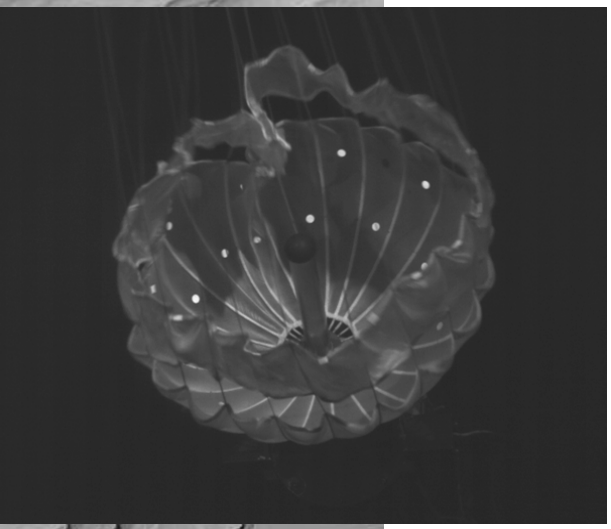

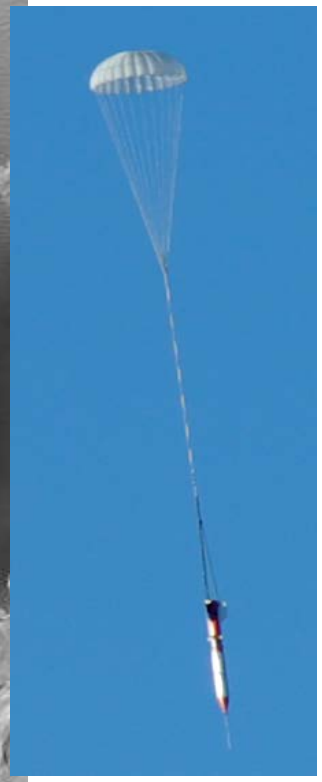

Subscale Testing for Planetary Parachute Developments

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IPPW-12 Cologne German
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Subscale Testing for Parachute Development

- Motivation - Wake induced fluid structure interaction not well quantified for parachute performance and survivability (MSL & Orion drogue qual)
- Data from a subscale test can support / optimize the full scale test design *at very low cost*
- Validation dataset for CFD-FSI Simulations of parachute system providing insight into the flow field

Viking Era Mach 2.72, 40 ft DGB)

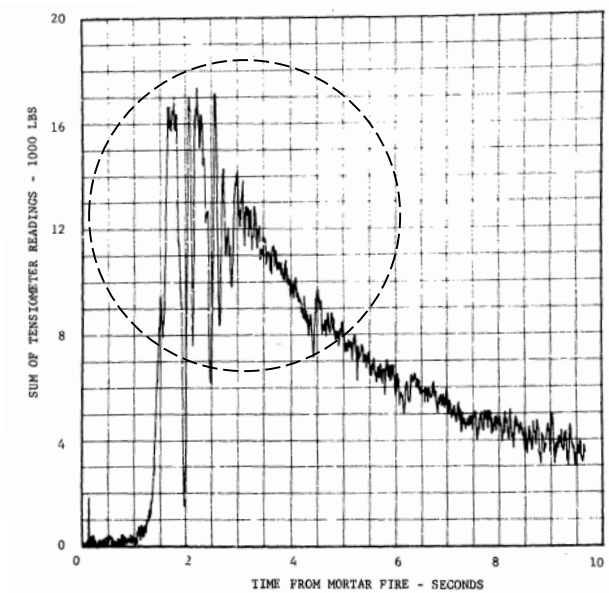


FIGURE V-3 PARACHUTE OPENING LOAD, 0-10 SECONDS

Parameter	Viking	Huygens	Army	MER	MSL
Type	DGB	DGB,CR	Cross, Quarter Spherical	DGB	DGB
Scale (%)	10	---	---	10	3
Do (m)	1.6	1.6	0.3	1.6	0.8
Mach	0.1-2.6	0.1-1.5	<0.8	0.3-0.5	2-2.5
q (kPa)	4.7	4-6	0.015-0.2	1.2	4-19

Test Architecture	Structural Assessment	Parachute Performance	Aerodynamic wake effect	Dynamic Wake Effect	Dynamic Model Validation	CFD validation dataset	Cost
Full Scale Flight w/o CM	Yes	Yes	No	No	No	No	Med
Full Scale with CM	Yes	Yes	Yes	Yes	Partial	Partial	High
Subscale Wind Tunnel	No	Yes	Yes	Yes	Yes	Yes	Low
Full Scale Wind Tunnel	Yes	Partial	Partial	No	Partial	Partial	Med

Supersonic Parachute Flight

Subscale Test Requirements and Diagnostics

- Simulate flight like wake in a subscale environment (Re and Mach)
- Achieve geometric and construction similarity to the full-scale article
- Minimize effects of wind tunnel blockage
- Minimize Aerodynamic Interference
- Spatial and temporal resolution
- Quantitative measurement of flow-field
- Physical insight into the flow-field
- Heritage from past NASA parachute developments
- CFD validation should be a focus

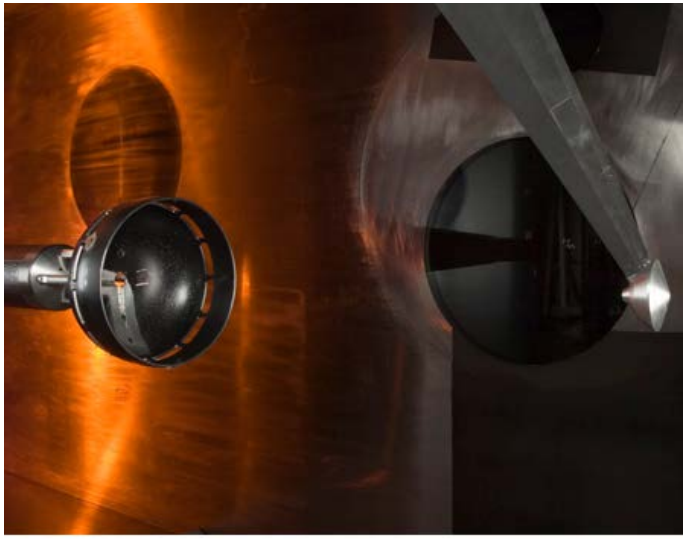
Technique	Parameter
Parachute Load Cell	Parachute aero
Force balance	Capsule aero
PIV	3D Flow field
High Speed Video	Shape reconstruction Dynamic motion
Pressure Sensors	Pressure distribution

Designing the Experiment for Mars Deployment Conditions (MSL)

