Feasibility Study for Design, Development, Qualification of Human Rated

Environmental Control and Life Support System (ECLSS)

for Gaganyaan

HUMAN SPACE FLIGHT CENTRE

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Annexures:

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II. Design Factors
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Acronym /Abbreviations

ARS	:	Air Revitalization System
CES	:	Crew Escape System
CM	:	Crew Module
CO_2	:	Carbon-di-oxide
CPCS	:	Cabin Pressure Control System
CPMU	:	Cabin Pressure Maintenance Unit
CVU	:	Cabin ventilation unit
DAQ	:	Data Acquisition Unit
ECLSS	:	Environmental Control and Life Support System
EEE	:	Electrical, Electronic and Electro-mechanical
EP valve	:	Electro-Pneumatic Valve
ETL	:	Environmental Test Levels
FDI	:	Fault Detection and Isolation
GSE	:	Ground servicing equipment
HSFC	:	Human Space Flight Centre
ISRO	:	Indian Space Research Organisation
KO2	:	Potassium superoxide
LOI	:	Limited Oxygen Index
MC	:	Mission computer
NDA	:	Non-Disclosure Agreement
O_2	:	Oxygen
OM	:	Orbital Module
P&ID	:	Process and Instrumentation Diagram
PDR	:	Preliminary Design Review
PGW	:	Propylene glycol water
ppO2	:	Partial pressure of Oxygen
QC-DC	:	Quick Connect- Disconnect

RH	:	Relative Humidity
SE	:	Systems Engineering
SM	:	Service Module
SRV	:	Safety relief valve
THCS	:	Thermal and Humidity Control System
TMR	:	Triple Modular Redundancy
WPS	:	Welding Procedure Specification

1. Introduction

The Gaganyaan mission is the first manned mission planned by ISRO to carry up to three crew members to Low Earth Orbit (LEO) and return them safely to a pre-determined destination on earth. The Gaganyaan Orbital module (OM) has a habitable Crew Module (CM) and a Service Module (SM). HRLV is a Human rated GSLV Mk3 launch vehicle planned to be used as a launcher for Gaganyaan mission. The mission profile for Gaganyaan involves three phases, Ascent phase, Orbit phase and Re-entry /Descent phase.

The mission duration is for various phases are given below

Mission Phase	Time
Ascent Phase	~ 16 minutes
Orbit Phase	~ 3 to 7 days
De- boost to splash down (Re-entry)	~ 50 minutes
Orbit inclination	51.5 deg

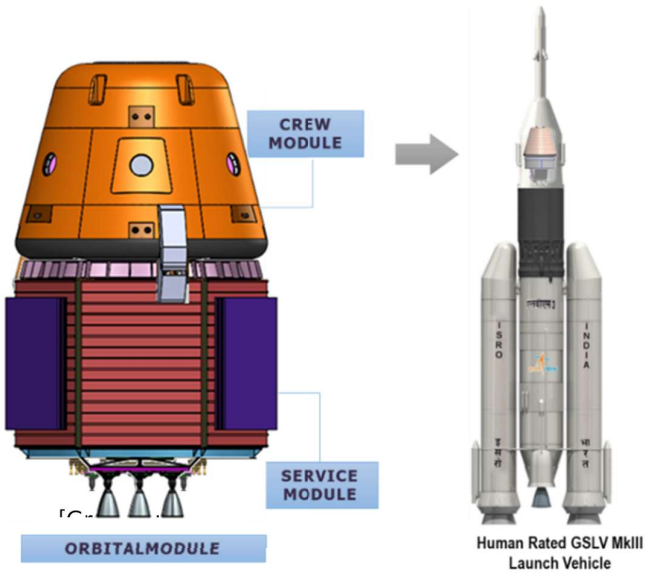


Figure 1: Orbital Module and HRLV

After the orbital phase, the Orbital Module will be de-orbited by firing the onboard propulsion system and the Crew module will be separated from the Service module and made to re-enter the atmosphere and deaccelerated using parachutes.

2. Scope of work:

1. Party shall carry out the feasibility study to design, develop and qualify the ECLSS system using hardware qualified to human rating requirement along with certificate, ground servicing equipment (electrical and mechanical) as per the requirements for ECLSS sub systems mentioned in the following sections 3 to 9 for ECLSS sub systems.

2. Feasibility of delivering 5 sets of ECLSS hardware including electrical, mechanical, sensors etc. (there is no physical delivery of hardware) shall be assessed as part of the feasibility study. The cost and schedule for the qualification and delivery shall be provided as part of feasibility study.
3. The design shall be presented to ISRO for review and approval. All certifications of the proposed components sought by ISRO shall be provided (Heritage certificate / sample certificate) and suggestions shall be implemented based on mutual understanding
4. Expected outcome is a detailed feasibility study document containing
   - P&I diagram and pneumatic/hydraulic/electrical circuit of ECLSS, Component specification (quantity, heritage and design feasibility of new component)
   - Operation sequence and control methodology
   - Philosophy (Algorithm) for Failure detection and isolation (FDI)
   - Integration at ISRO facility (party shall provide details of requirement of facilities required for carrying out the integration at ISRO and special process, if any shall be mentioned in the report)
   - Accommodation and systems engineering in crew module and service module for ECLSS
   - Detailed P&I diagram and pneumatic /hydraulic /electrical circuit of ground servicing equipment (GSE),
   - Mass, power, volume, electrical and mechanical interfaces,
   - Test requirement and scheme
   - Sensors, DAQ and electronics requirement
   - The party shall give the cost of developing/qualifying and delivering 5 sets ECLSS system for which party has done the feasibility study. Apart from 5 sets of ECLSS hardware, the qualification hardware shall be accounted separately by the vendor
   - Schedule for developing/qualifying and delivering the 5 sets ECLSS hardware and sensors for which party has done the feasibility study.

Note: 1. Based on successful completion of this feasibility study, order for supply of 5 sets of ECLSS hardware either in full or sub system wise (as per outcome of this feasibility study) may be considered by HSFC for Indian human space missions.
2. The party shall submit their willingness to accept the contract for design, developing, qualifying and delivering the ECLSS in part or full subsystems for which feasibility study would be conducted and completed, in case HSFC decides to go for such a contract.
3. However, HSFC does not make any commitment in this regard, financial or otherwise, at this stage.

2.1. Environmental Control and Life Support System (ECLSS):

ECLSS consists of a number of sub-systems providing independent and overlapping functions. It is a 'system of systems' and consists of the following sub-systems:

a. Thermal & Humidity Control System (THCS)

b. Cabin Pressure Control System (CPCS)

c. Air Revitalization & Trace Contaminant Control System (ARS)

d. ECLSS Control system

The Environment control and life control system has to cater to 3 crews for 7-day mission. The cabin specifications considering the human physiological requirements and comfort are as follows:

a. Cabin Pressure : 101 kPa (Nominal) 98 to 116 kPa
b. Oxygen Partial pressure : 21 kPa (nominal) 19-23 kPa
c. Cabin CO_2 partial Pressure : < 670 Pa
d. Cabin Temperature : 23 ± 3°C (18 °C for pre-chilling)
e. Cabin Relative Humidity : 30-70 %

The human metabolic data required for the design of ECLSS is given in table 1.

Table 1: Consumption and effluent data per person per day

Intake	kg	Output	kg
Oxygen	0.86	Carbon dioxide	0.96
Food Solids	0.60	Respiration & Perspiration	1.50
Water (Drink)	2.00	Urine	1.20
Water in food	0.50	Faeces	0.30
Total Intake	**3.96**	**Total Output**	**3.96**

The integrated life support system schematically is shown in figure 1:

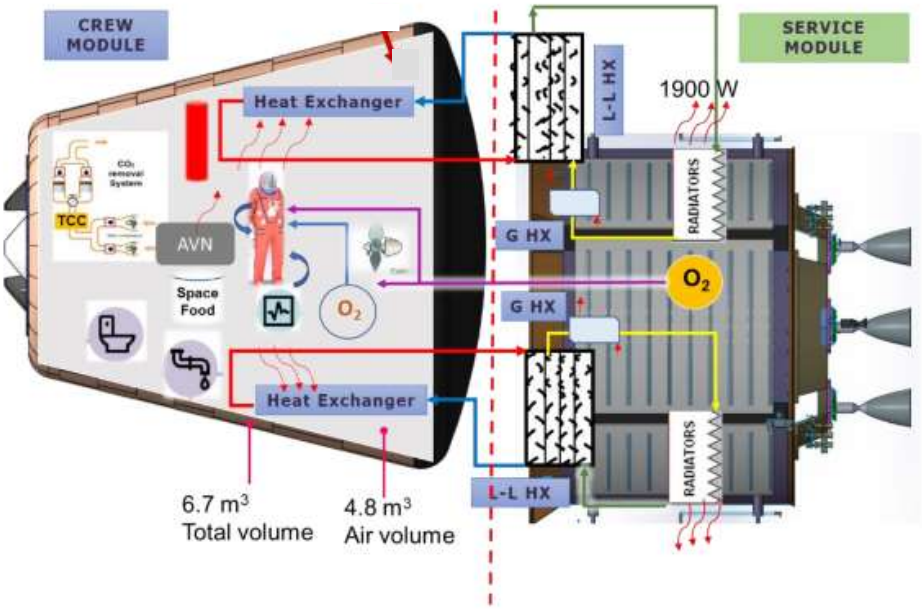
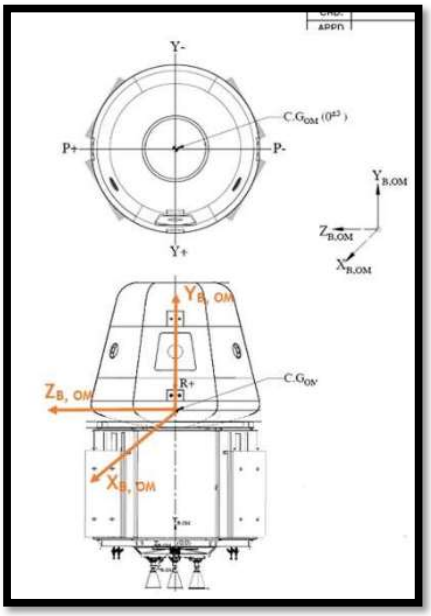


Figure 2: ECLSS subsystems overview

3. Loads for ECLSS

3.1. Axis reference

Axis definition for Orbital module is as follows:



Axis of OM (Geometry)	Attitude convention
+ $X_{B,OM}$	Positive Yaw (Y+)
+ $Y_{B,OM}$	Positive Roll (R+)
+ $Z_{B,OM}$	Positive Pitch (P+)

Figure 3: Orbital Module axis

3.2. Inertial Loads

The g loads experienced by ECLSS systems is given in Table 2:

Table 2: g-Loads

Mission Phase		g-load (Flight levels)	
		Longitudinal (Roll)	Lateral (Pitch & Yaw)
Ascent: Static + Dynamic		4.3 g compression 0.7 g tension	± 1.4 g
Nominal Descent		4 g	0.5 g
Worst case Abort		18 g	1.5 g
Pad Abort using CES	Max. Axial Acc.	-14.14g	P-: 0.01g Y+: -0.112g
	Max. Lat. Acc.	-9.88g	P-: -0.3g Y+: 3.52g

Impact	0 deg	30.1g, 34.7 ms	-
	Side impact (12 deg)	25.5g, 30ms	5.7g, 30 ms

* Qualification test factor: 1.4 to be applied on the above loads

3.3. Environmental test levels

The indicated ETL are given in Annexure VIII, which is subjected to revision.

