Payload Fairing Geometries as Space Stations with Flexible "Plug and Play" Rack System

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This paper outlines a design methodology of modifying launch vehicle payload fairing geometries into pressurized single or multi-element space stations. The project investigates how Carbon Fiber Reinforced Polymer with Aluminum honeycomb core (CFRP-Al/HC) fairing structure used for deploying satellites can be applied to function as space habitats. Large volume, low budget microgravity space stations that can be achieved along with the utilization of a pre-integrated flexible "Plug and Play" rack system prior to launch on the ground.

Nomenclature

LEO	=	Low-Earth Orbit
CFRP	=	Carbon Fiber Reinforced Polymer
P&P	=	"Plug & Play" Rack System
TRL	=	Technology readiness level
TPS	=	Thermal Protection System
psi	=	Pounds per square inch
IDSS	=	International Docking System Standard
MMOD	=	Micro-meteoroid orbital debris

I. Introduction

WITH the necessity of generating return on investments, private space companies are focusing on reusability, optimization and commonality of architecture and systems to get to orbit. Efficient and sustainable commerce is proving to be the way the space industry will become a democratized reality. Looking to generate returns in sending satellites into orbit, launch companies are effectively solving the conventional and new methods to reaching Low-Earth Orbit (LEO) and Geostationary Orbit (GTO). In 2018 alone there were more than 110 successful launches to orbit by both international agencies and private companies.

Following the growing trend of the space industry, is to be noted that launch and payload capacities are getting larger and costs are decreasing. But even with this rise in mass launch capabilities, space station modules and resupply mission modules to the ISS have maintained the same volumes and similar architectural concepts for a number of decades. Understanding that this industrial growth is largely dedicated to satellite deployment, if the preexisting infrastructure of fabricating launch vehicle fairings could be redesigned for pressurized habitats, then a new methodology may be applied industry-wide.

Complying with redundancy and risk mitigation requirements, the aerospace industry has been applying a "structure inside structure" strategy to habitat design with the sizing of habitat modules and structures to fit internal dimensions of payload fairings. This paper investigates the idea of removing the internal module structure to decrease overall weight and facilitate more pressurized volume for diverse missions (Figure 1). For the proposal of designing payload fairings initially intended for satellites and ressuply missions as pressurized structures, the paper will use the flight proven Ariane 5 fairing geometry as a case study.

Under the assumption that LEO is the point of departure for ideas of colonizing other planets like the Moon, Mars and other places in our Solar System, it seems that only one active space station is not meeting the industry's growing trend. Even though LEO is the physical space outside of Earth where most humans have lived in through extended periods of time in micro-gravity conditions, it has yet to be democratized to a greater public.

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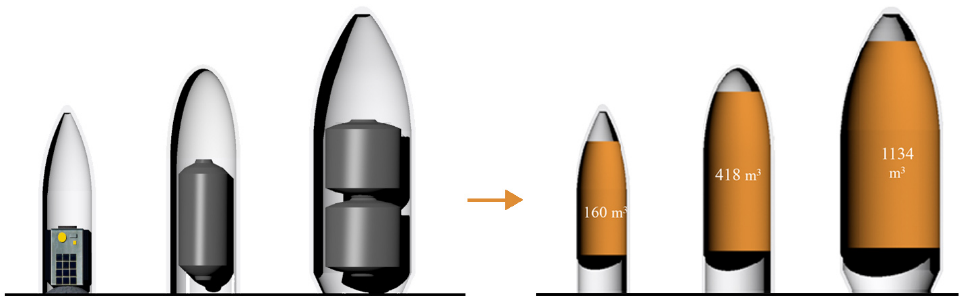

Figure 1. Diverging from "structure inside structure" concept

A. Hypothesis

If payload fairing's CFRP-Al/HC could be redesigned as pressurized structures and this methodology can be geometrically adapted to diverse launch vehicles, new space architectures could be proposed. Through the utilization of flight proven TRL, the design approach benefits include larger usable volumes, reduction of launches, and lower mass to orbit. If proven this proposal could serve as a key strategy in the global effort to advance space exploration while attaining its affordability.

B. Research and Paper Organization

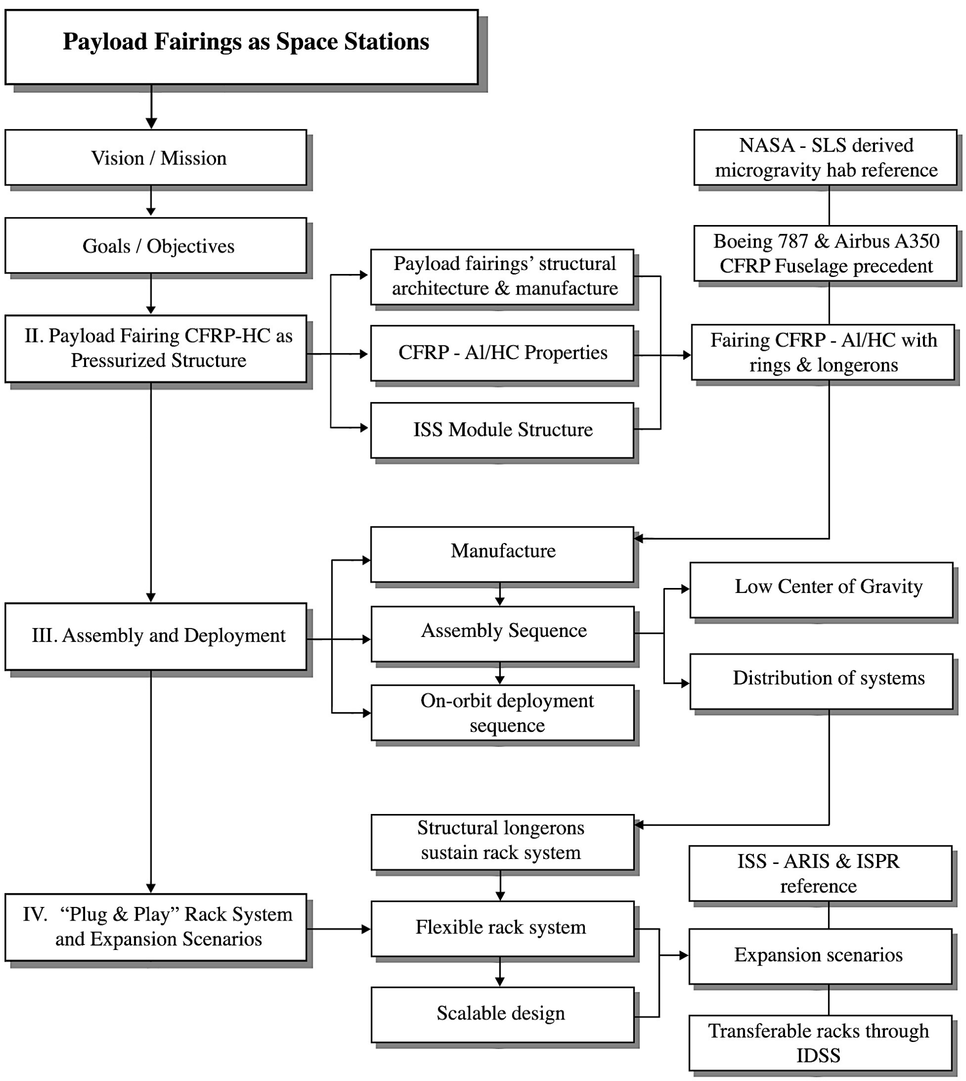

Figure 2. Research and Paper Organization

Illustrated in Figure 2 is the organization used for the project proposal of adapting launch vehicle payload fairings initially intended for satellite deployments into pressurized single or multi-element space stations.

Starting with research into the habitat structure capabilities of Carbon Fiber Reinforced Polymer with Aluminum honeycomb core (CFRP – Al/HC), a preliminary design case study of Arianespace's Ariane 5 dimensions[9] will be proposed. Projecting an optimized assembly sequence previous to on-orbit deployment sequence, could promote a scalable concept of deploying LEO Space Stations to other fairing geometries. The application of larger and more flexible interiors can facilitate optimized commercial spaces in micro-gravity for scientific research, manufacturing (3d printing), larger medical laboratories, multidisciplinary workshops and potentially allow tourism with space for activities and visuals to Earth. This project promotes the idea of large volume commercial space stations, which can be pre-integrated on Earth to reduce on-orbit assembly related risks.

C. Vision

Provide methodology to diverse launch vehicle manufacturers for designing their fairing geometries as pressurized habitat structures. Utilizing preexisting infrastructure along with the metholodogy may provide new space-exploration capabilities to a satellite-focused sector of the space industry.

D. Mission

Validate how the properties of carbon fiber reinforced polymer with aluminum honeycomb core (CFRP – Al/HC) can be applied as sealed habitat structure for space environments. Through a case study of the satellite intended Ariane 5 fairing geometry as a pressurized structure, a scalable concept for geometries of diverse launch vehicles will be presented. Through the use of an adaptable Plug & Play system, the design methology can promote new spaces for LEO mission capabilities.

