High Ice Water Content Research

International Collaboration and Field Campaign

Presented to: In-flight Icing Users TIM
By: Tom Bond
Date: February 25, 2015
Statement of Need

- Over the past 10+ years, it has been recognized that jet engine power-loss events occur around deep tropical convection at higher altitudes.
  - Theorized cause was flights in high ice crystal concentrations
  - Power-loss results from ice crystals entering the engine core, melting and refreezing inside the engine
  - Engine Harmonization Working Group proposed new certification criteria; FAA issued Notice For Proposed Rulemaking; develop new regulations for certification to address ice crystal ingestion
- International partnership formed High Ice Water Content (HIWC) project
- Group proposed a field campaign using an instrumented research aircraft to characterize this environment
HIWC Partnership

• HIWC partnership research activity started in 2005 – 2006; proposed a field campaign in Darwin, Australia during monsoon period which occurs between December and March – ideal location to collect these conditions

• Pursued research over the first 3-4 years:
  – Instrumentation development to address ice crystal environmental, high-speed sampling, probe tip effects, humidity issues, ice water content measurement, etc.
  – Developed Science Plan and operations documents
  – Work expanded to address ice crystal engine ingestion, facility capabilities, weather tools, and detection technologies

• Research aircraft development through NASA
HAIC-HIWC: Partnership Request

• HIWC had major problems with research aircraft development – caused delays, changes in aircraft, and eventual termination of activity in Sept. 2012.

• HIWC made request to work together with the European Commission High Altitude Ice Crystal (HAIC) project for a 2014 field campaign in Darwin, Australia.

• Offer accepted, first coordination meeting in late January 2013. On-going monthly meetings and exchanges to build partnership. Significant challenges for very short time line
  – Adapt instrumentation & integrate plans for use on SAFIRE Falcon 20 aircraft
  – Coordination of objectives, work plans, logistics, etc.
  – Develop new iso-kinetic probe to measure IWC
What Will the Flight Campaign Deliver?

• The overarching goal of the HIWC flight campaign is to acquire a **benchmark database** of the atmospheric environment that causes engine and air data sensor failures that threatens air transportation safety.

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<tr>
<th>Validate new design and certification standards for engines and sensors to operate within this environment</th>
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<tr>
<td>Develop HIWC detection methods (onboard, ground-based, space-based) and wx diagnostic &amp; forecast tools to enable threat avoidance</td>
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<td>Develop engine ice models/simulations and guide future experimental activities for means of compliance &amp; fundamental ice growth studies</td>
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<td>Understand the fundamental cloud microphysical processes that cause High IWC to occur and, by doing so, improve the ability to forecast or detect it</td>
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### FAA - Icing Crystal Icing (ICI) Research Goals

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<th>Goal</th>
<th>Approach</th>
<th>Timeframe</th>
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| 1. Enable safe flight through high ice water content regions of convective weather systems by developing engines and air data systems that are robust to these environments. | • Verify Part 33 Appendix D engineering standards representative of a 99th percentile environment and develop means of compliance for engines and air data systems to be certificated  
✓ Regulations apply to new type design turbine engines | Target 2014: Regulations start (future fleet) |
| 2. Enable safe flight by remotely detecting HIWC conditions onboard the aircraft to tactically avoid (est. 60-80 nmi detection) flying into hazardous ice crystal icing conditions. | • Utilize modern onboard weather radar with new data management algorithms.  
✓ Current and future fleets | Target 2017+ timeframe to be in service |
| 3. Enable safe flight by delivering nowcasting/forecasting tools to identify areas of HIWC to support flight mission planning and to avoid flying into hazardous ice crystal icing conditions. | • Develop and validate the HIWC diagnostic/forecast tool ALPHA (being developed by FAA Aviation Weather Research Program).  
✓ Current and future fleets | Target 2018+ timeframe to introduce in selected service |
Field Campaign – Arrival (1/12/2014)

- Mid-Jan to Mid-Mar 2014
- Target of 150 research flight hours in Ice Crystal Icing (ICI) conditions

CNRS Falcon 20
Centre National de la Recherche Scientifique
Field Campaign – Aircraft Prep (First 4 Days)