4. General design considerations

Cabin total volume of crew module is 6.7 m^3, while the cabin air volume is 4.8 m^3.The typical time duration to be considered for planning the consumables, power, etc. is as follows-

a. No of Crew : 3
b. Mission duration (in orbit) : 7 days
c. Pre-Launch duration : 2.5 Hrs.
d. Ascent time : 20 minutes
e. Descent time (Nominal) : 50 minutes

f. Emergency time : 180 minutes (total)
   - In – Orbit : 130 minutes
   - During descent : 50 minutes

Cabin specification

a. Cabin air volume : 4.8 m^3
b. Cabin temperature : 23 ± 3˚C (Nominal)
   : To be prechilled to 18 ˚C before ascent and deboost
c. Relative humidity : 30 – 70%
d. Cabin pressure to be maintained : 101 kPa (Nominal);
   98-116 kPa (Nominal mission)
e. Electronic equipment temperature : <45˚C
f. Pre-chilling : 18 ± 1˚C

Crew Metabolism:

a. Crew Heat generation : 150 W / Crew
b. Humidity generation : 1.5 kg/crew/day
c. O_2 consumption/person/day : 0.84 – 1.1 kg

Suit Specification:

- Empty volume of suit : 70-90 litres
- O_2 flow rate (emergency mode)/ Flight Suit : 22 ± 1.5 nlpm (180 minutes max.)

- Suit inlet line pressure : 4.5 ± 0.5 bar

4.1. General design considerations for the ECLSS systems

1. Open loop (without resupply) ECLSS for a duration up to 7 days supporting 3 crew for LEO orbit of 400 km. **System shall be modular which can be scaled for different mission duration 3-7 days and number of crews from 1-3.**
2. The design shall be human centric considering crew ergonomics, anthropometry, human in loop etc. The design shall be as per NASA-STD-3001 Vol 2: Human factors, Habitability and Environmental health and NASA/SP-2010-3407/Rev1: Human Integration Design Handbook (HIDH)3001.
3. Close loop control with fault detection and isolation (FDI) logic shall be implemented. Human in loop requirements shall be clearly brought out.
4. It shall withstand all the flight loads occurring during different phases of the mission as given in section 2.
5. The structural factor of safety for the human rating of various types of components shall be considered as per NASA Std. JSC65828, Rev. B. The design shall be verified for fracture also as applicable.
6. Noise levels of all the systems in the cabin put together shall be less than 72 dBA on-orbit. Level shall be within NC 50 curve during on orbit operations.
7. All the material selected shall meet the flammability, off-gassing, and compatibility requirements mentioned in NASA-STD-(I)-6001B for the worst-case anticipated end use environment [viz. Max. Pressure: 250 bar for components as per the circuit design, Medium: Pure O_2; O_2 flow velocity: as per components design, System level qualification temperature: -40°C to + 70°C in SM, + 10°C to +40°C in CM, RH: 20 - 90%, LOI: 40% O_2 at 53kPa]. Necessary documents with test result shall be supplied.
8. Non-metallic materials exposed to breathing-oxygen or breathing-air supplies must meet the criterion of odour assessment test for objectionable odours as per NASA-STD-(I)-6001B standard. Odour shall be removed from cabin atmosphere.
9. Human-in-the-Loop Requirements: The system shall provide the crew on board the vehicle with proper insight, intervention capability, control over system automation, authority to enable irreversible actions and critical autonomy from the ground. This shall be implemented as per the state-of-the-art philosophy used in other manned mission modules as per requirement given in Section 4.3 & 4.7
10. The ECLSS parameter analysers shall have continuous real–time monitoring capabilities and monitors shall be equipped with audible and visible alarms.
11. The natural frequency constraints of the plumbing shall be met i.e., >100 Hz at the integrated level. Mounting frequency of components shall be > 60 Hz.
12. Hydraulic, pneumatic and electrical lines between SM & CM shall be separable to enable SM separation. It shall have automatic sealing device between SM & CM

fluid lines after SM separation. Inter connections between SM & CM shall take care of the dilations and deflections of the structure. The configuration shall be as per the CM-SM connect –disconnect system. The separation dynamics rate to ongoing module shall be limited to < 2 deg/s.

13. Mechanical process / components selected shall be space grade. All sensors shall be space grade and materials used / processes followed shall meet human rating requirements.
14. All systems should operate in 25-42 V DC.
15. Powering scheme for redundancy and management of all the hardware unit shall be clearly brought out.
16. System shall have critical parameters displayed in CM display console with provision for alarms, crew intervention in case of prime system failure.
17. The system shall have interfaces with ECLSS controller which in turn has link with the CM computer and ground station control.
18. Necessary algorithm shall be developed and implemented for various scenarios of operation. FDI philosophy to be brought out.
19. Ground servicing, leak check, functional testing, filling/draining, checkout requirements, assembly and integration requirements of ECLSS shall be brought out in detail (For CPCS, considering safety aspect for high pressure oxygen system). Welding Procedure Specification (WPS), In-situ welding qualification, subsequent cleaning procedure shall be clearly brought out in the document.
20. Testing philosophy to meet the human rating requirements for ECLSS shall be clearly brought out. Qualification / Acceptance test plan for components, sub-system, system and integrated system level shall be prepared and shall be submitted to ISRO for review.
21. Relief and venting provision in ground filling/venting system shall be provided. Requirement document for ground servicing system shall be brought out.
22. Abort parameters during various phases of flight and emergency conditions shall be provided by the supplier based on the practice followed in other manned missions.
23. The service life/cycles requirement of the components used shall be defined and demonstrated on an equivalent setup, before human flight use. It shall be minimum 10.5 days.
24. ECLSS shall be accommodated in the volume and space given as per the 3D model shown in **Annexure I.** 3D model will be shared based on NDA and successful placement of PO.
25. Systems engineering for ECLSS and controller shall be done.
26. Mass and power constraints shall be adhered to.

27. ECLSS operation requirements before flight to be provided by supplier.

4.2. Intra system dependency

1. Air revitalisation system produces humidity and heat. This shall be considered for design of Thermal and Humidity Control System and vice versa.
2. The temperature excursions, humidity variation, CO_2 addition and O_2 addition in the cabin shall be accounted in the cabin total pressure calculation.

4.3. Human intervention and intervention provision

For functioning of ECLSS, following are the crew activities required.

a. ARS system
   - Canister replacement after its usage: on-board timer information along with ARS blower health and CO_2 level will be indicated.
   - On failure of main blower and switchover to redundant blower
   - Connection to O_2 generation and CO_2 removal system post landing

b. CPCS system
   - Opening of manual valve on entry into crew module.
   - On failure of electro-mechanical valve in electric mode: manual intervention of electro mechanical valve. Failure of electrical actuation shall be indicated to the crew based on the monitoring along with recommended action.
   - Manual operation is required for cabin oxygen supply and suit supply in case of failure of automatic mode.
   - Enabling of Cabin Pressure Maintenance Unit (CPMU) in case of requirement of de-pressurization.
   - Post touch down ventilation

c. THCS system
   - Operation of distributing valve for temperature and humidity control
   - Manual pumping operation of condensate removal system considering the design.
   - Switching On-Off cabin fans and Heat exchanger

4.4. Crew Safety Aspects

Crew safety is of paramount importance to Gaganyaan mission and ECLSS shall include the following provisions to ensure crew safety.

1. Redundancy in systems including crew intervention as mentioned in section 4.7
2. System which will generate O_2 and remove CO_2 in case Cabin Ventilation Unit (CVU) is not operational.
3. Adequate structural margins as per JSC 65828
4. Continuous health monitoring of the system which will give intimation to crew and on-board controller.

4.5. Human rating certification requirements:

1. All human rating requirements shall be adhered to in the design.

4.6. ECLSS control philosophy

The controller commands the system, based on sensor information and acts based on the pre-programmed logic/algorithm for each system;

a) Triple redundancy with FDI and re-configuration logic for sensors and electronics – Detailed FDI algorithm shall be generated
b) Provision for crew override/manual operation for mechanical systems
c) Provide real time display/warnings to crew about critical parameters

ECLSS controller shall communicate with on-board computer (OBC) for information transmission to ground during nominal operation and in abort conditions/criticalities. It shall have the necessary data acquisition systems for acquisition of sensor data.

4.7. Redundancy plan

4.7.1. Mechanical systems

For all active system first failure shall not lead to degraded system performance or hamper crew safety but may involve crew intervention. Sufficient capability in terms of alternate measure, reliability and redundancy shall be available for return of crew to safety, although compromising mission duration and/or crew comfort. The passive systems shall have adequate demonstrated margins, design pedigree and redundancy. Alert flag shall be raised to MC after the primary system fails.

4.7.2. Avionics systems

Overall redundancy of ECLSS controller shall be triple chain. The overall electronics system shall be able to tolerate two failures. After primary chain failure, the mission will be aborted and descent will be initiated. During the descent phase, secondary chain failure shall also be tolerated and mission is still supported by tertiary chain. The control system shall be designed and configured to meet these requirements. All control system elements shall be in Triple Chain Configuration.

Table 3: ECLSS redundancy plan

Sl No	Systems	Redundancy
I. Avionics		
1.	ECLSS controller	Triple chain
2.	Sensors for control	Triple redundancy
3.	Health monitoring system	Dual redundancy
4.	Data acquisition system	Triple chain
5.	Driver unit	Triple chain
II. Mechanical		
1.	All active components	Dual redundancy*

*Manual intervention can be the second leg of redundency

5. Thermal and Humidity Control System (THCS)

Cabin environment shall be provided adequate systems to support and maintain crew health, comfort, convenience and well-being throughout all the operational phases. The life support system shall maintain thermal conditioning of the CM so as to ensure crew health and comfort and to ensure that all systems/ equipment can be maintained within their operating temperature envelopes by removing or adding sensible heat. The main function of cabin thermal control system is to maintain the cabin temperature within 23±3^{o}C (Nominal) and relative humidity 30 to 70%. The equipment temperature shall be maintained using cold plate.

