NASA/TM-2009-215793

Shuttle Orbiter-like Cargo Carrier on Crew Launch Vehicle

Zoran N. Martinovic
Langley Research Center, Hampton, Virginia

September 2009

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at 443-757-5803

- Phone the NASA STI Help Desk at 443-757-5802

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076-1320

NASA/TM-2009-215793

Shuttle Orbiter-like Cargo Carrier on Crew Launch Vehicle

Zoran N. Martinovic
Langley Research Center, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

September 2009

Trade names and trademarks are used in this report for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
443-757-5802

Content

List of figures

List of Tables

Abstract

The following document summarizes the results of a conceptual design study for which the goal was to investigate the possibility of using a crew launch vehicle to deliver the remaining International Space Station elements should the Space Shuttle orbiter not be available to complete that task. Conceptual designs and structural weight estimates for two designs are presented. A previously developed systematic approach that was based on finite-element analysis and structural sizing was used to estimate growth of structural weight from analytical to "as built" conditions.

Introduction

The objective of this study is to design primary structure and determine structural analytical weight for a Space Shuttle orbiter-like cargo carrier concept that was defined before the Exploration Systems Architecture Study (ESAS) (ref. 1). The carrier would be required to fly attached to the top of a crew launch vehicle and would be used to transport from Earth to the International Space Station (ISS) any remaining Station elements if the Shuttle orbiter were for some reason unavailable to perform that function. The Space Station elements would fit in an orbiter-like payload accommodation environment, and no modifications to existing payload hardware would be required. This study assumes that some type of interface would be required, such as a service module and docking adapter, but does not address their designs or weights.

A process for rapid structural design and weight estimation is applied, and two designs are evaluated. This process is based on finite element analysis and sizing of the vehicle with commercially available codes. A review of the structural weight for the Shuttle orbiter is made, and its findings are used to define non-optimal structural weight.

Objective and general requirements

During the period when the Space Shuttle fleet was grounded as a result of the loss of *Columbia* and while NASA's Exploration Systems space program was in the early phase of architecture definition, a limited study was carried out at NASA Langley Research Center's Systems Analysis and Concepts Directorate. The scope of that study was to evaluate the structural weight of a possible replacement for the orbiter, which would be integrated with a new launch vehicle. The crew launch vehicle, or CLV, was the initial launch vehicle, which has since come to be known as the Ares I element of NASA's Constellation Program system architecture.

The objective of this study was to define the structural design and find the optimum weight of a vehicle that would be integrated onto the top of the vertically launched CLV and serve to transport the remaining elements to the ISS until its completion.

*Presented in part at the Finite Element Modeling Continuous Improvement (FEMCI) Workshop at NASA Goddard Space Flight Center, MD, October 2006.

The new cargo vehicle was required to offer the same accommodation for payload elements as the Shuttle orbiter: 15 ft of inner diameter, 49.8 ft of length, and 55,000 lb of payload capacity. No requirements for modification of the remaining Space Station elements were imposed.

Vehicle size and configuration

Figure 1 shows the overall dimensions of the vehicle. The length of the cargo bay equals the useful length of the orbiter payload bay as configured with an ISS external airlock and orbiter docking structure. The outer diameter of the vehicle is 18 ft and equals the diameter of what would be the second stage of the CLV. An interface with the service module is 2 ft long, and the length of the nose cone is 16.7 ft.

In addition to the payload bearing structure, the carrier has a single door, which is not shown on the figure. The door shrouds the cargo from aerodynamic forces and is ejected when the vehicle reaches Space. This door is not structurally designed to meet general fuselage bending and shears loads.

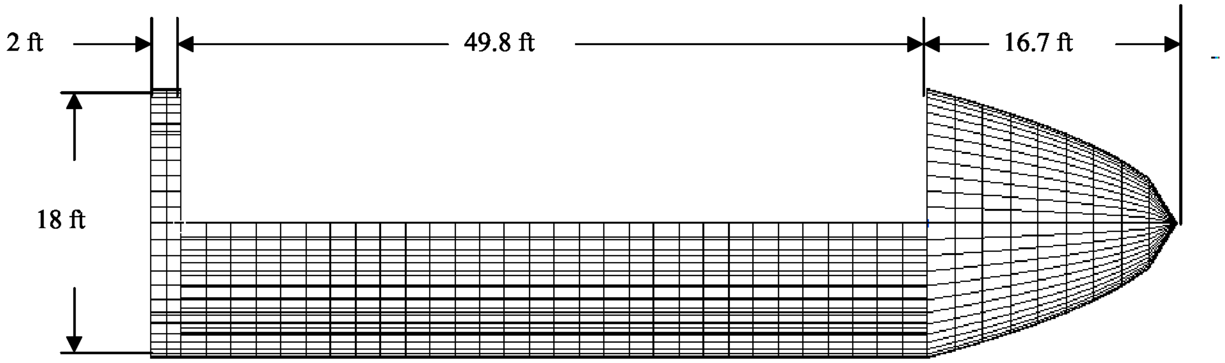


Figure 1. General dimensions of the cargo carrier.

Design process

A general outline of the process that is used to estimate the structural weight during the conceptual design of new design vehicles is presented (see figure 2). This process is based on finite element analysis (FEA) and sizing of the vehicle by the use of commercially available codes (ref. 2). Interaction between these codes has been facilitated through the integration and use of in-house-developed programs to reduce the effort of the designer.