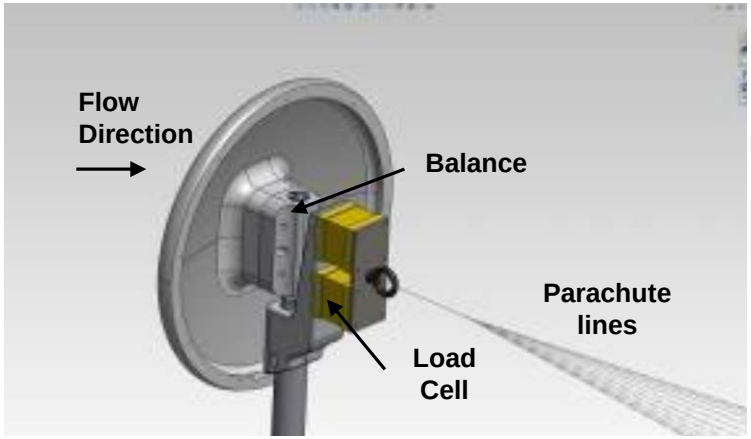
- NASA GRC Closed Loop Supersonic Wind Tunnel
  - 10 x 10 x 40 ft (3x3x12 m) test section
  - Mach 2 to 3.5
  - Variable pressure to match Re
  - IRIG B time stamp for all data
- 3.7% of MSL scale, 5% Viking scale
  - **Supersonic sleeve deployment**
  - Maximize size but prevent capsule shock reflection into wake region
  - Re and Mach number matching for aerodynamic similarity, Q for dynamic (different test articles)

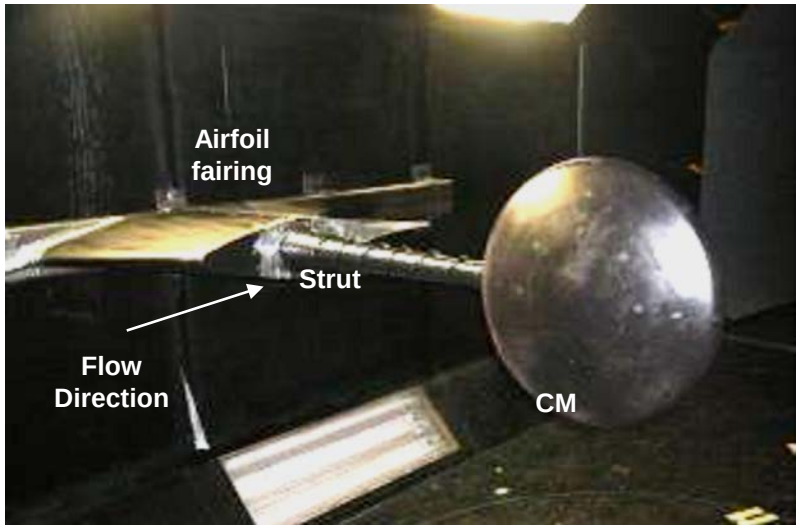
G. Candler, University of Minnesota, US3D

Dynamic Pressure	Mach	*Re* ($x10^6$)	*q* (kPa)	d/D_o	D_o *(m)*	*x/d*
Low	2.0	0.20	4.3			
	2.2	0.24	3.8	0.21	0.8	10.6
	2.5	0.25	3.1			
High	2.0	1.0	16.8			
	2.2	1.1	18.3	0.21	0.8	10.6
	2.5	1.2	19.8			



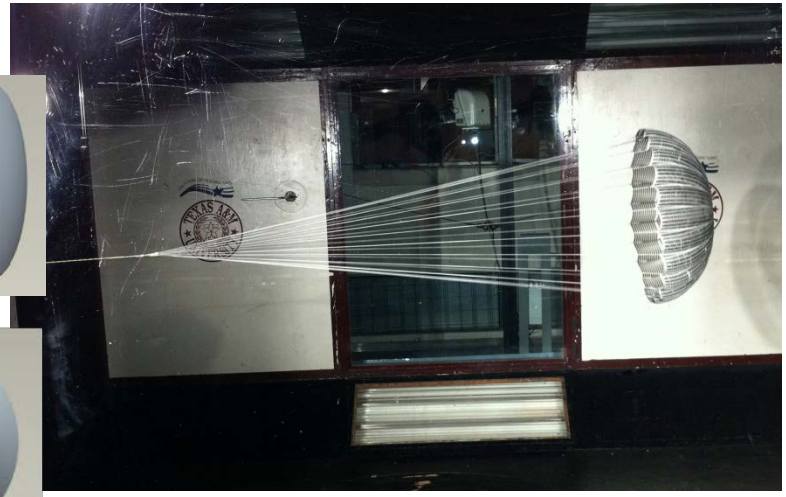
Designing an Experiment for Earth Deployment Conditions (Orion)



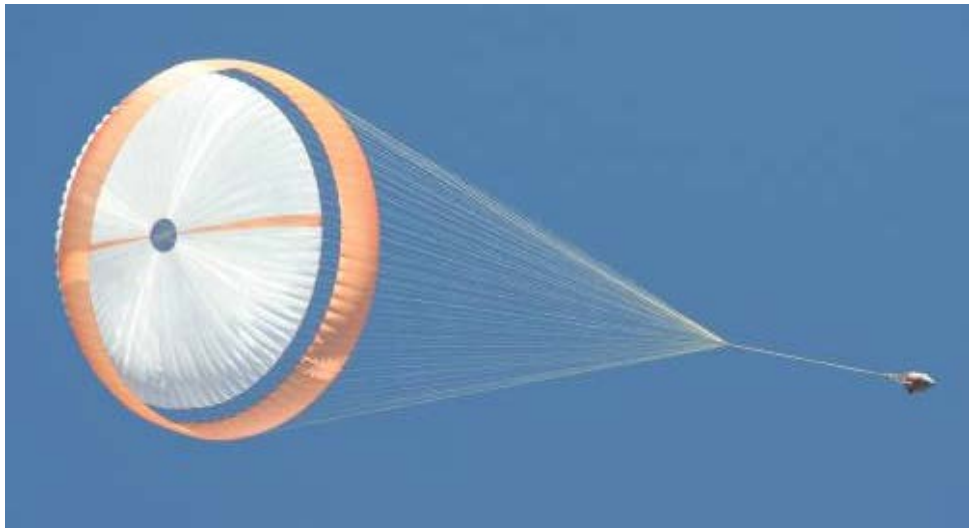


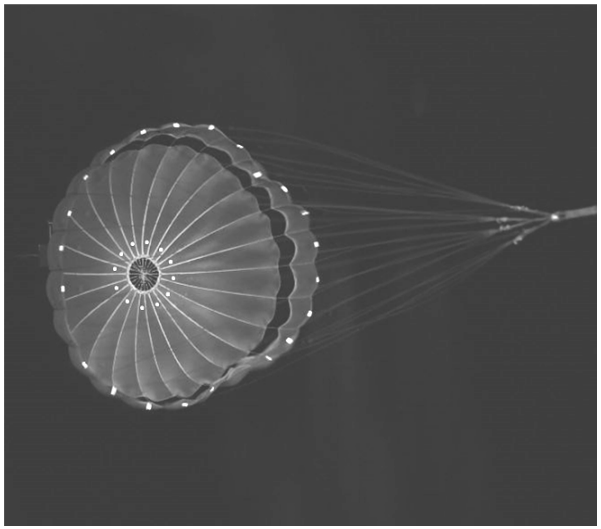
- Trip dots to control/force transition
- Capsule rotated on sting to explore 0, 30, and 50 deg angle of attack relative to the free stream (180, 150, 130 pitch plane)

