



# Probability Of Loss Of Crew Achievability Studies For NASA's Exploration Systems Development

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# Introduction



- Over the last few years, NASA has been evaluating various vehicle designs for multiple proposed design reference missions (DRM) beyond low Earth orbit in support of its Exploration Systems Development (ESD) programs.
- This paper addresses several of the proposed missions and the analysis techniques used to assess the key risk metric, probability of loss of crew (LOC). Probability of LOC is a metric used to assess the safety risk as well as a design requirement.
- These assessments or studies were categorized as LOC achievability studies to help inform NASA management as to what “ball park” estimates of probability of LOC could be achieved for each DRM and were eventually used to establish the corresponding LOC requirements. Given that details of the vehicles and mission are not well known at this time, the ground rules, assumptions, and consistency across the programs become the important basis of the assessments as well as for the decision makers to understand.

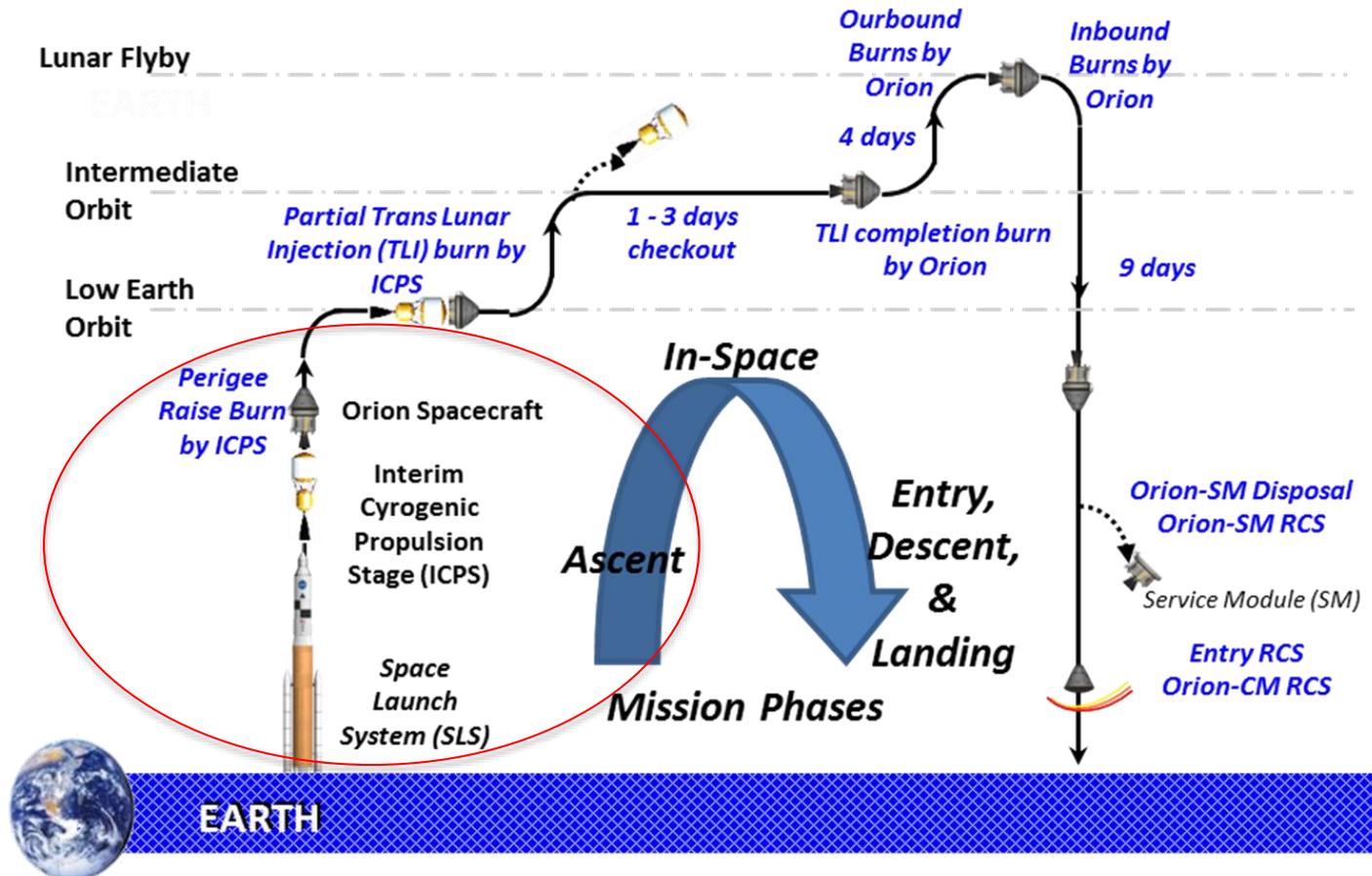
# Design Reference Missions (DRMs)



