

Ares V: Designing the Heavy Lift Capability to Explore the Moon

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Abstract

NASA's Vision for Exploration requires a safe, efficient, reliable, and versatile launch vehicle capable of placing large payloads into Earth orbit for transfer to the Moon and destinations beyond. The Ares V Cargo Launch Vehicle (CaLV) will provide this heavy lift capability. The Ares V launch concept is shown in Fig. 1. When it stands on the launch pad at Kennedy Space Center late in the next decade, the Ares V stack will be almost 360 feet tall (Fig. 2). As currently envisioned, it will lift 136 metric tons (300,000 pounds) to a 30-by-160 nautical mile orbit at 28.5-degree inclination, or 55 metric tons (120,000 pounds) to trans-lunar injection. This paper will cover the latest developments in the Ares V project in 2007 and discuss future activities.

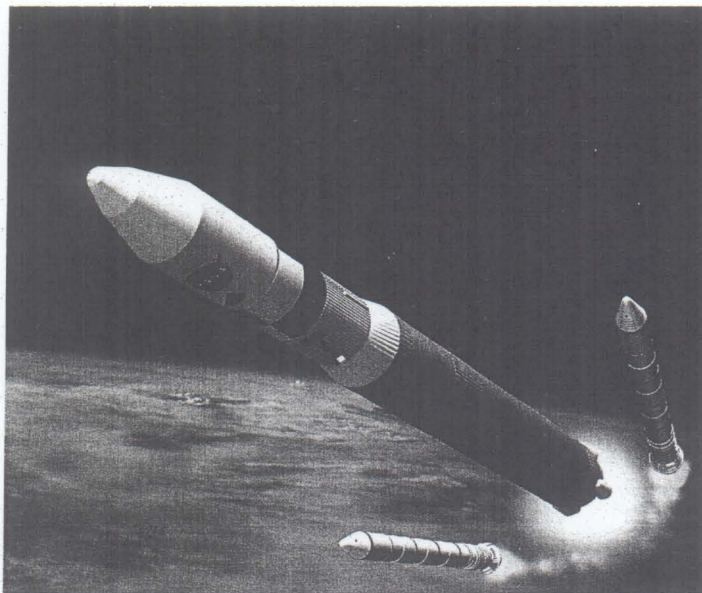


Fig. 1. Ares V launch concept.

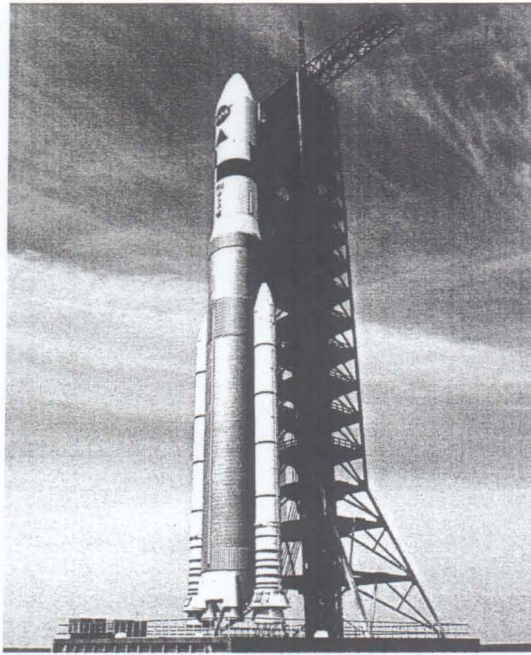


Fig. 2. NASA concept of the Ares V on the launch pad.

The Ares V consists of a Core Stage, two Reusable Solid Rocket Boosters (RSRBs), Earth Departure Stage (EDS), and a payload shroud. For lunar missions, the shroud would cover the Lunar Surface Access Module (LSAM). The Ares V Core Stage is 33 feet in diameter and 212 feet in length, making it the largest rocket stage ever built. It is the same diameter as the Saturn V first stage, the S-IC. But its length is about the same as the combined length of the Saturn V first and second stages. The Core Stage uses a cluster of five Pratt & Whitney Rocketdyne RS-68 rocket engines, each supplying about 700,000 pounds of thrust. Its propellants are liquid hydrogen and liquid oxygen.

The two solid rocket boosters provide about 3.5 million pounds of thrust at liftoff. These 5-segment boosters are derived from the 4-segment boosters now used on the Space Shuttle, and are similar to those used in the Ares I first stage. The EDS is powered by one J-2X engine. The J-2X, which has roughly 294,000 pounds of thrust, also powers the Ares I Upper Stage. It is derived from the J-2 that powered the Saturn V second and third stages. The EDS performs two functions. Its initial suborbital burns will place the LSAM into a stable Earth orbit. After the Orion crew vehicle, launched separately on an Ares I, docks with the LSAM/EDS, the EDS would ignite a second time to put the combined 65-metric ton vehicle into a lunar transfer orbit.

Although Ares I remains NASA's top priority, the Exploration Launch Projects Office is making progress on the early steps needed for Ares V to carry out the lunar mission before the next decade is out. The Ares V completed a preliminary design cycle in 2006. For this early phase, engineers took the basic information about payload requirements and combined them with some general assumptions about engines, aerodynamics, etc. to develop some basic designs and estimates on masses, trajectory, heating, facility

considerations, and more. The results of these studies are being compiled and will inform future, more detailed design cycles.

NASA also is pursuing a common engine with the Air Force for use on the Delta IV and Ares V per direction received from the NASA Administrator in August 2006. With the proposed joint upgrades, the improved RS-68 would deliver more thrust and be safer, more reliable, and more efficient than the current RS-68, while maintaining low manufacturing and operating costs. An Upgrades Requirements Review of the RS-68 engine began in October 2006. A turbopump Preliminary Design Review was conducted in November 2006. NASA and the Air Force completed a Memorandum of Understanding in December 2006. An Interagency Agreement remains in negotiations. NASA hopes to conclude negotiations in February 2007, move to additional design reviews on the RS-68 engine by June, and begin early testing by August. These and other developments are discussed in more detail below.

References

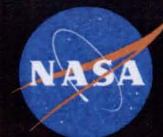
¹ National Aeronautics and Space Administration. *The Vision for Space Exploration*. February 2004, www.nasa.gov/mission_pages/exploration/main/

² National Aeronautics and Space Administration. *NASA's Exploration Systems Architecture Study Final Report*. NASA-TM-2005-214062. November 2005.

³ NASA Exploration Launch Projects Crew Launch Vehicle/Cargo Launch Vehicle Commonality Assessment, May 2006.

