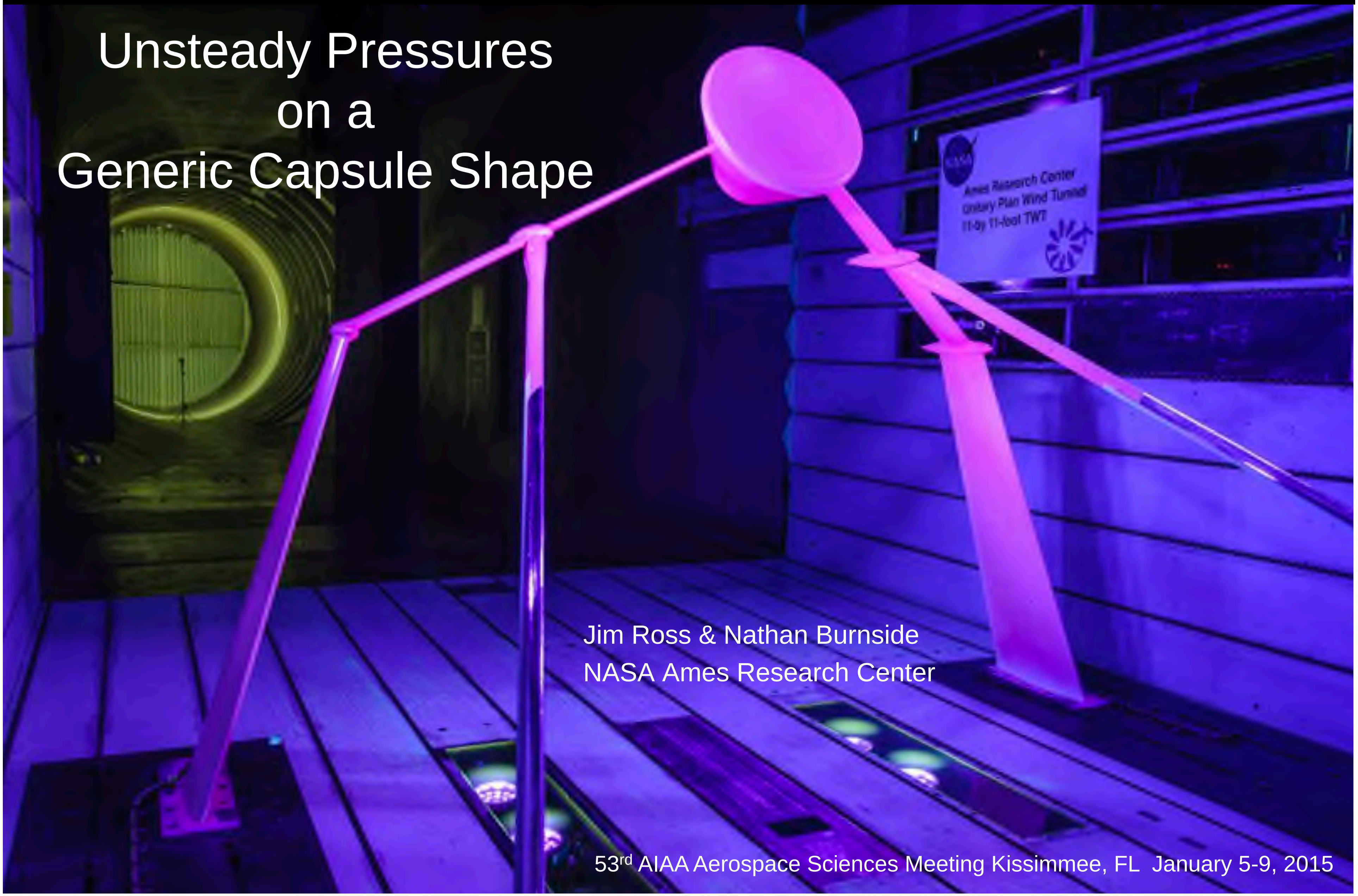
National Aeronautics and Space Administration

Unsteady Pressures on a Generic Capsule Shape



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Outline

- Background
- Test Objectives
- Test Description
  - Model design
  - Instrumentation
  - Flow conditions tested
- Unsteady Pressure Processing
- Selected Results
- Concluding Remarks

Background

- Agreement between CFD and experiments for Orion CM was poor below Mach 0.7
  - Uncertainty in the CFD-determined capsule flow
  - Wind-tunnel and CFD did not match low-M results from pad-abort flight test
- Wind-tunnel testing of Orion showed boundary-layer state on heat shield significantly affected CM aerodynamics
  - Reynolds number sensitive for Mach numbers below about 0.7
  - Method of tripping flow also had an effect on the aerodynamics
- NASA Engineering and Safety Center funded study to make measurements on and around an idealized Orion Crew Module shape
- General test overview and preliminary results
  - Ross, J. C., et al., "Comprehensive Study of the Flow Around a Simplified Orion Capsule Model," AIAA paper 2013-2815, 31st AIAA Applied Aerodynamics Conference, San Diego, CA, June 24-27, 2013.

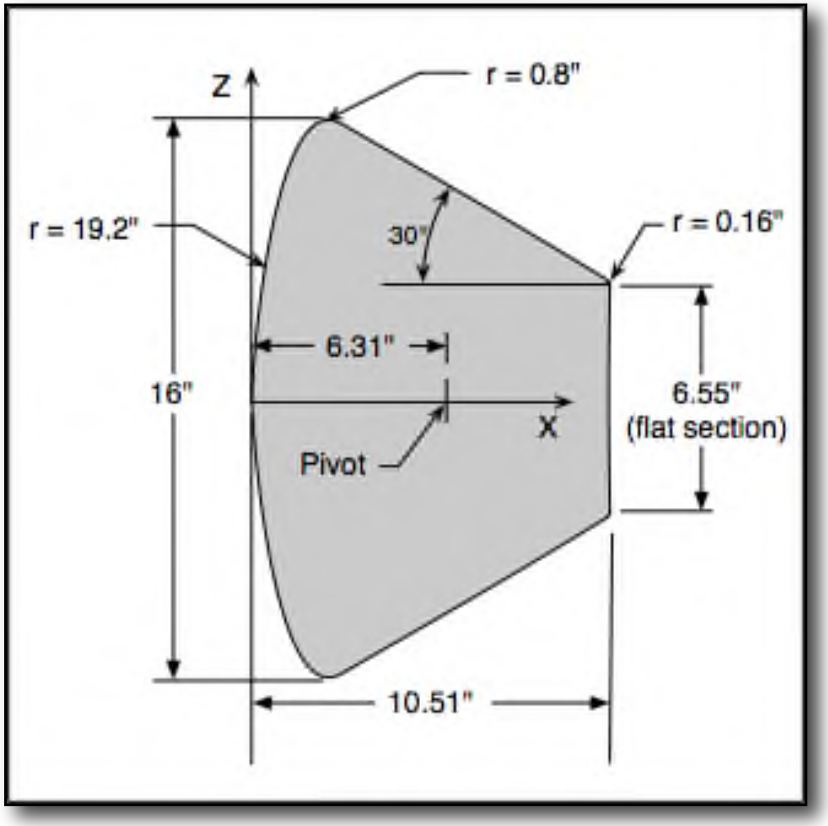
Objectives

- Detailed characterization of the flow around a capsule shape for subsonic/transonic flight
- Document effect of heat-shield roughness
  - Post-entry Avcoat is very rough
- Comprehensive measurement suite
  - **44 Unsteady pressures around heat-shield shoulder and on back shell**
  - Wake velocity from near the capsule to ~5.5 capsule diameters downstream - Particle Image Velocimetry (PIV)
  - Detailed pressure over entire model surface - Pressure Sensitive Paint (PSP)
  - Boundary-layer transition and separation locations - IR Thermography
  - Boundary-layer profiles at one location on the heat shield
  - High-speed shadowgraph videos (6,000 frames per second)

