Key Challenges and Opportunities in Developing the Altair Lunar Lander

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The Integrated Challenge

Create a lander design based on the limitations of physics and human performance…

…that balances performance, cost, risk and reliability of the lander project, and

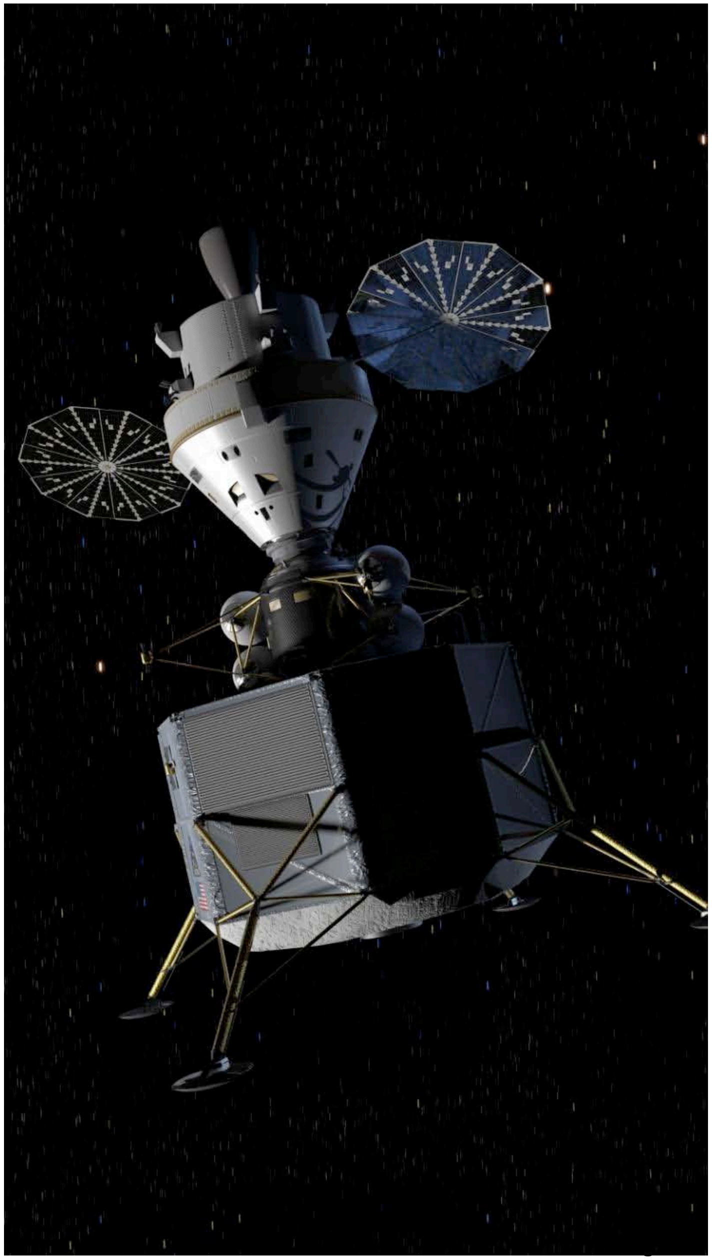
…that exists within the integrated architecture performance, cost profile, schedule, and integrated risk/ reliability targets of the Constellation Program, and

…that fulfills the policy direction of NASA's strategic plan, Congressional Authorization Acts, and Administrative/ OMB policy and budget guidance

Lunar Lander Basics

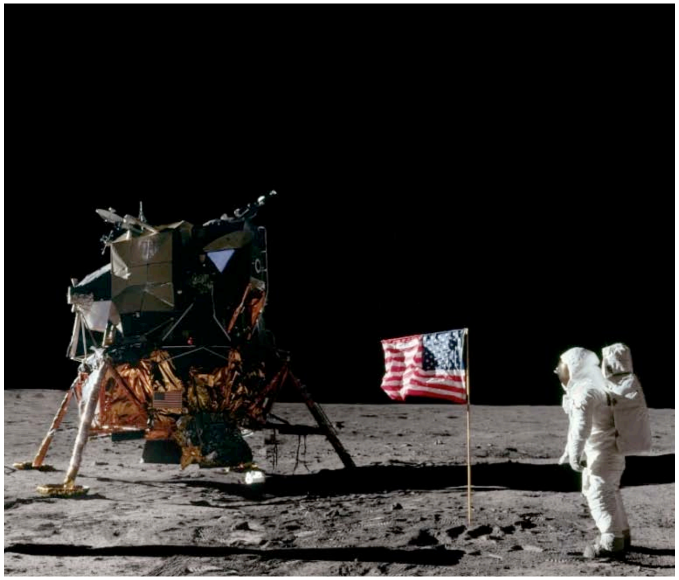
- Lander must perform large delta-V maneuvers
  - ~1000 m/sec Lunar Orbit Insertion
  - ~2000 m/sec Descent and Landing
  - ~2000 m/sec Ascent and Rendezvous
- Lander must sustain a crew of 4 for up to 7 days on the surface
- Lander must meet significant safety and reliability requirements
  - A significant fraction of Constellation's LOC and LOM targets