- **High Lunar Orbit (HLO)** – 14 day mission to orbit the moon, then return
- **Direct Retrograde Orbit (DRO)** – 25 day mission to go into orbit around the moon but at a much larger orbit where it takes about six days to partially orbit the moon. This orbit is consistent to where an asteroid would be parked after a robotic mission retrieves it from its current location to one in orbit around the moon for a future crewed mission would rendezvous with it.
- **Asteroid Redirect Crewed Mission (ARCM)** - the actual crewed mission of following a DRO DRM, but rendezvousing with an asteroid, collecting samples, and returning to Earth.
- **Hybrid** – 14 day mission with 30 hours in low Earth orbit (LEO) before heading to orbit the moon, then return via using the moon's gravity to throw Orion back to Earth.

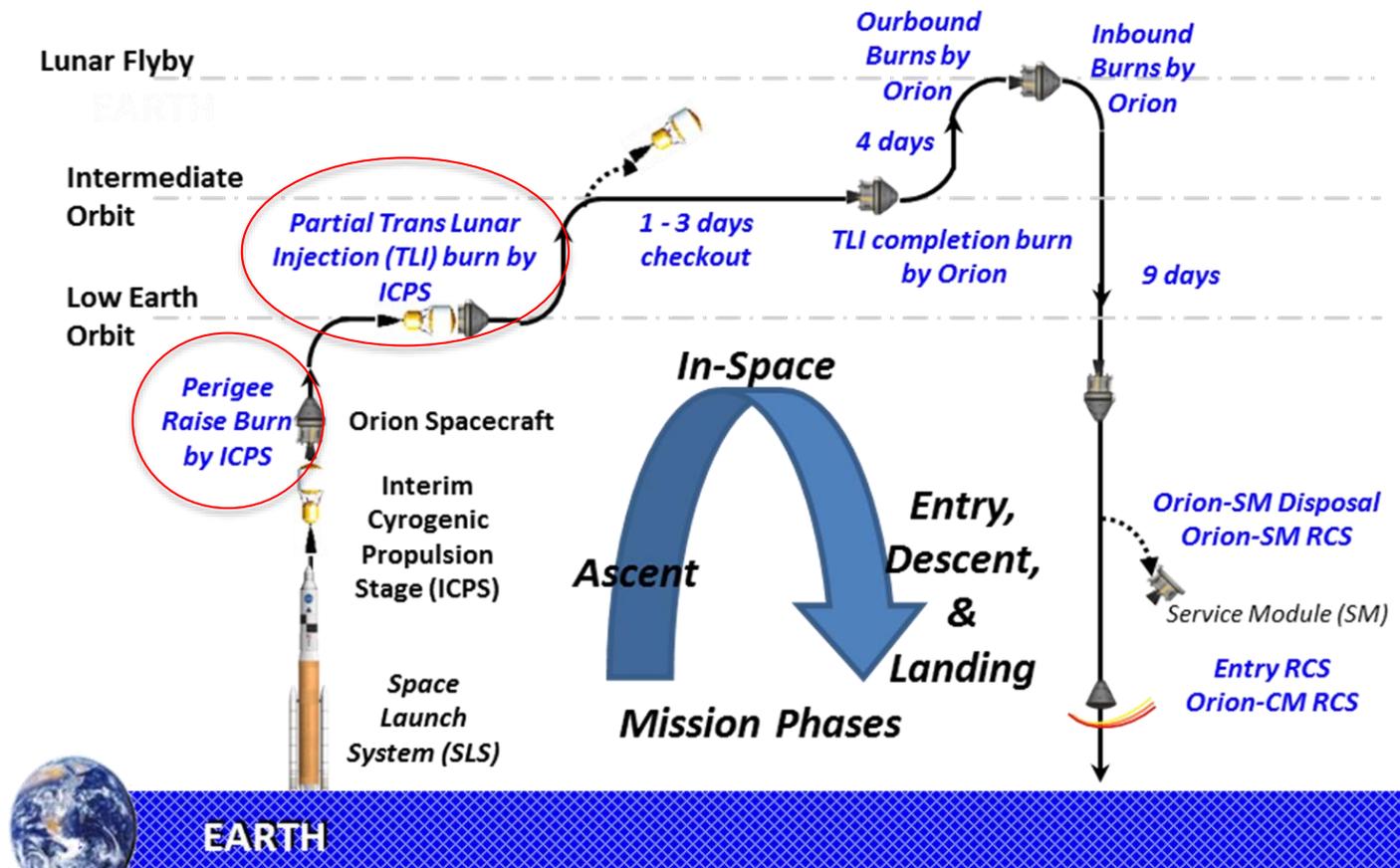
# Hybrid DRM

- Begins with pre-launch activities, such as tanking and crew boarding.
- Upon lift-off, the Space Launch System (SLS), the Interim Cyrogenic Propulsion Stage (ICPS), and the Orion spacecraft together as an integrated vehicle.
- During ascent, Orion's launch abort system (LAS) can be used to pull the crew to safety if sufficient warning time is available for something that may go wrong.



