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INTEGRATION OF LAUNCH VEHICLE SIMULATION/ANALYSIS TOOLS AND LUNAR CARGO LANDER DESIGN (PART2/2)

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Introduction

The Graphical User Interface (GUI) design using Matlab for Maveric II's inputs and outputs and the Maveric II conversion from UNIX to PC is discussed in part 1 of this project (Page XL-1).

Part 2, which will be discussed in this report, will discuss the development of a Lunar Cargo Lander (unmanned launch vehicle) that will transport usable payload from Trans-Lunar Injection to the moon. The Delta IV-Heavy was originally used to transport the Lunar Cargo Lander to TLI, but other launch vehicles have been studied. In order to uncover how much payload is possible to land on the moon, research was needed in order to design the sub-systems of the spacecraft. The report will discuss and compare the use of a hypergolic and cryogenic system for its main propulsion system. The guidance, navigation, control, telecommunications, thermal, propulsion, structure, mechanisms, landing gear, command, data handling, and electrical power sub-systems were designed by scaling off other flown orbiters and moon landers. Once all data was collected, an excel spreadsheet was created to accurately calculate the usable payload that will land on the moon along with detailed mass and volume estimating relations. As designed, The Lunar Cargo Lander can plant 5,400 lbm of usable payload on the moon using a hypergolic system and 7,400 lbm of usable payload on the moon using a cryogenic system.

Problem Statement

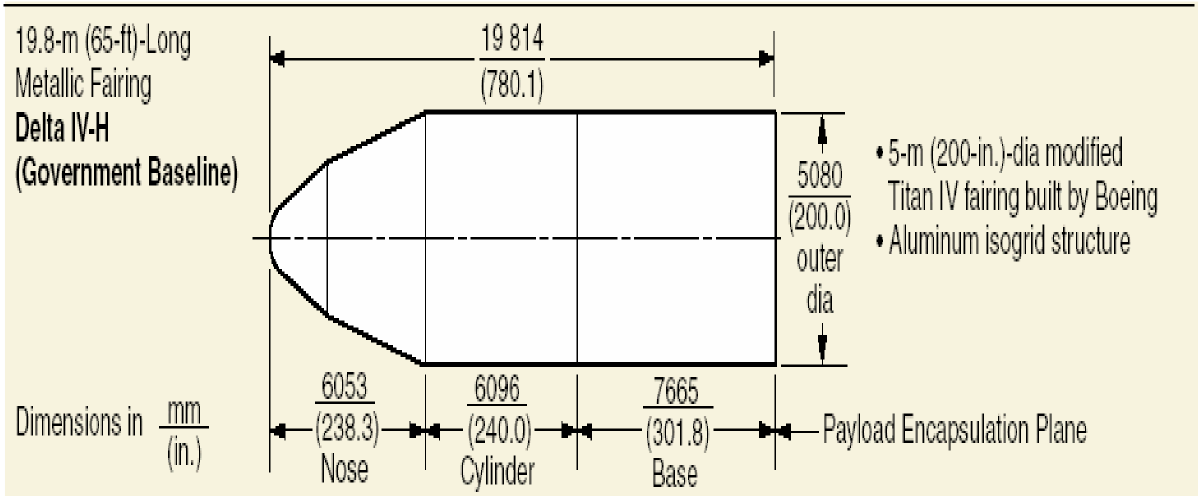
Develop a vehicle capable of being launched on a Delta-IV Heavy Launch Vehicle which can land on the moon with the goal of pre-implanting cargo for a new lunar mission. Consider other launch vehicles capable of inserting a payload into Trans-Lunar Injection (TLI).

Lunar Cargo Lander Travel

The Delta-IV Heavy Launch Vehicle will transport the Lunar Cargo Lander (LCL) from earth to TLI. After reaching TLI, the LCL will be released. The LCL will then start its propulsion system in order to make the first burn from TLI to Lunar Orbit Insertion (LOI). The LCL will then make its second burn, which is from LOI to landing on the moon.

Research

Initial research consisted of accumulated data from many sources, including Boeing engineers, Johnson Space Center, websites, software, and vehicle weight statements from other flown vehicles. The Delta IV values used for the LOI burn and the Landing burn were 3609 ft/sec and 6562 ft/sec. The LCL constraints, which is decided by what can fit in the payload of the Delta-IV Heavy, for the mass was 21,197 lbm and for the size was based upon the dimensions shown in the figure below:



The research then continued on into the type of engines that would be used for the propulsion system. For the Main Propulsion System (MPS), the cryogenic engine and the hypergolic engine were designed for the LCL in order to compare the results of the two types of engines. For the other main components of the spacecraft sub-system, which includes the Reaction Control System (RCS), Legs, Guidance, Navigation and Control (GNC), Telecommunications (Comm), Command and Data Handling (CDH), Thermal (Th), Electrical Power (EP), and Structure and Mechanisms (SM), the mass, volume, and surface area were scaled off of the Apollo Lunar Module, Clementine, Lunar Schooner, Surveyor, Orbital Maneuvering Vehicle, and Prospector.

