Design for Safety - The Ares Launch Vehicles Paradigm Change

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Although the Constellation Program has been redirected, the concepts and practices for the Ares 1 and Ares V vehicles are still valid for application to future crew launch vehicle and heavy launch vehicle designs

Agenda

- The Paradigm change
- The Safety and Mission Assurance (S&MA)Functional Roles Change
- The S&MA Operating Environment Change
- The S&MA Early Involvement in the Ares I Design Process
- The Ares V/Earth Departure Stage (EDS) Conceptual Phase Loss of Mission (LOM) Assessment
- Post conceptual Phase - Reliability Discussions
- Concluding Remarks

The Paradigm Change

- In the past, space vehicle designers focused on performance.
- Lessons learned from the Space Shuttle and other launch vehicles showed the need to optimize launch vehicles for other system parameters (reliability, safety, cost, availability, etc.) besides performance.
- These lessons learned have forced a paradigm change on how to design and build new launch vehicles.
- This paradigm change created a risk informed design environment which led to an early involvement of S&MA in the design process.

The S&MA Functional Roles Change

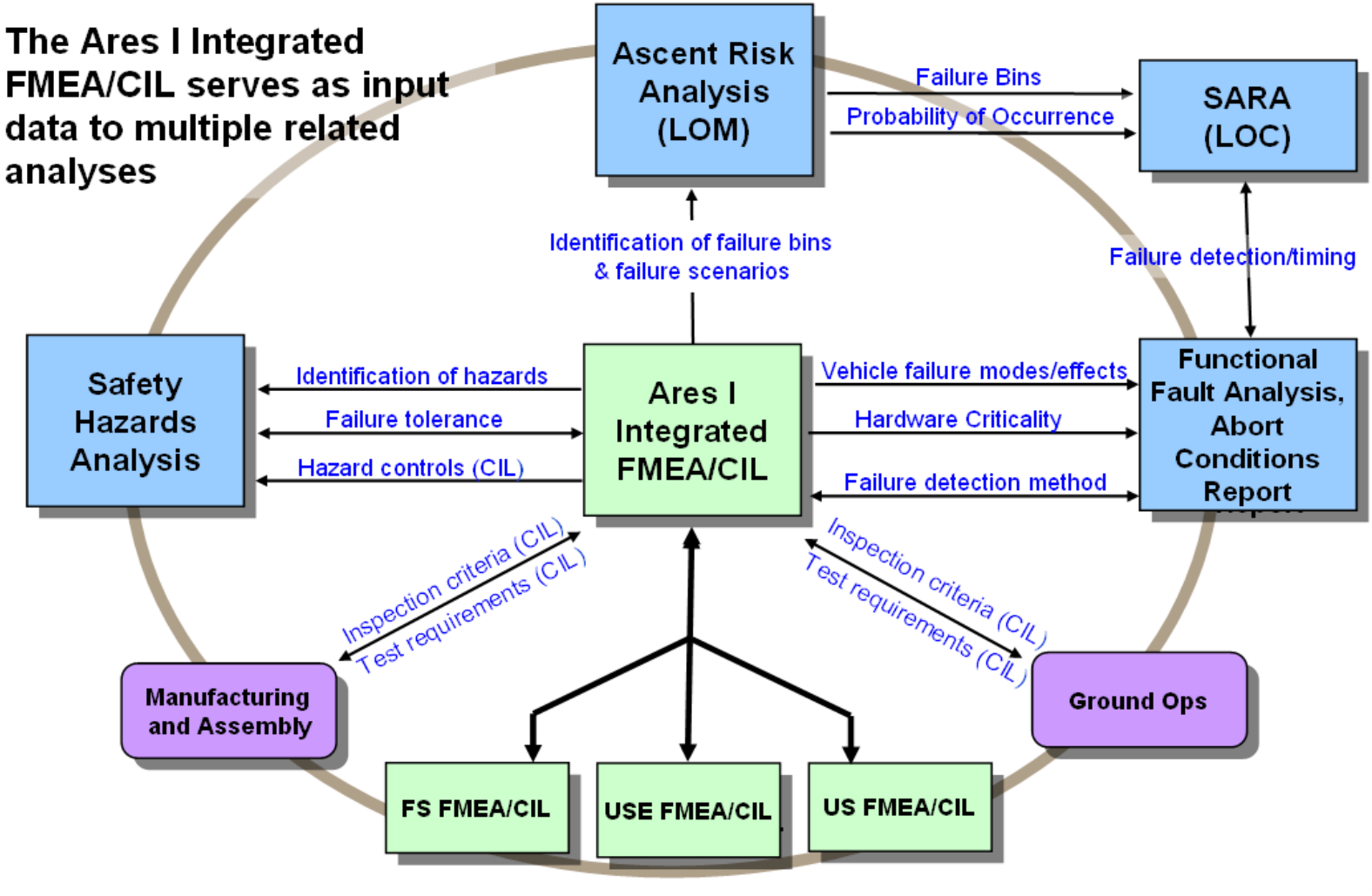
- In the past, S&MA was tasked mainly to do the assurance function: Making certain that specified activities performed by others are performed in accordance with specified requirements. (Upper stage Engine and First Stage). Examples of the activities include:

- Assess Hazard Analyses, FTAs, FMEA/CIL, PRA, etc.
- Approving Material Review Board (MRB) dispositions.
- Performing government inspections, audits, and surveillance.
- Independent assessments.
- Evaluating engineering and manufacturing changes, or proposed variances (adaptations, deviations, and waivers), for impacts to safety, reliability, and/or quality
- Evaluating the disposition of problems, including corrective actions (e.g., PRACA problem reports)

- Currently, in addition to its assurance function, S&MA is tasked to do an in-line function: Under the in-line function, S&MA activities are performed in direct support of the program/project to ensure that the program/project will achieve its objectives (Upper Stage and Vehicle Integration). Examples of the activities include:

- Establish and implement S&MA programmatic and technical requirements.
- Perform Probabilistic Risk Assessments, Reliability Analysis, Integrated System Failure Analysis, Hazard Analyses, Fault Tree Analyses, FMEA/CIL, etc.
- Develop S&MA plans and methodologies.
- Establish and implement Industrial Safety.

