A relocatable lander to explore Titan's prebiotic chemistry and habitability

Dragonfly Mission Entry and Descent Modeling and Simulation Overview

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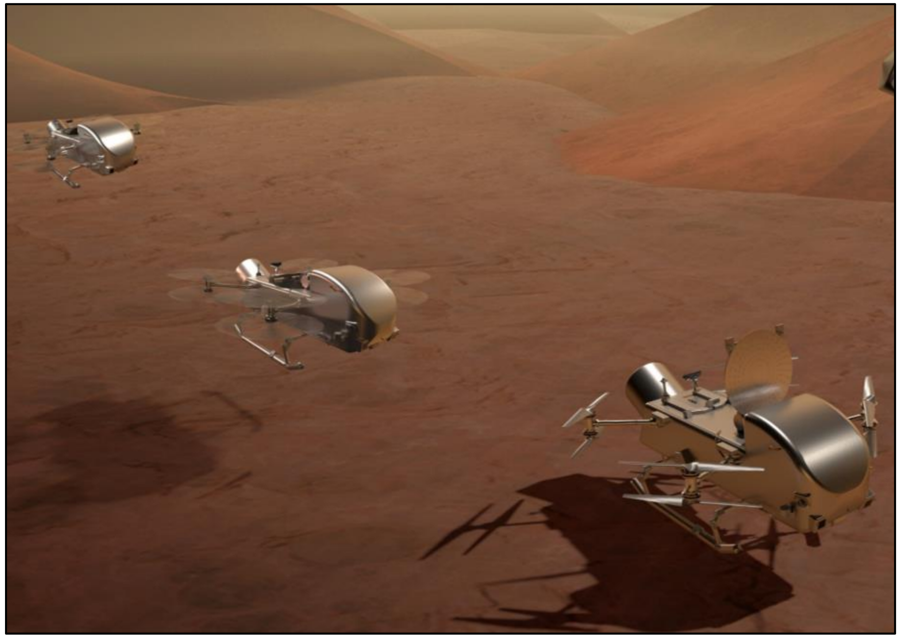
Overview

- Dragonfly is a New Frontiers Program mission that will deliver a rotorcraft lander to Saturn's moon, Titan for the first time since Huygens Probe landed in 2005
  - Currently set to launch in 2028 and arrive in the mid 2030s
- Dragonfly will enter the Titan Atmosphere at a comparable latitude and near-identical season as Huygens
- This mission is designed to explore diverse locations to characterize the habitability of Titan's environment.
- This mission is led by The John Hopkins Applied Physics Laboratory and the EDL Phase is led by NASA Ames and Langley Research Center
- The purpose of this presentation is to give an overview of the status of Dragonfly Flight Mechanics Entry and Descent modeling since the preliminary design review (PDR) in 2022.

