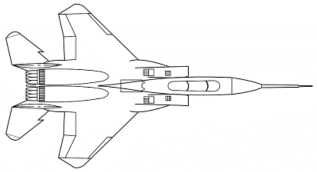

Detection and Characterization of Boundary-Layer Transition in Flight at Supersonic Conditions Using Infrared Thermography

13th International Symposium on Flow Visualization

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Edwards, California USA

Nice, France
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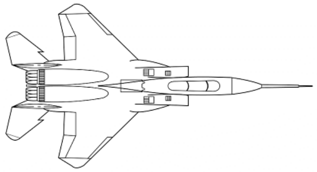


AGENDA

- Introduction
- IR Transition Detection
- Background
- Test Configuration
- Results
- Summary

INTRODUCTION

- **Flight test using infrared (IR) thermography to investigate transition characteristics of a test article in flight at supersonic conditions**
  - Test article mounted on centerline store station of F-15B
  - Leading-edge (LE) sweep angles of 15° and 30° (reversible)
  - Test article designed to minimize Tollmien-Schlichting (TS) instabilities
    - » 15° LE produce large runs of laminar flow
    - » 30° LE produce cross-flow dominant transition
  - Target Mach~1.8 at approximately 40,000 ft / 12,000 m
  - High resolution analog and digital recordings

Infrared Transition Detection
-How it works at high Mach numbers-

- **Higher recovery factor in turbulent flow than in laminar flow**

  ⇒ **higher flow temperature near surface in turbulent region**
- **Higher skin friction in turbulent region**

  ⇒ **higher convective heat transfer in turbulent region**
- **Turbulent region is warmer than laminar region**

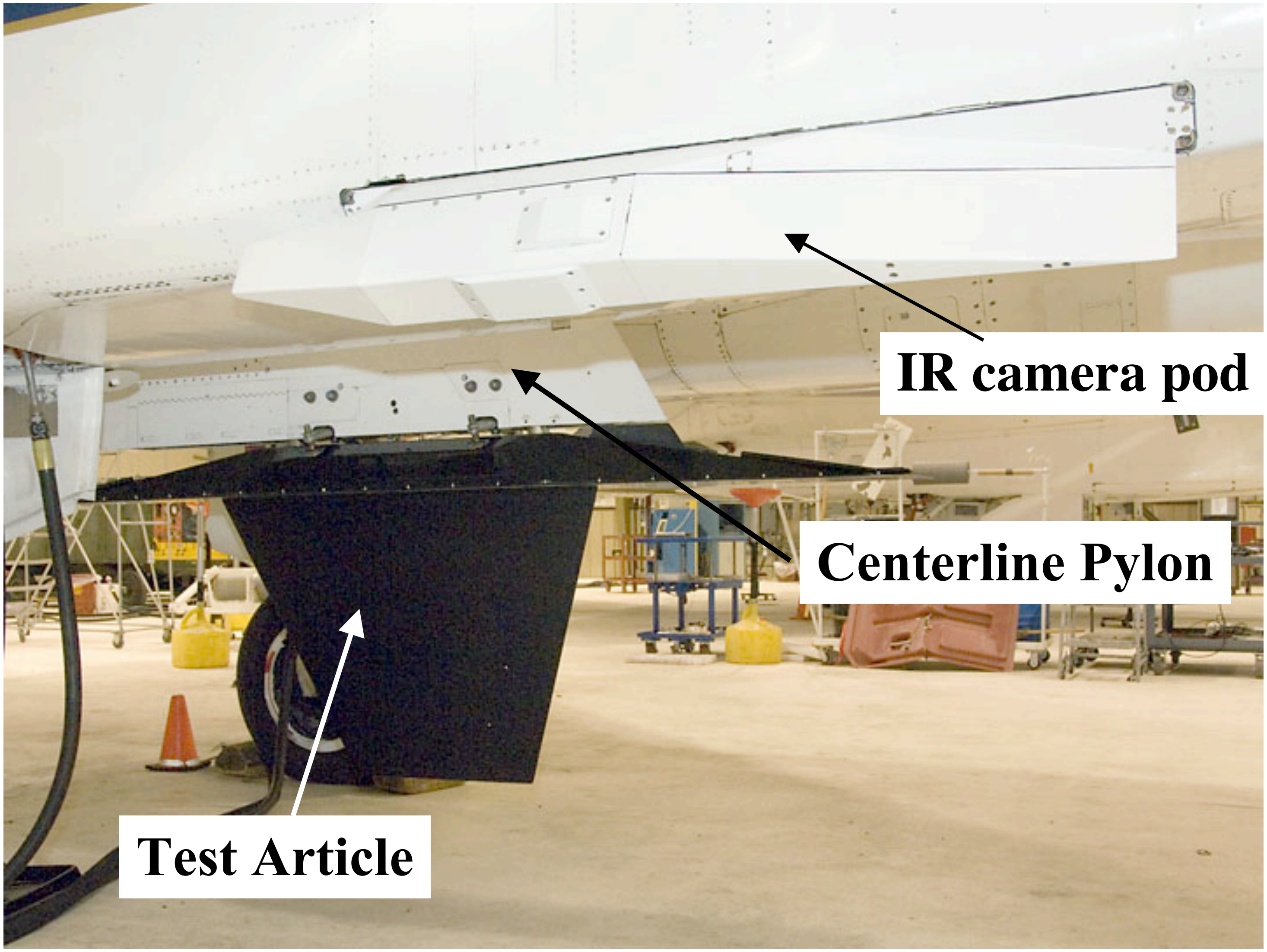
  ⇒ **higher thermal radiation emittance in turbulent region**

