Performance of Supersonic Parachutes behind Slender Bodies

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Introduction

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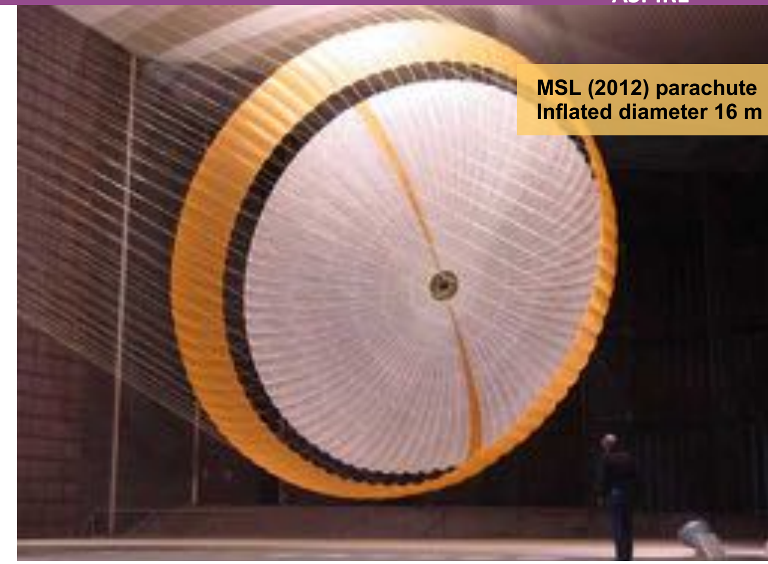
- Supersonic Disk-Gap-Band (DGB) parachutes have been used on every United States mission to Mars.
- ASPIRE* project was launched to test full-scale parachutes at Mars relevant conditions.
    - The qualified parachute will be used at Mars behind a blunt body for the upcoming Mars2020 mission.
    - Parachutes delivered to high altitudes over Earth on a Sounding Rocket Platform
    - Parachute deployed in the wake of a slender body.
    - Three successful flight tests helped qualify a parachute for Mars2020 mission

Advanced Supersonic Parachute Inflation Research and Experiments

Test	Parachute	Parachute Inflation load	Inflation Mach Number	Dynamic Pressure
SR01 (Oct 2017)	MSL	32, 400 lbf	1.77	495 Pa
SR02 (Mar 2018)	Mars2020	55, 800 lbf	1.97	626 Pa
SR03 (Jul 2018)	Mars2020	67, 400 lbf	1.85	1020 Pa

