Designing Struts for the Low-Fidelity Orion Cockpit Mockup

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The objective of the project was to design and construct nine struts to be installed in the low-fidelity Orion cockpit mockup (Rev F; located at NASA's Johnson Space Center in Houston, TX) as simplified representations of the existing flight designed struts designed by engineers at Lockheed Martin (the primary contractor of the Orion). The project design included: researching the existing flight designs, brainstorming design upgrades, developing three unrelated three-dimensional (3D) strut designs using Pro/ Engineer Wildfire 3.0, choosing the best fit design, locating materials and their sources, implementing the chosen design, and making design modifications. The project resulted in making simple modifications to the existing struts used in the last Orion cockpit mockup. The project is relevant to NASA, because upgrades to the low-fidelity Orion cockpit mockup progresses NASA's goals of developing and testing a new spacecraft, conducting the spacecraft's first crewed mission by 2015, returning to the moon by 2020, and exploring Mars and other planets in the future.

Nomenclature

3D	=	three-dimensional
CAD	=	computer aided design
CEV	=	crew exploration vehicle
Dia.	=	diameter
EA3	=	Systems Architecture and Integration Office at NASA JSC
ft	=	feet
ft^3	=	cubic feet
h	=	height
in	=	inches
in^3	=	cubic inches
ISS	=	International Space Station
JSC	=	Johnson Space Center
L	=	length
NASA	=	National Aeronautics and Space Administration
Pro/ E	=	Pro/ Engineer Wildfire 3.0
W	=	width
wt	=	weight

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I. Introduction

On January 14, 2004, former President George W. Bush announced his Vision for Space Exploration policy. The policy calls for the National Aeronautics and Space Administration (NASA) to complete the International Space Station (ISS) by 2010, retire the Space Shuttle in 2010, develop and test a new spacecraft (the Crew Exploration Vehicle (CEV)) by 2008, conduct the CEV's first crewed mission by 2014, and return to the moon by 2020.[2] As a part of the Vision for Space Exploration policy to develop and test a new spacecraft, making upgrades to the low-fidelity Orion cockpit mockup located at the Johnson Space Center in Houston, TX are aligned with the policy's goals.

Similarities	Differences		
	Orion	SIZE	*Apollo*
	16.5ft	Diameter	12.8ft
CONE SHAPE	10.8ft	Height	11.4ft
	31,000 lb	Empty Weight	12,787 lb
	$692ft^3$	Habitable Volume	$218ft^3$

Table 1. Similarities and Differences in the General Shape and Size between the Orion and Apollo spacecrafts. [3]

Orion	Differences	*Apollo*
	COCKPIT CONTROLS	
Touch Screen		Switches
	COMPUTER SYSTEMS	
Open architecture that will allow software and hardware upgrades		Limited power and memory
	MOON ATMOSPHERE	
Nitrogen-Oxygen Mix		Pure Oxygen
	SPACECRAFT DURABILITY	
Reusable		Non-reusable

Table 2. Technology, Moon Atmosphere, and Spacecraft Durability Differences between the Orion and Apollo spacecrafts[4]

The Orion's concept is borrowed from the Apollo Command Module which is similar in shape, but differs in size (see Table 1), technology (see Table 2), moon atmosphere (see Table 2), spacecraft reusability (see Table 2), mission scenarios, and other attributes.

II. Project Objective and Design

The objective of the project was to design and construct nine struts, using commercially available parts within budget, to be installed in the low-fidelity Orion cockpit mockup as simplified representations of the existing flight designed struts designed by engineers at Lockheed Martin (the primary contractor of the Orion). The project design includes: researching the existing flight designs, brainstorming design upgrades, developing three unrelated three-dimensional (3D) strut designs using Pro/ Engineer Wildfire 3.0, choosing the best fit design, locating materials and their sources, implementing the chosen design, and making design modifications (during the implementation phase).

A. Research

Research was the initial phase of the project which included: education on the various components of the Orion cockpit mockup, their purposes, relationships to one another, and gathering a strong understanding of the project's objective. In addition to identifying the miscellaneous components of the mockup, researching the flight design by taking measurements of the struts using a 3D model in Pro/ Engineer was an essential task of the project. The measurements included the lengths of the struts, their diameters (each strut of which has multiples), their locations on the pallet, the angles they form in relationship to the pallet, and identifying the types of fixings used. In the existing flight design, there are

[2]Bush, G. W., "President Bush Announces New Vision for Space Exploration Program," *The White House President George W. Bush Archives* [online database], URL: http://georgewbush-whitehouse.archives.gov/news/releases/2004/01/print/20040114-3.html [cited 16 April 2009].

