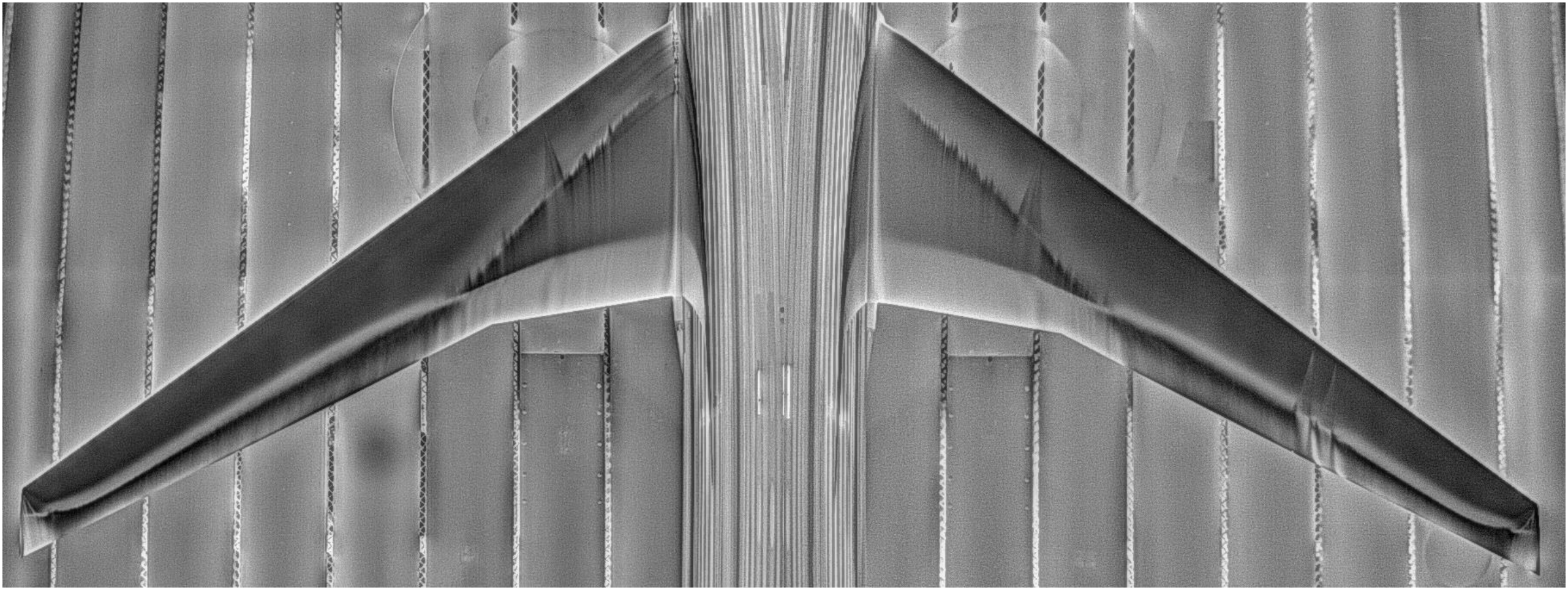
Flow Visualization to Complement Modern Wind Tunnel Testing



AMT-18, Advanced Flow Visualization I

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Overview

- In recent times, wind tunnel testing at NASA Ames Unitary Plan Wind Tunnel (UPWT) seeks to validate computation
- We find that flow visualization helps to provide *context* to results:
    - "Why does this drag polar look different?"
    - "What is the source of this tone in the microphone data"
    - "Why is C_{prms} higher in this location?"
  - Bound the experiment / computation
    - "Are our trip dots the correct size?"
    - "Are these shocks sitting where we think they should be?"
- Supplement other test techniques
- Discover something unforeseen

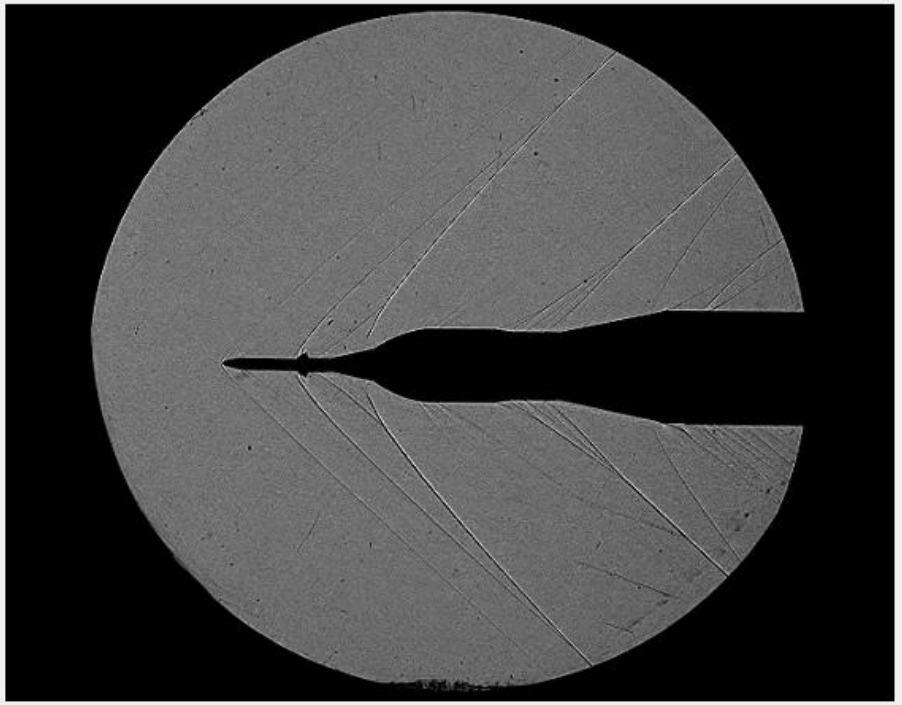
- Drawbacks to adding flow visualization to an experiment
    - Can be costly (dedicated runs impact test productivity)
    - Open to interpretation
- At the NASA Ames UPWT we have sought to integrate a selection of flow visualization data systems
    - Low impact on test productivity
    - Real-time results
    - Optical test section upgrade

Background: Optical Test Section Upgrades

Image Credit: NASA Ames / Dominic Hart

Background: Utilization / Integration of Imaging Based Data Systems

High-Speed Shadowgraph[1]



Infrared Flow Visualization[2]

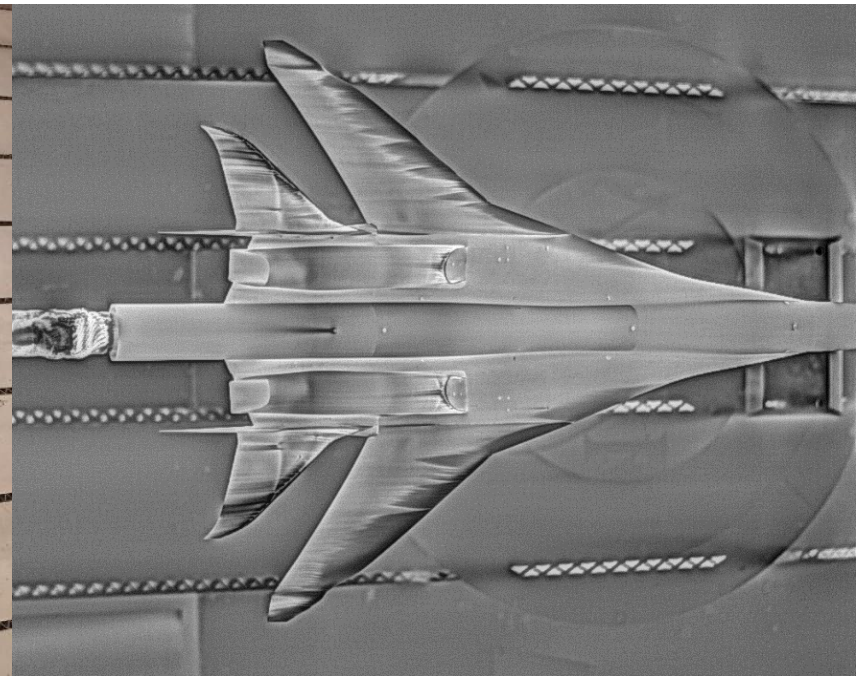
[1] Garbeff, Baerny, Ross, *"Wind Tunnel Flow Field Visualizations of the Space Launch System Vehicle Ascent"*, AIAA Aviation 2019 Forum, (10.2514/6.2019-3299)

[2] Garbeff, Baerny, *"A Qualitative Investigation of Selected Infrared Flow Visualization Image Processing Techniques"*, AIAA Aviation 2019 Forum, (10.2514/6.2019-2907)

Overview of Infrared Flow Visualization at NASA Ames UPWT

Flow phenomena influence wind tunnel model local surface temperatures:

- Boundary layer transition
- Shock impingement
- Vortex footprint
- Flow separation
- Buffet

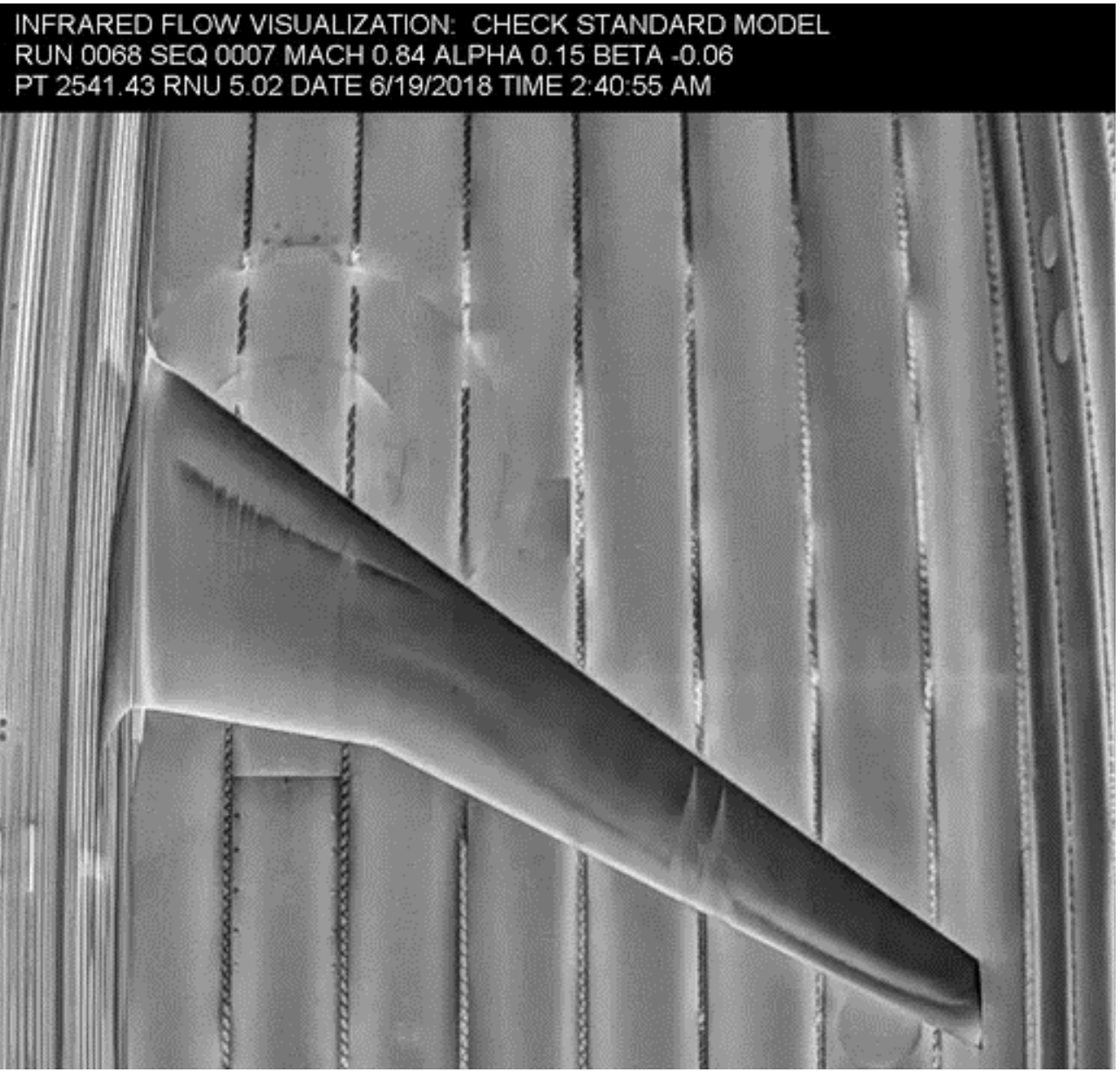


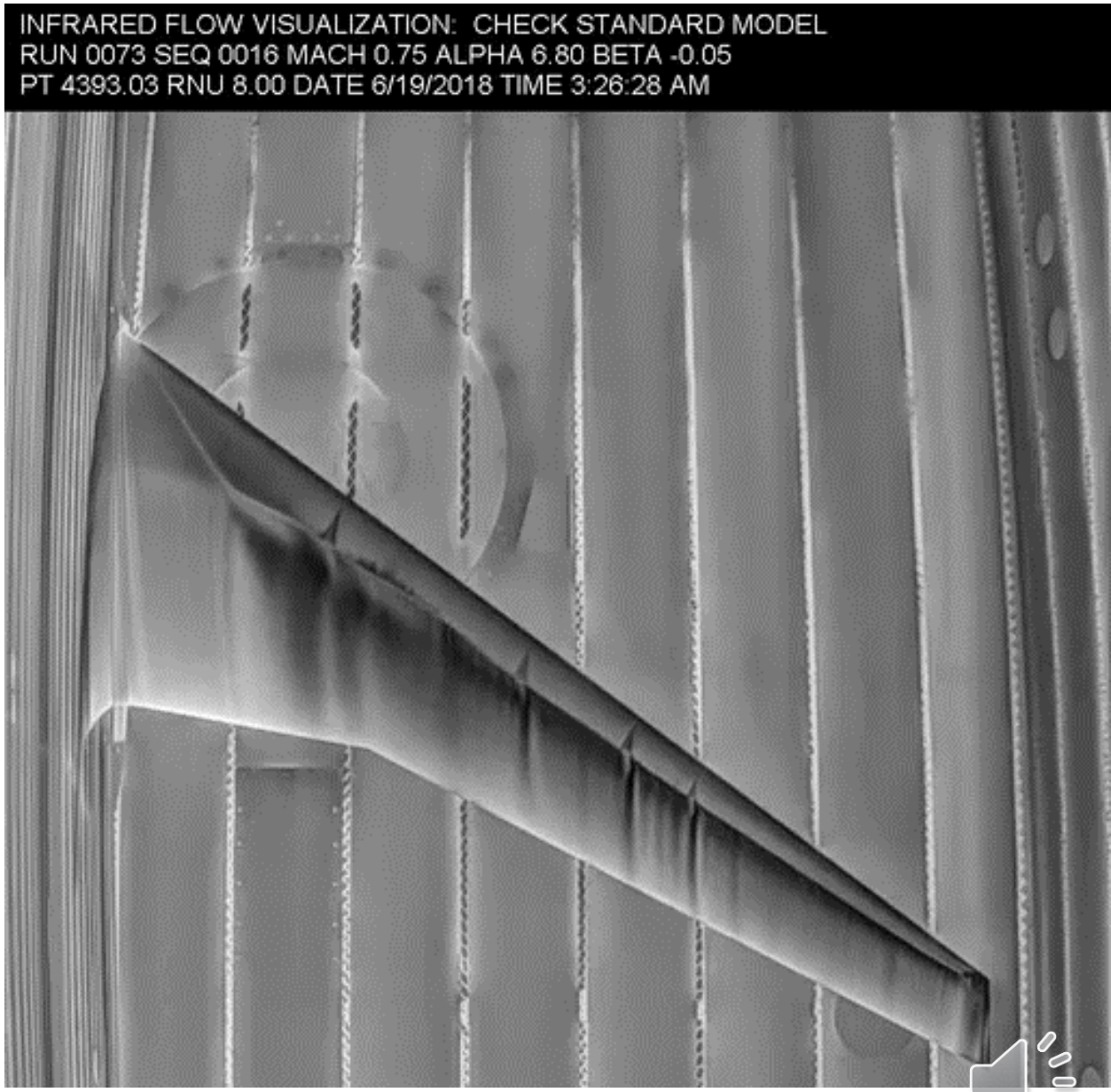
Requirements

- Sufficiently sensitive IR cameras
- Imaging data systems with real-time image processing
- Model surface with proper emissivity and thermal properties