• Sensors installed, aircraft checked out; research flights beginning
Field Campaign – Briefings

• Weather team & support groups on site and coordinating weather evaluation with ops team

- Current Wx Observational Data & Forecast Models
- Pre-Flight Weather Briefing
- Post-Flight Pilot/Research Crew Debrief
- Post-Flight Science Team Debrief
Field Campaign – ICI Research Flights

FS140018 - 3.4 F/H – Flight in system located North/West of Broome. 6 legs performed at FL310 / -30°C with sustained IWC at 1.0g/m3 and peaks from 1.5g/m3 to 2.5g/m3 (1 peak).
Field Campaign – Pilot Awareness Support

Ice crystals “streaming” on windshield at high altitude
Field Campaign – Maintenance and Instrumentation Checks & Calibrations Needed Every Day – Planned and Unplanned!

Lightening strike - in at nose boom, out at trailing edge of IKP

Erosion damage - radome, wing tip, & LWC sensor
HAIC-HIWC Current Status

• Darwin Field Campaign ended early due to multiple Falcon 20 aircraft problems; funding partners terminated in early March 2014
  – Conducted 23 research and calibration flights
    ➢ Used 72 of 150 research flight-hours available
  – Acquired cloud microphysical and remote sensing data during 100 level transects at various altitudes.
    ➢ 11 legs at -50C; 44 legs at -40C; 41 legs at -30C; 4 legs at -15C/-10C
    ➢ Required 100 transects of 20 nautical mile scale length at each of -50C, -30C, -10C altitude levels to achieve 99th percentile statistics
• Data from campaign being analyzed
Additional Flight Research

• Second field campaign – planning underway: use SAFIRE Falcon 20 with same instrumentation package – May 2015 in Cayenne, French Guiana
  – Bringing back almost all of 1st campaign science team
  – Use leftover flight research hours from 1st campaign + additional resources
  – Add 2nd research aircraft for lower altitude data capture

• Other Flight Research
  – Need weather radar capabilities for on-board detection of ice crystal icing (ICI) conditions to support in-flight avoidance. This awareness technology is best option for current fleet to avoid ICI
Ice Crystal Data Analysis – Both HAIC-HIWC Campaigns

- Anticipate completed data package from campaigns at end of CY 2015
  - No time to look at data for regulatory purposes before 2nd campaign
  - Analysis of ice crystal data for comparison to Appendix D start in 2016.

Campaign data evaluated for regulatory purposes

Results reviewed by EIWG

Decision on App D update

Results reported to FAA/EASA

CY 2016

CY 2017
## ICI Flight Research – Progress to Date

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<th>Goal</th>
<th>Progress</th>
<th>Missing</th>
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<td>1 Engine Design Regulations (new type designs)</td>
<td>• Acquired significant cloud physics data to characterize Appendix D,</td>
<td>• Data set is biased towards decaying storms. Developing storms are likely to have higher IWC.</td>
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<td>– Also supports review of ground test facility ICI cloud definition</td>
<td>• Insufficient data acquired at high and mid altitudes - a consequence of aircraft performance and the foreshortened campaign.</td>
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<td>• Significant amount, but it is not sufficient</td>
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<td>2 Onboard Detection (current and future fleet)</td>
<td>• Unable to install modern weather radar on SAFIRE aircraft due to 2013 aircraft preparation rqmts for other equipment, schedule conflicts, and lack of STC</td>
<td>• Minimal progress of onboard weather radar for remote detection.</td>
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<td>• Need additional flight campaign with acceptable research aircraft to support this goal.</td>
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<td>3 Weather Forecasting Tools (current and future fleet)</td>
<td>• Acquired significant amount of satellite, ground radar, and weather model data during campaign for ALPHA nowcast tool development</td>
<td>• Need to evaluate current data set &amp; use for calibration / algorithm development</td>
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<td>• Need future flight test for validation of ALPHA</td>
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Backup Slides
Engine Power-loss & Damage Event Rate Statistics

Since 2003 increased identification of events

Increased awareness and reporting of events

2008: 2 new engines & vibration symptom