Nominal predicted parachute load during Mars2020 entry: 35,000 lbf



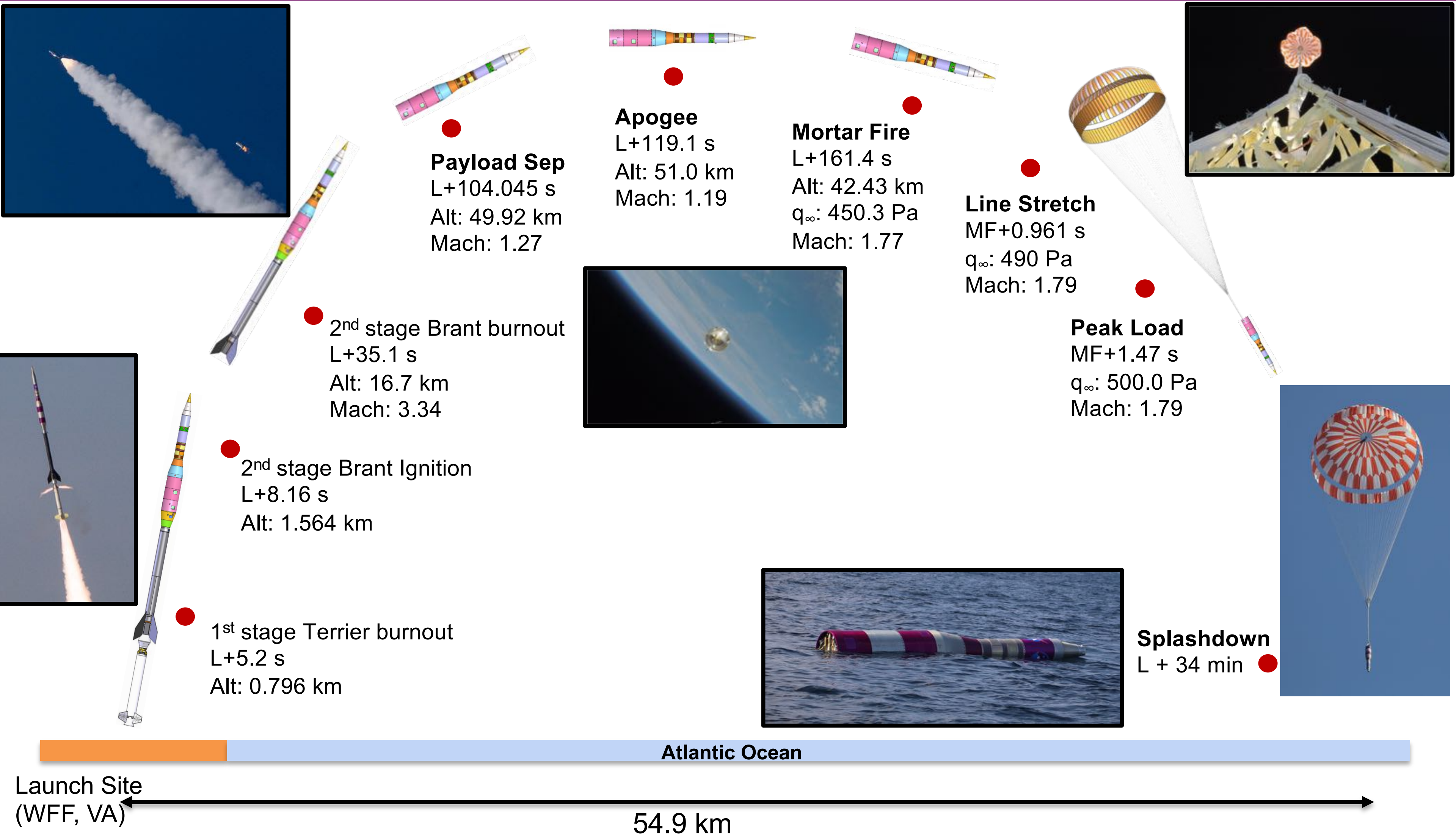
MSL (2012) parachute
Inflated diameter 16 m

ASPIRE leading body
Max diameter 0.74 m
Max length 6.6 m

Mars2020 capsule
Max diameter 4.5 m
Max length 2.9 m

This talk provides a brief look at the flight tests and the parachute performance

ASPIRE Flight Test



Note: The numbers indicate actual quantities from first flight test (SR01), Oct 2017.