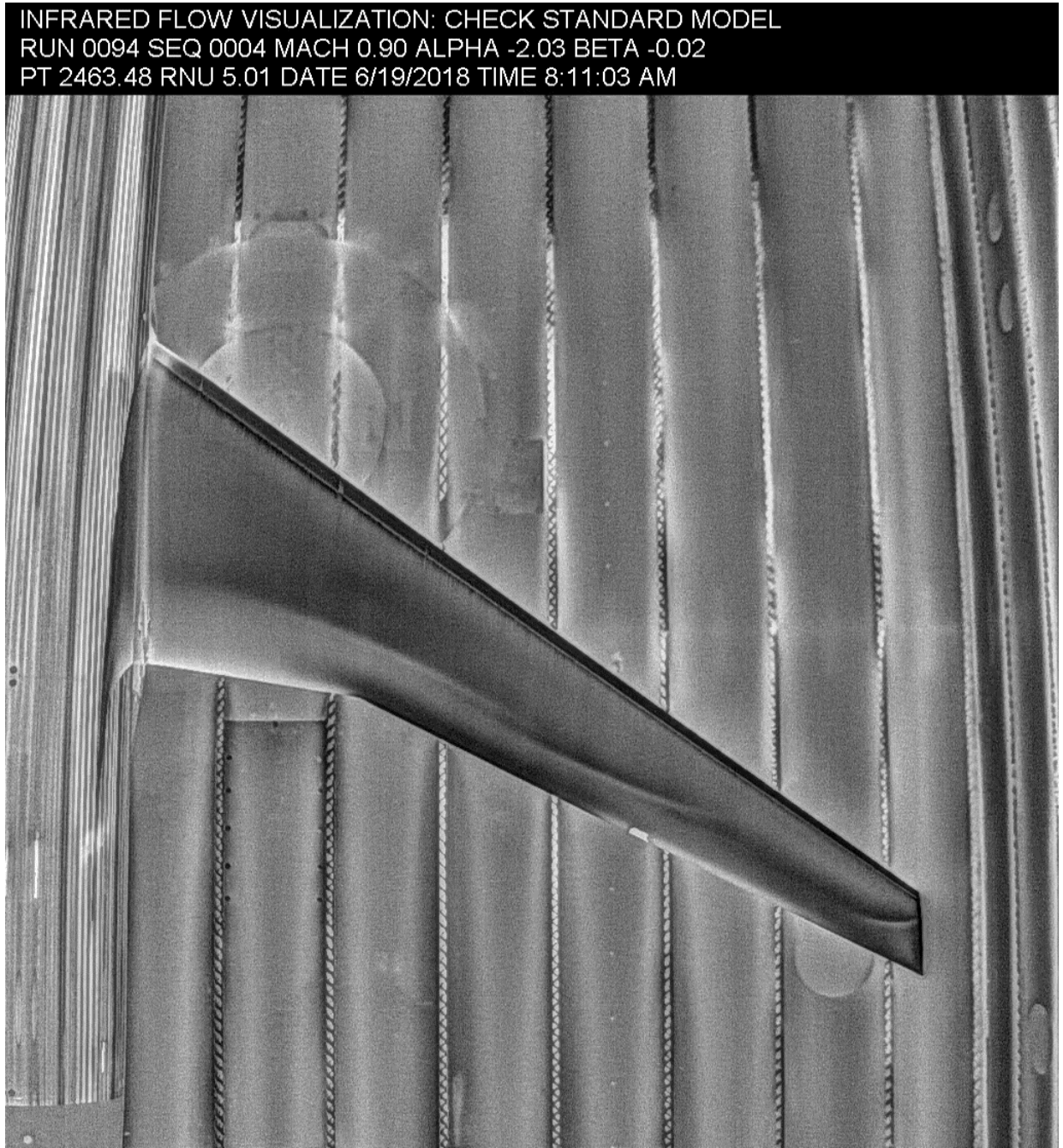
Infrared Flow Visualization: Boundary Layer Transition

Infrared Flow Visualization: Pitch Polars





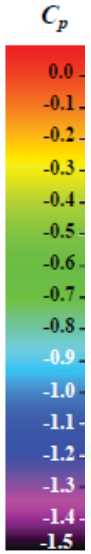
Infrared Flow Visualization: Shock Buzz

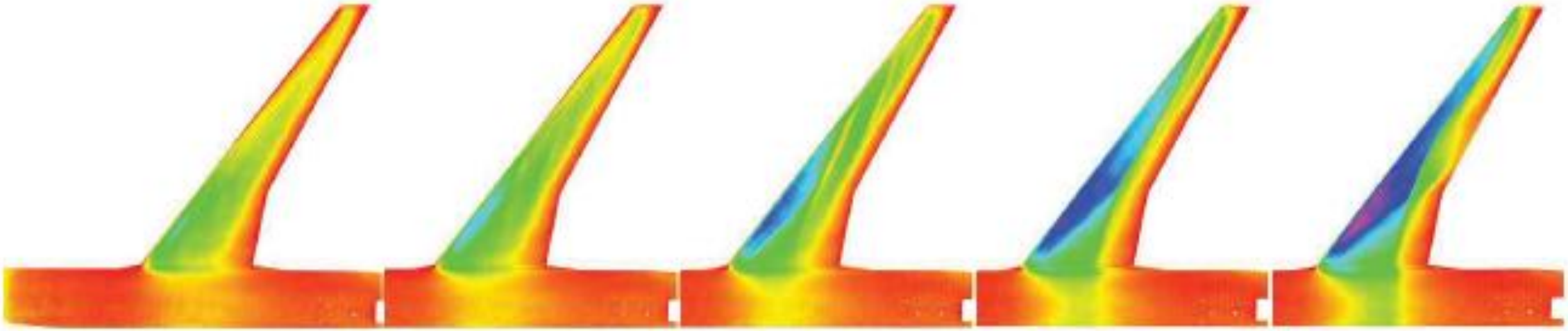


Comparison: Pressure Sensitive Paint and Infrared Flow Visualization

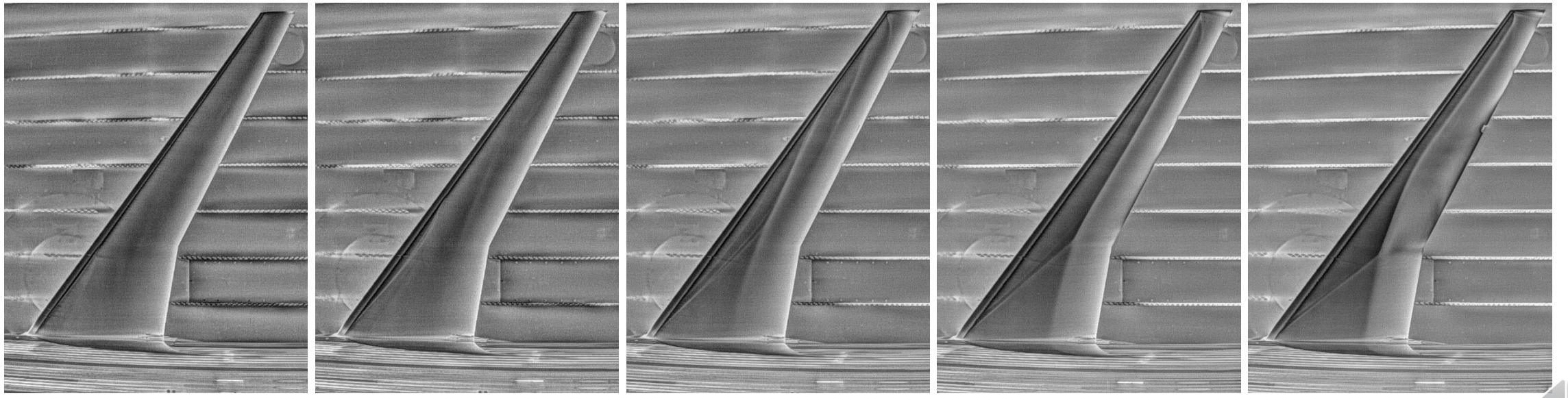
Mach 0.85 Ames UPWT 11-by-11ft

Common Research Model (PSP)[3] Ames Check Standard Model (IR Flow Visualization), Upper Surface