Engine Alternatives

The cryogenic system uses an engine that is fed liquid oxygen (LO_2) as its oxidizer and liquid hydrogen (LH_2) as its fuel. This system produces a higher performance, but oxidizer and fuel must be kept at cryogenic temperatures of -270^{o}F and -430^{o}F. Two specific engines were chosen for the cryogenic system. The first engine is a Pratt&Whitney RL 10B-2, which supplies a thrust of 24,750 lbf, an Isp of 465.5 sec, a mass of 610 lbm, and an oxidizer fuel ratio of 5.88. The second engine is a Pratt&Whitney RL 10A3-3A, which supplies a thrust of 16,500 lbf, and an Isp of 444.4 sec, a mass of 310 lbm, and an oxidizer fuel ratio of 5.88. The RL 10A3-3A was given consideration since the vehicle weight when it is approaching the moon will be around 9,000 lbm, which does not need the amount of thrust that is supplied by the RL 10B-2. The RL 10A3-3A is also 300 lbm less than the RL 10B-2. Therefore, both engines were considered even though the RL 10B-2 has a higher Isp.

The hypergolic system uses an engine that is fed dinitrogen tetroxide (N_2O_4) as its oxidizer and monomethylhydrazine (MMH) as its fuel. The system produces a lower performance, but the fuel and oxidizer are storable and reliable. One engine was chosen for the hypergolic system, which is the Rocketdyne RS-72. The RS-72 supplies a thrust of 12,500 lbf, an Isp of 338 sec, a mass of 340 lbm, and an oxidizer fuel ration of 2.08.

Lunar Cargo Lander Excel Sheets

After all of the data was found, two excel sheets were created to estimate the amount of usable payload that the Lunar Cargo Lander (LCL) could put on the moon. One excel sheet controls the hypergolic system while the other is set up for the cryogenic system. Both sheets have the same format, but the cryogenic sheet is set up to have a bigger thermal sub-system because of the cryogenic temperatures. The input needed to run the sheet is mass before LOI burn (mass initial), delta V for the LOI and Landing burn, Engine specifications (Isp, Oxidizer/Fuel Ratio, and Thrust), and Tank specifications (for fuel, oxidizer, and pressure chemical: ullage, density, tank diameter). The excel sheet then outputs the following general information: mass after LOI burn, MPS propellant used for LOI burn, mass before Landing burn, MPS propellant used for Landing burn, mass flow rate, LOI burn time, Landing burn time, Propellant total for MPS and RCS, Landing weight, weight of Spacecraft sub-systems, usable Payload landed on the moon. The input also feeds the calculation of all components of the propulsion system by derived equations to give its mass, volume, surface area, and height. The components of the propulsion system that are listed are the tanks for MPS and RCS and the tank's insulation, anti-vortex, slosh add-in, and engine insulation. The input also feeds the calculation of the propellant used for the MPS and RCS system. The mass estimation for the landing gear is scaled off of the Lunar Module and Surveyor. The mass for GNC, Comm, CDH, EP are scaled off of Clementine and Prospector. The mass estimation for the Thermal sub-system is scaled off of the Orbital Maneuvering Vehicle. The mass estimation for the Structure and Mechanism sub-system used several vehicles to scale from including the Lunar Module, OMV, Surveyor, and Clementine. The figure below shows a part of the mass estimating relation page:

Spacecraft Sub-system	**2937.44**				
Propulsion	**794.18**				
MPS		730.18			
-Engine			349.84		
--Boeing RS 72 (1)				340.00	website
--insulation				9.84	intros
-Tanks (cylinder) (contains MPS & RCS fuel)			288.24		
--MMH tank				102.70	calculated and intros
--MMH insulation				11.62	calculated and intros
--MMH antivortex				1.65	calculated and intros
--N2O4 tank				122.96	calculated and intros
--N2O4 insulation				13.38	calculated and intros
--N2O4 antivortex				3.18	calculated and intros
--N2O4 slosh				0.79	calculated and intros
--Helium tank				23.32	calculated
--Helium insulation				3.65	calculated
--metal bladders for MMH&N2O4 tank				5.00	Clementine
-Valves,pipes,plumbing,fitting			92.10		OMV
RCS		64.00			
-Thrusters (16)			64.00		Clementine
Landing Gear	**162.00**				
-Leg (4)		162.00			LM
GNC	**42.42**				

Lunar Cargo Lander Excel Sheet – Future Work

Future work will include adding the same features that the Propulsion sub-system has to all of the other spacecraft sub-systems, which includes deriving formulas to estimate the mass, volume, and dimensions for all sub-components featured in the spacecraft sub-system. Future work will also include the flexibility to have list boxes to choose if it is a hypergolic system or cryogenic system, lists of engines, and lists for choosing fuels, oxidizers, and substance used for pressure-fed system. The ability to choose different sub-components for each sub-system will also be looked into. Power consumption and Cost estimating relations will also be added. The goal is to have a program that can have the ability to create an initial design for any launch vehicle needed to go from TLI to the moon.

