Jet Engine Power Loss in Ice Particle Conditions – An Aviation Industry Problem

J. Walter Strapp, Environment Canada

Thomas P. Ratvasky, NASA Glenn Research Center

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The Aviation Problem and the Meteorological Hypothesis

- More than 100 events of jet-engine power-loss while flying in vicinity of deep convection
  - More than 40 have adequate information for analysis of the meteorological conditions

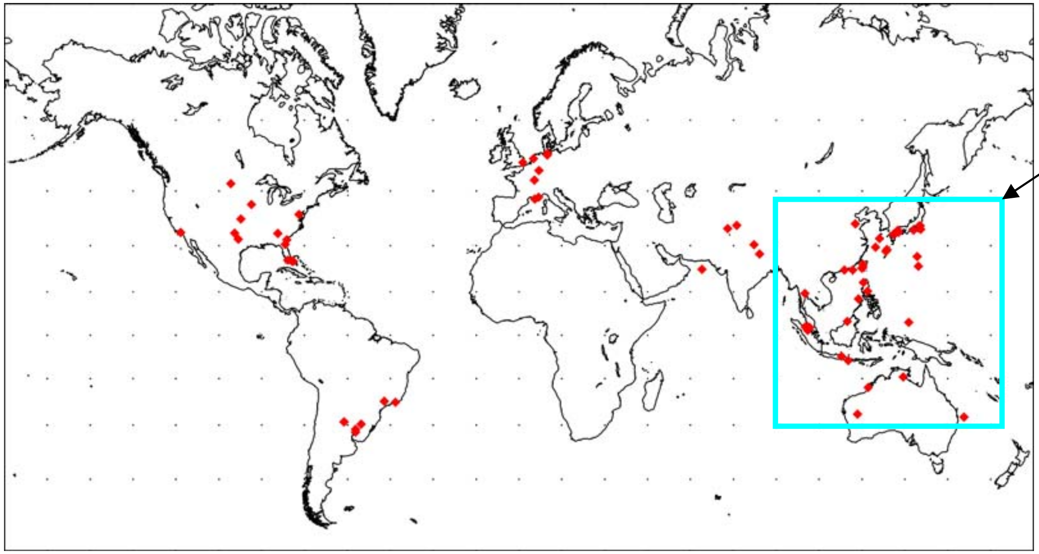
- All types/sizes of aircraft, all types/sizes of engines

- Hypothesis: aircraft flying in region of high mass concentrations of ice crystals ("High IWC"), and supercooled LWC not required

- For more information:
  - **Mason, J.G., J.W. Strapp, and P. Chow, 2005: The ice particle threat to engines in flight. *44th AIAA Aerospace Sciences Meeting, Reno, Nevada*, 9-12 January 2006, AIAA-2006-206.**

Event Locations and General Notes

Updated to Dec. 2008



57% of events

- Occur from tropics to mid-latitudes
- Concentration of events in southeast Asia / Australasia
- Oceanic and continental convection; isolated convection up to tropical storm scales
- Never in frontal clouds or stratus/stratocumulus
- Sometimes while diverting around a red-echo region at altitude
- Often no high-reflectivity radar echoes at flight altitude

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Types of Engine Events:

- **Stall, Surge, Flameout:**
  - momentary loss of power events due to the effect of shed ice passing through the compressor or combuster
  - recoverable at altitude (often automatically) if proper procedures are followed
- **Rollback** :
  - uncommanded spoolback of engine – thought to be due to ice buildup on rotor blades blocking the airflow
  - aircraft must descend to warmer air to clear – seen on smaller jet engines

ALL POWERLOSS TYPES RESULT IN INSIGNIFICANT THRUST FROM THE AFFECTED ENGINE(S)

THERE HAVE BEEN SOME EVENTS WHERE ALL ENGINES WERE AFFECTED SIMULTANEOUSLY (I.E. NO THRUST)

Engine Event Concerns:

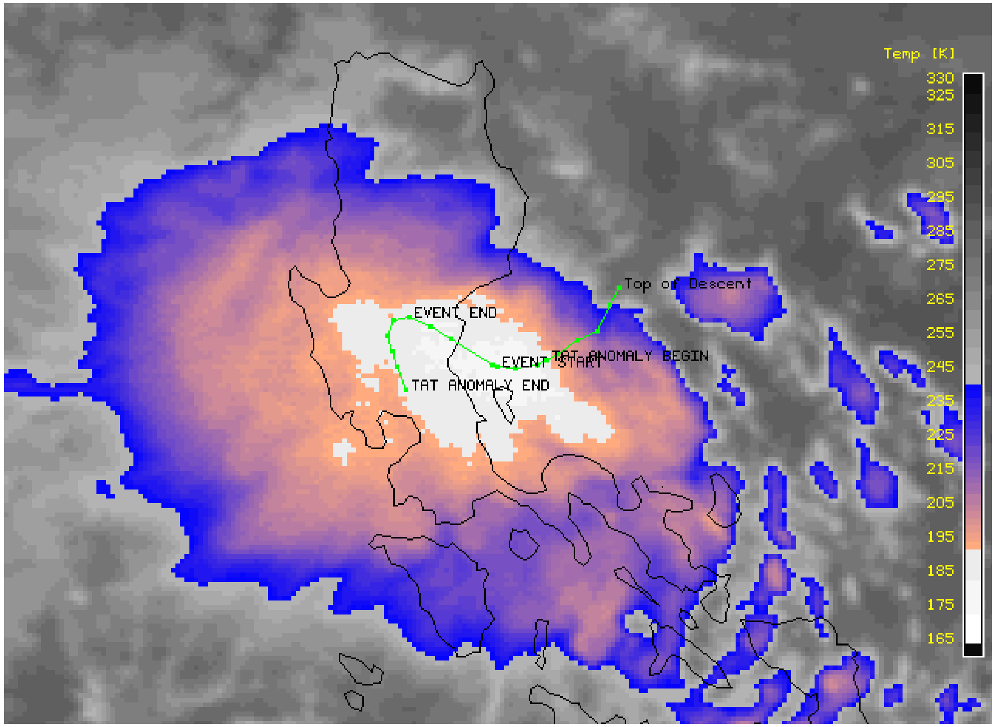
- **Cost**
  - Ice shed down the compressor can lead to costly engine damage, and aircraft out of service for several days (~$100K+ for airlines)
- **Safety:**
  - 4-engine rollback (all engines) in one powerloss event
    - re-started 400 m above the ocean
  - Dead-stick landing in Florida (aircraft landed with no engine power)
  - 747 descent into southeast Asia had multiple powerloss events, all engines affected during the sequence
  - FAA: **"Precursor to a fatal accident"**

Common Observations from Pilots and Flight Data Recorders:

1. High altitude, cold temperature, atmosphere is significantly warmer than standard atmosphere
2. Aircraft in the vicinity of convective clouds/thunderstorms and in Instrument Meteorological Conditions (IMC) (in visible cloud)
3. Light to moderate turbulence, lightning infrequent
4. Aircraft total air temperature probe (TAT) anomaly
5. Lack of observations of significant airframe icing
6. Low flight-level radar reflectivity (pilot's radar) at the location and altitude of the aircraft engine event
7. Precipitation on windscreen, often reported as rain

Example of Engine Event:

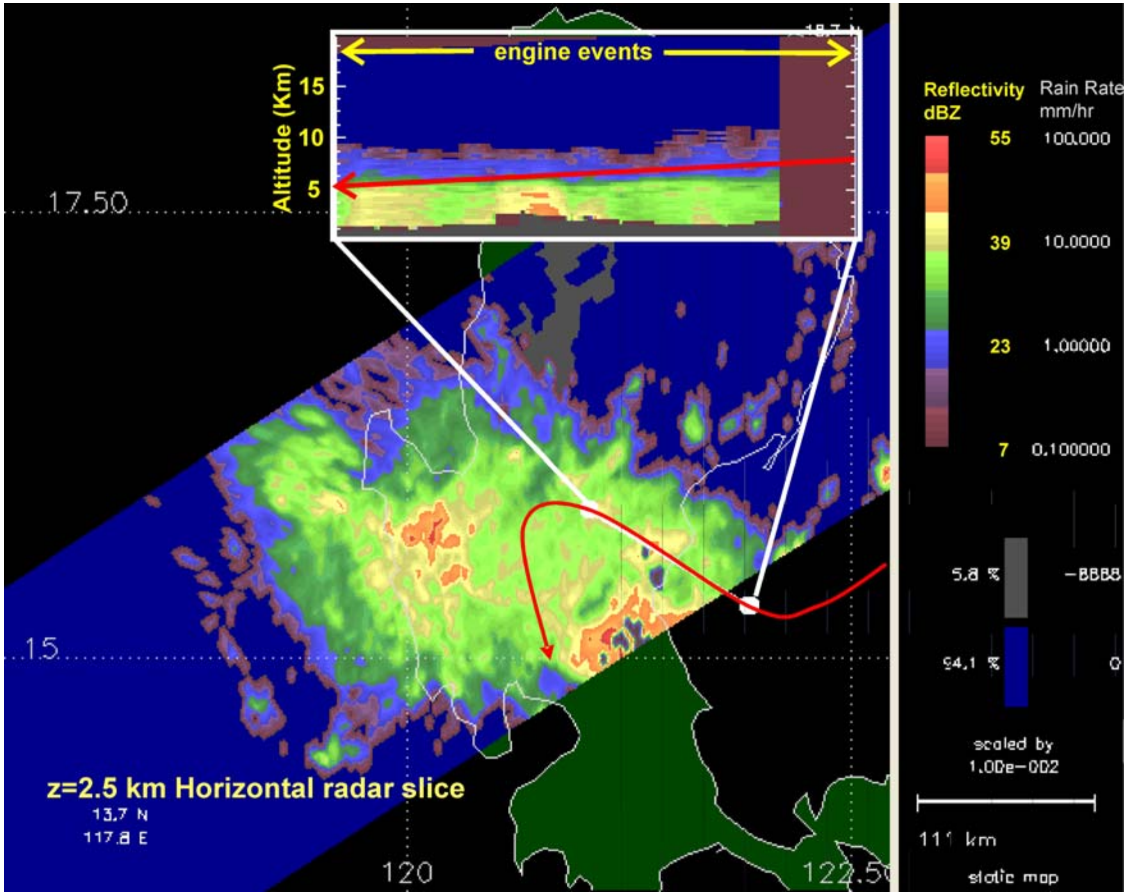
- 747 on descent in Southeast Asia through area of quasi-stationary deep convection
- TAT anomaly (corrupted air temperature readings) observed entering deepest cloud (-85 C, 16.8 Km) – we now recognize this as a warning sign for high IWC
- multiple engine events occurred ;at one point 3 out of 4 engines flamed out



