radiation, Net Radiation, Land surface temperature, NDVI etc which can be used in diffrent energy balance equations for retrieval of latent heat fluxes, LAI etc.
F2.8	**Concepts of multidate/multisensor fusion of different scales and resolutions and uncertainty analysis in relation to agro-ecosystems (NRSC)** Multisensor data fusion techniques helps in enhancing the spectral/spatial informations present in the satellite image. Different fusions techniques need to be explored and comparision is needed for applying in different agriculture monitoring projects. The pros and cons of the merging procedures need to be evaluated. The proposal should also cover the utilization of texture informations present in the fused image for characterizing agro-ecosystem.

F2.9	**Newer tools and techniques development for quick assessment of temporal dynamics of crops/vegetations using Indian multi temporal satellite data (NRSC)** Temporal optical/radar data provides informations on crop phenologies like start of the season, peak greenness, rate of scenescence, date of harvesing etc. The proposal is needed for development of indicators derived from the temporal phenological curves for assessing crop growth stages. The project should involve the analysis of multi-temporal NDVI/EVI data, its smoothening, gap filling and extraction of phenometric using different tools/softwares.
F2.10	**Development of mathematical/matching algorithm in spectral library development using hyperspectral data (NRSC)** This includes development of the hyperspectral library of soil/crops with its physical and chemical properties. These libraries will be helpful in retrieving soil/crop properties of unknown spectra. There is need to develop different curve fitting and wavelet matching techniques for comparing the spectra with the spectral libraries. The proposal may focus on using leaf or canopy radiative transfer model for retrieving properties from the reflectance spectra.
F2.11	**Modelling soil carbon sequestration in relation to cropping systems and climate change (NRSC)** Soil carbon is one of the driving parameter for soil productivity and sustainability. Assessment of Soil carbon helps in understanding the carbon sequestration and its dynamics and its simulation in climate change scenarios. The proposal should incorporate the calibration and validation of biogeochemical models like RothC, DNDC, Century etc and simulating carbon sequestrations in different climatic and land-use scenerios.
F2.12	**Development of farming systems models with RS inputs/products (NRSC)** RS derived inputs strengthen any Decision support system for agricultural applications. There is need to devise a farming system model where RS derived inputs can be fed to provide decision support to the farmer communities. The proposal may also explore any such existing models and can suggest necessary changes in terms of input or its structure.
F2.13	**Applications of RS/GIS in horticulture studies (NRSC/NESAC)** Horticultural crops are unique in nature due to its canopy structure and prevailing plant spacing. These are also grown in an orchards environment which are generally having a typical geometric shape. Using these criteria object based image analysis techniques can be proposed for rapid mapping of the horticultural crops. The proposal also should focus of the orchard age, its condition and yield modeling.
F2.14	**Geostationary data utilization in crop assessment (NRSC)** Geostationary data provides frequent observations hand helpful during cloudy season. Geostationary imager data can be utilized for generation of temporal crop growth profile, start of the season and regional crop condition assessment. The focus should be given in large area assessment of crop generic condition assessment, drought monitoring etc.

F3	Sub Area	Environment Sciences and Hydrological Modeling (NRSC/ IIRS/NESAC)
F3.1	**Green House Gases estimation (NESAC)** One of the recent trends in remote sensing understands the climate change through space measurements. Atmospheric Green house gases concentration and measurements of flux are important research Area. Currently available sensor system includes GOSAT, ENVISAT-SCIAMACHY, MOPITT etc. India has plans to launch such mission (ENVSAT Series) in future with other countries (OCO of USA, GOSAT-2 of Japan). There is need to develop radiative transfer scheme to model and retrieve the gases concentration. There is need to in situ measurement of CO2, CH4, N2O etc fluxes for validation of satellite products.	
F3.2	**Hydrological modeling (IIRS)** Hydrological modeling at Basin as well as India level is needed to understand the distribution and balance of water balance components. Projecting the water requirements in the future climate scenario are another area of important research. SAC and IIRS has initiated hydrological modeling activities related with role of forest ecosystem in influencing the hydrological component over a large region using satellite and ground based measurements. There is need to develop model to retrieve hydrological variables (rainfall, Soil Moisture, Evapotranspiration) using satellite data. Snow and glacier hydrology is an important thrust area of research. Inland waters level monitoring using altimeter data.	
F3.3	**Regional monitoring, mapping and inventory analysis of Trace and Green house gases (NRSC/ NESAC)** 1. Establishment of trace gases measurements network across the country using cost effective technology. 2. Creating a consistent and reliable centralized long-term data base on trace gases for various stuides. 3. Ground based trace gases data to improve the satellite retrievals accuracy. 4. Identification of hotspots of trace gases and their causative factors.	
F3.4	**Retrieval of green house gases using satellite data (NRSC/ NESAC)** 1. Retrievals of columnar GHGs namely CO2, CH4, CO, O3 and N2O from the satellites over the Indian region. 2. Comparative analysis of satellite retrievals against ground-based retrievals to improve the retrieval accuracy. 3. Precise columnar GHGs to predict and estimate source and sink regions of the Indian sub-continent. 4. Addressing seasonal and intra season variations using satellite retrieved columnar GHGs.	

G	Area	Disaster Management (SAC/ NRSC/ IIRS/ NESAC)
G1	Sub Area	Geo-hazards (SAC /NRSC /IIRS/ NESAC)
G1.1	**Earthquake Precursor Analysis for moderate to high magnitude earthquakes in India for understanding the spatio-temporal likelihood of earthquakes (SAC / NRSC/ NESAC)** Earthquake prediction is still a challenging task, recent studies have shown that numerous geophysical and geochemical parameters are closely associated with earthquakes. When the earthquake happens, an energy transfer due to a breakdown between source and environment is made. These changes prior to the earthquake or along with it may have different physical and chemical effects on the lithosphere, atmosphere and ionosphere. Occasionally and in the cases of large magnitude earthquakes, these changes are detectable. A large number of researchers across the world over the past decades have attempted in understanding such “earthquake precursors” from “Thermal Anomalies” and “Total Electron Count Variations” occurring in the lithosphere and the ionosphere. Thermal anomaly is an unusual increase in Land Surface Temperature (LST) that occurs around 1–24 days prior to an earthquake. In addition to this, Total Electron Content/Count (TEC) has emerged as one of prime candidates of earthquake pre-cursors studies that need to be thoroughly understood in order to get appropriate forewarning of earthquake events. Therefore, the two primary areas of focus will be “Thermal precursors” and “Total electron count anomaly” prior to an earthquake event.	
G1.2	**Early warning of landslides (NRSC/NESAC/IIRS)** Landslides are mainly triggered by rainfall. Daily as well as antecedent (cumulative) rainfalls are responsible for saturation of soil and subsequent landslide in hilly areas. Therefore, a rainfall intensity-duration relationship was developed by NRSC for experimental landslide early warning. Bhuvan platform is currently used to disseminate daily landslide early warning for selected road corridors in the Himalayas. Daily 72 hrs rainfall forecast received from IMD or SAC (MOSDAC) is used as an input to the landslide early warning model. Then the available landslide susceptibility map is integrated with rainfall probability to generate landslide early warning in Bhuvan. Early warning in four categories (Warn, watch, advisory and no warning) are issued regularly through Bhuvan. Currently the landslide early warning system is operational experimentally in selected routes of Himachal Pradesh, Uttarakhand, Meghalaya, Assam and Mizoram. Further development of rainfall intensity-duration relationship is required specific to different landslide prone areas of India.	
G1.3	**Landslide modelling, mapping and monitoring (IIRS)** Satellite based information can be very useful in modelling and monitoring of landslides. This project aims in utilizing space based inputs, DGPS based surveys and geo-physical instruments for mapping, monitoring and field validation of landslides.	
G1.4	**Automated detection of landslide using AWIFS and Cartosat-1 derived DEM (IIRS)** The creation of a landslide inventory map by manual interpretation of remote sensing images is very time-consuming. This project aims at developing an automated procedure for the detection of landslides from multi-spectral remote sensing images.	