Cryogenic and Hypergolic Mass Comparison

The Lunar Cargo Lander Excel Sheet was used to compare the cryogenic system with two different engines and the hypergolic system. The main emphasis of the sheet is to find out how much actual payload can be put on the moon based on the delta IV-Heavy transporting the LCL to TLI. The results were as follows:

	Cryogenic		Hypergolic
Engine	RL10 B2	RL10 A3-3A	RS-72
Propulsion	1422.15	1131.27	804.05
LG	196.94	179.68	165.23
GNC	44.1	44.1	42.42
Comm	52	52	50.14
CDH	52.7	52.7	50.69
Thermal	266.6	266.6	238.42
EP	165.7	165.7	158.67
S&M	1316.55	1316.55	1440.93
Total Sub-system	3516.73	3208.6	2950.54
Propellant	11081.95	11437.11	13611.56
Payload	**7401.35**	**7354.28**	**5437.9**

The comparison shows that the cryogenic system will put approximately 2,000 pounds more usable payload on the moon; however, the hypergolic system is more reliable. When the cost estimation relation is added on, the best system will be chosen. As for now, the best system is obviously the cryogenic model, which also gives the ability to use the liquid hydrogen and liquid oxygen residuals as water if needed.

Analysis of 10% changes to the initial mass and delta V for LOI and Landing

For this analysis, the excel sheet gives the min and max for the following:

	min	max
LOI burn time	138.18	189.52
Landing burn time	161.32	228.63
Sub-system Weight	2906.17	2963.67
Propellant	11049.22	14385.13
Payload on moon	3620.65	6301.86

These values give a range of min and max for the burn times, sub-system weight, propellant used, and usable payload that will be landed on the moon. This analysis shows the range that the possible payload could put on the moon for a hypergolic system if major adjustments are needed during actual creation of the vehicle.

Historical Comparison

A comparison between the sub-systems of the Lunar Cargo Lander and other flown vehicles was also studied. The Surveyor and Apollo Lunar Module were studied closely since they were both lunar landers. The LCL's sub-systems for propulsion, landing gear, thermal, and structure and mechanics have nearly the same overall percentage of dry weight for each of those sub-systems as the LM and the Surveyor; therefore, it shows that the scaling for those sub-systems can be verified at an initial design level. The LCL's sub-systems for guidance, navigation, and control, electrical power, telecommunications, and command and data handling have a smaller overall percentage of dry weight for each of the sub-systems as compared to the Clementine, Prospector, and Lunar Schooner; however, the percentage is less than those vehicles because the electronics has a step increase thus allowing a larger vehicle like the Lunar Cargo Lander to have the same weight for the electronics as the smaller vehicles of Clementine and Prospector.

Using other Launch Vehicles

Other launch vehicles were looked at to see if there is a better option to carry the LCL to TLI than the Delta-IV Heavy. The Titan III was discovered to not be a possibility due to its inability to have a large enough payload bay to carry the LCL. The Ariane 5 and the Atlas V (500 series) was discovered to allow the LCL to land around 3,900 lbm on the moon for a scaled down model of the LCL. The Delta IV-Heavy enables a larger payload to be put on the moon, but cost estimation is needed in order to accurately say which one of the three is the best option.

CAD Designs

Three Cad models were developed. Two models were created for the cryogenic system. One design has the payload on top of the sub-systems with a ladder to it for the astronauts to climb up to get what is in there. The other design has the payload folding down on the side of the Lunar Cargo Lander so that access to the payload will be much easier. Entry doors will be on the sides allowing the astronauts to have walk-in access. The hypergolic system has the payload contained on the sides sitting next to the sub-systems allowing the same walk-in access. Detailed cad designs are one of the areas future work will focus on.

Conclusions

The Delta IV-Heavy will transport the Lunar Cargo Lander to TLI where the LCL will transport 5,400 lbm of usable payload using a hypergolic system and 7,400 lbm of usable payload using a cryogenic system from TLI to the moon.

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References

1. George P. Sutton. Rocket Propulsion Elements: Sixth Edition. John Wiley & Sons, Inc. 1992.
2. James R. Wertz and Wiley J. Larson. Space Mission Analysis and Design. Microcosm Press and Kluwer Academic Publishers. 1999.
3. Delta IV Payload Planner's Guide Version Nov 2002.