α = 0° α = 1° α = 2° α = 3° α = 4°

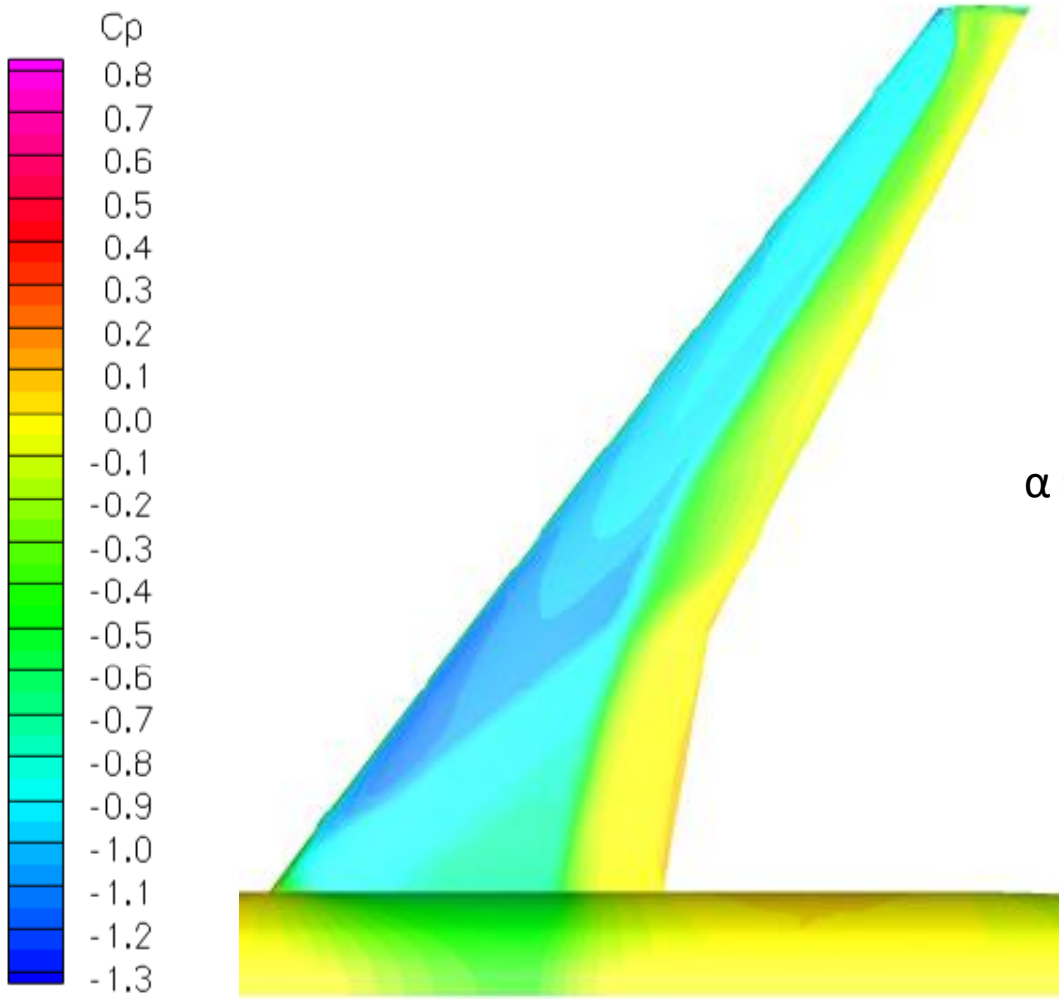


[3] Bell, *"Pressure-Sensitive Paint Measurements on the NASA Common Research Model in the NASA 11-ft Transonic Wind Tunnel"*, AIAA Aerospace Sciences Meeting, (AIAA 2011-1128)

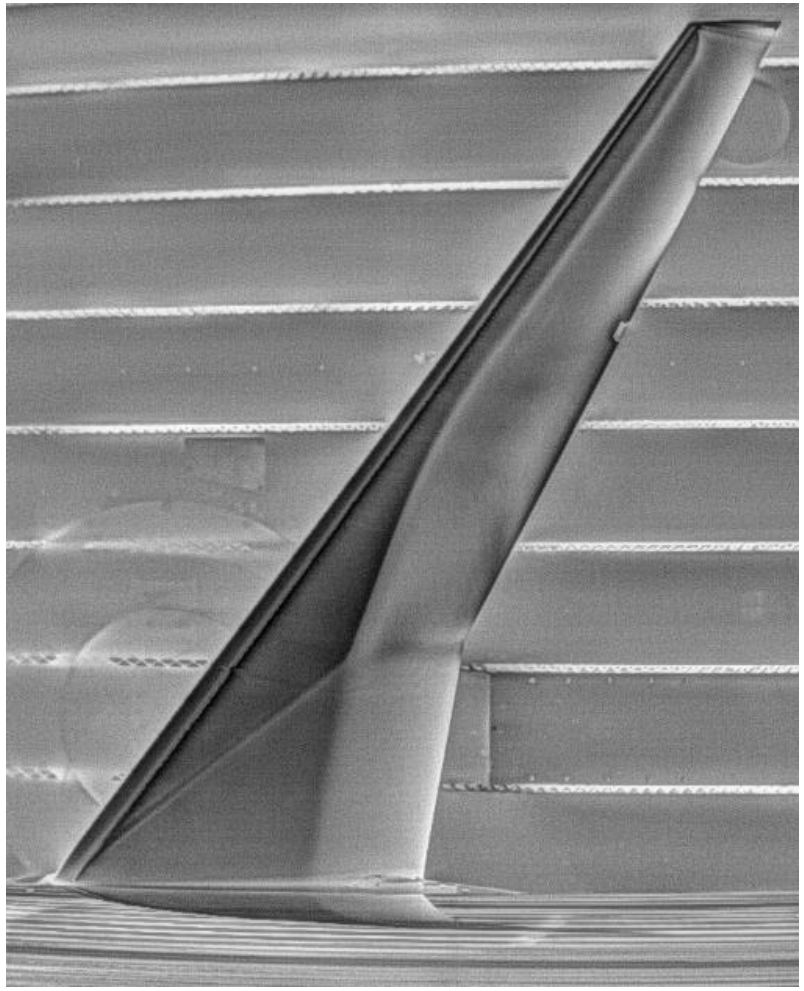
Comparison: Computational Fluid Dynamcis and Infrared Flow Visualization

Mach 0.85

Common Research Model (CFD)[4] Ames Check Standard Model (IR Flow Visualization), Upper Surface



α = 4°



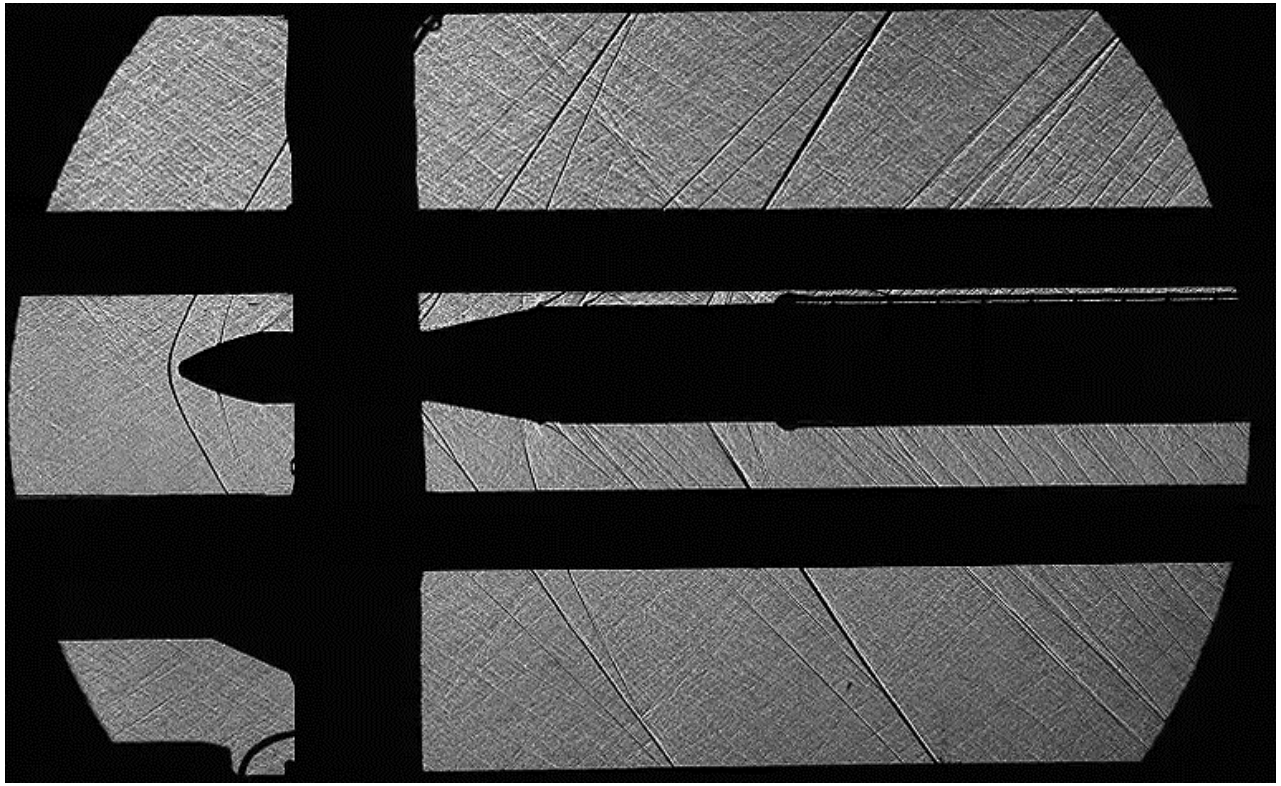
[4] Rivers, Hunter, Campbell *"Further Investigation of the Support System Effects and Wing Twist on the NASA Common Research Model"*, 30th AIAA Applied Aerodynamics Conference, (AIAA 2012-3209)