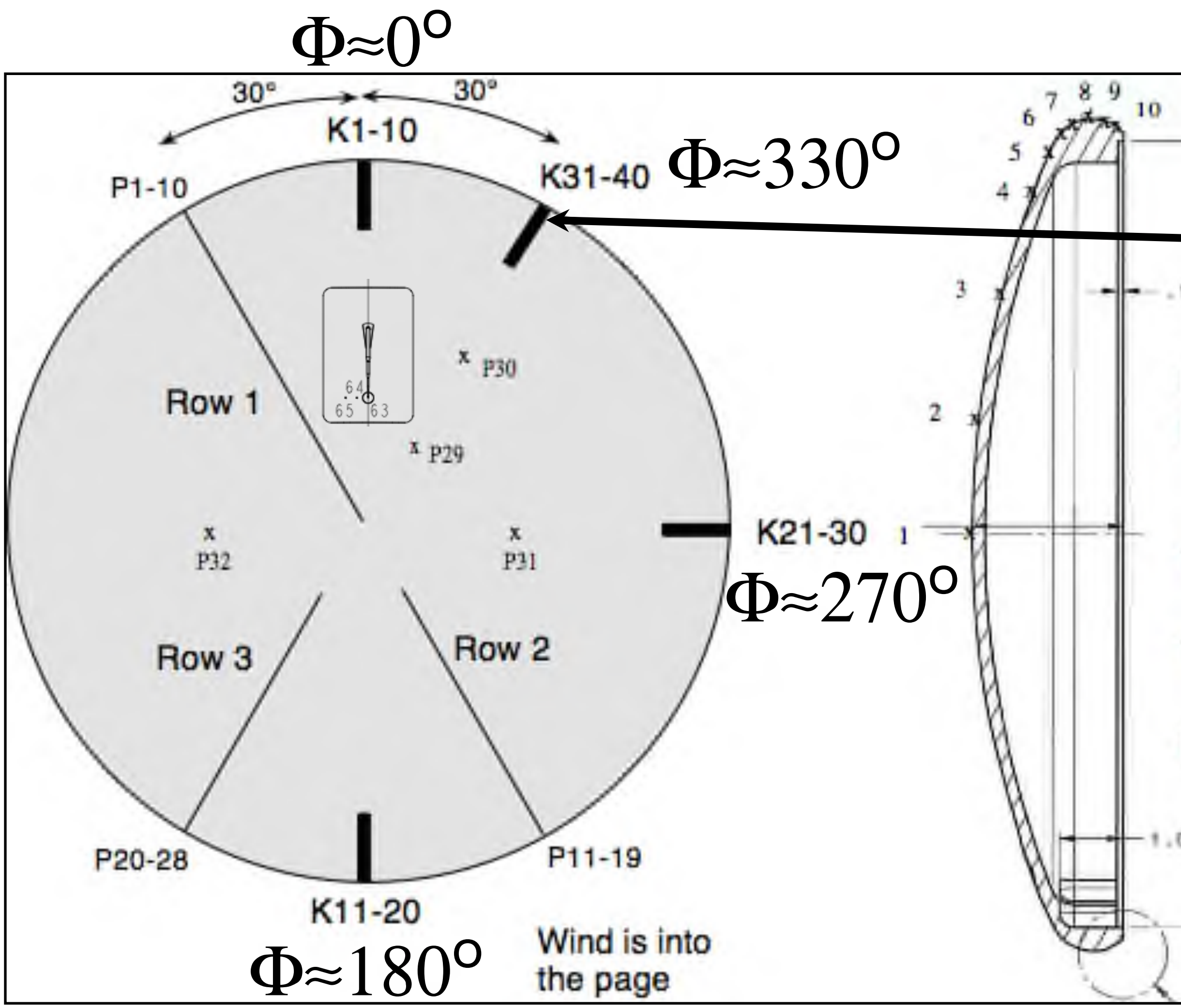
Model Description

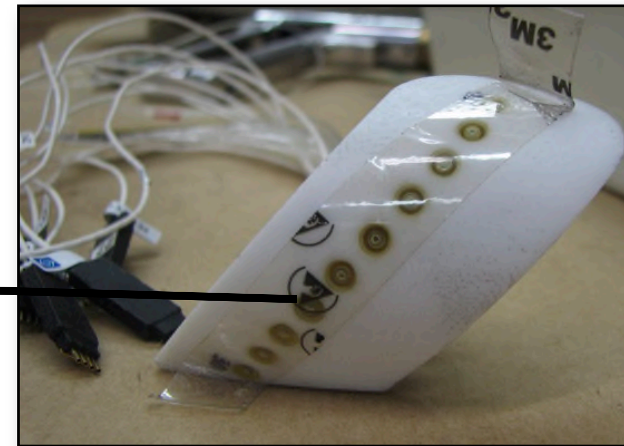
- Model is axi-symmetric based on the analytic description of the Orion CM
  - Smooth heat shield
  - Rough heat shield to represent post-entry Avcoat roughness pattern
- Struts used for support
  - Side entry to keep the strut wakes out of measurement plane
  - Stiff support to minimize model deflections and motion
  - Provide optical access for all of the cameras

