

Altair Lander Life Support: Design Analysis Cycles 1, 2, and 3

Molly Anderson, Su Curley, Imelda Stambaugh and Henry Rotter
NASA

This is the work of the U.S. Government.

ABSTRACT

NASA is working to develop a new lunar lander to support lunar exploration. The development process that the Altair project is using for this vehicle is unlike most others. In "Lander Design Analysis Cycle 1" (LDAC-1), a single-string, minimum functionality design concept was developed, including life support systems for different vehicle configuration concepts. The first configuration included an ascent vehicle and a habitat with integral airlocks. The second concept analyzed was a combined ascent vehicle-habitat with a detachable airlock.

In LDAC-2, the Altair team took the ascent vehicle-habitat with detachable airlock and analyzed the design for the components that were the largest contributors to the risk of loss of crew (LOC). For life support, the largest drivers were related to oxygen supply and carbon dioxide control. Integrated abort options were developed at the vehicle level. Many life support failures were not considered to result in LOC because the effects take long enough to develop that the mission can be ended safely before the situation becomes life threatening. These failures were then classified as LOM failures. Many different options to reduce each LOC risk were considered, and mass efficient solutions to the LOC problems were added to the vehicle design at the end of LDAC-2.

In LDAC-3, the new design was analyzed for large contributors to the risk of LOM. To avoid ending the mission early or being unable to accomplish primary

objectives like performing all planned extravehicular activities (EVAs), various options were assessed for risk reduction achieved and mass and power cost. This paper outlines the major assumptions, design features, and decisions related to the development of the life support system for the Altair project through LDAC-3.

INTRODUCTION: THE ALTAIR PROJECT

The Constellation Program is an ambitious effort that has been said by some to compare to the efforts of Apollo with the Orion Crew Exploration Vehicle (CEV) and Altair Lander Lunar missions, the Space Shuttle with Orion CEV missions to the International Space Station (ISS), and the ISS with the establishment of continuous human presence on the moon. Whether one agrees with that statement or not, there is no doubt that it is a significant effort with significant funding challenges in the current NASA environment.

A small NASA internal team was formed in 2007 to begin developing design concepts and requirements issues for the Lunar Lander. The initial team included approximately 50 people focusing on a basic design concept to establish feasibility for a Lander concept. This design was the "Minimum Functionality" Lander (Jones, 2008). Life support and thermal control were organized as separate subsystems for this work.

Eventually, this team became NASA's Altair Project within the Constellation Program. The team has grown in size as the design has grown more robust, more complex, and more detailed. Over time NASA's

interaction with the contractor community on Altair has grown as well.

ALTAIR LIFE SUPPORT SYSTEM FUNCTIONS

The life support system on performs a number of functions in the Altair vehicle.

The first set of functions control the environment of the crewmembers within certain standards to protect their health. Controlling the environment includes the temperature, total pressure, oxygen, nitrogen, humidity, carbon dioxide, trace gas levels and odors, and particulates (including lunar dust) in the air or breathing gas of the ascent module and airlock habitable volumes.

The life support system provides gas and liquid consumables (air and water, but not food) for the crewmembers. For now, the life support system is responsible for conditioning those resources, such as heating and cooling water or maintaining the water within required quality standards. In the future, a separate crew equipment group or subsystem may be created to best integrate with the hygiene, housekeeping, or other systems that need the resources.

Additionally, the life support system provides breathable gas or cooling fluid to space suits via umbilicals while in or near the vehicle as well as providing water and oxygen to the Portable Life Support Systems (PLSSs) for activities away from the vehicle. The life support system provides consumables such as oxygen or water to medical equipment or systems, but not the treatment devices themselves.

The life support system manages metabolic wastes from the crewmembers, including carbon dioxide, respiration and perspiration, urine and feces, by collecting them and either containing or disposing of them in a safe manner. It collects thermal loads from the cabin air, and transfers that energy to the active thermal control system that is ultimately responsible for rejection of that heat from the vehicle.

Finally, the life support system monitors the environment for off-nominal conditions such as smoke and fire or high trace gas levels. Particulate levels may need to be monitored for lunar missions as well. The life support system includes fire suppression and emergency breathing gases or masks to provide a survivable environment for the crew in these emergency situations

Some of the life support functions (such as emergency systems) are not a part of a minimum functionality vehicle and are not included in early versions of the design. As performance enhancements and additional functions are evaluated, more of these functions, and more elaborate versions of these functions, may be included.