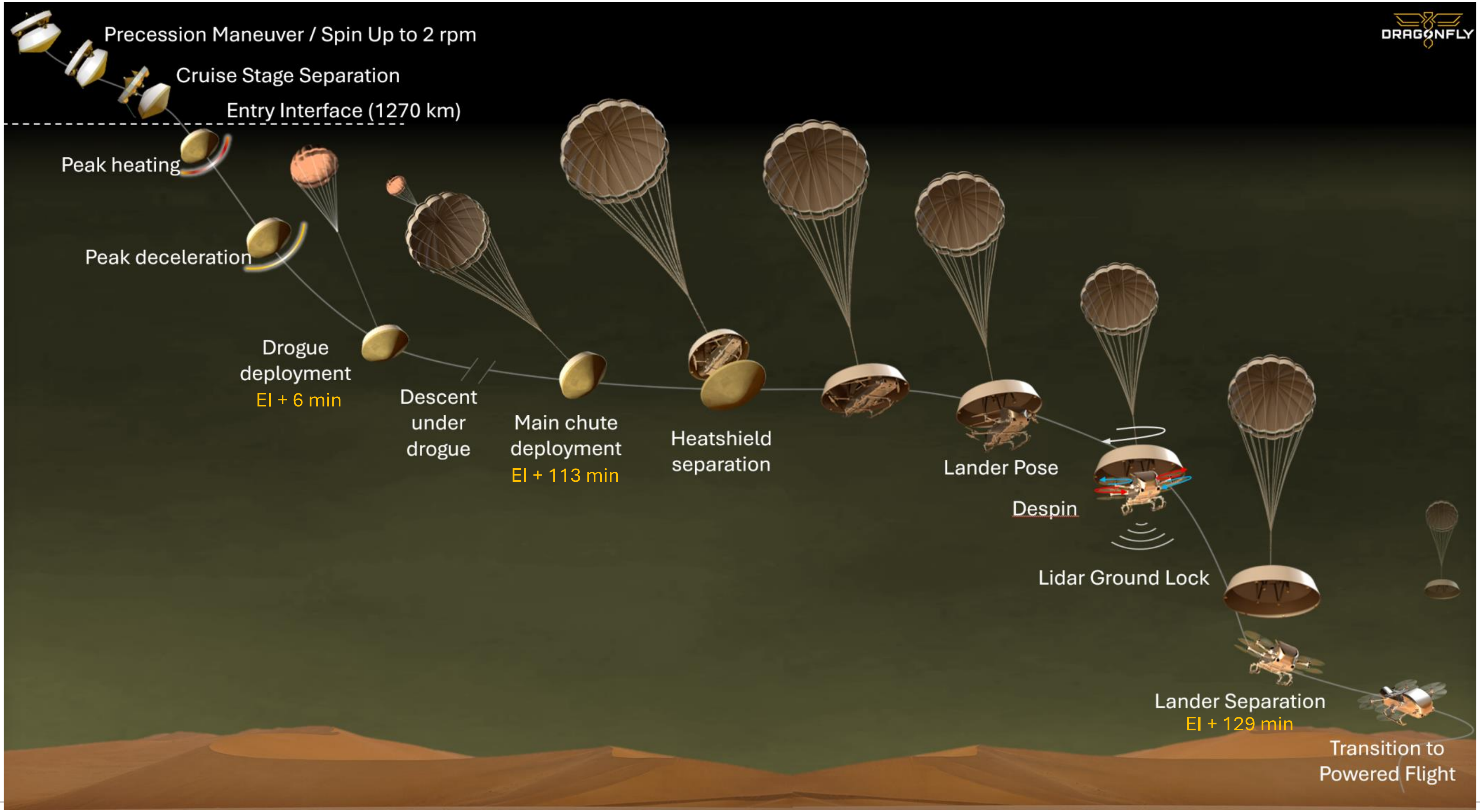


Credit: APL

Outline

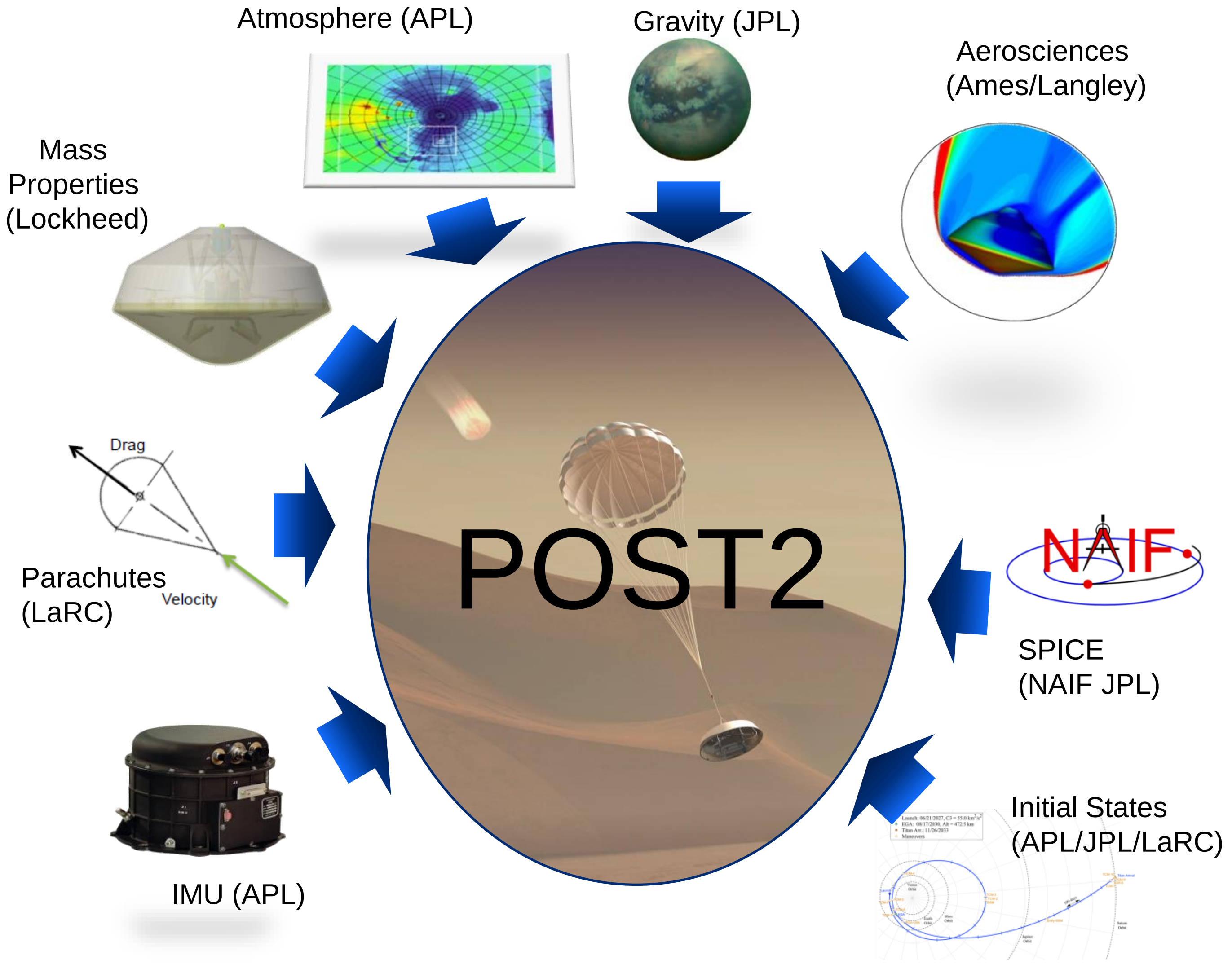
- Dragonfly Entry, Descent and Landing (EDL) Concept of Operations
- Modeling and Simulation Overview
- Titan Overview
- Dragonfly Entry Vehicle and Parachute Design
- Baseline Analysis
- Monte Carlo Analysis
- Future Work and Conclusion

Dragonfly EDL Concept of Operations



Modeling and Simulation Overview

- The EDL sequence was modeled using Program to Optimize Simulated Trajectories II (POST2)
- System performance is assessed through augmented cluster computing scripts that enable Monte Carlo and sensitivity analyses
- POST2 analysis is used to evaluate 4 scenarios
  - Mass Properties: MPV and CBE
  - Primary and Backup Launch Opportunities

