Hazard Analysis for a Forward Looking Interferometer

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• The project supports NASA work objectives under the Integrated Intelligent Flight Deck Technologies Research Program as described in scope item (d) “development of a comprehensive surveillance system design that enables robust detection of external hazards with sufficient time-to-alarm for safe maneuvering to avoid the hazards.”

• The previous project supported MS 2.5.1 (mid-FY 07) Initial Definition of External Hazard Monitoring Function, by investigating the potential of a forward-looking interferometer to detect and/or mitigate six aviation hazards.

• The current project will support MS 1.1.2 (end of FY 07) Initial Sensor Models and MS 1.3.3 (1Q FY 09) Baseline External Hazard Algorithms. The Sensitivity Studies element determines the required spatial, spectral, and temperature resolutions of the sensor for each hazard, which is the essential first step toward developing a sensor model.
Research Team

- Glen Perram
- Wayne Feltz
- Leanne West
- Bill Smith
- Larry Cornman
- Glen Perram
Previous Research (Phase 1)

- FLI Radiance Sensitivity Studies and Characterization Studies Performed
- EOF Regression Technique Developed
- Instruments Requirements/Parameters Defined
- Method to relate statistics of atmospheric turbulence to sensor measurements investigated
- Airborne Radiometric Detection of Aviation Hazards Workshop Held in Aug 2006
The Forward-Looking Interferometer

- High spatial resolution provided by imaging
- High spectral resolution provided by interferometer
- High radiometric resolution with cooled detector
- Remote sensing techniques developed for satellites

Horizontal Path Simulation (U.S. Std. Atmosphere)

Spectral signal increases with increasing altitude.
Radiance Contribution to the FLI

- Signal close to an aircraft is sensed in relatively opaque regions.
- Signal far from an aircraft is sensed in relatively transparent “window” regions.
Application to Multiple Hazards

- **Turbulence**
  - Temperature or moisture variability associated with updrafts and downdrafts; relate to amplitude of CO2 lines and H2O spectral structure

- **Volcanic Ash**
  - Silicate emissivity/reflectivity spectral signature

- **Wind Shear**
  - Water vapor streaks in water vapor radiance imagery?

- **Wake Turbulence**
  - Water vapor eddies seen in water vapor radiance imagery? Temperature differences?

- **Slant Range Visibility/Improved Runway Vision**
  - Infrared “Window” Split-Window 11 μm -12 μm / Corrected Window Imagery

- **Icing**
  - Ice vs water refractive index 8 - 12 microns, in flight and on runway
Interferogram Resonance

Commercial Aircraft Case

Use temperature perturbations only in the CO$_2$ band range
($\nu = 650$-$750$ cm$^{-1}$, $\lambda = 13.3 - 15.4$ $\mu$m)

The Nearly Uniform CO$_2$ line spacing ($\sim 1.5$ cm$^{-1}$) in range
650-780 cm$^{-1}$ causes interferogram resonance in the 0.60-0.75 cm region,
when temperature inhomogeneities occur.

Interferogram ratio $(I-I_0)/I_0$

altitude = 9.5 km
Temperature and Moisture Fluctuations Associated with Turbulence

Downdrafts: Warm & Dry  Updrafts: Cold & Moist

Temp  Moisture

300 hPa Level (~ 9 km)
NOAA G-IV Research Aircraft Case

Use both temperature and water vapor perturbations in the extended wavenumber range ($\nu = 650-1650 \text{ cm}^{-1}, \lambda = 6.1 - 15.4 \text{ m}u$)

Severe turbulence encounter over convection at 2006UTC
Brightness Temperature Difference, BT[-230] – BT[90 s]

- $t = -230\ s$
- $t = -190\ s$
- $t = -170\ s$
- $t = -150\ s$
- $t = -120\ s$
- $t = -90\ s$
- $t = -60\ s$
- $t = -30\ s$
- Begin Turbulence, $t = 0\ s$
- $t = +30\ s$
- $t = +60\ s$
- $t = +90\ s$
Empirical Orthogonal Function (EOF) Regression Technique

• Compresses a large volume of spectral radiance measurements into a small number of statistically independent pieces of information

• Enhances S/N by an order of magnitude, or more, depending on the spectral resolution and spectral range

• Is a very fast retrieval algorithm suitable for real-time processing of hyperspectral radiance observations. The intensive computational burden is performed off-line and before the application of the algorithm

• Algorithm was tested for the problem of producing scene background imagery from low visibility measurements with an imaging FLI

• Algorithm should be equally successful in its application to other weather hazards, including CAT, icing, volcanic ash, wake vortices, and wind shear detections
Empirical Orthogonal Functions (EOFs) Applied to Slant Range Visibility

The FLI brightness temperature eigenvectors (EOFs) for urban and rural aerosol conditions. The eigenvectors are computed for an aircraft altitude of 4000 ft and the view angle is 20° below the horizon. The spectral resolution is 2.5 cm\(^{-1}\).

