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ALTAIR LUNAR LANDER DEVELOPMENT STATUS: ENABLING LUNAR EXPLORATION

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ABSTRACT

As a critical part of the NASA Constellation Program lunar transportation architecture, the Altair lunar lander will return humans to the moon and enable a sustained program of lunar exploration. The Altair is to deliver up to four crew to the surface of the moon and return them to low lunar orbit at the completion of their mission. Altair will also be used to deliver large cargo elements to the lunar surface, enabling the buildup of an outpost. The Altair Project initialized its design using a "minimum functionality" approach that identified critical functionality required to meet a minimum set of Altair requirements. The Altair team then performed several analysis cycles using risk-informed design to selectively add back components and functionality to increase the vehicle's safety and reliability. The analysis cycle results were captured in a reference Altair design. This design was reviewed at the Constellation Lunar Capabilities Concept Review, a Mission Concept Review, where key driving requirements were confirmed and the Altair Project was given authorization to began Phase A project formulation. A key objective of Phase A is to revisit the Altair vehicle configuration, to better optimize it to complete its broad range of crew and cargo delivery missions. Industry was invited to partner with NASA early in the design to provide their insights regarding Altair configuration and key engineering challenges. NASA intends to continue to seek industry involvement in project formulation activities. This paper will update the international community on the status of the Altair Project as it addresses the challenges of project formulation, including optimizing a vehicle configuration based on the work of the NASA Altair Project team, industry inputs and the plans going forward in designing the Altair lunar lander.

FULL TEXT

Altair and the Constellation Transportation Architecture

The Altair lunar lander is an integral component of NASA's Constellation Program. It is joined by the Orion crew exploration vehicle, the Ares I crew launch vehicle and the Ares V heavy-lift launch vehicle to complete the Constellation transportation system. Altair's fundamental function is to transport crew and cargo from lunar orbit to the moon's surface, and to return crewmembers back to lunar orbit. Altair is also closely coupled to Constellation's Lunar Surface Systems, providing transportation and selected services to lunar surface habitats, rovers, science experiments and logistics.

Altair performs 3 distinct, but related, missions. A "sortie" mission will deliver a crew of 4 and up to 500 kg of payload to any point on the lunar surface and support the crew for up to 7 days prior to returning to low lunar orbit (LLO). An "outpost" mission will deliver a crew of 4 to the site of a lunar outpost or other suitable pre-deployed assets, and remain on the lunar surface for up to 210 days in long-duration quiescent mode until the crew returns to LLO. And a "cargo" mission will autonomously deliver up to 14.5 mt of cargo to the lunar surface.

In crewed modes, Altair's first function is to perform Orion-Altair stack attitude control and Trajectory Correction Maneuvers (TCM) during trans-lunar coast. It also performs stack Lunar Orbit Insertion (LOI), stack attitude control in LLO prior to lunar descent, de-orbit, lunar landing, lunar ascent, LLO rendezvous with Orion, and disposal. Cargo landers perform attitude control and Trajectory Correction Maneuvers (TCM) during trans-lunar coast, LOI, de-orbit and autonomous lunar landing. As part of project formulation activities, a detailed operations concept and function derivation has been performed in order to inform the definition of Altair system requirements.

The Altair System

Altair currently consists of four major components: an Ascent Module (AM), a Descent Module (DM), an Airlock and the Ares V Earth Departure Stage/Altair Adapter (EDSA). The AM is built around a crew cabin that serves as the primary habitable volume for the crew during at least the descent and ascent phases of the crewed sortie mission, and provides pressurized access to the Airlock and Orion. Altair's DM main function is to deliver hardware (AM with crew, Airlock, cargo) to the surface of the Moon, and is built around the descent propulsion system, landing gear, and structure necessary to carry loads through all flight phases. The Airlock module provides ingress/egress access to the Altair AM in the Sortie mission mode. The Airlock allows the crew to perform split operations (e.g. two crew members perform EVA while two crew members remain in the Altair) and serves as one of the primary mechanisms used to control the transport of lunar dust into the AM. Different combinations of these modules yield 3 separate configurations of the lander for crewed sortie missions (AM+DM+airlock, see Figure 1), crewed outpost missions (AM+DM) and dedicated cargo delivery (DM only).

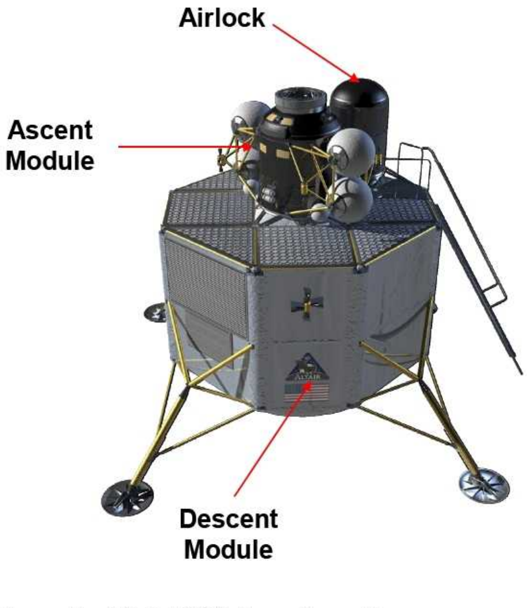


Figure 1. Altair P905-A configuration

This initial design was chosen with some thought. Over the past decades, NASA has well over 100 discrete lander designs that explored the trade space variables of staging, delta-V split, propellant types, crew size, surface duration, launch configuration, landing configuration, launch shroud dimensions, abort capabilities, crew access, cargo accessibility and offloading, C.G. control, and a myriad of other, often competing, design drivers. Based upon this history of studies, and the specific features of the overall Constellation architecture, the Altair Project selected a configuration to begin its risk-informed design process – a two stage vehicle using a large, efficient LOX/LH2 stage for LOI and landing, a small, lightweight ascent stage for crew habitation and "flight deck" functions, and a separate airlock.

This choice of initial configuration was necessary to initialize the risk-informed design process, and has been held constant to enable this design process to proceed. Freezing a design early in the process does create a risk that this initial (likely non-optimal) design choice becomes confused with THE ultimate design. However, an important step that has been inserted into the Altair design process is to periodically "step back" and re-evaluate the vehicle configuration to assess if the team is pursuing the most optimum design. Having just completed the initial cycles of risk reduction and reliability improvements, the next step in the Altair project will be re-assessing overall vehicle configuration.

Risk-Informed Design

The Altair project is using a design approach that is unique to prior NASA human spacecraft projects[1]. A typical NASA project first begins with a set of requirements that describe the entirety of the functions and performance a spacecraft must possess, and a vehicle is then designed to satisfy all of these requirements. This process results in a design that initially attempts to meet all requirements equally, and from which it is difficult to extract capability if the vehicle is found to exceed mass or cost limitations. Altair's approach was to first design a vehicle that meets only a minimum set of requirements, and then incrementally add functions and performance back into the design. This approach allows the decision to accept each additional requirement to be informed by its individual impact to cost, performance and risk.

This process was derived in part from NASA Engineering Safety Center Report NESC PR-06-108, "Design, Development, Test and Evaluation (DDT&E) Considerations for Safe and Reliable Human-Rated Spacecraft Systems"[2].

After defining the "minimum functional" vehicle in the first Lander Design Analysis Cycle (LDAC-1), subsequent design cycles identified major risks that affected the safety of the crew (LDAC-2), and the success of the mission (LDAC-3). By using risks to inform these early design cycles, the Altair Project was able to identify the specific performance "cost" of each increment of crew safety and mission reliability that was added to the minimum spacecraft design. Residual spacecraft risks will continue to be re-evaluated as subsequent design cycles assess the performance, cost and risk impacts of adding additional vehicle functionality, and other factors such as manufacturability and maintainability. Figure 2 illustrates the timeline of the Lander design cycles.

