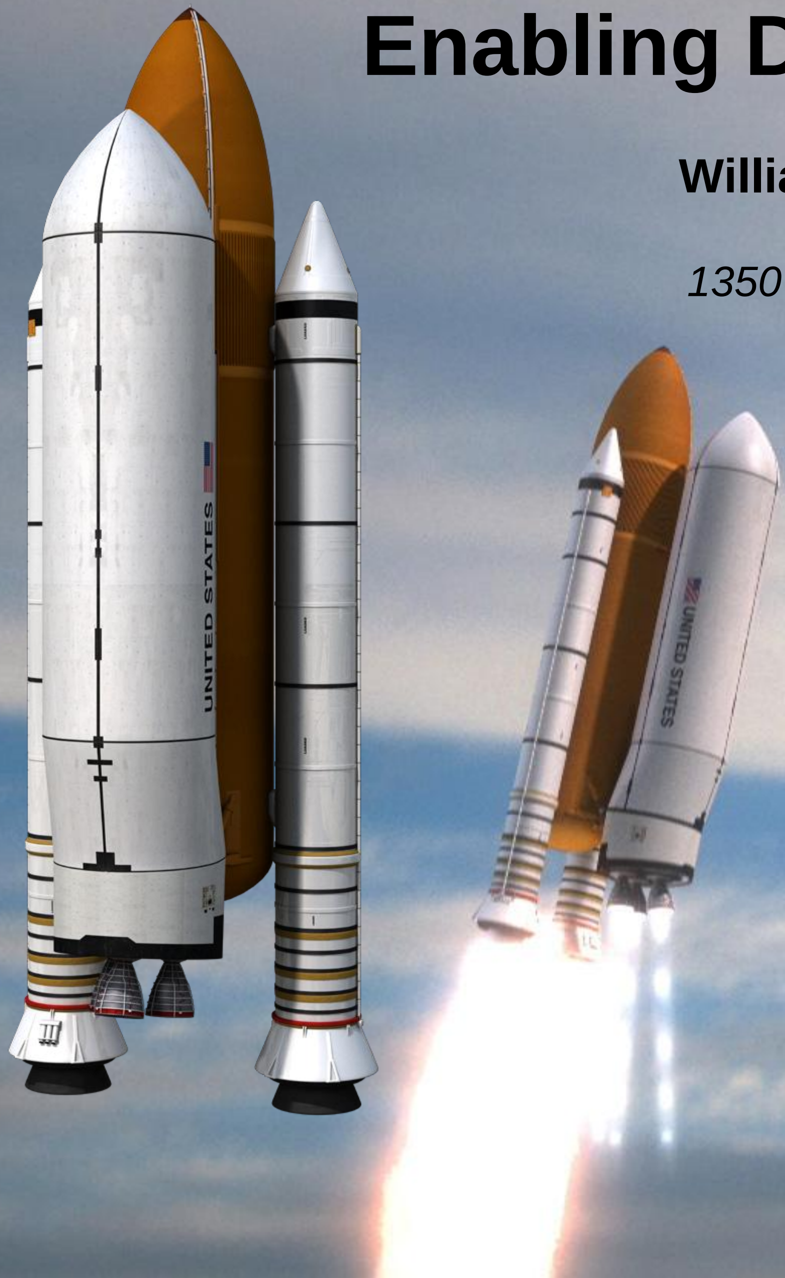
# A Foundational Heavy Lift Launch Vehicle Enabling Deep Space Missions



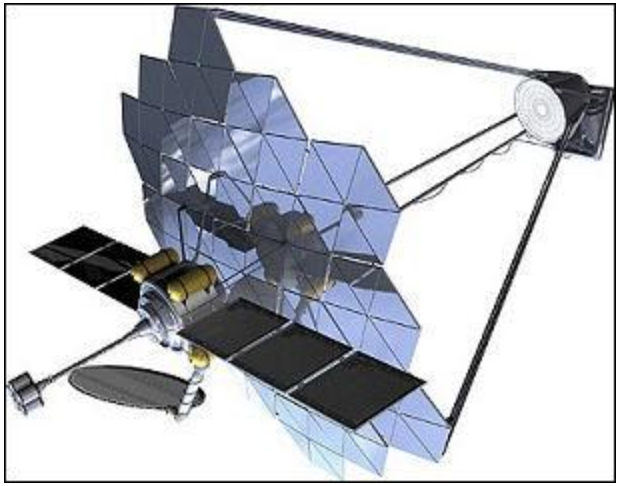
**William J. Rothschild and Theodore A. Talay**
*John Frassanito & Associates, Inc.*
*1350 NASA Parkway, Suite 214, Houston, TX 77058*

