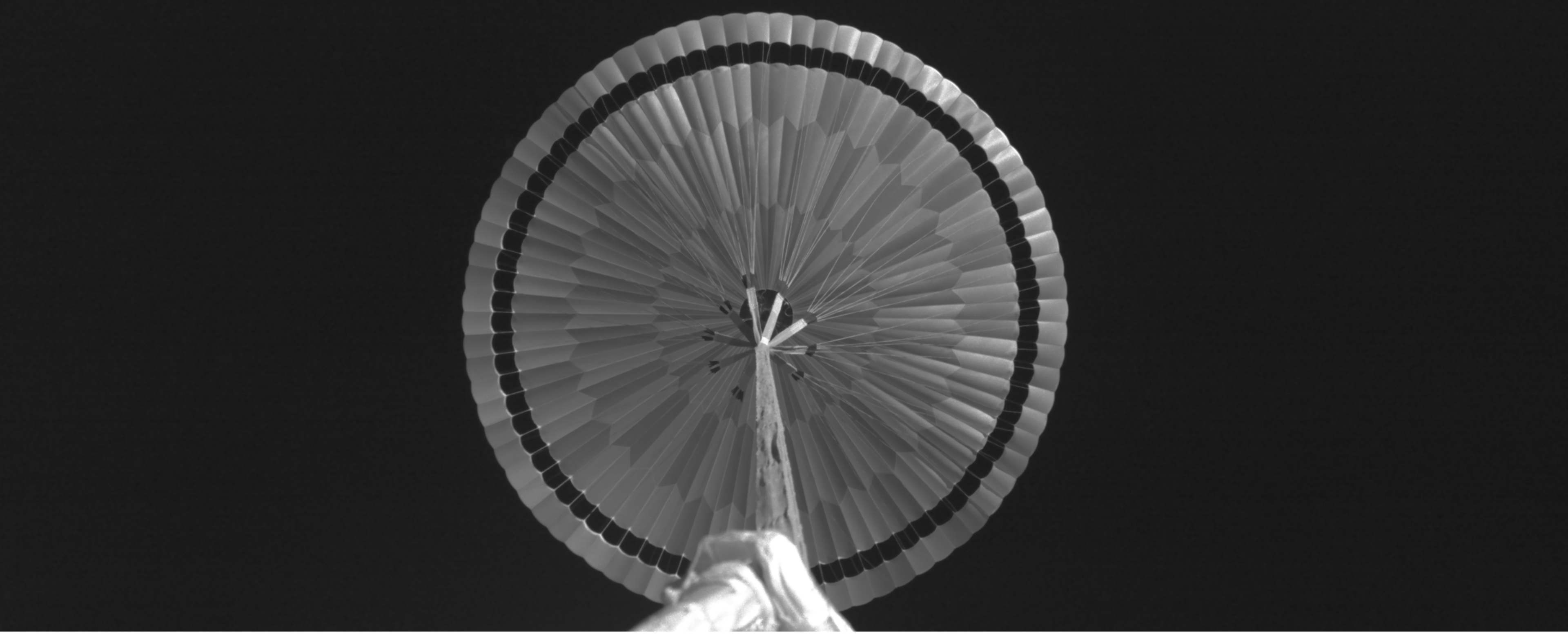


Reconstructed Disk-Gap-Band Parachute Performance During the Third ASPIRE Supersonic Flight Test

16th International Planetary Probe Workshop

July 08-12, 2019 – Oxford, UK

Chris Tanner, Clara O'Farrell, Ian Clark, Bryan Sonneveldt

Jet Propulsion Laboratory, California Institute of Technology

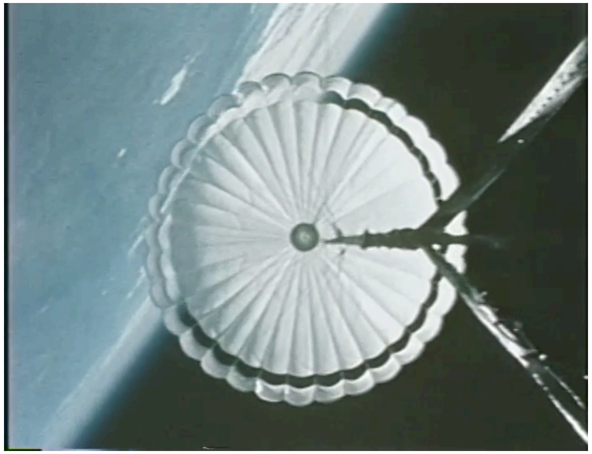
ASPIRE

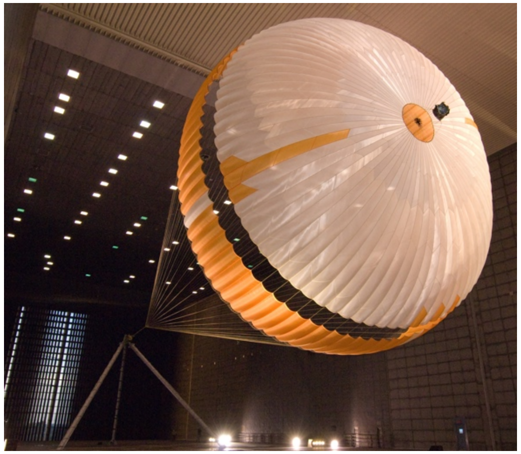
Jet Propulsion Laboratory
California Institute of Technology