Shadowgraph at NASA Ames UPWT

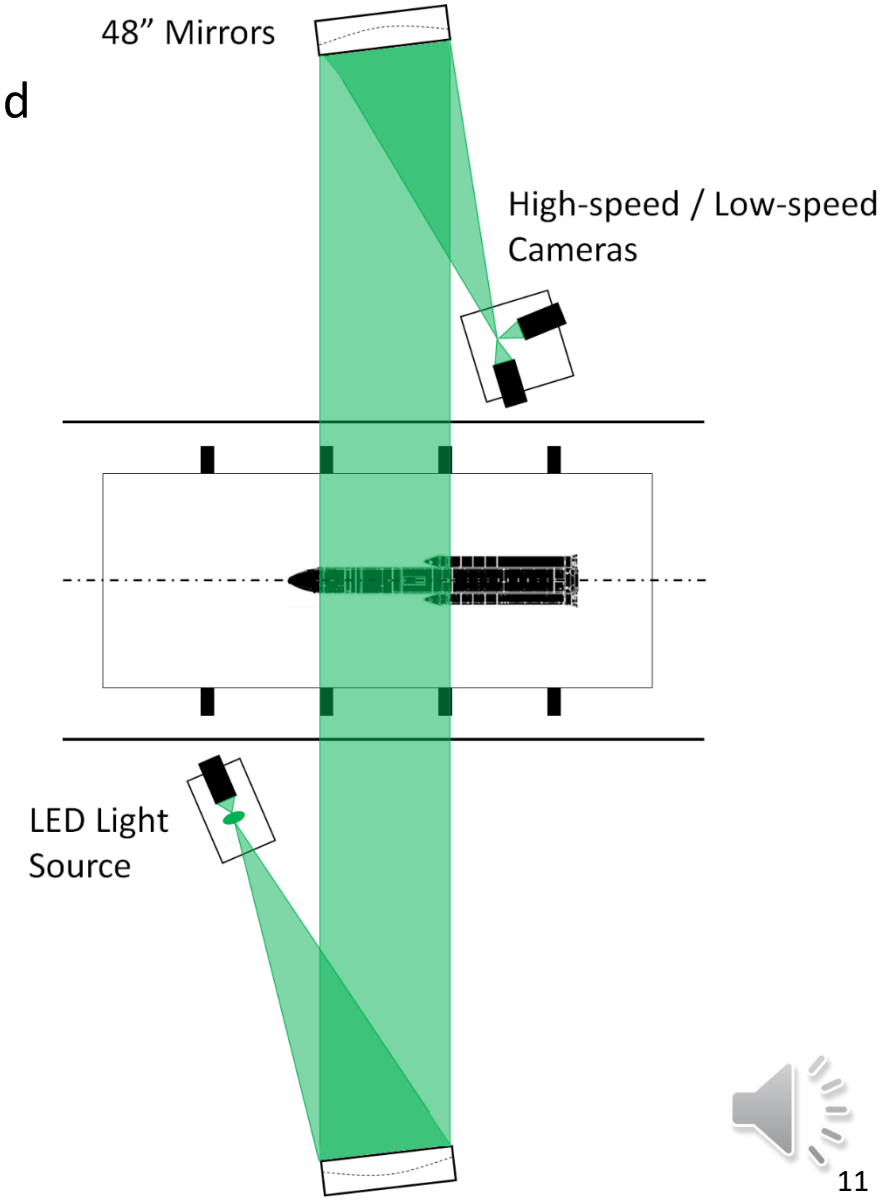
- Traditional Z-type setup / Dual Camera
- High-speed Camera
  - Phantom v2511
  - 51k frames per second (FPS) typical
  - 6 micro-second exposure times
- Low-speed Camera
  - Imperx Bobcat, 4MP, 30 FPS
  - Long duration

- High-powered LED light source
- Actively damped vibration isolation
- Automated data collection and processing

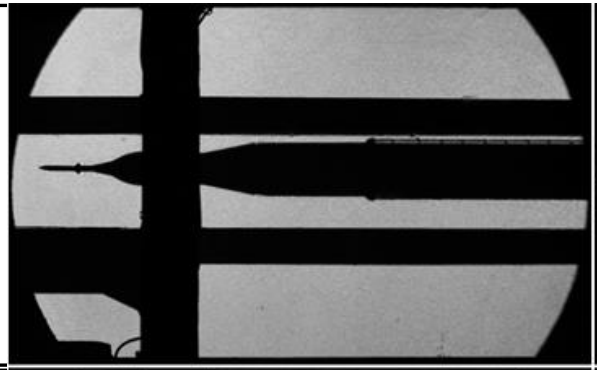
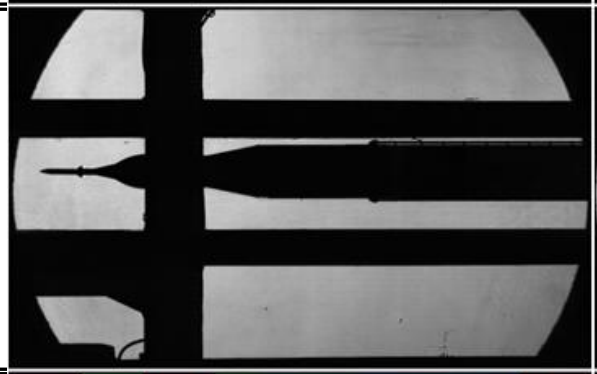
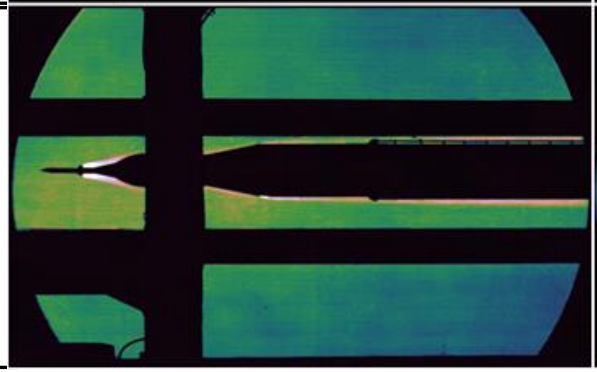
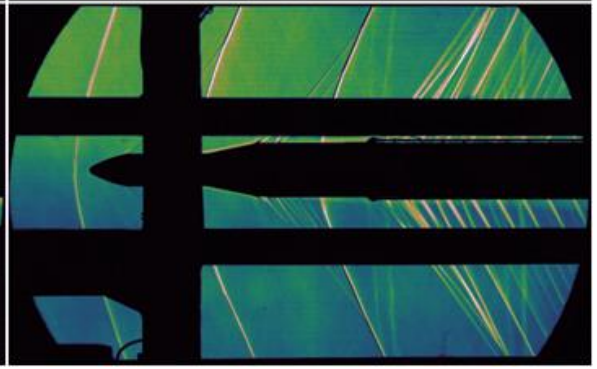
Supersonic, 51,000 FPS, 6 micro-second exposure time



