Flight Tests of a Supersonic Natural Laminar Flow Airfoil

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Outline

- Background and previous research
- F-15B IR system
- Experiment overview
- Flight test results
  - Transition with Mach number
  - Transition with Reynolds number
  - Transition due to roughness elements
- Summary
- Questions

Background

- NASA has a current goal to eliminate barriers to the development of practical supersonic transport aircraft
- Drag reduction through the use of supersonic natural laminar flow (S-NLF) is currently being explored as a means of increasing aerodynamic efficiency
  - Tradeoffs work best for business jet class at M<2
- Conventional high-speed designs minimize inviscid drag at the expense of viscous drag
  - Existence of strong spanwise pressure gradient leads to crossflow (CF) while adverse chordwise pressure gradients amplifies and Tollmien-Schlichting (TS) instabilities
- Aerion Corporation has patented a S-NLF wing design (US Patent No. 5322242)
  - Low sweep to control CF
  - $dp/dx < 0$ on both wing surfaces to stabilize TS
  - Thin wing with sharp leading edge to minimize wave drag increase due to reduction in sweep
- NASA and Aerion have partnered to study S-NLF since 1999
- Series of S-NLF experiments flown on the NASA F-15B research test bed airplane
- Infrared (IR) thermography used to characterize transition
  - Non-intrusive, global, good spatial resolution
  - Captures significant flow features well

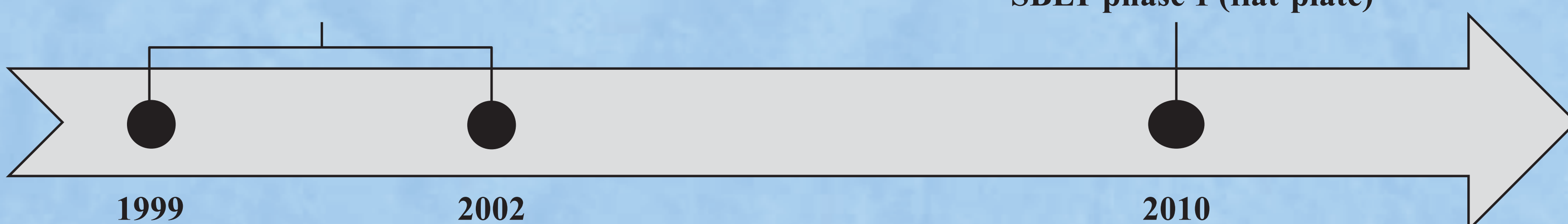
Partnership with Aerion Corp.

Previous Research

- Supersonic Natural Laminar Flow (SSNLF)
  - Bi-convex test article
  - Demonstrated extended runs of S-NLF up to Re_c = 10 million at Mach 1.8
- Supersonic Boundary Layer Transition (SBLT)
  - Large chord flat-plate test article
  - Measured plate pressures and local inflow conditions up to Mach 2.0
  - Pressure data used to help design follow on S-NLF test article

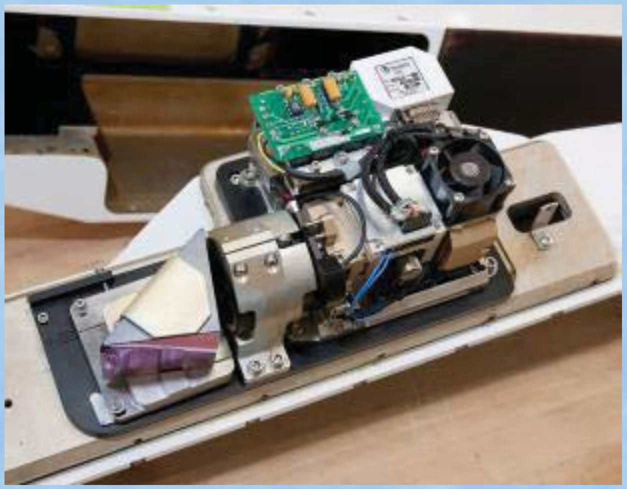
SSNLF

SBLT phase 1 (flat-plate)