E. Goals

- Validate how the properties of CFRP – Al/HC can be applied as orbital habitat structures.
- Maintain high TRL.
- Optimize ground assembly.
- Reduce mass / costs orbit.

F. Objectives

Primary

- Research properties and precedents related to CFRP – Al/HC as basis of structure.
- Design, architecture and mission concept of satellite-focused fairing (Ariane 5) as orbital habitat.
- Demonstrate scalability to different dimensions and capacities.
- Through a Plug & Play (P&P) rack system, interior architecture can be flexible to different purposes such as science operations, multidisciplinary workshops, tourism, logistics and in-space manufacturing.

Secondary

- Show applications for three types of fairing sizes.
- Mission concept and architecture for different applications.
- Docking and expansion scenarios.

II. Payload Fairing CFRP – Al/HC as Pressurized Structure

Diverse launch systems are used to deploy satellites in Geostationary orbit (GTO) and for ISS resupply and crew delivery missions. The paper investigates how the geometries of payload fairings used for deploying satellites can be applied to accommodate space habitats. Different from a direct repurposing of fairings as pressurized structures, (repurposing augments risk and complexity), this proposal promotes entirely new premilinary design and assembly strategies for existing fairing geometries. For this, a study of the current state and details of launch vehicle capabilities to both GTO and LEO was conducted. Chapter 2 shows the main considerations and properties of current orbital launch systems as well as takeaways from current ISS modules and systems.

Members of the Deep Space Habitat design team at NASA Marshall Space Flight Center studied concept of utilizing an SLS Shroud Derived Microgravity Habitat was studied but determined undesirable.[5, 13] Given it possible that the SLS shroud may be oversized to function as a pressurized vessel and other reasons mentioned in Section E, no internal layouts were developed.[5] As opposed to concentrating solely on the SLS fairing, this paper looks to focus on smaller commercial launch vehicles' fairing geometries and propose a scalable design to larger architectures.

A. Launch Vehicles and Sizes

Given the variety of existing launch vehicles with different capacities and sizes, these were separated into three categories: Type A, B and C. The first considers mostly already launched vehicles purposed for mainly commercial satellites, resupply and crew delivery missions to ISS and other stations (18 – 31t range). Type B includes Space X's launched Falcon Heavy and Blue Origin's New Glenn (49 – 75t range). Finally, type C can be considered as the new generation vehicles are projected to take bigger payloads to orbit, expanding overall growth in the space industry in the upcoming decades (100+ t).

Table 1. Current launch vehicle capabilities.

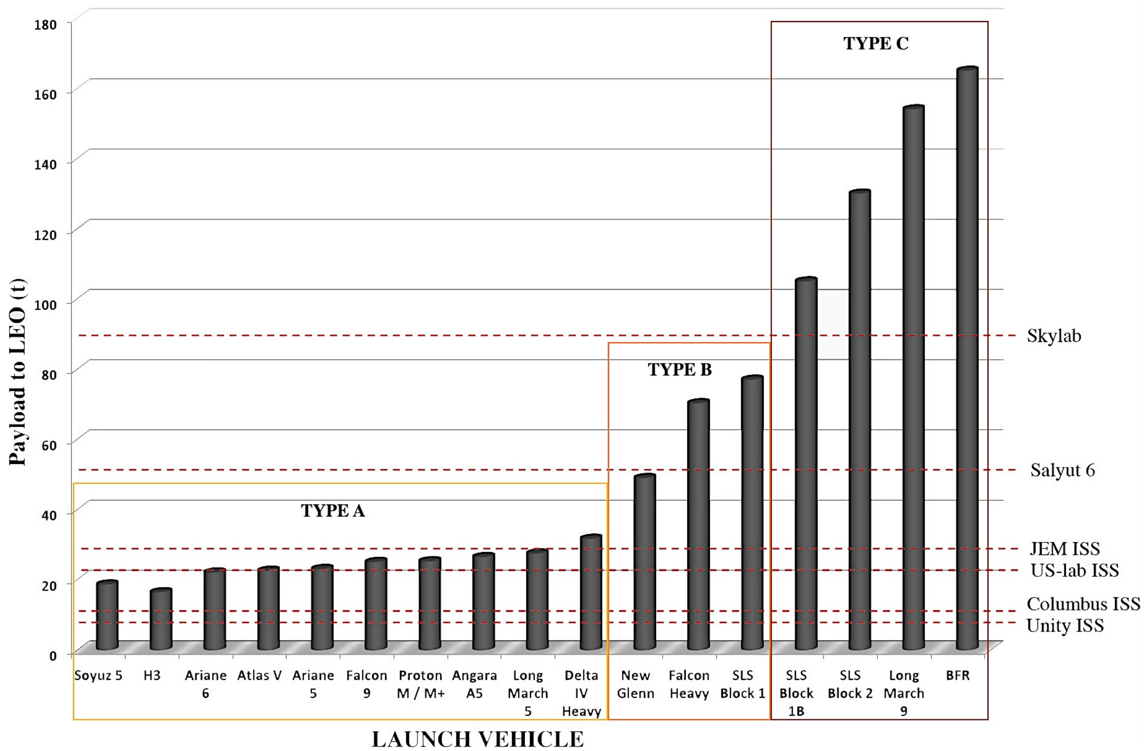

Table 1 Illustrates how if previous station and modules where to be launched using today's capacities, most ISS modules could be taken to orbit in satellite launch vehicles. Understanding this weight cross-reference is key to proving that if the satellite launch companies were to use their infrastructure to produce pressurized habitats, the weight capabilities to LEO would allow such concept. This is considering no modifications to reduce mass were done to the mentioned aluminum ISS habitat modules.

As stated in the introduction of this chapter, different from utilizing a Type C (such as SLS Shroud Derived Micrograity Habitats) this paper will focus on Type A satellite-focused shroud geometries. When comparing volumes of Type A and B fairings to active ISS modules and proposed Inflatables, we find noteworthy increase in potential habitable space (Figure 3). Starting with research into the habitat structure capabilities of Carbon Fiber Reinforced Polymer with Aluminum honeycomb core, a preliminary design case study (Arianespace Ariane 5) will be proposed. This can promote a scalable concept of deploying LEO Space Stations to other fairing geometries like those of Blue Origin's New Glenn or SpaceX's Falcon 9 and Falcon Heavy.

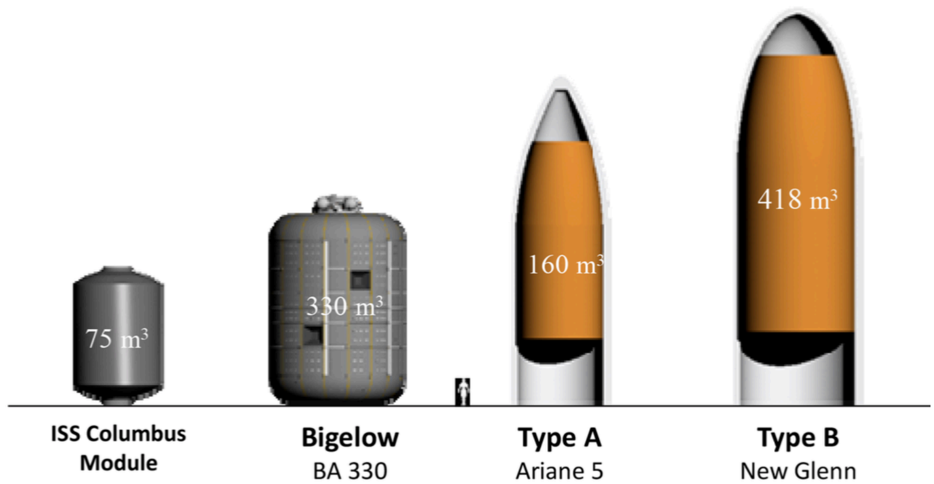

Figure 3. Payload Fairings vs pressurized habitats.

In Ch. 25.2.2 of the book *Human Spaceflight, Mission analysis and Design*,[1] when describing launch vehicle details the author states: "*Conceivably, all the vehicles in Table 25-2 could launch human beings into space, assuming they were safe and performed well enough. But not all have equipment to support crew"*. Given that this book was published almost 2 decades ago, the launch vehicles mentioned have changed characteristics and rockets with more capacities have been manufactured and intended for orbital launches (Table 1). From this, the question that arises is: What equipment is necessary to support crew? And in that same sense, what characteristics do pressurized habitats have that payload fairings miss in order to be human rated? Figure 4 Illustrates how merging the existing hardware of fairings with an ISS Module Section helps avoid the redundancy of having a structure inside of another structure.