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*AIAA Space 2007
September 2007*

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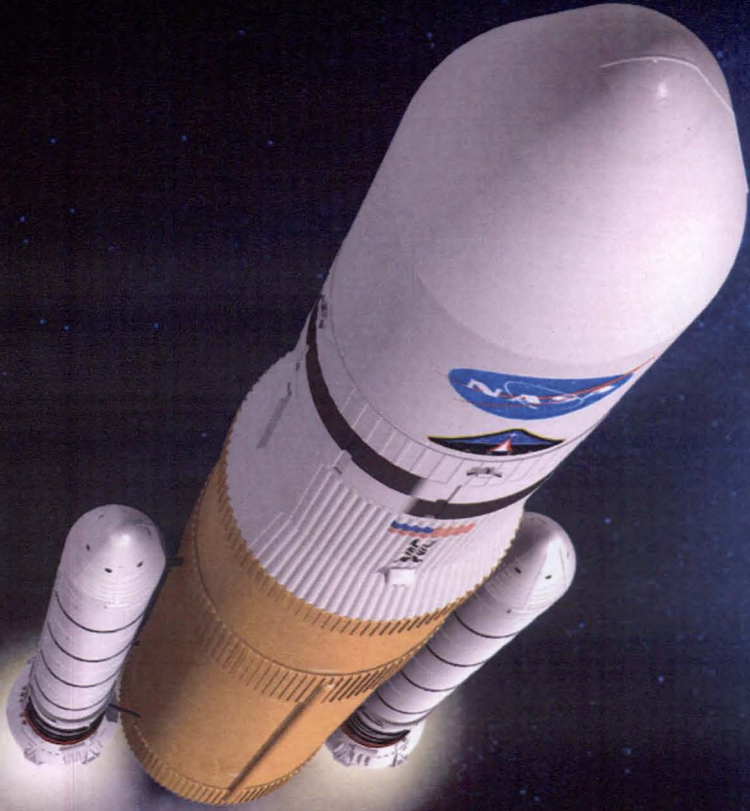
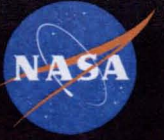




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- ◆ **Vehicle Concept Analysis**
- ◆ **Nosecone Analysis**
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- ◆ **Conclusions**

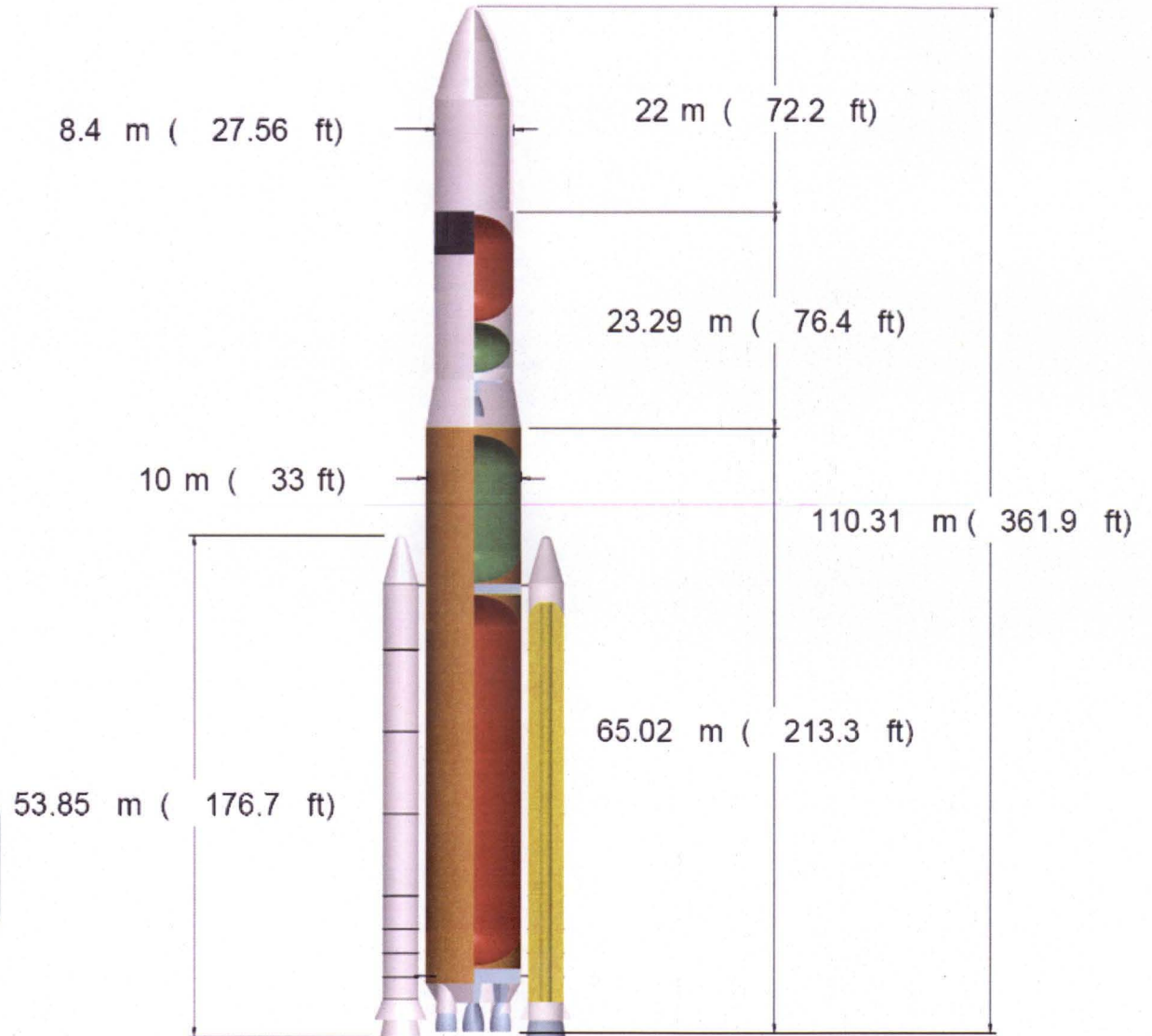
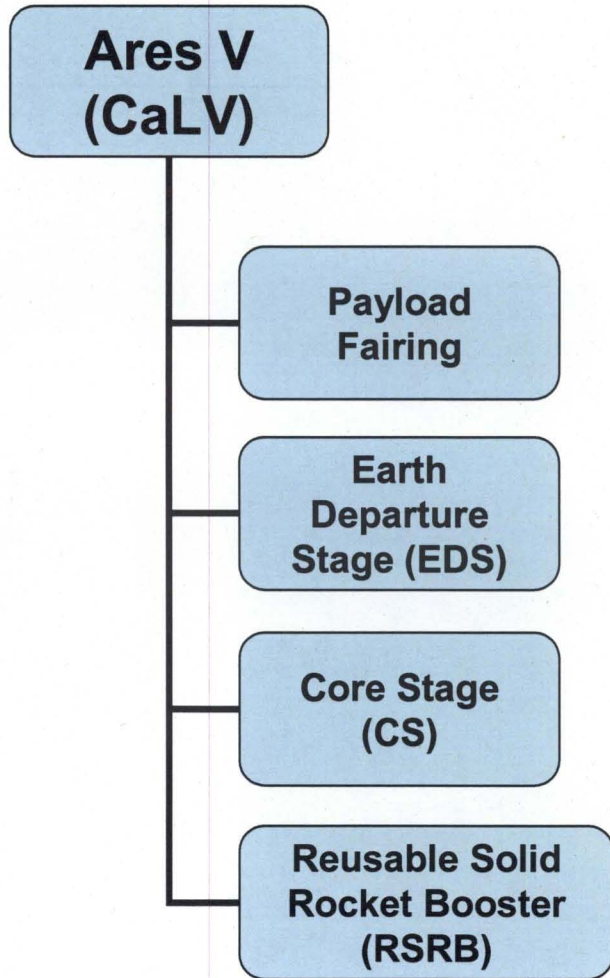


