Advancement in Space Deployable Habitat Verification, Validation, and Certification

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Continued successful development testing of an 8.2-meter (27-feet) diameter Space Deployable Habitat Module for LIFE (Large Integrated Flexible Environment) application, jointly designed, and fabricated by ILC Astrospace and Sierra Space, has validated and advanced many critical structural components of the habitat's "softgoods" shell. The objective of this paper is to present further results from successful Ultimate Burst Pressure (UBP) tests with integrated blanking plates and Accelerated Systematic Creep (ASC) tests performed in late 2022 and 2023. The additional UBP tests further verify that the structural integrity of the system is at or above the 4.0 factor of safety required by NASA for certification. The ASC tests verify that the creep life of the structural components is much higher than the required 60 years (4X 15-years life). This paper will also discuss updated structural and system architectures that would enable greater capabilities in expanding usable volume and mission operations.

Nomenclature

ABS	=	air barrier system
ASC	=	accelerated systematic creep
ASTM	=	American Society for Testing and Materials
CISS	=	crewed inflatable softgoods structures
CLD	=	commercial LEO destinations
DIC	=	digital image correlation
ECLSS	=	environmental control and life support systems
FOS	=	factor of safety
FSR	=	factor of safety requirements
JSC	=	NASA Johnson Space Center
LEO	=	low earth orbit
LIFE	=	Large Integrated Flexible Environment

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M	=	meter
MDP	=	mean design pressure
MEOP	=	mean expected operating pressure
MIL	=	military
MLI	=	multilayer insulation
MMOD	=	micrometeoroid and orbital debris
MSFC	=	NASA Marshall Space Flight Center
NASA	=	National Aeronautics and Space Administration
psi	=	pound per square inch
STD	=	standard
TTF	=	time-to-failure
UBP	=	ultimate burst pressure
UTS	=	ultimate tensile strength

I. Introduction

Beginning in 2018 Sierra Space and ILC (Dover) Astrospace have been collaborating on the design and build of space habitat test modules fabricated using softgoods components. During this time the teams have been following the recommendations laid out by NASA in JSC-67721 Certification Guidelines for Crewed Inflatable Structures. Adhering to these recommendations has seen the teams performing numerous ultimate burst pressure (UBP) and accelerated systematic creep (ASC) tests at the module level (ref section IV) as well as ultimate tensile strength (UTS) and creep testing at the component (webbing) level (ref section V). Leveraging this robust test campaign heritage and continuing to advance the technology of softgoods structures for space habitation, 2023 was a banner year of testing and pushing these structures to their limits. In 2023, Sierra Space and ILC Astrospace completed a series of habitat validation tests at both subscale (LIFE 10) and full-scale (LIFE 285) architectures (Figure 1) The primary objective of these module-level tests is to evaluate the maximum capabilities of the structural softgoods components; however, in stressing these components to their limits other systems including critical metallic hardware components and interfaces are put to the test as well. The successes of the validation tests are laying the groundwork for space habitation utilizing softgoods structures with greater capabilities and potential enabling future space missions.

Figure 1. LIFE 10 Subscale Module with One Blanking Plate and LIFE 285 Module with Two Blanking Plates 180 Degree Apart.

The LIFE 10 (subscale) validation units enable Sierra Space and ILC Astrospace to fabricate test units more quickly and at lower cost, while gaining valuable verification and validation test data of various subsystems. The validation of the LIFE 10 module not only paved the way for a successful LIFE 285 (Full-Scale) unit validation test; at ~12m^3 of interval volume, LIFE 10 module is applicable for airlock, storage, and node connector applications. All tests performed to date on LIFE 10 test modules show that this inflatable habitat structural softgoods architecture is robust and exceeds the factor of safety guidelines recommended by NASA ([CISS 34] *Ultimate burst pressure tests should be performed on flight-like test articles of the inflatable design to demonstrate that the architecture meets or exceeds the ultimate design factor of safety specified in NASA-STD-5001B* [FSR 45][1])[2] (Table 1)[3] for these articles to support human habitation.

