Model Attitude and Deformation Measurements at the NASA Glenn Research Center

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Abstract

The NASA Glenn Research Center is currently participating in an American Institute of Aeronautics and Astronautics (AIAA) sponsored Model Attitude and Deformation Working Group. This working group is chartered to develop a best practices document dealing with the measurement of two primary areas of wind tunnel measurements, 1) model attitude including alpha, beta and roll angle, and 2) model deformation. Model attitude is a principle variable in making aerodynamic and force measurements in a wind tunnel. Model deformation affects measured forces, moments and other measured aerodynamic parameters. The working group comprises of membership from industry, academia, and the Department of Defense (DoD). Each member of the working group gave a presentation on the methods and techniques that they are using to make model attitude and deformation measurements. This presentation covers the NASA Glenn Research Center's approach in making model attitude and deformation measurements.

Model Attitude and Deformation Measurements at the NASA Glenn Research Center

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Introduction

- NASA Glenn Research Center, Cleveland, Ohio
  - Space Research
  - Aeronautic Research (Propulsion)
  - Variety of test facilities to support space & aeronautic research efforts

- The measurement of model attitude is the primary area of interest and experience in regards to the working group
  - Served as a Test Engineer in GRC's wind tunnel facilities
  - Experienced with using on board sensors to make attitude measurements

- We are interested in developing a capability to make optical measurements in the areas of :
  - Model attitude
  - Model deformation

Test Facilities

- Major GRC Wind Tunnel Facilities
  - 8x6 SWT/ 9x15 LSWT
  - 10x10 SWT

- 8x6 Supersonic Wind Tunnel / 9x15 Low Speed Wind Tunnel
  - 8’x6’ test section, Mach 0.25 to 2.0
  - 9’x15’ test section, Mach 0 to 0.22

- 10x10 Supersonic Wind Tunnel
  - 10’x10’ test section, Mach 2.0 to 3.5

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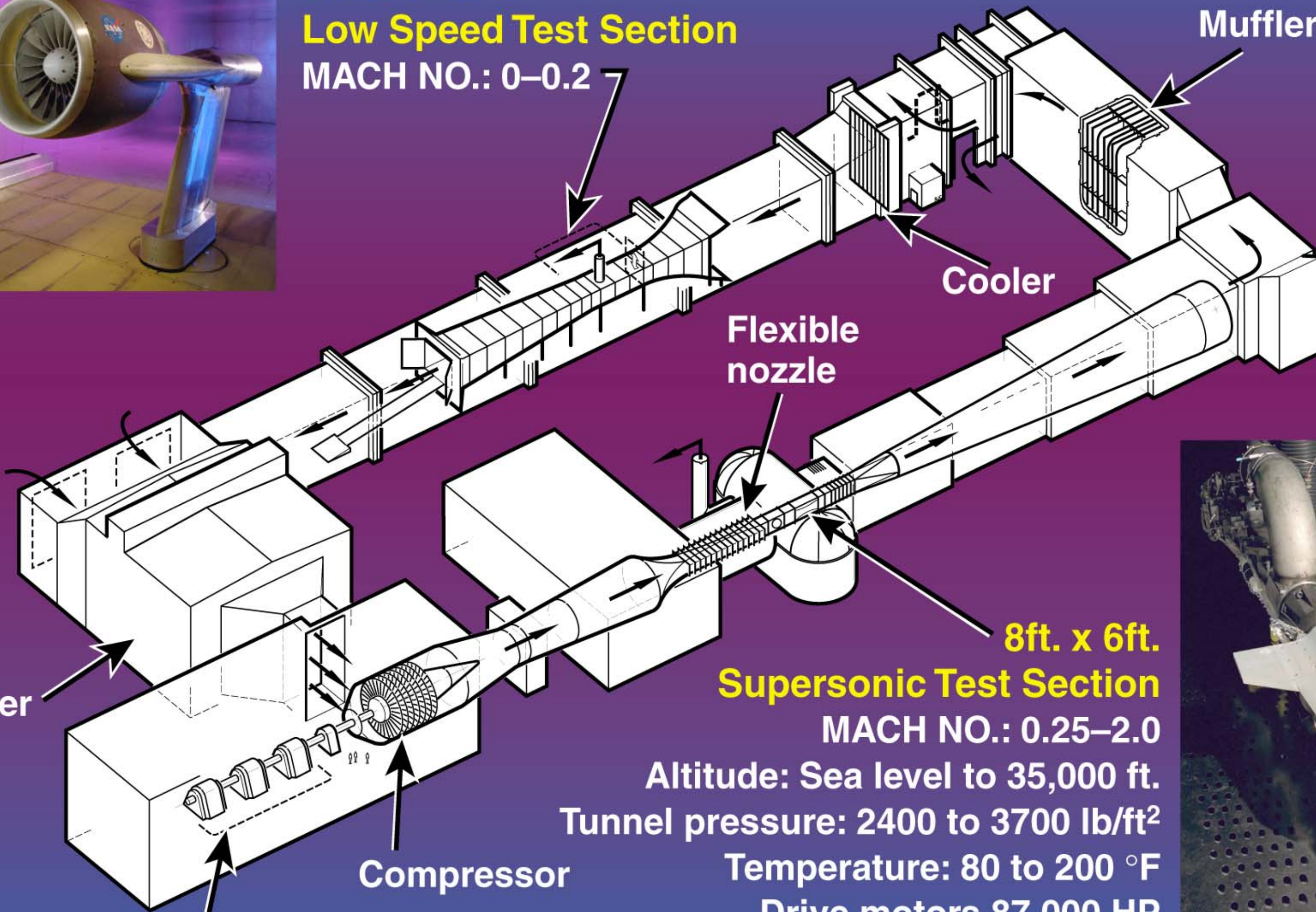
8x6 SWT/9x15 LSWT Wind Tunnel Complex