[3]Banke, J., "Orion vs. Apollo: NASA's 21st Century Moonshot," *Space.com* [online], URL: http://www.space.com/businesstechnology/080929-nasa50-orion-apollo.html [cited 16 April 2009].

[4]Ibid.

nine struts with attachments from the pallet to either the ceiling, also known as the forward bulkhead, or to one of the walls of the cockpit. (See Figure 1, 2, and Table 3)

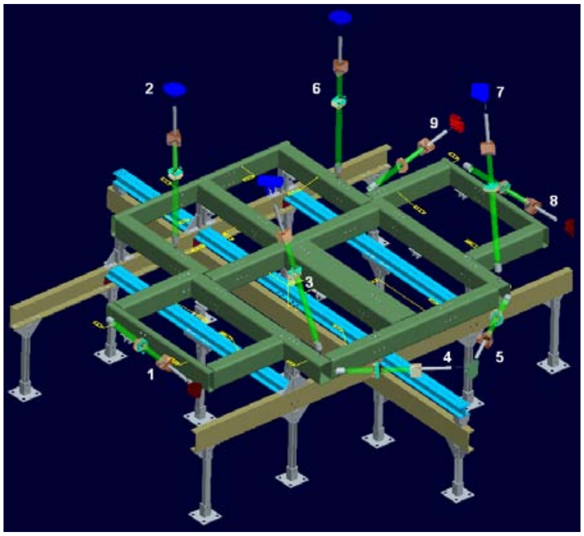

Figure 1. Nine Flight Design Struts, 3D model in Pro/ E by Lockheed Martin; numbered from 1-9.

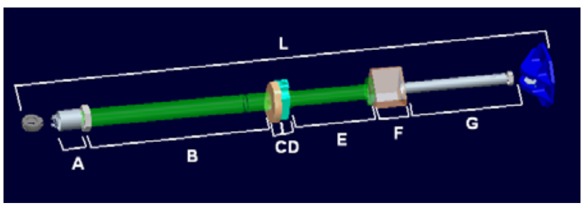

Figure 2. Flight Design Strut with Noted Sections as References for Table 3.

Strut	Length (L)		
1	41.1”		
2	48.5”	A Dia.	E Dia.
3	47.11”	1.812”	1.37”
4	37.75”	B Dia.	F Dia.
5	37.75”	1.625”	3.322”*
6	47.11”	C & D Dia.	G Dia.
7	48.5”	4”*	0.996”
8	41”		
9	41.1”		

Table 3. Length (L) of Struts and the Diameters of the Noted Sections in Figure 2.
*estimated

B. Brainstorming

A majority of the brainstormed design concepts were results of limiting the designs to using commercially available hardware. The primary source of the hardware was McMaster-Carr, a reputable online hardware supplier. In addition, the concepts had to meet criteria including, a low overall project cost, strength (load-bearing quality), and how accurately the design matches the flight design.

C. Developing Design Concepts

The three 3D design concepts developed using Pro/ E include, a pair of 12” long ½”-20 fully threaded steel male threaded rods screwed into one ½”-20 aluminum female threaded rod (24”, 30”, or 36” in length) with high strength steel rod ends, steel rods, channel brackets, and nuts on each end (see Figure 3), a pair of gas spring struts (18.62” or 22.36” each, 30 force, lb) connected by a coupling nut high strength steel rod ends, steel rods, channel brackets, and nuts on each end (see Figure 4), and a 3” diameter steel pipe housing two standard unistrut beams with various u-bolt fixings, bolts, washers, and nuts (see Figure 5).