Disk-Gap-Band Parachute Testing

ASPIRE

- The Disk Gap Band (DGB) parachute was developed in the 60's to perform high altitude weather experiments and in the 70's for the Viking program
  - It has been a workhorse parachute for planetary entry ever since
- Pre-Viking, supersonic DGB parachutes were launched using sounding rockets and high-altitude balloon launched vehicles to test supersonic parachutes in analogous conditions to Mars
- Modern DGBs were drop tested and flown in wind tunnels to verify strength and workmanship, but leaned on similarity to Viking data to verify supersonic inflation characteristics
- Recent supersonic testing of ringsail parachutes indicated that subsonic testing may not sufficiently bound stresses and loads seen in supersonic inflations





- **ASPIRE project was started as a risk reduction activity for the Mars 2020 mission**

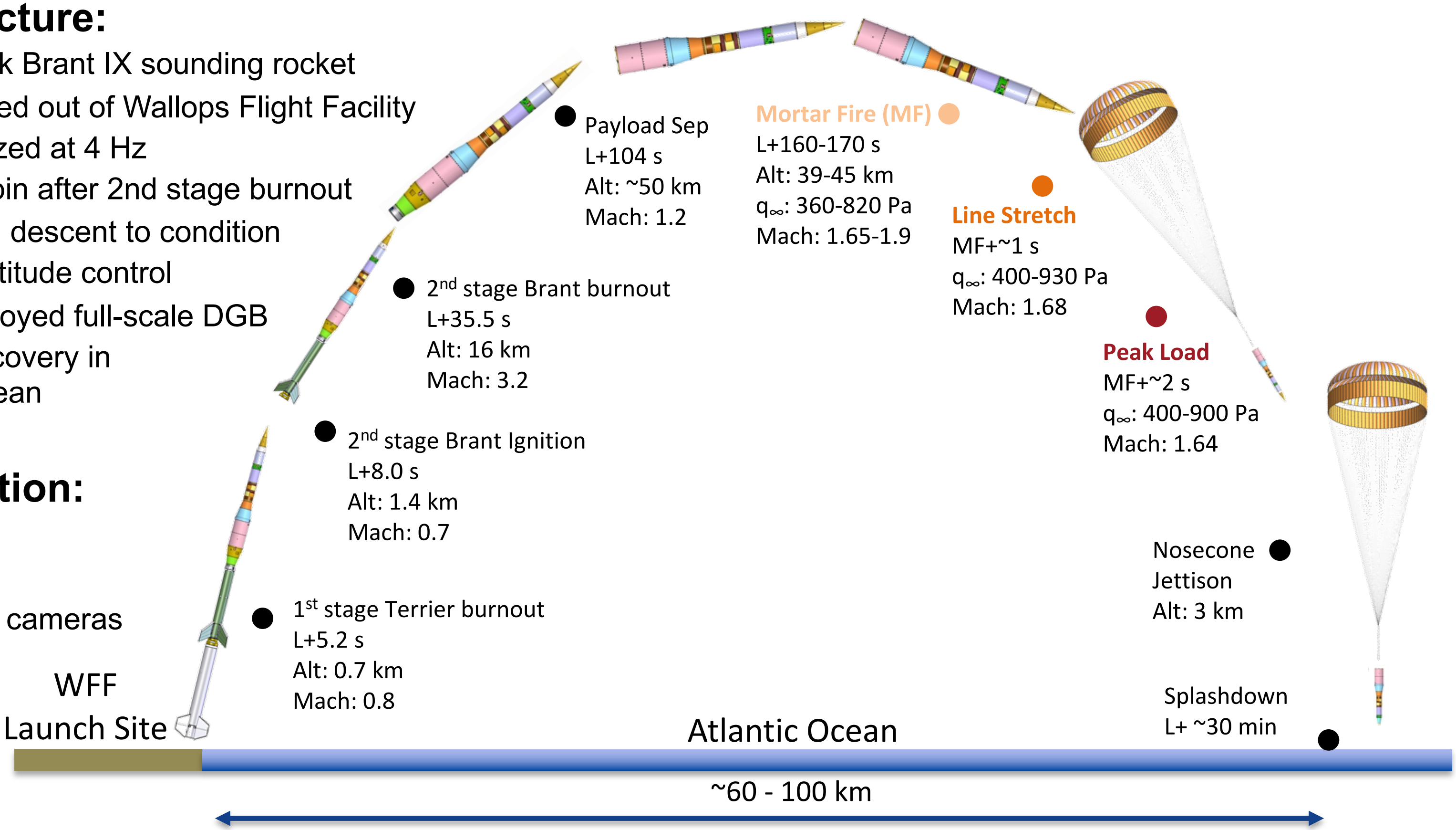
The ASPIRE Project

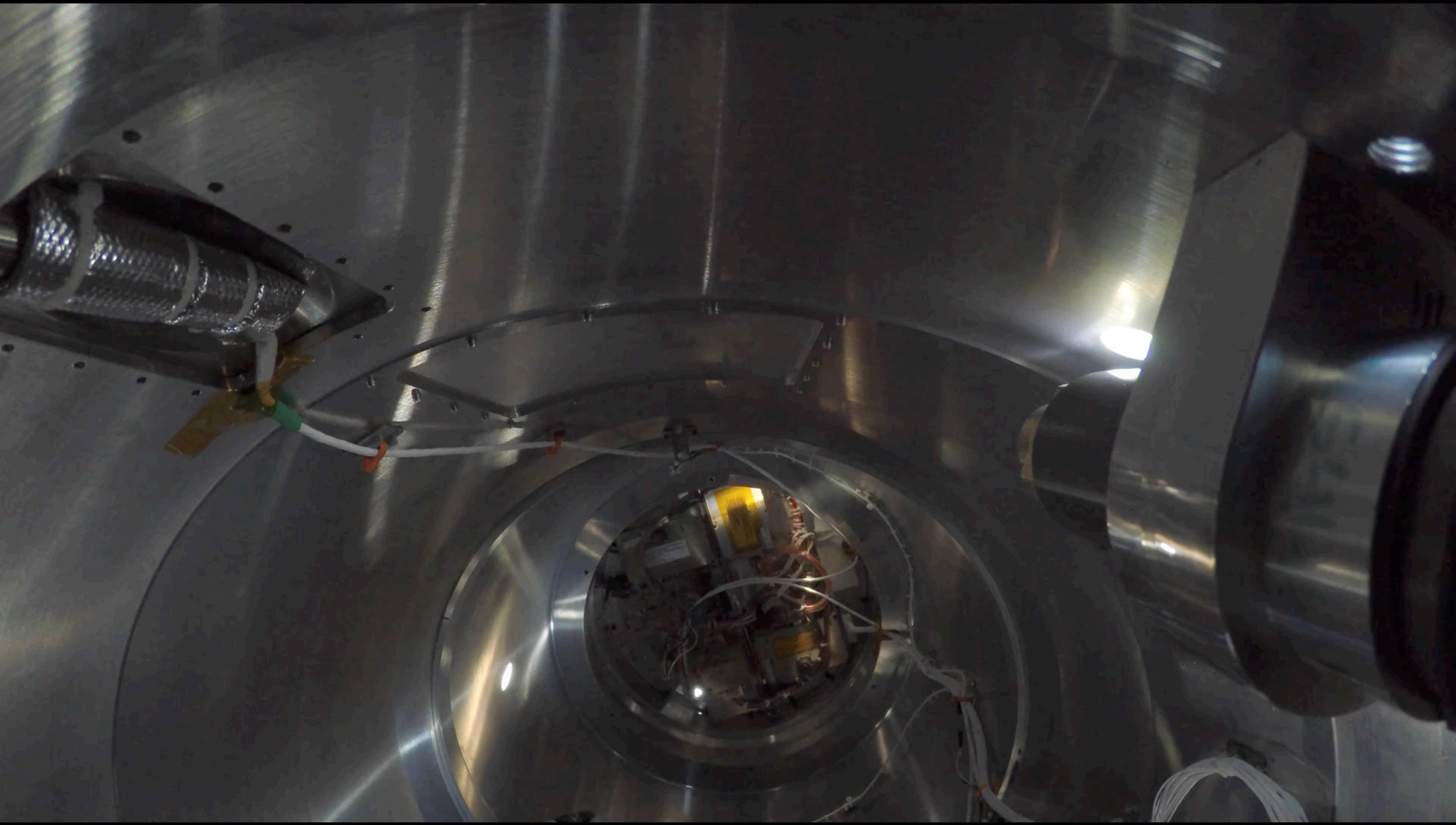
- **ASPIRE** = **A**dvanced **S**upersonic **P**arachute **I**nvestigation and **R**esearch **E**xperiments

