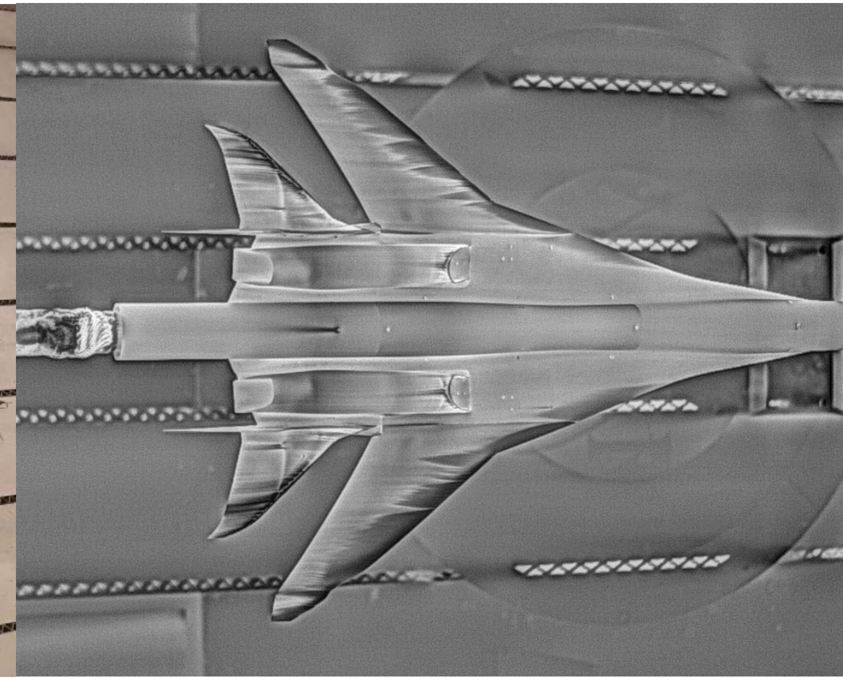
NASA Ames Unitary Plan Wind Tunnel: Infrared Flow Visualization



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Overview of Infrared Flow Visualization

Flow phenomena influence wind tunnel model local surface temperatures:

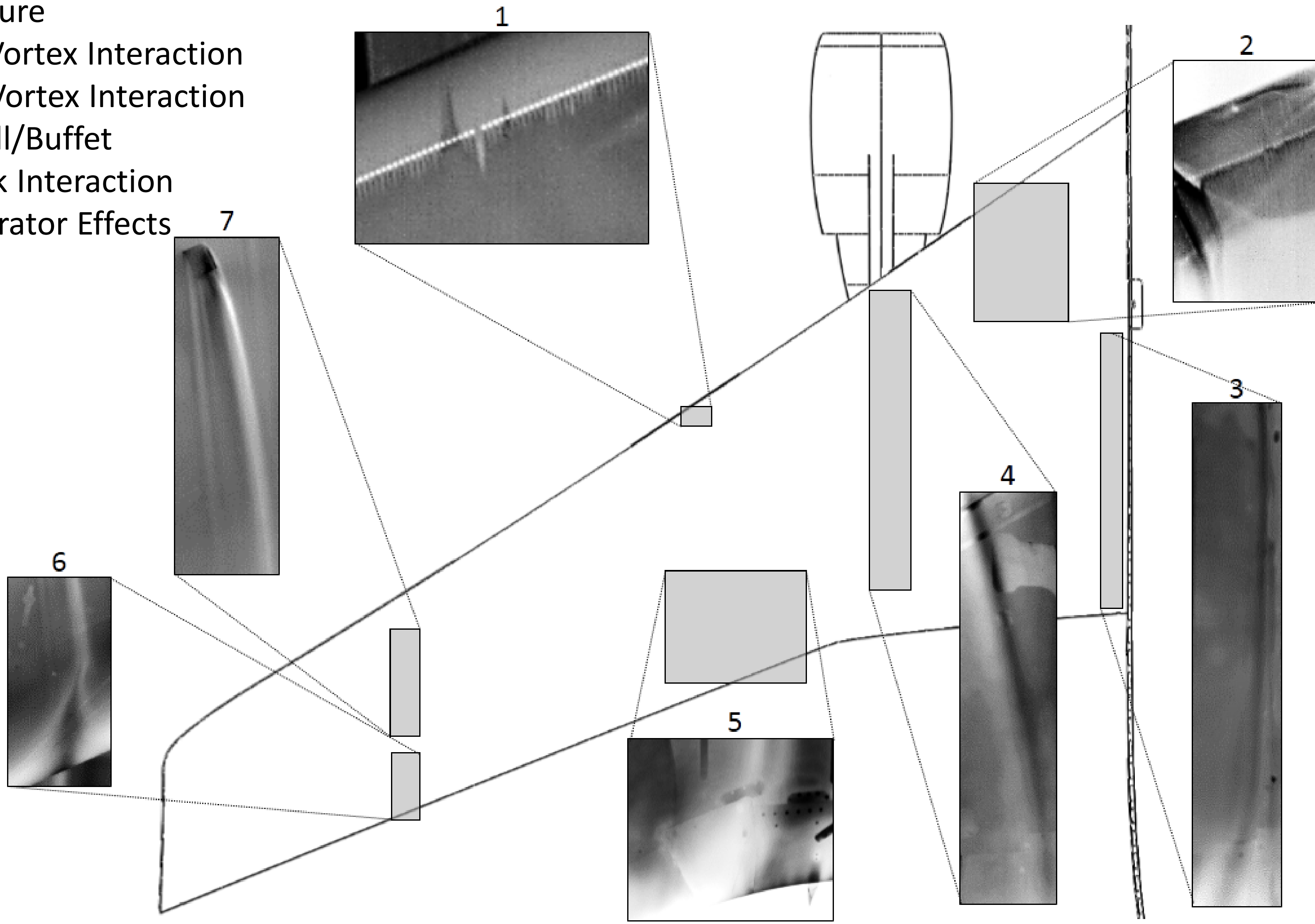
- Boundary layer transition
- Shock impingement
- Vortex footprint
- Flow separation
- Buffet