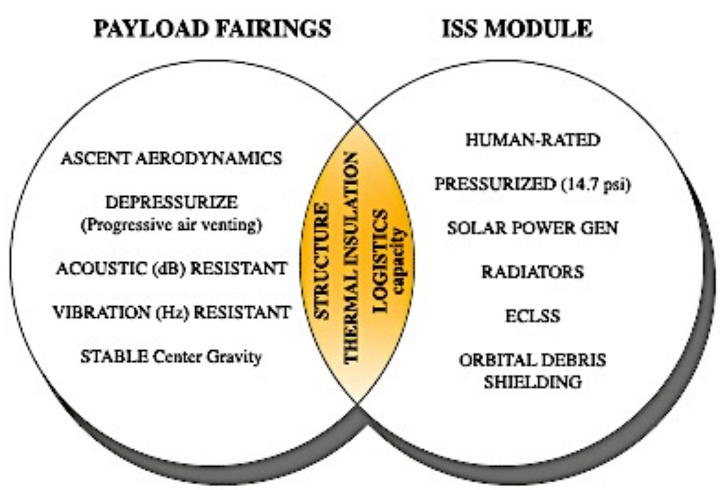

Figure 4. Payload Fairings vs Pressurized Habitats.

B. Payload Fairings' Structural Architecture

> "The key functions of the Payload Fairing is to provide protection for the payload from thermal, aerodynamic, acoustic, and environmental conditions during vehicle processing, liftoff and ascent. In addition to the primary structure, subsystems functions must provide for acoustic treatment, environmental control, thermal protection, and separation from the launch vehicle." [6]

In order to propose a scalable design methodology, we first have to understand the current physical architecture, systems and engineering of current fairings. As an evaluation criteria for comparing 8 composite construction technologies for payload fairings, the NASA technical report *Composite Payload Fairing Structural*

Architecture Assessment and Selection,[6] analyzed characteristics of mass, TRL, damage tolerance, costs, acoustic transmissibility, thermal tolerance, joining, and inspectability.

Figure 5 describes the properties of an ARES V, we find conventional attributes that are common to most payload fairings. No matter the size and diameter, all shrouds maintain comparatively common external aerodynamic shapes. A long cylindrical barrel holds a superior ogive that leads to the tip; in some cases as in Blue Origin's New Glenn, the superior section is presents an ovaloid. Payload shrouds are divided in two by separation rails, which serve as the jettison propulsion line. They also include access doors supported by an internal structure, as well as ring frames at the top and bottom of the barrel.[6] These characteristics are key to presenting a new design methodology adaptable to all fairings without having to change the already established external aerodynamics of the shell.

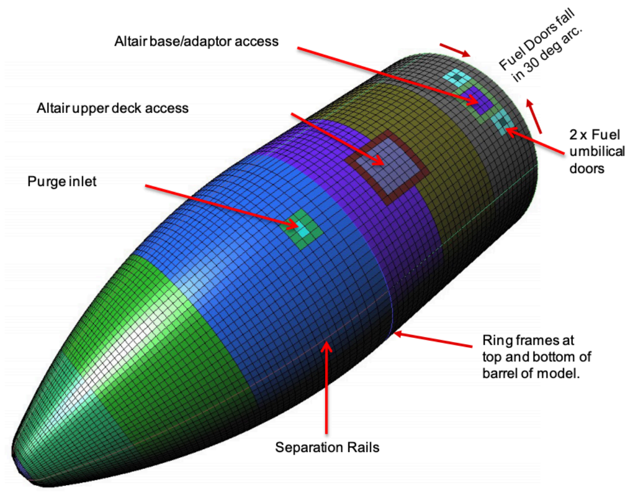

Figure 5. Payload shroud PS-02 finite element model.
Complement of NASA[6]

Accounting for 45% of the mass of a fairing, the basic mass of the structure is a key figure of merit (FOM) to comparing the diverse composites.[6] According to the study, comparatively light structural concepts that can operate at higher temperatures like the *carbon fiber reinforced polymer with honeycomb sandwich core*, require less Thermal Protection System (TPS), which can normally amount to 19% of the total mass. It is important to note that the "strength to weight ratio" and added thermal insulation properties (designed to maintain internal temperatures between 50^{o}-120^{o}F), are physical considerations common to pressurized human-rated-habitats.

Given its TRL 9 properties, most commercial launch vehicles like SpaceX's Falcon 9 and the Ariane 5 utilize CFRP-Al/HC. Although the elemental properties of fairings with composite materials like CFRP have the capacity to withstand the extreme environments, they are designed to depressurize and be jettisoned upon reaching orbit at around altitudes of ~120km (~300km distance to LEO)[8]. Given the mentioned criteria and the condition that many satellite deploying-intended fairings such as the successful SpaceX Falcon 9, Falcon Heavy and the Ariane 5 already utilize the composite CFRP-Al/HC as the main structure, this proposal advances to internally redesign the architecture for pressurized habitats.[8, 9]

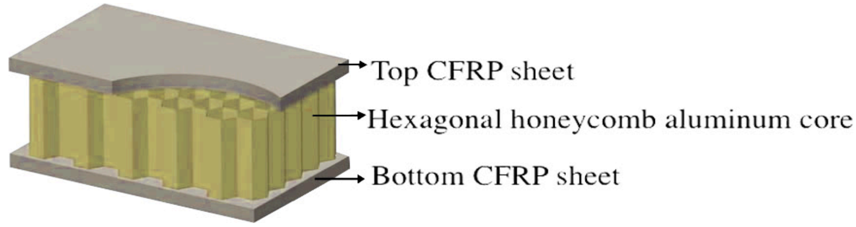

Figure 6. CFRP – Al/HC Structure Section

CFRP – Al/HC as MMOD Shield

With the structure, temperature and pressure variables considered for the habitat's structure, it is of importance to see the function of CFRP – Al/HC when faced with space debris. Many of today's satellites utilize CFRP – Al/HC as the external mitigation of micrometeoroid and orbital debris (MMOD). In order to consider this same structural material for human pressurized habitats, a Human-Rating Certification Process would have to be conducted. Before this process, studying the qualities and properties of CFRP sheets is of main importance to the concept presented in this paper.

In the *International Journal of Impact Engineering* article: *Hypervelocity impact on CFRP: Testing, material modeling, and numerical simulation* we find numerical and physical experiments reproducing the impact of projectiles on this composite material. The results of the article provide good agreement between simulations and experiments of the impact scenarios, aggregating confidence in using CFRP – Al/HC as a reduction of necessary MMOD shielding.[4] Given that utilizing the presented material in space for human-rated MMOD would take more research and development, in the next sections we find how in combining the structural rings and lighter micrometeoroid shielding layers used in proven ISS can promote a more resilient structure.

C. ISS Module Section

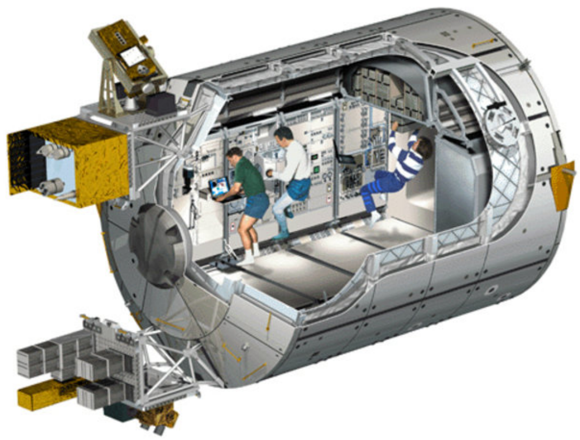

Figure 7. Cutaway View of Columbus Laboratory

The ISS modules were designed to be pressurized (14.7 psi), maintain a shirtsleeve internal human-rated environment for experimental operations, as well as protect astronauts from the micrometeoroids (MMOD Shielding) and the vacuum of space. As shown in Figure 8, a module's pressure structure is two layers of aluminum, separated by structural rings, along with multilayer sheets for thermal insulation and micrometeoroid shielding. Understanding that ISS modules have ring frames that complement layers of aluminum sheets is key to the proposal of pressurizing payload fairings. Another important takeaway that we find is the necessity and use of a thermal barrier, to protect the internal environment from the external vacuum of space.

Here we note the overlapping in the physical properties of the aluminum layers in the ISS modules with the aluminum in the thicker honeycomb-core of fairings. Along with this, we find that both type aerospace vessels look to maintain insulation and a thermal barrier from extreme external conditions. The following section proposes the merging of the ISS module section with that of fairings' CFRP-Al/HC, promoting a more robust usable structure.

