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Proposal for Certifying Expandable Planetary Surface Habitation Structures

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Abstract

A factor-of-safety (FS) of 4.0 is currently used to design habitation structures made from structural soft goods. This approach is inconsistent with using a FS of 2.0 for metallic and polymeric composite pressure vessels as well as soft good structures such as space suits and parachutes. This inconsistency arises by using the FS to improperly account for the unknown effects of a variety of environmental and loading uncertainties. Using a 4.0 FS not only results in additional structural mass, it also makes it difficult to gain insight into the limitations of the material and/or product form and thus, it becomes difficult to make improvements. In order to bring consistency to the design and certification of expandable habitat structures, the approach used by the Federal Aviation Administration (FAA) to certify polymeric composite aircraft structures is used as a model and point of departure. A draft certification plan for Expandable Habitat Structures is developed in this paper and offered as an option for placing habitats made from soft goods on an equal footing with other structural implementations.

Introduction

In general, three sets of documents are necessary to develop structural systems for aerospace applications. The first is a Requirements Document that contains specifications (in categories such as performance, safety, damage tolerance, etc.) that must be demonstrated as being met by the final product. The second and third documents define the information and processes needed to demonstrate that an as-built structural system complies with all of the specified requirements. The second document, a Certification Plan, sets forth a general framework and means of showing compliance with the requirements. The third document, a Certification Test Plan, is derived from and expands on the Certification Plan. It contains the detailed test procedures, plans, success criteria, test element definitions, number of tests, etc. that are necessary to demonstrate compliance.

The requirements for a particular system application (such as a planetary habitat) should be general and apply to all design implementations being considered. For example, all habitation structures considered for a specific application must be designed to the same set of structural requirements (including Factors of Safety), load conditions, and survive the same environment for a specified life time. The Certification Plan begins to address specific implementations at a very general level and may distinguish between major classes of materials, such as metallic, polymeric composite or structural soft goods. The Certification Test Plan is written to test a specific system implementation. This current document is being written to describe one possible substantiation of a Certification Plan for expandable (sometimes referred to as inflatable) pressurized habitation structures, where all or a portion of the pressure containment and support structure is constructed from soft goods.

Background

Soft goods are used in a variety of applications, such as space suits, parachutes, airbags and inflatable habitats. In typical structural design applications, a key requirement is the Factor of Safety (FS) that must be applied to limit (or operating) loads to obtain ultimate (or failure) loads. The minimum factor of safety for pertinent pressure vessel and soft good applications are listed in Table 1 (from references 1 and 2).

The FS value of 4.0 required for structural soft goods stands out and appears inconsistent compared to a value of 2.0 for the rest of the applications. For pressure vessels, which include those made of metallic materials, Habitable Modules, and Space Suits, the FS is 2.0. For soft goods in safety critical applications, such as Space Suits and Parachute/Parafoil systems, again the FS is 2.0. The question that arises is; why is the FS 4.0 for Structural Soft Goods instead of 2.0, or alternatively, why doesn't the 4.0 value apply to space suits and Parachutes/Parafoils? This discrepancy cannot be based on pressure being a load condition, or the item being safety critical since items in both of those categories use a FS of 2.0. Based on discussions with those who have designed, built and tested inflatable/expandable Habitation structures, the need to account for a variety of factors (see examples in Table 2) have been described to account for the higher FS.

Table 1. Minimum factors of safety for pressurized structures.

Application	Condition	Factor of Safety
Metallic Pressure Vessels (Ref. 1)	Design Burst Pressure	2.0 X Maximum Design Pressure (MDP)
Habitable Modules (Ref. 1)	Ultimate (Pressure Only)	2.0 X MDP
EVA Space Suit Element (Ref. 2)	Ultimate Pressure	2.0 X Maximum Operating Pressure
Parachute and Parafoil Systems – Safety Critical components (Ref. 1)	Ultimate (Pressure or Mechanical Load)	2.0 X Maximum Operating Load
Structural Soft Goods (excluding parachute, parafoils, and space suits) – Safety Critical (Ref. 1)	Ultimate (Pressure or Mechanical Load)	4.0 X Maximum Operating Loads

Table 2. Examples of Adjustment Factors for structural soft goods.

