Space Exploration Systems

Potential Impact of a LEO Propellant on the NASA ESAS Architecture

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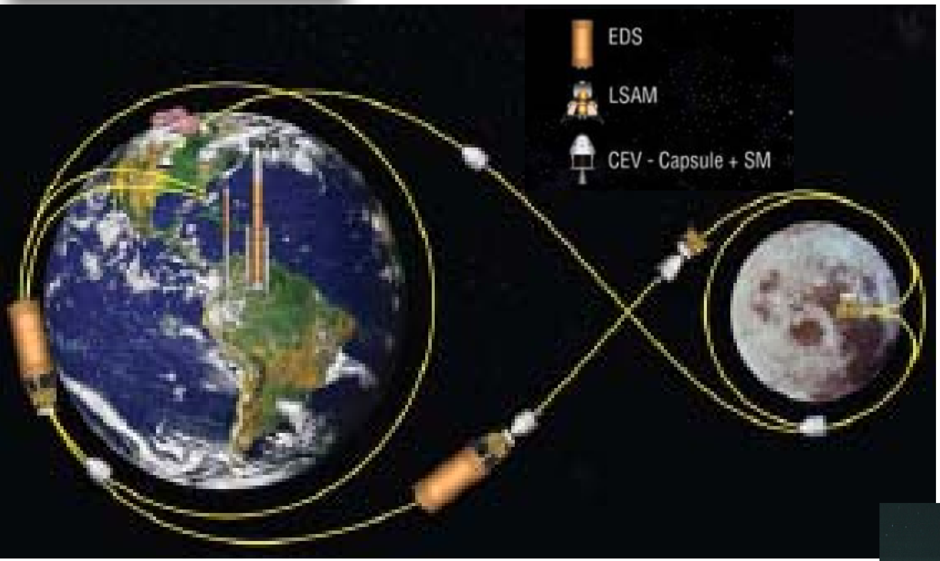
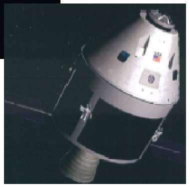
BOEING

First, There was the Vision. . .

Then, the ESAS Final Report. . .



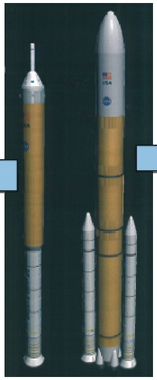
- 1.5 Launch architecture
- Earth orbit rendezvous: CEV to LSAM/EDS
- EDS performs Earth orbit insertion & circularization and TLI burn
- LSAM DS performs LOI with CEV and lunar descent and landing
- Lunar orbit rendezvous: LSAM AS to CEV
- LOx/LH in EDS and LSAM DS
- Lox/Methane in LSAM AS and CEV



Crew Exploration Vehicle

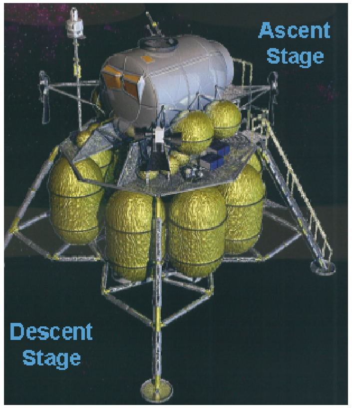
Exploration Departure Stage

CEV LV Upper Stage



Crew LV   Cargo LV

Lunar Heavy Cargo LV Upper Stage (EDS)



Lunar Surface Access Module

NASA's Exploration Architecture September, 2005

Followed by Dr. Griffin's Comments at 52nd AAS Annual Meeting in Houston, 11/05

- "But if there were a fuel depot available on orbit, one capable of being replenished at any time, the Earth departure stage could after refueling carry significantly more payload to the Moon, maximizing the utility of the inherently expensive SDHLV for carrying high-value cargo."
- "The architecture which we have advanced places about 150 metric tons in LEO, 25 MT on the Crew Launch Vehicle and 125 MT on the heavy-lifter. Of the total, about half will be propellant in the form of liquid oxygen and hydrogen, required for the translunar injection to the Moon."
- "If the Earth departure stage could be refueled on-orbit, the crew and all high-value hardware could be launched using a single SDHLV, and all of this could be sent to the Moon."

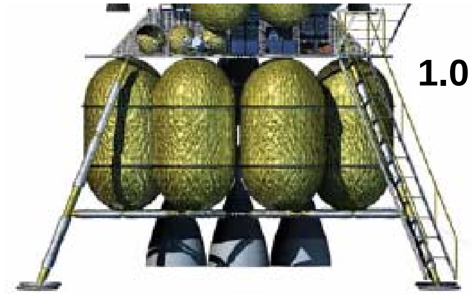
What Impacts Could a Depot Have. . .

- **If the CaLV (Ares V) capability is retained?**
- **If the LSAM launch mass is the right value?**
- **If the LSAM landed mass is the right value?**
- **If the ESAS Recommended Architecture is “unchanged”**

ESAS Recommended Architecture

CASE 0 – ESAS Recommended Architecture (Final Report Chapter 6): Comparative Baseline

1.0



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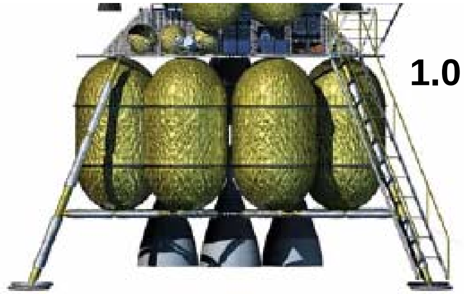
Margin Payload = 19.5 klbm

ESAS Recommended Architecture and Potential Updates without Depot

CASE 0 – ESAS Recommended Architecture (Final Report Chapter 6): Comparative Baseline

1.0



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Margin Payload = 19.5 klbm

CASE A – ESAS LSAM DS (Chapter 4) and CEV (Chapter 5); downsized AS

1.0

0.94

0.74

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Margin Payload = 29.0 klbm

ESAS Recommended Architecture and Potential Updates without Depot

CASE 0 – ESAS Recommended Architecture (Final Report Chapter 6): Comparative Baseline


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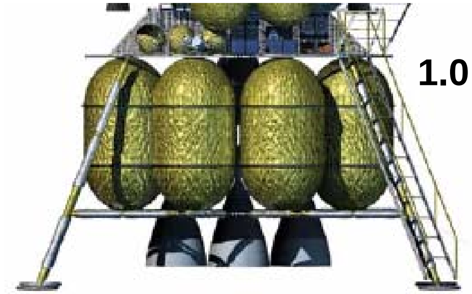
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Margin Payload = 19.5 klbm