Requirements

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

Examples of use

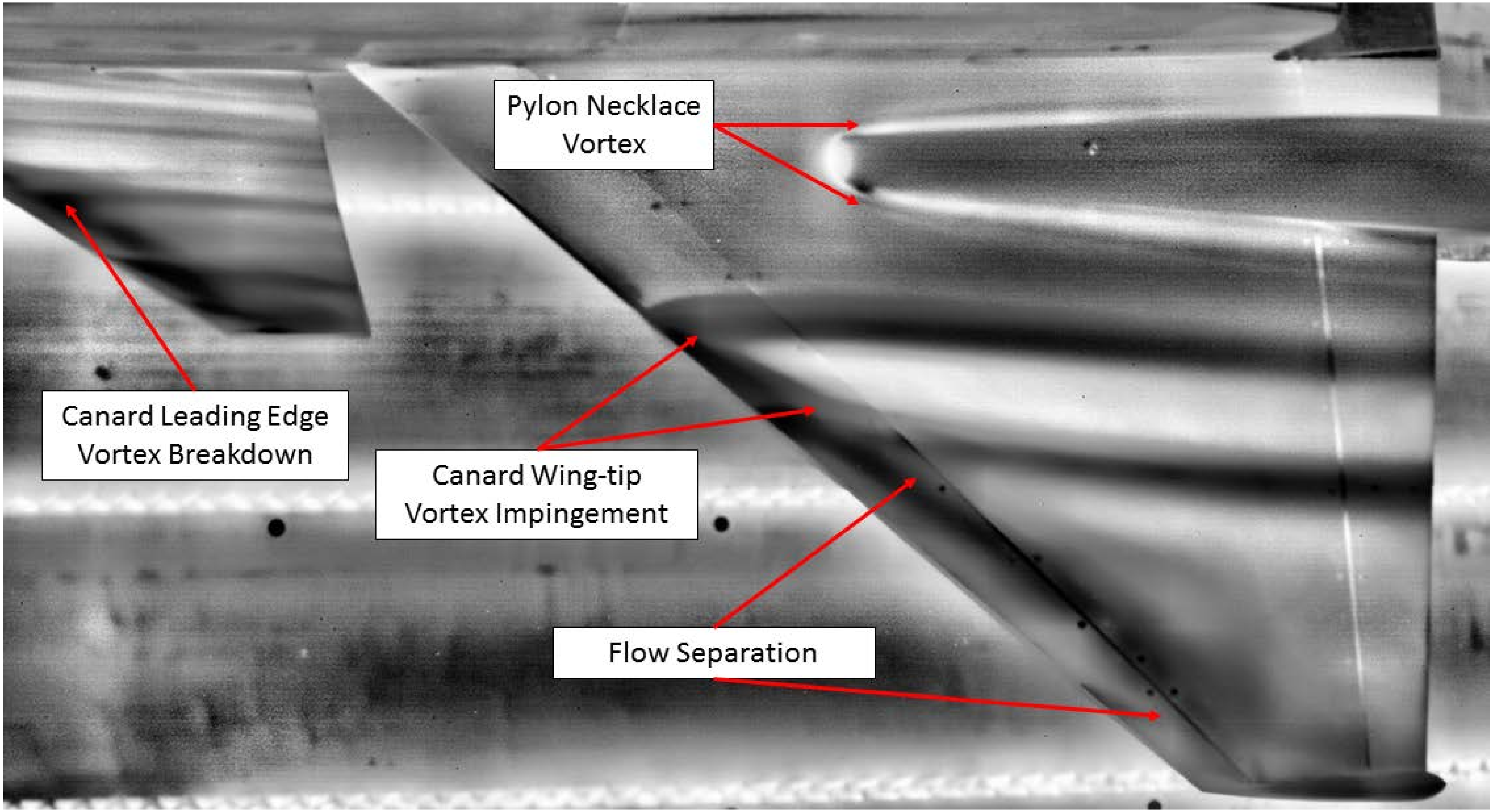
1. Transition/Trip-dot Effectiveness
2. Shock Structure
3. Wing-body Vortex Interaction
4. Pylon-wing Vortex Interaction
5. Onset of Stall/Buffet
6. Vortex-Shock Interaction
7. Vortex Generator Effects



Boundary layer transition on tunnel startup:

Shock structure and angle-of-attack:

Vortex impingement and flow separation:



Shock Structures

Flow Separation

Boundary layer transition on launch vehicles

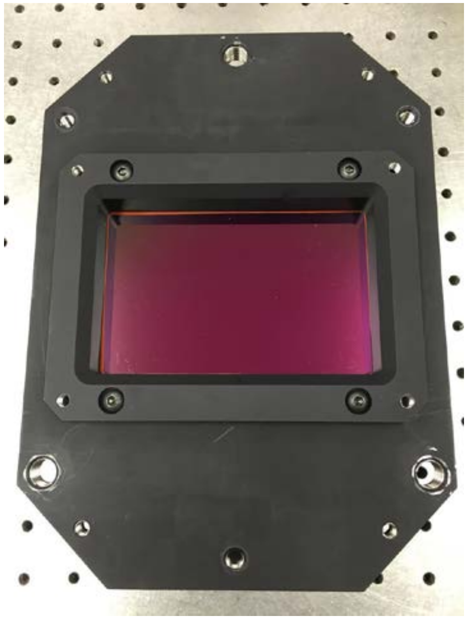
Hardware: Cameras and Windows

IR Cameras

(4x) FLIR SC8200
(1x) FLIR A8300sc

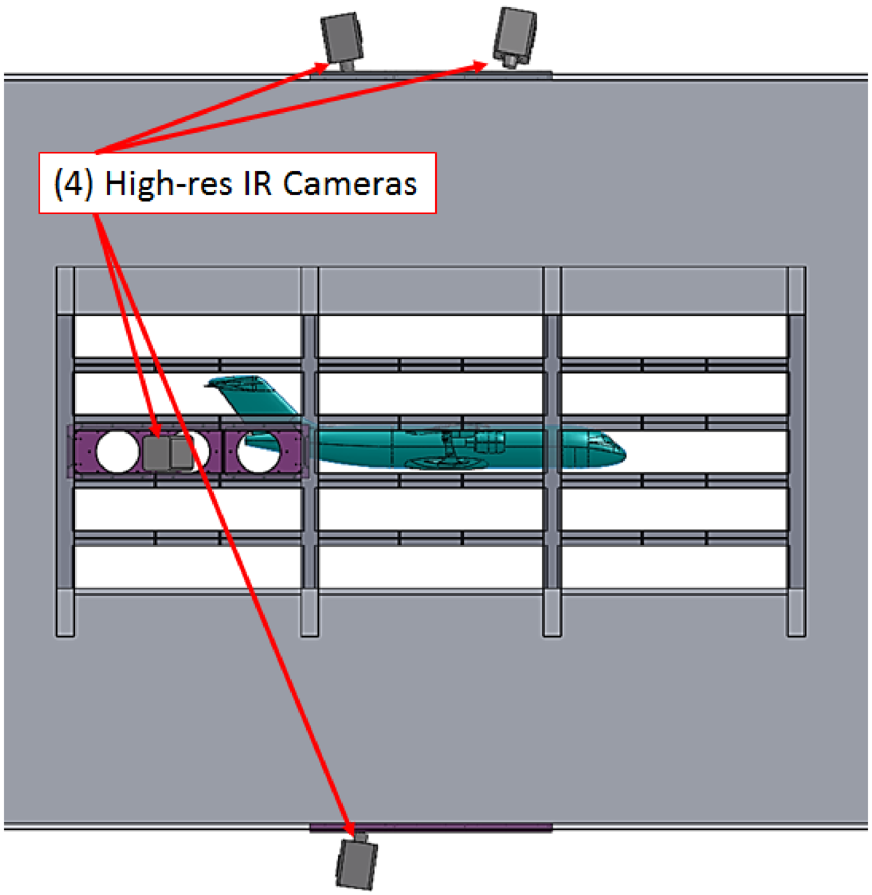
- 1024x1024 pixels
- 3-5 um
- 13mm, 25mm, 50mm, 100 mm lenses

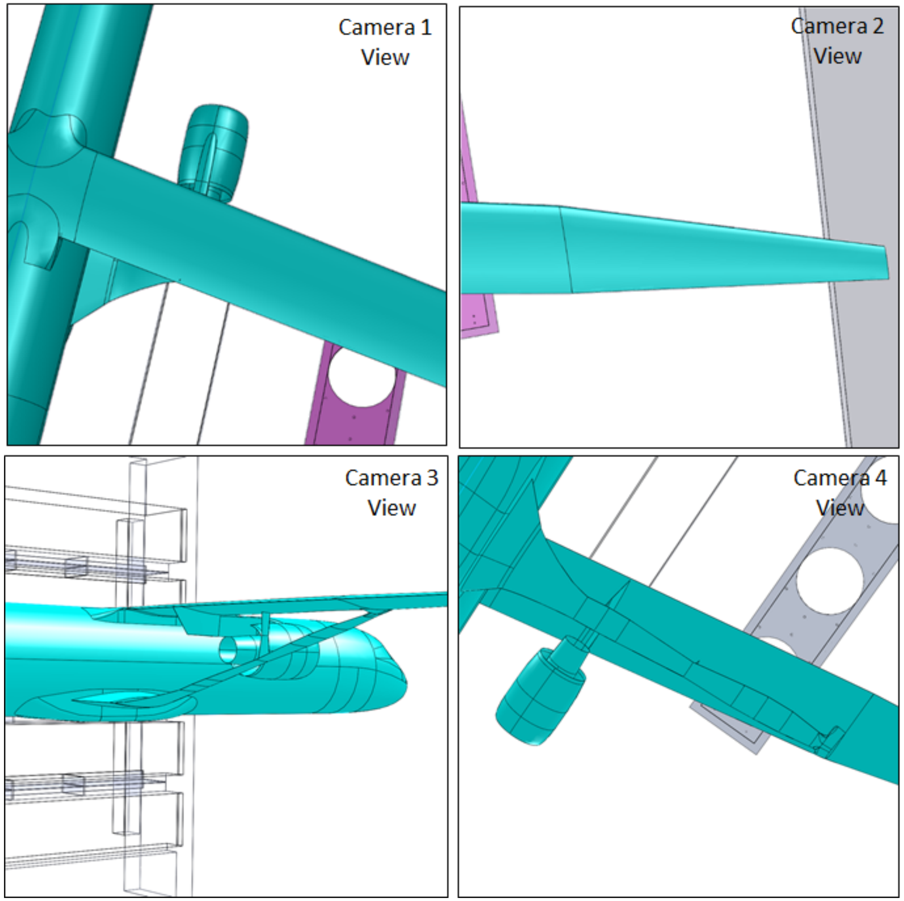
IR Viewing Ports



- (8x) Germanium
- (2x) Sapphire
- Modular inserts
- 3-5µm broadband AR coating

Test Planning: Camera Location / Image Rendering





In-House Developed IR Data Systems for 11 by 11 foot

- Simultaneous acquisition of four IR cameras
- Acquisition automated and synchronized with tunnel data system.
- Stream-to-disk image data with tunnel conditions
- In-line image processing with distributed video for customer viewing
- Data product securely delivered to customer through data diode

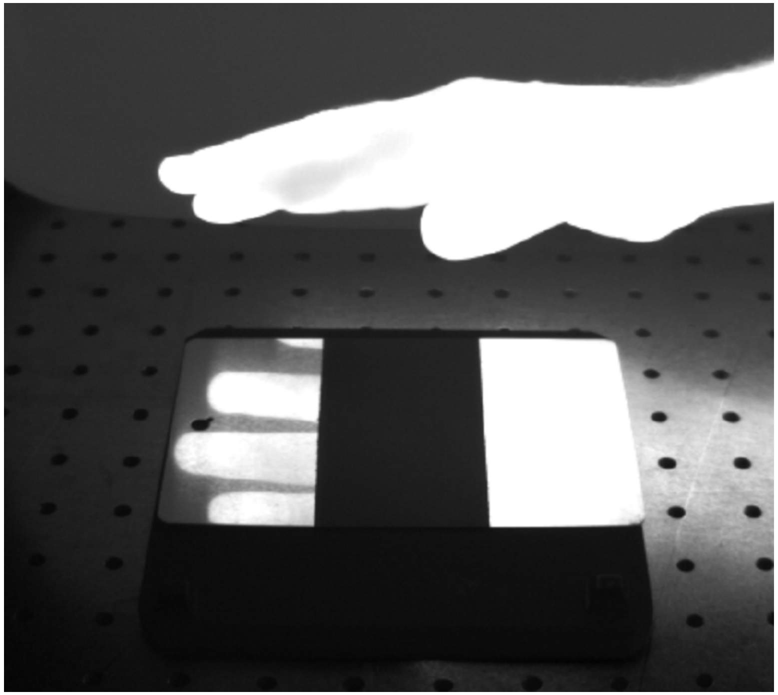
Model emissivity and thermal conductivity:

The test article must be emissive in 3-5 µm IR band

- Higher emissivity = larger signal
- Steel / aluminum models painted flat black
    - Typical emissivity ~85%

The test article must have high heat capacity

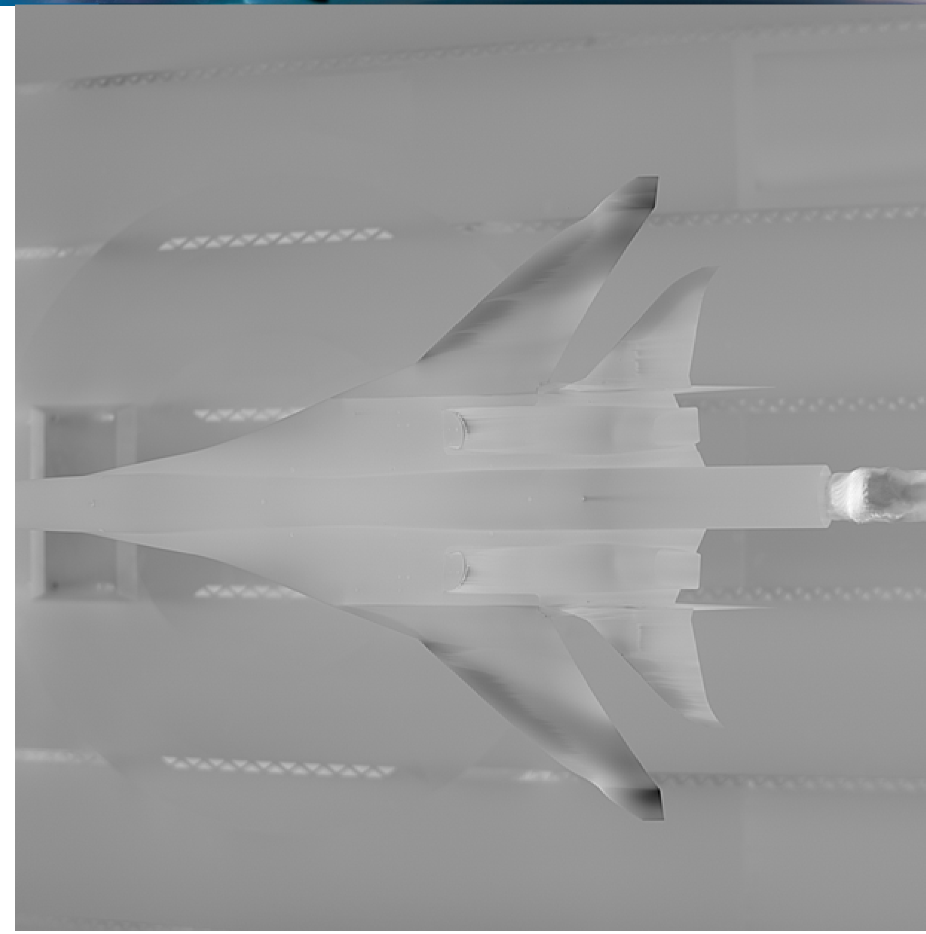
- More time for temperature gradient to establish on surface = higher contrast
- Flat-black polyurethane and acrylic paints have worked well
    - ~0.002” thick, ~25 µin roughness

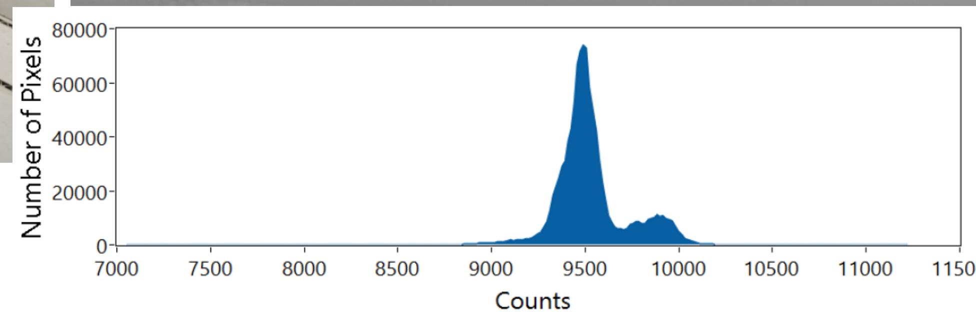


Varying physical features of the test article (cover plates, plaster, differing materials) result in varying thermal properties across the model, appear as artifacts in the image data.

Contrast Enhancement is Essential

- Test article in NASA Ames UPWT
- Mach = .95, Pt = 2116 psf
- Surface Emissivity ≈ 0.85
- Surface Roughness ≈ 30μin
- 14-bit pixel depth