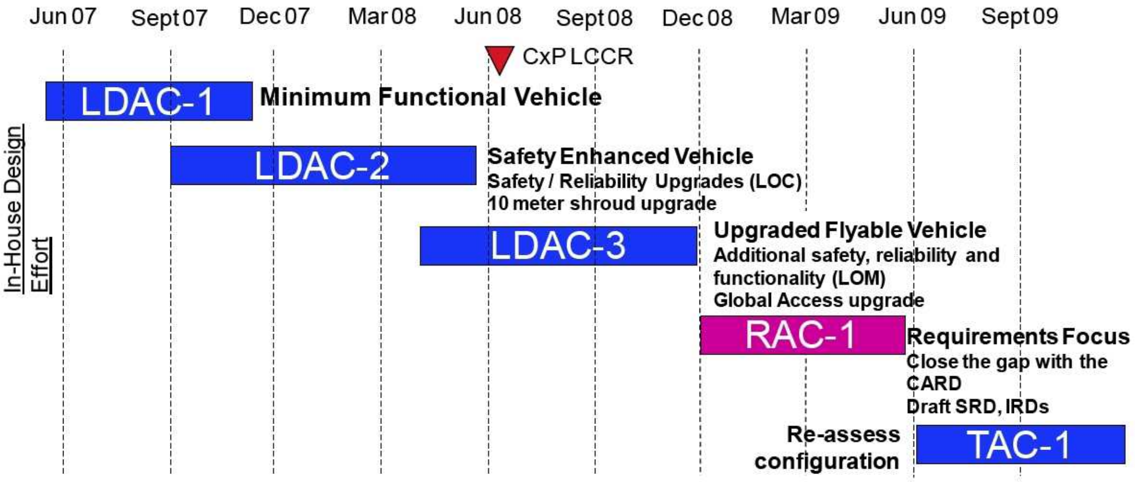


Figure 2. Altair Lunar Lander Design Cycles

Design Analysis Cycle Summaries

The first step of the process is to establish a "minimum functionality" baseline design. This requires that the design team scrub the vehicle requirements back to a small number that described the essential functions and constraints of the lander. For the Altair lander these "core" requirements were to carry 4 crew to the surface for 7 days with 500 kg of payload, to loiter for up to 210 days at a polar outpost, to deliver 14,500 kg of dedicated cargo, to package within the Ares V shroud, to perform the lunar orbit insertion burn with the Orion spacecraft attached, to carry an airlock, and to work within the Constellation EOR-LOR architecture. Key constraints were control masses of 45,000 kg for crewed missions and 53,600 kg for cargo missions.

The Minimum Functional design provided the baseline from which to identify vehicle risks in order to mature the design from one that was essentially "single string" to one that was "safety enhanced". Risks that contributed most directly to the Loss of Crew (LOC) would be first identified, and mitigation options would then be studied for these risks. Decision processes were developed for both selecting the LOC risks to be studied, and evaluating the mitigation options that would be incorporated into the LDAC-2 design. For this initial risk reduction cycle, the primary measures would be mass and change to risk. The outcome of Altair's LOC risk reduction design cycle was to reduce LOC from 1:6 to 1:206 by expending 1300 kg of mass for more robust components, selective redundancy, or dissimilar system backups[1]. This very first cycle of risk-informed design brought the lander design close to the target LOC requirement of 1:250.

The third Altair design cycle focused on Loss of Mission (LOM) risks in the same way that LOC risks were addresses in the previous cycle. Lander reliability risk areas were identified, and options studied that would increase reliability at different levels of mass expenditure. The team also began to incorporate other capabilities, such as the ability to land on any site on the lunar globe. This “Global Access” capability will be “bought back” in the same way that safety and reliability are re-introduced into the minimum design – with known impact to risk and performance. The progression of Altair designs through the design cycles described above is shown in Table 1.

LLPO Design Cycle:	LDAC-1	LDAC-1Δ	LDAC-2	LDAC-3
Sortie Mission				
Ascent Module	5,340 kg	5,075 kg	5,300 kg	6,494 kg
Hab Module	1,843 kg	949 kg (Airlock only)	1,053 kg (Airlock only)	1,173 kg (Airlock only)
Descent Module	33,976 kg	32,718 kg	33,845 kg	33,483 kg
PMR	3,511 kg	2,858 kg	3,130 kg	2,008 kg
Unallocated	331 kg	3,652 kg	1,671 kg	1,254 kg
Cargo Mission				
Descent Module	33,743 kg	34,248 kg	35,656 kg	37,177 kg
PMR	2,304 kg	1,974 kg	2,135 kg	2,003 kg
Unallocated	14,136 kg	17,378 kg	15,808 kg	14,794 kg
Crew to Outpost Mission				
Ascent Module	5357 kg	5,356 kg	5,525 kg	6,763 kg
Descent Module	33,868 kg	32,684 kg	33,711 kg	33,099 kg
PMR	3,009 kg	2,691 kg	2,940 kg	1,899 kg
Unallocated	2,766 kg	4,269 kg	2,824 kg	2,653 kg

Table 1. Altair Lander Configuration and performance maturation using Risk-Informed Design

Risk-informed design provides early, critical insight into the overall viability of the end-to-end architecture, and provides a starting point to make informed cost/risk trades so that risks can consciously be bought down. The Altair team has used the education afforded by risk-informed design to look at risk reduction in its many forms and not to blindly apply fault tolerance rules or preconceived risk reduction solutions. The process inherently produces risk metrics for each added capability, and cost analysis can easily be added to facilitate evaluation of the true cost and risk changes that accompany each added capability. Perhaps most importantly, risk-informed design creates a true “Smart Buyer” team that inherently understands the balance of risk drivers and mass performance within the design.

Industry Lander Studies

In 2008, the Altair office signed contracts with 5 aerospace contractors to conduct parallel studies of risk-informed lander design. The companies were given the same set of requirements used by NASA’s in-house Altair team and asked to independently derive their own “minimum functionality” lander design, and then to suggest innovative approaches to improving the safety and reliability of this design. The contractor teams identified areas where NASA’s initial design could be further minimized, and where it required additional performance to achieve only the essential functions. Each using their own form of risk-informed design, the contractors prioritized safety "buyback" candidates, identifying propulsion, structures and physical configuration trades as the largest performance drivers.

The contractor teams were also encouraged to pursue alternative configurations and innovative design solutions. The teams created lander concepts that investigated alternative tank configurations, alternative propellants, different numbers of engines and engine placement, alternative ascent module pressure vessels, different structural systems, and even variants to the number of landing gear. An example of the alternative contractor concepts is shown in Figure 3. In addition to the innovative design work, the contractors also exhibited a willingness to work with NASA and with each other in a collaborative work environment where ideas could be shared and discussed openly. The industry studies validated NASA's risk-informed design approach, and provided an excellent initialization for future design cycles that will partner NASA and industry.

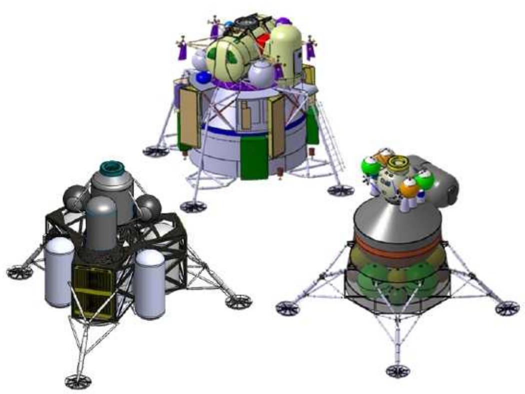


Figure 3. Examples of Industry lander concepts

Revisiting Configuration Decisions and Maturing the Design

Risk-informed design works best when the configuration of the spacecraft is held constant, so as not to introduce additional variables into the design. It is also a time consuming process that may not work for projects with compressed schedules (the first 3 design analysis cycles took the Altair team approximately 24 months to complete). To optimize the risk-based design effort, the Altair team chose to hold the vehicle design constant throughout the design cycles, with a plan to revisit vehicle configuration once LOC and LOM "buyback" cycles were complete.

