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ACT Payload Shroud Structural Concept Analysis and Optimization

Bart F. Zalewski
ZIN Technologies, Inc., Middleburg Heights, Ohio

Brett A. Bednarcyk
Glenn Research Center, Cleveland, Ohio

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Bart F. Zalewski
ZIN Technologies, Inc., Middleburg Heights, Ohio

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Glenn Research Center
Cleveland, Ohio 44135

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Bart F. Zalewski
ZIN Technologies, Inc.
Middleburg Heights, Ohio 44130

Brett A. Bednarcyk
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Abstract

Aerospace structural applications demand a weight efficient design to perform in a cost effective manner. This is particularly true for launch vehicle structures, where weight is the dominant design driver. The design process typically requires many iterations to ensure that a satisfactory minimum weight has been obtained. Although metallic structures can be weight efficient, composite structures can provide additional weight savings due to their lower density and additional design flexibility. This work presents structural analysis and weight optimization of a composite payload shroud for NASA's Ares V heavy lift vehicle. Two concepts, which were previously determined to be efficient for such a structure are evaluated: a hat stiffened/corrugated panel and a fiber reinforced foam sandwich panel. A composite structural optimization code, HyperSizer, is used to optimize the panel geometry, composite material ply orientations, and sandwich core material. HyperSizer enables an efficient evaluation of thousands of potential designs versus multiple strength and stability-based failure criteria across multiple load cases. HyperSizer sizing process uses a global finite element model to obtain element forces, which are statistically processed to arrive at panel-level design-to loads. These loads are then used to analyze each candidate panel design. A near optimum design is selected as the one with the lowest weight that also provides all positive margins of safety. The stiffness of each newly sized panel or beam component is taken into account in the subsequent finite element analysis. Iteration of analysis/optimization is performed to ensure a converged design. Sizing results for the hat stiffened panel concept and the fiber reinforced foam sandwich concept are presented.

Introduction

The design of structural components involves ensuring their capability to withstand strength, stiffness, and stability requirements. However, one may design a structure that will not fail, and may not be significantly over-conservative, in a manner that it is unnecessarily heavy and therefore inefficient. Although, in traditional structural design, the efficiency of the design is recommended, the importance of structural component efficiency becomes more apparent for aerospace systems. The effort to optimize the structure in terms of its overall performance is mainly driven by two factors: mission objectives and cost. One can view the first factor as the lower bound of the project objective as it gives the minimum mission requirements, which must be met. The second factor can be viewed as an upper bound on the project objective as it gives the upper bound on the overall cost of the project. It may very well happen that the mission requirements are not feasible with the established budgetary constraints either due to a low budget, unrealistic mission objectives, and/or limited or undeveloped technology. Assuming that cost is guiding the project, it is important to develop a system, which achieves the project goals with a reasonable monetary constraint. For aerospace structures, like the one considered in this work, one of the main objectives is to produce the lightest weight, yet safe, design. Assuming that the technology development to achieve this goal doesn't produce unrealistic negative time and cost effects, structural weight optimization provides a solution to both primary project drivers, namely: mission objectives and cost.

This work presents structural optimization of the payload shroud of NASA's next generation heavy lift vehicle, Ares V. Ares V has a mission objective of carrying approximately 1.6 times the mass of Saturn V's capability to the low Earth orbit (LEO) and 17 times that of space shuttle's capability. The payload shroud, or payload fairing, will protect the payload, which currently consists of ALTAIR lunar lander, from the exterior environment. This exterior environment includes, but is not limited to, aerodynamic, acoustic, and thermal loading. Previous studies showed that choosing a correct geometry for the outer mold line (OML) allows for minimization of the weight of the total engineering system including structural weight, weight of thermal protection, and weight of acoustic blankets. The shape chosen to minimize the overall weight of these three aspects is a tangent ogive. This work will elaborate on the structural optimization of this shape to obtain the optimum design. Thermal and acoustic environments were not considered in the analysis.

In this work structural optimization consisted of a material and a geometry optimization. Due to improvements in material characteristics and manufacturing quality over the last two decades, composite materials were chosen to provide additional weight savings when compared to metallic construction. The material chosen for this study was an IM7/977-3 graphite epoxy composite with pristine autoclave tape properties. The study compares two composite panel architectures, which after preliminary analysis, showed great potential to provide a low-weight design for the payload shroud, the hat stiffened panel and the fiber reinforced foam sandwich panel (FRF). Although, the hat stiffened panel can be made from fabric material, especially in the stiffeners, and the FRF concept is an out-of-autoclave concept, the material choice was fixed for closer comparison of the two architectures and not their manufacturing heritage. Further work will be needed to obtain true material properties of the manufacturable concepts. These two concepts were sized using sizing software coupled to finite element solver. Sizing strategies and basics of the sizing software, HyperSizer, will be discussed in the subsequent sections.

Description of the Hat Stiffened Panel

The hat stiffened panel (Figure 1) is currently used as a fuselage on Boeing 787 and Airbus A350 as well as a concept for airplane wing construction. Its design variables include panel height, facesheet thickness, web thickness, stiffener spacing, crown width, flange width, and web angle (Figure 2). Due to its high efficiency in carrying axial loads, the hat stiffened panel with co-cured stiffeners has been considered for the construction of the Ares V payload shroud. A significant portion of the shroud, the cylindrical barrel, is subjected to such loading. The hat stiffened panel can also have a high buckling resistance if the panel is combined with cylindrical ring frames, as it usually is. Global buckling in the cylindrical sections is usually mitigated, provided the ring frames are stiff enough such that buckling occurs between the ring frames. This effectively reduces the buckling length of the panel to that of the ring spacing. An addition of ring frames may not have a significant impact on the mass of the structure, as even light ring frames can significantly increase the circumferential stiffness of the panel. However, the hat stiffened panel is not as efficient as some of the sandwich panels under biaxial bending loads. In this type of loading, the hat concept may be more susceptible to buckling and addition of ring frames may not be adequate to preclude such behavior. In the shroud, the ogive section is subjected to high biaxial bending loads. Therefore, due to its additional bottom facesheet, a corrugated concept was chosen to better treat the effects of bending in the ogive region (Figure 3 to Figure 5). The decision of choosing a corrugated sandwich was based on the assumption that the transition between the hat stiffened panel and the corrugated sandwich can be performed without a circumferential joint due to the similarity of the two concepts. In addition, the forward end of the ogive is composed of a thicker solid laminate. This was dictated by manufacturing as the stiffeners in the corrugated panel cannot converge to a point (Figure 3). The high curvature of the shroud in this region allowed the use of solid laminate to be fairly efficient.

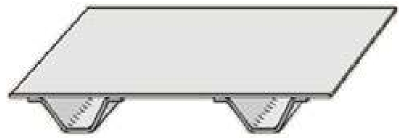


Figure 1.—Hat stiffened panel.