Source: The Boeing Co.

Example of Engine Event (cntd):

- Tropical Rainfall Measurement Mission overpass within 30 minutes of event
- TRMM data swath shows area of convection with low level reflectivity reaching 55 dBZ
- Cross-section (inset) shows vertical distribution of reflectivity (next slide)



Source: the Boeing Co. – data from the Tropical Rainfall Measurement Mission project

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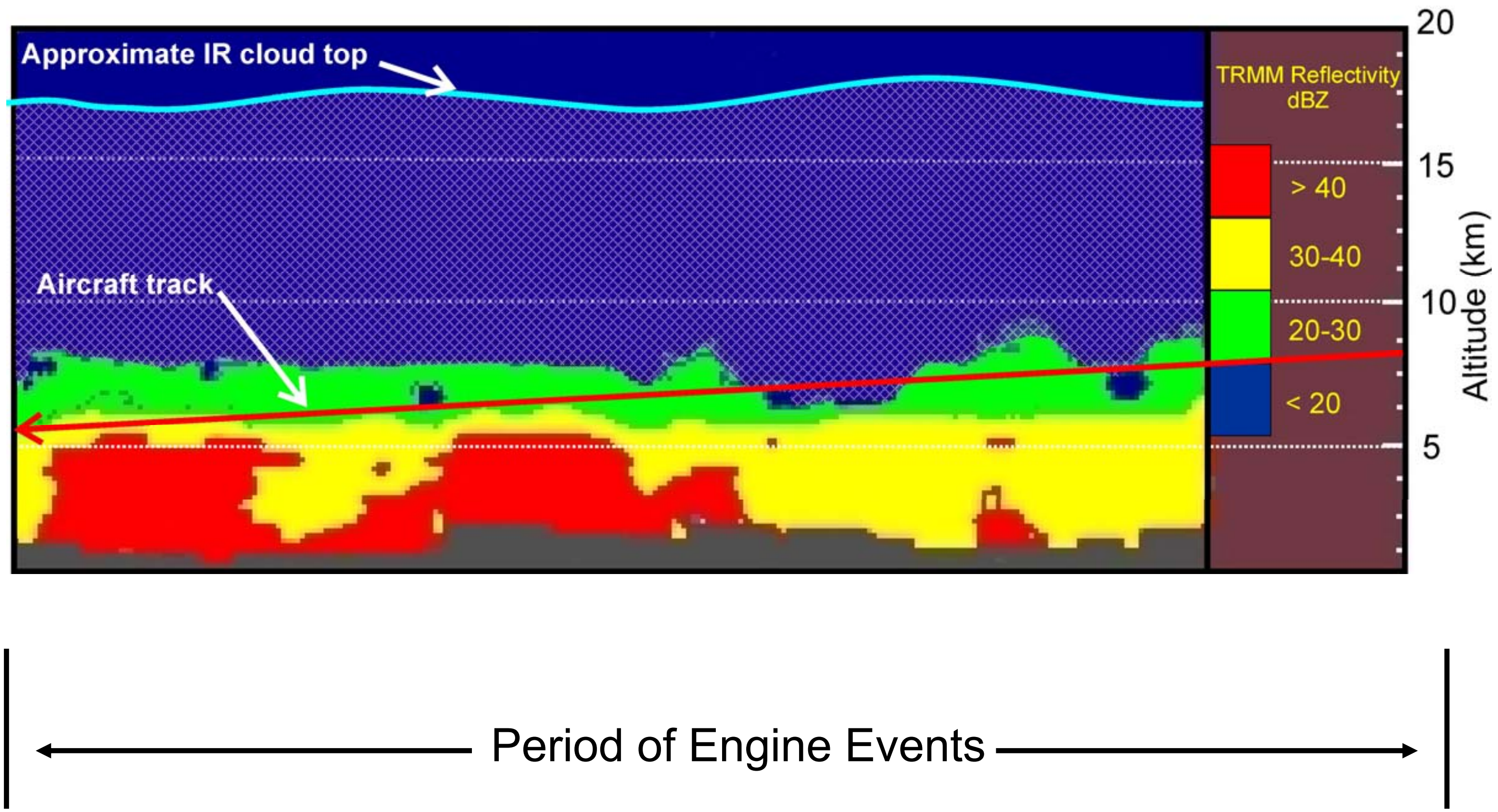
Example of Engine Event (cntd): Using pilot's radar colour scheme



