Section 4C
Airlock Study

Appendix 4C – Airlock Study

LSAM Airlock Decision Information

Introduction

The purpose of this task was to generate the background information required to support a decision on whether to include an airlock in the Lunar Surface Access Module's (LSAM's) configuration. It is important to note that it was not the charter of the ESAS team to recommend a decision. This team was limited to only providing the necessary information to make an informed decision. The information generated during this task drew heavily upon findings from recent Exploration Systems Mission Directorate (ESMD) studies (ESMD 0020.05). Using ESMD findings as a starting point, the team modified and added information, as necessary, to generate a final set of inputs that fit into the context of ESAS lunar architecture.

The decision was made by the ESAS team to include an airlock in the LSAM configuration, based upon the information produced during this effort.

Summary

Placing an airlock on the LSAM would provide operational flexibility, while protecting against hazards and contingencies that could pose problems to crew health and/or mission success. The team that performed this task focused primarily upon the hazards and contingencies that an airlock would mitigate. In doing so, the team first agreed upon the set of hazards and contingencies, to which an airlock was a solution. Next, the team systematically assessed each hazard/contingency, listed alternate solutions, and described the end-state that each solution provided. It was found that an airlock placed on the LSAM would protect against two classes of problems:

- Constant: Dust, and
- Contingencies: Illness, injuries, suit malfunctions.

Dust is a quantifiable, known problem that must be controlled. The Apollo astronauts found that dust posed a hazard to hardware and crew health. Transcripts and anecdotal comments from some of the Apollo astronauts describe the magnitude of the problem posed by dust. Dust permeated throughout the crew cabin, covered Extra Vehicular Activity (EVA) suits/tools, and soiled the field experiment hardware. It also proved to be a source of respiratory and eye irritation for a number of the crew members.

Contingency scenarios need to be considered in terms of likelihood, vehicle design/operations options, and mission/crew risk. Many of the contingency situations that were considered had a low likelihood of occurring. Furthermore, many of the contingencies had either vehicle design and/or operational work-arounds that did not carry the mass and configuration impacts that an airlock would impose. For each work-around, the impacts to mission and crew risks were assessed. Coupled together, this information provides the necessary insight to assess the risk posed by the contingencies. In the end, the decision is largely based upon the level of risk that the program is willing to accept.

Finally, while hazard and contingency mitigation was the focus of this activity, mention should be made to the operational flexibility that would be gained if an airlock were to be included in the LSAM configuration. The primary operational benefit afforded by an airlock is that it allows for split-crew operations. Split-crew operations can be advantageous in at least two major scenarios. First, it allows one team to go EVA while the other team remains inside the vehicle with suits doffed (perhaps safing the LSAM after landing or prepping the vehicle prior to lunar-surface-departure). Secondly, it allows for multiple EVA teams to split off in different directions on the lunar surface and return to the LSAM when their team's tasks are complete without being required to wait for the other team(s) to complete their tasks.

Discussion

The hazards/contingencies, alternative solutions, and respective end-states that were considered are presented in Table 1. Therefore, this paper will not go into all details of each case, but a few notes are worth pointing out.

First, in listing out the hazards/contingencies, it was found that it was necessary to list the time period during which the hazard/contingencies might occur. For example, it would not have made sense to list "Injured Crew member" and then try to find mitigation techniques that served as alternatives to airlocks. Instead, it was necessary to define whether the injury occurred in the crew cabin prior to donning an EVA suit or whether the injury occurred while on EVA. The available solutions and end states to these two problems were different. Additionally, if the latter were to occur, the former would still require a solution for the injured crew member, but not vice versa.

Secondly, a column titled "Comments" was added to the table, which was used to either further define the problem of interest or to parse the problem into categories. An example of a problem that required further definition can be found in the discussion of a "crew member illness or injury." It was necessary to point out that this problem only required a solution if the crew member was too ill or injured to don a suit, but not ill or injured to the point to merit a return to Earth. Obviously, this significantly limited the severity of the illnesses or injuries under consideration and centered the discussion on the likelihood of such an illness or injury. An example of a problem that required further parsing can be found in the discussion of a "suit malfunction." This problem required that the team examine solutions to malfunctions that were too large to fix, as well as those that could be fixed in-situ. Again, the available solutions and end states to these two classes of problems were different.

Finally, it should be noted that for each hazard/contingency, viable work-arounds were found. As stated previously, many of these work-arounds did not carry the mass and configuration impacts that an airlock would impose. However, when taken together and added to the operational flexibility afforded by an airlock, it was felt that a strong case could be made for the inclusion on an airlock in the LSAM configuration.

Ultimately, as stated previously, the decision to include an airlock in the LSAM configuration is largely dependent upon the level of risk the program is willing to accept. As such, it must be made in the context of the key mission parameters and program guidance, as currently defined by the ESAS team:

1. There will be ~4 sortie missions in the early lunar program;
2. All other missions (potentially spanning decades) will be to the vicinity of a habitat or some other pressurized element. In this situation, the crew will egress the lander upon landing and ingress the lander at the end of the surface mission. The assumption can be made that the lander will not be ingressed nor egressed more than this, during these types of missions;
3. There will be 4 crew members;
4. The surface mission duration requirement is 4 days (may be extended to 7 days);
5. EVA by all crew members is assumed on all 4 days;
6. As currently defined, the lunar sortie surface mission objectives are to perform science, demonstrate the transportation system, opportunistic technology demonstration, and opportunistic surface operations demonstration. In other words, the future missions (such as habitat deployment) are <u>not</u> dependent upon the success of the sortie missions.