G1.5	**Debris flow modelling and risk assessment (IIRS)** The entire Himalayan range is prone to debris flow and associated hazards. This project aim in modelling the debris flow using geospatial data and field parameters using state-of-the-art numerical simulation model RAMMS (Rapid mass movement software) that predicts the motion of a naturally occurring mass from a head (release area) to base (deposition area) in three dimensions.
G1.6	**Simulation of inundation in urban environment using hydrologic and hydraulic models (IIRS)** To simulate urban flood propagation and inundation of the ground's surface, coupling of the 1D and 2D hydrodynamic model is necessary to consider flow interactions between underground pipes and the ground's surface, and therefore in this project 1D model and 2D model in the coupled mode together with spatial inputs derived from satellite remote sensing will be used to simulate flows in the pipe/river drainage system and surface inundation, respectively.
G1.7	**Integration of satellite based inputs along with DEM for forecasting a flood discharge and to provide early warning (IIRS)** Hydrological modelling of large river catchments due to its complexity in collecting and handling of both spatial and non-spatial input data such as rainfall, gauge-discharge data, and topographic and hydraulic parameters, has always been a challenging task. This project aims to develop a flood forecasting model using space inputs and through rainfall runoff modelling, hydrodynamic flow routing, calibration, and validation of the model with field discharge data.
G1.8	**Assessing the possibility of cloudburst/flash flood using INSAT images (IIRS)** Frequent flash-floods cause immense devastation in the Himalayan region during monsoons and therefore necessitate an improvement in the real-time forecasting system. The use of meteorological satellite images like INSAT images in estimating rainfall can be a good option for improving the performance of flood forecasting-and-warning systems. In this project a rainfall estimation algorithm using the infrared (IR) information from the INSAT Meteorological Satellite is proposed to be developed for complementing the flood forecasting and early warning system.
G1.9	**Flood Monitoring using SCATSAT-1 Satellite (IIRS)** Satellite plays important role in detection and monitoring of flood inundation extents over large regions. Microwave remote sensing due to its cloud penetration capability senses the surface hydrological characteristics. This project aims for using data from SCATSAT-1, for the detection of the flood situations over India by using backscattering and brightness temperature data to delineate flooded, partially submerged and areas with different soil wetness conditions.
G 1.10	**Algorithm development for INSAR-3D data for forest fire detection (IIRS)** The INSAT 3D a geostationary meterological satellite has EO capability in MIR and TIR region. With a high temporal imaging capability, the satellite has the potential to detect

	forest fires over Indian landscape continuously and provide the severity and duration of burning in the forest fire prone regions of India. The project aims to develop algorithms, which can use the capability of the satellite to automatically process the data and detect fire occurrence for effective mitigation measures.
G 1.11	**Climate change induced forest fire risk modelling (DGVM) (IIRS)** According to IPCC AR5 report, there is potential of increase in the forest fire incidences across the world due to a rise in temperature by 1.5-1.8 °C. With the current trends in the greenhouse gas increase, it is becoming a reality. The project will aim to generate ground-based information on the vegetation, ecological and edaphic parameters along with the climatic parameters, which can be used in dynamic global vegetation models to identify the fire risk due to climate change in the Indian landscape.
G 1.12	**Health hazard due to forest fire incidence (IIRS)** Impact of forest fire during summer season in Western Himalayas has shown significant increase of gaseous and particulate pollutants. Apart from the ecological loss, the fires have also caused environmental and health issues such as poor air quality, which caused a lot of discomfort to the people. There was significant increase in particulate matter, ozone, NOX and Carbon Monoxide levels. The physical properties of Aerosol and the gaseous pollutants can be captured as variations in the atmospheric profiles and as changes in the aerosol optical properties.
G 1.13	**Geospatial modelling for species loss and vulnerability (IIRS)** There is an urgent need to understand the propagation of forest fires and its impacts on the natural resources in Indian conditions. There are numerous models for forest fire propagation and spread across the world, but most of them are for temperate regions and Australian outbacks where the ecological conditions are markedly different for that of Indian conditions. The research will help to understand the various meteorological, topographical and vegetation parameters to identify in near real-time the probability of spread of forest fire and its intensity and rate of movement for control measures.
G 1.14	**Mapping and modelling exotic species invasion due to climate change (IIRS)** Invasive species is one of the five reasons of biodiversity loss in the world. Till date there is no established method for identification and mapping of the invasive species. The study aims to develop methodology for identification of biological invasion by the exotic species using the Earth Observation.
G 1.15	**Flood prone area mapping, modeling/forecasting & risk assessment using geospatial tools (IIRS)** Flooding during the monsoon season is a recurring problem in many parts of India. Different Indian states, especially North West Himalayan (NWH) states (J&K, HP and UK), along with other flood prone areas of India have experienced large number of hydro-meteorological disasters such as high intensity precipitation and subsequent flooding in downstream areas in the last few years. The flood of Bihar-Kosi (2008), Leh (2010), Uttarakhand (2012, 2013), J & K, Srinagar (2014), Parts of H.P. (2015, 2018), Gujarat

	(2015, 2017), Chennai (2015) and recent Kerala (2018), to name a few major floods. Therefore, this project aims to conduct systematic and scientific study of such flood prone areas, using multi-scale RS, weather forecast and hydro models, vulnerability curves and risk model, to generate timely flood forecast, long term flood vulnerability and flood risk maps in few of these sites.
G 1.16	**Urban flood vulnerability analysis and risk modelling (IIRS)** Reliable and timely prediction of flood extents in urban catchments is a challenging issue. Many cities in India has seen significant urban growth and increase in urban areas, which in turn reduces the open space, reduces the infiltration capacity of an area and increases surface runoff. Various modelling approaches are available ranging from data driven to physically based, from conceptual to detailed 1D-2D modelling. These approaches are then embedded in the wider context of flood risk assessment and disaster management. An integrated model that simulates the sewerage-network, river-network and 2D mesh-network are desirable to obtain flood extents in urban areas so that whenever overflows occur due to insufficient drainage capacity, the resultant surface flooding and/or levee break could be predicted and finally prepare urban flood vulnerability and risk maps..
G 1.17	**Drought assessment and monitoring using remote sensing (IIRS)** Drought is classified as calamity that can affect economy and society at regional to national extents. Drought is a phenomenon having slow onset, progress and ending. For decades, it has always been a challenge for the decision makers to monitor the arrival and growth of drought and identify its end. Although the drought events are initiated by the deficit in precipitation, simply rainfall as an indicator for assessing severity of drought and its resultant impacts is insufficient. Combination of various reasonable indicators must be included with regular observation for an effective drought assessment system to examine both drought severity and its consequences. The present study aims at utilizing remote sensing data in conjunction with observed data for development techniques for drought assessment and its monitoring sub-monthly level throughout the growing seasons. Emphasis will be given on utilization/integration of satellite based data, model forecast data and ground observations for improving assessment and monitoring accuracy.
G 1.18	**2D Flood Inundation Modelling - Simulation of flood inundated areas for a given discharge using DEM and other inputs from satellite data (NRSC/ NESAC/IIRS)** To explore the applicability of hydro-dynamic equations in various conditions of overland flood wave propagation on different floodplain topographies. Inter comparison of different DEM products for 2 dimensional hydraulic simulations.
G 1.19	**Flood Early Warning System (FLEWS) (NESAC)** Calibration and validations of all distributed river/tributary models in Brahmaputra and Barak river valleys with available hydro-logical and river geometry datasets. Sensitivity analysis of various model parameters to understand the hydrologic response of various types of river catchments in the said study area.

G 1.20	**Flood Hazard zonation and risk assessment in major riverine and urban flood prone catchments (NESAC)** Applicability of various approaches of flood hazard zonation such as flood frequency based hydraulic simulations, inundation occurrence based FHZ and NESAC developed multi-criteria analysis in both riverine and urban flooding conditions.
G 1.21	**Simulating climatic response through long-term Phenological and Dendrochronological studies (IIRS)** Dendrochronology is an important tool for tracing the impact of climate variability in the past and identification of the climatic extremes. Using dendrochronological information it can be possible to recreate the spatial Phenological patterns in the past to understand/ model the climate variability.
G 1.22	**Forest fire spread modelling (IIRS)** Forest fire spread is one of the important aspects of mitigation and control of forest fire. Work need to be carried out in fire spread modelling using state of art mathematical and geospatial modelling.
G 1.23	**Forest fire risk modelling (IIRS)** Forest fire is one of the major disasters in the natural ecosystems. Identification of the location and place of probable incidence of forest fire can help in its control and mitigation.
G 1.24	**Participatory GIS mapping towards hazard identification and risk mapping (IIRS)** Knowledge of where the vulnerable groups are concentrated within communities and the general nature of their circumstances is an important step towards effective emergency management.
G 1.25	**Flood monitoring using microwave passive remote sensing (IIRS)** Microwave observations are sensitive to soil moisture conditions and, thus, can detect antecedent surface conditions conducive to efficient runoff generation and the development of regional-scale flooding events.
H	**Area** — **Urban and Regional Studies/ Processes (IIRS)**
H1	**Urban spatial growth modelling (IIRS)** The recent thrust on urban growth modelling using geospatial data and techniques are- i) to implement cellular automata (CA) based models to simulate urban growth in Indian cities, ii) to evaluate the efficacy of Artificial Neural Networks (ANN) in formation of transition rules for CA based modelling and its comparison with the traditional Multi-Criteria Evaluation (MCE) based CA model, iii) to investigate the effects of different neighbourhood sizes and neighbourhood types in calibration of CA based models, iv) to evaluate the performance of CA based models using Moran, Percent Correct Match and Shannon's Entropy and v) to generate ANN based urban growth zonation maps depicting zones of urban growth potential.