- **Objective**: To expose large DGB parachutes to a supersonic inflation environment and acquire sufficient data to characterize the flight environment, loads, and performance.

- **Test Architecture:**
  - Terrier Black Brant IX sounding rocket
  - Rail-launched out of Wallops Flight Facility
  - Spin-stabilized at 4 Hz
  - Yo-yo de-spin after 2nd stage burnout
  - Gravity turn descent to condition
  - Cold gas attitude control
  - Mortar-deployed full-scale DGB
  - Payload recovery in Atlantic Ocean

- **Instrumentation:**
  - IMU + GPS
  - Load pins
  - High speed cameras
  - SitVid cameras





NASA

JPL
Jet Propulsion Laboratory
California Institute of Technology

NASA WALLOPS FLIGHT FACILITY GSFC
WFF

Advanced Supersonic Parachute Inflation Research and Experiments (ASPIRE)
Flight # 003
Date: 07 September 2018
Location: Wallops Flight Facility, Wallops Island, VA
Payload: 21.55 m D_0 Disk-Gap-Band Supersonic Parachute

ASPIRE

Airborne Systems

GENERAL DYNAMICS
Ordnance and Tactical Systems

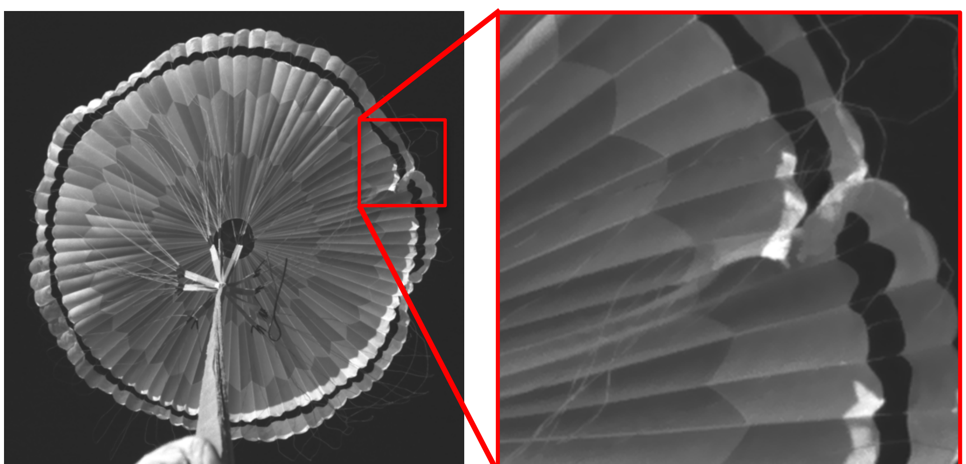
This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Post-Flight Parachute Inspection