The testing performed in 2023 was capped off with the successful conclusion of the first LIFE 285 UBP validation test. LIFE 285 has the same architecture as LIFE 10, it simply utilizes a scale factor of 3 on all major dimensions and quantities of components, while keeping certain key dimensions consistent. Scaling the dimensions in this manner allows the development team to correlate and utilize LIFE 10 test data and design features on LIFE 285, while increasing the volume from ~12.3m^3 on LIFE 10 to ~285m^3 on LIFE 285. The LIFE 285 test unit leveraged the proven softgoods architecture of LIFE 10 while incorporating lessons learned from LIFE 10 test units regarding both design and fabrication of structural softgoods units.

Table 1. Minimum Design and Test Factors for Structural Softgoods.

Hardware Criticality Classification	Ultimate Design Factor	Prototype Test Factor	Proof Test Factor
Loss of Life or Vehicle	4.0	4.0	1.2
All Others	2.0	2.0	1.2

The final two tests of 2023 performed by Sierra Space and ILC Astrospace were UBP tests of LIFE test units that also contained blanking plates integrated into the structural softgoods layer. Blanking plates refer to a metallic component that interfaces directly with the softgoods architecture (Figure 2). The blanking plate hardware is a

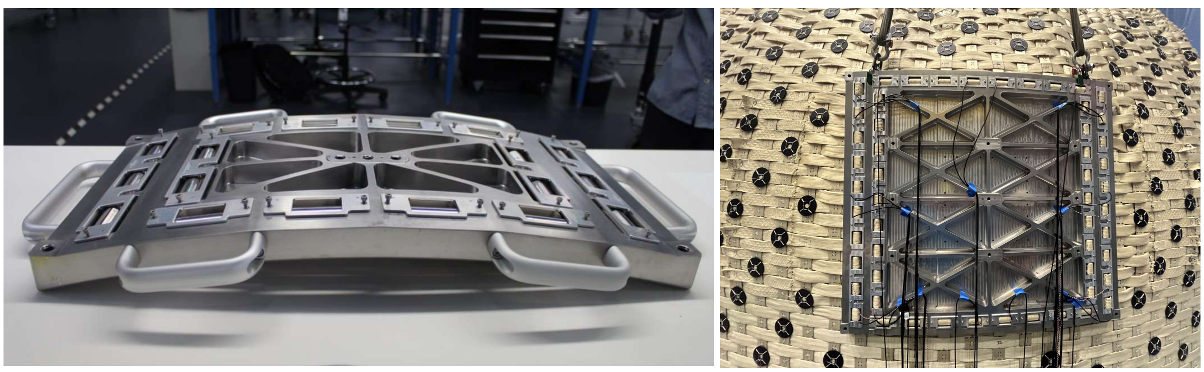

Figure 2. Metallic Blanking Plates, LEFT: LIFE 10 Blanking Plate, RIGHT: LIFE 285 Blanking Plate.

multifunctional system that can be used as a window interface, berthing portal, or other spacecraft equipment structural support. UBP testing of a structural softgoods module with the inclusion of blanking plates was performed on both LIFE 10 and LIFE 285 architectures, surpassing the NASA recommended FOS in both cases. These test results will be explored more in-depth in section IV.

II. LIFE Module Architecture

The LIFE module's distinct design features Softgoods materials in a series of layers that provide the same capabilities as traditional metallic structures, while enabling them to be packed into a much smaller volume upon launch. Figure 3 shows the Softgoods layers that comprise LIFE in its deployed state.