A_U	Adjustment factor for Ultraviolet Exposure, Weathering, and Service Loads
A_C	Adjustment factor for creasing, folding, or repair temperatures
A_B	Adjustment factor for biaxial stress state
A_D	Adjustment factor for load duration and temperature

Thus, using a FS of 4.0 for structural soft goods appears to be a method for accounting for the unknown impact that a wide variety of environmental and other effects have on the material performance in a soft good structure. This is a nonstandard and improper way to use Factor of Safety. The FS should be applied to a limit load to establish the ultimate load for design.

Establishing and using a FS is intended to insure an equal level of reliability across a variety of material and structural implementations. The FS provides for structural reliability by requiring that the design structural strength be greater than the stresses induced by external loads by at least the factor of safety. Historically, the FS accounts for uncertainties such as occurrence of extreme loads, inaccuracies of stress prediction methods, variability in fabrication workmanship, and structural strength deterioration over the lifetime of an airframe. The values used for FS have evolved and typically been reduced as greater knowledge and reduced variability in materials and processes were obtained (Reference 3). A serious limitation of using an increased FS approach for structural soft goods, is that it offers no insight into the limitations of the material and/or product form and thus, makes it difficult to make improvements. It also forces structural soft goods to always have twice the mass necessary to meet the equivalent level of reliability of all other material/structural systems.

If the true factor of safety is separated from effects corresponding to the adjustment factors listed in Table 2, then the FS for soft good structures can be lowered to 2.0 and made equivalent with all the other material/structural applications and forms listed in Table 1. As an example of a problem caused by using a higher FS to account for the factors in Table 2, consider the terms A_U and A_D which address degradation of material due to environmental exposure. The correct way to address environmental exposure in structures made from soft goods would be to determine the material design properties at the end of life (EOL), after the material has been subjected to lifetime exposure to the expected service environment. Those EOL properties should be used to design and analyze the soft good structure. Similarly, for a particular application, the appropriate bend radii, the number of folding/unfolding cycles, duration and pressure applied while folded, etc. should be defined for each major structural component. Then the particular form of the soft good (strap, membrane, etc.) should be subjected to the proper series and cycle of folds, and tested to determine the resulting strength, with this strength value used in design, analysis and sizing. Ideally, a complete property set should be established for the structural soft good, taking into account its environment, load level (for creep), product form, and duty cycle, with those values used in design. If that is done, then it should be acceptable to use the standard FS of 2.0 for structural soft goods.

Separating the issues associated with the adjustment factors allows the materials developer, designer, etc. to retain the benefits of using structural soft goods without paying any undue penalty imposed by using a FS of 4.0. This is especially true for applications where some or all of the various factors listed in Table 2 are not present or can be mitigated by various means. For example, if a particular soft good material is susceptible to strength degradation when exposed to Ultraviolet (UV) radiation, many solutions are possible. In the case of a Habitat structure, the soft goods may be covered in thermal insulation and micrometeoroid protection layers, in which case the material is protected from and never exposed to UV radiation in service. If strength degrades during long-term exposure to constant load and reaches an unacceptable level at a certain temperature, the amount of material could be increased (to reduce the stress level), or the exposure temperature could be reduced to an acceptable level. Again, take the example of a habitation structure; the straps that form the restraint structure are one of the most interior layers of the total habitat shell wall (bladder, restraint layer, thermal insulation, micro-meteoroid protection, radiation protection). By being adjacent to the interior of the habitat, the straps are protected from the harsh lunar temperatures and likely will be at, or close to the internal habitat

temperature. Thus, long-term creep due to temperature is not likely to be an issue, and associated material degradation will not occur. As a final example, if creasing the material leads to unacceptable material degradation, a packaging scheme might be developed that results in no material being creased in critical areas. Perhaps the most egregious consequence of using the 4.0 FS is that there is little or no incentive to understand and mitigate the issues listed in Table 2. Even if all issues are completely eliminated, the soft goods must still pay the mass penalty associated with the increased FS.