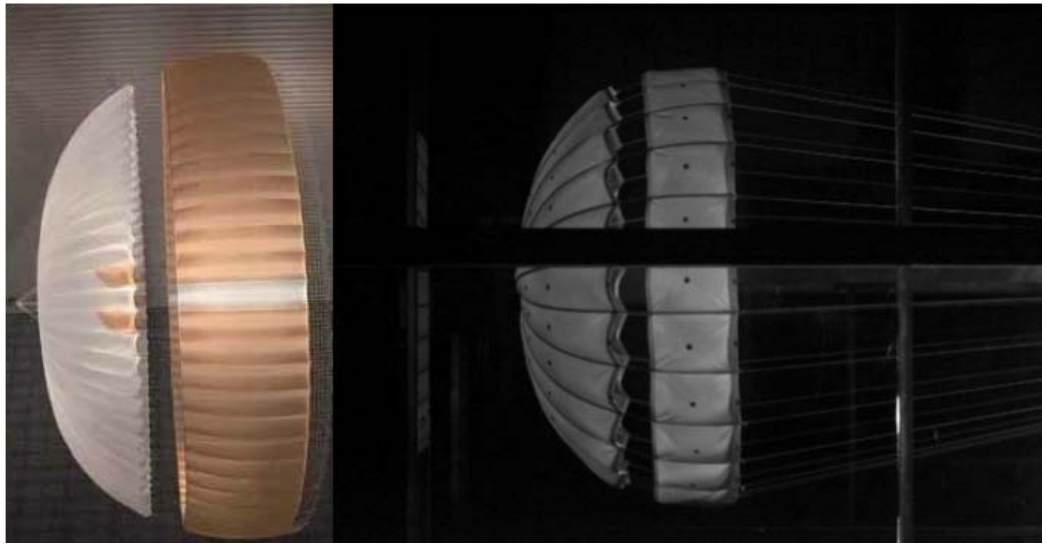
Configuration	Do (m)	x/d	α (deg)	q_{Max} (kPa)	Re_{max}	Reefing Stage
CM only	0.7	3.5,6,8 3.5,6,8 3.5,6,8	0 0 50	4.8	$3x10^6$	N/A
Parachute with no CM*	0.7	N/A	N/A	4.8	10^5	Open 1st 2nd
Two Parachutes with no CM*	0.7	N/A	N/A	4.8	10^5	Open 1st Open and 1st
Single Parachute with CM	0.7	6,8,9.5 6,8,9.5 6,8	0 30 50	4.8 4.8 4.8	$3x10^6$	Open, 1st, 2nd Open, 1st, 2nd Open
Two Parachutes with CM	0.7	6 6 6 6 6 6	0 0 0 30 30 30	4.8 4.8 4.8 4.8 4.8 4.8	$3x10^6$	Open, 1st 1st and 2nd Open and1st Open 1st Open and 1st



DGB Test Article for MSL (3.7% scale)







AIAA, Kandis, M. et al.

Conical Ribbon Test Article for Orion (10% scale)

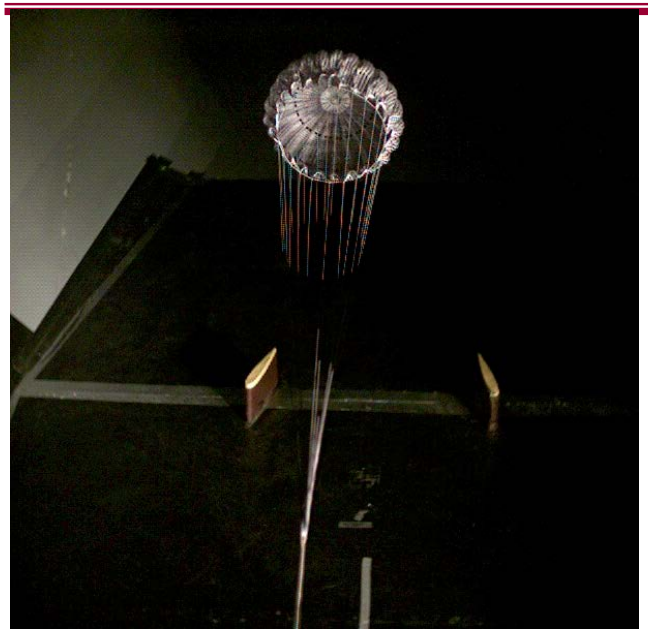
- Laser cut gore to simulate ribbons
- 1st, and 2nd stage reefing was accomplished with a skirt reefing line

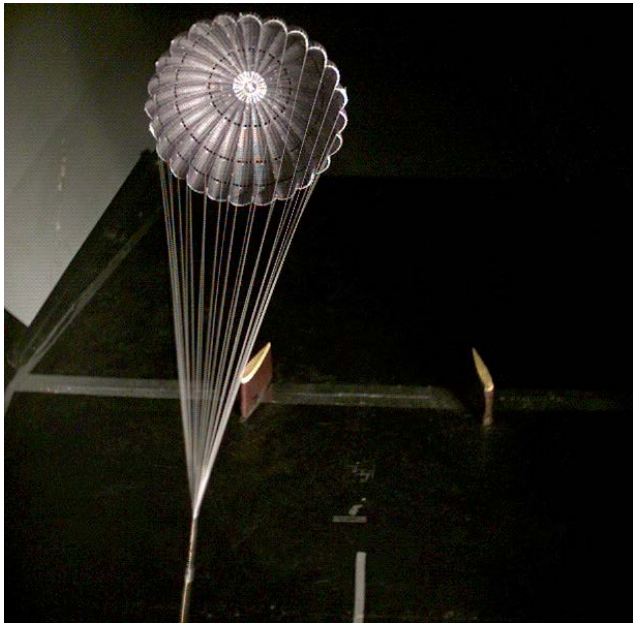
Parameter	Symbol	Full Scale	Subscale
Parachute Type	---	VPCR	VPCR
Nominal Diameter (m)	D_o	7	0.7
Number of Gores	---	24	24
Number of Ribbons	---	52	52
Geometric Porosity	---	19.2%	19%
Trailing Distance	x/d	6	6-9.5
Suspension Line Length	L_s	$1.5D_o$	$1.5D_o$
Reefing Ratio (%)	RR	48-70	48-70
Reynolds Number ($x10^6$)	Re	1-7	3
Dynamic Pressure (kPa)	Q	1.4-8	0.1-4.8
Mach Number	M	0.1-0.7	0.1-0.3