Operating mode: Aerodynamic–Closed loop
Propulsion–Open loop

9ft. x 15ft.
Low Speed Test Section
MACH NO.: 0–0.2



8ft. x 6ft.
Supersonic Test Section
MACH NO.: 0.25–2.0
Altitude: Sea level to 35,000 ft.
Tunnel pressure: 2400 to 3700 lb/ft^2
Temperature: 80 to 200 °F
Drive motors 87,000 HP

CD-98-77052

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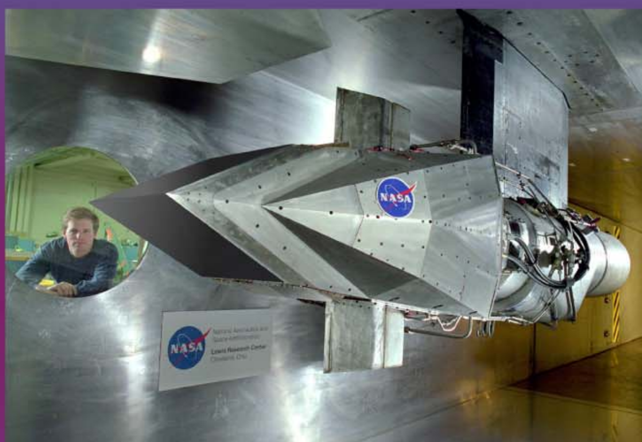
10x10ft. Supersonic Wind Tunnel

NASA

Test Section
10ft.x10ft.x40ft. long

Supersonic and Subsonic test modes
Aerodynamic–Closed loop
Propulsion–Open loop



Mach No.: 2.0 to 3.5
and 0 to 0.4 (240 knots)
Altitude: 50,000 to 150,000 ft.
Temperature: 60° to 680°F
Fuels: Liquid JP, hydrogen and oxygen
Continuous Operation: 250,000 hp drive motors
Remotely accessible real-time data display

CD-98-77058

Test Facilities

- Unique features
  - Size, relatively large facilities can accommodate large test articles
  - Propulsion test facilities……..capable of accommodating fuel burning models

- Testing emphasis
  - Primarily test inlets, nozzles, engine systems, etc.
  - Some force & moment testing, but historically not a lot…….However, we are getting more force & moment tests
  - Experienced with using sensors to make attitude measurements

- Challenges
  - Temperature!
    - 8x6 at Mach 2.0 T=~200 degF
    - 10x10 at Mach 3.5 T=~300 degF
  - On board sensors require cooling or some form of environmental protection to operate at these temperatures