The process begins with the collection of relevant data (e.g. information about geometric configuration and structural arrangement, and additional design information including knowledge of subsystem masses) which is used in the load-definition process. An in-house-developed finite element model (FEM) mesh-generating program LOFT (unpublished, Lloyd Eldred) is used to parameterize the vehicle geometry and group the mesh into vehicle structural panels and beams. LOFT output is finite element model definition which is loaded into the Unigraphics Solution Inc./I-Deas® (ref. 3) commercial computer engineering analysis (CEA) program, where preliminary values of structural mass and stiffness are introduced. The external loads are modeled, and the FEM is analyzed for different load cases. The results of each load case that is run (in form of running loads or line loads) and the FEM geometry are imported to another commercial software application from Collier Research called HyperSizer® (ref. 4). The FEM element property definitions are changed in HyperSizer to accommodate applied loadings. The elements are also hierarchically grouped in HyperSizer. Elements of common construction type, materials, and design-variable limits are grouped together to facilitate the definition of the required input design criteria. This grouping is facilitated again through the use of an in-house-developed computer program – HSLoad (unpublished, Lloyd Eldred) and through the automated application of the HyperSizer group design templates. HyperSizer is a structural-component design and analysis program that sizes each of the panels/beams to a minimum weight within a predefined design-variable range. The newly sized vehicle will have updated structural mass and stiffness that are representative of the sizing changes that are required to satisfy the margins of safety for multiple FEM-defined load cases. The updated FEM is imported to I-Deas to resolve the inconsistencies between the FEM input and the resized panel and beam geometry. Several iterations between this analysis and sizing process are necessary to arrive at a converged stiffness-to-internal-load-distribution design state.

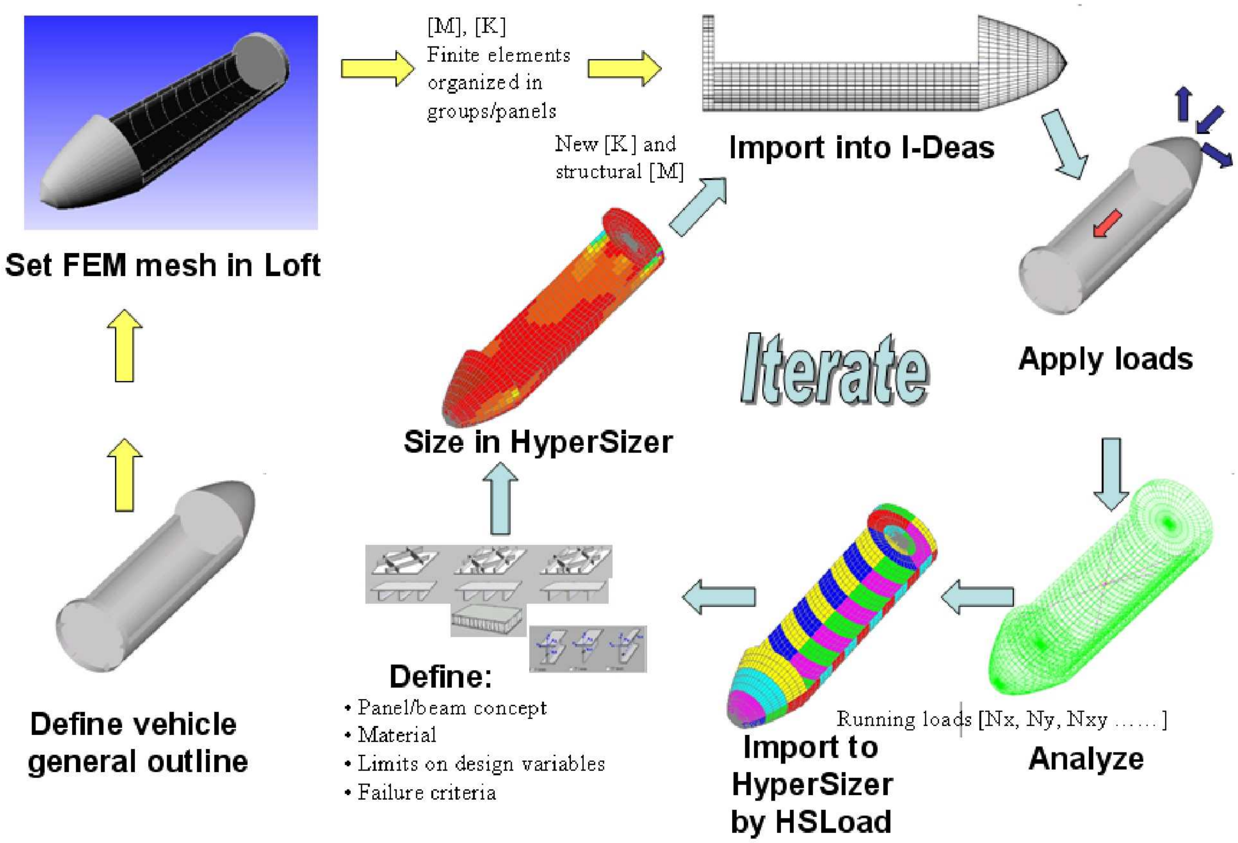


Figure 2. Outline of the design process.

Structural requirements

Payload attachments in the cargo bay were required to be identical to those of the existing orbiter and were required to be statically determinate (ref. 5), see figure 3. The safety factor, which is defined as the ratio between the ultimate and the applied load, was equal to 1.5, and the limit load was equal to the applied load. The margin of safety for any component is required to be greater or equal to zero. In the buckling analysis, no reduction was taken for the knockdown factor for plates and columns. The added weights for drilled holes in stiffeners and panels and for taper, filets, or cutouts were not taken into account.

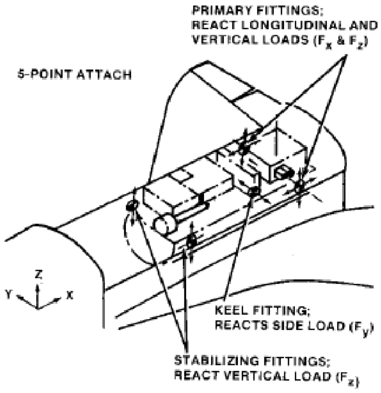


Figure 3. Definitions of five attach points on the Shuttle orbiter.