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In-flight Warning and Detection Challenges

- **Forward warning on aircraft:**
  - **Problem:** Weather conditions appear to be low radar-reflectivity high-IWC, and optically dense deep clouds (small ice crystals in high concentration at high-altitude)
  - Only current in-flight tool is radar, but High IWC areas are often invisible at current radar sensitivity (~20dBZ)
  - Higher sensitivity pilots' radars are in development (0 dBZ), but forward warning strategy needs development
  - avoid flying over areas of heavy rain below the aircraft in areas of active convection
- **Methods for real-time in-condition detection (but escape strategy currently unknown):**
  - TAT anomaly,
  - 'rain' on windscreen at cold temperatures,
  - possibility of a real-time in-situ detector for aircraft in future

Forecasting/Nowcasting Challenges

- **Forecasting/nowcasting:**
  - No 'off the shelf' solutions
  - Currently, no clear way to isolate high IWC/ low reflectivity areas with ground or satellite remote sensing – low-reflectivity warnings could trigger many false alarms
  - Satellite schemes may have promise but need validation
  - Models: main active areas in convection can have relatively short and quasi-random time scales and cannot be predicted with enough accuracy for flight diversions (maybe also warning areas may be too large)

- **Refinement of the conceptual model of high IWC is required**
- **Remote sensing validation is required**

Engine Harmonization Working Group (EHWG) and Future Plans

- **Committee of airframe manufacturers, engine manufacturers, regulators, government agencies**

- **Since 2004 has studied the data base of jet-engine powerloss events, developed the meteorological hypothesis, provided advisory and rulemaking material, and made recommendations for a path forward (Technical Plan)**

Proposed Airborne Measurements HIWC Study:

- Sample oceanic monsoon and continental convection out of Darwin Australia with a well-instrumented cloud physics aircraft in Jan-Mar 2012
- Objectives:
  - Collect IWC characterization measurements for industry needs, and improve pilot recognition of High-IWC environment
  - Improve understanding of basic cloud microphysics in active areas of convection
  - Improve remote sensing products for deep convection (radar/satellite) through comparison to in-situ and other measurements
  - Improve cloud resolving models simulations of deep convection through comparison to in-situ and remote sensing
  - Improve the conceptual model of High-IWC in deep convection, and develop nowcasting techniques

Science Partners
HIWC Study:

- **Environment Canada (Strapp, Korolev, Isaac):**
  - fundamental cloud physics processes, cloud characterization, development of mixed phase.
- **NASA Glenn: (Ratvasky):**
  - cloud characterization, engine icing
- **Australian Bureau of Meteorology (May, Potts, Keenan, Protat):**
  - fundamental cloud physics processes, validation of radar products (TWC, particle type, updraft velocity), nowcasting
- **NASA GISS (Ackerman, Fridlind):**
  - fundamental cloud physics processes, validation of model products
- **NCAR (Politovich, Haggerty):**
  - nowcasting High-IWC
- **NASA Langley (Minnis):**
  - validation of satellite-produced cloud products

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End of Presentation

More detailed information at poster P18

Merçi, thank you

walter.strapp@ec.gc.ca

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