Model Definition



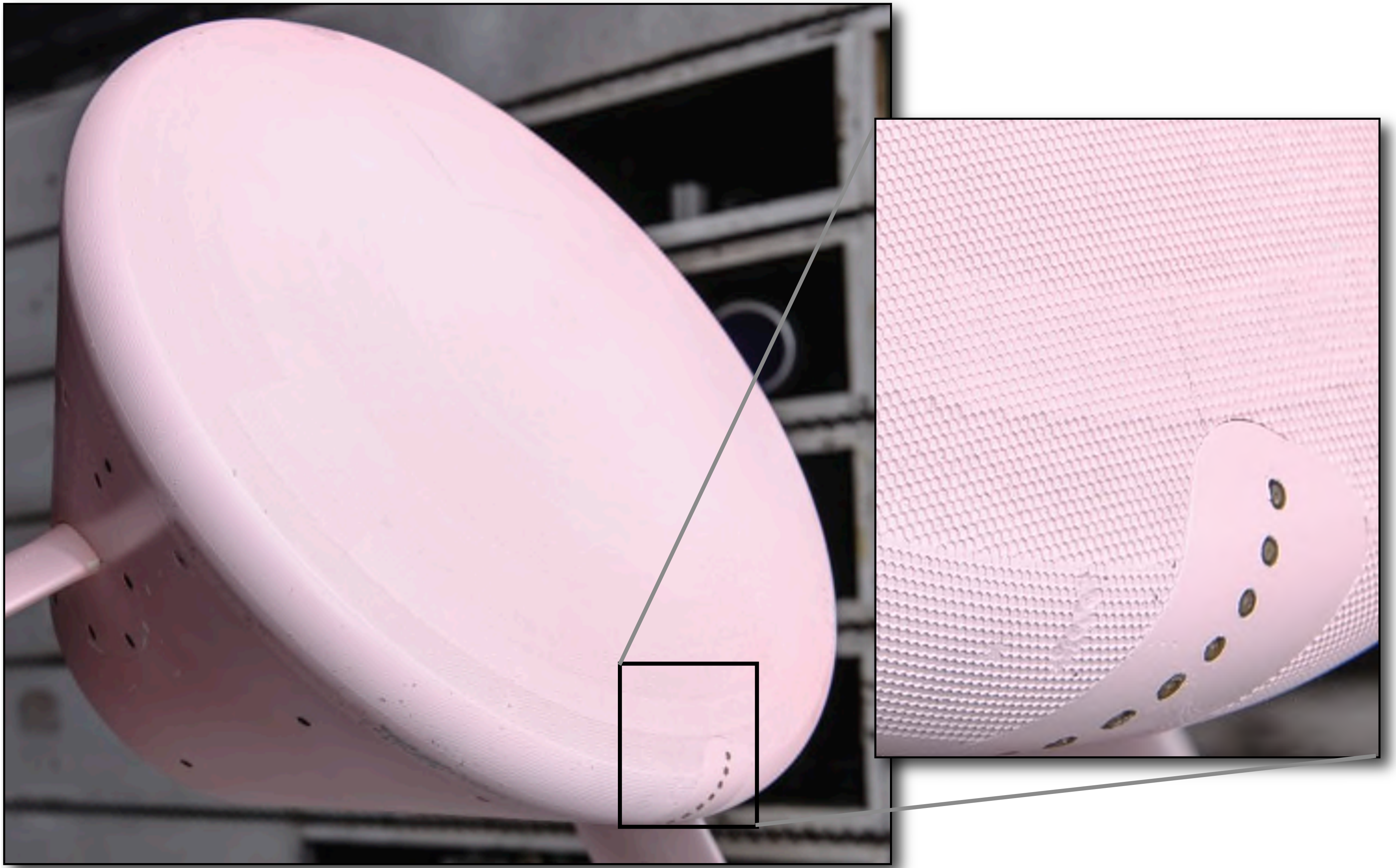
Heat Shield Details





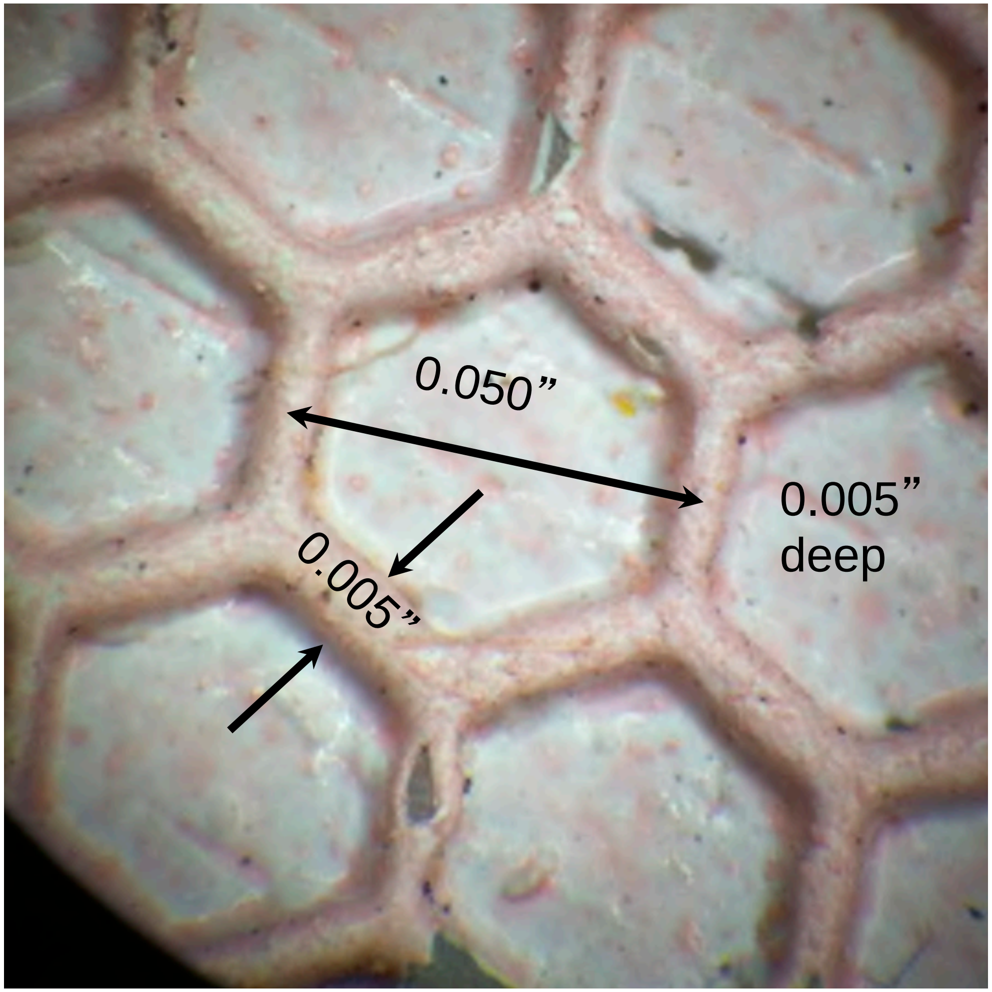
- Two-layer heat shield fabrication
  - ! ” aluminum structural layer
  - ! ” polycarbonate outer surface
- Provides enhanced IR signatures for transition/separation visualization

