COMPOSITE INTERSTAGE STRUCTURAL CONCEPT DOWN SELECT PROCESS AND RESULTS

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ABSTRACT

NASA's Advanced Composites Technologies (ACT) project evaluated several composite construction options for the Ares V Interstage to support the Constellation Program's goal of reducing the mass of vehicle dry structures. In Phase 1 of the project, eight candidate construction concepts were evaluated for the Ares V Interstage design. Trade studies were performed using finite element analyses to determine weight estimates for the construction concepts. An evaluation process was then used to down select the construction concepts down to two concepts for further consideration in Phase 2 of the project. In Phase 2 of the project, additional trade studies were performed using detailed finite element analyses of the Interstage and a final down select process was used to choose the recommended Interstage construction concept. The results of the study showed that a honeycomb sandwich design was the most favorable Interstage construction concept based on advantages in manufacturing cost. Details of the Phase 1 and Phase 2 trade studies and down select process with final results are presented in the paper.

1. INTRODUCTION

In 2008, NASA's Exploration Technology Development Program (ETDP) initiated the Advanced Composites Technologies (ACT) Project to support the Constellation Program's goal of reducing vehicle dry structure mass through the use of composite materials (Ref. 1). The objective of the ACT Project was to identify, optimize, and evaluate composite construction technologies for use of the design of the Ares V Heavy Lift Launch Vehicle. A NASA agency-wide team with members from Ames Research Center (ARC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), Kennedy Space Center (KSC), Langley Research Center (LaRC), and Marshall Space Flight Center (MSFC) was assembled to perform structural concept studies for the Ares V Payload Shroud, Interstage, and Core Stage Intertank vehicle components as shown in Figure 1. The team collaborated with engineers from the aerospace industry, including representatives from Boeing, Northrop Grumman, ATK, Lockheed Martin, and Collier Research Corporation.

Each vehicle component had its own unique set of requirements and design drivers. These included inertial, aero, thermal, and acoustic loads as well as operational and other requirements. For the ACT Project, a requirements document was developed with direct linkage to the Ares V vehicle requirements. The ACT Structural Concepts team evaluated several composite structural concepts to assess basic structural performance of the Payload Shroud, Interstage, and Intertank structural components in terms of analytically predicted weight, margins of safety on stresses and buckling, and other structural factors. Objectivity of the process for comparing structural concepts was assured by use of a set of figures of merit based on design considerations to capture considerations for mass, cost, damage tolerance, manufacturability, repairability, inspectability, technological maturity, and the ease of adding secondary attachments. The best two concepts were carried forward for detailed study. A documentation of the studies done for the Payload Shroud and Intertank can be found in Refs. 2-4.

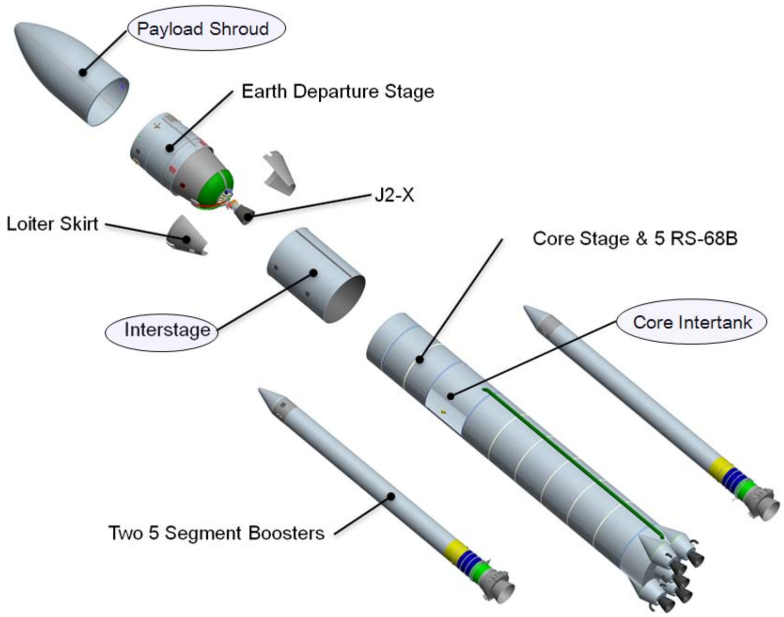

Figure 1 Ares V Launch Vehicle Components.

The ACT Structural Concepts Interstage team was assigned the task of evaluating composite construction options for the Ares V Interstage. In Phase 1 of the project, eight candidate construction concepts were evaluated for the Ares V Interstage design. A structural evaluation process was developed using the trade study results to down select from the initial eight composite construction concepts down to two concepts for further evaluation in Phase 2 of the project. In Phase 2 of the project, additional trade studies were performed and the structural evaluation process was again used to down select to a recommended panel construction concept for the Ares V Interstage. The purpose of this paper is to describe the structural concept down select process and results for the composite Ares V Interstage. The outline of the paper is as follows. Section 2 of the paper describes the Evaluation Criteria used in the down select process. Section 3 describes the trade study process used to determine the construction concept weights. Section 4 presents the trade study and down select results for the Phase 1 and Phase 2 studies. Lastly, Section 5 summarizes the paper.

2. EVALUATION CRITERIA

The success criteria for the ACT Project were defined as meeting mission requirements with demonstrated improvements in Key Performance Parameters (KPPs) over current state-of-the-art technology. The primary KPP for which this study was formulated was the reduction of vehicle dry structure mass. Minimal structural mass on its own, however, cannot be used to determine the best overall structural concept. Other performance requirements need to be considered, and the overall trade space must also include cost, manufacturing, and schedule.