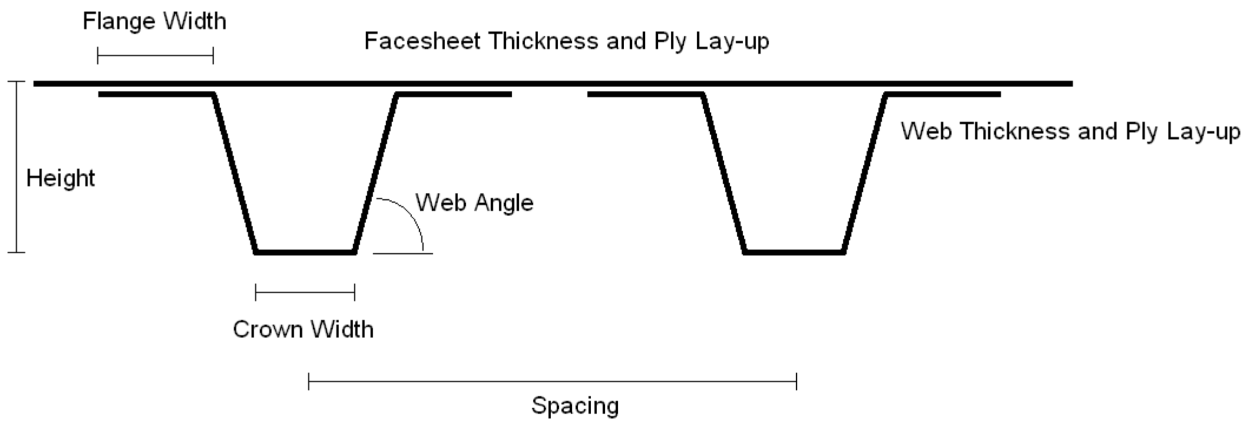


Figure 2.—Hat stiffened panel design variables.

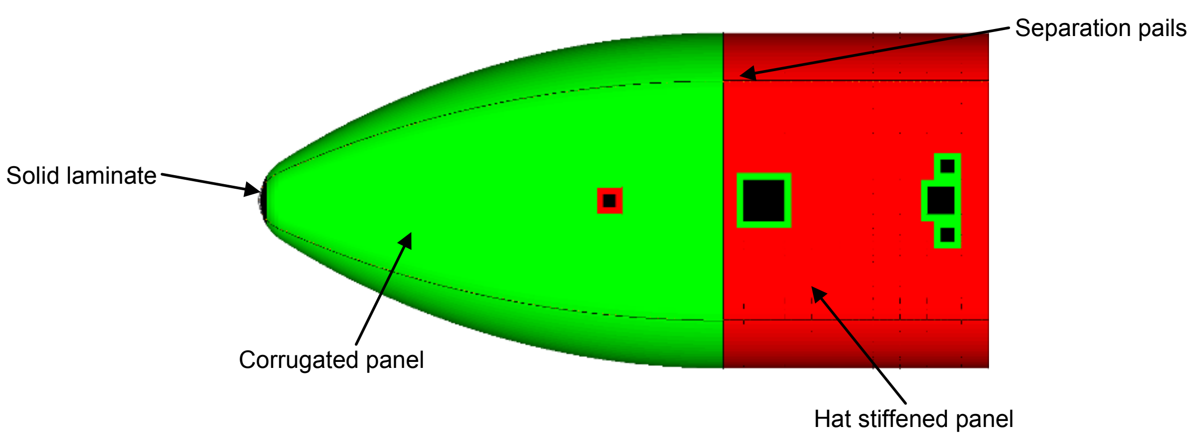


Figure 3.—Shroud concepts.

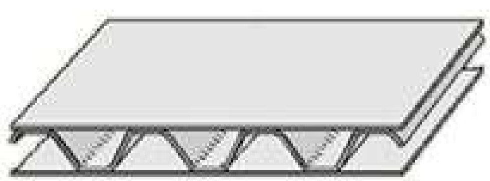


Figure 4.—Corrugated panel.

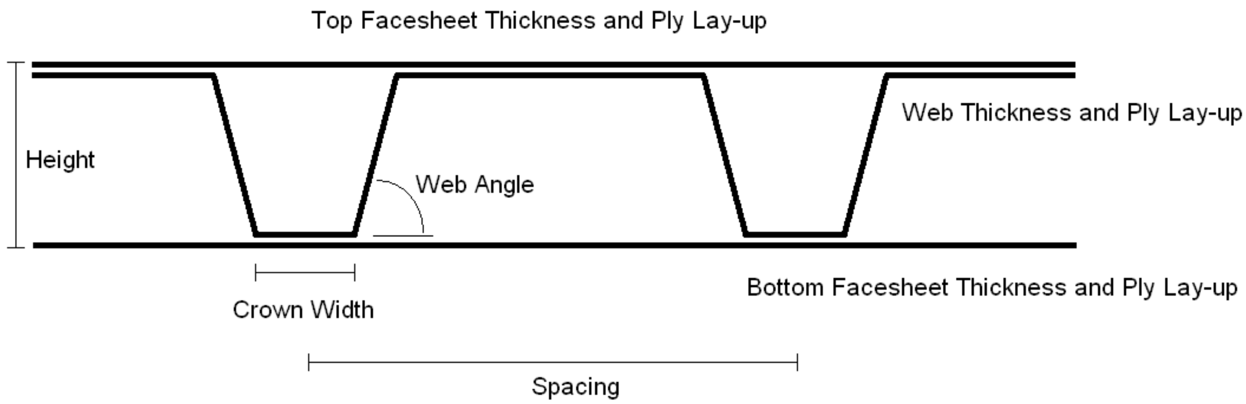


Figure 5.—Corrugated panel design variables.

The corrugated panel (Figure 5) design variables include panel height, top facesheet thickness, bottom facesheet thickness, web thickness, stiffener spacing, crown width, and web angle. Due to the many similarities in cross section geometry and design variables between the hat stiffened concept and the corrugated concept, it is assumed that the two can be joined readily and do not require a circumferential joint.

Description of the Fiber Reinforced Foam Sandwich Panel

The primary application of the FRF concept to date has been in wind turbine blades, where the concept reduces cost and improves performance compared to balsa and PVC foam designs. Because cost is a primary driver in this application, glass fibers are typically used rather than carbon fibers. FRF is also currently employed in marine structural applications, such as hulls, decks, bulk-heads, cockpit floors, hard tops, and fishing tower platforms. Additional non-aerospace applications include specialty shelters, high impact matting, and bridge decks. Aerospace applications for FRF include the ATK shroud boat tail demonstration article, an impact-resistant turbine fan case designed and fabricated with NASA Glenn Research Center, and a weapons bay door for a Boeing UCAV, all of which were designed and manufactured using carbon fibers. In addition, a FRF sandwich panel preliminary design for the NASA Crew Exploration Vehicle Crew Module was developed (Bednarcyk et al. 2007).

