Passive A-Band Wind Sounder (PAWS)
For Measuring Tropospheric Wind Velocity

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PAWS Overview

- **Instrument Incubator Program (2004)**

- **Objectives**
  - Demonstrate an instrument concept for passive measurement of tropospheric wind speed using Doppler shifts in oxygen absorption features

- **Motivation**
  - Improve global coverage of wind measurements
  - Improve weather forecasting
  - "number one unmet measurement objective for improving weather forecasts" NRC Decadal Survey

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**On-Orbit Viewing Concept**

- LEO
- Lines of sight
- Limb 0-20 km
- Sun
- FOV1
- FOV2
- Tangent Limb Track
- Spacecraft Ground Track
- Position 1
- Position 2

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## Heritage for PAWS

<table>
<thead>
<tr>
<th></th>
<th>WINDII</th>
<th>HRDI</th>
<th>PAWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Coverage</td>
<td>80 – 300 km</td>
<td>10 – 115 km</td>
<td>0 – 20 km</td>
</tr>
<tr>
<td>Vertical Interval</td>
<td>2 km</td>
<td>2.5 km</td>
<td>1 km</td>
</tr>
<tr>
<td>Horiz. Cell Size</td>
<td>140 km</td>
<td>500 km</td>
<td>250 km</td>
</tr>
<tr>
<td>Spectral Signal</td>
<td>Emission</td>
<td>Absorption</td>
<td>Absorption</td>
</tr>
<tr>
<td>Target Species</td>
<td>O and OH</td>
<td>O₂ B and γ Bands</td>
<td>O₂ A-Band</td>
</tr>
<tr>
<td>Spectrometer</td>
<td>Imaging Michelson, fixed FOV</td>
<td>Triple Fabry-Perot</td>
<td>Imaging Michelson, fixed FOV</td>
</tr>
<tr>
<td>Meas. Approach</td>
<td>Large OPD, scan across one period</td>
<td>Gimbal telescope Angle/gap scan</td>
<td>Large OPD, fixed tilted mirror</td>
</tr>
<tr>
<td>Accuracy</td>
<td>~ 5 m/s</td>
<td>~ 3 to 12 m/s</td>
<td>~ 5 m/s (TBD)</td>
</tr>
</tbody>
</table>

### Upper Atmosphere Research Satellite

- Wind Imaging Interferometer (WINDII) — Sep 1991 to Dec 2005
- High-Resolution Doppler Imager (HRDI) — Sep 1991 to ~2000
PAWS Instrument Approach

Limitations of the Technique
- Daytime-only measurements
- Will not provide the accuracy, precision, or spatial resolution anticipated for Doppler lidar

Potential Advantages of the Technique
- Simple components with flight heritage
- Low cost, risk, and platform requirements, and insensitive to spacecraft altitude
- Much better wind data than is currently available
Measurement Approach
Oxygen A-Band Transmission & Line Selection

- Lines are in a clear region of the atmospheric absorption spectrum
- Lines are extremely sharp and well resolved
- Wide range of line strength is available to optimize SNR
- Oxygen is an excellent tracer molecule for the troposphere
- A-band wavelength region is compatible with technology for high spectral resolution
Measurement Approach
Detecting Doppler Shift with a Michelson Interferometer

\[ \delta v = v_0 \frac{u_w}{c} \approx 10 \text{ of } fm \]

\[ \delta \phi = 2\pi (OPD)v_0 \frac{u_w}{c} + F(\text{OPD}) \]
Years 1 and 2: PAWS Breadboard and Analysis

Path-finding tool – sacrifices stability for versatility
Years 1 and 2: Lessons Learned

- Breadboard very sensitive
  - Need to improve stability by 100x
  - Wind speed error ± 20 m/sec
- Require extremely rigid construction
- Combining air-spaced etalon and Michelson reduces sensitivity to pressure and temperature
- Temperature and pressure stability
  - 0.07 K and 0.7 Torr = 0.5 m/sec EDS
- Spatially homogeneous light sources
- Using an absorption doublet doubles the SNR
- The shot noise limited wind speed detection is about 0.1 m/sec
- Optical path difference of 1.5 cm with one etalon (baseline)
- Demo and calibration requires wind tunnel and deep absorption
Engineering Unit Diagram

- Modular, Fiber-Coupled Design
- Emphasizes Stability
- Three Vertical Elements in FOV
Engineering Unit Filtering Approach

- **Pre-Filter (0.22 nm FWHM)**
  - Stability is critical
    - Fixed-spacing ideal for flight, but too expensive for IIP to achieve nm spacing tolerance
  - Tuning is required for EU
    - Angle tuning is not desirable due to field dependence of filter function
    - Pressure tuning is complicated and less compatible with space platform
    - PZT tuning allows normal incidence and high sensitivity

- **Filter: Air-Spaced Etalon**
  - Centered near 13100 cm\(^{-1}\) (763.35 nm)
  - Modest finesse requirement
Engineering Unit Filter Section

- **Modular Filter Section**
  - Simplifies design; Improves versatility
- **External aluminum housing (± 0.7K)**
- **Internal ceramic housing**
  - Low CTE & thermal conductivity; stiff
- **Etalon(s) bonded to ceramic (± 0.07K)**

- **Etalon Tuning**
  - Maximize metrology signal on CCD
  - CCD readout to PZT driver to tune etalon

- **Etalon Stabilization**
  - Capacitance sensor to PZT to hold capacitance
External aluminum housing (± 0.7K)
- Internal ceramic housing
  - Low CTE & thermal conductivity; stiff
- Components bonded to ceramic housing

Cube beam splitter and Zerodur mirror
- Hydroxide catalysis bonded to Zerodur base
- Temperature controlled to ± 0.07K
Engineering Unit Laboratory Testing

- Instrument sealed in pressure-stabilized chamber
- LED source provides artificial sunlight
- Telecom fiber optic switches provide differential wind measurement and metrology source injection
Wind Tunnel for Laboratory Testing

- Less than 2 dB loss round trip
- ~50-m path will give ~80% absorption at 763 nm
- Easily produces ~20 m/sec air flow
Summary and Conclusions

- **PAWS targets the troposphere, so absorption lines are used rather than emission**
  - Narrow absorption lines buried in a relatively broad background signal
  - Complicates the sensitivity of the measurement
  - Imposes tough requirements on system stability

- **Engineering unit approach**
  - Air-spaced etalon and Michelson interferometer
  - Fiber coupled, modular design
  - Rigid, low thermal expansion housing
  - Measure two absorption lines: doubles SNR
  - Minimize temperature and pressure fluctuations
  - Engineering unit will be capable of measuring wind at 5 m/s with the wind tunnel

- **Path to Flight**
  - Fixed-space etalons (is tuning required?)
  - Two or more filter modules of optimal performance over 20-km limb
  - A-band emission lamp for on-board calibration
  - Couple with A-band spectrometer for peak shape (pressure, cloud height)