CFD towards Flight Test Design

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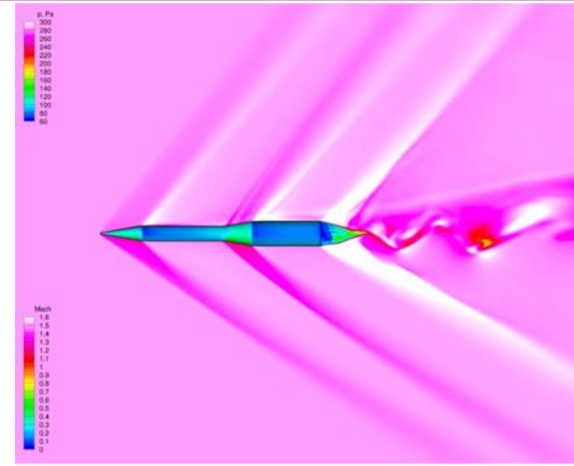
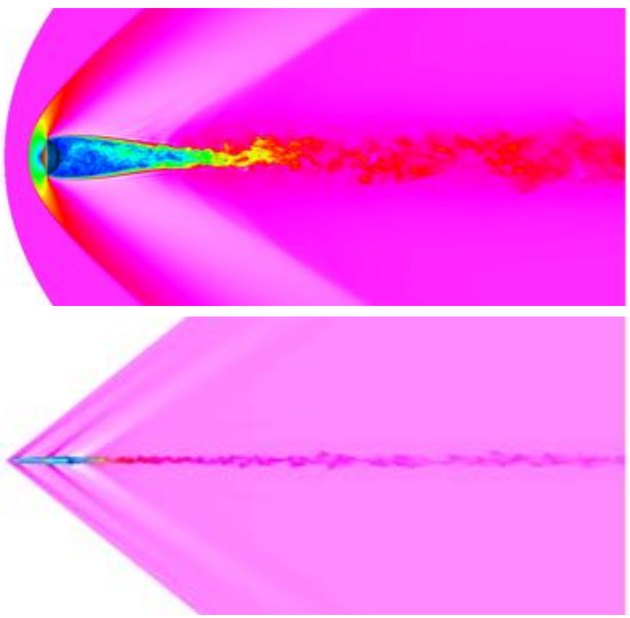
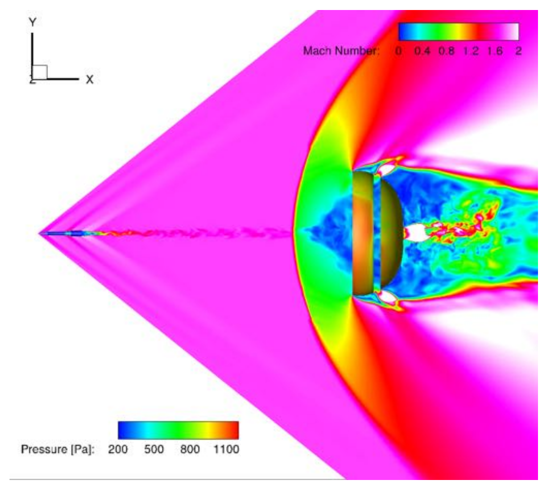
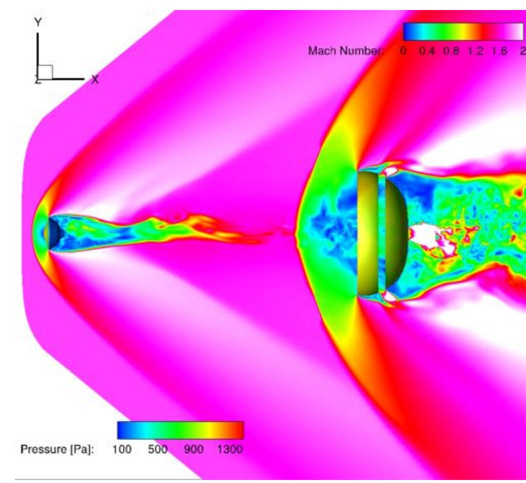
- Slender Body Simulations - to generate payload aerodynamic database.
- Wake Simulations - to explore blunt vs slender body differences, help with targeting during the flight test.
- Rigid Parachute Simulations - to investigate effect of leading body in parachute drag, generate pre-flight parachute drag model.
- Simulations in CO_2 - to extrapolate parachute performance over Earth and predict performance at Mars.