S&MA leading the Integrated Reliability and Safety Analysis (Example)



The S&MA Early involvement in the Ares I design process

- **Example of S&MA involvement in the Ares I Design**
  - Influenced the choice of the solution to the Thrust Oscillation issue. Jointly working with engineering and Ares I project, S&MA assessed the reliability, quality and safety impacts of the various design solutions to the thrust oscillation issue.
  - Influenced the design solution to the First Stage-Upper Stage separation issue. Jointly working with engineering and Ares I project, S&MA assessed the reliability and safety impacts of the various design solutions to the First Stage-Upper Stage separation issue.
  - Influenced the change of Linear Shape Charge (LSC) initiation timers from percussion to Flexible Confined Detonation Cord initiated timers (Flight Termination System)
  - Recommended pressurization line be moved out of cable tray to reduce risk to LSC and avionics (upper Stage)
  - Optimized valve design for reliability and safety for LH2 and LO2 pressurization.
  - Identified issue with use of KC fittings in safety-critical applications and approach to qualifying fittings as providing two seals (upper Stage)

The Ares V/EDS Conceptual Phase LOM Assessment

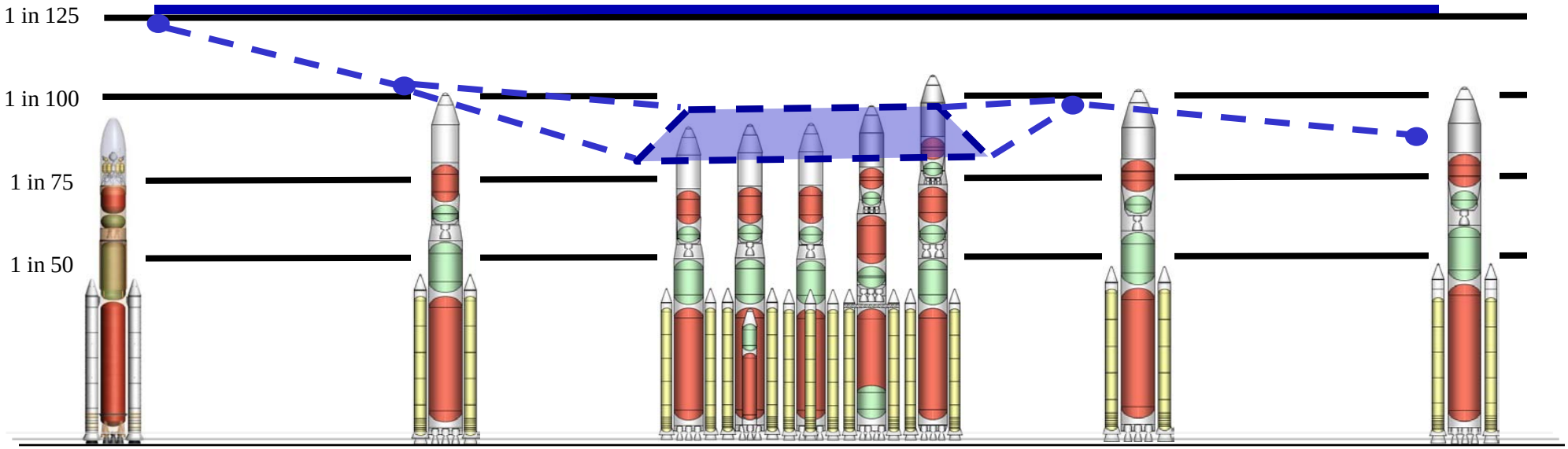
The Ares V Conceptual Phase LOM Assessment

- **The S&MA lessons learned from Ares I were used to effectively support the Ares V conceptual design phase and help in planning for post conceptual phases.**

- **The following set of charts contains a summary of the Ares V/EDS LOM risk assessment.**

Note: The following information are intended to share the LOM methodology and approach used during the conceptual design phase of Ares V and not meant to present the up-to-date absolute LOM numbers.

Traceability to the NASA's Exploration System Architecture Study (ESAS)



Original ESAS Capability
8.4 m OML
46.0 MT Lander
20.0 MT CEV
No Loiter in LEO
TLI total Δv = 10,235 ft/sec
7.4 MT TLI perf. reserve
73.4 MT CaLV gross payload at TLI capability

Change to RS68 Core Engines
10 m dia. Core
490K Fvac to 750k Fvac
452.1 Ispv to 414.7 Ispv
FSB Propellant change from HTPB to PBAN (Ares I 53-06 thrust trace)

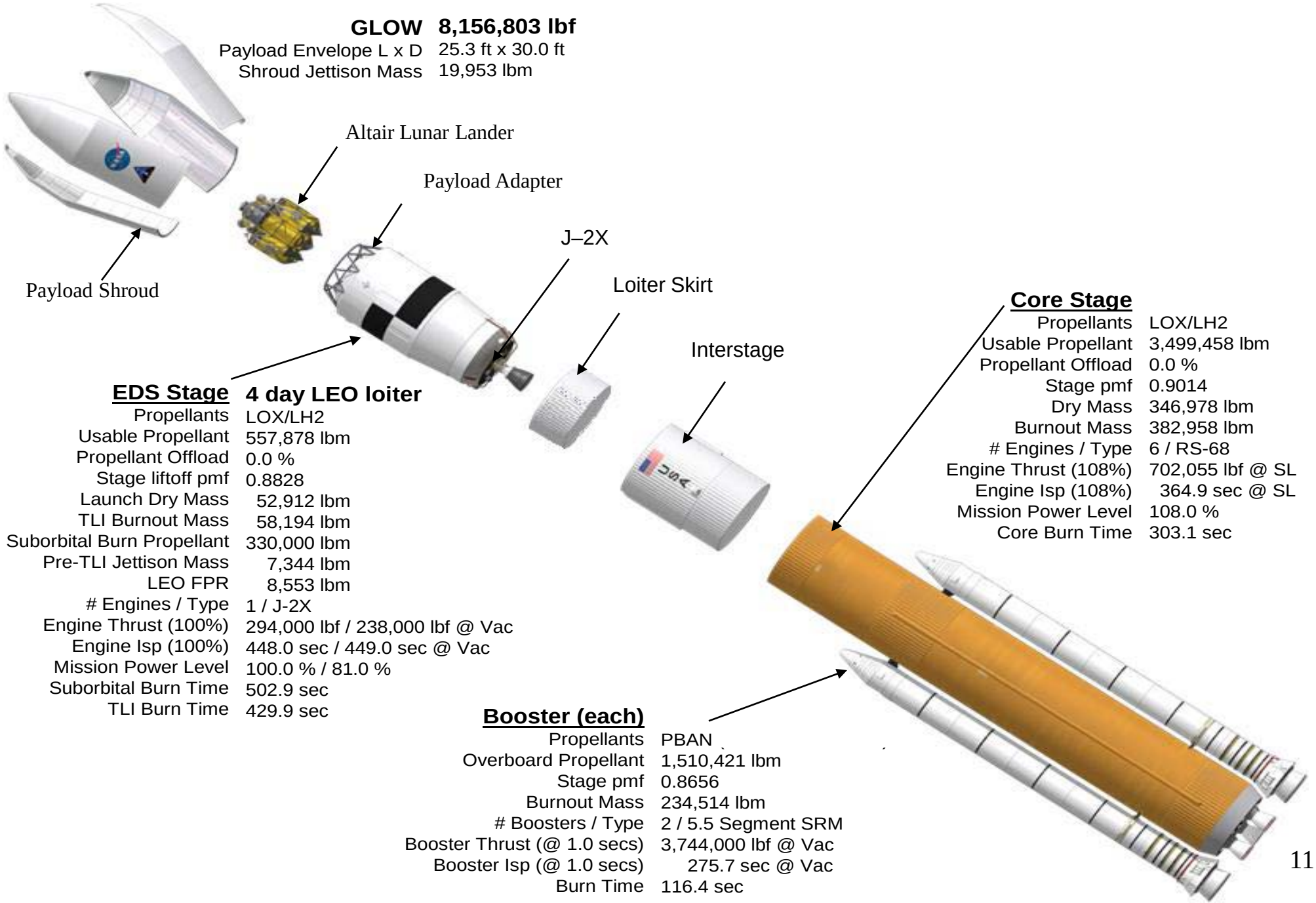
IDAC 3 Trade Space
SRM Propellant
Stage Materials
Extra Strapons
Engine Type
10+ m dia. Core
Number of Stages
Shroud Material
Shroud Size

