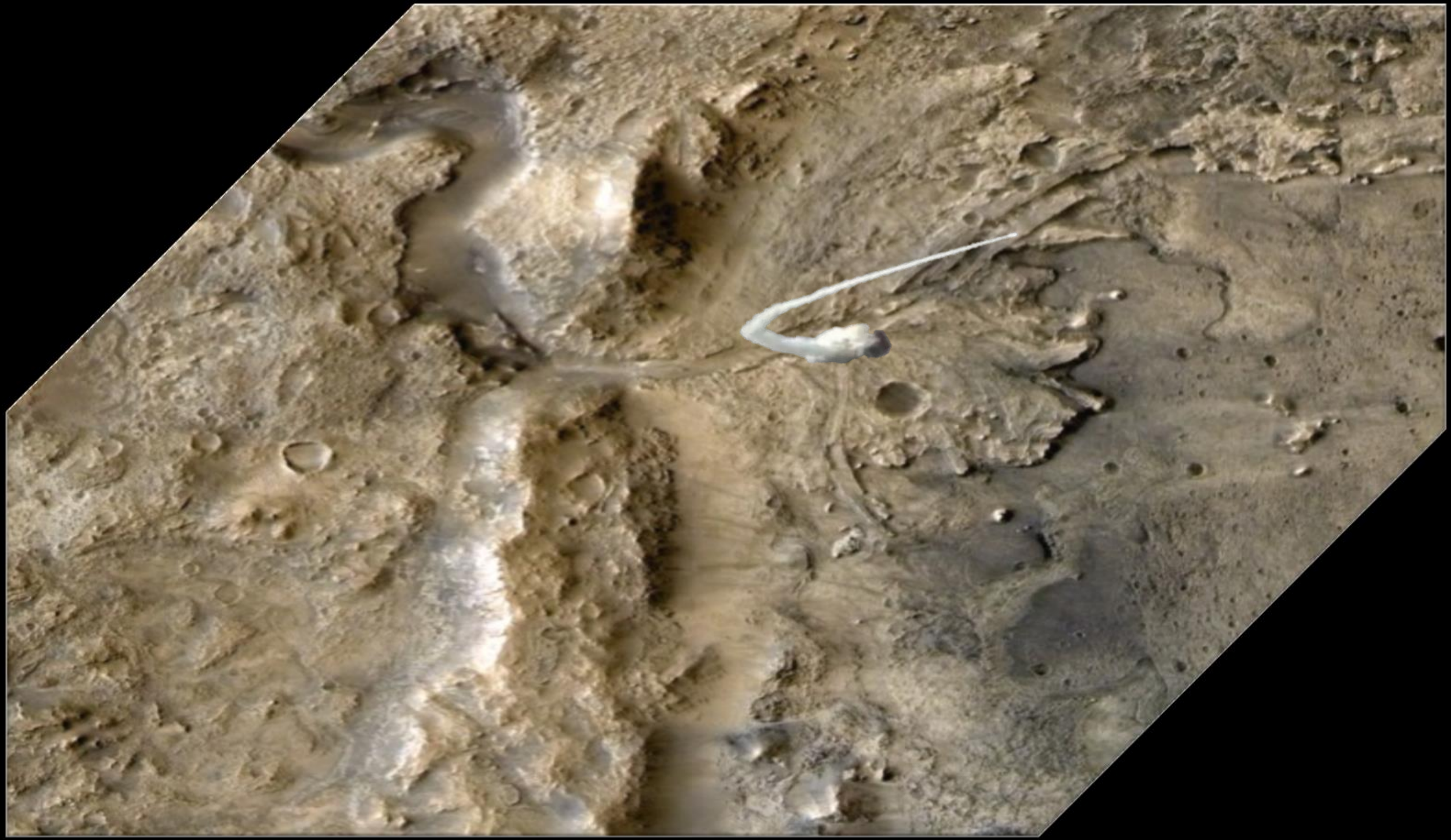
ASPIRE2

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



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Motivation

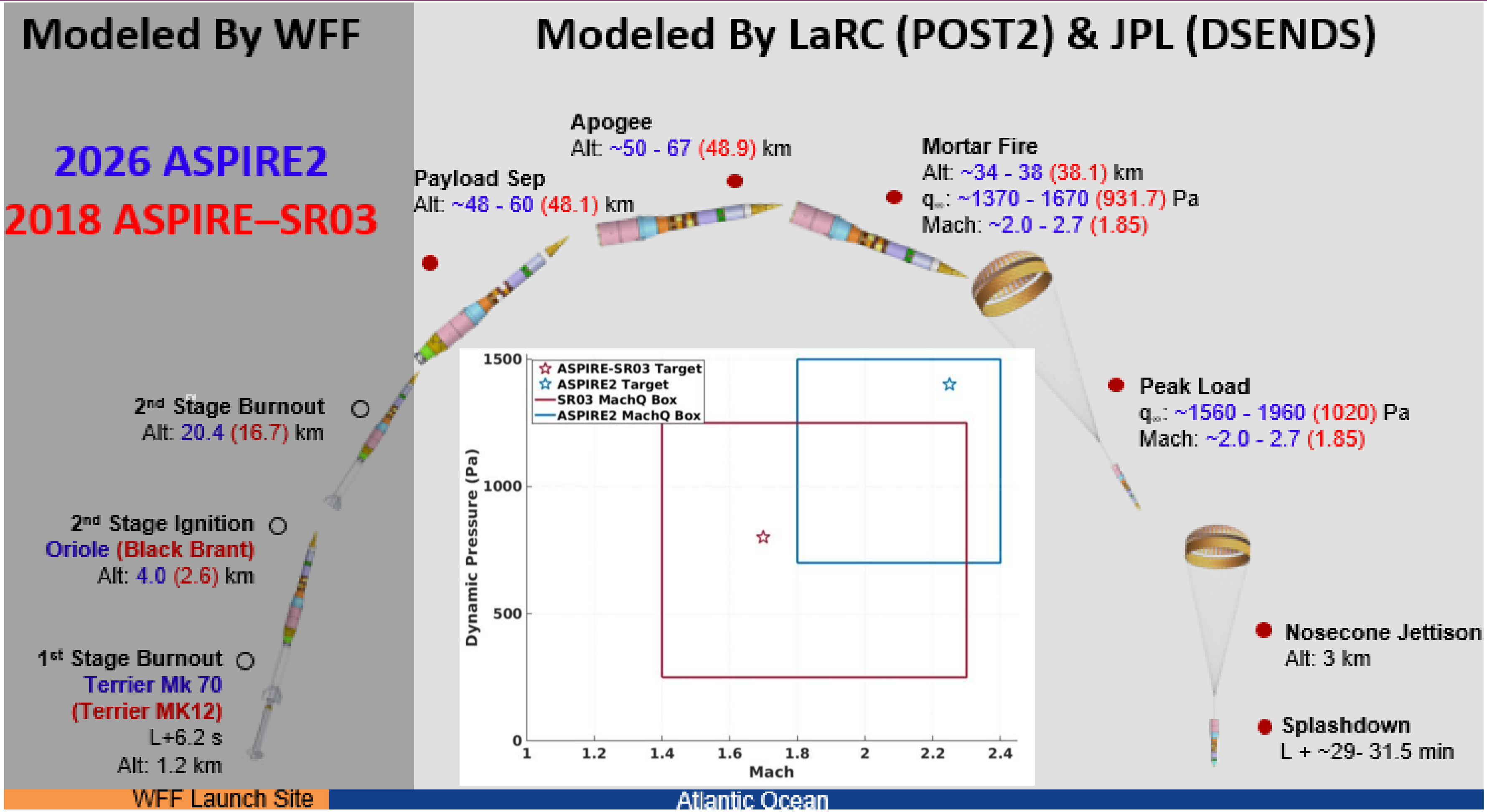
- Advanced Supersonic Parachute Inflation Research Experiment 2 (ASPIRE2) builds off the successes of its predecessor program, ASPIRE
  - Three sounding rocket flights in 2017 and 2018 [1] to qualify the 21.5m Mars2020 supersonic parachute (deployed at Mach 1.85)
- Sample Retrieval Lander (SRL) segment of Mars Sample Return (MSR) campaign is doubling entry and landed mass over Mars2020 mission
  - Larger parachute and inflation load testing is needed (ASPIRE2)!
- ASPIRE2 seeks 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 [2]