5.1. Design inputs

The Thermal and Humidity Control System (THCS) is envisaged as a sub system of ECLSS to maintain thermal conditions (Cabin air: 23±3°C and Electronic equipment mounted on the cold plate< 45°C) and moisture content (RH: 30 to 70%) of closed cabin. THCS shall perform the following tasks:

1. THCS shall maintain thermal conditioning of cabin to safeguard the health and comfort for crew and to ensure that all electronic components in the cabin shall be maintained within their operating temperature range. Temperature and humidity control shall have manual control by crew.
2. It shall be able to accept thermal energy from crew and various components (it includes electronic components, pumps, heat exchangers, fans & cold plates).
3. It shall be able to transport the thermal energy from heat source (CM) to heat sink (SM radiators) using close loop mechanically pumped system.
4. It shall have provision to dump the thermal energy collected from various sources by means of radiation of heat to space environment. Modular radiators are to be designed as a part of the Service Module (SM) for radiating heat out to space environment. The area availability will be shared.
5. Two coolant based thermal control system circuit are preferred: Habitable Compartment Loop (HCL), which takes away the heat from CM and External Radiator loop (ERL), which rejects the heat to outer space.
6. Habitable compartment loop shall use only non-toxic, incombustible, explosion-proof coolants that does not expand on freezing and shall have wide operating temperature range better than - 8 °C to + 40 °C. PGW is preferred.
7. External Radiator Loop (ERL) coolant shall have very good operating range of temperature typically in the range better than +100 ^{o}C to -80^{o}C. Novec 7100 is preferred.
8. It shall be able to maintain moisture level in cabin atmosphere by removing water vapour generated in cabin using suitable sub-system like a water separator or wick based system. This sub-system has to function in micro-gravity condition and shall be

able to remove the humidity generated by the crew and ARS at the same rate and shall maintain cabin RH in off-nominal condition also.

9. The system shall maintain a ventilation rate within the internal atmosphere such that in two-thirds (66.7%) of the cabin volume, velocities are between 0.076 m/s and 0.6 m/s, except during suited operations, toxic cabin events, or when the crew is not inhabiting the vehicle.
10. Radiator shall be qualified for meteorite impact hazards.
11. Thermal insulation shall be provided to the coolant lines, wherever necessary to avoid condensation during ground operation.
12. The coolant lines shall have compensators to take care of the volume expansion/contraction of the coolant and leak from component (~1200 ml).
13. The system shall provide pre-chilling to CM volume at 18 ± 1^{o}C**,** before lift-off from launch pad and de-boost from orbit. 18 ± 1^{o}C to be finalised after doing a thermal analysis to keep the final temperature value at the end of flight within specification.
14. Necessary interfaces for ground chilling, the type and quantity of flow rate and temperature of coolant required at launch pad shall be worked out.
15. The Service Module (SM) shall have provision for ground chilling operations too, as the external radiator loop is ineffective at launch pad.
16. The feasibility of using a pump for providing thermal control of the crew cabin after landing in sea using seawater shall be explored
17. It shall be designed to perform all the above tasks maintaining redundancy as per section 4.7 for all active subsystems using flight heritage / flight-qualified components. It shall have provision for manual intervention on all active components inside crew module by the crew.
18. It shall have provision for closed-loop control using dedicated controller (along with data acquisition system, triple modular redundant sensors and control algorithm.
19. It shall have provision for leak / proof testing the system in integrated way.
20. Materials & seals for lines shall be compatible with coolants.
21. Mechanical joints shall be welded construction, wherever possible and considering the acceptance test and integration sequence for flight.
22. The layout of thermal control system has to be finalised with HSFC team.
23. System shall be fully instrumented to monitor the system health, status of components, cabin parameters like cabin temperature, %RH, fan speed, pump speed, flowrate, coolant pressure, level, coolant leak, temperature at different locations etc.
24. Requirement of passive thermal protection systems like coatings, heaters in cabin and coolant lines, insulation foams, etc. shall be clearly brought out.

25. Cold plates for mounting critical avionic packages with heat dissipation requirement (~350W) shall be designed.
26. Ground servicing, leak check and checkout requirement shall be brought out in details considering the functional requirements of coolant filling.

The thermal management of SM avionics is not part of this system.

5.2. Thermal Load

Table 4: **Overall-Heat Load**

Overall-Heat load in Flight	
Component	**Heat Load, W**
CM avionics	~ 1082
Electro-mechanical components of ECLSS	~ 450
En-route PGW pumps	22
En-route Novec pumps in SM	73
ARS Exothermic reaction	100
Heat of condensation (HOC)	0
Crew Metabolism (including HOC)	~ 450
Total Heat Load	**~ 2267**
On Orbit heat leak through TPS	**~ 350**
Nominal on-orbit heat load	**~ 1917**

5.3. Humidity Load

Table 5: Humidity Load

Component	**Humidity Load**
Humidity generated by Crew	1.5 kg/day/crew
Humidity generated by ARS	1.5 kg/day

5.4. Systems Engineering

a. Maximum mass : 487 kg (CM: 162 kg, SM: 325 kg)
b. Maximum Power : 430 W (for THCS component)
c. Envelope constrains as per annexure I

6. Cabin Pressure Control System (CPCS)

The Cabin Pressure Control System (CPCS) is a subsystem of the Environment Control and Life Support System. The main function of CPCS is to monitor the total pressure of cabin and to control the partial pressure of O_2 within the specified limits for a cabin air volume of 4.8m^3 and to supply 99.5% pure gaseous medical grade O_2 to flight suits, in case of emergency.

6.1. Design inputs – functional requirement

CPCS shall perform the following tasks:

1. CPCS shall maintain the total cabin pressure in the crew cabin between 98-116 kPa.
2. It shall maintain the cabin Oxygen partial pressure in the crew cabin between 19 - 23 kPa
3. It shall prevent over-pressurization of the cabin. The cabin internal-to-external differential pressure shall not exceed 120 kPa and external to internal differential pressure shall not exceed 10 kPa
4. The system shall have provision for cabin depressurization, in case of emergency meeting human tolerance requirement.
5. In case of emergency, (when the cabin pressure goes below 50 kPa) gaseous Oxygen shall be supplied to the flight suit at the rate of 22 ± 1.5 lpm per suit (22.5 lpm measured @ 1 bar) for 180 minutes while in orbit. The flight suit inlet line pressure shall be 4.5 ± 0.5 bar. There will be three flight suits and provision shall be there to deliver Gaseous Oxygen to one or two or three suits independently or simultaneously at the required rate and pressure.
6. Crew Module shall have Oxygen storage to support the crew breathing or emergency Oxygen supply to suits during descent for 50 minutes. Resources shall be planned for the total emergency time duration of 180 (130 + 50) minutes.
7. It shall have provision to passivate Oxygen tanks upon command. Crew Module Oxygen tank pressure shall be reduced to ~ 1 MPa before landing. The sequence of passivation shall be provided.
8. Service module gas storage shall have provisions to passivate the gas bottles.
9. It shall have provision for cabin pressure equalization in case CM is descending with lower cabin pressure.
10. It shall have provision for post-landing ventilation, ensuring communication of external atmosphere to the cabin after touchdown, for crew comfort, breathing.
11. It shall be designed to perform all the above tasks maintaining redundancy as per section 4.7 for all active subsystems using flight heritage/flight-qualified components. It shall have provision for manual intervention on all active components by the crew.
12. It shall have provision for closed-loop control using dedicated controller (along with data acquisition system, triple modular redundant sensors and control algorithm.
13. It shall have provision for leak / proof testing the system in integrated way.
14. Cleaning procedure and safety practices for Oxygen system shall be provided. Standard followed shall be mentioned.
15. Ground servicing, leak check and checkout requirement shall be brought out in details considering the functional requirements of oxygen filling.
16. Redundancy in coils for solenoid valves, electro-pneumatic valves, etc. is preferred (optional). Manual intervention provision is essential feature in case of primary

system failure. Any deviation in fault tolerance requirements shall be addressed in the circuit design.

17. The natural frequency constraints of the fluid system's plumbing shall be met i.e., >100 Hz at the integrated level.

6.2. Systems Engineering

a. Maximum mass : 187 kg (CM: 99 kg, SM: 88 kg)
b. Maximum Power : 10 W
c. Envelope constraints as per annexure I.

7. Cabin Air Revitalization and Trace Contaminant Control system

Providing breathable, oxygenated air is a necessity and top priority for human exploration space crafts. The ability to remove Carbon dioxide (CO_2) that human exhale is just as important. Too much CO_2 (hypercapnia) can cause dizziness, confusion and breathing difficulties for the crews. The life support system shall maintain the air composition suitable for crew, by removing CO_2, odour and controlling trace contaminant and monitors the major constituent in the cabin atmosphere. Trace gas contaminants shall be controlled with the specified SMAC (Spacecraft Maximum Allowable Concentration) limits as per NASA standard.

7.1. Design Inputs

1. System shall collect the air from cabin and after removing CO_2 and trace contaminants, re-circulate the conditioned air back into the cabin. The air is driven by a fan/blower.
2. Shall adsorb the CO_2 exhaled by crew [0.96 kg/day/crew] and to maintain the CO_2 partial pressure < 670 Pa in cabin.
3. Carbon dioxide control: – Canisters of passive CO_2 sorbent required for a dust-free, low pressure drop, volumetrically efficient (high packing density) Carbon Dioxide Control Assembly with very good adsorbing capacity. The canister shall absorb trace contaminants and odour. In other words, the canister shall be modular.
4. Design of canisters should be such that it can support a three-person crew for minimum 20 hrs. Proper cover for canister shall be provided when not in use inside CM.
5. The consumable sorbents shall be easily replaceable. A proper packing method to be evolved for storage of canisters so that it can be stored for a specific period without any degradation in its efficiency.
6. Contingency option- after splashdown, in case if the crew is unable to establish ventilation with ambient atmosphere, a canister system to remove CO_2 and provide O_2 shall be provided. This canister shall work and support 3 crew for 12 hrs. Heat output of this cannister shall be provided.

7. Provision for audible or visual alarm cautioning the time to change the canisters shall be implemented.
8. Automated system with FDIR logic to be implemented. Human in loop requirements shall be clearly brought out. The system design shall be one fault tolerant.
9. Fully instrumented system to monitor the system health, status of components, cabin parameters like pCO_2, trace contaminant level, %RH, fan speed, flowrate, sorbent life etc.
10. The system shall have interfaces with ECLSS controller which in turn has link with the on-board computer and Ground Station Control. Necessary algorithm shall be provided for the close loop functioning of system.
11. It shall be designed to perform all the above tasks maintaining redundancy as per section 4.7 for all active subsystems using flight heritage/flight-qualified components. It shall have provision for manual intervention on all active components by the crew.
12. It shall have provision for closed-loop control using dedicated controller (along with data acquisition system, triple modular redundant sensors and control algorithm).
13. It shall have provision for leak / proof testing the system in integrated way.
14. The service life/cycles requirement of the components used shall be defined and demonstrated on an equivalent setup, before human flight use.

