National Aeronautics and Space Administration

DEEP SPACE

EXPLORATION SYSTEMS

NASA Exploration Mission 2 Mission Design

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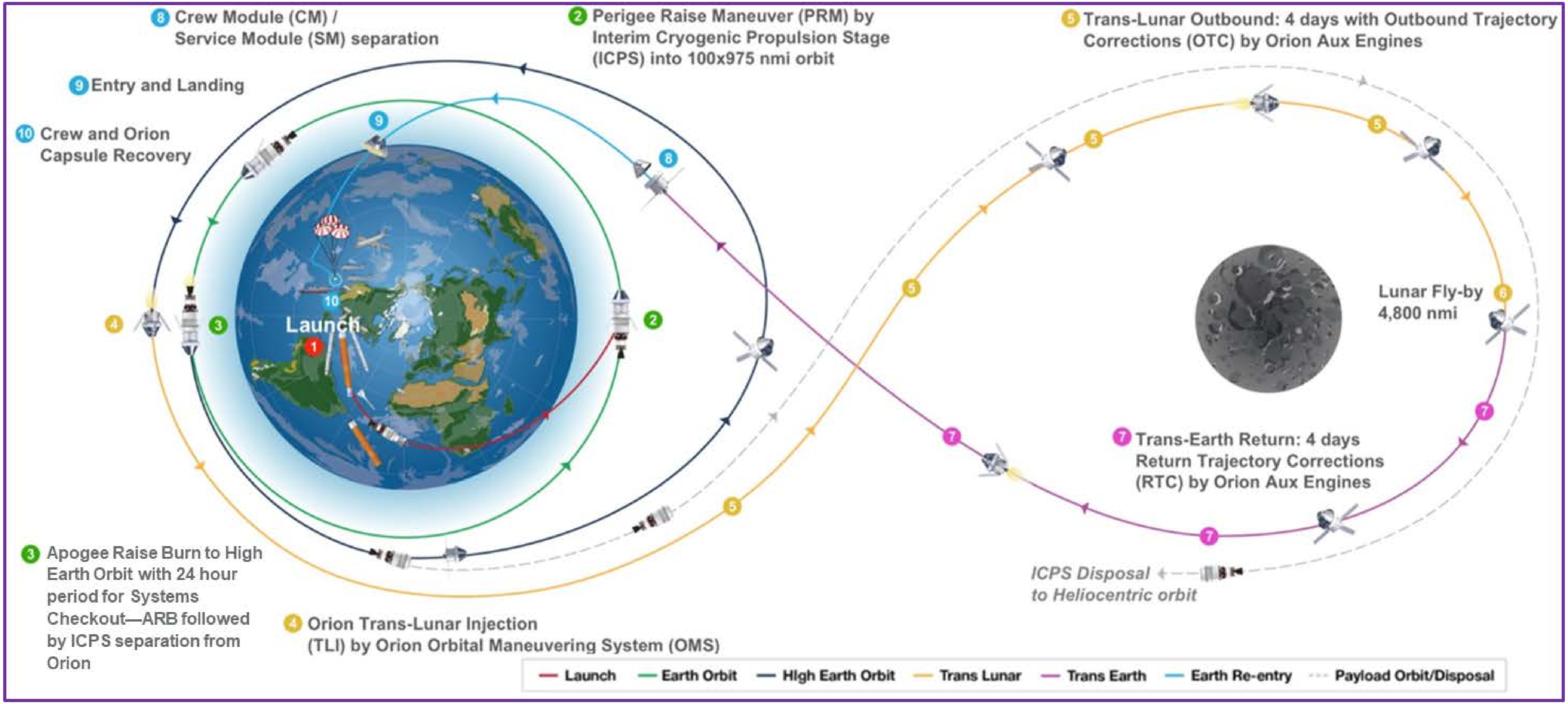
Background for Trade