Based on the Interstage requirements, the ACT Project Team put significant effort into defining a complete set of Figures of Merit (FOMs) to encompass the Interstage trade space. This was a collaborative effort between the Structural Concepts Team, the Materials & Manufacturing Team, the Test & Evaluation Team, and industry partners. Importance with respect to the requirements and KPPs, relevance to the structural concepts, influence on operations, and independence with respect to each other were all considered while defining the FOMs. In cases where FOMs were clearly dependent on each other, those FOMs were redefined and combined. Other FOMs that were considered to be unaffected by differences in structural concepts were excluded from the study.

The result was the selection of nine Figures of Merit with weightings that reflect the team's assessment of their importance toward achieving a successful Ares V mission. The FOM design considerations chosen for the Interstage were: Basic Mass, Joint Mass, Non-Recurring Cost (tooling, facilities, fixtures, etc.), Development Cost (cost to increase Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL)), Recurring Cost (cost of materials, labor, fabrication), Damage Tolerance, Non-Destructive Evaluation (NDE) Ability/Inspectability, Repairability (ease of repairing damage due to defects and accidents), and the Ease of Adding Secondary Attachments. A brief description of each figure of merit is included in the paragraphs that follow.

Minimum Basic Mass is a Pro/Engineer Computer-Aided Design (CAD) model mass estimate based on the HyperSizer/Nastran sizing results for the panel acreage and internal ring frames. The mass does not take into account benefits of reduced systems (i.e. TPS or Acoustic Blankets). The concepts with a lower mass receive a higher Basic Mass FOM score.

Minimum Joint Mass is a ranking of the estimated joint mass (longitudinal and circumferential end joints) for each concept based upon recommendations by the Interstage Joints Team). The concepts with a lower mass receive a higher Joint Mass FOM score.

Minimum Non-Recurring Cost is a ranking based upon the one-time costs associated with material property development, autoclave, facilities, tooling, handling fixtures, etc.

Minimum Development Cost (To raise MRL, TRL, etc.) is a ranking based upon the difficulty to raise the Manufacturing Readiness Level (MRL) and Technology Readiness Level (TRL) from current levels to a level of 6.

Minimum Recurring Cost is a ranking based upon the anticipated cost of each panel concept including materials, fabrication labor costs, etc. The manufacturing and assembly for each concept is considered. The concept that lends itself to lower recurring costs receives a higher FOM score.

Damage Tolerance is the ability of a concept to sustain damage during both ground and flight operations without structurally failing. The concepts that can safely incur more damage receive a higher FOM score.

Non-Destructive Evaluation (NDE) ability/Inspection is a rating of how well current techniques can be used to inspect the concept for flaws or damage. The concept that lends itself towards better inspectability receives a higher FOM score.

Repairability is the capability to repair a detected manufacturing flaw or subsequent damage, eliminating the need to remake the composite part. The concepts that can be more easily repaired receive a higher FOM score.

Ease of Adding Penetrations & Secondary Attachments is a ranking based on the level of difficulty to incorporate penetrations such as access doors and vents. The concept that lends itself towards easier additions of penetrations and secondary attachments receives a higher FOM score.

The FOMs were used to rank the composite concept construction technologies for the Ares V Interstage. In order to properly compare the concepts, subject matter experts around the agency with expertise in composite manufacturing, damage tolerance, and non-destructive evaluation and inspection were contacted and asked to provide FOM scores to rank the Interstage construction concepts for each design consideration. Computer-aided design model weights based on sizing results were used for the basic mass and joint mass scores. A weighting factor was multiplied by each FOM score and the totals for each structural concept were ranked. The weighting factors were biased towards performance (mass). The selected FOMs and their relative weightings are shown in Table 1.

Table 1 Ares V Interstage Down Select Figures of Merit.

FOM Design Consideration:	Weighting Factor
Minimum Basic Mass	8
Minimum Joint Mass	1
Minimum Non-Recurring Cost (Tooling, Facilities, fixtures, etc.)	2
Minimum Development Cost (To raise MRL, TRL, etc.)	2
Minimum Recurring Cost	4
Damage Tolerance	3
NDE Ability / Inspectability	2
Repairability (Defects, Accidents, etc.)	3
Ease of Adding Secondary Attachments	1

3. DESCRIPTION OF TRADE STUDY PROCESS

The ACT Structural Concepts Interstage team identified the following eight composite construction technologies (concepts) as appropriate for study as candidates for the Ares V Interstage primary structure. (See Figure 2)

1. Skin / Stringer Stiffened
2. Orthogrid
3. Hat Stiffened
4. Corrugated Sandwich
5. Foam Core Sandwich
6. Honeycomb Sandwich
7. Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS)
8. Fiber Reinforced Foam Core

The trade study process was divided into Phase 1 and Phase 2 efforts. In the Phase 1 effort, preliminary design trade studies were performed on all eight composite construction technologies. Structural sizing of acreage panel concepts was performed using the HyperSizer® (Ref. 5) structural sizing software, in conjunction with MSC Nastran™ (Ref. 6), BOSOR (Ref. 7), and PANDA2 (Ref. 8) analyses for global buckling and strength, to determine the acreage panel concept designs which were used to create CAD models for each panel concept as shown in Figure 3. At the end of the Phase 1 effort, the FOM for each of the panel concepts were scored and ranked. The top two concepts were selected for detailed design, analysis, and sizing in the Phase 2 effort based on the set of figures of merit discussed in the previous section. The two down selected structural concepts for the Ares V Interstage were an aluminum honeycomb panel design with composite facesheets and a composite hat-stiffened skin design. HyperSizer and MSC Nastran were again used in the detailed analyses and sizing in the Phase 2 effort. At the end of the Phase 2 detailed design effort, a down select process was used to choose the most favorable structural concept based on the set of figures of merit. The honeycomb sandwich design was selected as the best concept based largely on advantages in manufacturing and ability for non-destructive evaluation and inspectability. A flow chart of this down select process for the Interstage is shown in Figure 4.