Rough Heat Shield

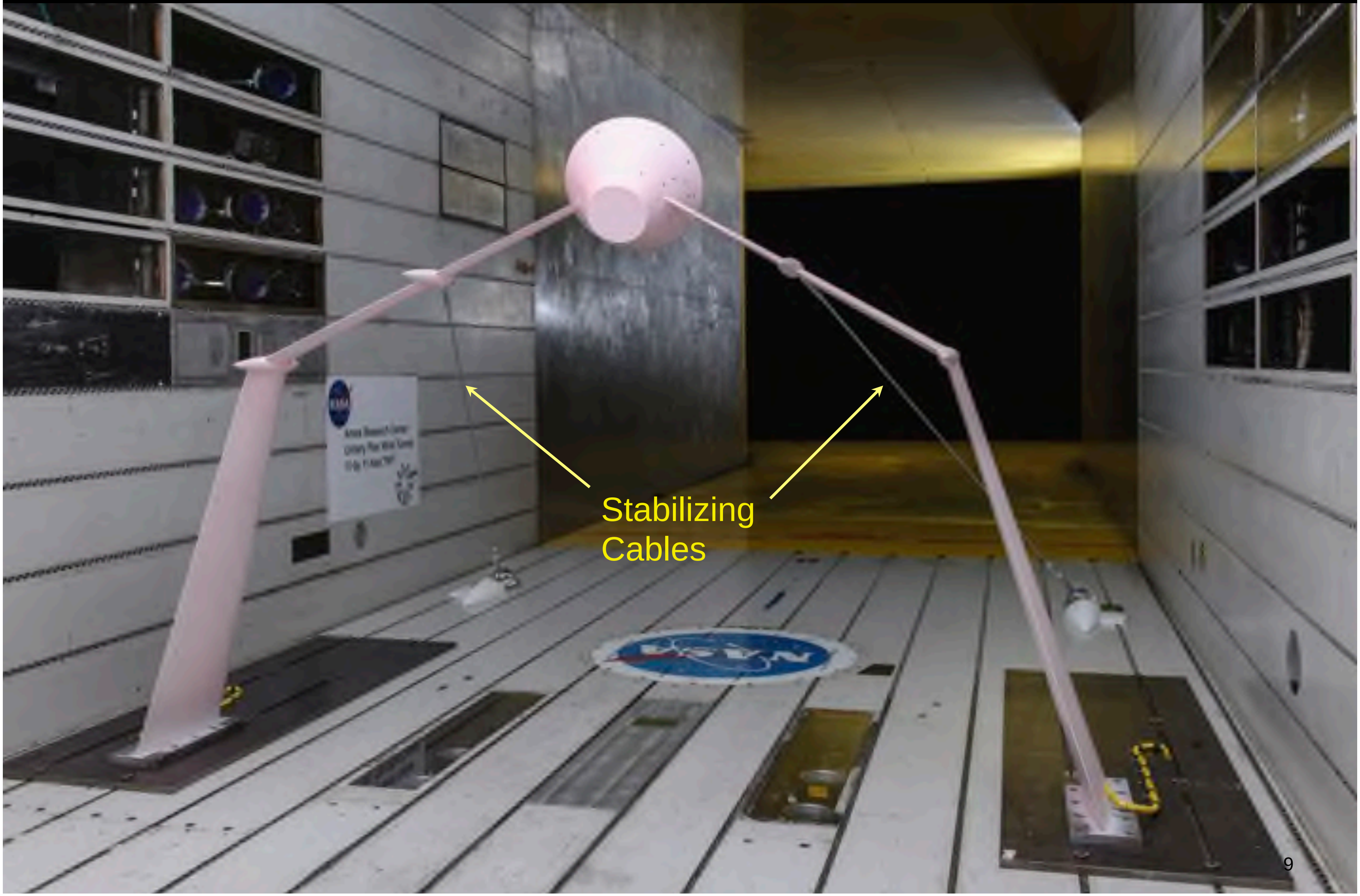


Micrograph of Dimpling

- Hex pattern scaled from post-entry Avcoat honeycomb roughness (Orion and Apollo)
- ~75,000 dimples machined into plastic outer layer
- PSP coating ~0.002" thick



Tunnel Installation



Test Conditions for Various Measurements

PSP, IR Thermography, Unsteady Pressures, Shadowgraph

Heat Shield	Angle of Attack	Mach 0.3	Mach 0.5	Mach 0.7	Mach 0.9	Mach 1.05
Smooth	30°			1.3×10^6		1.3×10^6
Smooth	30°	5.3×10^6	8.7×10^6	10×10^6	10×10^6	6.6×10^6
Rough	15°	5.3×10^6	8.7×10^6	10×10^6	10×10^6	6.6×10^6
Rough	30°			1.3×10^6		1.3×10^6
Rough	30°	5.3×10^6	8.7×10^6	10×10^6	10×10^6	6.6×10^6

Boundary-Layer Surveys, Skin Friction, IR Thermography

Heat Shield	Angle of Attack	Mach 0.3	Mach 0.5	Mach 0.7	Mach 0.9	Mach 1.05
Rough	0°	5.3×10^6	8.7×10^6	10×10^6		
Rough	15°	5.3×10^6		10×10^6		6.6×10^6
Rough	30°	5.3×10^6		10×10^6		6.6×10^6

PIV, Unsteady Pressures, Shadowgraph - Rough heat shield

Model Position	Angle of Attack	Mach 0.3	Mach 0.5	Mach 0.7	Mach 0.9	Mach 1.05
Downstream	15°	5.3×10^6	8.7×10^6	10×10^6		
Upstream	15°	5.3×10^6	8.7×10^6	10×10^6		

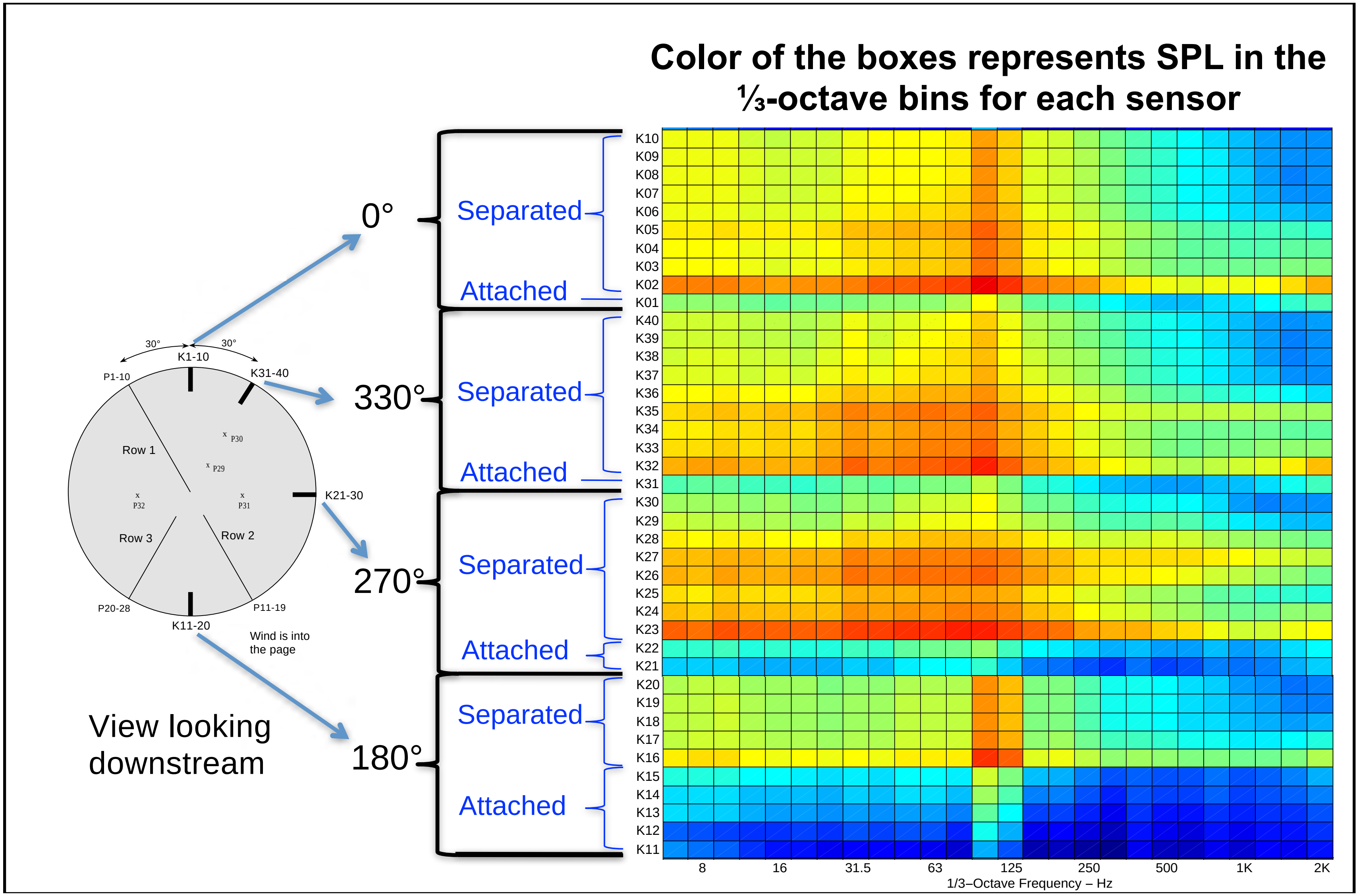
Numbers in green boxes indicate Reynolds number tested

