Propulsion-Airframe Integration Flight Test Instrumentation

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Outline

- Introduction
- Current Capabilities
  - On- and off-surface flow measurements
  - On- and off-surface flow visualization
  - Thrust estimation
- Capabilities in Development
- Needed Capabilities
- Concluding Thoughts

Introduction

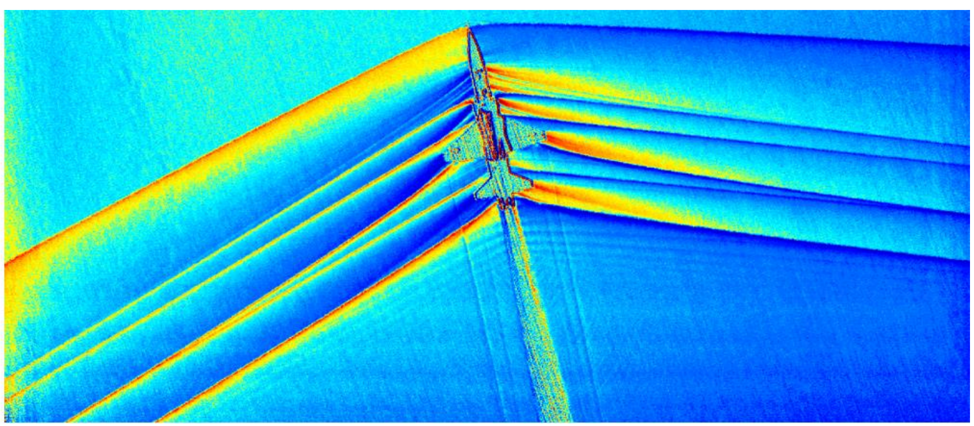
- This presentation focuses on flight test instrumentation for flow measurements applicable to PAI
  - Since internal engine instrumentation is not substantially different for in-flight measurements, this area isn't covered in detail
  - There are some technologies for strain measurement, e.g. Fiber Optic Strain Sensing (FOSS), that have applications for PAI, but they are not covered in detail
  - Not intended to cover everything currently used in the flight test environment
- Current and potential future measurement technologies at NASA Armstrong Flight Research Center are discussed

NASA Armstrong Flight Research Center

- Mission: Advancing technology and science through flight
- Vision: To fly what others only imagine
- 70+ years of flight test and flight research history and experience
- Located on Edwards Air Force Base
- Some of the aircraft tested and flown at AFRC:
  - X-15
  - F-8 Digital Fly-By-Wire
  - F-8 Supercritical Wing
  - HL-10 Lifting Body
  - X-29
  - X-31
  - F-18 HARV
  - F-16XL
  - X-43A
  - SOFIA
  - X-56

Aerodynamics and Propulsion Branch

- Competencies include:
  - Aerodynamics
  - Propulsion and Performance
  - Flow Physics
  - Aerospace Meteorology
- Responsibilities include both research and airworthiness support

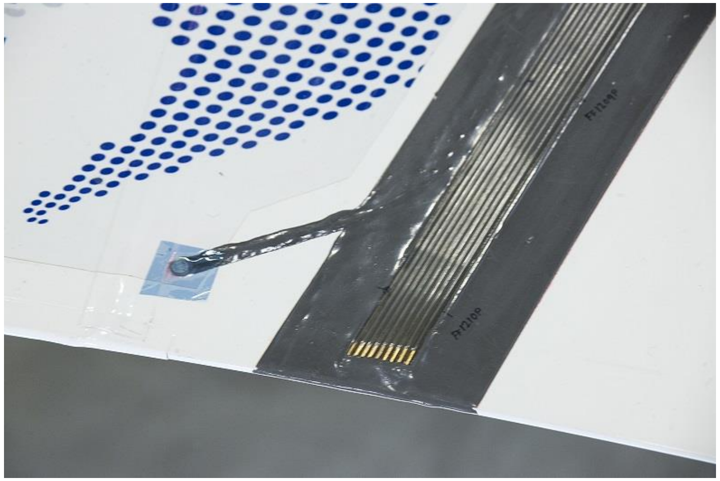


Current Capabilities

- A wide variety of flight test instrumentation exists to characterize the flow in and around a propulsion system
- Capabilities exist to provide flow measurements on and off of surfaces and to provide flow visualization on and off surfaces
- Techniques exist to estimate as-installed thrust during flight

On-Surface Flow Measurements

- Electronic Scanned Pressure Sensors
  - Are used to measure a large number of relatively steady pressures
  - Generally installed via drilled ports or surface-mounted strip-a-tube
  - Due to tubing, difficult to use for dynamic pressure environments
  - Requires temperature control of measurement unit for reasonable accuracy in-flight