  - Goal is to structurally qualify the parachute for use on the Sample Retrieval Lander (SRL) segment of the Mars Sample Return (MSR) campaign
- This work involves developing a 6DOF flight mechanics simulation to support mission requirements verification for ASPIRE2, which is shown to meet flight mechanics requirements

Outline

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

ASPIRE2 Overview

- Sub-orbital flight launching from Wallops Flight Facility (WFF) in 2026
- 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 2.2)



Concept of Operations (CONOPs) relative to ASPIRE-SR03

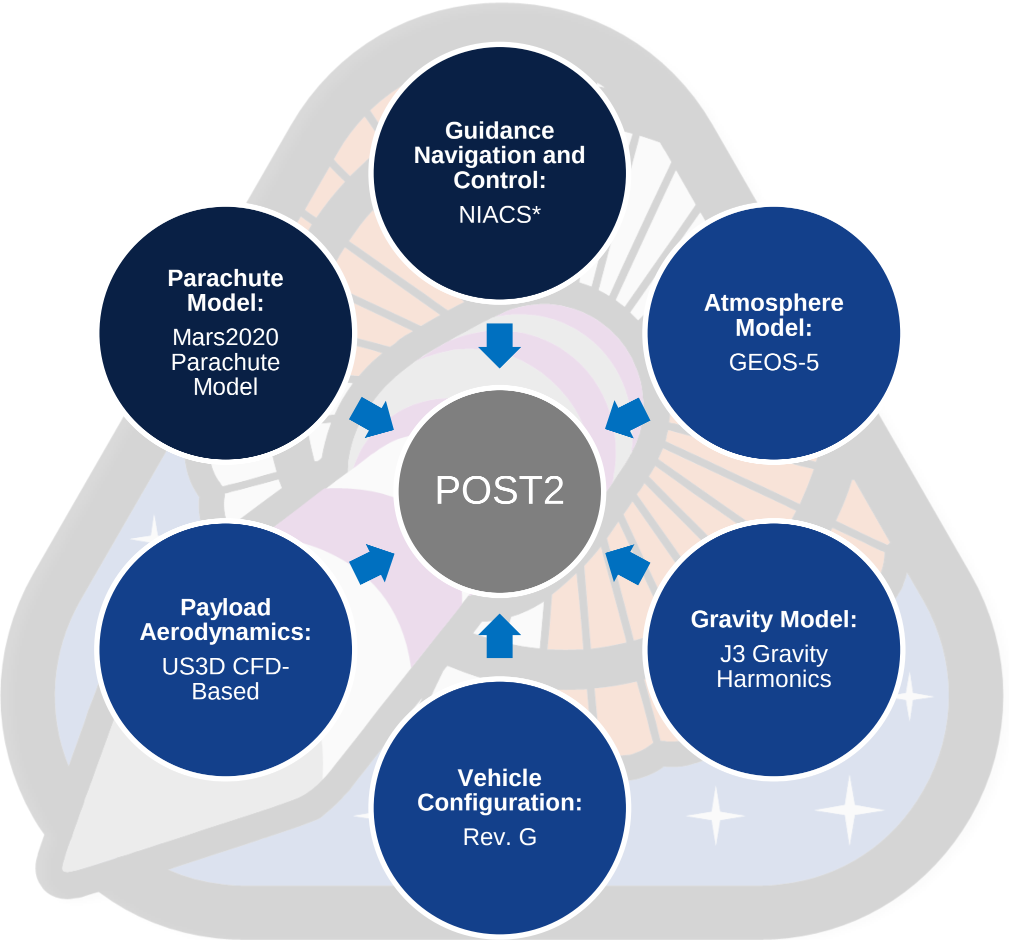
LaRC – Langley Research Center
DSENDS – Dynamics Simulator for Entry, Descent, and Surface Landing