Black boxes indicate conditions not tested

Unsteady Processing Parameters

- Sample rate of 6400 samples / sec
  - 2.5 kHz bandwidth
- 4096 point FFT
- 25% overlap
- Energy corrected Hanning window
- 30 to 50 averages
- Cp’ spectra
  - $dB = 20 \log_{10}(Cp')$

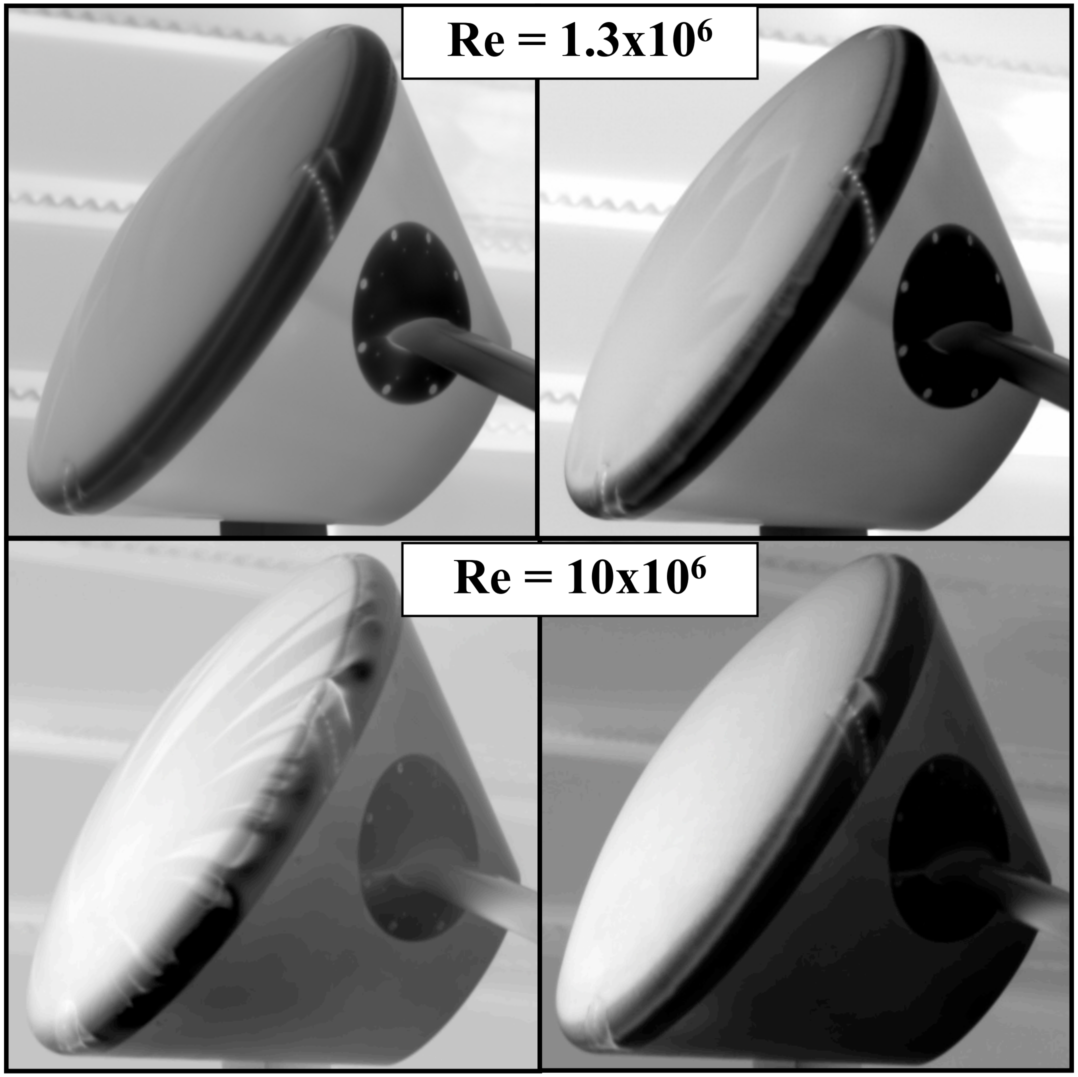
Separation
Rough Heat Shield, M 0.7, " = 30°, Re$_D$ = 10x10^6



12

Effect of Heat Shield Roughness on Capsule Flow
M = 0.7, " = 30°, $Re_D = 10x10^6$

