ASPIRE2

Advanced Supersonic Parachute Inflation Research Experiment 2 (ASPIRE2) Flight Mechanics and Parachute Performance

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Motivation

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- Advanced Supersonic Parachute Inflation Research Experiment 2 (ASPIRE2) builds off the successes of its predecessor program, ASPIRE
  - Three sounding rocket flights in 2017 and 2018 to qualify the 21.5m Mars2020 supersonic parachute (deployed at Mach 1.85)
- Sample Retrieval Lander (SRL) segment of Mars Sample Return (MSR) campaign is expected to be much heavier than the Mars2020 mission
  - Larger parachute and deployment load testing is needed (ASPIRE2)!
- The ASPIRE2 flight currently on hold, but current ASPIRE2 plans seek to test a 24m disk-gap band (DGB) parachute with a max inflation load limit of 140 klbf deployed at Mach 2.1 or higher
- This work involves developing a 6DOF flight mechanics simulation to support mission requirements verification for ASPIRE2 as of mid-2024

Outline

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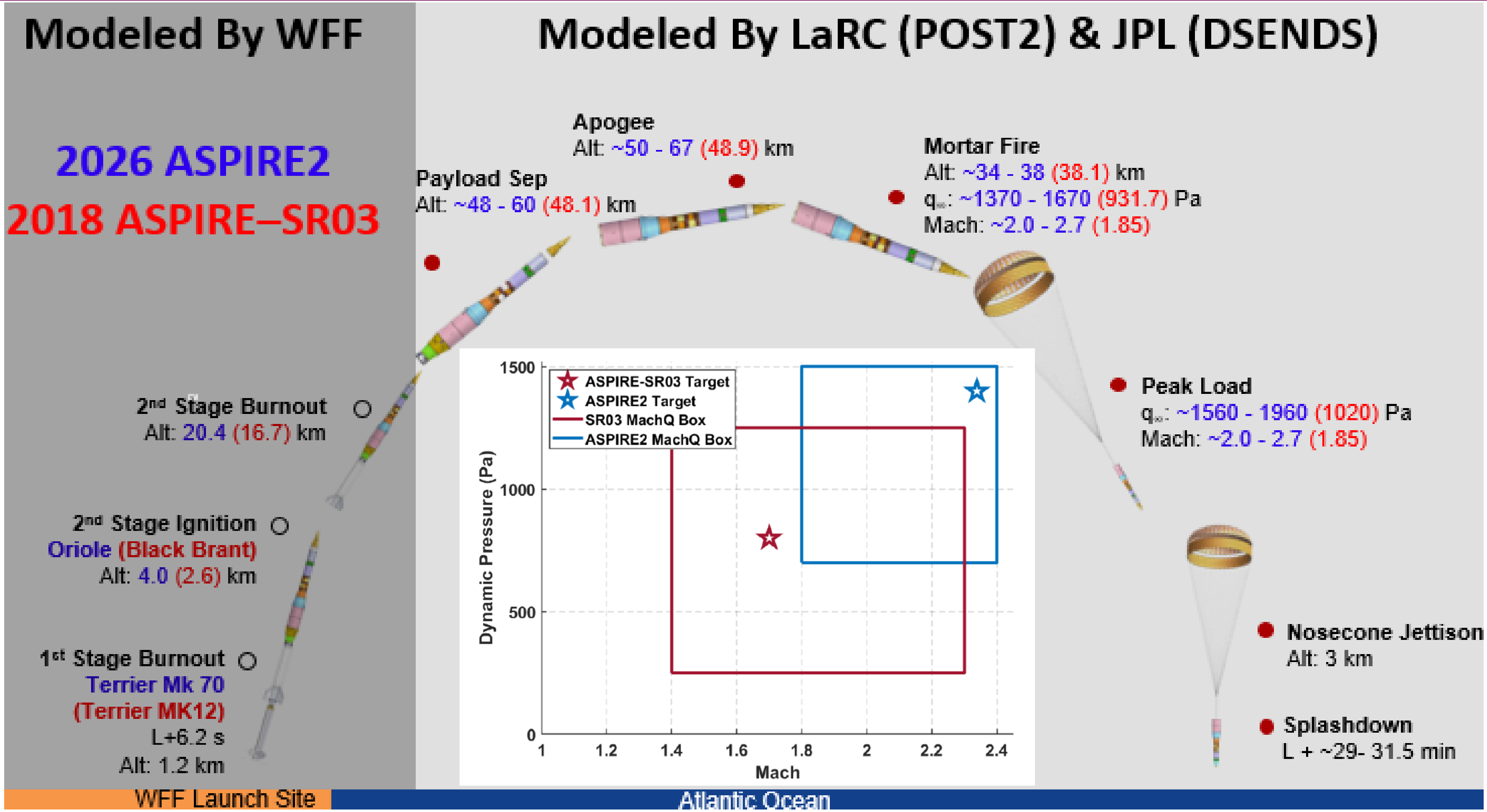
- Mission Overview
- Modeling Overview
  - Atmospheric model
  - Guidance, navigation and control model
  - Parachute model
- Parachute and Flight Mechanics Results
- Summary/Future Work