Table 1. Airlock-Related Hazard and Contingency Assessment

Problem or Failure	Time Period	Comments	Mitigation or Solution	End State
Dust	Constant	Solution must meet SMAC limits and hardware design specs.	Airlock serves as mudroom during suit donning, doffing, and maintenance.	Majority of dust is contained in the airlock. Small percentage enters crew cabin.
			A volume (without airlock capabilities), separate from crew cabin, serves as "mudroom."	Majority of dust is contained in the separate volume. Small percentage enters crew cabin.
			Dust removed by cleaning method prior to ingress into crew cabin.	Majority of dust removed prior to ingress. Small percentage enters crew cabin.
Crew member illness or injury	Prior to donning suit	Needs a solution: too ill/injured to don suit, but not ill/injured enough to merit a return to Earth.	Airlock allows affected crew member to stay inside Lander crew cabin.	Ill/injured crew member refrains from EVA. No LOM.
			Internal pressurized volume houses affected crew member.	Ill/injured crew member refrains from EVA. No LOM.
			Cease all EVAs until illness/injury subsides.	Mission might proceed – depends on status of ill/injured crew member.
	During EVA	Crew member needs to return to Lander and doff suit.	Airlock allows ill/injured to ingress Lander an doff suit prior to return of other crew members.	Ill/injured crew member is safe. Other crew members' activities are unaffected. No LOM.
			Internal pressurized volume allows ill/injured to ingress Lander an doff suit prior to return of other crew members.	Ill/injured crew member is safe. Other crew members' activities are unaffected. No LOM.
			Operationally constrain EVA traverse distances and distances between EVA teams.	Ill/injured crew member is safe. All crew members return to Lander together and repress cabin. Mission might proceed – depends on status of affected crew member.

Problem or Failure	Time Period	Comments	Mitigation or Solution	End State
Suit Malfunction	Prior to initiation of Lunar Descent	Assume problem is too big to fix with available tools/parts.	Airlock allows affected crew member to stay inside crew cabin.	All crew, except affected crew member, performs EVA. No LOM.
			Internal pressurized volume houses affected crew member.	All crew, except affected crew member, performs EVA. No LOM.
			Affected crew member remains inside Lander using Launch/Ascent suit.	All crew, except affected crew member, performs EVA. No LOM.
			Mission is scrubbed.	Return to Earth.
		Assume problem can be fixed with available tools/parts.	Airlock allows affected crew member to fix suit in crew cabin.	All crew performs EVA (affected crew member joins when ready). No LOM.
			Internal pressurized volume provides area for crew member to fix suit.	All crew performs EVA (affected crew member joins when ready). No LOM.
			Scrub EVA until suit is fixed.	All EVA scrubbed until suit is fixed. No LOM.
	Prior to egress from Lander for EVA	Assume problem is too big to fix with available tools/parts.	Airlock allows affected crew member to stay inside crew cabin.	All crew, except affected crew member, performs EVA. No LOM.
			Internal pressurized volume houses affected crew member.	All crew, except affected crew member, performs EVA. No LOM.
			Affected crew member remains inside Lander using Launch/Ascent suit.	All crew, except affected crew member, performs EVA. No LOM.
			Mission is scrubbed.	Return to Earth.
		Assume problem can be fixed with available tools/parts.	Airlock allows affected crew member to fix suit in crew cabin.	All crew performs EVA (affected crew member joins when ready). No LOM.
			Internal pressurized volume provides area for crew member to fix suit.	All crew performs EVA (affected crew member joins when ready). No LOM.
			Scrub EVA until suit is fixed.	All EVA scrubbed until suit is fixed. No LOM.

Problem or Failure	Time Period	Comments	Mitigation or Solution	End State
Suit Malfunction	During EVA	Assume catastrophic suit failure.	None.	Loss of crew member.
		Assume major failure – can be contained or controlled in order to allow crew member to return to Lander, but with no time to spare.	Airlock allows affected crew member to ingress Lander prior to others returning from EVA.	Other crew members' activities are unaffected. No LOM.
			Internal pressurized volume houses affected crew member prior to others returning from EVA.	Other crew members' activities are unaffected. No LOM.
			Affected crew member ingresses Lander, repressurizes, and dons Launch/Ascent suit.	This is a conditional work-around – time to doff surface suit and don Launch/Ascent suit may be unacceptable.
			Operationally constrain EVA traverse distances and distances between EVA teams.	All crew members return to Lander together and repress cabin. Mission might proceed – depends on status of affected crew member.
		Assume minor failure – can be contained or controlled, allowing crew member to return to Lander with time to spare.	Airlock allows affected crew member to fix suit in crew cabin.	Other crew members' activities are unaffected. Affected crew member resumes EVA when ready. No LOM.
			Internal pressurized volume provides area for crew member to fix suit.	Other crew members' activities are unaffected. Affected crew member resumes EVA when ready. No LOM.
			Suit is connected to umbilical to resupply resource that is being depleted.	This is a conditional work-around. Only applicable if the malfunction is consumables-related. Consumables must be available.
			Affected crew member ingresses Lander, repressurizes, and dons Launch/Ascent suit.	This is a conditional work-around – time to doff surface suit and don Launch/Ascent suit may be unacceptable.
			Operationally constrain EVA traverse distances and distances between EVA teams.	All crew members return to Lander together and repress cabin. Mission might proceed – depends on status of affected crew member.