F-15B IR System

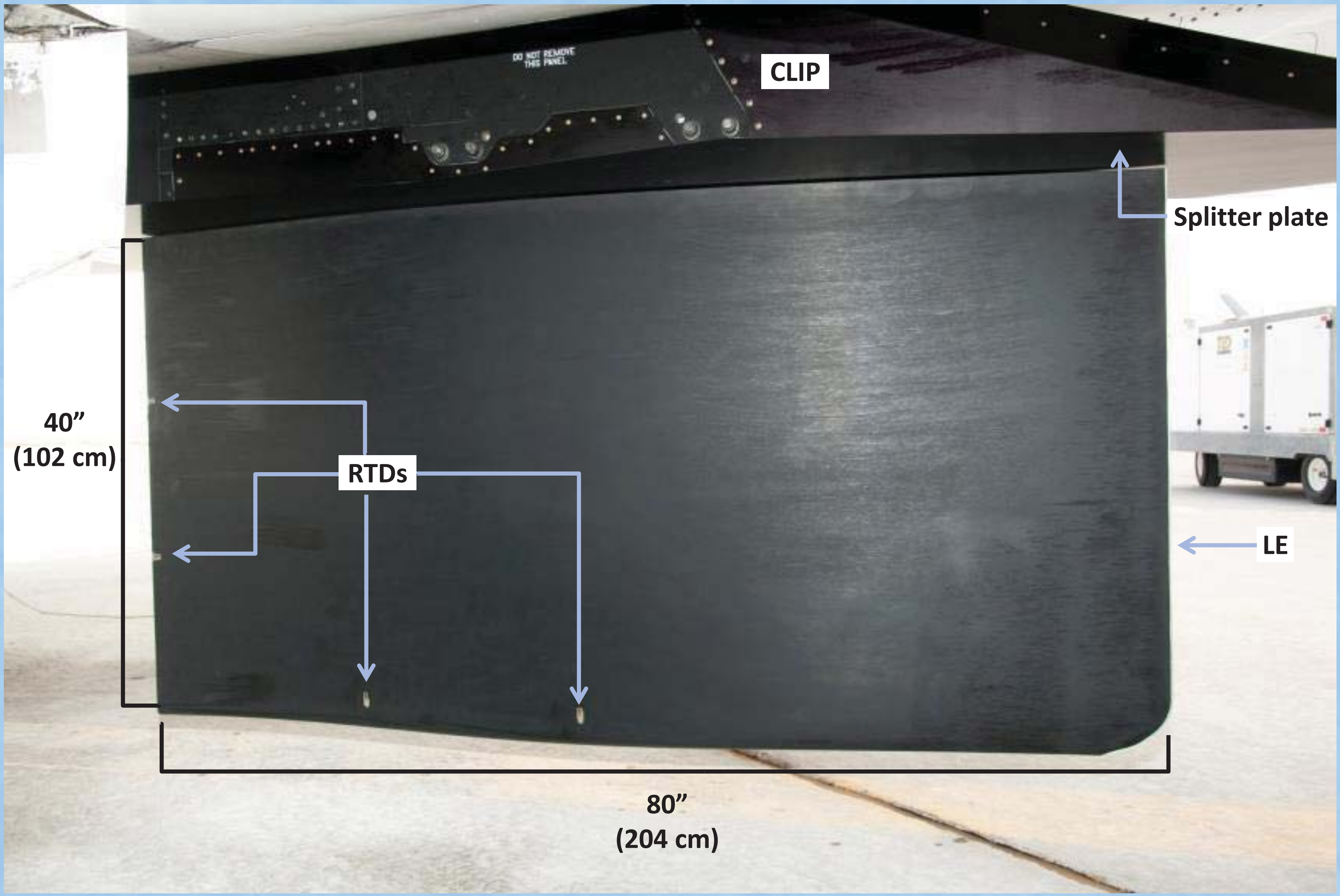
- Camera
  - L3 Cincinnati 640x512 NC
  - 640x512 Indium-Antimonide (InSb) focal plane array with 28 micron pitch
  - Mid-wave (3-5 micron spectral range)
  - 13 mm lens
  - Simultaneous 14-bit digital and RS-170 analog output
- Camera pod
  - Streamlined pod mounted on starboard armament rail
  - Silicon window with anti-reflection coating
  - Right-angle prism to redirect image to camera
- Onboard Recorders
  - 8 mm (Hi-8) recorder for analog output
  - Digital Design Corp. VAADR-1 unit