ASPIRE2 Overview

- Sub-orbital flight launching from Wallops Flight Facility (WFF)
- Payload separation to splashdown modeled by LaRC using Program to Optimize Simulated Trajectories 2 (POST2)
- Higher apogee, dynamic pressure, and Mach target (1400 Pa, Mach 2.3)



Concept of Operations (CONOPs) relative to ASPIRE-SR03

LaRC – Langley Research Center
DSENDS – Dynamics Simulator for Entry, Descent, and Surface Landing

***Disclaimer – Launch date/CONOPs based work as of mid-2024 prior to NASA-led re-architecture studies. Development subject to change**

Flight Mechanics Modeling

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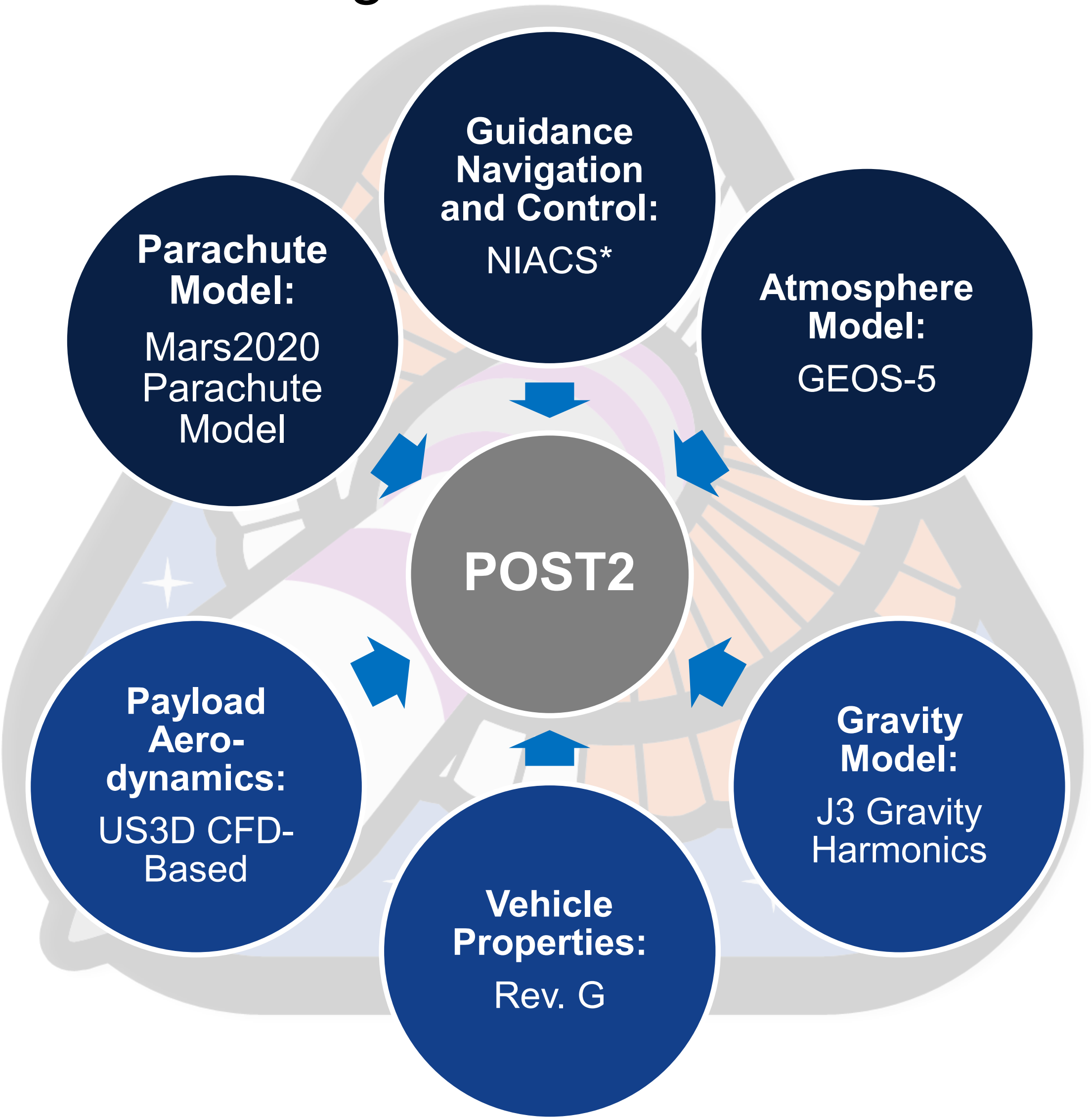
POST2 Flight Mechanics Simulation