CASE A – ESAS LSAM DS (Chapter 4) and CEV (Chapter 5); downsized AS


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Margin Payload = 29.0 klbm

CASE B – ESAS LSAM AS (Chapter 4) and CEV (Chapter 5); upsized DS


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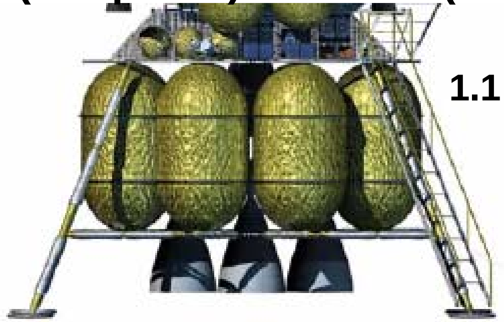
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1.33


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Depot Architecture Options Examined

CASE 0 – ESAS Recommended Architecture (Final Report Chapter 6): Comparative Baseline

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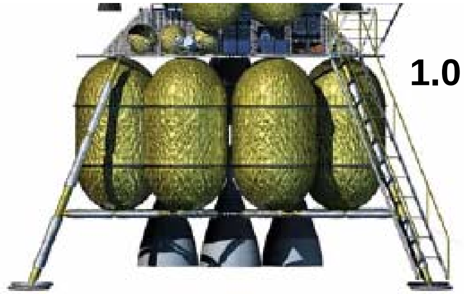
Margin Payload = 19.5 klbm



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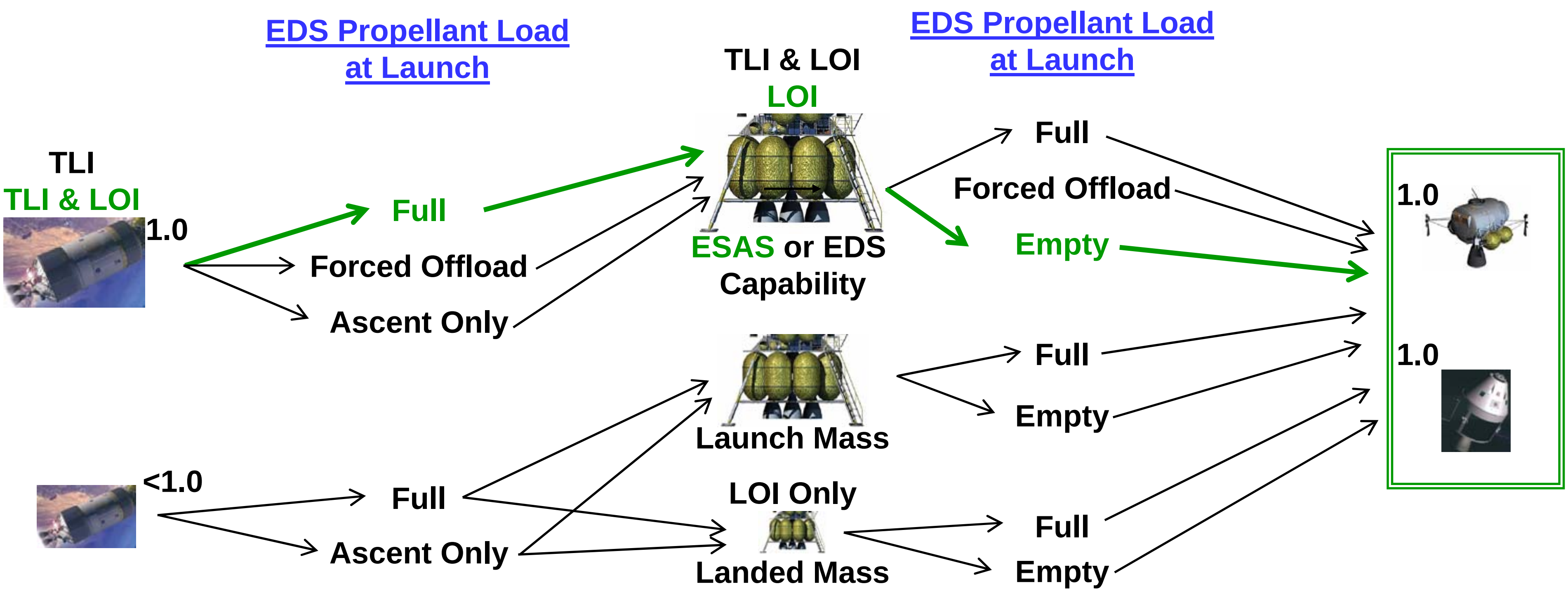
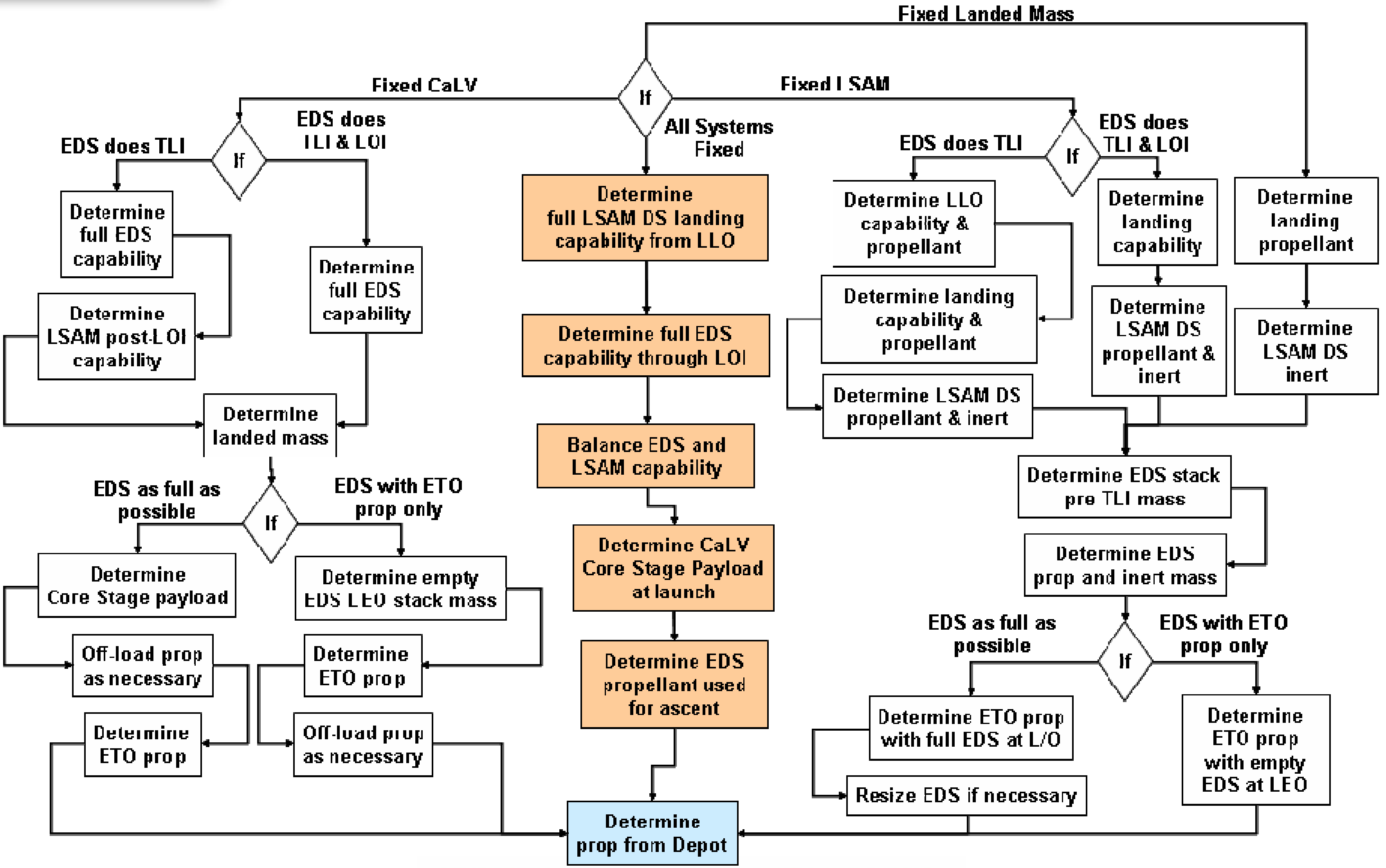