Approach for Developing a Certification Plan For Expandable Habitat Structure (Based on FAA Certification of Composite Aircraft Structures)

The Requirements and Provisions for designing Commercial Transport Aircraft are contained in Federal Aviation Regulation (FAR) Part 25 - Airworthiness Standards: Transport Category Airplanes (Reference 4). Section 25.21 states that each requirement must be met and that this be shown by tests and analysis (with conditions defined for each). Section 25.571 (Damage tolerance and fatigue evaluation of structure) requires that an “evaluation of the strength, detail design and fabrication must show that catastrophic failure due to fatigue, corrosion, manufacturing defects, or accidental damage, will be avoided throughout the operational life of the airplane.” This evaluation must be conducted “... for each part of the structure that could contribute to a catastrophic failure ...” It is during the evaluation process of a specific design implementation where all “... principal structural elements and detail design points, the failure of which could cause catastrophic failure of the airplane ...” must be identified. Obviously, the structural elements that qualify as “principal” will be very dependent on the specific material and structural concept and design implementation for each structural application. As a result, the means and methods for demonstrating compliance are not contained in this (FAR Part 25) document. This distinction is important because the requirements are established to ensure an equivalent level of reliability for any and all design implementations that might be developed in creating a new commercial transport. Thus, the design requirements are independent of implementation, including materials and structural concepts used. However, the means and methods for demonstrating compliance to the requirements in FAR Part 25 can differ for different materials and structural implementations (skin-stringer, sandwich, bonded, mechanically fastened, stitched, etc.). As an example, with the introduction of polymeric composite materials and primary structures for commercial transports, the FAA developed guidance “for composite structures that it considers acceptable to the FAA for showing compliance with certification requirements of civil composite aircraft” (References 5 and 6). The original guidance was issued in 1984 (Reference 5) with a significant update subsequently issued in 2009 (Reference 6).

The FAA Composites certification process is a good model to use for structural soft goods for a number of reasons and is the basis for the approach recommended in this paper. First, polymer composite and soft good structures share many features; they are generally planar structures, are made up of layers, have orthotropic properties, consist of polymer materials (in the matrix), and fibers (in plies or the restraint layer) predominantly determine most mechanical properties. Second, material qualification is critical to ensuring structural integrity, but can be a burden because of the large number of material systems available and the cost to qualify each. Third,

quality control of manufacturing (including processing cycles) is imperative if predicted performance is to be demonstrated. For composite structures, in addition to the compliance guidance established in References 5 and 6, the FAA has also issued information on “Material Qualification and Equivalency for Polymer Matrix Composite Material Systems” (Reference 7) and “Quality Control for the Manufacture of Composite Structures” (Reference 8).

The intent of this document is to provide a initial basis for discussing and ultimately deriving guidance for certifying in-space and planetary surface Expandable Habitat Structures. Only Reference 5 was available at the time this process was originally proposed and the following section was based on its contents. With the recent issuance of Reference 6 (which cancelled Reference 5), a more comprehensive set of data and criteria now exist for composite structures, and would become the point of departure for the next iteration of a Expandable Habitat Structures Certification Plan. Impact Damage, for example, is an especially important topic that receives greatly expanded and more comprehensive coverage in Reference 6.

An example of a draft Certification Plan for Expandable Habitation Structures constructed from structural soft goods is contained in the next section.

Draft Certification Plan For Expandable Habitat Structures

(Note: extensive use is made of both the content and language of reference 5 in this section. Familiarity with reference 4 is also necessarily assumed.)

1. Purpose:

This document sets forth acceptable means for demonstrating compliance of structural soft good materials and structures, with requirements as provided in a In-Space and Planetary Surface Habitat Structures Requirements Document (which still needs to be developed as discussed previously).

2. General:

a. The procedures outlined in this document provide guidance for soft good structures and are considered acceptable to NASA for showing compliance with certification requirements for in-space and planetary surface habitats. This document is published to aid in the evaluation of certification programs for soft good structure applications and reflects the current status of soft goods technology. It is expected that this document will be modified periodically to reflect technology advances.

b. The extent of testing and/or analysis and the degree of environmental accountability required will differ for each structure depending upon the expected in-space or planetary surface environment, protective layers added to mitigate environmental exposures, service usage in that environment, the material selected, the design margins, the failure criteria, the data base and experience with similar structures, and on other factors affecting a particular structure. It is expected that these factors will be considered when interpreting this document for use on a

specific application.

c. Pertinent definitions are given in Section 7.