With the completion of the risk and reliability design cycles, the next step is to prioritize the configuration and maturation studies that would have the greatest impact on the vehicle design. Altair considered a list of over 200 potential configuration/maturation trades, and from that list chose the following studies as the basis for a Trade Analysis Cycle (TAC) that was inserted into the vehicle's development schedule. This list includes:

- Alternate Descent Module Configuration
- Alternate Ascent Module and Airlock configuration
- Alternate AM/DM separation concepts and analyses
- Structural Stiffness Design
- Descent Module Tank Residuals
- Human piloting capability maturation
- Ops Con/Ops Timeline maturation
- Spacecraft "safe" configuration for critical faults

The completion of the Trade Analysis Cycles will result in a fresh look at the lander design to determine if the current configuration is optimum for the current architecture. Possible changes may include a reduced number of descent tanks, alternative descent stage structure, alternative placement of the ascent module and airlock, change of the ascent module pressure vessel shape, and alternative methods of packaging cargo. It is important for a design to be revisited on occasion – engineers sometimes become enamored with our designs and fail to see large innovative or even subtle alternatives that may improve the design solution. Scheduling regular revisits of the design configuration into the design process flow offers the team the opportunity to "step back" and better optimize the design solution.

Looking Ahead

The Altair lunar lander team now possesses the knowledge of risk and reliability improvements that can be "bought back" into any lander design. The Altair team will use this knowledge to inform the totality of activities that must be performed during Phase A. Contractors have validated the risk-informed design process, and suggested alternative configurations, and other potential areas of study. From the combination of these early analysis cycles the Altair office has assembled a master list of over 200 tasks that it will undertake to re-assess lander configuration, mature subsystem designs, and continue decrementing LOC and LOM risks. At the same time the office is conducting these technical studies, it is also validating system requirements in preparation for a Constellation Program Systems Requirements Review for the early lunar missions[3], as well as maturing its own Systems Requirements, Interface Requirements, and other documents in preparation for its own upcoming Systems Requirements Review. These are critical Phase A activities. The Altair Project has sought to streamline NASA processes and combine the design expertise of NASA and industry, and will continue to combine the best of NASA and industry as it moves from conceptual design into its preliminary design phase.

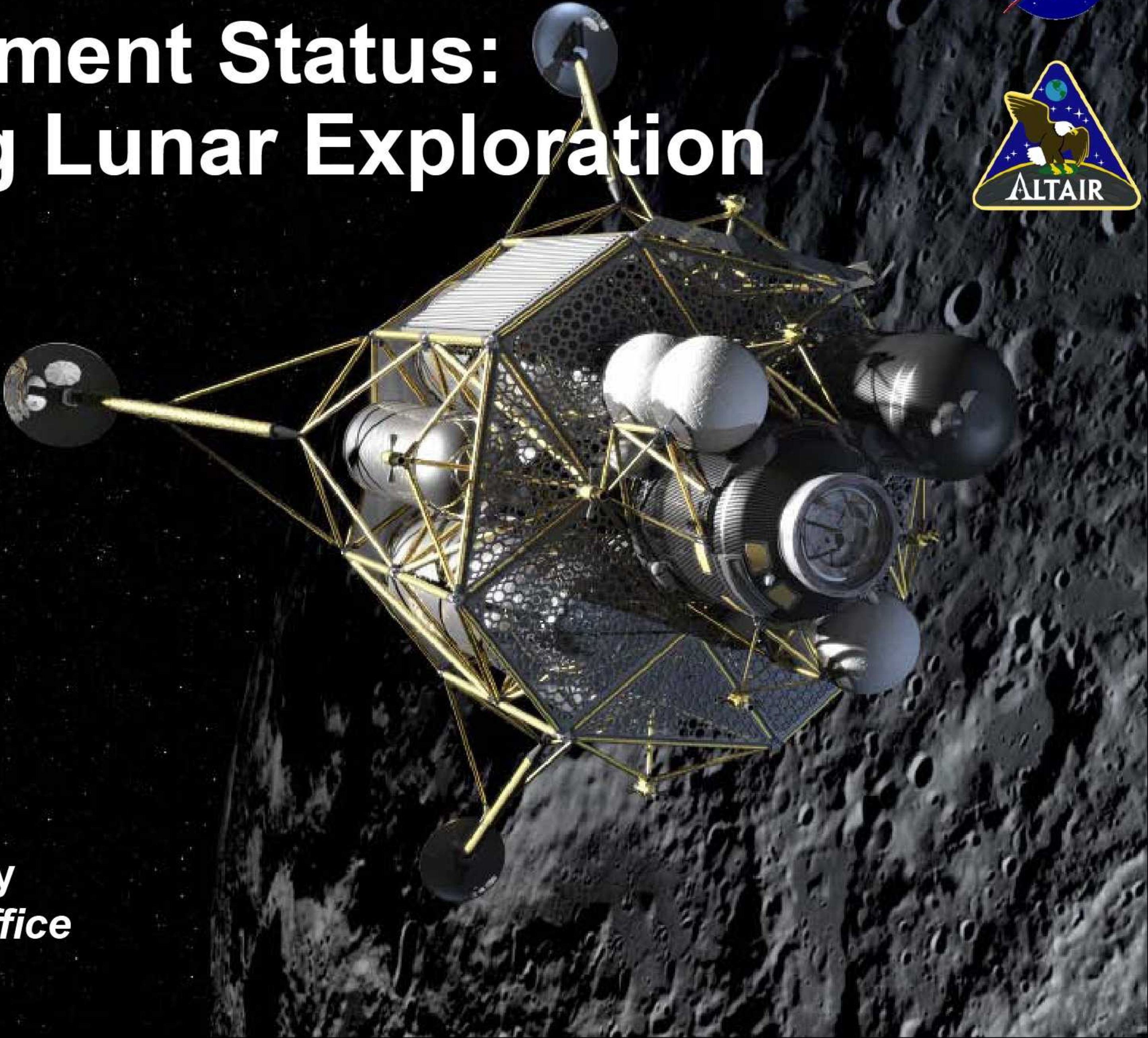
References

1 International Astronautics Congress (2009), Hansen, Lauri and Connolly, John, “The Altair Design and Minimum Functionality Approach”, IAC-08-D2.9.-D1.6, Glasgow, Scotland, October 2008

2. NASA Engineering Safety Center Report NESC PR-06-108, “Design, Development, Test and Evaluation (DDT&E) Considerations for Safe and Reliable Human-Rated Spacecraft Systems”, 2007

3. International Astronautics Congress (2009), Jeff M. Hanley, Lawrence D. Thomas, and Jennifer L. Rhatigan; NASA Johnson Space Center, Houston TX “NASA’s *Constellation* Program: Milestones Toward the Frontier”, Dejeon, Korea, September 2009