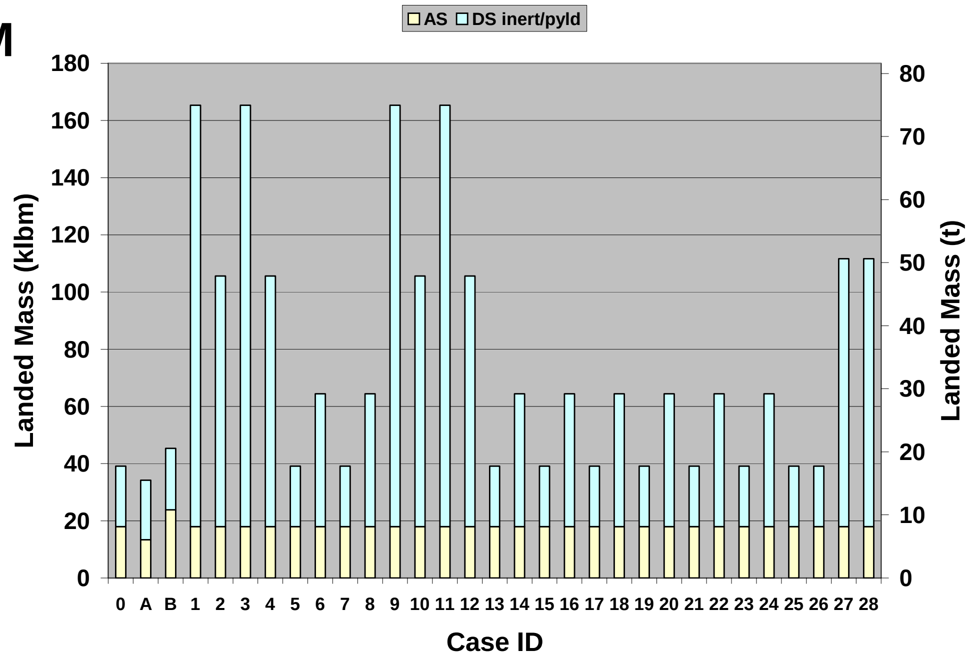
Analytical Path Defined by Major Options



Space Exploration Systems

Architecture Can Deliver 18-75 t to Lunar Surface With LEO Depot

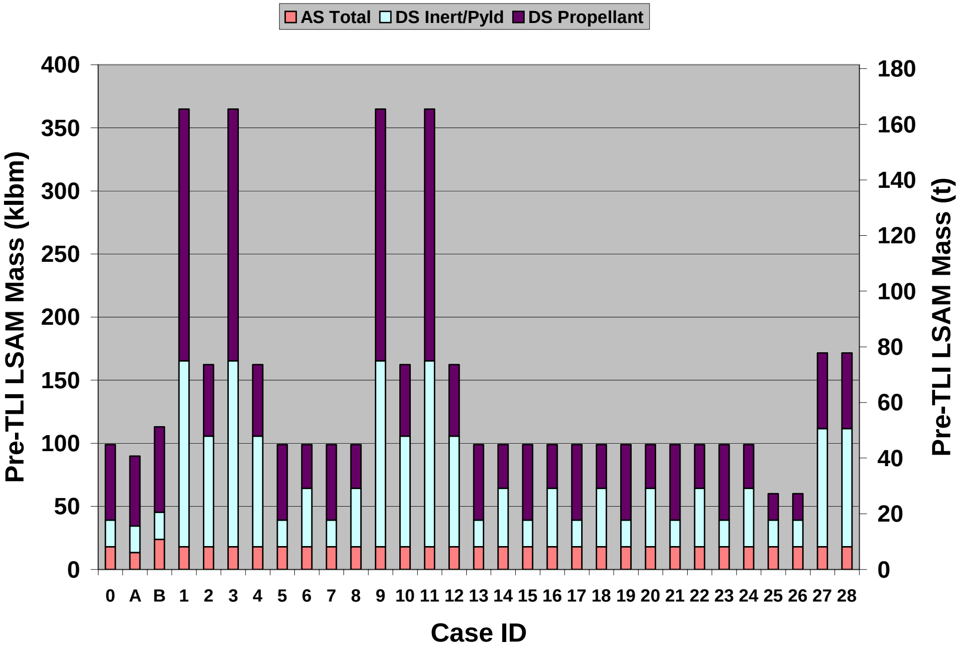
- **ESAS Recommended Architecture provides 18-20 t landed mass**
- **Same capability with downsized LSAM and EDS with Depot**
- **30 t capability if LOI allocated to EDS; LSAM initial mass unchanged; and EDS downsized**
- **48 t capability if LOI allocated to EDS; EDS characteristics unchanged; and LSAM upsized**
- **50 t capability if LOI allocated to EDS and ESAS systems unchanged**
- **75 t capability if EDS unchanged; LSAM upsized to full EDS to TLI capability**



5 distinct capabilities to lunar surface when LEO Propellant Depot added to Exploration Architecture

Depot Architecture LSAM + Payload Mass Can Be 50% to 400% of ESAS LSAM

- **ESAS LSAM mass, plus payload, is 45 t**



6 distinct LSAM configurations when LEO Propellant Depot added to Exploration Architecture

With a LEO propellant depot, LSAM mass is. . .