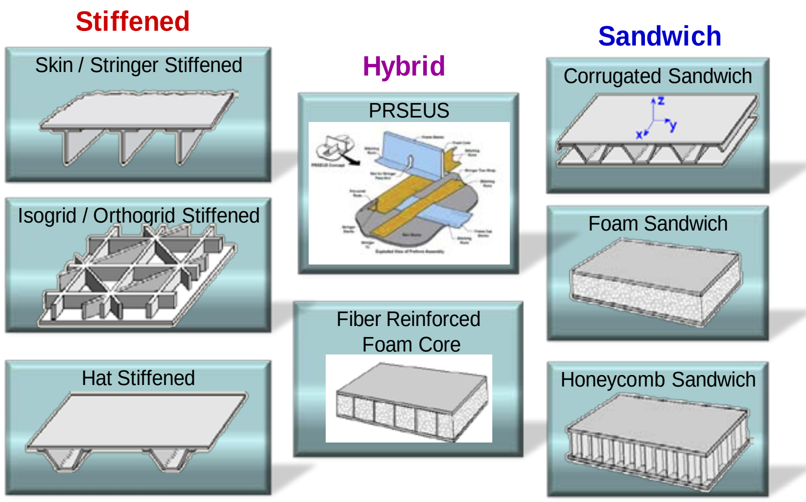

Figure 2 Composite Construction Technologies for Ares V Interstage Primary Structure.

Structural models used in this trade study process were developed with MSC Patran™ (Ref. 9), and analyzed using the MSC Nastran finite element analysis software in conjunction with the HyperSizer structural sizing software. A document for best practices using HyperSizer was used in the project (Ref. 10). In using HyperSizer, the finite element (FE) model is subdivided into several groups of elements, internally referred to as "components", each sharing a common material property set. For each component, the user defines a design space by selecting the beam type (i.e., I-beam, C-beam, T-beam) or panel type (i.e., hat-stiffened, honeycomb sandwich, orthogrid) and sets the upper and lower limits on geometric parameters (i.e., beam height, panel height, facesheet thickness, web spacing) and the number of permutations to consider for each geometric parameter. In addition, the user defines the dimensions and radius of curvature for each panel or beam, and the materials to be considered for each component. HyperSizer interfaces with MSC Nastran in the sizing process by retrieving the finite element analysis (FEA) element forces from the Nastran output file and then using these forces to size each structural component via closed-form methods for a wide range of strength- and stability-based failure criteria. The lightest candidate beam or panel design that has all positive margins for all chosen failure modes in all load cases is then selected as the optimal design. After completion of a sizing analysis, HyperSizer updates material properties in the FE model for components that have changed. The updated model is reanalyzed in Nastran and a new distribution of element forces is obtained. This procedure is repeated multiple times until a user-defined level of convergence for the weight has been achieved. The next section discusses the trade study and down select results of the Phase 1 and Phase 2 trade studies. Additional results can be found in reference 11.

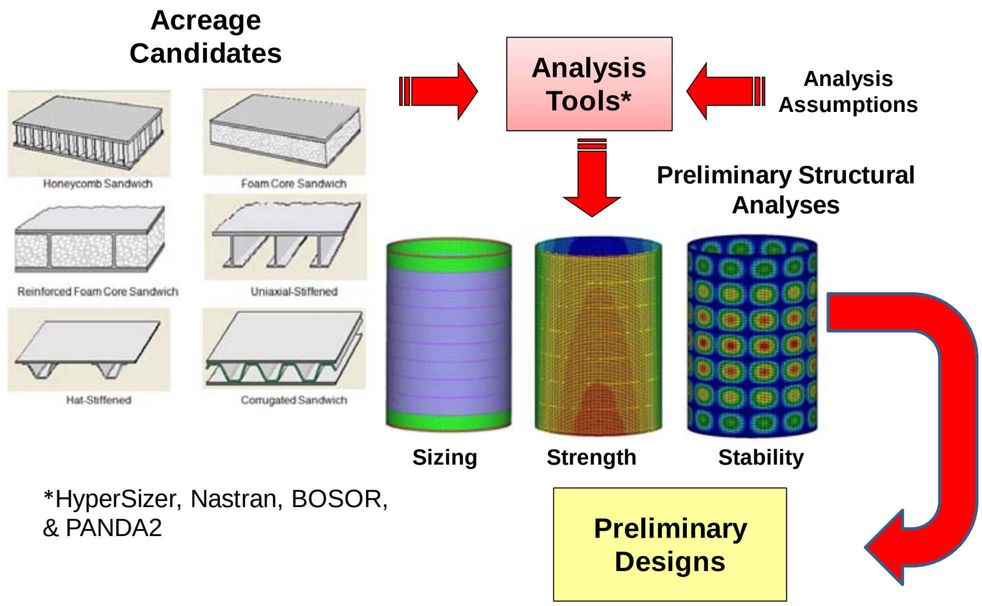

Figure 3 Preliminary Design Trade Study Process.