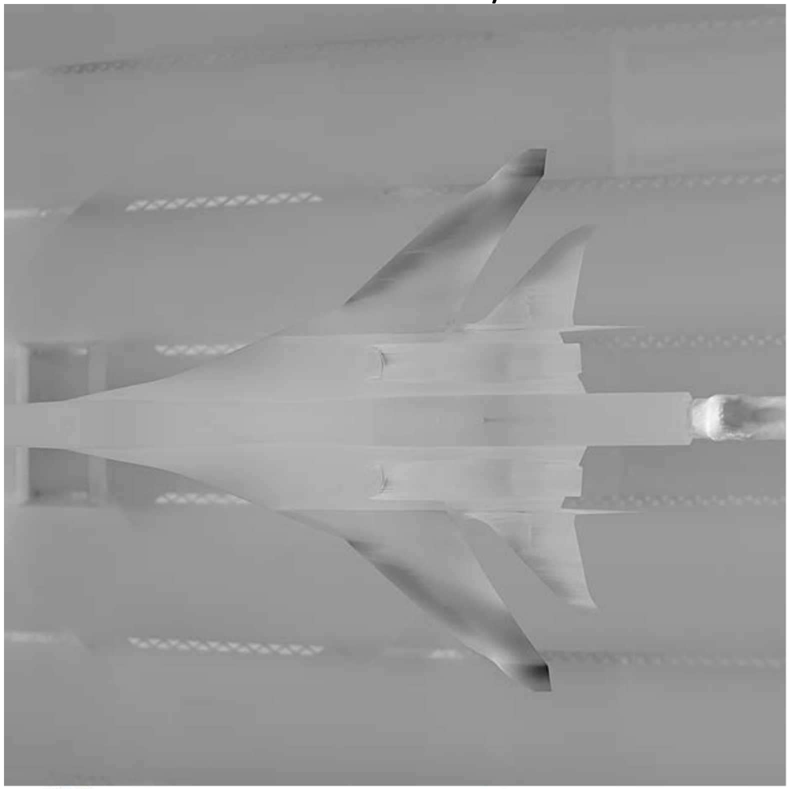


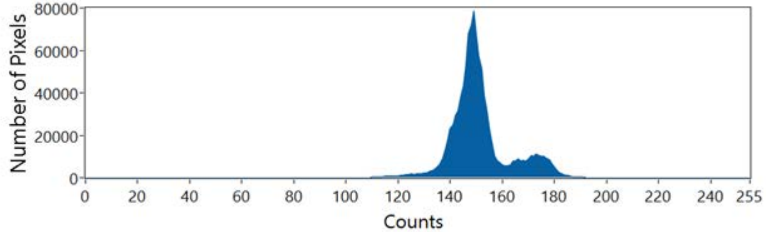


Contrast Enhancement

<u>Linear</u>

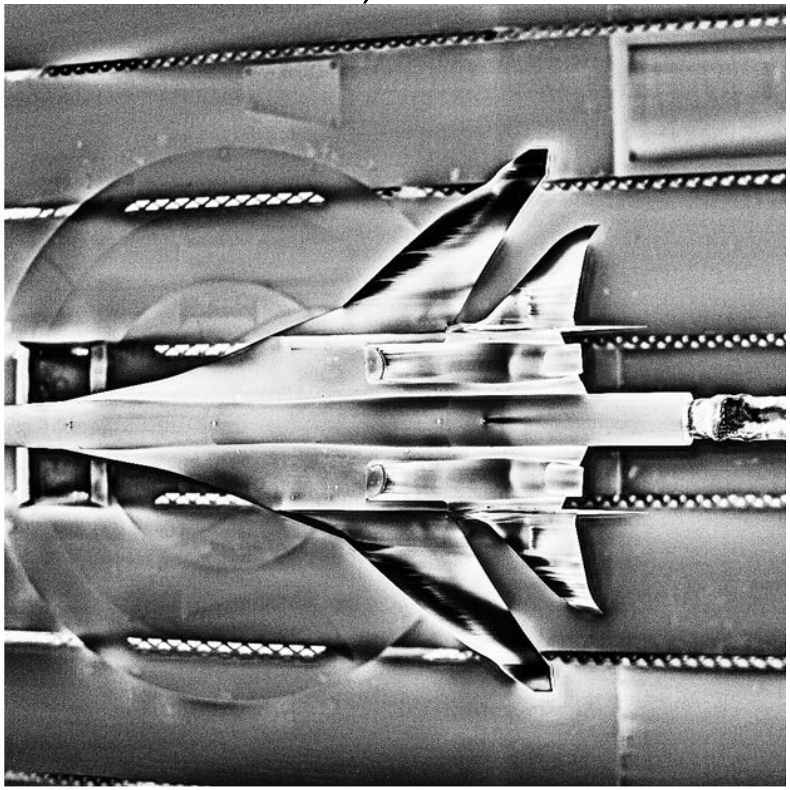
- Preserves shape of histogram
- Unable to enhance small / local features