Finite-element model

The finite-element model consisted of quadrilateral and triangular shell elements and linear beam elements. The 55,000 lb payload weight was modeled as a lump mass with the inertia properties of a 500 in long cylinder with a diameter of 168 in. The mass located at the middle of the cargo bay and was rigidly connected to two primary and three stabilizing fittings, as shown in figure 4.

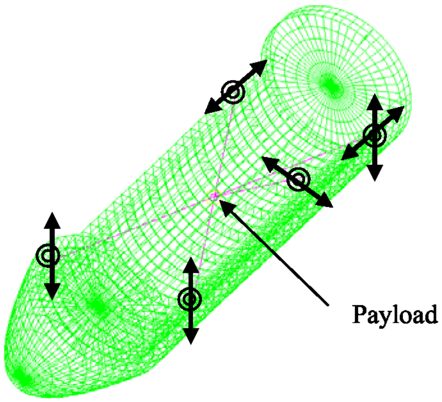


Figure 4. Model of the payload attachment to the cargo carrier.

Loads and vehicle interface

The inertia and aerodynamic loadings were the design loads used in this study.

The inertial loads result from the accelerations to which the vehicle is subjected during ascent. The axial acceleration was equal to 4 g, where g equals Earth's gravitational acceleration, and acts along the longitudinal axis of the vehicle. A lateral acceleration of 1 g was applied normal to the longitudinal axis of the vehicle. The 1.41 g was the combined lateral acceleration.

A dynamic pressure of 850 lb/ft^2 was used to define the aerodynamic loads. Aerodynamic coefficients were selected for a vehicle speed greater than Mach 2 and for an angle of attack equal to 1 deg (ref. 6). The drag coefficient C_D was equal to 0.05, and the lift coefficient C_L had a value of either 0.01 or 0.014. The aerodynamic loads were applied to the nose cone and cargo doors.

Both inertial and aerodynamic loads were combined in six load cases (see figure 5).

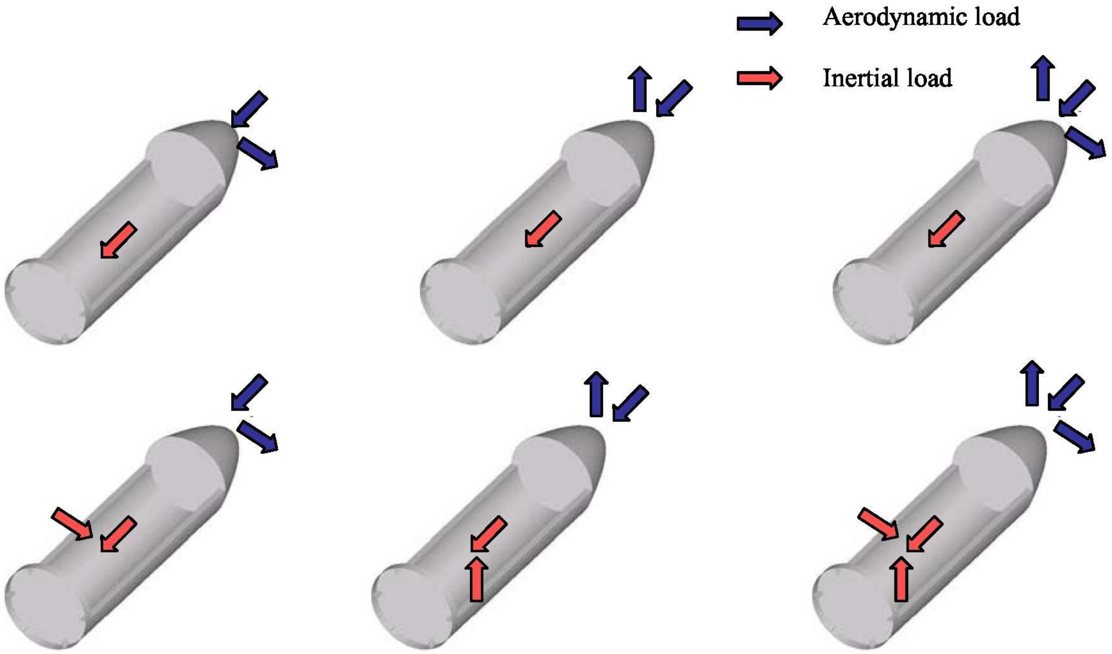


Figure 5. Six load cases.

Six ball joints, which transfer forces and offer no resistance to moments and torques (see figure 6), model the vehicle interface requirements with the CLV/service module. Ball joints were located circumferentially 60° apart at six major load-carrying longerons.

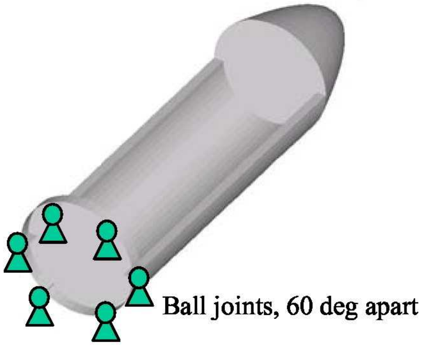
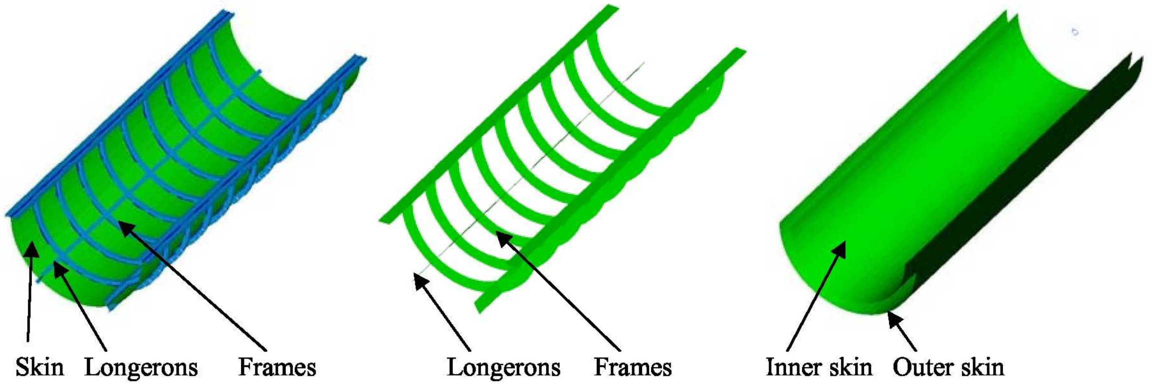