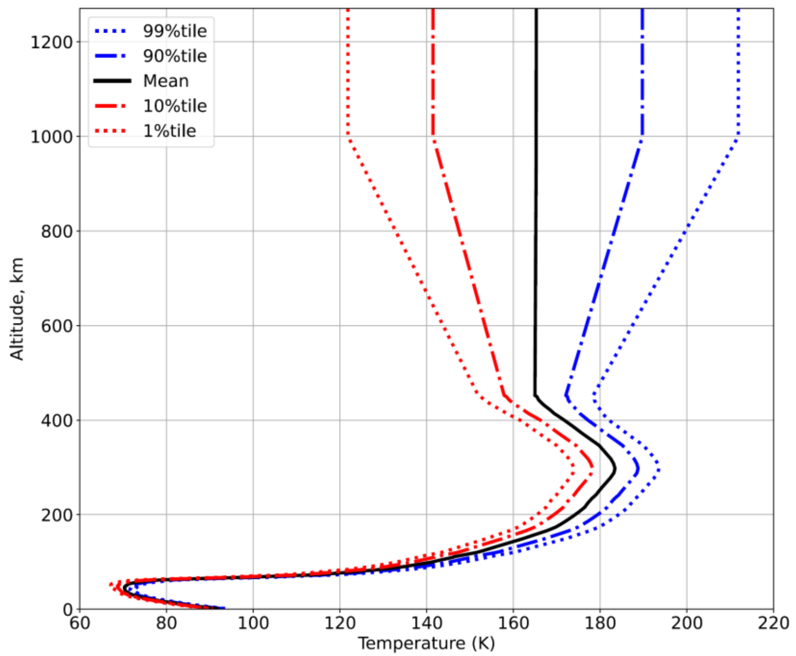


LaRC – NASA Langley Research Center
APL – Applied Physics Laboratory
JPL – Jet Propulsion Laboratory
Ames – NASA Ames Research Center
Lockheed – Lockheed Martin Space Company

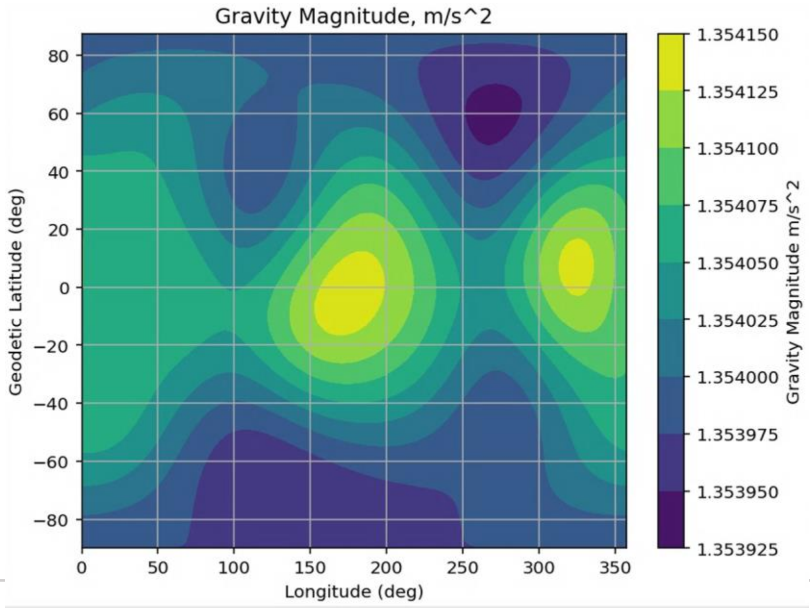
MPV - Maximum Possible Value
CBE - Current Best Estimate

Titan Overview

- Taller, denser atmosphere and lower gravity leads to much longer descent time relative to Earth/Mars
  - Under parachutes > 2.5 hours
  - Results in thermal and power challenges
- Atmosphere Models include density, temperature, composition, winds, and gust models
  - Pressure and speed of sound are derived quantities
- Dragonfly atmosphere have been updated from new information collected from
  - Atacama Large Millimeter Array (ALMA)
  - Re-evaluating Cassini radio occultation
  - More details in upcoming talk
- Gravity model modeling verification efforts have been completed to ensure the model is consistent among the team.



Data Source: R. Lorenz (APL)