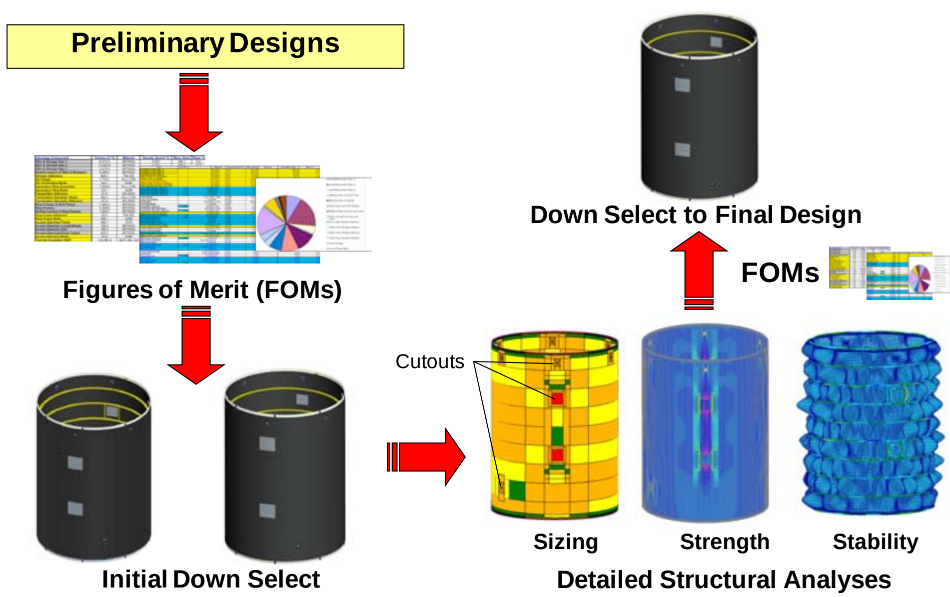

Figure 4 Interstage Down Select Process.

4. TRADE STUDY AND DOWN SELECT RESULTS

4.1 Phase 1 Trade Study and Down Select Results

4.1.1 Finite Element Model, Loading, and Boundary Conditions

In the preliminary design of the Ares V Interstage structure, the geometry of the Interstage was 14.5 m long (47.5 ft) with a diameter of 10.1 m (33.0 ft). A schematic of the initial Interstage design is shown in Figure 5. The preliminary design had no cutouts and included an end ring joint in which the acreage design fit into a clevis on the end ring joint. Multiple FE models were developed with a varying number of internal ring frames (from 1 to 18). A typical model is shown in Figure 6 with 18 internal ring frames The internal ring frame spacing was determined such that the ring frames were symmetric about the center of the Interstage. These models were used to size all Interstage construction concepts. Shell elements were used to model the acreage panels and the end ring joint components as shown in the detailed picture in Figure 6. A single property group was used to size the Interstage acreage. Multiple property groups were used to size the different sections (clevis, taper, and neck) of the end ring joint. Beam elements were used to model the inner ring frames and the flange of the end ring joint. Preliminary studies focused on design of the acreage (panels and inner ring frames) and the end ring joint.

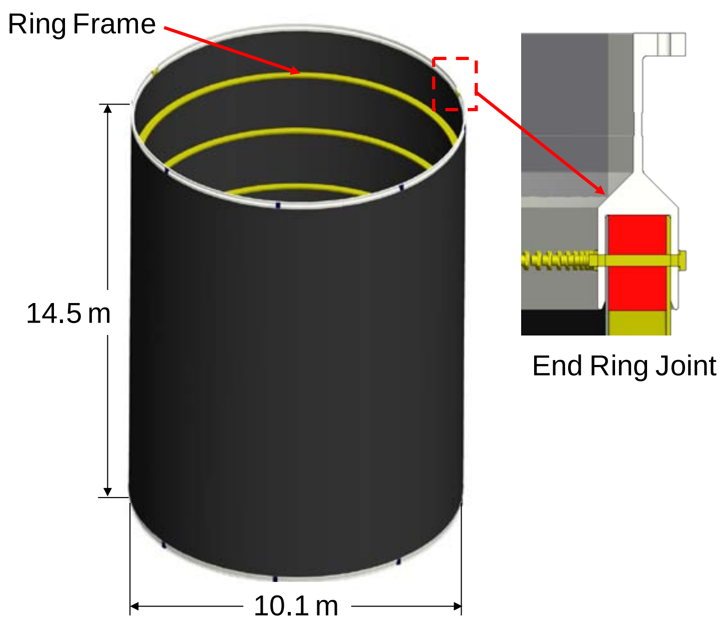

Figure 5 Interstage Preliminary Design.

Three initial load cases corresponding to a maximum dynamic pressure load (max Q) during ascent were used for the preliminary design as listed in Table 2. Two additional load cases (4 & 5) were added later in the preliminary design process. Load introduction extension structures 1.5 m long (60 in) (see Figure 6) were added to the forward and aft ends of the Interstage using a direct matrix input at grid points (DMIG) in Nastran to simulate the boundary conditions of the forward and aft skirt structures attached to the Interstage. The stiffness of the DMIG extension structures was approximately 1.5 times the stiffness of the acreage panels of the Interstage structure to force any buckling failures to occur in the Interstage structure. The max Q loads were applied to the models at the top of the extension structure with a rigid body element (RBE2) at the center of the vehicle using a "wagon-wheel" approach as shown in Figure 6. The axial (z) and tangential (θ) translational degrees of freedom of the bottom nodes of the lower extension structure were constrained using a cylindrical analysis coordinate system.