H2	**Solar potential assessment in urban areas (IIRS)** The world's energy problem and the huge scarcity of sources producing energy, drifts our attention towards renewable energy sources. It is important to identify areas that receive maximum solar radiation, and to prevent losses in solar gain due to obstructions from surrounding buildings and topographic features. Recent research has shown that net-zero energy buildings are achievable if site analysis and various climatological factors are taken into consideration while designing a building, house or a community.
H3	**Linking urban air quality with built-form using geospatial techniques (IIRS)** Air pollutants occur both, outdoor and indoor, and can be natural or man-made. The major indicators of air pollution are SO2, CO, NO2, O3, NH3, H2S, particulate matters (PM2.5 and PM10), etc. The major sources of air pollution in urban areas are vehicular emission, solid waste burning, domestic fuels, power station, industries, etc. With the increasing trend of air pollution in urban areas, its analysis is required for understanding causative factors, better planning and for general awareness using geospatial tools.
H4	**Synergetic utilization of multi-sensor data for urban features extraction & modelling (IIRS)** Extraction of important features in an urban area (such as 2D & 3D building parameters, individual trees, tree plantations, parks, play grounds, built-up area, etc.) is important for various planning, management and decision making at various levels. Availability of multi-sensor/ temporal data coupled with advanced algorithms are useful for features extraction in an urban area.
H5	**Urban flood modelling and drainage adequacy assessment (IIRS)** Reliable and timely prediction of flood extents in urban catchments is a challenging issue. Various modelling approaches are available ranging from data driven to physically based, from conceptual to detailed 1D-2D modelling. These approaches are then embedded in the wider context of flood risk assessment and disaster management. An integrated model that simulates the sewerage-network, river-network and 2D mesh-network are desirable to obtain flood extents in urban areas so that whenever overflows occur due to insufficient drainage capacity, the resultant surface flooding and/or levee break could be predicted.
H5	**Urban water distribution modelling (IIRS)** The advanced water network modelling combined with Supervisory Control and Data Acquisition (SCADA) enables a real-time operational management system in urban areas. The benefit of this system enables proactive online operation, pressure management, reducing leakage, access to critical information and key performance indicators (KPIs) and contingency management, i.e. incident and risk reduction.
H6	**Urban micro and meso-scale climate modelling and urban canopy parameters estimation (IIRS)** Urban climate refers to climatic conditions in an urban area that differ from neighbouring rural areas, and are attributable to urban development. Temperatures are higher in cities than

	the surrounding rural areas—which is popularly manifested as Urban Heat Island (UHI). Urban climate is an effective issue on the local and global climates which is influenced by several factors such as urban morphology and density, the properties of urban surfaces and vegetation cover. The urban built-form due to its dense development, high-rise character and increase in impervious, absorptive surfaces is responsible for the trapping of heat and reduction in evaporative cooling due to decrease in vegetated, soft, pervious surfaces in urban areas. The study of urban climate is gaining further importance in the scenario of climate change. Research is ongoing for the generation of 3D urban database, urban parameterization in numerical weather models, urban canopy parameters estimation and understanding the micro and meso scale urban climate phenomenon. Currently, the emphasis is given to development of urban parameterization and micro and meso scale modelling. It will be further extended to the simulation of urban growth vis-à-vis urban climate.
H7	**3D Modelling of urban areas/ 3D city modelling (IIRS)** The 3D models of urban areas assist in better visualization of urban areas as well can be useful for building typologies, landscape morphological characteristics, urban climate studies and many more applications for urban planners. This involves review and development of algorithms for automatic extraction of buildings, reconstruction of building planes and construction of 3D model using LiDAR and high-resolution stereo pair data. Currently, emphasis is given to develop methods for generating the 3D models using high-resolution stereo satellite data and Laser scanner based data.
H8	**Utilization of remotely sensed data for species and vegetation health assessment and development of indices for urban green spaces (IIRS)** Objective assessment of urban green spaces for planning purposes is necessary for optimal distribution of urban green spaces. This involves development of easy to use comprehendible indices for the assessment of urban green spaces using remote sensing derived parameters. Further, availability of high-resolution multi-band data can also assist in identification of vegetation species as well as assessment of plant stress in urban areas.
H9	**Urban area characterization using very high resolution optical and microwave images (IIRS)** Most of the traditional processing algorithms fail when the resolution increases significantly. For instance, conventional statistical learning becomes intractable with hyperspectral data due to the data dimensionality. Similarly, while it is easy to classify urban versus non-urban areas with medium resolution data, very high resolution data enable the accurate classification at the building scale, but the use of such data requires completely re-designing the whole processing chain.

H10	**Thermal remote sensing for urban areas and understanding of UHI phenomena (IIRS)** Urban expansion involves land conversions from vegetated moisture-rich to impervious moisture deficient land surfaces. With growing urbanization, the local weather and climatic conditions of the area are varying considerably. Thermal remote sensing is a powerful tool to study the causes of changing land use pattern and the Urban Heat Island (UHI) effects. The thermal infrared data is useful for studying UHI over urban areas and plan the open spaces, accordingly.
H11	**Urban seismic risk assessment (IIRS)** Urban areas are growing at a rapid pace, as a consequence, urban areas have encroached upon areas not suitable for urban growth. There is an urgent need to quantify the urban risk due to seismic activity in terms of damage to buildings, infrastructure etc. These analysis will provide an input into the disaster preparation process.

4.0 Space Sciences Programme

A	Area	Investigation on Near Earth Environment (PRL)
A1	Sub Area	Thermosphere – Ionosphere System (PRL)
	Thermosphere and ionosphere are a mutually coupled system with neutral and plasma affecting each other on different time scales. In addition, this part of the atmosphere/ ionosphere also gets affected from the forcing above, by sources of solar origin and also from lower atmosphere. Thus comprehensive studies using various techniques are needed.	
A1.1	Thermospheric Airglow, Aurora and the associated processes (PRL)	
A1.2	Plasma and neutral dynamics in thermosphere-ionosphere system (PRL)	
A1.3	Coupling of High-low latitude thermosphere-ionosphere system (PRL)	
A1.4	Effects of solar eclipse, on ionosphere (PRL)	
A1.5	Waves and instabilities in ionosphere (PRL)	
A1.6	Geomagnetism: Ionospheric, magnetospheric and solar wind induced variable and transient (pulsations) phenomena (PRL)	
A1.7	Ionospheric modification (PRL)	
A1.8	Study of height profiles of electron density, electric field, and neutral wind in the equatorial F region (PRL)	
A1.9	Linking lower atmospheric forcing on the dynamics of the upper atmosphere (PRL)	
A1.10	Measurements of upper mesospheric temperature and winds (PRL)	
A1.11	Atmosphere coupling through wave forcing through observations and modeling (PRL)	
A1.12	Simulation of Rayleigh Taylor instability (PRL)	
A1.13	Modelling of equatorial electrojet (PRL)	
A1.14	Mesosphere lower thermosphere interactions (PRL)	
A2	Sub Area	Study of Low Latitude Ionosphere (PRL)
A2.1	Study of low latitude ionosphere applied to satellite based communication and navigation systems (PRL)	
A2.2	Ionospheric phenomena using TEC by GPS and other parameters (PRL)	
A2.3	GNSS based ionospheric retrieval under Equatorial Spread F events (PRL)	

A2.4	GNSS observations and ionospheric forecasting for quiet geomagnetic conditions (PRL)	
A2.5	Study of space weather events and geomagnetic storms in nearly same longitude zone to evaluate the latitudinal ionospheric response in the same local time zone. Similarly, study of longitudinal differences in such response (PRL)	
A2.6	Study of Electro-dynamical and thermospheric processes leading to positive and negative ionospheric storms in low latitudes (PRL)	
A3	**Sub Area**	**Magnetosphere Processes (PRL)**
	The understanding of the magnetic environment of the earth is important as it protects from high energetic solar wind particles and cosmic rays. Geo effective disturbances are important to be investigated not only to understand the response of magnetosphere but also to protect earth orbiting satellites.	
A3.1	Plasma instability processes (PRL)	
A3.2	Micro plasma process in magnetic reconnection region (PRL)	
A3.3	Triggering of sub storms and impact on global ionosphere (PRL)	
A3.4	Relationship between geomagnetic storms and sub-storms (PRL)	
A3.5	Investigation on plasma waves and their propagation characteristics. Turbulence: MHD Turbulence, Compressible Turbulence (PRL)	
A3.6	Wave particle interaction (PRL)	
A4	**Sub Area**	**Impact of Space Weather (PRL)**
	Disturbances in the sun, their propagation in the interplanetary medium, interaction of solar wind with magnetosphere decides the effectiveness of the solar disturbances that impact the near Earth environment.	
A4.1	Identification of structures and turbulence in solar wind plasma (PRL)	
A4.2	Interaction between solar wind and magnetospheric boundary (PRL)	
A4.3	Impact of space weather processes in ionosphere, thermosphere system (PRL)	
B	**Area**	**Atmospheric Dynamics and Coupling (NARL)**
B1	**Sub Area**	**Observations, Modelling and Simulations (NARL)**
B1.1	Modelling of atmospheric tides (NARL) Atmospheric tides are generated due to solar insolation absorption by water vapour, ozone, nitrogen and oxygen molecules. They play a major role in determining the thermal structure, circulation and ionospheric variabilities. The atmospheric tidal solutions can be obtained by solving Laplace tidal equations, which are basic fluid dynamical equations	