Data Source: JPL

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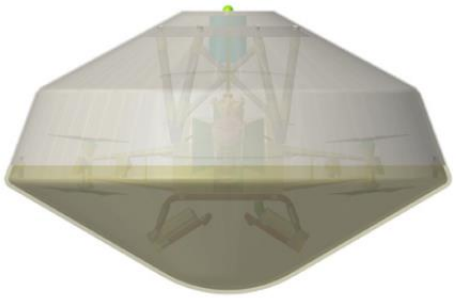
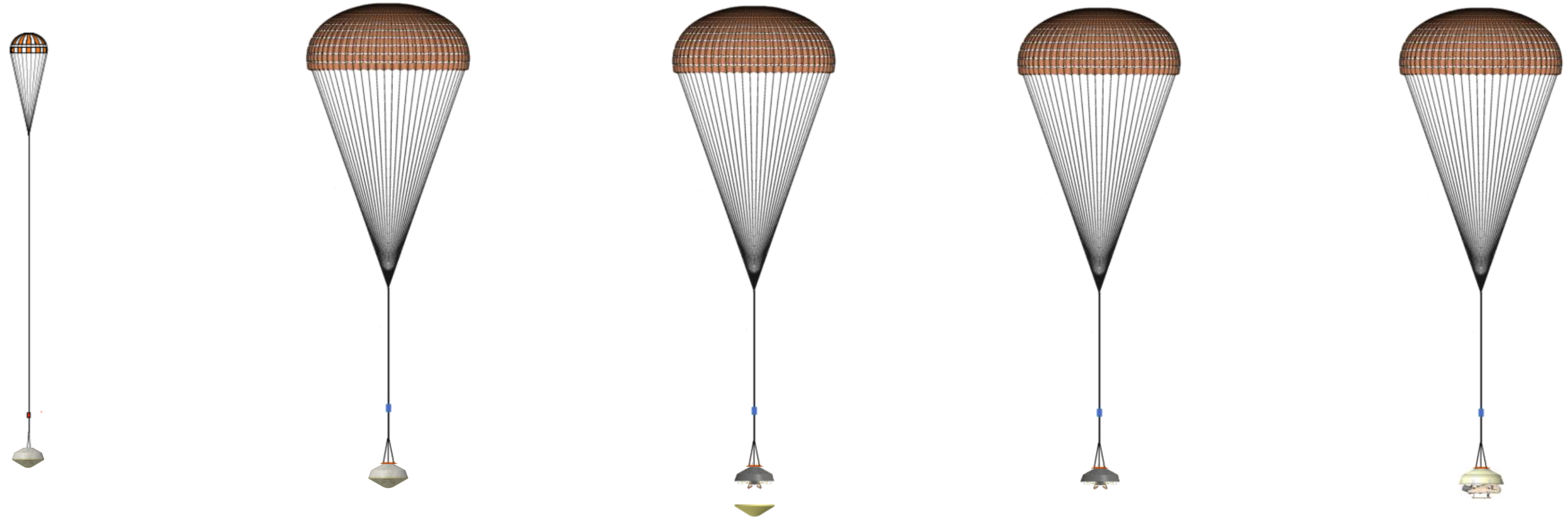
Aerodynamic Configurations (1/2)

* EI = entry interface
* Scales and times are approximate

Capsule	Capsule on Drogue	Capsule on Main	Heatshield Separation	Stowed Lander in Backshell	Posed Lander in Backshell
Entry to Mach 1.5	Mach 1.5 to 7 m/s	Subsonic	Subsonic	Subsonic	2.9 m/s
EI – 10 min to EI + 6 min	~100 min	2 min	Main + 2 min	3 min	~5-20 min



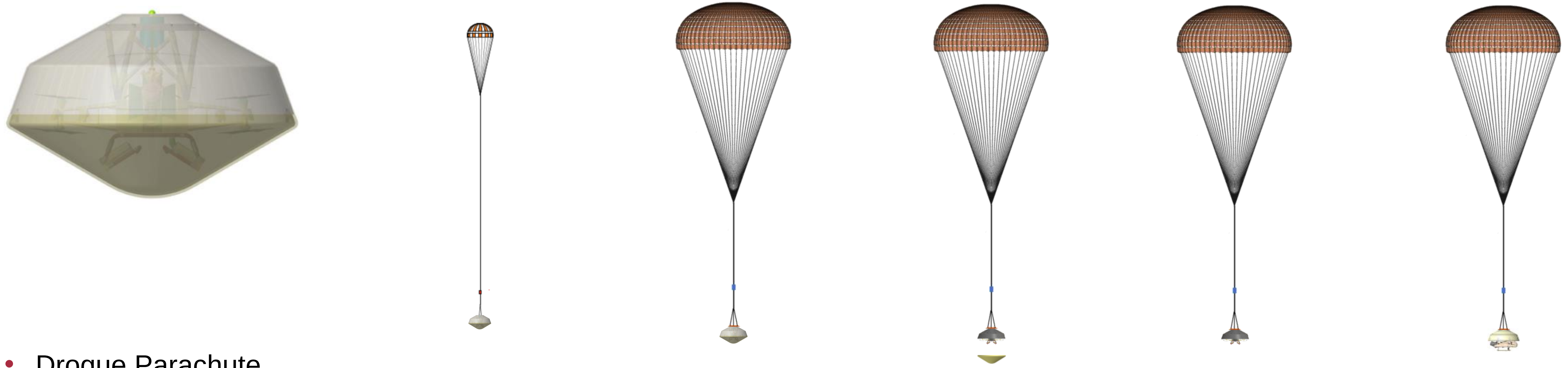


- Entry Vehicle:
  - Maximum Possible Value (MPV) Mass Increased (2600 kg)
  - Diameter: 4.5 m
  - Sphere Cone Angle: 60°
  - Based on Genesis Sample Return Capsule
  - Aerodatabase uses computational fluid dynamics (CFD), the Langley 12’ low speed wind tunnel, the Langley Vertical Spin Tunnel (VST), the Langley Transonic Dynamic Tunnel (TDT), and the National Full-Scale Aerodynamics Complex 80x120-Foot Wind Tunnel.

Aerodynamic Configurations (2/2)