3. Material and Fabrication Development:

To provide an adequate design data base, environmental effects on the design properties of the material system should be established.

a. Environmental design criteria should be developed that identify the most critical environmental exposures, including radiation and temperature, to which the material in the application under evaluation may be exposed. This is not required where existing data demonstrate that no significant environmental effects, including, but not limited to, the effects of temperature, vacuum and radiation, exist for the material system and construction details, within the bounds of environmental exposure being considered. Experimental evidence should be provided to demonstrate that the material design values or allowables are attained with a high degree of confidence in the appropriate critical environmental exposures to be expected in service. The effect of the service environment on static strength, fatigue and stiffness properties should be determined for the material system through tests; e.g., accelerated environmental tests, or from applicable service data. The effects of environmental cycling (i.e., radiation, vacuum, temperature, etc.) should be evaluated. Existing test data may be used where it can be shown directly applicable to the material system.

b. The material system design values or allowables should be established on the structural level that is appropriate to the product form (straps for restraint layers, sheet for bladder layers, etc.) by either test of the product form or by test of the product form's constituents in conjunction with a test validated analytical method.

c. For a specific structural configuration of an individual component (point design), design values may be established which include the effects of appropriate design features (holes, joints, seams, integration with hard structure [such as hatches, windows, floors], etc.).

d. For specific packaging/deployment configurations, design values may be established which include effects of creasing, bend radii, repetitive fold/unfold cycles, pressure applied to folded element, etc.

e. Impact damage is generally accommodated by limiting the design strain level. (Note, much more comprehensive coverage of this topic is contained in Reference 6 and should be included in future discussions of Expandable Habitat Structures certification.)

4. Proof of Structure – Static:

The static strength of the structural soft good design should be demonstrated through a program of component ultimate load tests in the appropriate environment, unless experience with similar designs, material systems and loadings is available to demonstrate the adequacy of the analysis supported by subcomponent tests, or limit load component tests. (Note, coupon, element,

subcomponent and component definitions are given in Section 7.)

- a. The effects of repeated loading and environmental exposure which may result in material property degradation should be addressed in the static strength evaluation. This can be shown by analysis supported by test evidence, by tests at the coupon, element or subcomponent level, or alternatively by relevant existing data.
- b. Static strength structural substantiation tests should be conducted on new structure unless the critical load conditions are associated with structure that has been subjected to a repeated loading and environmental exposure. In this case either (1) the static test should be conducted on structure with prior repeated loading and environmental exposure, or (2) coupon/element/subcomponent test data should be provided to assess the possible degradation of static strength after application of repeated loading and environmental exposure, and this degradation accounted for in the static test or in the analysis of the results of the static test of the new structure.
- c. The component static test may be performed in an ambient atmosphere if the effects of the environment are reliably predicted by subcomponent and/or coupon tests and are accounted for in the static test or in the analysis of the results of the static test.
- d. The static test articles should be fabricated and assembled in accordance with production specifications and processes so that the test articles are representative of production structure.
- e. When the material and processing variability of the soft goods structure is greater than the variability of current metallic structures, the difference should be considered in the static strength substantiation (1) by deriving proper allowables or design values for use in the analysis, and the analysis of the results of supporting tests, or (2) by accounting for it in the static test when static proof of structure is accomplished by component test.
- f. It should be shown that impact damage that can be realistically expected from manufacturing and service, but not more than the established threshold of detectability for the selected inspection procedure, will not reduce the structural strength below ultimate load capability. This can be shown by analysis supported by test evidence, or by tests at the coupon, element or subcomponent level.

5. Proof of Structure - Fatigue/Damage Tolerance:

The evaluation of soft good structure should be based on the applicable requirements of the Habitat Structural Requirements Document (which does not exist at this time). The nature and extent of analysis or tests on complete structures and/or portions of the primary structure will depend upon applicable previous fatigue/damage tolerant designs, construction, tests, and service experience on similar structures. In the absence of experience with similar designs, NASA-approved structural development tests of components, subcomponents, and elements should be performed. The following considerations are unique to the use of soft good material systems and should be observed for the method of substantiation selected by the applicant. When selecting the damage tolerance or safe life approach for a particular principle structural element, attention should be given to geometry, inspectability, good design practice, and the type of

damage/degradation of the structure under consideration.

a. Damage Tolerance Evaluation.

(1) Structural details, elements, and subcomponents of critical structural areas should be tested under repeated loads to define the sensitivity of the structure to damage growth. This testing can form the basis for validating a no-growth approach to the damage tolerance requirements. The testing should assess the effect of the environment on the flaw growth characteristics and the no-growth validation. The environment used should be appropriate to the expected service usage. The repeated loading should be representative of anticipated service usage. The repeated load testing should include damage levels (including impact damage) typical of those that may occur during fabrication, assembly, and in-service, consistent with the inspection techniques employed. The damage tolerance test articles should be fabricated and assembled in accordance with production specifications and processes so that the test articles are representative of production structure.