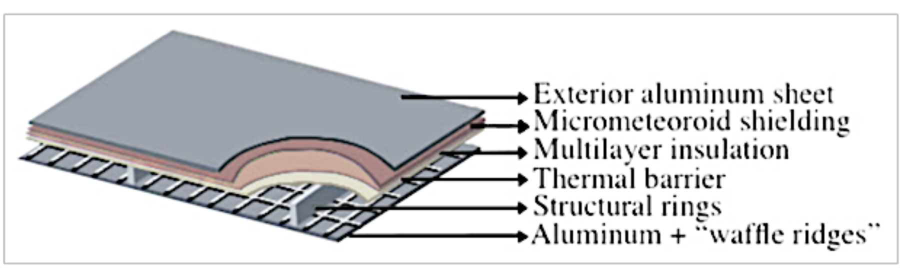

Figure 8. Abstracted ISS Module Section

D. CFRP – Al/HC With Ring and Longeron Frame

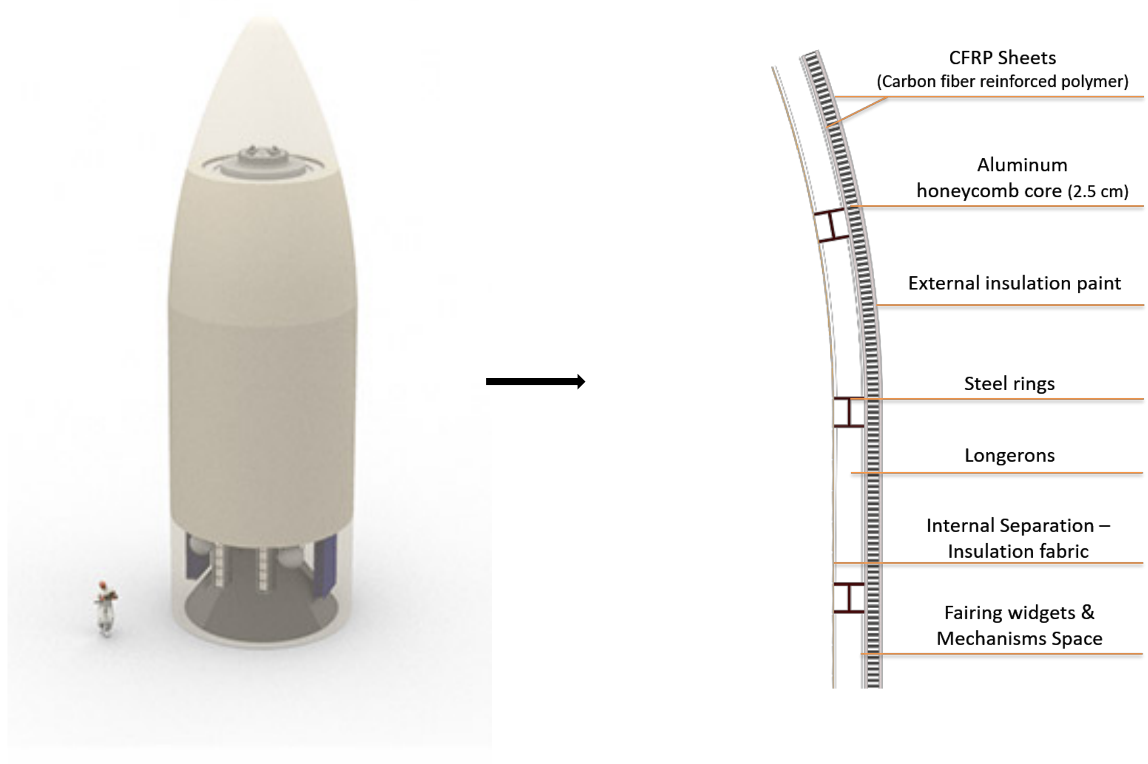

Figure 9. Fairing Space Station Structure Section

If you were to merge both structural properties of a ring framed ISS module and a CFPR-Al/HC fairing (Figure 9), the external aerodynamic geometry of the ascent vehicle can be maintained, while at the same time functioning as a pressure vessel on-orbit. This methodology would avoid having substantial internal layers of aluminums, extra thermal barriers and potentially reduced micrometeoroid shielding. This could serve as a thicker and more robust shell, while saving materials (mass and cost) and presenting more functional volume.

Just as in the functioning ISS modules, the steel rings and longerons frame support the internal pressurization of the cylindrical volume and serves as the system that supports the distribution of utilities and subsystems along the wall. Figure 10 displays how this same frame is key to the assembly sequence, in distributing ~1 ton IDSS bending loads during the 3g ascent to orbit. Chapter III expands on the overall design decisions for the assembly methodology, distribution of systems and deployment sequence.

In proposing this combined structure, it is important to reference analogous aerospace precedents. Fortunately, we find the combined structures (CFRP shell with internal rings and longerons) in the main frame of the airplanes Boeing 787 and the Airbus A350.[7, 10] In both already human-rated and operational cases, the advanced composite accounts for more than 50% of the structure and in more than 90% of the pressure vessel. Figure 11 illustrates how an airliner's pressurized fuselage structure can serve as an assembly precedent for this paper's proposal.

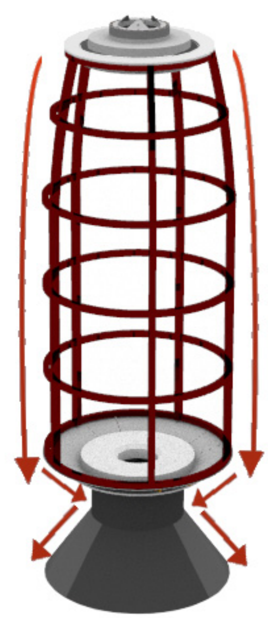

Figure 10. External Frame

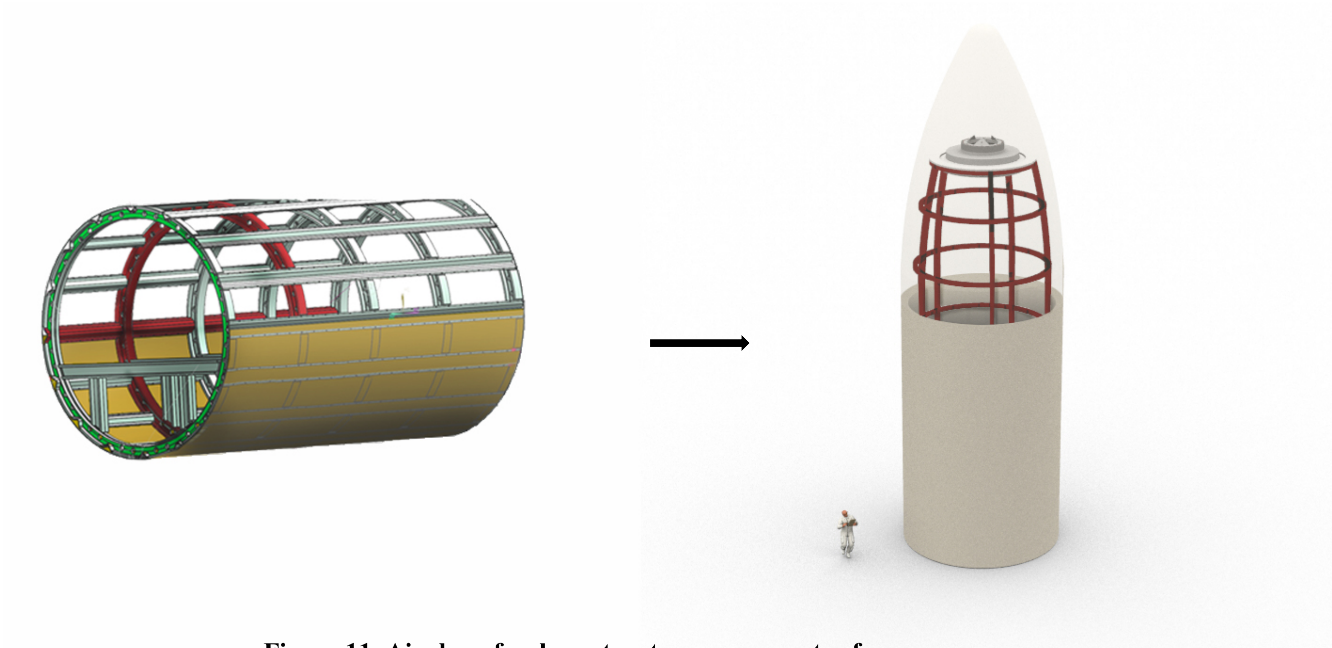

Figure 11. Airplane fuselage structure as concept reference

E. SLS Shroud Derived Microgravity Habitat Reference

NASA's Robert L. Howard, Jr., PhD references in his publication: *Concepts for a Shroud or Propellant Tank Derived Deep Space Habitat*,[5] that the Deep Space Habitat design team quickly determined SLS Shroud Derived Microgravity Habitat undesirable.[12] As mentioned in the beginning of this chapter, as opposed to concentrating solely on the SLS fairing, this paper looks to focus on smaller on commercial launch vehicles' fairing geometries and propose a scalable design to larger architectures.