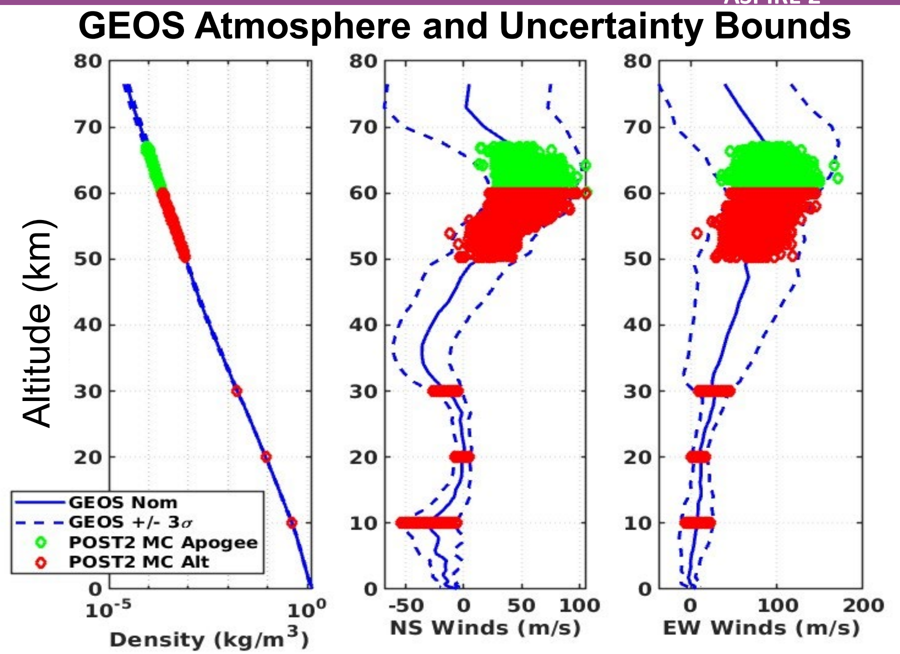


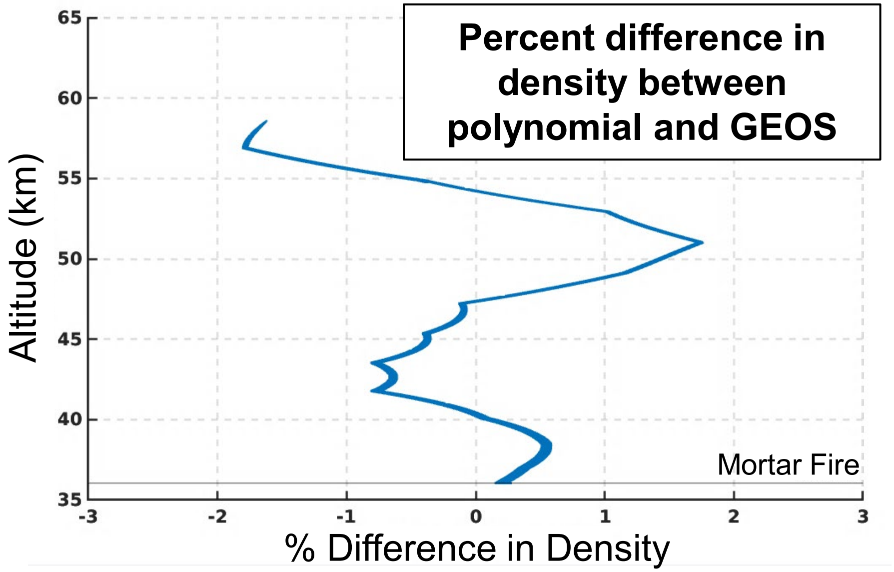
- POST2 used for 6DOF flight mechanics modeling and performance assessment
- NSROC Inertial Attitude Control System (NIACS) maintains attitude prior to mortar fire via cold-gas thrusters
- Goddard Earth Observing System (GEOS-5) atmospheric data and uncertainties estimate day of flight atmosphere
- Parachute Model upgraded to Mars2020 model

*NSROC: NASA Sounding Rocket Operations Contract

GEOS Atmosphere/NIACS

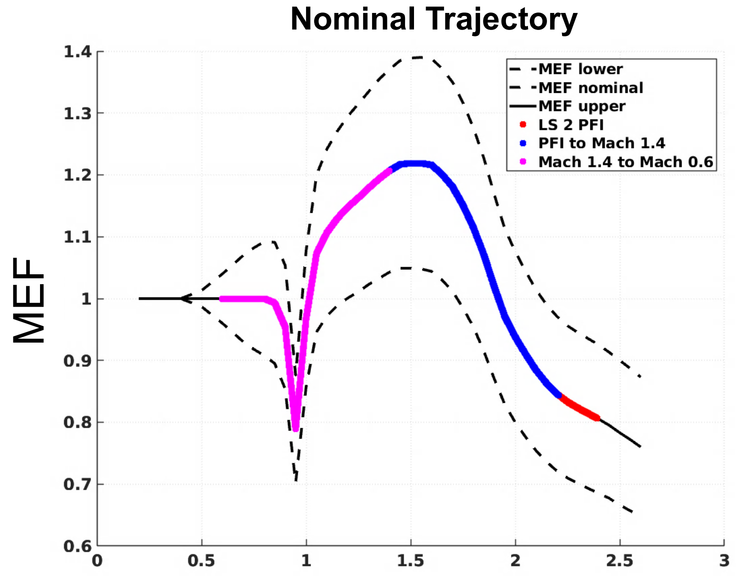
- To emulate day of launch operations, the atmospheric profile is generated from GEOS-5 forecast data for a specified day within the same month as expected launch
  - Note that Earth Global Reference Atmospheric Model (EarthGRAM) will be used for range safety analysis prior to launch
- A 6th order polynomial fit of the GEOS atmosphere is generated for the NIACS flight software to estimate atmospheric properties
  - Computationally efficient as compared to table look up
  - Percent difference with GEOS within ±2% at all altitudes
- NIACS triggers parachute mortar fire upon 4 consecutive dynamic pressure estimates at or above target value

