Visvesvarayya Space Lab: Preliminary Space Lab Demonstrator

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Abstract. In this paper preliminary design of a space lab module is realised with bottom-up approach. Initial design iterations are performed on hexagonal cross-section module design assembled together in T shape. Design consists of research and human habitable sections integrated. Structural finite element analysis is performed on the design, further iterated to obtain suitable design configuration for both orbital and ground cases. Modal analysis is performed on the orbital design to study suitability of launch vehicle adaption. Thus obtained preliminary design concept along with theme of sub-system design is implemented in real-world, life-sized demonstrator at the institution. The demonstrator served as test bench to apply, test, observe functionalities, proving capability and engineering principles. Demonstrator performance was optimised for its respective operating condition i.e., orbital and ground. The work serves as preliminary design towards realising an in-space operating space lab.

Keywords: space station demonstrator · space station design · prototype

1 Introduction

Idea to create a habitable environment in the low earth orbit is age old. There exists hundreds or more engineering concepts for a space station like habitat. While designs pre-exist, each new generation of design is profoundly new. It is diverse in terms of application and uses for space missions that it renders to. Designs are reflection of the technology readiness level of that time and with evolution of technology, designs tend follow the trend of readiness level. First of its type to be implemented, skylab consisted of minimal components to study human habitation in space. Possibilities for docking the crew module, establish ground-space transportation ports, components for research that could be performed by crew on-board etc., astronauts stayed for about 90 days. In 1979, Skylab re-entered Earth atmosphere and the mission ended its presence in the orbit. It was replaced with International Space Station (ISS). ISS proved to be technically superior, flexible in terms of operations and far more advanced, with lessons learned

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from Skylab. It was launched at 400 km altitude, roughly size of football field and it hosted multiple crews over two decades including from United States, Russia, Japan and European Union. In Skylab and also ISS, mechanical structure of modules among many play key role in deciding the longevity of the mission. The structure is primary defence and also safety element to the crew from micro-meteors [1–4, 18].

Design and concept, operation and research on-board ISS is well known and documented. Third party and third country involvement is severely restricted with ISS missions. By end of 2030, ISS may be decommissioned or operated with new arrangements with private players due to various reasons listed in [4]. As of 2023, every space enabled country is eyeing their own space station with vision to commercialize it. For instance, "Tiangong" space station from China is made up of three large modules connected in a T-shaped configuration launched in April 2021. With further plans on Tiangong to expand the crew and research activities in near future. The costs of such ambitions restrict the possibility to realise the plans. One among those challenges is economic access to low earth orbit (LEO). Launching modules from Earth requires launch vehicles with payload capacity to lift off at least 25–30 tonnes at a time into the prescribed orbit. The cost to run such launch vehicles are still expensive and also availability of such launchers, capable for the job are few in the world. Since 2014, private companies have steadily increased presence and market share overall in comparison to previous decades. Development of reusable micro-launchers are challenging established companies to develop large-payload capacity launchers in order to remain in competition. Price per kilogram of payload insertion to LEO is already as low as 2000 US$ and possibly when promises of new space era is met, goal is to reach 10 US$ per kg or similar scale. Such developments will result with ease of access, enable effective launch of large payloads, multiple times to LEO. It also enables low cost human missions to LEO for tourism etc. Collectively, it is a leap towards a sustainable model towards colonising space [4–6].

Engineering solutions and its development are important towards implementation of new ways of living and human life enhancement. Among many important media of communication, especially in democracies that connects government programs and development of space for peaceful purpose is "public interest". Access to "space-experience" through government setups such as museums etc to provide an informative know-how of space-tech and its influence on everyday life is essential. Such human and technology interfaces are necessary to be established at every foot and corner of country to foster positive informed opinion among public at large and also to motivate involvement, especially stu dents.

In this paper, design for human habitat module with research module is envisioned as preliminary step. Study for its implementation in terms of readiness, capability and maturity to realise flight ready design is investigated. Finite element model is prepared to study the structural and modal behaviour. Based on the results, design iterations were performed to realise suitable design for both ground and orbital implementation. The performance of the design is realised by building real-life sized demonstrator named here after as Visvesvarayya Space Lab (VSL). The demonstrator which was built at academic institution campus served engineering interests in testing, developing the concept, challenges associated with implementation and also was utilised for public outreach. Here, a small portion of the investigation is showcased as proof of the study. Experimental data and findings, know-how, detailed design of sub-systems are withheld intentionally.

2 Design and Definitions

A hollow tube with square cross-section is welded into hexagonal shape with 'n' nodes extended by length 'L' along-Z axis shown in Figure 1. The shape provides flat surface area on each side of the hexagon. Even though the second moment of inertia is slightly lower compared to the circular cross-section, hexagonal cross-section foresee relatively better resistance to impact loads. Also, it is easier to replace a single panel of hexagonal module rather than to replace entire circular section in case of damage. Stress concentration along the edges of the hexagonal cross-section is overcome by strategic welding and design to an extent. The shape maximises storage space and can be stacked easily on launch vehicle adapter platform for launch. Energy method is applied assuming, work done by external forces equals the energy stored in the structure under applied load. It is safe to assume that deformation and corresponding stress is small. Therefore, the relation between stress (σ) and strain (ϵ) can be considered within the elastic limits of the material. Approximate deformation function can be represented in matrix form using variable 's' as shown in Eq. 1.