When deployed, starting from the inside of the module, is the air barrier system (ABS). The ABS is the primary hermetic layer that keeps the air inside the module. Additionally, the ABS is the only layer that the crew have direct access to, which presents unique challenges and opportunities when considering the materials to be used as well as how they need to be tested to ensure they remain capable

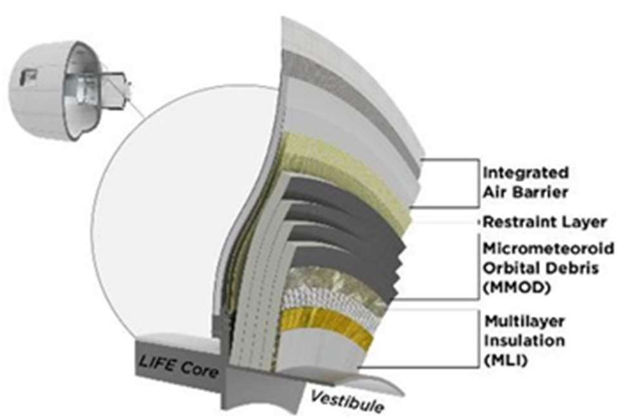

Figure 3. LIFE Module Softgoods Architecture.

of successfully retaining air inside the module to sustain life long-term. More on testing and validation of the ABS in section V.

As you progress towards space when looking at the layers that makeup LIFE, external of the air barrier is the restraint layer. The restraint layer is the structural softgoods layer capable of carrying the pressure load that the air barrier and the volume of air inside the module pushes outward toward space. All the tests Sierra Space and ILC Astrospace have performed to date have been stress-testing the restraint layer enabling the understanding what the materials and architecture are capable of when pushed to their limit.

Outwards of the restraint layer is a series of layers called the Micrometeoroid and Orbital Debris (MMOD) Shield. The primary function of the MMOD Shield is to protect the two layers inward of it (air barrier and restraint layer) in the case that the LIFE module encounters orbital debris while on orbit; ensuring that the restraint layer is not impacted, and the air barrier is not penetrated. To provide this level of protection, the MMOD Shield comprises a series of layers of material that reduce the size and inertia of projectiles, spaced off from one another by foam spacers. Combined, these layers provide a robust protection for the LIFE module against space debris of all kinds.

The outermost layer of the LIFE module softgoods structure is the Multilayer Insulation (MLI). MLI is imperative to the overall success and longevity of the LIFE module by protecting the materials in all layers from the harsh environment of space. Protection against this environment comes in the form of numerous layers of aluminized mylar spaced apart appropriately to provide insulation to the LIFE module. Additionally, beta cloth material is used as the very outermost layer, which protects all the materials from atomic oxygen which is incredibly detrimental to materials.

III. LIFE Module Applications

The key differentiator of Softgoods technology vs. Aerospace industry standard metallic solutions lies in the mass to volume ratio. LIFE can be packed onto a smaller fairing than a standard metallic solution of the same volume, reducing launch costs. Once LIFE reaches its operational location it is pressurized and deploys to an internal volume of ~285m^3, producing a structure whose usable internal volume outsizes a standard metallic structure with a comparable launch vehicle fairing size. A module with larger usable interior volume has apparent advantages for human habitation and exploration in space – increased cargo space, additional station capabilities, crew quality of life, and more. As missions in space become farther reaching and longer in duration, the need for livable volume becomes more imperative than ever.

Softgoods are considered to have lesser heritage in structural spaceflight applications than their metallic aerospace structure counterparts, therefore NASA urges structural performance of softgoods are held to a 4.0 factor of safety (FOS), compared to a 1.4 FOS for metallic structures.[4] For human-rated softgoods applications this 4.0 FOS gets applied to both the module's mean expected operating pressure (MEOP) and life expectancy. Sierra Space is targeting LIFE 285 to be a human-rated module with a MEOP of no greater than 15.2psi and a life expectancy of 15 years. For LIFE 285, these requirements with the FOS applied result in a target UBP of 60.8 psi (15.2 psi x 4.0 FOS). Since LIFE 10 has the same architecture as LIFE 285, but is dimensionally scaled down by 3, the target UBP for LIFE 10 to meet the 4.0 FOS is 182.4 psi (15.2psi x 4.0 FOS x 3).