Vehicle & Requirements Overview





Reference Ares V Concept Overview



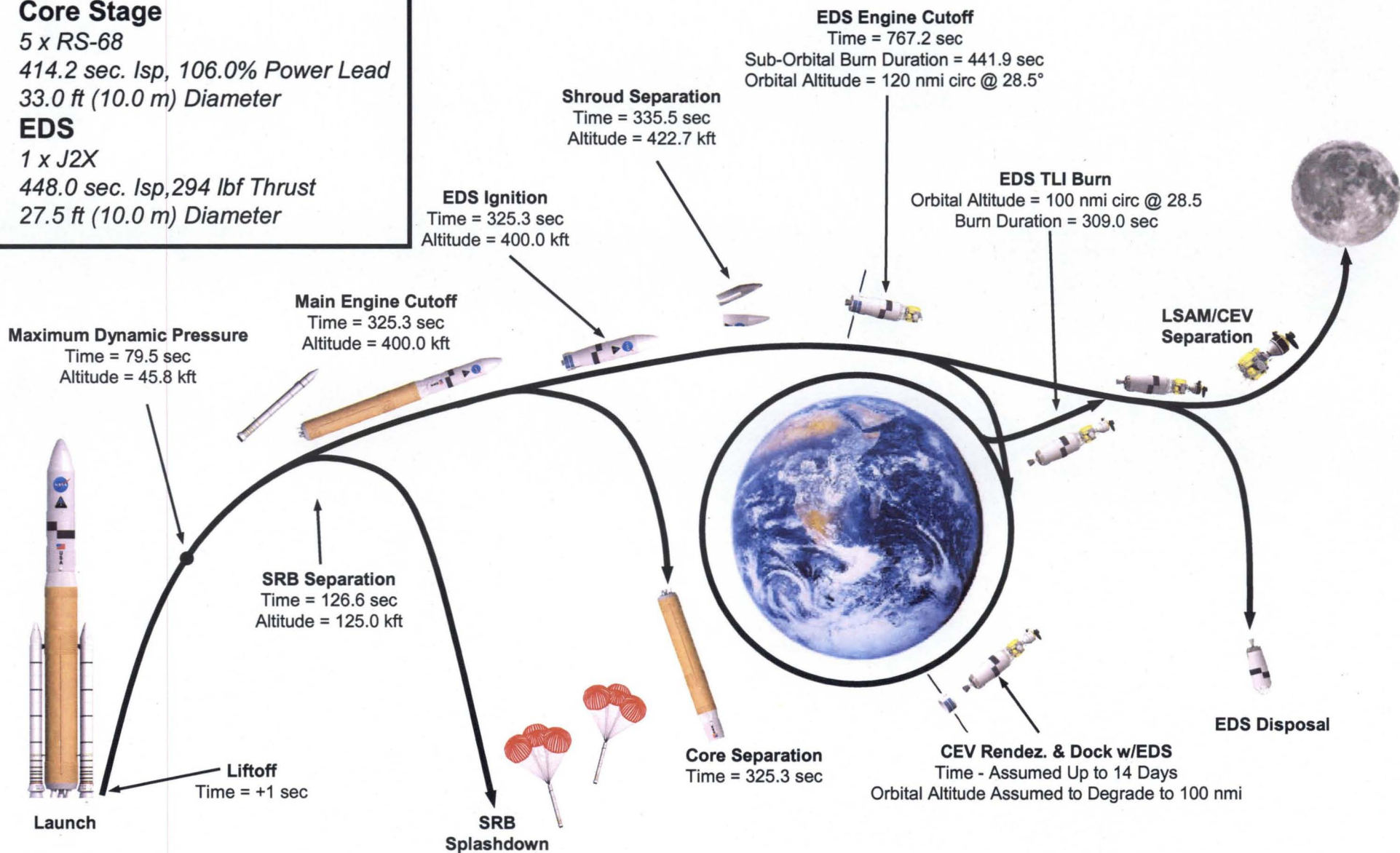


Ares V Ascent Profile



Core Stage
 5 x RS-68
 414.2 sec. Isp, 106.0% Power Lead
 33.0 ft (10.0 m) Diameter

EDS
 1 x J2X
 448.0 sec. Isp, 294 lbf Thrust
 27.5 ft (10.0 m) Diameter





Ares V Driving Requirements from CARD



CARD Req't	Requirement	Rationale
CA0391-HQ	The CaLV shall utilize twin shuttle-derived 5-segment SRBs along with a core stage that employs 5 modified RS-68 engines for first stage propulsion.	<ul style="list-style-type: none"> ◆ Draws Performance Constraints around Booster Selection and Core Stage Design ◆ Boosters and Core Stage Provide ~70% of Delta V for LEO Insertion
CA0847-PO	The CaLV EDS shall deliver at least 66,939 (TBR-001-076) kg (147,266 lbm) from Earth Rendezvous Orbit (ERO) to the start of the Trans-Lunar Coast (TLC) for crewed lunar missions.	<ul style="list-style-type: none"> ◆ Defines TLI Payload most strenuous performance parameter ◆ TLI Payload Sizes EDS
CA0836-PO	The LSAM shall have a Control Mass of 45,000 (TBR-001-075) kg (99,180 lbm) at the time of launch for Lunar Sortie and Lunar Outpost crew missions	<ul style="list-style-type: none"> ◆ Defines LEO Payload for Crew Mission ◆ Contribute ~2/3 Mass for TLI Payload ◆ TLI Payload Sizes EDS
CA4139-PO	The CEV shall have a Control Mass of 20,185 (TBR-001-159) kg (44,500 lbm) at the time of CaLV rendezvous.	<ul style="list-style-type: none"> ◆ Contribute ~1/3 Mass for TLI Payload ◆ TLI Payload Sizes EDS
CA0051-PO	The CaLV EDS shall provide a minimum translational delta-V of 3,150 (TBR-001-258) m/s (10,335 f/s) for the TLI for crewed lunar missions.	<ul style="list-style-type: none"> ◆ Defines Delta V thus propellant Needed for Delta V ◆ TLI Delta V Sizes EDS
CA0850-PO	The CaLV EDS shall meet its requirements after loitering in low Earth orbit (LEO) at least (TBD-001-975) days after orbit insertion for crewed lunar missions.	<ul style="list-style-type: none"> ◆ Defines Propellant Reserves for EDS Stage ◆ Major Factor in subsystem Selection and Design for EDS
CA0282-PO	The CaLV shall deliver at least 125,000 (TBR-001-220) kg (275,578 lbm) to a (TBD-001-072) Earth orbit for Mars exploration missions.	<ul style="list-style-type: none"> ◆ Defines Mars Mission Max Payload per launch ◆ Orbit and Payload size the Ares V
CA3215-PO	The CaLV shall launch cargo into a (TBD-001-565) Earth orbit for Mars missions.	<ul style="list-style-type: none"> ◆ Further defines performance capability of Ares V

- All Missions
- Lunar Requirements
- Mars Requirements



Performance Comparison

ESAS CaLV to Ares V Current Reference



◆ Original ESAS Capability

- 46.0 mt Allowable Lander Mass
- 20.0 mt CEV Mass
- No Loiter in LEO
- TLI total $\Delta v = 10,236$ ft/sec
- 7.4 mt TLI performance reserve
- 73.4 mt CaLV gross payload at TLI capability