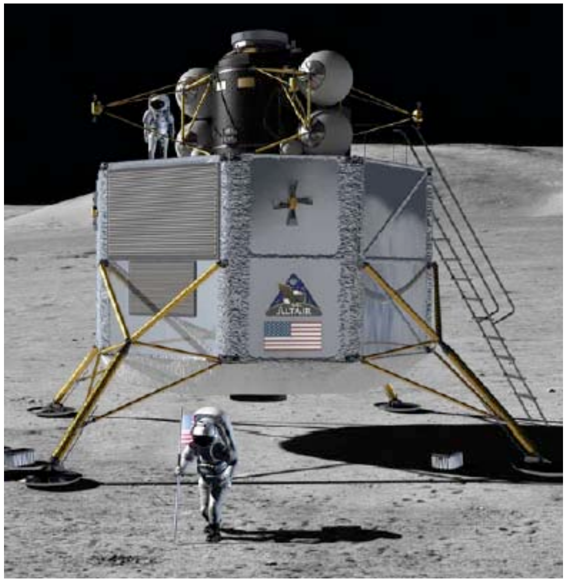
- **opportunity → use many of the lessons learned from the Apollo program**
- **challenge → the lander "looks like the LM"/ appears to "lack innovation"/ doesn't resemble the Millennium Falcon**



Apollo and Altair By the Numbers

By the Numbers	Apollo Lunar Module	Altair Lunar Lander
Crew Size (max)	2	4
Surface Duration (max)	3 days	7 days (Sortie missions), Up to 210 days (Outpost missions)
Landing site capability	Near side, equatorial	Global
Stages	2	2
Overall height	7.04 m (23.1 ft.)	9.75 m (32.0 ft.)
Width at tanks	4.22 m (13.8 ft.)	8.8 m (28.9 ft.)
Width at footpad centers (diag.)	9.45 m (31 ft.)	13.5 m (44.3 ft.)
Crew module pressurized volume	6.65 m^3 (235 cu. ft.)	17.5 m^3 (618 cu. ft.) – crew module + airlock
Ascent Stage mass	4,805 kg (10,571 lbs.)	6141 kg (13,510 lbs.)
Ascent Stage engines	1 – UDMH-NTO	1 – MMH-NTO
Ascent engine thrust	15.6 Kn (3,500 lbf.)	24.5 Kn (5,500 lbf.)
Descent Stage mass	11,666 kg (25,665 lbs.)	37,045 kg (81,500 lbs.)
Descent Stage engines	1 – UDMH-NTO	1 – pump-fed, throttling, LOX/LH2
Descent engine thrust	44.1 Kn (9,900 lbf.)	83.0 Kn (18,650 lbf.)





Apollo LM and Altair

Apollo LM

- "Eagle"
- Some preliminary design studies in the years leading up to the Apollo program
- Constraints: schedule, mass, cost
- ~7 years from start of design to first crewed flight
- Performs deorbit, landing, ascent
- Single configuration (sortie)
- 4 landing legs
- 2 stages
- Crew stands during flight