Background

- **Continuation of earlier test (1999 - 2002)**
- **Modified and refurbished test article**
  - **Larger leading-edge radius and t/c**
  - **Some surface temperatures and pressures**
- **New state-of-the-art IR camera**
  - **L-3 CMI 640 NC**
- **New state-of-the-art digital video recorder**
  - **Digital Design Corp. (DDC) VADR-1**

Objectives: To qualify new hardware (camera and recorder) and to gather additional data to support larger more complex supersonic boundary layer transition test starting later this year.

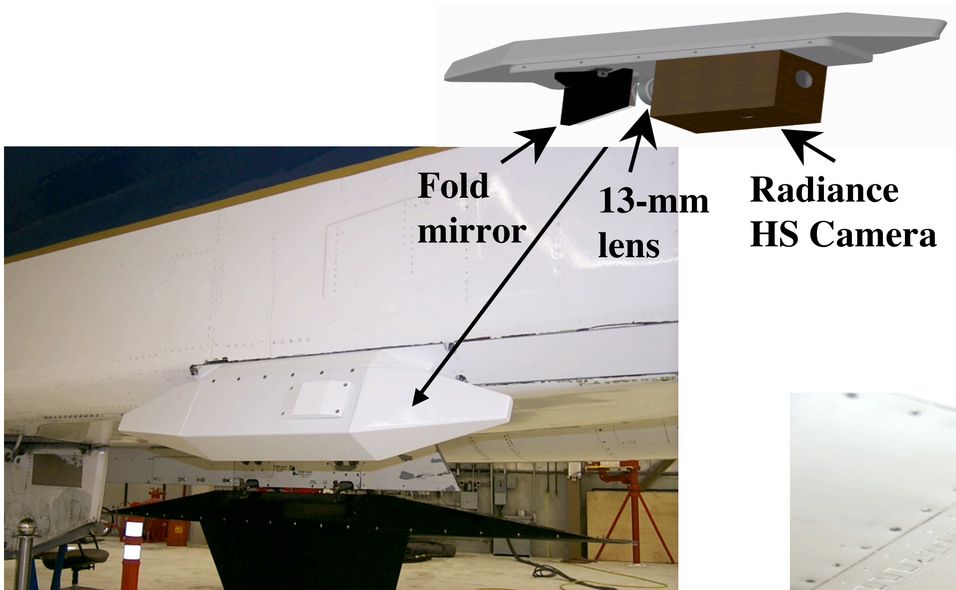
Test Article and IR Camera Pod on F-15



IR Camera System

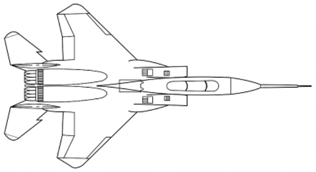
- **Current Camera**
  - L3 Cincinnati 640 x 512 NC
  - Mid-wave (3 to 5 micron spectral range)
  - 640 x 512 Indium-Antimonide (InSb) focal plane array
  - Simultaneous 16-bit digital and RS-170 analog output
- **Pod Optics**
  - 13 mm lens
  - Single fold mirror
  - Coated silicon window
- **Previous Camera**
  - Raytheon Radiance HS
  - Mid-wave
  - 256 x 256 InSb focal plane array
  - Simultaneous 12-bit digital and NTSC analog output