◆ Concept refinement to reduce cost and maximize commonality between Ares I and Ares V

- Core Stage
 - SSME derived to RS-68
 - SSME Isp = 452.1 sec
 - RS-68 Isp = 414.7 sec
 - 27.5 ft. to 33 ft. diameter
- RSRB
 - ESAS RSRB used HTPB, MEOP = 1066 psi, thrust trace optimized for CaLV
 - Current RSRB uses PBAN, MEOP = 1016 psi, thrust trace optimized for Ares I (53-06)
- EDS
 - 2 J-2S+ (451.5 sec) engines to 1 J-2X engine (448 sec)
- Other concept and analysis maturation
- 73.1 mt CaLV gross payload at TLI capability
- CxCB approval May 2006

◆ CARD Requirements and Groundrules Changes- Current Baseline Reference

- 14 Day Loiter Requirement Assumed (CARD TBD)
- TLI total $\Delta v = 10,417$ ft/sec
- FPR 2.4 mt propellant (400 ft/sec)
- Parking Orbit change (160 to 120 nmi)
- 64.6 mt CaLV gross payload at TLI capability



5 RS-68 Core, 5 Seg. SRB, 1 J-2X EDS 1.5 Launch TLI – 14 Day Loiter



Vehicle Concept Characteristics

EDS Stage 14 day Loiter

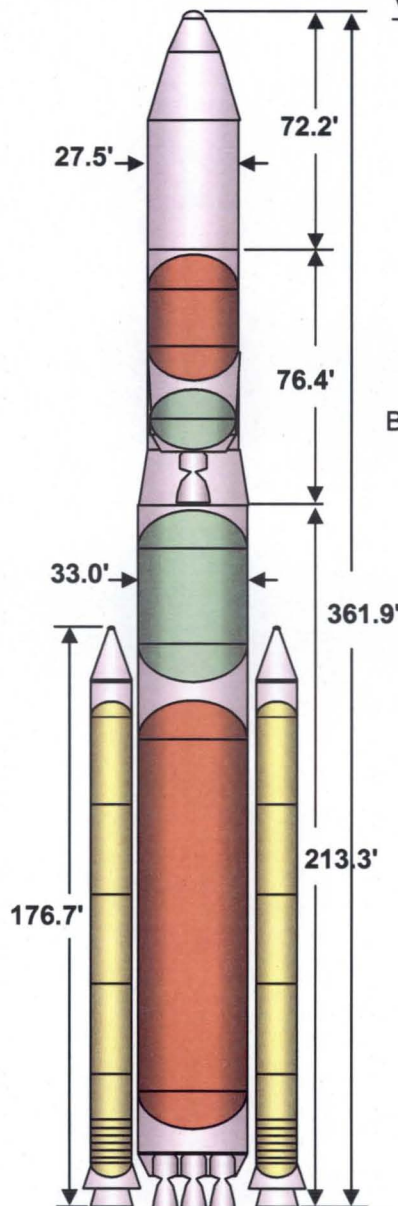
Propellants	LOX/LH2
Usable Propellant	492,753 lbm
Propellant Offload	0.0 %
Stage pmf	0.8853
Dry Mass	47,503 lbm
Burnout Mass	48,735 lbm
Suborbital Burn Mass	290,000 lbm
Pre-TLI Overboard Mass	9,757 lbm
FPR	5,319 lbm
# Engines / Type	1 / J-2X
Engine Thrust (100%)	294,000 lbf @ Vac
Engine Isp (100%)	448.0 sec @ Vac
Mission Power Level	100.0 %
Stage Burn Time	751.7 sec

Delivery Orbit 1.5 Launch TLI

LEO Delivery	120 nmi circular @ 28.5°
TLI Payload from 100 nmi	142,543 lbm 64.6 MT*
Performance Reserve	8,913 lbm 4.0 MT
CEV Payload Mass	44,500 lbm 20.2 MT
LSAM Payload Mass	89,130 lbm 40.4 MT
Insertion Altitude	122.0 nmi
T/W @ Liftoff	1.36
Max Dynamic Pressure	637 psf
Max g's Ascent Burn	3.86 g
T/W @ Booster Separation	1.35
T/W Second Stage	0.44
T/W @ TLI Ignition	0.75

Delivery Orbit

LEO Payload @ 120 nmi	283,913 lbm 128.8 MT
Single Launch Lunar Direct	119,521 lbm 54.2 MT



GLOW 7,326,376 lbf

Payload Envelope L x D	33.0 ft x 24.5 ft
Shroud Jettison Mass	12,868 lbm

Booster (each)

Propellants	PBAN (166-06 Trace)
Overboard Propellant	1,380,873 lbm
Stage pmf	0.8558
Burnout Mass	232,608 lbm
# Boosters / Type	2 / 5 Segment SRM
Booster Thrust (@ 0.7 sec)	3,510,791 lbf @ Vac
Booster Isp (@ 0.7 sec)	267.4 sec @ Vac
Burn Time	126.6 sec

Core Stage

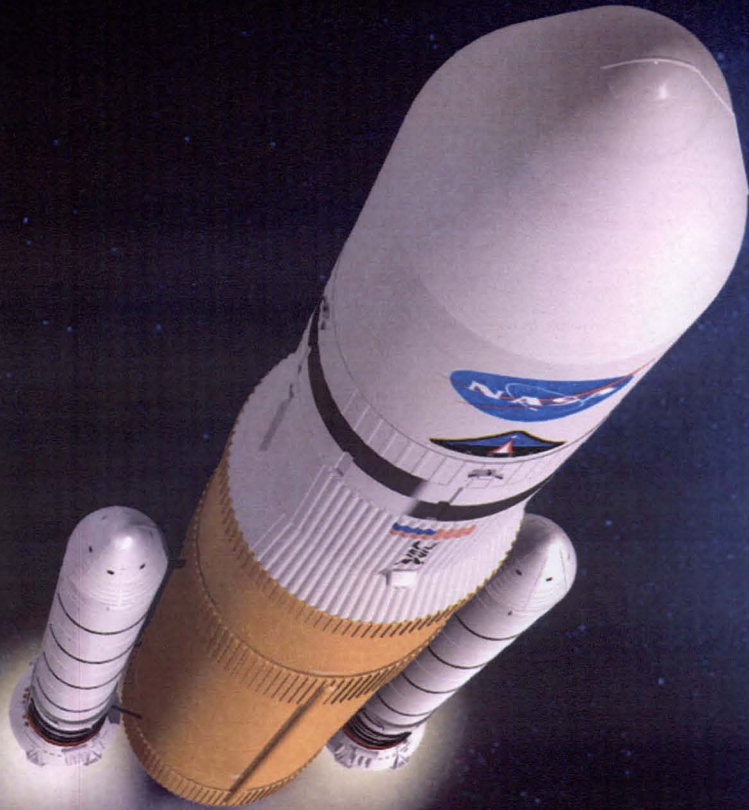
Propellants	LOX/LH2
Usable Propellant	3,078,410 lbm
Propellant Offload	0.0 %
Stage pmf	0.9017
Dry Mass	301,883 lbm
Burnout Mass	335,684 lbm
# Engines / Type	5 / RS-68
Engine Thrust (106%)	688,693 lbf @ SL 784,000 lbf @ Vac
Engine Isp (106%)	360.8 sec @ SL 414.2 sec @ Vac
Mission Power Level	106.0 %
Core Burn Time	325.3 sec