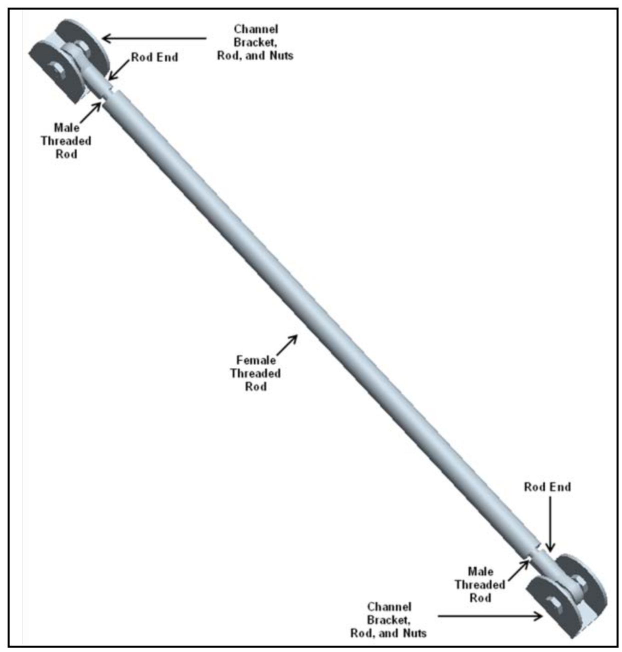

Figure 3. Design Concept #1, 2 Male Threaded Rods, 1 Female Threaded Rod, 2 Rod Ends, 2 Rods, 2 Channel Brackets, and 8 Nuts.

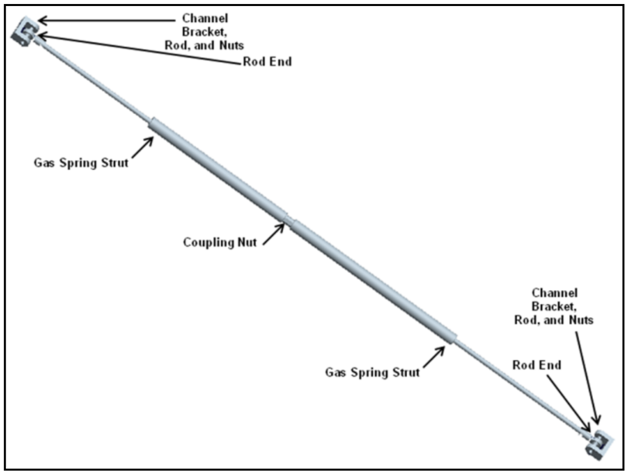

Figure 4. Design Concept #2, 2 Gas Spring Struts, 1 Coupling Nut, 2 Rod Ends, 2 Rods, 2 Channel Brackets, and 8 Nuts.

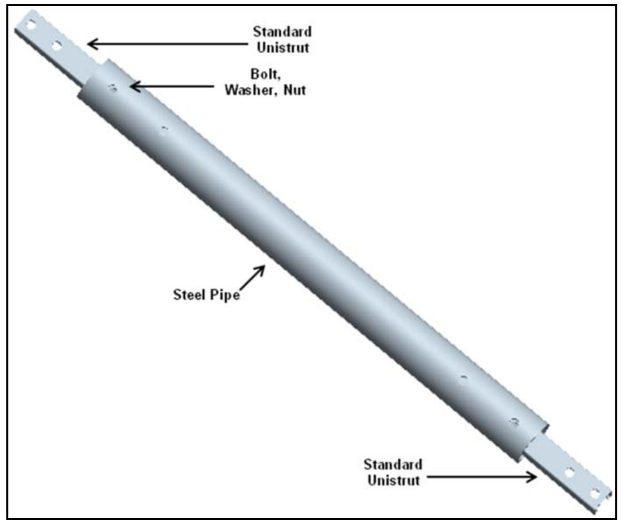

Figure 5. Design Concept #3, 2 Standard Unistrut beams, 1 Steel Pipe, and Fixings

D. Choosing a Design

From comparing and contrasting the three design concepts, design three best fit the goals of the project; which were to design and construct load-bearing yet cost efficient struts. Design one ranked second in strength, third in cost, while design two ranked third in strength, and second in cost. Therefore, design number three was a undisputed choice, because it ranked highest in both the strength and cost evaluation.

E. Materials

To maximize cost efficiency, materials from the existing struts were recycled and used to construct new struts. In order to keep the materials organized, the steps followed included: taking inventory of the available materials (see Table 6), reallocating the materials (see Table 7), creating a list of modifications (see Table 7), creating a list of items needed (see Table 7), and acquiring the necessary items.

F. Implementation & Modification

After prearranging the materials necessary for the project, implementing the design began with disassembling the existing struts, regrouping the materials, and constructing new struts. Design modifications were expected and occurred throughout the implementation phase.

III. Project Results

While disassembling the existing struts, it was discovered that the amount of available material originally anticipated was inaccurate, creating a shortage in materials. Therefore, the design had to be modified to satisfy the amount of materials available and the primary objective of the project. The inaccuracies in the amount of unistrut available caused the design of the struts to change. For example, instead of existing strut number seven having 45.5 inches of unistrut available to be cut in half to make two 22.75” beams to be used in new strut number six, only two 12” beams of unistrut were available (see Figure 6). All of the existing struts followed similar scenarios.