Camera and Pod



Old Camera and Pod

New Camera and Pod



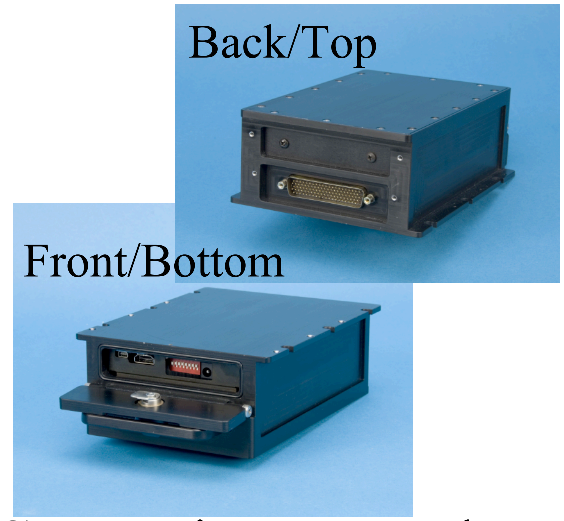
Digital Video Recorders

- **1st / 2nd Generation Recorders**
  - “Home Grown” using off the shelf PC parts and ruggedized
  - Assembled by PVP Advanced EO Systems
  - Recorded from high speed parallel connection (10ft / 3m max)
  - Maximum 17GB data capacity (2nd gen)
  - Mounted on isolation tray with shock mounts
  - Limited success due to high vibration level in bay beneath inlet

- **3rd Generation Recorder**
  - Digital Design Corp. VADR-1 unit
  - Records from high speed serial connection
    - » allows remote location from camera (currently > 50 ft / 15m)
  - 120 GB capacity (maximum 288 GB +)
  - Designed for rugged applications
    - » such as high speed maneuvering aircraft
  - Currently in trials on test aircraft