Interstage Core/EDS

Dry Mass	17,847 lbm
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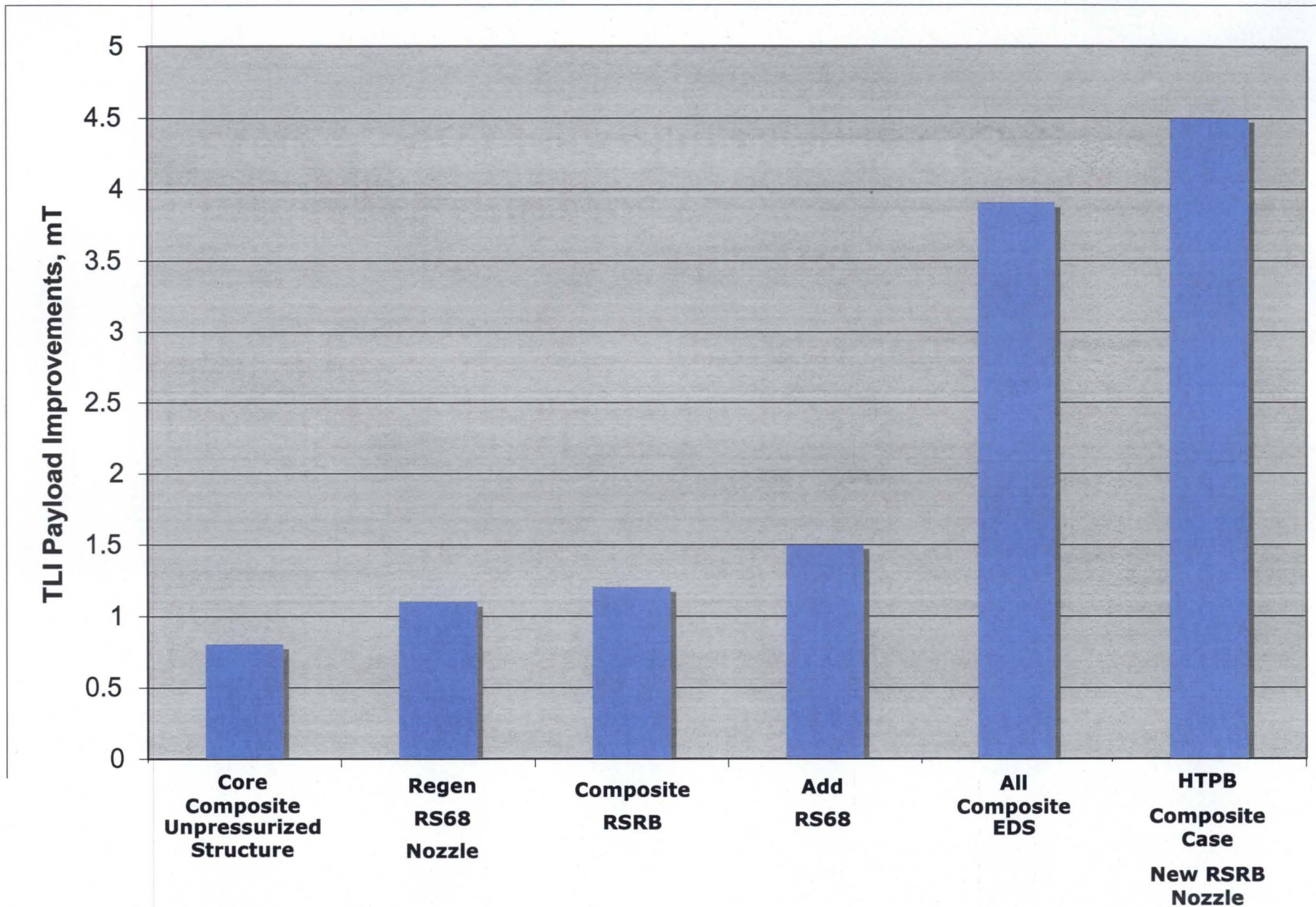
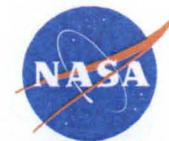
Vehicle Concept Analysis

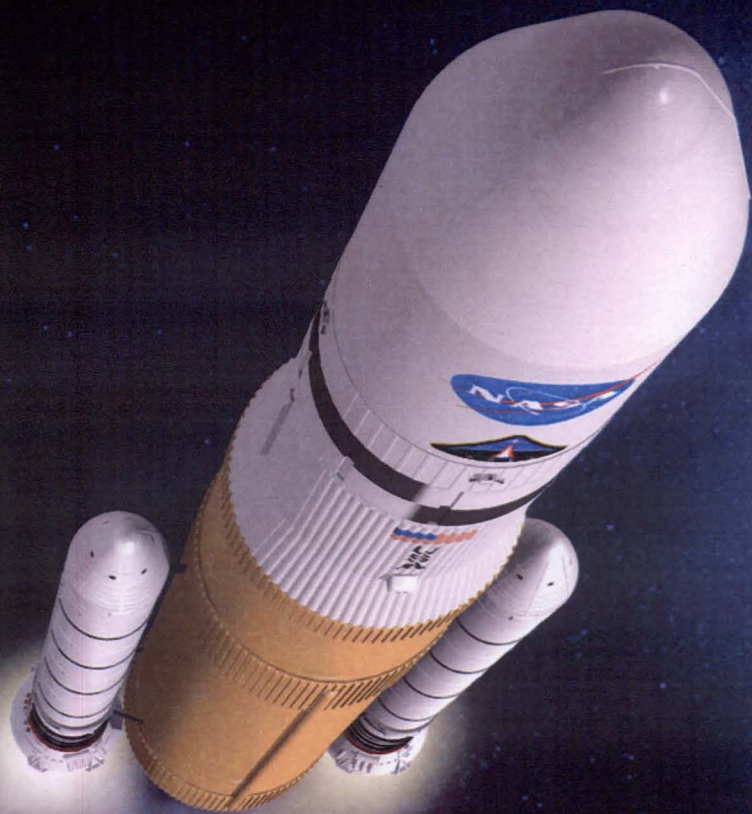
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Ares V Performance Improvement Options





Nosecone Analysis





Task Description



◆ Objective:

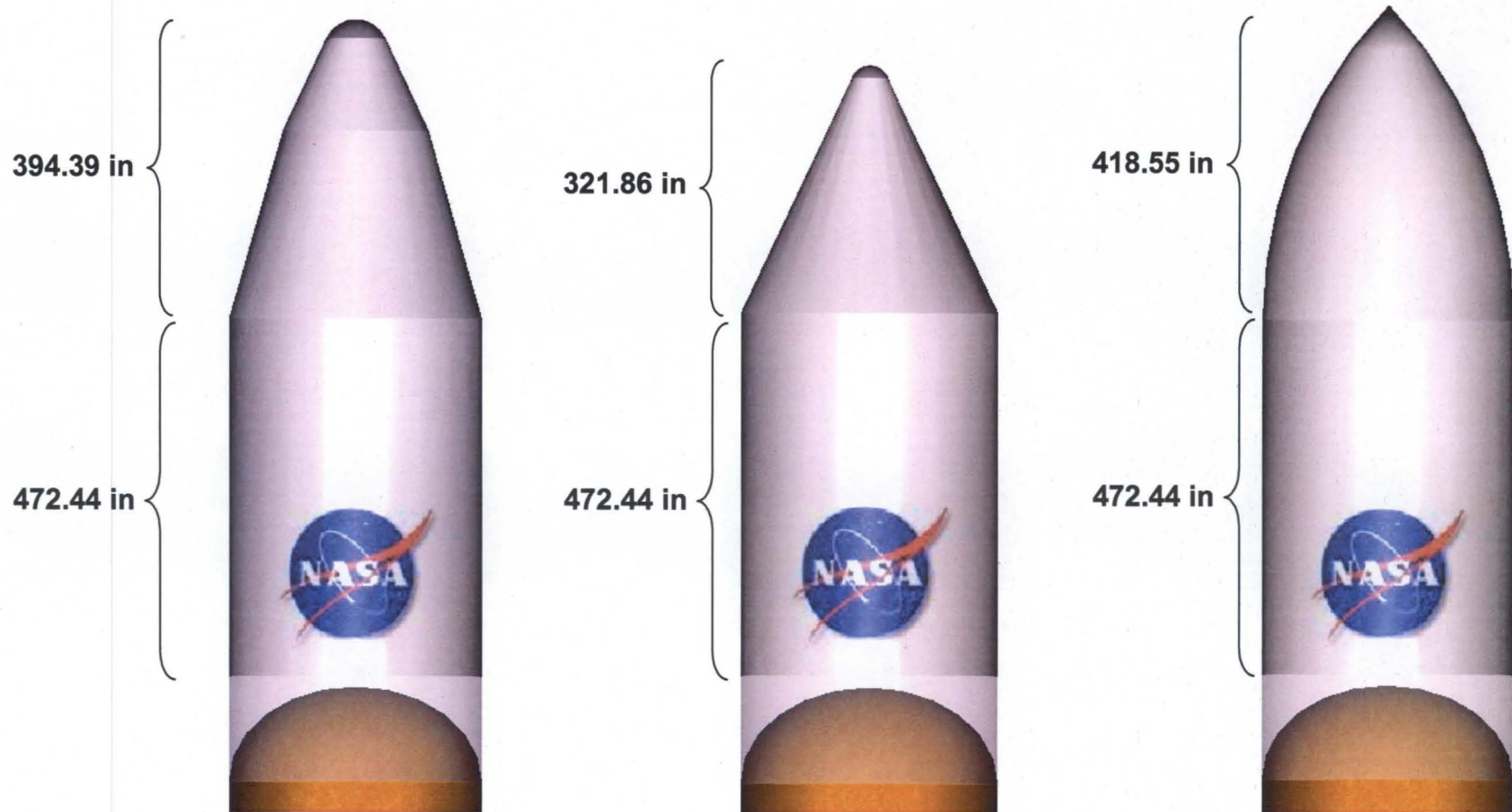
- Determine if a tangent ogive or single angle nosecone would yield better performance than the reference bi-conic angle nosecone for the reference Ares V concept

◆ Task

- Determine the relative performance of an Ares V vehicle equipped with a single angle nosecone and a tangent ogive nosecone
- Analysis includes updated aerodynamics, shroud masses, and resulting performance gains / losses



Shrouds Analyzed



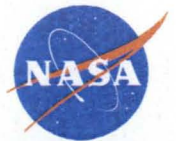
Reference Bi-conic
13,189 lbs

Single Angle
10,719 lbs

Ogive
14,922 lbs

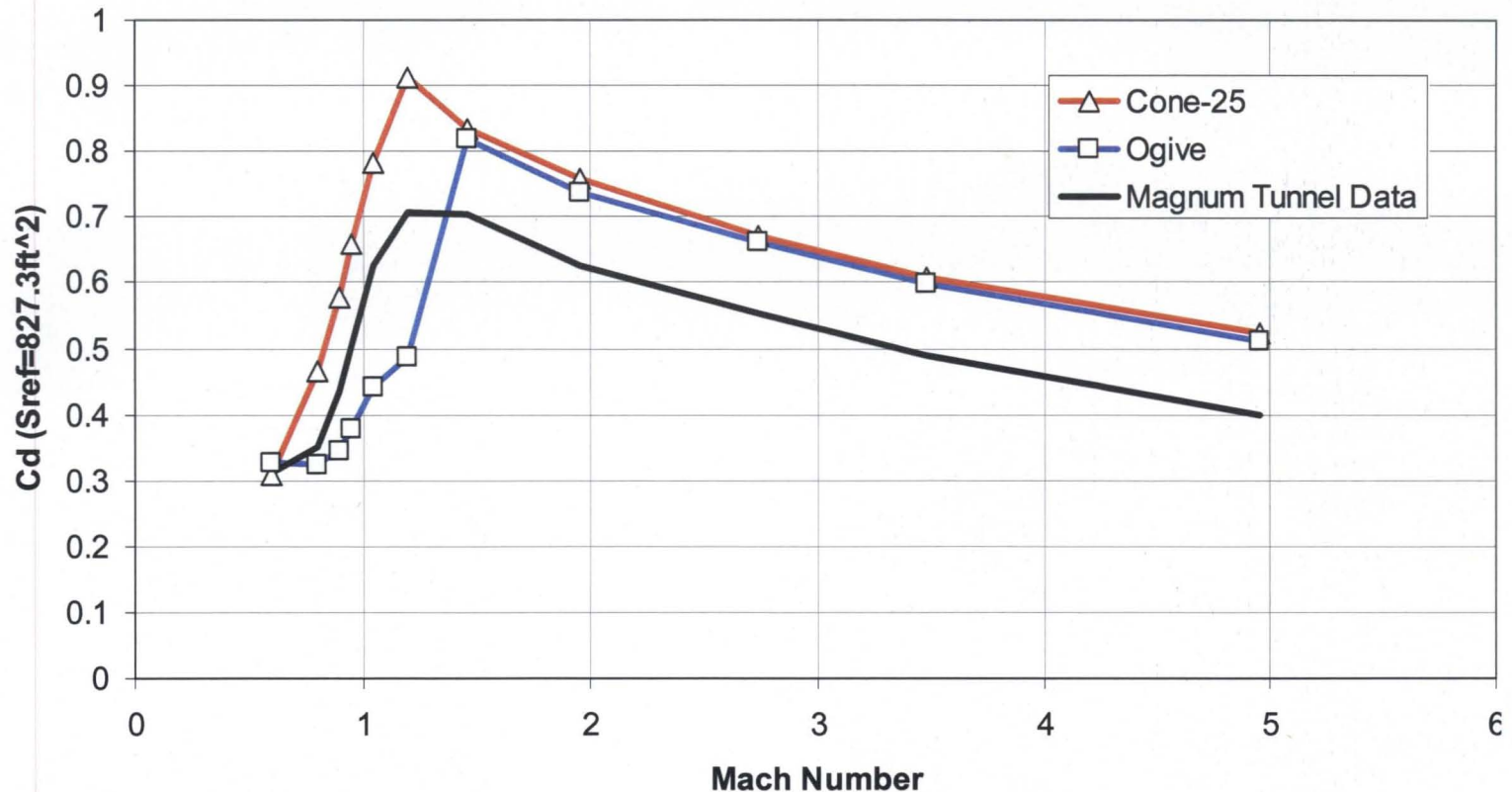


Alternate Nosecones / Aero



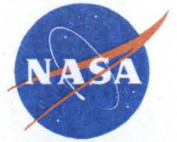
- ◆ Estimated drag for the Magnum vehicle with tangent ogive and conic nosecone, with SRB's attached.