- Transition from B1B to B1 for EM-2 drives necessary re-optimization to account for ICPS performance
  - Assumed roughly similar mission design of Hybrid-Free Return
  - B1B EUS assumed 100 nmi circular departure orbit not achievable by ICPS
  - EM-2 Orion mass is different than EM-1
  - Maturing system design results in available performance margins
- Initial MAIA analysis narrowed trade scope based on performance to key drivers
  - Conducted from May through July for initial B1 update
  - Eliminated circular orbits, lower HEO apogees, and alternate disposal targets
- Key drivers identified to evaluate trade results:
  - Mission availability resulting from integrated performance
  - Orion abort performance for both LEO and in-space
  - Activation & checkout operations & Orion LEO performance
  - MMOD risk from LEO exposure

Stakeholder EM-2 Block 1 Trajectory



Trajectory Design Ground Rules and Assumptions

- SLS
  - Copernicus calls a database of ascent trajectories to find the optimal ascent for the mission constraints
- ICPS
  - Mass and propulsion data is derived from data provided to support EM-1
  - ICPS will perform 3 RL10 burns on EM-2 where EM-1 only had 2 burns
  - ICPS disposal targets a Earth barycenter relative C3 of 0.35 km^2/sec^2 10 days after lunar flyby
- Orion
  - Mass is the Not to Exceed requirement
    - 300 lbm (136 kg) of propellant is offloaded to meet this requirement
  - OME provides all the major maneuvers
  - A short separation burn is performed using the auxiliary thrusters after ICPS separation
  - Spends approximately 1 rev in the HEO
  - Free return duration is ~8 day
- Launch availability was assessed from June 7, 2022 through June 7, 2023.
- ICPS and Orion performance are weighted equally in the objective function

Parametric Analysis

- Perigee Raise Maneuver Timing
  - Allow more continuous time for Orion checkouts prior to the ARB
  - Orion can delay solar array deploy until after PRM if performed early enough
  - Performance impact increases as the PRM is moved earlier in the trajectory
- Core Stage Insertion Apogee
  - 975 nmi (baseline)
  - 1200 nmi
- Intermediate Orbit Period
  - 24 hour (original baseline)
  - 42 hour
- First Revolution Apogee Raise Burn
  - Reduces the number of passages through the heavy orbital debris bands

