ICE CRYSTAL ICING
&
HOT TOWERS

John Salamankas
“Hot Towers” presented to CAB in 2007
  – Gulfstream encounters described and analyzed

“Ice Crystal Icing” addressed in 2008
  – Data base of air carrier encounters
  – Few Gulfstream encounters

Both topics presented numerous times
  – Question arose

Are these hot tower encounters or not?
  – If not, what?
Hot Towers or Not

Definition

• NASA definition: “Towering rain cloud that reaches the top of the tropopause”

• Associated with tropical cyclones and hurricanes

• Occur between 36º N and 36º S latitude

• Diameter up to 3½ miles

• Duration ½ to 2 hours

• Size and duration make them difficult to study

• Useful predictors of hurricane growth
Tropical Rainfall Measurement Mission

Place mouse pointer on map and right click to play movie clip
Hot Towers or Not

FL410 over equatorial Africa
  – Scattered thunderstorms below
  – Cirrus cloud, light turbulence, SAT -63°C

A/T disconnect, CAS messages

SAT at -48°C continued warming to -26°C

EPR indicated low, Mach reduced to .67

After 22 minutes, temperature rapidly returned to -56°C

All systems normal
Hot Towers or Not

GIV Encounter

- Second event, over the Pacific
- Weather conditions and aircraft reaction similar
- Engine vibration developed to exceedance levels
  - Engine to idle, reversed course to exit conditions
  - Set course for alternate and descended
- Vibration diminished during descent, gone at 15,000’
- Engines inspected - completely normal
Hot Towers or Not

GV Encounter

- FL410, Pacific ocean near equator
  - Scattered thunderstorms below
  - Light turbulence, cirrus cloud, -63°C

- A/T disconnect, “L-R Eng Backup Air Data”, “MADC Miscompare”

- SAT -48°C continued warming to -24°C

- Altimeters and Mach indications all disagreed.

- Slow descent after speed decayed

- After 25 minutes temperature rapidly returned to -56°C
Hot Towers or Not

Hot Tower Conditions

- High altitude, ISA or colder temperatures
- Heavy moisture in lower altitudes
- Nearby convective activity
  - No radar returns at event location
- In cirrus cloud
- Light to moderate turbulence
- TAT probe anomaly
Hot Towers or Not

Ice Crystal Icing

- Convective activity lofts ice crystals in significant quantities into the upper atmosphere
  - Ice crystals, not liquid water
- Invisible to aircraft radar and ice detectors
- No airframe icing
- Crews unaware of potential hazards
- Greatest hazard is loss of engine power
- 150 air carrier events in FAA/Industry data base
Hot Towers or Not

Ice Crystal Icing

- Ice crystals previously thought harmless
- Theory – bounced off airframe and engine surfaces
- Reality – crystals melt due to compression effects
  - Pass through fan section
  - Enter core and melt on warm surfaces
  - Moisture traps additional crystals
  - Ice builds up, sheds into compressor
  - Engine surges, rolls back, and flames out
Hot Towers or Not  Ice Crystal Icing Risk

• No engine can be considered immune

• Engine susceptibility varies with design
  – Blade arrangement and geometry
  – Engine control technology
    • Variable bleed valve scheduling

• Events have driven AD’s and AFM changes
  – CF6-80 engine on B747, B767, and MD-11
    • Engine anti-ice ON any time TAT 10º or lower
  – Beechjet (Hawker 400XP) dual engine flameouts
    • Engine anti-ice ON during high altitude flight in the vicinity of visible moisture and convective activity
• 2007 report by a GIV of high engine vibration in VMC conditions during an enroute descent
  – Had flown in vicinity of strong convective activity for a long time
  – Fan blade icing suspected

• GV report of high EVM during VMC descent
  – Airplane had just exited IMC
  – Fan blade icing suspected

• G550 reported high EVM during VMC descent
  – Flew over thunderstorms in tropical storm system
  – Fan blade icing suspected
Hot Towers or Not  Gulfstream Ice Crystal Events

• GIV dual engine flameout in 1991
  – In vicinity of a huge convective storm
  – Surrounded by towering cumulus

• Both engines were successfully restarted

• FDR analysis showed abnormal TAT indications prior to the event

• Report attributed flameout to heavy water ingestion

• In retrospect, ice crystal icing should be considered as the probable cause
• FAR 25 requires flight testing in natural icing

• **Equipment and Systems** – Perform their intended function under any foreseeable operating conditions

• **Airplane** – Safely operate in “continuous maximum” and “intermittent maximum” icing

• **Engines** – Operate throughout flight power range, including idle, with no adverse effects from ice accretion

• “**Maximum Icing**” defined by
  – *Liquid* water content
  – Droplet size
“Continuous Maximum” – difficult to find
- Narrow altitude bands
- Small temperature range
  - Total temp below freezing
  - -8°C Ideal
  - -13°C Snow
  - -20°C Solid

Testing performed in moisture laden stratus clouds below 20,000 ft.