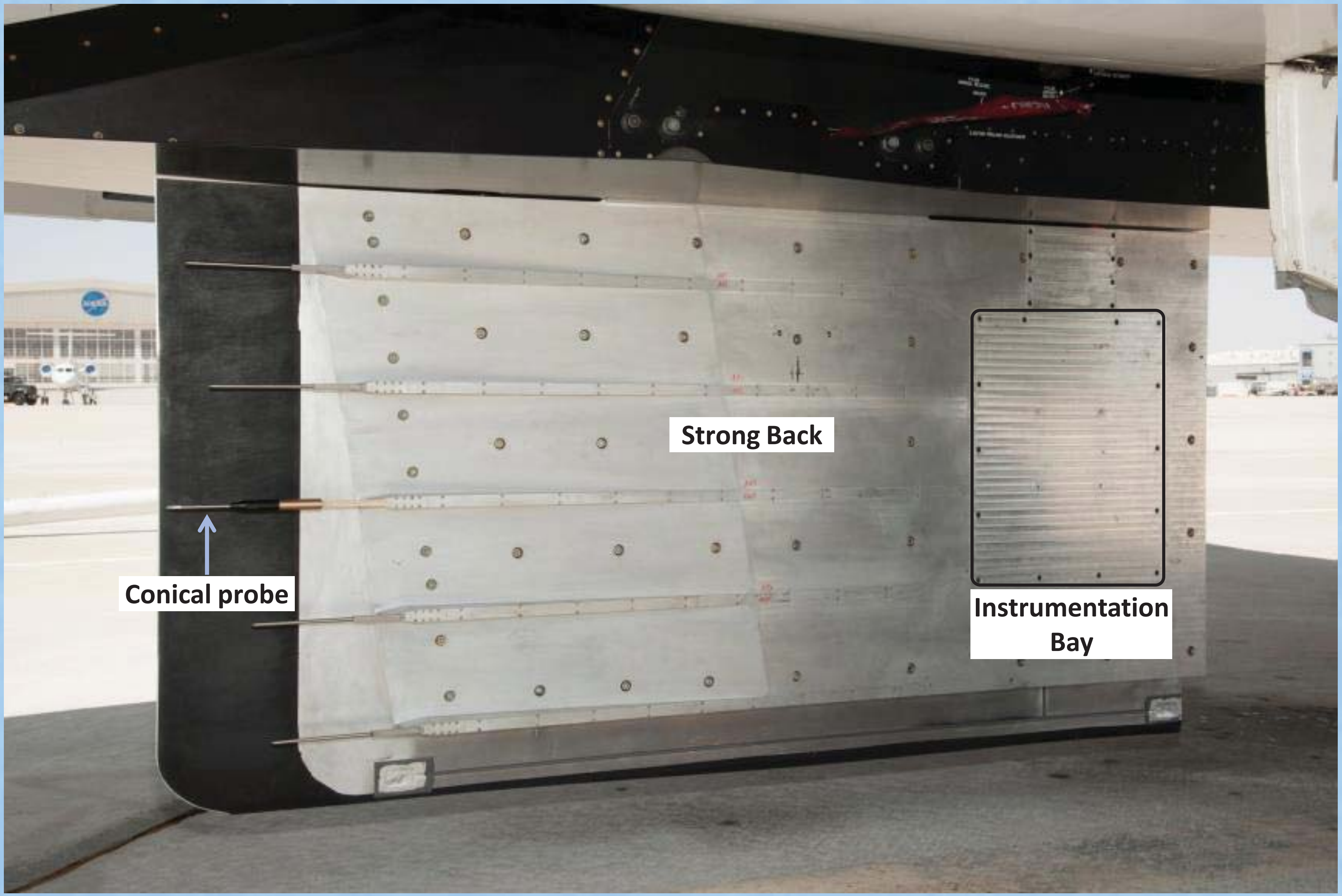
IR camera

IR camera pod

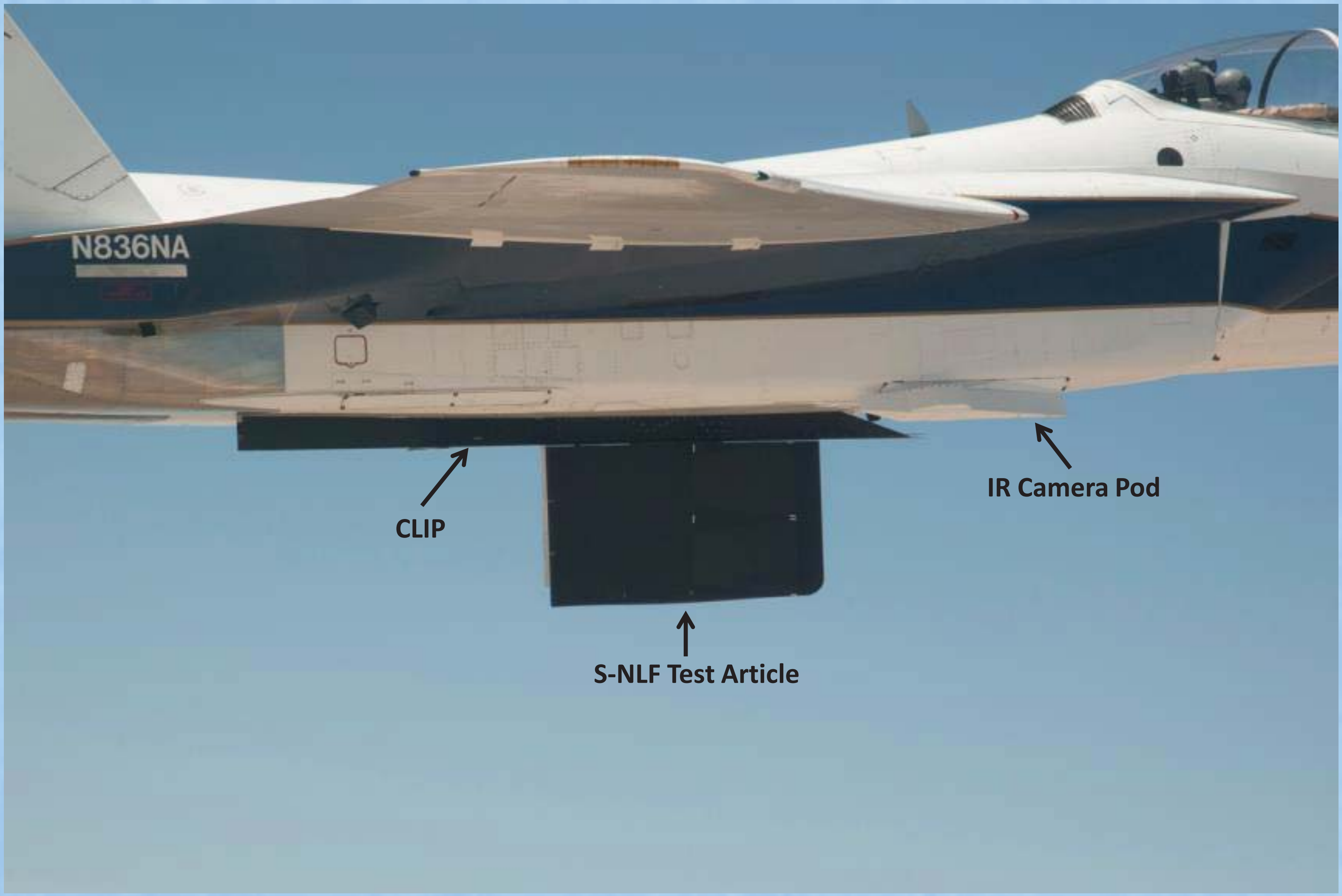
S-NLF Test Article



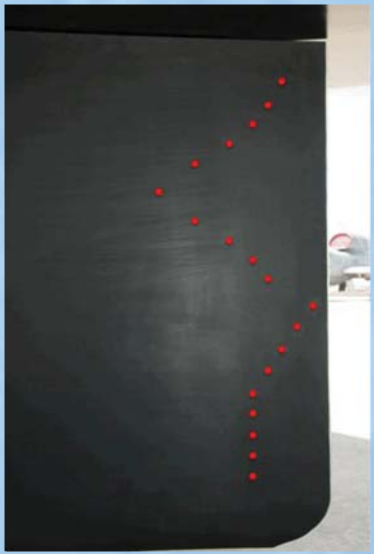
Strong Back Side



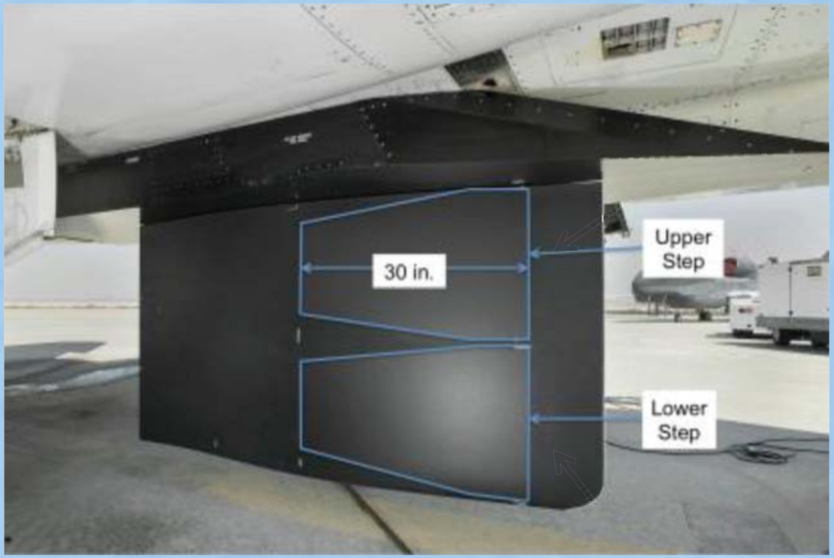
F-15B Test Configuration



Roughness Elements



Trip dots
(highlighted in red)