Altair Lunar Lander Development Status: Enabling Lunar Exploration



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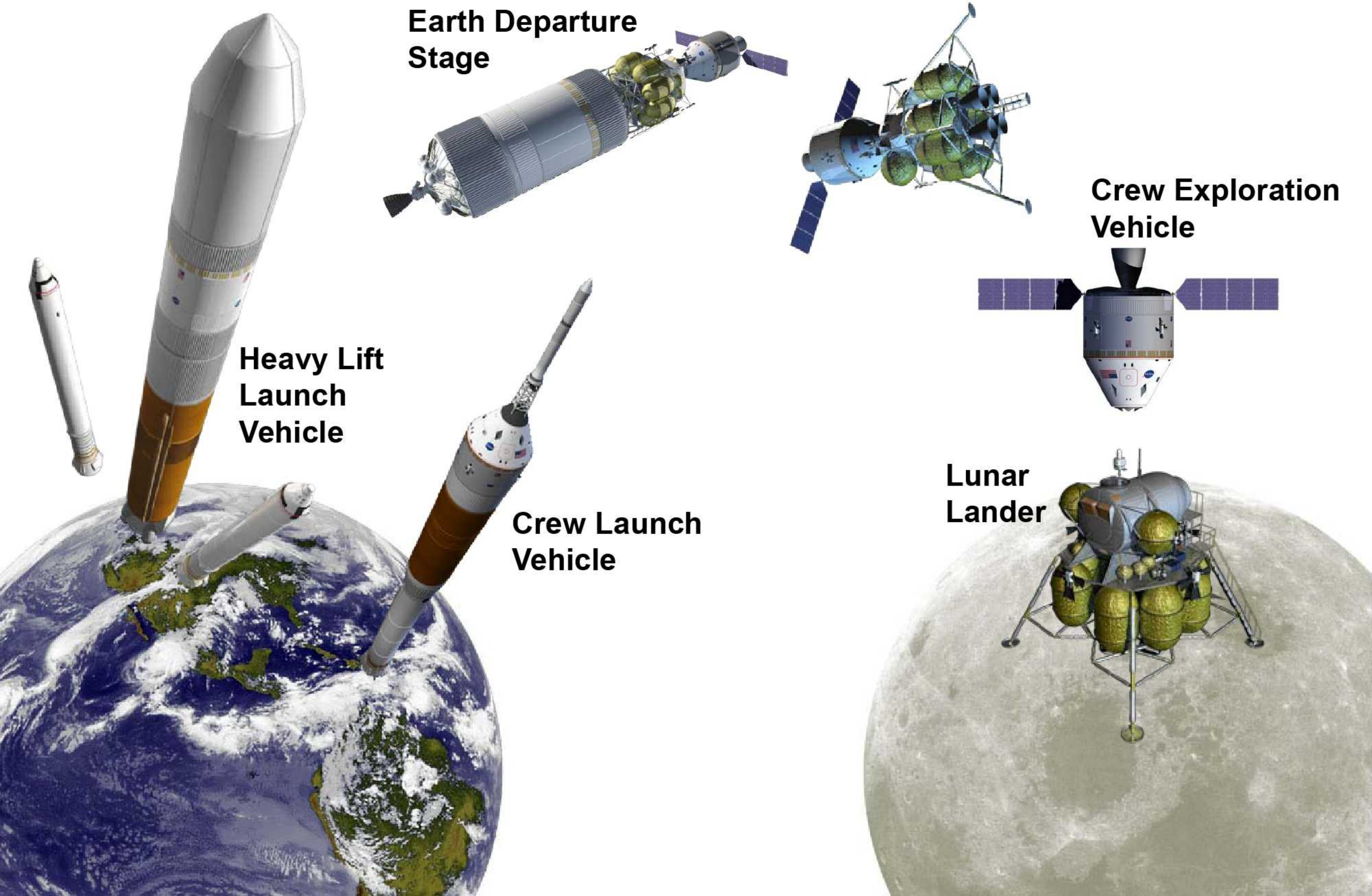
13 October 2009

Overview

- Altair Mission Overview
- Altair Risk Informed Design Approach
- Current Lander Design Overview
- The Path Forward
- Summary

Components of Program Constellation



Earth Departure Stage

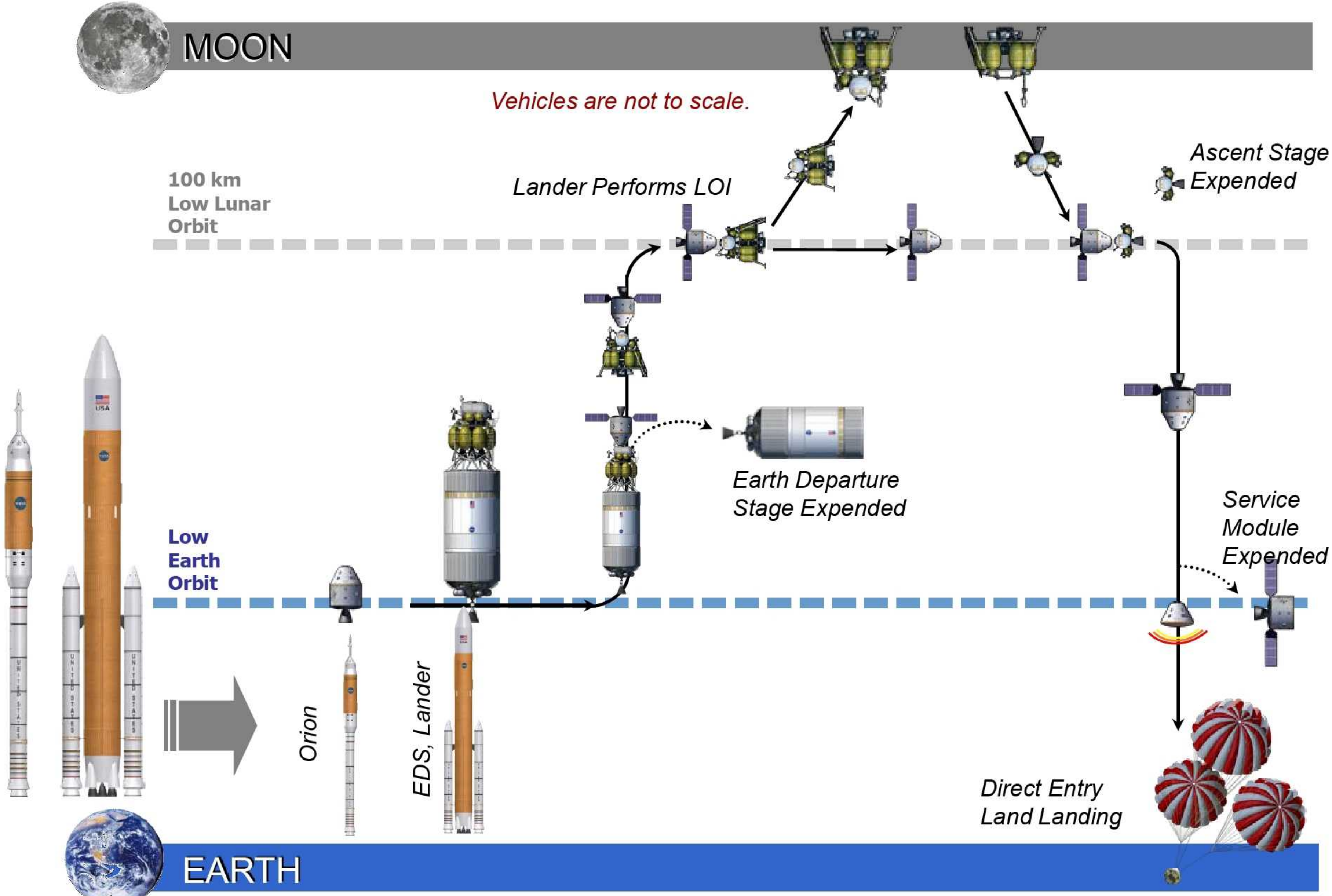
Crew Exploration Vehicle

Heavy Lift Launch Vehicle

Crew Launch Vehicle

Lunar Lander

Typical Lunar Reference Mission



MOON

Vehicles are not to scale.