Fiber Reinforced Foam (FRF) (WebCore Technologies, LLC) is a novel sandwich panel concept that combines aspects of foam sandwich panels and stiffened panels (Figure 6). The panel is constructed by starting with long strips of closed-cell structural foam, such as Rohacell (Evonik Industries), with rectangular cross sections. These strips are wrapped with dry carbon fibers and placed adjacent to each other on a tool with dry carbon fiber facesheet preforms on the top and bottom. The panel is then infiltrated with resin via vacuum-assisted resin transfer molding (VARTM) (Berg and Higgins 2008). Once the panel is infiltrated and cured, the fiber overwraps located between the foam strips form integral composite webs (Figure 6). The webs provide significantly improved through-thickness shear strength compared to foam sandwich panels, while the foam provides support for the webs against local buckling. The webs also provide some limited axial strength and stiffness, however, this is not their primary purpose as they typically do not contain axial fibers, as the wrapping procedure requires a minimum helical angle of approximately 5°. Facesheets provide most of the panel’s bending stiffness as they are located farther from the panel neutral axis. The FRF panel design variables include panel height, top facesheet thickness, bottom facesheet thickness, web thickness, web spacing, and core type (Figure 7). Compared to aluminum honeycomb sandwich panels, FRF sandwich panels can have the advantage of not requiring an adhesive between the facesheet and core, which adds parasitic mass, and debonding between facesheet and core is not typically an issue with FRF. Furthermore, FRF sandwich panels provide improved through-thickness shear strength in the web direction compared to aluminum honeycomb sandwich panels and they do not exhibit reduced shear strength as the panel thickness increases. Finally, the FRF sandwich concept is highly damage tolerant as its multiple webs, which are supported by the foam, provide redundant load paths, and, as stated above, the facesheets do not tend to delaminate from the core. The FRF preform can also be stitched prior to resin infiltration to further improve damage tolerance. Since FRF incorporates advantages of both sandwich and stiffened panels, the shroud design studied was composed entirely of this architecture (Figure 8).

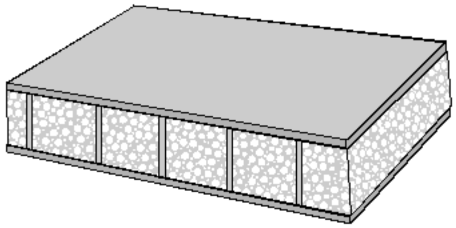


Figure 6.—Fiber reinforced foam panel.

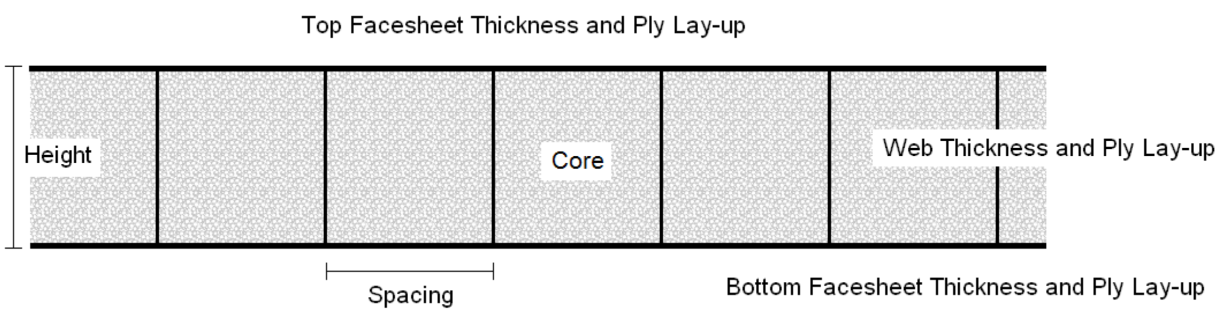


Figure 7.—Fiber reinforced foam panel design variables.

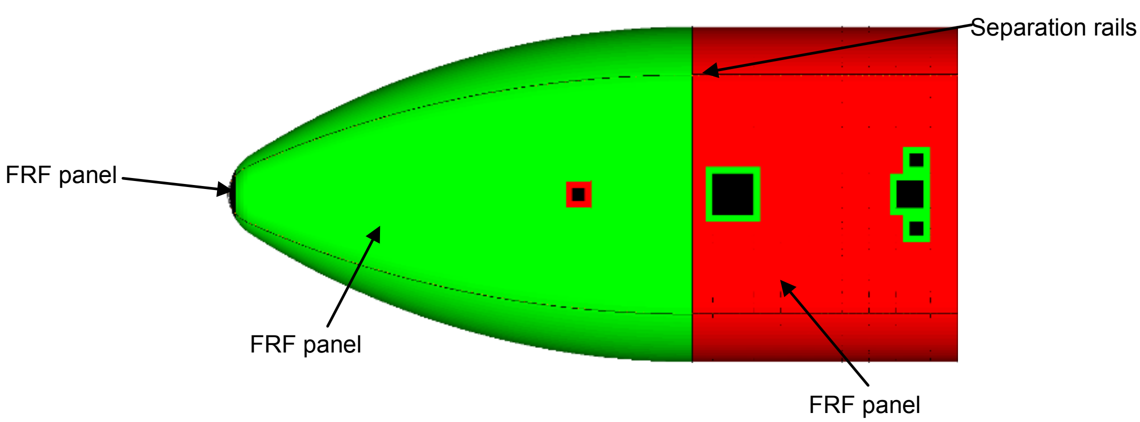


Figure 8.—Fiber reinforced foam panel design variables.

Description of the Payload Shroud

The payload shroud, or fairing, safeguards the payload from the external environment, which can include external loading such as aero loads, acoustic vibrations, and thermal effects, among others. Some of the effects of these external loads can be mitigated by the shroud's geometry. From previous studies, the geometry that provides the greatest overall mitigation to the examined loads was a cylinder/tangent ogive configuration (Figure 9).

The OML diameter of the barrel as well as the aft portion of the ogive measures 33 ft (10.0584 m) (Figure 10). The height of the barrel is 8 m and the height of the ogive is 14 m (Figure 10). To improve buckling characteristics of the barrel section, ring frames spaced at roughly 1 m were added in both concepts (Figure 10 to Figure 11). Two ring frames were also added in the ogive section for the FRF concept (Figure 11) to decrease buckling susceptibility in this region. The corrugated construction did not require this modification.

Both concepts included a ring frame at the interface of the cylinder and ogive sections as well as four separation rails oriented in the axial direction. Five penetrations were considered in this shroud configuration, one in the ogive, the other four in the barrel. Buildup regions were also added around the penetrations. The penetrations and separation rails were not sized in this work.

