National Aeronautics and Space Administration

Dynamic Modeling of Ascent Abort Scenarios for Crewed Launches

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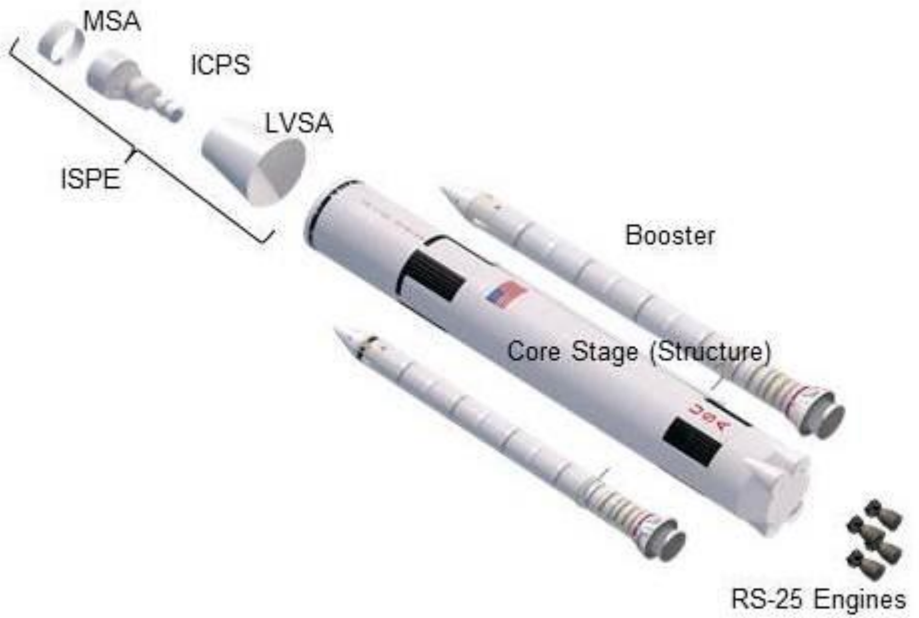
Introduction

- NASA is developing a new launch vehicle and spacecraft to provide the return of the United States to beyond Low Earth Orbit (LEO), otherwise referred to as deep space.
- The new launch system is being developed with an abort system that will enable the crew to escape launch failures.
- NASA has developed a comprehensive PRA of the integrated system, including the launch vehicle, spacecraft and ground launch facilities to optimize the risk reduction associated with designing this new launch system.
- The scope of the analysis is focused on the ascent portion of the mission.

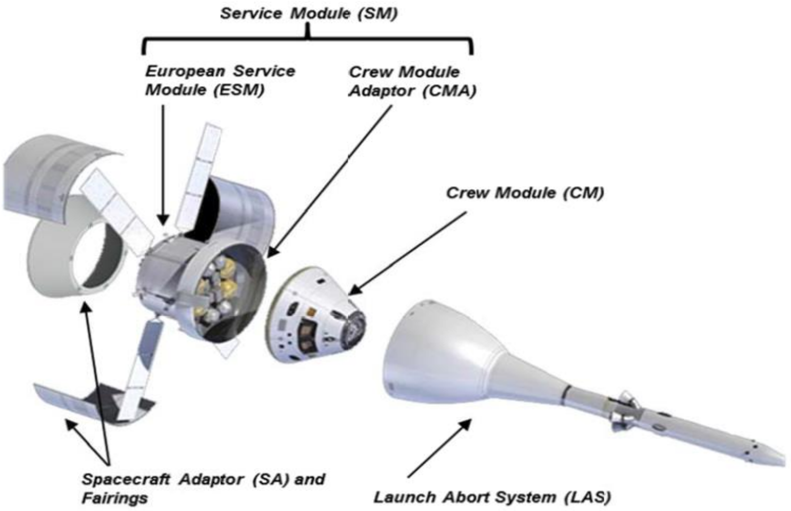
Overview of Space Launch System

- The Space Launch System (SLS) provides the capability to place exploration elements (e.g., Orion) into Low Earth Orbit (LEO) for transfer to higher orbits and beyond.
  - Liquid oxygen/liquid hydrogen Core Stage (CS)
  - Two Solid Rocket Boosters (SRBs)
  - Upper Stage