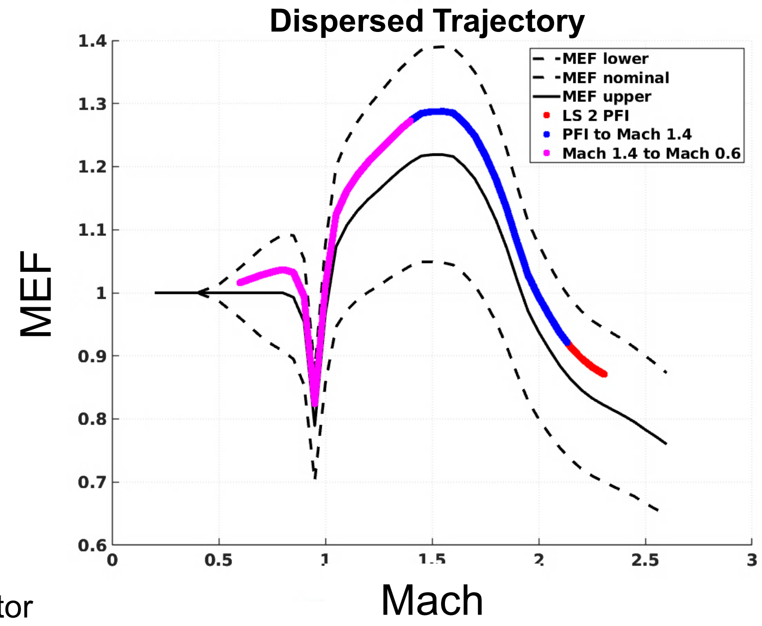




Mars2020 Parachute Model

- Low-density supersonic decelerator (LDSD) flight tests uncovered gaps in parachute testing methodology, leading to more sophisticated model and testing process
- This Mars2020 parachute model has replaced the ASPIRE-era LDSD model in the ASPIRE2 simulation
- Behavior-based model
  - No parachute bag is simulated. Time from mortar fire to line stretch computed directly
  - SRL/ASPIRE2 introduce an “initial area ratio” parameter to match expected vehicle behavior over specific physics
- At line stretch, parachute is spawned as a single, rigid body behind primary vehicle at dispersed cone/clock angles
  - Initial angles informed from previous ASPIRE flights and engineering judgement