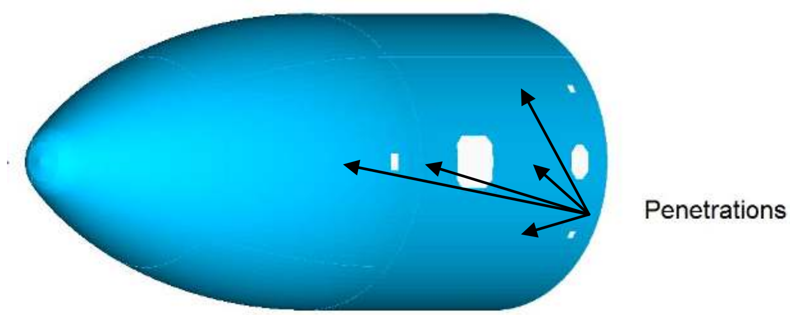


Figure 9.—Shroud geometry.

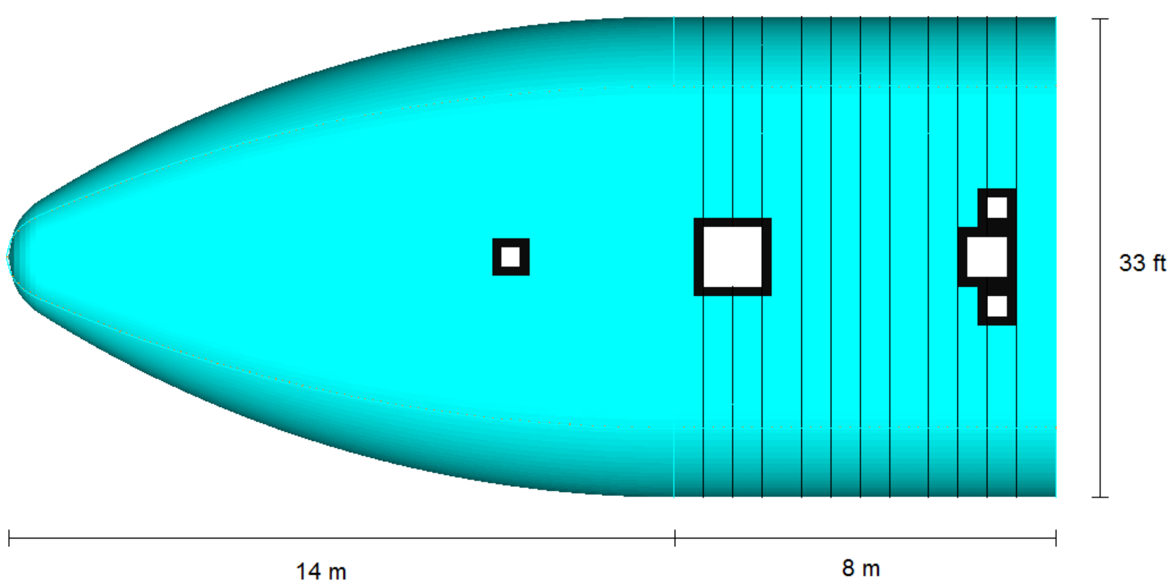


Figure 10.—Ring stiffeners for the hat stiffened panel.

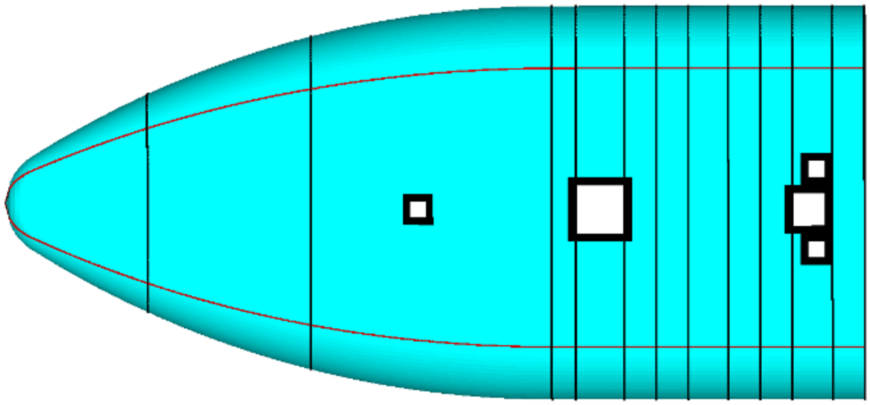
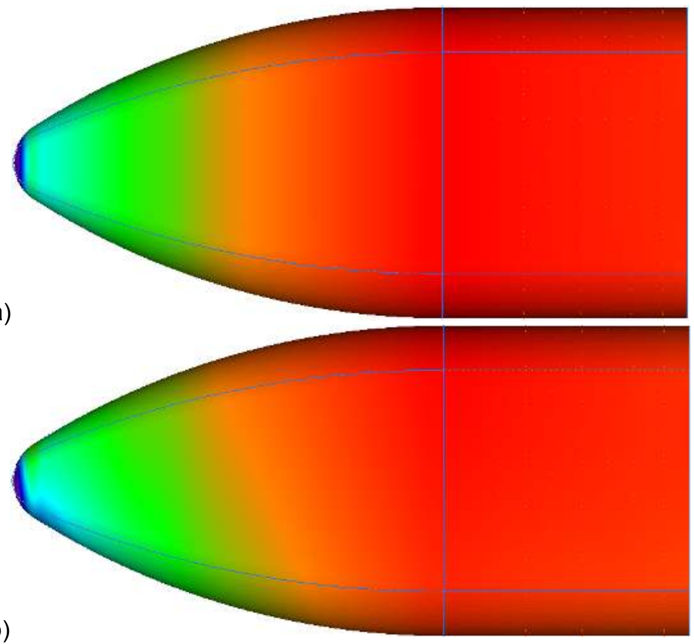


Figure 11.—Ring stiffeners for the FRF panel.



(a)

(b)

Figure 12.—Applied pressure load: (a) Max Q loading; and (b) Max Q-α loading.

Description of Loading, Safety Factors, and Failure Criteria

The finite element shroud model was subjected to three types of loading conditions: max G loading condition, max Q loading condition, and max Q-α loading condition. Four orientations of the max Q-α loading were chosen for this preliminary sizing for various Mach numbers; however, these may not lead to the worst case behavior of the shroud. In future work, more orientations of the max Q-α loading should be considered for more accurate mass estimates. Applied pressures contours for max Q and max Q-α are shown (Figure 12). Exaggerated deflection shapes due to each loading condition are also shown (Figure 13 and Figure 14), although the scaling factors among the figures are not the same. Material properties at an elevated temperature of 220 °F were used when considering the max G loading condition. Boundary conditions restraining all translational and rotational degrees of freedom were applied at the aft (barrel) end. The mechanical limit safety factor was chosen to be 1 and the ultimate limit safety factor was chosen to be 1.4. While there was no local buckling knockdown, the global buckling knockdown was set at 0.65.