Figure 6. Cargo carrier interface.

Structural design

Two designs that were considered are shown in figure 7. The open-wall design consists of skin that is stiffened with stringers, four longerons, and frames. The closed-wall design has an additional inner skin that, together with the outer skin, longerons, and frames constitutes a series of closed structural cells. The second design (closed-wall) would be more resistant to torque loads which are a consideration because the vehicle has a large door opening.



a) Open-wall design.

b) Closed-wall design.

Figure 7. Open- and closed-wall designs.

Figure 8 shows the cargo door design. The door consists of stiffened skin, two longerons, and four frames.

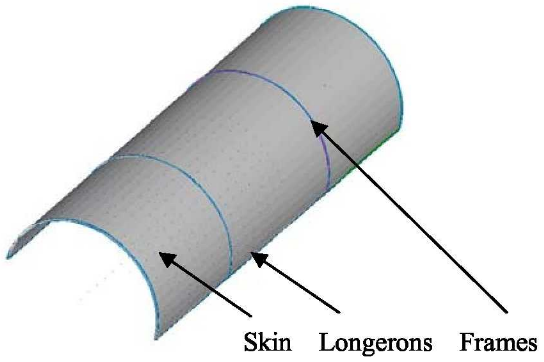


Figure 8. Cargo door.

Open-wall design

An analytical study was done on a representative curved aluminum panel that was axially loaded by 1,500 lb/in of compressive ultimate running load (ref. 7). The results of the study showed that honeycomb panels offered the least weight for the same amount of loading compared with uni-axially stiffened, corrugated, or isogrid panels. These results were used to guide further design.

The open-wall design (see figure 9) has a skin that is stiffened with riveted I-profile stringers. The I-profile beams are used to model longitudinal longerons and the ring and semi-ring frames. The material for the skin and the stringers is aluminum Al 2024-T3, and the frames and longerons are made of Al 7075-T6. Two isogrid bulkheads close the cargo bay and are made of Al 2024-T3. The nose cone is a sandwich structure and has Al 2024-T3 face sheets and Hexcel 1/8-5052-.0015 honeycomb core.

The optimization process determines the design-variable values for the thickness and spacing between stringers and for the skin thickness as required to reach a minimum weight design. Variables were also used for beam sizes and thicknesses, sandwich panel face sheet and core thicknesses, and isogrid sizes and thicknesses.

Spacing between the frames was constant and equal to 59.8 in. The longerons were located circumferentially 60° apart.

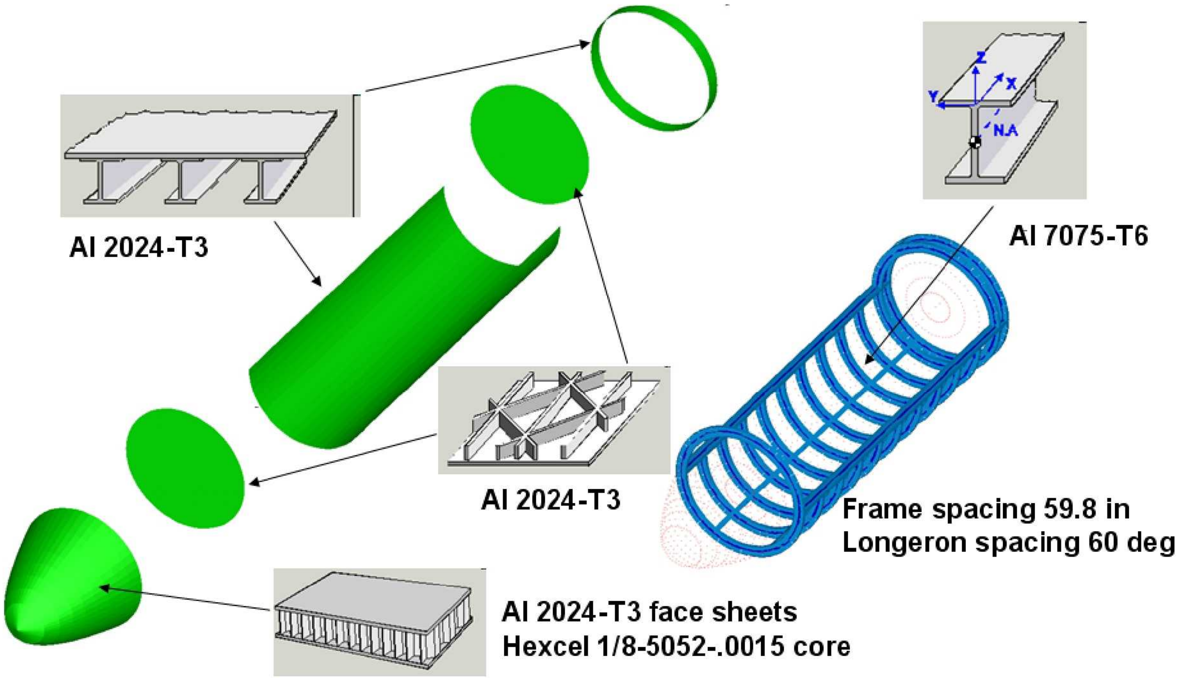


Figure 9. Open-wall design.