LANDER DESIGN ANALYSIS CYCLE 1 (LDAC-1)

The purpose of the LDAC-1 effort was to develop a concept for a minimum functionality lander. The requirements for the vehicle were reduced to only what would be required to perform a basic mission. This basic mission was roughly defined as transporting 4 crewmembers to the south pole of the moon, enabling them to survive for 7 days, and allowing them to perform EVAs to explore the surface of the moon. The design does not take into account contingencies or off-nominal situations. It does not include redundancy for system failures. It also neglects many requirements that are not critical to completion of the basic mission, but might be considered to enhance performance. For example, some level of communication is required to successfully navigate to the moon and dock with the Orion CEV. But high definition television feed, while highly desirable for many reasons, is not required to get to the moon. Providing sustenance for the crew is required to enable them to perform EVAs, but providing a pleasant (or even more than minimally tolerable) diet is not.

It is important to note that no one in NASA, especially on the Altair team, ever intends for the minimum functionality design vehicle to be manufactured and flown. The design establishes a reasonable minimum mass to see if the project can be considered feasible from a mass perspective. Going through this process is also intended to make the members of the Altair team "Smart Buyers" who will understand the reason that each requirement and resulting system is in place. The design can be built up from the minimum functionality vehicle by considering each safety and performance enhancing improvement piece by piece.

LDAC-1 OVERALL LANDER CONCEPT - The initial lander concept in LDAC-1 included an ascent module, a habitation module, and a descent module, as shown in Figure 1. The lander ascent stage had a pressurized cabin just big enough for four suited crewmembers. The crewmembers would be in this vessel during descent to the lunar surface in case of descent aborts. They would perform an EVA to move into the habitat for the duration of the surface mission, and to move back to the ascent stage once the surface mission was complete. At the end of the mission, the ascent vehicle and its engines would lift the crew back to lunar orbit to rendezvous with the Orion CEV. The habitat, or habitation module, was included to support the crew during their 7-day sortie missions with suitlocks on either end to perform EVAs. The habitat was carried by the descent module. It was considered a separate module because it would not be included in unmanned cargo missions. The descent module was the location of the descent stage engines that provided propulsion to perform the Lunar Orbit Insertion (LOI) maneuver and land safely on the surface of the moon.

The two pressure vessels in this concept had distinctly different duration and functional requirements. The ascent vehicle was only used to support the crew for a matter of hours, and they would wear spacesuits nearly all of that time. The habitat was needed to support shirtsleeve habitation for seven days, support EVAs, and provide food, hygiene, and waste facilities.

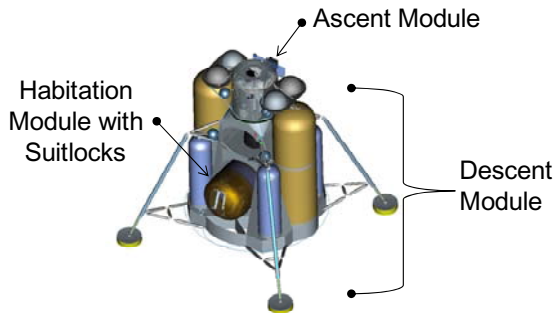


Figure 1: Major Modules of the LDAC-1 Lander

LIFE SUPPORT FOR THE LDAC-1 ASCENT STAGE -
The primary drivers of the life support system design were the mission duration and the operations concept that assumed suited crewmembers. The ascent stage was only required to provide life support for the crew for a 12 hour duration. This meant that it could rely on consumable technologies without the mass growing too large. The operations concept assumed that the Orion CEV would provide life support to the crew working in the Altair ascent stage in a shirt-sleeve environment when the two vehicles were docked. The ascent stage had no airlock, so depressurized operations were required for egress and ingress on the surface. The vehicle provided life support to suited crewmembers via umbilicals.

Using the EVA PLSSs that the crewmembers use during lunar surface exploration was considered as an option, but the PLSSs don't provide all required functions (such as cabin pressurization and ventilation to dock to Orion). They also provide functions that are not useful in a powered, pressurized spacecraft (such as communication systems, power storage in batteries, and heat rejection by water evaporation). Therefore, bringing PLSSs rather than using a vehicle life support system was ultimately rejected because it was a more massive solution.

The ascent stage life support design was very simple with only pressure control, air revitalization, and a small cooling water subsystem. The ascent stage was assumed to operate at 70 kPa (10.2 psia) because it had to dock with the Orion CEV at that pressure. A positive pressure relief valve would vent gas during the ascent from the Earth's surface so that the structure did not have to maintain a 101 kPa (14.7 psi) differential pressure. Valves on the hatches to equalize with the CEV or vent to the lunar environment were also included. The ascent stage only carried oxygen as stored gas. Repressurization of the mixed-gas cabin before launch from the lunar surface would be provided by nitrogen tanks stored on the descent stage. The oxygen tank was also used to provide pressure on the gas side of the bellows on the water storage tank shared between life support and thermal.