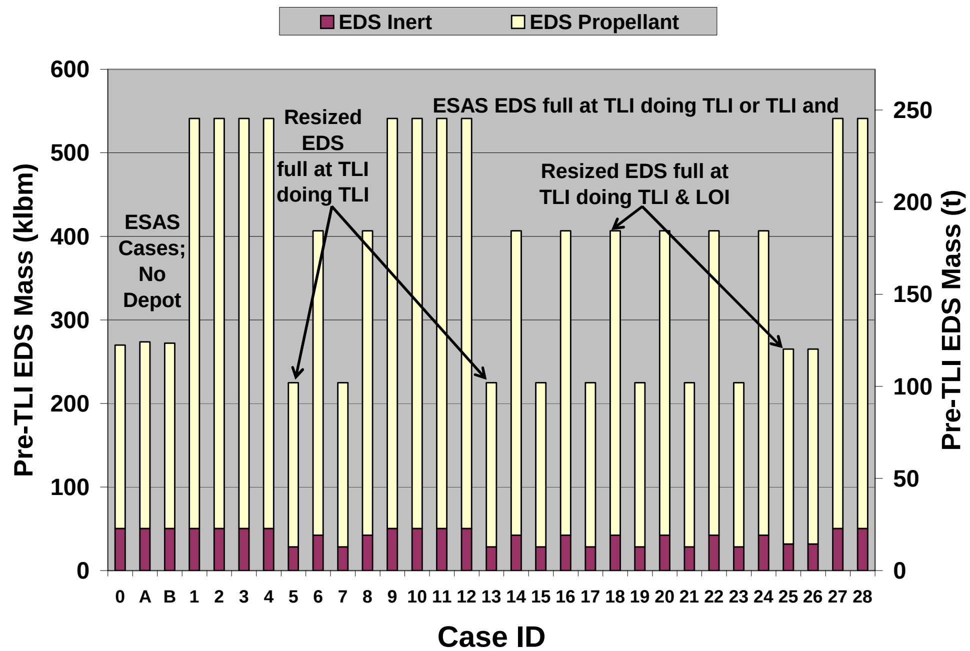
- **23 t if sized for landed mass from LLO**
- **75 t if EDS does TLI & LOI and EDS is unchanged**
- **80 t if all ESAS systems unchanged; LSAM DS tanks launched empty**
- **165 t if EDS is unchanged and does TLI only**

Propellant Depot Architecture EDS Can Be 67%, 50% or 30% of ESAS EDS

- ESAS EDS capacity is 225 t
- 100 t propellant in ESAS EDS in LEO

With a LEO propellant depot . . .

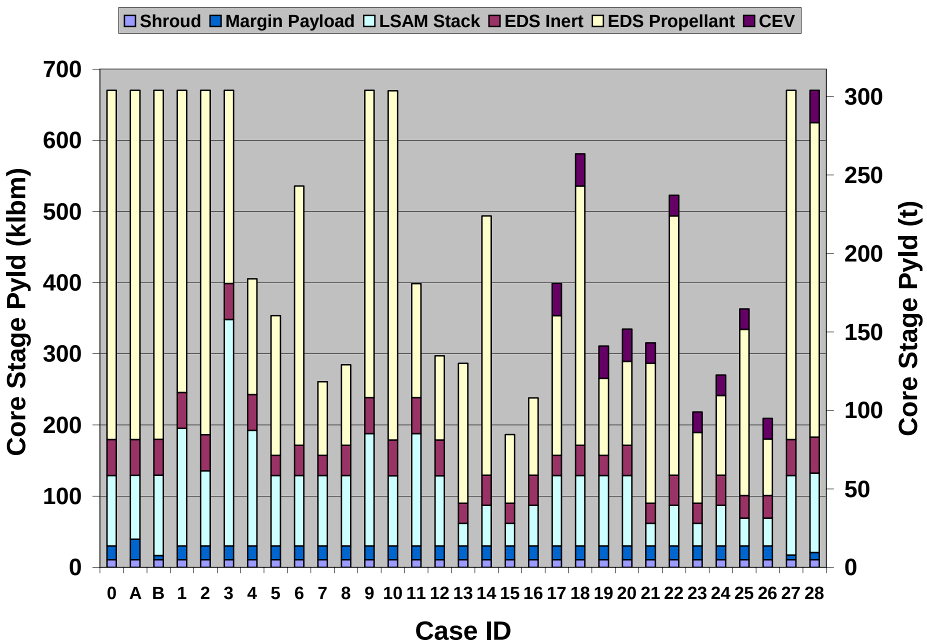
- 125 t propellant used during ascent can be replaced in LEO to deliver . . .
  - 165 t to translunar trajectory
  - 93-98 t to low lunar orbit
- EDS can be downsized to 180 t or 100 t to deliver 43 t to . . .
  - Translunar trajectory
  - Low lunar orbit
- EDS can be downsized to 130 t to deliver 23 t to low lunar orbit



4 distinct EDS configurations when LEO Propellant Depot added to Exploration Architecture