- Minor damage in the canopy was observed
  - Mostly minor weave separation
  - Some evidence of suspension line abrasion
  - Damage
  - Damage was not detrimental and did not appear to propagate

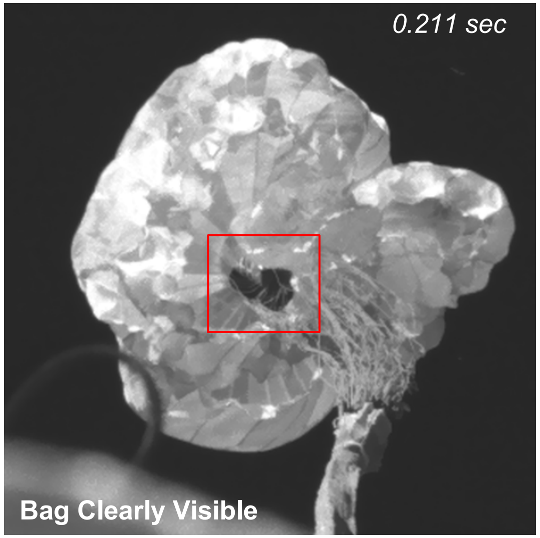
- Overall, the parachute was in remarkably good condition given the flight environment

Damage potentially caused by panel interaction during inflation

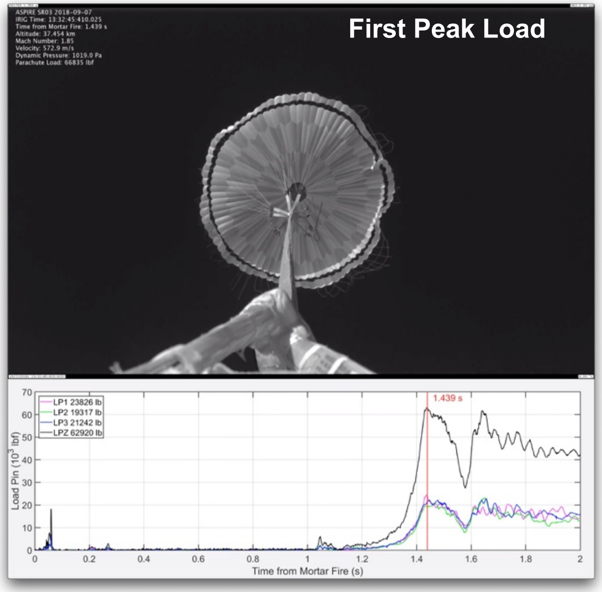


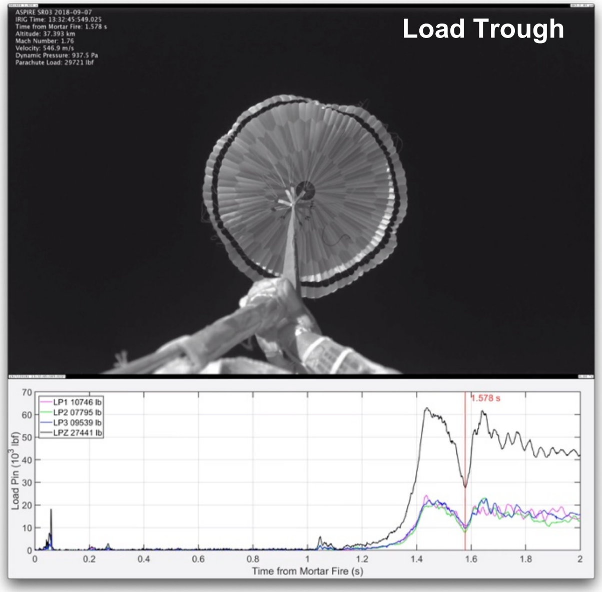
Key Observations

- High speed video indicates that bag strip likely occurred prior to pre-flight estimates
  - Bag did not invert immediately upon strip as well



- Peak load does not correlate with peak area
- Second load peak can be equal to, or greater than, first peak
- “Area oscillation” phenomena are more likely pressure oscillation as opposed to physical change in projected area
- Minor damage may be inevitable due to rapid inflation and abrasion





ASPIRE Flight Summary

ASPIRE

- All three ASPIRE flights resulted in successful inflations
- ASPIRE inflation conditions were equivalent to, or more stressing than, both MSL reconstruction and estimated Mars 2020 parachute conditions
- The ASPIRE program:
  - Successfully deployed the largest supersonic parachute, at the highest Mach number, highest dynamic pressure, and highest load ever tested in US history
  - Sufficiently reduced risk associated with the Mars 2020 supersonic parachute, paving it's way to flight on Mars
  - Demonstrated an economically viable platform to perform test-as-you-fly verification of supersonic parachute strength and performance for future missions

	MSL Reconstruction	ASPIRE SR01	ASPIRE SR02	ASPIRE SR03	M2020 Estimated*
Mortar Velocity (m/s)	44	49	47	47	42 - 47
Inflation Time (s)	0.635	0.506	0.456	0.410	0.4 – 0.7
Peak Load (lbf)	34,600	32,400	56,000	67,300	30,000 – 50,000
Mach Number @ Peak Load	1.7	1.8	2.0	1.9	1.6 – 1.9
Dynamic Pressure (Pa) @ Peak Load	474	495	747	1020	460 - 664

**Mars 2020 parachute performance estimated at deployment (not inflation) as of June 2019. Estimates are subject to change.*

Acknowledgements and References

ASPIRE

- The author would like to acknowledge the following plethora of people:

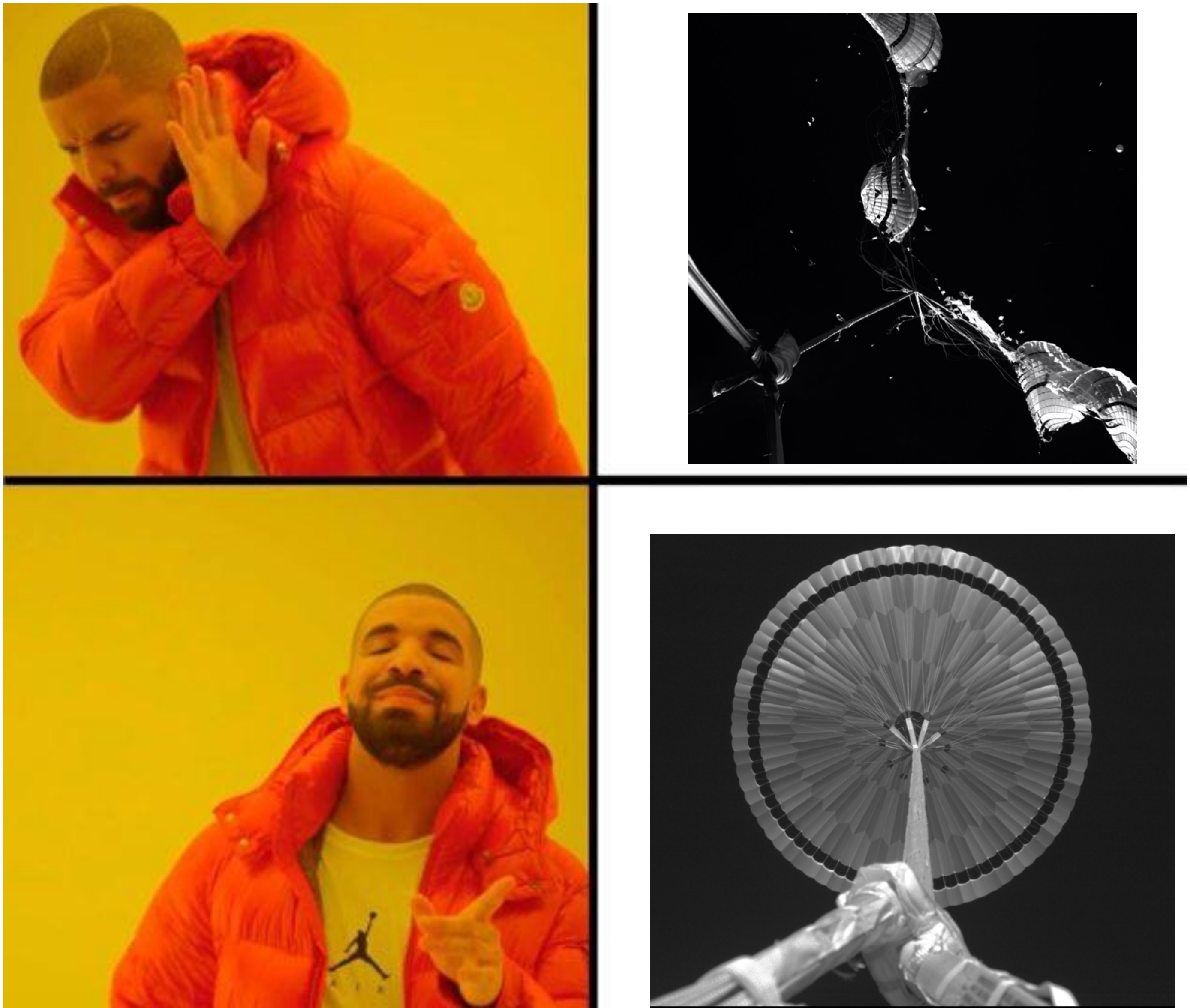
  - JPL ASPIRE team
  - JPL Mars 2020 team
  - NASA Wallops Flight Facility
  - Thomas Reed Boat Crew
  - NASA Ames Research Center
  - NASA Langley Research Center
  - Airborne Systems North America
  - General Dynamics Ordnance and Tactical Systems

- References regarding ASPIRE testing and the Mars 2020 parachute:

  - Sonneveldt, B., O'Farrell, C., Clark, I., "Summary of the ASPIRE Rocket Tests with a Disk-Gap-Band Parachute," 2019 AIAA Aviation Forum, Dallas, TX, June 2019.
  - Muppidi, S., O'Farrell, C., Van Norman, J. W., Clark, I. G., "ASPIRE Aerodynamic Models and Flight Performance," 2019 AIAA Aviation Forum, Dallas, TX, June 2019.
  - O'Farrell, C., Sonneveldt, B., Clark, I., "Reconstructed DGB Performance During the ASPIRE SR01 & SR02 Supersonic Flight Tests," 15th International Planetary Probe Workshop, Boulder, CO, June 2018.
  - Sonneveldt, B., O'Farrell, C., Clark, I., "Overview of the First Two Flights of the ASPIRE Supersonic Parachute Test Program," 15th International Planetary Probe Workshop, Boulder, CO, June 2018.
  - Tanner, C., Clark, I., Chen, A., "Overview of the Mars 2020 Parachute Risk Reduction Activity," 2018 IEEE Aerospace Conference, Big Sky, MT, March 2018.

Questions?