Laminar | Transitional

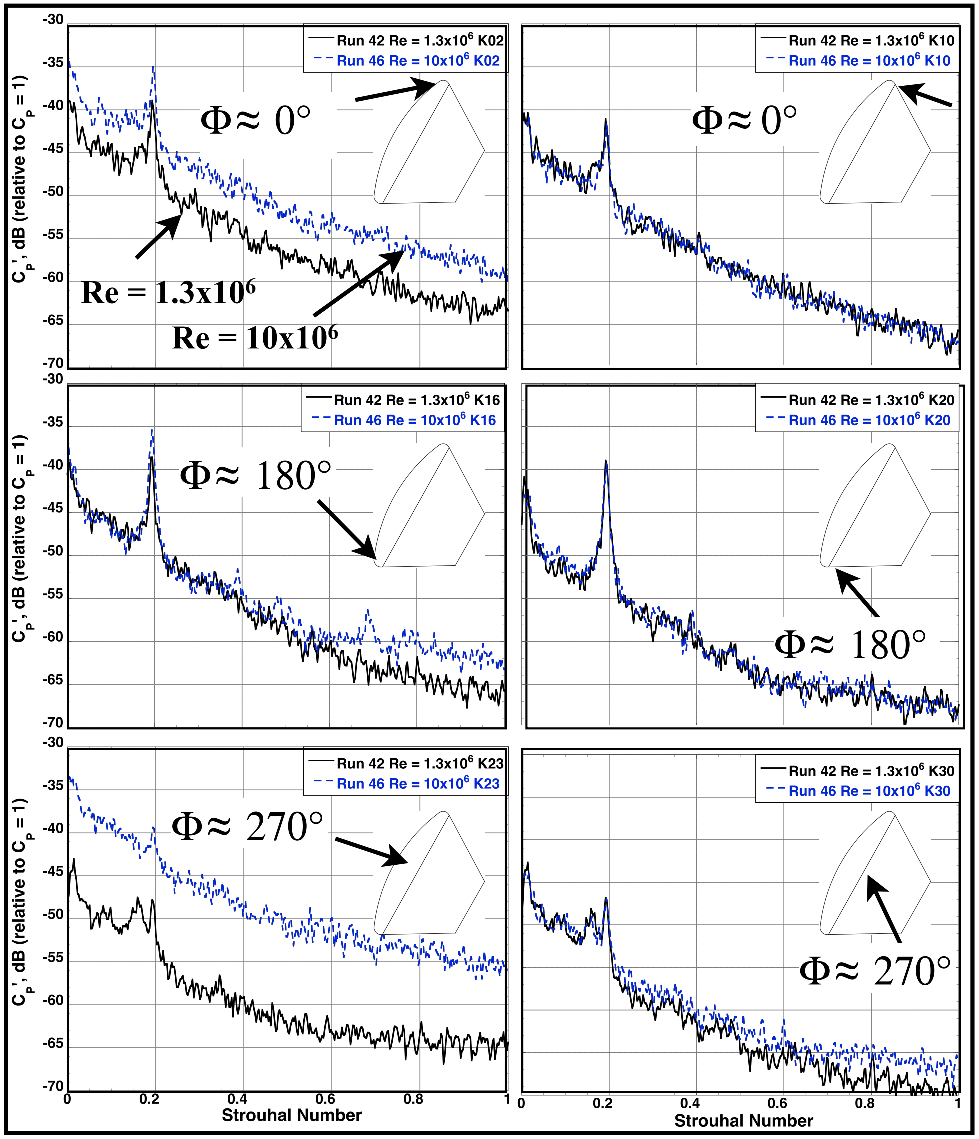


Transitional | Turbulent

Smooth heat shield | **Rough heat shield**

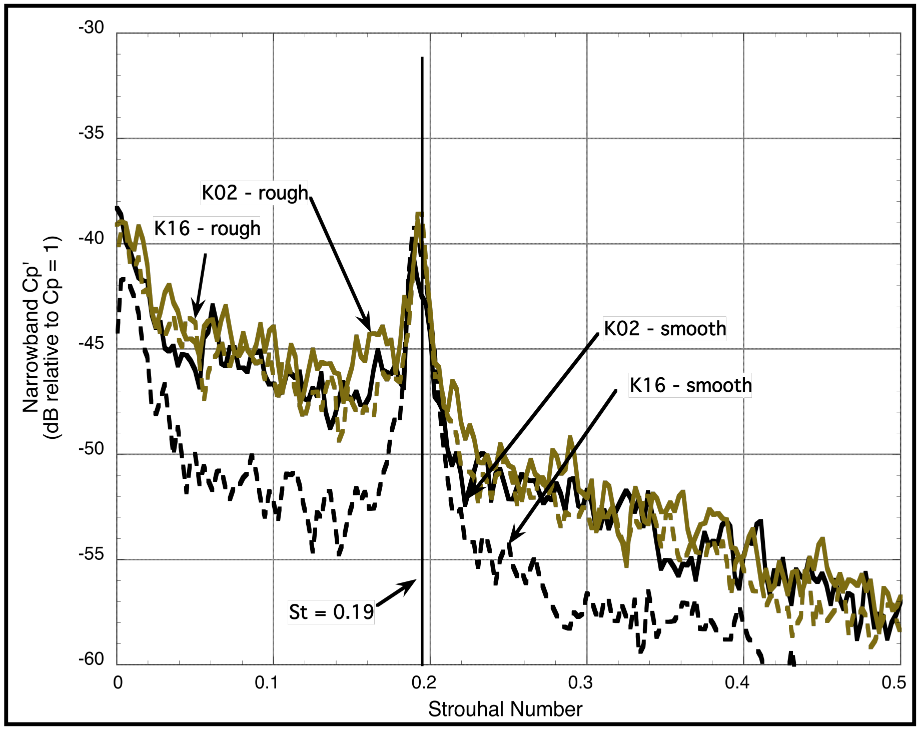
Effect of Reynolds Number on Spectral Amplitude
M = 0.7, " = 30°