100 km
Low Lunar
Orbit

Lander Performs LOI

Ascent Stage
Expended

Earth Departure
Stage Expended

Service
Module
Expended

Low
Earth
Orbit

Orion

EDS, Lander

Direct Entry
Land Landing

EARTH

Altair Risk Informed Design Approach

"Minimum Functional" design
8.4 m Ares V shroud, 45 mt control mass

"Safety Enhanced" design
10 m Ares V shroud

"Reliability Enhanced" design

Altair Design Cycle:	LDAC-1	LDAC-1Δ	LDAC-2	LDAC-3

Altair Design Analysis Cycles (LDAC) Focused on Risk

LDAC-1 – Minimum Functional Vehicle

LDAC-1 – Minimum Functional Vehicle with optimized descent module structure

LDAC-2 – Safety/Reliability (crew) Upgraded Vehicle

LDAC-3 – Safety/Reliability (mission) Upgraded Vehicle

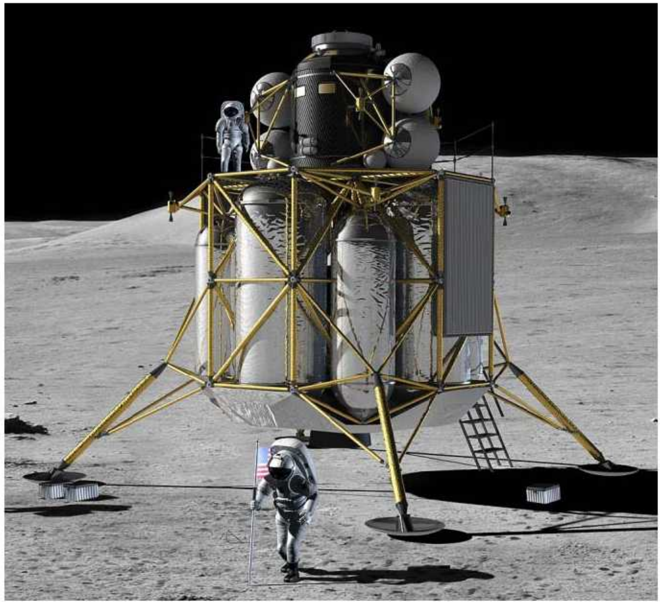
Benefits of Risk Informed Design

- Provides early, critical insight into the overall viability of the end-to-end architecture
- Provides a starting point to make informed cost/risk trades and consciously buy down risk
- Inherently minimizes interfaces leading to a vehicle that is not over designed and costly
- Facilitates derivation of mandatory design requirements
- Facilitates evaluation of what other capabilities cost
- Builds and informed Project team
- Eliminates mass added due to blind application of fault tolerance rule
- Minimizes amount of redesign required at the end of the design process due to vehicle exceeding mass budget

Understanding risk drivers enables mass, power, cost trades to be done in a fully informed manner

LDAC-1 Starting Point – DRMs and Requirements

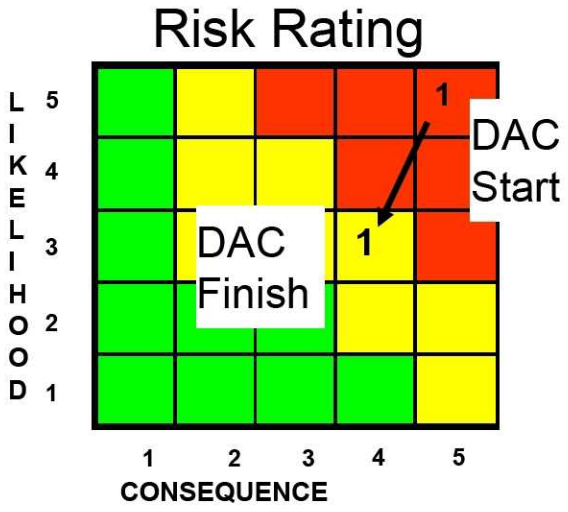
- **3 DRMs with Mission Timelines and Functional Allocations**
  - Sortie Mission to South Pole
    - 4 Crew / 7 Days on Surface / No support from surface assets
    - No restrictions on 'when' (accommodating eclipse periods)
  - Outpost Mission to South Pole
    - 4 Crew with Cargo Element (LAT Campaign option 2)
    - Outpost provides habitation on surface (down and out)
    - 210 Days with surface support (power)
  - Cargo Mission to South Pole
    - Short duration, large payload



- **'Hard' Requirements**
  - 4 Crew
  - 7 Day Sortie
  - 210 Day Outpost
  - Airlock (implemented on sortie mission only)
  - CxP transportation architecture
    - 8.4 meter shroud, TLI Loads, Lander performs LOI burn, CEV IRD, etc
  - Control Mass
    - Total Lander mass at TLI for crewed missions: 45,000 kg
    - Total Lander mass at TLI for cargo missions: 53,600 kg
  - Delivered payload: 500 kg (sortie DRM), 14,500 kg (cargo DRM)
  - Returned payload: 100 kg min/250 kg goal (sortie, outpost mission DRMs)

LDAC-2: Improving Lander Safety

- **Purpose:**
  - **Upgrade the Lander from a minimum functional vehicle to a minimum flyable vehicle by incorporating safety and reliability design changes that target the highest risks identified in LDAC-1**
- **Key Questions:**
  - **What data is required to evaluate the proposed design changes intended to reduce risk?**
  - **What concepts will be incorporated in the DAC-2 Lander?**
- **Analysis Products**
  - **Fault Tree**
  - **Subsystem architecture with Δ Reliability**
  - **Subsystem operation during degraded modes**
  - **Requirements for Abort Scenario's**
  - **System Performance During Abort Scenario**
- **Measures**
  - **Δ Risk Rating**
  - **Δ Mass**
  - **Δ Cost**



LDAC-2 Integrated Risk Analysis Tasks

Task #	Task Title

Vehicle Performance/Control

2	Vehicle Dynamic CG Management
3	Determine Vehicle Performance for Surface Landing
6	Prevent Ascent Module Re-Contact During Launch
16	Improve Reliability of the GN&C System with respect to Ascent, Descent, Landing and LLO
33	Improve Communication System Reliability to be Able to Update the State Vector
14	Develop Mission Abort Timelines for Descent and Ascent

Propulsion

8	Improve Reliability of Descent Main Engine
9	Improve Reliability of Descent Reaction Control System
20	Improve Reliability of Ascent MPS and RCS
25	Improve Reliability of Thrust Vector Control for Descent Main Engine
26	Improve Reliability of Main Propulsion System Instrumentation
28	Increase Reliability of Ascent Module Main Engine
29	Prevent freezing of the Hypergol Main and RCS (ascent and descent) Propulsion Systems
34	Improve Reliability of the Descent Main Propulsion System

Power

10	Improve Reliability of Descent Module Power System
11	Improve Reliability of Ascent Module Power System
30	Improved Safety of Main Ascent Module Battery
32	Improve Fuel Cell Safety
5	"Lifeboat" Minimum AM Power Requirements

Life Support

12	Increase Reliability of CO2 Scrubbing System
13	Increase Reliability to Prevent Loss of Breathable Atmosphere
17	"Lifeboat" minimum breathable atmosphere requirements

Structures

15	Increase reliability of ascent stage/airlock separation system
23	Improve Landing Gear Deployment, Locking and Load Attenuation Reliability
24	Increase Reliability of AM/DM Attachment and Separation Mechanisms