Digital Video Recorders

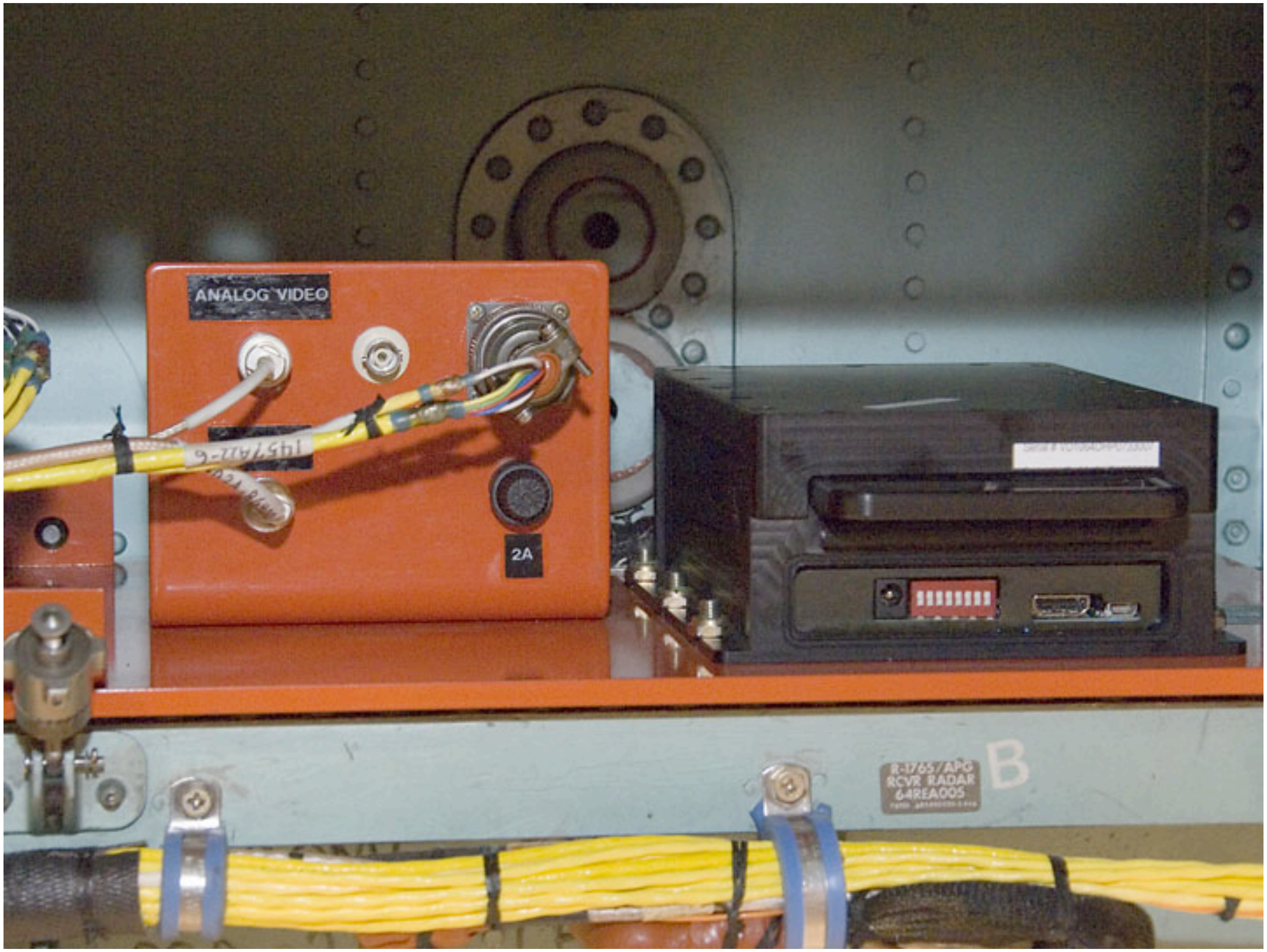
1st Generation Recorder



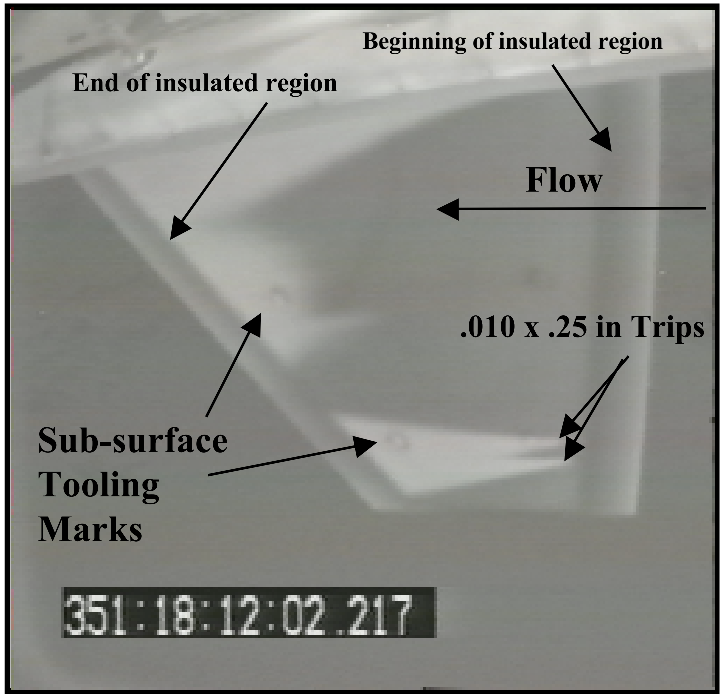
3rd Generation Recorder

2nd Generation Recorder

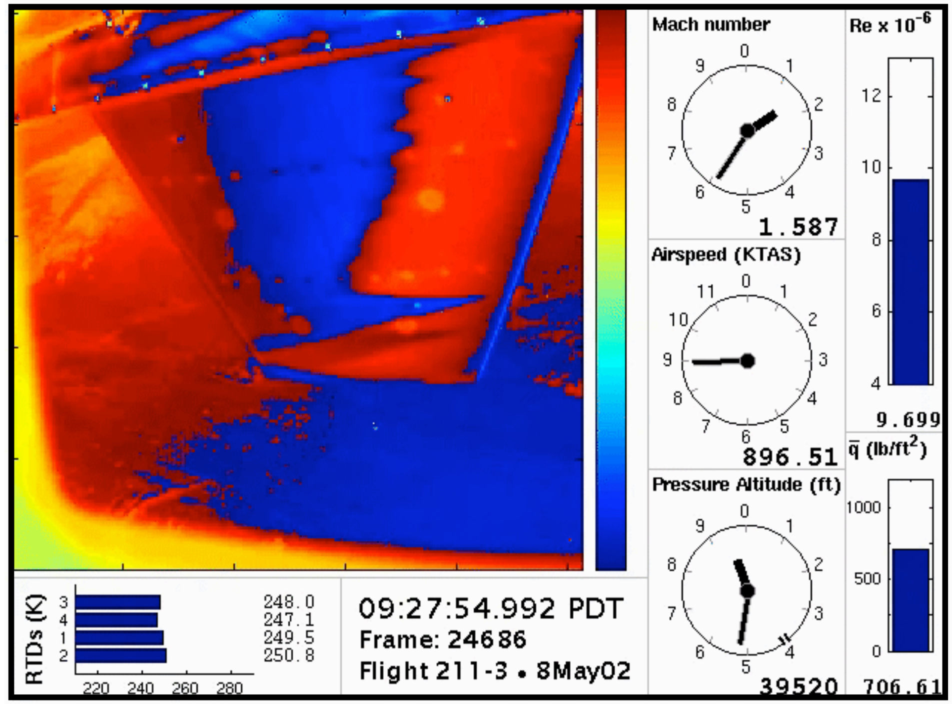
Installed Digital Video Recorder



Phase I (1999-2002) Images



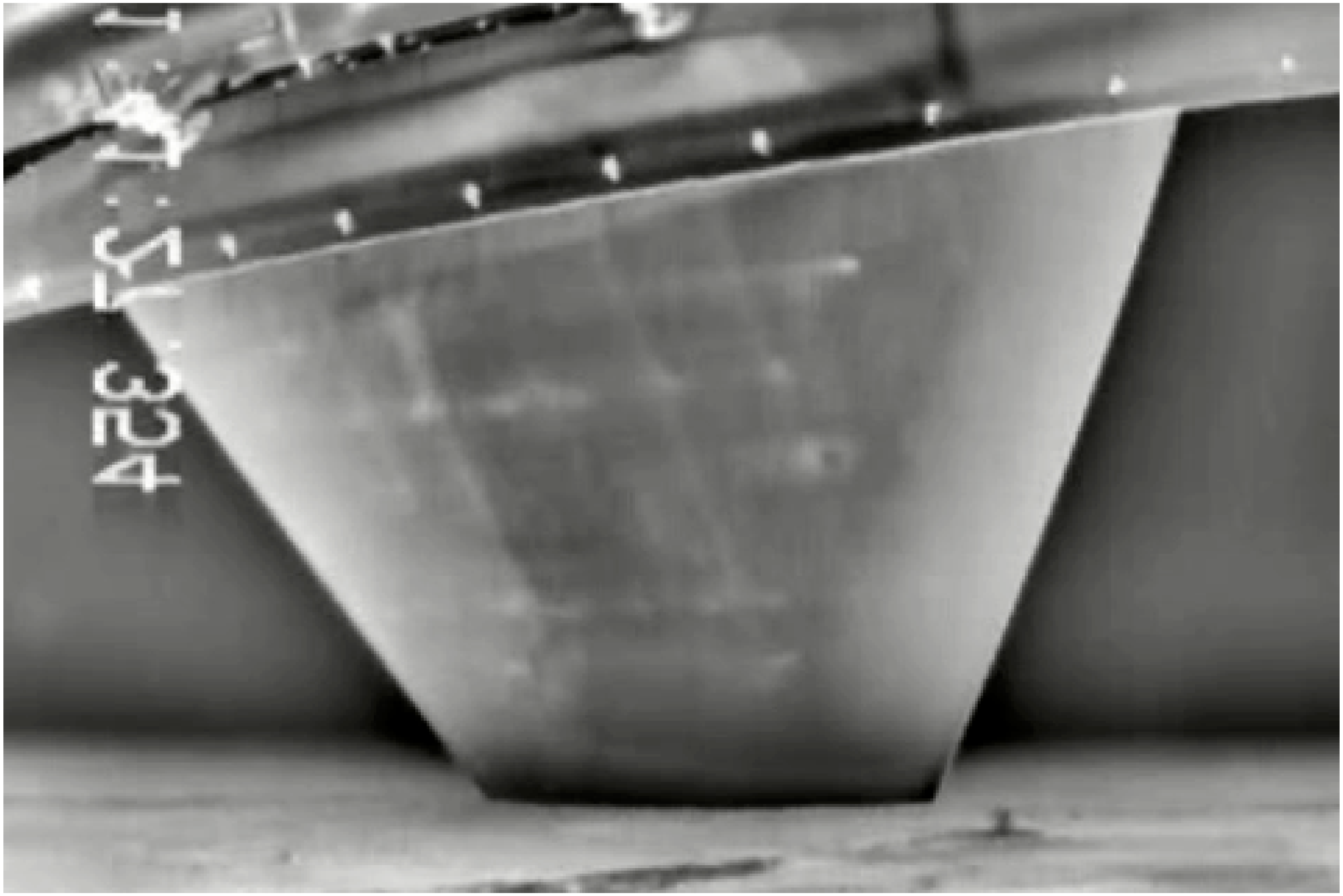
Analog 15° LE M~1.8