*Disclaimer – Launch date/CONOPs subject to change

Flight Mechanics Modeling

ASPIRE 2

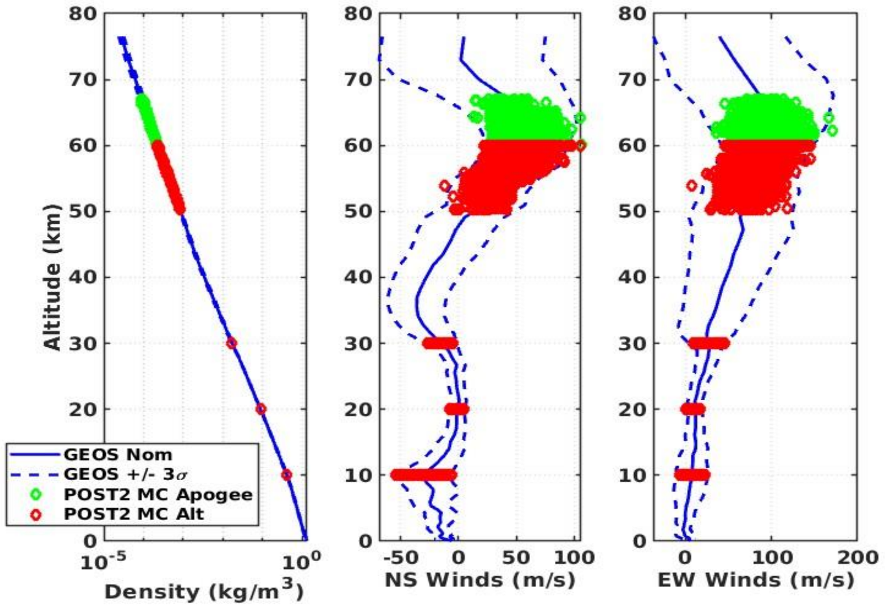
- POST2 used for 6DOF flight mechanics modeling and performance assessment
- NSROC Inertial Attitude Control System (NIACS) maintains attitude prior to mortar fire via cold-gas thrusters
- Goddard Earth Observing System (GEOS) atmospheric data and uncertainties estimate day of flight atmosphere
- Parachute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