- Absolute pressure sensors
  - Are used to measure absolute pressure at a single location
  - Variety of form factors and sizes provide options for drilled ports or surface mounting
  - Wide range of potential response rates
  - Temperature sensitivity can be problematic in-flight

On-Surface Flow Measurements

- Differential pressure sensors/microphones
  - Are used to measure differential pressure at a single location
  - Variety of form factors and sizes provide options for drilled ports or surface mounting
  - Wide range of potential response rates
  - Some temperature sensitivity, but not as large a concern as for absolute sensors
  - Location of reference pressure measurement is critical to understanding the results
- Thermocouples
  - Provide a surface temperature when mounted on a surface
  - Established technology, but it can be difficult to install such that the air temperature at the surface is measured instead of the structural temperature

Off-Surface Flow Measurements

- Flow rakes
  - Are used to provide off-surface flow properties for a variety of geometries, including pressure, temperature, flow velocity and direction (calibration required for flow velocity and direction)
  - Can be designed to provide steady or dynamic measurements
  - Hardware must be designed for flight environment
  - Calibration often needed
  - Measured flow is affected (to various degrees) by the rake itself

Off-Surface Flow Measurements

- Multi-hole probes
  - Are used to provide pressure, flow velocity and direction, and sometimes temperature at a specific off-surface location
  - A large variety exist, ready to purchase off-the-shelf
  - Calibration is required
  - Measured flow is affected (to various degrees) by the probe itself

Inlet Rake

- Typically used for new design long inlets to characterize inlet flow characteristics. Industry standard is a 40 probe rake (8 rakes with 5 probes each)

- total pressure distortion (transient and steady state)
- acoustic phenomenon (inlet buzz)
- flow angularity
- average total recovery (P2ave/P0)
- stall margin
- thermal distortion
- Inlet mass flow
- vibration
- shock wake determination

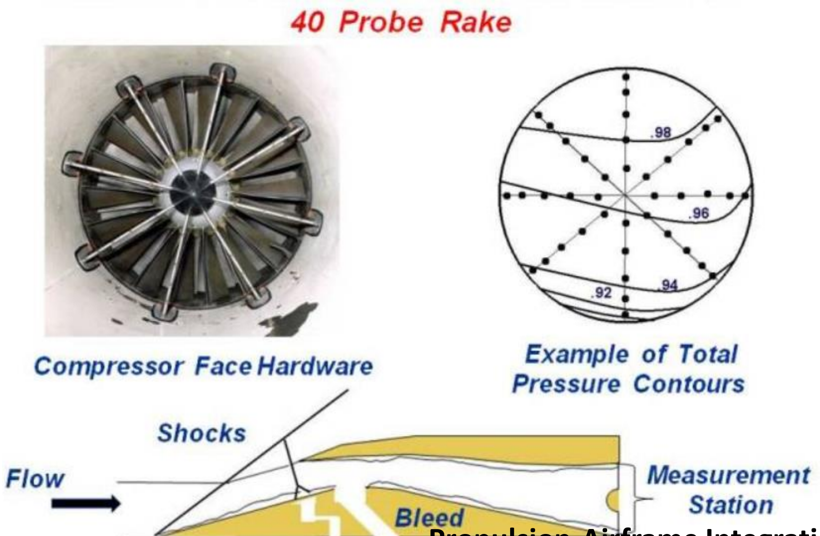
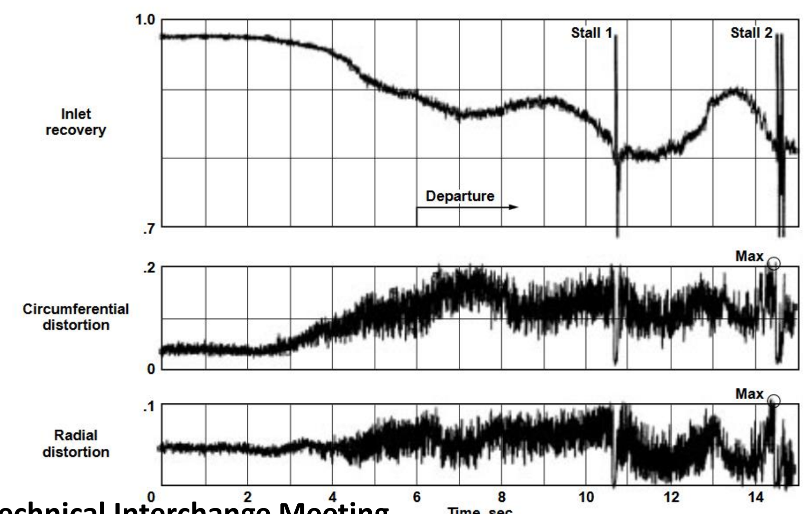


Figure 3. Measured time histories of inlet and engine entry descriptors for airflow quality and performance for a stall event.