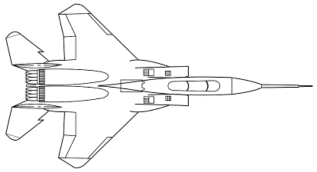
Digital 30° LE M~1.6

F-15B Test Bed In Flight

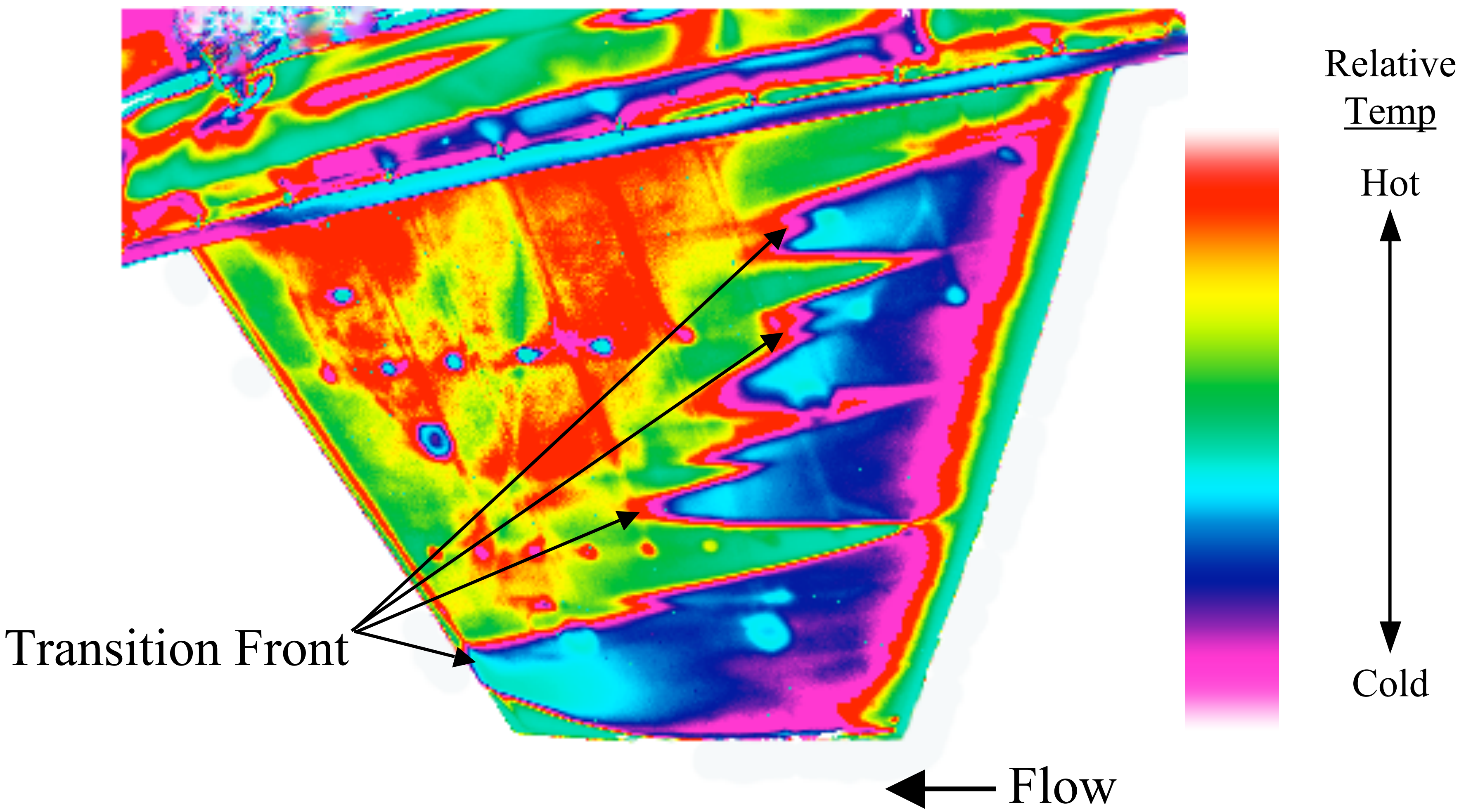
Supersonic Accel with 30° LE

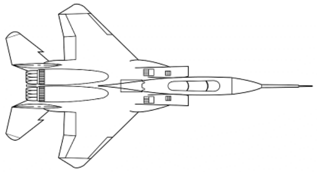


Supersonic Accel with 15° LE

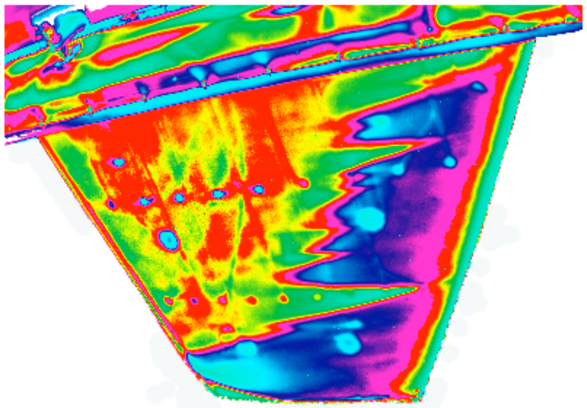


Digital False Color Image
30° LE, M~1.72

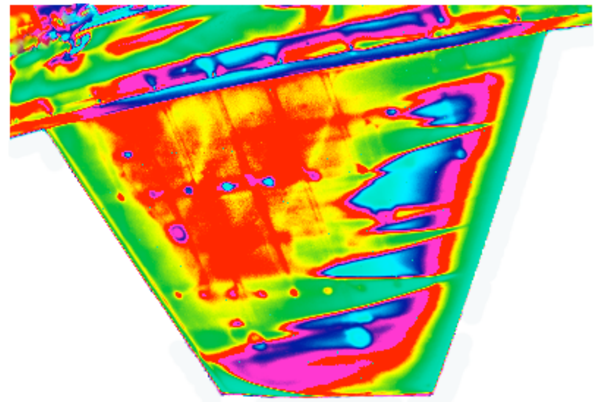