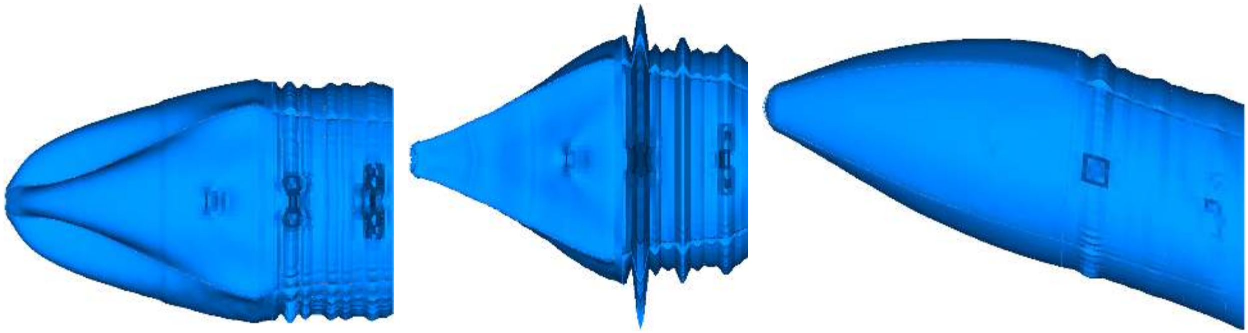


Figure 13.—Hat panel deformation: Max G loading, Max Q loading, Max Q-α loading. Note that the scaling factors are not the same.

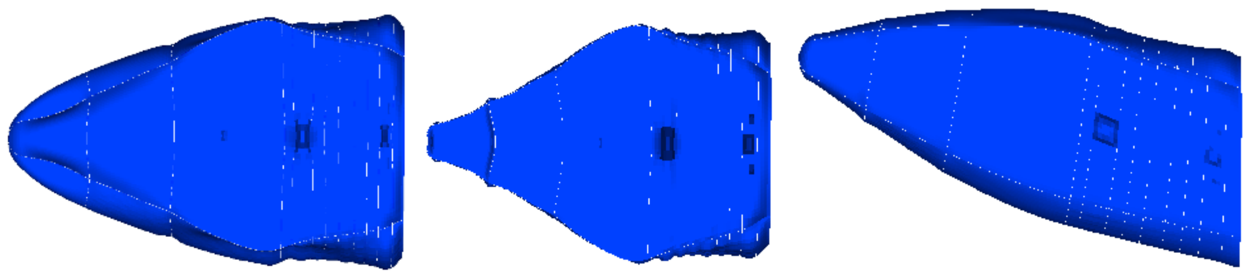


Figure 14.—FRF panel deformation: Max G loading, Max Q loading, Max Q-α loading. Note that the scaling factors are not the same.

Various failure criteria were used to determine the failure mechanism of the panels. Although other failure criteria are available, HyperSizer 5.8.11 standard failure criteria were used at this stage. It was determined that these failure criteria are sufficient at this sizing stage. These include checks for the:

- Composite strength, max strain 11, 22, and 12 directions
- Composite strength, max stress 11, 22, and 12 directions
- Composite strength, Tsai-Hill
- Composite strength, Tsai-Wu
- Composite strength, Tsai-Hahn
- Composite strength, Hoffman
- Composite strength, LaRC03 Matrix Cracking
- Composite strength, LaRC03 Fiber Failure
- Composite strength, crippling MIL-HDBK-17-3E including D_{ij} terms
- Global buckling, curved panel
- Local buckling, longitudinal, transverse, and shear directions

Description of the Analysis Process

The goal of the analysis was to obtain preliminary mass estimates for the Ares V payload shroud. These estimates were obtained from a sized acreage panel design of the hat stiffened/corrugated panel and the fiber reinforced foam sandwich panel. This design aims to accommodate most of the structural loads with the assumption that design details and stress concentrations will not alter the final configuration significantly. The analysis process was composed of two parts, which were performed iteratively, finite element analysis and structural sizing. For the first finite element analysis, solid laminate properties were used to obtain preliminary elemental force and moment distribution. The analysis was performed using

NX NASTRAN for the hat stiffened/corrugated concept and using MSC NASTRAN for the FRF concept. Only shell elements for composite panels and bar elements for beams were used in the model. These element types were used since their element forces can be imported into the structural sizing software. Also, the cross section of both elements is only accounted for in the stiffness matrix formulation and does not alter the mesh, making these elements convenient to use for iterative sizing.

Sizing of the structure was performed using sizing software HyperSizer 5.8.11 (Collier 1994, Collier 1996, Collier et al. 1997), which uses a brute force optimization to find the lightest design that also has positive margins of safety. HyperSizer 5.8.11 obtains element forces and moments from a finite element analysis. The FE computed generalized forces are then subjected to statistical analysis which determines the mean of the loads and their standard deviation. For this sizing, a mean load plus two standard deviations are applied to the panel concept. These statistical loads are then used in strength of materials type calculations using composite material properties to distribute them to the various parts of the panel whose limits and range on the geometry are defined. Hence, free body diagram calculations are performed on numerous panel configurations. Buckling and strength criteria are checked for panels ordered from lightest to heaviest such that the lightest panel with positive margins can be chosen without performing calculations for the heavier panels. If no panels within the limits have positive margins, the user needs to augment the limits or range of variables. Assuming the optimal panel is found, A, B, and D matrices are computed for a unit thickness shell element such that the correct stiffness properties are captured in that element. The procedure is analogous to the method of transformed sections commonly used in composite beam calculations. These properties are imported into a finite element code to update the element stiffness such that new updated force and moment distribution can be computed. The updated element forces and moments are imported into HyperSizer 5.8.11 where a new optimization is performed. The process of optimization and finite element analysis continues until the mass of the structure stabilizes. At this point the geometry of the design should also stabilize, although this is not a convergence criterion and should be checked by the analyst. The HyperSizer optimization process is depicted below (Figure 15).

The payload shroud was divided into several components. Each component was sized individually in HyperSizer 5.8.11 and thus had its own cross section geometry. The component subdivision for the hat stiffened/corrugated and FRF panels are shown below (Figure 16 and Figure 17).