Measurement Techniques

- Measurements
  - Model angle of attack (pitch)
  - Model yaw

- Use double knuckle stings to set pitch & yaw

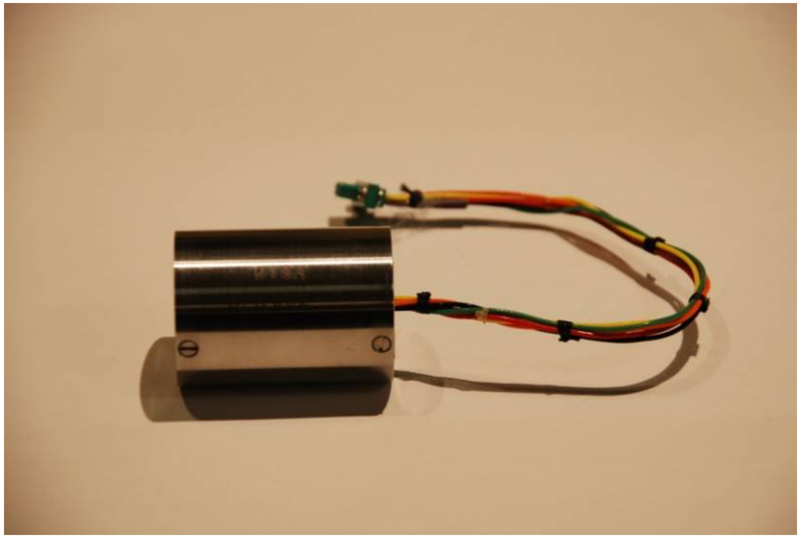
- Angle of attack
  - On board sensors
    - Q-Flex sensor (Accelerometer)
    - Electrolytic tilt sensors
  - Potentiometers

- Yaw
  - Horizontal or “non-gravity” direction
  - Potentiometers

Model in the 8x6 test section

Q-Flex (Accelerometer) Sensor

- On board sensor, mounts in the test article
- Accelerometer based system
- Designed by LaRC, manufactured by Wyle Labs (LaRC contractor)
- Standard at GRC since late 2001



Q-Flex sensor

- Precision servo accelerometer (Honeywell QA1400) to sense angle from vertical
  - Seismic mass wrapped in a coil
  - Displacement is sensed and mass is forced to a null position
  - Angle is a function of the current required to null mass

Q-Flex (Accelerometer) Sensor

- Standard at GRC is to record the output of the Q-Flex system into our steady state “Escort” system.
  - DEC Alpha based system
  - X1 second update rate for all inputs and calculation
  - Real time display of input and calculations
  - Data can be recorded in single scan or averaged mode
  - Filtered output from Q-Flex system is read into an Agilent 34401A multimeter
  - The multimeter is interfaced to the data system via GPIB (IEE488)
  - Filtered sensor output has a time constant of .36s, 1s settling time
  - Consistent with how we take data (pitch & pause method)

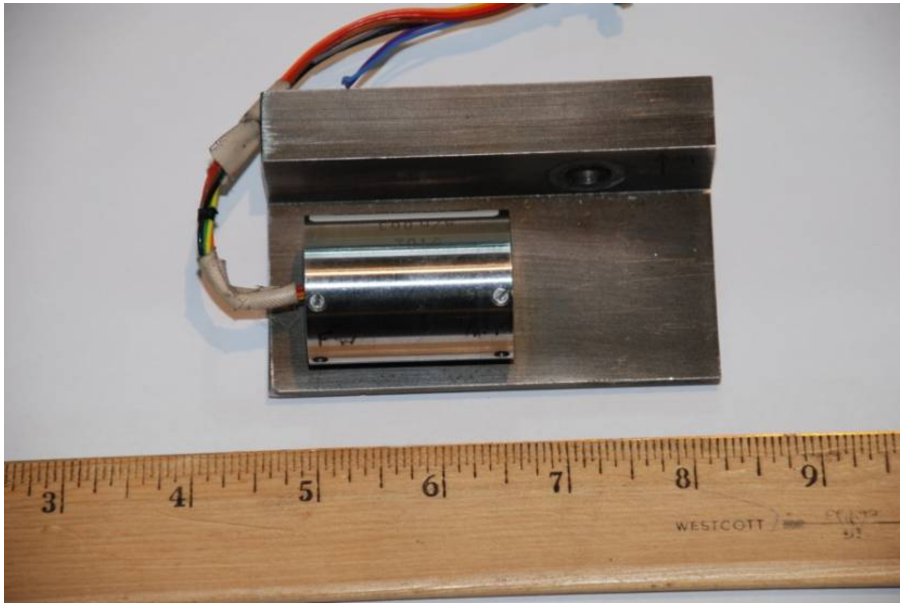
- Quoted accuracy of +/- 0.01 degrees over a range of +/- 20 degrees angle of attack with in a temperature range of 40 to 160 deg F

- Works well in our test facilities and for the type of testing we do

Q-Flex (Accelerometer) Sensor

- Cooling air is provided or the sensor is mounted in an environmental box for applications where it will see temperatures over 160 deg F
- The Q-Flex sensor and its support electronics are calibrated on a yearly basis by the manufacturer (used to be Wyle Labs, now done by Simco Electronics)
- The sensor is check calibrated as installed on the model on a daily basis as part of our pre-run check outs.