**Edward M. Henderson**
*NASA John Space Center, Houston, TX*

**Presented at the**
**46th Joint Propulsion Conference**
**Nashville, TN**
**July, 2010**

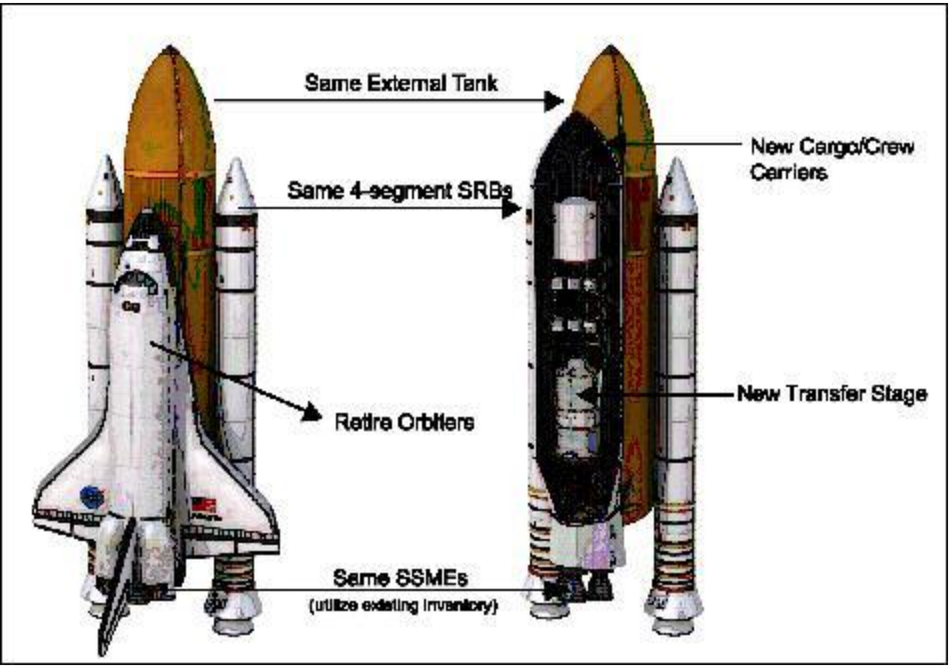
JF&A
Strategic Visualization ®

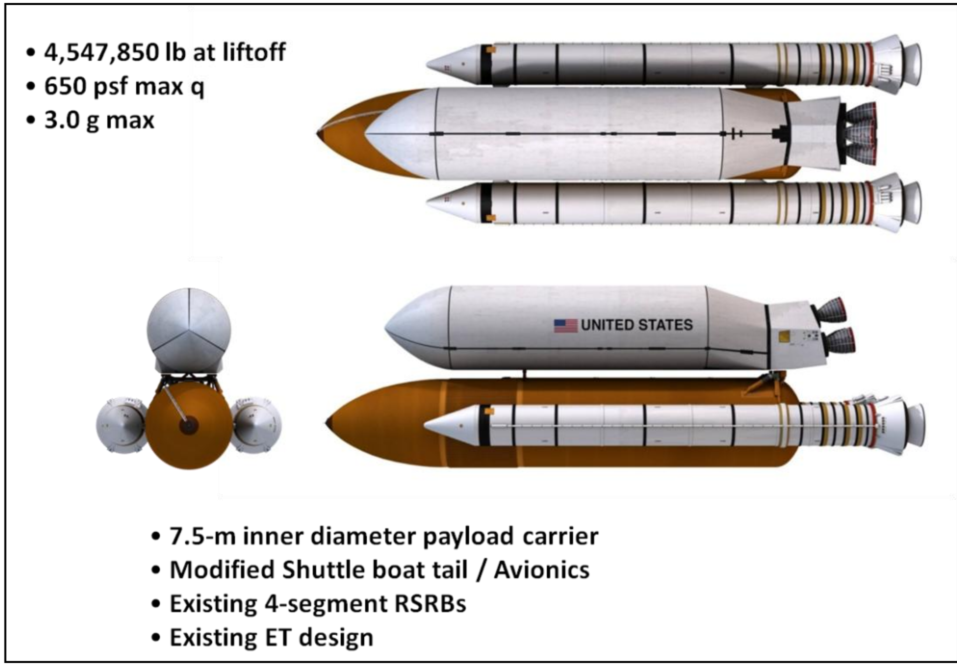
# Presentation Outline



- Heavy Lift Launch Vehicle Description
- Deep Space Missions
- Schedule, Costs & Risks
- Summary

# Using Existing Shuttle Elements Provides Early Heavy Lift Capability With Very High Confidence





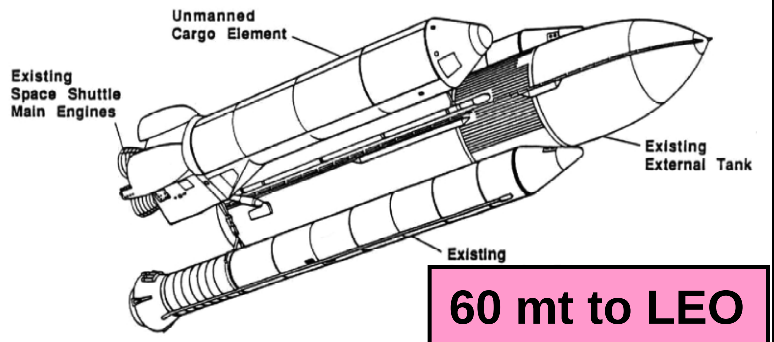
- 4,547,850 lb at liftoff
- 650 psf max q
- 3.0 g max

- 7.5-m inner diameter payload carrier
- Modified Shuttle boat tail / Avionics
- Existing 4-segment RSRBs
- Existing ET design

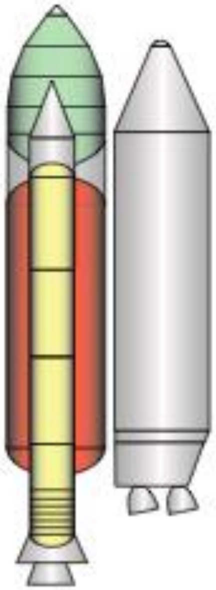
**The Heavy-lift Launch Vehicle (HLV) enables a wide range of useful missions**

# Side-Mounted Shuttle Derived Vehicle Concepts Have Matured Thru Several Major Design Studies

**1990's NASA sponsored Shuttle C**



**60 mt to LEO**

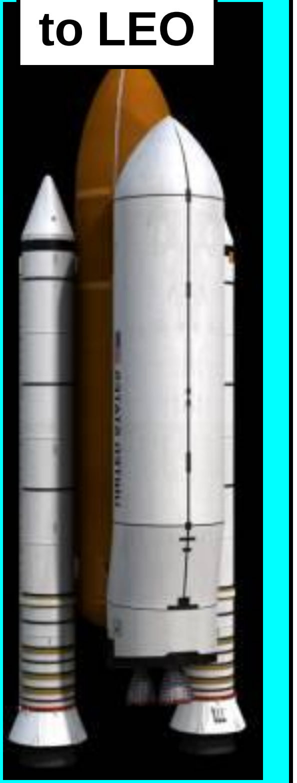


**2005**
**Exploration Systems Architecture Study (ESAS)**

**66 mt to LEO**

**68 mt to LEO**

**2004 - 2005**
**Shuttle Derived Launch Vehicle Industry Team Concept B**

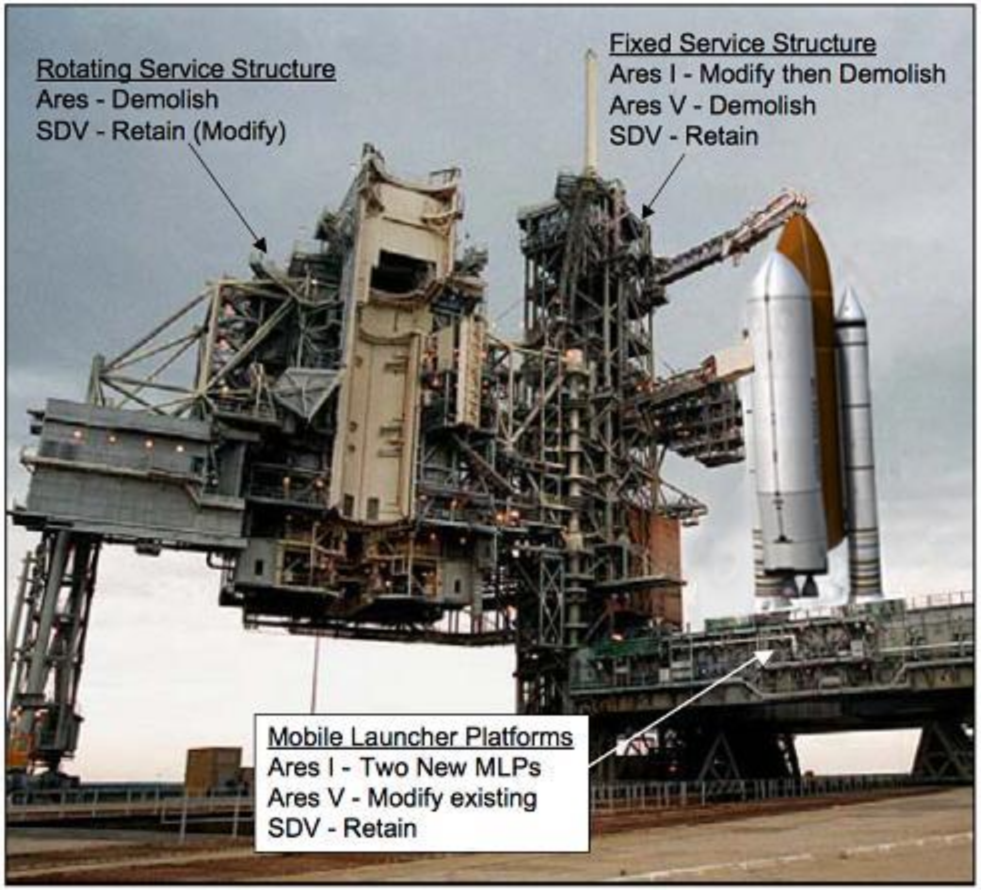


**72 mt to LEO**

**2009**
**HLV Concept**

**All performance values are net payload to 120 nm circular orbit at 28.5 deg inclination (consistent 10% performance reserve)**