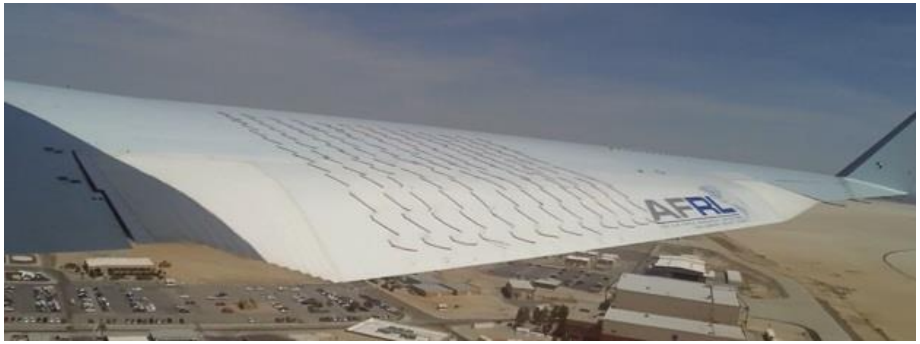
On-Surface Flow Visualization

- Oil Flow/Liquid crystal
  - Can identify flow direction, transition, shock locations
  - Minimal recent use
  - Techniques are messy and material can be hazardous

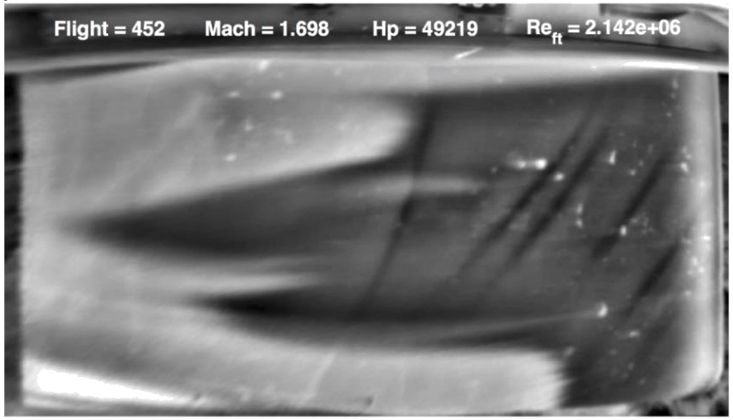
- Sublimation chemicals/ Emitted dyes or glycol
  - Can identify turbulence and separated flow
  - Minimal recent use
  - Only one test point per flight
  - Techniques are messy

On-Surface Flow Visualization

- Tufts
  - Can identify flow direction and separated flow
  - Easy and cheap to install
  - Careful consideration of installation required to avoid influencing the flow
  - Variety of types of materials used
    (flow cones, parachute cord, wool yarn, etc.)



- Infrared imaging
  - Can be used to detect laminar, transition, and turbulent flow and shocks
  - Most easily used at supersonic flight conditions
  - Requires temperature difference
  - Requires specialized viewing system