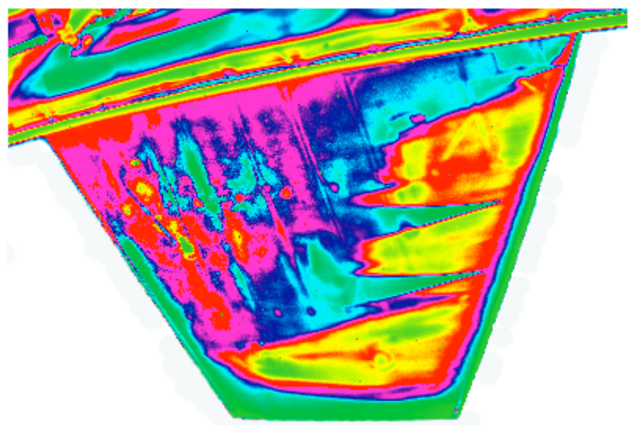
Digital False Color Images 30° LE



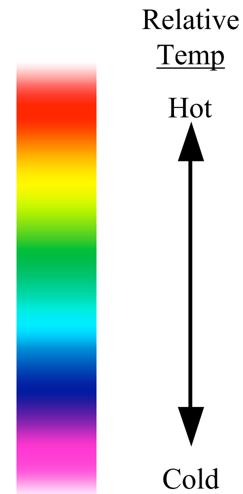
M~1.68



M~1.80



M~1.16 decelerating



SUMMARY

- **Infrared thermography is a powerful tool for investigating fluid mechanics on flight vehicles**
  - Can be used to visualize and characterize transition, shock impingement, separation etc.
- **Updated onboard F-15 based system was used to visualize supersonic boundary layer transition test article**
  - Tollmien-Schlichting and cross-flow dominant flow fields
- **Digital Recording improves image quality and analysis capability**
  - Allows accurate quantitative (temperature) measurements
  - Greater enhancement through image processing allows analysis of smaller scale phenomena