Each EOF displays a different spectral feature of the observed radiance spectrum.
Phase 1 Results

• Imaging FLI data together with EOF analysis are optimal for the detection of aviation weather hazards. (demonstrated for Slant Range Visibility Enhancement problem)

• Spatial coherence of retrieved product imagery will enable the flight crew to distinguish a hazard (e.g., CAT or a wake vortex) from instrumental or atmospheric noise.

• Instrument parameters defined for the detection of various aviation weather hazards.
# Instrument Requirements

<table>
<thead>
<tr>
<th>Measurement Specification</th>
<th>Turbulence (T)</th>
<th>Turbulence (T/H₂O)</th>
<th>Volcanic Ash</th>
<th>Slant Range Visibility</th>
<th>Wake Turbulence</th>
<th>Icing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technique</td>
<td>CO₂ emission</td>
<td>Water Vapor Radiance Variability</td>
<td>“Window” Spectral Signature</td>
<td>“Window” Imagery</td>
<td>Water Vapor Radiance Imagery</td>
<td>“Window” Imagery</td>
</tr>
<tr>
<td>Spectral Range (cm⁻¹)</td>
<td>≤690 - ≥715</td>
<td>1200 – 1600 and/or 1600 - 2000</td>
<td>800 – 1400</td>
<td>800 - 1200</td>
<td>700 - 1600</td>
<td>1000 - 1200</td>
</tr>
<tr>
<td>Spectral Resolution (cm⁻¹)</td>
<td>≤0.625</td>
<td>≤ 2.5</td>
<td>≤ 2.5</td>
<td>≤ 2.5</td>
<td>≤ 2.5</td>
<td>≤ 2.5</td>
</tr>
<tr>
<td>Field of View (mrad)</td>
<td>≥ 50 (500m@ 10 km)</td>
<td>≥ 50 (500m@ 10 km)</td>
<td>≥ 50 (500m@ 10 km)</td>
<td>≥ 500 (0.5 km@ 1 km)</td>
<td>≥ 500 (0.5 km@ 1 km)</td>
<td>≥ 500 (0.5 km@ 1 km)</td>
</tr>
<tr>
<td>Pixel Resolution (mrad)</td>
<td>≤ 50 (500m@ 10 km)</td>
<td>≤ 50 (500m@ 10 km)</td>
<td>≤ 50 (500m@ 10 km)</td>
<td>≤ 0.1 (1.0m@ 1 km)</td>
<td>≤ 0.1 (1.0m@ 1 km)</td>
<td>≤ 0.1 (1.0m@ 1 km)</td>
</tr>
<tr>
<td>NEdT @ 220 K Scene T (K)</td>
<td>≤ 0.1</td>
<td>≤ 0.1</td>
<td>≤ 0.3</td>
<td>≤1.0</td>
<td>≤1.0</td>
<td>≤1.0</td>
</tr>
<tr>
<td>Dwell Time (Seconds)</td>
<td>≤ 2</td>
<td>≤ 2</td>
<td>≤ 2</td>
<td>≤ 0.1</td>
<td>≤ 0.1</td>
<td>≤ 0.1</td>
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<tr>
<td>Refresh Rate (frames/second)</td>
<td>≥ 0.25</td>
<td>≥ 0.25</td>
<td>≥ 0.25</td>
<td>≥ 10</td>
<td>≥ 10</td>
<td>≥ 10</td>
</tr>
</tbody>
</table>
Current Research (Phase 2)

Modeling and Simulations

Further Sensitivity Studies
- Application of EOF Regression technique to CAT using 3-D data

Theoretical analysis
- Connect the measured FLI radiances to the turbulent properties of the temperature and the water vapor fields

Ground-Based Measurements

Boulder, CO
- Dec 2007
- CAT, Mountain Waves
- D & P Spectrometer and aircraft reports, 3-16 microns
- Aircraft data

Madison, WI
- Feb 2008
- Vortices, Slant Range Visibility
- Telops FIRST Imager, 3-5 microns
- AERInago, 3-25 microns
Where we are now

- Official Start: Aug 2007
- All partnering institutions under contract
- Dec Field Test planning trip occurred Sept 07
- Dec Field Test plan in development
- Developing/updating radiative transfer models
- Developing 3D convective turbulence model
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