$$\boldsymbol{u} = [u(s,z), v(s,z), w(s,z)]^T \tag{1}$$

Corresponding stress and strain relation can be represented in matrix form as shown in Eq. 2,

$$\sigma = E\epsilon = \begin{bmatrix} E/1-v^2 & E/1-v^2 & 0 \\ E/1-v^2 & E/1-v^2 & 0 \\ 0 & 0 & E/(2(1+v)) \end{bmatrix} \epsilon \tag{2}$$

where ν is Poisson's ratio, E is Young's modulus of material. Further, Heat flow into the module through thickness is calculated using Fourier's law along each direction and through the thickness. By neglecting convective effects,

$$Q_{heat} = -k_{cond} * A_{CRS} * \frac{\delta(T)}{b} \tag{3}$$

Heat balance is obtained by considering main heat sources,

$$dQ_{total} = dQ_{sun} + dQ_{backgnd-rad} + dQ_{on-board} + dQ_{albedo} \tag{4}$$

where in Eq. 2, A_{CRS} area of cross-section, δ (T) is temperature difference between inner wall and outer wall of the section, b is total thickness of the layer, k_{cond} material equivalent thermal conductivity of mult-layered insulation taken to be 0.85 W/m-K, Q_{heat} heat conducted through the layers of insulation in each direction of thickness of the wall. In Eq. 4, dQ_{total} is the total heat on the module, dQ_{sun} is the heat from sun in orbit which is constant at 1 AU at 1360 W/m^2 approximately, $dQ_{on-board}$ heat from equipment on-board, dQ_{albedo}, earth albedo in orbit, $dQ_{backgnd-rad}$ background radiation. For each human on-board the space station, heat dissipation is considered equivalent to 100 watt when resting and while performing activity 250 watt is assumed [21].

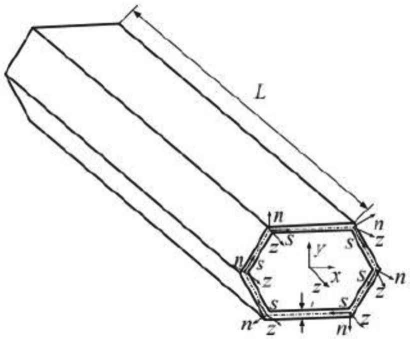

Fig. 1. Global (x, y, z), local coordinate system (s, n, z) of the cross-sections

2.1 Design

Design and development of complex structure such as a space station is not a one step process but a continuous evolution with time as per mission needs. The work presented in this paper serves as a preliminary study with a bottom up approach. Therefore, in this section preliminary orbital design concept referred to as "Module 2014" and ground implemented design concept referred to "Module 1729" or VSL is presented. Both represent the same concept but former is adopted for orbital environmental conditions and later for ground conditions.

Purpose of developing the design with bottom-up approach and then building the demonstrator is:-

1. Project initially drew inspiration from "There are some who question the relevance of space activities in a developing nation. To us, there is no ambiguity of purpose. We do not have the fantasy of competing with the economically advanced nations in the exploration of the moon or the planets or manned space-flight. But we are convinced that if we are to play a meaningful role nationally, and in the community of nations, we must be second to none in the application of advanced technologies to the real problems of man and society." as quoted by Sarabhai [19].
   1. Develop module with state of art facility to enable scientific research on-board and to identify functional challenges.
   2. Develop accessibility to on-board data recorded from various studies, ability to live and work in space
   3. Provide test-bed facility to develop technology at higher Technology Readiness Level (TRL)
   4. Provide a collaborative environment towards easy access to low earth orbit including reduced travel cost and for tourism purpose/space taxi implementation.
   5. Build a prototype to apply engineering principles, test it, to work around and optimise the solution. Prove engineering and personal capability, capacity and vigour to make the same possible for space. Finally, to open the prototype for public outreach and experiences.

Table 1. Design principles

Domain	Problems	Remedy
Environment	Vacuum corrosion Solar Radiation, Earth albedo, Asteroids,/meteors/space debris Station keeping	Use paints and Multi layered insulation to guard against radiative effects and corrosion. Design multi layer collision barriers to reduce the damage due to asteroids strikes. Use cold gas thrusters for station keeping if required
Launch challenges	Limitation of fairing size Limitation of payload mass cost per kg	Promising developments of heavy launchers i.e., star-ship from SpaceX may enable one time launch of whole concept. While improving the affordability to LEO
Sub systems	Limit Mass, Volume Limit Power consumption, plan for dissipation Location without compromising the attitude dynamics Dimension reduction	Efficient design, material choice
Structural Parts	Reduce stress, improve stability weld-ability and reduce corrosion to environmental and operating conditions limit Thermal expansion and thermal inertia, limit warping over the operation period, Static, dynamic behaviour and match the needs of the launch vehicle, Homogeneity, affordability	Efficient design, material choice, suitable launch vehicle, extensive testing of the design using FEA software to ensure static and dynamic behaviour s in accordance of the mission needs
Operation coverage	Communication range at all times with ground station, Energy consumption, Human waste management, Emergency situation preparedness levels,	efficient design and mission planning
Maintenance	Cleanliness, safe handling of research equipment's, safe disposal of bi-products from experiments, Accessibility, limit EVA technical downtime etc	astronaut training on ground, use autonomous-AI-enabled probe, efficient and detailed design of ventilation system [17]

Design features of laboratory module shall be capable of fulfilling the requirements such as data collection through sensors etc. of various activities on-board. Validation in comparison with mathematical model or simulation results. Repeatability of on-board activities and readability of thus recorded data. Generic equipment to facilitate variety of experiments on-board. Risk tolerance through optimised design and mitigation through training and precautions. In the case of human habitat, study of observability, training to work in space. Develop ability to adapt for "change of plan" for on-board activity, testing and so on. To design the habitat module with capacity to accommodate adequate number of crew numbers on-board for given mission task at all times.