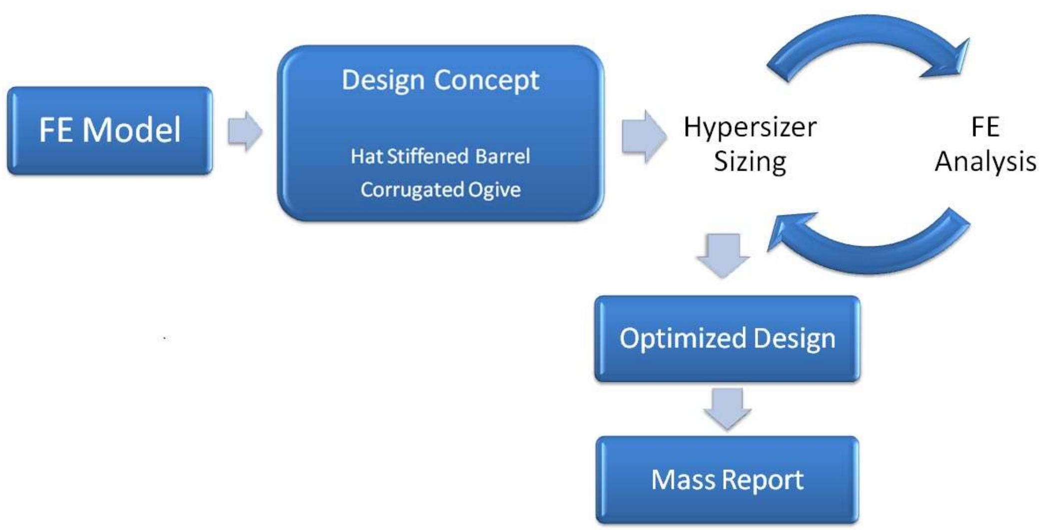


Figure 15.—HyperSizer sizing process.

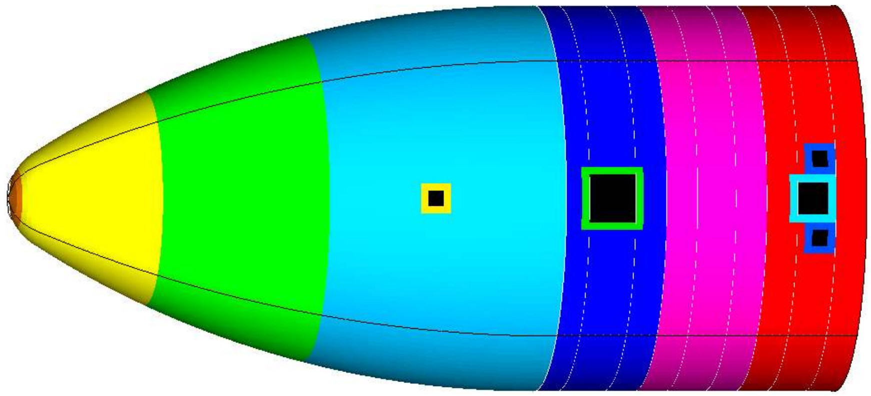


Figure 16.—Hat stiffened/corrugated sizing components.

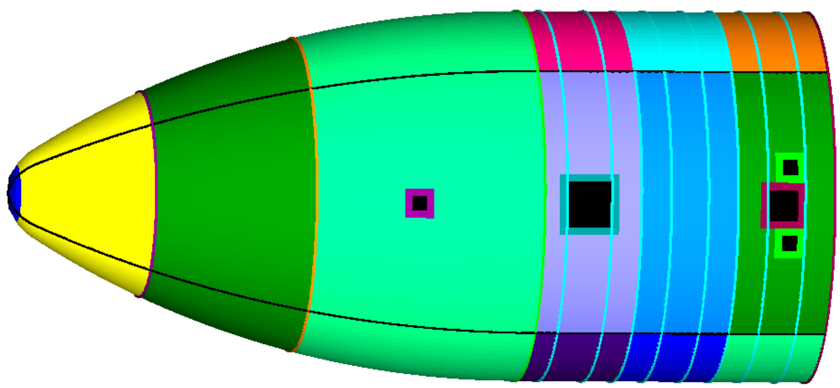


Figure 17.—FRF sizing components.

For the hat stiffened/corrugated concept, seven different major sizing components were considered (Figure 16), four of them in the ogive and three in the barrel. The ogive nose was sized using a solid laminate while the rest of the ogive used a corrugated panel concept. The barrel was sized using a hat stiffened panel concept. Separate solid laminate components around the penetrations were also considered. The FRF concept had additional components in the barrel (Figure 17). Each of the hat stiffened components was further subdivided into four components circumferentially. This allowed for the better design-to load assessment, which benefitted the FRF design, since statistical load analysis is performed for an individual component. The four circumferential sections were then linked to ensure that they are composed of the same cross section. Due to different manufacturing constraints, the FRF concept penetration buildups and ogive nose were sized as FRF panels. For both concepts, ring frames were sized such that they precluded global buckling. The barrel ring frames were considered as being one component, and therefore had the same geometry, while the remaining ring frames were all sized independently. Separation rails and penetrations were not sized. The material used in this sizing was a graphite epoxy composite IM7/977-3 with the following properties at 75 °F and 220 °F. At 75 °F the properties are:

- $E_{Tension11}$ = 22.18 Msi [152.93 GPa]
- $E_{Tension22}$ = 1.29 Msi [8.89 GPa]
- $E_{Compression11}$ = 21.73 Msi [149.83 GPa]
- $E_{Compression22}$ = 1.29 Msi [8.89 GPa]

- Poisson's Ratio$_{Tension12}$ = 0.329 GPa]
- Poisson's Ratio$_{Compression12}$ = 0.329
- Shear modulus$_{12}$ = 0.71 Msi [4.90 GPa]
- Allowable tensile stress$_{11}$ = 275.06 ksi [1896.54 GPa]
- Allowable tensile stress$_{22}$ = 15.765 ksi [108.70 GPa]
- Allowable compressive stress$_{11}$ = 227.285 ksi [1567.13 GPa]
- Allowable compressive stress$_{22}$ = 19.443 ksi [134.06 GPa]
- Allowable shear stress$_{12}$ = 9.149 ksi [63.08 GPa]

At 220 °F the properties are:

- $E_{Tension11}$ = 22.18 Msi [152.93 GPa]
- $E_{Tension22}$ = 1.12 Msi [7.72 GPa]
- $E_{Compression11}$ = 21.73 Msi [149.83 GPa]
- $E_{Compression22}$ = 1.12 Msi [7.72 GPa]
- Poisson's Ratio$_{Tension12}$ = 0.383
- Poisson's Ratio$_{Compression12}$ = 0.383
- Shear modulus$_{12}$ = 0.54 Msi [3.72 GPa]
- Allowable tensile stress$_{11}$ = 275.454 ksi [1899.26 GPa]
- Allowable tensile stress$_{22}$ = 12.25 ksi [84.46 GPa]
- Allowable compressive stress$_{11}$ = 152.966 ksi [1054.70 GPa]
- Allowable compressive stress $_{22}$ = 9.951 ksi [68.61 GPa]
- Allowable shear stress$_{12}$ = 6.837 ksi [47.14 GPa]

Both concepts were sized using equivalent orthotropic materials with different ply percentages (Table 1).