4.1.2 Materials

Composite material properties were based on IM7/8552 unidirectional carbon/epoxy prepreg tape. Open hole compression allowables were used in the preliminary sizing study for strength-based failure criteria. The IM7/8552 material properties and design allowables are not releasable, but can be found in Ref. 12. Metallic material properties for aluminum lithium alloy 2195-T8 were obtained from the MSFC Handbook 3513. (Ref. 13) For the honeycomb sandwich cores, Hexcel cores (Ref. 14) were used. Due to expected elevated temperatures during flight, material properties at 49°C (120°F) were used.

Table 2 Preliminary Design Loading.

	Max Q Load Case	Mechanical Loading[†]	Pressure Loading
Initial Load Cases	1. Effective Line Load	Uniform compressive axial load	None
	2. Component loading with 34.5 kPa (5 psi) Max. Internal Pressure	Axial load, F_x Shear load, F_y Bending Moment, M_z*	34.5 kPa (5.0 psi) internal pressure
	3. Component Loading with 17.2 kPa (2.5 psi) Crush Pressure	Axial load, F_x Shear load, F_y Bending Moment, M_z*	17.2 kPa (2.5 psi) crush pressure
Additional Load Cases	4. Effective Line Load with 34.5 kPa (5 psi) Max. Internal Pressure	Uniform compressive axial load	34.5 kPa (5.0 psi) internal pressure
	5. Effective Line Load with 17.2 kPa (2.5 psi) Crush Pressure	Uniform compressive axial load	17.2 kPa (2.5 psi) crush pressure

[*] Moment adjusted by subtracting moment due to shear load
[†] Magnitudes of loads are not releasable.

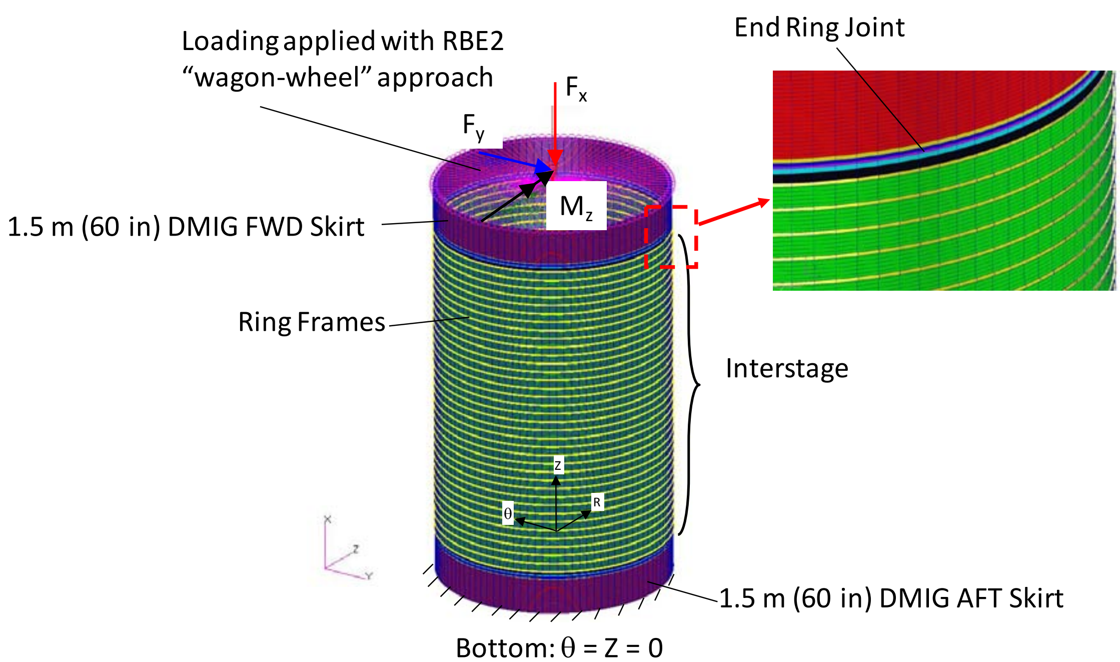

Figure 6 Ares V Preliminary Finite Element Model Loading and Boundary Conditions.

4.1.3 Sizing Methodology

The sizing methodology discussed in Section 3 was used to perform the preliminary design studies for the Phase 1 effort. An ultimate load factor of 1.4 was applied to the design loads listed previously in Table 2 for the acreage composite components according to NASA Standard 5001A (Ref. 15). In addition, a shell buckling knockdown factor of 0.65 was applied during buckling analyses (see Ref. 16). The first global buckling eigenvalue should be higher than 2.15 which is calculated by dividing the 1.4 ultimate factor of safety by the 0.65 shell buckling knockdown factor. Another requirement was that the global buckling had to occur between the ring frames. Because of this, the ring frame stiffness had to be adjusted as needed. The maximum strain failure criterion was used for sizing composite strength failures.