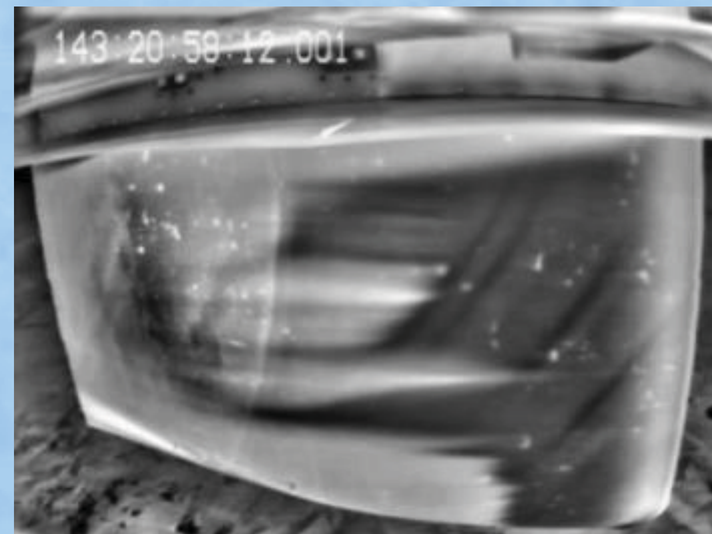


2-D steps
(highlighted in blue)

- Roughness elements installed during select flights to investigate effects on transition
- Trip dots
  - 19 dots were installed near leading edge of the test article
  - Dots were formed from aluminum and polyimide adhesive tapes with thicknesses of 2, 3, and 4.5 mil (0.051, 0.076, and 0.114 mm)
- 2-D steps
  - Created from 30 inch (76 cm) strips of 4.5 mil (0.114 mm) thick adhesive backed vinyl film
  - Leading edge located approximately 8.5 inches (21.6 mm) back from leading edge
  - Layered to create addition step heights of 13.5 and 22.5 mil (0.343 and 0.572 mm)

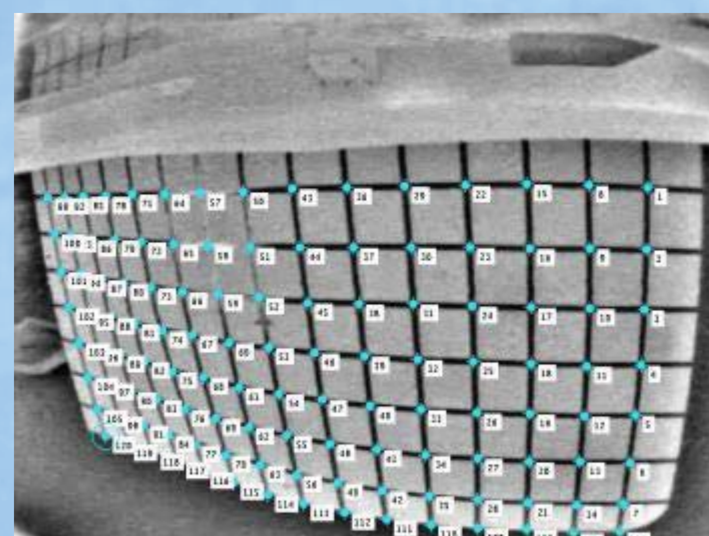
IR Image Transformation

- IR images have perspective distortion (foreshortening)
  - Wide-angle lens
  - Camera pod mount position
- Calibration grid applied to test article for image registration
- Control point pairs used to transform distorted image into reference perspective
- Transformation applied frame-by-frame to IR video