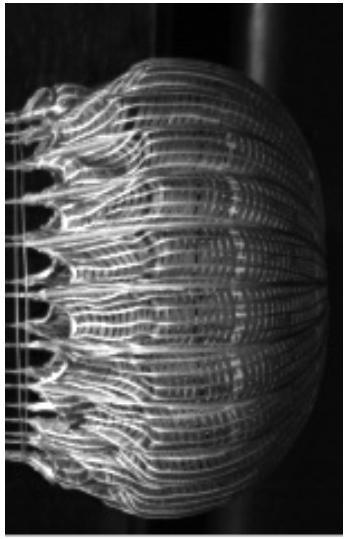
Subscale Gore Layout

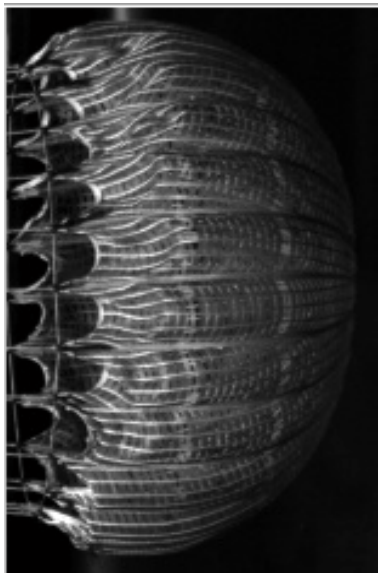
Full Scale

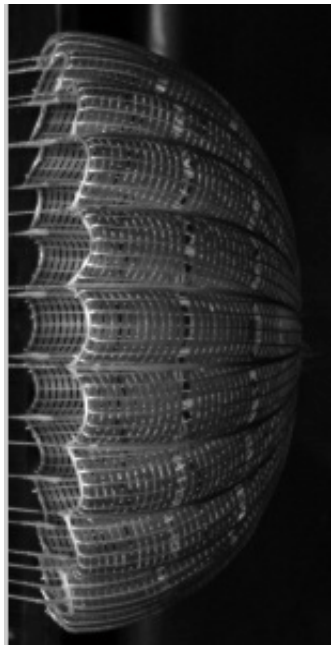
Reefing of Subscale Test Articles





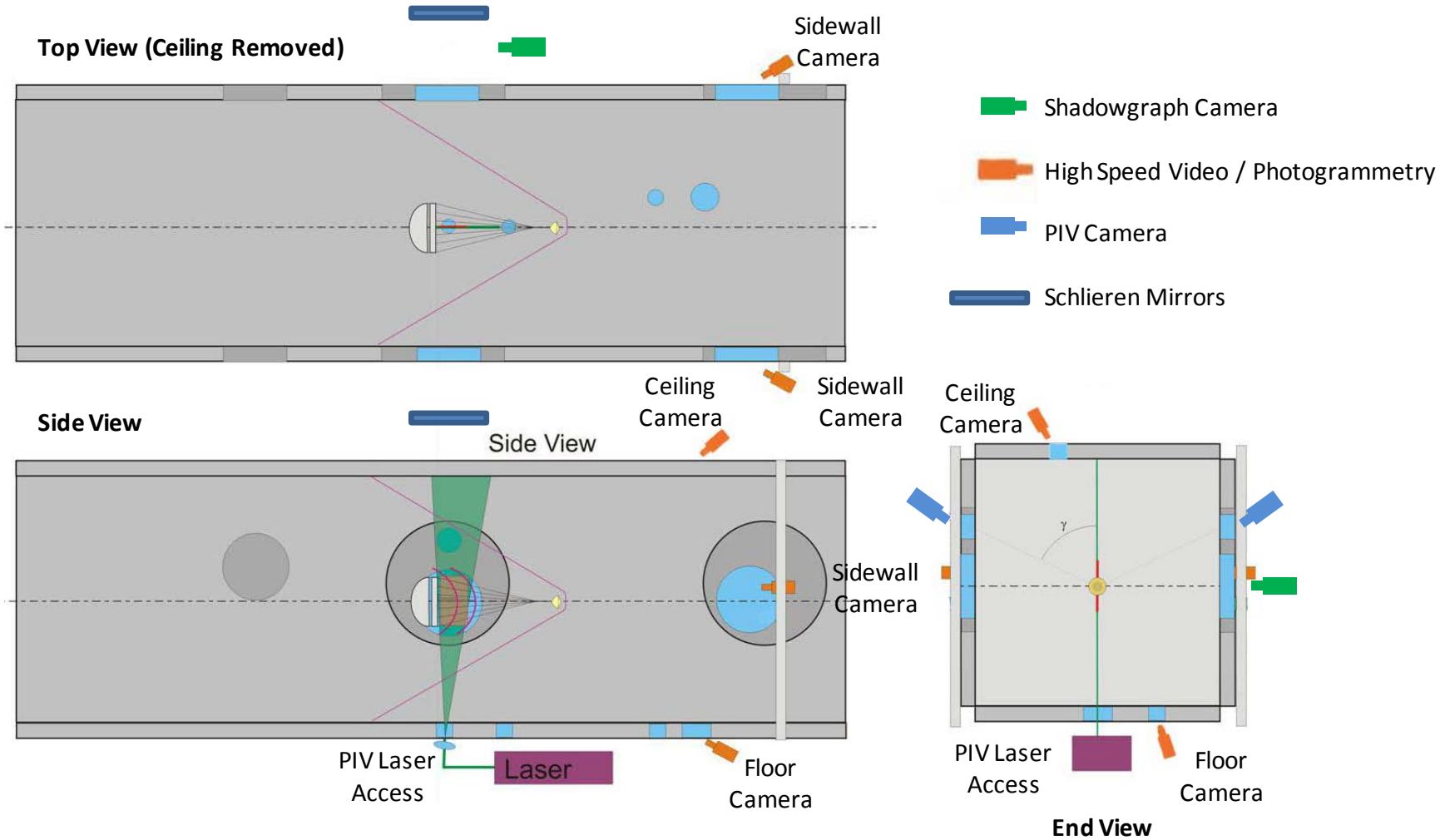






- Profile views of the first stage reefed, second stage reefed, and unreefed 10% Orion Conical Ribbon Drogue parachute
- Enables investigation of parachute failure scenarios (partial disreef, one failed)

Nonintrusive Optical Diagnostics



Sengupta et al.