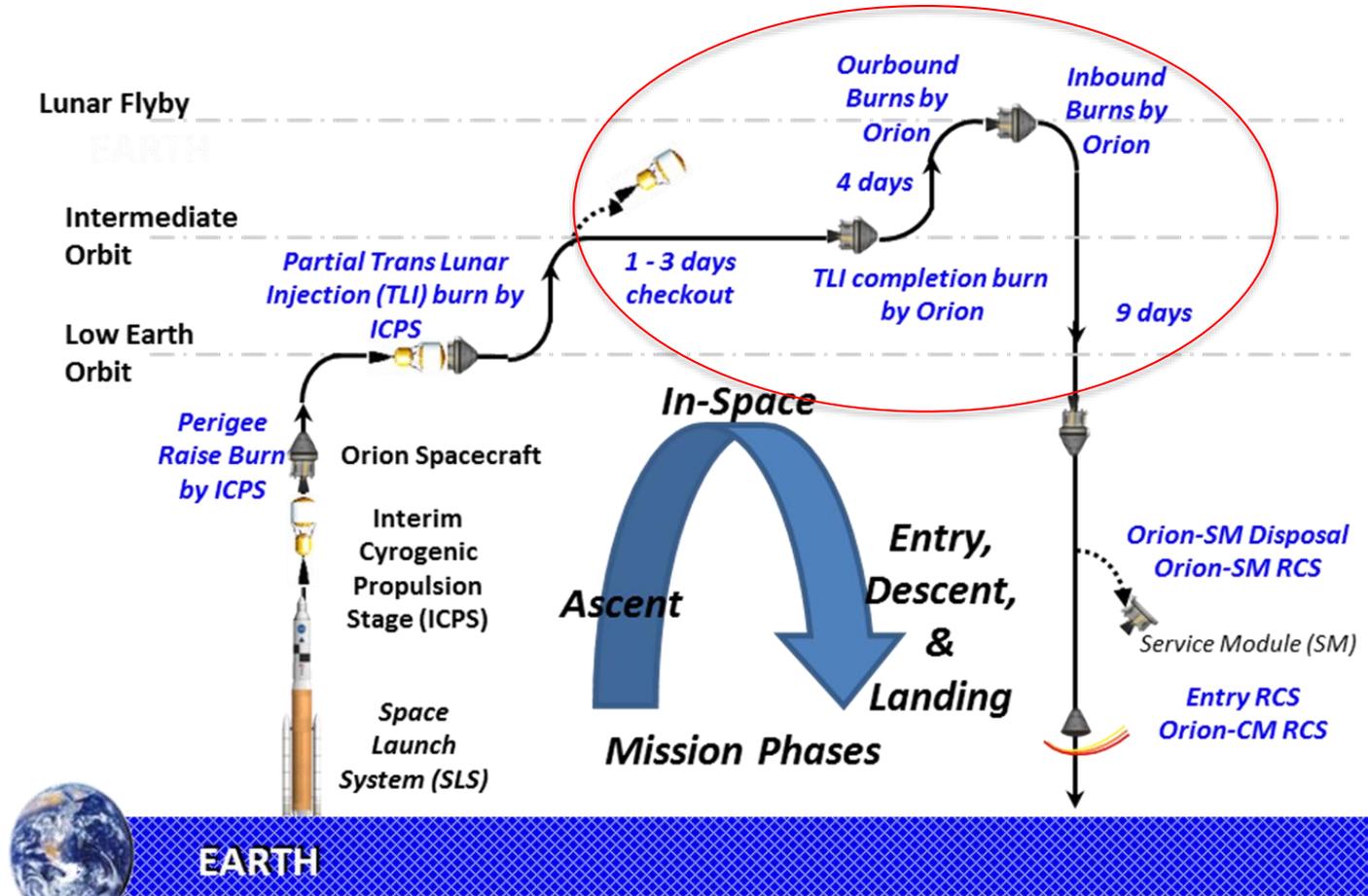
# Hybrid DRM continued

- Following the separations of the solid rocket boosters (SRBs) and the core stage, the ICPS and Orion continue to orbit where the ICPS engine fires to circularize the orbit.
- The ICPS again fires to put Orion in a partial trans-lunar injection (TLI) path.
- A second phase of abort scenarios exist post-circularization when an early return to Earth may be possible. Otherwise, it may become a race with the clock as observed with Apollo 13.