Q-Flex (Accelerometer) Sensor



Q-Flex sensor installed on a mounting plate

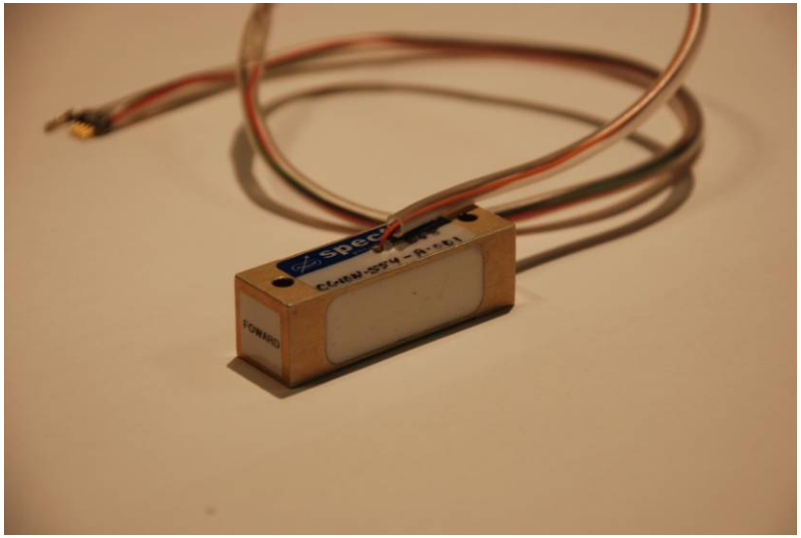
Q-Flex sensor signal conditioning

Electrolytic Sensors

- On board sensor, mounts in the test article

- Used commercially available devices (Spectron, etc.)

- Used at GRC pre 2001
  - Still used on some test articles



Electrolytic sensor

- Electrolyte filled sensor
  - Basically functions as a voltage divider
  - Resistance is changed as device is tilted from null position
  - At null voltage divider ratio ~1/2…increases/decreases as device is tilted

Electrolytic Sensors

- Sensor is excited with an AC signal
  - Sensor comes with an universal signal conditioner (i.e. Spectron MUPI-2)
  - Generates the required excitation voltage (5Vpp @ 1KHZ is typical)
  - De-Modulates the output of the sensor into a DC voltage
  - Typical time constant of 0.2s
- Standard at GRC is to record the output of the sensor into our steady state “Escort” system.
  - Same as is done with Q-Flex sensors
  - Read the signal into the Escorts Neff 400 or Neff 600 subsystems for analog to digital conversion
- The quoted accuracy of the electrolytic sensors that we used (Spectron L212-557A) was +/- 0.1 degree
  - These were purchased sometime in the early to mid 1990’s

Electrolytic Sensors

- Temperature compensation was attempted for these devices by measuring the devices temperature and applying corrections in the data system
  - Devices were calibrated over a temperature range to get correction data
- We were never quite comfortable with doing this
  - Cooling air or environmental control was usually provided to keep sensor at an acceptable temperature range
- Our experience was with devices from the mid 1990’s
  - Electrolytic sensors are now available that can operates at higher temperature ranges (~250 degF)
  - Appear to be internally temperature compensated
  - Have not yet used these newer electrolytic sensors in our facilities

