Algorithm for Determination of Orion Ascent Abort Mode Achievability

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For human spaceflight missions, a launch vehicle failure poses the challenge of returning the crew safely to earth through environments that are often much more stressful than the nominal mission. Manned spaceflight vehicles require continuous abort capability throughout the ascent trajectory to protect the crew in the event of a failure of the launch vehicle. To provide continuous abort coverage during the ascent trajectory, different types of Orion abort modes have been developed. If a launch vehicle failure occurs, the crew must be able to quickly and accurately determine the appropriate abort mode to execute. Early in the ascent, while the Launch Abort System (LAS) is attached, abort mode selection is trivial, and any failures will result in a LAS abort. For failures after LAS jettison, the Service Module (SM) effectors are employed to perform abort maneuvers. Several different SM abort mode options are available depending on the current vehicle location and energy state. During this region of flight the selection of the abort mode that maximizes the survivability of the crew becomes non-trivial. To provide the most accurate and timely information to the crew and the onboard abort decision logic, on-board algorithms have been developed to propagate the abort trajectories based on the current launch vehicle performance and to predict the current abort capability of the Orion vehicle. This paper will provide an overview of the algorithm architecture for determining abort achievability as well as the scalar integration scheme that makes the onboard computation possible. Extension of the algorithm to assessing abort coverage impacts from Orion design modifications and launch vehicle trajectory modifications is also presented.

I. Introduction

Several factors determine which type of abort mode should be performed following a failure during ascent. At the highest level of this decision tree is the vehicle configuration. The LAS is nominally jettisoned during ascent to increase payload to orbit. Once through the denser portion of the atmosphere, the LAS thrust is no longer required to escape the launch vehicle. This configuration change leads to two broad categories of aborts, LAS and SM. If the LAS is still attached then typically, a LAS abort will be performed. After the LAS is jettisoned nominally, an SM abort will be performed. This paper will focus on the selection of the SM abort mode.

The next lower level of selection is the functional capability of the vehicle. Some SM aborts require using the Orion Main Engine (OME) and potentially all of the available SM propellant. If an Orion failure exists such that the OME or some amount of propellant is not available, then those abort modes may be excluded from consideration.

If all Orion systems are operational, then abort mode selection becomes primarily a performance decision, i.e. given the current system, which abort modes could be achieved within defined constraints? This paper will focus on how this performance evaluation is completed onboard Orion.

There is an additional layer to be evaluated if more than one abort mode is available. Given that two abort modes are available, a determination must be made as to which one has priority. This prioritization typically turns into a relative risk evaluation among the achievable abort modes. This evaluation is performed by software onboard Orion, but is beyond the scope of this paper.

It is also desireable to be able to quickly assess abort capability for modified launch vehicle trajectories. Given the current Orion configuration and a launch vehicle trajectory, the abort achievability algorithm can be run to

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indicate when different abort modes are achievable to determine whether continuous abort capability exists for the modified trajectory. In fact, the launch vehicle trajectory can be modeled internally to allow finding abort boundaries during ascent before they occur. This is potentially useful for determing if there are gaps in abort coverage (no achievable abort mode) before they occur. Alternatively, Orion configuration changes, alternate SM options for instance, can be assessed quickly as well given that current assumptions and constraints are not changed.

A. Abort Mode Achievability Determination

Previous human rated vehicles determined conservative boundaries pre-launch for onboard use and computed "real-time" abort mode boundaries on the ground using the current vehicle state. These real-time boundaries were called up to the vehicle during ascent, while the onboard boundaries were only employed for loss of communication scenarios. Orion requirements stipulated that the vehicle must be able to automatically determine achievable abort modes without support from the ground. The previous method of employing conservative pre-launch boundaries was considered. However, during the RTAL/TAL overlap region, very little margin exists for maintaining continuous abort coverage. Onboard real-time abort achievability was shown to increase overlap by removing the launch vehicle trajectory dispersions from the pre-flight computed boundaries.

Performing the real-time computations onboard requires a fairly simple algorithm that can be executed for multiple abort modes (commonly referred to as hypothetical scenarios) during a single time step. The algorithm chosen uses a 3-DOF scalar integration of the abort trajectory within a predictor/corrector scheme to determine whether trajectory constraints can be achieved for the given initial condition. This algorithm uses the same fundamental models that are employed for guidance during the abort burns, so there is also a great deal of software re-use through modularity.