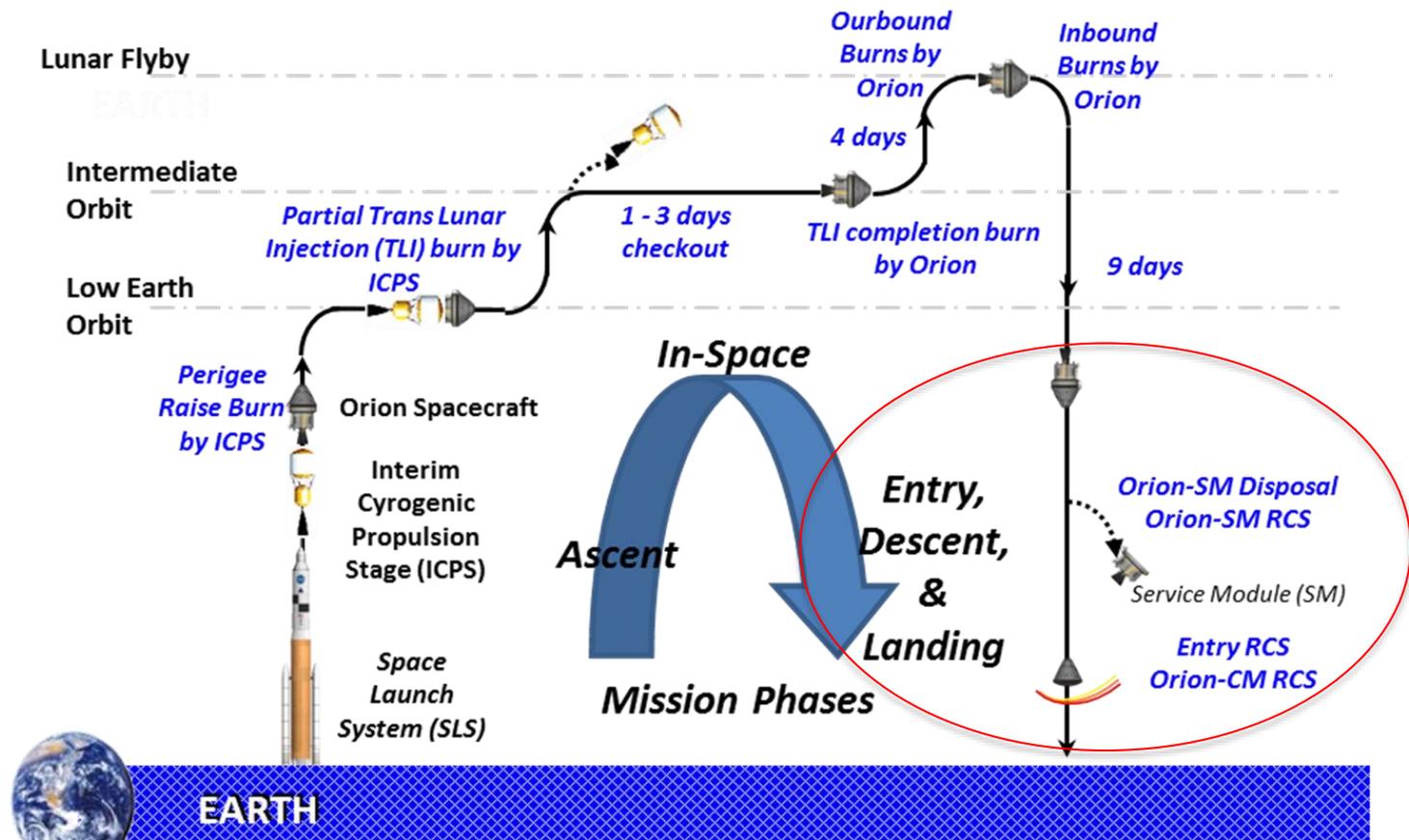
# Hybrid DRM continued

- For the next one to three days, the crew can check out the Orion spacecraft systems before committing to the remainder of the TLI burn using Orion's service module (SM) engines. Again, if an early return is warranted, options are available to the crew depending on their location in the TLI path.
- Using the gravity of the moon to pull Orion and throw it back to Earth, Orion will travel back in about nine days.



# Hybrid DRM continued

- Upon reaching Earth, the SM will separate from Orion before entering the Earth's atmosphere.
- After re-entry, the parachutes are deployed, the capsule lands in the Pacific Ocean off of California's coast, and a recovery vessel collects the capsule prior to the crew exiting. Problems can occur at any point along the way and the solution will vary based on its location in the mission.



# Key Design Reference Mission Attributes Comparison



DRM Information	HLO DRM	DRO DRM	Hybrid DRM	ARCM DRM
Mission Duration	14 Days	25 Days	14 Days	25 Days
Crew Size	4	2	2	2
ICPS MMOD Exposure in LEO	5 Hours	5 Hours	~3 Hours	5 Hours
Time Spent in Earth's Vicinity	5 Hours	5 Hours	~30 Hours	5 Hours
# of Major SM Prop Burns	3	7	3	7
Return Type	Propulsive	Propulsive	Free Return	Propulsive
Contingency EDL During 1st 30 Hours of DRM	Days	Days	Hours	Days
Docking/Undocking	N/A	N/A	N/A	1
EVA	N/A	N/A	N/A	Two, 2-crew, 4 hours each

# Approach



- **LOC Achievability Study** - These risk assessments typically cover the **concept phase** of a DRM, i.e. when little more than a general idea of the mission is known and are used to help establish “best estimates” for proposed program and agency level risk requirements.
- **Three mission phases:** pre-launch / ascent; in-space; and entry, descent, and landing (EDL)