ASPIRE



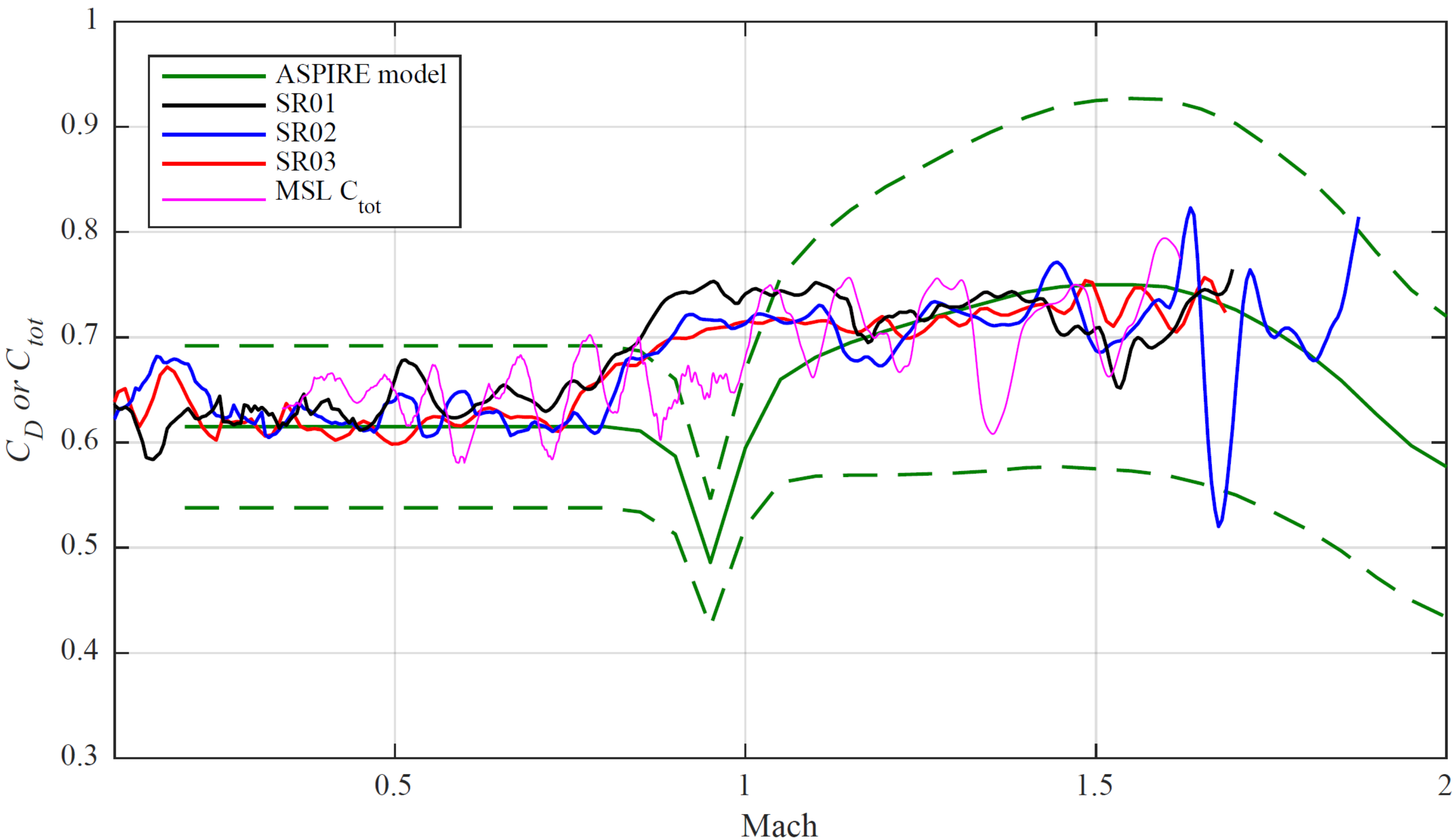
ASPIRE

Backup

Parachute Aerodynamics

ASPIRE

- C_D vs Mach: good agreement between SR01-3 & with MSL
- Good agreement with C_D model below M = 0.75 , but over-estimated C_D for M >1.15
- C_D remained constant across the transonic region