Before Separation After Separation

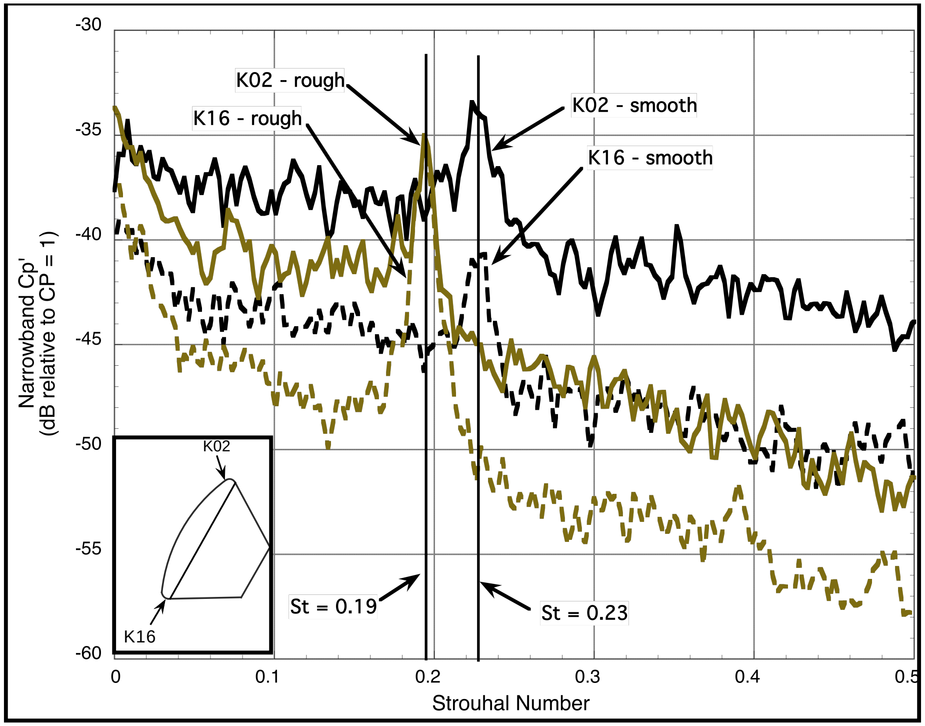


Effect of Reynolds Number on Shedding Frequency
M = 0.7, " = 30°

$Re_D = 1.3 \times 10^6$



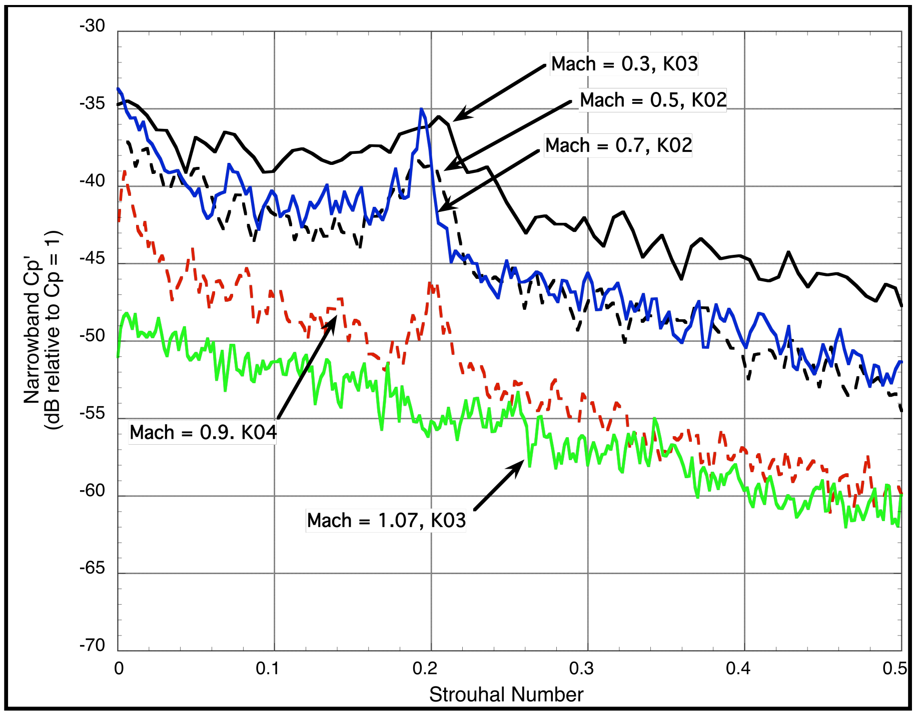
$Re_D = 10 \times 10^6$



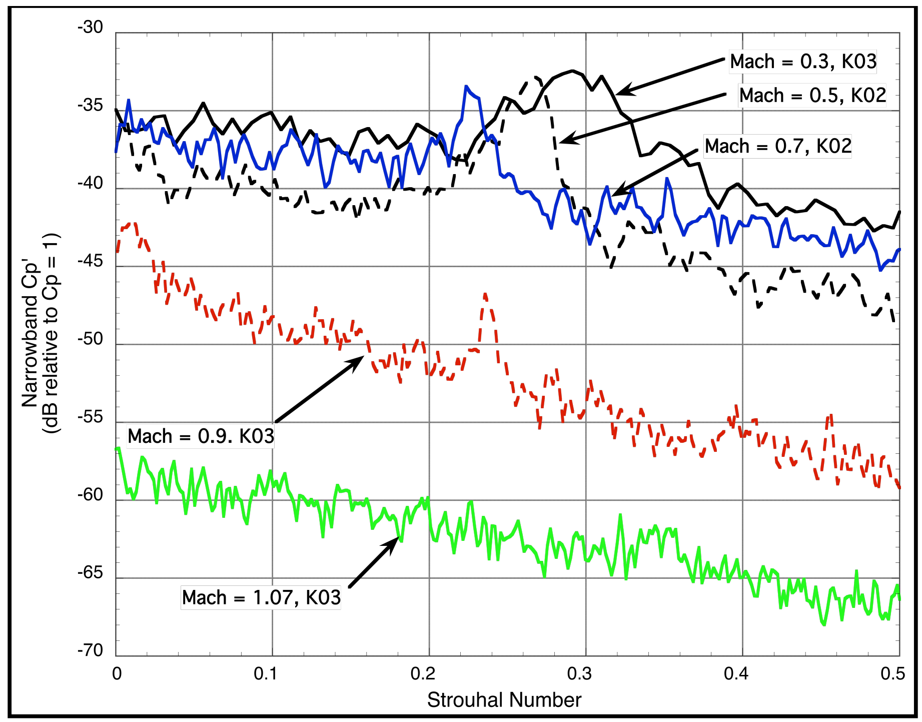
Shih, W.C.L., Wang, C., Coles, D., and Roshko, A., "Experiments on Flow Past Rough Circular Cylinders at Large Reynolds Numbers," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 49, pp. 351-368, 1993.