Currently, the limiting factor in the size of structural softgoods habitats is driven by NASA's recommended 4.0 FOS combined with material performance of softgoods components available today. Until softgoods technologies have enough historic data to justify lowering the FOS requirement like metallics have now, the focus of structural softgoods module testing will be on demonstrating additional capability beyond the 4.0 FOS. As test results continue to show greater margin beyond this mark, applications utilizing structural softgoods technology can further capitalize on the value proposition in mass to volume efficiency. Testing completed over the last 12 months by the team demonstrates that LIFE has room to get larger in size and remain structurally compliant, without any change to design or material selection.

Validation tests of the structural softgoods architecture with integrated blanking plates demonstrate a critical element of the inflatable habitat structural shell. Once this blanking plate interface design is validated it opens many design and mission possibilities – from windows, to hatches, to equipment racks, and beyond. Validation of blanking plates and their numerous use cases within structural softgoods modules begins with understanding the interface between the softgoods and metallics. Before Sierra Space and ILC Astrospace delved into the effort of incorporating a blanking plate into the softgoods structure, two each of UBP and ASC tests had been successfully executed as subscale. These tests provided a solid foundation to explore greater capabilities for the softgoods structure. From these tests, strain data of the structural softgoods webbings was gathered as they were exercised from an unpressurized to a maximum pressure rupture event. This strain data was essential in informing key analyses that provided insight into how the structural softgoods components respond to the integration of a metallic structure like a blanking plate. These analyses were where the effort began on integration of blanking plates. To prove the validity and applicability of these analyses, UBP testing of LIFE 10 was performed. This UBP test was imperative in understanding the maximum capability of all three key components: the softgoods, the metallics, and the interface between the two.

IV. LIFE Module Validation Testing

ICES 2023 contained a paper presented by Sierra Space and ILC (Dover) Astrospace which documented successful completion of two LIFE 10 ultimate burst pressure (UBP) tests performed in 2022.[5] In addition to the two tests documented, a single LIFE 10 accelerated systematic creep (ASC) was successfully executed at the tail end of 2022 (Figure 4). The two successful LIFE 10 UBP tests and single successful ASC test of 2022 demonstrated the structural softgoods layer satisfies the 4.0 FOS recommendation and projects a life at operational pressure far exceeding Sierra Space's target 15-year mission requirement. The first test, performed in July 2022 at NASA JSC, was the first test of Sierra Space's run-for-record test campaign. This test of a LIFE 10 was continuously pressurized until the softgoods reached their material limit and burst at 192 psi. This result exceeded 182.4 psi burst pressure target and overall threshold which Sierra Space is looking to surpass to validate and prove the structural softgoods architecture is fit for a long life in space. Just a few short months later, the Sierra Space and ILC Astrospace team developed and fabricated a second LIFE 10 test unit and headed to NASA MSFC for the next UBP test. Factoring in test execution lessons learned from the first LIFE 10 UBP test performed at JSC, the MSFC team supported the second run-for-record UBP test which resulted in even better results. This was proven and validated when the second test article burst at 204 psi. This result further exceeded the safety requirement Sierra Space is seeking to achieve.

Figure 4. Subscale Creep Test Article #1

In NASA's Softgoods Certification Guidelines document (JSC-67721)[6] it is recommended that multiple accelerated systematic creep (ASC) tests be performed on test articles to predict the lifetime performance of the module as well as provide data supporting the repeatability of the LIFE design and manufacturing methods. Creep testing "is a destructive material testing method by which test engineers load the test unit – a subscale version of the inflatable habitat – with a sustained amount of pressure over time until it fails"[7]. With two UBP tests concluded an UBP average can be obtained, which, in conjunction with component (webbing) level accelerated creep testing, allowed the team to select a pressure for an ASC test. A trendline created from the component level time-to-failure (TTF) data is used to inform a TTF prediction of the ASC test article for various hold pressure. The pressure selected corresponds to a percentage of the UBP average. For Sierra Space's first ASC test of LIFE 10 the pressure selected predicted that the test article would not reach a burst failure for 100 hours. The test article surpassed that mark and survived for 157 hours before finally succumbing to the pressure and bursting. This result exceeded the NASA-recommended safety requirement and further validated that structural capability of the LIFE module at operating pressure far-exceeds mission requirements.