The algorithm is also primarily data driven. This allows simple accommodation of vehicle configuration changes, such as alternate SM engines, or the ability to account for known vehicle failures or performance degradations before committing to a particular abort. The latter is only possible in combination with a vehicle manager that can update the vehicle configuration used by the algorithm.

B. Background

1. Vehicle Configuration

Figure 1 below shows all components which comprise the CEV system. The vehicle configuration for Service Module ascent aborts is composed of the Service Module (SM) and the Crew Module (CM). This configuration provides the capability to separate from the CLV, perform any maneuvers or burns required, and deliver the CM to the proper atmospheric entry attitude for subsequent touchdown in any allowable landing zone. This configuration must also support propellant and attitude control requirements for a variety of nominal missions. Therefore, the Reaction Control System (RCS) and Orion Main Engine (OME) cannot be optimized for abort performance, but rather are primarily designed to provide optimal performance for Lunar missions.

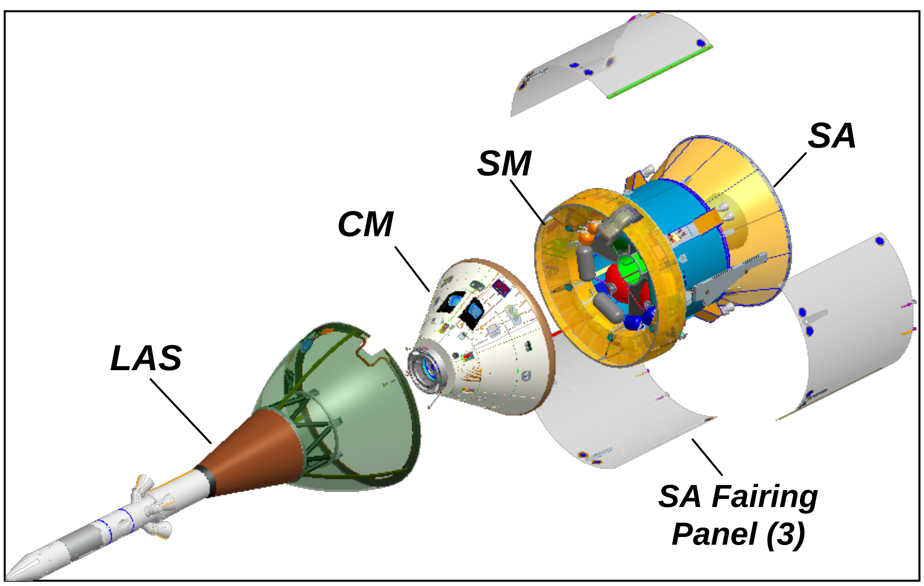

Figure 1 CEV Component Definition

2. Abort Mode Definitions

SM Abort modes are defined by the energy state and geographical location at the time of the upper stage engine failure in relation to desired landing areas or exclusion zones. Where overlap between modes occurs, priority is given to the mode that results in the most thermally and dynamically benign trajectory. Based on the initial conditions, several different types, or modes, of aborts are required. The sections below summarize the abort modes employed by Orion to provide continuous coverage.

Untargeted Atlantic Splashdown (UAS)

This abort mode, also referred to as a Mode 2 abort, is the result of failures after the jettison of the LAS until reaching sufficient velocity such that the CM can no longer land near St. John's Newfoundland without firing the OME . This abort mode is prime over the largest portion of the ascent trajectory, as the launch vehicle remains close to the East Coast for the majority of powered ascent.

Targeted Abort Landing (TAL)

This abort mode, also referred to as a Mode 3 abort, requires firing the SM OME to impart additional velocity to the spacecraft in order to achieve landing near designated recovery sites. For ISS missions, TAL is targeted to splashdown near Shannon, Ireland.

Retrograde TAL (RTAL)

RTAL aborts comprise a small region during ascent between TAL and UAS. During this portion of the ascent, there is insufficient energy and SM propellant to use the OME thrust to reach a TAL site, but too much energy to remain on the western side of the Atlantic using entry lift control alone. For these cases, a small SM OME burn is performed to decrease horizontal velocity and lower the flight path angle. RTAL extends the capability to remain on the west side of the Atlantic.

Abort to Orbit (ATO)

These aborts, also referred to as Mode 4 aborts, result when the US engine failure occurs late enough that the SM has sufficient thrust and propellant to achieve sustainable orbit. These aborts are characterized by a first burn to raise apogee to 100 nm and a subsequent burn to circularize the orbit. ATO is the primary abort near the end of the powered ascent trajectory.