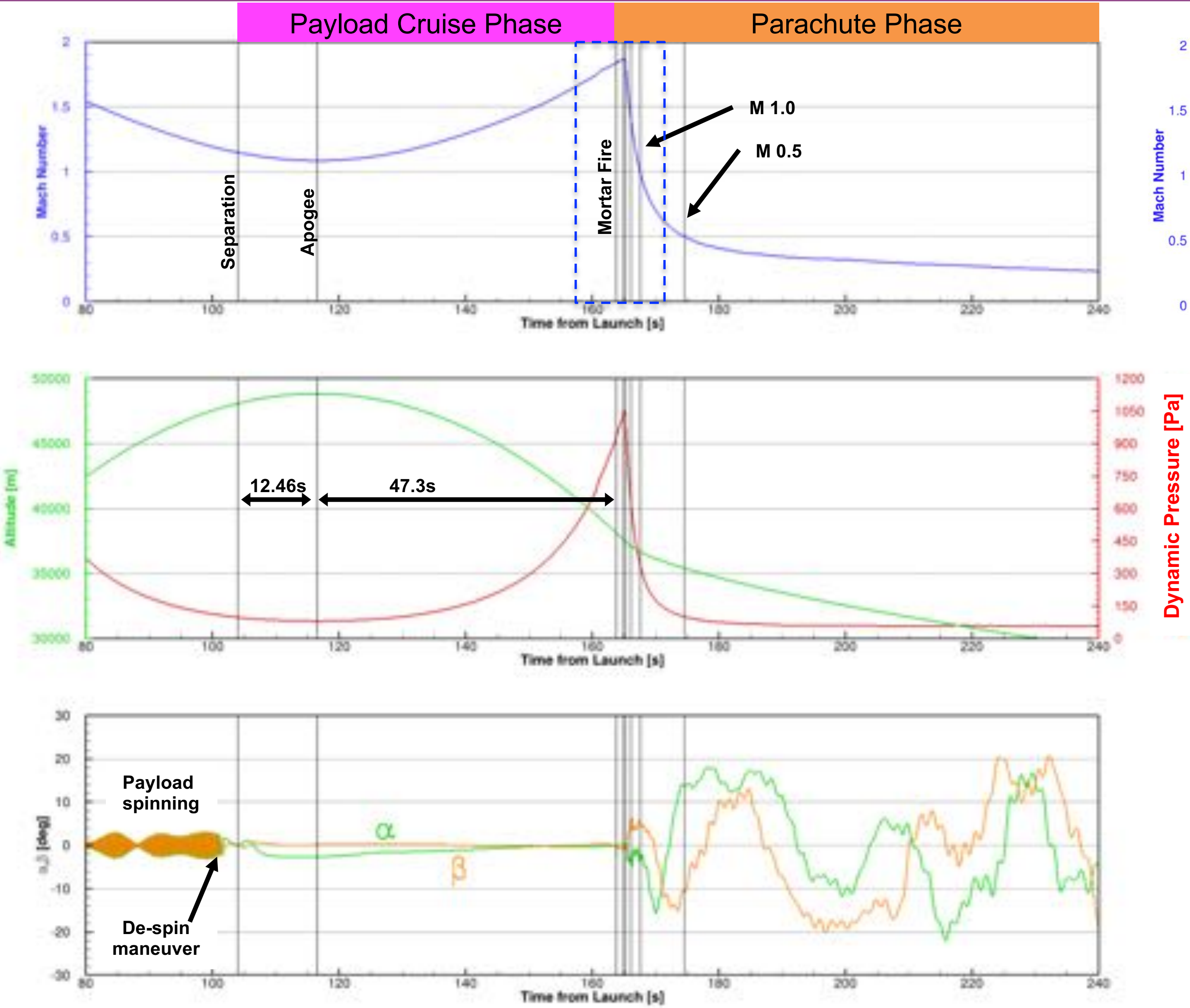


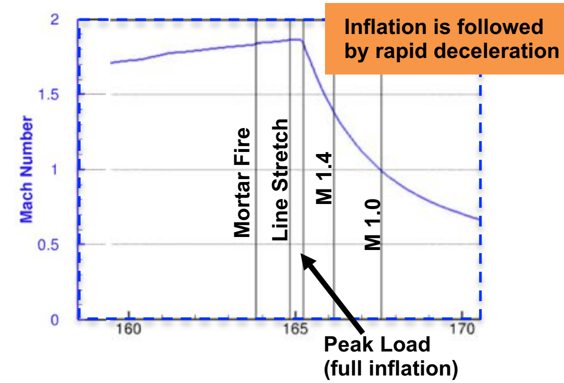


APS DFD 2017: Simulations of Wakes and Parachute Environments for Supersonic Flight Test Design

AIAA Aviation 2018: Modeling and Flight Performance of Supersonic Disk Gap Band Parachutes in Slender Body Wakes

Flight Trajectory (SR03)





Payload Separation	
Altitude	48.1 km
Dynamic Pressure	96.4 Pa
Mach Number	1.17
Velocity	372.5 m/s
Apogee	
Altitude	48.85 km
Dynamic Pressure	79.36 Pa
Mach Number	1.11
Velocity	354.8 m/s
Mortar Fire	
Altitude	38.12 km
Dynamic Pressure	931.74 Pa
Mach Number	1.85
Velocity	575.8 m/s
Peak Parachute Load	
Altitude	37.46 km
Dynamic Pressure	1020.0 Pa
Mach Number	1.85
Velocity	573.18 m/s