Figure 10 shows the division of the vehicle structure into panels that were optimized for minimum weight in several iterations between the structural-analysis program I-Deas and the structural-sizing program – HyperSizer.

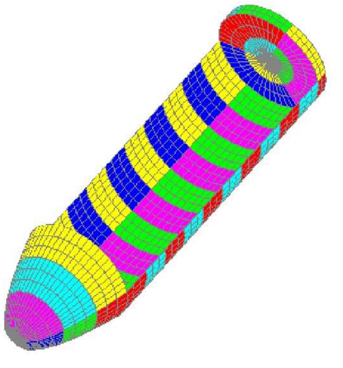


Figure 10. Vehicle divided into structural panels.

The sizing process produced the optimum panel and beam shapes, in addition to the thickness and stiffener sizes for different parts of the vehicle that satisfy all margins of safety. The process stopped when the weight converged after two successive iterations. The resulting weights following each iteration of structural optimization are given in table 1.

Note that all designs in table 1 are feasible designs for a given load magnitude and distribution. Vehicle mass and mass distribution will change during iteration. Therefore it is necessary to update the inertial load in the next iteration in FEA and do another vehicle sizing in HyperSizer. Next it is necessary to check for vehicle weight convergence. Inertial loads will stop changing when the design, hence the mass, stop changing. The definition of the load/weight convergence depends on the designer's established goal and in this study was between 1% and 2% between successive iterations.

Table 1. Structural Weight of the Open-Wall Design

Iteration number	Weight (lb)
1	12,408
2	13,671
3	15,104
4	14,944
5	15,307
6	15,042

A breakdown of the total structural weight at iteration 5 shows that the panels account for 5,333 lb and all of the beam elements account for the remaining 9,973 lb. In the sixth iteration design, the panel weight is 4,742 lb and the beam weight is 10,300 lb. These results indicate that the optimizer "favored" strengthening the longerons and frames at the expense of the stiffened skin. This result is not surprising because the open-wall design must withstand large fuselage section loads because of the large cargo bay opening. Therefore, the optimization process emphasized the load-carrying capability of the frames and longerons over the stiffened skin. There are several reasons why weight in table 1 varies between higher and lower values as it progresses through iterations. HyperSizer is a sizing program and not a formal optimizer. The user specifies bounds and a discrete set of values for each design variable. The program performs a scan through the variable permutations to find the lowest weight combination that has a positive margin of safety. This discrete approach may respond to small changes in element loads from iteration to iteration with large changes in the design. For instance, a main load path may shift from one longeron to another. Therefore, there may have been inconsistencies in careful selection of upper and lower bounds, as well as the intermediate values, of designs between successive iterations. It was obvious from the beginning that the Open-Wall Design was not weight efficient and therefore caused variations in the design topology in successive iterations as illustrated by the results of the 5th and 6th iteration. This could be exacerbated by the fact that the structural problem poised is inherently non-linear. A substantial portion of the element loading comes from the inertial loads. Iteration is required to produce a sizing result that that will support the inertial loads resulting from its own mass. An iterative feedback loop of heavier loads causing heavier structure and visa verse can tend to cause large oscillations, and even divergence, in the iteration history.

Closed-wall design

The objective that led to the closed-wall design (see figure 11) was to design a closed-wall box that consisted of a number of cells that were formed by stiffened skin, longerons, and frames. This design would be more resistant to fuselage section torques and bending moments.

The new design frames and longerons were modeled with separated sandwich webs (FEM shell elements) and extruded caps (FEM beam elements). The caps had two different cross sections (J and T). Only the ring frame at the interface with the CLV/Service Module was modeled with strong extruded I-beam elements. All of the beam elements were made of Al 7075-T6. A new inner skin was added to the design to help build a closed-box structure; this inner skin was made of aluminum honeycomb panels. The remaining structure had the same features as the open-wall design.

Table 2 lists the changes in the structural weight of the closed-wall design during the optimization process. After the fourth iteration, convergence in weight was achieved, and the final structural weight was 8,171 lb. This represented a 47-percent reduction in weight over the open-wall design. Of the total weight, the panels weighed 6,675 lb, and the beams weighed only 1,496 lb. The increase in the skin weight, the significant decrease in the longeron and frame weights, as well as the 47-percent reduction in total weight over the earlier design indicates that the closed-wall design is a more efficient structural design.