Existing Strut Measurements				
#	PIPE L	PIPE W	WALL THICK.	UNI
1	19	3	0.25	29.5
2	19	3	0.25	29.5
3	18	3	0.25	27.5
4	38	3	0.25	53
5	41	3	0.25	44.5
6	41	3	0.25	44.5
7	34.5	3	0.25	45.5
8	34.5	3	0.25	45.5
9	39.5	3	0.25	58

Table 6. Inventory (Existing Strut Measurements). *measurements in inches

MATERIALS				
NEW		FROM	FINAL	Orig. Length
1	**UNI 1**	STRUT 1 (WHOLE)	19	STRUT 1 (U), L 29.5
	UNI 2	STRUT 3 (WHOLE)	27.5	STRUT 3 (U), L 27.5
	PIPE	STRUT 8 (WHOLE)	34.5	STRUT 8 (P), L 34.5
2	**UNI 1**	STRUT 9 (1/3 - 19.33)	18.53	STRUT 9 (U), L 58
	UNI 2	STRUT 9 (1/3 - 19.33)	18.59	STRUT 9 (U), L 58
	PIPE	STRUT 1 (WHOLE)	19	STRUT 1 (P), L 19
3	**UNI 1**	STRUT 8 (1/2 - 22.75)	22.75	STRUT 8 (U) L 45.5
	UNI 2	STRUT 8 (1/2 - 22.75)	22.75	STRUT 8 (U) L 45.5
	PIPE	STRUT 9 (1/2 - 19.75)	19.75	STRUT 9 (P), L 39.5
4	**UNI 1**	STRUT 5 (1/2 - 22.25)	21	STRUT 5 (U), L 44.5
	UNI 2	STRUT 5 (1/2 - 22.25)	18.5	STRUT 5 (U), L 44.5
	PIPE	STRUT 6 (WHOLE)	25	STRUT 6 (P), L 41
5	**UNI 1**	STRUT 6 (1/2 - 22.25)	21	STRUT 6 (U), L 44.5
	UNI 2	STRUT 6 (1/2 - 22.25)	18.5	STRUT 6 (U), L 44.5
	PIPE	STRUT 5 (WHOLE)	25	STRUT 5 (P), L 41
6	**UNI 1**	STRUT 7 (1/2 - 22.75)	22.75	STRUT 7 (U), L 45.5
	UNI 2	STRUT 7 (1/2 - 22.75)	22.75	STRUT 7 (U), L 45.5
	PIPE	STRUT 9 (WHOLE)	19	STRUT 9 (P), L 39.5
7	**UNI 1**	STRUT 9 (1/3 - 19.33)	18.53	STRUT 9 (U), L 58
	UNI 2	STRUT 4 (20" ONLY)	18.59	STRUT 4 (U), L 53
	PIPE	STRUT 2 (WHOLE)	19	STRUT 2 (P), L 19
8	**UNI 1**	STRUT 4 (13" ONLY)	13	STRUT 4 (U), L 53
	UNI 2	NEED 14.5	14.5	FIND/ BUY
	PIPE	STRUT 4 (WHOLE)	37.25	STRUT 4 (P), L 38
9	**UNI 1**	STRUT 4 (20" ONLY)	19	STRUT 4 (U), L 53
	UNI 2	STRUT 2 (WHOLE)	27.5	STRUT 2 (U), L 29.5
	PIPE	STRUT 7 (WHOLE)	34.5	STRUT 7 (P), L 34.5

Table 7. Material Reallocations, Modifications, and Needed.
*measurements all in inches

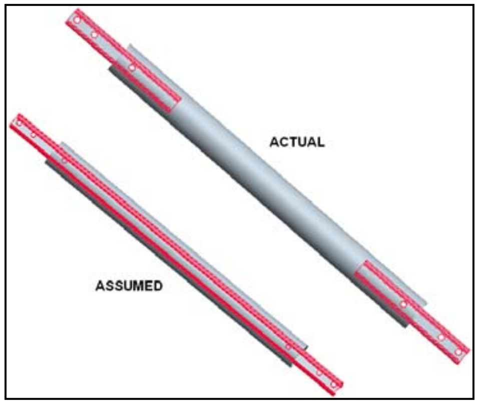

Figure 6. (Left) Assumed Amount of Unistrut Available, (Right) Actual Amount of Unistrut Available.
*scale does not apply

