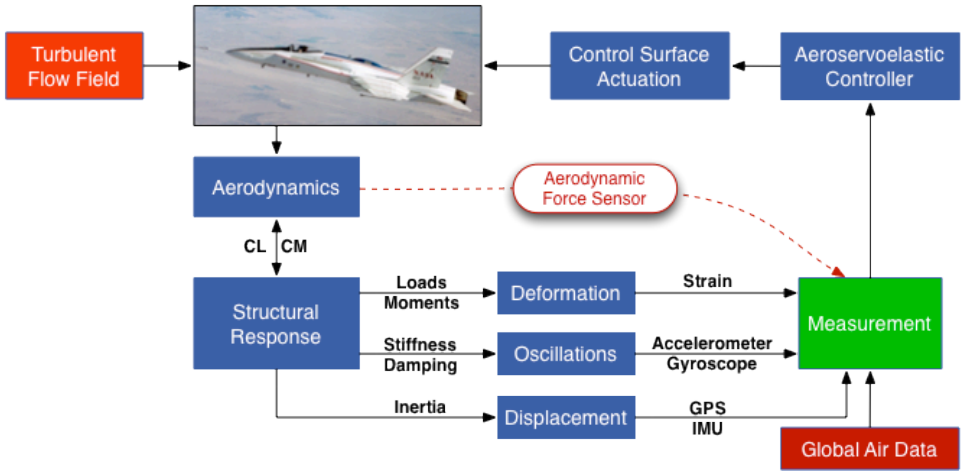
Ultra-Low Power Sensor For General Force Feedback Aircraft Control

(NASA Dryden 2010 NASA Innovation Fund, Martin.J.Brenner@nasa.gov)

Brief Problem Statement

- Aerodynamic/structural reliability/efficiency in nominal/off-nominal flight conditions depend critically on **accurate aerodynamic forces**
- State-of-the-Art
  - Integrated pressures (lagged, tubing)
  - Estimation from structural response (lagged, uncertain)
  - Angle-of-attack inaccuracy in presence of flow separation
- IPP addresses need for force sensor that has (1) minimal lag, (2) minimal power requirements, (3) low profile, (4) capability to estimate aerodynamic force, (5) capability to be weather-proof



Sensor for Aerodynamic Force Feedback

IPP Technical Objectives

- Characterize potential state-of-the-art sensors for real-time wind tunnel/flight test applications
- Determine guidelines for further development efforts

IPP Technical Approach

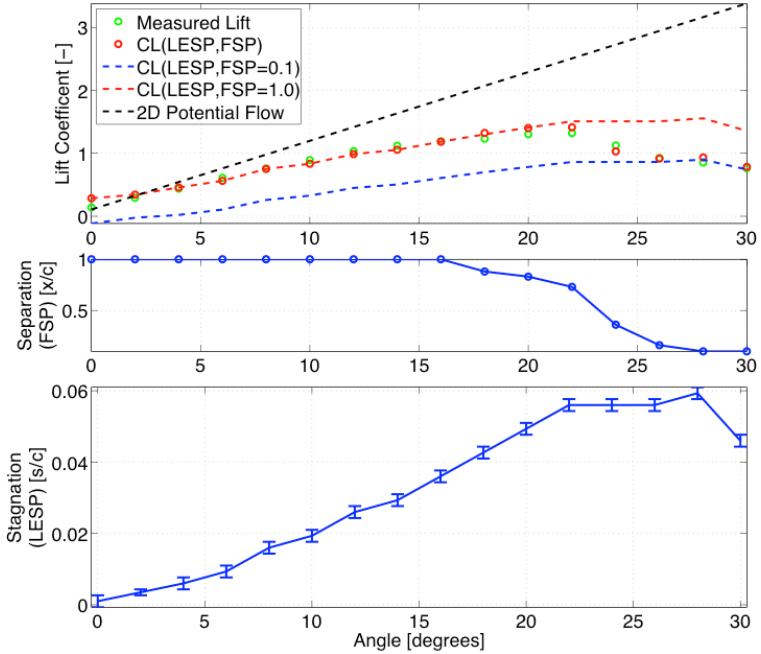
- Identify candidate sensor materials and fabrication processes amenable for real-time force estimation
- Design and fabricate candidate sensor(s)
- Test candidate sensors for signal-to-noise ratio, bandwidth, and magnitude/phase response