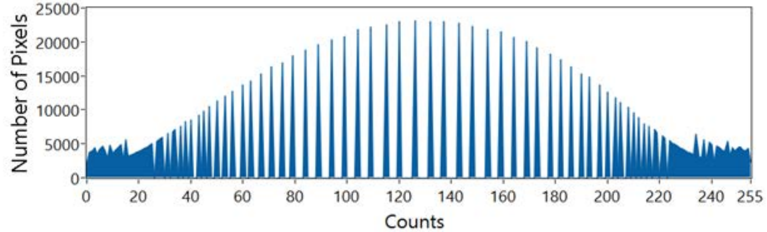




<u>Global Histogram Equalization</u>

- Automatic, "Stretches" histogram
- Increased contrast, features saturated

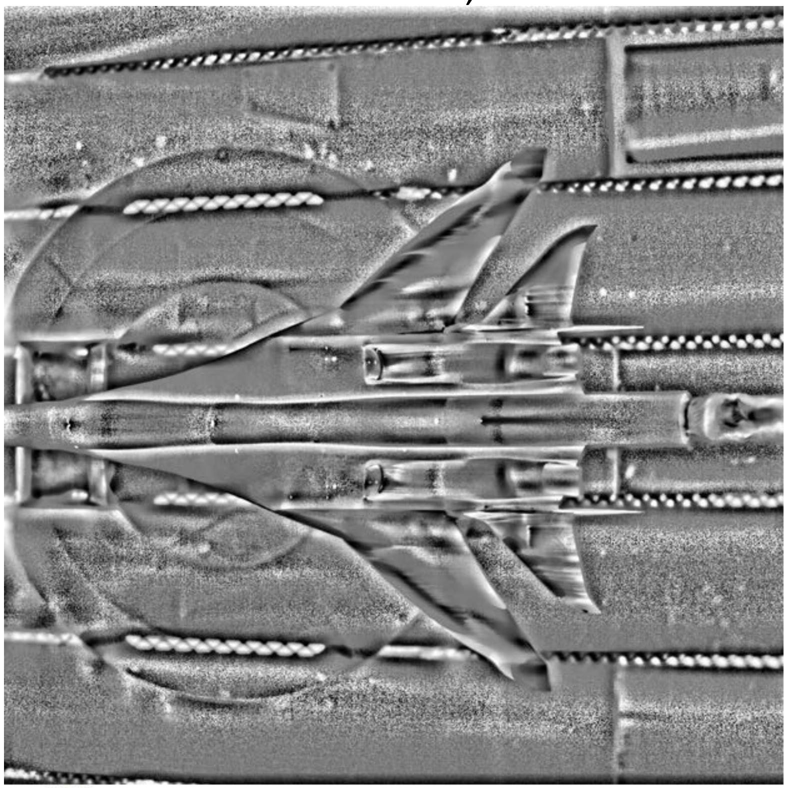


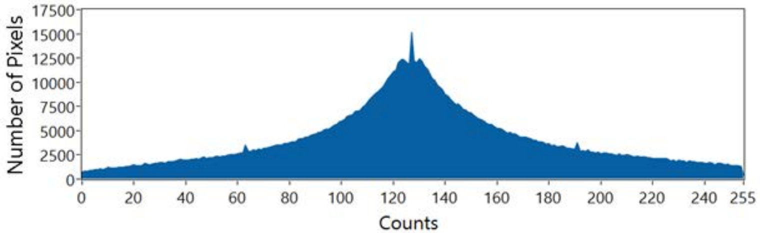


Contrast Enhancement

Adaptive Histogram Equalization

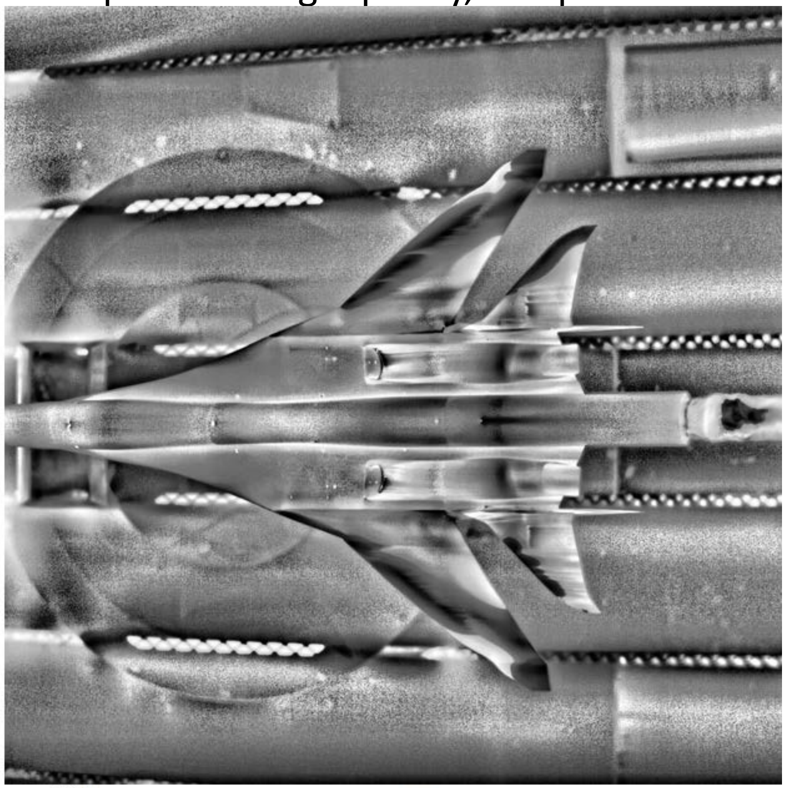
- Fixed-scale, equalization convolution
- Local features enhanced, but with artifacts