# HLV Uses Existing Facilities & Infrastructure With Very Few Modifications



Rotating Service Structure
Ares - Demolish
SDV - Retain (Modify)

Fixed Service Structure
Ares I - Modify then Demolish
Ares V - Demolish
SDV - Retain

Mobile Launcher Platforms
Ares I - Two New MLPs
Ares V - Modify existing
SDV - Retain

# HLV Performance Is Based On Well Proven Shuttle Elements

Overall height: 184 ft

Jettison carrier aero fairings (26,004 lbm)
at 238.4 sec @ 356 kft
Heating Rate = 0.1 BTU/ft²-sec

| **Trajectory Parameters** | LEO Mission |
|---|---|
| Injection Orbit | 30 x 120 nmi @ 29.0° |
| Insertion Altitude | 78.3 nmi |
| T/W @ Liftoff + 1 sec | 1.53 |
| Max Dynamic Pressure | 650 psf |
| Max g's Ascent Burn | 3.00 g |
| T/W @ SRB Separation | 0.93 |

## Vehicle Concept Characteristics

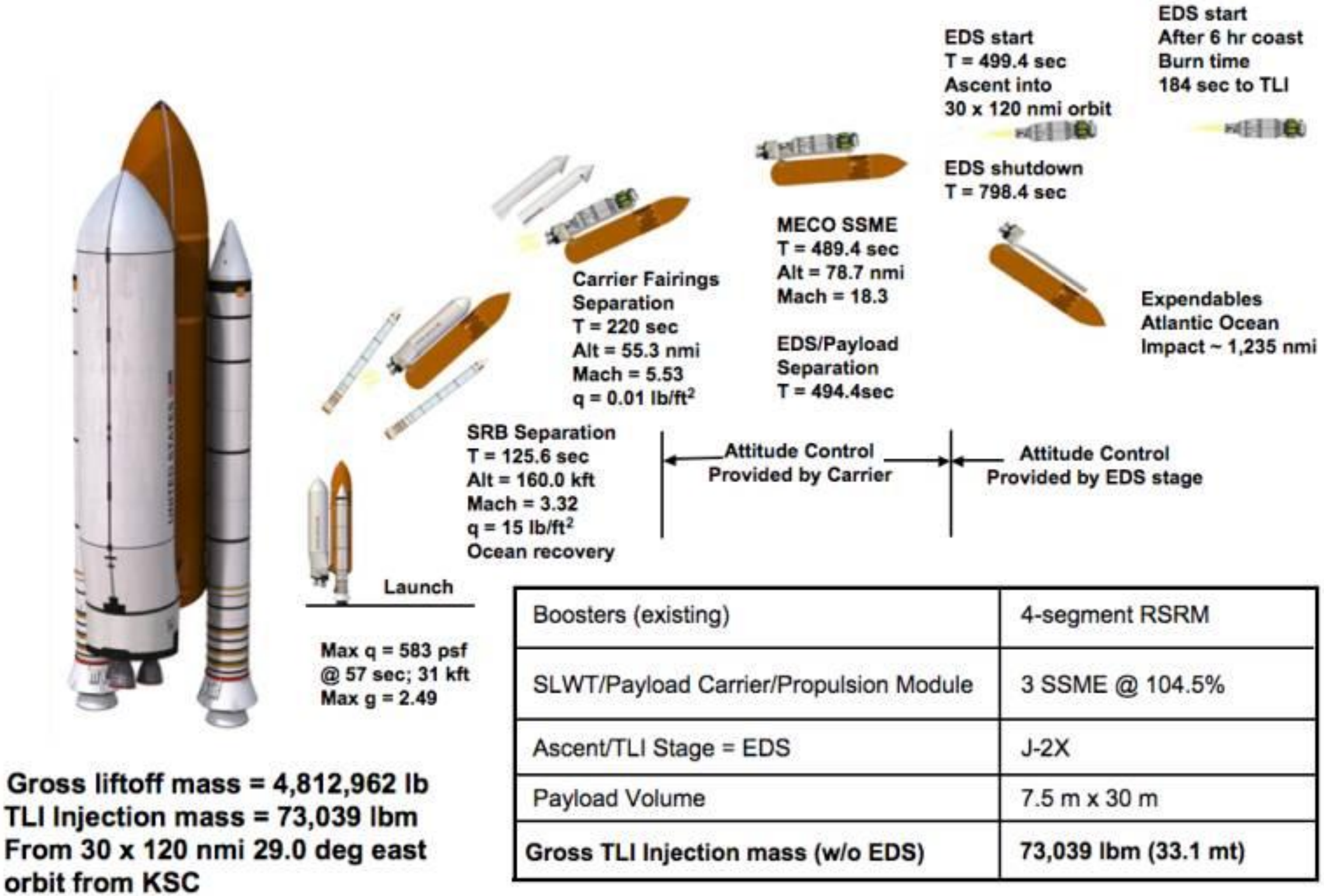
| | |
|---|---|
| **GLOW** | **4,547,850 lbf** |
| Carrier Dynamic Envelope L x D | 98.4 ft x 24.6 ft |
| Carrier Jettison Mass | 26,044 lbm |
| **Booster (each)** | |
| Propellants | PBAN (074-99 Trace) |
| Overboard Propellant | 1,111,604 lbm |
| Burnout Mass | 186,863 lbm |
| # Boosters / Type | 2 / 4 Segment SRM |
| Booster Thrust (@ 1.0 sec) | 3,117,005 lbf @ Vac |
| Booster Isp (@ 1.0 sec) | 266.9 sec @ Vac |
| Burn Time | 125.6 sec |
| **Tankage** | |
| Propellants | LOX/LH2 |
| Nominal Ascent Propellant | 1,589,784 lbm |
| Dry Mass | 60,700 lbm |
| Burnout Mass | 74,311 lbm |
| **Carrier** | |
| Dry Mass | 107,466 lbm |
| Burnout Mass | 81,422 lbm |
| # Engines / Type | 3 / SSME BLK II |
| Engine Thrust (104.5%) | 396,236 lbf @ SL<br>492,230 lbf @ Vac |
| Engine Isp (104.5%) | 363.5 sec @ SL<br>452.8 sec @ Vac |
| Mission Power Level | 104.5 % |
| Burn Time | 507.6 sec |

**Reference Orbit 30 x 120 nmi @ 29.0 deg**
**Gross delivered 179,354 lbm (81.4 mt)**

**Reference Orbit 120 x 120 nmi @ 29.0 deg**
**Gross delivered 176,154 lbm (79.9 mt)**

**HLV delivers 72 mt to LEO**
**(plus a 10% performance reserve)**

# HLV Has A Benign Ascent Trajectory
# Suborbital Staging Provides Additional Payload



Launch

Max q = 583 psf
@ 57 sec; 31 kft
Max g = 2.49

SRB Separation
T = 125.6 sec
Alt = 160.0 kft
Mach = 3.32
$q = 15\ \mathrm{lb/ft^2}$
Ocean recovery