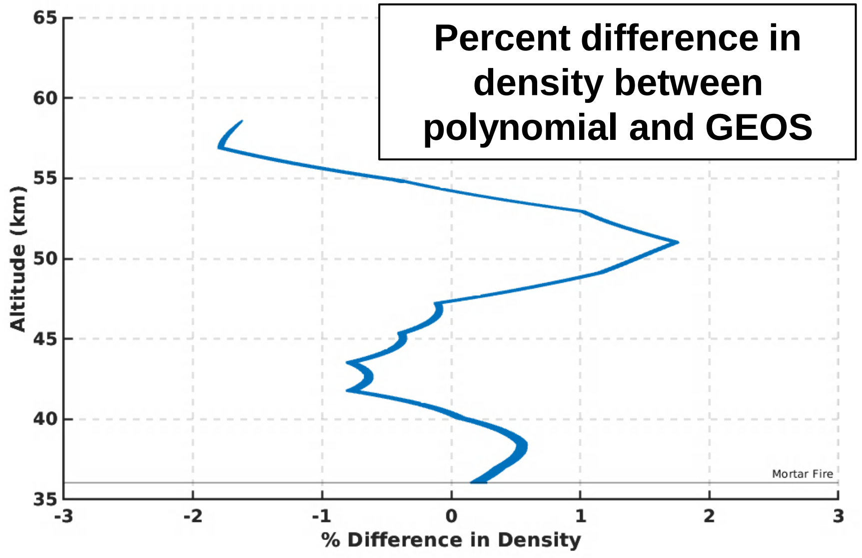


GEOS Atmosphere/NIACS

- 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

GEOS Atmosphere and Uncertainty Bounds

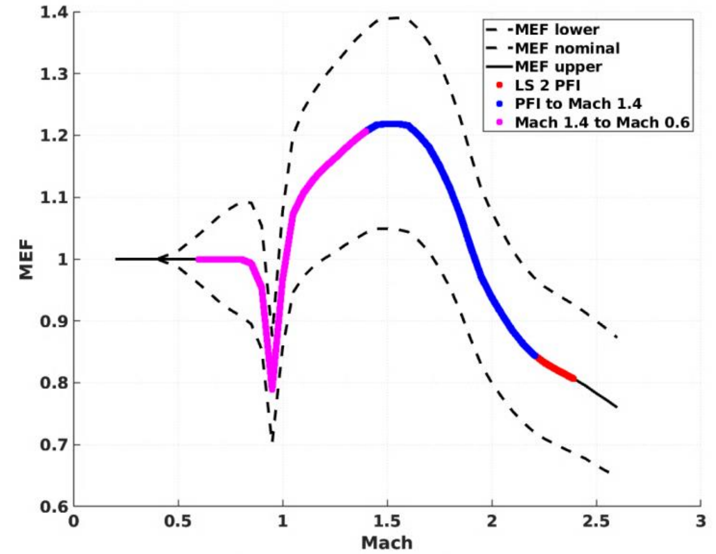




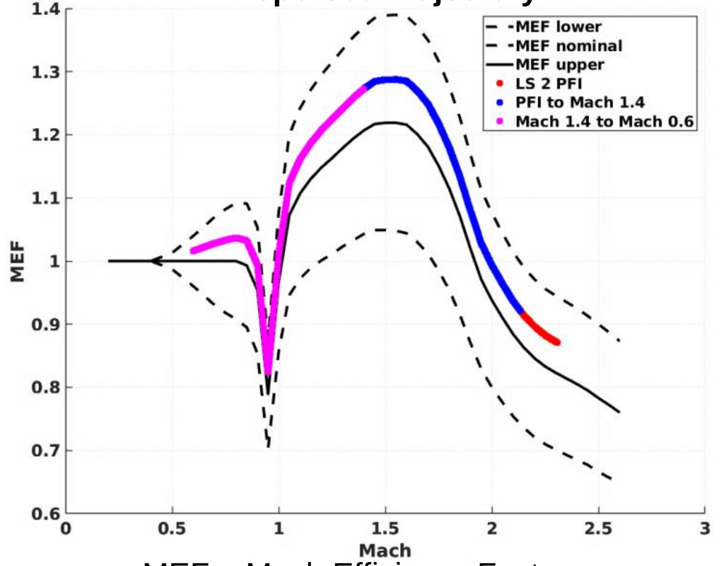
Mars2020 Parachute Model

- Low-density supersonic decelerator (LDSD) program uncovered gaps in parachute testing methodology, leading to more sophisticated model and testing process [4,5]
  - 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