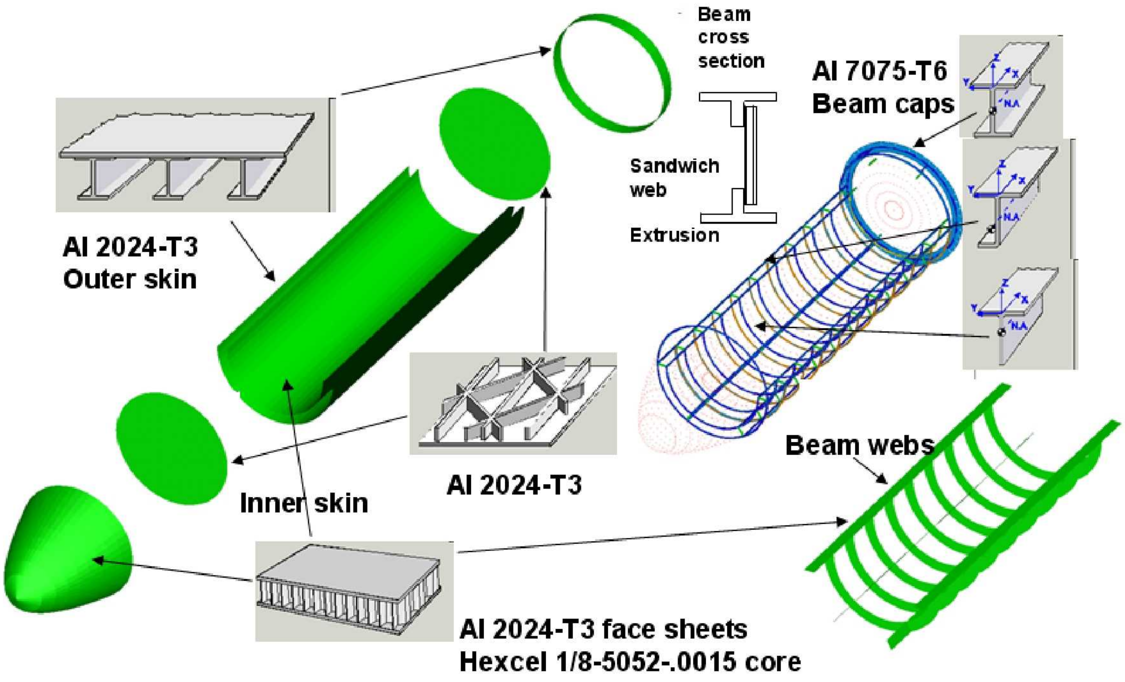


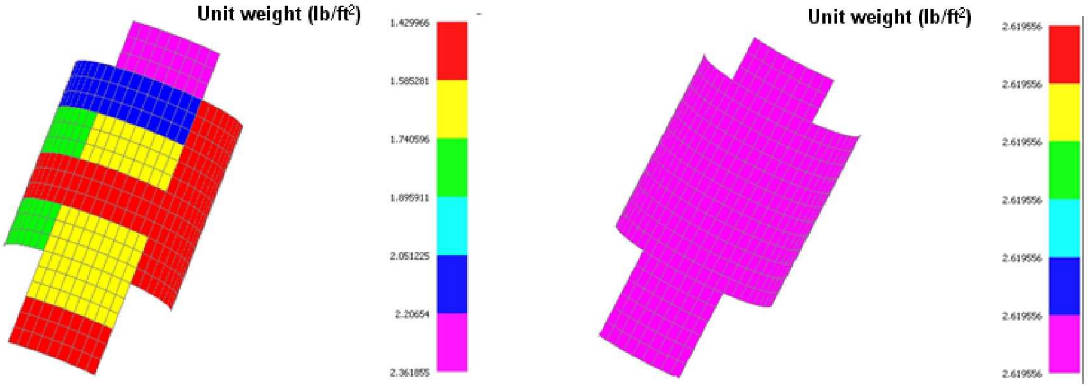
Figure 11. Closed-wall design.

Table 2. Structural Weight of the Closed-Wall Design

Iteration number	Weight (lb)
1	8,647
2	7,858
3	8,062
4	8,171

Design standardization process

The design process, shown in figure 2, produces an axially asymmetric vehicle as a result of the asymmetric loading conditions. In addition, for ease of manufacturing, assemblies of panels with common gauges may be required. Further, at the conceptual level, a modeler typically would not cover all possible scenarios, such as payload distributions which might cause additional design loads. To account for these uncertainties and omissions in the conceptual design, several additions were required to the outlined analysis process to standardize material gauge. An identical design was applied to groups of panels to redistribute the weight as shown in figure 12. The margins of safety were reviewed, and the design of the component that was most limited in structural margin was assigned to a group of panels, or beams. A single reanalysis was run in HyperSizer to obtain a new analytical structural weight of the stronger, but also heavier, design.



a) Before standardization.

b) After standardization.

Figure 12. Unit weight of a group of panels before and after the standardization process.

The application of the standardization process on the closed-wall design caused an increase in the analytical structural weight of the vehicle from 8,171 to 10,525 lb.

Cargo door design

The same six combinations of aero and inertia loads that were applied to the reminder of the vehicle also were applied to the cargo door design. Four ball joints were used to model the door attachments to the vehicle (see figure 13).

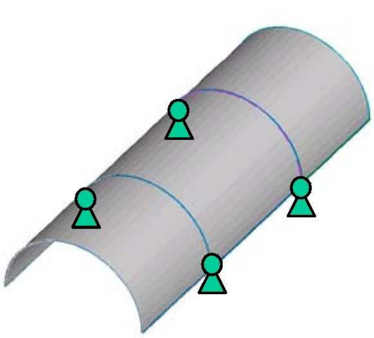


Figure 13. Cargo door hinges.

Aluminum honeycomb panels were used to model the skin of the cargo door and aluminum AL 7075-T6 I-section beams were used to model the doorframe (see figure 14).

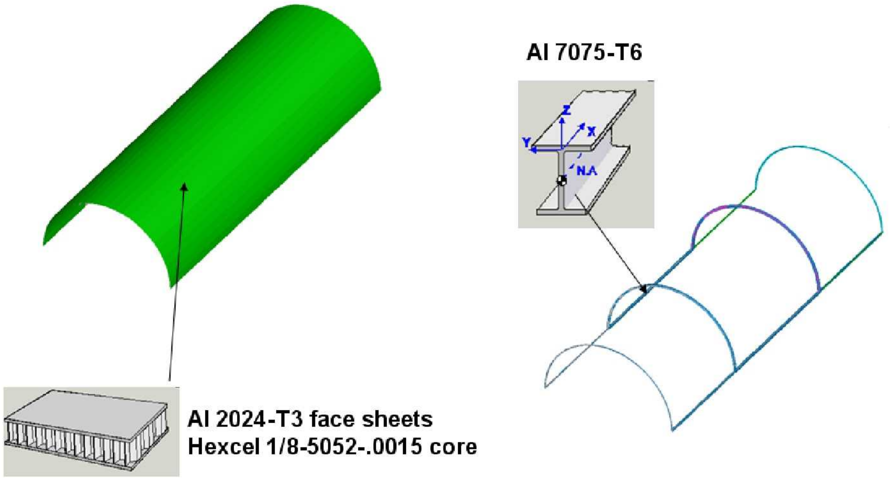


Figure 14. Cargo door design.