It is mentioned that composite structures are optimized for launch loading only and not sealed for pressure.[5] In presenting the combination of the ISS ring structure with the CFRP – Al/HC, just as pressurized airplane vessels answers this by reasoning. In mentioning the coating required by composites to survive the space environment is directly found in SpaceX's *Falcon User Guide* - Chapter 4.3.8,[8] an external thermal insulation layer is attached to the fairing. Dr. Howard also mentions:

> "Composite shrouds do not have inherent micrometeorite and orbital debris shielding and the difficulty of adding shielding may outweigh the benefit of using the shroud. Similarly, they do not have any inherent means of attaching internal structure." [8]

However, if the CFRP – Al/HC composite already used as satellites' MMOD shielding,[4] is designed for human-rated vessels, then necessity for heavier protection layers is reduced. With regards to attaching an internal structure, in Figure 5 we find that fairings already apply structural rings as reinforcement at the top and bottom of the barrel and another in the ogive.[6] This project proposes creating an internal "Ring and longeron" structure, analogous to airplanes' fuselage but applied to fairing shapes. The application of this structure is key to the adaptation of the architectural Plug & Play (P&P) design. This assembly, deployment, and architecture is presented in the next chapters.

III. Assembly and Deployment

A. Redesigned Fairing Manufacture and Separation Rails

Much like the proposed "Starship" by SpaceX, the Spacecraft for this project will take the exterior shape of a standard shroud. In theory, the outer physical aerodynamics of the fairing would function in the same way. Instead of a cylindrical and conical shape intended for payload, it would be a pressurized habitat with that shape. With the same aerodynamics and maintenance low mass variables throughout the design would allow the same ΔV as the one seen in taking satellites to LEO/GTO.

Figure 12.
Payload Fairing Half Manufacture

The world leading supplier of composite technology payload fairings, RUAG Space, produces the payload fairings for different launch vehicles like Ariane 5, Vega and others.[11] Given the Ariane 5 main missions are deploying satellites, its geometry will be used as the proof for the assembly, deployment and architecture. Using new technology for molding CFRP – Al/HC into two fairing shells, optimizes the assembly process along separation rails, which then allow benign jettison of the structure once in orbit. Figure 12 illustrates a manufactured half.

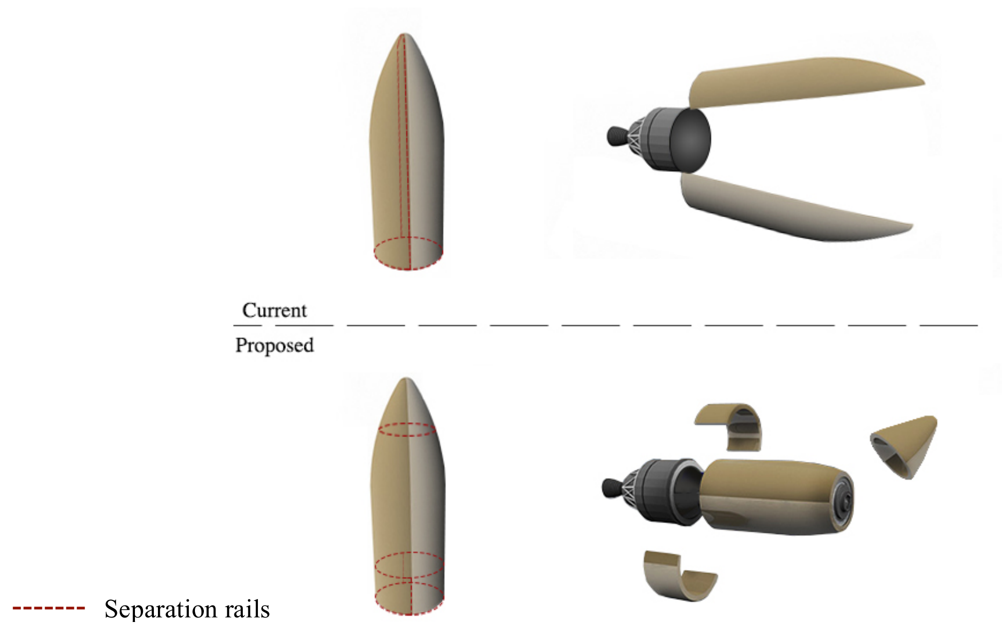

Figure 13. Current separation rails vs proposed

Figure 13 demonstrates that if during the manufacturing process, the rails with mechanical latches were allocated at a ring at the top of the fairing and at the lower end where to split a barrel, then the pressure vessel could be deployed. Using the same jettison technology that SpaceX uses on its logistics resupply and Crew- Dragon vehicle to open the cap, underneath the cap of the fairing a docking system could be allocated.

Figure 14 illustrates how fairings can be geometrically abstracted as a series of circles (cylinder) that decrease in diameter, as they get closer to the top. For aerodynamic purposes, above the cylinder, the shape becomes an ogive or paraboloid. Given that all shrouds maintain these relative geometries, as you reach the top of the structure, eventually you will all have a 3.5 m diameter. The diameter is key given that it can support a complete superior International Docking System (IDSS). Allocating the ~ 1 ton system on top of the structure, would allow the launch loads to be distributed uniformly along the wall.

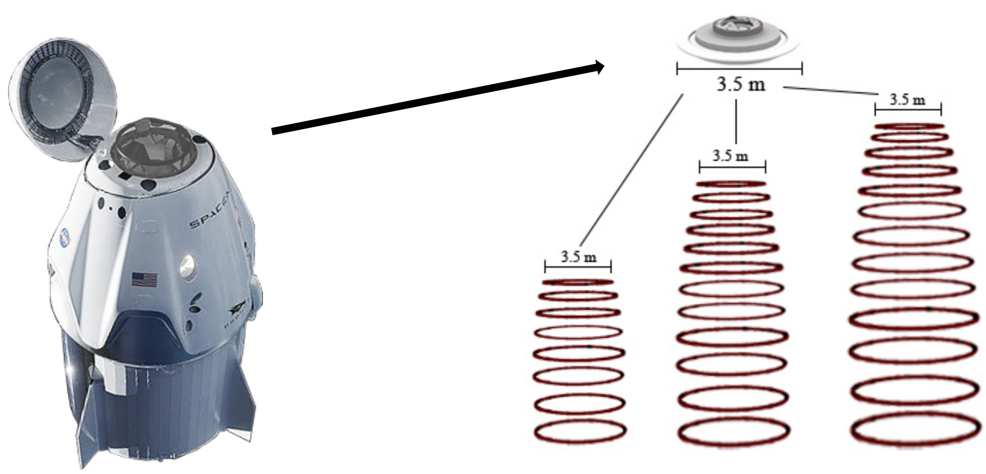

Figure 14. SpaceX Dragon Superior IDSS Concept Reference

B. Assembly Sequence

Upon understating the generic Payload Fairing's structure and geometry as the space habitats main design driver, the assembly sequence was generated to promote an optimized development. Locating the heavy power generators and converters, solar array, and attitude control systems in a lower detachable space, allows for a more stable CG for the launch environment. The transfer of loads along the structural wall and to the Payload Adapter, through an elephant stand, looks to avoid risks associated to the launch environment. This idea of locating the heavier systems towards the bottom section of the architecture also has benefits for on-orbit functions.

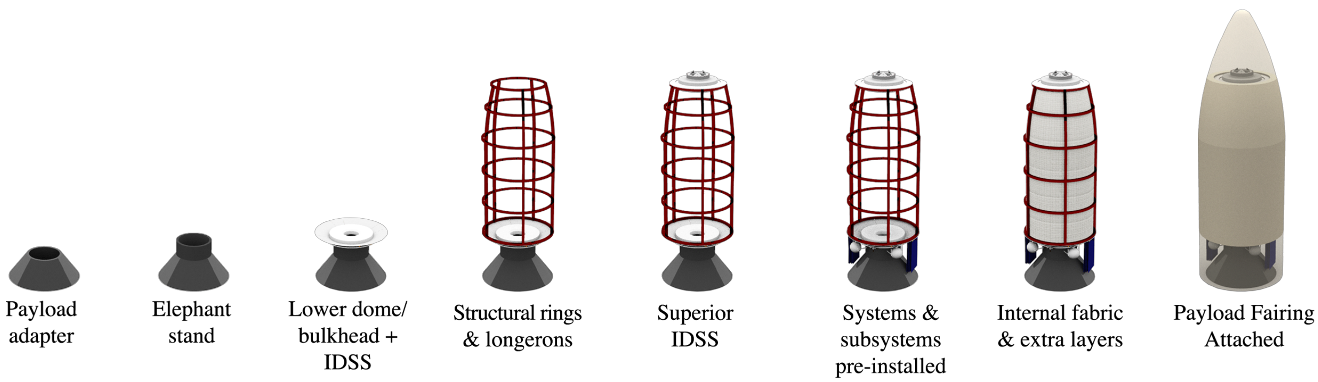

Figure 15. Assembly Sequence

C. Distribution of Systems

Locating two International Docking System (IDSS) hatch towards the top and bottom of the structure, can allow multiple mission configurations and expansions with double egress/ingress just as ECLSS modules in the ISS. Depending on the chosen mission function and human-operation prerequisites, instead of a superior hatch a window or cupola could be allocated to view Earth from orbit. The internal distribution of spaces is mission specific and facilitated by attachable and detachable racks. This window and tourism application is expanded in Chapter IV-D. Figure 16 demonstrates the distribution of systems.