Nominal Trajectory



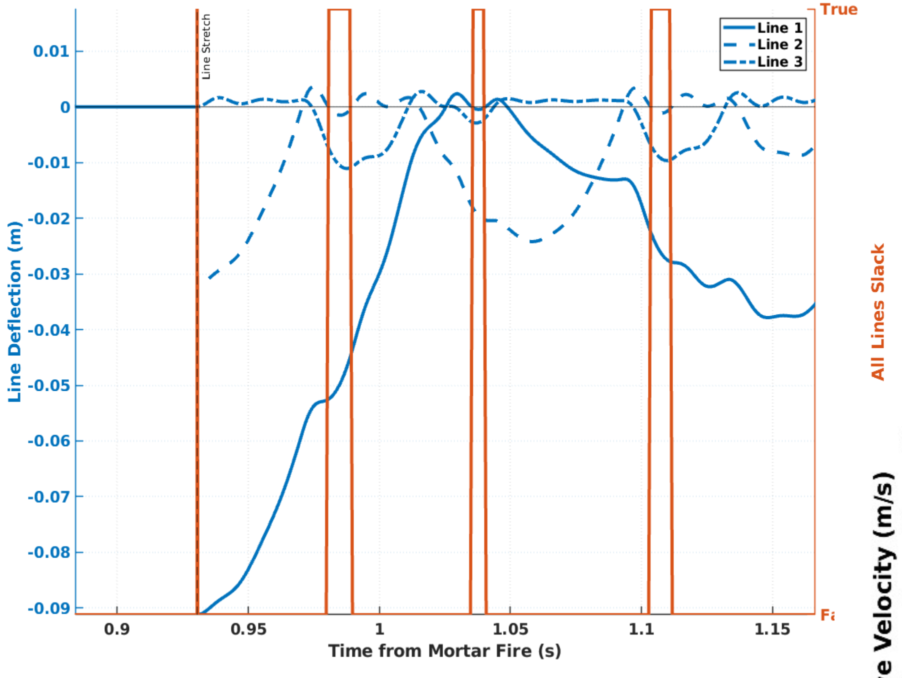
Dispersed Trajectory



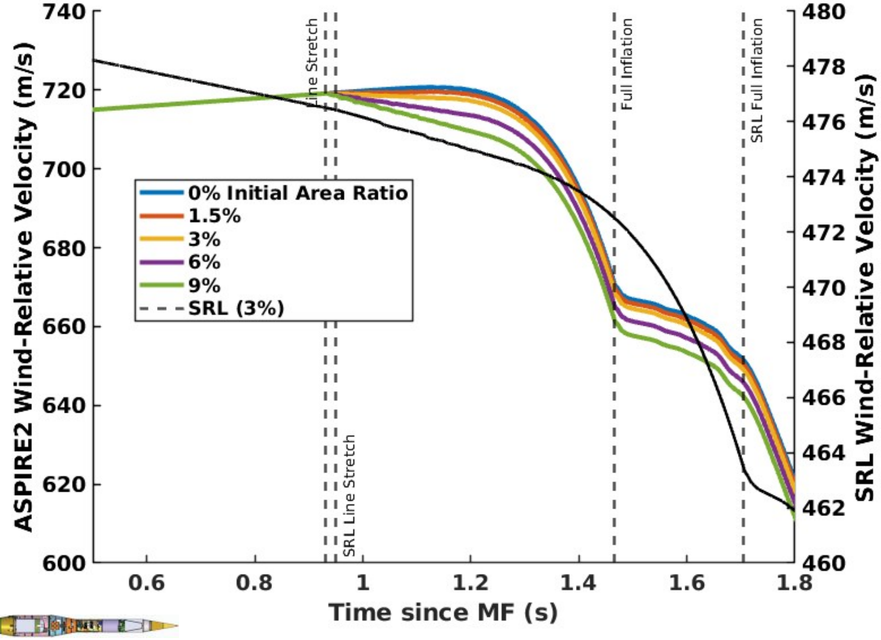
MEF – Mach Efficiency Factor

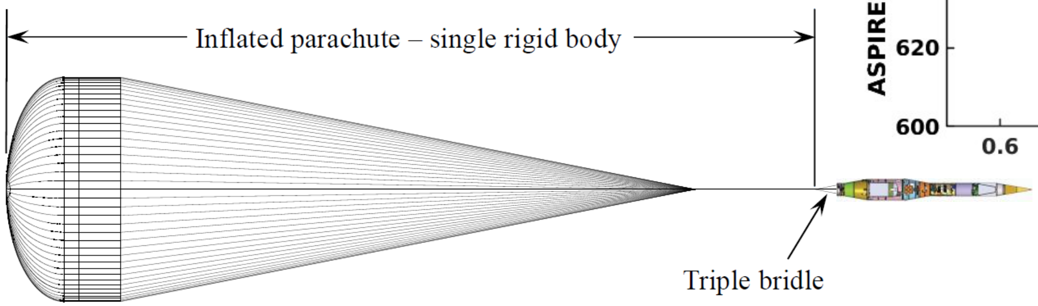
Parachute Model – Initial Area Ratio

- 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%



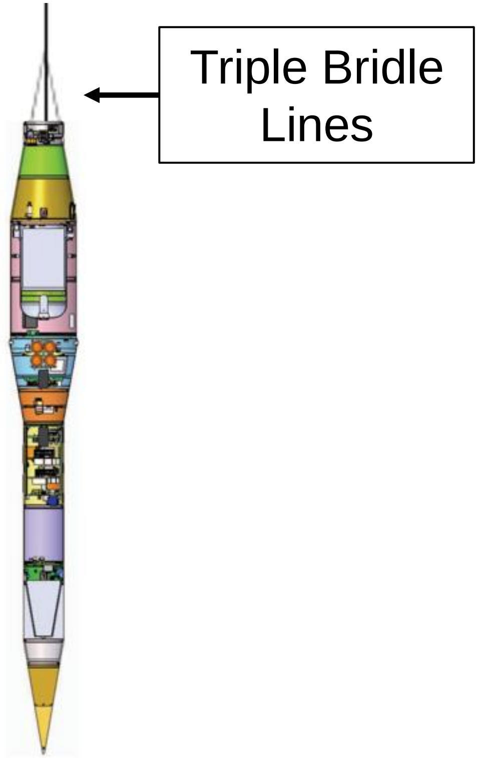
Initial Area Ratio	99%-tile, Percent time slack LS->FI
3%	6.80%
6%	2.87%
9%	0.89%
12%	0.38%