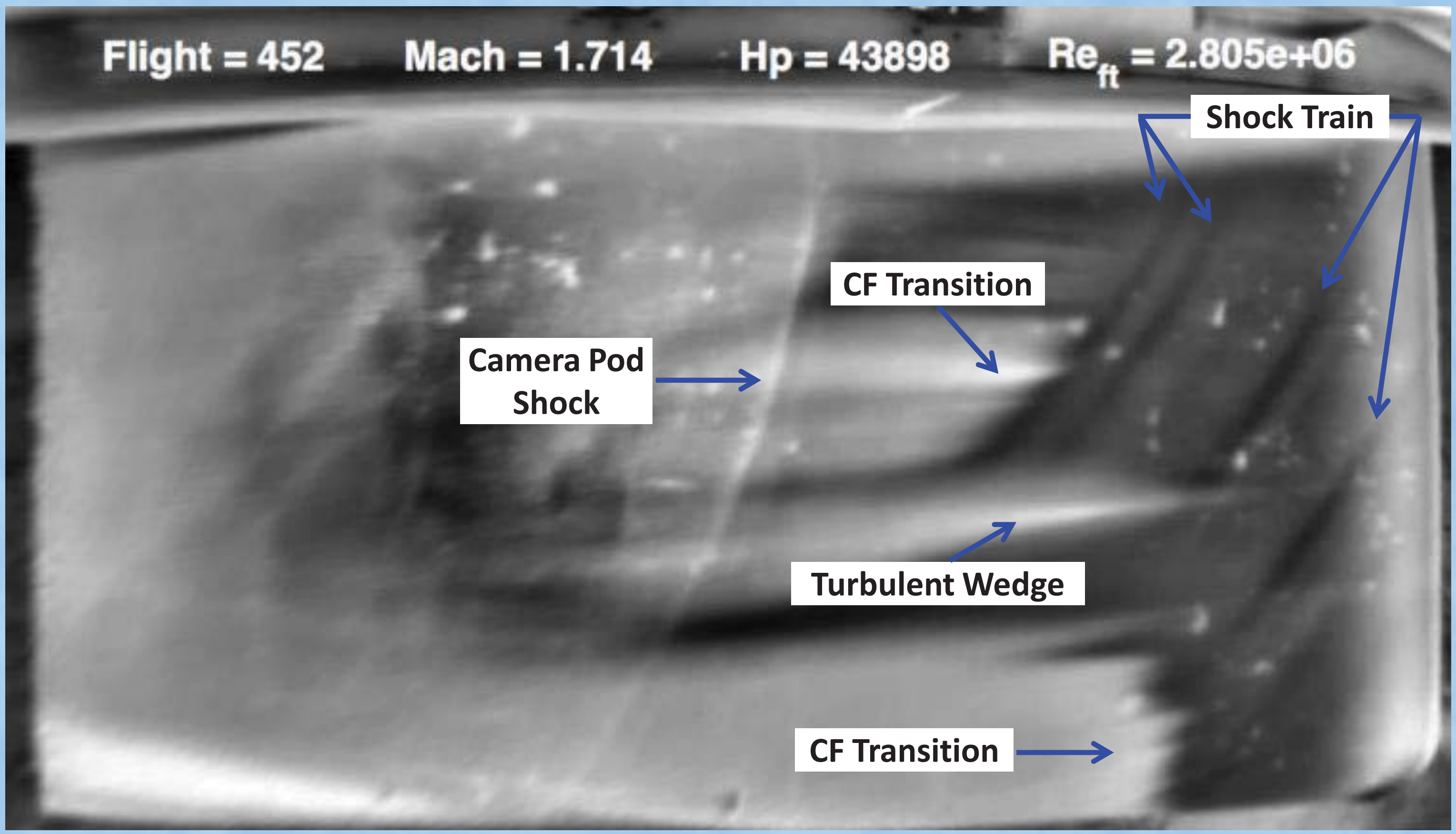
Analog IR image from flight

Target image with control points

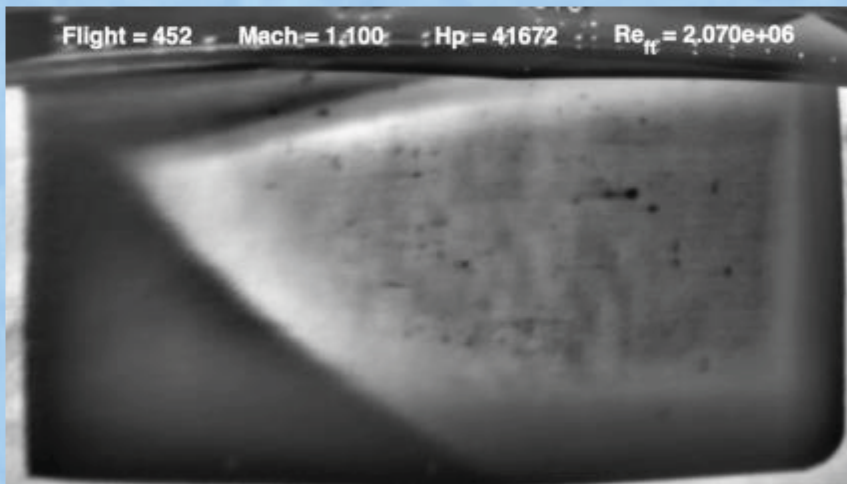


IR image with control points

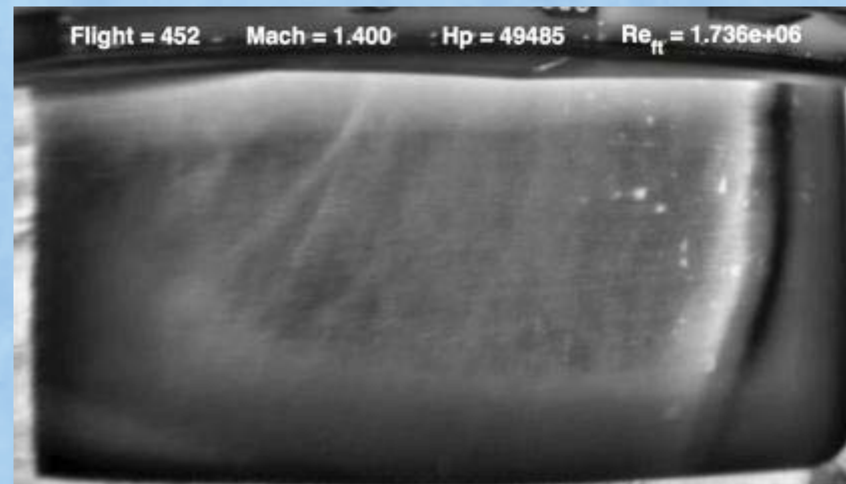
Transformed IR Image



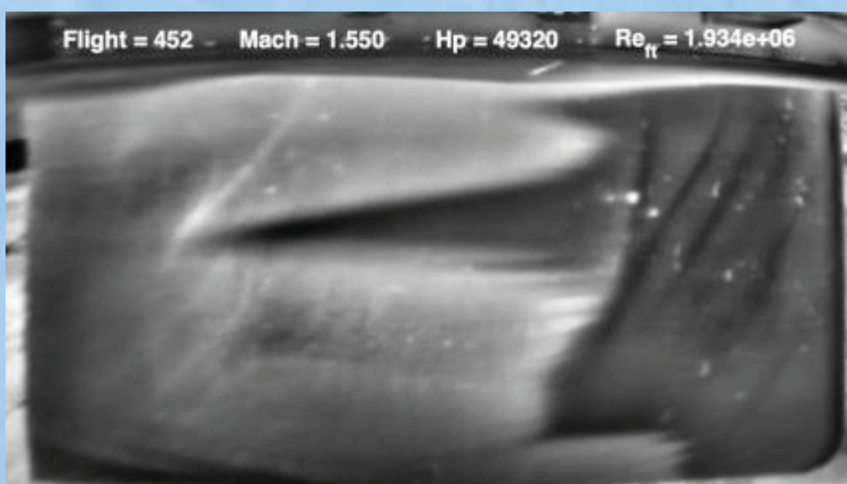
Transition with Mach Number



M=1.1, 42 kft (12.8 km) , accelerating



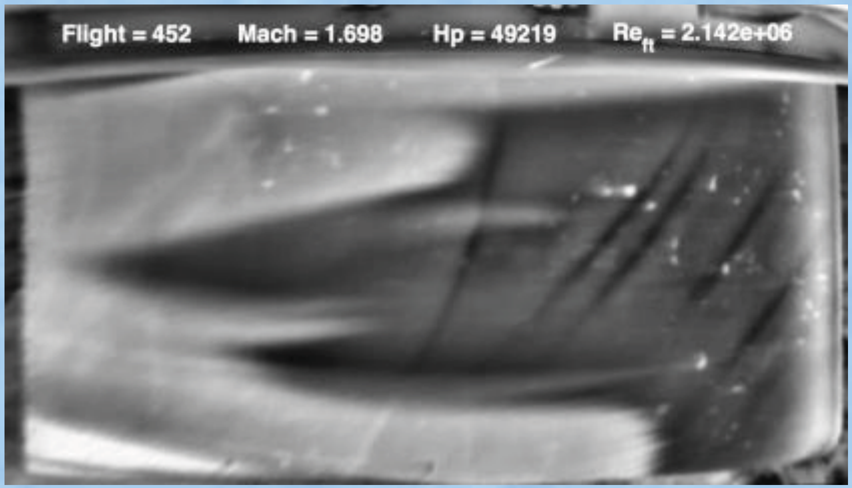
