High Ice Water Content Research

International Collaboration and Field Campaign

Presented to: In-flight Icing Users TIM

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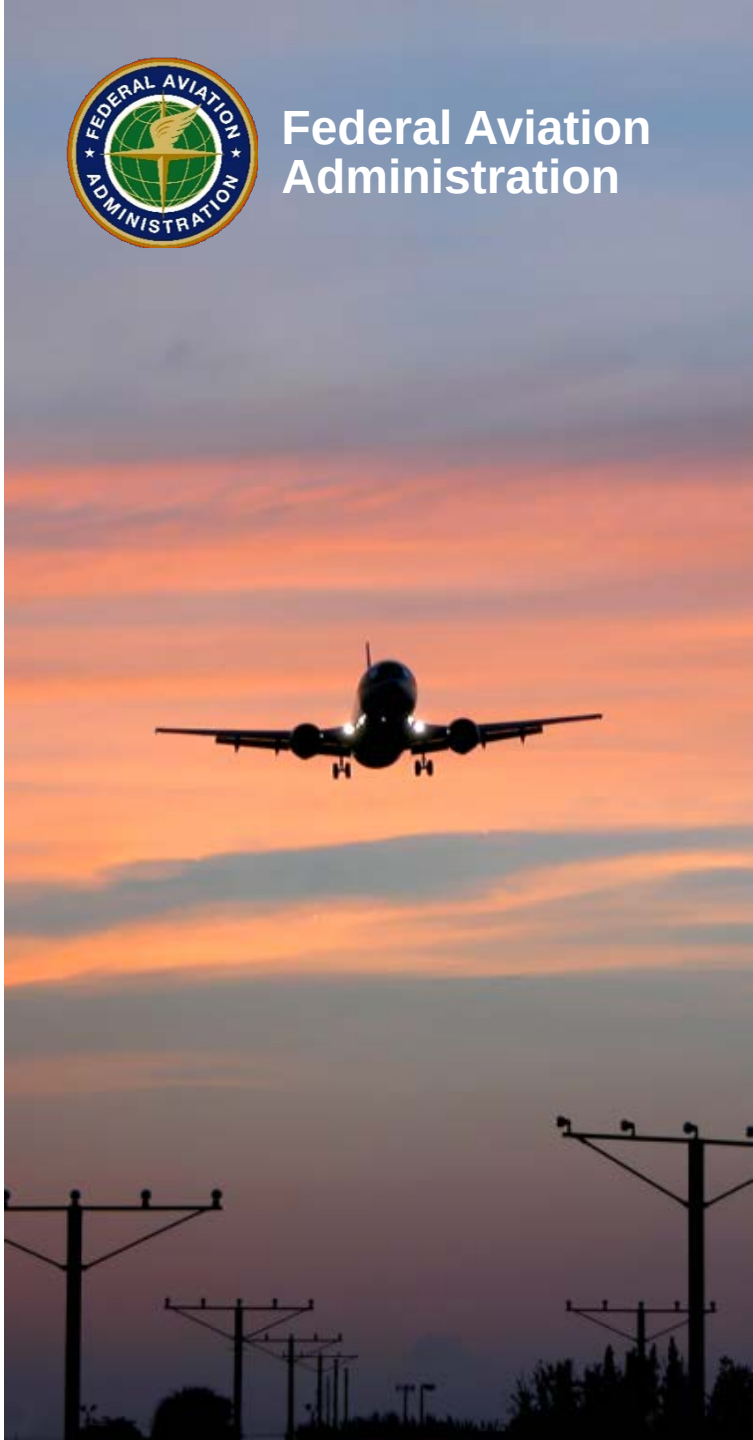
Federal Aviation Administration



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 - *FAA, NASA, Boeing, Environment Canada, Australian Bureau of Meteorology, National Research Council of Canada, Science Engineering Associates, National Center for Atmospheric Research, Airbus, and Transport Canada.*
- 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

Validate new design and certification standards for engines and sensors to operate within this environment

Develop HIWC detection methods (onboard, ground-based, space-based) and wx diagnostic & forecast tools to enable threat avoidance

Develop engine ice models/simulations and guide future experimental activities for means of compliance & fundamental ice growth studies

Understand the fundamental cloud microphysical processes that cause High IWC to occur and, by doing so, improve the ability to forecast or detect it