Payload Aerodynamic Performance

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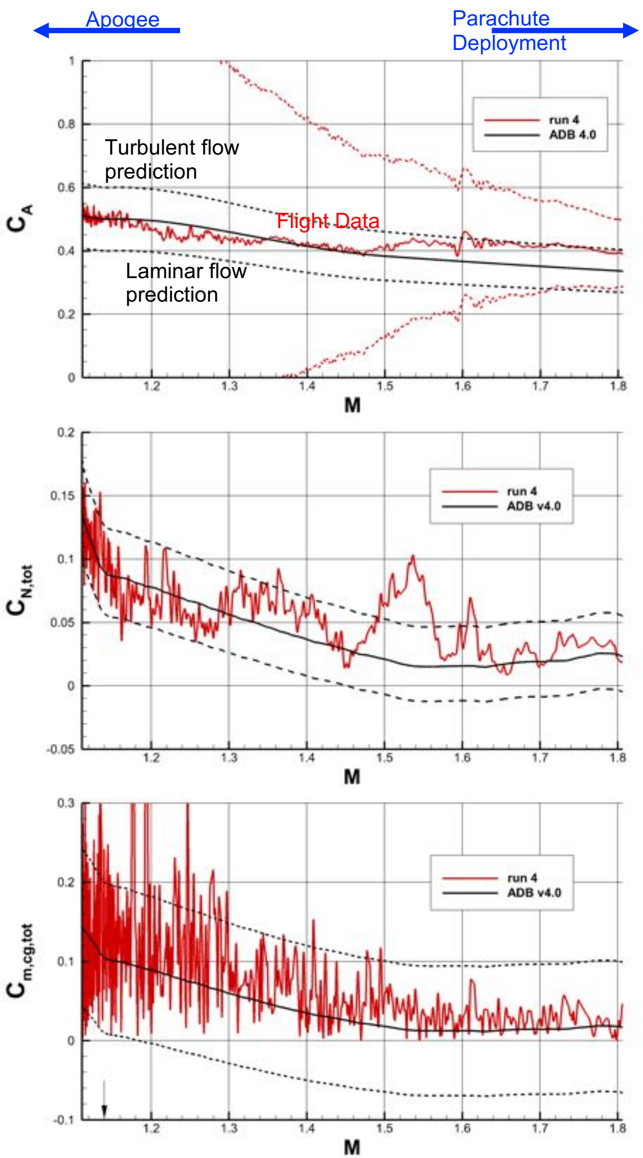
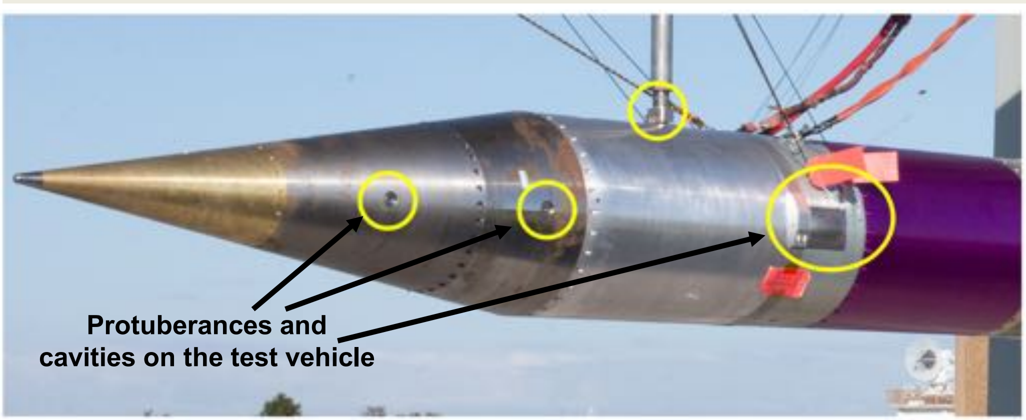
SR03 Flight data



- Pre-Flight Database: laminar and turbulent CFD simulations, at a variety of Mach numbers and attitudes.
    - Slender Body Effects: Viscous effects are sizeable, turbulent aerodynamics considerably different from laminar.
    - Nominal predictions based on the average of laminar and turbulent predictions
- Flight data compares reasonably with pre-flight predictions
    - closer to turbulent flow predictions than laminar flow predictions (particularly as the velocity increases).

Pre-flight database assumes a smooth geometry ;
Vehicle surface contains non-smooth features → flow is likely to trip



Parachute Deployment and Inflation

- Tension measurements using three load pins (Parachute force = tension + payload mass *x* acceleration)
- Peak Aerodynamic Load during SR01 : 32.4 k lbf (144.07 kN)

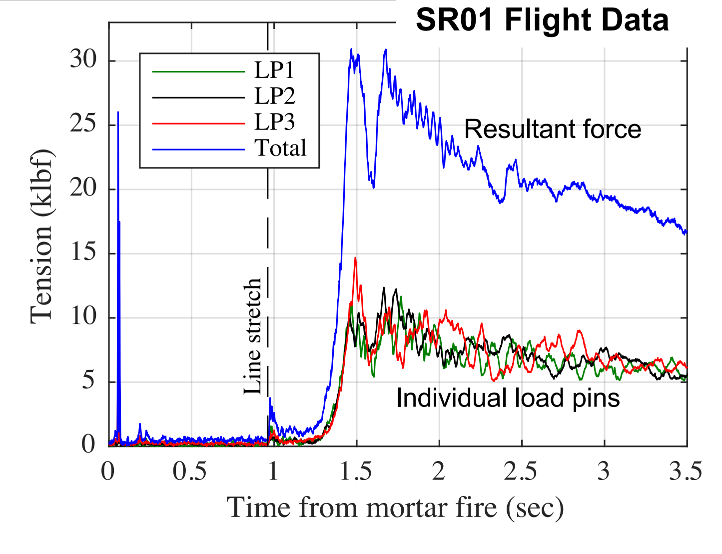
  (Pre-flight prediction 35,000 lbf)
- Inflation load indicator $F_{peak} = k_p(2q_\infty S_p)$