Diameter Change
10 m dia. Core, EDS, and Shroud

LCCR BASELINE
57.00.XX
10 m OML
Booster Options

2005 | 2006 | 2007 | 2008

The Ares V System Baseline Overview



GLOW	**8,156,803 lbf**
Payload Envelope L x D	25.3 ft x 30.0 ft
Shroud Jettison Mass	19,953 lbm

EDS Stage — **4 day LEO loiter**

Propellants	LOX/LH2
Usable Propellant	557,878 lbm
Propellant Offload	0.0 %
Stage liftoff pmf	0.8828
Launch Dry Mass	52,912 lbm
TLI Burnout Mass	58,194 lbm
Suborbital Burn Propellant	330,000 lbm
Pre-TLI Jettison Mass	7,344 lbm
LEO FPR	8,553 lbm
# Engines / Type	1 / J-2X
Engine Thrust (100%)	294,000 lbf / 238,000 lbf @ Vac
Engine Isp (100%)	448.0 sec / 449.0 sec @ Vac
Mission Power Level	100.0 % / 81.0 %
Suborbital Burn Time	502.9 sec
TLI Burn Time	429.9 sec

Core Stage

Propellants	LOX/LH2
Usable Propellant	3,499,458 lbm
Propellant Offload	0.0 %
Stage pmf	0.9014
Dry Mass	346,978 lbm
Burnout Mass	382,958 lbm
# Engines / Type	6 / RS-68
Engine Thrust (108%)	702,055 lbf @ SL
Engine Isp (108%)	364.9 sec @ SL
Mission Power Level	108.0 %
Core Burn Time	303.1 sec

Booster (each)

Propellants	PBAN
Overboard Propellant	1,510,421 lbm
Stage pmf	0.8656
Burnout Mass	234,514 lbm
# Boosters / Type	2 / 5.5 Segment SRM
Booster Thrust (@ 1.0 secs)	3,744,000 lbf @ Vac
Booster Isp (@ 1.0 secs)	275.7 sec @ Vac
Burn Time	116.4 sec

Methodology

- **Building on ESAS Analysis: with similar analysis methodology but Ares focused.**
- **Models use:**
    - **Physics-informed parametric algorithms.**
    - **Vehicle and system heritage data.**
    - **Expert solicitation and engineering judgment.**
    - **Models are designed to interface with performance analysis output.**