* EI = entry interface
* Scales and times are approximate

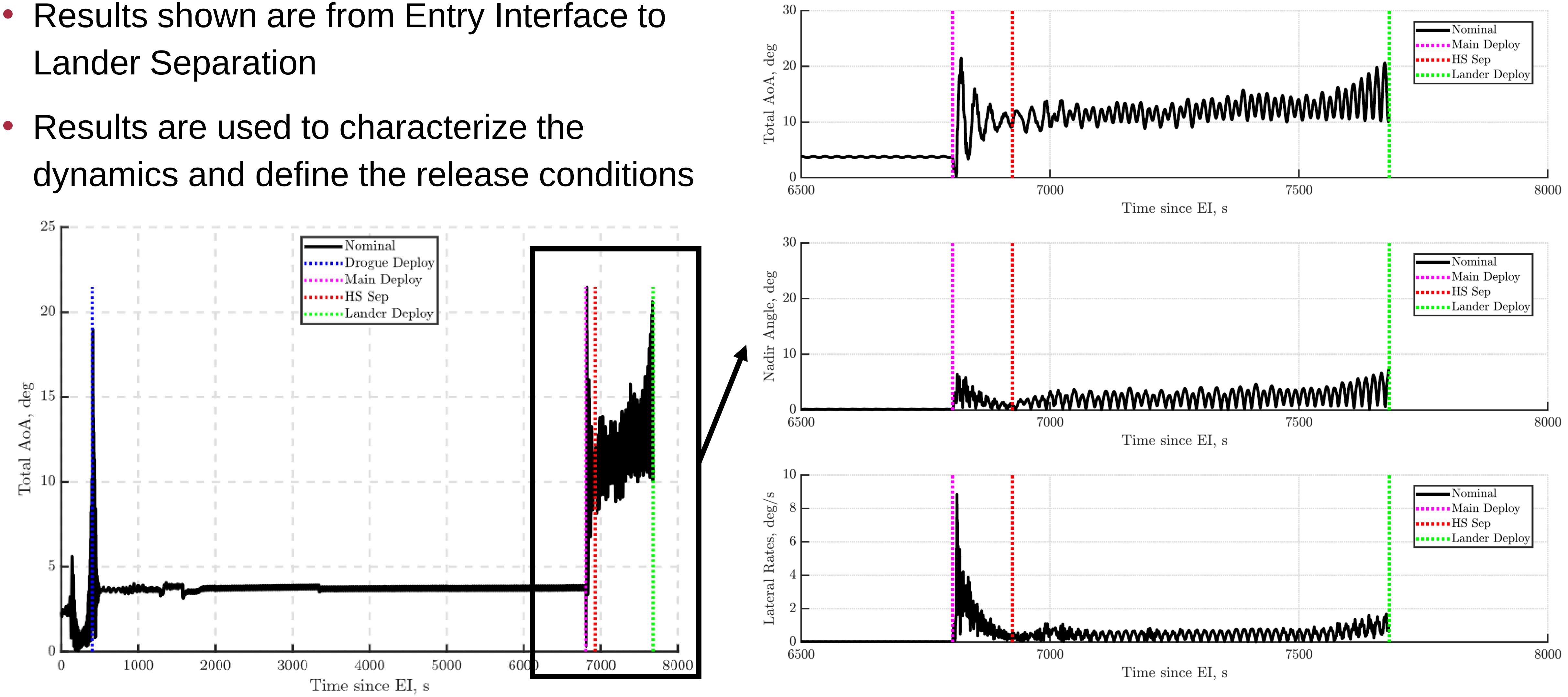
Capsule	Capsule on Drogue	Capsule on Main	Heatshield Separation	Stowed Lander in Backshell	Posed Lander in Backshell
Entry to Mach 1.5	Mach 1.5 to 7 m/s	Subsonic	Subsonic	Subsonic	2.9 m/s
EI – 10 min to EI + 6 min	~100 min	2 min	Main + 2 min	3 min	~5-20 min



- Drogue Parachute
  - 8.25 m Disk Gap Band (DGB) increased to address stability issues
- Main Parachute
  - 16.7 m Ringslot increased to address mass properties
- Aerodynamic models are derived from literature and parachute models are being updated from data collected from drop test campaigns which have served as a way to validate the simulation tools