	and necessary heating. The equations can be solved to get the height and latitudinal profiles of different modes of tides
B1.2	**Generation and propagation of atmospheric wave modes (NARL)** The upper atmosphere is governed by dynamics in addition to radiation and chemistry. The atmospheric waves play a major role in determining the dynamics of the upper atmosphere. The waves range from acoustic gravity waves to planetary scale waves. They have different generation mechanisms, namely, latent heat release in the deep convection, land sea thermal contract, orography, instability mechanisms etc. It is necessary to understand the generation mechanisms of different atmospheric waves and their vertical propagation, which depend on the background winds and thermal structure.
B1.3	**Numerical simulations of stratospheric sudden warming and their global influence (NARL)** Sudden stratospheric warming is the sudden rise in temperature in the cold polar stratosphere during some winters. It occurs due to anomalous growth of planetary waves and their interaction with background wind. Though it occurs at high latitude stratosphere, it influences globally. The occurrence of SSW and their effect needs to be understood through numerical simulations
B1.4	**Gravity wave-tidal -mean flow interactions (NARL)** Tidal variability at mesospheric heights influences E-region electrodynamics, as the latter is mostly governed by tidal wind dynamo mechanism. The tidal variability can be influenced by gravity wave tidal interaction. Momentum deposition by gravity waves can accelerate/decelerate the mean wind and affect the amplitude and structure of tides. The eddy diffusion of gravity waves can affect the tidal variabilities. It is important to understand how gravity wave stress affects tidal amplitudes and background circulation.
B1.5	**Simulations of QBO, SAO and Intra-Seasonal Oscillation (NARL)** Equatorial middle atmosphere is characterized by quasi-biennial oscillation (QBO) in the lower stratosphere, semi-annual oscillation in the upper stratosphere and mesosphere. Besides, middle atmospheric parameters exhibit intraseasonal variability. The equatorial waves play major role in driving these oscillations. It is aimed to develop a model, which can simulate these long-period oscillations with realistic wave forcing and background wind parameters.
B1.6	**Influence of lateral wave forcing on tropical weather and climate (NARL)** Tropical weather and clime is influenced by potential vorticity intrusions. These intrusions trigger deep convection and control rainfall. How the extra tropical atmosphere influences the tropical weather and climate needs to be understood quantitatively. In addition, annular modes can influence the tropical weather. What is the impact of these extratropical forcing on Indian monsoon needs to be investigated.

B2	**Sub Area**	**Mesosphere-lower thermosphere system along with lower ionosphere (D and E-regions) (NARL)**
	This region acts as a buffer between upper atmosphere and lower atmosphere where wave activities are more. The region which filters out a lot of wave modes is not yet understood due to lack of systematic measurements.	
C	**Area**	**Sun and Solar System (PRL/URSC/VSSC-SPL)**
C1	**Sub Area**	**Planetary atmospheres (PRL)**
	Research at PRL involves the applications of stable and radioactive isotopes to characterize and determine time scales of processes occurring in the early solar system. The aim is to study the origin and evolution of the solar system with focus on inner planets. Further understanding physical and chemical processes of planetary atmospheres using observations, theoretical simulations and modelling of planetary atmospheres (Earth & Mars) and comets is also initiated. The subtopics include	
C1.1	**Formation of ionospheric layers in Mars and other planets (PRL)**	
C1.2	**Effect of dust in Martian and other planetary atmospheres (PRL)**	
C1.3	**Formation of planetary magnetospheres (PRL)**	
C1.4	**Planetary aurora and airglow (PRL)**	
C2	**Sub Area**	**Study of Comets (PRL)**
	Comets represent pristine solar nebular matter and hence studying comets is very important to understand the early solar system itself.	
C2.1	**Composition of dust and plasma tails (PRL)**	
C2.2	**Dust formation, distribution and characterization of dust tail (PRL)**	
C2.3	**Plasma processes in plasma tail (PRL)**	
C2.4	**Processes involving dusty plasma (PRL)**	
C3	**Sub Area**	**Solar Physics (PRL)**
	Udaipur Solar Observatory, as the name suggests is a dedicated facility to study the sun, the nearest star. Investigations of the Sun at USO revolve around the central theme of solar magnetic and velocity fields, solar activity, solar eruptive processes and high resolution solar observations. Efforts are being made to get a handle on the forecasting of these violent solar events. Basic physical phenomena of the birth and development of active regions, and flare mechanism can also be studied. The two major experimental facilities currently are the Global Oscillation Network Group (GONG) project and the Multi Application Solar Telescope (MAST)..	
C3.1	**Origin of Sun and Solar system (PRL)**	

C3.2	**Transient Phenomena: Flares, Eruptive Filaments/Prominences, Coronal Mass Ejections (PRL)** CMEs inject large amounts of mass and magnetic fields into the heliosphere, causing major geomagnetic storms and interplanetary shocks, which are a key source of solar energetic particles. CMEs are often ssociated with erupting prominences and flares but our physical understanding of how and why CMEs are initiated is poor. It is important to carry out long term and high resolution studies of source regions of CMEs and also monitor their manifestations in the solar wind. Further, study of halo-like CMEs, which suggest the launch of a geoeffective disturbance toward Earth is also very important for space weather forecasting purpose.
C3.3	**Surface Phenomena: Granules, Supergranules, Sunspots (PRL)** Understanding the thermal, magnetic, and kinematic structure of sunspots has been one of the frontier topics in solar physics. While the magnetic field can be inferred with high spatial resolution in the photosphere owing to bigger telescopes and sensitive polarimeters, its estimation is constrained over a narrow height where the spectral line is formed. Since the physical parameters from spectral line inversions are stratified with respect to optical depth, a geometrical transformation is necessary to derive physical quantities such as electrical current density, helicity, Wilson depression, plasma β, etc. This requires observing with several spectral lines spanning a large height range in the solar atmosphere, so as to satisfy the condition of force balance between structures such as the umbra and penumbra, that are relatively depressed by about 300 km
C3.4	**Magnetic field and velocity mapping (PRL)** Solar surface magnetic field is measured to monitor magnetic energy storage and evolution of the stresses leading up to these eruptions combined with the velocity measurements on the surface. Above the surface, physical parameters of the chromospheric and coronal phenomena are being used to predict the geoeffectiveness of these eruptions.
C3.5	**Solar cycle variation, prediction of activity cycle (PRL)** The 11-year activity cycle is a dominant characteristic of the Sun and also the solar dynamo that generates the solar magnetic field. The discovery of solar magnetic fields introduced a 22-year periodicity, as the magnetic polarities of the polar regions change sign every 11 years. Correlations have been identified and quantified among all the measured parameters, but in most cases such correlations remain empirical rather than grounded in physical processes. For a better physical understanding of solar physics a systematic reassessment of solar activity indices and their usefulness in describing and predicting the solar activity cycle is required.
C3.6	**Multi-wavelength studies of the Sun (PRL)** Our understanding of the solar interior, the visible outer layers, and the “invisible” corona are not complete.:New developments in the observational techniques from ground and space in optical, X-ray, ultra-violet and radio regimes of the electromagnetic spectrum are expected to continuously extend the frontiers of knowledge of the Sun in particular the eruptive phenomena such as flares and CMEs

C3.7	**Helio –seismology (PRL)** Helioseismology is based on precise measurements of solar oscillations and is being used as a tool to monitor pressure impulses generated by eruptions as well as the physical dynamics beneath solar active region producing the eruptions. Use of Global Oscillation Network Group (GONG) data	
C3.8	**MHD simulations for Solar and Stellar Atmospheres (PRL)** The solar eruptive events occur at regions where the magnetic field gradient is large. Since the coronal magnetic field cannot be measured reliably till date, a three-dimensional magnetic map of the corona needs to be constructed numerically. The basic idea is to exploit the magnetic field measured on the photosphere to extrapolate coronal magnetic field.	
C3.9	**Study of CMEs and space weather (PRL)** Coronal mass ejections (CMEs) shake the Earth's magnetic field causing current surges in power lines that can destroy equipment and disrupt communication, electric power transmission, particularly in high latitude regions. They pump energy into the radiation belts. The enhanced electromagnetic radiations released during the course of explosive solar flares ionize the Earth's upper atmosphere, and also pose a threat to astronauts. The stormy space weather can physically damage satellites, change their orbits and shorten mission lifetimes.	
C4	**Sub Area**	**Planetary Sciences (NARL /URSC)**
C4.1	**Saturn's upper atmosphere (NARL)** Plasma in the Saturn's upper atmosphere, magnetosphere, radiation belts, interaction with its rings and moons, the rotation period of Saturn	
C4.2	**Investigations on the problem of Methane on planetary atmospheres: Mars and Pluto (NARL)**	
C5	**Sub Area**	**Geosciences (PRL)**
C5.1	Understanding the origin and evolution of the planet earth and its various components, with special emphasis on timescales and processes. Very broadly, the main themes pursued at PRL are : (1) Solid Earth Studies; (2) Aquatic and Terrestrial Biogeochemistry; (3) Paleoclimate; (4) Isotope Hydrology; and (5) Aerosol Chemistry. Most of the geoscience research requires extensive field work for field observations and collection of required samples from various geological and environmental reservoirs and repositories (geological formations, cave deposits, tree rings, coral reefs, terrestrial and oceanic sediments, seawater, groundwater, river water, estuaries, rain, snow, atmospheric moisture and aerosol). The data so painstakingly collected is then analysed using state of the art instruments which include various mass spectrometers, chromatographs and gas analysers following detailed and dedicated protocols developed for each study.	