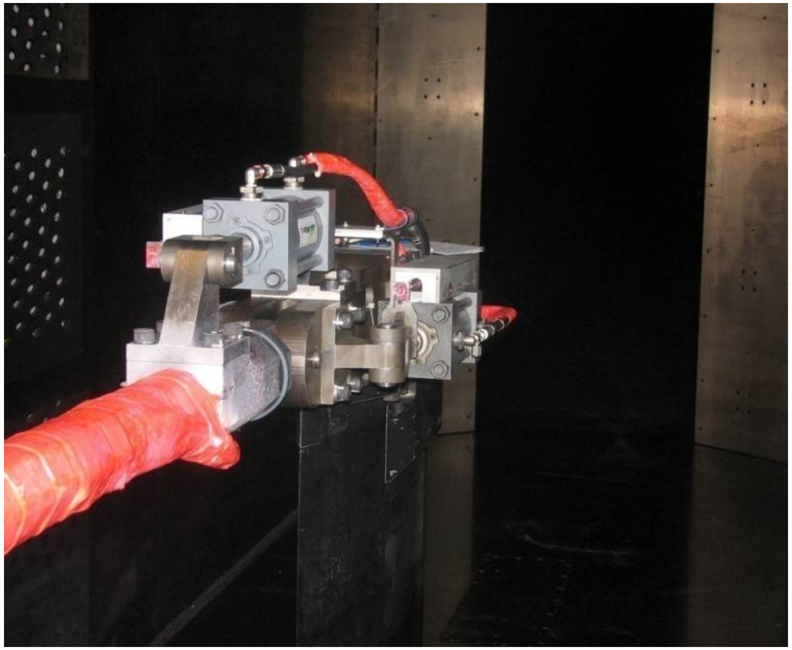
Electrolytic Sensors

- The electrolytic sensor and its signal conditioner are calibrated on a yearly basis (or as needed) by the manufacturer

- The sensor is check calibrated as installed on the model on a daily basis as part of our pre-run check outs.

Potentiometers

- Linear potentiometers are used on the double knuckle sting to provide closed loop servo control for the pitch & yaw actuators



- Dual Element potentiometers are used
  - Element 1 for control
  - Element 2 for data
- For angle of attack measurements
  - On board sensor is primary measurement device
  - Potentiometer is secondary device for data
- For yaw measurements (horizontal direction)
  - Potentiometer is primary (only) measurement device

Potentiometers

- Potentiometers are calibrated in-situ
- Angle of Attack (Pitch)
  - Potentiometer is calibrated over its entire range of operation by measuring angle with a reference inclinometer mounted or held on a reference plane on the model
- Yaw
  - Potentiometer is calibrated using the geometry of the test article as installed in the tunnel. Data points taken over entire operation range
  - Angle is calculated from measurements taken in the tunnel.
    - Tip of model to wall distance
    - Wall to pivot point distance
    - Tip of model to pivot point distance
- Accuracy is quoted at +/- 0.10 degree for both angle of attack and yaw using potentiometers

Accuracy Requirements / Capabilities

- Historically most applications we have tested require us to have an accuracy of +/- 0.10 degree for angle of attack and yaw
- With current systems we quote a measurement accuracy of
  - +/- 0.01 degree for angle of attack (Q-Flex)
  - +/- 0.10 degree for yaw (potentiometer)

Calibration Techniques

- Sensor and support electronics are calibrated on at least yearly basis
  - This is the calibration that is input into the data systems when the sensor is used
  - Q-Flex system is done by Simco Electronics (used to be Wyle at LaRC)
  - Electrolytic sensors are done by the manufacturer
  - Require calibrations traceable to NIST
  - An “as received calibration” is done along with a final calibration

- Check calibrations of the devices are done on a daily basis as installed on the model as part of the pre-run setup procedures

Calibration Techniques

- Angle of Attack Check Calibration
  - A precision reference inclinometer is placed on a reference plane located on the test article
  - Its reading is compared to the on board sensor's reading over the entire angle of attack range
  - If it deviates outside an acceptable tolerance corrective actions are taken
  - A Wyler Clino2000 inclinometer is used as the check reference (accuracy +/- 0.01)
  - Have used customer (LaRC) provided Angle Measurement System (AMS) as an in-situ reference……..currently in the process of obtaining one for GRC
- Yaw Check Calibration
  - Reference yaw angle points (with tolerance circles) are laid out on the test section floor as part of the original calibration
  - The test article is moved to these points and the yaw reading is compared to the yaw reference angle
  - If not within tolerance a full calibration is done

Calibration Techniques

Wyler Clino2000 Inclinometer

Pros & Cons

- On board angle of attack sensor
  - Comments apply to the Q-Flex system as it is the standard we use at GRC
- Pros
  - Highly accurate, meets our requirements
  - Works well with our type of testing
  - Integrates well with our data system and facility cabling
- Cons
  - At high Mach, high Temperature conditions it requires some type of environmental control (i.e. cooling air, environmental box, etc.)
  - Size does become an issue on small test articles
  - Will not work in “non gravity” horizontal measurement directions…like yaw

Summary

- At GRC we typically use onboard sensors to measure model angle of attack.
  - The Q-Flex (Accelerometer) is our current standard
  - Have used electrolytic sensors
- Potentiometers are used to measure model yaw (horizontal direction)
- Interested in using optical techniques for making model attitude and deformation measurements, but have no experience in these areas to date