The module design process is as represented in Fig. 2, follows initial design problem statement of bottom up approach. Based on which an preliminary design was sketched using first principles. CAD model was created and then simulation was performed with different factor of safety (FOS) for both flight and ground conditions. FOS for ground was taken to be at minimal 1.6 and for flight it was about 1.2. In parallel, detailed design calculation were made with material properties. The findings were compared with an optimised solution thus obtained from Finite Element Analysis (FEA) simulation. Design underwent iterations until satisfactory criterion was met thus, constituting the delta phase. When the two models both space and ground design agree to the mechanical constrains, the design is implemented.

2.2 Module 2014

Orbital module – 2014 (first designed in year 2014) is launched to an altitude of 450 kilometer circular orbit with 0 degree inclination. This altitude accounts for long orbital decay time, good connectivity with ground communications thus relatively non-critical conditions for station keeping requirements. The module is initially made of two sections which will be launched separately. The first section of the module is of 15 meter

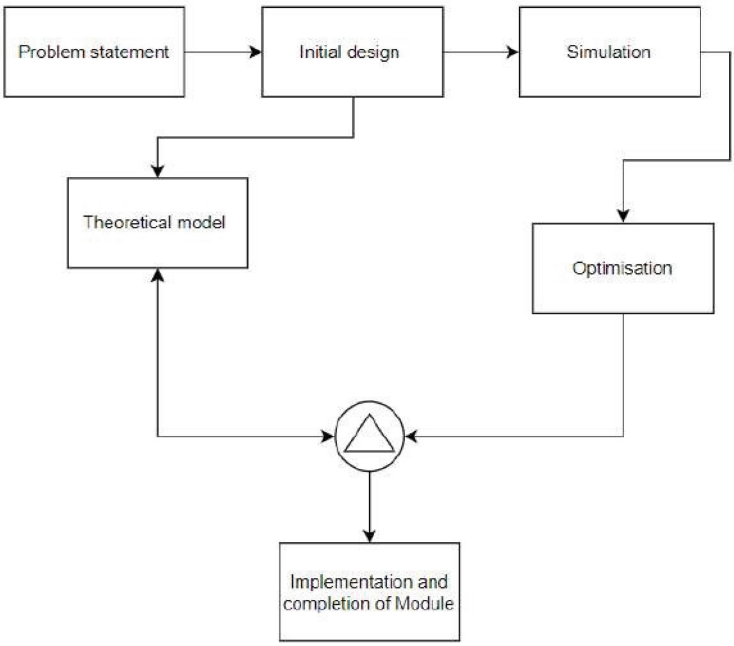

Fig. 2. Design iterative process of module

in length about the horizontal, ˜7 m height from base along the vertical direction. The second module, 10.2 m in length and 7.7m in height with same cross-section as of first section. The design size of the modules are by far limited by cost, weight and fairing size of launch vehicle of the current day with possibilities for modifications. Early design concept is representation of the Module 2014 and same holds good for ground module – VSL and is presented in Figs. 3, 4, and 5 represents the individual design cross-sections of both orbital and ground modules. Key points considered while developing the design principles while formulating the solution is presented in Table 1 [8].

Both ground and orbital modules are realised by assembling two sections in T-shape configuration. Geometry of the assembled sections of module is presented here, with -x direction of co-ordinate is parallel to Earth surface shown in Fig. 6. The same reference holds good for both orbital and ground design. The geometry for the primary structure design is chosen to be similar to regular hexagonal prism with varying length of each module. The definition of the geometry provides additional flat-faces both internally and externally. Design in Figs. 3 and 6 is combined with planned functional logic which is presented in Fig. 7. In Fig. 7, functional logic with EVA ports for maintenance support, space walks and docking ports, for cargo/re-supply to the space lab for both research and crew is shown with the associated module.

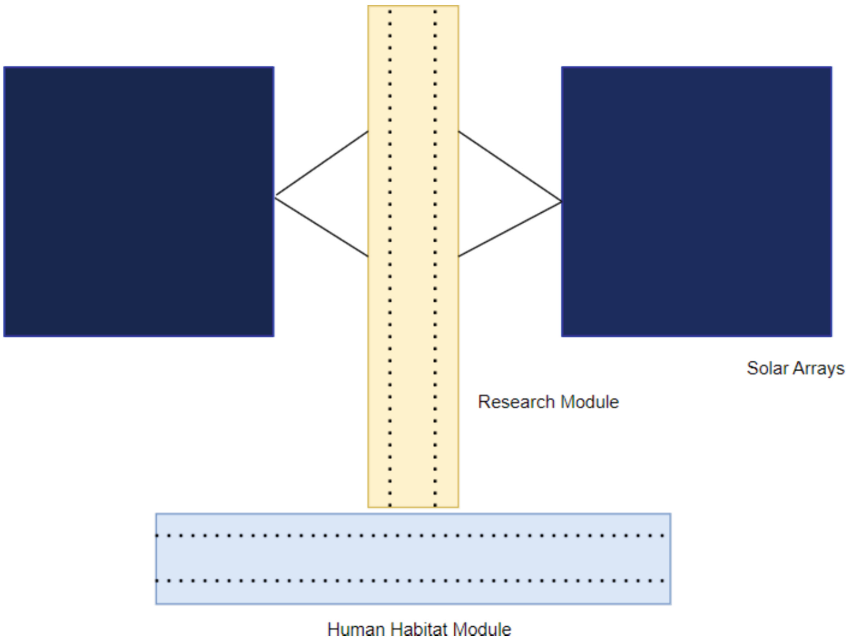

Fig. 3. Early design concept of Space Module of Module 2014/Visvesvarayya Space Lab