Altair

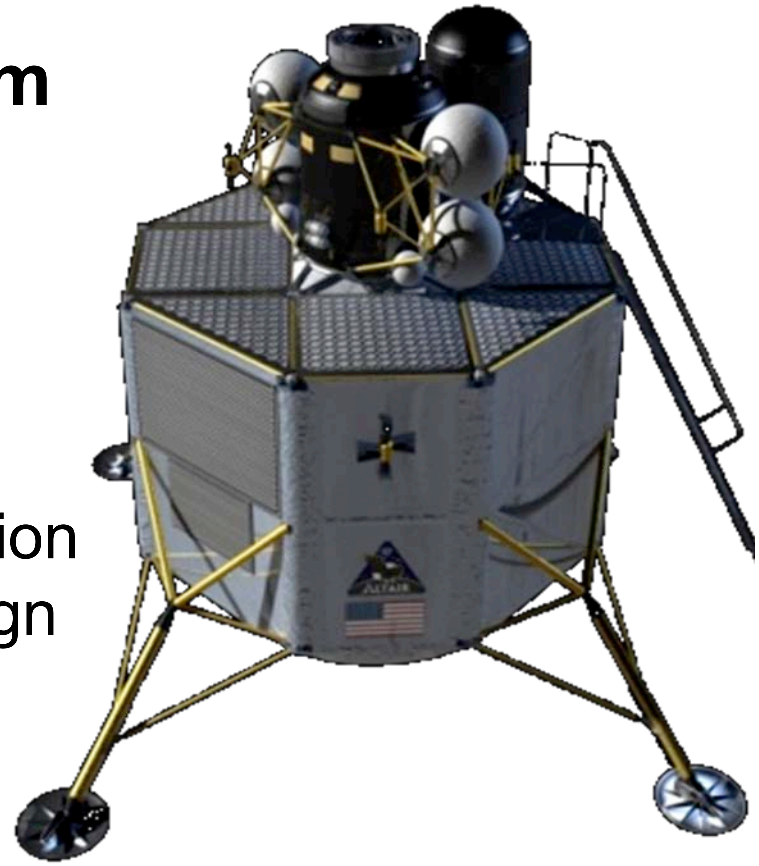
- "Altair" = brightest star in the Eagle constellation (Aquila)
- Extensive design studies, especially over the past 20 years
- Constraints: Risk, mass, cost, schedule
- ~12 years from start of preliminary design (2008) to scheduled first crewed flight (2020)
- Performs LOI (with Orion), deorbit, landing, ascent, disposal
- Separate modules configurable for sortie, cargo and crewed outpost mission
- 4 landing legs
- 2 stages
- Crew stands during flight

So Why the Similarities?

- **Both the LM and Altair are “physics machines” – their primary roles are to provide velocity changes to their systems, operate in the space environment and support human crewmembers.**
  - Physics rules
- **Technology has advanced incrementally since Apollo, but not in areas that will significantly open up new design solutions**
  - Much greater computational power/kg, but this system is <<1% of the vehicle mass
  - Some improvements in structures (composites) – will have some effect
  - Little improvement in propulsion technology
- **If physics remains fixed and technology has improved only incrementally, the design solutions will only improve incrementally**
  - We <u>really</u> wanted this lander to look like the Millenium Falcon, but physics dictates much of its form
- **The guys who designed the LM were pretty smart.**

Lunar Lander Technical Challenges

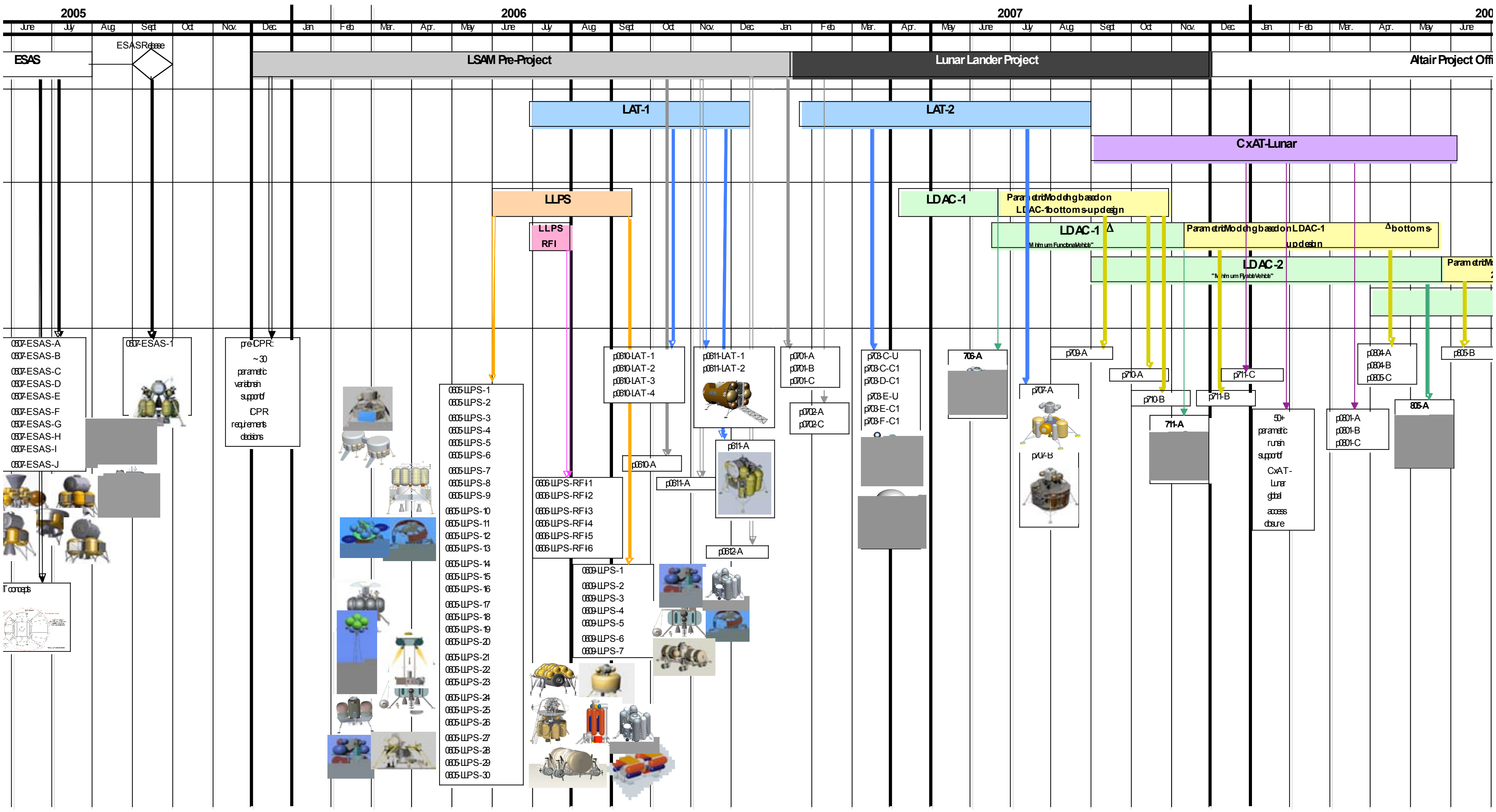
- **Do we have the right/optimum design? (configuration, innovative solutions, technology choices, lowest mass)**
  - Opportunity →Current configuration is an outcome of risk-based design
  - Opportunity → 2018 first flight schedule gives us ample opportunity to explore innovative internal and external configurations