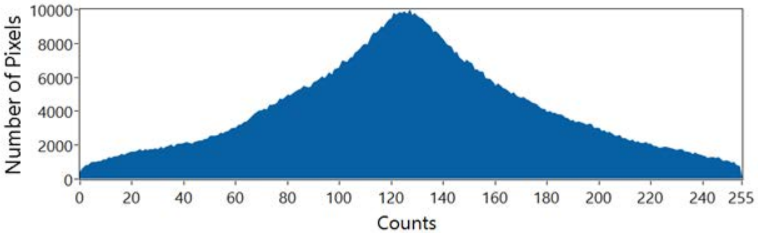




Multi-scale Adaptive Histogram Equalization

- Multi-scale, equalization convolution
- Improved image quality, compute bound

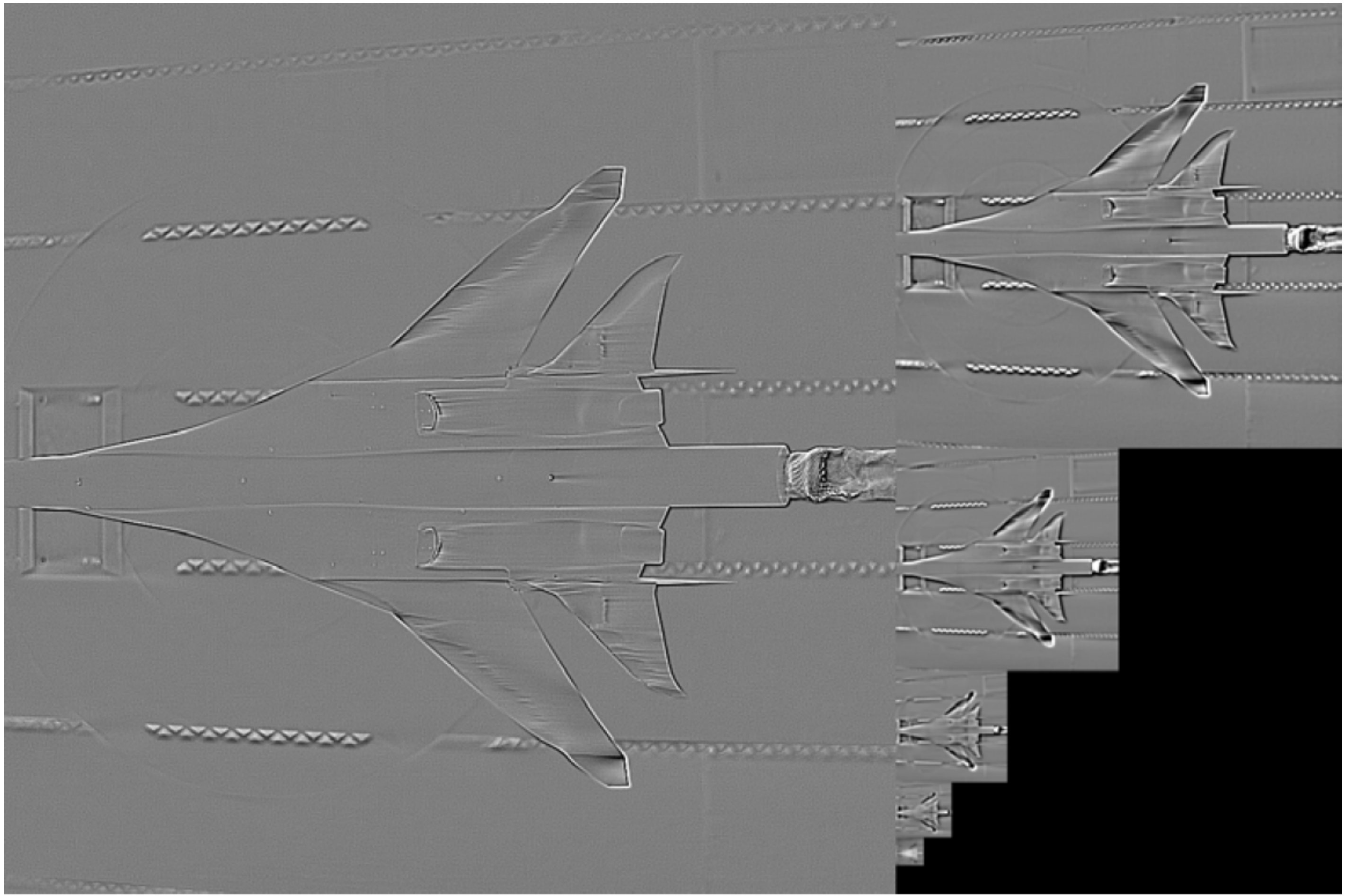




Contrast Enhancement

Normalized Laplacian Pyramid

- Decompose image into multi-level spatially filtered band-pass images
- Pixels are typically normally distributed at each band-pass level
- Normalize each level, weight and reconstruct pyramid

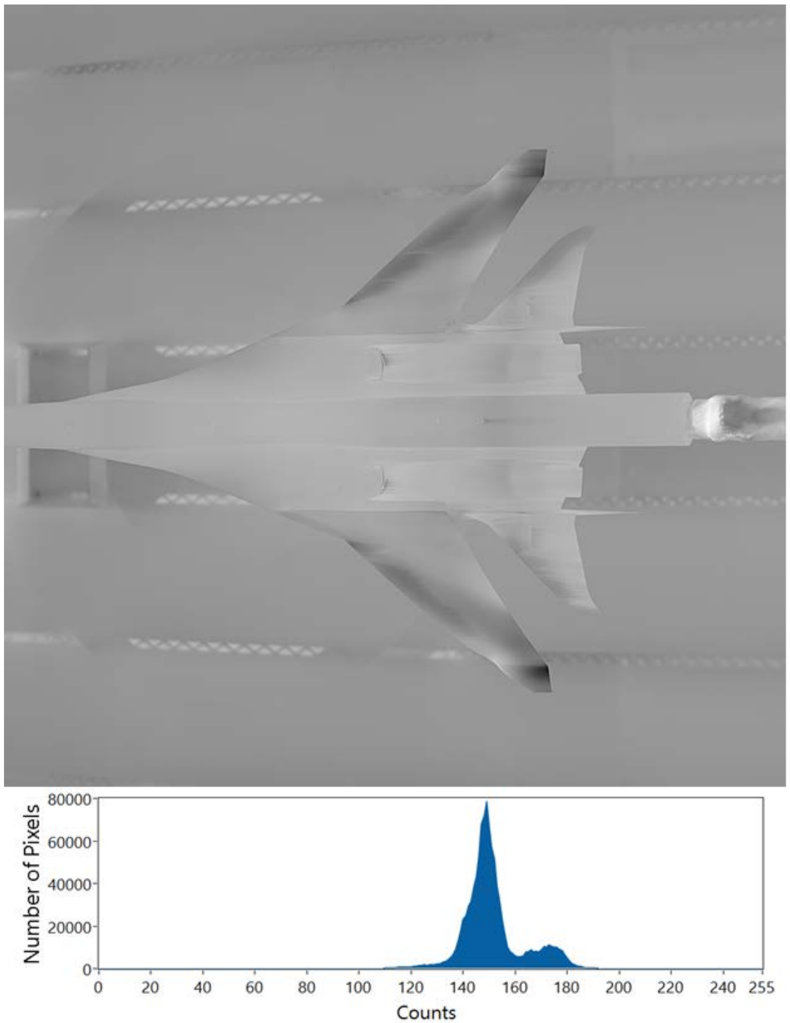


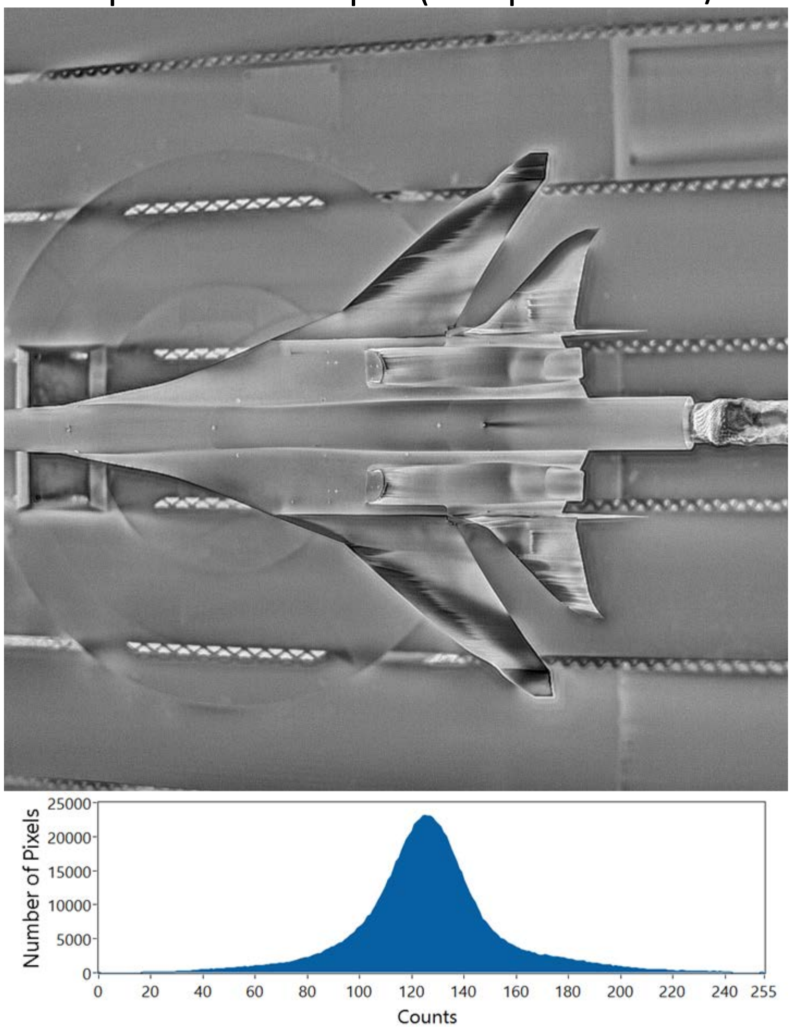
Contrast Enhancement

Normalized Pyramid Reconstruction

- Multi-scale contrast enhancement
- Fast (based on separable filters)
- Requires some input (two parameters/scale)