Ares V Core Stage Payload Can Be As Low As 85 t With LEO Depot in Architecture

- ESAS Architecture Ares V Core Stage Payload is 300 t

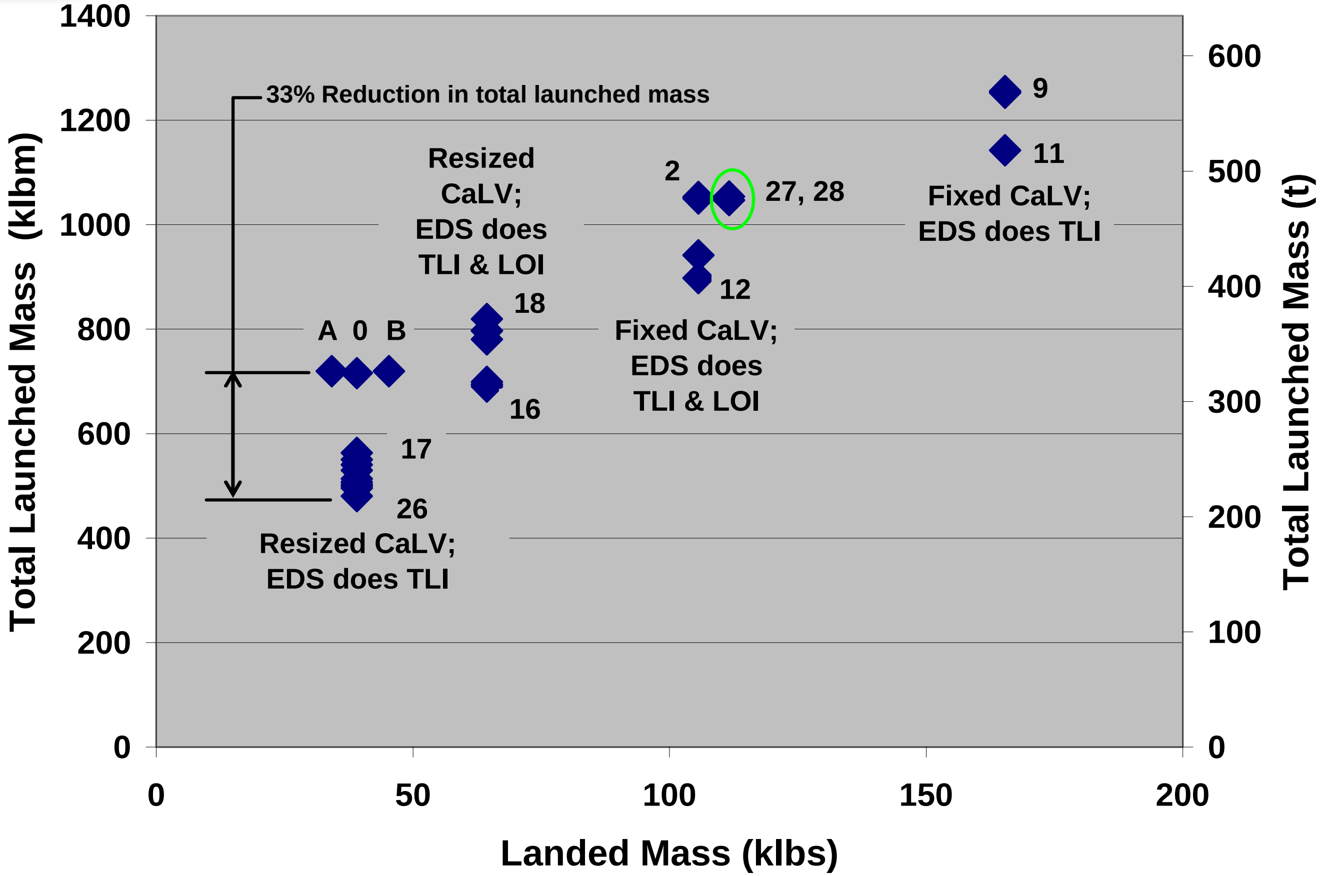


With a LEO propellant depot . . .

- 22 different heavy lift launch vehicle configurations possible
- Orion can be launched on Ares V
- Reduced Core Stage Payload options between 80 t and 265 t

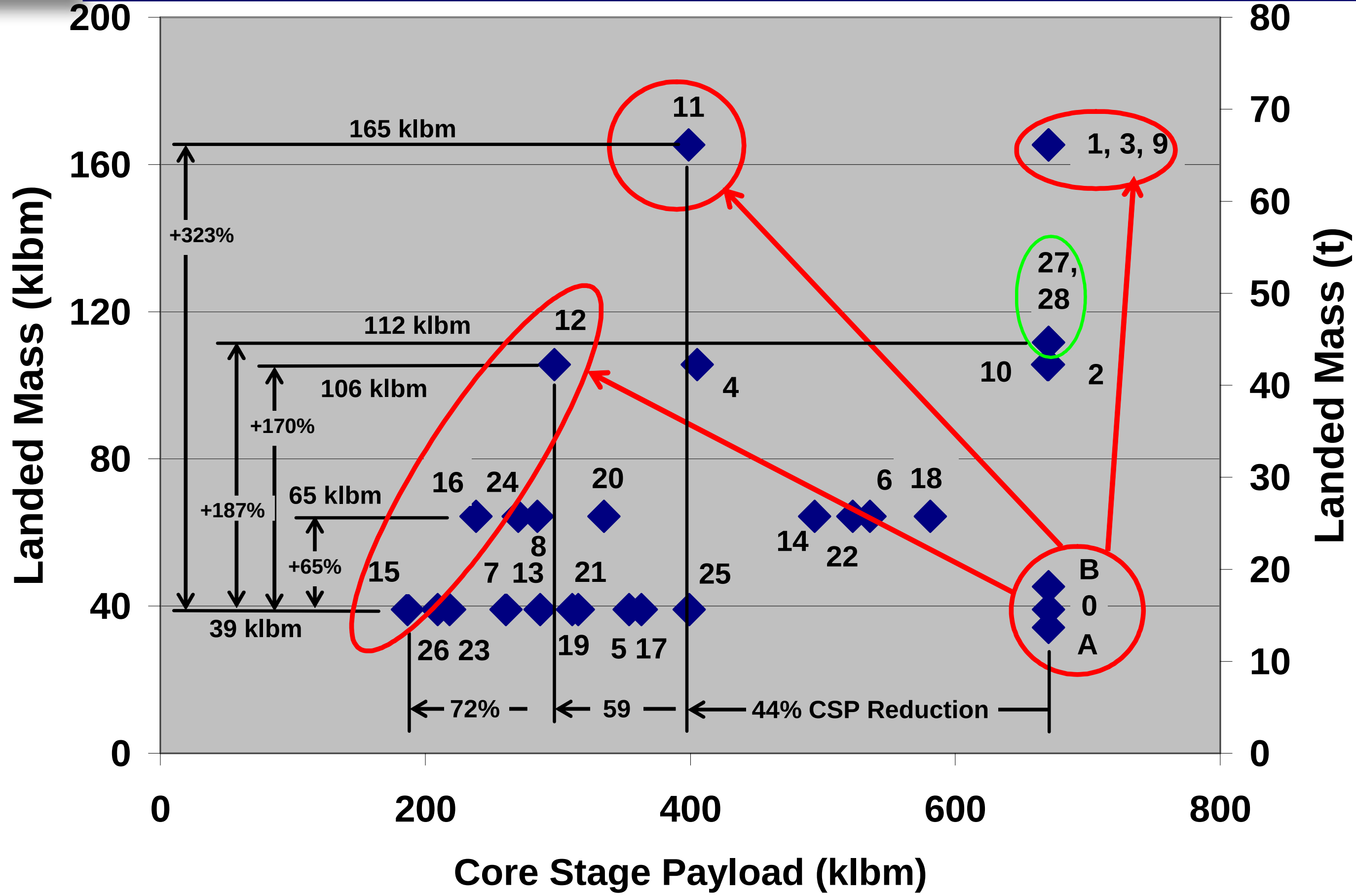
Ares V Core Stage Payload can be reduced by 72%when LEO Propellant Depot added to Exploration Architecture