7.2. Specification of Air Revitalization System

1. Life of Canister for 3 crew is ~ 20 hours.
2. CO2 level below 670 Pa in cabin

7.3. Systems Engineering

a. Maximum mass : 60 kg (CM: 60 kg, SM: 0 kg)
b. Maximum Power per blower : < 50 W
c. Envelope constraint as per annexure I.

8. ECLSS Control System

Closed loop system with an independent controller shall be the control philosophy for ECLSS. The controller controls and commands the system, based on sensor information. It acts based on the pre-programmed logic/algorithm for each system.

Based on the functional requirements, various subsystems are configured for measurement and control of ECLSS control system. They are located in the crew module and service module. The subsystems are mentioned here.

1. ECLSS Controller for crew module and service module subsystems
2. Data Acquisition (DAQ) system for crew module subsystems
3. DAQ system for service module subsystems

4. Environment monitoring system in crew module
5. Sensors for control and monitoring in crew module and service module
6. Closed loop control algorithms
7. Ground checkout and servicing equipment

ECLSS subsystems such as Cabin Thermal and Humidity Control System, Cabin Pressure Control System, Air Revitalization System and Interfaces need to be operated in closed loop including measurement of critical parameters and driving the actuators to meet the specifications. In open loop mode, the control parameters cannot be maintained within the required specifications. Hence, the control system architecture and design are configured to operate in closed loop mode.

8.1. Design Inputs for ECLSS Controller and drive unit

1. All electronics component shall be space grade qualified to Gaganyaan levels.
2. Controller shall have the closed loop control algorithms for temperature/humidity control, ARS system and cabin pressure control system. The controller should ensure that the execution time requirement of each subsystem is met with respect to data acquisition, transfer of sensor data, processing and loop algorithm execution, command posting to actuator followed by execution.
3. Controller shall handle the telemetry and tele-command interface with Mission computer for all subsystems over 1553B bus or raw bus commands. Formatting of all subsystem, sensor, actuator health and control loop parameters have to be carried out and passed onto mission computer for telemetry and storage requirements.
4. Controller and drive unit shall have Failure Detection and Isolation (FDI) algorithms to isolate a failed data acquisition system, sensors or actuators. Upon detection of failure, the subsystem is to be isolated and remaining subsystems have to be configured for further action.
5. The ECLSS control system including controller, Data acquisition system and Environment Monitoring System etc, shall be implemented in triple modular redundancy.
6. Controller shall provide ON/OFF commands for the actuators as well as speed commands for the actuators as per the operational requirement.
7. Controller shall interact with drive unit in service module for driving the actuators in service module.
8. Controller shall interact with all subsystems to get sensor data and drive the required actuators.
9. Sampling time, ranges for sensors shall be defined.
10. Controller shall switchover to healthy power bus in case of power bus failure.

11. Controller shall share the data and flags to be shown in crew display as telemetry
12. Controller shall be implemented in triple chain configuration so that even after two failures, system is still functional. Controller shall be designed such that a healthy controller shall drive the actuators in case of failure.
13. Controller shall monitor the critical parameters of all ECLSS subsystems and request for an abort in case of deviation or failures.
14. Controller shall be designed such that back EMF effects of the actuators shall not affect the main power bus.
15. Controller shall be powered from on-board power bus, 25V-42V. It shall have ON/OFF circuits for powering sequence. It shall provide the necessary power conditioning to ensure actuator performance.
16. Provision for crew intervention for manual override shall be provided for cases such as temperature change, pressure control, actuator ON/OFF etc, all actuators in crew module shall have crew intervention provision for switching ON, the crew commands are given from the crew display system.
17. System architecture shall be such that required actuators such as blowers, pumps, fans shall be operated post touchdown with optimized power requirement.
18. The system shall be developed using EEE components in line with the component philosophy for ISRO which can be defined during the design phase.
19. The overall ECLSS including control system, actuators, DC-DC converters shall follow grounding scheme which can be defined during the design phase
20. Ground checkout system for the ECLSS shall be designed for meeting the servicing requirements for on-board system. The requirements shall be finalized during the design phase.
21. System shall be designed with optimized mass, power and footprint.

9. Technical requirements:

The party shall provide a detailed technical proposal with the development plan and shall address the below-mentioned requirements

9.1. Design requirements

a. Party shall propose a ECLSS circuit having maximum number of heritage components and remaining components designed and qualified to human rating requirements as per NASA & ESA standards & requirements specified by HSFC.

9.2. Systems engineering of ECLSS

a. System layout including accommodation of components, proper routing and layout finalization, based on inputs provided in **annexure I**. 3D model of CM & SM required for doing the layout will be provided by HSFC against NDA. Layout shall consider the human ergonomics and anthropometry.

b. The modular approach of the functional modules shall be followed wherever possible, for independent installation/ testing at the subsystem level.
c. The system which requires manual intervention in case of emergency shall be ergonomically positioned.
d. The proposed system shall be accommodated in the envelopes provided by HSFC for ECLSS system.

9.3. Review & Design documents

a. Party shall make a detailed document, for review, of component design, component selection, 3D models, structural model, system layout, integrated analysis, control algorithm, detailed test plan for component testing & integrated system-level functional testing.

9.4. Mass and Power Budget

The estimated mass and power budget of Gaganyaan ECLS systems are as follows

- Total ECLSS mass budget is 745 kg
- Total ECLSS power budget is 630 W

9.5. Ground servicing equipment

a. Party shall provide detailed specifications of ground servicing equipment, filling console for pneumatic leak test, Gaseous Oxygen filling and draining at high pressure, coolant filling and draining.
b. Ground servicing equipment (mechanical and electrical components) interface control document shall be provided. Installation requirements shall be provided.

9.6. Schedule

a.	NDA	:	T0
b.	Feasibility study	:	T0 + 2 months
c.	ECLSS and Ground servicing equipment PDR	:	T0 + 4 months
d.	PDR	:	T0 + 4 months
e.	Final feasibility study report after implementing PDR suggestion	:	T0 + 4.5 months

T0: Date of NDA signing

10. Technical Compliance Matrix

SL No	Description	Compliance by party	Party's remarks/ Documentary References	Mandatory /Preferred
1.	ECLSS circuit (PID) to be provided List of components (developed in house or through tie up with other reputed industries), quantity, flight heritage history			**Mandatory**
2.	Compliance to functional requirements as mentioned in Section 3-9		A detailed technical proposal by the party shall be provided.	**Mandatory**
3.	Compliance to Design inputs as mentioned in Section 3-9		A detailed technical proposal by the party shall be provided.	**Mandatory**
4.	List of Applicable standards followed for human rating and the processes		Details to be provided	**Mandatory**
5.	Compliance to Scope of work as mentioned in Section 2		A detailed technical proposal by the party shall be provided.	**Mandatory**
6.	Compliance to Technical Requirements as mentioned in Section-9 with detailed technical proposal		A detailed technical proposal by the party shall be provided.	**Mandatory** If any change in tech req. demanded by party, party has to give detailed technical explanation

				acceptable to ISRO
7.	Quality and human rating certification		A detailed plan and route to certification to be submitted. With Applicable Standards	**Mandatory**
8.	Compliance to Price bid format (Annexure IV)			**Mandatory**
9.	Compliance to Commercial terms			**Mandatory, any difference in view shall be mutually agreed upon**
10.	Execution/Development plan for future 5 sets of hardware to be submitted If the party is planning to sub contract the activities; MoU/Contract between prime and sub-contractor shall be provided to department for reference and verification. Sub contract can be given to party with heritage of supplying similar components for human flight.			**Preferred**
11.	All mechanical & electrical interfaces shall be provided by the party for implementation in Gaganyaan OM			**Mandatory**

12.	Ground Servicing equipment specifications		To be provided	**Mandatory**
13.	Implement review/suggestion from ISRO			**Mandatory**
14.	a. Willingness to deliver 5 sets of ECLSS hardware after successful completion of feasibility study if a future contract is awarded to party b. At least 1 set of ECLS Subsystem (THCS, CPCS, ARS, ECLSS controller) integration and ECLS System Integration to Orbital Module in India, by the party, as part of future hardware delivery contract, if any.		Willingness to be indicated	**Mandatory**
15.	Solution & Standard product	Product heritage or TRL level (min 7)		**Mandatory** Certificates
16.	Proposed delivery Schedule, cost, Mass and Power budget			**Mandatory**
17.	Party shall provide their experience in designing similar system for manned space mission with declaration (subject to verification). If the party is planning to collaborate with another vendor; MoU/Contract between prime and sub-contractor shall be provided to department for reference and verification. Collaboration can be done with vendor having proven heritage of supplying similar components for human flight.	Yes/No	Only parties with prior experience or collaboration with party having prior experience in manned mission hardware design and delivery will be considered	**Mandatory**

TRL definition:

Technology Levels are as defined below
TRL-1: Basic principles observed and reported.
TRL-2: Technology concept and/or application formulated.
TRL-3: Analytical and experimental critical function and/or characteristic proof-of-concept.
TRL-4: Technology basic validation in a laboratory environment.
TRL-5: Technology basic validation in a relevant environment.
TRL-6: Technology model or prototype demonstration in a relevant environment.
TRL-7: Technology prototype demonstration in an operational environment.
TRL-8: Actual technology completed and qualified through test and demonstration.
TRL-9: Actual technology qualified through successful mission operations

Annexure I

System layout

CM to SM connection is through an automatic sealing device, which is part of a separable umbilical. All lines into CM pressurized compartment are through location

Crew Module:

Defeatured structure (without any support, cross-members) of Gaganyaan Crew Module is shown in Figure 1 to illustrate the nomenclature of Crew Module structure.

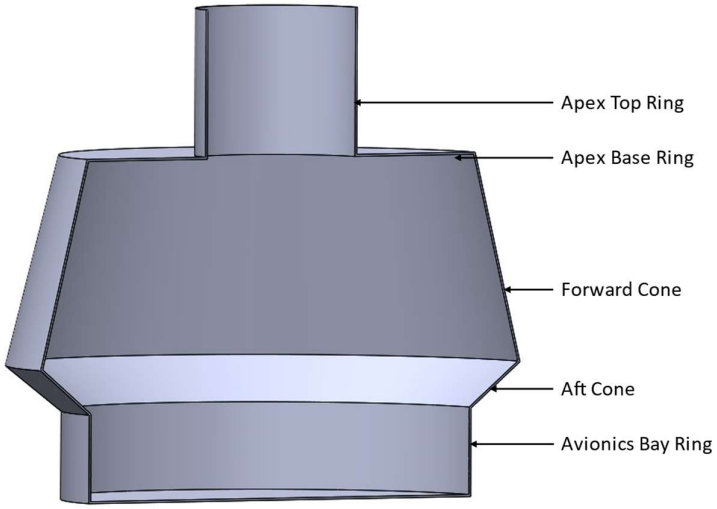


Figure 3 Nomenclature of Crew Module Structure

Accommodation of various ECLSS systems and components in CM is shown in Figure 2 (Isometric View) and Figure 3 (Viewed from Y+ axis).