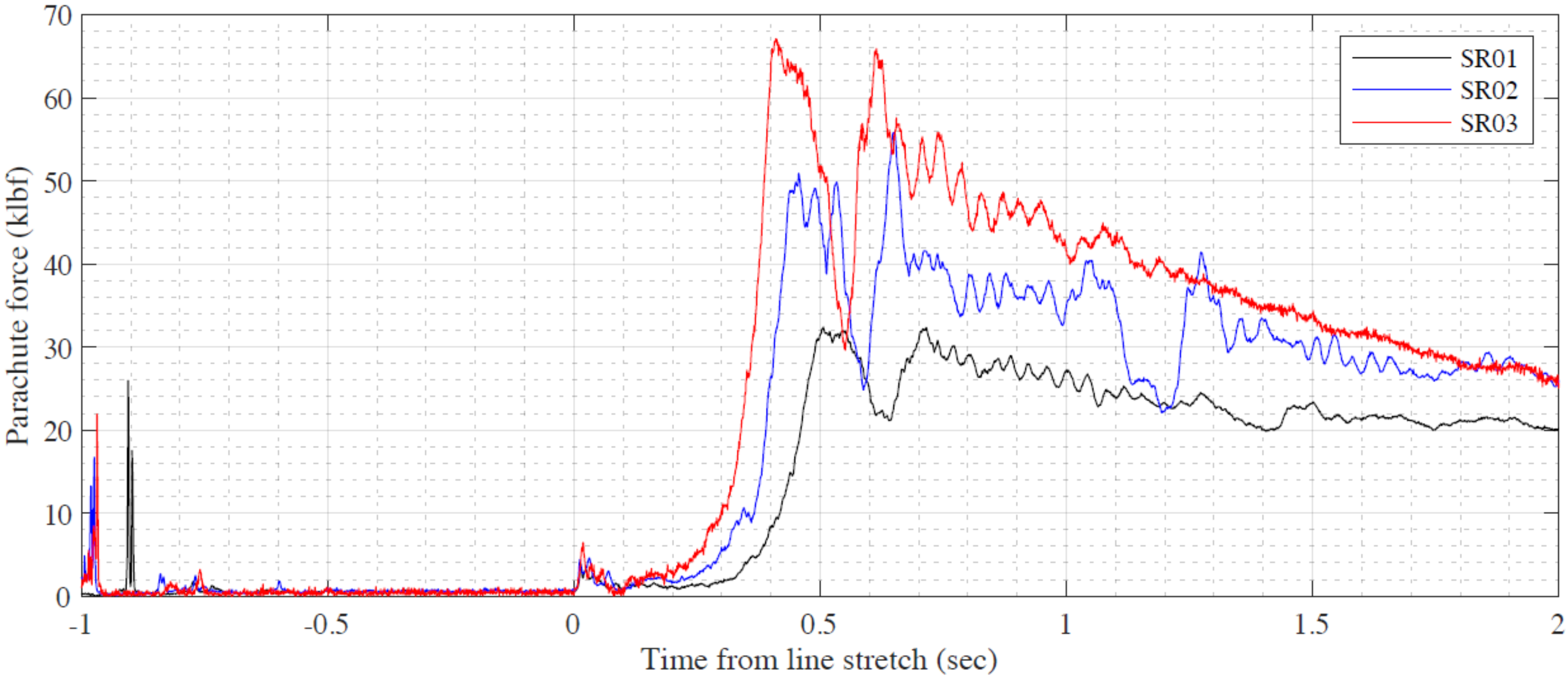


see "ASPIRE Aerodynamic Models and Flight Performance"-Muppidi for additional details on aerodynamic performance and updated drag model

Parachute Inflation and Peak Load

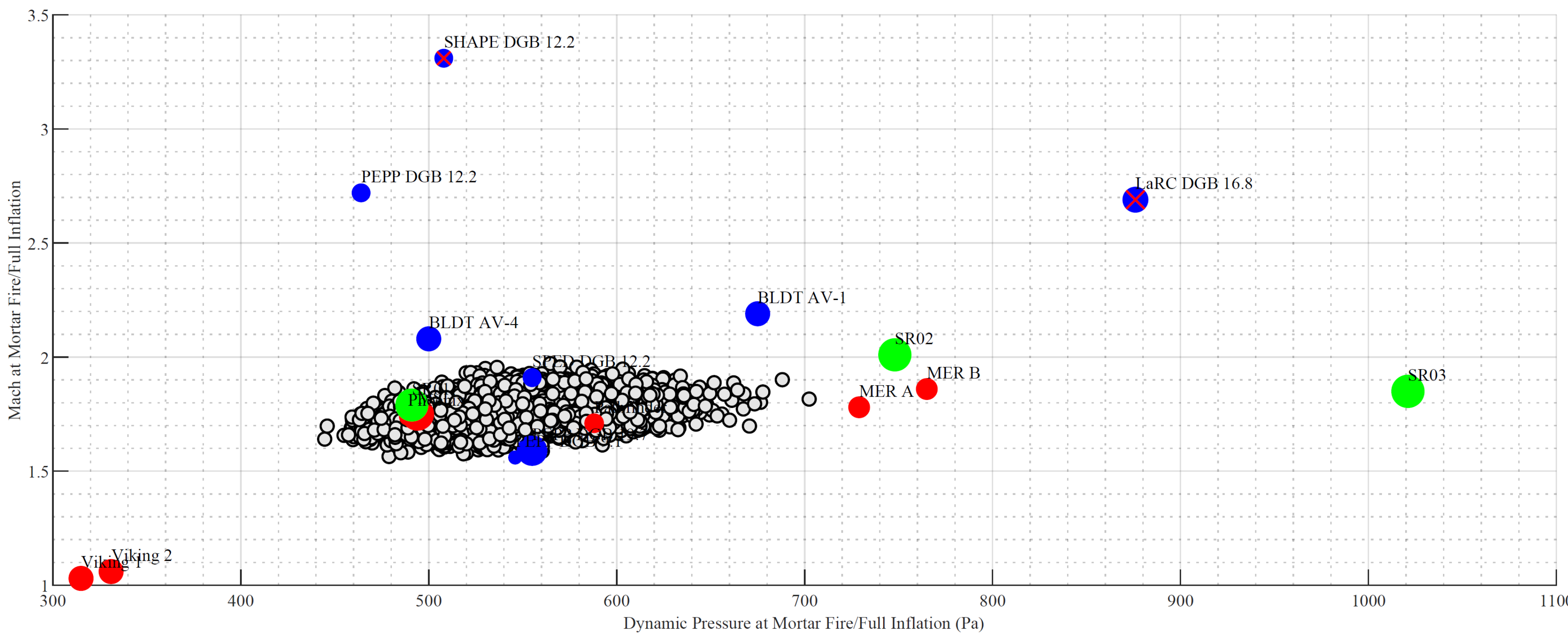
ASPIRE

- Behaviors that occurred on all three flights
  - Initial peak load occurred before full projected area of parachute is seen
  - Inflation time decreased for each progressive flight
  - ~50% decrease in load after first peak in all three flights
  - Reduction in area after first peak is much less significant than reduction in parachute force