Stereo Particle Image Velocimetry

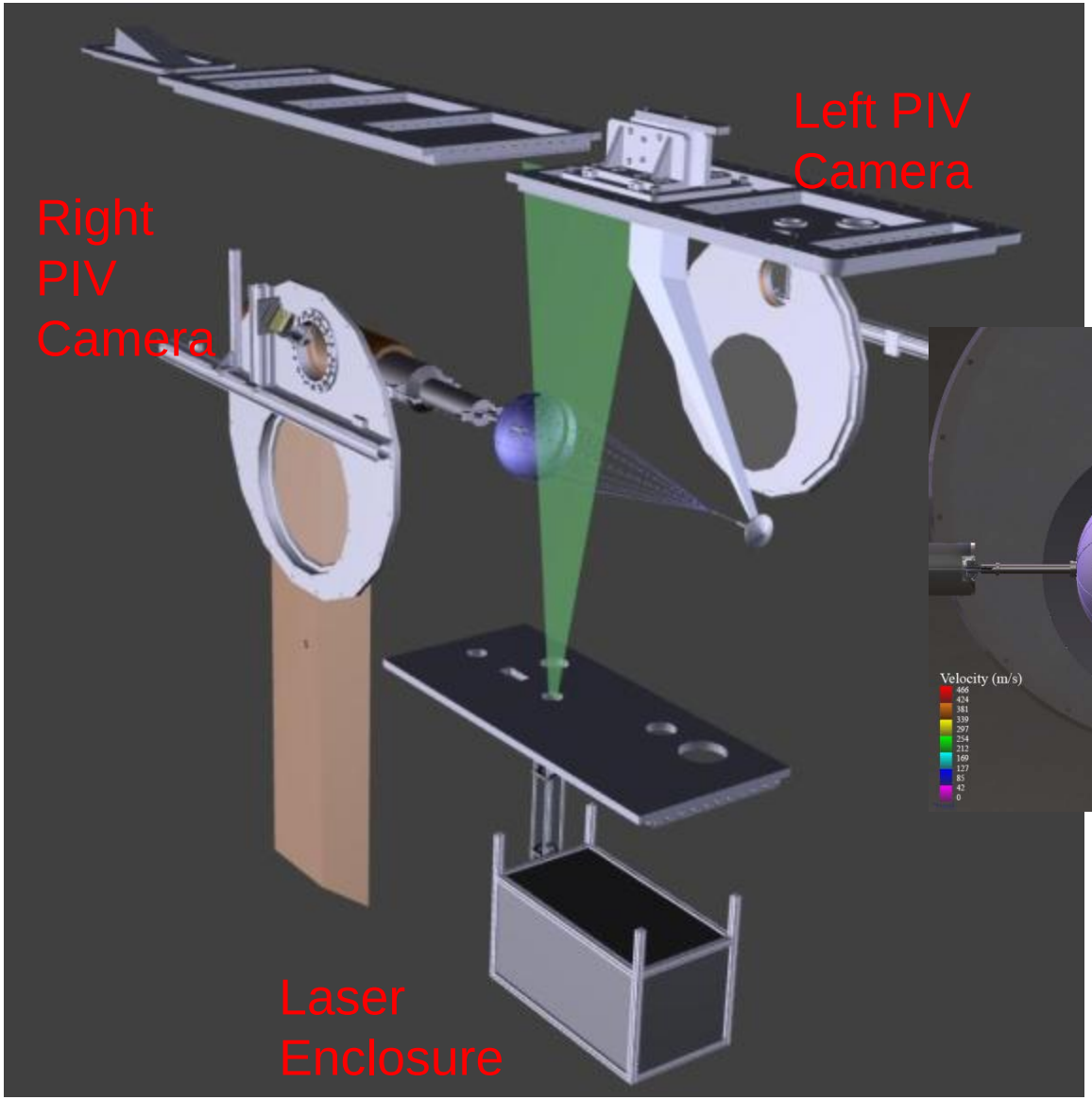
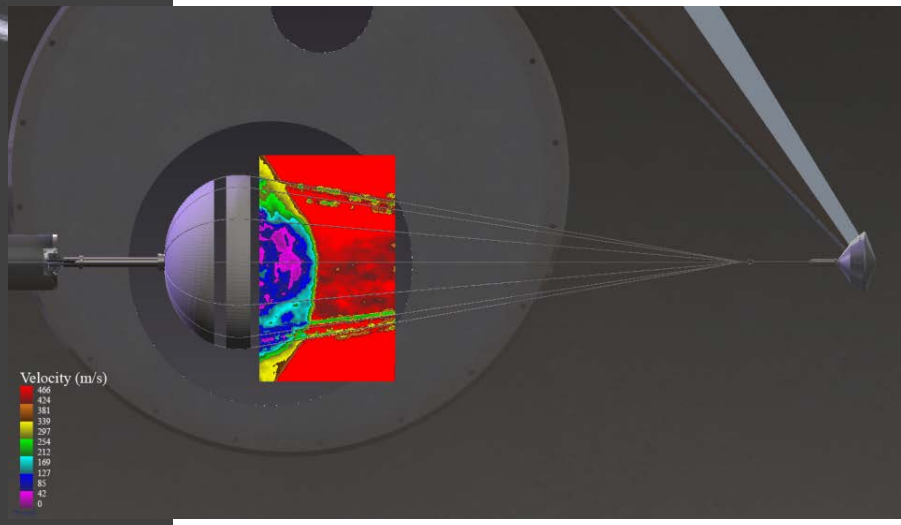
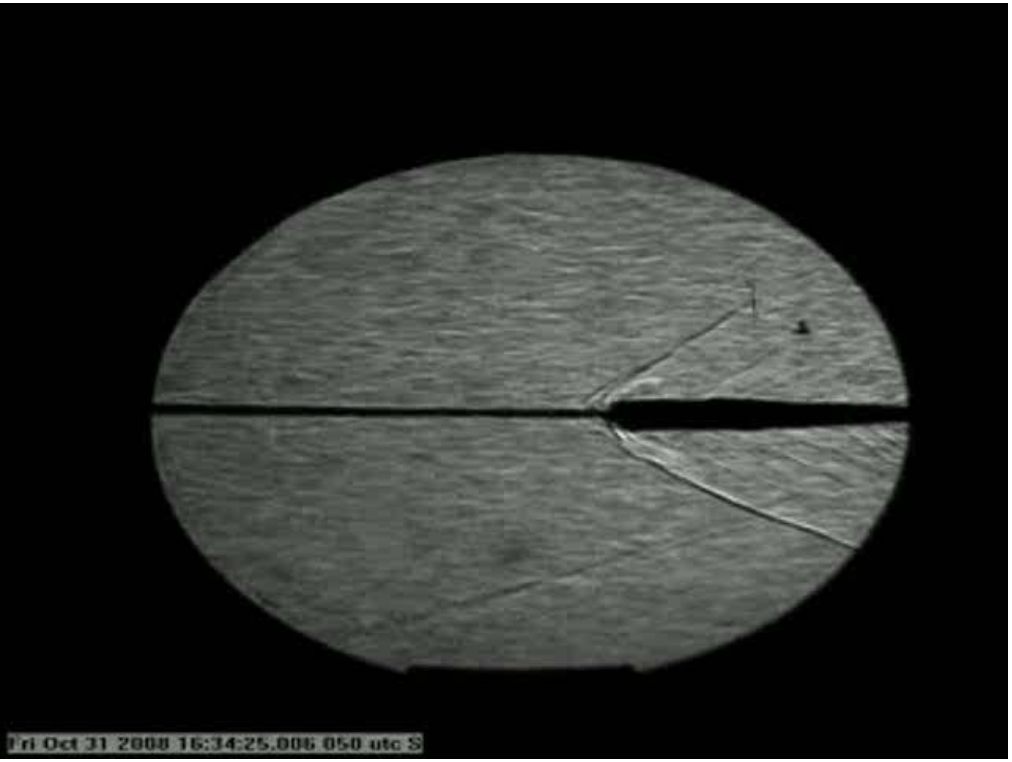