A. Solution

The solution to the shortage was to reallocate materials and adjust the existing struts to fit the lengths of the new struts. The shorter existing struts had unistrut beams measuring between 10”-12”, while the longer struts had unistrut measuring between 12”-14”. By ranking the 3” diameter steel pipes by length, as well as ranking the overall lengths of the new struts, we were able to assign the longer pipes to the longer struts; as well as the shorter pipes to the shorter struts. In addition, matching the unistrut beams based on the need each strut. The attachments to the pallet, walls, and forward bulkhead, changed from u-bolts to bolts and steel hinges. (See Table 8)

NEW #	LENGTH	OLD #
1	40”	2
2	46.6”	4
3	47”	5
4	35.5”	1
5	35.5”	3
6	47”	6
7	46.6”	9
8	42”	7
9	45.5”	8

Table 8. New Struts’ Lengths and Assigned Old Strut Numbers.

B. More Results

Solving the material shortage minimized the amount of labor, time, and money spent on the project. Since the unistrut beams no longer needed to be machined, or cut, as initially planned, labor, time, and money were saved. In addition, the u-bolts purchased were not used, and instead bolts and steel hinges were recycled from the previous struts.

C. Installation

After the new struts were constructed, they were installed in the mockup by technicians according to the locations (based on lengths from given points) found by utilizing the 3D model in Pro/ Engineer. (See Image 1, 2, and Figure 7)

Image 1. Orion Cockpit Mockup Pallet before the Strut Installation.

Image 2. Orion Cockpit Mockup Pallet after the Strut Installation.

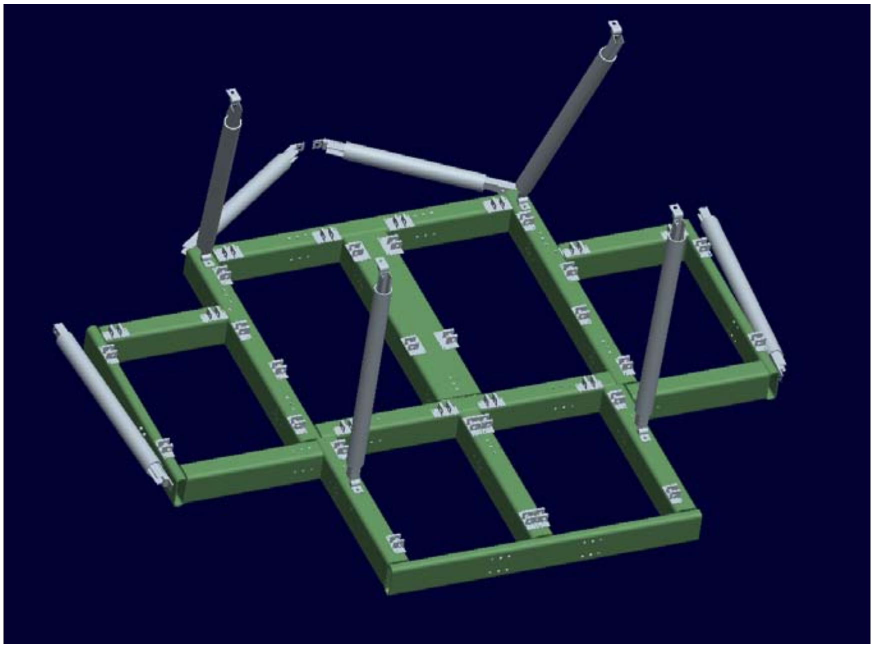

Figure 7. Struts Attached to the Pallet, 3D Model in Pro/E.

IV. Conclusion

Fulfilling the project's objective of installing accurately sized load-bearing struts in the Orion cockpit mockup has contributed to the quality of testing performed in the mockup by various teams at the Johnson Space Center in Houston, TX. Examples include the umbilical team working on placement of supply umbilical cords to be attached to the astronauts' suits while in the spacecraft (see Image 3), and the spacesuit team evaluating the design and functions of their suits (see Image 4).

Image 3. Umbilical Team in the Orion Cockpit Mockup.

Image 4. Suited Astronaut During an Evaluation in the Orion Cockpit Mockup.

Acknowledgments

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[2]Bush, G. W., "President Bush Announces New Vision for Space Exploration Program," *The White House President George W. Bush Archives* [online database], URL: http://georgewbush-whitehouse.archives.gov/news/releases/2004/01/print/20040114-3.html [cited 16 April 2009].

[3]Banke, J., "Orion vs. Apollo: NASA's 21st Century Moonshot," *Space.com* [online], URL: http://www.space.com/businesstechnology/080929-nasa50-orion-apollo.html [cited 16 April 2009].

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