Systems/Subsystems in Unpressurized region of CM:

1. O_2 Storage Tanks

Systems/Subsystems in Pressurized region of CM:

1. ARS Canisters (Green)
2. KO_2 Canister (Green)
3. Condensing heat Exchanger (Teal)
4. Non-Condensing Heat Exchanger (Teal)
5. CPCS Control Panel (Blue)
6. CVU Inlet & Exhaust Assembly (Blue)
7. SRV (Yellow)

ARS canisters are mounted on Forward cone. KO_2 canister is mounted on Aft cone. Non-Condensing Heat Exchanger, CPCS Control Panel, CVU Inlet & Exhaust Assembly, SRV are mounted on Apex base ring. Condensing Heat Exchanger is accommodated on Avionics deck (Not shown in figure). Subsystems shall have direct mounting interfaces to the Crew Module structure.

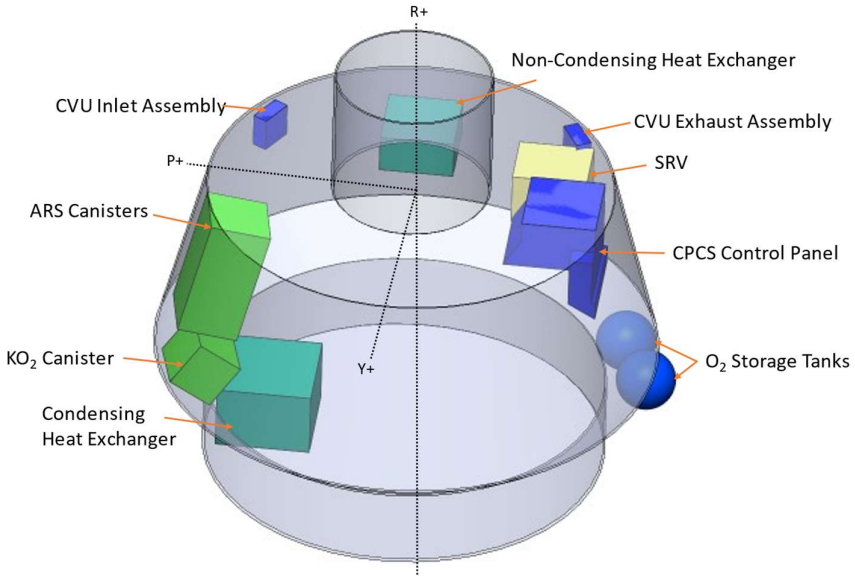


Figure 4 Isometric View of Crew Module with ECLSS subsystem Envelopes (translucent structure)

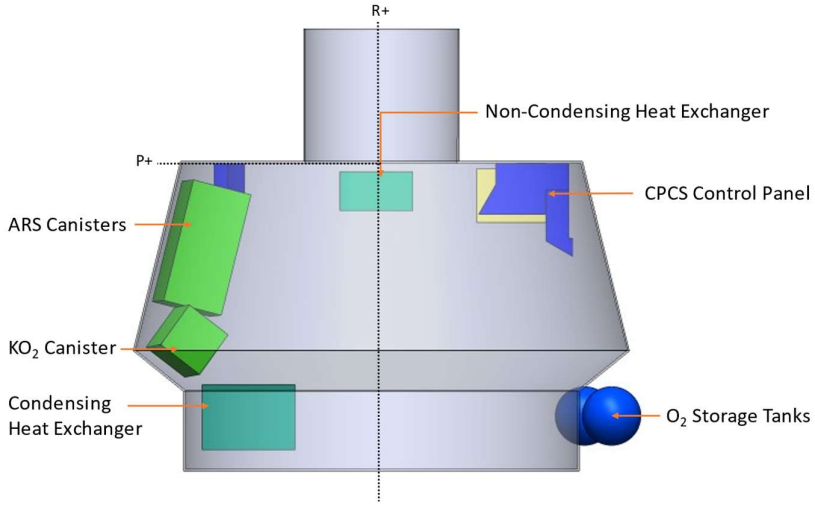


Figure 5 Crew Module Viewed from Y+ axis (Translucent structure)

Defeatured CM structure along with subsystem envelopes will be provided in. STEP format after PO and NDA.

Service Module:

The defeatured model of Service Module (SM) structure along with ECLSS component envelopes marked in it is given below.

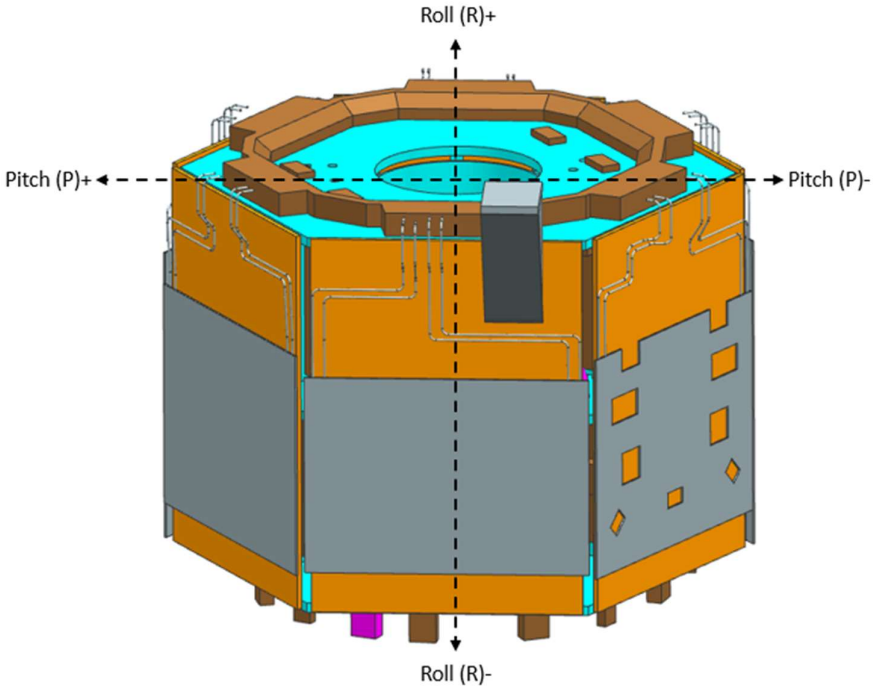


Fig 1: Defeatured SM model

1. Defeatured SM structure without any cuts, ribs, strengthening mechanism & anchoring mechanism. However, details relevant with the ECLSS standpoint are present in the model. The defeatured SM structure consist of the following components. (Ref: fig 2 & 3)
   - **i)** Horizontal decks i.e., Top deck, intermediate deck & bottom deck
   - **ii)** Six shear webs (SW 01 to SW 06)
   - **iii)** SM external structures i.e., six vertical decks (VD 01 to VD 06)
   - **iv)** Cut-outs present on shear webs and horizontal & vertical decks
   - **v)** Inner cylinder
2. THCS component envelopes (Ref: fig 4,5,6,7 & 9)
3. CPCS component envelopes (Ref: fig 6,7,8 & 9)
4. Radiators and supporting plumblines on vertical decks (Ref: fig 2)
5. CM-SM connect disconnect system envelope on VD 01 (Ref: fig 2)