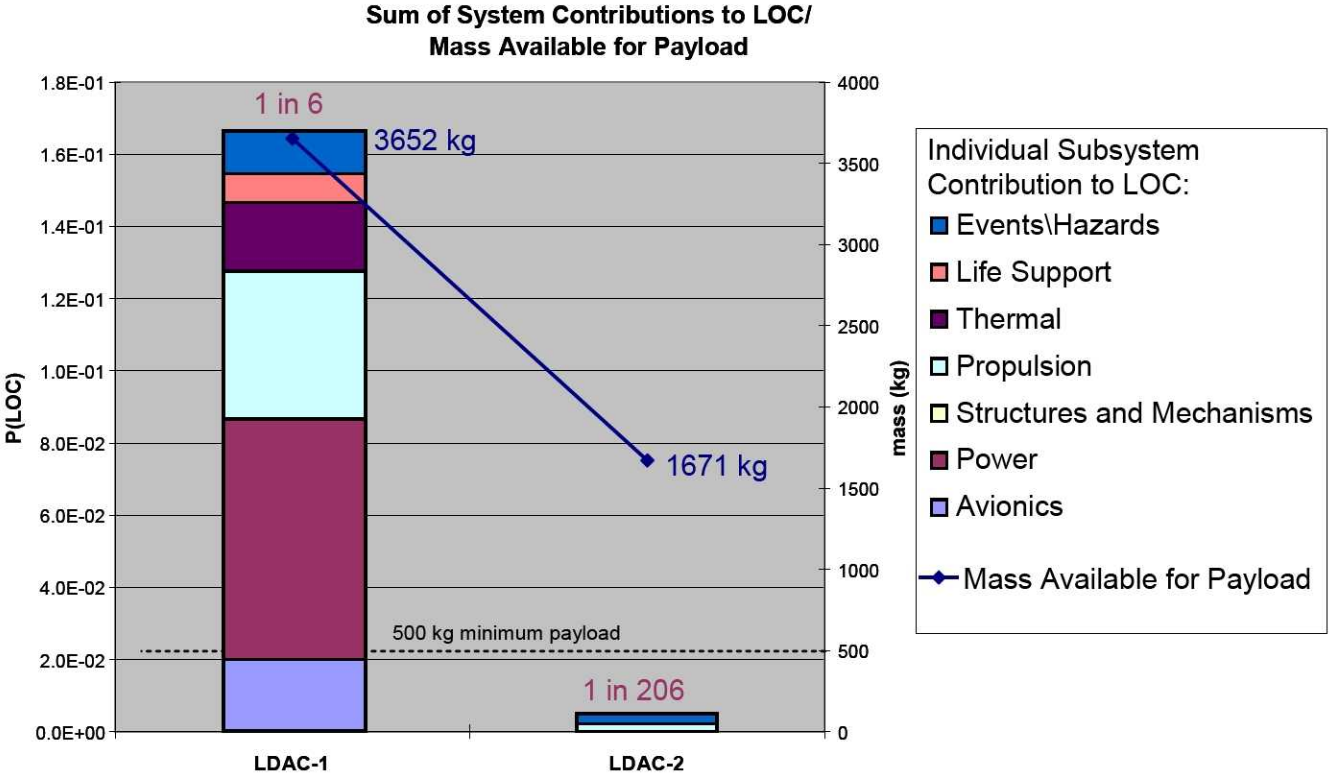
Thermal

4	Improved Thermal System Reliability

Environment

19	Determine Radiation Environment and Mass Threat for Protection
21	Determine MMOD Environment and Mass Threat for Protection

Summary LDAC-2 Results: Probability of Loss of Crew, Mass Available for Payload



Note: P(LOC) based on simplified models and identified risk

Note: The LDAC-2 vehicle was not a "fully functional" design

LDAC-2 Lander Design

- **LDAC-2 work resulted in "preliminary design" with system level products**
  - Detailed subsystem schematics based on required vehicle functionality
  - Preliminary component sizing based on performance analysis
  - MEL based on subsystem-level details
- **LDAC-2 design incorporated LOC mitigation upgrades to "minimum functional" design**

LDAC-3 Overview

- **Primary objective was to identify loss of mission (LOM) risk drivers and develop potential changes that improve overall loss of mission risk**
  - Some general vehicle design and analysis maturation activity was also completed
- **Loss of crew is easily understood, but LOM definition / understanding proved more difficult**
- **LDAC-3 LOM assessment used as a "tool" to support design development and not as some operational success type of measure**
  - In this context, loss of mission was different than mission success
  - Loss of mission - Inability to fully complete significant / primary mission objectives (this is more stringent)
  - Mission Success – Measure for how successful a given mission is given desired vs actual accomplishment (easier to achieve)
- **8 mission objectives defined for LDAC-3; violation of any one was declared LOM**

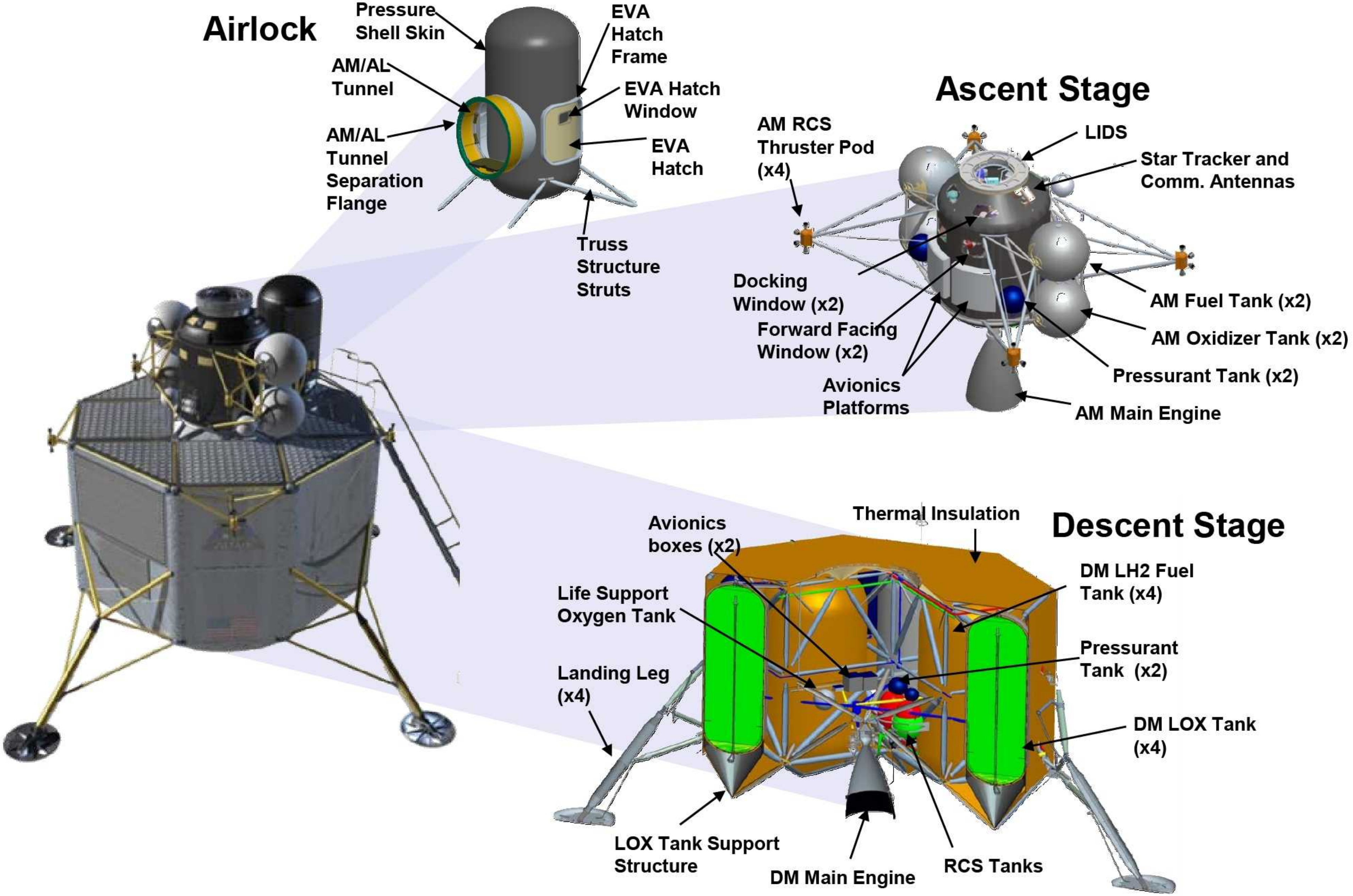
LOM Reduction Buy Back Summary

Subsystem	Changes
Power	• Updated cable mass assumptions • Improved reliability of the power bus by adding circuit bypass and change to latching relays • System resized to 3kW average and 6kW peak power
Propulsion	• Implemented series –parallel redundant bi-prop valves with vehicle supplied pneumatics for the Ascent Main Engine • Added three-string regulators with pyro ladder on AM RCS to isolate NTO during surface stay • Incorporated autogeneous pressurization to DM system (reduces He need) • Adopted warm / cold He strategy for fuel / oxidizer pressurization • Added redundant injector heaters and heat pipes for DM RCS
Structures / Mechanisms	• Updated DM, EDSA, ad RCS struts to composite construction • Updated Airlock pressure shell design to composite • Improved fidelity of AM pressure vessel and hatch (to Orion) design • Selected guillotine cutter concept for umbilical separation and matured EDSA separation system
Life Support	• Cabin air and suit loop O2 LOM reliability improvement • Sized potable "fixed charge" and ECLSS bellows water tanks for redundancy • Added handheld water mist extinguisher for local fire suppression • Added point of use filters at water supply valves