C6	Sub Area	Planetary Science (VSSC-SPL)
C6.1	**Modelling the atmospheres of Venus, Mars and other planetary atmospheres (VSSC-SPL)** Modelling of planetary atmospheres for atmospheric circulation, thermodynamics, ionospheric features, emissions and chemical composition, and escape of gases of different planetary atmospheres are gaining significance and are achieving rapid strides with several planetary exploration missions being planned and also plans for sample return. As a first step numerical simulation of the planetary atmosphere, its dynamics and climate systems can be attempted. The Global Circulation Models for planets can yield a simulation of the global atmosphere and the global climate. The challenging area in this topic is developing the limited area (meso/micro scales) to interpret landed space craft data and also to examine the meteorological systems in the planetary atmospheres on sub-global scales, which can simulate the boundary layer of the planets.		
D	**Area**	**Astronomy and Astrophysics (PRL)**
D1	**Sub Area**	**Galactic Astronomy, Extra-galactic Astronomy and Cosmology (PRL)**
D1.1	**Interstellar medium (PRL)** Star formation in giant molecular clouds. Disks and Jets around low/high mass proto-stars. Cluster identification, classification and characterization. Proto Planetary nebulae, Chemically peculiar Planetary Nebulae. Asymmetric Planetary nebulae Extinction curves and their modelling in various wavelength regions: infrared and far – Ultra-violet. Origin of 217.5 nm feature. Polycyclic Aromatic Hydrocarbon molecules and their contribution to interstellar extinction.		
D1.2	**Astro-biology and astro-chemistry (PRL)** Formation of pre-biotic molecules in interstellar matter origin of life. Formation of interstellar giant molecules in star forming clouds. Experiments of astrobiological importance to detect most important biomolecules and their precursors that would provide clues on the origin of life.		
D1.3	**Dust formation in Stellar Ejecta Modelling of Circum-stellar matter (PRL)**		
D1.4	**Star spots: Photometric and spectroscopic variability studies (PRL)**		
D1.5	**Chemically Peculiar Stars: stars with abundances different from solar abundances (PRL)**		
D1.6	**Astro-seismology: Variability in spectral line profiles at high resolution (PRL)**		
D1.7	**Extra-Solar-Planets: Transit observations using a small facility (PRL)**		
D1.8	**Binary Star Phenomena: Novae, Supernovae Type-I, Cataclysmic variables, X-ray binaries with Black Hole and Neutron Star companions, Transient phenomena Quasi-Periodic oscillation in X-ray binaries (PRL)**		

D1.9	**Ultra-luminous X-Ray Sources, Micro-quasars, Study of environments of Black Holes of different masses: 105 Solar mass to Stellar mass (PRL)**	
D1.10	**Studies on the galactic centre (PRL)**	
D1.11	**Studies on Elliptical and Spiral Galaxies, ISM in external galaxies, Star formation and evolution in external galaxies (PRL)**	
D1.12	**Investigation of Active galactic Nuclei, Star-burst galaxies, Intergalactic medium (PRL)**	
D2	**Sub Area**	**Theoretical Astrophysics (PRL)**
D2.1	**Theoretical and Observational studies on Dark Matter and Dark Energy, Theoretical and Observational Cosmology (PRL)**	
E	**Area**	**Space Instrumentation (PRL)**
E1	**Sub Area**	**Ionosphere/Thermosphere (PRL)**
E1.1	**Plasma measurements, airglow emissions experiments (PRL)** Magnetometer Electric Field Electron/ Ion Density & Temperature Imagers/Photometers/Spectrometers Winds and temperature (neutral) Drift Meter, Composition measurements Radio Beacon and Occultation	
E2	**Sub Area**	**Earth's Lower/Middle Atmosphere (PRL)**
E2.1	**Aerosols, minor constituents & Trace Gases experiments (PRL)** 1. Optical Photometers 2. Infrared Photometers 3. Infrared Spectrometer 4. Visible photometer for lightening 5. Active Experiments like Lidar, SAR, Scatterometer	
E3	**Sub Area**	**Planetary Exploration (PRL)**
E3.1	**Atmosphere experiments (PRL)** 1. Charge particle measurements 2. Composition (Mass Spectrometer) 3. Vertical distribution of Electron Density 4. Vertical distribution of Species	

E4	Sub Area	Planetary Atmosphere (PRL)
E4.1	**Surface measurements (Elemental composition) experiments (PRL)** 1. X ray Spectrometer 2. Laser induced breakdown spectroscopy 3. Surface & Subsurface Temperature 4. Dust and surface charging 5. Microwave radar	
E5	**Sub Area**	**Astronomy (PRL)**
E5.1	**Instrumentation for ground-based and space-borne facilities (PRL)** 1. Visible & Infrared Photometers, Polarimeters and Spectrometers for ground-based and space-based facilities. 2. Ultra-violet spectro-photometers and spectrometers for space-based facilities. 3. X- ray instrumentation for space-based facilities (Imaging and Spectra and polarization) 4. Gamma Ray Spectrometer for space-borne platforms 5. Space telescopes. 6. Active and Adaptive optics for diffraction limited imaging. 7. Detector arrays for UV, Visible, IR and X-ray regions.	
E6	**Sub Area**	**Astronomical Instrumentation (URSC)**
E6.1	**Liquid crystal development for near infra-red spectroscopy (URSC)** National Large Solar Telescope(NLST) is a ground based system which requires a novel detector for faster Spectro-polarimetry as to minimize induced cross-talks. Development of Liquid Crystal controllers within India is a critical pre-condition for high accuracy polarimetry.	
E6.2	**Multilayer coated mirror characterization for X-ray optics–Process and charaterization (URSC)** X-ray multilayer mirrors is a critical technology involved in the use of Imaging Spectrometer for Solar Wind charge exchange from exospheres. Characterization of X-ray multilayer coated mirrors is required.	
E7	**Sub Area**	**Solar Studies (PRL)**
E7.1	**Charge Particle & Radiation Flux in X, UV, Optical & IR wavelengths experiments (PRL)** Optical Photometers/ Spectrometers Infrared Photometers/ Spectrometers Charge particle energy & flux measurements	
E7.2	**Active and adaptive optics for diffraction limited imaging (PRL)**	

E8	**Sub Area**	**X-ray transients (URSC)**
E8.1	**Timing and spectral studies of X-ray transients (URSC)** Timing and spectral studies of X-ray transients like Cataclysmic variables, searching for new QPOs and coherent pulsations in X-ray binaries using archival data. Some of the scientific problems that can be addressed under these studies are: Estimation of the mass of compact objects in binaries Modeling the complex emission mechanisms from accretion disk around Galactic and extragalactic X-ray sources	
E9	**Sub Area**	**Exo-planets: Exo-planet studies with archival data (URSC /PRL)**
E9.1	**Experiments to detect biosignatures of planetary / exoplanetary systems (PRL)**	
F	**Area**	**Remote sensing data analysis from planetary exploration missions (PRL/SAC/IIRS)**
F1	**Sub Area**	**Moon (PRL/ SAC/ IIRS)**
F1.1	**Chemical, mineralogical and morphological studies (PRL)**	
F1.2	**Lunar surface sciences (SAC)** The main research themes for research includes Lunar Surface composition, Lunar morphology, Hyperspectral data analysis for Lunar Surface, Thermal Remote Sensing of the Moon, Spectral characterization of Lunar analogues, Lunar surface dating and lunar volcanism. Multi-frequency microwave SAR studies for H2O / Ice detection on Lunar surface.	
F1.3	**Lunar gravity and crustal thickness studies (SAC)** Using the surface elevation and satellite tracking data lunar gravity can be deduced and this gravity data can be further modelled using gravity reduction methods to find out the lunar crustal thickness, which provide information about the lunar interior processes. The main research themes include Lunar gravity modelling, inversion modelling for crustal thickness and lunar interior.	
F2	**Sub Area**	**Mars (PRL/ SAC/ NRSC)**
F2.1	**Surface and atmospheric processes on Mars (PRL)**	
F2.2	**Records of aqueous activities on Mars (PRL)**	
F2.3	**Solar interaction and atmospheric loss processes (PRL)**	
F2.4	**Studies related to Martian surface and polar ice (SAC/ NRSC)** Major research themes are Characterization of Martian analogues rocks in India, Hyperspectral analysis of Mars data, Thermal remote sensing of Mars, Martian Atmosphere. Surface composition of mars Remote Sensing for Trace gases. Study of Phobos & Deimos (Moons of Mars).	

F2.5	**Terrestrial analogue studies (SAC)** Geochemical, Spectroscopic, X-ray & astro-biological studies of the terrestrial analogues of Moon and Mars.	
F2.6	**Development of Polarimetric SAR based Model for Lunar and Martian surface parameter retrieval (SAC)** ISRO's future planetary missions to Moon and Mars will be equipped with SAR payloads imaging the planetary surfaces/ sub-surfaces by multi-frequency polarimetric radars and radiometer. SAC is engaged in development of algorithms for retrieval of surface parameters such as dust/regolith roughness, thickness, dielectric constant and detection and quantification of sub-surface water-ice in the Lunar and Martian environment. New research is required for development of algorithms, simulation models and tools for retrieval of geo-physical parameters of Lunar and Mars surfaces.	
F3	**Sub Area**	**Planetary Data Processing (SAC)**
F3.1	**Vision based horizontal velocity estimation of lander craft using optical flow methods (SAC)** It will involve study of algorithms and development of software for vision based horizontal velocity computation, useful for soft landing of lander craft (Chandrayaan-2).	
F3.2	**DTM generation from terrestrial stereo images & path guidance algorithm development for rover instrument (SAC)** This calls for (i) study and understanding the methodology/techniques and related software development for deriving DTM from terrestrial stereo images using close range photogrammetry concepts (for Chandrayaan-2 Rover camera) and (ii) Derivation of optimum path between two points using the terrain information over moon surface.	
F4	**Sub Area**	**Minor Solar System Objects (PRL)**
F4.1	**Meteorite asteroid connection- Comparison of reflectance spectra (PRL)**	
F5	**Sub Area**	**Astronomical Data Processing and Analysis (SAC)**
F5.1	**Autonomous spacecraft navigation using Pulsars (SAC)** To evaluate the usability of fast spinning and strongly magnetized neutron stars, also known as pulsars, in defining and external reference system suitable for deep space navigation. To propose a methodology that can be used in deep space navigation for operational purpose.	
F5.2	**Study of anomalous X-Ray Pulsars (SAC)** The objective of this study is to review and add understanding of recent observation as well as analysis of Anomalous X-Ray Pulsars with an emphasis on timing, variability, and spectra. This study should contribute in deeper understanding of AXP in terms of its high and variable magnetic field, its evolution and its importance in life cycle of a star. Astrosat Data will be used for study and other contemporary satellites data will be used for validation.	