TABLE 1.—EQUIVALENT LAMINATES USED IN SIZING

Laminate	Percent of 45 plies	Percent of 0 plies	Percent of 90 plies
1	20	20	60
2	30	30	40
3	20	70	10
4	40	50	10
5	50	25	25

Analysis Results

The majority of both structures experienced failure by either local buckling or global buckling (Figure 18 and Figure 19). Buckling analysis for both concepts was performed using finite element analysis (Figure 20 and Figure 21). The total mass of the hat stiffened/corrugated shroud was 2495 kg and the total mass of the FRF shroud was 2163 kg. The general sizing summary is shown (Table 2 to Table 5). Note that the mass of the separation rails and the mass of the penetration panels, which were not sized, is excluded. It is noted that the hat stiffened/corrugated shroud ring frames totaled 436 kg whereas the FRF ring frames totaled 73 kg. This 363 kg ring frame mass savings accounts for the entirety of the mass savings of the FRF design, which was 332 kg lighter than the hat stiffened/corrugated design. It is expected that the hat stiffened barrel should require heavier ring frames compared to the FRF barrel as the hat stiffeners provide no circumferential stiffness or strength.

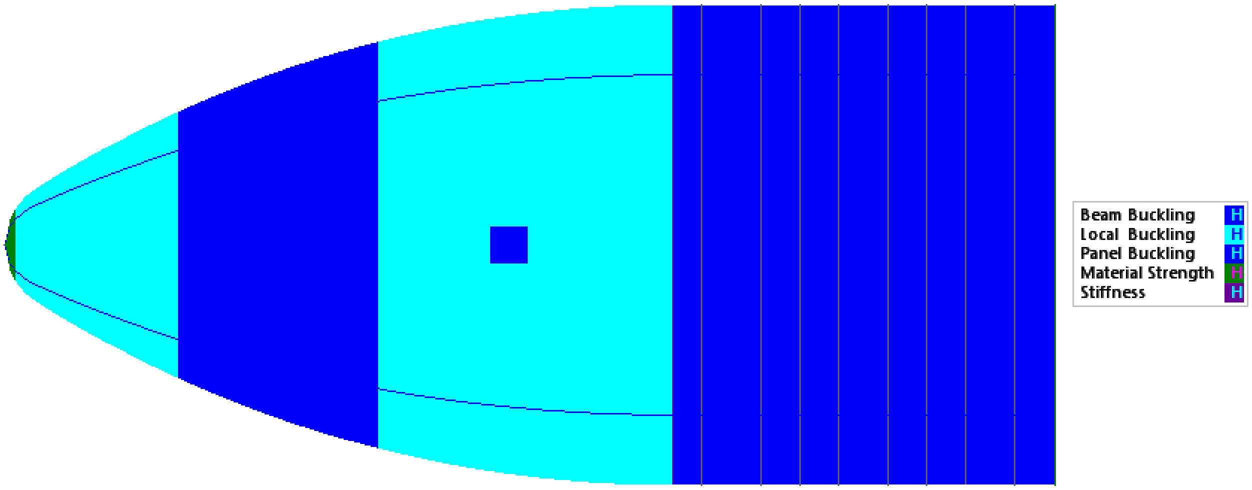


Figure 18.—Hat stiffened/corrugated failure modes.

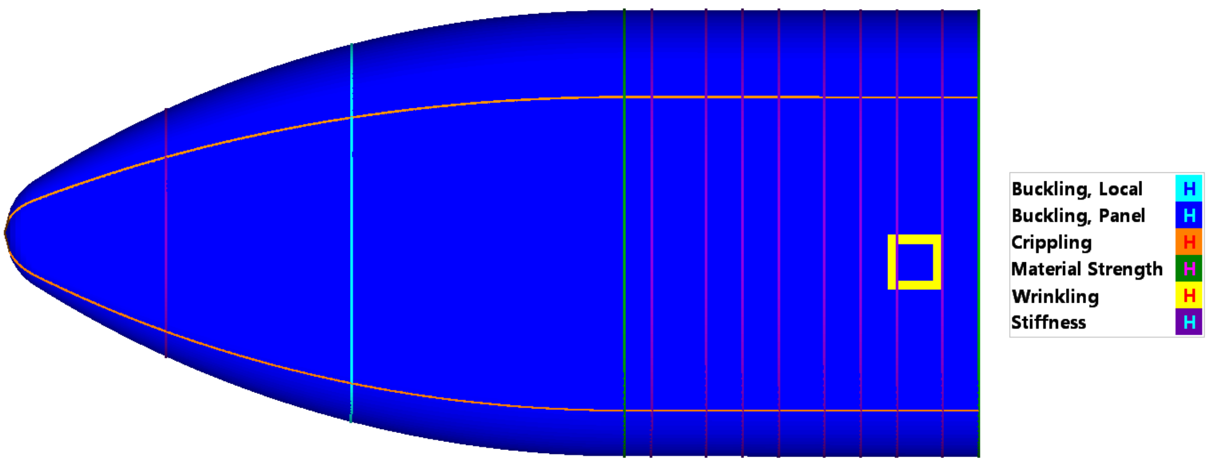


Figure 19.—FRF failure modes.

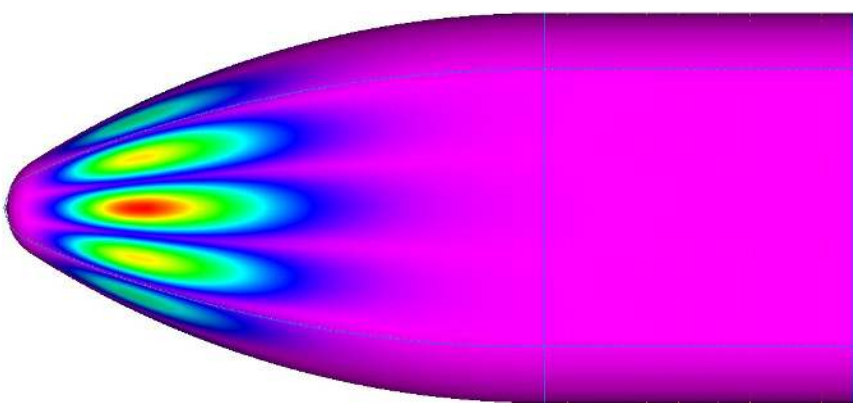


Figure 20.—Hat stiffened/corrugated first buckling mode (Eigenvalue = 2.43).