Overview of Multi-Purpose Crew Vehicle (MPCV)

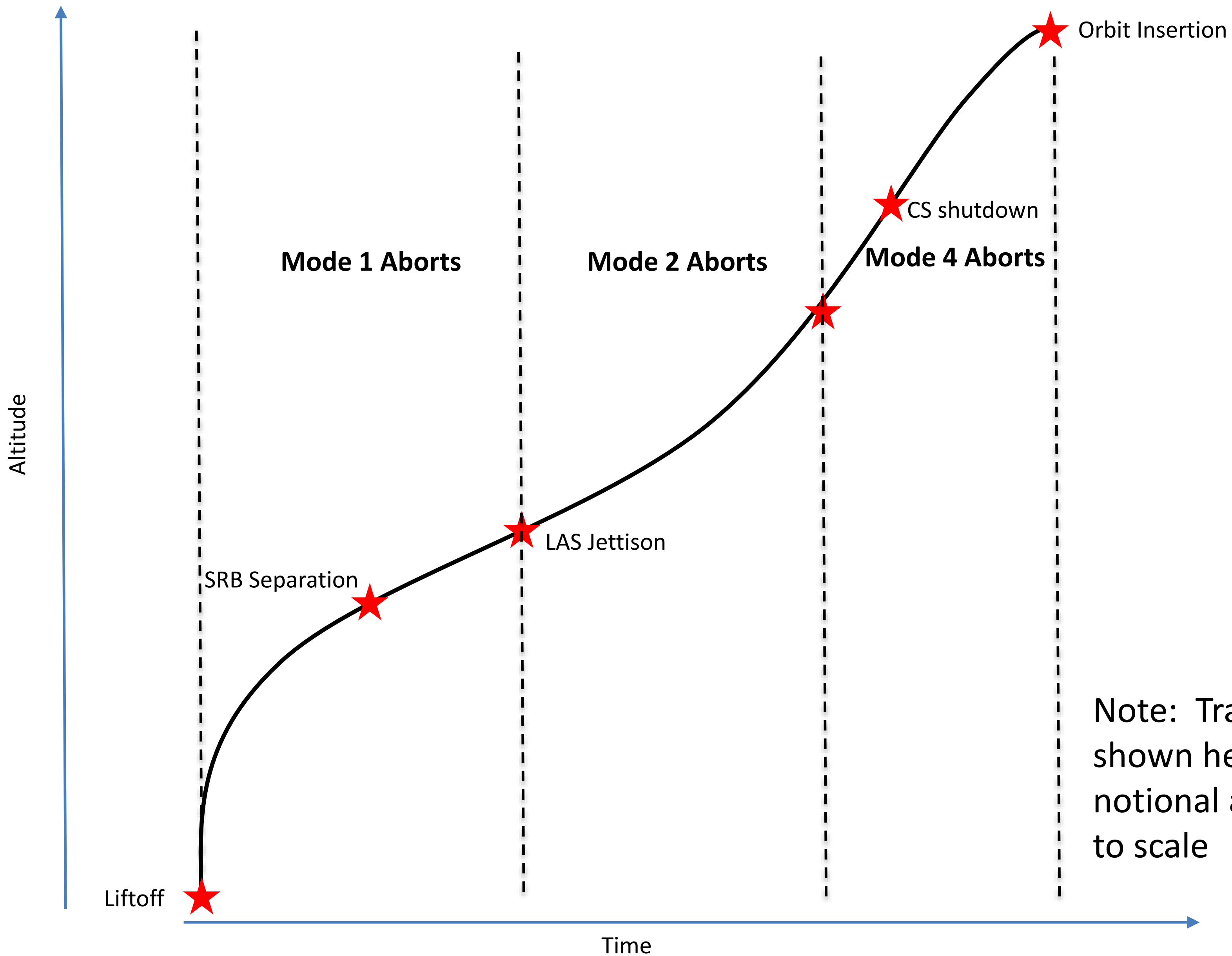
- The MPCV consists of a Crew Module (CM), a Service Module (SM), Spacecraft Adaptor (SA), and a Launch Abort System (LAS).
  – The CM provides a habitable pressurized volume to support crew members.
  – The SM provides services to the CM in the form of propulsion, consumables storage, heat rejection and power generation. The SM also provides abort capability for higher altitude aborts.
  – The LAS provides an abort capability to safely transport the CM away from the launch vehicle stack in the event of an emergency on the launch pad or during ascent, particularly lower altitude aborts.