Table 3 shows the results of the structural optimization for the cargo door. The final weight of 1,484 lb was divided between 1,333 lb for the honeycomb skin and 151 lb for the frame. During the last iteration, the constraint forces that were caused by the door loads were computed at the hinge locations and were saved for further design (see figure 15).

Table 3. Structural Weight of Cargo Doors

Iteration number	Weight (lb)
1	1,596
2	1,483
3	1,484

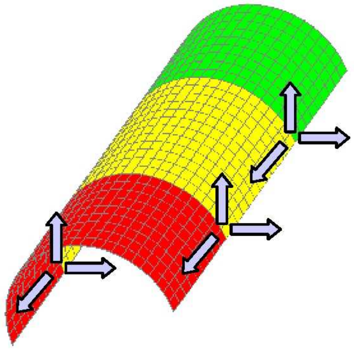


Figure 15. Cargo door reactions.

Closed-wall design with cargo door loads

The six sets of concentrated loads on the cargo door hinges were added to the six earlier load cases that acted on the cargo carrier, and a new optimization analyses was done (see figure 16).

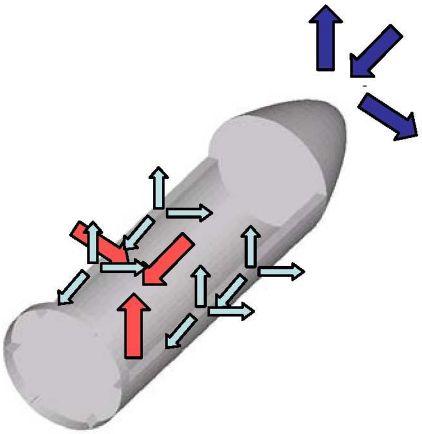


Figure 16. Addition of cargo door loads to the vehicle loads (only one of six load cases shown).

Table 4 summarizes the results of the two iterations and of the standardization analysis. This last series of analyses resulted in a structural weight of the vehicle of 10,613 lb, where 8,963 lb was the weight of the stiffened skin panels and 1,650 lb was the weight of the frame and the longeron caps.

Table 4. Structural Weight of Closed-Wall Design With Loads From the Cargo Door

Iteration number	Weight (lb)
1	7,882
2	7,897
Standardization	10,613

Cargo carrier total analytical structural weight

The structural weights that were analyzed in these last two sections were added together to obtain the total analytical weight. Therefore, the cargo door weight of 1,484 lb and the closed-wall concept weight of 10,613 lb were added to obtain the total analytical structural weight of the cargo carrier of 12,097 lb. This is not a final estimate of the structural weight because it does not account for structural elements that were not modeled, such as fittings, panel edges, fillets and so on.

Estimate of the as-built structural weight

The analytical structural weight from the previous section also did not account for the secondary structure and, therefore, represented an analytical weight of the primary structure. A method for estimating the added weight that results from the secondary structure and the un-modeled elements was applied.

The Space Shuttle orbiter mid-fuselage was used for guidance. Figure 17 shows an area of the orbiter between stations 582 and 1307 that surrounds that part of Shuttle structure (highlighted in the figure) which resembles the structure of the cargo carrier payload bay (ref. 8).

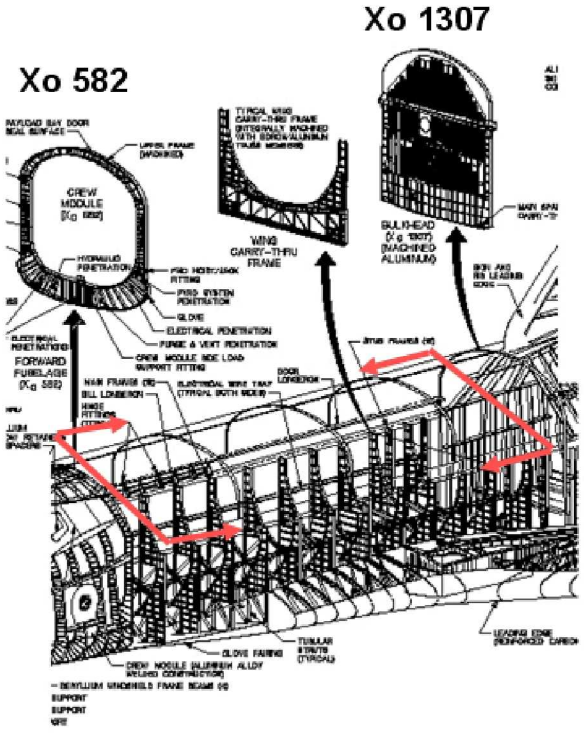


Figure 17. Orbiter mid-fuselage structure.

Table 5 provides the orbiter weight, broken down by structural components between station 600 and station 1191 (ref. 9). The table contains a list of the orbiter structural components in two columns. The second column contains those components that correspond closest to the cargo carrier modeled structure. The weights of those of structural components that were not modeled for the cargo carrier are listed in the third column. The percentage of the weight of the un-modeled structure with respect to the overall weight of the orbiter's mid-fuselage structure was 13.3 percent.