The air revitalization system, referred to as the "suit loop", maintained the air quality either of open cabin air or of gas flowing to and returning from suited crewmembers in a closed loop. In suited mode, the air revitalization system treated the oxygen flowing to and from the fully suited crewmembers via umbilicals. These umbilicals would also be used on the Orion CEV, so they were removable. When the umbilicals were not in place, the cabin air could be conditioned during the periods before the crew fully donned and leak checked their EVA suits for descent and when they opened their helmets after ascent when docked to CEV. The suit loop included a High Efficiency Particulate Air (HEPA) filter, Lithium Hydroxide (LiOH) canisters with a small amount of charcoal sorbents, and a condensing heat exchanger.

A water loop with a filter, gas liquid separator, pump, and heat exchanger provided cooling to suited crewmembers via their liquid cooling garment (LCG). Water stored for use in the vehicle's sublimator during ascent was also used as the accumulator and to provide pressurization to the water loop. Drinking water and waste facilities were not included because the crewmembers were assumed to be wearing spacesuits during the few hours in which the ascent vehicle was used. This water was not treated with a residual biocide because there were concerns that the sublimator would be sensitive to the accumulation of silver in the porous foam.

An overall schematic for the LDAC-1 Ascent Stage life support system is shown in Figure 2.

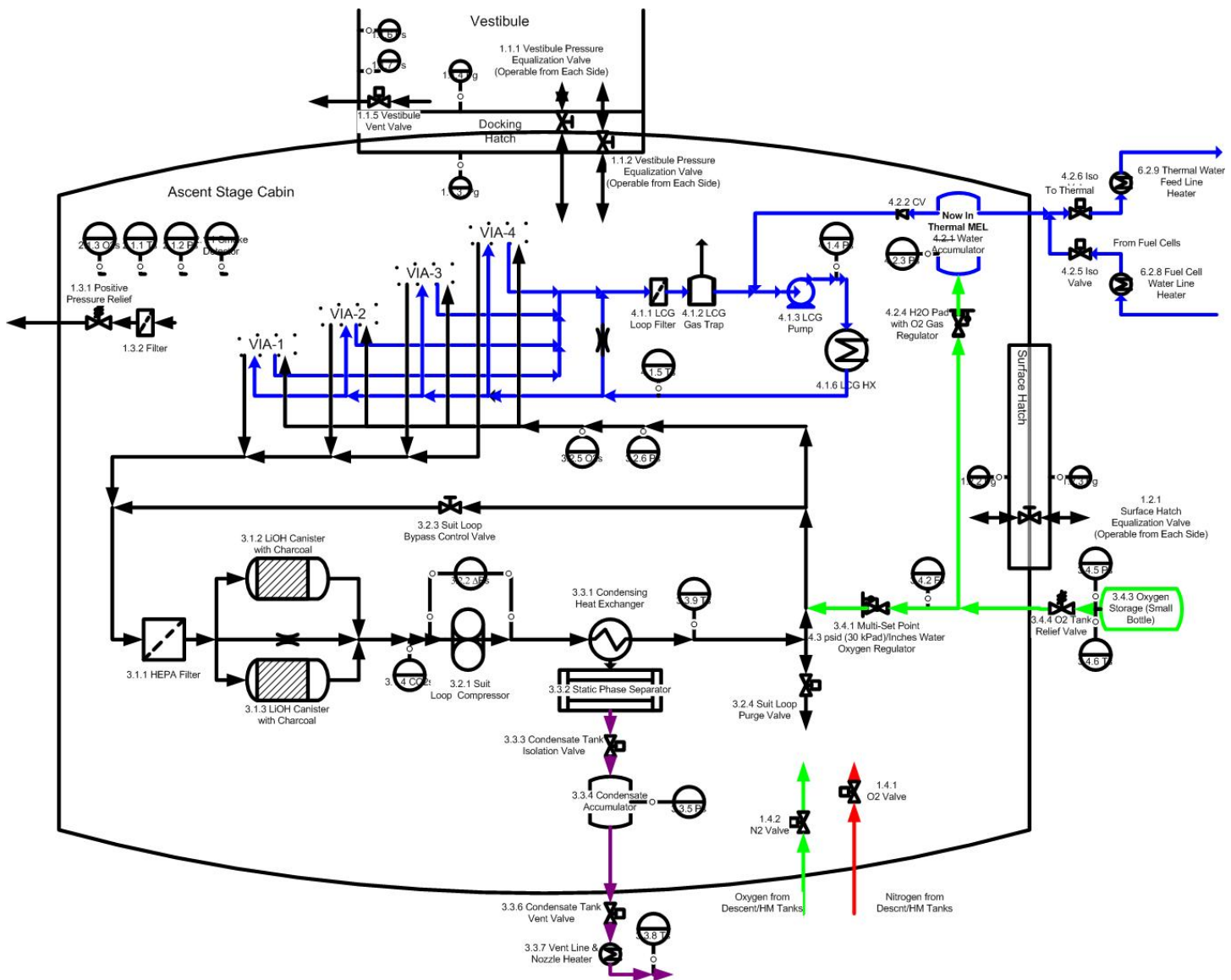


Figure 2: Altair LDAC-1 Life Support for the Minimum Ascent Stage

Blue lines represent water flow, orange lines represent nitrogen flow, green lines represent oxygen flow, black lines represent mixed gas flow, and purple lines represent waste flows

LIFE SUPPORT FOR THE LDAC-1 HABITAT - The LDAC-1 lander habitat provided more functions than the ascent stage and had a more complex life support system. The functions required for the 7 day duration included air revitalization and pressure control, providing potable water, and managing wastes.

The life support system provided and maintained a mixed gas environment. The pressure control system regulated an oxygen-nitrogen mixture at 57 kPa (8.3 psia) controlled to just under 34% O₂. Oxygen and nitrogen were stored in high pressure tanks. The nitrogen feed was also available as fire suppression by routing the flow to areas with large collections of electronics. To maintain air quality, the cabin air was drawn from vents throughout the volume and the waste and hygiene area. The air was filtered, and then slip streams were passed through trace contaminant control and CO₂ and H₂O removal systems. Trace contaminant

control was primarily assumed to be carbon sorbents, with some ambient temperature oxidation catalysis, and sorbents treated for ammonia removal. Control of carbon dioxide and humidity removal was performed with two amine swing beds common to the Orion CEV design. The dried air was drawn through the cabin fan. Finally, the air flowed through a non-condensing heat exchanger with a bypass for temperature control.