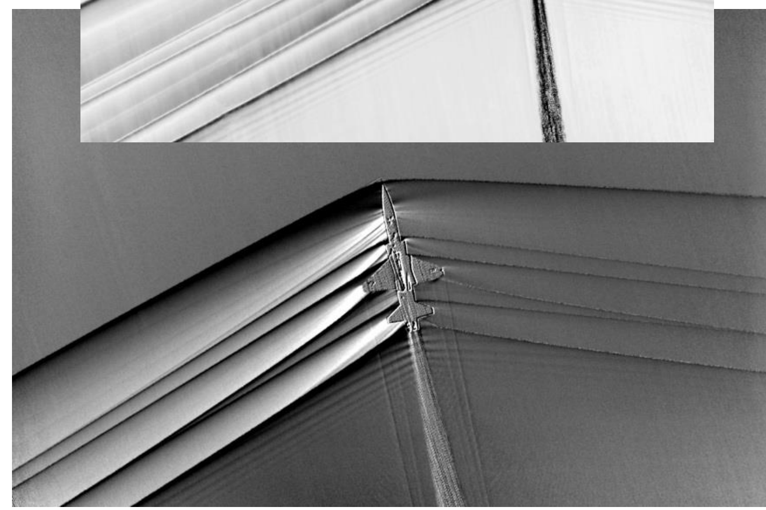


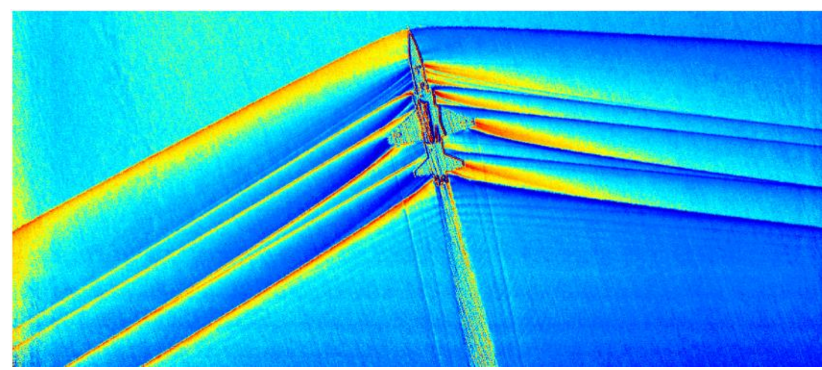
Off-Surface Flow Visualization

- Smoke
  - Can be used to visualize vortical flow, separated flow, and streamlines
  - Minimal recent use
  - Requires substantial modifications to aircraft to use
  - Substantial fire hazard
- Natural Condensation
  - Can be used to visualize vortical flow, shocks, shear layer instabilities
  - Minimal recent use
  - No modifications required to aircraft, but not reliable and difficult to repeat
- Schlieren
  - Can be used to visualize density changes from shock structures from supersonic shocks, subsonic and supersonic vortices
  - Two methods currently used for flight: AirBOS and BOSCO

AirBOS

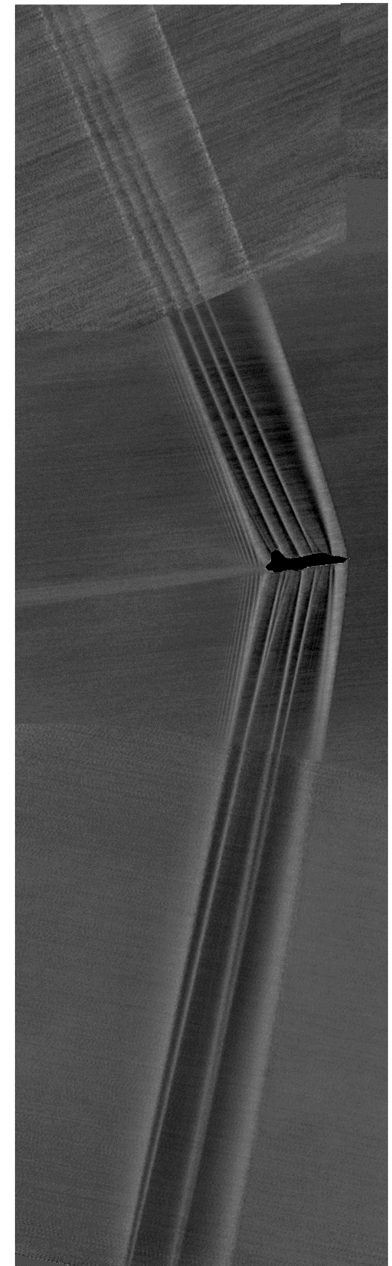
- Airborne Background Oriented Schlieren
  - Downward looking at desert vegetation or ocean speckles
  - Wide field of view, very detailed
  - Currently using KingAir to look down on target
  - Imaged F-18, F-15, and T-38
  - Only T-38 releasable currently





BOSCO

- Background Oriented Schlieren using Celestial Objects
  - Ground based (upward) or air-to-air (side view) looking at Sun/Moon
  - 0.5 deg field of view
  - Working toward air-to-air capability



Thrust Estimation

- Extremely difficult to directly measure thrust
  - Previous efforts involved strain gauges on thrust links or string pots that require installed thrust stand run to calibrate
- Engine model is used in conjunction with instrumentation and other information from engine to estimate thrust
  - **Bill of Material engine sensors:** N1, N2, fuel flow, pressures, temperatures, nozzle area, guide vane positions
  - **Engine/Airframe communication**: All buss communication between engine and airframe
  - **Performance testing requirements**: Flight test quality fuel flow, fuel sample lab testing for all flights
- Technique is highly reliant on accurate modeling
  - Generic models can have errors as large as 20%
  - OEM models are an improvement (errors as small as 2%), but uncertainties due instrumentation and fuel are still present

Capabilities in Development

- Low-profile conformal pressure sensors
- Low-profile conformal shock and transition detection sensors
- Carbon-based heating layer for laminar/turbulent flow visualization
- Pressure sensitive paint (PSP) for in-flight use
- Wireless sensor and instrumentation sensor technologies

Needed Capabilities

- Improved off-surface flow measurements and visualization
  - In-flight Particle image velocimetry (PIV) has been targeted for future efforts, but currently unfunded
- Improved flight-capable pressure sensors
  - Less intrusive, less temperature dependence, cost effective
- Less intrusive sensors and visualization techniques
- Improved engine modeling for flight test

Concluding Thoughts

- Current flight test instrumentation capabilities have been adequate for conventional aircraft configurations but have limitations, including potential for affecting flow
- New and improved instrumentation may be needed to properly evaluate future configurations
- NASA AFRC is continually looking for opportunities to take new flight test instrumentation to flight

Questions?

Thanks:
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