Shadowgraph Plan-View

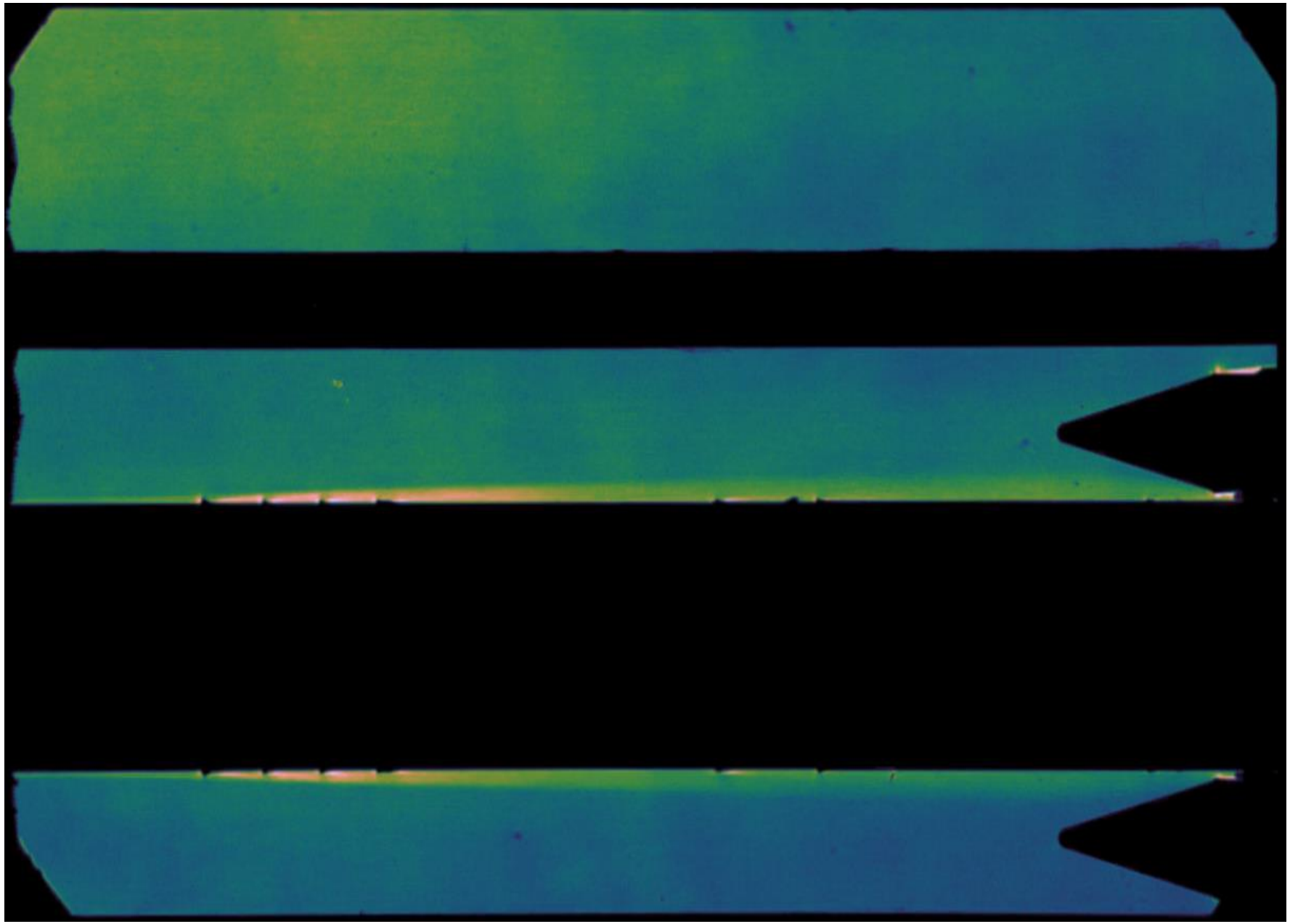


High-Speed Shadowgraph Statistical Images[1]

	Subsonic	Supersonic
Still Image Instance (Snapshot) • Subsonic = not much detail • Supersonic = shocks and traveling waves		
Pixel Time History Mean • Subsonic = not much detail • Supersonic = shocks more clearly defined, traveling waves average out		
Time History Standard Deviation • Subsonic = separated flow, boundary layer development • Supersonic = shocks and boundary layer		

[1] Garbeff, Baerny, Ross, *"Wind Tunnel Flow Field Visualizations of the Space Launch System Vehicle Ascent"*, AIAA Aviation 2019 Forum, (10.2514/6.2019-3299)

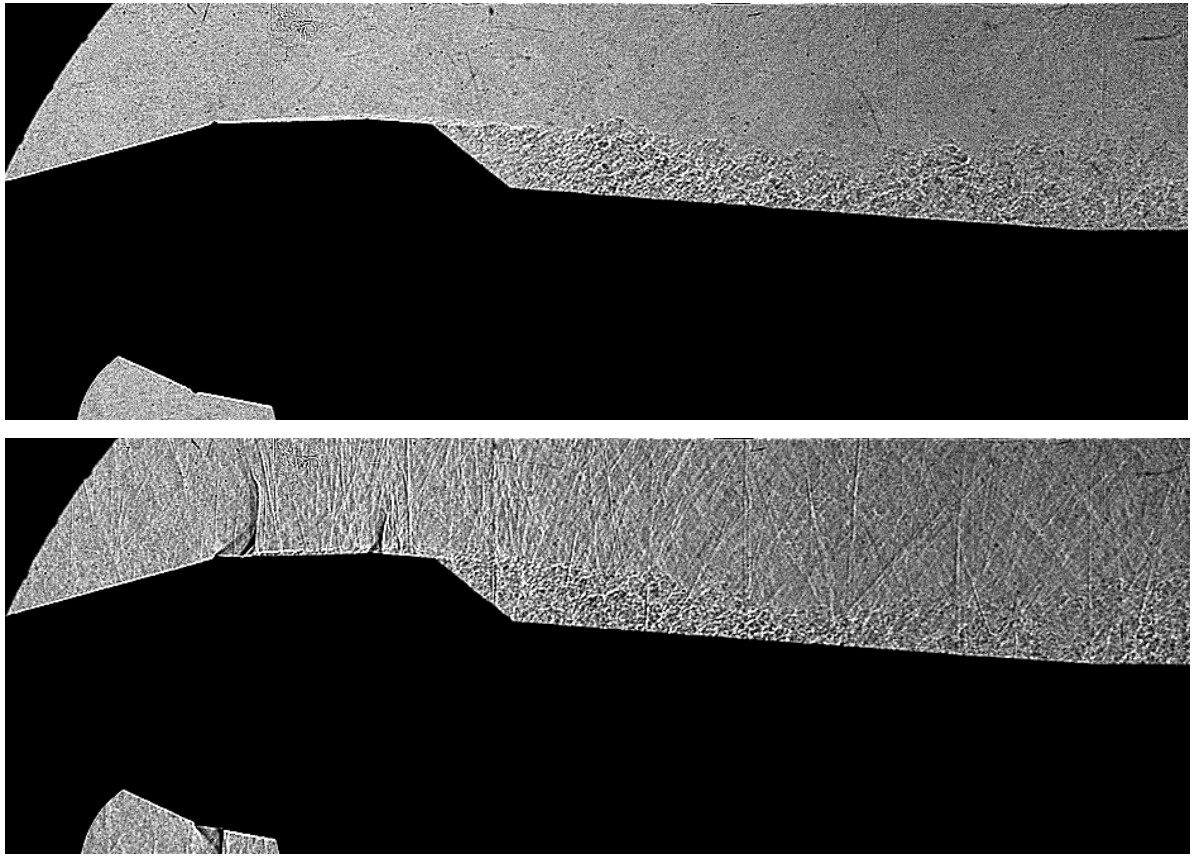
Transonic Through Supersonic Flow

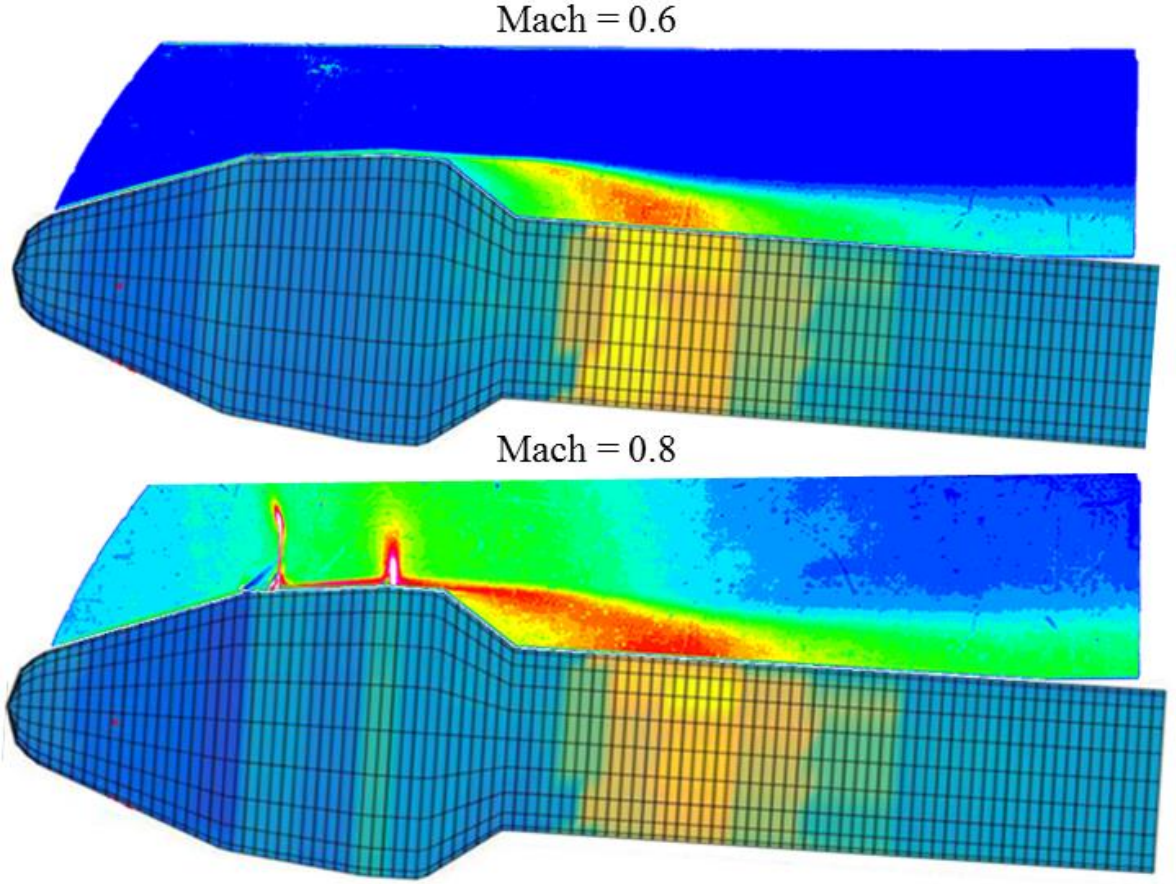


Comparison[5]: Statistical Images and C_{prms}

- C_{prms} measured by Kulite sensors, mapped to surface grid
- Statistical images computed from high-speed shadowgraph
- Results colorized and merged