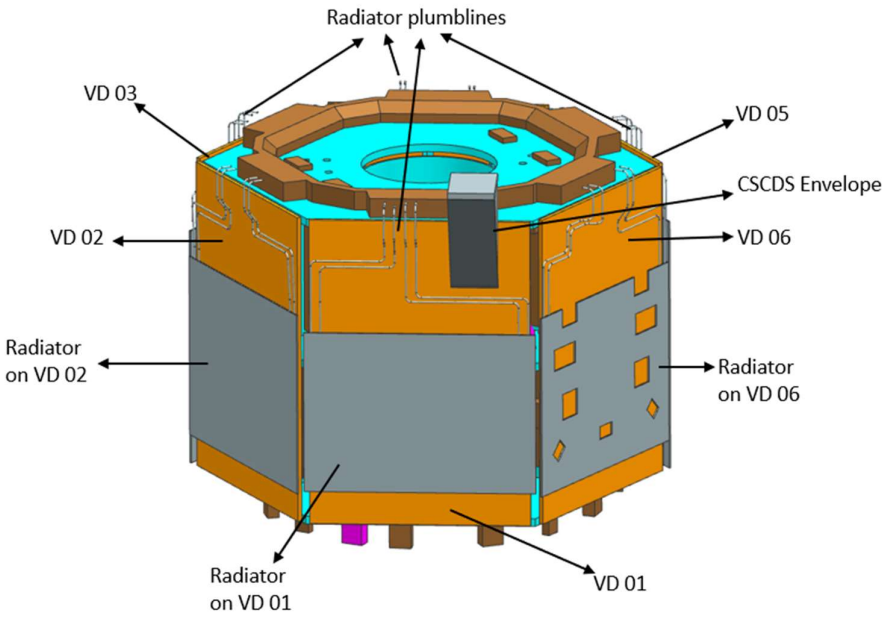


Fig 2: Defeatured SM structure model with vertical decks

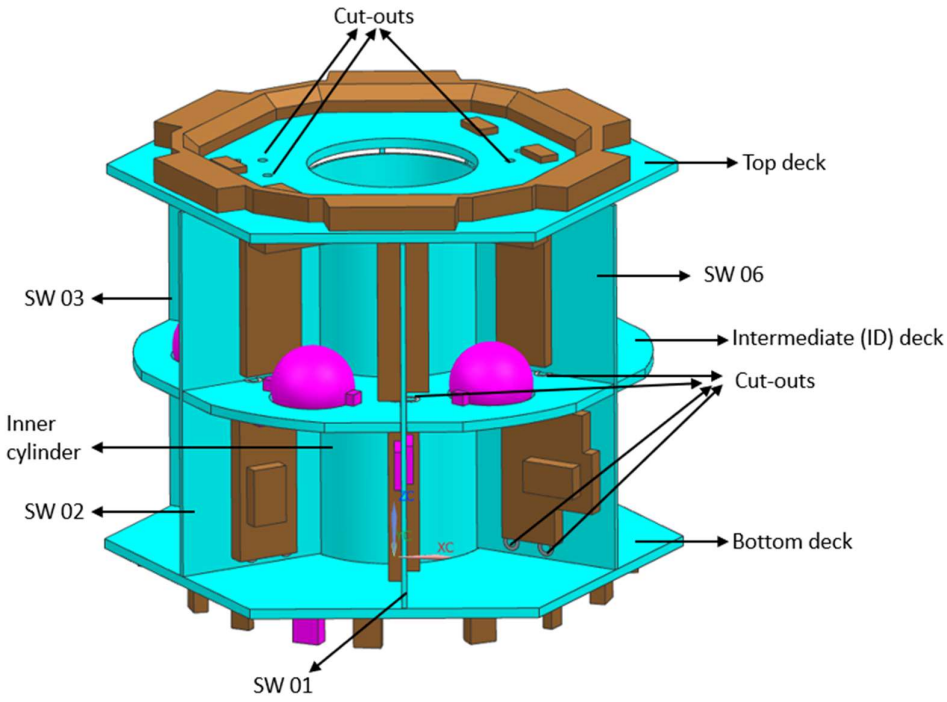


Fig 3: Defeatured SM structure model without vertical deck

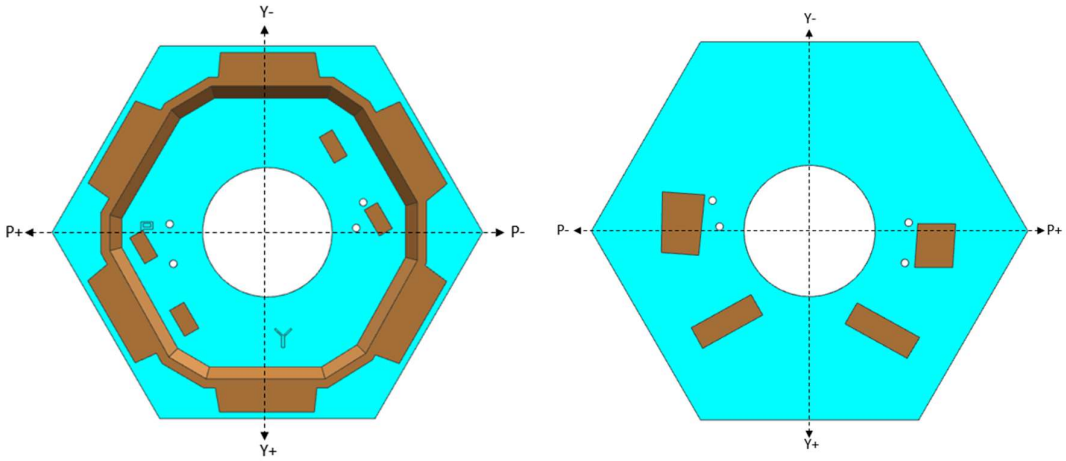


Fig 4: THCS components & plumbline envelopes (Brown colored) on top deck R+ & R- faces

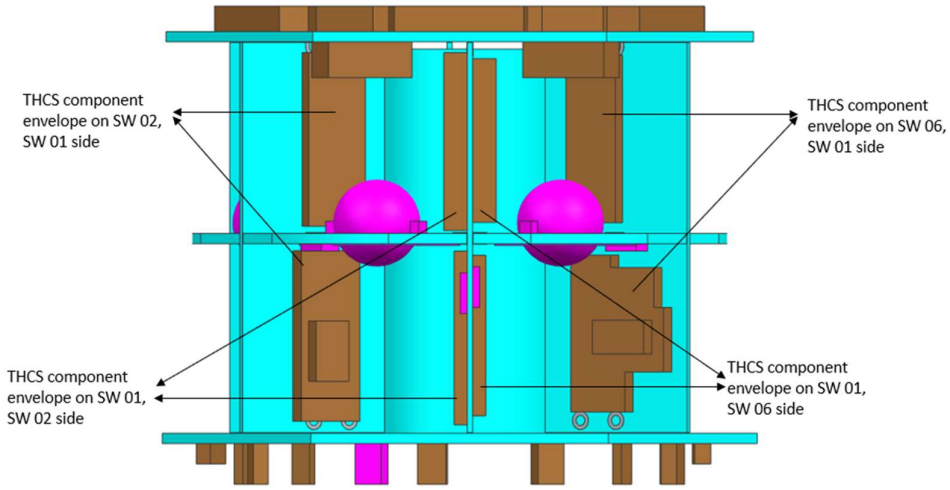


Fig 5: THCS components & plumbline envelopes (Brown colored) on SW 01,02 & 06

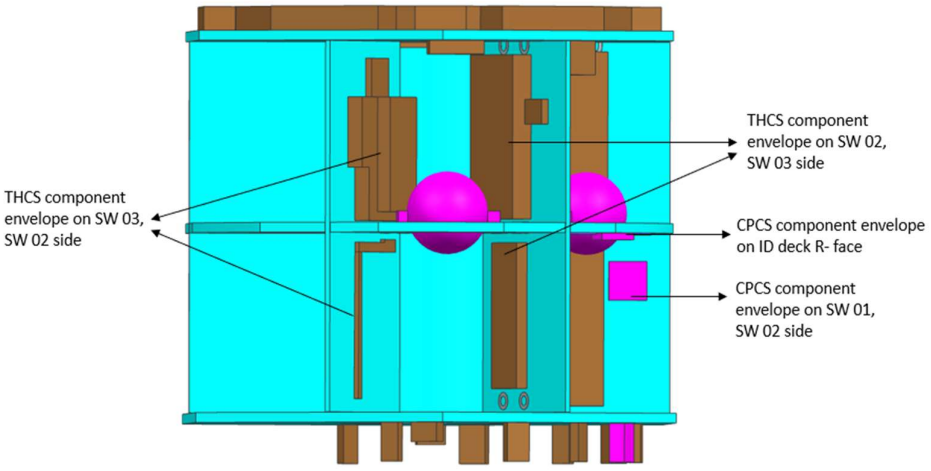


Fig 6: THCS & CPCS components & plumbline envelopes on SW 02 & 03

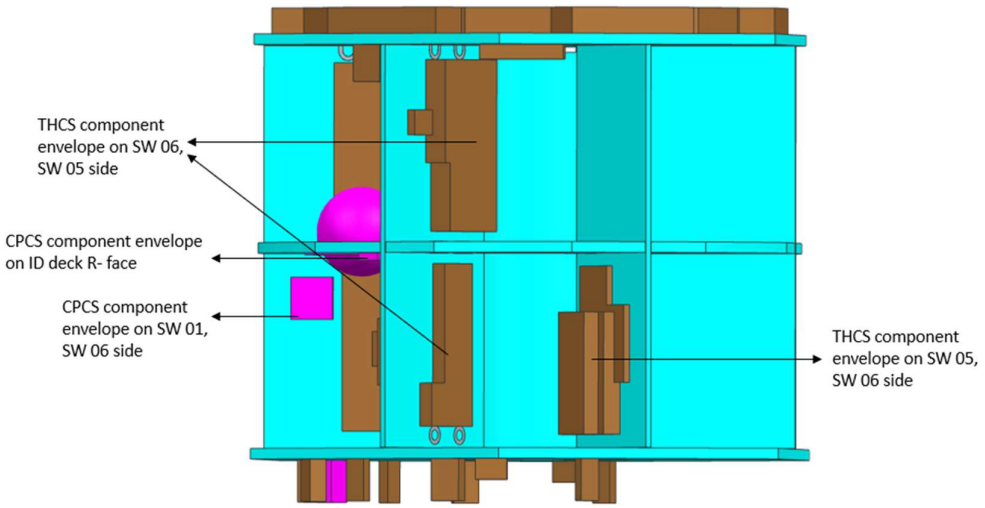


Fig 7: THCS & CPCS components & plumbline envelopes on SW 05 & 06

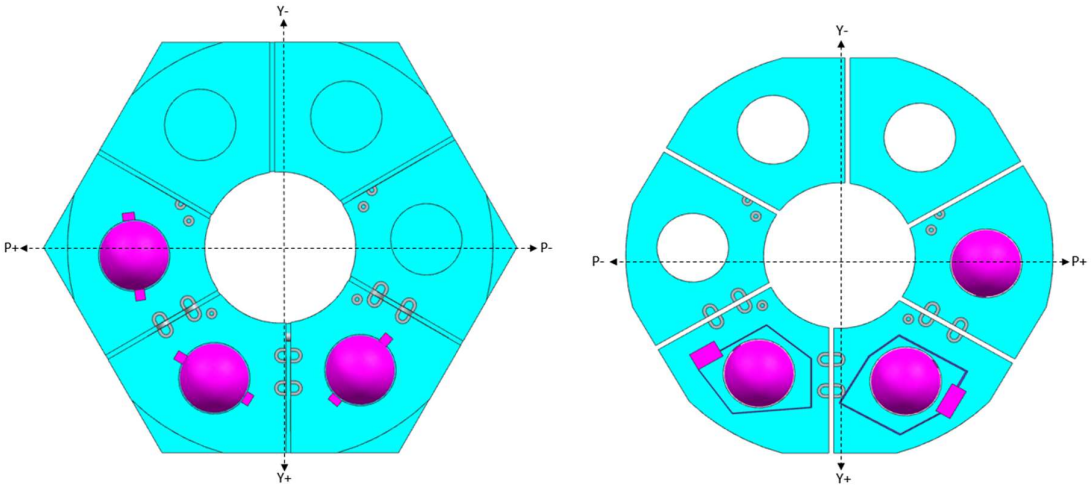


Fig 8: CPCS components & plumbline envelopes (Magenta colored) on ID deck

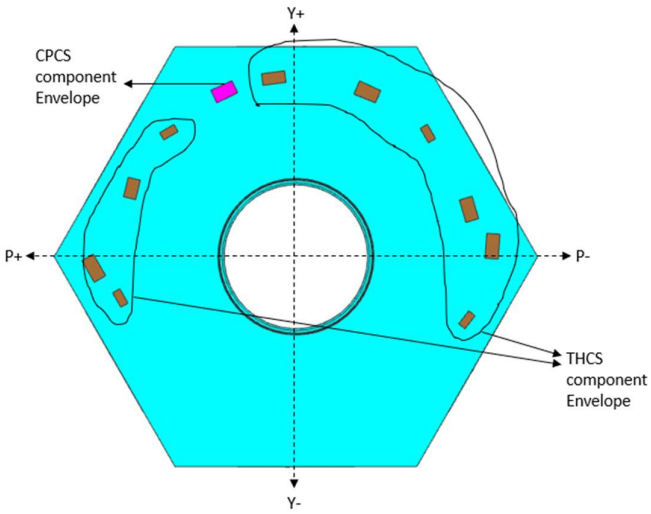


Fig 9: THCS & CPCS components & plumbline envelopes on bottom deck R- face

❖ **Color code for the components:**

Sl. No	Component	Color
1	SM horizontal decks, inner cylinder & shear webs	Sky blue
2	SM vertical decks (VDs)	Yellow
3	Cut out in decks & shear webs	Gray
4	CSCDS envelope	Gray
5	THCS components & plumblines envelope	Brown
6	CPCS components & plumblines envelopes	Magenta
7	Radiators & supporting plumblines	Gray

Design Factors

The factors of safety applicable for different types of structures are given in the following sections

Pressure Vessels

The pressure vessels include Gas bottles, pressurant tanks and propellant tanks mounted internally.