M=1.4, 49.5 kft (15.09 km), accelerating



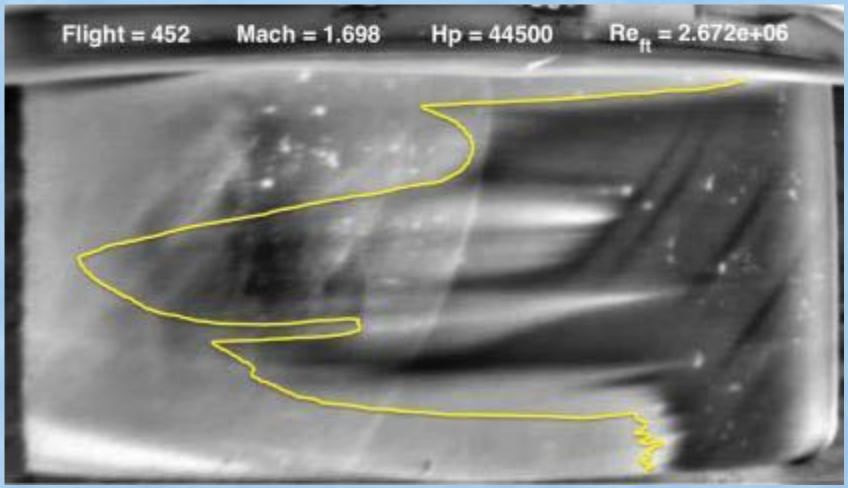
M=1.55, 49.5 kft (15.09 km), accelerating

M=1.7, 49.5 kft (15.09 km), steady state

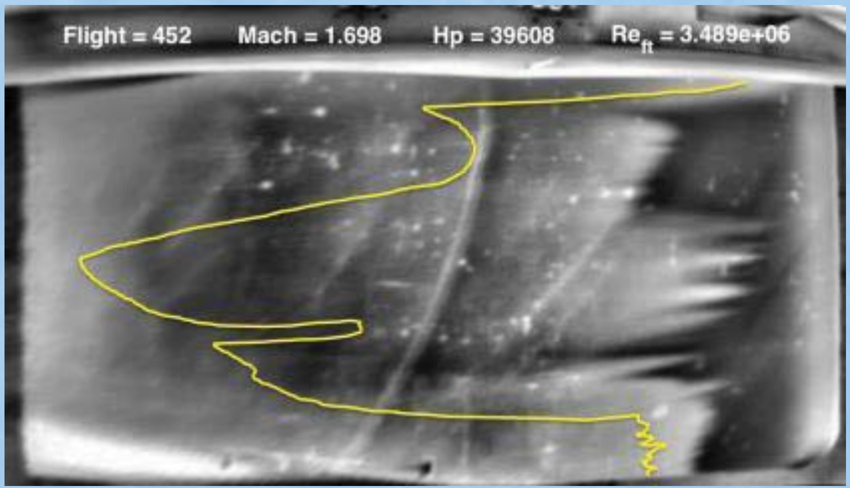
Reynolds Number Effects M=1.7



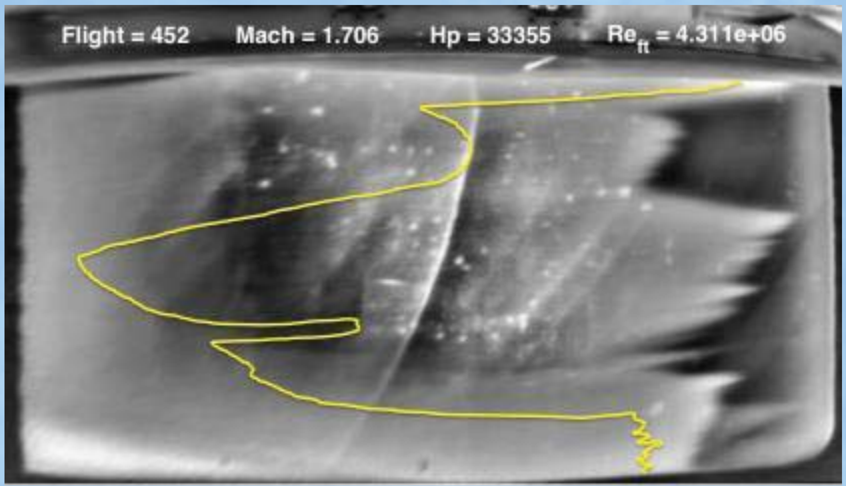
M=1.7, Re_{ft}=2.14 million/ft (0.652 million/m)



M=1.7, Re_{ft}=2.67 million/ft (0.814 million/m)