LOM Reduction Buy Back Summary

Subsystem	Changes
Thermal	• System resized to ~6.1kW, increasing radiators to four • Implemented sublimator bypass and accumulator with bubble filter for LOM redundancy
C&DH	• Included capacitive discharge pyro firing circuit architecture • Implemented three flight computers (from two)
C&T	• Improved fidelity of RF cable mass estimates • Implemented a single transponder, two software defined radios architecture
GN&C	• Added optical navigation sensor suite, third IMU, and sixth descent radar antenna for LOM • Enhanced lidar targets and added running lights to support RPODU operations
EVA	• Updated battery charger to a three-channel Li-Ion charger • Added additional contingency equipment • Added two suit donning stands in Airlock
Vehicle System	• Added vehicle functional checkouts to timeline / ops con baseline • Incorporated basic hardware for lunar surface propellant scavenging

Current Altair Reference Design Overview



Airlock

Pressure Shell Skin

AM/AL Tunnel

AM/AL Tunnel Separation Flange

EVA Hatch Frame

EVA Hatch Window

EVA Hatch

Truss Structure Struts

Ascent Stage

AM RCS Thruster Pod (x4)

LIDS

Star Tracker and Comm. Antennas

Docking Window (x2)

Forward Facing Window (x2)

Avionics Platforms

AM Fuel Tank (x2)

AM Oxidizer Tank (x2)

Pressurant Tank (x2)

AM Main Engine

Descent Stage

Avionics boxes (x2)

Thermal Insulation

Life Support Oxygen Tank

DM LH2 Fuel Tank (x4)

Pressurant Tank (x2)

Landing Leg (x4)

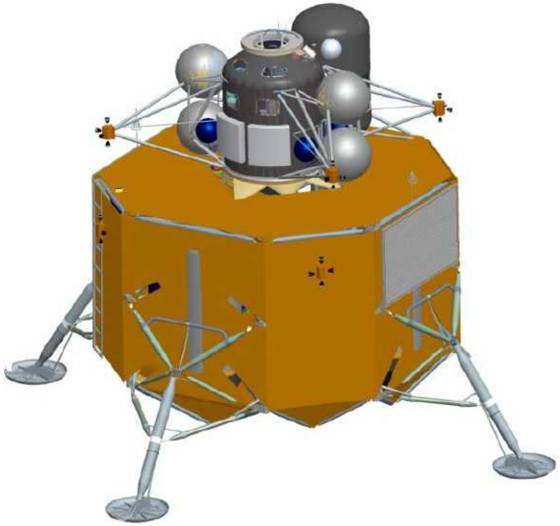
DM LOX Tank (x4)