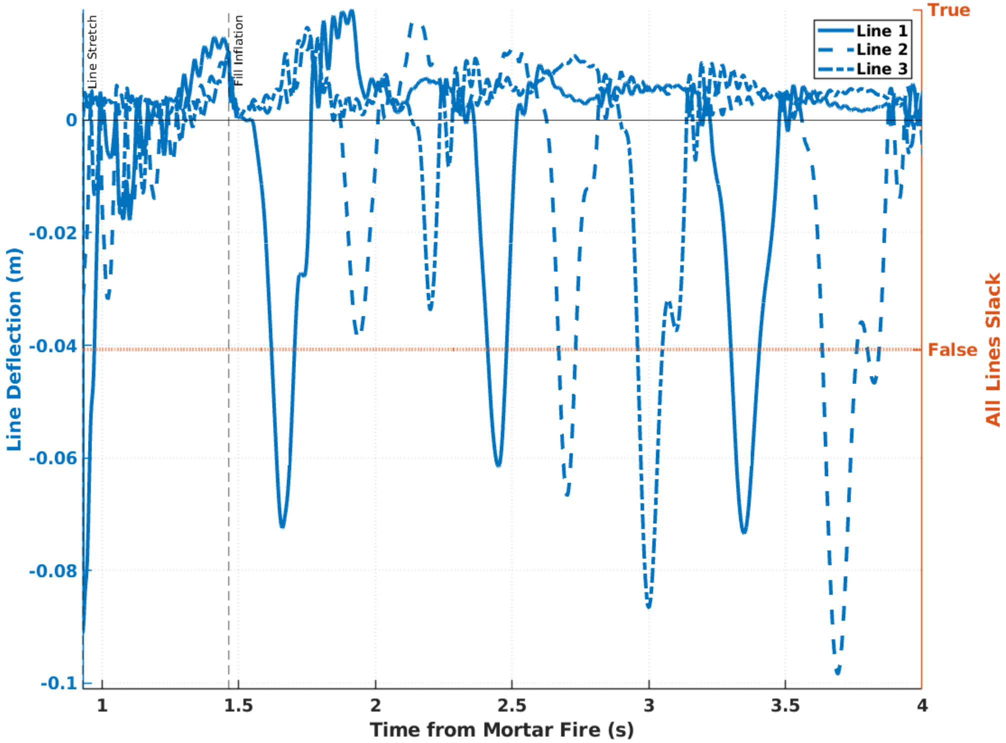


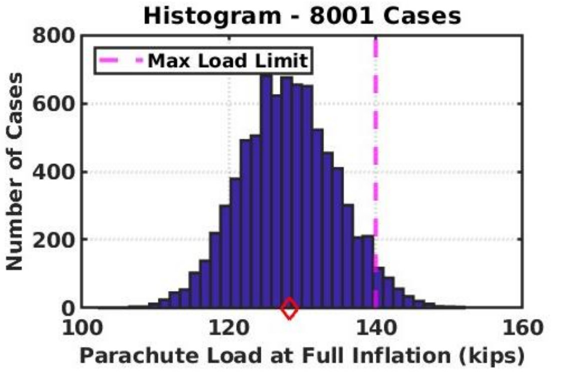


Parachute Performance Results

- 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):
----------------------------
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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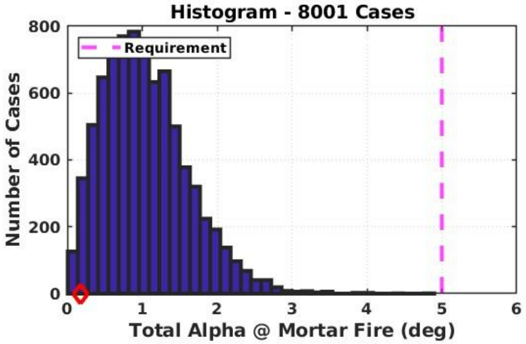
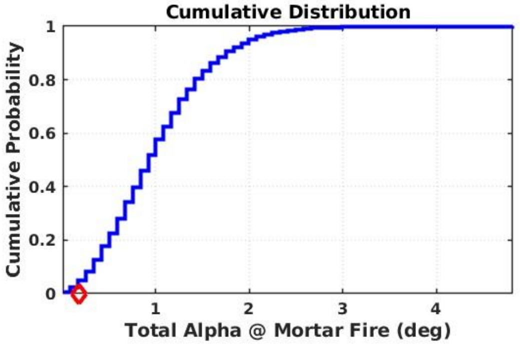
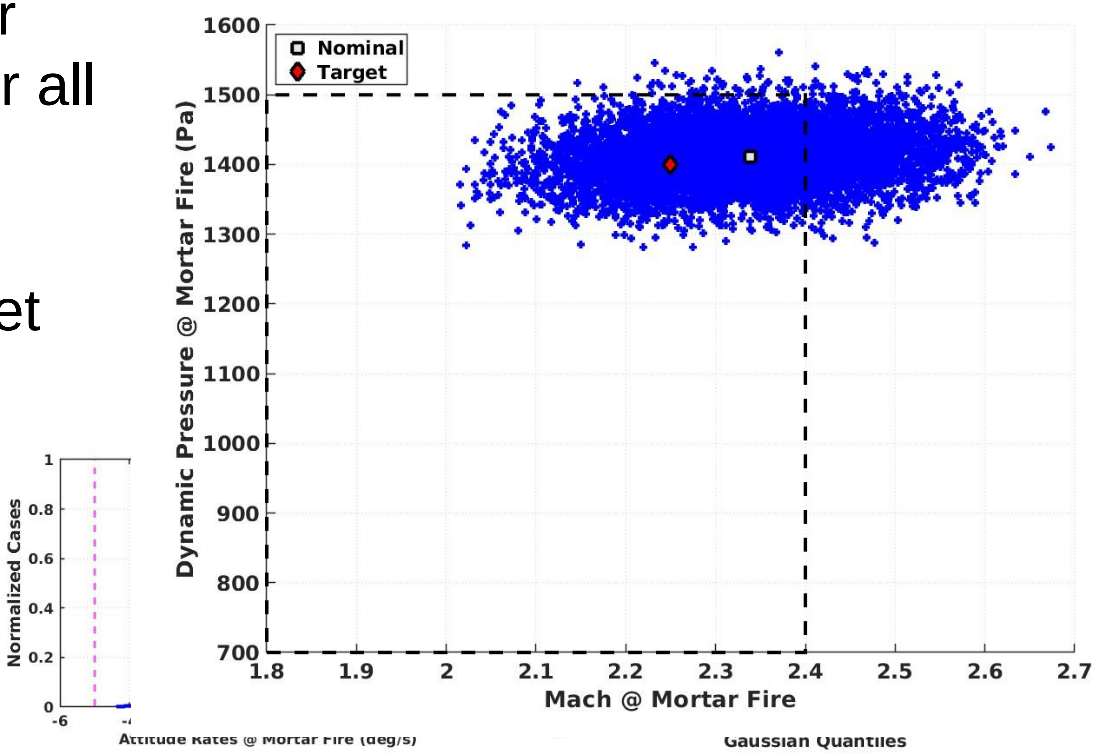
Flight Mechanics Performance