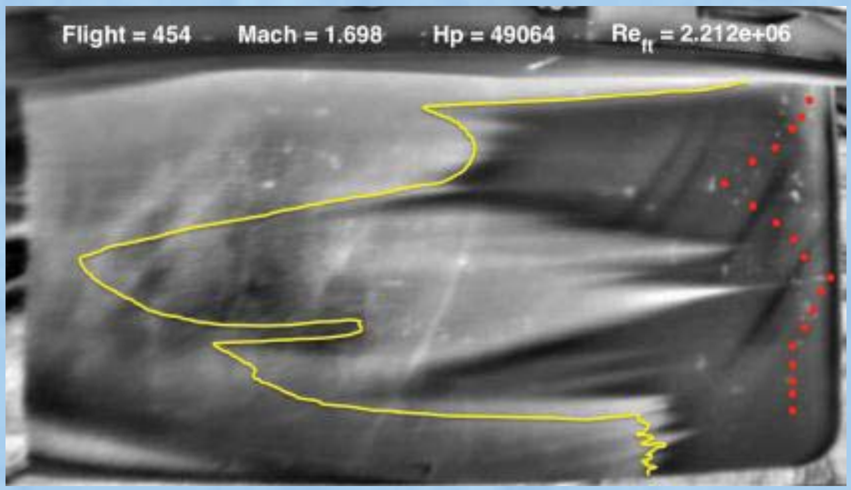


M=1.7, Re_{ft}=3.49 million/ft (1.06 million/m)

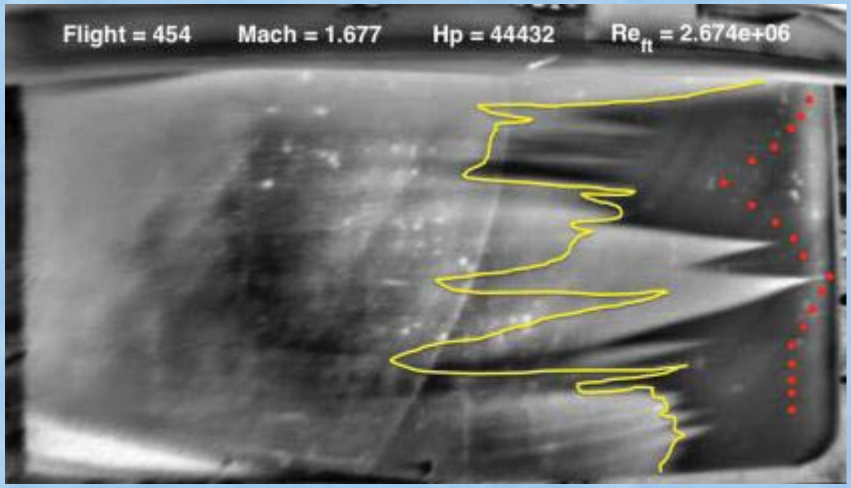


M=1.71, Re_{ft}=4.31 million/ft (1.31 million/m)

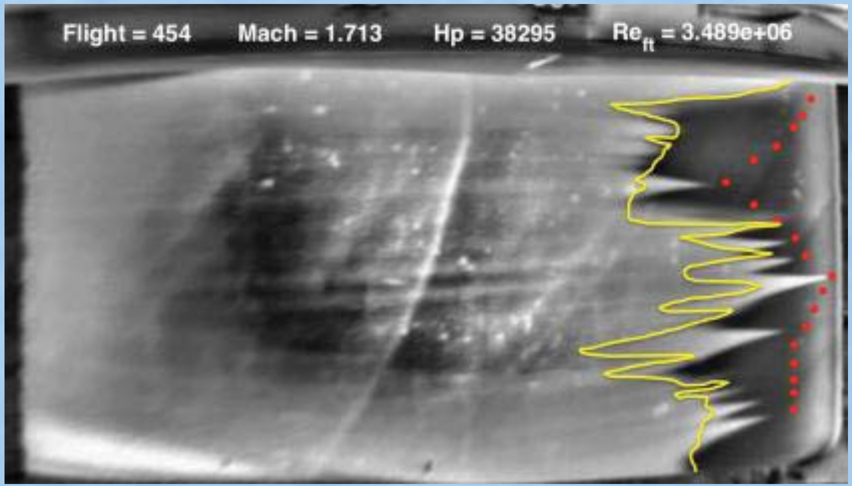
Trip Dots M=1.7



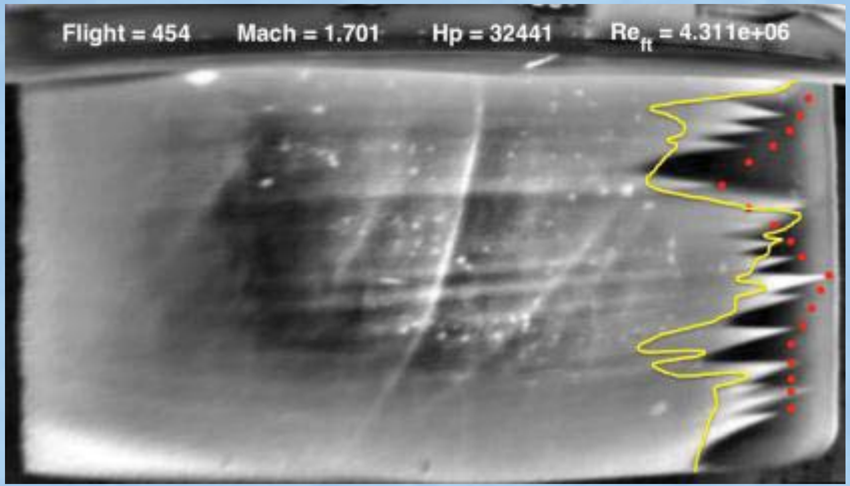
M=1.7, Re_{ft}=2.21 million/ft (0.674 million/m)



M=1.68, Re_{ft}=2.67 million/ft (0.814 million/m)