2.3 Sub-System Definition – Research Payloads

In this section, preliminary identification of sub-systems that are minimal to satisfy objective is listed. Detailed design of each sub-system is not included in this paper however, function of the same is proven by implementation in the ground module 1729/VSL. A total of five minimum payloads are part of the research module design definition. They satisfy basics of research mission,

1. Inert environment:- During previous missions, samples from asteroids etc. are returned to Earth through capsules and mostly 10 g or similar sample size. Towards end of mission, samples endure critical mission design sequences such as re-entry into the atmosphere. The risks associated with such events can be mitigated to large extent with sample collection at an orbital station. The sample can be studied and tested on-board. This option also prompt to increase the mass of sample to be collected because of lack of need of thermal shielding necessary during re-entry. The inert nature of the chamber enables on-board researcher to perform research activities safely. Able to study the specimen with respect to its fundamental physical properties. Able to derive test specimens from extra-terrestrial samples and also for biological experiments without contamination. The design is a cuboid with volume of approximately 2 m^3 and fitted with high density pump able to operate up to 6 bar. Hand interface is provided to the crew to modify the sample. Within the chamber volume, slots are available to store the samples etc. With availability of gases such as nitrogen, carbon di-oxide, Argon, Xenon and helium for test-chamber environment support. The chamber is operated at wide range of pressure from near vacuum few milli-bar to 5 bar pressure with unique choices for chamber gas, used to create inert environment for testing. The resulting design is represented Fig. 18 [19].
2. Storage bins:- It is well known that anything unattached in space tends to move without resistance, all the secondary equipment such as computer hardware, human needs such as food, water etc., samples used for experiments and on-board solid and liquid waste require a multiple sections of storage bin to keep them in place and also to avoid contamination with local environment inside the module. The same is represented by Fig. 21.

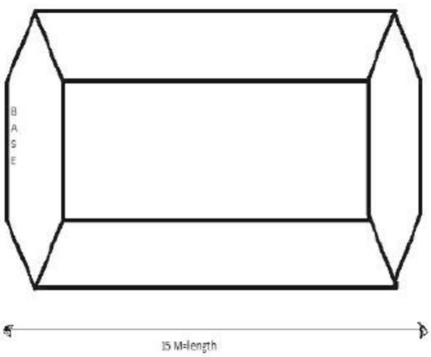

Fig. 4. 15 m hexagonal section for Research activity of T shaped module

3. Waste disposal system/micro gravity-toilet:- For human waste disposal as part of the human habitat. Liquid waste can be recycled with passive filtration system while all waste samples are returned to Earth for further study. The design employs principle of suction creation operating from the line drawn from ventilation pressure line with manipulation of valves. Suction is able to actively clear the solid wastes while liquid wastes are chemically neutralised and recycled. Design is emphasised to be familiar and simple with consideration of human comfort. The design familiar to ground based system are employed. The representation of which is made in Fig. 23.
4. Communication:- Vital to be able to communicate to the ground mission control center and also for tracking the space station while in orbit for station- keeping. The availability of continuous high-bandwidth communications to ground enables quick rescue in an emergency. The bi-directional nature of the existing communications enables an space station module to close iterative investigation and service loops, allow software reconfiguration, and support multiple scientists while one uses the on-board facility. Further, the availability of ever increasing communication features will enable real-time video teleconferencing options as part of daily operations to better create a virtual presence of scientists aboard the space station. Several antennas are placed on the space station for real-time data communication. The space station also provides a platform for Earth observation with synthetic aperture radar (SAR) systems in L and S band frequencies to study various land, sea and ice applications. The design of the same is presented in Fig. 20. [10]
5. On-board habitat:- apart from human habitat, several experiments can be conducted to grow and reap produce from plants while using recycled liquid waste on-board. Sleeping ca-coons, tread-mills for exercise to benefit health of crew on-board. Space suits are provided on-board suitable for extra-vehicular activity (EVA). EVA is a generic term which include both scheduled and unscheduled activity including critical tasks performed by on- board crew during emergencies. The configuration of the same is represented in Fig. 21. However, this particular area of development is best reserved for later stages of mission.