NASA and Non-NASA Applications

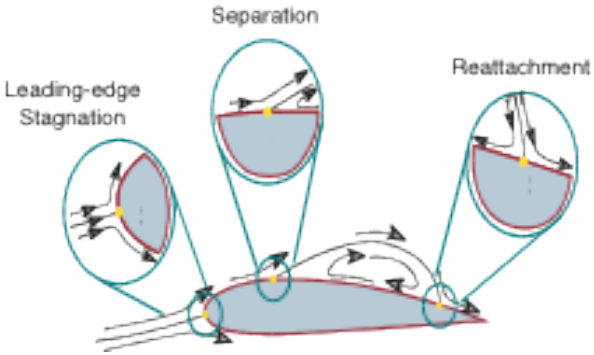
- **NASA**
  - Increased fuel efficiency: active cruise control, span load control
  - Improved reliability/ride-quality: gust load alleviation (GLA), flutter suppression
- **Non-NASA**
  - Reconnaissance aircraft: deformation compensation, GLA, endurance/range
  - Wind Turbine: energy capture, GLA

Technical Background

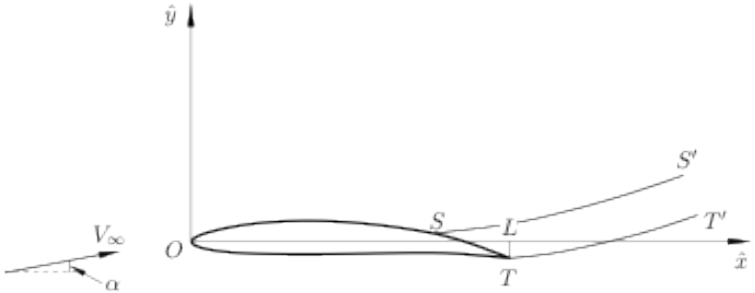
- Premise: sensor output uniquely mapped to aerodynamic forces
  - Flow bifurcation point (FBP), e.g., leading edge stagnation point (LESP) and flow separation point (FSP)
  - Analytical model for flow field with LESP & FSP
  - Obtain lift coeff (CL) as a function of LESP & FSP
  - Sensor provides FBP locations => CL(LESP,FSP)
- Sensor fabrication characteristics
  - Adequate sensitivity, bandwidth, and robustness to utilize real-time signal processing techniques to track FBP locations



Validated Analytical Model @ WPAFB



Flow Bifurcation Points



Analytical Model

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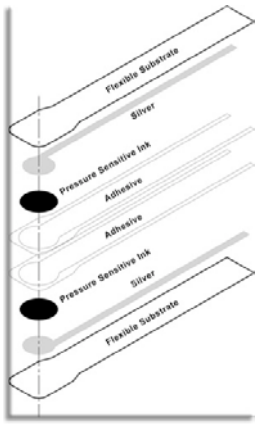
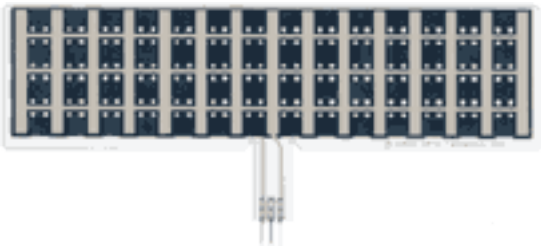
Sensor Fabrication

- State-of-the-art sensors & transduction mechanisms
  - Piezoresistive Sensor
    - + Inexpensive arrays
    - - High noise floor
  - Quantum Tunneling Composite (QTC)
    - + Resistive, high signal-to-noise ratio
    - + Mass-manufactureable
    - - Proprietary process
  - Copolymer piezoelectric
    - + Self-generating, no excitation required
    - - Highly susceptible to electromagnetic noise





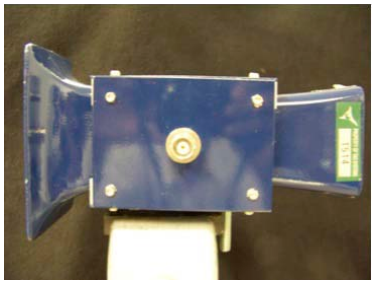
Piezoresistive Multi-Layer Sensor / Matrix

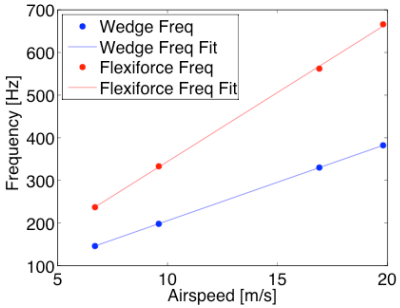
Test Results

- Low airspeed probe contains a wedge w/ hot-film
  - Wedge in air flow provides vortex shedding
  - Vortex shedding frequency related to airspeed
- Piezoresistive multi-layer sensor mounted on wall
  - Sensor capable of picking up vortex shedding

Future Work

- Test other transduction mechanisms to down-select
- Fabricate down-selected sensor array for wind tunnel tests to track LESP/FSP
- Develop/implement real-time signal processing algorithm for new sensor array





Piezoresistive Sensor: Strouhal Frequency