67-175% of ESAS Total Launch Mass Provides 100-423% Lunar Landed Mass



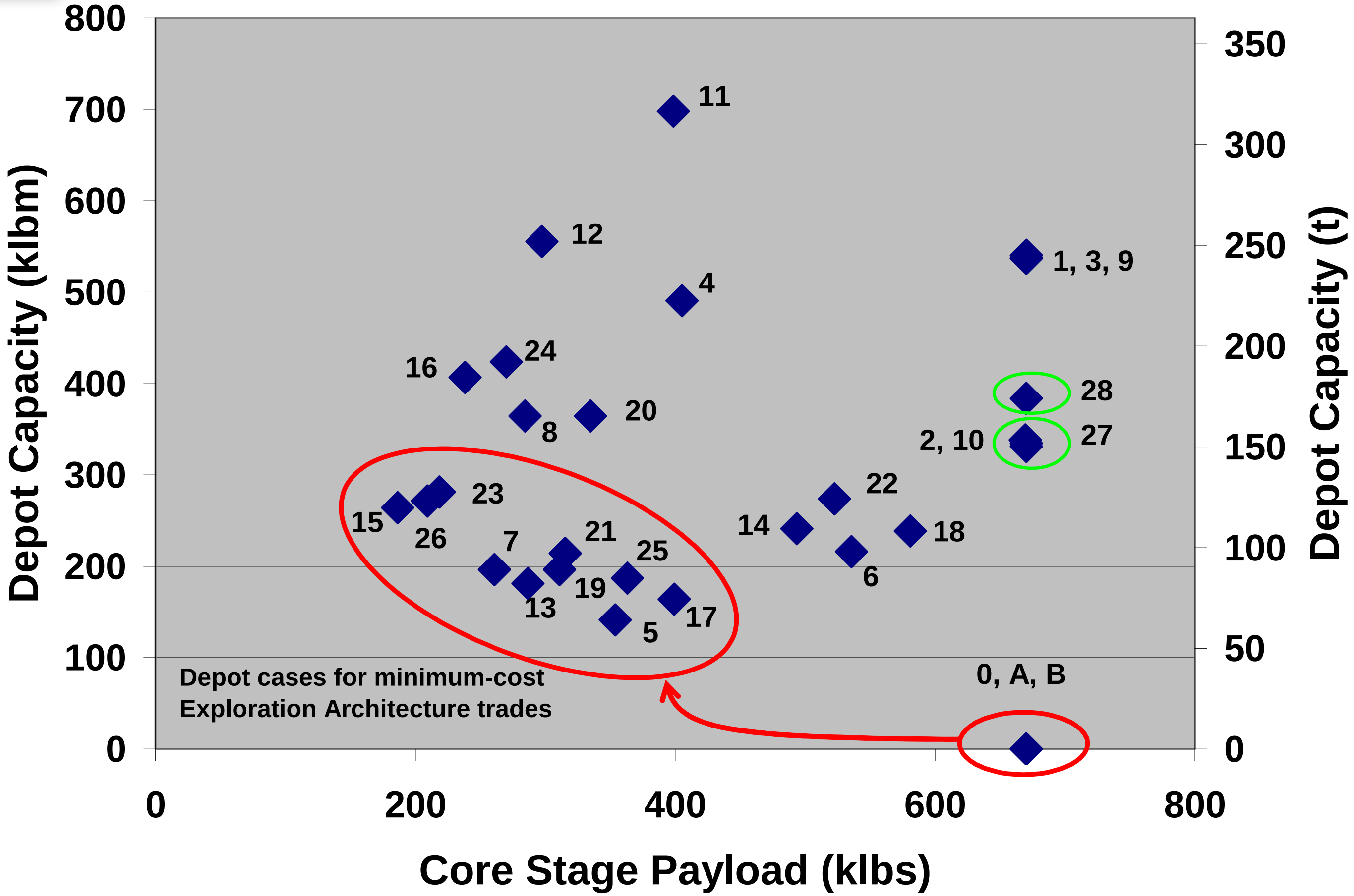
ESAS Architecture Systems with LEO Propellant Depot provides 200% more landed mass for 50% additional launched mass