1) Double Egress/Ingress & Circulation

With a superior and inferior docking node, safety measures promote that a direct 2m+ circulation is maintained regardless of the habitat's diameter.

2) Power & Attitude Control Systems

All heavy power generation and distribution systems, avionics, attitude control and Oxygen tanks, are kept in the lower area for more stable CG variables in the launch scenarios.

3) ECLSS & H_2O

Environmental Control & Life Support Systems (ECLSS) racks are also part of the baseline systems to have a stable atmosphere and pressure. H_2O tanks, hygiene and logistics spaces also are crucial points for a functioning human-rated habitat.

4) Flexible Mission Operations

Looking to be adaptable to diverse mission profiles and short duration commercial or tourism missions, a P&P rack system is presented. Chapter IV-B expands on this architectural design feature.

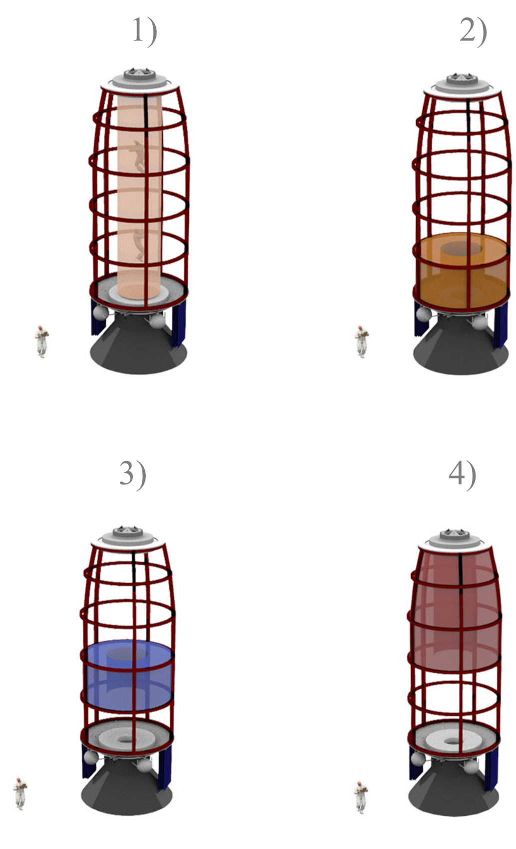

Figure 16. Distribution of systems

D. On-orbit Deployment Sequence

Figure 17 illustrates the sequence. Once in orbit, the compacted solar arrays and radiators open and are directed towards the sun. Also with locating the attitude control system thrusters and gimbals beside the solar array power converters, a SEP could be achieved through the ionization of external Xe tanks. During the launch and ascent, only the necessary systems and racks (Figure 19) will be launched. Posterior to the first rendezvous of the Crew Transfer Vehicle, the Interior architecture can accommodate versatile functions through the P&P rack system explained in Chapter IV.

- Launch environment
- Separation from second stage.
- Cap is jettisoned with pneumatic pusher technology. TRL defined by SpaceX and Boeing CST-100 Starliner.
- Lower unpressurized fairing walls are ejected with pneumatic pusher technology
- Orientation towards Earth, attitude control.
- Deployment of Solar Arrays and activation of pointing control system.
- Orient to solar inertial attitude and altitude.
- First Crew Transfer Vehicle rendezvous with crew.
- Crew allocates the centered racks to the structure.
- Activate Station and conduct mission specific Con-Ops.
- Complete ~20 day mission.
- Prepare workshop for storage, crew transfer to Crew Transfer Vehicle.
- Undock Vehicle.
- Prepare for next Crew Transfer Vehicle with crew.

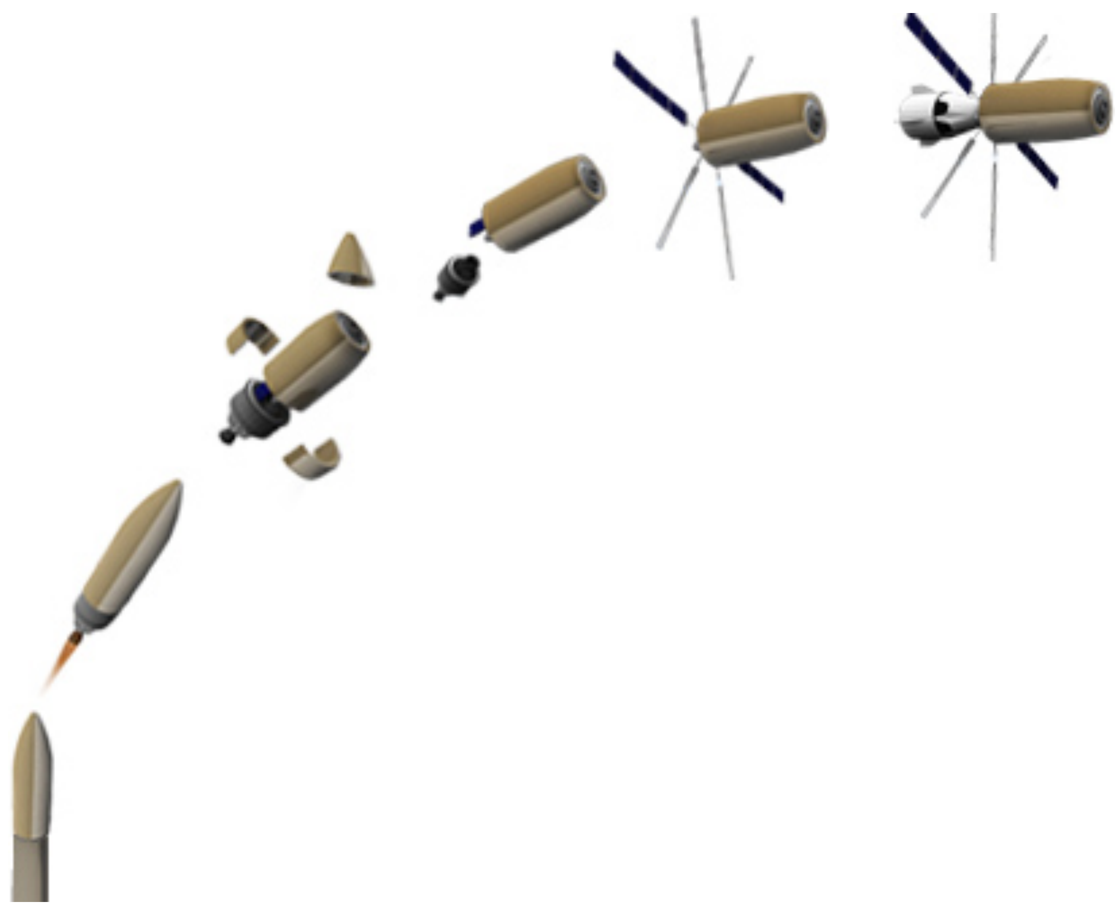

Figure 17. Deployment Sequence

IV. Architecture, "Plug & Play" Rack System and Expansion Scenarios

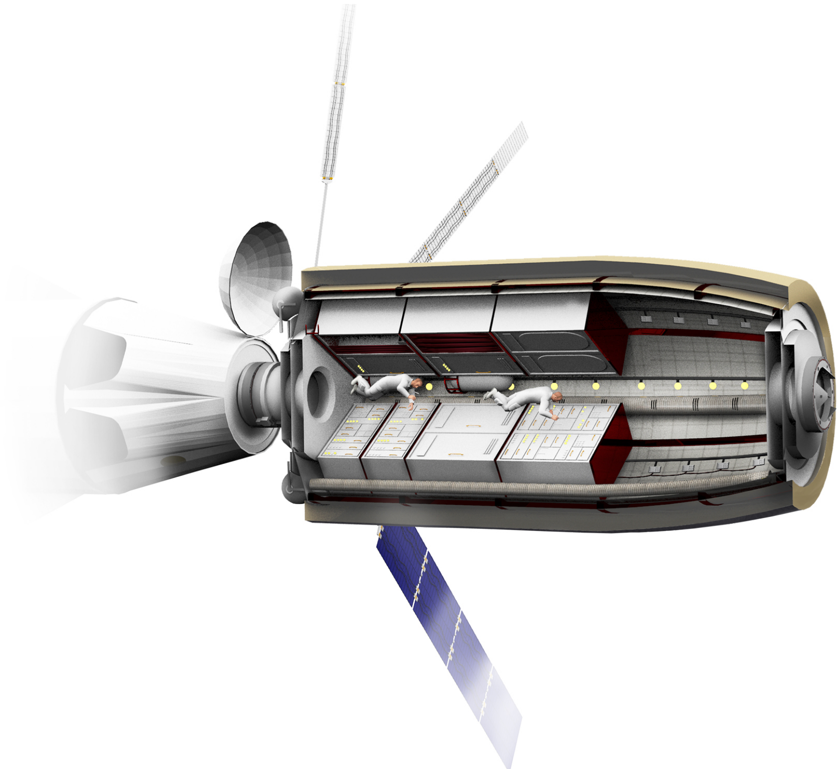

Figure 18. Fairing Space Station concept

A. Mission Specific Adaptable Architecture

This chapter discusses utilization of a P&P system in fairing habitats that can be adapted on orbit for different missions and applications. The system allows flexible architecture that accommodates diverse types of functions including R&D laboratories, manufacturing facilities, and crew quarters. The paper concludes with benefits of the minimalist space station design approach that include simple structures, optimized interior volume, reduction of launches, and utilization of proven technologies.