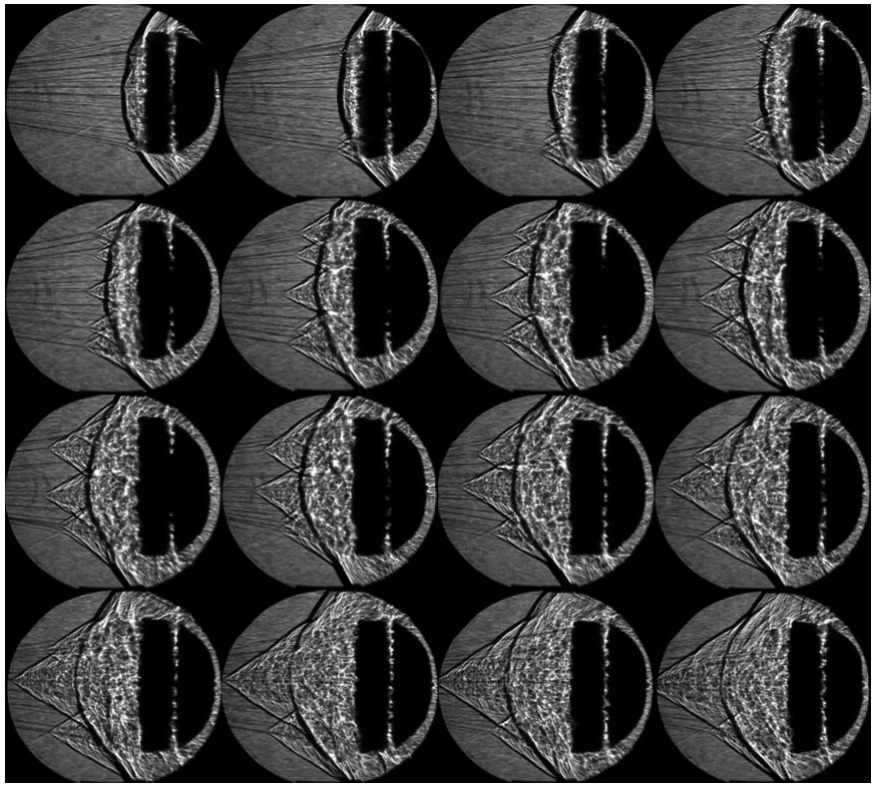
Image plane of x/d=6 to 10



Wernet et al, 2009, AIAA.

Shadowgraph and Schlieren Provides Unique Insight into FSI

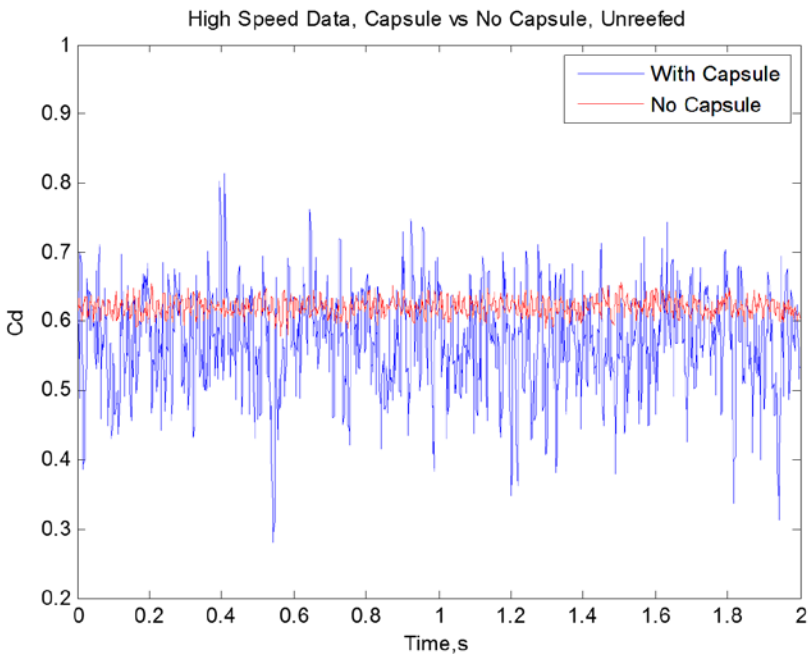


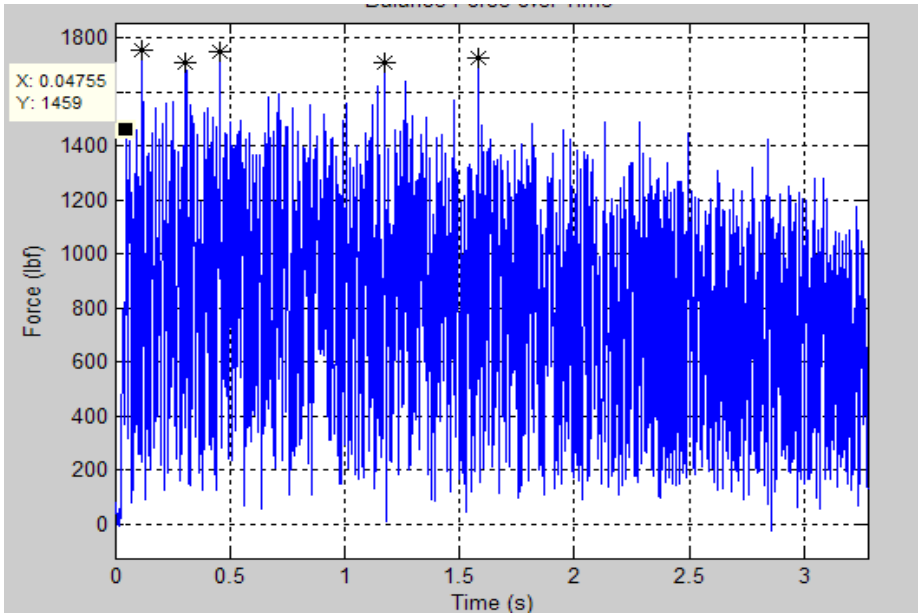


Sengupta et al.