Carrier Fairings
Separation
T = 220 sec
Alt = 55.3 nmi
Mach = 5.53
$q = 0.01\ \mathrm{lb/ft^2}$

MECO SSME
T = 489.4 sec
Alt = 78.7 nmi
Mach = 18.3

EDS/Payload
Separation
T = 494.4sec

EDS start
T = 499.4 sec
Ascent into
30 x 120 nmi orbit

EDS shutdown
T = 798.4 sec

EDS start
After 6 hr coast
Burn time
184 sec to TLI

Expendables
Atlantic Ocean
Impact ~ 1,235 nmi

Attitude Control
Provided by Carrier

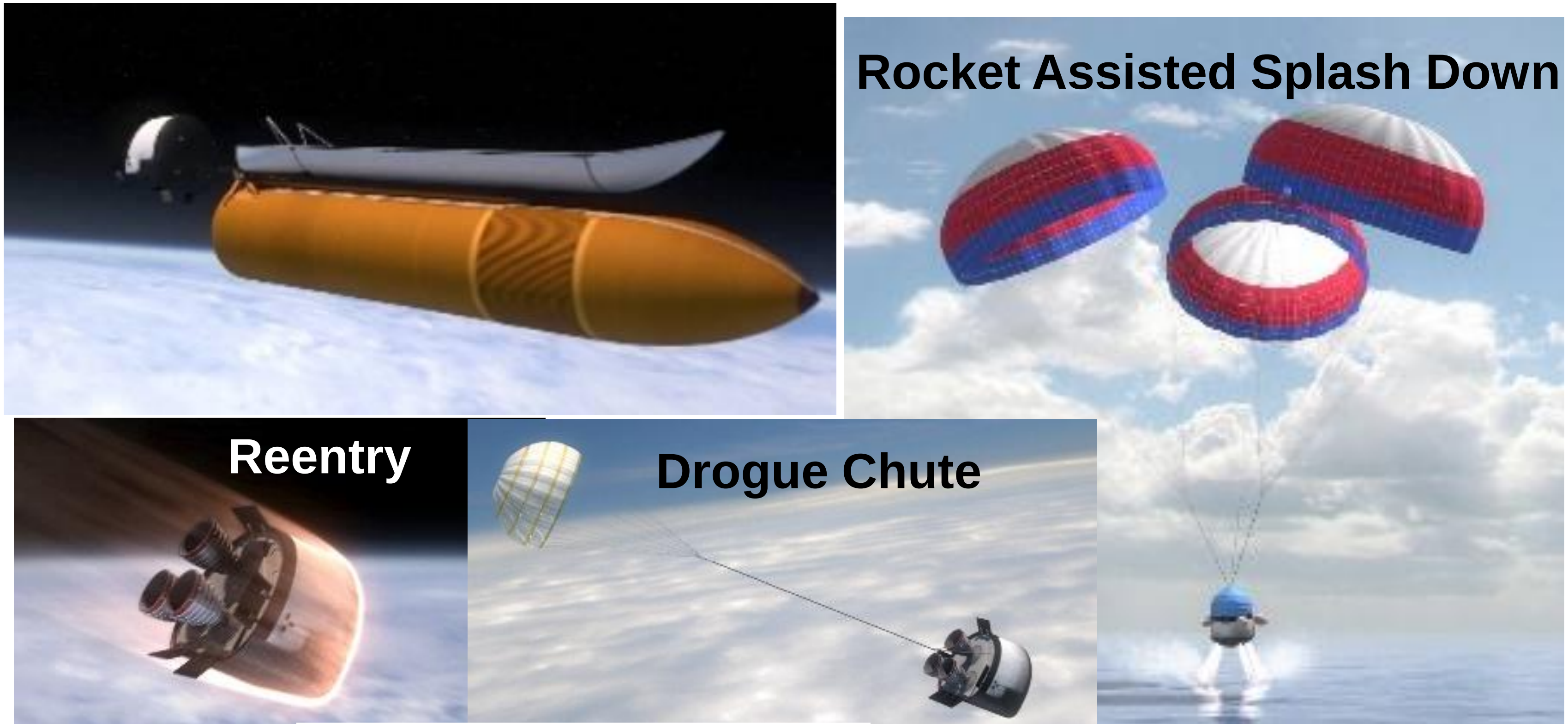
Attitude Control
Provided by EDS stage

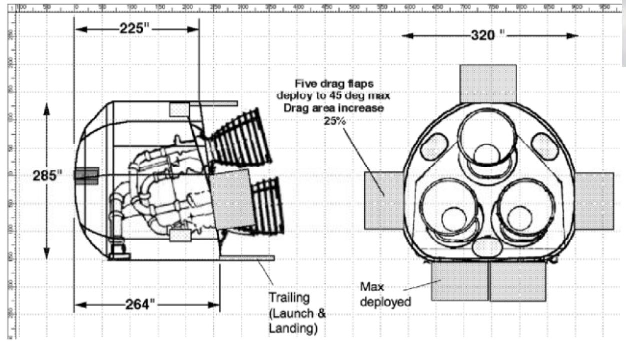
Gross liftoff mass = 4,812,962 lb
TLI Injection mass = 73,039 lbm
From 30 x 120 nmi 29.0 deg east
orbit from KSC

| | |
|---|---|
| Boosters (existing) | 4-segment RSRM |
| SLWT/Payload Carrier/Propulsion Module | 3 SSME @ 104.5% |
| Ascent/TLI Stage = EDS | J-2X |
| Payload Volume | 7.5 m x 30 m |
| **Gross TLI Injection mass (w/o EDS)** | **73,039 lbm (33.1 mt)** |

**HLV delivers 33.1 mt to TLI**
**(plus a 10% performance reserve)**

# HLV Recoverable Propulsion/Avionics Module (PAM) Based on a Successful Flight Demonstration





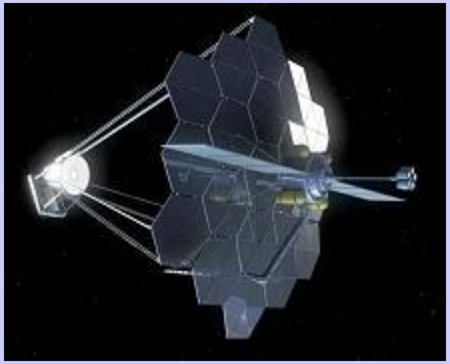
Drag flaps added to reduce max entry g's and control entry

- Gross mass = 69,164 lbm
- Staging Mach 24
- Downrange landing = 2,400 nmi
- DDT&E ~ $1 B
- Recurring costs ~ $25 M per flight
- Savings per flight (4 fpy) ~ $175 M