*MEF – Mach Efficiency Factor

Parachute Model – Initial Area Ratio

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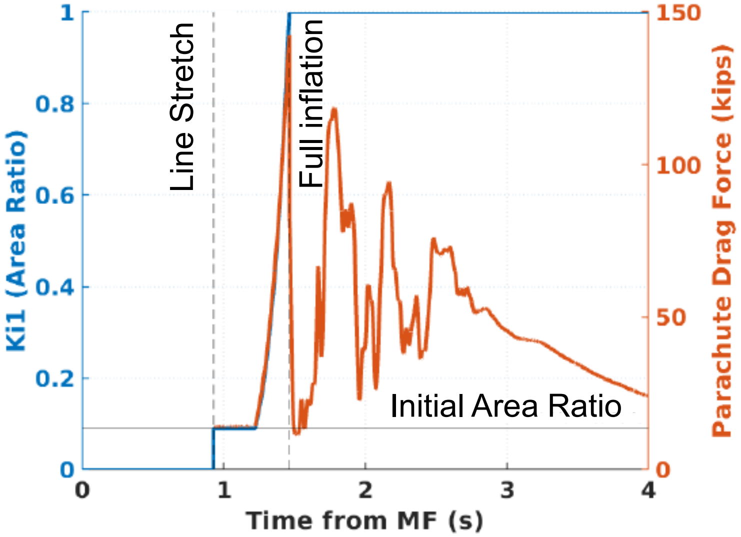
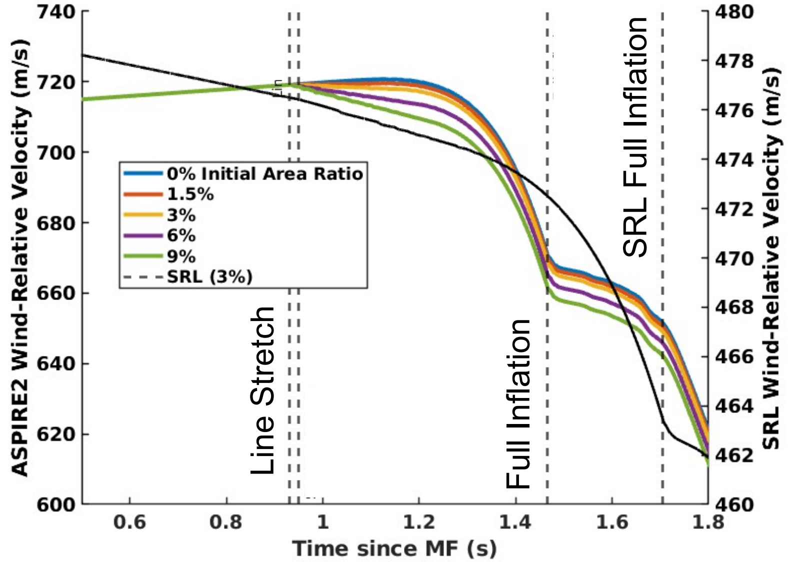
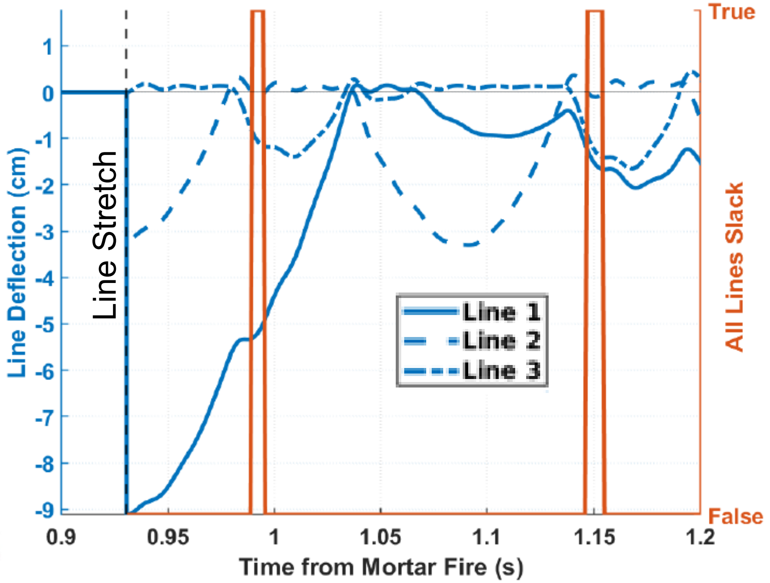
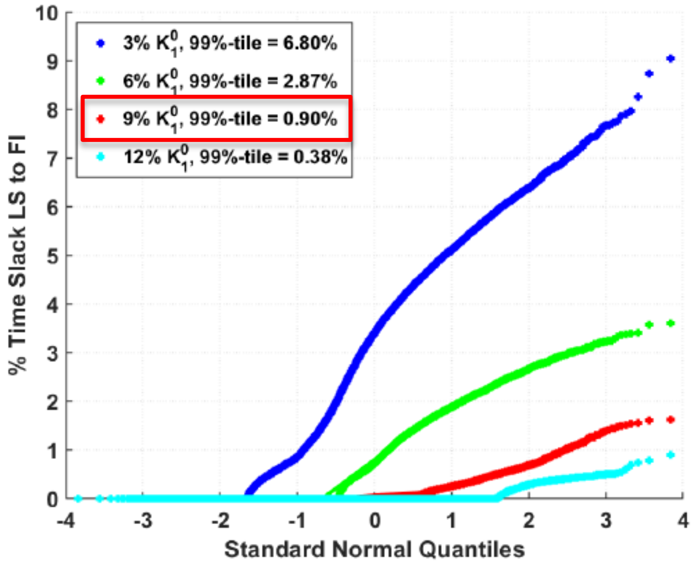
- Initial parachute area ratio is a tuning parameter to ensure the range between parachute and primary vehicle does not decrease from Line Stretch (LS) to Full Inflation (FI)
  - Bridle lines should not all go slack
- **How to tune this parameter for ASPIRE2?**
- Comparing wind-relative velocity:
  - SRL is decelerating whereas ASPIRE2 nosecone is accelerating (higher ballistic coeff.)
- 9% initial area ratio chosen:
  - Matches SRL deceleration at LS
  - Reduces 99%-tile full-slack time (LS->FI) to < 1%

Bridle Lines (x3)