Overview of Abort Operations

- On the pad and at lower altitudes, MPCV Mode 1 abort (i.e., LAS Abort) capability is provided by the Orion LAS and may be performed any time after the LAS is armed on the launch pad until LAS jettison.
- An emergency egress capability also exists on the pad to rescue the crew in the event of an emergency.
- At higher altitudes, the SM is used to abort.
  - MPCV Mode 2 aborts are sub-orbital aborts that rely on the spacecraft separation mechanism to provide the separation.
  - MPCV Mode 4 abort capability leverages the SM Orbital Maneuvering System (OMS) engine to place Orion in orbit prior to return to Earth's surface.
- In all abort cases, the MPCV landing systems (e.g., chutes, etc.) must operate to ensure a successful abort and safe recovery of the crew.

Overview of Abort Modes

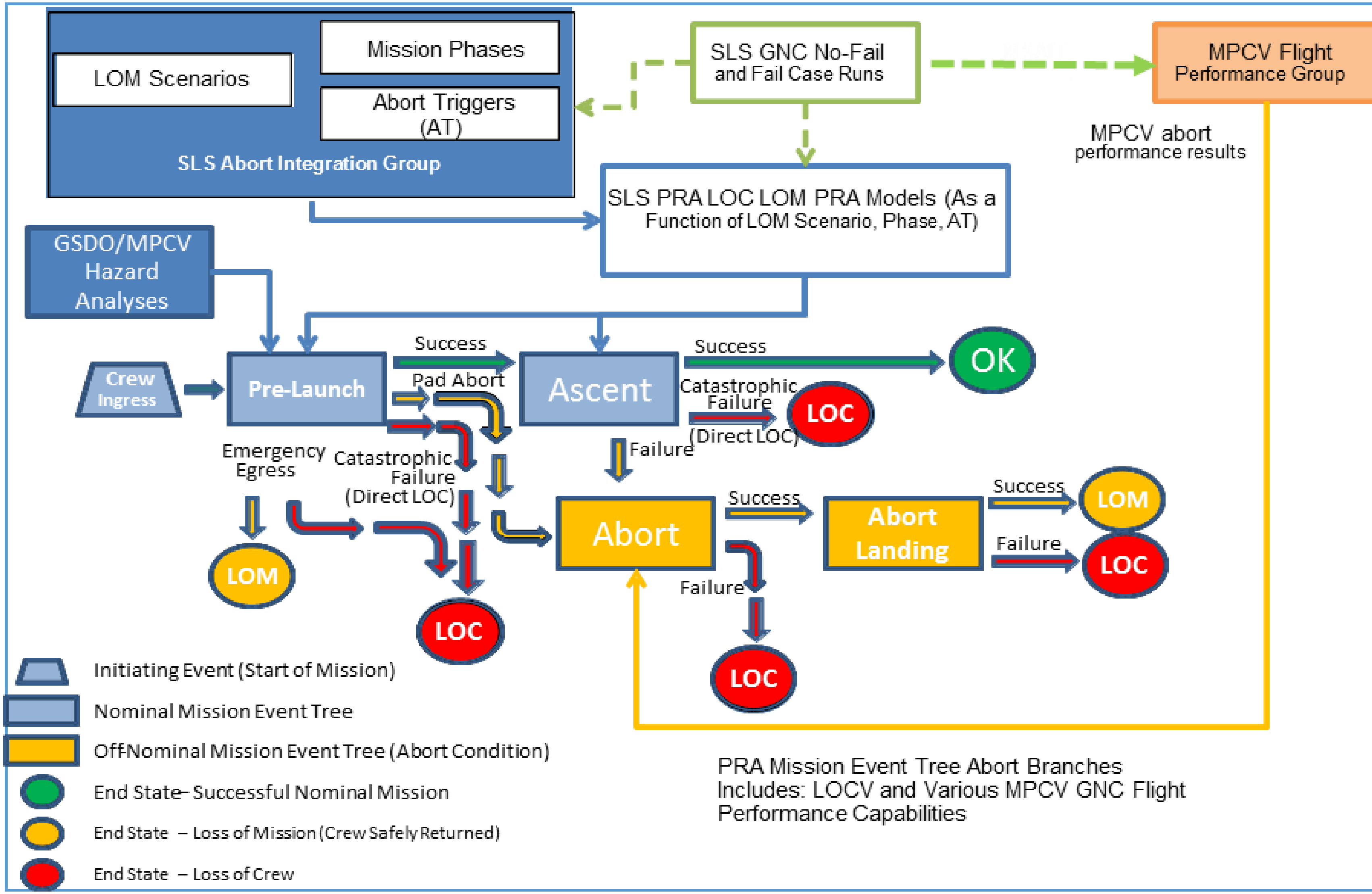


Note: Trajectory shown here is notional and not to scale

Overview of Cross PRA Model

- The Cross PRA (XPRA) model is a linked event tree – fault tree model.
  - Model was constructed using the Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) tool.
  - A Methodology Document was developed to guide all participating programs in development of their models for input into the XPRA model.
  - The XPRA model consists of four event trees that are linked to hundreds of fault trees through decision logic and event tree rules.
  - Fault trees for MPCV, SLS, and Ground Systems Development Operations (GSDO) are mapped to the event tree top events.
  - In addition, the XPRA team created fault trees to integrate off-line simulation and Human Reliability Analysis (HRA) inputs into the model.
  - The three end-states that exist in the model are as follows: Loss of Crew (LOC), Loss of Mission (LOM), and OK.