(2) The extent of initially detectable damage should be established and be consistent with the inspection techniques employed during manufacture and in service. Flaw/damage growth data should be obtained by repeated load cycling of intrinsic flaws or mechanically introduced damage. The number of cycles applied to validate a no-growth concept should be statistically significant, and may be determined by load and/or life considerations. The growth or no growth evaluation should be performed by analysis supported by test evidence or by tests at the coupon, element, or subcomponent level.

(3) The extent of damage for residual strength assessments should be established. Residual strength evaluation by component or subcomponent testing or by analysis supported by test evidence should be performed considering that damage. The evaluation should demonstrate that the residual strength of the structure is equal to or greater than the strength required for the specified design loads (considered as ultimate). It should be shown that stiffness properties have not changed beyond acceptable levels. For the no-growth concept residual strength testing should be performed after repeated load cycling.

(4) An inspection program should be developed consisting of frequency, extent, and methods of inspection for inclusion in the maintenance plan. Inspection intervals should be established such that the damage will be detected between the time it initially becomes detectable and the time at which the extent of damage reaches the limits for required residual strength capability. For the case of no-growth design concept, inspection intervals should be established as part of the maintenance program. In selecting such intervals the residual strength level associated with the assumed damages should be considered.

(5) The structure should be able to withstand static loads (considered as ultimate loads) which are reasonably expected during a completion of the (interplanetary) flight or expected planetary surface life on which damage resulting from obvious discrete sources occur (i.e., micro-meteoroid, lander ejecta, etc.). The extent of damage should be based on a rational assessment of service mission and potential damage relating to each discrete source.

(6) The effects of temperature, radiation, vacuum, and other environmental factors which may result in material property degradation should be addressed in the damage tolerance evaluation.

b. Fatigue and Creep (Safe-Life) Evaluation.

Fatigue and Creep substantiation should be accomplished by component fatigue/creep tests or by analysis supported by test evidence, accounting for the effects of the appropriate environment.

The test articles should be fabricated and assembled in accordance with production specifications and processes so that the test articles are representative of production structure. Sufficient component, subcomponent, element or coupon tests should be performed to establish the fatigue/creep scatter and the environmental effects. Component, subcomponent, and/or element tests may be used to evaluate the fatigue/creep response of structure with impact damage levels typical of those that may occur during fabrication, assembly, and in service, consistent with the inspection procedures employed. The component fatigue/creep test may be performed with an as-manufactured test article if the effects of impact damage are reliably predicted by subcomponent and/or element tests and are accounted for in the fatigue/creep test or in analysis of the results of the fatigue/creep test. It should be demonstrated during the fatigue/creep tests that the stiffness properties have not changed beyond acceptable levels. Replacement lives should be established based on the test results. An appropriate inspection program should be provided.

6. Additional Considerations:

a. Flammability.

(1) The existing requirements for flammability and fire protection of in-space and planetary surface habitation structure attempt to minimize the hazard to the occupants in the event ignition of flammable fluids or vapors occur. In addition, components exposed to heat, flames or sparks should withstand these effects. The use of soft good structure should not decrease this existing level of safety. Compliance may be shown by analysis supported by test evidence that habitat soft good structure and interior structural material subjected to these hazards can withstand fire and heat as required in the Habitat Structures Requirements Document.

(2) The habitation soft good structure elements required to be fire resistant are specified in the Requirements Document.

b. Protection of Structure.

Weathering, abrasion, erosion, ultraviolet radiation, chemical environment (glycol, hydraulic fluid, fuel, cleaning agents, etc.) and other factors may cause deterioration in a soft good structure. Suitable protection against and/or consideration of degradation in material properties should be provided for and demonstrated by test.

c. Quality Control.

The overall plan required by the certifying agency should involve all relevant disciplines, i.e., engineering, manufacturing and quality control. This quality control plan should be responsive to special engineering requirements that arise in individual parts or areas as a result of potential failure modes, damage tolerance and flaw growth requirements, loadings, inspectability, and local sensitivities to manufacture and assembly.

d. Production Specifications.

Specifications covering material, material processing, and fabrication procedures should be developed to ensure a basis for fabricating reproducible and reliable structure. The discrepancies permitted by the specifications should be substantiated by analysis supported by test evidence, or tests at the coupon, element or subcomponent level.

e. Inspection and Maintenance.