Methodology
Functional/System Breakdown

Mission Parameter Data

Preliminary Vehicle Performance and Sizing Inputs

BOOSTER

CORE

EDS

Propulsion Data

# of Segments

Propellant type

# of Boosters

# of Engines

Power level

Burn Time

# of Engines

Power level

Burn Time

Reliability Database

Propellant Management

Auxiliary Power

Thermal Control

Reaction Control

Stage Separation

Payload Shroud Separation

Loiter Skirt Jettison

MMOD Shield Jettison

Solar Array Deployment

Automated Rendezvous and Docking

Parametric Response Algorithms

SRB Strap-On Reliability

Core Engine Reliability

Core TVC Reliability

EDS Engine Reliability

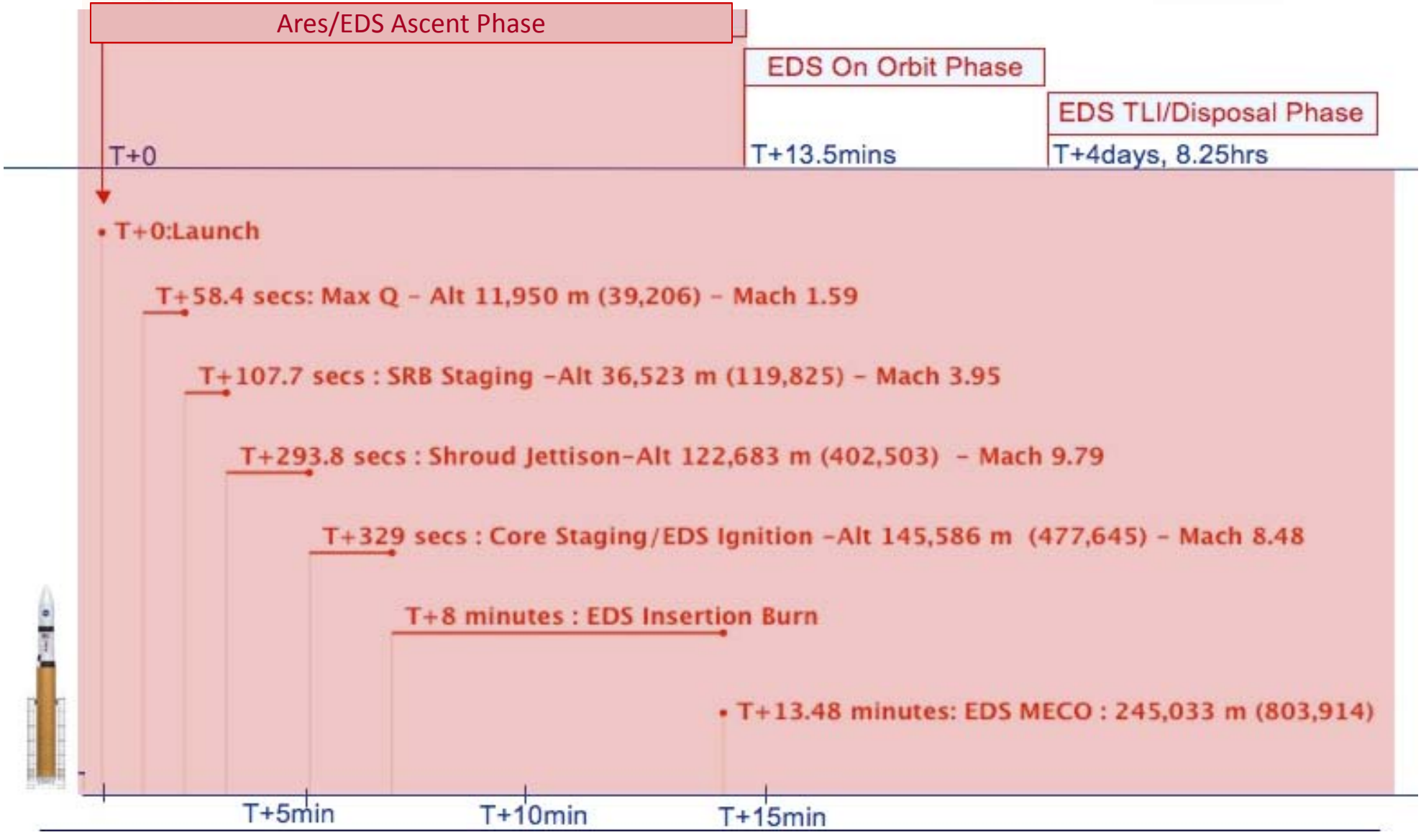
EDS TVC Reliability

Core Reliability Estimate

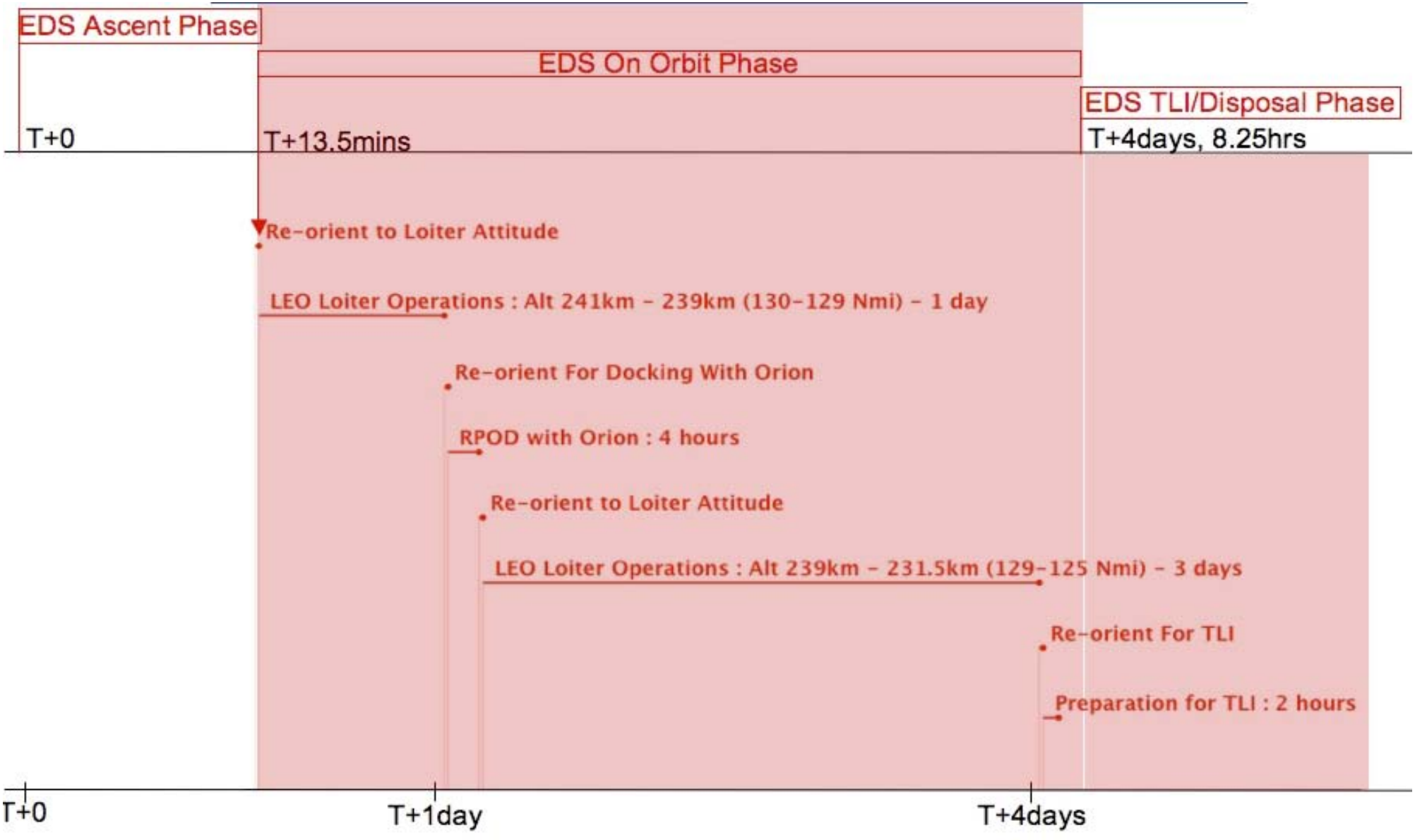
EDS-to-Orbit Reliability Estimate

Orbit to TLI Reliability Estimate

Ares V/EDS Operational Timelines



The Ares V/EDS Operational Timelines



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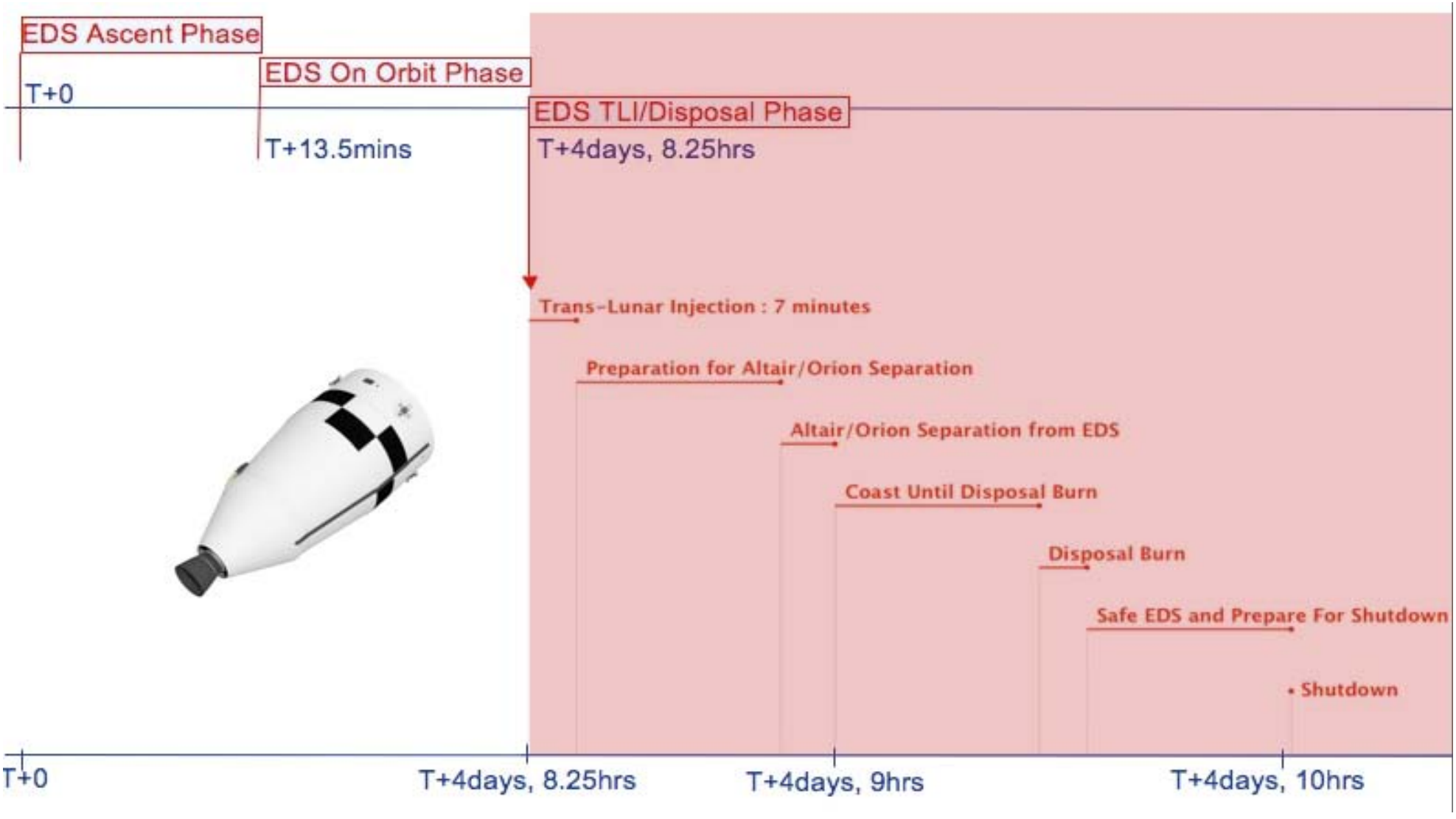
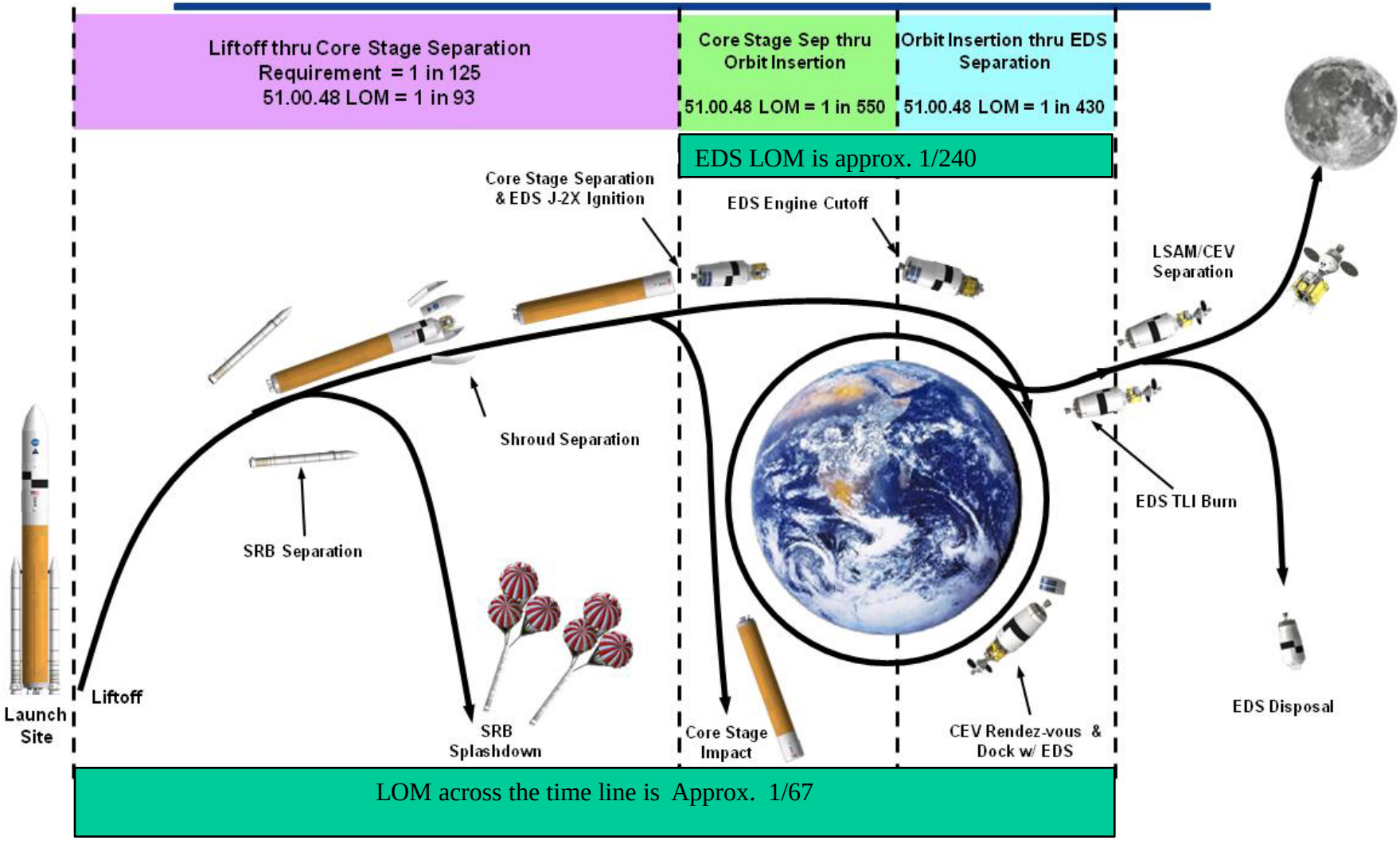
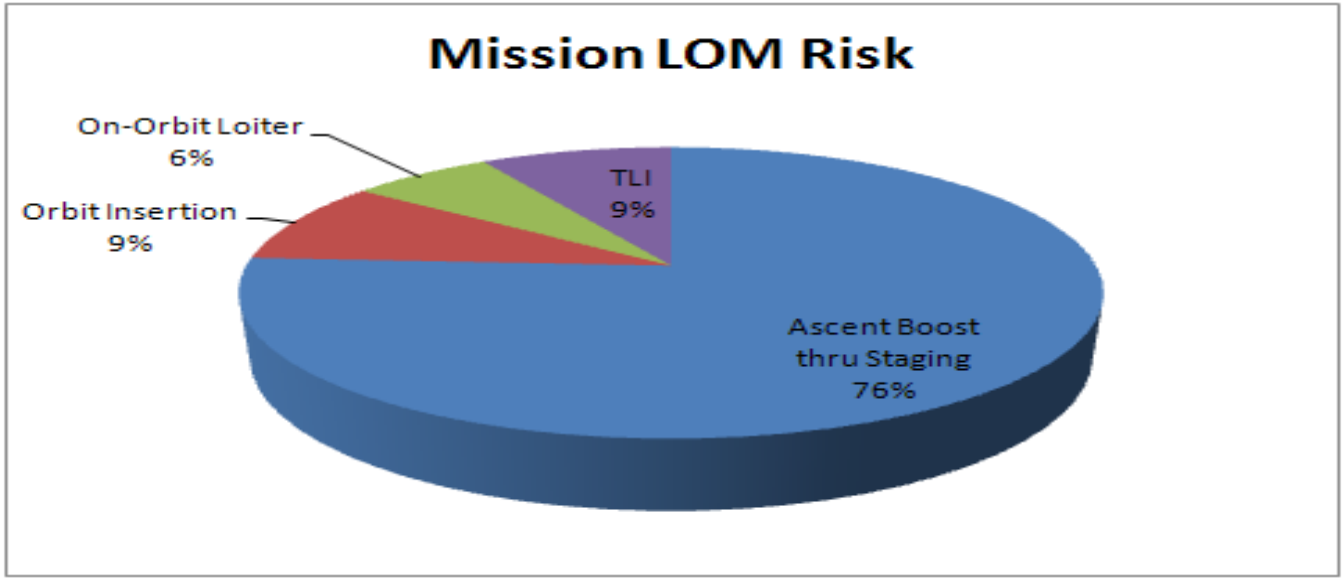
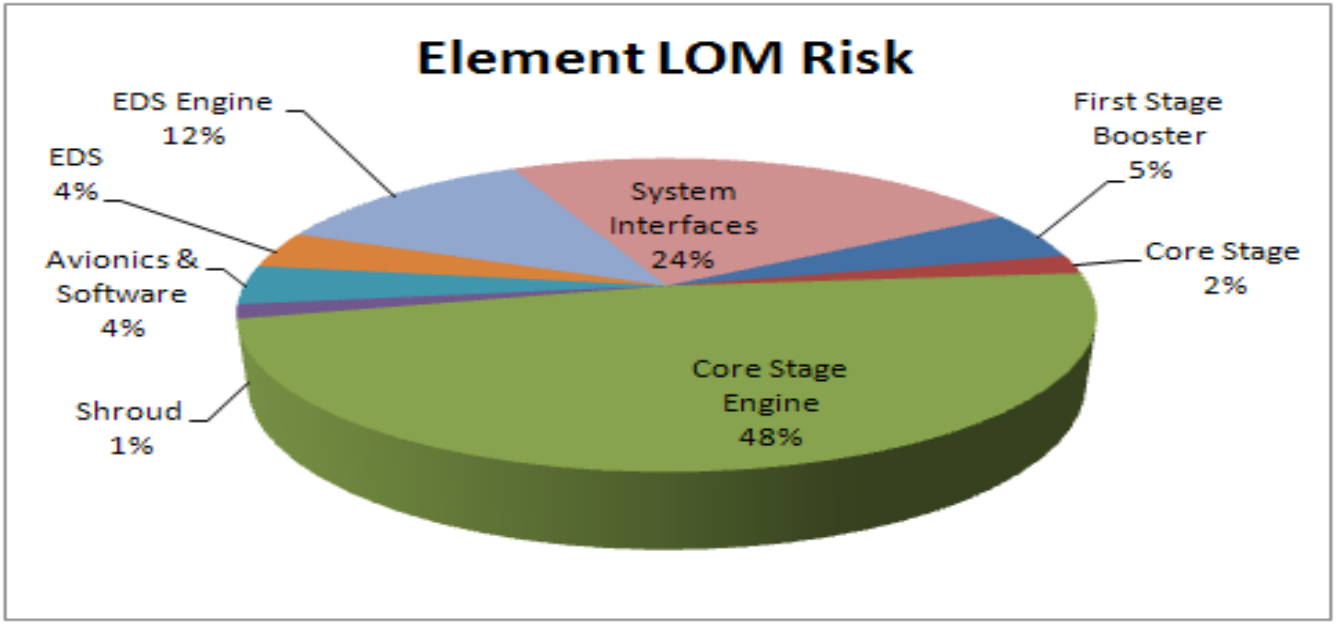