Process Flow Diagram of XPRA Ascent Model



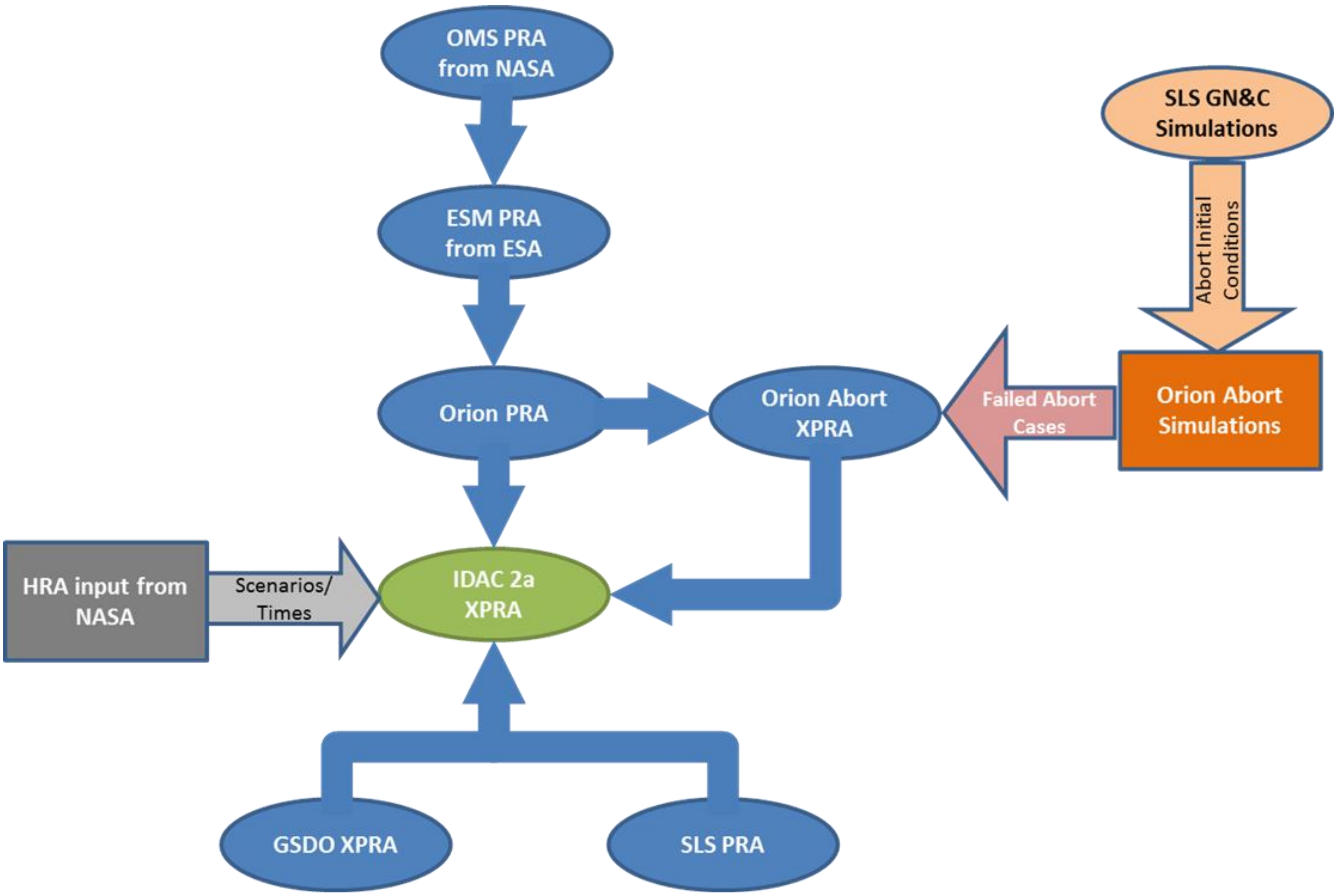
Dynamic Inputs to Cross PRA Model

- The XPRA ascent model is a time-averaged based model; however, it does include results of off-line analyses:
  - Risk associated with abort environments (e.g., debris, blast, fireball) that exceed the capability of the Orion were assessed separately outside the model based on off-line time-dependent analysis.
  - MPCV abort performance was assessed separately outside the model based on off-line Guidance, Navigation and Control (GN&C) trajectory analyses, based on simulated performance against selected abort performance metrics.

Human Reliability Analysis Overview

- Given that some aborts must be initiated by the crew or ground, human error events were identified and included in the model.
- Given the immaturity in the understanding of the operations of the vehicle at this early stage of the design, a screening methodology was utilized to quantify any human error events that were identified.
- Human error events identified in this analysis were provided to the crew and operations for review.
- At this point in the design, all of the assessments are considered preliminary.

Cross PRA Model Inputs



Applications of the Cross PRA Model

- This model serves two important purposes:
  - It is used to verify whether the integrated system is meeting LOC/LOM requirements.
  - Provides a capability of showing risks of the integrated system that the individual program models (SLS or Orion) do not capture that can support a risk-informed design process.
    - This information can be used for example to optimize the abort triggers to try to maximize the risk reduction achievable with the abort system.
    - It can also point out areas of uncertainty where our knowledge of the design, operations and/or interfaces is not well understood, and more analysis and/or testing needs to be performed to better understand them.

Challenges

- Numerous challenges have been encountered in the development of the XPRA ascent abort model, some of which are listed below:
  - There are issues associated with using the PRA in the design phase as opposed to the operational phase.
  - Trying to integrate very complex and dynamic events, which are not well understood, poses another challenge to this effort.
  - Following a self-integration approach across these NASA programs can yield some variations in modeling.
  - Given multiple programs with associated LOC requirements, it can be very difficult to separate the risks and assign to the various programs.

Conclusions and Forward Plan

- Despite the challenges associated with this analysis, it is believed that this model represents a very useful tool to the agency help verify LOC/LOM requirements and to support trade studies, which look at various design and/or operational options to optimize the allocation of resources to obtain the most risk reduction within all other constraints.
- This model will be expanded in future updates to include additional mission phases, such as in-space and nominal EDL, and challenges identified will be addressed to improve the overall quality of the model.