Figure 5. Subscale Creep Test Article #2

Given that NASA recommends that multiple ASC tests be performed on test articles to predict the lifetime performance of the module as well as provide data supporting the repeatability of the LIFE design and manufacturing methods, another LIFE 10 test article was assembled, and ASC testing was again performed at NASA MSFC in early 2023 to gather another data point on LIFE's TTF plot (Figure 5). The first ASC test performed by Sierra Space and ILC Astrospace was set to a pressure that the teams predicted would result in test article rupture at 100 hours. To generate a curve from a second subscale article creep test, a lower pressure was selected to correlate to a longer predicted TTF. At the pressure (percentage of UBP average) it was predicted that the LIFE 10 test article would reach burst failure at 800 hours of testing of maintaining constant internal pressure. The test article survived for 457 hours before a rupture of the structural softgoods layer was the means of failure for the unit. While this TTF appears lower than the estimated duration of survival, the curve generated by the systematic creep test data points still exceeds the creep life requirement of LIFE by a wide margin.

Testing continued in 2023 with the team shifting its focus back to UBP testing, now with the inclusion of a blanking plate integrated into pressure shell of the unit in the cylindrical section (Figure 6). This inclusion and interface between softgoods and metallic structures was an incredibly ambitious goal set by the development team. Inclusion of a blanking plate is a significant design modification that introduces design challenges related to ensuring an even load distribution between the webbings that terminate into the plate and those that run adjacent to the plate. The orders of magnitude difference in stiffness between the woven webbing and metallic blanking plate produces a lack of strain in the webbing region spanning the blanking plate at high pressures that must be addressed to reduce stress concentrations in the webbings and prevent premature failure. Numerous analyses and component-level tests were performed by the teams to ensure that the interface between the metallic blanking plate and the softgoods restraint layer would not reduce the UBP performance of the test article compared to previous UBP tests performed in 2022. With incredible support from NASA MSFC's testing capabilities, a UBP test of LIFE 10 with included blanking plate occurred in August 2023. This test, burst at an exceedingly high pressure of 242 psi. This result far exceeded both previous UBP testing on articles of this scale and the NASA-recommended 4.0 FOS of 182.4 psi for LIFE 10 modules. This test validated the structural softgoods design as well as the softgoods-to-metallic interface at the blanking plate, giving the team great confidence going into the biggest challenge yet: a full-scale LIFE 285 test with two blanking plates.

Figure 6. Subscale Burst Test w/Blanking Plate.

The first LIFE 285 UBP test article fabricated and tested by Sierra Space and ILC Astrospace concluded an incredible year of testing for the team (Figure 7). All the article-level tests performed during 2022 and early 2023 were at LIFE 10 scale, which provided a great opportunity to test the overall design and architecture at a smaller scale, allowing the teams to move faster and with reduced cost compared to testing large-scale units. This LIFE 285 test unit would build upon the inclusion of a single blanking plate into a subscale unit, by adding a second blanking plate to the cylinder section of the test article. The two blanking plates were metallic plate structures integrated with the structural restraint layer only. They were located in-line with each other, 180 degrees apart, centered in the cylinder section of the article. The restraint layer architecture that interfaces with the blanking plates remained consistent with the prior LIFE 10 UBP article, apart from the modified length of the restraint layer webbings which interface with the blanking plate scaling up to account for the scaled nature of LIFE 285 compared to LIFE 10. Integration of the softgoods and blanking plates to the metallic test core was performed at NASA MSFC. At the conclusion of integration, the test article underwent preparatory tests to ensure its readiness for UBP testing; leak testing of the entire system and a proof test to validate the design where the test article was pressurized to 1.5x the unit's MDP for 5 minutes. Once all these prior tests and systematic checkout were accepted, the teams moved into the burst test procedure.

Figure 7. LIFE 285 Ultimate Burst Pressure Test Unit #1.