FAA - Icing Crystal Icing (ICI) Research Goals

	Goal	Approach	Timeframe
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

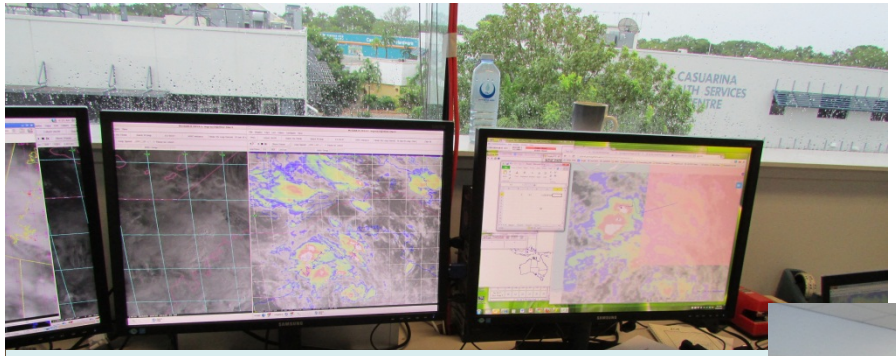
CNRS Falcon 20
Centre National de la Recherche Scientifique

Field Campaign – Aircraft Prep *(First 4 Days)*

- Sensors installed, aircraft checked out; research flights beginning

Field Campaign – Briefings

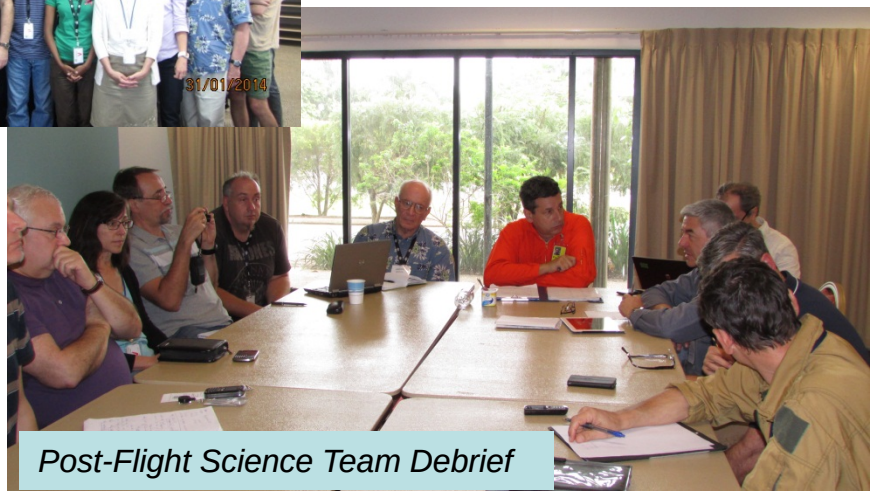
- Weather team & support groups on site and coordinating weather evaluation with ops team



Current Wx Observational Data & Forecast Models

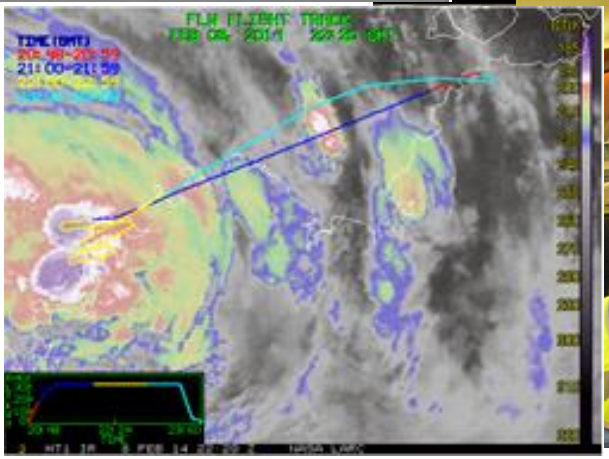
Post-Flight
Pilot/Research Crew Debrief

Pre-Flight Weather Briefing



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!