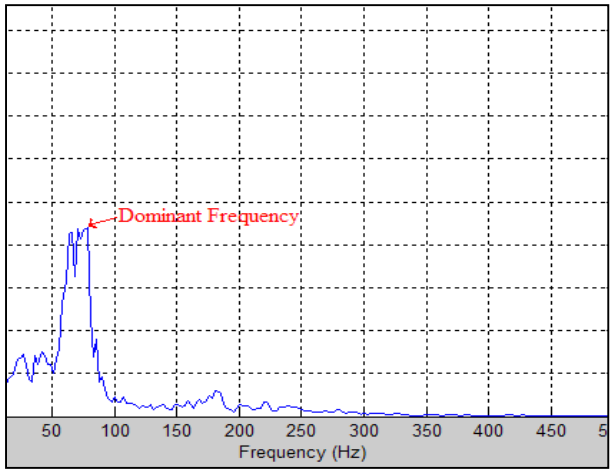
Quantification of the Wake Effect

Time Resolved Load

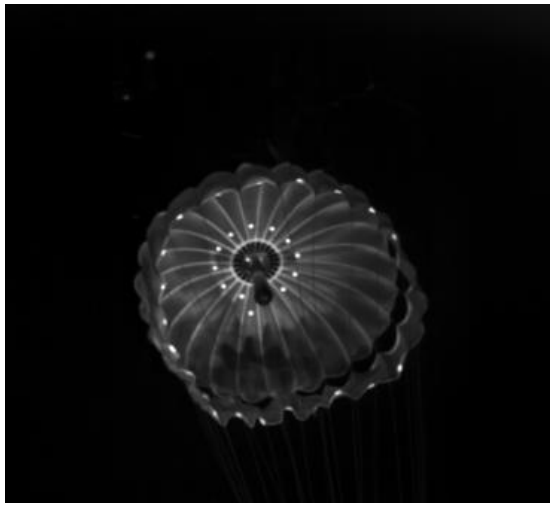


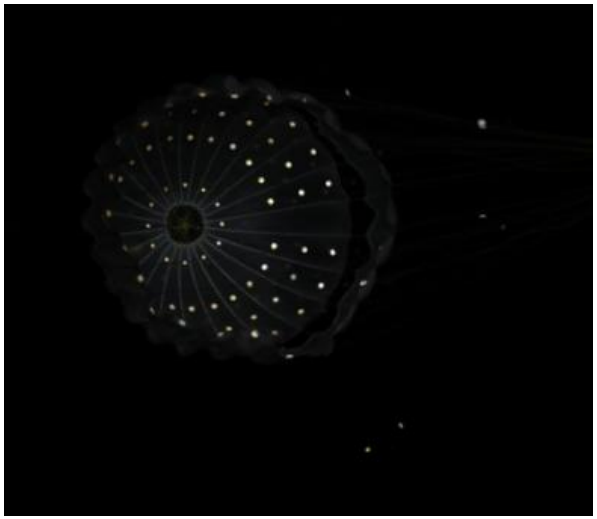


- Wake effect makes dynamic drag the structural driver and performance limiter

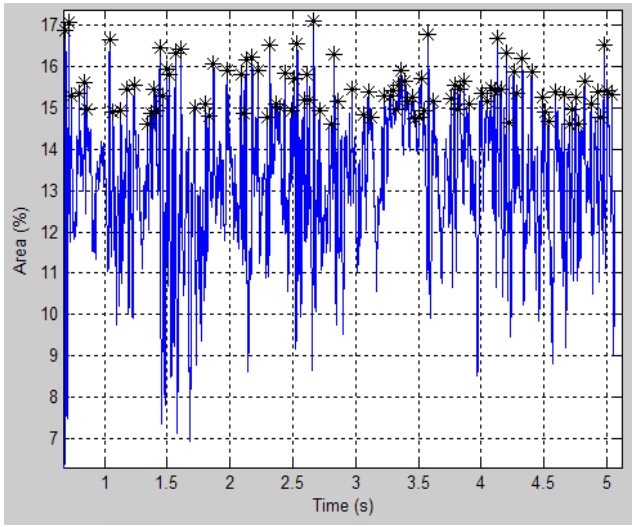


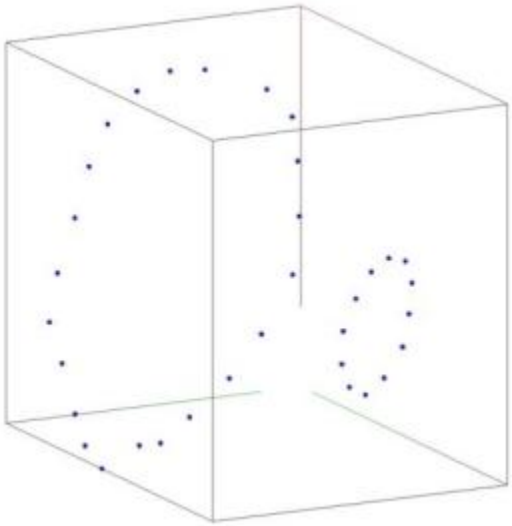
High Speed Video Allows Shape Measurement with Photogrammetric Reconstruction