Effect of Mach Number on Shedding Spectra
" = 30°, # = 0, High Re

Rough

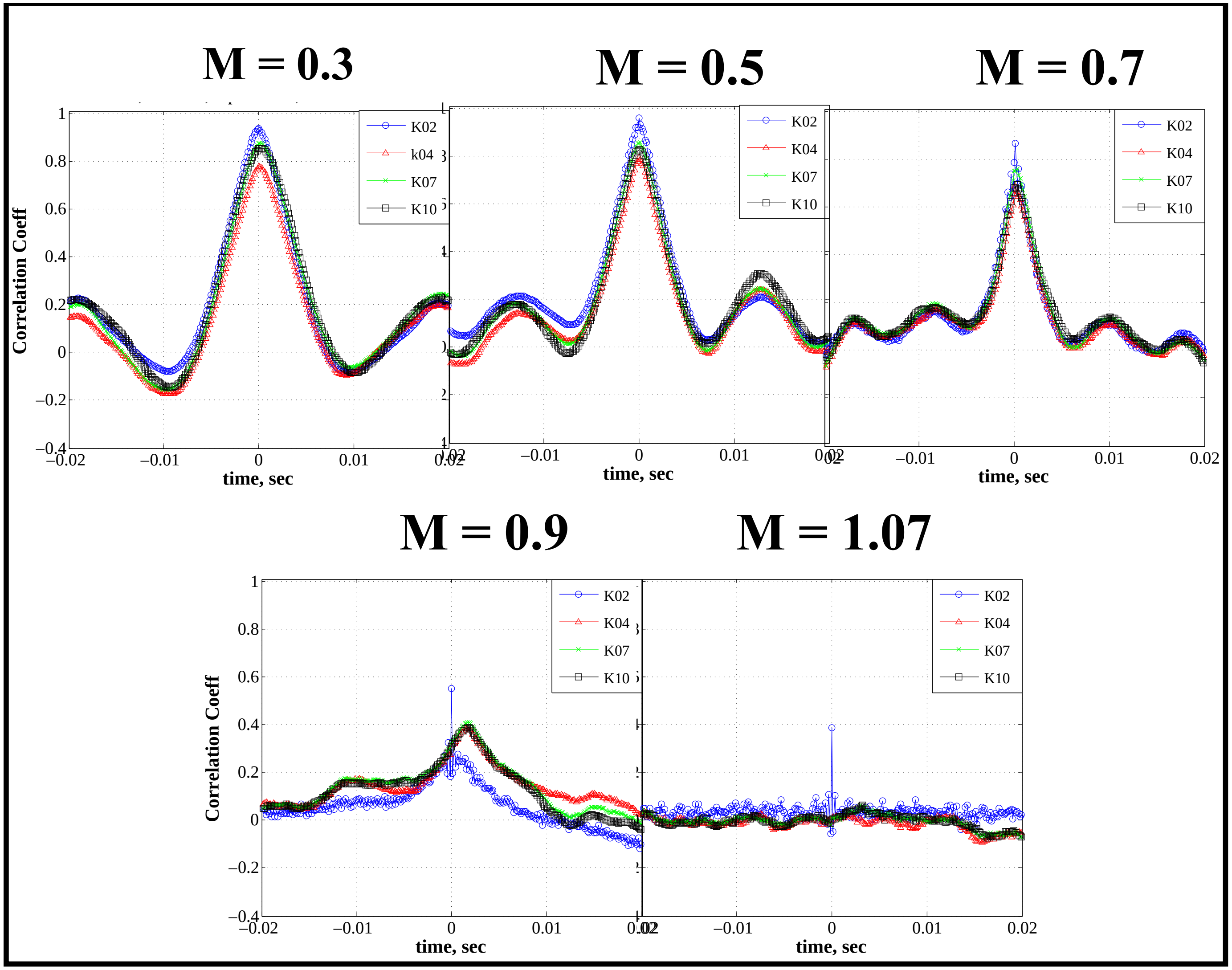


Smooth

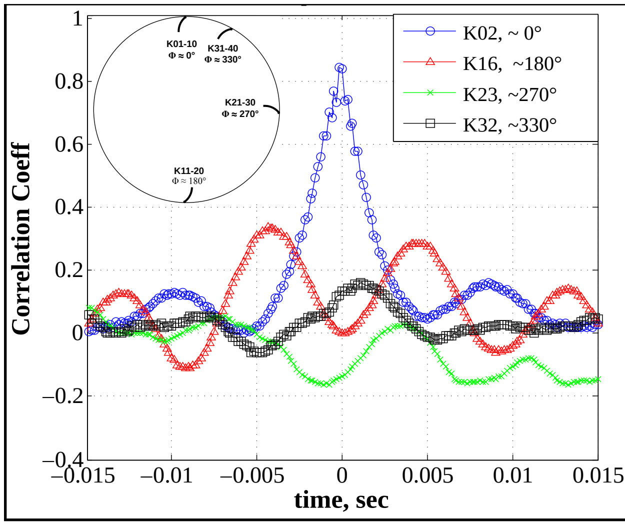


Effect of Mach Number on Azimuthal Correlation
" = 30°, High Re, Rough Heat Shield

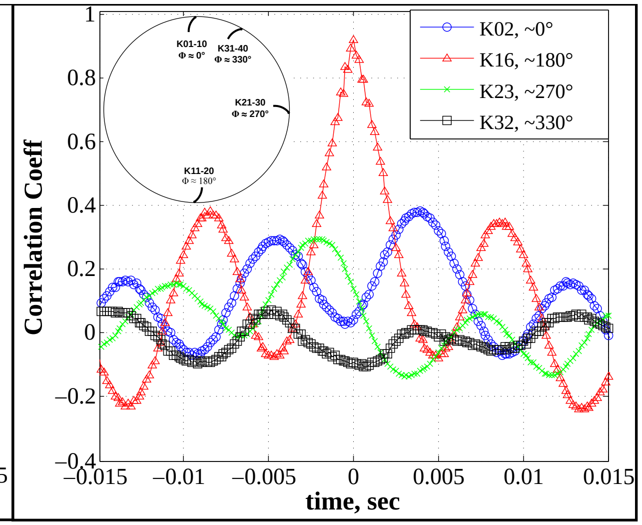
Referenced to K01



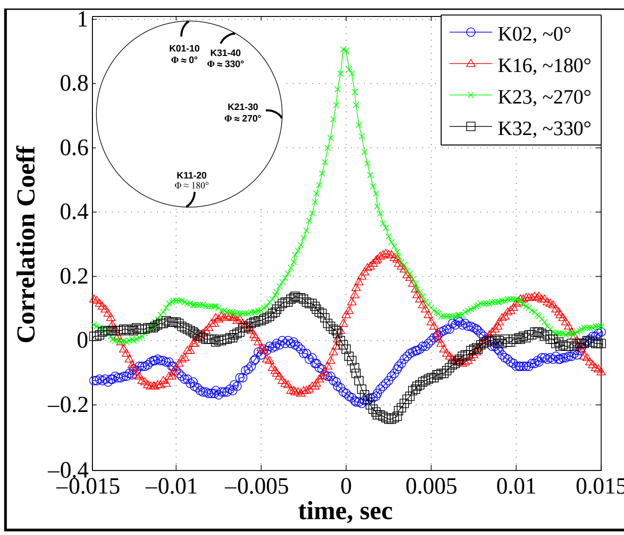
Helical Shedding Mode
M = 0.7, " = 30°, $Re_D = 10x10^6$, Rough Heat Shield



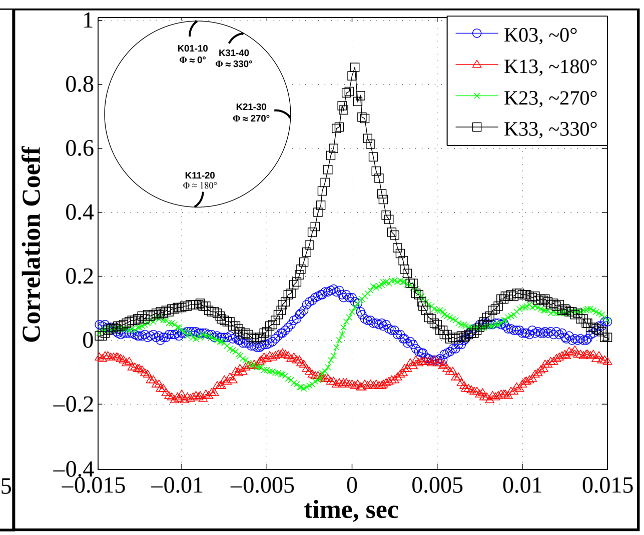
a) Referenced to K03 (Φ ≈ 0°)



b) Referenced to K17 (Φ ≈ 180°)



c) Referenced to K24 (Φ ≈ 270°)



d) Referenced to K33 (Φ ≈ 330°)

Summary

- Comprehensive data set now available of flow around generic capsule at variety of subsonic/transonic conditions
- Unsteady pressure results
  - Spectra is a good indicator of separation
  - Spectra is Reynolds dependent
  - Shedding frequency shifts for rough heat shield at high Re
  - Capsule is more stable at higher Mach
  - Helical shedding is similar to CFD results