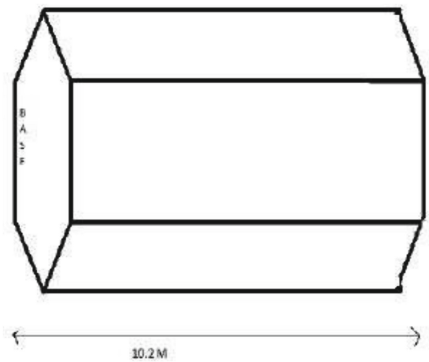

Fig. 5. 10.2 m hexagonal section for human habitat of T shaped module

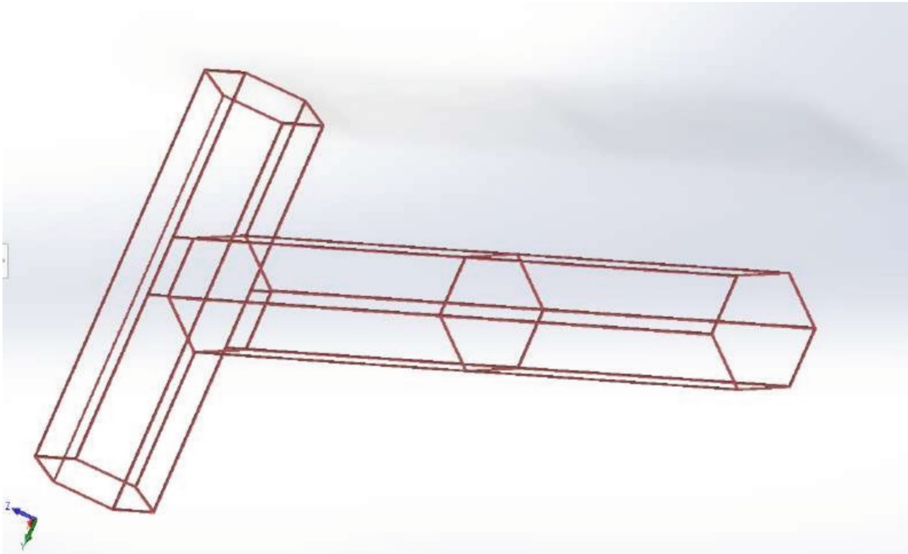

Fig. 6. Primary structure of assembled T shaped module to scale

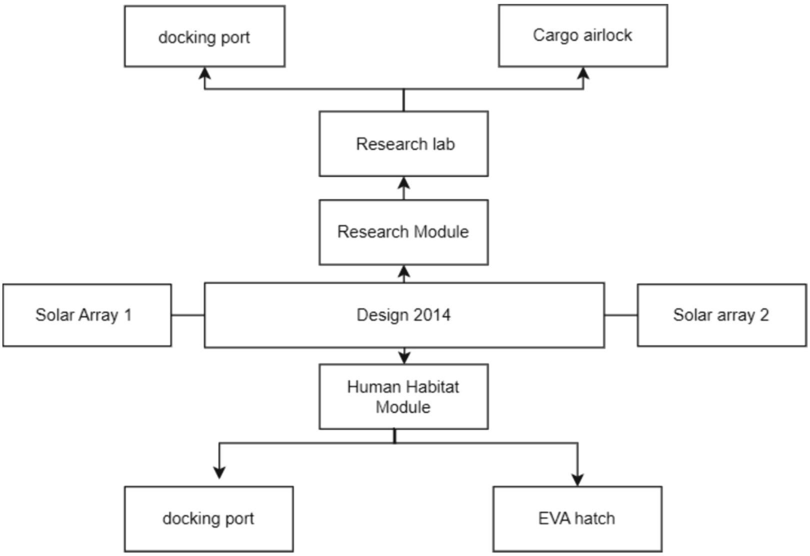

Fig. 7. Module 2014 functional design layout arrangement

Module 2014 In this section material properties defined for orbital module is presented along with its mass budget. The material properties utilised for simulating the primary structure assembly is presented in Table 2. The structure is made of aluminum 7075 alloy suitable for enduring mechanical loads at relatively low mass density. The panels are made of Carbon Fiber Reinforced Plastics (CFRP) for both structural strength and thermal insulation properties. However, additional surface finishing is necessary in-order to avoid degradation of material in vacuum conditions. Multi-layered insulation (MLI) concept is adopted to insulate the module from surroundings and is applicable for orbital module only. Goal is to restrict the thermal conductivity through walls to 0.8 W/m-K or lower [21].

Table 2. Orbital Module 2014 material reference

Reference	Material	Young's Modulus	Optical Coating
Primary structure	Al-7075	70 GPa	None
Secondary Structure	Al-7075	70 GPa	None
Panels	CFRP + Metallic		
sheet/finishing	-	Thermal	
barrier Coating			
Insulation	MLI	-	-

In Table 2, thermal barrier coating refers to white paint with very low absorptivity and for corrosion protection. The position of the center of mass presented in Table 3 is obtained from CAD model presented in Fig. 8.

Table 3. Center of mass position for both module

Center of Mass position		
X = .61	Y = 3.75	Z = −2.66

Mass budget of preliminary mission for operation in low earth orbit is given in Table 4. The budget is dependent on the duration of the mission, research objectives and launcher capability. Power source for this design is solely solar power from the solar panels. Projected power budget of 7.5 kilo watt is allocated for the operation of two modules and then an additional kilo-watt for sub-systems.

Finite Element Analysis of Module 2014. For Module 2014, loads are applied to full scaled CAD assembly and is presented in Table 5. The study is performed on CAD assembly with mass blocks representing each subsystem of module 2014. Each subsystem is represented by point mass definition in AN- SYS student software. Maximum loads are experienced during flight. Loads are presented in Table 5 and is applied assuming acceleration due to gravity = 9.81 m/s at all times during the flight. Arbitrary force of 4.5 kilo-newton is also applied along the axis to simulate maximum loading conditions with higher margin to better understand the mechanical behaviour. Acceleration experienced during liftoff is also applied and is presented in Table 5. Additionally, modal analysis is performed using the same constrains applied previously for static structure analysis. In Fig. 9 mesh generated consists of, total nodes = 11147, 5568 total elements for primary structure shown in Fig, 6 and 10930 nodes for assembled module shown in Fig. 10.

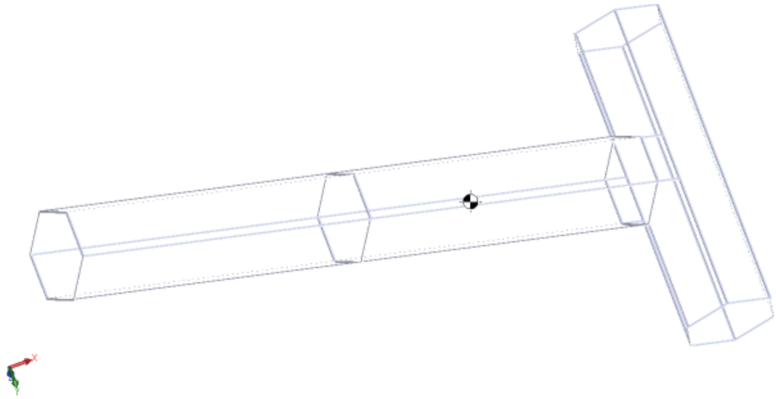

Fig. 8. Center of mass reference in CAD

Table 4. Preliminary mission mass budget in kilogram (approx) for module

Primary structure	3300
Secondary Structure, Walls	3750
Asteroid Impact protection Structure	2100
Batteries	500
Storage bin	210
Per Space suit	90
food etc	250
Research Payload	1850
Communication	750
Misc	1000