4.1.4 Trade Study and Down Select Results

After the preliminary design sizing analyses were performed in HyperSizer, computer-aided design (CAD) models using Pro-Engineer were developed based on the HyperSizer panel acreage and internal ring frame designs for each of the construction concepts. A down selection process was then performed to rank the designs by a set of figures of merit. The basic mass scores were based on the Pro-Engineer CAD model weights. A summary of the HyperSizer total mass and CAD mass results for all panel concepts except the orthogrid is shown in Table 3. The orthogrid construction concept was eliminated early on in the Phase 1 study due to its higher mass compared to other Interstage panel concepts and difficulties in its manufacturing. The differences in HyperSizer mass results were primarily a result of the sizing process which had a requirement of obtaining positive margins of safety for all failure modes specific to each panel concept. Each panel concept had unique failure modes which were considered in the HyperSizer sizing analyses. The differences in the CAD and HyperSizer mass results were a result of additional hardware (joints and structural systems) that were included in the CAD model, but not included in the FE model. Fastener weights were estimated for all panel concepts and considered in the joint mass scores. Subject matter experts around the agency ranked the other FOM design considerations and provided the scores in Table 4. The design considerations denoted by an asterisk in the table had their scores scaled based on minimum and maximum values. The other scores ranged from a minimum score of 1 to a maximum score of 9. The highest FOM scores for each design consideration are shaded in green. The top Interstage panel concepts were the honeycomb sandwich closely followed closely by the hat-stiffened panel concept as highlighted in bold. The honeycomb sandwich panel concept had the highest FOM ranking based on development costs, non-recurring costs, recurring costs, and ability for non-destructive evaluation. The hat-stiffened panel concept had the overall lowest mass. These concepts were considered for detailed sizing in Phase 2 of the project.

Table 3 Phase 1 Down Select Construction Concept Mass Results.

Interstage Construction Concept	HyperSizer Total Mass, kg (lbm)	CAD Mass, kg (lbm)
Skin/Stringer Stiffened	5,422 (11,954)	5,691 (12,547)
Hat-Stiffened	4,217 (9,297)	5,075 (11,188)
Corrugated Sandwich	4,959 (10,933)	5,479 (12,079)
Foam Core Sandwich	5,038 (11,106)	6,679 (14,725)
Honeycomb Sandwich	4,583 (10,103)	5,532 (12,195)
PRSEUS	5,219 (11,507)	5,861 (12,921)
FRF Core	4,445 (9,800)	5,318 (11,724)

Table 4 Interstage Phase 1 Down Select FOM Results.

Design Considerations	Weighting Factor	Skin/Internal Stringer	Hat Stiffened External Stringer	Corrugated Sandwich	Honeycomb Sandwich	Foam sandwich	Fiber Reinforced Foam Sandwich	PRSEUS
Minimum Basic Mass*	8	5.9	9.0	7.0	6.7	1.0	7.8	5.1
Minimum Joint Mass	1	8.0	8.0	5.0	5.0	5.0	5.0	5.0
Minimum. Non-Recurring Cost (Tooling, Facilities, fixtures, etc.)*	2	3.0	3.0	3.0	7.0	5.0	5.0	5.0
Minimal Development Cost (To raise MRL, TRL, etc.)*	2	5.7	5.7	4.3	7.0	7.0	3.0	3.0
Minimum Recurring Cost*	4	4.3	4.3	5.7	7.0	7.0	5.7	3.0
Damage Tolerance	3	5.0	6.0	4.5	4.5	4.5	6.0	5.0
NDE Ability / Inspection	2	6.0	5.0	2.0	9.0	8.0	3.0	3.0
Repairability (Defects, Accidents, etc.)	3	5.0	5.0	4.0	6.0	6.0	4.0	3.0
Ease of Adding Penetrations & Secondary Attachments	1	9.0	9.0	1.0	5.0	1.0	5.0	5.0
Total Figures of Merit (FOM)		141.1	**166.7**	128.7	**169.3**	113.5	147.0	108.6

4.2 Phase 2 Trade Study and Down Select Results

4.2.1 Finite Element Model, Loading, and Boundary Conditions

In the detailed design of the Ares V Interstage structure, the length of the Interstage was shortened slightly under the direction of the Constellation Program to 13.6 m long (44.6 ft), while retaining the 10.1 m (33.0 ft) diameter. The detailed model for the hat-stiffened design, shown in Figure 7, included four doors (0.9 m x 0.9 m (36 in x 36 in) in size and located 180° apart) for access to the Interstage during manufacturing and vehicle assembly, six vent holes, and one Environmental Control System (ECS) port. Longerons running between the ring frames were placed on both sides of the doors to distribute the loads efficiently around the doors. Three FE models were created for the detailed Interstage design based on the results of the preliminary design study. Two models were developed for the honeycomb sandwich design with internal ring frame spacings of 2.0 m (78 in) for a 6 ring frame model and 3.4 m (134 in) for a 3 ring frame model. The model for the 6 ring frame honeycomb sandwich design is shown in Figure 8. The main difference in the detailed design model compared to the preliminary design model was the addition of the cutouts (doors, vents, and ECS port). In addition, multiple property groups as shown as different colors in Figure 8 were used to size the Interstage acreage and pad-up regions around the cutouts. A similar model was developed for the hat-stiffened design which had 8 ring frames with a spacing of 1.5 m (60 in).

The load cases used in the detailed design were also updated after the preliminary design. The updated loads corresponding to a maximum dynamic pressure load at an angle of attack, α, (max Q-alpha) during ascent are listed in Table 5. Additional load cases were added for the component load cases because the mechanical loads were clocked at 45 degree intervals so that all components of the Interstage would see similar loads. The updated component loads for the detailed design caused the effective line load to increase by nearly 17% from the loads used in the preliminary design. Load introduction extension structures were again added to the forward and aft ends of the Interstage using a DMIG in Nastran to better simulate the boundary conditions of the forward and aft skirt structures attached to the Interstage. The max Q-alpha loads were applied to the model at the top of the extension structure using a RBE2 element using a "wagon-wheel" approach. The bottom nodes of the extension structure were constrained axially (z) and in torsion (θ) using a cylindrical analysis coordinate system.