LOM Results Across the Mission Profile



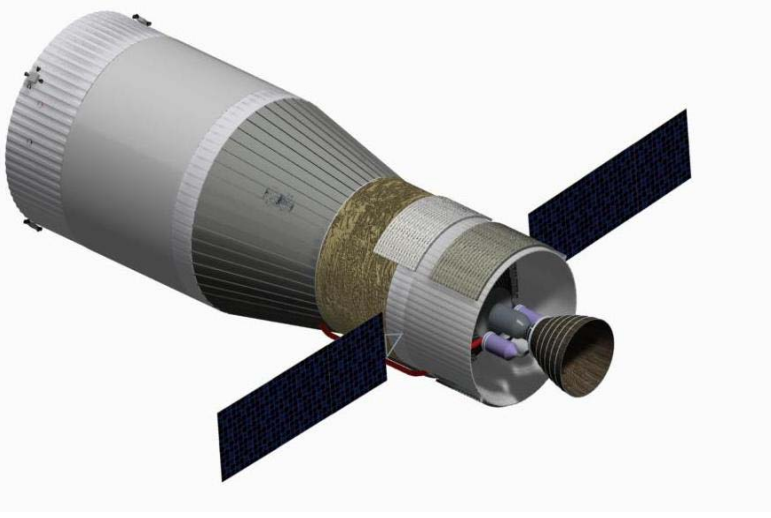
LOM Results

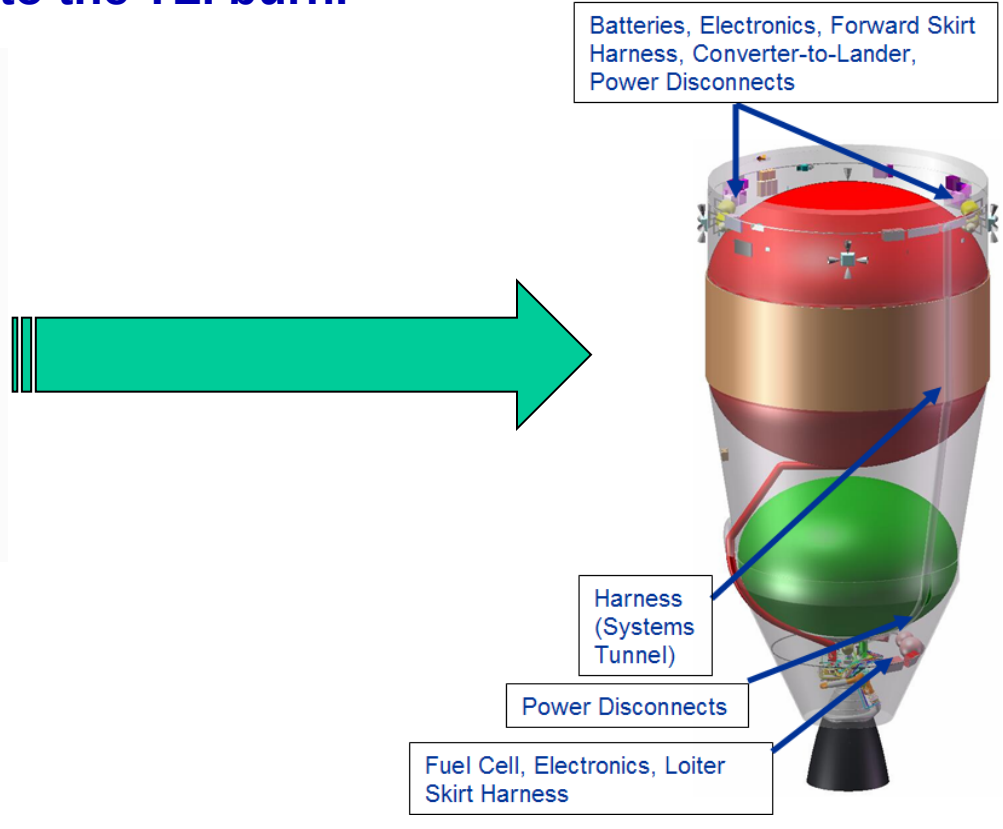

Mission LOM Risk
On-Orbit Loiter
6%
TLI
9%
Orbit Insertion
9%
Ascent Boost
thru Staging
76%