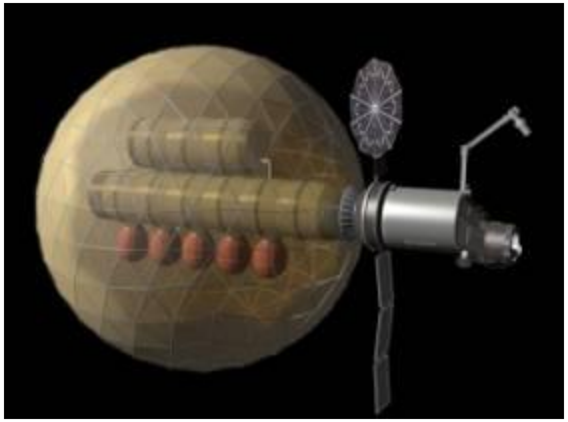
# Potential HLV Missions

ISS Upgrades & Logistics Support
(45 mt per HLV launch)

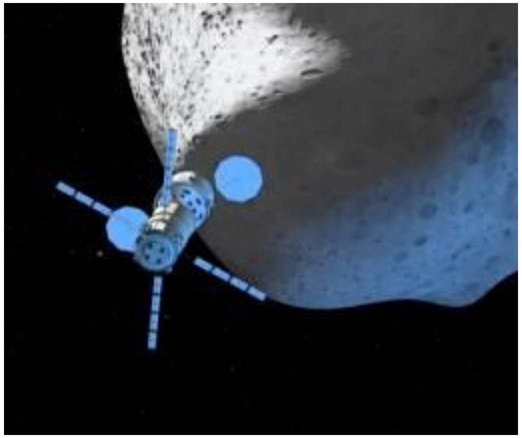
Lunar Robotic Landers
(10 mt landed on the moon)



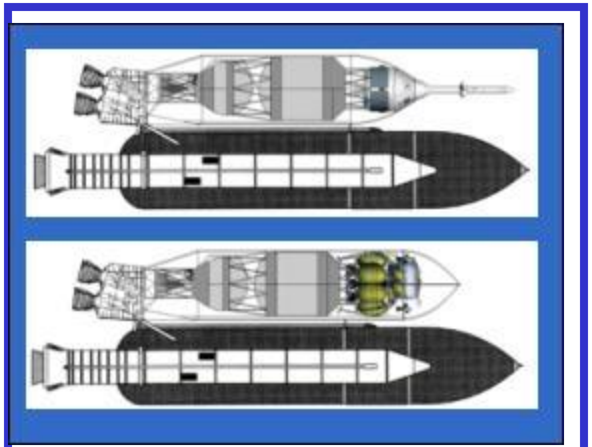
1 MW Space Solar Power Prototype
(30 mt to GEO)



Propellant Depot at L-1
(20 mT to  L-1)

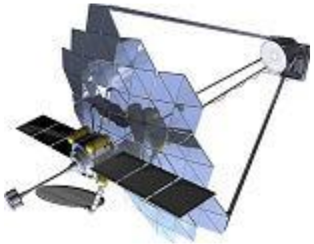


Crew of 4 to a NEO
(2 HLV launches = 66 mt to TLI)

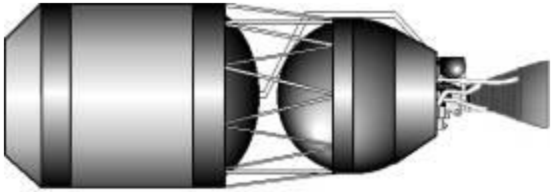


Human Lunar Missions
(2 HLV launches = 66 mt to TLI)

# HLV Launch Configuration
# For Space Solar Power Satellite Demo



| HLV w/SPS Demo | Mass, lbm | Mass, kg |
|---|---|---|
| | | |
| Payload - SPS Demo w/Electric Stage | 100,001 | 45,352 |
| | | |
| Carrier/Prop + EDS | 488,132 | 221,375 |
| Payload Carrier | 44,180 | 20,036 |
| Prop/Avionics Module | 69,164 | 31,367 |
| Aft payload adapter | 9,800 | 4,444 |
| EDS stage | 364,988 | 165,527 |
| EDS usable propellant | 327,046 | 148,320 |
| EDS inert | 37,942 | 17,207 |
| | | |
| External tank | 1,664,095 | 754,692 |
| ET empty | 60,700 | 27,528 |
| Residuals | 13,611 | 6,173 |
| Usable Propellant | 1,589,784 | 720,990 |
| | | |
| SRB Gross | 2,596,932 | 1,177,747 |
| SRB Separation | 385,227 | 174,706 |
| SRB Usable Propellant | 2,211,705 | 1,003,041 |
| | | |
| Total Liftoff | 4,849,160 | 2,199,166 |