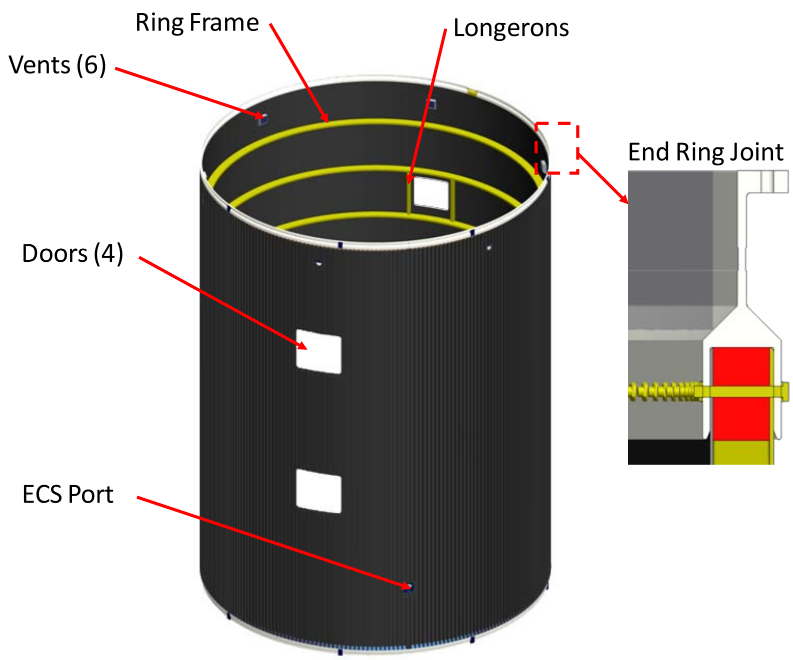

Figure 7 Ares V Interstage Detailed Design.

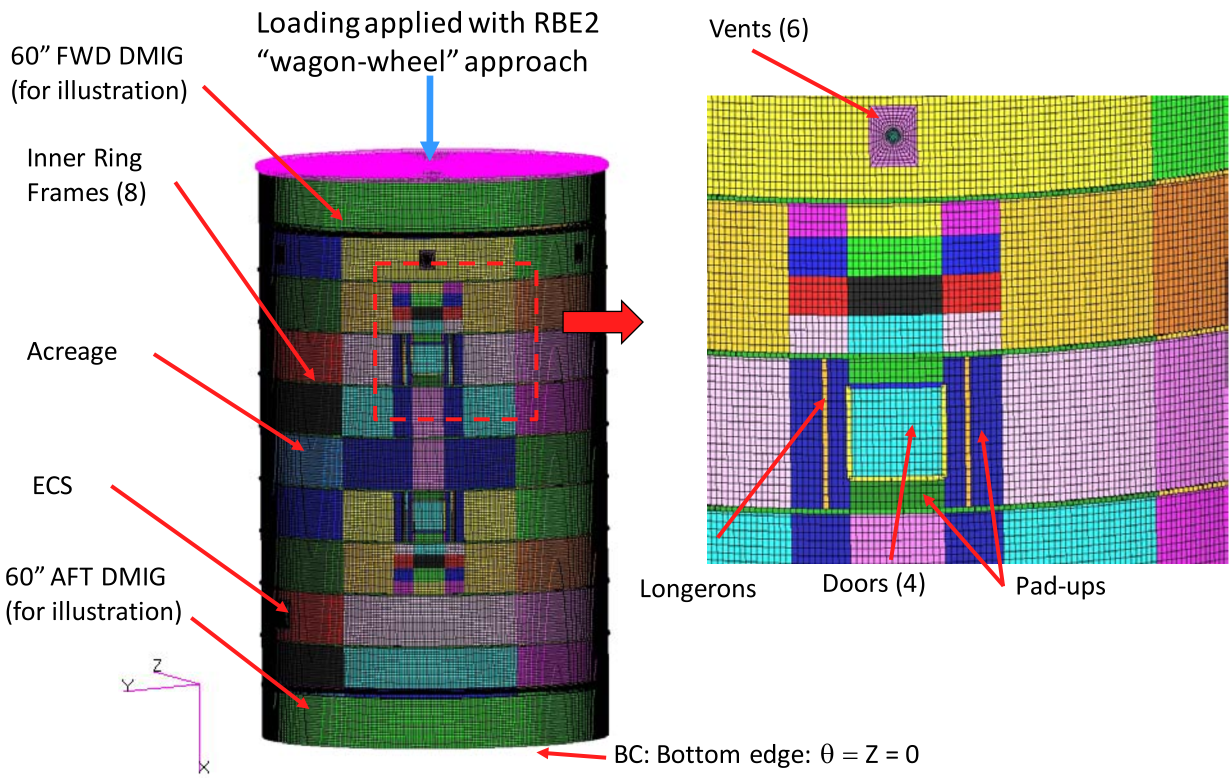

Figure 8 Honeycomb Sandwich 6-Ring Frame Interstage Detailed Finite Element Model.

Table 5 Detailed Design Loading.