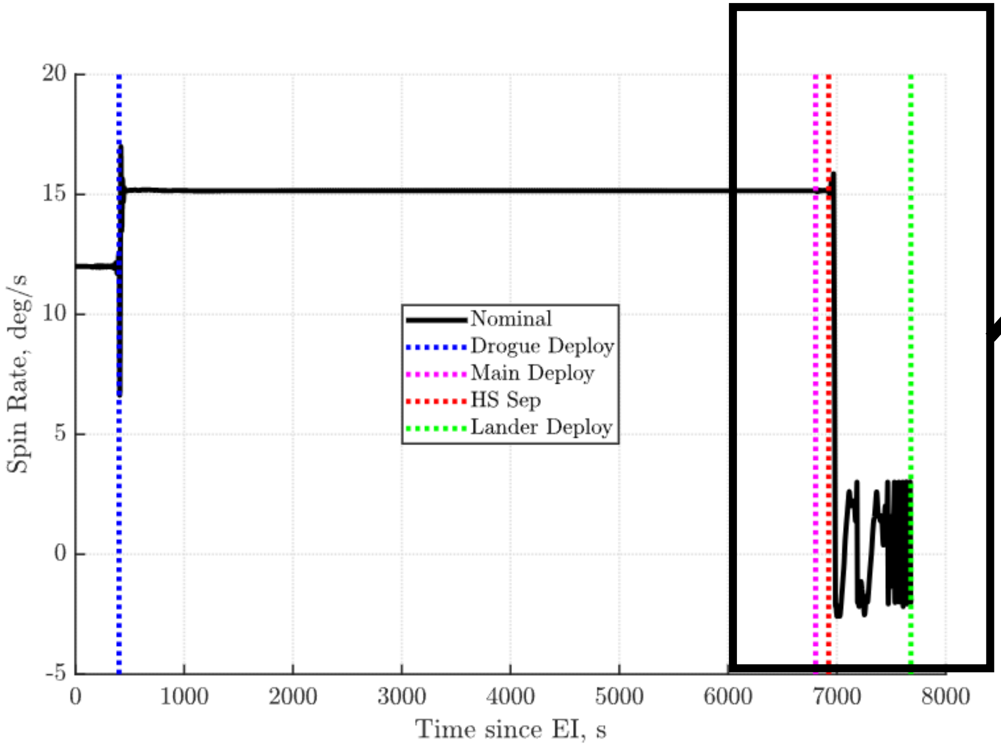
Baseline Results

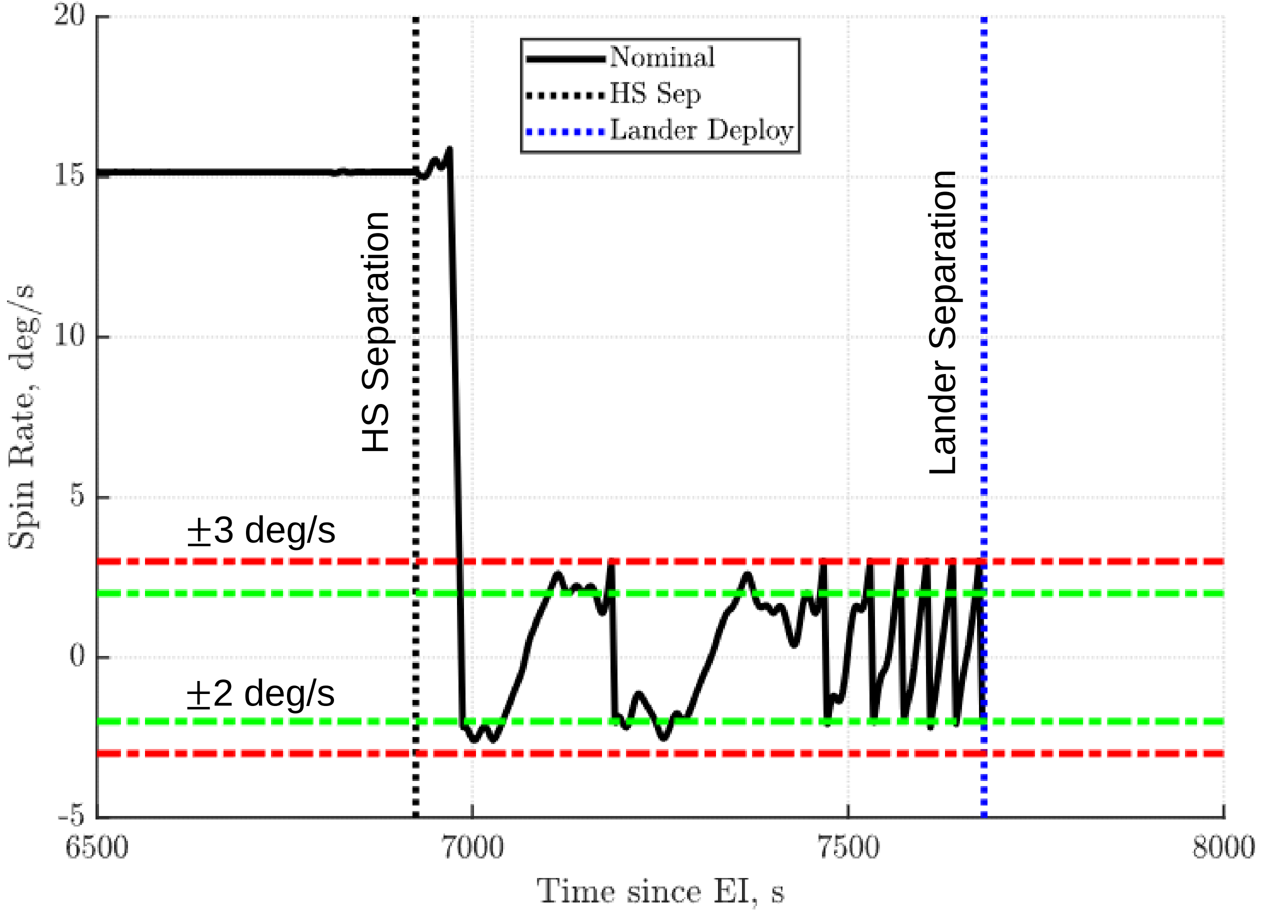
- Results shown are from Entry Interface to Lander Separation
- Results are used to characterize the dynamics and define the release conditions



Baseline Results – Spin Rates

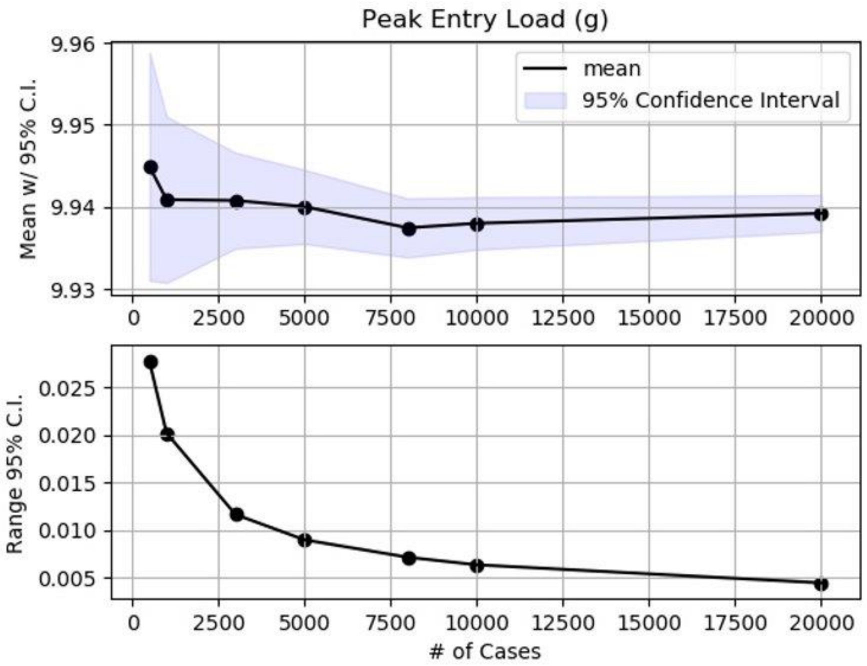
- Spin stabilized at 2 RPM during entry
- High spin rate under drogue
- Lander Rotors are used to control spin rate (AIAA 2024-2118)