Test Conditions

	SR01			SR02			SR03		
Event	**Mortar Fire**	**Line Stretch**	**Peak Load**	**Mortar Fire**	**Line Stretch**	**Peak Load**	**Mortar Fire**	**Line Stretch**	**Peak Load**
T+ (sec)	161.41	162.37	162.88	177.59	178.63	179.08	163.82	164.85	165.26
Mach	1.77	1.79	1.71	1.97	2.00	1.97	1.85	1.88	1.85
Dyn Pres (Pa)	452.4	491.7	494.7	670.6	744.6	746.5	931.7	1028.4	1020.1
Altitude (km)	42.40	42.01	41.80	40.77	40.27	40.03	38.12	37.65	37.45

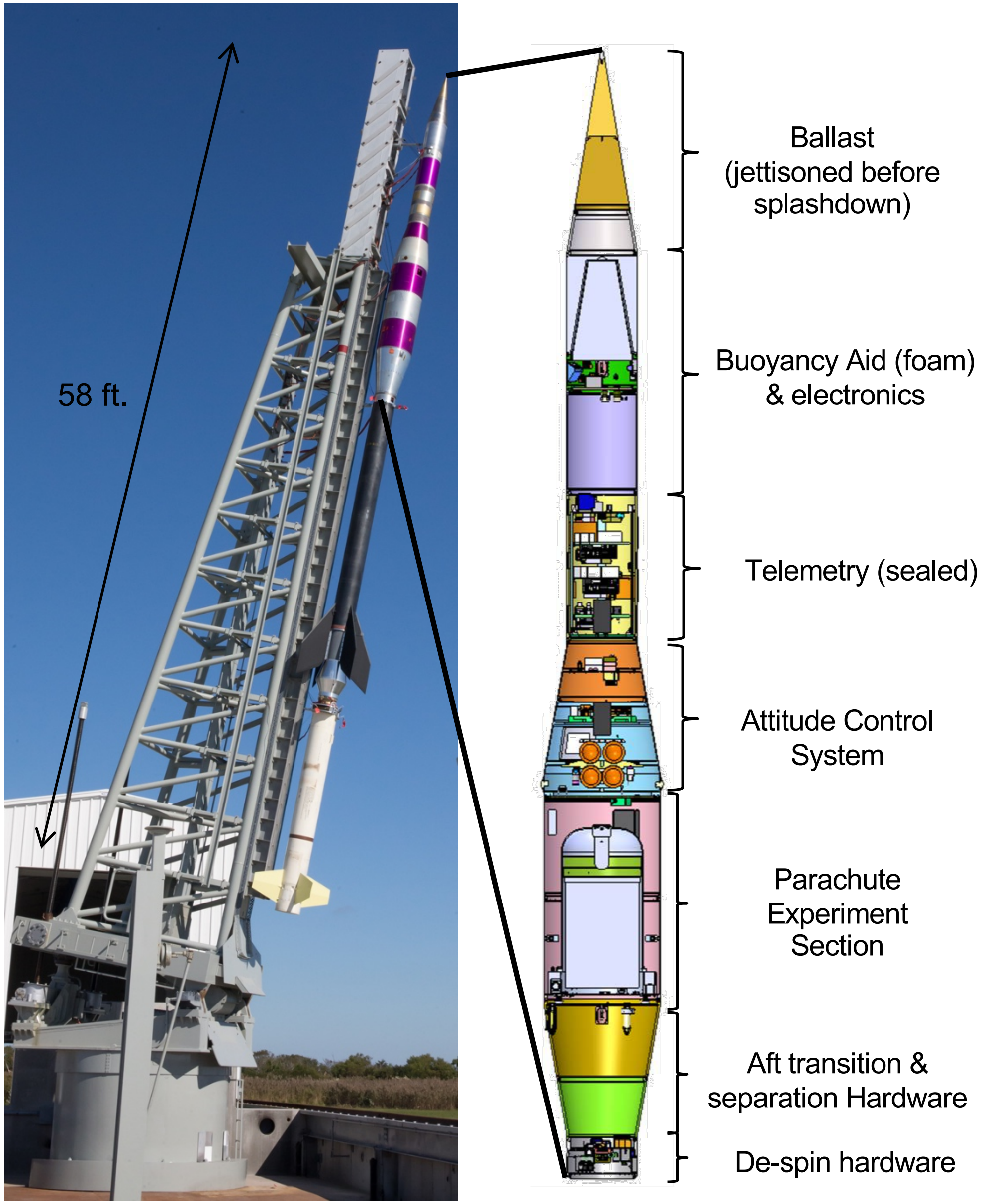


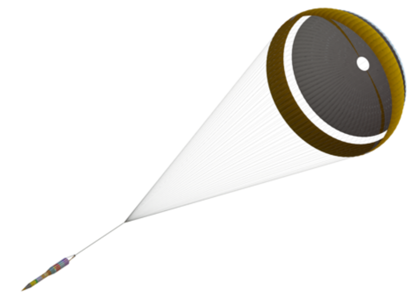
Legend

: Mars Flight : ASPIRE : Earth Test (other than ASPIRE) : Earth Test, failed chute : Mars 2020 Simulation

Payload Configuration & Instrumentation

ASPIRE





Onboard Instrumentation	Rate	Resolution
GLN-MAC IMU	400 Hz	-
GPS	20 Hz	-
C-band transponder (radar tracking)	50 Hz	-
Parachute Triple-Bridle Load Pins	1 kHz	1100 lbf
High Speed Cameras (x3)	1000 fps	3840x2400
Situational Video (x3)	120 fps*	1920x1080*

*One Situational Video Camera set to 4K resolution and 30 fps

Meteorological instrumentation:

- 6x meteorological balloons carrying Radiosondes: temperature, density, winds to 37 km
- GEOS Analysis: temperature, density, winds above 37 km