# ICE CRYSTAL ICING
# &
# HOT TOWERS

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# Ice Crystal Icing & Hot Towers

- "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

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**Place mouse pointer on map and right click to play movie clip**

# Hot Towers or Not

## GIV Encounter

- FL410 over equatorial Africa
  - Scattered thunderstorms below
  - Cirrus cloud, light turbulence, SAT -63ºC
- A/T disconnect, CAS messages
- SAT at -48ºC continued warming to -26ºC
- EPR indicated low, Mach reduced to .67
- After 22 minutes, temperature rapidly returned to -56ºC
- 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, -63ºC
- A/T disconnect,"L-R Eng Backup Air Data", "MADC Miscompare"
- SAT -48ºC continued warming to -24ºC
- Altimeters and Mach indications all disagreed.
- Slow descent after speed decayed
- After 25 minutes temperature rapidly returned to -56ºC

# 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

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- Ice crystals previously though 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

# Hot Towers or Not Gulfstream Ice Crystal Events

- 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

# Hot Towers or Not





- 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

# Hot Towers or Not





- "Continuous Maximum" – difficult to find
  - Narrow altitude bands
  - Small temperature range
    - Total temp below freezing
    - -8ºC Ideal
    - -13ºC Snow
    - -20ºC 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

# Hot Towers or Not

## Similarity a Coincidence

- 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
  - 4ºC Strong
  - 5ºC to 7ºC Severe
  - 30ºC “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

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**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

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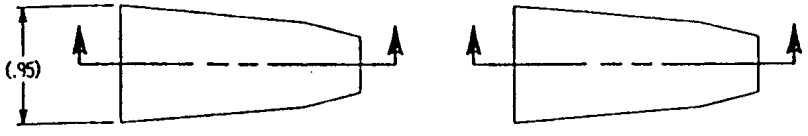


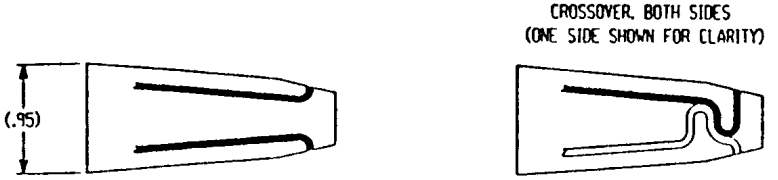


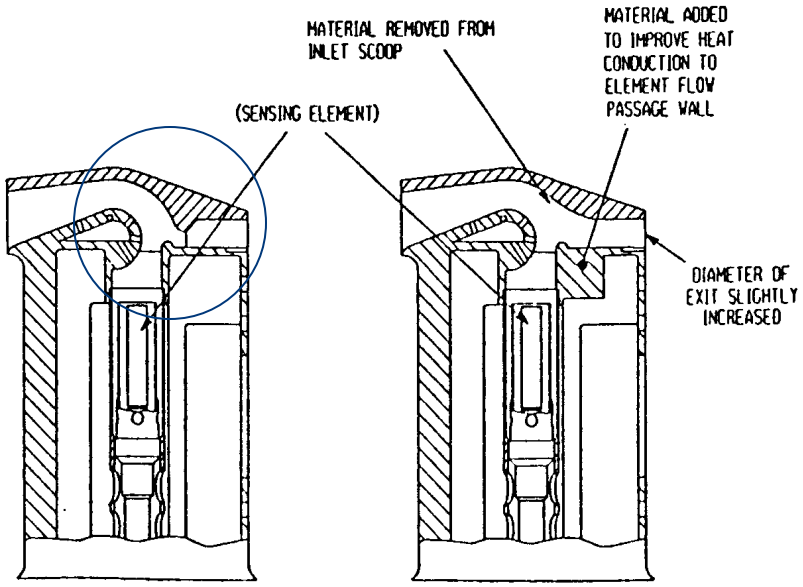


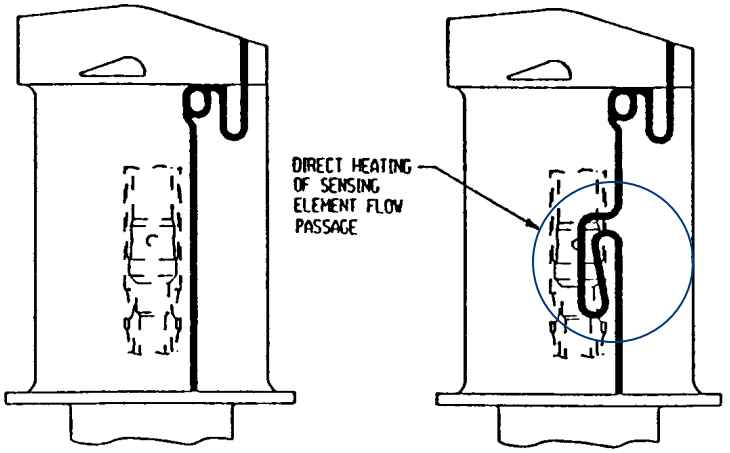


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# Hot Towers or Not Goodrich Total Temp Probe

- Goodrich engineering confirmed
  - Ice crystals can overwhelm heater and clog probe
  - Reduced airflow allows heater to warm sensor
  - Sensor may read 0ºC, ice point of melting crystals
    - 0ºC 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

# Hot Towers or Not

## Additional Data

- 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

# Hot Towers or Not

## Additional Data

- **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

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**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 overheats
  - Is ECS affected by ice crystals
- Why is the temperature in the tower often near -26ºC
  - 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**

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# Questions

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