B. Plug & Play Rack System

The fairing habitats define a Plug and Play (P&P) system that can be manipulated on orbit for different missions and applications such as R&D laboratories, manufacturing facilities, and/or crew quarter; allowing flexible architecture without a strict static space distribution. Figure 19 illustrates how in order to not cause extra-loads on the faring wall for ascent, the primary racks related to power systems, ECLSS and avionics racks are centralized and then distributed on orbit. The distribution of these racks and other subsystems along the frame structure would be mission and fairing size specific.

Given the different payload fairing diameters found throughout the space industry, this design system looks to adapt experiment rack isolation systems (0.85m x 2m) to previously assembled and sized structural longerons. With each short-duration commercial mission, new racks could be transferred to the station, plugged onto flexible points on the structural longerons, and electrically connected to the stations power cables. The adaptability to different shroud diameters allows for optimal and versatile usage of space in docking scenarios (Figure 20).

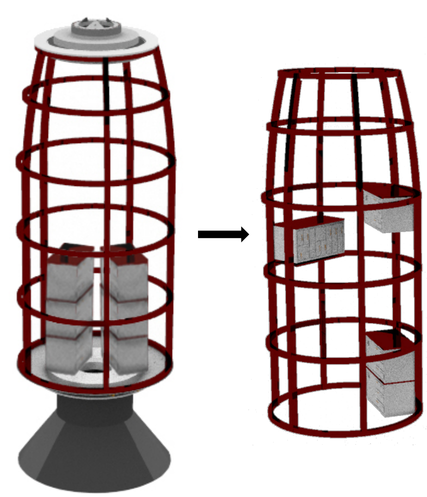

Figure 19.
Ascent to On-orbit Rack Distribution

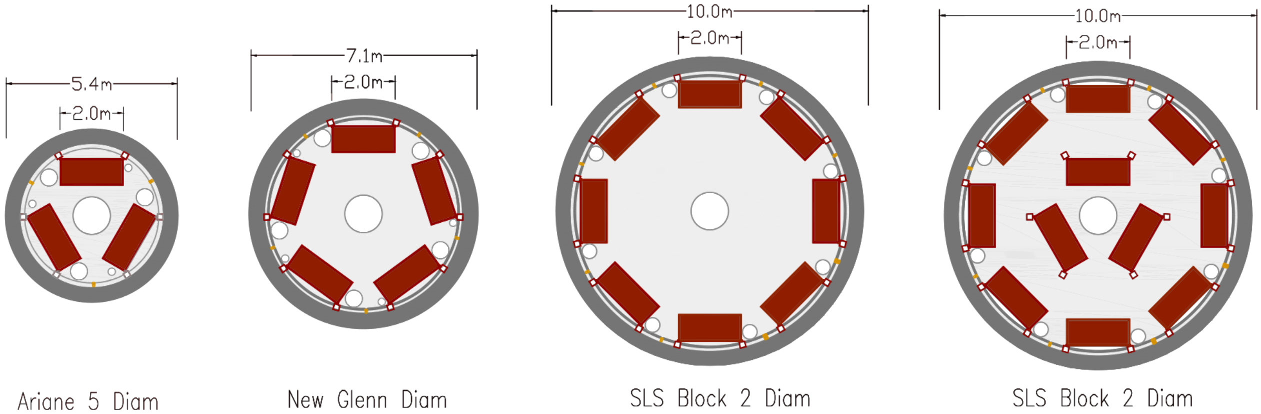

Figure 20. Longeron Distance Defined by P&P

C. Expansion Scenarios

Having structure, design and architecture capabilities for the different types of shrouds, the next step in the proposal would be to expand on docking scenarios to create multi-element space stations. For this, the considerations and requirements derived through the research were detailed and focused on tradeoffs regarding feasibility and optimization to make the space endeavor's cost variables more sustainable.

The fairing habitats define a P&P system that can be manipulated on orbit for different missions and applications such as R&D laboratories, manufacturing facilities, and/or crew quarter; allowing flexible architecture without a strict static space distribution. As detailed in in the previous section, regardless of the fairing station size, racks can be distributed according to the specific mission. As two or more of these Stations start to dock, internal volume can facilitate greater production of manufacturing and development of different micro-gravity specific missions.

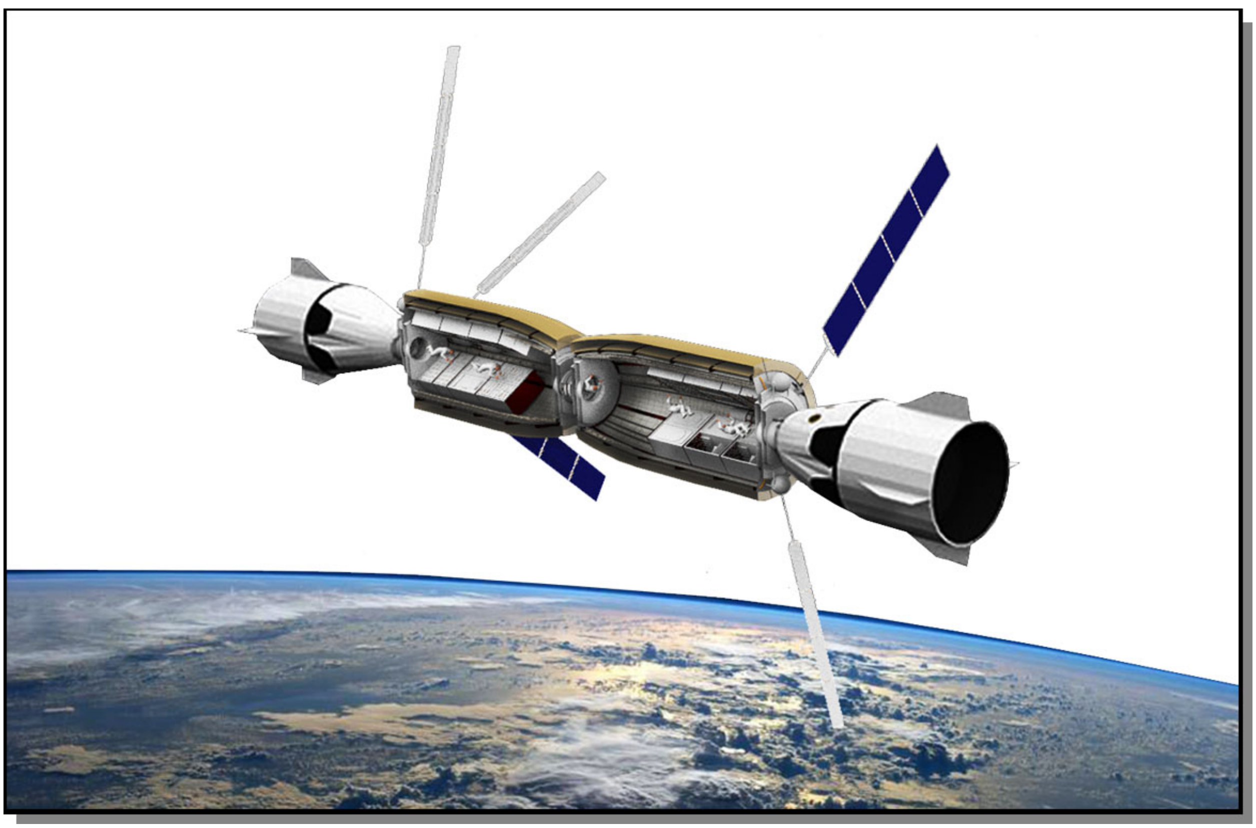

Figure 21. Multi-Element Expansion

D. Earth-View Window Configuration

It is of importance to the survival of the space industry that LEO becomes democratized to a larger population. With the ISS being the only active Space Station with a maximum capacity of 6 astronauts, it logical to assume that private commercial stations have to be deployed. The Payload Fairing as Space Stations concept proposes tourism scenario configuration. Instead of supporting a superior docking port, a large window could be allocated under the deployable cap.