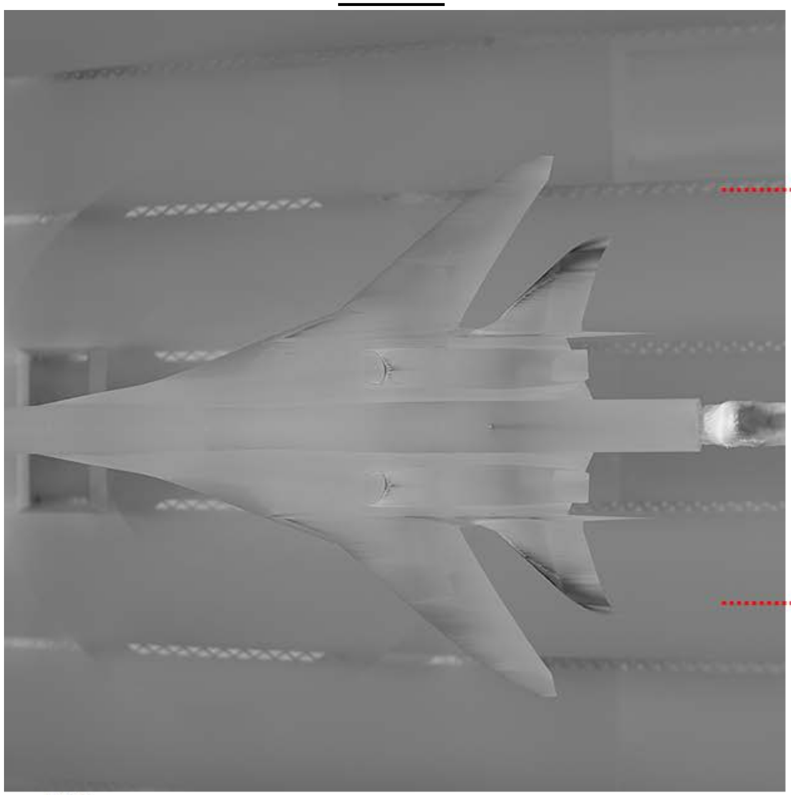
Linear

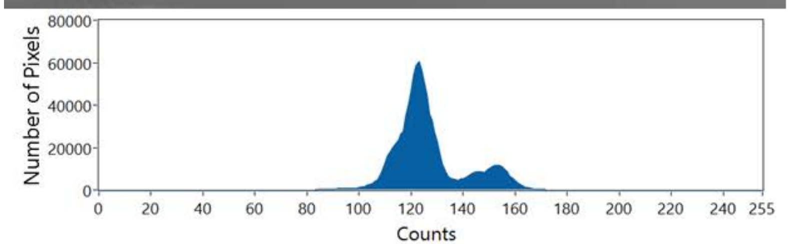




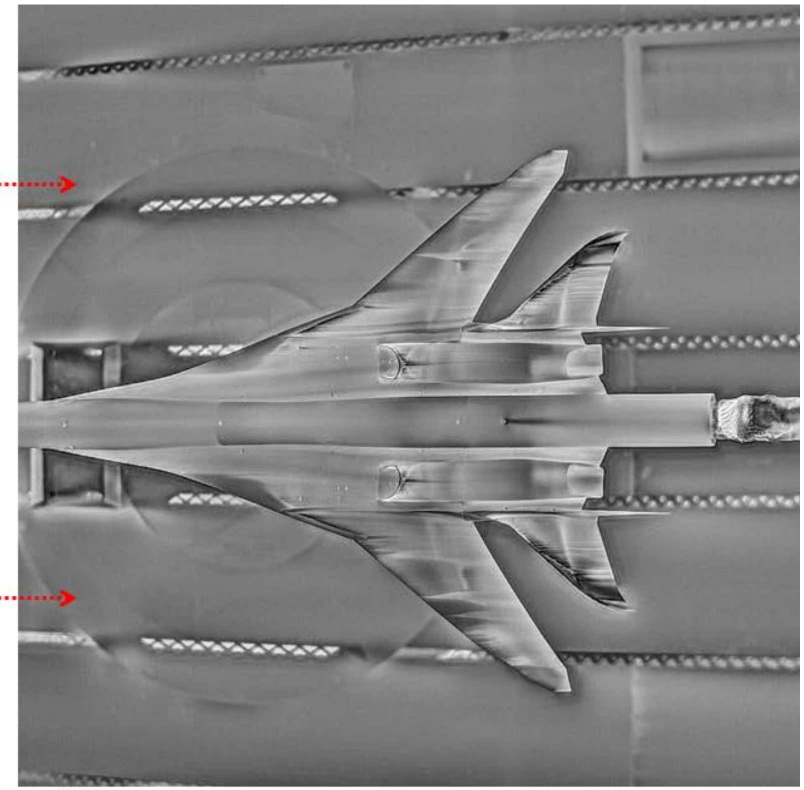
Contrast Enhancement

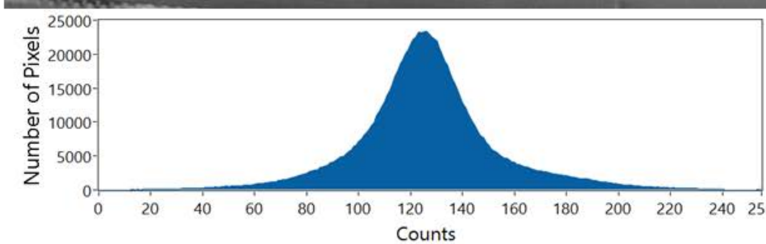
Linear





Normalized Pyramid Reconstruction





Conclusions

- Infrared imaging enables real-time flow visualization
- Integrated, multicamera, IR data systems are a powerful tool to investigate flow features on wind tunnel models
- Care must be taken to ensure the model surface is emissive and has comparatively low thermal conductivity
- Image processing is key

The presenter would like to thank the following principal investigators for generous use of wind tunnel model imagery: Greg Gatlin (Truss-Braced Wing), Don Durston (Boeing N+2 Sonic Boom Performance model), and Max Amaya (NASA Ames Check Standard Model)

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Questions?