G	**Area**	**Laboratory study of Astromaterials (PRL)**
G1	**Sub Area**	**Meteorites from asteroids (PRL)**
G1.1	**Early solar system processes and time scales (PRL)**	
G2	**Sub Area**	**Moon and Mars Meteorites (PRL)**
G2.1	**Composition, evolution and chronology (PRL)**	
H	**Area**	**Study of terrestrial analogues of Moon and Mars (PRL)**
H1	**To understand surface properties and aqueous processes on Mars (PRL)** Geochemical, Spectroscopic, X-ray & astro-biological studies of the terrestrial analogues of Moon and Mars	
I	**Area**	**Payloads for upcoming planetary missions (PRL)**
I1	**Experiments based on EM radiation, particle irradiation and nuclear reactions can be devised to understand surface and subsurface composition and the equipment can be realized in a miniaturized space qualified form (PRL)**	

5.0 Meteorology

A	Area	Weather and Climate (NARL/ SAC/IIRS/ NESAC)
A1	Sub Area	Modelling and Computer Simulations for Weather Prediction (NARL/SAC/NESAC)
A1.1	**Estimating wind and solar energy resources over Indian region and the development of forecasting system for predicting wind potentials using mesoscale Weather Research and Forecasting model (NARL)** Increasing concerns over the global warming and environmental pollution prompts the policy makers to look for the alternate energy resources in place of the conventional energy sources. Solar and wind energy are prominent renewable energy resources to us the last few decades, though considerable effort has been made to use renewable energy resources effectively in the western countries, Asian region still lags in the effective utilization these alternate resources. One of the primary steps in renewable energy filed is the resource assessments for identifying the optimal locations for extracting the winds and solar energies which needs high resolution wind and solar data sets.	
A1.2	**Development of fully coupled ocean-atmospheric model for improving the forecasts of Indian Summer Monsoon at medium-range and seasonal timescales (NARL)** The relative failures of numerical weather prediction models to capture the observed variability of Monsoon on medium range to seasonal time scale and failure to estimate the intensity of extreme events prompts to search for in-abilities of the atmospherics models. One of such problems in NWP models is the lack of precise ocean feedback to atmosphere which is highly essential for understanding and predicting monsoon behavior from long-range to medium-range temporal scales. Development of fully coupled ocean-atmospheric model can certainly improve the forecast skill of NWP model for prediction Indian Summer Monsoon at medium-range and seasonal timescales.	
A1.3	**Analysis of extreme weather events over Indian region using numerical modelling tools (NARL)** Understanding tele-connections and the analysis dynamical and physical mechanisms behind the frequent occurrence of extreme rainfall events over Indian region is essential for improving the physical parameterizations in NWP models. The recent studies over Monsoon variability reveals the number of extreme weather events during monsoon season are increasing, potential mechanisms are extremely required to models these process and predicting accurately.	
A1.4	**Development optimal assimilation methods for assimilation X-band DWR in NWP models (NARL)** Commencement of dense network of X-band Doppler weather radar provides us opportunity to have various profiles of hydrometeors which can effectively assimilated in numerical weather prediction models using different assimilation strategies for improving operational weather prediction systems. Development of optimal assimilation methods are highly	

	essential for effective assimilation of hydro-meteors and radial velocities from the dual polarized Doppler weather radar (ISRO X-band DWR) data for improving the forecasts of mesoscale convective systems such as thunderstorms, cyclones and extreme heavy rainfall events.
A1.5	**Numerical weather prediction with general circulation models (SAC/NESAC)** Real time weather forecast is an essential component during satellite launches from the launch pad as the launch vehicle is exposed to weather 2-3 days before the launch. Short range weather prediction is made using numerical weather prediction model and assimilation of satellite data. The same technique is also used for All India weather forecast in 5 km resolution. This involves dynamic modelling, physical parameterization and assimilation of satellite data. Better understanding of the monsoon processes thus needs to be resolved by both NWP models and reanalysis data using high-resolution satellite data. Cloud classification and to understand the role of various clouds/rains in monsoon performance and its variability.
A2	**Sub Area** — **Atmospheric sciences and climate (SAC/ NESAC/IIRS)**
A2.1	**Retrieval of geophysical parameters from satellite data (SAC/ NESAC)** ISRO has planned for launching a number of meteorological and oceanographic satellites in near future. It has already INSAT-3D, Megha-Tropiques and SARAL satellites in the orbit. In near future it has planned to launch GISAT. It is a challenging work to retrieve geophysical parameters from the sensor data of these satellites. This involves Radiative Transfer modelling and the Inverse modelling techniques for retrieval of highly accurate precipitation and atmospheric wind products.
A2.2	**Cyclone track and intensity prediction using satellite data and numerical models (SAC)** Cyclone track and intensity prediction is very important activity as there is huge damage occurred due to cyclones and is being done by using numerical models and satellite data that involves empirical and dynamic modelling and assimilation techniques.
A2.3	**Climate prediction with coupled Atmosphere-Ocean-Land-Ice models (SAC/ NESAC)** For long term prediction of climate, Coupled model of Atmosphere, Ocean, Land and Ice is very important component. In these models, coupling is an important area of research as different components have different spatial and temporal variability.
A2.4	**Atmospheric sounding (measurement and understanding of vertical distribution of physical properties of the atmospheric column such as pressure, temperature, wind speed and wind direction, pollution and other properties using remote sensing and in situ observation) (IIRS/ NESAC)**
A2.5	**Assimilation of satellite data in numerical weather prediction models (SAC)** Accurate prediction of high-impact weather events and the area of the greatest threat represent a major challenge for planners to minimize the loss of lives and damage to

	property. Advance research is being planned to be carried out for non-linear data assimilation of satellite derived parameters in numerical weather prediction models. ISRO is aiming at improving short to long range weather forecasting using satellite based observations. For this activity various satellite observations are ingested in Numerical Weather Prediction (NWP) model using various data assimilation (DA) techniques.
A2.6	**Seasonal prediction of Indian Summer Monsoon (ISM) using climate model (SAC)** In the Indian subcontinent, the most well-known seasonal phenomenon is the Indian summer monsoon (ISM) occurring every year from June through September. This is one of the most dominant features of the global hydrological cycle as well. Though the onset of the monsoon over Kerala in India takes place at the start of June with the seasonal reversal of wind over the Arabian Sea with a consistent manner from year after year, the monsoon rainfall is characterized by significant intra-seasonal and inter-annual variability over and around India. Therefore, there is a recognized need for seasonal prediction of ISM well in advance describing the spatial and temporal variability of AIR.
A2.7	**Diagnostic studies for monsoon (SAC/NESAC)** For better prediction of Indian Monsoon, it is necessary to understand the physical mechanism of convective processes and monsoon dynamics. The data from Indian satellites are extensively used to understand the meteorological and oceanographical processes that govern the Indian summer monsoon and its variability. A lot of diagnostic studies are being carried out using satellite data like vertical profiles of atmospheric temperature and humidity.
A2.8	**Satellite derived cloud microphysical parameters (SAC)** Clouds are modulators of Earth's climate and hydrological cycle. Microphysical parameters are also important for studying the evolution of high impact cloud system and understanding cloud-aerosol interactions
A2.9	**Satellite based weather now casting for heavy rainfall events (SAC)** Timely alert of extreme precipitation events has a huge societal impact. Data acquired from geostationary satellites are helpful in predicting the evolution of convective systems. Weather now casting over a time scale of few hours play a very important role.To further improve the skills of thunderstorm forecasting, new techniques will be developed using satellite data(Environmental, thermodynamic and stability parameters, Stability indices like Lifted Index, CAPE, CINE, K-Index), NWP model forecast and forthcoming dense DWR networks.
A3	**Sub Area** — **Convection/Precipitation/Boundary Layer (NARL)**
A3.1	**Understanding the decadal changes in solar radiation flux at surface and relation with sunspot activity/ solar cycle (NARL)** Pyrheliometer can be used to measure direct beam radiation from the Sun and it can be used to measure the total hemispherical radiation (beam + diffuse radiation). The duration of sunshine intensity can be measured using a photoelectric sunshine recorder. Changes in solar radiation fluxes during active Sun period vs. quiet period over a longer period of time is proposed to be studied for one or more latitudes.