This can support the idea of the "Overview Effect" on people, where in seeing the Globe from above, promotes a feeling of the world as a whole functioning organism. (Figure 22) illustrates how the large volume station can allow different tourism applications, while sustaining a Nader position and attitude. The small SEP thrusters can be used to stabilize the position, and the docked crew transfer vehicle will support emergency scenarios.

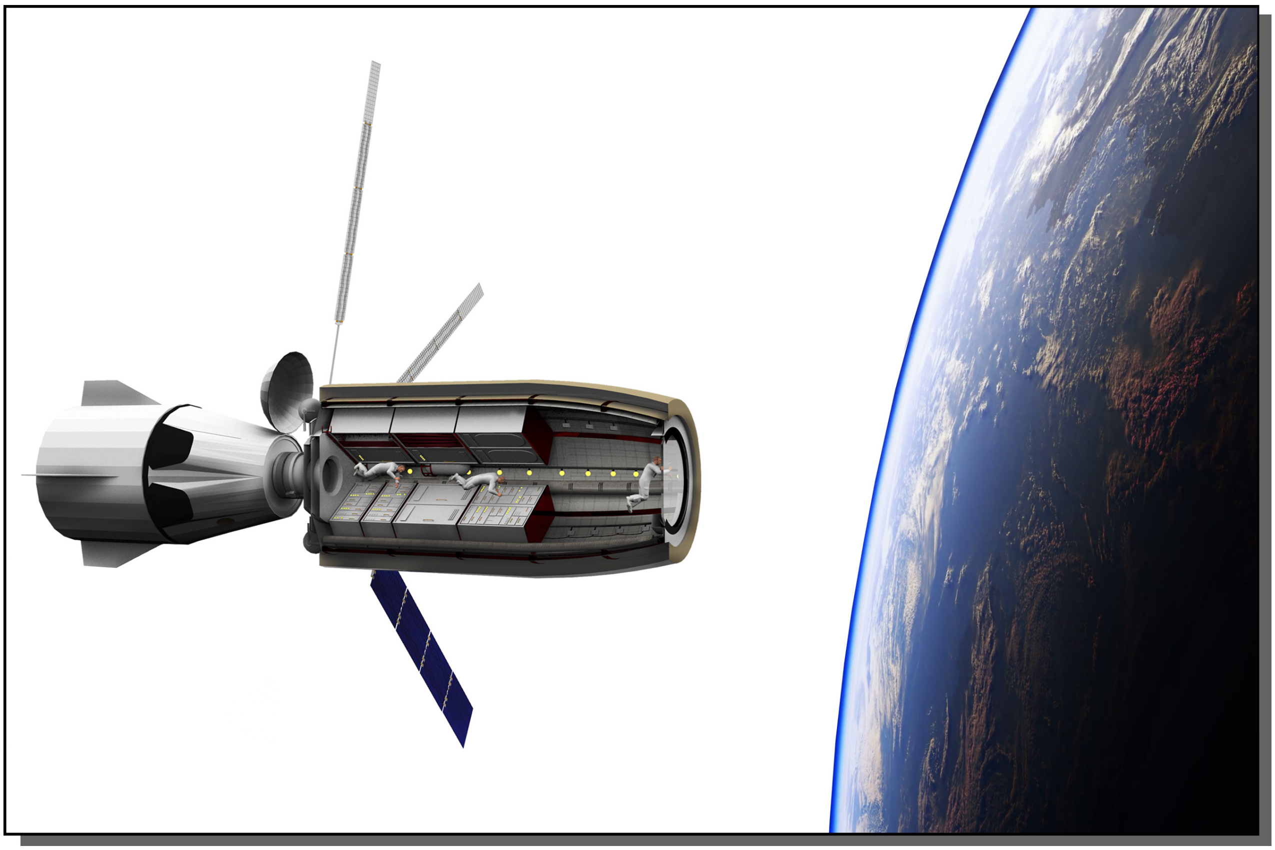

Figure 22. Earth-View Window Configuration

V. Conclusion

With the growth of the space industry and increment in number of launches per year, having adaptable fairings could help create a more diverse expansion to space. Including satellite focused launch vehicles from different agencies by having an adaptable system could help lead towards an accelerated growth in the future of Space exploration. Given that all space exploration ideas pertain within the industry itself, we find the stagnant repetition of the same type of proposals. With the presentation of cross-reference ideas between the commercial (Satellite focused) and public realm (International Space Exploration), new possibilities arise. The concepts of optimization, commonality of systems, flexibility, commerce, efficiency and sustainability are proving to be the only way the space industry becomes a democratized reality.

Through a minimalist approach, this proposal outlined a design methodology of redesigning launch vehicle payload fairings geometries into pressurized single-element space stations. Low budget adjustable space stations with large volumes, and that can be achieved through application of a methodology for outfitting modules with pre-integrated systems on the ground. With only one launch and deployment, a free-flying station can be achieved.

A. Next Steps

1) *Structural Analysis*

Given that the design approach to pressurizing CFRP – Al/HC with internal frame has not been tested for human-rated space habitats, structural simulations would need to be conducted and analyzed. Using the aircraft's Boeing 787 and the Airbus A350 as a pressurized concept corollary promotes an initial validation for the proposal. Also, in reference to a reviewer's commentary regarding other type of structures such as filament-wound composites or over-pressurization during ascent to resist buckling during ascent, will also be considered in trade-off scenarios in structural tests.

2) *Technical Details of P&P*

Functioning an important design proposal of the project, details of how the interchangeable racks attach and detach to the longerons is of importance and trade-offs will be conducted to propose a more optimal solution.

3) *Utility Distribution System*

The distribution of utilities study such as electrical circuits, water-flow, airflow and vent distribution along the external wall (Function goes along with P&P proposal) will looked to be resolved. As mentioned Chapter III-C, all the necessary power and ECLSS system are located towards the bottom of the structure for ascent purposes; cables, ducts and cooling systems will originate from this sector of the vessel.

4) *Mission Specific Interior Architecture*

As mentioned through the paper, the proposed pressurized fairing geometry structure will allow for diverse mission scenarios. Visualization of potential internal configurations, materials, and subsystems will be proposed for functions including R&D laboratories, manufacturing facilities, tourism capabilities and/or crew quarters. This will at the same time open trade-offs regarding Con-Ops and economic variables to more complex decisions.

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References

Books

[1] Larson, W. J., & Giffen, R. B. (1999). *Human Spaceflight. Mission Analysis and Design*. McGraw-Hill Companies, Inc.

[2] Bannova, O., & Hauplik-Meusburger, S. (2016). *Space Architecture Education for Engineers and Architects*. Springer International Publishing.

Proceedings

[3] Feldman, Stuart, et al. "Analysis of shroud options in support of the human exploration of Mars." *2010 IEEE Aerospace Conference*. IEEE, 2010.

Reports, Theses, and Individual Papers

[4] M. Wicklein, S. Ryan, D.M. White, R.A. Clegg. Hypervelocity impact on CFRP: testing, material modelling, and numerical simulation. International Journal of Impact Engineering, Elsevier, 2008, 35 (12), pp.1861. <j.ijimpeng.2008.07.015>. <hal-00542562>

Electronic Publications

[5] Howard, Robert L. "Concepts for a Shroud or Propellant Tank Derived Deep Space Habitat." (2012).

[6] Krivanek, T. M., & Yount, B. C. "Composite payload fairing structural architecture assessment and selection." (2012).

[7] *Boeing 787 from the Ground Up, QTR_04, 06*, Boeing. Accessed on: February 26, 2019, URL: https://www.boeing.com/commercial/aeromagazine/articles/qtr_4_06/AERO_Q406_article4.pdf

User's Guide/Manuals/Handbook/User

[8] *Falcon User's Guide,* SpaceX, January 2019. Accessed on: February 25, 2019, URL: https://www.spacex.com/sites/spacex/files/falcon_users_guide_02182019.pdf

[9] *Ariane 5 User's Manual, Issue 5 Revision 2,* Arianespace, October 2016. Accessed on: February 25, 2019, URL: http://www.arianespace.com/wp-content/uploads/2011/07/Ariane5_Users-Manual_October2016.pdf

Private Communications and Web Sites

[10] https://www.compositesworld.com/articles/a350-xwb-update-smart-manufacturing
[11] Launcher Fairings & Structures, RUAG Space. URL: https://www.ruag.com/en/products-services/space/launchers/launchers
[12] https://www.esa.int/Our_Activities/Human_and_Robotic_Exploration/Columbus/European_Columbus_laboratory

Unpublished Papers and Books
[13] Brand Griffin, Deep Space Habitat Launch Shroud Derived, PowerPoint Presentation, NASA, October 2011 (Unpublished)