Parachute Performance Results

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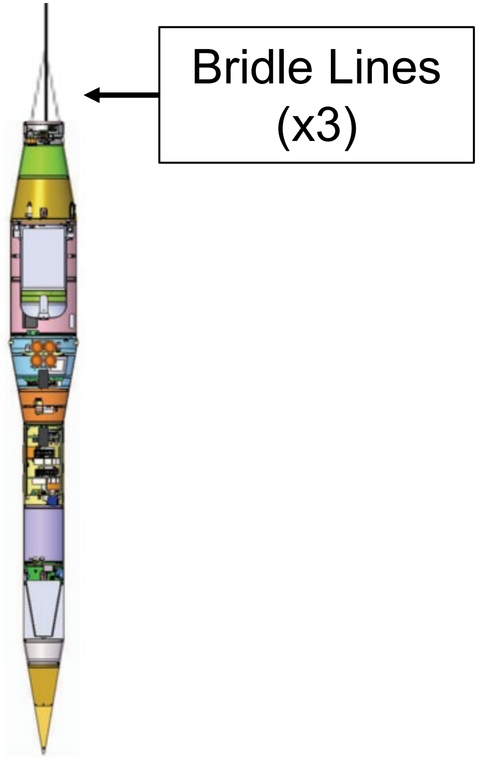
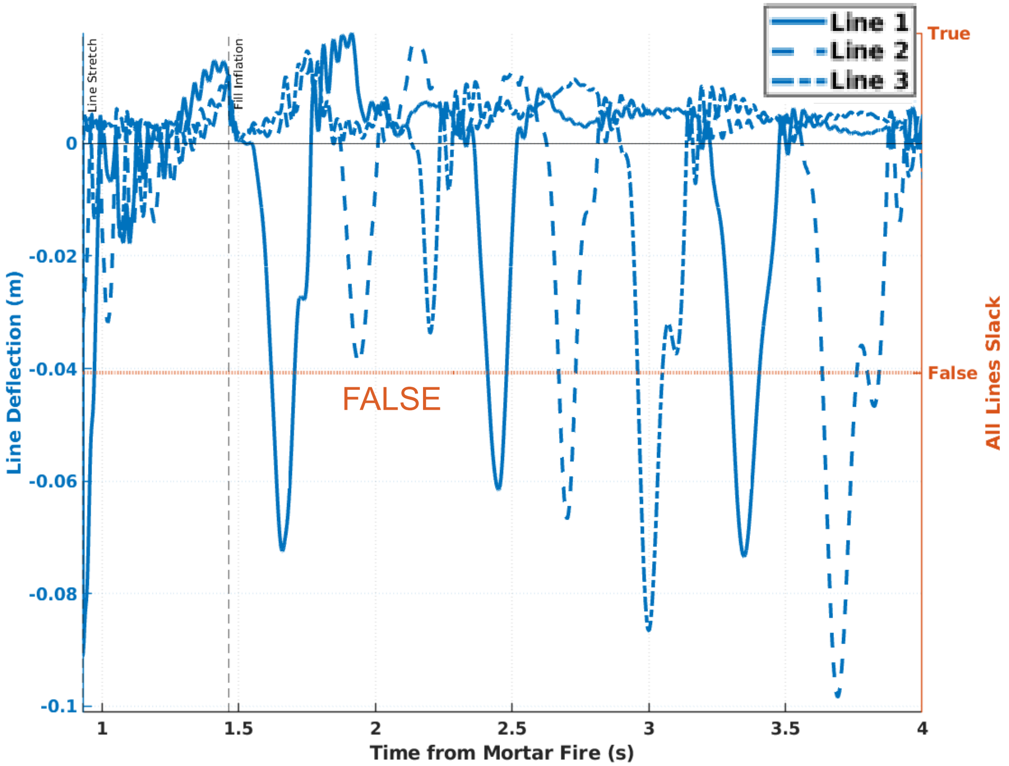
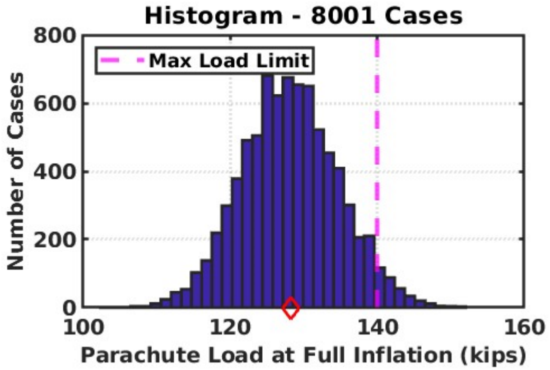
- Setting initial area ratio to 9% results in tension applied to all bridle lines throughout inflation
- Peak parachute load at full inflation shows 140 klbf limit at 96.2 %-tile
  - Mission is still in the design process so nominal load and max limit are subject to change
  - Mission is still meeting goal of testing parachute inflation at increased load limit





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Statistics for
Parachute Load at Full Inflation (kips):
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Nominal       = 128.2947
Mean          = 128.1189
1-Sigma       = 6.5537
Minimum       = 102.2875
01.000 %-tile = 113.0395
50.000 %-tile = 128.0472
97.725 %-tile = 141.547
99.000 %-tile = 143.6853
Maximum       = 152.0249
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Flight Mechanics Performance

