

A Fire Suppression Analysis for the Altair Project

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ABSTRACT

This paper presents a fire suppression analysis for the Altair project. The architecture of the Altair systems relevant to fire safety is briefly reviewed. This is followed by an outline of a fire safety analysis of the spacecraft including an outline of a probabilistic risk analysis (PRA). The particular emphasis of this analysis is the change in risk as the vehicle moves to lower pressure, higher operating voltage and increased oxygen mole fraction. The analysis shows that all of these changes increase the likelihood and intensity of a fire. The paper then outlines the options for a suppression system followed by a trade analysis of the different options. The candidate systems include inert gas agents (nitrogen, carbon dioxide and helium), water-based systems (spray, mist and foam) and chemically active agents. Chemically active agents are included for reference purposes since they are not likely candidates for the Altair vehicles.

INTRODUCTION

NASA's new space exploration vision calls for extending a human presence into space beyond low Earth orbit, returning to the Moon, and then to Mars and beyond. Because a rapid return to Earth is not an option on long duration missions outside of low-Earth orbit,

the crew must have the equipment, systems, and procedures to safely deal with both prompt-effect and delayed-effect hazards. Prompt-effect hazards are those requiring an immediate and effective response for alleviation. Delayed-effect hazards are those requiring less urgent or timely response.

Fire is a significant prompt-effect hazard, but it also contributes to the delayed-effect hazards through atmospheric contamination, and spacecraft damage. Hence, NASA's fire-protection strategies must cover a wide range of areas from the control and suppression of the fire to the restoration, repair, and cleanup activities after a fire event. The first line of defense in a Fire Safety policy is fire prevention through material selection and control. Experience in manned space flight, however, demonstrates that this control is not sufficient to prevent fires on spacecraft.

This document presents a fire safety analysis of the Altair spacecraft. Based on the results of this analysis, a recommendation for a handheld, crew-operated fire suppression system is presented. The document builds on a review of fire suppression issues in human-crewed spacecraft [1] and a trade study for spacecraft suppression systems [2] presented at previous ICES meetings.

BACKGROUND

The Constellation (Cx) program provides the capability to launch the Altair lunar lander into low earth orbit (LEO). The lander will launch in an unpowered state. The ambient environment during launch will be air ($Y_{O_2} = 0.21$) at near atmospheric pressure ($P = 760 \text{ mmHg}$). During this time, the vehicle will be un-manned and the fire detection and suppression systems will be non-operational.

The crew will transfer from the CEV to the Lander in LEO at which time the lander will power up. At this time both the fire detection and suppression systems must be active and operational. The ambient environment of the lander will then be the nominal operating conditions of $Y_{O_2} = 0.34$ (balance nitrogen) and $P = 424 \text{ mmHg}$ (8.2 psia). During transit from LEO to lunar orbit and while in lunar orbit, the lander will be operating in a microgravity environment.

The lander will then descend to the lunar surface for planetary operations. The ambient during the lunar sorties will be the same high oxygen, reduced pressure quoted above. The expected mission duration is 7 days. For extended duration stays on the lunar surface, the lander will be un-manned and essentially dormant for up to 210 days. The ambient environment inside the lander during this time is TBD, but could be vacuum, nominal pressure and oxygen, or reduced pressure and/or reduced oxygen. Table 1 shows a list of the equipment inside the cabin [3] that could contain both flammable material and a source of ignition.

RISK ANALYSIS

OVERVIEW

Figure 1 is a flowchart that shows the sequence of events leading up to an accidental fire. The probability that a hazardous condition exists ($\mathcal{P}(\mathcal{E})$) reflects the likelihood that a fuel and flammable material (two legs of the fire triangle) are present. The hazardous condition is represented by $\mathcal{E}$.

The next occurrence is a failure (F), the likelihood of which is given by $\mathcal{P}(F)$. This failure is accompanied by a release of energy (E) that is distributed according to $f(E : F)$. If the energy released by the equipment failure, E , is greater than the minimum energy required to start a fire in environment $\mathcal{E}$, $E \geq E_{min}(\mathcal{E})$, then a fire event will occur.

The fire will then burn and grow reaching a point in time (τ_D) when the particulate or species generated by the fire and transported to the fire detector exceed the threshold value for the indication of a fire. The detection could be an automated fire detector or the crew smelling the fire. The critical point here is that the fire will continue to grow until the crew initiates the fire response.

After detection, the crew will initiate a fire suppression sequence that is TBD. This may involve de-energizing equipment, donning protective equipment, turning off ventilation and/or activating a suppression system. This action will then suppress the fire event denoted by $\mathcal{F}$ in a time given by τ_{sup} .

In all likelihood, the damage (whether it be atmospheric contamination or direct equipment damage) caused by the fire is directly related to the mass burned during the fire,

$$M(F) = \int_{t=0}^{(\tau_D + \tau_{sup})} \dot{m}_f(t) dt. \quad (1)$$

The mass burning rate ($\dot{m}_f$) increases as the fire spreads and involves more flammable material. The time dependence of fire growth is typically described by a power law [4],

$$\dot{Q}_f = \dot{m}_f \Delta h_c = \alpha t^n, \quad (2)$$

for terrestrial fires. The quantity Δh_c is the energy released per unit mass of material burned, and thus $\dot{Q}_f$ is the energy release rate from the fire (a useful, but not singular, measure of the hazard posed by the fire). The growth constant (α) describes the growth of the fire. The exponent (n) is typically 2.0 for terrestrial compartment fires.