Element LOM Risk
EDS Engine
12%
First Stage
Booster
5%
EDS
4%
System
Interfaces
24%
Avionics &
Software
4%
Core Stage
2%
Core Stage
Engine
48%
Shroud
1%

A Major Design Change

- **One of the main changes made to the original LCCR EDS design is the replacement of the Solar Arrays with Fuel Cells which are jettisoned along with the Loiter skirt prior to the TLI burn.**





- **With an expected improvement in reliability**

Achievability Assessment

- **The Ares V LOM Requirement:** *Ares V shall limit their contribution to the risk of Loss of Mission (LOM) for Lunar missions to no greater than 1 in 125.* Applicability: Ares V as stated in the requirement has been assumed to mean the basic launch vehicle (Core Stage, First Stage Booster, RS-68 Engines, necessary guidance and control, etc.) performing ascent to EDS separation.
  - Achievability:
    - The LOM assessment showed that achievability may be a challenge, particularly with a configuration of 6 RS-68 engines having no engine-out capability.

- **The EDS LOM Requirement:** *Ares V EDS shall limit their contribution to the risk of Loss of Mission (LOM) for Lunar missions to no greater than 1 in 250.*
  - Achievability:
    - The LOM assessment showed that the EDS shows promise of being able to meet the requirement.

Post conceptual Phase - Reliability Discussions

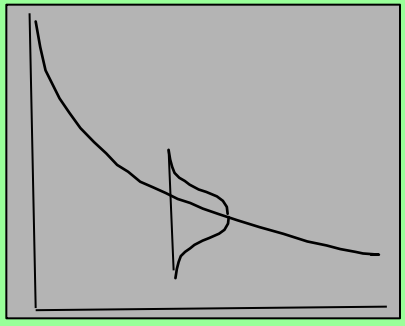
Post Conceptual Design Phase

- **During conceptual design phase:**
  - Probabilistic risk Assessment (PRA) is intended to support the system configuration selection, functional analysis is used, and basic events are at the box level (e.g. loss of propulsion due to SRB, SRM, J2-X, etc.)
- **In Post conceptual design phases:**
  - PRA is intended to support component and system design
  - The standard PRA methodology is applied.
  - Issues are identified and more in-depth analysis are performed.
  - Extensive reliability effort is planned to support the Ares V subsystem and component design.