LEO Propellant Depot Increases Landed Mass and/or Reduces Ares V Requirement



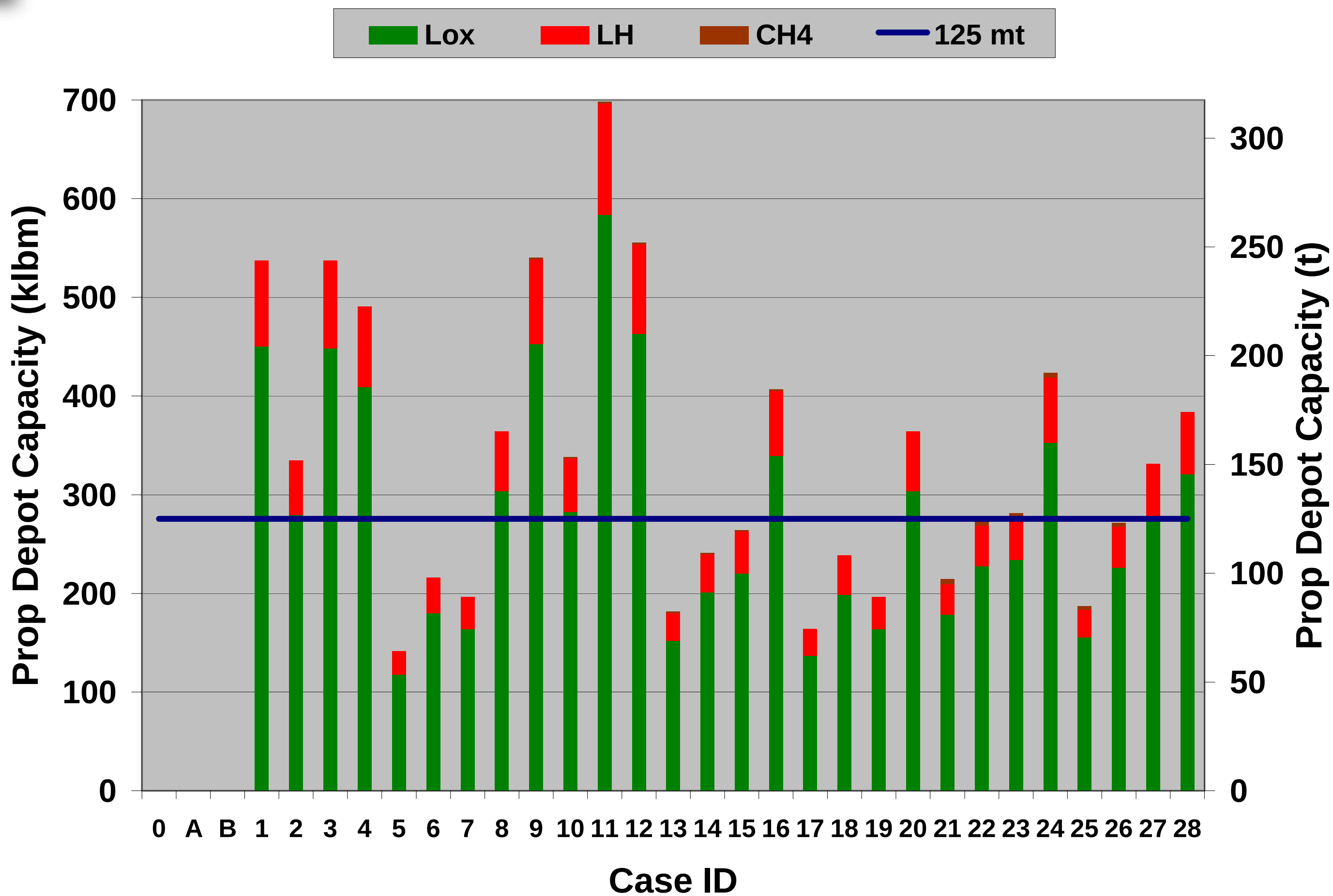
186% increase in lunar surface delivery capability using ESAS Architecture Systems with LEO Propellant Depot

64-317 t Capacity Depot Required for Various Exploration Architectures



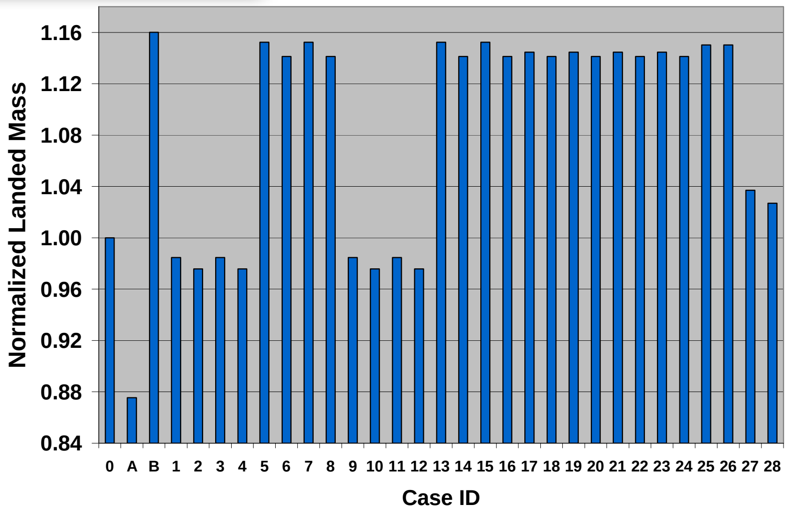
A propellant depot needs a 150-175 t capacity if incorporated into the ESAS Recommended Architecture

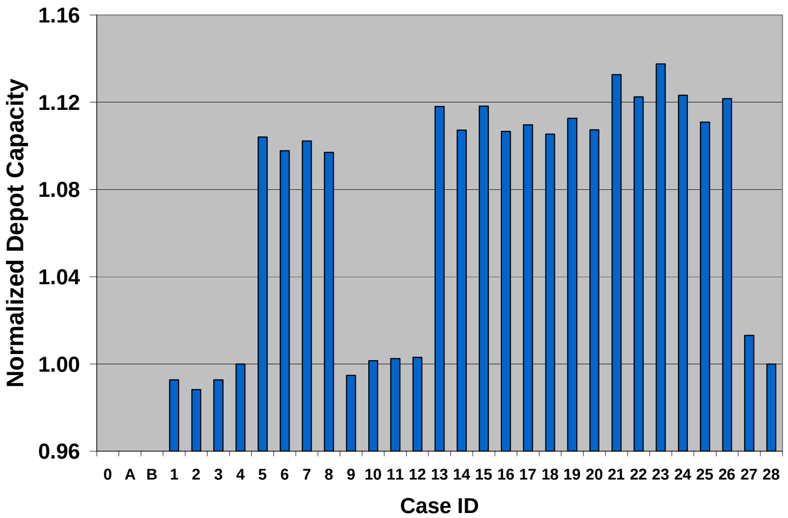
A 150-175 t Depot Needed to Maximize ESAS Recommended Architecture Benefits



Launching Orion on Ares V instead of Ares 1 accounts for 30 t difference in depot capacity between Cases 27 and 28