The UBP test was originally started on December 11th, 2023. However, the test setup was unable to complete pressurization to burst. All test steps preceding the burst event were completed successfully, but the test setup was unable to increase the internal pressure of the test article above 63 psig. Troubleshooting occurred and it was determined that further inspection was needed at the test site to determine the root cause. The decision was made to release pressure until the test article's internal pressure was lowered to 1-2 psig so that the team could safely return to the test site and further investigate. This was deemed a partially successful test result as the article surpassed the 60.8 psi threshold to meet the 4.0 FOS required by NASA in JSC-67721.

During the team's investigation into the pressurization system's issue, it was discovered that the venting system was not operating correctly. Repairs occurred the following day by the NASA MSFC team, allowing the test procedure to be restarted. Sierra Space decided to re-run the test to determine the UBP even though the article had surpassed the pressure threshold during the first test. On December 12th, 2023, the test system was repaired and approved to re-run the UBP in the evening. The second attempt of the UBP test followed the same steps as the prior day and resulted in the article bursting at 77 psi (Figure 8), far exceeding the NASA-recommended 4.0 FOS for structural softgoods articles. This result is within 4% of the LIFE 10 with blanking plate UBP test result when scaled comparatively. This meant that the additional blanking plate and scaling differences did not negatively affect the structural performance of LIFE at ultimate failure.

Figure 8. Full-Scale Burst Unit #1 Captured at the Moment of Bursting.

V. Inflatable Habitat Material Validation Testing

A. Primary Structure Validation

Component-level UTS (ultimate tensile strength) and real-time creep testing was conducted by Sierra Space in late 2023 on the Vectran webbings which comprise the structural softgoods restraint layer of the LIFE module. This produces a cost-effective pool of data to help predict system-level performance and provides an understanding of differences in performance when straps are woven into system level architecture. Given the structural architecture of the softgoods layer, it necessitates the use of a structural seam. The seam was selected for further evaluation at the component-level since it can potentially be the weakest link in the restraint layer and therefore dictates the overall system level performance. UTS testing of both pristine (non-seamed) and prepared (seamed) webbings were conducted by Sierra Space and ILC Astrospace, providing a robust UTS-average for the components that makeup LIFE's structural restraint layer. With UTS-averages obtained, real-time creep was performed on pristine and prepared specimens by applying a load and holding the specimens at that load until the specimen fails. The specimens were loaded to percentages of the UTS-average between 60 and 90% and held until failure, obtaining creep results in the form of time-to-failure (TTF) times. Creep results can be plotted with TTF on the horizontal axis, hold load on the vertical axis, and drawing a trendline between data points to predict TTF at operational pressure loads. (Figure 9)[8] The real-time creep testing performed by Sierra Space on the seams used in LIFE modules predicts an operational life on the order of 2.5 million years, far exceeding Sierra Space's mission requirement of 15-years. System level creep testing performed on two LIFE 10 articles in late 2022 indicate better creep performance when compared to component level testing at the same percentages. It is hypothesized that the woven structure and friction between straps helps the structural layer act as a system, supporting load sharing and redistribution of load among neighboring straps when they get damaged as they are reaching their material limit. Previous ASC tests held at high percentages of UBP have shown that the complete failure of the first hoop strap does not necessarily propagate into catastrophic failure of the system until many hours later.

