Preliminary Flight Deck Observations During Flight in High Ice Water Content Conditions

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Outline

• Background

• Precipitation on Windscreen Analysis

• Atmospheric Turbulence Level Analysis
Background

List of common observations in engine power-loss events *(from Mason et al, AIAA-2006-0206)*:

- High altitude, cold temperature
- Aircraft in vicinity of convective clouds/thunderstorms
- Significantly warmer than standard atmosphere
- Visible moisture / Instrument Meteorological Conditions
- **Light to Moderate Turbulence**
- **Precipitation on the windscreen, often reported as rain**
- Aircraft total air temperature (TAT) probe anomaly
- Lack of observations of significant airframe icing
- No flight-radar echoes at the location and altitude of the engine event
Since 2006, Mason and others have collected information from pilots via interviews and questionnaires to substantiate earlier observations and support event analyses.

In SAE 2011-38-0094, Mason and Grzych reported

- Vertical acceleration data showed increases in turbulence prior to engine event
  - Pilots reported the turbulence was usually light to moderate, but it was not unique to HIWC clouds
- Pilot observations of rain on the windscreen are varied.
  - Many pilots indicated no rain was observed, while others indicated moderate rain was observed with a unique sound of impacts.
  - Variation in reports may be due to variation in ice concentration, particle size, and temperature
This presentation will show preliminary results using data from the SAFIRE Falcon 20 to substantiate the pre-Darwin pilot observations and analyses of windscreen and turbulence by Mason et al.
Precipitation on Windscreen Analysis

• Post-Flight Debriefs

• GoPro Hero 3+
## Precipitation on Windscreen Analysis

<table>
<thead>
<tr>
<th>Flight No</th>
<th>Water Streaming</th>
<th>Impact Sound</th>
<th>Max IKP TWC (g/m³)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS140001</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Instrument checkout, Question not asked formally</td>
</tr>
<tr>
<td>FS140002</td>
<td>Yes</td>
<td>Yes</td>
<td>3.5</td>
<td>Dots on windscreen, loud sound</td>
</tr>
<tr>
<td>FS140003</td>
<td>N/A</td>
<td>N/A</td>
<td>2.4</td>
<td>Not clear from debrief notes. TWC mostly &lt; 1.5. only momentary spike to &gt;2</td>
</tr>
<tr>
<td>FS140004</td>
<td>No</td>
<td>N/A</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>FS140005</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>RASTA / hotwire cal; clear air</td>
</tr>
<tr>
<td>FS140006</td>
<td>Yes</td>
<td>N/A</td>
<td>3.8</td>
<td>Water on windscreen associated with higher TWC and updrafts</td>
</tr>
<tr>
<td>FS140007</td>
<td>Yes</td>
<td>No</td>
<td>1.5</td>
<td>Less water streaming than previous flight</td>
</tr>
<tr>
<td>FS140008</td>
<td>No</td>
<td>No</td>
<td>4.8</td>
<td>Pilots reported seeing ice crystals on windscreen in SAFIRE flt notes</td>
</tr>
<tr>
<td>FS140009</td>
<td>No</td>
<td>No</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>FS140010</td>
<td>Yes</td>
<td>Yes</td>
<td>4.0</td>
<td>Water streaming when TWC&gt;2g/m3. Sounds from ice/graupel impacts</td>
</tr>
<tr>
<td>FS140011</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Transit back from Gove</td>
</tr>
<tr>
<td>FS140012</td>
<td>Yes</td>
<td>Yes</td>
<td>5.7</td>
<td>Water streaming when TWC&gt;2g/m3. Sounds from ice/graupel impacts</td>
</tr>
<tr>
<td>FS140013</td>
<td>Yes</td>
<td>Yes</td>
<td>4.3</td>
<td>Windscreen totally frozen @ 05:42 Ts=-30C</td>
</tr>
<tr>
<td>FS140014</td>
<td>No</td>
<td>No</td>
<td>3.5</td>
<td>Debrief from Gove; No water streaming noted in SAFIRE flt notes too</td>
</tr>
<tr>
<td>FS140015</td>
<td>Yes</td>
<td>Yes</td>
<td>4.5</td>
<td>Water streaming when TWC&gt;2g/m3.</td>
</tr>
<tr>
<td>FS140016</td>
<td>Yes</td>
<td>Yes</td>
<td>3.8</td>
<td>Water streaming when TWC&gt;2g/m3.</td>
</tr>
<tr>
<td>FS140017</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Transit from Broome; clear air cal for hotwire probes</td>
</tr>
<tr>
<td>FS140018</td>
<td>Yes</td>
<td>No</td>
<td>2.9</td>
<td>Water streaming when TWC&gt;2g/m3.</td>
</tr>
<tr>
<td>FS140019</td>
<td>Yes</td>
<td>No</td>
<td>3.7</td>
<td>Light water streaming during IWC peak</td>
</tr>
<tr>
<td>FS140020</td>
<td>No</td>
<td>No</td>
<td>n/a</td>
<td>Transit from Broome</td>
</tr>
<tr>
<td>FS140021</td>
<td>N/A</td>
<td>N/A</td>
<td>n/a</td>
<td>RASTA cal; clear air</td>
</tr>
<tr>
<td>FS140022</td>
<td>Yes</td>
<td>No</td>
<td>3.5</td>
<td>Water streaming during peak IWC and updraft</td>
</tr>
<tr>
<td>FS140023</td>
<td>Yes</td>
<td>Yes</td>
<td>4.9</td>
<td>Size of drops correlate with IWC; sounds correlate to larger particles</td>
</tr>
</tbody>
</table>
Precipitation on Windscreen Analysis