S_p: Parachute Projected Area
q_∞: Freestream dyn. press.
k_p: Inflation constant

Test	dyn. press.	Inflation Load	k_p
SR01	495 Pa	32,400 lbf	0.77
SR02	626 Pa	55,800 kbf	0.78
SR03	1020 Pa	67,400 lbf	0.76

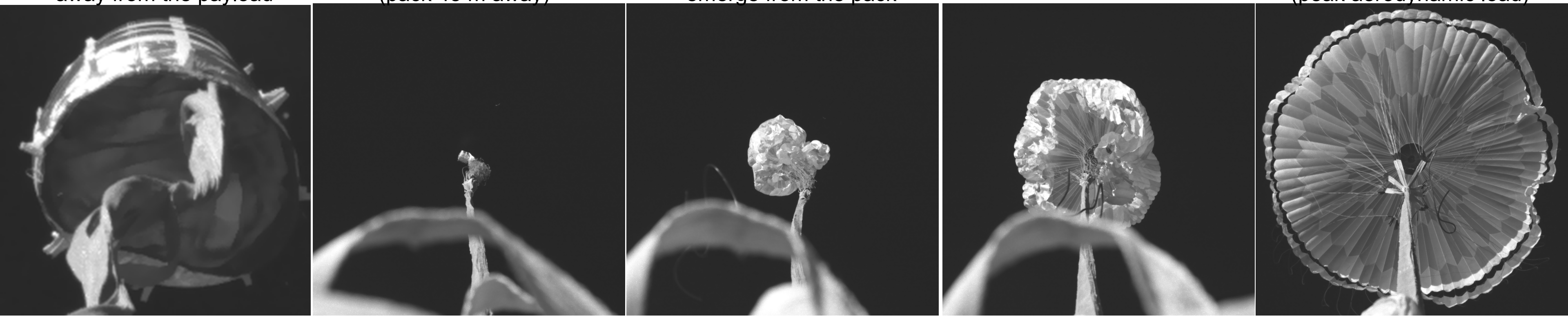
Pre-flight range for k_p (informed using CFD) : 0.76 - 0.98

SR01 Flight Data



k_p consistent across the three flights ; towards the lower end of the pre-flight prediction.

Parachute pack sailing away from the payload | Line Stretch (pack 45 m away) | Parachute begins to emerge from the pack | Parachute Fully Inflated (peak aerodynamic load)