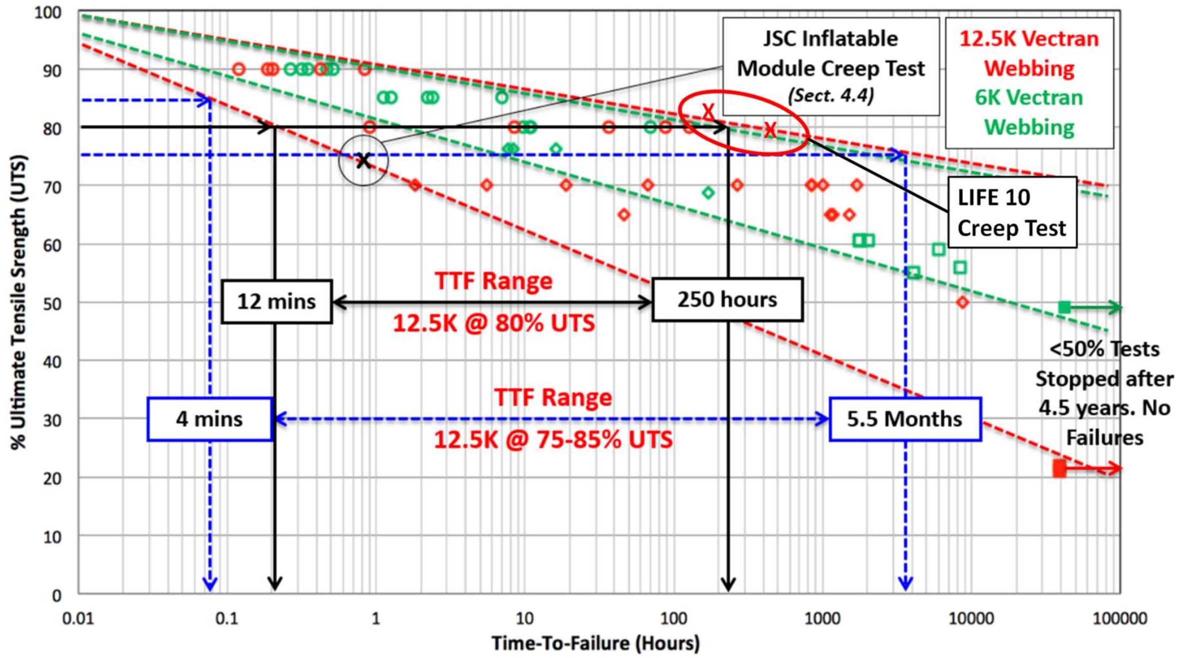

Figure 9. LIFE 10 Creep Test Results Plotted with Past Creep Results.

B. Air Barrier System Validation

The Air Barrier System (ABS) is an integral part of the inflatable habitat softgoods shell. It needs to be well fitted with the webbing restraint system in terms of sizing and indexing. Sizing deals with relative run lengths among layers so that at operational pressure or MDP all layers are at the intended and prescribed size and stress. Indexing deals with relative position among layers such that at MDP all layers are located correctly without high stress concentration. This multilayered softgoods system serves many critical functions safeguarding the health and safety of crew members to ensure mission success. Key requirements that need to be validated through material and functional tests are Permeability, Flammability, Cut and Puncture Resistance, Anti-microbial Property, and Mechanical Property for Secondary Structural (Accessory) Attachments. Because individual layers are not able to meet all requirements, and the system shall be single fault tolerant, the current ABS uses a multilayered approach.

Permeability refers to the Oxygen transmission rate through the barrier film at MDP. To validate the material and the barrier system, permeation tests are performed on both pristine condition and operational condition, with both material only and seam construction test coupons. Operational condition accounts for material property degradation due to handling during fabrication, transportation, packing, deployment, and exposure to operational environments. The permeation requirement has a direct impact on mission cost because air is a consumable and depending on mission parameters, resupply could be difficult and costly.

Flammability of the Air Barrier System is tested and validated according to NASA's Technical Standard, NASA-STD-6001B, Flammability, Outgassing, and Compatibility Requirements and Test Procedures. The current Air Barrier design includes fire/flame protection layer(s) that will self-extinguish when flame source is removed. The fire/flame protection layer not only enabled the ABS to meet flammability requirements it also improved puncture and cut resistance for the system.

The use of Anti-microbial materials in the ABS is a passive way of reducing microbial growth in the habitable environment. This does not eliminate the need to use active system such as chemical-iodine or ionic silver biocides or physical-point of use (POU) air sterilization filters. In addition to anti-microbial properties, the interior facing layer of the inner most layer, shall be cleanable with hydrophobic properties to repel water. Validation tests will include MIL-STD-810H Environmental Engineering Considerations and Laboratory Tests and ASTM F22 Standard Test Method for Hydrophobic Surface Films by the Water-Break Test.