• Review of Post-Flight Debriefs
  ‣ 12 of 17 flights (70%) in HIWC clouds, pilots reported water streaming on windscreen
  ‣ 7 of 17 flights (41%) in HIWC clouds, pilots reported impact sounds on windscreen
    – Sound usually associated with larger particles or graupel

  ‣ Pilots identified IWC > 2 g/m$^3$ as a threshold for water streaming
    – 92% of cases when pilots noted YES to water streaming, IWC > 2 g/m$^3$
      • Exception: In FS14007, IWC peaked to 1.5 g/m$^3$
    – 60% of cases when pilots noted NO to water streaming, IWC < 2 g/m$^3$
      • Exceptions:
        ‣ In FS14008, IWC peaked to 4.8 g/m$^3$, post-flight report noted ice crystal on windscreen
        ‣ In FS14014, IWC peaked to 3.5 g/m$^3$
Precipitation on Windscreen Analysis

- GoPro Windscreen Video Example, FS140019, 9-Feb-2014, 23:13 UTC

Impact area

Water Streaming

Water Streaming
Precipitation on Windscreen Analysis

- FS140019, 9-Feb-2014, Run 2
  - Pressure Alt: 38 kft
  - Static Temperature: -46°C

Video clip

IKP TWC (g/m²)

Vertical Accel (G)
Precipitation on Windscreen Analysis

- FS140019, 9-Feb-2014, Run 2
Precipitation on Windscreen Analysis

- FS140019, 9-Feb-2014, Run 2, 23:11 Pilot Weather Radar

Radar Parameters
Azimuth = 12.13
Tilt = -0.25
Min Range(mm) = 0.00
Gain Compensation = Off

Display Parameters
Date = 2014-02-09
Time = 23:11:20
Total Range(mm) = 50
Rings(mm) = 2

Location of HIWC

Aircraft Parameters
Lat = 0.0000
Long = 0.0000
Alt(ft) = 0.0
A/F (ft/s) = 0.0
Ground Speed = 0.0
Heading = 0.0
V(V) (ft/s) = 0.0

Reflectivity(dBZ) vs Pause

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

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Precipitation on Windscreen Analysis

Conclusions:

• Pilot Debriefs:
  ▸ Pilots/flight team identified a useful visual indicator for IWC threshold
  ▸ Pilot debriefs after each flight are a valuable source of information

• Windscreen Video
  ▸ Example case confirms pilot observations of water streaming when IWC > 2 g/m³
  ▸ Video/audio a valuable source of information to link with other data sets such as TWC, turbulence, weather radar
  ▸ Sound of ice impacts differs from sound of rain impacts

• Way forward:
  ▸ Identify particle images to video/sound
  ▸ Utilize GoPro cameras in future flights
  ▸ Need improved timestamp to synchronize with other data sets
Atmospheric Turbulence Level Analysis