Lunar Lander Design: Tradeoffs Among Many Competing Factors

- **Delta-V – large velocity changes for lunar descent, ascent**
  - Large LOI velocity change with CEV attached
- **Propellant tank size**
  - Large H2 tanks – packaging challenge
- **Launch shroud diameter and length**
  - "building a ship in a bottle"
- **Launch and TLI loads – control buckling, bending and stack frequencies**
- **c.g. control – packaging propellant, stages and payloads to keep c.g. on/near centerline for vehicle control**
- **Ascent – duration, life support, power, returned payload**
- **"Fire in the hole"**
- **Abort capabilities throughout all mission phases**
- **Crew access (both among modules and to surface)**
- **Cargo unloading and access**
- **Crew visibility – for landing, docking**

Lander Concept Timeline



Minimum Functionality/Risk-Informed Design Approach

- **Altair took a true risk informed design approach, starting with a minimum functionality design and adding from there to reduce risk.**

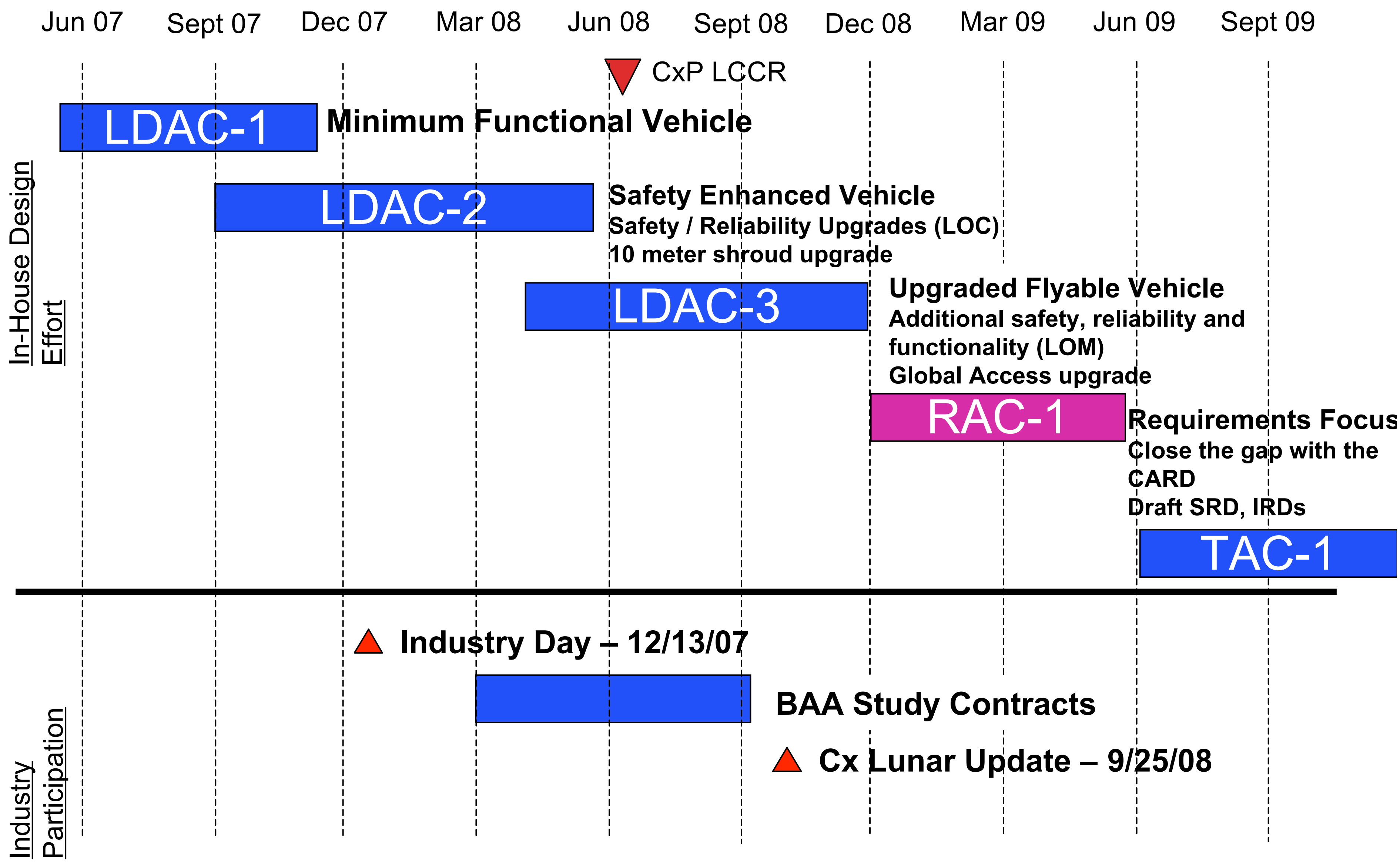
- **Lunar Design Analysis Cycle (LDAC) 1 developed a "minimum functional" vehicle.**
  - "Minimum Functionality" is a design philosophy that begins with a vehicle that will perform the mission, and no more than that
  - Does not consider contingencies
  - Does not have added redundancy ("single string" approach)
  - 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
  - <u>A "Minimum Functionality" vehicle is NOT a design that would ever be contemplated as a "flyable" design!</u>

- **LDAC-2 determined the most significant contributors to loss of crew (LOC) and the optimum cost/risk trades to reduce those risks.**

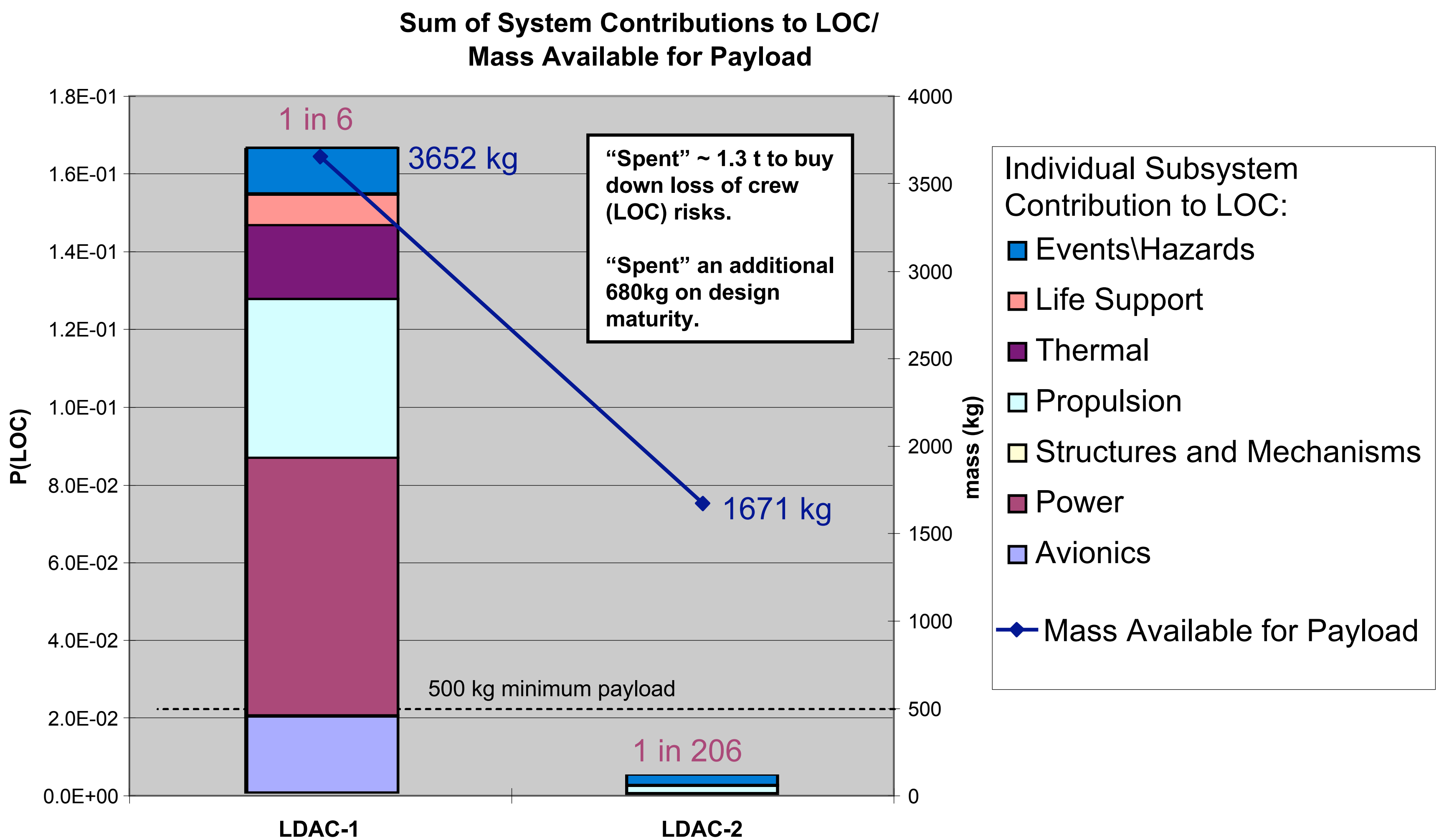
- **LDAC-3 assessed the biggest contributors to loss of mission (LOM) and optimum cost/risk trades to reduce those risks.**