LOX Tank Support Structure

DM Main Engine

RCS Tanks

Altair Configuration Variants

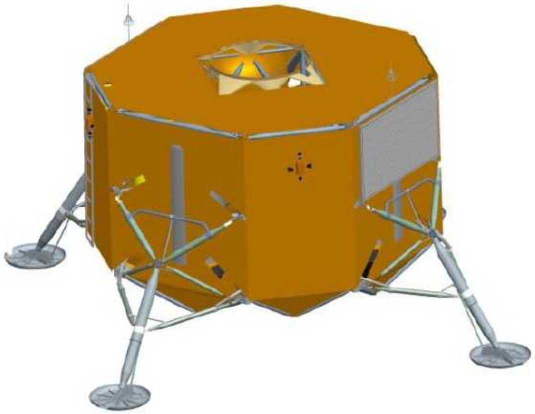


Sortie Variant

Descent Module
Ascent Module
Airlock

Outpost Variant

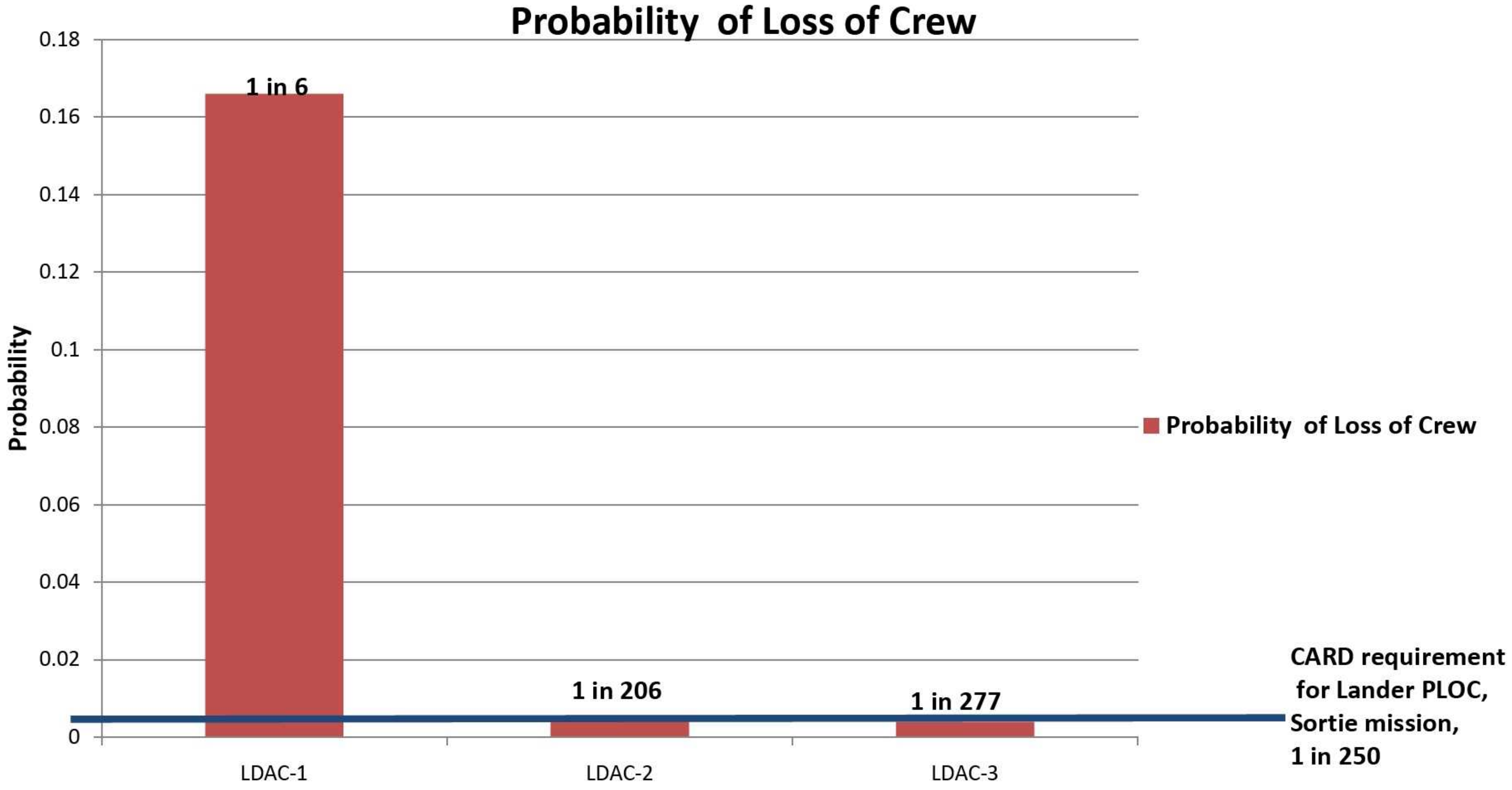
Descent Module
Ascent Module



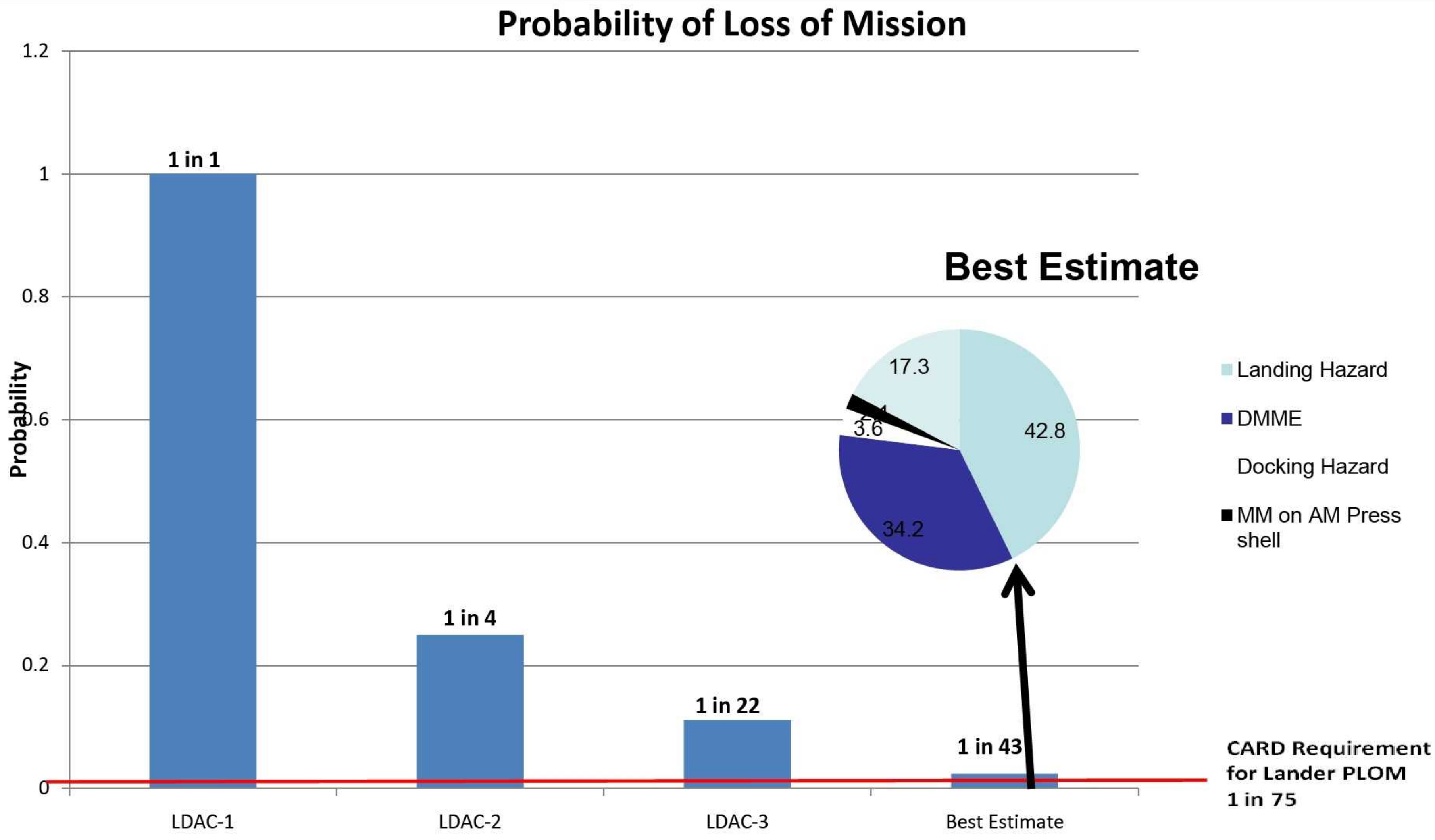
Cargo Variant

Descent Module
Cargo on Upper Deck

Altair Probability of Loss of Crew Post LDAC-3



Altair Probability of Loss of Mission Post LDAC-3



CARD Requirement for Lander PLOM 1 in 75

Altair Basic Vehicle Configuration / Architecture Background

- **The basic Altair configuration / architecture is subject to multiple design drivers:**
  - Cost, schedule, and risk
  - General performance, mass, and functionality to reach the moon and return within a given lunar transportation architecture
  - Specific functions and capabilities necessary/desired to achieve mission objectives including outpost buildup
  - Other

- **Altair efforts to date have focused on areas #1 & #2**

- **Item #3 is more important to vehicle utilization and other constellation elements, especially surface systems.**

- **Numerous alternate architecture options exist. Many tend to address a specific concern, capability, feature, or other figure of merit (FOM) from #3**
  - Achieving these often compromise #1 or #2
  - No architecture will satisfy everything
  - Project challenge is to avoid investing too much into a configuration that addresses only a specific concern/capability/FOM and invest in configurations that provide highest potential to achieve the best balance.

Selected Lessons Learned From Risk-Informed Design

- **Full redundancy was usually heaviest, frequently NOT most effective for improving LOC**
  - Investigate other means for driving down critical risks – dissimilar redundancy, higher reliability parts/designs, increased testing, etc.
- **LOC and LOM are often interrelated, so risk buy-down decisions should be made on the basis of the best balance between the two**
- **Quantitative risk tool was necessary to <u>inform</u> good design decisions**
  - Always necessary to correlate engineering judgment with tool results
  - Tool forces team to reconsider
  - However, cannot rely solely on tool results. Must be able to technically explain decision.
- **A risk tool the designers can interact with is a significant aid – improves tool and design**
  - e.g., when a result did not correlate with engineering experience, designers could easily understand model in tool. Sometimes changed model and sometimes did not.
- **Design for Minimum Risk is the way to go if you are trying to build a smart design team**

The Path Forward

- **Continue Project Formulation (Phase A) activities in a risk informed manner**
  - Demonstrate that there is a mission concept that “fits in the box”.
  - Develop sound bottoms-up requirements for Altair.
    - Utilize model based system engineering principles
  - Provide data and knowledge for project to project integration.
    - Altair team includes representatives from Orion, Ares V, GO, EVA, and LSS.
  - Provide data and knowledge for Level 2 integration and architecture trades
  - Provide informed data for cost estimation
    - Have detailed bottoms-up and top-down cost data to support project planning
  - Complete other Project formulation tasks, including
    - Upfront system engineering to enable cost, risk, schedule, and requirements trades
    - Technology maturation planning
    - Concept of Operations
    - End to end testing guidelines

Summary

- **The Altair Project began with the 100+ Lander concepts developed after ESAS, assessed the alternatives, and began design work.**
- **Altair has taken methodical, risk informed design approach**
- **A real design concept exists**
  - Current Master Equipment List includes over 4000 items for the sortie lander
  - CAD models contains >3500 parts and subassemblies
  - Detailed structural analysis (FEM, Nastran)
  - Integrated schematics and individual system schematics, etc.
- **Current design concept is a POD, not necessarily “the” design**
  - Too early to downselect to point design
  - However, a critical part of the process to:
    - Understand design drivers well enough to write good requirements for SRR
    - Ensures integration with overall Cx architecture
    - Ensures a viable mission concept exists