- Total angle of attack and attitude rates at mortar fire within 5º, ±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

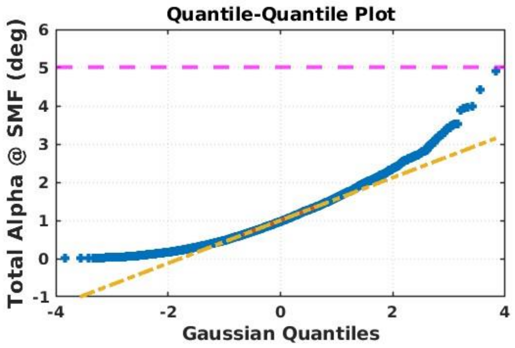






Statistics for
Total Alpha @ Mortar Fire (deg):

Nominal	= 0.17669
Mean	= 1.0444
1-Sigma	= 0.56743
Minimum	= 0.0053587
01.000 %-tile	= 0.10889
50.000 %-tile	= 0.97377
97.725 %-tile	= 2.3599
99.000 %-tile	= 2.6366
Maximum	= 4.8982



Statistics for:	Roll Rate	Pitch Rate	Yaw Rate
Nominal =	-0.8930	0.0404	0.2354
Mean =	-0.5433	-0.0031	0.0033
3-Sigma =	4.4214	0.6668	0.6688
Minimum =	-4.3654	-0.9378	-0.8264
1.00 %-tile =	-2.6614	-0.4700	-0.4599
5.00 %-tile =	-2.4405	-0.3249	-0.3177
10.00 %-tile =	-2.2668	-0.2753	-0.2761
50.00 %-tile =	-0.7786	-0.0075	0.0043
90.00 %-tile =	1.7149	0.2770	0.2784
95.00 %-tile =	2.1170	0.3213	0.3290
99.00 %-tile =	2.5193	0.4604	0.4809
Maximum =	4.0388	1.0782	0.8306
Num Cases =	8001	8001	8001

Conclusions/Future Work

- ASPIRE2 seeks to qualify 24m disk-gap band (DGB) supersonic parachute deploying above Mach 2.1 for the Sample Retreival 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
- Forward Work
  - Solidify Mach-Q target and parachute load limit requirements
  - Perform center of gravity trade studies to inform future revision mass property changes
  - Investigate and validate NIACS control implementation