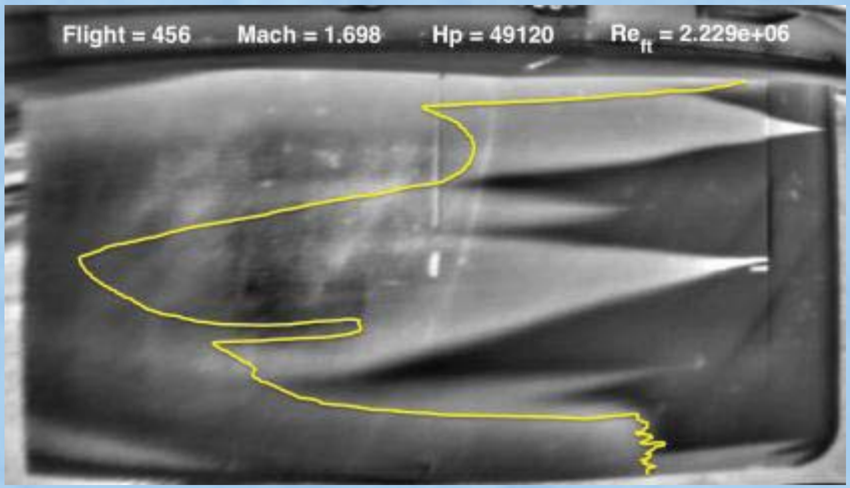
M=1.71, Re_{ft}=3.49 million/ft (1.06 million/m)



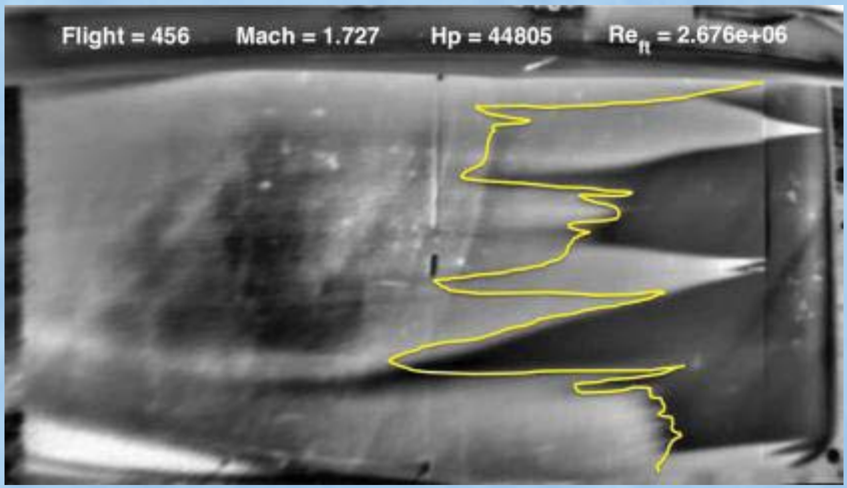
M=1.7, Re_{ft}=4.31 million/ft (1.31 million/m)

2-D Steps M=1.7

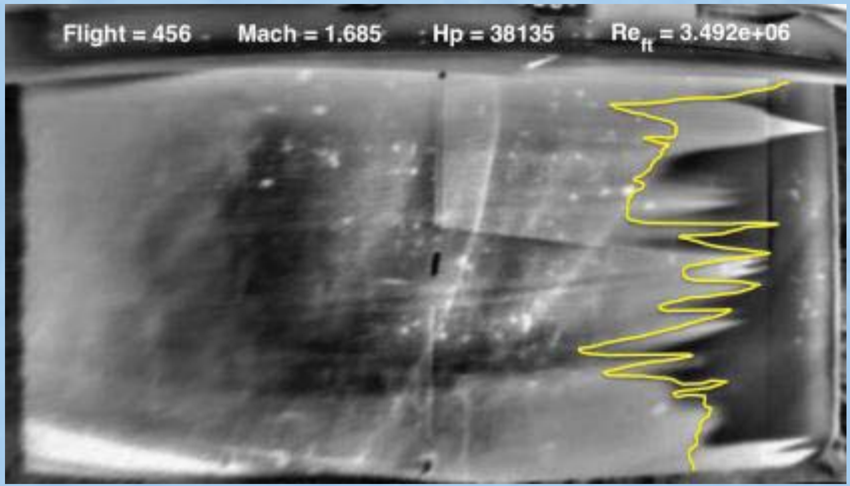
(upper 0.343 mm, lower 0.114 mm)



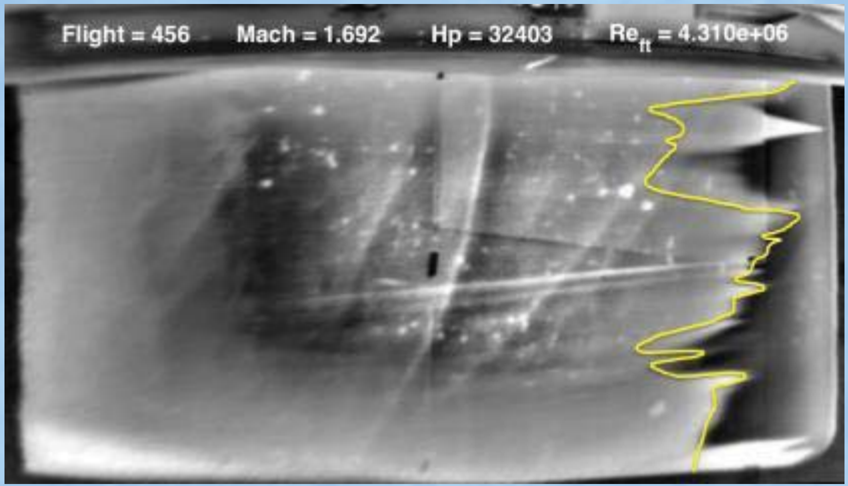
M=1.7, Re_{ft}=2.14 million/ft (0.68 million/m)



M=1.73, Re_{ft}=2.67 million/ft (0.814 million/m)



M=1.69, Re_{ft}=3.49 million/ft (1.06 million/m)



M=1.69, Re_{ft}=4.31 million/ft (1.31 million/m)

Flight 452

Flight 454

Flight 456

Summary

- IR thermography was used to characterize the transition front on a S-NLF test article at chord Reynolds numbers in excess of 30 million
- Changes in transition due to Mach number, Reynolds number, and surface roughness were investigated
  - Regions of laminar flow in excess of 80% chord at chord Reynolds numbers greater than 14 million
- IR thermography clearly showed the transition front and other flow features such as shock waves impinging upon the surface
- A series of parallel oblique shocks, of yet unknown origin, were found to cause premature transition at higher Reynolds numbers


Questions?
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