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Atmospheric Turbulence Level Analysis

Data sets from SAFIRE

• 1 Hz files (e.g. F20_1Hz-HAIC_base_aipov_v2_20140116_fs140001)
  ‣ vertical acceleration from AIRINS inertial measurement unit
  ‣ True airspeed
  ‣ Angle of attack (α) and angle of sideslip (β) from noseboom
  ‣ Winds (up, north, east) from noseboom
  ‣ etc

• 5 Hz files (e.g. F20_5Hz-HAIC_RICE_and_angles_20140116_fs140001)
  ‣ Az, Ay, Az accelerations from AIRINS inertial measurement unit
  ‣ True airspeed
  ‣ Angle of attack (α) and angle of sideslip (β) from noseboom
  ‣ RICE
  ‣ Etc

• Post-Flight reports and debriefs
Atmospheric Turbulence Level Analysis

• 1 Hz files processed to:
  ‣ Remove component of vertical acceleration due to turns

Flight 19 no filter for turns

Flight 19 with filter for turns
Atmospheric Turbulence Level Analysis

- 1 Hz files processed to:
  - Convert airspeed and flow angles into u, v, w wind components
  - Calculate RMS values of wind components $\sigma_u$, $\sigma_v$, $\sigma_w$ (1km distance scale)
  - Apply turbulence level criteria defined in MIL-F-8785C

![Graph showing atmospheric turbulence levels](image-url)
Atmospheric Turbulence Level Analysis

- Reviewed specific runs for each flight per Strapp’s initial overview slides

Flight 19, Run 2

![Graphs showing turbulence levels](image)

- avg (Az) 1.001
- std (Az) 0.040
- max(Az) 1.378
- min(Az) 0.647
- peak high 0.377
- peak low -0.354
Atmospheric Turbulence Level Analysis

Analysis of 5 Hz data initiated:
• Specific time periods to be examined based on 1 Hz analysis
  ‣ e.g. Az time history and power spectral density analysis for Flt 19, run 2
  ‣ Peak Az values in 5Hz data exceed 1Hz (~0.3G)
  ‣ Peak power indicates some periodicity in Az every 24 seconds for this case
### Atmospheric Turbulence Level Analysis