Table 2. Minimum Design & Test Factors of Safety for Pressure Vessels

Types of Pressure vessel	Design Factor of Safety		Test Factor of Safety	
	Proof	Burst	Proof	Burst
Metallic	1.5	2.0	1.5	2.0
Composite	1.5	2.0	1.5	2.0
Composite overwrapped with metallic liner	1.5	2.0	1.5	2.0

Fracture control may require higher factors if the proof test will be used for flaw screening. When factors different from the above are used, the following relation may be used for determination of proof pressure

fproof = (1+fburst)/2, when fburst < 2.0

fproof = 1.5, when fburst > 2.0

Airbus clarification: o.k.

Pressurized Components

Table 3. Minimum Design & Test Factors of Safety for Pressurized components

Type	Types of PC	Proof Factor	Burst factor
Metallic Pressurised Components	Lines & Fittings Dia <38mm	1.5	4.0
	Lines & Fittings Dia >38mm	1.25	2.5
	Fluid Return sections	1.5	3.0

	Fluid Return Hose	1.1	5.0
	Other pressure components	1.5	2.5
Composite Overwrapped Special Pressurised Equipment's		1.25	1.5

*As per ECSS-E-ST-32-02C Space Engineering- Structural Design & Verification of pressurized hardware

Fracture Control

For Gaganyaan programme, it is required that designs of all critical flight hardware like pressure vessels such as gas bottles, propellant tanks etc., shall be based on Fracture Control Procedures when structural failure from crack propagation can result in a catastrophic event.
All flight hardware shall be assessed and classified for fracture criticality. Any part or component whose individual failure would result in a catastrophic event will be evaluated under Fracture Control. The design, manufacture, and use shall be managed to minimize the risk of catastrophic failure due to manufacturing and service-induced flaws, damage or crack-like defects.
Springs (Ref.NASA-STD-5017A). Helical compression and tension springs should be designed to develop a maximum shear stress of no more than 80% of the allowable shear yield strength. Helical compression springs should have closed and ground coils for interfaces. If torsion springs are used, they should be under load in the direction of winding (i.e., the load should tend to further close the winding) at all times. Compression springs usually retain some measure of performance after fracturing. In order to depend on this type of failure tolerance, it has to be ensured that broken halves of coil springs cannot thread into one another after breaking.

Environmental Test Levels (Tentative)

The test levels given below is only for preliminary design.

Sine Vibration Level:

Sine vibration specifications ***for all ECLSS components*** are given in Table 4 for Gaganyaan spacecraft.

Table 4 Sine Vibration levels for LSS & TCS components (Ref: Environmental Test Specifications: Crew Module for TV-D1, Pg:54)

Axis	Frequency (Hz)	Acceptance level	Qualification Test level
Longitudinal	5-20	16.5 mm DA	24.8 mm DA
	20-70	13.3g	20 g
	70-100	6.7g	10 g
	Sweep rate	4oct. / min	2 oct. / min.
Lateral	5-18	15.4 mm DA	23.0 mm DA
	18-70	10g	15g
	70-100	5.3g	8g
	Sweep rate	4 oct. / min	2 oct. / min.

Random Vibration level for Orbital module:

Table 5 Longitudinal Random vibration levels for LSS & TCS components (Ref: GSAT-29 specification, pg: 54)

Frequency (Hz)	Longitudinal PSD (g2/Hz)		Components applicable
	Qualification level	Acceptance level	
20-100	+ 3 dB/oct.	+ 3 dB/oct.	All ECLSS components except O_2 Gas bottle
100-700	0.33	0.15	
700-2000	- 6 dB/oct.	- 6 dB/oct.	
Overall rms	19.1g	12.7g	
Duration	120s	60s	

Table 6 Lateral Random vibration levels for ECLSS components (Ref: GSAT-29 specification, pg: 54)

Frequency (Hz)	Lateral PSD (g2/Hz)		Components applicable
	Qualification level	Acceptance Level	
20-100	+ 3 dB/oct.	+ 3 dB/oct.	All ECLSS components except O_2 Gas bottle
100-700	0.1	0.04	
700-2000	- 3 dB/oct.	- 3 dB/oct.	
Overall rms	11.8g	7.9g	
Duration	120 s	60 s	

Table 7: Random vibration levels for O_2 tanks in all three axes (Ref: GSAT-29 specification, pg: 47)

Frequency (Hz)	PSD (g2/Hz)		Components applicable
	Qualification level	Acceptance level	
20-100	+ 6 dB/oct.	+ 6 dB/oct.	O_2 Gas bottle
100-1200	0.27	0.12	
120-2000	- 6 dB/oct.	- 6 dB/oct.	
Overall rms	19.6g	13.1g	
Duration	120s	60s	

. Shock levels

4.1 Shock levels for Crew module: (Ref: Environmental Test Specifications: Crew Module for TV-D1, Pg:51)

Shock specifications for components of ECLSS are given here.

Table 8 : SRS Test specification for location 1 (Apex region)

Freq (Hz)	SRS
100-600	12 dB /oct
600-5000	1500g
No of Shocks	2 pulses/axis

Table 9 : SRS Test specification for location 2 (Conical region) (Ref: Environmental Test Specifications: Crew Module for TV-D1, Pg:51)

Freq (Hz)	SRS
100-600	12 dB /oct
600-5000	600g
No of Shocks	2 pulses/axis

Table 10 : SRS Test specification for location 3 (Bottom deck region) (Ref: Environmental Test Specifications: Crew Module for TV-D1, Pg:51)

Freq (Hz)	SRS
100-1300	12 dB /oct
1300-5000	3000g
No of Shocks	2 pulses/axis

4.2 Shock levels for Service module:

Table 11 : SRS on decks in all three axes (Ref: GSAT-29 specification, pg: 72)

Frequency (Hz)	SRS
100 – 600	15 dB/oct
600 - 2000	2 dB/oct
2000 - 5000	3000 g
5000 - 10000	-6 dB/oct

Table 12 : Cylinder/Tanks (Axis: Normal to mounting plane) (Ref: GSAT-29 specification, pg: 72)

Frequency (Hz)	SRS	Components applicable
100 – 600	15 db/oct	O_2 Gas bottle
600 - 2000	5.5 db/oct	
2000 - 5000	6000 g	
5000 - 10000	-6 db/oct	

In addition to above levels ECLSS components are to be tested to the level given below

- Acceleration : 50g
- Duration : 10 ms
- Shape : Half sine
- No. of shocks : One / axis / direction
- Axis : All 3 axes

Acoustic levels for LSS & TCS components:

Octave band freq. (Hz)	SPL (dB) (Ref: GSAT-29 specification, pg: 61)		
	Qualification level	Acceptance level	Tolerance
31.5	132	129	+4/-2
63	135	132	+3/-1
125	133	130	+3/-1
250	134	131	+3/-1
500	131	128	+3/-1
1000	126	123	+3/-1
2000	114	111	+3/-1
Overall	140.5	137.5	+3/-1
Duration	120 s	60 s	

Thermal tests:

- Initial Bench Test: Functional, Performance and Interface verification.
- Hot & Cold Soak (Optional): For Proto flight Models; One Cycle with 12 to24 hrs dwell in hot and 12 to 24 hrs dwell in cold temperature extremes.
- Qualification temperature: -40 deg C (Lower limit) & 70 deg (upper limit)

Note: For CM component: Qualification temperature: +10 deg C to +40 deg C

Thermo-Vacuum test: (Ref: Environmental Test Specifications: Crew Module for TV-D1, Pg:53)

- Thermo-vacuum Cycling and Soak Test: Five short cycles (2hrs dwell at each of hot and cold temperature extremes) and one long cycle (24hrshrs dwell at each of hot and cold temperature extremes)
- Final Bench Test: Functional, Performance and Interface

  Thermo-vac test profile / plan is as shown in figure 1 and the test Specifications are as given below

Pressure	: $1x10^{-5}$ torr or better
Qualification temperature	: -40 deg C (Lower limit) & 70 deg (upper limit)
Acceptance temperature	: 10 deg lower with qualification temperature

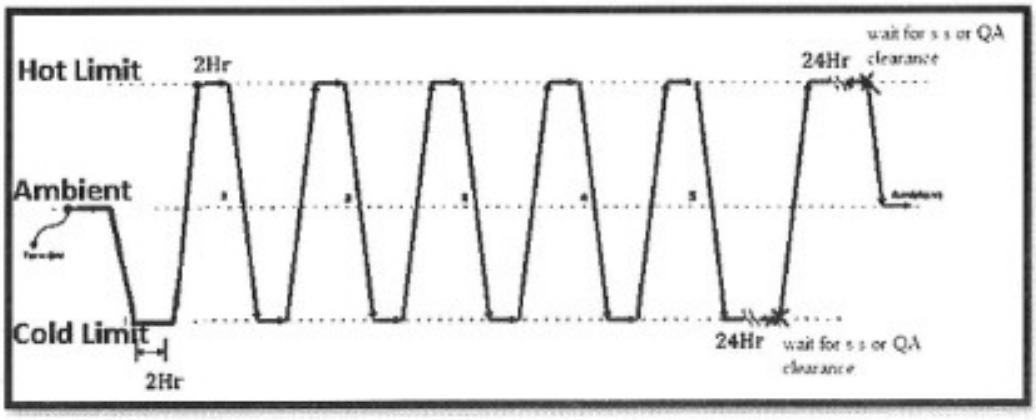


Figure 1: Thermal cycling

Note: For CM component: Qualification temperature: +10 deg C to +40 deg C

Annexure-IV

Price – Bid Format

S No	Deliverables	Man Hour	Cost per hour	Unit Cost (In Rs)	No of Sets	Total Cost (in Rs)
1	**Feasibility study cost**					
1.1	Design and analysis cost					
1.2	PDR					
1.3	Documentation cost					
2.	**Other costs***					
				GST		
				Grand Total Cost		

*Details to be provided by party

Annexure-V

Commercial Terms and Conditions

1. **Definitions:** Wherever used hereinafter in this document, the following expressions shall have meaning as given:

   - HSFC: The Human Space Flight Centre of the Indian Space Research Organization, Department of Space, Government of India.
   - ISRO: The Indian Space Research Organization under Department of Space.
   - Department: President of India or his successors, representatives or assigns, in this case, The Director, Human Space Flight Centre, ISRO HQ, Bengaluru.
   - The term 'Purchase Order / Contract' shall mean the communication signed on behalf of the Purchaser by duly authorized Officer intimating the acceptance on behalf of the Purchaser on the terms and conditions mentioned or referred to in the said communication accepting the tender or offer of the contractor for supply of stores, plant, machinery, equipment and services.

1.1 Conditions hereunder, the documents as per Annexures and figures hereto form integral part of this tender document and are complimentary to each other.