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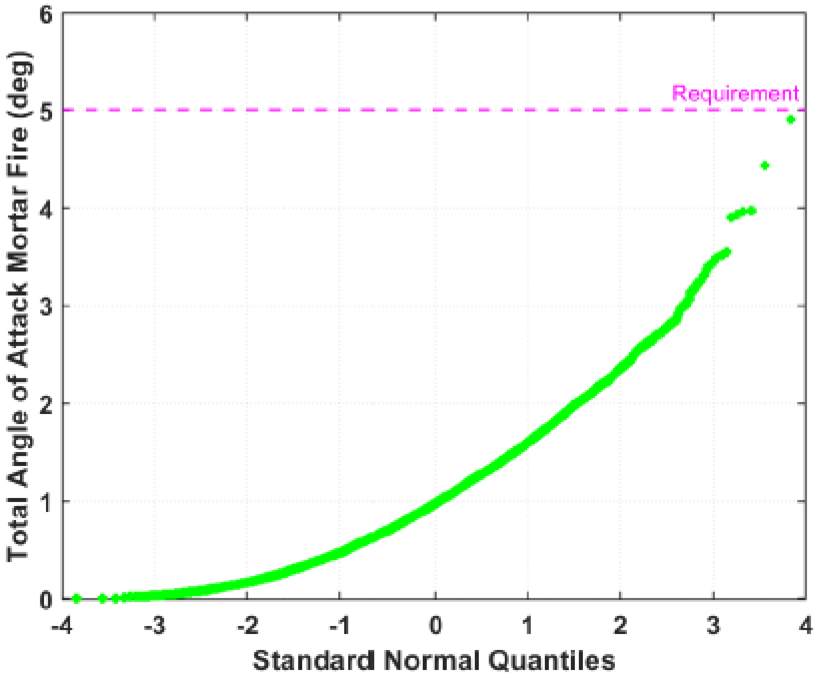
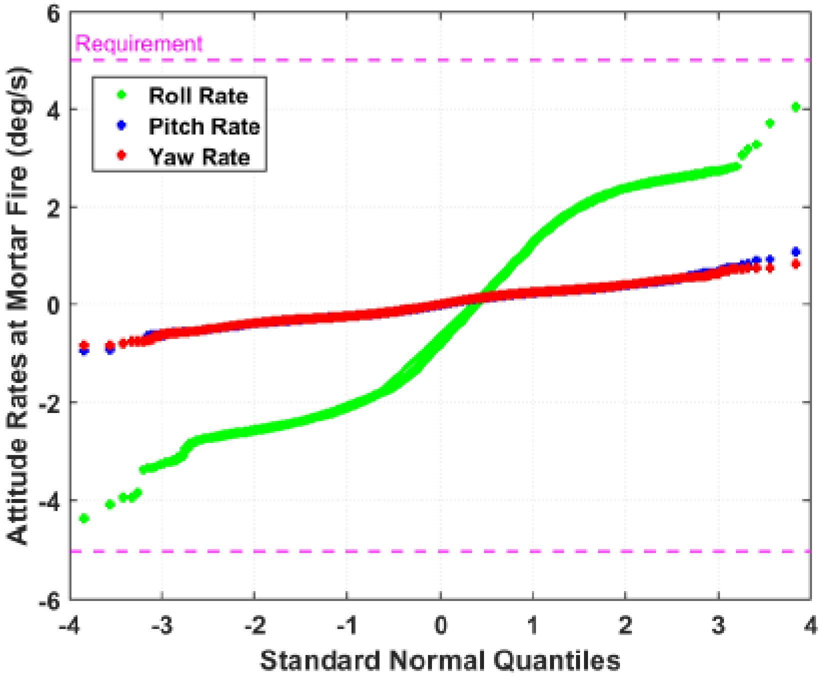
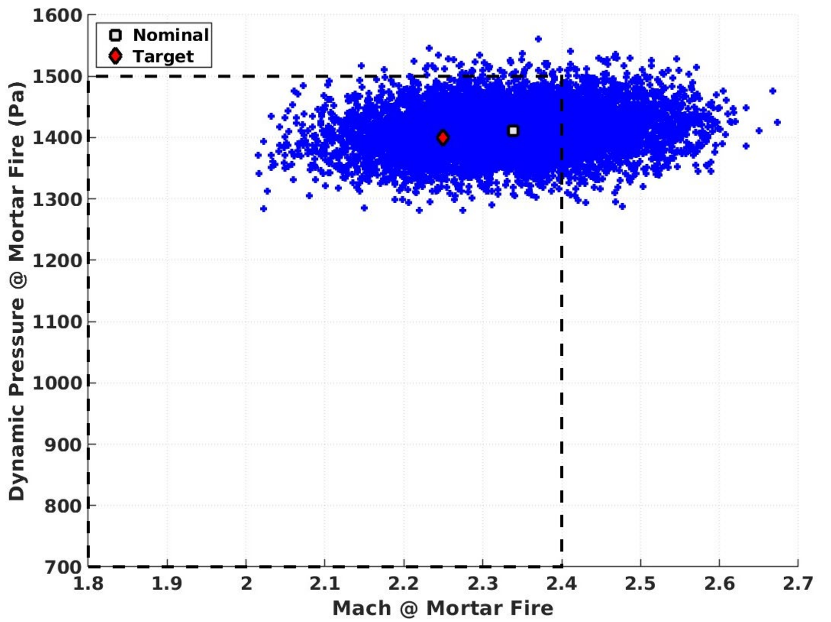
- Total angle of attack and attitude rates at mortar fire within 5°, ±5 deg/s mission requirements for all 8001 Monte Carlo cases
- Dynamic pressure and Mach target is close to mission target. Monte Carlo data envelops target