Operational Reliability

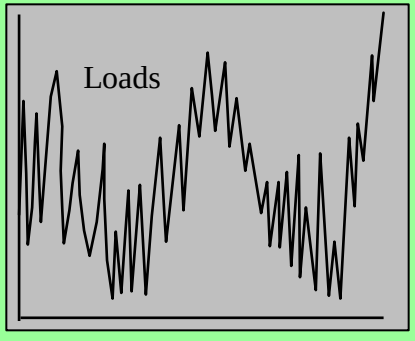
Operational Reliability

Materials Properties



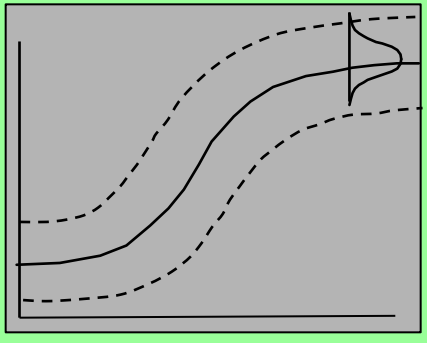
Material Models

Loads & Environments



Historical data and models

Operations

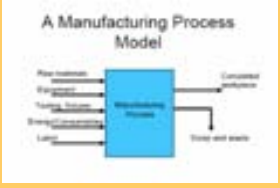


Operating conditions

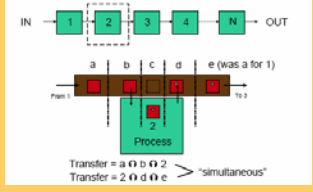
Design Reliability

Process Reliability

Processing

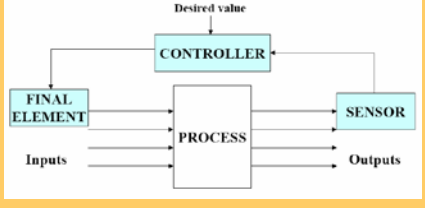


Manufacturing Models

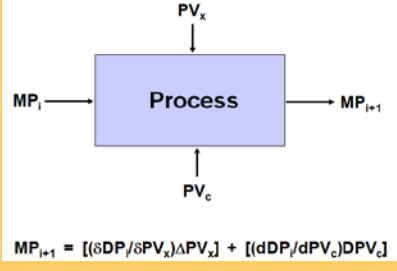


Processing Models

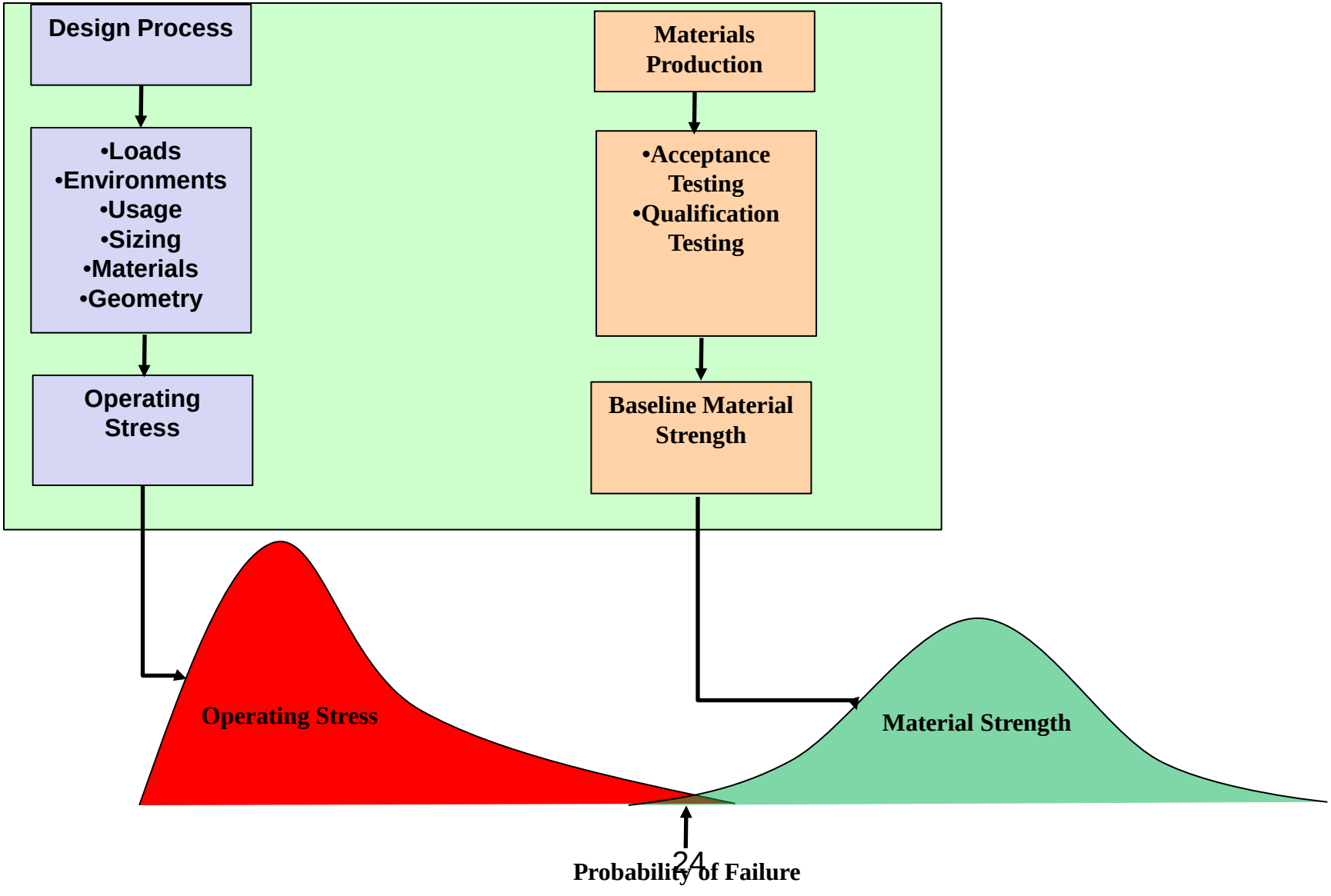
Process Control



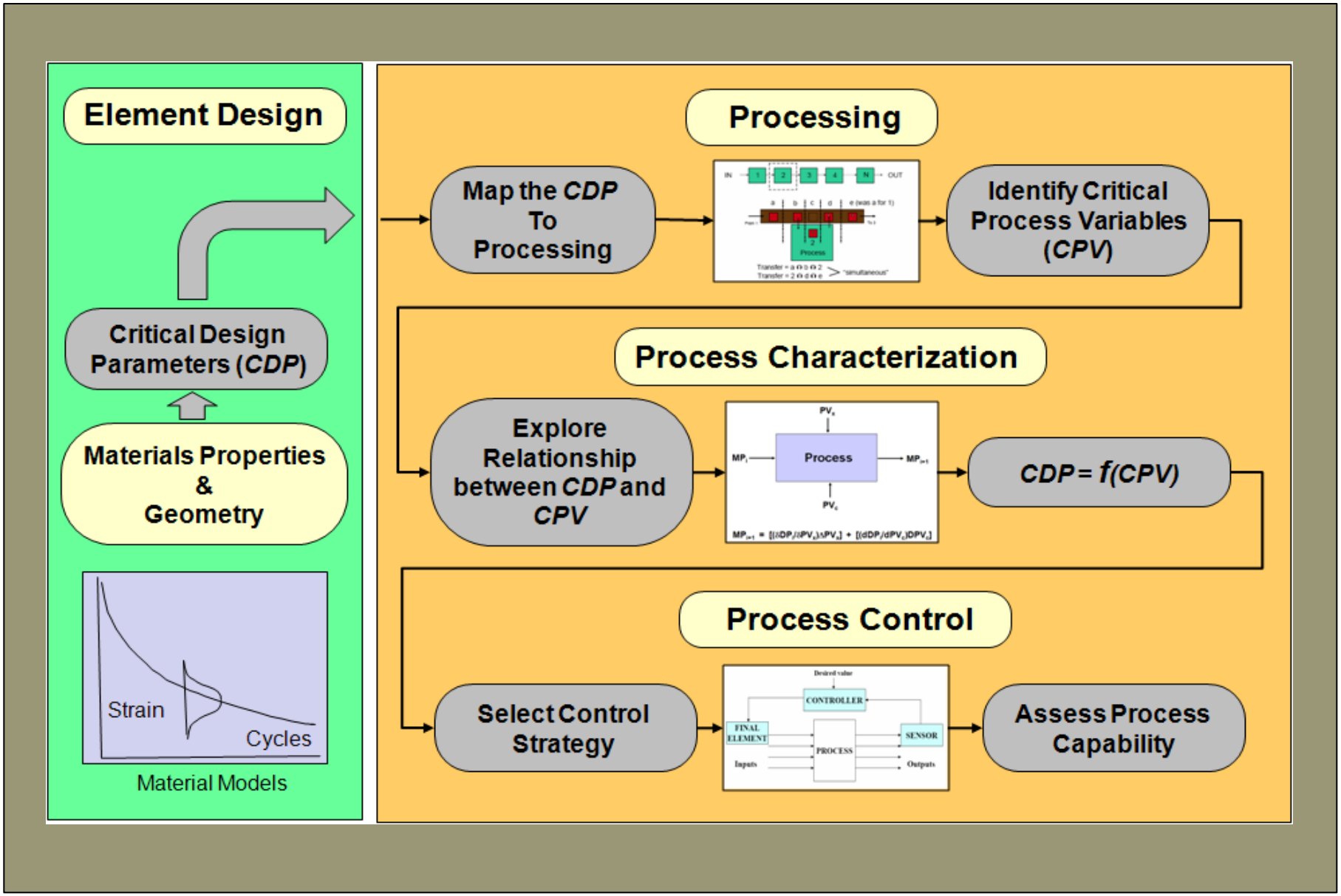
Process Characterization



Design Reliability



Process Reliability



Concluding Remarks

- **The lessons learned from the S&MA early involvement in the Ares I launch vehicle design phases proved that performing an in-line function jointly with engineering is critical for S&MA to have an effective role in supporting the system, element, and component design.**
- **These lessons learned were used to effectively support the Ares V conceptual design phase and planning for post conceptual design phases.**
- **The Top level Conceptual LOM assessment for Ares V performed by the S&MA community jointly with the engineering Advanced Concept Office (ACO) was influential in the final selection of the Ares V system configuration.**
- **Post conceptual phase, extensive reliability effort should be planned to support future Heavy Lift Launch Vehicles (HLLV) design. In-depth reliability analysis involving the design, manufacturing, and system engineering communities is critical to understand design and process uncertainties and system integrated failures.**