1.2 The Party shall not give any publicity of any kind of whatsoever regarding this tender document to anyone without prior written approval of the Department.

2 Organization of Work

2.1 The Party shall identify key persons for critical activities. They shall be replaced only by persons of equivalent qualification, knowledge and experience and with the prior intimation to the Department in writing.

2.2 Party shall ensure that the progress of the work under the Contract shall not be affected due to the absence of the key personnel.

2.3 The Party shall identify all the personnel responsible for executing the job with clear demarcation of work and the same shall be informed to the Contract Manager of the Department.

2.4 Party shall provide all Process documents, Plans, Reports, Registers etc. as envisaged.

2.5 Party shall provide necessary support to the visiting team from Department for carrying the tasks envisaged in the Contract.

3 Security Deposit

The Party shall execute security deposit for 3% (Three Percent) value of the Contract to ensure due satisfactory performance of the Contract. The security deposit shall be executed within 15 days after receipt of Purchase Order or any extension thereof.

The security deposit is to be furnished in the form of Account Payee Demand Draft or Fixed Deposit Receipt or Bank Guarantee from a Nationalized Bank/Scheduled Bank. The security deposit must be kept valid till completion of all the deliverables and an additional period of 60 days beyond the receipt of deliverables. The security deposit will not carry any interest and shall be returned by department after receipt of all deliverables.

4 Payment term

100% payment terms within 30 days from the date of receipt and acceptance of feasibility study report from our side.

5 Liquidated Damages

Liquated damages shall be applicable for the feasibility study of design, developing, qualifying and delivering 5 sets of ECLSS hardware, If the Party fails to deliver the same as per the delivery schedules specified in the Contract or any extension thereof. Department shall recover liquidated damages of 0.5% (Zero-point two five percent) per week of unperformed contract value or part thereof subject to a maximum of 10% of the contract value.

The delivery date will be reckoned from the date of delivery targeted. Accordingly, LD will be calculated. However, on account of any delay by the Department in attending Inspection, delays in communicating approvals or any hold from the Department, the same will not be accounted for levy of Liquidated Damages.

6 Force Majeure

Should a part of or whole of deliverables covered by the Contract be delayed in delivery due to reasons of force majeure which shall include lock-outs, strikes, riots, civil commotions, fire accidents, acts of god like flood, earthquake, epidemics & quarantine restrictions (including future consequences of the Covid-19 pandemic) and war, stoppage of deliveries by any Government, change of law, refusal of or non-receipt of export or import license for raw-materials or finished parts, the delivery period referred in the Contract shall be extended by a period(s) not in excess of duration of such force majeure. Each Party undertakes to advise the other within thirty (30) days of becoming aware of the circumstances of such force majeure, so that actions under the provisions of the Contract can be mutually reviewed and agreed upon between the Party and the Department. If the force majeure condition extends over a period of six months, both the parties of the Contract shall mutually discuss and arrive at an agreement for continuation or termination of the Contract.

If the Contract is terminated under this Clause, the Department shall be at liberty to take over from the Party at price to be fixed by the Committee appointed by department which shall be final, all unused, damaged and acceptable materials, bought out components and stores in course of manufacture, in the possession of the Party at the time of such termination or such portion thereof as the Department may deem fit excepting such material, bought-out components and stores as the Party may, with the concurrence of the Department, elect to retain. Also, the Department shall compensate

the Party for its cost reasonably incurred under this Contract until the date of termination of the Contract.

The Party shall not be liable for any failure to carry out the obligations this contract for events of force majeure which are beyond the reasonable control of the Party.

7 Jurisdiction, Applicable Law and Infringement There off

The Contract shall be governed by the substantive laws of India. The Courts in India only shall have jurisdiction to deal with and decide any legal matters or disputes, if any, whatsoever arising out of this Contract. The Department shall not be responsible, if the Party infringes the Laws.

8 Arbitration

In the event of any dispute or difference arising out of any terms and conditions of this Contract, the parties shall strive to find mutually acceptable solution, failing which, all disputes or differences arising against this Contract or in connection with the agreement shall be settled in accordance with in accordance with the Indian Arbitration and conciliation Act 1996.

The number of arbitrators shall be three, one of which shall be appointed by the Party, the second arbitrator shall be appointed by the Department and the presiding arbitrator shall be elected by two appointed arbitrators. The arbitrators shall not be related to, or employed, or have any material business relationship with any Party. The place of arbitration shall be Bangalore, India. The arbitration proceedings shall be held in English. The arbitrators shall be qualified and licensed to practice law in the country whose laws apply to this Contract. The award of the Arbitration shall be final and binding on both the parties of this agreement.

9 Secrecy

9.1 The technical information, drawings, specifications and all related documents forming part of the Contract and exchanged between Department and the Party to each other shall not be used for any other purpose except for execution of the Contract. All rights for materials supplied by the Department including rights in the event of grant of patent and registration of design are reserved by the Department. The technical information, drawings, specifications and any other documents shall not be modified divulged and/or disclosed to any third Party except with the written consent of the Department. Distribution by the Party shall be allowed to the approved Sub-parties and to its affiliated companies, handling its administrative / legal services is herewith allowed to the extent needed for the completion of this Contract and under the provision that the entity is bound to confidentiality in the relationship with the Party.

9.2 The drawings and documents sent along with the Contract shall form part of vital documents and same should be kept confidential. Under any circumstances, Party shall not part with or transfer the technology / contents of drawings and documents whatsoever to any third party / agency without Department's prior written consent. If at any time, it is brought to the Department's notice that the documents have been

transferred by Party intentionally or otherwise to any third Party/ agency, Party shall be liable to indemnify the loss / damage incurred by the Department. In addition, Department reserves its rights to resort to legal remedies as per applicable law.

9.3 The Party shall not take any document / process sheet / data of the results / CD etc. issued to them containing work details to, outside the place of work in any form.

9.4 The Party or his employees shall not divulge any information that is made known to him across to any person not authorized to receive such information.

9.5 Any violation of secrecy, detected at any time of the Contract, by any of the employees of the Party shall attract serious consequences. Company shall execute necessary remedial action & submit report, failing which Department can terminate Contract itself as deemed fit.

9.6 Notwithstanding any access, audit and approval rights assigned to the Department under this contract, in no case shall Party (or its suppliers) be obligated under this contract to provide any Party's or its supplier's financial and/or proprietary information to the Department or to give access such information to the Department.

10 Deviation of Any Process / Inspection Procedures

Party shall not deviate from any of the approved process documents or inspection procedures unless Department approves either by waiver or amendment to the concerned process documents or inspection procedures in writing.

11 Amendment to the Contract

Modifications or amendments to the Contract, as well as changes in the scope or any specification applicable under this Contract leading to additional cost for the Party, and/or changes of delivery dates, shall be affected only in writing, after recommendation of committee appointed by the Department and the Party's authorized representatives exercising their mutual consent to the modifications or amendments involved.

12 Packing, Forwarding and Delivery/Mode of Dispatch

The Party shall safely & securely pack the documents and delivery shall be for HSFC.

12.1 Following dispatch documents shall be dispatched along with each consignment, as applicable:

- 1 soft copy
- 3 sets of hardcopies
- Invoice & Packing list.
- Following technical documents shall accompany deliveries:
  - (a) As built configuration record.
  - (b) Action closure reports.

12.2 The Ultimate Consignee is The Purchase & Stores Officer (Stores), Govt. of India, Department of Space, Human Space Flight Centre, Antariksh Bhavan, ISRO Hq Campus, Bengaluru-560094, Karnataka State, India.

13 Indemnity

The Party shall indemnify the Department against any action, claim or proceedings relating to infringement of all or any of the prevailing labour laws in country of origin during the currency of the Contract. Party shall not be responsible for compliance with labour laws regarding Department personnel performing tasks at Party's premises.

The Department shall indemnify the Party against any claim by a third party or by the Department employees or agents for any damage caused to such third party, employee or agent.

14 Intellectual Property Right

The ownership of intellectual property rights whether statutorily protected or not and generated in the course of or resulting from work undertaken for the purpose of this Contract shall vest with the Department unless the generated intellectual property is derived from the Party's existing intellectual property rights.

The Party is strictly forbidden to make use of or transfer the technology gained in the course of executing the Contract to manufacture by themselves or transfer for use, the same to the third Party.

15 Non-Disclosure Agreement

The Party and Department has to sign a Non-Disclosure agreement before signing the contract.

16 Short Closing / Termination of Contract

16.1 Under normal circumstances short-closing/termination of the Contract is not foreseen. However, in case of continued non-performance of the Party resulting in inordinate delays in the delivery dates in spite of repeated written requests for meeting the delivery schedule as provided for in the Contract, the Department reserves the right to terminate wholly or partly the Contract by giving a notice of not less than one month.

In case of major changes in the policies of the Government of India as a result of which the Department may curtail its requirements wholly or partly, the Department and the Party shall enter into negotiations to mutually agree to terminate this Contract wholly or partly.

Department and Party share the interest in the highly ambitious time schedule. Therefore, in case of termination of this Contract for delay, Department shall compensate Party for already procured material, unavoidable procurement commitments regarding hardware and services and for work in progress. The amount of the cost shall be demonstrated for evaluation to the CMC for final decision about the compensation.

In the event of short-closing/termination of the Contract, the following procedure shall be followed:

a) The Department shall give a notice of not less than one month.

b) On receipt of the notice the Party shall take all necessary steps for winding up of the Contract in line with the notice within a reasonable period, but in any case, not exceeding three months from the date of posting the notice.

c) The compensation to be paid to the Party shall be agreed to by mutual negotiations. The Department shall in no circumstances be liable to pay any sum which, when added to the other sums paid, due or becoming due to the Party under this Contract, exceeds the value of this Contract.

16.2 Party's default liability:

The Department reserves the right to terminate the Contract in whole or in part as per its discretion and also under the circumstances noted below giving sufficient notice to the Party:

(i) If the Party commits material breach of any of the terms of the Contract due to gross negligence, fraud or willful misconduct.

(ii) If the Party fails to rectify, reconstruct or replace any defective part/assembly within a reasonable period mutually agreed to after the Department having given a notice to this effect.

(iii) Except for any claim arising from Party's gross negligence, fraud or willful misconduct, in no event shall the Party be liable for any consequential, indirect, incidental, special exemplary or punitive damages, lost profits or revenues of diminution in value, arising out of or relating to any breach of this contract.

(iv) In no event shall Party aggregate liability arising out of breach of contract, tort (including negligence) or otherwise, exceed the total of the amount paid to the Party for the goods sold hereunder.

16 Safety

The Party shall ensure strict compliance of the provisions of Factories Act and the Workman's Compensation Act as applicable. Any liability for the persons employed by the Party shall be the responsibility of the Party.

17 Other Points

All registers & records maintained by the Party shall be returned to the Department at the end of the Contract or termination of the Contract, as applicable.