- **Mission duration** is the biggest risk driver due to hardware, MMOD, and crew health
- **Number of launches** required becomes the 2<sup>nd</sup> major risk driver (e.g. Mars missions)
- **Software risk and human reliability** combined to be about what was estimated for Space Shuttle



# Conclusions

- Currently **PLOC requirements** set for Orion and SLS programs divided into their relevant association with the ascent and descent phases of the overall mission.
- HQ is finalizing plans to **select the first crewed mission** in 2021 as well as establish PLOC thresholds and goals.
- The mission is expected to be of some form of returning humans to the vicinity of the moon and safely returning them. Variations of this mission are being assessed against mission objectives, current design capabilities, and crew safety. The missions discussed today are prime candidates.
- **PLOC thresholds** are being established to raise a flag when risk is estimated to be larger than the agency is willing to accept, thus requiring the program that violates the threshold to explain why it should be allowed to continue.
- The **PLOC goals** are set as a stretch above the programs' PLOC requirements.

## Conclusions (Cont'd)



- PRA is used to **verify whether each PLOC requirement is being met** and how plans are being devised to address the major risk drivers.
- **Hindsight** would lead to assessing multiple DRMs as part of a coordinated design process for a true multi-purpose crewed vehicle instead of assuming a single mission is sufficient. However, reality still points to funding and schedule constraints yielding a “quasi” multi-purpose vehicle instead of an unlimited one. By evaluating the various DRMs to date, NASA has had more insight into mission and vehicle design instead of having just evaluated one mission.