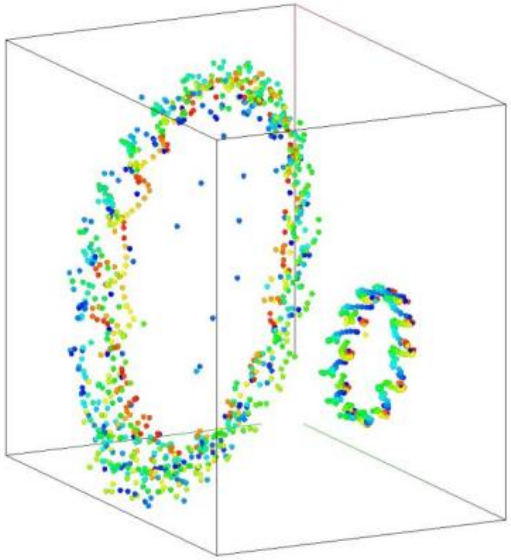


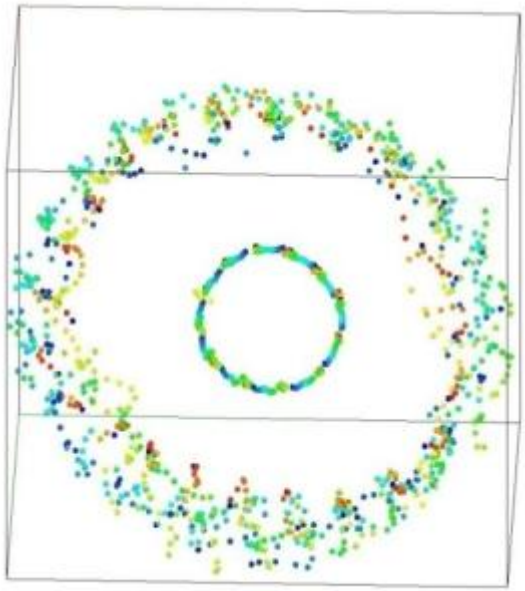
Mach 2.2 Re= 2e5





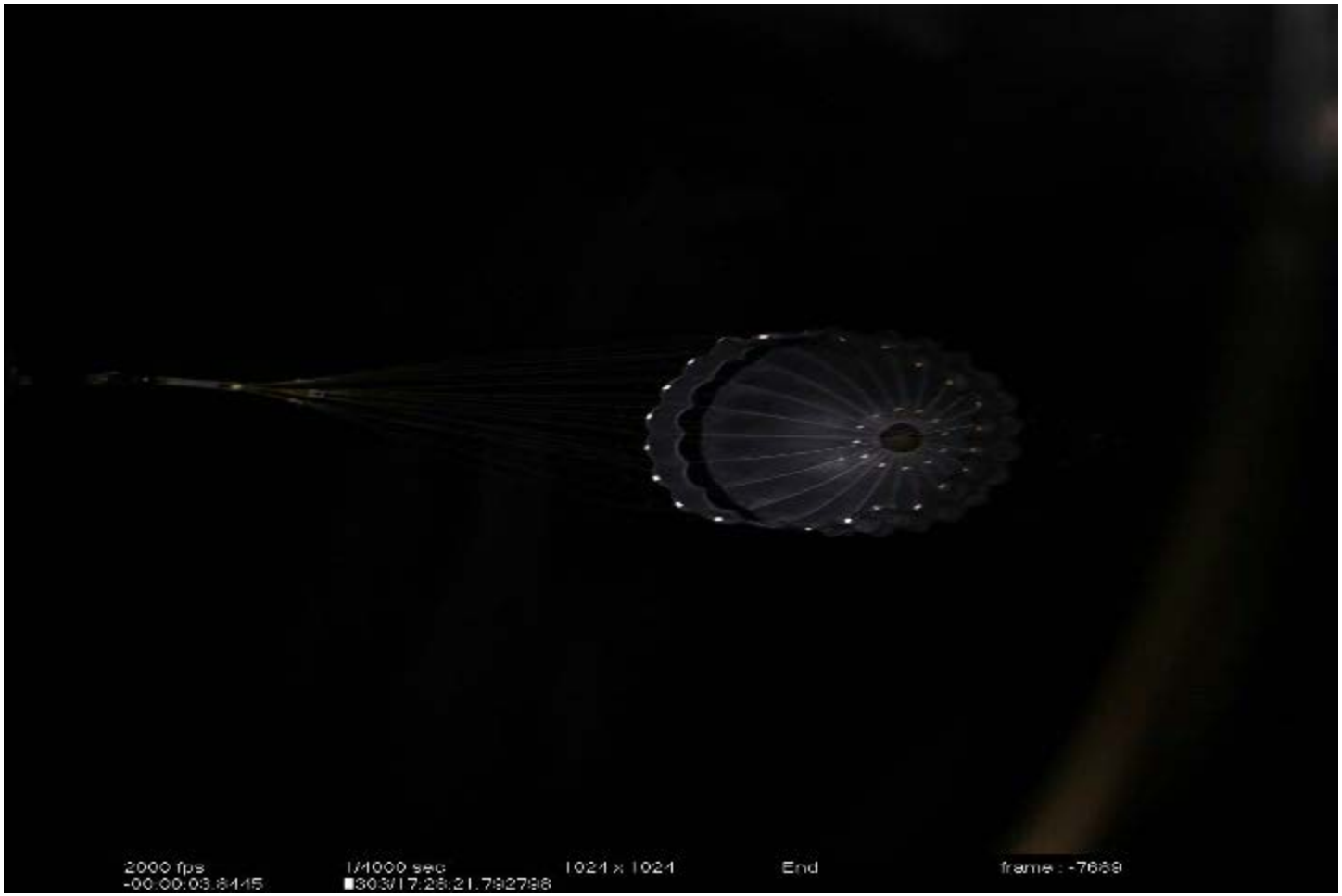
1 Frame





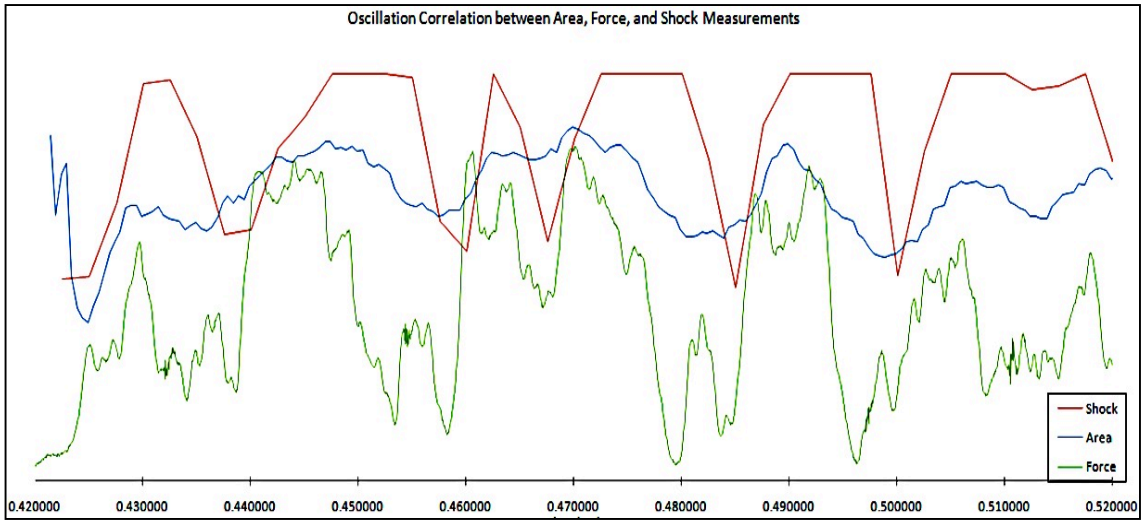
50 Frame Sample

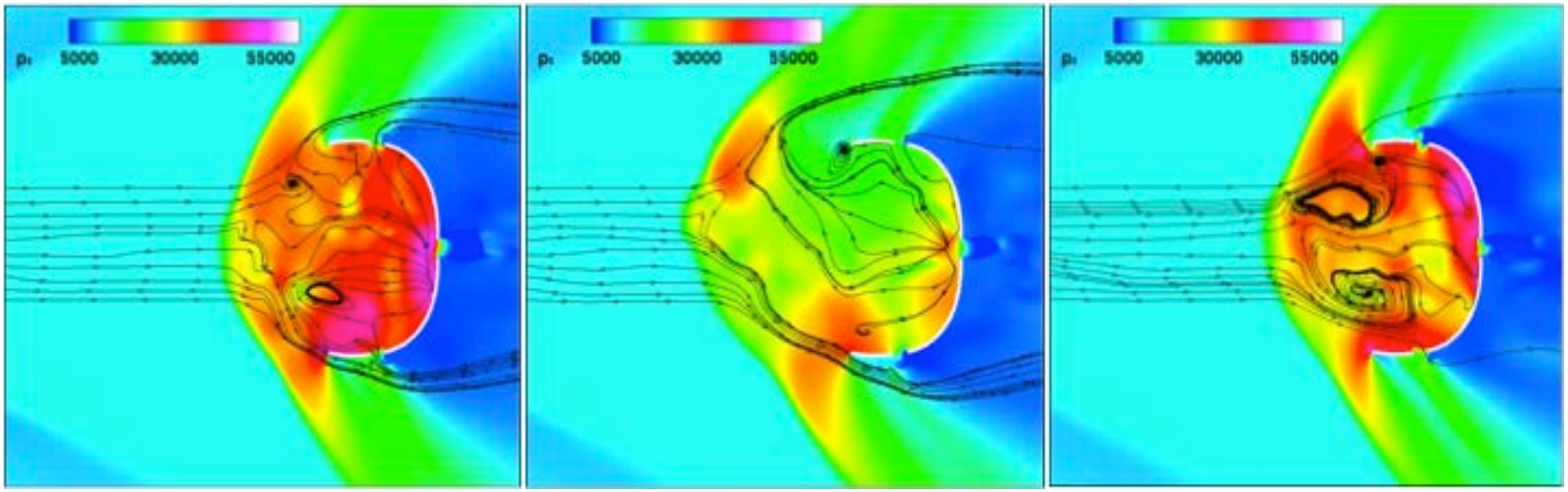
High Speed Video



Common Timing Reference for Temporal Correlation of all chute behavior

(1) Canopy starts in high pressure state
(2) Shock moves upstream becoming conical, diverting the streamlines, and depressurizing the canopy,
(3) Shock collapses, the streamlines re-enter the canopy and re-pressurization occurs





Barnhardt et al, (2007)

Conclusions and Lessons Learned

- Deployment of the Parachute is very complex supersonically
- Need to trade Reynolds number effects with dynamic pressure as it effects flow field and test article design
- The temporal behavior of parachutes is important both in terms of drag performance and survivability
  - It is critical to temporally resolve this regime to capture the dynamic variation in drag and parachute motion that is hidden in the averaging process of drag coefficient and static stability coefficient determination.
  - Temporal aspect may lead to 45% higher load than the mean, resulting in a structurally challenging environment for the textile materials.
- Dependence on Reynolds number is evident in both the amplitude and frequency of the load and area variation
- Increased turbulence in the wake results in reduced parachute lifetime and drag performance, for the same Mach number
- The results of these programs suggest that non-dimensional aerodynamic and geometric parameters are valid in understanding the physics of subsonic and supersonic flight in the regime of interest to a Mars and Earth deployments.