<table>
<thead>
<tr>
<th>Flight No</th>
<th>Turbulence</th>
<th>Max IKP TWC (g/m^3)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS140001</td>
<td>No</td>
<td>N/A</td>
<td>Instrument checkout, Question not asked formally</td>
</tr>
<tr>
<td>FS140002</td>
<td>No</td>
<td>3.5</td>
<td>(debrief indicated No)</td>
</tr>
<tr>
<td>FS140003</td>
<td>Light/Moderate</td>
<td>2.4</td>
<td>Post-flight report noted a few occurrences of Light to Moderate (debrief indicated No)</td>
</tr>
<tr>
<td>FS140004</td>
<td>Moderate</td>
<td>2</td>
<td>Post-flight report noted moderate turbulence @ 24:27 for 20 seconds (debrief indicated No)</td>
</tr>
<tr>
<td>FS140005</td>
<td>Light</td>
<td>N/A</td>
<td>Post-flight report noted light turbulence @ 06:56 (debrief indicated No)</td>
</tr>
<tr>
<td>FS140006</td>
<td>Moderate</td>
<td>3.8</td>
<td>Post-flight report noted moderate turbulence @21:12, 21:47, 22:45, 22:55</td>
</tr>
<tr>
<td>FS140007</td>
<td>Light</td>
<td>1.5</td>
<td>Post-flight report noted light turbulence @20:34 and moderate @ 22:11</td>
</tr>
<tr>
<td>FS140008</td>
<td>Moderate</td>
<td>4.8</td>
<td>Post-flight report noted moderate turbulence @21:35, 22:11, 22:40 (debrief indicated No)</td>
</tr>
<tr>
<td>FS140009</td>
<td>No</td>
<td>2.1</td>
<td>Post-flight report noted light turbulence prior to landing 23:34 (debrief indicated No)</td>
</tr>
<tr>
<td>FS140010</td>
<td>Moderate</td>
<td>4</td>
<td>Post-flight report noted light turbulence @ 21:27, moderate turbulence @21:42, 21:51. Debrief noted moderate plus. Autopilot disconnect, climb 3000 in updraft. Highest turbulence so far.</td>
</tr>
<tr>
<td>FS140011</td>
<td>No</td>
<td>N/A</td>
<td>Transit back from Gove</td>
</tr>
<tr>
<td>FS140012</td>
<td>Light/Moderate</td>
<td>5.7</td>
<td>Post-flight report noted multiple occurrences of light and moderate turbulence. Debrief noted mostly light</td>
</tr>
<tr>
<td>FS140013</td>
<td>Moderate</td>
<td>4.3</td>
<td>Post-flight report noted moderate turbulence @ 05:12 (debrief noted mostly light).</td>
</tr>
<tr>
<td>FS140014</td>
<td>Moderate/Heavy</td>
<td>3.5</td>
<td>Post-flight report noted multiple occurrences of light and moderate turbulence. Moderate-heavy turbulence @ 23:03. Heavy turbulence @ 23:09. Debrief noted light-heavy over smaller cells</td>
</tr>
<tr>
<td>FS140015</td>
<td>Moderate/Heavy</td>
<td>4.5</td>
<td>Post-flight report noted multiple occurrences of light and moderate turbulence. Moderate-heavy turbulence @ 25:48. Debrief noted moderate near cells</td>
</tr>
<tr>
<td>FS140016</td>
<td>Light/Moderate</td>
<td>3.8</td>
<td>Post-flight report noted light turbulence @22:20 and moderate @ 22:27, 23:19 in new cell</td>
</tr>
<tr>
<td>FS140017</td>
<td>No</td>
<td>N/A</td>
<td>transit from Broome to Darwin - clear air calibrations for hot wire probes.</td>
</tr>
<tr>
<td>FS140018</td>
<td>Light/Moderate</td>
<td>2.9</td>
<td>Post-flight report noted mostly light turbulence with few moderate turbulence.</td>
</tr>
<tr>
<td>FS140019</td>
<td>Moderate/Heavy</td>
<td>3.7</td>
<td>Debrief noted moderate to vigorous at FL380 (leg 4, last cell with IWC peak)</td>
</tr>
<tr>
<td>FS140020</td>
<td>No</td>
<td>n/a</td>
<td>Transit from Broome</td>
</tr>
<tr>
<td>FS140021</td>
<td>No</td>
<td>n/a</td>
<td>RASTA cal; clear air</td>
</tr>
<tr>
<td>FS140022</td>
<td>Light/Moderate</td>
<td>3.5</td>
<td>Post-flight report noted occasional light and moderate turbulence (23:12, 24:00)</td>
</tr>
<tr>
<td>FS140023</td>
<td>Light/Moderate</td>
<td>4.9</td>
<td>Post-flight report noted light turbulence @ 22:18 and moderate turbulence @ 22:23, 23:40</td>
</tr>
</tbody>
</table>
Atmospheric Turbulence Level Analysis

Conclusions:

• From 1 Hz analysis:
  ▶ Revealed peaks in IWC generally correlated near peaks in turbulence, vertical acceleration, and updraft velocities
  ▶ Identified specific time periods for further analysis using the higher frequency (5 Hz) data
  ▶ Turbulence levels (based on MIL-F-8785C) mostly in the light-moderate and range, and few occurrences of moderate-severe.

• From 5Hz analysis:
  ▶ Peak vertical accelerations in 5 Hz are significantly greater than 1 Hz
  ▶ Power spectral density may identify characteristic time (distance) of turbulence

• From review of post-flight report/debrief
  ▶ Most flights in light-moderate to moderate range with few occurrences of moderate-severe
  ▶ Some inconsistencies between flight reports and debriefs
Atmospheric Turbulence Level Analysis

Way Forward:
• For 1 Hz data:
  ‣ Develop method to objectively categorize turbulence levels for a specific run.

• For 5 Hz data:
  ‣ Examine time histories and PSD of other acceleration axes ($A_X$ and $A_Y$) and turbulence parameters $\sigma_u$, $\sigma_v$, $\sigma_w$
  ‣ Compare flights to identify correlations

• Document results!