High-Speed Shadowgraph Video



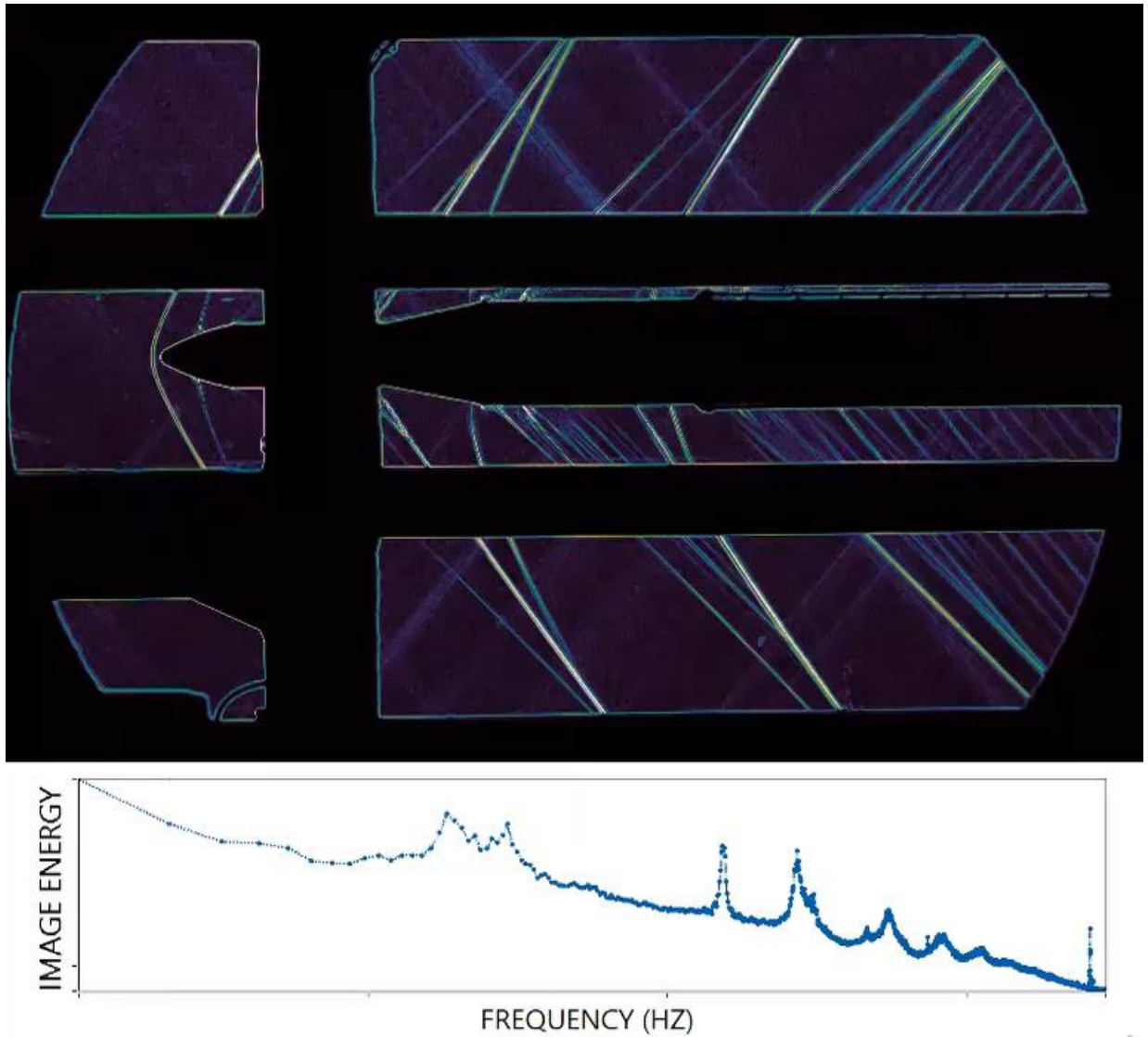


[5] Garbeff, Panda, Ross, *"Experimental Visualizations of a Generic Launch Vehicle Flow Field: Time-Resolved Shadowgraph and Infrared Imaging"*, 55th AIAA Aerospace Sciences Meeting, (AIAA 2017-1403)

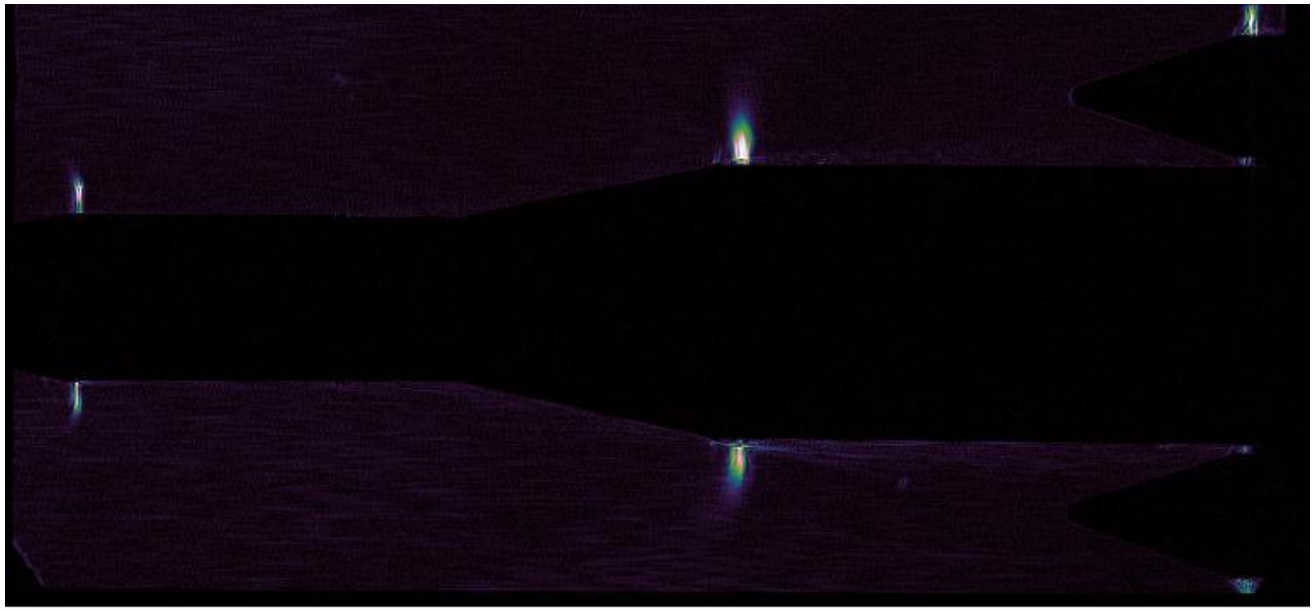
High-Speed Shadowgraph Frequency Domain Analysis

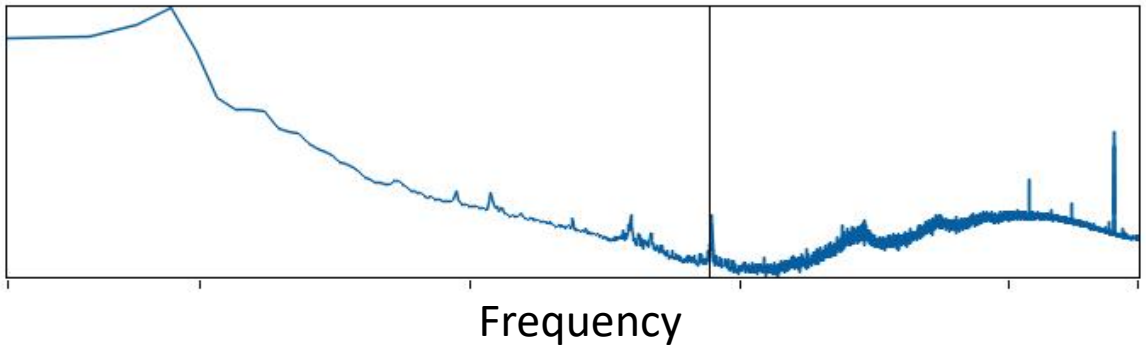
Given high-speed shadowgraph image burst:

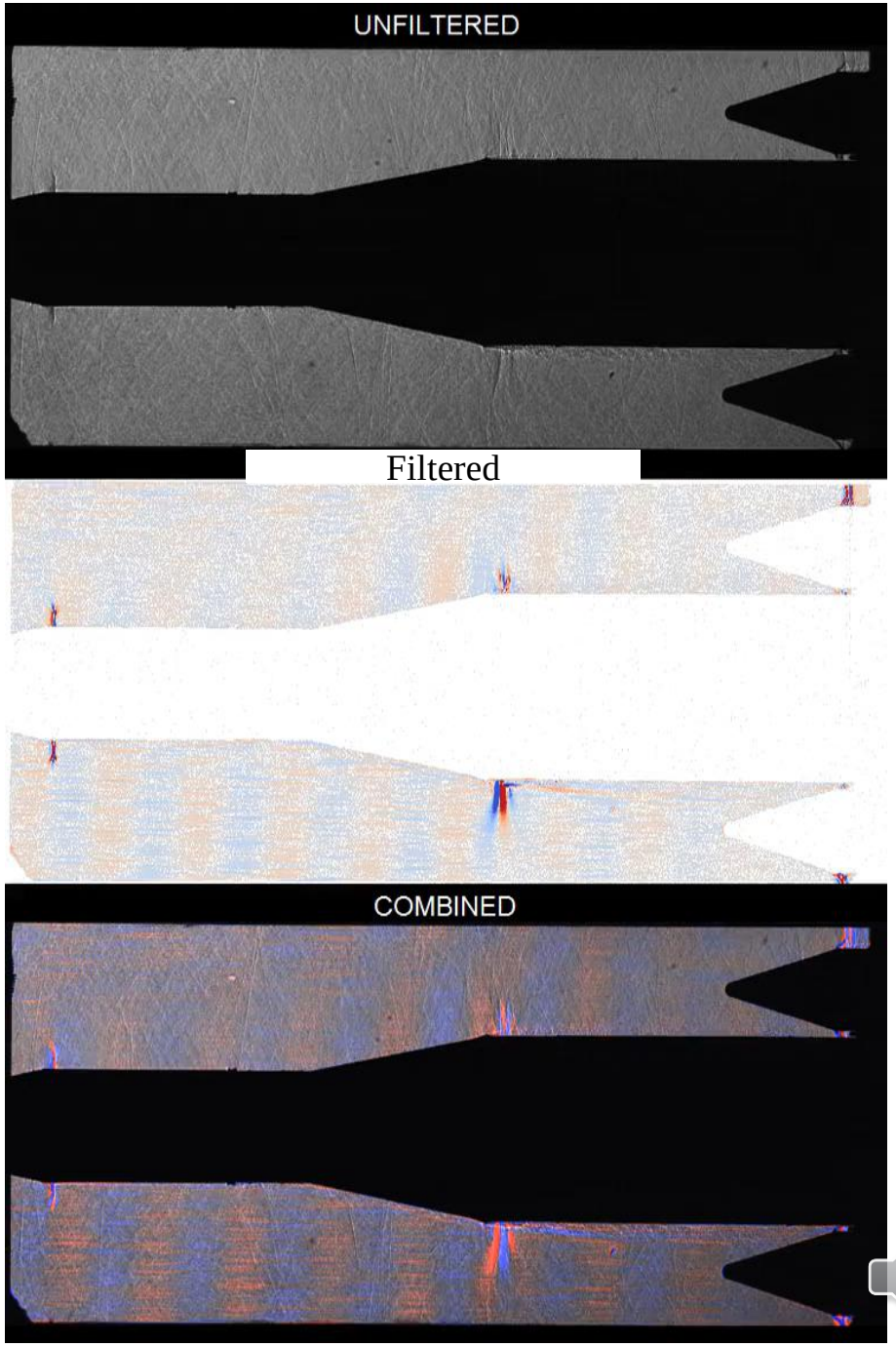
- Periodograms produced from time histories pixel by pixel
- Energy at frequency summed across all pixels to produce a frequency map of total image energy versus frequency
- Each frequency map image details concentration of energy at fixed frequency



Future Development: Advanced Video Processing

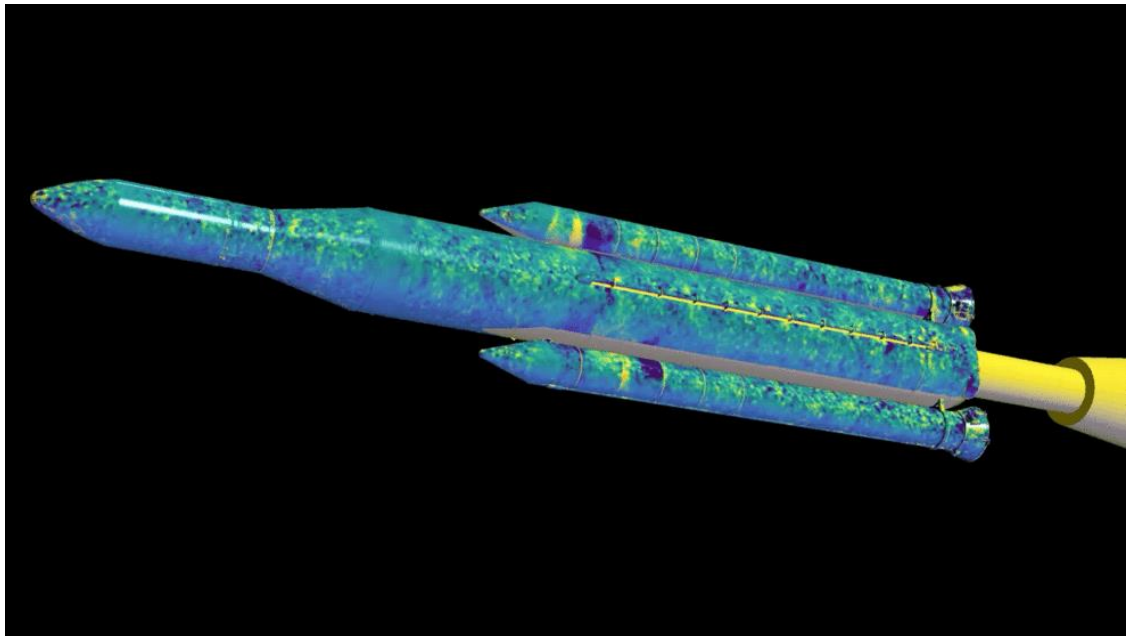




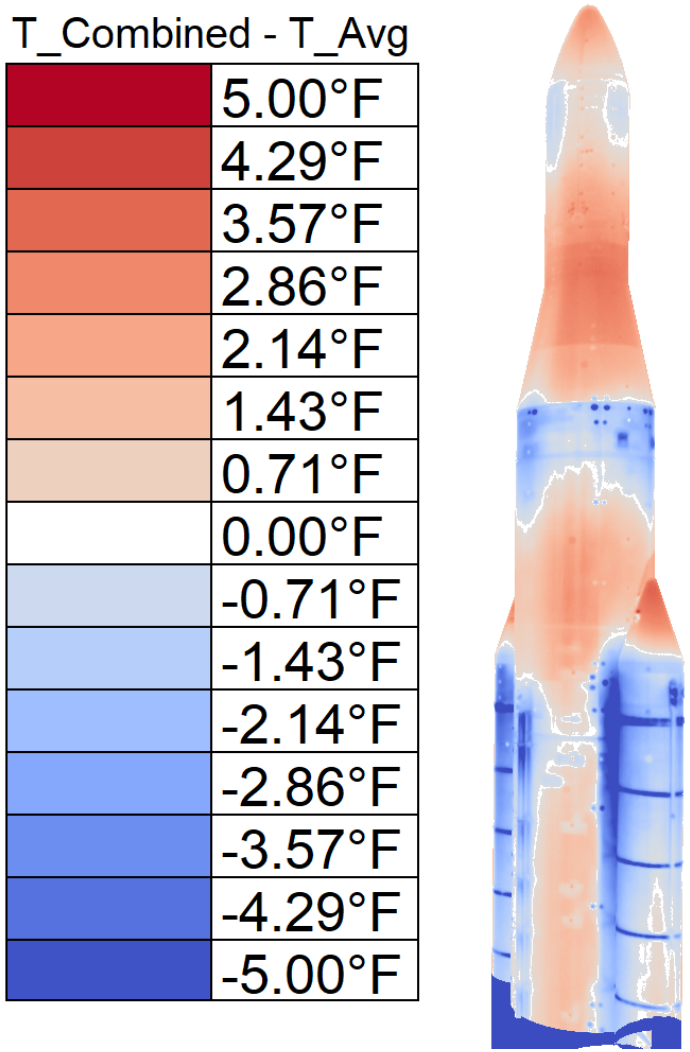


Future Development: Integration with Unsteady Pressure Sensitive Paint

Lifetime / Unsteady Pressure Sensitive Paint[6]



[6] Roozeboom, et. al, *"Recent Developments in NASA's Unsteady Pressure-Sensitive Paint Capability"*, AIAA Scitech 2020 Forum, (10.2514/6.2020-0516)



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The SLS aero sciences team and in particular Andy Herron, and Patrick Shea for generous use of wind tunnel model imagery

Questions?