Load Case #	Max Q-alpha Load Case	Mechanical Loading†	Pressure Loading
1.	Effective Line Load	Uniform compressive axial load	None
2.	Effective Line Load with 34.5 kPa (5 psi) Max. Internal Pressure	Uniform compressive axial load	34.5 kPa (5.0 psi) internal pressure
3.	Effective Line Load with 17.2 kPa (2.5 psi) Max. Internal Pressure	Uniform compressive axial load	17.2 kPa (2.5 psi) crush pressure
4.-11.	Component loading with 34.5 kPa (5 psi) Max. Internal Pressure	Axial load, F_x Shear load, F_y Moment, M_z*	34.5 kPa (5.0 psi) internal pressure
12.-19.	Effective Line Load with 17.2 kPa (2.5 psi) Crush Pressure	Axial load, F_x Shear load, F_y Moment, M_z*	17.2 kPa (2.5 psi) crush pressure

* Moment adjusted by subtracting moment due to shear load
† Magnitudes of loads are not releasable.

4.2.2 Materials

The same composite material properties and allowables for the IM7/8552 unidirectional carbon/epoxy prepreg tape were used in the detailed design study. Again, metallic material properties for the end ring joint were those of the aluminum lithium alloy 2195-T8. Due to expected elevated temperatures during flight, material properties at 49°C (120°F) were again used.

4.2.3 Sizing Methodology

The design methodology discussed earlier using HyperSizer and Nastran was used to design and size the Ares V Interstage in the detailed design phase of the ACT Project. Again, an ultimate load factor of 1.4 was applied to the design loads in Table 5 along with a shell buckling knockdown factor of 0.65. The maximum strain failure criterion was used for the composite strength-based failure modes.

4.2.4 Trade Study and Down Select Results

After the detailed sizing analyses were performed on the composite hat-stiffened Interstage and honeycomb sandwich Interstage designs, a down selection process was again performed to rank the designs by the set of figures of merit. The details of the design studies were documented in Ref. 11. The rankings for all design considerations were the same as the Phase 1 results presented in Table 4 except for the basic mass ranking. The detailed design mass comparison based on the HyperSizer results for the two designs is presented in Table 6. The FOM scores are listed in Table 7. The basic mass scores were determined from the total mass of only the two down selected structural concepts from the detailed sizing results performed using HyperSizer. The score for the honeycomb sandwich basic mass was reduced by the percent difference in mass from the hat-stiffened design. Fastener weights were estimated for both designs and were considered in the joint mass scores. Again, the honeycomb sandwich panel concept had the highest FOM ranking based on development costs, non-recurring costs, recurring costs, and ability for NDE. The hat-stiffened panel concept still had a lower mass.

Table 6 Ares V Interstage Detailed Design Mass Summary.

Interstage Construction Concept	HyperSizer Total Mass, kg (lbm)
Hat-Stiffened	4,425 (9,756)
Honeycomb Sandwich	5,144 (11,341)

Table 7 Ares V Interstage Detailed Design Figures of Merit.

Design Considerations	Weighting Factor	Hat Stiffened External Stringer	Honeycomb Sandwich
Minimum Basic Mass	8	9.0	7.7
Minimum Joint Mass	1	8.0	5.0
Minimum. Non-Recurring Cost (Tooling, Facilities, fixtures, etc.)	2	3.0	7.0
Minimal Development Cost (To raise MRL, TRL, etc.)	2	5.7	7.0
Minimum Recurring Cost	4	4.3	7.0
Damage Tolerance	3	6.0	4.5
NDE Ability / Inspection	2	5.0	9.0
Repairability (Defects, Accidents, etc.)	3	5.0	6.0
Ease of Adding Penetrations & Secondary Attachments	1	9.0	5.0
Total Figures of Merit (FOM)		166.7	**177.7**

5. SUMMARY

NASA's Advanced Composites Technologies (ACT) project evaluated several composite construction options for the Ares V Interstage as identified by the Constellation Program to support a manned lunar mission via mass reduction of vehicle dry structures. In Phase 1 of the project, eight candidate construction concepts were evaluated for the composite Ares V Interstage design. Finite element models were developed based on Ares V vehicle configuration and sizing analyses were performed on all construction concepts using MSC Nastran and HyperSizer to determine their structural masses. Detailed descriptions of the concepts were relayed to subject matter experts, who evaluated the concepts and provided Figures of Merit scoring for design considerations such as technology readiness level, cost, manufacturing, damage tolerance, and inspectability. The FOMs were then given weighting factors based on their relative importance. The sizing results and FOM scoring were used to down select from the eight concepts down to two concepts for further evaluation for the Ares V Interstage in Phase 2 of the project. The honeycomb sandwich and hat-stiffened panel concepts were selected for the Interstage detailed design and analysis studies in Phase 2 based on the FOM scoring.

In Phase 2 of the project, detailed finite element models were generated for the two candidate panel concepts based on an updated Ares V Interstage configuration. These finite element models were used to perform Nastran and HyperSizer analyses to size and generate mass estimates for the two down selected Interstate concepts. Again, subject matter experts evaluated the two candidate panel concepts and provided FOM scoring for various design considerations. The sizing results which provided the mass for the two candidate concepts and the FOM scoring were use to down select the recommended design panel concept for the Interstage. The honeycomb sandwich was selected as the recommended design for the composite Interstage design based on FOM scoring, largely due to advantages in manufacturing and ability for non-destructive evaluation and inspectability. Although the Constellation Program was cancelled, the down select process outlined in this paper and recommended panel concepts chosen for the Interstage structure should be considered in the development of a future heavy lift launch vehicle.

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