The total hazard then posed by a fire event ($\mathcal{H}(\mathcal{F})$) is

$$\mathcal{H}(\mathcal{F}) = \mathcal{P}(\mathcal{F}) \cdot |\mathcal{F}|. \quad (3)$$

The main point of Equation 3 is to emphasize that the hazard is both a function of the likelihood that a fire event will occur and the magnitude of the fire event should it occur. For example, a fire that is more likely but will do little damage could have a lower $\mathcal{H}(\mathcal{F})$ than a fire event that had a much lower probability of occurrence but would cripple the spacecraft.

While this analysis is simple in theory, the difficulty is in assigning numeric values to each of the relevant parameters. One important thing to note is that while the absolute magnitude of the hazards in the analysis may not be all that useful, the relative hazards posed by different scenarios are much more relevant and useful. For example, comparing the hazards in reduced, normal and microgravity and the hazards posed by enhanced oxygen ($Y_{O_2} = 0.34$) to those in ambient oxygen ($Y_{O_2} = 0.21$).

ALTAIR CONSIDERATIONS

The Altair lunar lander will operate in both microgravity and the reduced gravity (1/6g) of the moon. In a pre-

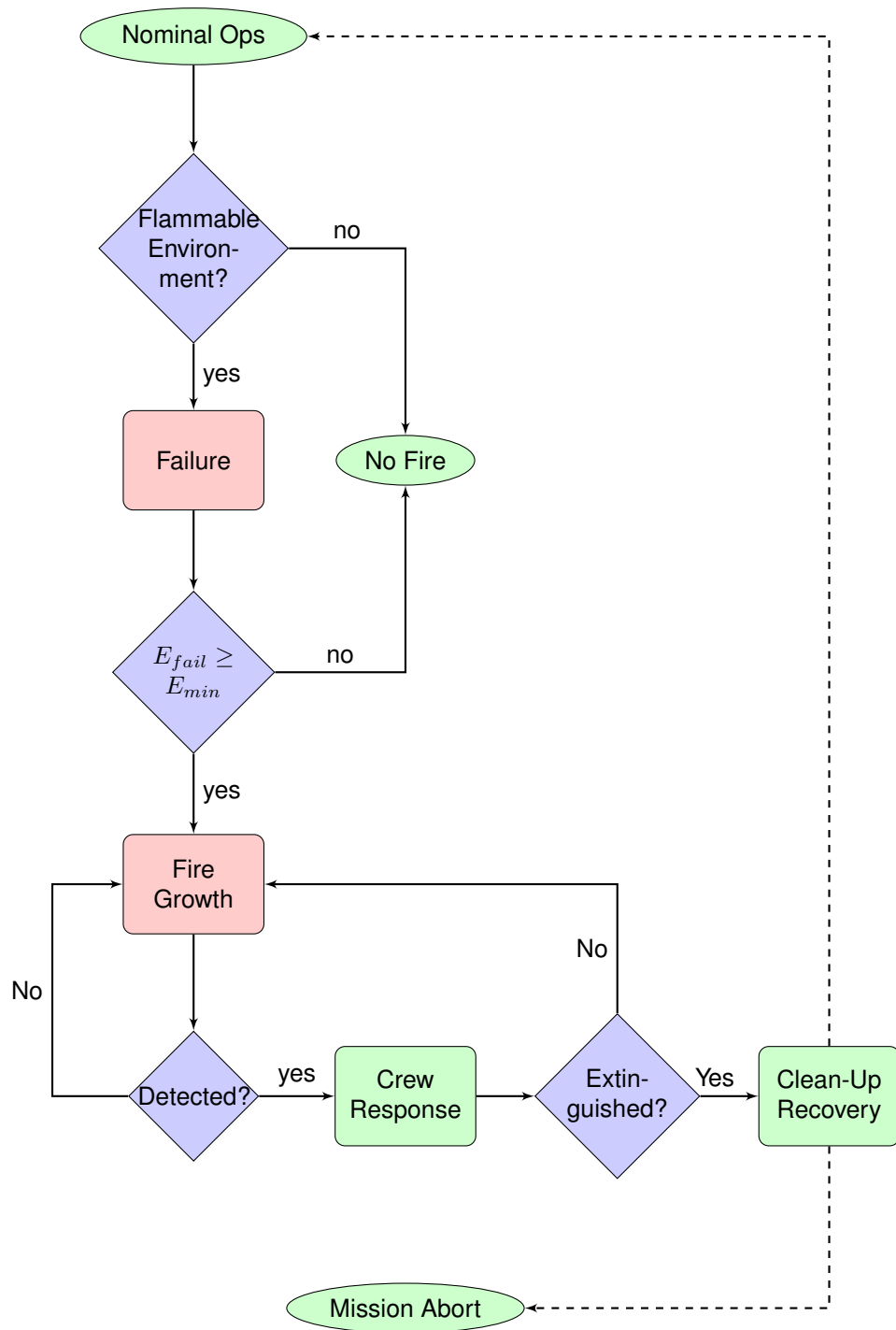


Figure 1: Flowchart showing the progression of events for an accidental fire.