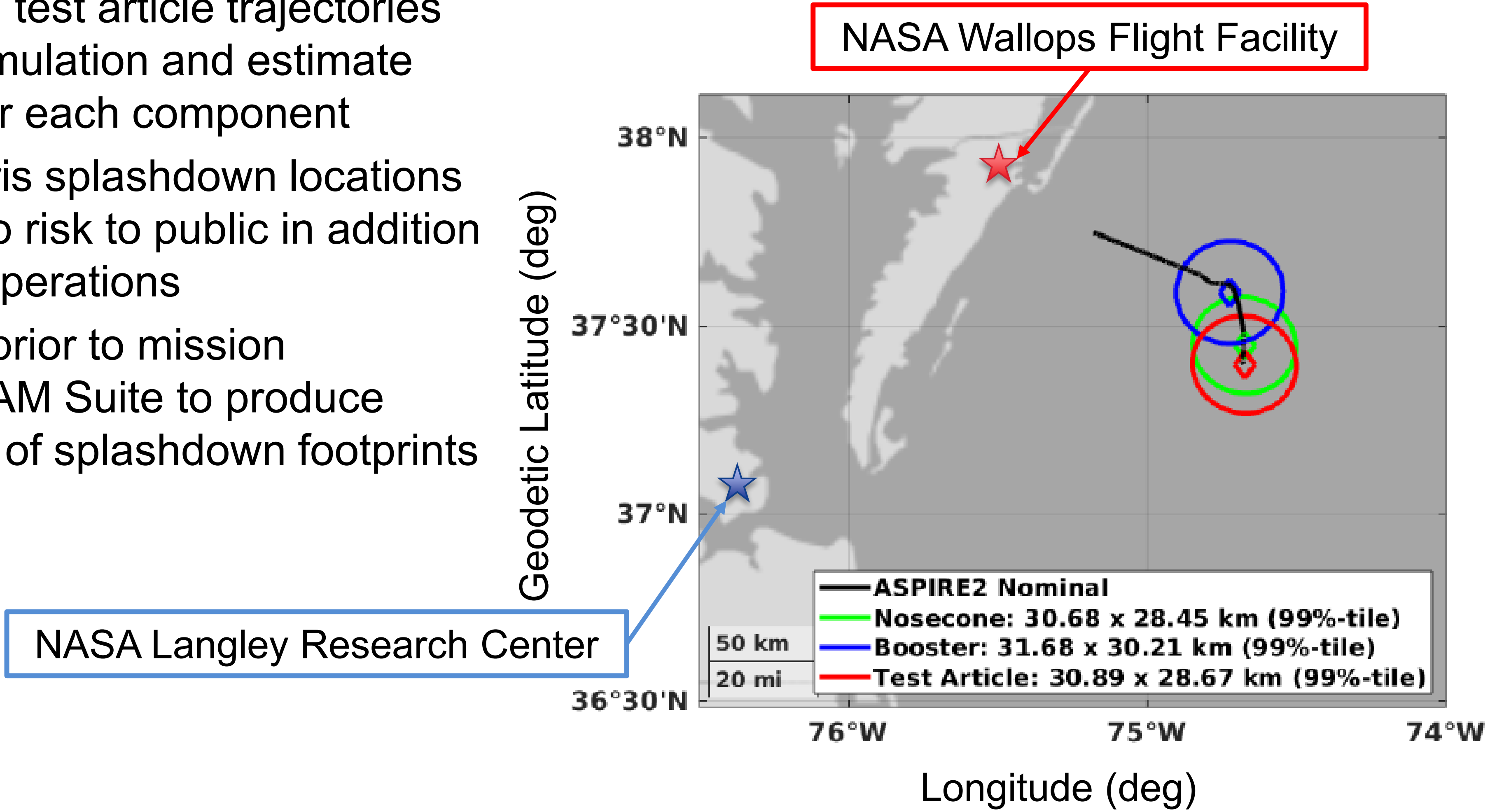






Range Safety Analysis

- Leverage POST2 multi-body capabilities to track booster, nosecone, and test article trajectories in each Monte Carlo simulation and estimate splashdown footprint for each component
- Estimating vehicle debris splashdown locations is useful for ensuring no risk to public in addition to test article retrieval operations
- Range safety analysis prior to mission operations will use GRAM Suite to produce conservative estimates of splashdown footprints



Summary/Future Work

- ASPIRE2 seeks to qualify 24m disk-gap band (DGB) supersonic parachute deploying above Mach 2.1 for the Sample Retrieval Lander (SRL) entry vehicle
- This work presented the 6DOF flight mechanics simulation methodology using POST2
- GEOS atmospheric data is simplified into a 6^{th} order polynomial to support NIACS mortar fire trigger
- Mars2020 parachute model was implemented, and sensitivity analysis used to select a parachute initial area ratio
- Initial results showing vehicle is meeting angle and attitude requirements at mortar fire event in addition to being capable of enveloping qualification target
- Potential Forward Work (assuming continuation of ASPIRE2)
  - Solidify Mach-Q target and parachute load limit requirements
  - Perform trade studies on center of gravity location to inform future revision mass property changes
  - Investigate and validate NIACS control implementation

References

QUESTIONS?

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