Revised Drag of Core + Boosters of Magnum for Various Nose Cones





Alternate Nosecones / Summary



Bi-conic



Shroud Weight
13,189 lbs

Conic, 25-degree



Shroud Weight
10,719 lbs

Delta Payload to Reference
- 845 lbs injected LEO

Tangent Ogive



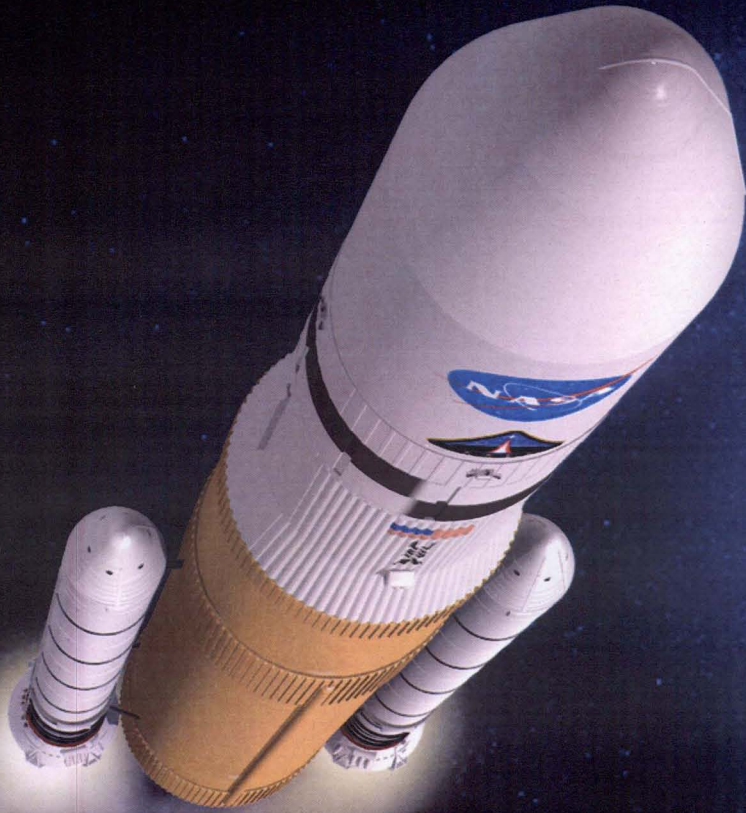
Shroud Weight
14,922 lbs

Delta Payload to Reference
- 1,168 lbs injected LEO

◆ The Reference Ares V Bi-conic nosecone exhibits...

- Highest injected payload mass to LEO
- Easier fabrication compared to ogive

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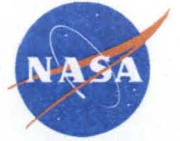
Payload Shroud Analysis

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Ares V Evaluating Multiple EDS/Shroud Configurations



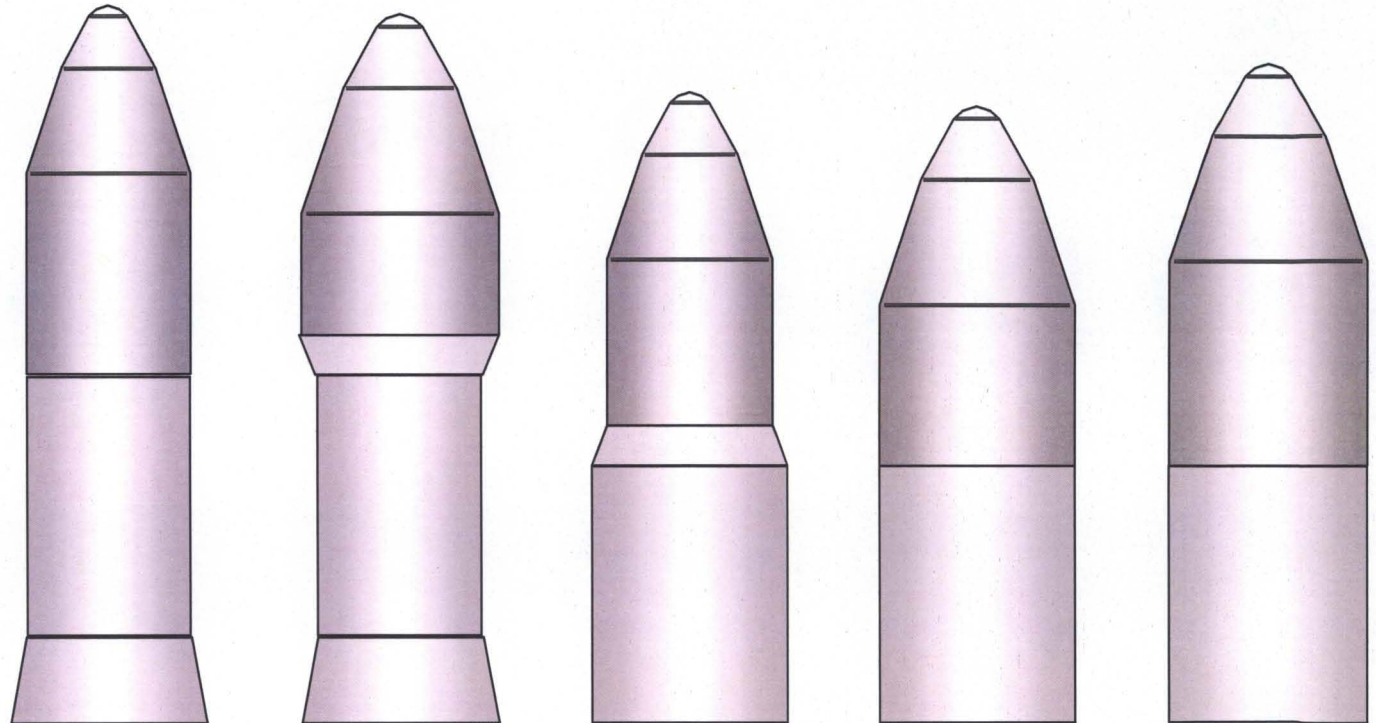
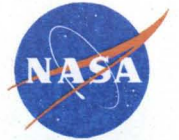
Option	EDS Diameter	Shroud Diameter	Usable Diameter	Usable Cylindrical Height
A Baseline	8.4m	8.4m	7.5m	10m
B	8.4m	10m	8.77m	7.31m
C	10m	8.4m	7.5m	10m
D	10m	10m	8.77m	7.31m
E	10m	10m	8.77m	9.31m



- ◆ Assumes 10m Short Shroud has same usable cylindrical volume as 8.4m Shroud: ~442m³