A3.2	**Understanding the decadal longwave emission by atmosphere and by earth (NARL)** Earth emits longwave radiation which is responsible for keeping the atmospherewarm. Longwave radiation from earth's surface can be measured using a pyrgeometer. Long term analysis needs to be done to understand the decadal changes in longwave emissions by the earth.	
A3.3	**Studies on logarithmic wind profile of boundary layer (NARL)** Wind speed and direction data obtained from anemometers fixed at logarithmic spacing in a 50 m tower is to be analysed to understand the log-profile of wind in the boundary layer. The study needs to extended over a longer period to understand the robustness and changes for the season and for different weather conditions.	
A3.4	**Understanding cloud characteristics and properties using lidars (VIS & IR) (NARL)** Visible and IR lidar data range-time-intensities need to analysed to detect clouds passing over the location. Cloud characteristics like base, top height, thickness, optical thickness, frequency of occurrence, non-sphericity of particle can be studied for a longer period.	
A3.5	**Cloud radiative forcing studies over Gadanki (NARL)** The radiation fluxes reaching the earth surface measured using shortwave, longwave and broadband radiometers/ pyranometer, pyrheliometer could be utilised. Differences in fluxes in the presence and absence of clouds gives the cloud radiative forcing.	
A4	**Sub Area**	**Radiation, Aerosols and Trace gases (NARL/IIRS/NRSC)**
A4.1	**Development of low cost nephelometer (NARL)** Nephelometer is an important instrument for aerosol optical properties which are needed to be known for the climatic effects. Current nephelometer technology uses halogen lamp and heavier parts, which are not suitable for balloon borne observations. Recent advancement in LED technology makes it possible to develop light weight low cost nephelomter with similar performance. This will be employed for the developing space-borne nephelometer for the regular and campaign mode observations.	
A4.2	**Development of OH analyzer (NARL)** Hydroxyl radical (OH-) is an important oxidiser in troposphere and responsible for the removal of green house gases. However due to high reactivity, very short life time, their concentrations are difficult to measure. Since there is no commercially available OH analyzer, it will be developed in house.	
A4.3	**Chemistry of minor and trace constituents that are precursors to ozone chemistry (IIRS)** Ozone is a secondary pollutant, a greenhouse gas and an oxidizing agent in the troposphere. It is produced in the atmosphere from the chain reactions of several primary pollutants like CO, NO, NO2 and hydrocarbons in the presence of sunlight. Ozone photochemistry is highly complex and varies from one location to other significantly. It is particularly important over the Indian region due to availability of sufficient water vapor and intense	

	solar radiation. Measurement of these gases are scarce over the Indian Subcontinent and satellite observations do not provide information on these gases with much accuracy specifically near the earth surface. Development of a dense network of these observations is required over India. A regional/global chemistry transport model based studies can help in better understanding on various processes influencing the distribution of these pollutant gases over the Indian Subcontinent.
A4.4	**Atmospheric modelling (NESAC)** Pixel based Aerosol Optical Depth (AOD) estimation by radiative transfer modelling using TOA radiance and validation with field instruments. Development of image based aerosol retrieval techniques over satellite imagery.
A4.5	**Aerosol characterization and its impact on solar radiation (NRSC)** Absorbing aerosols over Himalayas assume importance not only because of their enhanced radiative impacts when they reside over high albedo surfaces, but also due to their effects on snow whiteness and glacier retreat after deposition. In addition, absorbing aerosols over foot hills of Himalayas and Tibetan plateau are reported to have significant impacts on Indian summer monsoon and associated rainfall. Though several studies have been carried out, aerosol impacts on Indian summer monsoon are not yet clearly understood. In view of these, impacts of aerosols over Himalayan regions are being examined using satellite remote sensing and ground based measurements. Aerosol vertical distribution and contribution of dust in aerosol loading over Himalayas are examined using multi-year satellite observations. Measurements of Black Carbon (BC) concentration in atmosphere; snow and changes in spectral albedo due to BC deposition will be carried out by conducting field experiments over different regions of Himalayas.
B	**Area** — **Space Physics (VSSC-SPL)**
B1	**Sub Area** — **Atmospheric Studies (VSSC-SPL)**
B1.1	**Development of state-of-the-art inversion techniques for the retrieval of aerosol parameters over the ocean and land areas from the satellite-measured radiance (VSSC-SPL)** Assessment of the regional distribution of aerosols can be best carried out using satellite remote sensing of spectral radiances observed at the top-of-the-atmosphere. However, in addition to aerosols, theses radiances are contributed by several other sources, including surface reflectance, absorption, emission and scattering by air molecules, and multiple scattering by aerosols and molecules. Hence, determination of aerosol properties from satellite data requires several assumptions and adequate inversion schemes. Development of state-of-the-art inversion techniques for the retrieval of aerosol parameters over the ocean and land areas from the satellite-measured radiances (including polarization and angular measurements) observed at multiple wavelength bands, which incorporate multiple scattering, surface reflectance and absorption and scattering by aerosols and molecules is a challenging problem. The study can have two parts: (i) theoretical formulation, algorithm and software development, simulations and

	sensitivity analysis, (ii) inversion of the satellite data based on the above algorithm to derive aerosol properties and its validation based on comparison with other observations (including in-situ observations).
B1.2	**Development of state-of-the-art inversion techniques for the retrieval of trace gases over ocean and land from the spectral radiances in the UV, visible, and IR wavelength bands (VSSC-SPL)** Three-dimensional distribution of trace gases, their time evolution and long-range transport is a major aspect to be studied in the contest of increased greenhouse gas emission and climate change. This can be achieved by satellite remote sensing of the spectral radiances observed at the top-of-the-atmosphere in suitable configurations (e.g., limb viewing, nadir viewing, solar occultation). Development of state-of-the-art inversion techniques for the retrieval of trace gases over ocean and land from the spectral radiances in the UV, visible, and IR wavelength bands is a major problem which requires extensive radiation transfer simulations and development of appropriate mathematical inversion schemes. This study should comprise of theoretical formulation, algorithm and software development, simulations and sensitivity analysis, retrieval based on the available satellite data and its comparison with other observations.
B1.3	**Numerical modelling of the impact of aerosols and trace gases on regional climate over the Indian region incorporating space-based observations (VSSC-SPL)** It is well known that the atmospheric aerosols and greenhouse gases play a crucial role in modifying the climate, including changes in the atmospheric and surface temperatures, cloud development and precipitation pattern. Quantification of this aspect is a major ch allenge in the present scenario. Numerical modelling of the impact of aerosols and trace gases on regional climate (including atmospheric and surface temperature, rainfall, extreme weather events) over the Indian region incorporating space-based observations can be a problem to be taken up through RESPOND. This also includes the potential impact on monsoon circulation and associated rainfall changes.
B1.4	**Modelling of the atmospheric boundary layer parameters and processes based on improved parameterization schemes for tropical regions (VSSC-SPL)** Dynamics and time evolution of atmospheric boundary layer (ABL) plays a crucial role in the transfer of mass, momentum and energy from the surface to the atmosphere, mixing of aerosols, water vapour and pollutants (including trace species), exchange with free-troposphere, and development of convection and clouds. The boundary layer parameters and processes are parameterized in numerical models. Often, the ABL characteristics represented in models do not agree with those observed and is a major source of error in the numerical models, especially over the tropics. This requires the modification of the parameterization schemes for ABL parameters in numerical models. Modelling of the atmospheric boundary layer parameters and processes based on improved parameterization schemes suitable for tropical regions that reproduce the observed boundary layer fluxes and mixing height is a major problem that needs to be addressed.

B1.5	**Modelling of the propagation of atmospheric gravity waves and planetary waves, their dissipation and role in regulating the mean winds and temperatures in the middle and upper atmosphere (VSSC-SPL)** Atmospheric waves of various scales and sources generated in the lower atmosphere propagate through the middle atmosphere, carrying the momentum and energy to the middle and upper atmosphere. This is one of the most importance mechanisms of coupling between different atmospheric layers. Dissipation of these waves in the middle atmosphere is a major source for regulating the thermodynamics and circulation of the mioddle atmosphere. The generation of stratospheric quasi-biennial oscillation (QBO) and stratospheric and mesospheric semi-annual oscillations are classical examples of these processes. Dissipation of these waves in the upper atmosphere is a major cause for the ionospheric variabilities. Modelling of the propagation of atmospheric gravity waves and planetary waves, their dissipation and role in regulating the mean winds and temperatures in the middle and upper atmosphere is a challenging problem.	
B1.6	**Modelling the space weather impacts over the equatorial and low latitude regions (VSSC-SPL)** Earth's ionosphere plays a pivotal role in the propagation of radio waves and has applications in GPS navigation. This requires a detailed understanding and modelling of the ionospheric processes and characteristics. There are several important aspects to be investigated in this direction. This include the modelling of development and decay of different layers and phenomena (e.g., Spread-F, Counter Electrojet, Ionospheric ledges), spatio-temporal evolution of total electron content (TEC) over the low latitude and equatorial region, effect of dynamical forcing from the lower atmosphere, geomagnetic effects and space weather, and lateral and vertical coupling.	
C	**Area**	**Signal and Data Processing (NARL/ NESAC)**
C1	**Sub Area**	**Parameter Retrieval Algorithm Developments (NARL/ NESAC)**
C1.1	**Lidar signal inversion methods (NARL)** There are different types of light scattering, namely, Rayleigh, Mie, Resonance, and Raman. These scattered signals can be used to retrieve atmospheric parameters, namely temperature, scattering ratio, density of metal species, lidar depolarization ratio. Improvements in the retrieval methods are needed to retrieve these parameters more accurately.	
C1.2	**Retrieval of temperature and minor constituents in the atmosphere from the satellite based radiance measurements (NARL)** The radiance measured from the satellite borne radiometer at the limb viewing for different wavelength channels can be used to retrieve temperature and minor constituents. Usually the 15 um CO2 emission is used as the mixing ratio of CO2 is nearly constant. By inverting radiative transfer equation, the temperature and mixing ratios of chemical constituents can be derived.	