Table 5. Loading conditions for finite element analysis used on Module 2014

Load	Magnitude
Lateral Acceleration	± 3.5 g
Axial Acceleration	± 7 g
Axial force	4500 N

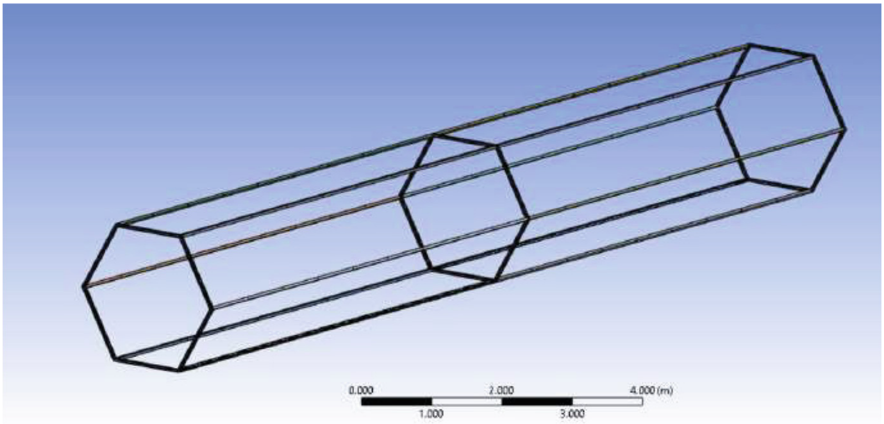

Fig. 9. Meshing of the primary structure of module 2014

At the preliminary design development stage, analysis is performed on the primary structure and fully assembled CAD model of the module. The mesh is presented in Fig. 10. Fixed support is applied on the base of the module. Fixed support represents the interface between the payload and the payload adapter in the launch vehicle.

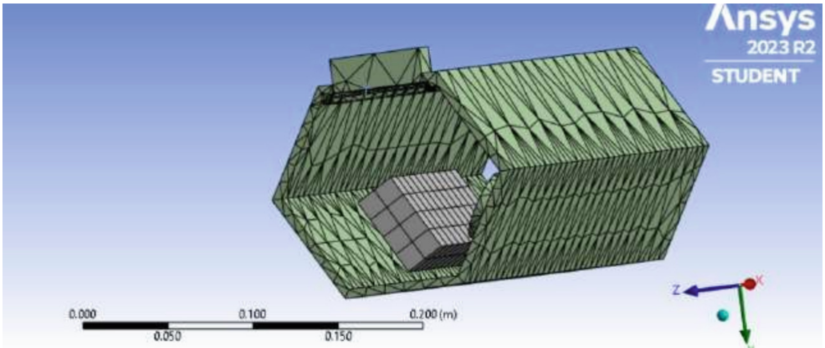

Fig. 10. Meshing of the assembled research section of Module 2014

FEA Results for Module 2014 As expected, maximum deformation is endured by the primary structure along its axis due to the load definition as shown in Fig. 11. Under the same loading constrains, static loading analysis performed on the assembly Module 2014, deformation is negligible while stress and strain values are greatly reduced as shown in Fig. 12. Modal analysis is performed on the assembly module 2014, results indicate that the primary mode is 446.3 Hz as shown in Fig. 13. The maximum deformation of 0.7 meter approximately. The preliminary results satisfy requirements for most launch vehicle currently capable of launching module 2014.

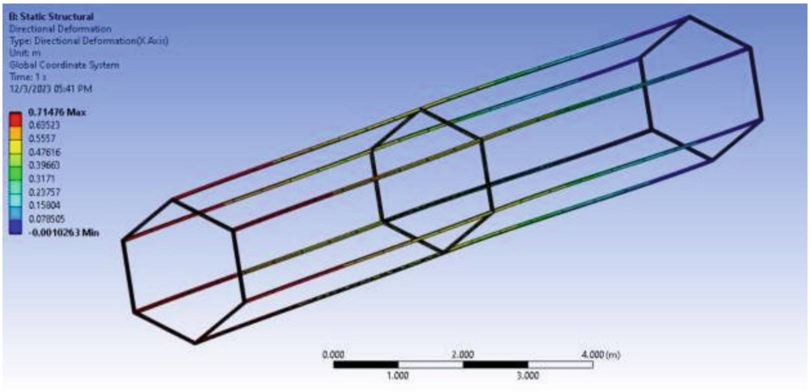

Fig. 11. Static structural result for axial deformation of the primary structure – module 2014

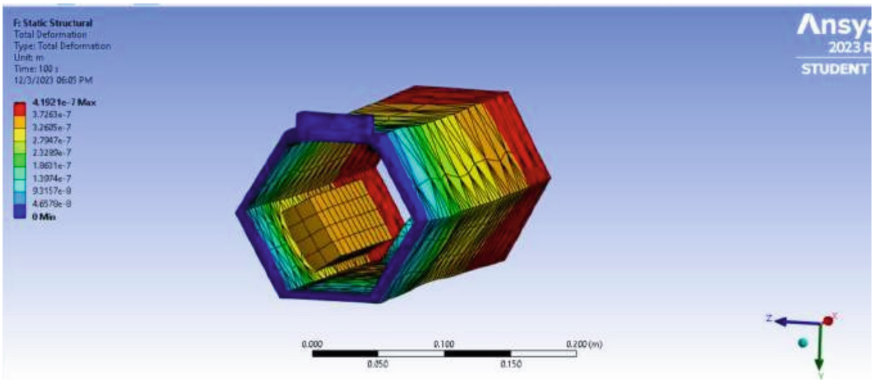

Fig. 12. Static structural result for axial deformation of the assembly- module 2014