Erosion damage - radome, wing tip, & LWC sensor

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

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

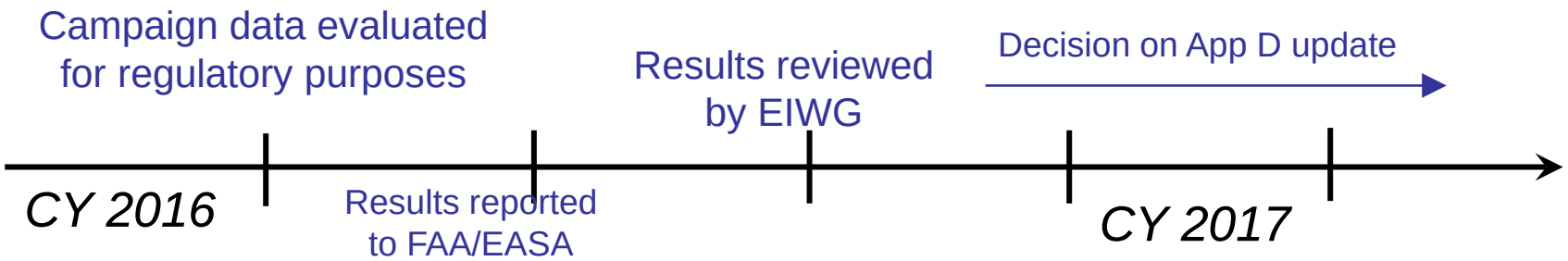
Additional Flight Research

- 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.

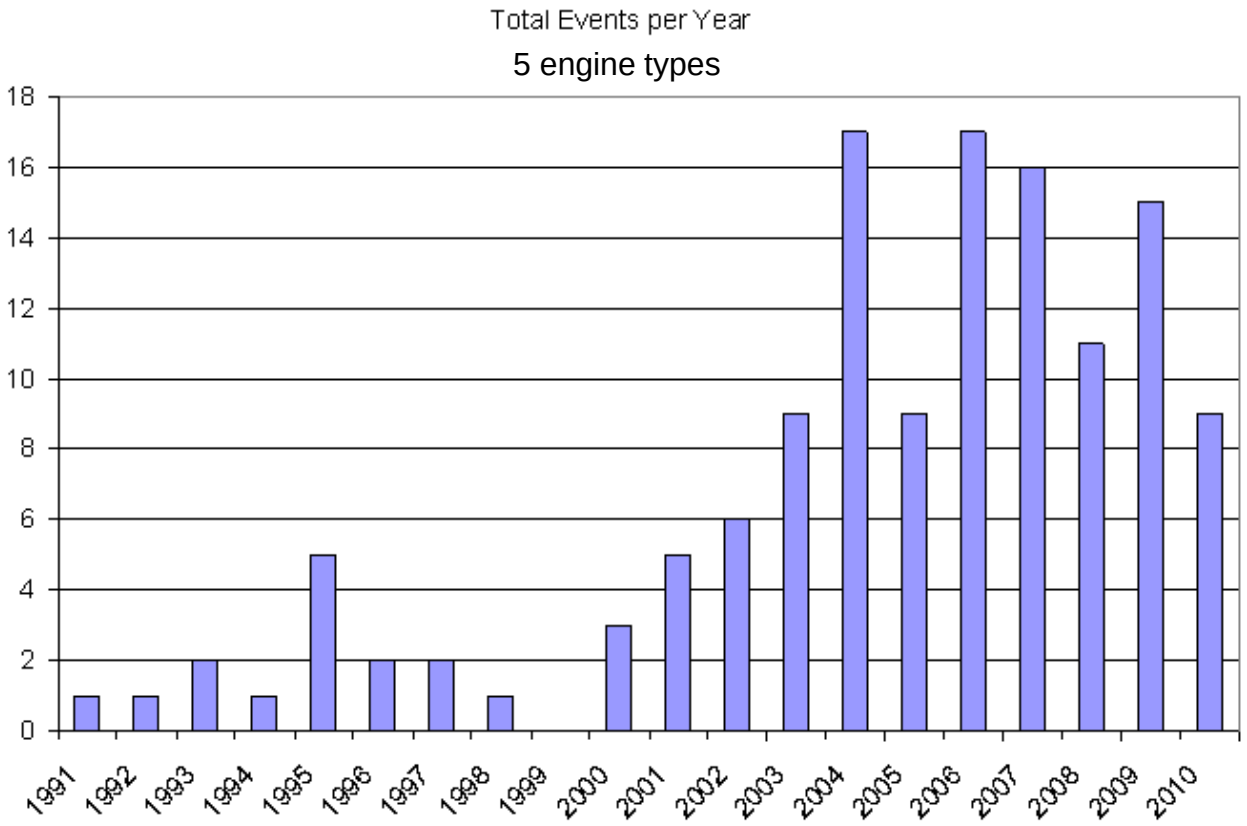


ICI Flight Research – Progress to Date

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

Backup Slides

Engine Power-loss & Damage Event Rate Statistics



From Mason & Gryzch, *"The Challenges Identifying Weather Associated With Jet Engine Ice Crystal Icing"*, SAE 2011-38-0094, June 2011

- Since 2003 increased identification of events
- Increased awareness and reporting of events
- 2008: 2 new engines & vibration symptom