To validate the materials and system for puncture and cut resistance, tests are performed according to applicable ASTM standards for films and fabrics.[9] [10] Like the permeation tests, these tests are performed on both pristine and as-built coupons.

A desirable design feature of the ABS is to carry some load from interior accessory attachments. The so called "Secondary Attachment" shall be designed to carry load(s) transferred from equipment attached to the interior surface with margin of safety, but at the same time this attachment feature shall release to prevent overloading the interior surface and cause potential damage of the ABS. A custom test apparatus (Figure 10) has been developed and successfully implemented to validate the secondary attachment feature for flight operation.

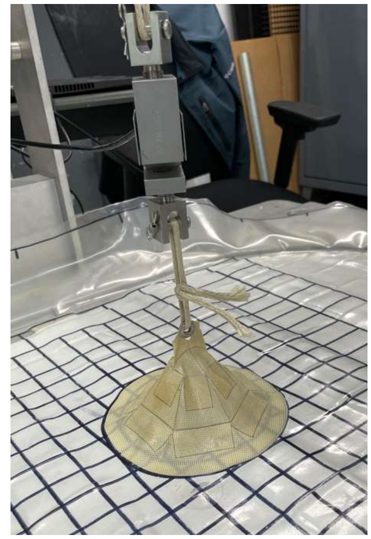

Figure 10. Custom ABS Test Apparatus.

VI. Conclusion

The successful burst and creep tests of both the LIFE 10 and burst of the LIFE 285 unit with blanking plate hardware demonstrated the robustness of this class of inflatable-deployable space habitat; opening the potential for even larger habitats at relatively low mass, further capitalizing on the mass-to-volume ratio that inflatable habitats realize. Hardware features validated by the inclusion of the blanking plates in UBP tests open the design possibilities for myriad spacecraft equipment and structural attachments in softgoods structures. The work of certification for flight continues with additional validation tests at both LIFE 10 and LIFE 285 scales in 2024.

Acknowledgments

Sierra Space and ILC Astrospace owe much of the success of our great testing performed to date to the NASA teams that we worked with. The team at NASA MSFC has proven time and again instrumental through their expertise in testing, diligent application of lessons learned, and incredible hard work, all of which has allowed rapid turn-around times between tests.

References

[1] NASA Technical Standard, NASA-STD-5001B, Structural Design and Test Factors of Safety for Spaceflight Hardware, w/Change 3: Revalidation w/Administrative/Editorial Changes, 2022-10-24.
[2] Section 4.4.3 Ultimate Burst Pressure (UBP) Testing, p34, NASA JSC-67721 Certification Guidelines for Crewed Inflatable Softgoods Structures, August 3, 2022.
[3] Section 4.2.6 Softgoos Structures, [FSR 45], p23, NASA Technical Standard, NASA-STD-5001B, 2022-10-24.
[4] Section 4.2.1 Metallic Structures, [FSR 24], Table 1, pp17-18, NASA Technical Standard, NASA-STD-5001B, 2022-10-24.
[5] Kirwan, J.A., et al., "Successful Testing of Advanced Space Habitat," 52nd International Conference on Environmental Systems, Calgary, Canada, July 2023, ICES-2023-458.
[6] NASA JSC Certification Guidelines for Crewed Inflatable Softgoods Structures (JSC-67721 Baseline), August 3, 2022.
[7] Section 4.3.5 Creep Testing of Prepared Softgoods Components, pp29-31, NASA JSC-67721 Certification Guidelines for Crewed Inflatable Softgoods Structures, August 3, 2022.
[8] Valle, G.D., et al., NASA Technical Report, JSC-E-DAA-TN63766, ID:20190000847, Review of Habitable Softgoods Inflatable Design, Analysis, Testing and Potential Space Applications, NASA JSC and AIAA, January 7, 2019.
[9] ASTM F1306-21 Standard Test Method for Slow Rate Penetration Resistance of Flexible Barrier Films and Laminates.
[10] MIL-STD-3010, Department of Defense Test Method Standard: Test Procedure for Packaging Materials, 30 Dec 2002.