An important issue when designing the air revitalization system was that the habitat was required to provide split-operations. This means that some (normally two) crewmembers could be outside performing surface exploration activities while the remaining crewmembers were inside the habitat in a shirt sleeve environment. The habitat featured two-person suitlocks on either side of the habitat's horizontal cylinder shape so the cabin did not need to be depressurized to begin an EVA. But the crewmembers who were preparing for EVA needed to

breathe pure oxygen while the others continued to breathe an oxygen-nitrogen mixture. A single air revitalization system cannot simultaneously condition pure oxygen and a mixed gas atmosphere. Rather than create two air revitalization systems, the airlocks were to be equipped with vacuum ports that would enable the PLSSs on the spacesuits to operate before the airlocks had been depressurized.

Oxygen tanks on the PLSSs needed to be refilled to high pressures before each EVA (Jeng, 2009). The pressure in the habitat O₂ storage tank began at a high pressure, but that pressure would decrease over the 7-day mission as the O₂ was used. To solve this issue, O₂ was taken from the habitat's storage tank and slowly compressed to 25000 kPa (3600 psi), so that it could be used to refill PLSS tanks to 21000 kPa (3000 psi). The compression system was a multi-stage system with both mechanical and sorption (solid-state) compressors. Since it was a multi-stage system, the early stages could be bypassed when the pressure in the source tank was still high.

The life support system provided water for drinking, food preparation, and hygiene in the habitat module, as well as resupply for the PLSSs and the ascent stage sublimator. The power system designed for DAC-1 featured fuel cells that produced water as a byproduct of reacting O₂ and H₂ to generate electrical power. The water produced by these fuel cells was stored by the life

support system. A small tank of concentrated silver ion solution was included to be added as a residual biocide to most of the water. The water provided to the ascent stage sublimator was not treated with the biocide because of concerns that it would be sensitive to accumulation of silver in the porous metal foam. Water was provided to the crew via lines and manual valves at a galley station, and in the waste and hygiene area. To support the PLSSs, water from a storage tank was circulated through a cooling system (much like in the ascent stage) and fed to the airlock. The PLSSs would accept this water to refill tanks and to circulate it through the LCGs of crewmembers preparing for EVA.

The waste system for the LDAC-1 habitat was very simple. In the waste area, urine would be vented directly overboard with a small amount of cabin air. Solid waste would be collected in a canister. The system included single-use bags, based on the Shuttle Extended Duration Orbiter Waste Collection System (Broyan, 2007), and an odor containment lid for the canister between uses. Since gravity is available on the lunar surface, a fan in the waste collection system is not required to entrain urine or fecal waste to draw it away from the human body.

The final schematic for the LDAC-1 habitation module is shown in Figure 3. This module was only present for Sortie missions.