Images from the on-board high-speed camera

Parachute Drag

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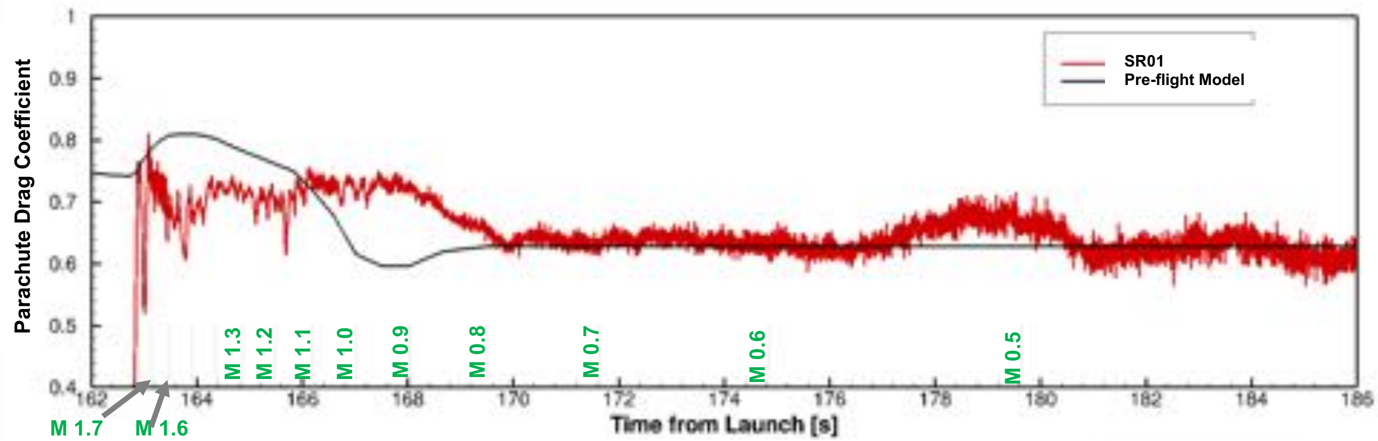
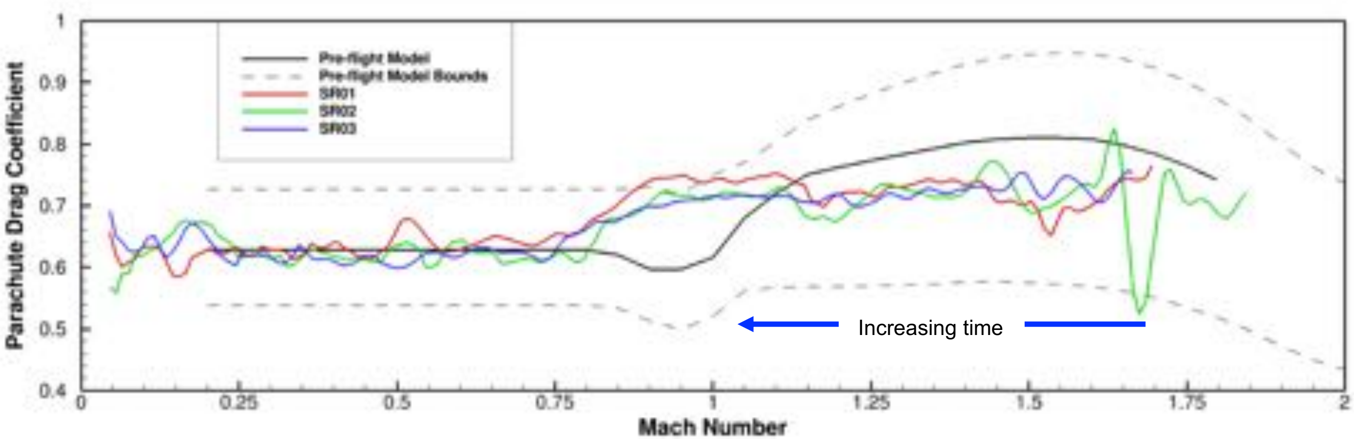


Good Agreement below Mach 0.75

Over-prediction above Mach 1.15

Test Data does not show a transonic drag reduction



Consistent drag performance across three flights

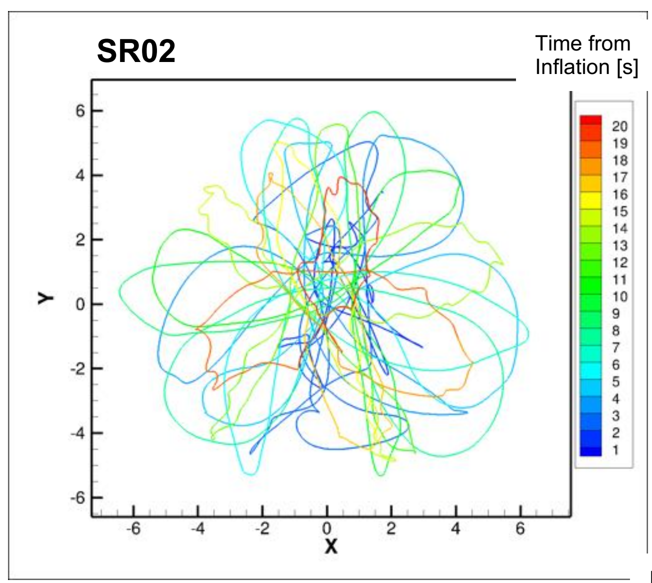
Pre-flight bounds capture all the data from three flights (about 90 min of flight data)

Flight data indicates a near-constant subsonic drag, and a near-constant supersonic drag

Ongoing (post-flight) analysis indicates that the transonic drag decrease is a blunt leading body effect.

Parachute Position and Motion

- Instrumentation provides parachute force vector, approximated as the parachute position.
- SR02: Parachute is mostly confined within a circle of radius 5m, exhibits smooth excursions within.