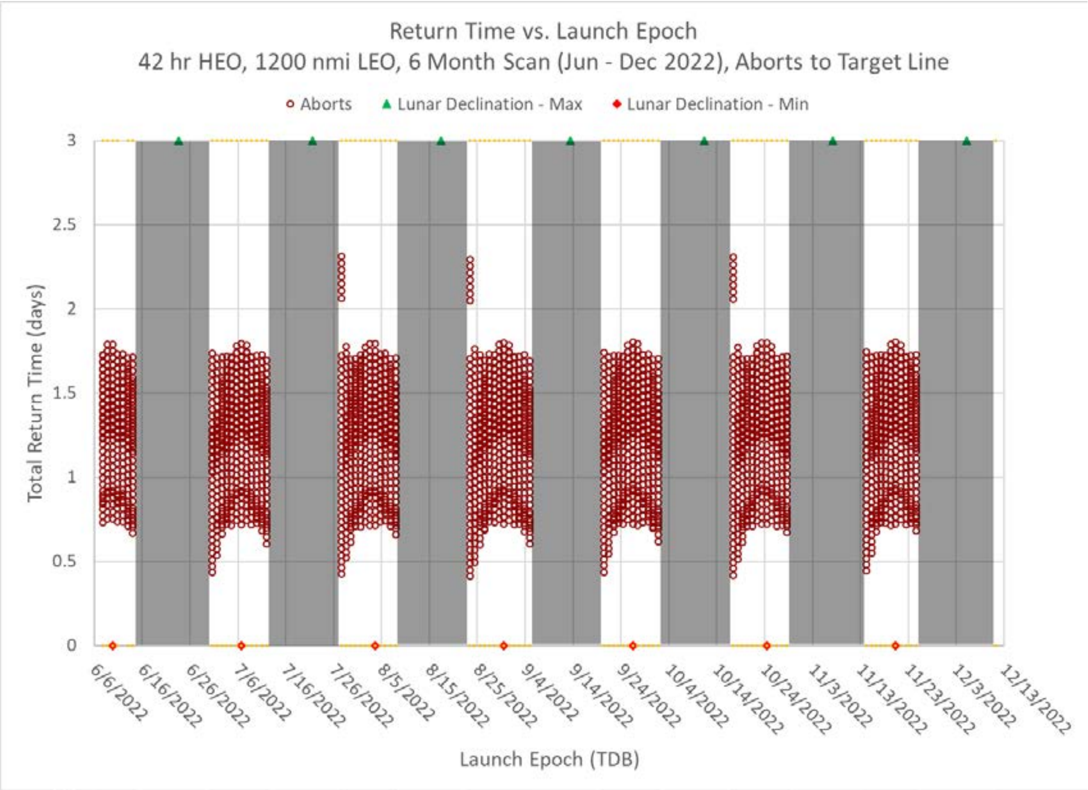
Mission Scans

- Mission Scans were run for a total of 10 trajectory cases listed here
- The grey shaded cases were not selected for further screening

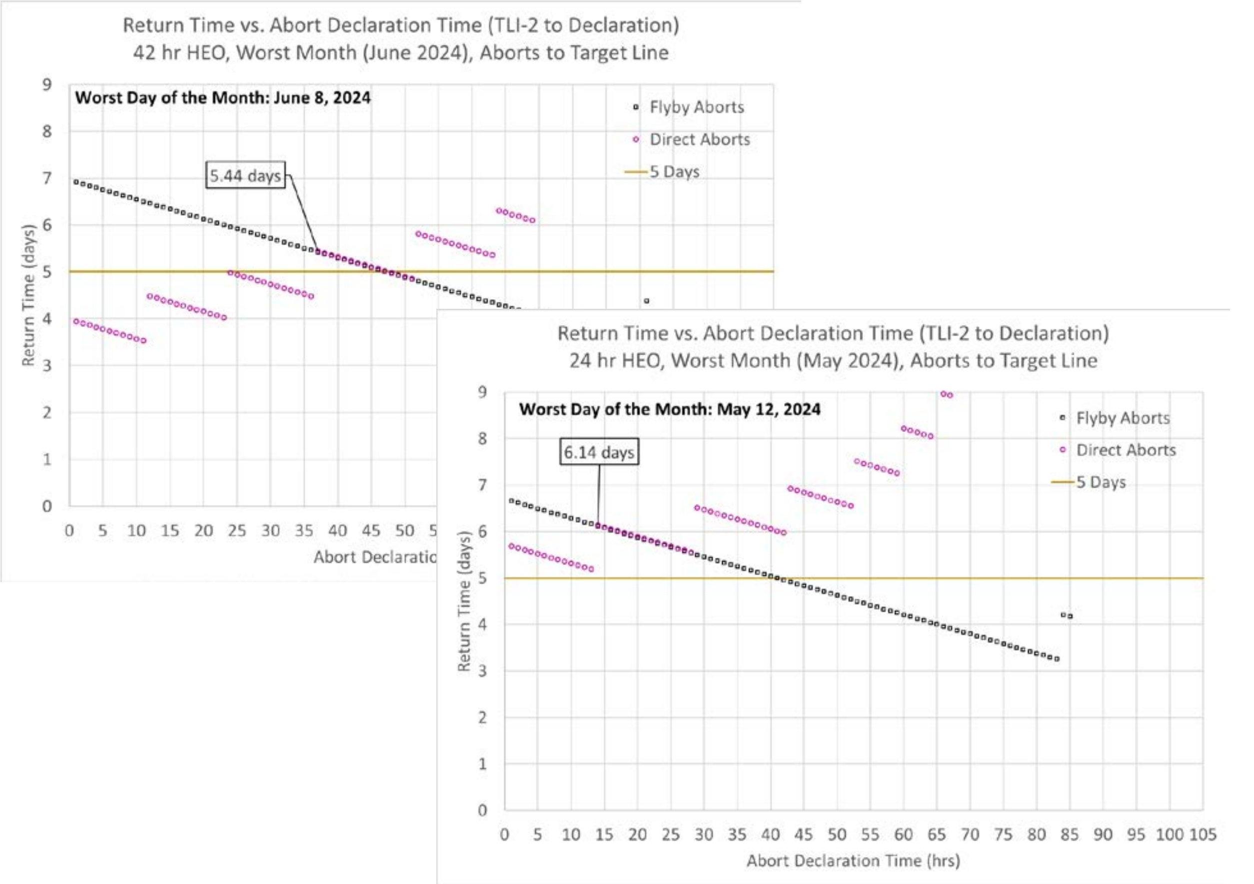
Option	Traj Case #	Insertion (nmi)	PRM Timing	Resulting LEO Apogee (nmi)	ARB Rev Start	HEO Period
A	1	975	apogee	975	2nd	24 hr
	2	975	10 min	1200	1st	24 hr
	3	1200	apogee	1200	2nd	42 hr
C	4	1200	10 min	1450	2nd	42 hr
D	10	1200	10 min	1450	1st	42 hr
	5	1200	2 min	variable	1st	42 hr
	6	1200	2 min	3100	1st	42 hr
B	7	975	apogee	975	1st	24 hr
E	8	1200	2 min	3100	1st	24 hr
F	9	1200	2 min	2000	1st	42 hr