Results of Shroud and EDS Diameter Configuration Study- Preliminary Results



**Option A
(Baseline)**

**Option B
(Constant Volume as A)**

Option C

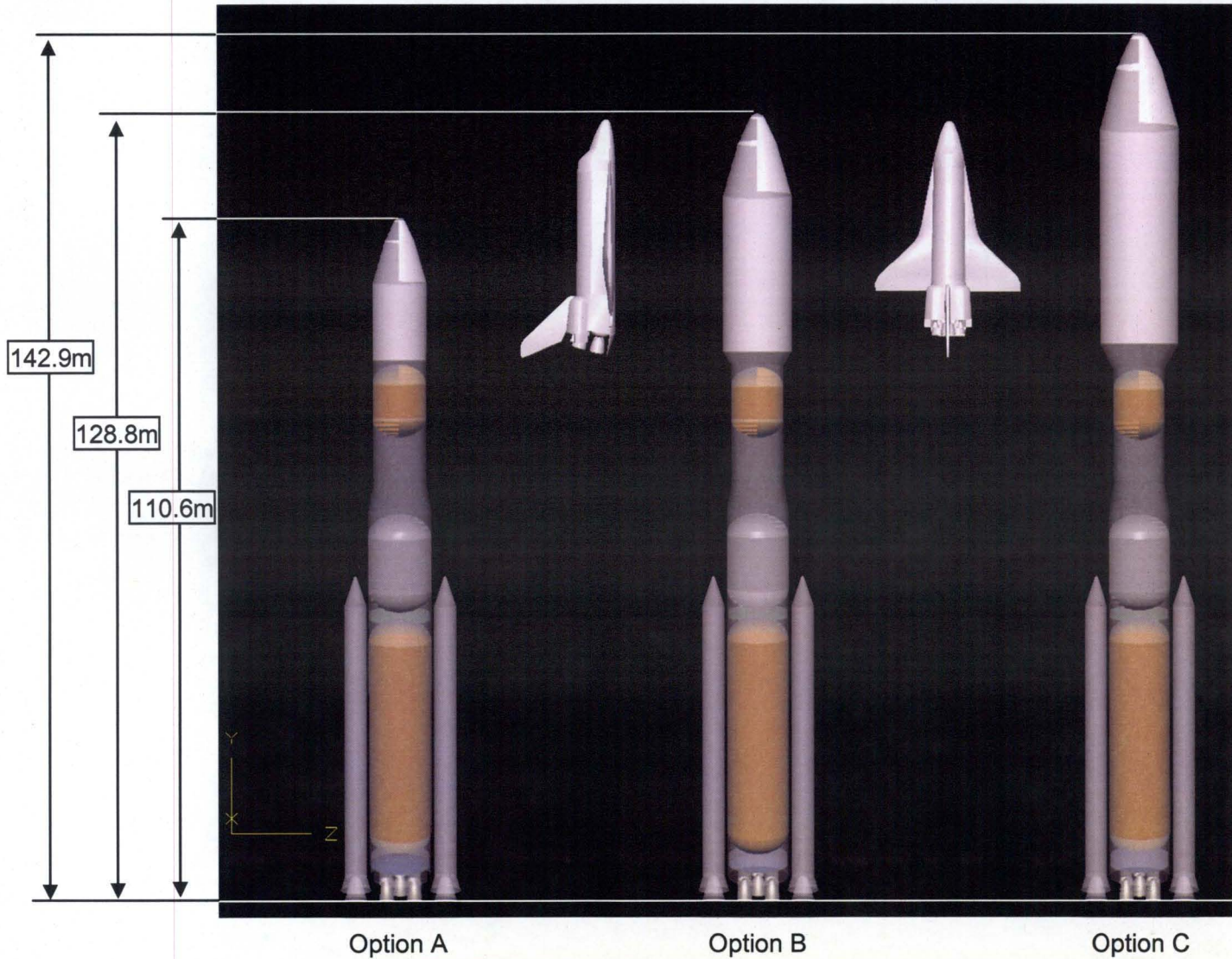
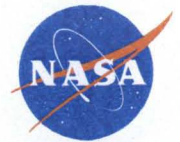
Option D

Option E

Shroud Diameter (Outside/Usable)	8.4m / 7.5m	10m / 8.77m	8.4m / 7.5m	10m / 8.77m	10m / 8.77m
Shroud Usable Cyl Length	10m	7.31m	10m	7.31m	9.31m
EDS Diameter	8.4m	8.4m	10m	10m	10m
TLI Payload Delta from Baseline	---	- 2.8 MT	- 0.7 MT	- 0.2 MT	- 0.5 MT



Ares V Mars Missions Drive Towards Larger Shroud Volumes



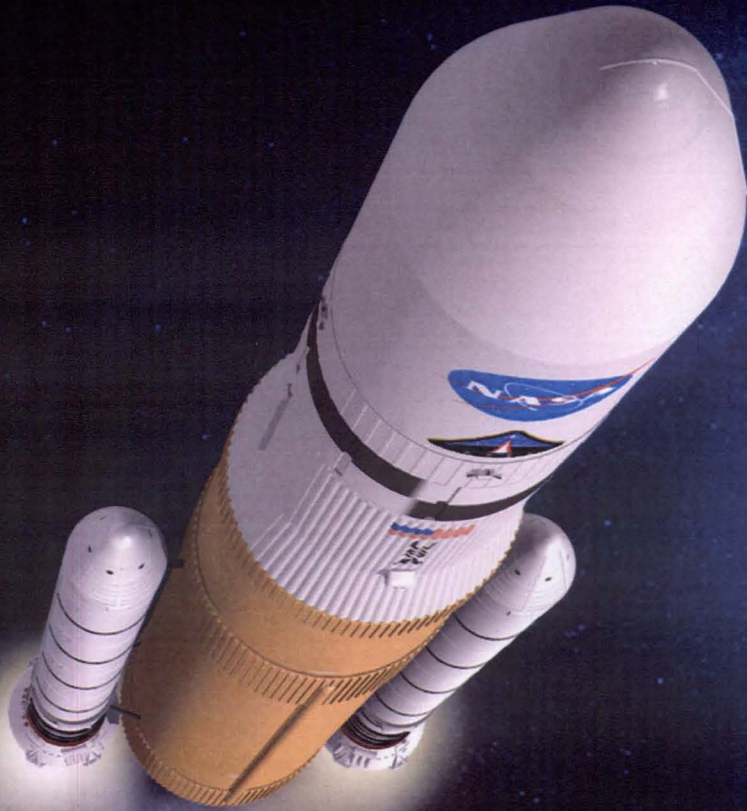
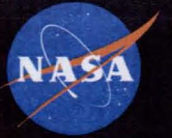
Option A (Baseline):
7.5m Inner Diameter
12m Barrel Length

Option B:
10m Inner Diameter
25m Barrel Length

Option C:
12m Inner Diameter
35m Barrel Length

**Current VAB door height clearance is approximately 122 m
Larger Shrouds Can almost encapsulate the Shuttle Orbiter**

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Conclusions

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Conclusions



- ◆ **Ares V Lift Requirement Needs to Be Better Understood and Defined**
- ◆ **Performance Enhancements have been Identified that Cover the Range of Anticipated Performance Needs Based on CARD Requirements and Lunar Architecture Team (LAT2) Results**
- ◆ **Bi-conic Nosecone confirmed as configuration of choice**
- ◆ **Common EDS Diameter and Payload Shroud Diameter is Optimal**