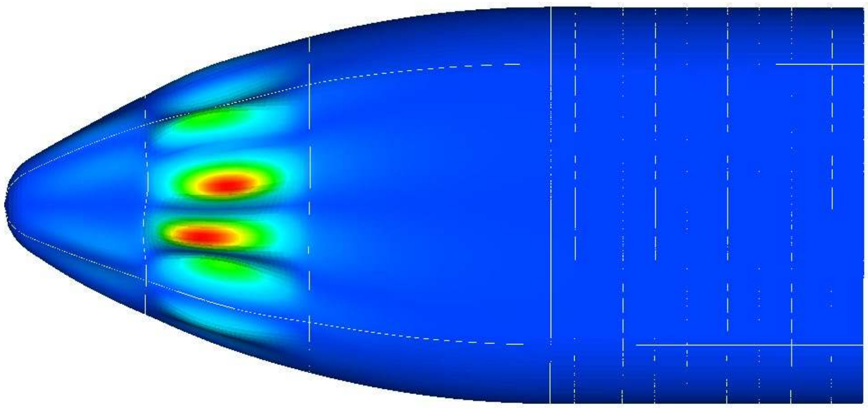


Figure 21.—FRF first buckling mode (Eigenvalue = 2.23).

TABLE 2.—HAT/CORRUGATED PANEL SIZING RESULTS SUMMARY

Component	Area (m^2)	Unit mass (kg/m^2)	Mass (kg)	Lowest MS	Controlling failure mode
Tip	1.99	1.28	2.54	2.539	Composite strength, Tsai-Wu
Ogive fwd	46.48	3.91	181.66	0.02121	Local buckling
Ogive mid	100.06	3.93	393.13	0.08008	Curved panel buckling
Ogive aft	185.99	3.73	694.45	0.0417	Local buckling
Barrel fwd	81.54	2.46	200.71	0.007769	Local buckling
Barrel mid	84.27	2.96	249.52	0.0316	Curved panel buckling
Barrel aft	81.37	3.58	291.48	0.009815	Curved panel buckling
Ogive buildup	0.46	7.70	3.54	0.04347	Curved panel buckling
Barrel fwd buildup	1.19	13.22	15.73	0.001398	Curved panel buckling
Barrel aft big buildup	0.85	13.64	11.59	0.02598	Curved panel buckling
Barrel aft small buildup	1.02	14.49	14.78	0.02739	Curved panel buckling

TABLE 3.—HAT/CORRUGATED BEAM SIZING RESULTS SUMMARY

Component	Length (m)	Unit Mass (kg/m)	Mass (kg)	Lowest MS	Controlling failure mode
Barrel ring frames	252.77	1.68	425.06	0.004364	Stiffness requirement
Barrel/ogive frame	31.61	0.35	10.93	0.01343	Stiffness requirement

TABLE 4.—FRF PANEL SIZING RESULTS SUMMARY

Component	Area (m^2)	Unit mass (kg/m^2)	Mass (kg)	Lowest MS	Controlling failure mode
Tip	1.99	3.114	6.204	0.2339	Curved panel buckling
Ogive fwd	46.48	3.709	172.4	0.1114	Curved panel buckling
Ogive mid	100.06	3.907	390.8	0.11	Curved panel buckling
Ogive aft	185.99	3.709	689.9	0.1291	Curved panel buckling
Barrel fwd	81.54	2.915	237.7	0.1402	Curved panel buckling
Barrel mid	84.27	3.114	262.4	0.1202	Curved panel buckling
Barrel aft	81.37	3.907	318.0	0.08725	Curved panel buckling
Ogive buildup	0.46	3.709	1.718	0.2055	Curved panel buckling
Barrel fwd buildup	1.19	3.114	3.719	0.1666	Curved panel buckling
Barrel aft big buildup	0.85	3.907	3.332	0.2235	Facesheet wrinkling
Barrel aft small buildup	1.02	3.907	3.999	0.1795	Curved panel buckling

TABLE 5.—FRF BEAM SIZING RESULTS SUMMARY

Component	Length (m)	Unit mass (kg/m)	Mass (kg)	Lowest MS	Controlling failure mode
Forward ogive frame	17.49	0.8388	14.67	0.01972	Stiffness requirement
Mid ogive ring frame	26.74	0.7456	19.94	0.00742	Local buckling
Aft ogive ring frame	31.60	0.08563	2.706	0.4286	Composite strength
Barrel ring frames	252.77	0.1304	32.97	1.213	Stiffness requirement
Barrel aft ring frame	31.61	0.08563	2.706	10000	Composite strength

Summary

This paper presents a preliminary design/sizing summary for the Ares V payload shroud. An 8 m high cylindrical barrel with a 33 ft (10.0584 m) diameter and a 14 m high tangent ogive with a 33 ft (10.0584 m) aft diameter was sized using a hat stiffened/corrugated concept and a fiber reinforce foam concept. Sizing using HyperSizer 5.8.11 and linear static analysis using NX NASTRAN and MSC NASTRAN were performed to obtain an optimum shroud design. To preclude buckling in the barrel, circumferential ring frames were added. The total mass of the hat stiffened/corrugated shroud is 2495 kg while the mass of the fiber reinforced foam shroud is 2163 kg, 13 percent lighter than the hat/corrugated design. The hat stiffened construction is very beneficial in the barrel portion of the shroud where the uniaxial loads dominate; however, the FRF construction is more efficient than the relatively heavy corrugated architecture in the ogive section where high biaxial loads are present. The mass of the two concepts is competitive; however, detailed analysis is needed to verify the preliminary mass estimates.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
Aerospace structural applications demand a weight efficient design to perform in a cost effective manner. This is particularly true for launch vehicle structures, where weight is the dominant design driver. The design process typically requires many iterations to ensure that a satisfactory minimum weight has been obtained. Although metallic structures can be weight efficient, composite structures can provide additional weight savings due to their lower density and additional design flexibility. This work presents structural analysis and weight optimization of a composite payload shroud for NASA's Ares V heavy lift vehicle. Two concepts, which were previously determined to be efficient for such a structure are evaluated: a hat stiffened/corrugated panel and a fiber reinforced foam sandwich panel. A composite structural optimization code, HyperSizer, is used to optimize the panel geometry, composite material ply orientations, and sandwich core material. HyperSizer enables an efficient evaluation of thousands of potential designs versus multiple strength and stability-based failure criteria across multiple load cases. HyperSizer sizing process uses a global finite element model to obtain element forces, which are statistically processed to arrive at panel-level design-to loads. These loads are then used to analyze each candidate panel design. A near optimum design is selected as the one with the lowest weight that also provides all positive margins of safety. The stiffness of each newly sized panel or beam component is taken into account in the subsequent finite element analysis. Iteration of analysis/optimization is performed to ensure a converged design. Sizing results for the hat stiffened panel concept and the fiber reinforced foam sandwich concept are presented.

15. SUBJECT TERMS
Structural design; Loads; Fiber composites; Foams; Finite element method; Launch vehicles; Composite structures; Structural analysis; Shrouds; Ares V cargo launch vehicle; Stability; Failure; Panels

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