**Ascent/Earth Departure Stage**

**Thrust, vac = 293,750 lbf; Isp = 448 sec**

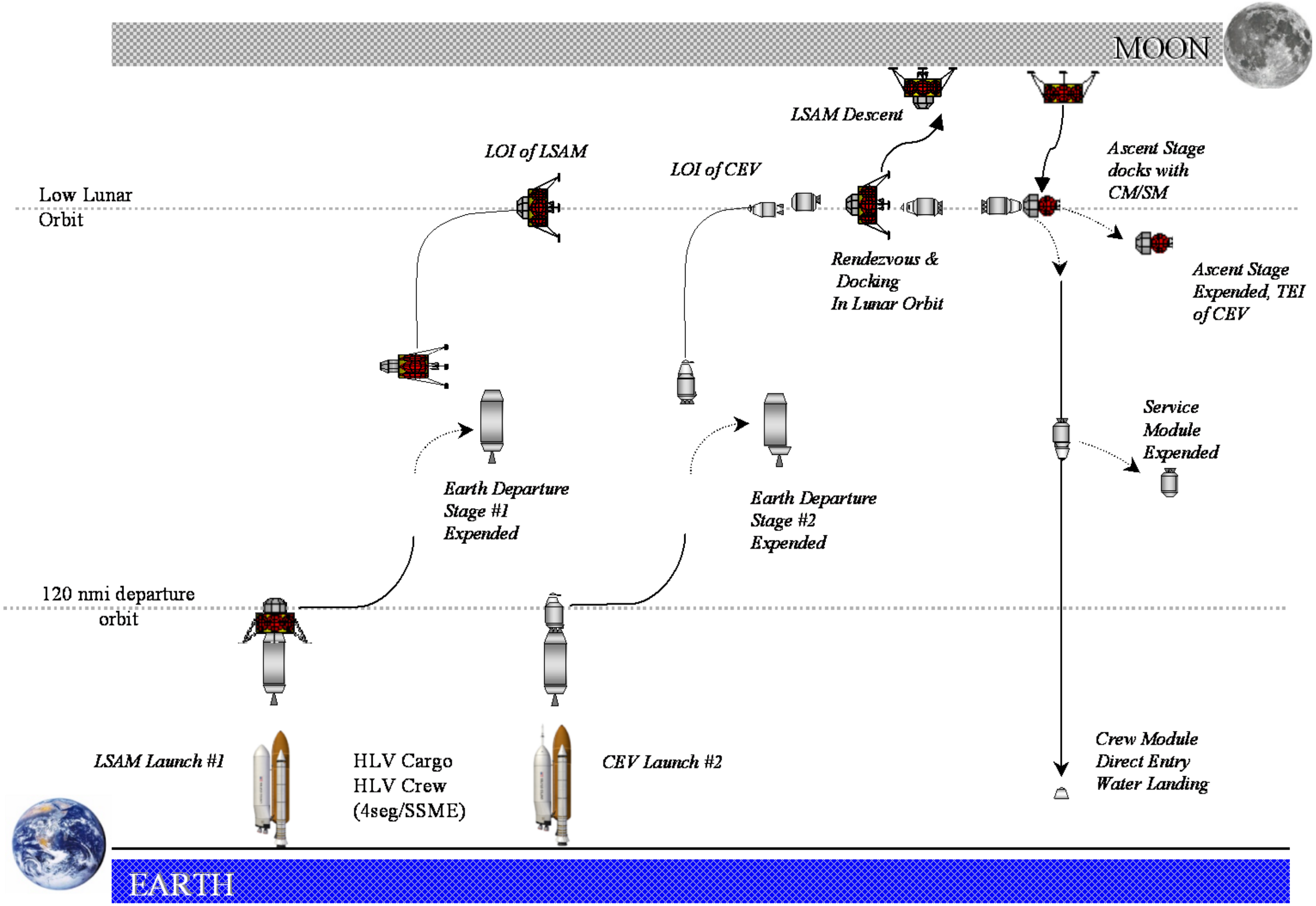
**Total stage mass = 364,988 lbm**

**Stage inert mass = 37,942 lbm**

**Propellant mass fraction = 0.896**

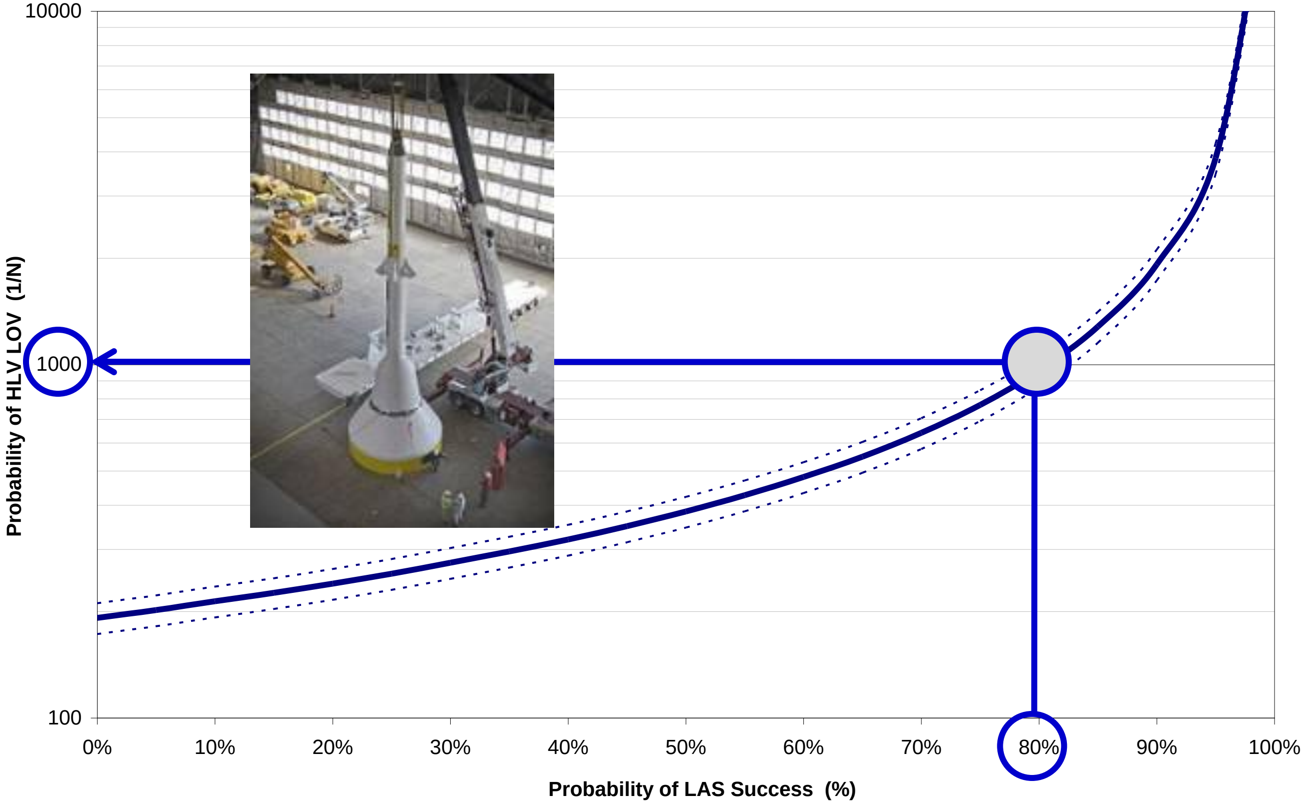
**HLV with an Earth Departure Stage delivers 45.4 mt to orbit beyond the Van Allen Belts (plus a 10% performance reserve)**

# A Pair of HLV Launches Satisfies The ESAS Requirements For Human Lunar Missions



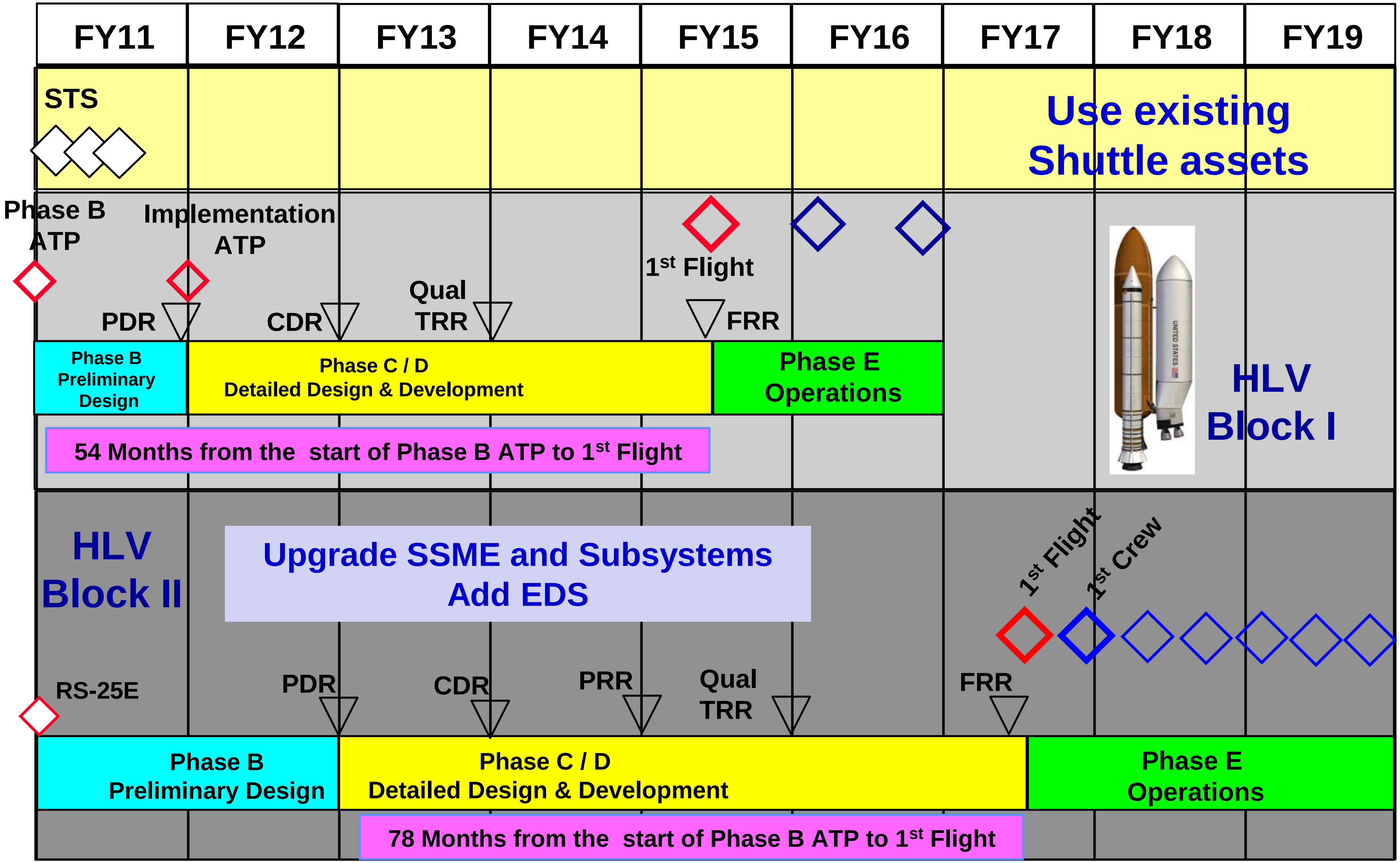
**HLV could deliver an LSAM twice the size of the Apollo LEM For Lunar Orbit Rendezvous with an Orion capsule**