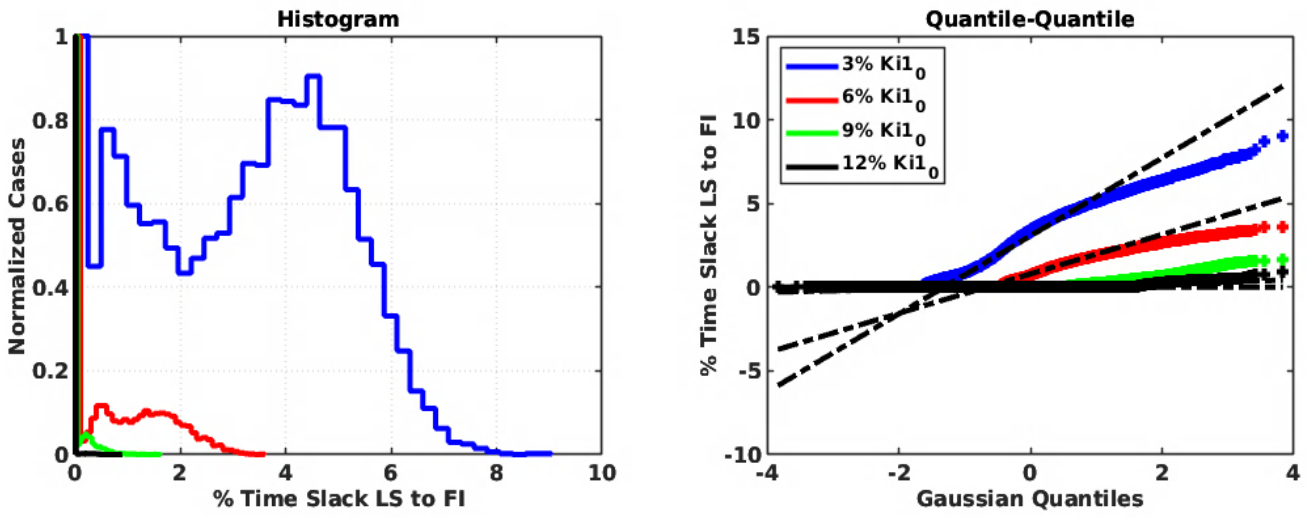
References

- [1] Dutta, S., "ASPIRE Parachute Modeling and Comparison to Post-Flight Reconstruction," AIAA Scitech 2020 Forum, 2020. https://doi.org/10.2514/6.2020-0756
- [2] O'Farrell, C., Leylek, E. A., Lobbia, M. A., and Siegel, K. J. Y., "ASPIRE2: The Mars Sample Retrieval Lander's Supersonic Parachute Test Program," 2023 IEEE Aerospace Conference, Big Sky, MT, USA, 2023, pp. 1-9, doi: 10.1109/AERO55745.2023.10115818.
- [3] Dutta, S., Karlgaard, C. D., Tynis, J. A., O'Farrell, C., Sonneveldt, B. S., Queen, E. M., Bowes, A. L., Leylek, E. A., and Ivanov, M. C., "Advanced Supersonic Parachute Inflation Research Experiment Preflight Trajectory Modeling and Postflight Reconstruction," Journal of Spacecraft and Rockets 2020 57:6, 1387-1407, doi: 10.2514/1.A34706.
- [4] Cruz, Juan R. and Way, David W. and Shidner, Jeremy D. and Davis, Jody L. and Adams, Douglas S. and Kipp, Devin M., "Reconstruction of the Mars Science Laboratory Parachute Performance," Journal of Spacecraft and Rockets, Vol. 51, No. 4, 2014. pp. 1185-1196, doi: 10.2514/1.A32816
- [5] C. L. Tanner, I. G. Clark and A. Chen, "Overview of the Mars 2020 parachute risk reduction activity," 2018 IEEE Aerospace Conference, Big Sky, MT, USA, 2018, pp. 1-11, doi: 10.1109/AERO.2018.8396717

QUESTIONS?

Backup

Bridle Line Sensitivity Study



Statistics for:	3% Ki1$_0$	6% Ki1$_0$	9% Ki1$_0$	12% Ki1$_0$
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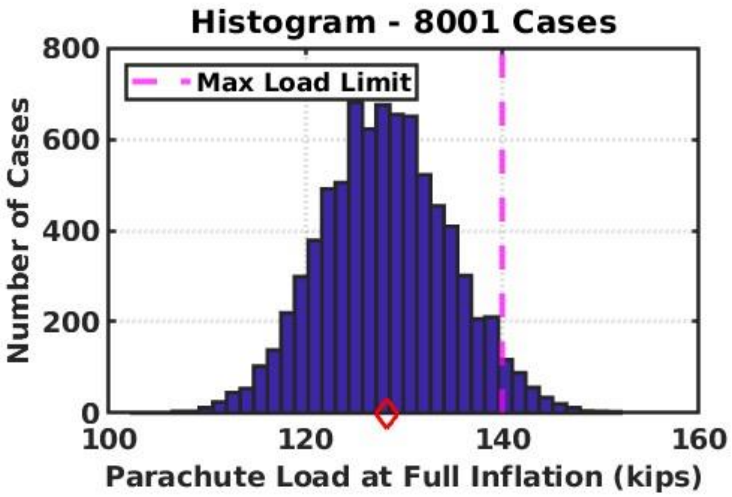
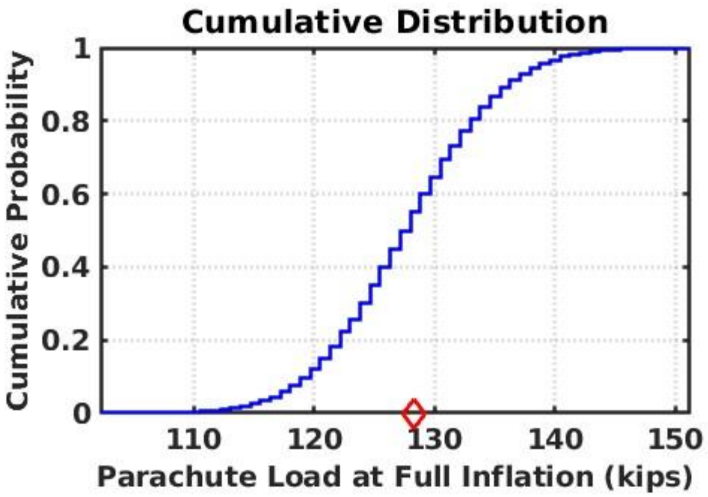
Nominal =	2.4894	0.0000	0.0000	0.0000
Mean =	3.1707	0.8966	0.0968	0.0138
3-Sigma =	5.5683	2.5528	0.5937	0.1965
Minimum =	0.0000	0.0000	0.0000	0.0000
1.00 %-tile =	0.0000	0.0000	0.0000	0.0000
5.00 %-tile =	0.0333	0.0000	0.0000	0.0000
10.00 %-tile =	0.5712	0.0000	0.0000	0.0000
50.00 %-tile =	3.3999	0.7193	0.0000	0.0000
90.00 %-tile =	5.5053	2.1148	0.3550	0.0000
95.00 %-tile =	5.9896	2.4118	0.5212	0.0672
99.00 %-tile =	6.8012	2.8689	0.8951	0.3787
Maximum =	9.0405	3.6002	1.6250	0.8919
Num Cases =	8001	8001	8001	8001



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