Table 5. Breakdown of Orbiter Mid-Fuselage Structural Weight

Components	Modeled Structure	Unmodeled Structure
Frame, main 600 - 1191	1485.8 lb	
Frame, main wing carry through	739.6 lb	
Frame, stub	252.2 lb	
• Joints, splices, fasteners		368.9 lb
Cover, side between longerons	2947.0 lb	
Cover, lower between longerons	3051.9 lb	
Cover, torque box upper	408.4 lb	
• Support structure trunion MLG NLG		182.0 lb
Longerons, side	1156.9 lb	
Longerons, lower	115.4 lb	
• Longitudinal partitions		82.0 lb
• Longitudinal stabilizing ribs		138.9 lb
• Doors, panels		82.4 lb
• Stabilizing struts and links		100.5 lb
• Mid-fuselage secondary Structure		603.4 lb
Total modeled weight	11,112.0 lb	
Total unmodeled weight		1558.1 lb
Total weight	11,715.2 lb	
Percent of unmodeled weight versus total weight	13.3 %	

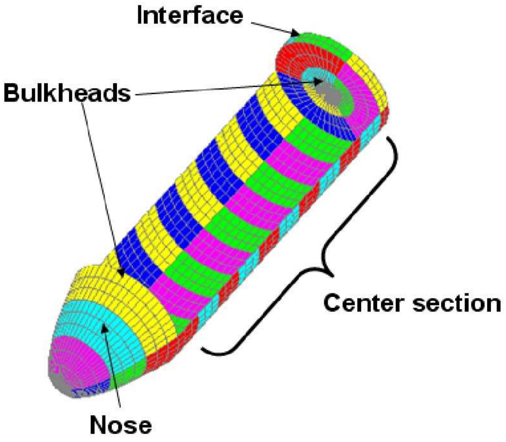


Figure 18. Cargo carrier center section.

The analytically predicted weight of the cargo carrier was compared with the as-built weight of the orbiter. Only 7,690 lb of the cargo carrier center section (see figure 18) were compared with the orbiter's 11,112 lb. Table 6 provides the weight per unit length between the comparable sections of the orbiter and the cargo carrier. The orbiter's higher unit weight was explained by different design loading conditions. The orbiter was designed both for ascent and descent loads, while the cargo carrier study addressed only a limited number of ascent load cases.

Table 6. Weight Per Unit Length

	Orbiter Xo 600 – Xo 1191	Cargo carrier center section
Weight (lb)	11,112	7,690
Length (in)	591	598
Weight/length (lb/in)	18.8	12.9

Based on the weight survey results that are given in tables 5 and 6, a structural non-optimum factor of 1.15 was established for the cargo carrier structure. This factor represents the increase in structural weight that results from the un-modeled structure. The final weight of the carrier, or the as-built weight, was obtained by multiplying the analytical weight of the primary structure by 1.15; thus, the final weight is equal to 13,912 lb.

Summary

The results are presented of a limited study for which the goal was to investigate the possibility of using a crew launch vehicle to deliver the remaining International Space Station elements should the Space Shuttle orbiter not be available to complete that task.

To obtain a structural weight and design definition for a cargo carrier a previously developed process that is based on finite element analysis and structural sizing was used. Two designs were evaluated to determine the most efficient design based on weight. A systematic approach provided gradual increase in the analytical weight of the design. A survey study of the details of the Shuttle orbiter structure helped to establish a non-optimum factor for use in this study to estimate a final “as built” weight.

References

1. “NASA’s Exploration Systems Architecture Study: Final Report”, NASA/TM-2005-214062, November 2005.

2. Martinovic, Z. N. and Cerro, J. A.: “A Procedure for Structural Weight Estimation of Single Stage to Orbit Launch Vehicles (Interim User’s Manual)”, NASA/TM-2002-211931, September 2002.

3. UGS/I-DEAS Simulation product, V 9.2, http://www.ugs.com/index.shtml, UGS Global Headquarters, Plano, TX., accessed May 16, 2008.

4. Collier Research/HyperSizer Automated structural detail analysis, local sizing optimization, and weight prediction composite software, V 4.0.7, http://www.hypersizer.com, Hampton, VA., accessed May 16, 2008.

5. National Space Transportation System Space Shuttle Program Definition and Requirements – NSTS 07700, Space Shuttle System Payload Accommodations, Vol. XIV, App. 4, System Description and Design – Structures and Mechanics, Revision L 5-29-01.

6. Bruhn, E.F., Ed., *Analysis and Design of Missile Structures*, Tri-State Offset Company, Cincinnati, Ohio, 1967.

7. Martinovic, Z.N.: "Structural Design and Analysis of Un-pressurized Cargo Delivery Vehicle", AIAA-2007-2370, April 2007.

8. *Shuttle Operational Data Book, Orbiter Emergency Rescue Data – Part 1*, NSTS – 08934, Volume IV, NASA, Lyndon B. Johnson Space Center, January 1988.

9. Unpublished work – Control Book Mass Properties Orbiter OV-103, Rockwell International, Space Division, April 1996.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)* 01- 09 - 2009	**2. REPORT TYPE** Technical Memorandum	**3. DATES COVERED** *(From - To)*

4. TITLE AND SUBTITLE Shuttle Orbiter-like Cargo Carrier on Crew Launch Vehicle	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Martinovic, Zoran N.	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER 304029.01.04.02.02
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, VA 23681-2199	**8. PERFORMING ORGANIZATION REPORT NUMBER** L-19711
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001	**10. SPONSOR/MONITOR'S ACRONYM(S)** NASA
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) NASA/TM-2009-215793

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 15
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The following document summarizes the results of a conceptual design study for which the goal was to investigate the possibility of using a crew launch vehicle to deliver the remaining International Space Station elements should the Space Shuttle orbiter not be available to complete that task. Conceptual designs and structural weight estimates for two designs are presented. A previously developed systematic approach that was based on finite-element analysis and structural sizing was used to estimate growth of structural weight from analytical to "as built" conditions.

15. SUBJECT TERMS
Finite element modeling; Launch vehicle; Structural design; Structural sizing; Weight estimation

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	24	(443) 757-5802