- **Goal of the design process is to do enough real design work to understand and develop the requirements for SRR, and to mature the lander design in-house through SDR.**

Lunar Lander Summary Schedule



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



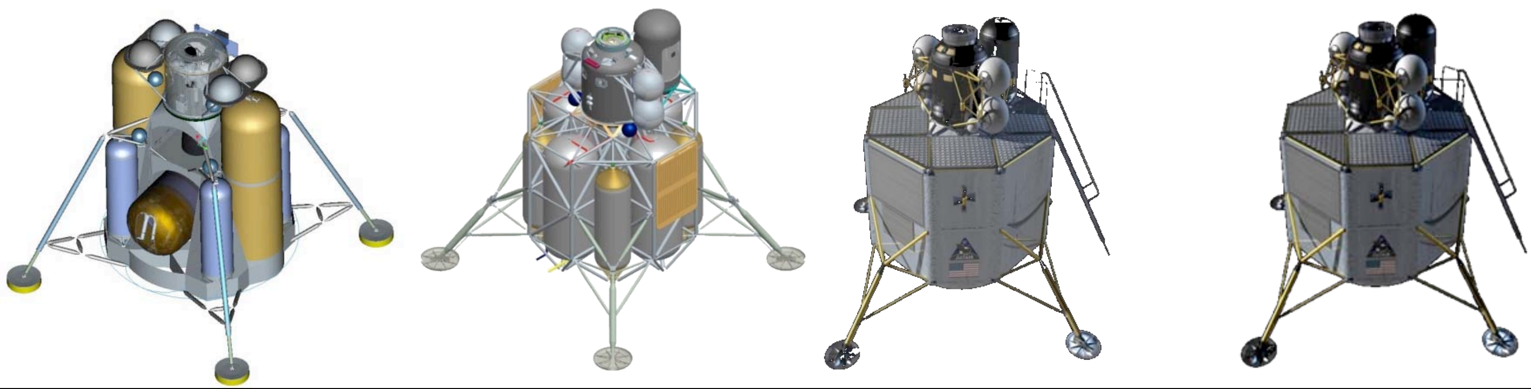
Note: P(LOC) based on simplified models and identified risk

Altair Project Lander Configuration and Performance Maturation using Risk-Based Design

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

"Safety Enhanced"
10 m Ares V shroud

"Reliability Enhanced"
Design maturation



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

Upcoming TAC-1 Configuration and Maturation Trades

- Alternate Descent Module Configuration Study
- Alternate Ascent Module & Airlock Configuration Study
- Alternate AM/DM separation analysis and concepts
- Design for structural stiffness
- Descent Module tank residuals
- Human piloting capability maturation
- OpsCon/Ops Timeline maturation
- Refine mass threats list
- Spacecraft “safe” configuration for critical faults

- (27 more prioritized from a master list of 210+ outstanding tasks)