# HLV Offers A Significant Improvement In Reliability and Safety Over the Shuttle



**Based on flight proven Shuttle reliability data and an assumed 80% success rate for the Launch Abort System, the HLV Loss of Crew Rate is estimated to achieve the NASA goal of 1/1,000.**

# HLV Development Plan



FY11 FY12 FY13 FY14 FY15 FY16 FY17 FY18 FY19

STS

Use existing Shuttle assets

Phase B ATP

Implementation ATP

1st Flight

PDR

CDR

Qual TRR

FRR

Phase B Preliminary Design

Phase C / D Detailed Design & Development

Phase E Operations

54 Months from the start of Phase B ATP to 1st Flight

HLV Block I

HLV Block II

Upgrade SSME and Subsystems
Add EDS

1st Flight

1st Crew

RS-25E

PDR

CDR

PRR

Qual TRR

FRR

Phase B Preliminary Design

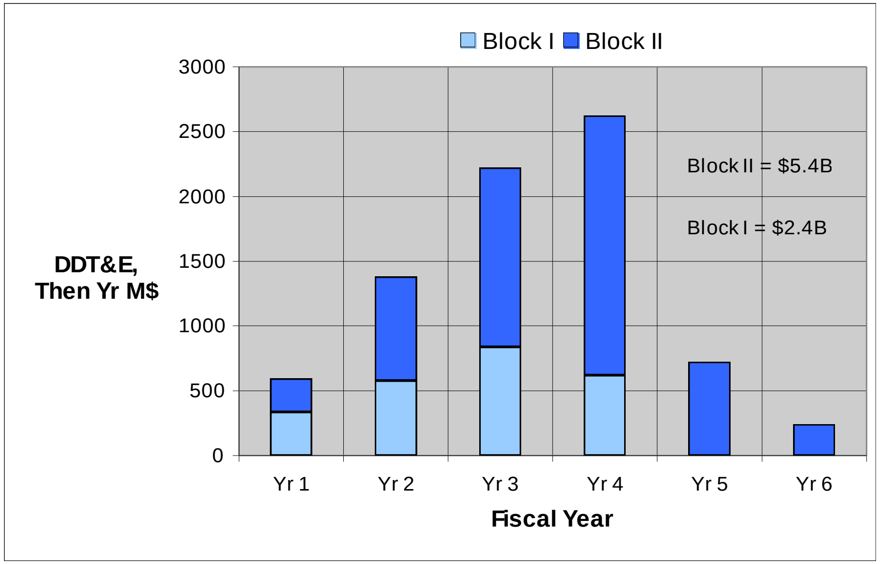
Phase C / D Detailed Design & Development