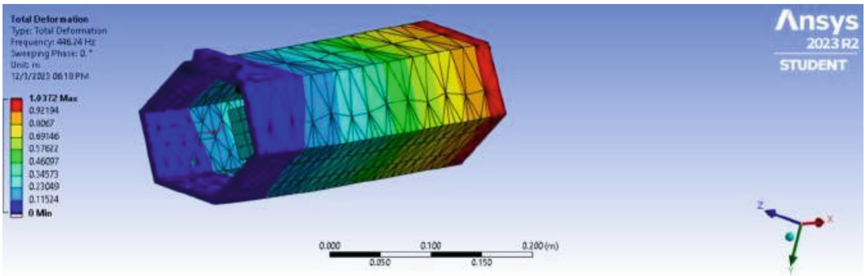

Fig. 13. Modal analysis result for first mode of deformation – module 2014

2.4 Module 1729/VSL

Life sized prototype based on the design definition and study conducted on Module 2014 was produced. In this case, the prototype is adapted for ground environment in Jaipur city of Rajasthan, India with location at 26.8779° North, 75.6892 East. The module 1729 was realised and named to be known as visves-varayya space lab (VSL). Approximately 65 m of area is occupied by the prototype, satellite image of which is shown in Fig. 14. Motivation to build life sized model began during academic year 2014–15 with following goals :-

Fig. 14. Satellite image of Visvesvarayya Space Lab. Courtesy:- Google earth taken on 24-April-2023

1. To demonstrate exploration, human presence in space..
2. Conducting research to benefit technological progress on Earth.
3. Enable the experience of space station to serve as a construction platform for Lunar and Mars missions and beyond.
4. Learning how to construct large structures for low earth orbit, testing conditions for the same on Earth.
5. Learning how to operate in space, in-situ resource utilisation and acting as an engineering test-bed.
6. Learning how to operate and survive in space for long term, Conducting research to support future long-duration space missions.

Table 6. Module 1729 material reference for ground environment

Reference	Material	Young's Modulus	Optical Coating
Primary structure	Steel	210 GPa	None
Secondary Structure	Steel	210 GPa	None
Panels	Wood, steel sheet		

(*continued*)

Table 6. (*continued*)

Reference	Material	Young's Modulus	Optical Coating
	Fermacell + paint	-	Water repellent
	and white paint		
Insulation	Cotton, open-cell		
	insulation material	-	-

VSL was realised using the same primary structure design as shown in Fig. 6 and the same sub-system design listed in Sect. 2.3 with minor adaptations. Material used is listed in Table 6, steel is used instead of aluminum 7075 because of cost, environmental condition at the location to which the structure will is subjected to. In this case, there is relatively less stringent restrictions on maximum allowable design mass.

Fig. 15. Primary structure, welded with meshed-steel sheet – module 1729

Steel square beams are welded together to form hexagonal cross-section and two sections of which is welded in T-shape. The secondary structure comprises of sheets of steel square mesh which are welded to the primary structure. T section module with research section and human habitat module is distinctly assembled as shown in Figs. 15 and 16. Design of subsystems is based on the theme described in Sect. 2.3. Figure 17 shows the wooden casing (material adopted for ground conditions) of the vacuum chamber/inert environment, every side of the inner wall is provided with vinyl plastic sheet finishing which was recycled in the process, one of the insulation materials used as part of ground MLI is also clearly visible in the Fig. 17. The ground MLI is based on concept of MLI used for space application however in this case, open cell foam, poly vinyl sheets, steel mesh and wood is used in layers. The same is mentioned in Table 6.

Fig. 16. Primary structure and secondary support structure of research section under construction – module 1729

The wooden casing of inert chamber was then provided with a layer of vinyl plastic sheet finishing. Acrylic sheet was cut to meet the dimensions of the casing and was fixed in place with place for hand-glove holdings. Care was taken to ensure the chamber was air tight. One of the hand gloves could be removed in order to place or replace chemical species inside the inert chamber. Piping was connected to ventilation from the compressor situated outside the module and on the steel platform made for the module. The same circuit would be present in Module 2014 only that the pressurised gas would be inert gas or depressurised to create near vacuum conditions in the chamber as shown in Fig. 18. Communication system is setup using sound system, microphone for input and speaker as output via the dish between the ground i.e, outside the module and the same is done inside the human habitat section of the module represented by Fig. 19.

The dish fitted on top of the module acts as an exchange device between the ground and the astronaut on-board the human habitat. The dish is mounted on custom welded tripod joint with ability to rotate 360° parallel to ground, at 35° about the vertical as shown in the Fig. 20.

Further, space suit was installed with modifications to clean-room suits to represent and explain the need for extra vehicular activity or commonly known as spacewalk. Then, the complexity of designing, working and testing of the space suits are represented. Therefore, entry view of the research section of the module 1729 is represented in Fig. 21.

One of the hulls in the hexagonal cross-section of human habitat section was converted into viewing deck with 3D earth picture as shown in Fig. 22. This particular section was installed to promote philosophical thought of oneness among diversity. Waste collection platform (ground reference) or Zero-g toilet was converted to pressure operated waste disposal system which can work in micro-gravity environment and in any orientation. The pneumatic circuit were drawn from parallel line leading from the compressor system, shown in Fig. 23.