Movement of the parachute during 20s after inflation

Parachute Position and Motion

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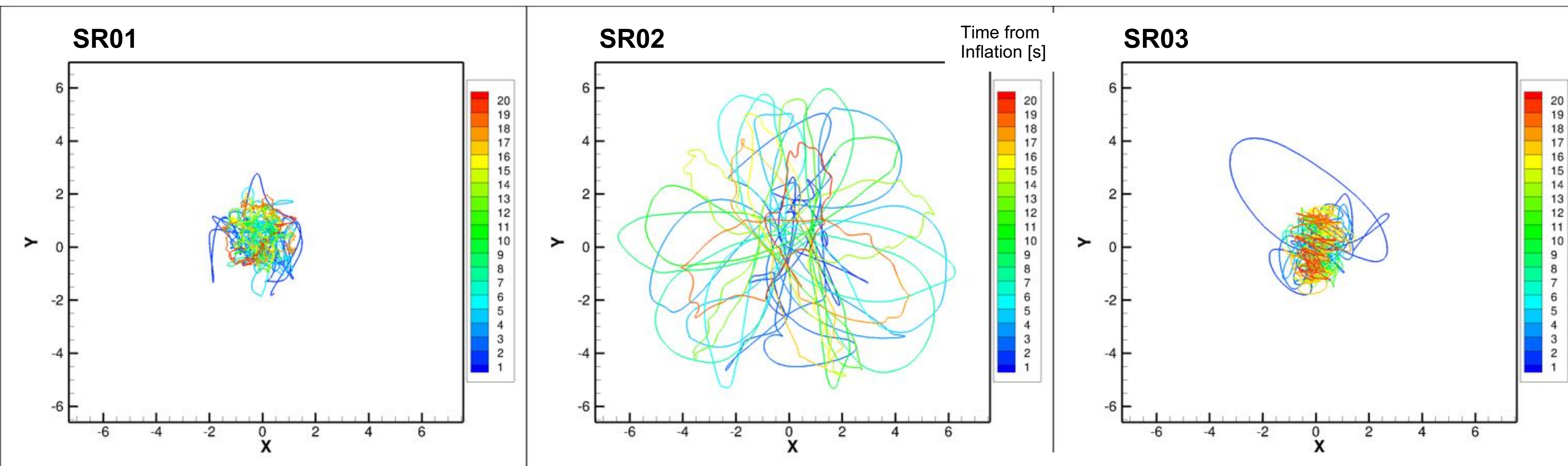
- Test data provides parachute force vector, approximated as the parachute position.
- SR02: Parachute is mostly confined within a circle of radius 5m, exhibits smooth excursions within.
- In contrast, the parachute movement is significantly restricted during SR01 and SR03.



Movement of the parachute during 20s after inflation

Open Question: Why is the parachute motion more dynamic during SR02 ?

Conclusions

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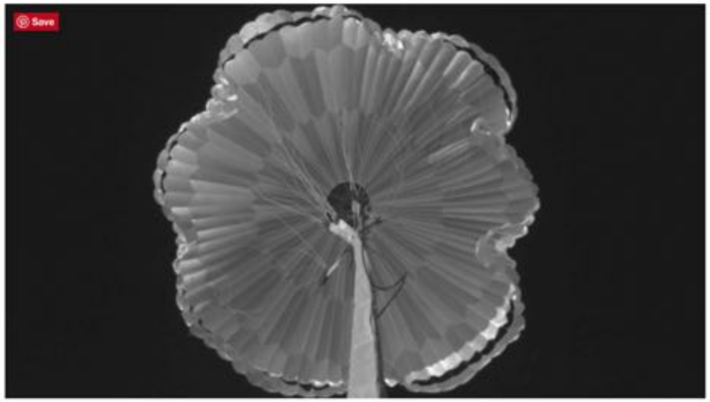
- ASPIRE project was launched to test supersonic parachutes at Mars relevant conditions; *first full-scale supersonic tests of parachute in over 40 years*.
- Three flight tests (Oct 2017, March 2018, Sep 2018) successfully inflated parachutes at ever-increasing parachute loads; provided valuable data and imagery.
- Pre-flight payload and parachute models/predictions compare well to the flight data.
- Through this test series <u>ASPIRE 'qualified' a parachute for upcoming Mars2020 mission</u> and broke records (fastest inflation, highest load for a parachute this size).

- Project close out: documentation and dissemination of flight test design information, test data, and parachute performance.
- Post-Test Flight Report (due in a few months) will include data as well as open questions.
- Please contact the authors if interested in accessing flight data.

Mars 2020 parachute is a 'go'

October 30, 2018, NASA



This high-definition image was taken on Sept. 7, 2018, during the third and final test flight of the ASPIRE payload. It was the fastest inflation of this size parachute in history and created a peak load of almost 70,000 pounds of force. Credit: NASA/JPL-Caltech