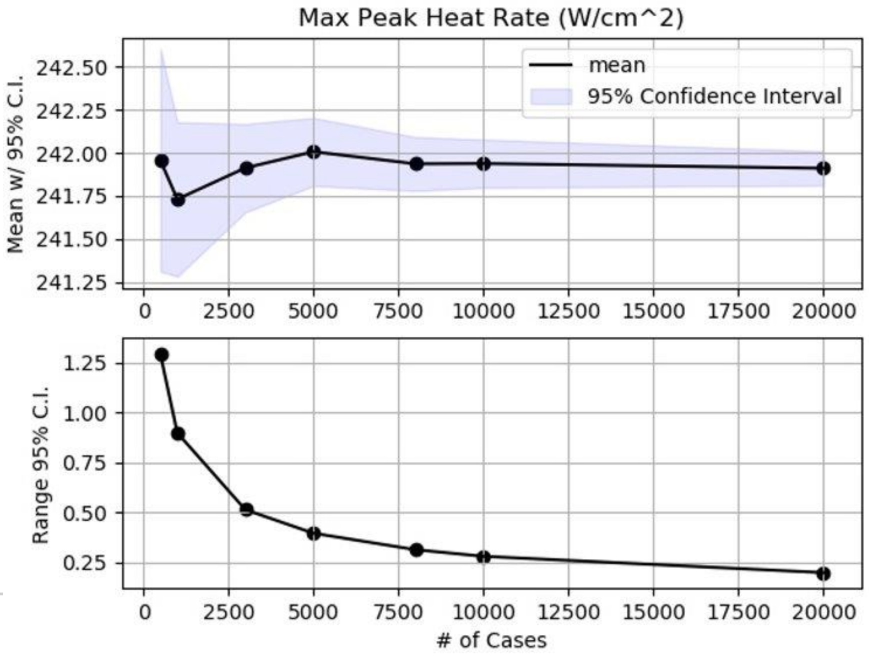




Monte Carlo Analysis

- How do we know the results of the Monte Carlos are of high quality?
- Evaluated the same Monte Carlo with various sample sizes ranging from 500 to 20,000 runs.
- Compared the mean value, 95% confidence interval, and range of the upper bound to lower bound of the confidence interval.
- Using 10,000 cases per Monte Carlo is the agreed methodology to produce acceptable statistics with desired confidence interval





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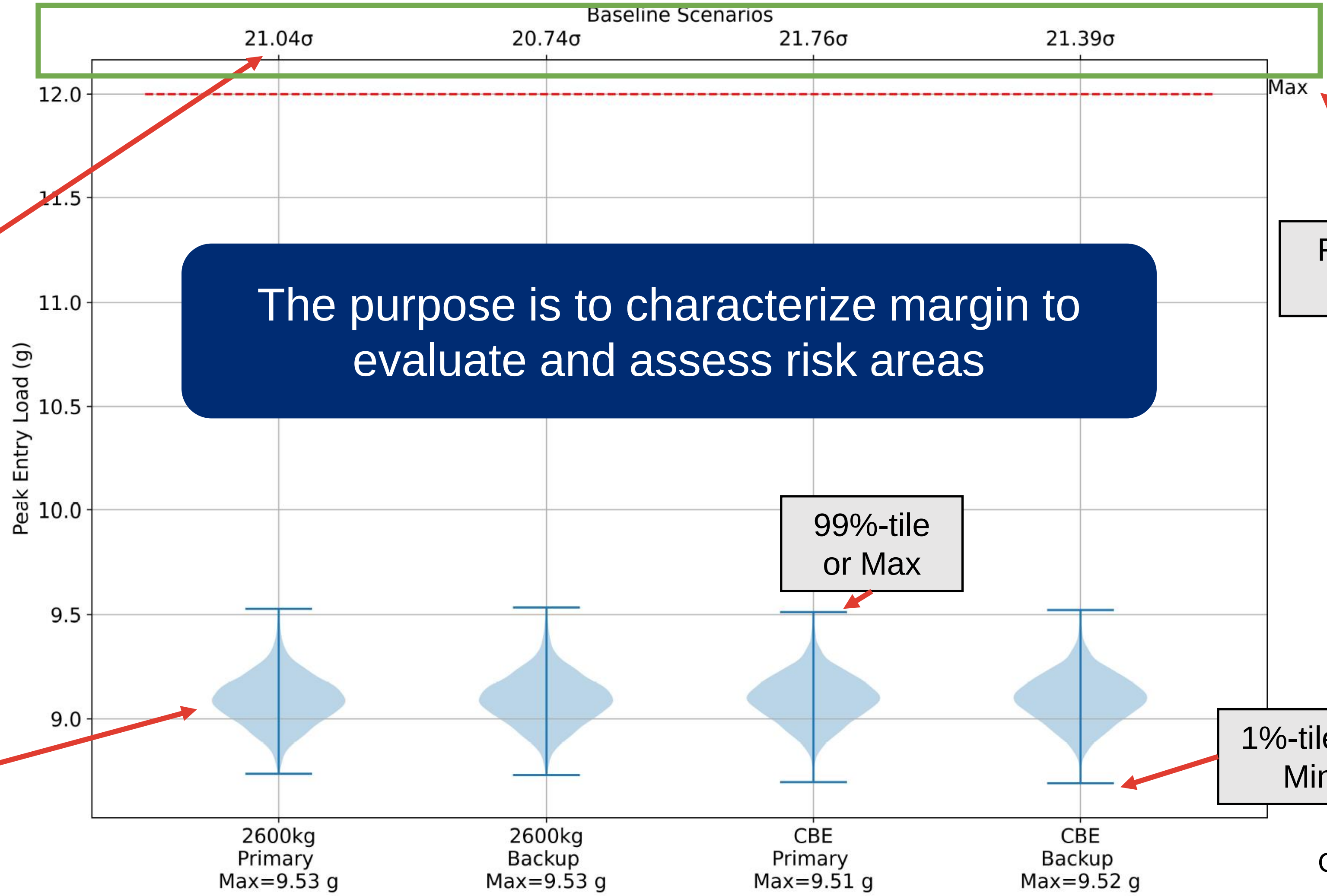
Monte Carlo Analysis