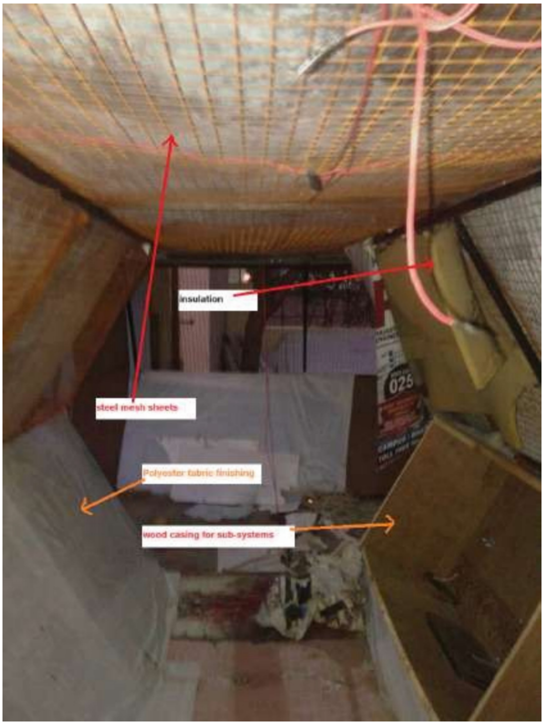

Fig. 17. Primary structure and secondary support structure with sub-system casing, insulation, finishing material during construction – module 1729

Fig. 18. Inert chamber demonstrator – module 1729

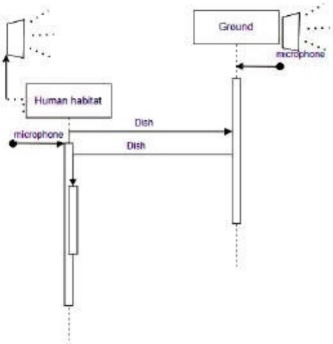

Fig. 19. Communication acoustic logic – module 1729

Fig. 20. Communication acoustic dish with custom welded tripod demonstrator – module 1729

Functionality of the above described sub-systems were performed twice and on special occasions until year 2019. The primary structure designed, assembly welded in year 2014–15, showed no warping until 2018–19. Gas line from the air pump situated outside the module directed fresh air through the pipes along the length of the module, allowing for the module to be completely shut during operation. The pressure was maintained slightly higher than atmospheric to keep away the dust entering from outside. Design and assembly of sub-systems and structure were parallely started in April 2015, while the entire Phase – I was completed by end of July 2015 and the Phase 2 was completed by beginning of 2017, final prototype is shown in Fig. 24 and at night in Fig. 25. During phase - 2, metallic sheets were replaced with Fermacell at non-critical areas identified from results of finite element analysis to reduce weight significantly.

Fig. 21. Research section demonstrator entry view - module 1729

Fig. 22. 3D Earth view demonstrator - module 1729

Fig. 23. Zero-g toilet / waste collection platform demonstrator - module 1729

Module 1729 when finished was able to host 5 fully grown adults inside at a time. Approximate mass (conservative) of the whole module 1729 is presented in Table 7.

Table 7. Conservative mass budget in kilogram (approx) for each operational Module 1729

Primary structure	500
Secondary Structure, Walls	400
Asteroid Impact protection Structure	0.0
Batteries	20.0
Storage bin	110
Per Space suit	80
food etc	2.0
Research Payload	850
Communication	150
Misc	500

Fig. 24. Top view of module design 1729 (Visvesvarayya Space Lab) by end of Phase 2 (taken during April 2018)

Fig. 25. Side view of module 1729 by end of Phase 2 or final version of visvesvarayya space module taken in year 2019

3 Conclusion

Preliminary setup for space station demonstrator was realised through bottom up approach. The paper illustrates the preliminary design, overview of sub- systems, FEM structure and modal analysis and implementation to build a life size demonstrator. Initially, a design concept is assessed based on engineering judgement, next with finite element method for static deformation, stress levels for the chosen material combination at maximum loading conditions. Modal analysis was performed with design iterations to find the correct configuration which could satisfy the launch vehicle payload requirements. The same is then applied to demonstrator utilizing the engineering principles studied during course. Constructed in two phases starting from year 2014/15 to realise a demonstrator like prototype which is operational on ground conditions. Additionally, an experience of designing, assessing, assembling and overcoming the challenges faced in realising an space station. Design of primary and secondary structure, along with thermal insulation concept during phase – 1 was successfully implemented. Then, implementation of all the sub-systems envisioned with advanced self-made mechanical solutions to various engineering problems during installation. During Phase-2, selective replacement of relatively heavier metallic sheets for light weight fermacell material resulting in significant reduction in overall weight with- out any noticeable change in performance of the structure and relative improvement in thermal behaviour. The demonstrator was opened to visitors, at a time it could house 5 fully grown adults, operate sub-systems and a 3D glass for an in-space earth viewing experience. The demonstrator strove towards motivating public interest in realising country own first space station and associated benefits. However, demonstrator requires constant maintenance due to the location which experiences extreme summers, cold winters and monsoon. Also, structure and material is prone to high degradation due to fine sand dust from dessert carried by wind.

> Future work include detailed design of each sub-systems with individual parts that are space qualified. Detailed design of impact protection shield, additional sub-systems such as robotic arms, in-space manufacturing & assembly. Update mass and power budget to accurately account for the final design and the materials considered. Also, to expand the knowledge base to other branches of engineering associated with the operation of space station.

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