Maintenance manuals developed by manufacturers should include appropriate inspection, maintenance and repair procedures for soft good structures.

f. Substantiation of Repair.

When repair procedures are provided in NASA approved documents or the maintenance manual, it should be demonstrated by analysis and/or test that methods and techniques of repair will restore the structure to a safe operating condition.

7. Pertinent Definitions:

Allowables - material values that are determined from test data at the fiber, sheet or lamina level on a probability basis, e.g., A or B base values [reference 3: FAR 25.615(a)].

Component - a major section of the habitat structure which can be tested as a complete unit to qualify the structure.

Constituent level material properties - established from test data for the lowest level material constituent, such as a fiber, sheet or ply.

Coupon - a small test specimen used for evaluation of basic material properties or properties of generic structural features (e.g., bonded or mechanically fastened joints).

Damage - a structural anomaly caused by manufacturing (processing, fabrication, assembly or handling) or service usage. Usually caused by trimming, fastener installation or foreign object contact.

Degradation - the alteration of material properties (e.g., strength, modulus, coefficient of expansion) which may result from deviations in manufacturing or from repeated loading and/or environmental exposure.

Design values - material, structural element, and structural detail properties that have been determined from test data and chosen to assure a high degree of confidence in the integrity of the completed structure [reference 3: FAR 25.613(b)].

Detail - a non-generic structural element of a more complex structural member (e.g. specific design configured joints, splices, soft good-to-hard structure interfaces).

Discrepancy - a manufacturing anomaly allowed and detected by the planned inspection procedure. They can be created by processing, fabrication or assembly procedures.

Element - a generic element of a more complex structural member (e.g., bladder, webbing, joints, or splices).

Environment - external, non-accidental conditions, separately or in combination, that can be expected in service and which may affect the structure (e.g., temperature, vacuum, UV radiation).

Flaw - a manufacturing anomaly created by processing, fabrication or assembly procedures.

Impact damage - a structural anomaly created by foreign object impact.

Point design - an element or detail of a specific design which is not considered generically applicable to other structure for the purpose of substantiation, e.g., seams and major joints. Such a design element or detail can be qualified by test or by a combination of test and analysis.

Principal structural element - an element that contributes significantly to carrying ground, launch, transit, planetary surface and pressurization loads and whose failure, if remained undetected, could eventually lead to loss of the habitat.

Subcomponent - a major three-dimensional structure which can provide complete structural representation of a section of the full structure.

Summary

A factor-of-safety (FS) of 4.0 is currently being used to design habitation structures made from structural soft goods. This approach is inconsistent with using a FS of 2.0 for metallic and polymeric composite pressure vessels as well as other soft good structures such as space suits and parachutes. This inconsistency arises by using the FS to improperly account for the unknown effects of a variety of environmental and loading uncertainties. Using a 4.0 FS not only results in additional structural mass, it also makes it difficult to gain insight into the limitations of the material and/or product form and thus, it becomes difficult to make improvements.

In order to bring consistency to the design and certification of expandable habitat structures, the approach used by the Federal Aviation Administration (FAA) to certify polymeric composite aircraft structures is used as a model and point of departure. The FAA Composites certification process is a good model to use for structural soft goods for a number of reasons and is the basis for the approach recommended in this paper. First, they both share many features; they are generally planar structures, are made up of layers, have orthotropic properties, consist of polymer materials (in the matrix), and fibers produce mechanical properties (similar to restraint layer). Second, material qualification is critical to ensuring structural integrity, but can be a burden because of the large number of material systems available and the cost to qualify each. Third, quality control of manufacturing (including processing cycles) structural items is imperative if predicted performance is to be demonstrated.

A draft certification plan for Expandable Habitat Structures is developed in this paper and offered as an option for placing habitats made from soft goods on an equal footing with other structural implementations. In a certification process, this draft certification plan would respond to a In-Space and Planetary Surface Habitat Structures Requirements document (which does not

currently exist), along with appropriate certification test plans for specific implementations of soft good materials. If implemented, this approach would give designers the flexibility to incorporate soft good structures into various space applications without the undue mass penalties associated with a 4.0 factor of safety. The reduction of the 4.0 factor of safety to 2.0 would make soft good structure implementation consistent with those of other materials, and would encourage material properties testing and the development of mitigation strategies for the varies loads and environmental uncertainties. In total, all of this is essential in order to make soft goods structures mass competitive, and to realize the potential benefits of soft goods materials across the wide range of space applications for which they might be considered.

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