Additional Technical Challenges

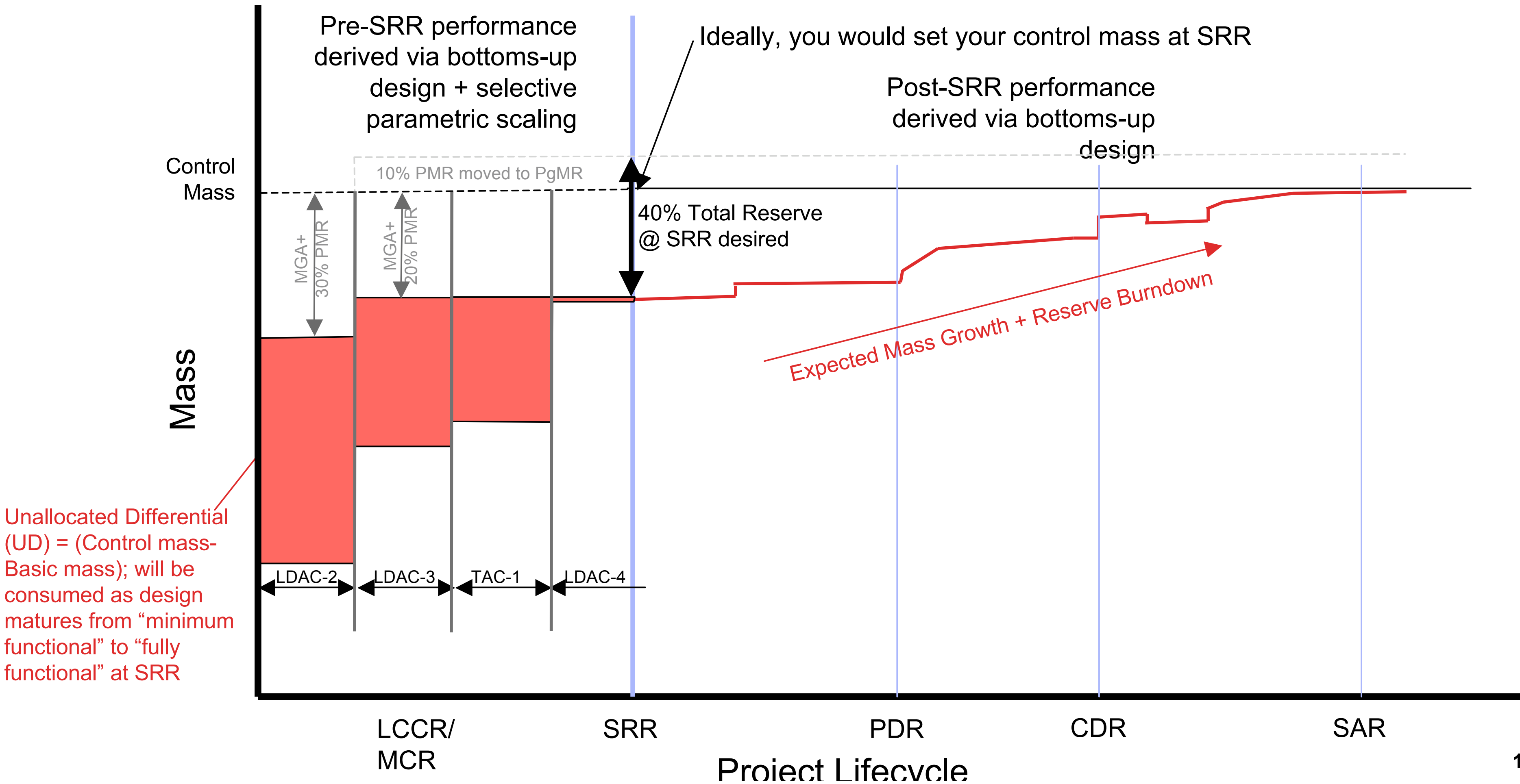
- **Descent Main Engine (DME) development**
  - Deep-throttling DME in current ETDP technology portfolio
- **Multiple-tank liquid level control**
  - Avoid uneven draining of low-density fluids in low acceleration environments → contained in ETDP portfolio
- **Propellant cryo scavanging**
  - Use residual prop for surface fuel cell power → contained in ETDP portfolio
- **Ascent main engine reliability**
  - Build upon Orion service module engine development
- **Integrated lander c.g. control**
- **Lander Ascent Stage c.g. control**
- **Stack Frequency during TLI Burn**
  - Stiffness of the Altair vehicle, the interface to Orion, and to Ares V