C1.3	**Retrieval of electron density from GPS occultation measurements (NARL)** Through receiving the GPS signals on the low-earth orbiting (LEO) satellite, the total electron content (TEC) along the GPS ray can be obtained. Under some specific configuration of the LEOGPS locations, the elevation angle of continuous LEO GPS rays can change from positive (negative) to negative (positive), which is recognized as an occultation event. The electron density profile (EDP) along the tangent points of these GPS rays under some assumptions using the TEC observations by employing Abel inversion method.
C1.4	**Radar signal processing (NARL)** From the time series of in phase and quadrature phase of the radar signals, noise removal and coherent integration for desired number of pulses, spectrum is obtained to compute the mean Doppler, Doppler width. The Doppler frequency obtained from three non coplanar directions is used to obtain wind information and the Doppler width is used to study turbulence.
C1.5	**Improvements in satellite rain retrievals using advanced statistical or physics based algorithms (NARL)** There was large variation among algorithms in the magnitude of the satellite-estimated rainfall, but the patterns of rainfall tend to be similar among algorithm types. Compared to the radar observations, most of the satellite algorithms overestimated the amount of rain falling in the region, typically by about 30%. Patterns of monthly observed rainfall were well represented by the satellite algorithms.
D	**Area** — **Radar and Lidar Instrumentation for Atmospheric Probing (NARL)**
D1	**Sub Area** — **Development of Radar and Lidar Accessories/Techniques (NARL)**
D1.1	**Time dependent attenuator for Lidar signal (NARL)** The time-dependent variable attenuator is used to reduce the dynamic range of lidar signals. The attenuator consists of a Pocket cell between two crossed polarizers that is incorporated into the receiving optic. The transmission is controlled electronically to attenuate the large signals from close ranges but to transmit far-range signal returns to their full extent. The signal dynamic range can be reduced even by a factor of 100.
D1.2	**Development of a fiber optic based IF filter for lidar to solve the problem of temperature dependence of filters (NARL)** Optical fibers are made from silica (glass) and hence carry some inherent advantages such as usability in harsh, high temperature and rugged environments, and immunity to electromagnetic interference. Besides, silica is also a chemically passive material and hence it is not affected by corrosive factors that might be present in the environment. Multiplexing capabilities that allow distributed sensing applications.

D1.3	**Digital up-converters (NARL)** Analog Devices digital up/down converters serve as the frequency translator and digital filter between data converters and digital signal processing blocks. These products enable highly programmable and configurable receive and transmit signal chains, allowing multichannel, multicarrier radio platforms. They also meet the digital data conversion requirements for many types of radar and communication applications
D1.4	**Digital synthesizer for radar exciter (NARL)** A radar exciter provide coherent frequency and timing relationships performed by direct digital synthesis, capable of creating high-resolution wideband waveforms for radar systems. The exciter provides fully coherent receiver local oscillator signals at radar frequency band as well as requisite, auxiliary high frequency clock signals.
D1.5	**Digital receiver for radar system (NARL)** With the development of digital processing technology, there are emerging trends toward digitization in radar receivers design. By applying direct intermediate frequency-to-digital conversion (IF sampling) and direct digital synthesis (DDS), digital radar receivers can be designed. The digital radar receivers can obtain much higher precision and stability than analog ones; moreover, it can retain the extreme flexibility of digital techniques.
D1.6	**Digital beam forming techniques (NARL)** Beam forming is a signal processing technique used in antenna arrays for directional signal transmission or reception by combining elements in an antenna array in such a way that signals at particular angles experience constructive interference while others experience destructive interference and it be used at both the transmitting and receiving ends in order to achieve spatial selectivity. Digital beamforming has the advantage over its analog counterpart that the digital data streams can be manipulated and combined in many possible ways in parallel, to get many different output signals in parallel. The signals from every direction can be measured simultaneously, and the signals can be integrated for a longer time when studying far-off scatters and simultaneously integrated for a shorter time to study fast-moving scatterers. Imaging radars need to be tested with different beam forming techniques (Fourier, capon to state a few) to select the technique, which will give high spatial and temporal resolution.
D1.7	**Clutter removal techniques (NARL)** Various non-atmospheric signals contaminate radar wind profiler data, which produce bias in estimation of moments and wind velocity. Especially, in ultra high frequency (UHF) wind profilers, ground clutter severely degrades wind velocity estimation. Moreover, noise dominates the clear air signal at higher heights. It is necessary to eliminate the clutter signal to detect the weak atmospheric signals buried inside the noise and to improve the SNR. Wavelet analysis is a powerful tool to differentiate the characteristics of the ground clutter and noise from the atmospheric turbulence echo at the time series level.

D1.8	**Radar imaging techniques (NARL)** An imaging radar is a kind of radar equipment used for imaging. A typical radar technology includes emitting radio waves, receiving their reflection, and using this information to generate data. For an imaging radar, the returning waves are used to create an image. When the radio waves reflect off objects, this will make some changes in the radio waves and can provide data about the objects, including how far the waves traveled and what kind of objects they encountered. Using the acquired data, a computer can create a two or three dimensional image of the scatterers. Current radar imaging techniques rely mainly on synthetic aperture radar (SAR) and inverse synthetic aperture radar (ISAR) imaging. Monopulse radar 3-D imaging is an emerging technology.
D1.9	**Dual-polarized patch antenna for radar applications (NARL)** The dual-polarized broadband antenna array is used for UHF wind profiler radar applications. It needs to have differentially probe-fed, stacked patch antenna features high port-to-port isolation and correspondingly good cross-polarization characteristics. Besides, it should have high efficiency and good port-to-port matching. It has to give good polarimetric performance over a wide scan range without excessive calibration requirements.
D1.10	**Design and development of solid state TR modules for radar applications (NARL)** The transmit/receive (T/R) module is a key component of radar antennas. Significant improvements in T/R module efficiency will reduce overall power consumption, simplify the thermal design and increase reliability. By miniaturizing the T/R modules, they can be used for both conventional ground based phased array antennas and in lightweight antennas for the ISRO space missions.

Annexure - 1

Addresses of ISRO/DOS Centres for the submission of Research Proposals

Sl. No.	ISRO/DOS Centre/Unit
1	**Director** Vikram Sarabhai Space Centre (VSSC) ISRO P.O, Thiruvananthapuram - 695 022 e-mail : director@vssc.gov.in
2	**Director** Satish Dhawan Space Centre (SDSC), SHAR Sriharikota Range P.O. - 524 124 Nellore District. Andhra Pradesh e-mail : director@shar.gov.in
3	**Director** Liquid Propulsion Systems Centre (LPSC) Valiamala P.O. Thiruvananthapuram- 695 547 e-mail : director@lpsc.gov.in
4	**Director** UR Rao Satellite Centre (URSC) P B No. 1795, HAL Airport Road Vimanapura Post, Bengaluru- 560 017 e-mail : director@isac.gov.in
5	**Director** Space Applications Centre (SAC) Jodhpur Tekra, Ambawadi Vistar P.O. Ahmedabad- 380 015 e-mail : director@sac.gov.in
6	**Director** National Remote Sensing Centre (NRSC) Balanagar, Hyderabad - 560 037(A.P.) e-mail : director@nrsc.gov.in
7	**Director** Indian Institute of Remote Sensing (IIRS) 4, Kalidas Road, PB No. 135 Dehra Dun- 248 001 e-mail : director@iirs.gov.in
8	**Director** Physical Research Laboratory (PRL) Navarangpura Ahmedabad - 380 009 e-mail : director@prl.res.in

Sl. No.	ISRO/DOS Centre/Unit
9	**Director** ISRO Inertial Systems Unit (IISU) Vattiyoorkavu PO Thiruvananthapuram - 695 013 e-mail : iisu_director_office@vssc.gov.in
10	**Director** National Atmospheric Research Laboratory (NARL) Gadanki - 517 112 Pakala Mandal, Chittoor Dist., Andhra Pradesh e-mail : director@narl.gov.in
11	**Director** Semi Conductor Laboratory (SCL) Sector 72,S.A.S Nagar -160 071 (Near Chandigarh), Punjab e-mail : director@scl.gov.in
12	**Director** ISRO Propulsion Complex Mahendragiri - 627 133 Tirunelveli District Tamil Nadu e-mail : director@iprc.gov.in
13	**Director** North Eastern Space Application Centre Department of Space, Umiam-793103, Shillong Meghalaya e-mail : director@nesac.gov.in

RESPOND & AI

Capacity Building Programme Office

ISRO HQ, Bengaluru