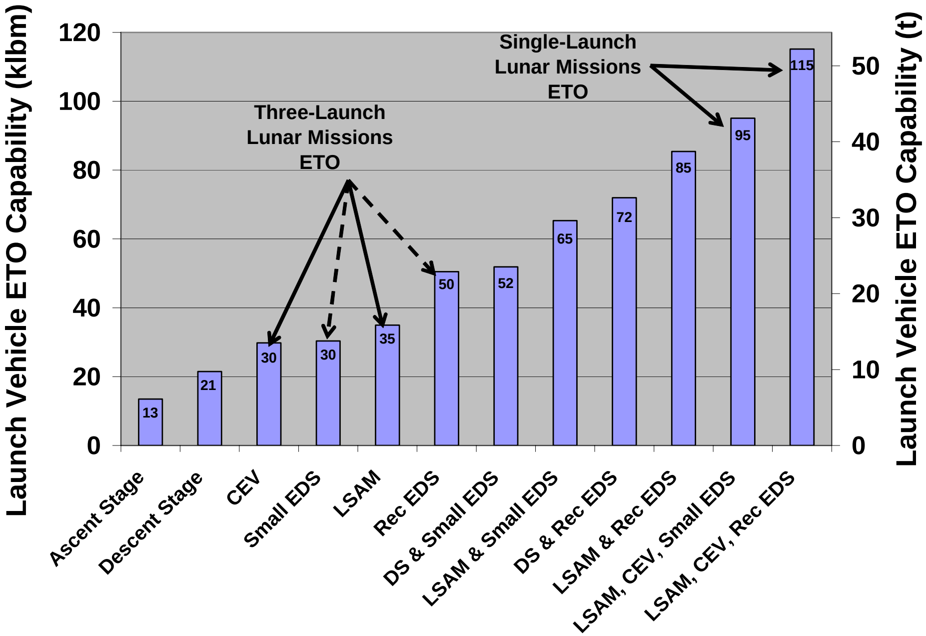
Using Detailed LSAM AS and CEV Mass Increases Landing and Depot Mass 10-15%





- ESAS Recommended Architecture updated using Chapter 4 and 5 masses
- CEV and LSAM AS mass used as quoted in ESAS Final Report
- LSAM DS mass increased to meet performance requirement
- For Cases 1-4 and 9-12, where Ares V lift capacity was held constant
  - 0.98 - 0.99 normalized landed capacity
  - 0.99-1.00 normalized propellant depot capacity
- Normalized ESAS Architecture with depot has
  - 1.03 times landed mass capacity
  - 1.00 times propellant depot capacity

ETO Requirements Significantly Reduced If All Systems Launched Dry



- **3 LV capabilities for single element launch**
  - **13 klbm – Ascent Stage**
  - **21 klbm – Descent Stage**
  - **30 klbm – CEV and small EDS**
- **30-36 klbm capability if LSAM launched as a system**
- **96-116 klbm capability for single launch**
- **2-launch lunar mission enabled by reusable LSAM (CEV + EDS)**

Payload volume requirement and increased rendezvous and docking events are key issues associated with small ETO requirements and individual launches

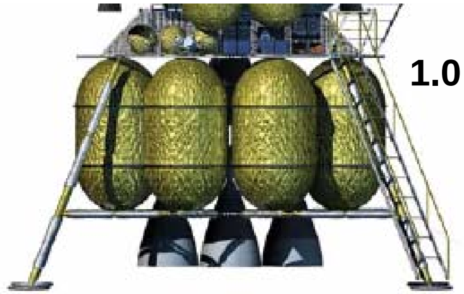
ESAS Architecture Landed Mass Tripled with Addition of LEO Propellant Depot

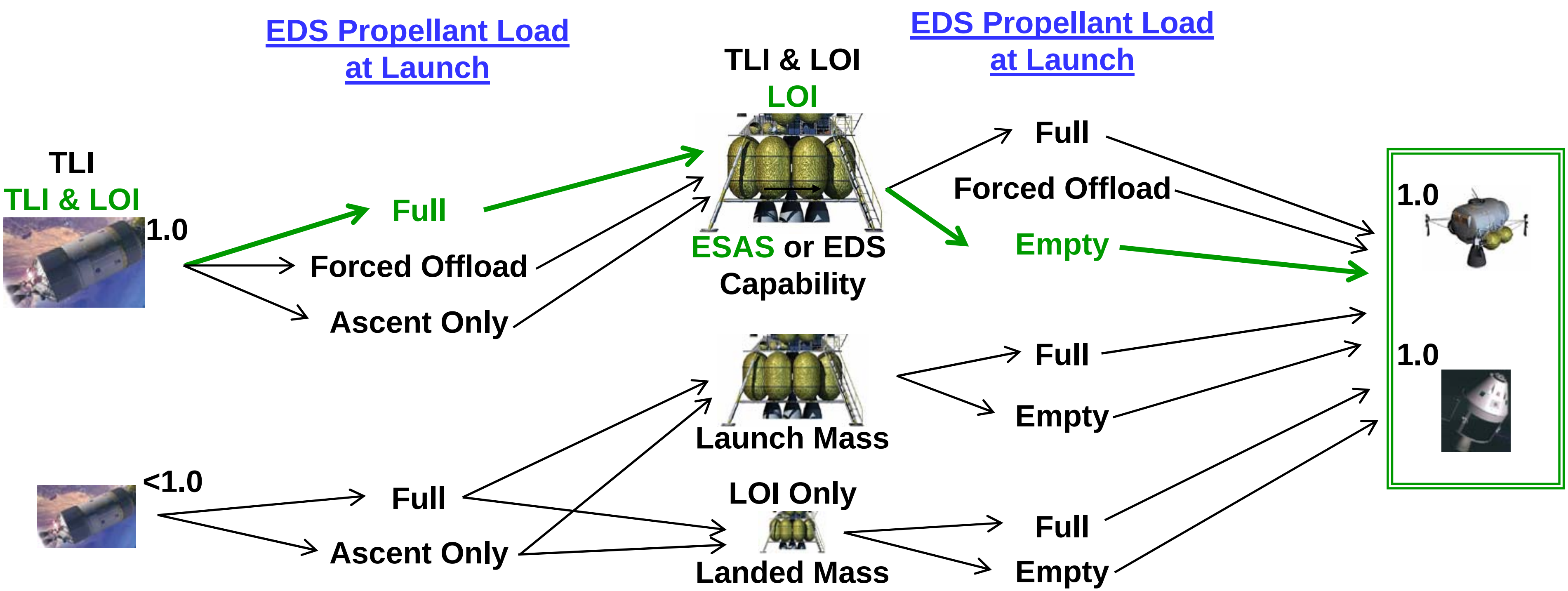
- 28 Depot Architectures assessed; 2 used as-defined ESAS systems
  - 1.5 Launch ESAS Architecture (Ares I and Ares V)
  - 1.0 Launch ESAS Architecture (Ares V only)
- 51 t LSAM landed for ESAS Arch with depot (18-75 t mass range)
- 670 klbm CaLV Core Stage capability (190-670 klbm range)
- 150 or 175 t depot capacity required (64-317 t range)
- Depot can be introduced into architecture at any time
  - AR&D and propellant receiving capability required on EDS
  - Propellant transfer between EDS and LSAM DS required

Questions?

CASE 0 – ESAS Recommended Architecture (Final Report Chapter 6): Comparative Baseline

Margin Payload = 19.5 klbm





References

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