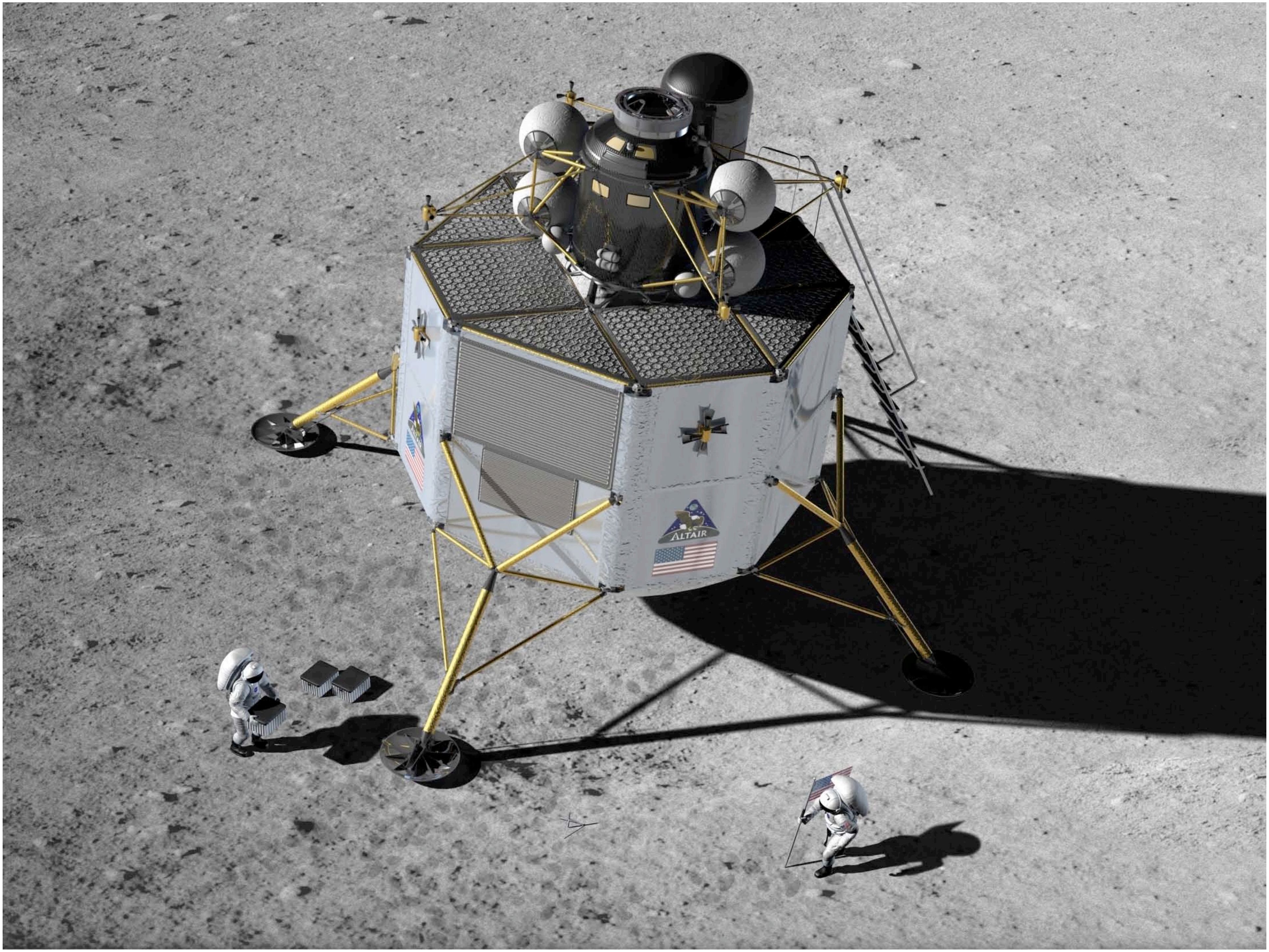
Lunar Lander Non-Technical Challenges

- **Lack of human spacecraft design and development expertise within NASA**
  - We simply don't have enough turnover of large human spaceflight projects to consistently train spacecraft developers
  - Spacecraft are typically developed by industry, with NASA insight/oversight
  - Opportunity → Altair taking design past SDR, bringing on contractors to mature the design
  - Opportunity → Use Apollo LM experience, robotic lander experience, STS and ISS development experience
- **Ramping up a project at the same time that Orion and Ares I are peaking in development**
  - Competition for resources
  - Peer projects at different parts of their lifecycles (how to create IRDs, how to keep requirements from becoming the "problem" of the less mature project)
- **Reserves and Margin**
  - What is the right level of MGA and PMR for a specific point in a project lifecycle

Performance Maturity Measure – "Unallocated Differential"

- As the Altair design moves through its initial DAC cycles, performance is measured as "Unallocated Differential" (UD), the difference between basic mass (with MGA) and Control Mass (less PMR)
- UD is Altair's measure of mass consumed by vehicle maturity as the design moves through the DACs, from "minimally functional" to "fully functional"




ALTAIR