No exposure to ice crystals
Hot Towers or Not

Ice Crystal Conditions

• High altitude, ISA or colder temperatures
• Heavy moisture in lower altitudes
• Nearby convective activity  
  – No radar returns at event location
• In or just exited cloud
• Light to moderate turbulence
• TAT probe anomaly
Hot Towers or Not

Hot Tower Conditions

- High altitude, ISA or colder temperatures
- Heavy moisture in lower altitudes
- Nearby convective activity
  - No radar returns at event location
- In cirrus cloud
- Light to moderate turbulence
- TAT probe anomaly
• Cause and effect explanations not equally credible

• Engine ice crystal icing explained by basic physics
  – Large data base of similar events
    • FDR data studied
  – P&W/FAA confirmation by flight test

• Experience and understanding have resulted in more stringent icing certification requirements
  – FAR 25 adding *Large* super cooled droplet icing
  – FAR 33 adding *Ice Crystal* and *Mixed Phase* icing
Hot Towers or Not

• Hot towers are real, but are the encounters?

• Parcel - environment temperature difference is a measure of updraft severity
  – 4°C Strong
  – 5°C to 7°C Severe
  – 30°C “Unprecedented”

• Events report only light to moderate chop

• No reports from inside top of towering CB

• Encounters of :20 to :25 minutes span up to 200nm
Tropical Rainfall Measurement Mission

Place mouse pointer on map and right click to play movie clip
Hot Towers or Not

If Not, What?

- Temp rise *assumed* due to hot tower
  - Is the indication correct?
  - Could there be another cause?

- Focus on Total Temperature Sensor
  - Gulfstream probes same as Boeing & many others
  - Identical externally
  - Minor internal variations by PN
    - Heater current type
    - Base plate contour
    - Connector type
Hot Towers or Not  Goodrich Total Temp Probe
Hot Towers or Not  Goodrich Total Temp Probe

- Review of sensor specs and fault history
  - High MTBR
  - 60% heater failures, 2% sensor failures

- Part Number change for PlaneView aircraft
  - Performance enhanced in extreme icing conditions
  - Inlet scoop change to reduce clogging by ice crystals
  - Improved internal heat conduction to critical surfaces
  - Increased heater power

- No Hot Tower reports from PlaneView aircraft
Hot Towers or Not

Probe Enhancements

102LA2AG  102LK2AG  102LA2AG  102LK2AG
Goodrich engineering confirmed
- Ice crystals can overwhelm heater and clog probe
- Reduced airflow allows heater to warm sensor
- Sensor may read 0°C, ice point of melting crystals
  - 0°C reported numerous times in airline data base
- Rapid return to normal is consistent with heater clearing ice from probe

Probes became logical suspects in tower events

Suspicion only, confirmation needed
• NOAA weather research GIV experienced several unexplained temperature increases at high altitude

• Aircraft records data from numerous sensors
  – Production standard total temp probe
  – Scientific temperature probes (2)
  – Dewpointers

• During some hot tower type events
  – Only two of the three temp probes reacted
    • Third probe continued to indicate normally
  – Dewpointers showed large increase in water vapor
• Recent events (Continued)
  – Dewpointer temperatures increased first
  – Dewpointer temperature was warmer than probes
    • Considered “meteorologically incorrect”

• Flight Meteorologist is investigating
  – “..has to be something going on to cause this around the tops of thunderstorms”
  – Important meteorological concept
  – Safety implications

• The answer to one question may hold the key
Hot Towers or Not

• If the air was really warmer –

  Why didn’t all three probes indicate a hot tower?
Hot Towers or Not

New Questions

Investigation has raised new questions

– What caused the self-clearing engine vibrations
  • Ice shedding procedure not used
– During one event, only one engine vibrated
– Did ice crystals affect the engines and not the TAT
– Why didn’t we know about probe icing
  • How much of a problem is it
– Some Gulfstream events included pack overheat
  • Is ECS affected by ice crystals
– Why is the temperature in the tower often near -26°C
  • Typical temp rise between SAT and TAT at M.80
Hot Towers or Not

• Title question may be answered
  – Towers are real
  – Encounters probably aren’t
Questions