Phase E Operations

78 Months from the start of Phase B ATP to 1st Flight

**HLV could be ready to launch within 5 years**

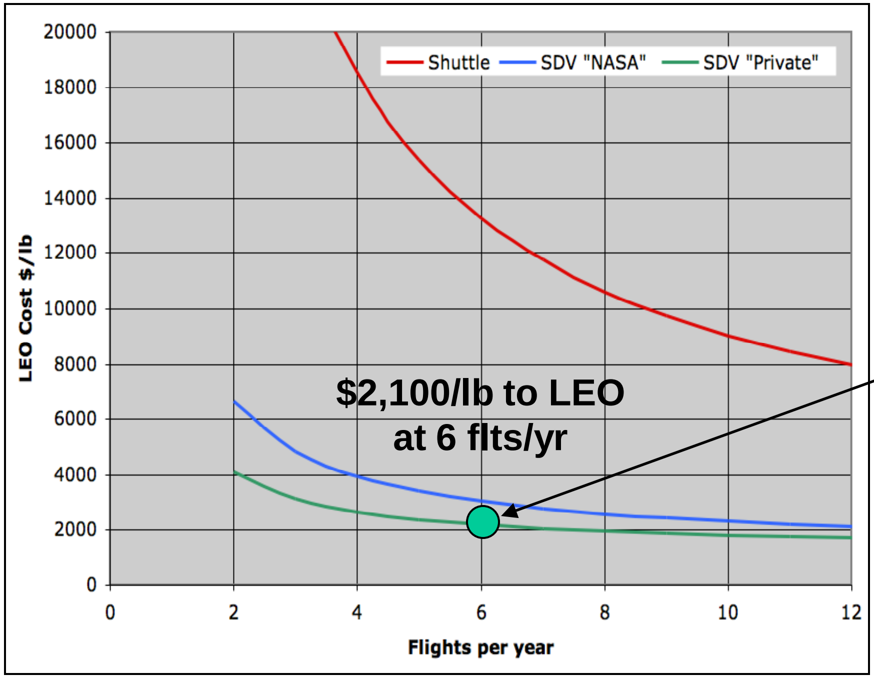
# HLV Cost Estimates Are Affordable



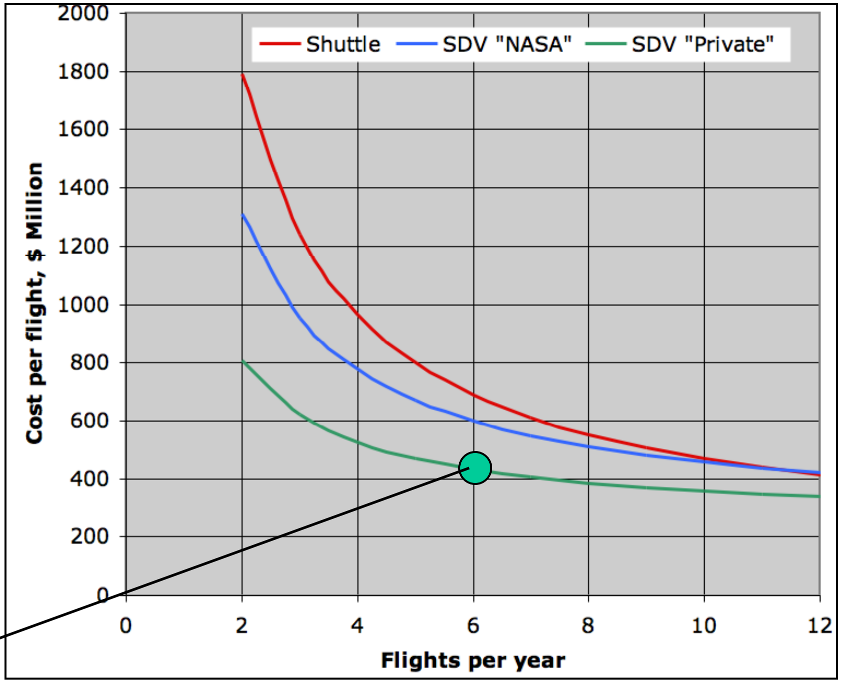
Block II = $5.4B

Block I = $2.4B

**DDT&E Cost < $8B including an Earth Departure Stage**

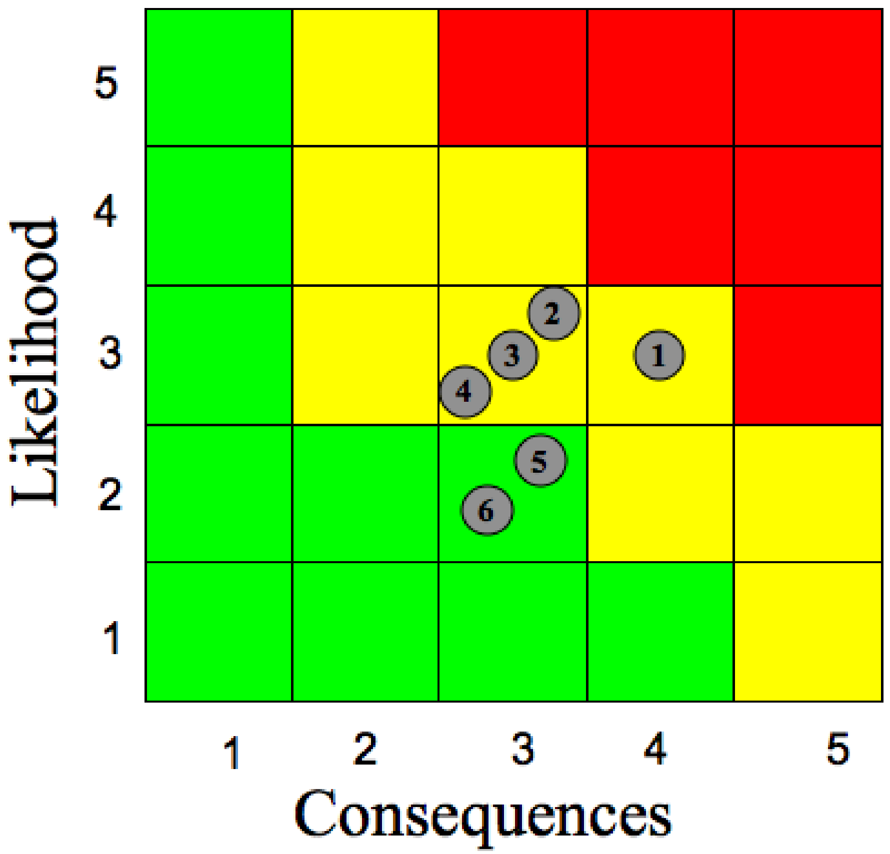


**$2,100/lb to LEO at 6 flts/yr**



**Ops Cost < $500M/flt at 6 per year (Commercial Launch Services)**

# HLV is Based on Mature Systems And Processes Offering Low Risks



1. Rehosting Shuttle flight software into new computer hardware and code.
2. Availability / Producibility of Shuttle avionics.
3. Development and verification of ground operations and launch control software.
4. Reusable Propulsion/Avionics Module.
5. Main propulsion producibility and flight certification.
6. Low thrust/weight propulsion effects on separation dynamics

**Based on SDLV Industry Team study - May, 2005**

# Summary

- HLV is based on mature Shuttle hardware, software, facilities, and processes
- HLV delivers 72 mt of payload to LEO
- Supports a broad range of deep space missions
- HLV has better reliability and safety than Shuttle
- HLV can be developed in < 5 years
- HLV can be developed for < $8B
- HLV can be operated at < $500m per flight

**Using proven technologies, a near-term, high confidence Heavy-lift Launch Vehicle could be developed at an affordable cost, enabling a broad range of deep space missions**

## BIOGRAPHY

*William J. Rothschild has 38 years of experience managing advanced aerospace systems design, development, test, and analysis projects. He is currently working as a consultant to NASA. Bill worked for Boeing for 10 years, retiring as the Director of Engineering Operations at the Space Exploration Division in Houston, TX. He led an industry consortium defining launch vehicle concepts derived from the Space Shuttle, including side-mount Shuttle derivatives and concepts that led to Ares 1 and Ares V launchers for the Constellation program. Bill held project management and engineering positions on the Space Shuttle, Orion, Orbital Space Plane, 2nd Generation Reusable Launch Vehicle, commercial Reusable First Stage booster, Air Force Space Maneuver Vehicle, Space Rescue Vehicle, and the Liquid Flyback Booster programs. Prior to joining Boeing, Bill worked at Pratt & Whitney in West Palm Beach, Florida for 7 years. where he served as Senior Project Engineer on advanced rocket engines, space propulsion architectures, and military jet engine development programs. Bill also served as an officer in the Air Force for 20 years, retiring from active duty as a Lt. Col. His broad range of experience during his military career included ballistic missile and guided weapons development. He has a BS from Penn State, and an MS from the Air Force Institute of Technology.*

*Theodore A. Talay is a senior engineer at John Frassanito & Associates, Inc. Since joining JF&A in 2004, he has authored or co-authored engineering white papers on Shuttle-derived launch and upper-stage systems, biconic crew transfer system design, Mars Sortie landing vehicle design and solar power satellite transportation systems and design. He retired from NASA's Langley Research Center in 2001 after thirty years of service. At NASA, Dr. Talay worked Mars Viking parachute design, Shuttle II, Personnel Launch System (PLS), HL-20 space taxi, and Crew Transfer Vehicle systems. His work at NASA and later at Starcraft Boosters, Inc. included small glideback booster design for cost-effective small satellite and rapid response missions. He served as Chief of the Vehicle Analysis Branch at NASA Langley before his retirement. He has a BS and MS from Rensselaer Polytechnic Institute and a PhD from Old Dominion University.*

**Bill Rothschild**
**wjrothschild@yahoo.com**

**Ted Talay**
**ttalay@cox.net**

JF&A
Strategic Visualization®

**John Frassanito & Associates**
**1350 Nasa Parkway, Suite 214, Houston, Texas 77058**
**281.333.4840**

**jack@frassamito.com**