- Example subset of requirements tracked

Performance Metric	Requirement Type	Value	Units	2600 kg Primary	2600 kg Back Up	CBE Primary	CBE Back Up
Peak Entry Load	max	x <12	g	100%	100%	100%	100%
Max Peak Heat Rate	max	x <310	W/cm^2	100%	100%	100%	100%
Peak Drogue Opening Load	99%	x <32	kN	100%	100%	100%	100%
Total AoA @ Drogue Chute Deploy	99%	x <15	deg	99.8%	99.5%	99.5%	99.3%
Time to Mach 1.4	99%	x <10	s	100%	99.9%	99.9%	99.4%
Low Altitude @ Main Deploy	1%	x >=4000	m	99.0%	99.0%	99.1%	99.0%
High Altitude @ Main Deploy	99%	x <=6000	m	99.8%	99.8%	99.7%	99.6%
Altitude @ Lander Release	1%	x >800	m	100%	100%	100%	100%
Down Atm. Rel. Velocity @ Lander Release	99%	x <2.9	m/s	100%	100%	100%	99.7%
Total Descent Time from atm interface	99%	x <150	min	100%	100%	100%	99.7%

EDL Performance Margin Evaluation



The purpose is to characterize margin to evaluate and assess risk areas

Number of standard deviations from requirement violation

Requirement (Max vs 99%-tile vs 1%-tile)

99%-tile or Max

Metric distribution (rotated and mirrored)

1%-tile or Min

Current Best Estimate (CBE)

Maximum Possible Value (MPV)

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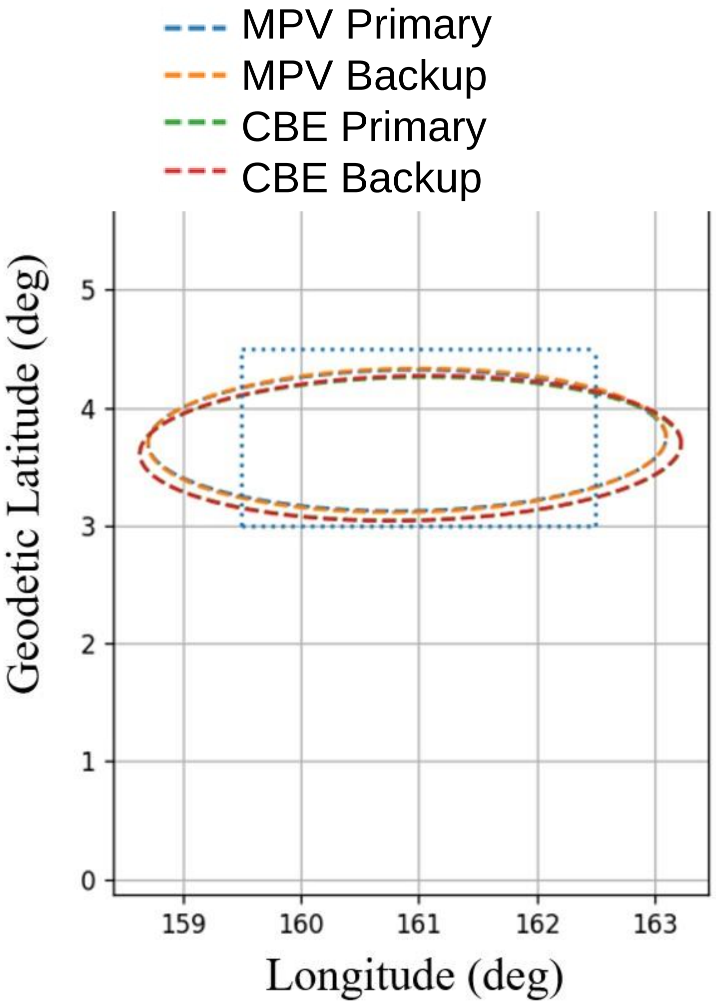
Lander Separation Performance

- Requirement:
  - The Ground System shall be designed such that 95% of the lander separation points are within a box on Titan's surface defined by: 3.0 N < latitude < 4.5 N, 159.5 E < longitude < 162.5 E.
- All four baseline scenarios meet this requirement

Scenario	% Lander Separation Pts
MPV Primary	96.3
MPV Backup	96.2
CBE Primary	95.2
CBE Backup	95.3



Conclusions and Future Work

- Dragonfly is a unique mission which presents numerous technical challenges, such dynamic stability
- Successfully folded in several model update since PDR to address various challenges such as the dynamic stability of the vehicle
- Current design meets all EDL trajectory requirements
  - Completed and assessed with Monte Carlo Analysis, Margin Characterization, Sensitivities, Lander Separation Performance

Future Work

- There is an ongoing effort to develop, refine, and update subsystem models with data collected from ongoing test campaigns
- The goal is to increase the fidelity of the simulation for risk assessment and characterize the entry and descent dynamics to inform development of the Dragonfly design