Orion Aborts Analysis

- Orion was able to abort to the entry interface target line in all instances from both the 24 and 42 hour HEO. Maximum return times were ~2.5 days.

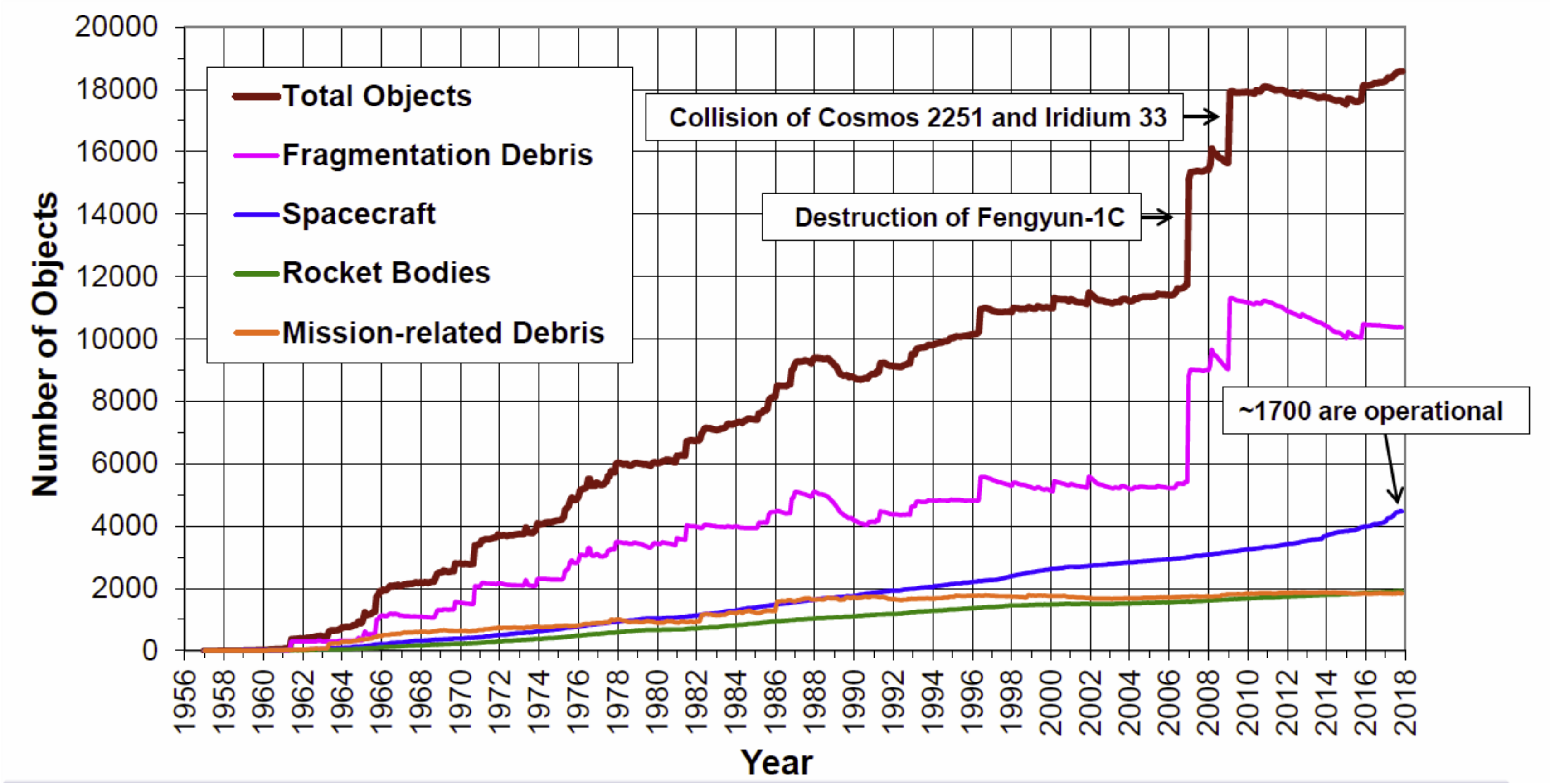


- The 42 hour HEO helped aborts by increasing the amount of propellant remaining on Orion, allowing for faster return times



MMOD Risks

- MMOD risks have increased steadily since the beginning of manned space ventures



Mission Design Parameter Effects

- Higher Insertion Apogee:
  - Improves mission availability by decreasing ICPS performance demand
  - Reduces core stage ascent margin
- Earlier PRM Timing:
  - Increases resulting LEO apogee and decrease time in MMOD field
  - Improves Orion checkout ops by removing PRM interruption
    - Solar array deploy occurs in stable orbit, array parking not required for PRM, PRM has no interference on checkout ops
  - Orion IVP improvement from high apogee
    - Decreases Earth albedo, increased orbits times for power generation solar insolation
  - Decrease in mission availability from ICPS performance impact
- Number of LEO Revs/time in LEO:
  - Decreases MMOD field transits
  - Decreases Orion LEO checkout time
    - FOD study indicates success oriented risk at 60min required, highly desired 90-120 min
  - Improves Orion IVP (power)
- Increasing HEO size:
  - Decreases Orion TLI prop use improving post-TLI abort capability
  - Decreases mission availability

Competing effects result in a challenge to balance risk across the system

System Trade Summary

	Insertion (nmi)	PRM (min)	Apogee (nmi)	Rev	HEO (hrs)	Msn Avail (dd/mm)	Total PRA (1 in x LOC)	MMOD Stack (1/x LOM/LOC)	Abort Capability	LEO Ops/Perf.
A	975	45	975	2	24	12-14	188	150/868	Degraded post-TLI	Required + Desired
B	975	10	1150	1	24	10-11	199	276/1,190	Degraded post-TLI	Required only
C	1200	10	1450	2	42	10-11	189	194/904	Improved post-TLI	Required + Desired
D	1200	10	1450	1	42	10-11	~205	374/1,380	Improved post-TLI	Required + IVP benefit
E	1200	2	3100	1	24	5-8	198	447/1,160	Degraded post-TLI	Required + Desired + IVP benefit
F	1200	2	2000	1	42	7-9	201	397/1,270	Improved post-TLI	Required + Desired + IVP benefit

- LEO discriminators are mission availability & MMOD
  - Adequate opportunity exists for LEO apogees in the 975-2000 nmi range
  - Balanced MMOD risk and checkout time set by tailoring apogee on 1st rev
- HEO primary discriminator is minimization of Orion Post-TLI abort times
  - HEO aborts capability and mission opportunities were similar between both options
  - Preference to maximize Orion post-TLI prop available and minimize crew contingency risk
- ULA has assessed the capability to perform these missions as low risk
  - Only perturbation would be the addition of an extra COPV for Option E (3,100 nmi apogee)—with no undue technical or schedule risk

Trade recommended Option F, but the JICB chose Option D due to the higher mission availability at the cost of checkout time in LEO