

Aircraft Propulsion System Icing

Challenges & Opportunities

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Causes of Engine Icing

- > **Supercooled droplets**
- > **Ice Particles**
 - **Glaciated clouds (crystals)**
 - **Snow**
 - **Hail**
- > **Mixed Phase atmospheres**

What are the possible effects on the engine

?

> **Vibration**

> **Operability**

- **Stalls / surges**
- **Rollback**
- **Flameout**
- **Slow Acceleration**

> **Temporary thrust/power loss**

- **Ice accretions cause aerodynamic losses, rotating stall etc.**
- **Cycle changes**

> **Damage**

- **Ice sheds can damage rotating blades, excite resonances**

Classical Icing Mechanisms

- > Ice forms when super-cooled droplets impact & freeze on sub-freezing surfaces

- > Ice forms due to runback from non-evaporative anti-icing systems – typically SLD (Supercooled Large Droplets – freezing rain or drizzle)

Crystal and Mixed-Phase Icing

Recent work by rulemaking committee has identified service events which are due to ice accretion on warm surfaces in glaciated or mixed-phase atmospheres.

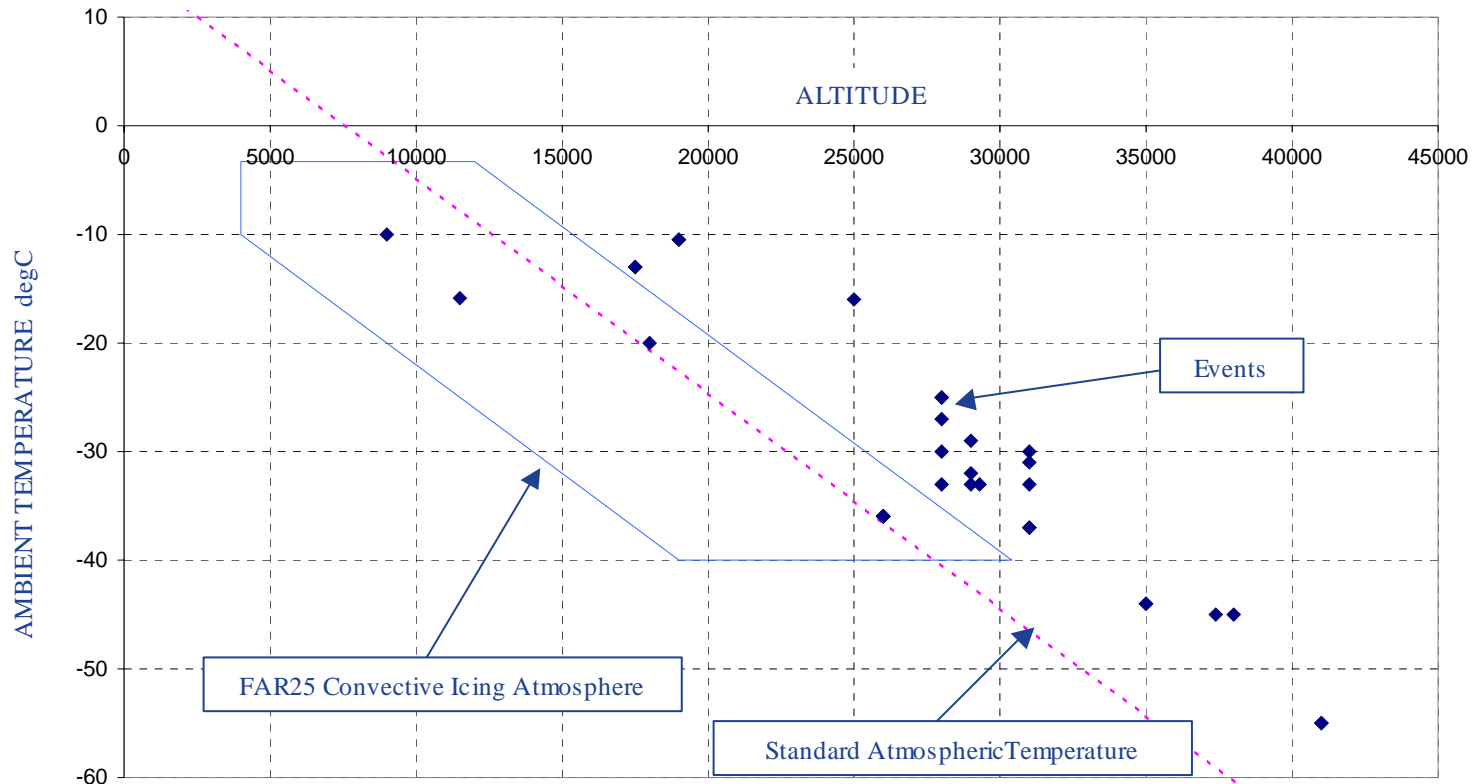
Although surface inside the engine is above freezing, the heat transfer processes which occur due to impacting ice crystals can result in significant ice accretion.

This is of concern for these reasons :

- Ice forms further aft in the engine resulting in effects which may not be seen in current certification testing
- In these atmospheres aircraft surfaces often do not ice, and ice detector systems may not detect, thus engine operating procedures for icing conditions may not be followed resulting in lower margins.

Industry Experience (larger turbofan engines)

Approx. 60 mixed phase / ice crystal related aircraft events in flight from 1989 thru 2003 with various symptoms - vibes, flameout, roll-back, surge, airfoil distress



Events with known altitude & Tamb plotted – tend to be ‘hot’ days, high freezing level

Crystal Icing Mechanism

- 1. Ice crystals enter engine primary flowpath, upstream surfaces are dry & cooler so no accretion**
- 2. At some point in the turbomachinery, warmer surfaces become wetted due to impacts with crystals and/or liquid**
- 3. Combination of further crystal impacts into wet layer and evaporation bring surface to freezing point.**
- 4. Ice begins to form with further crystal impacts.**

Where does ice accrete ?

- > Inlets
- > Fan blades & spinners
- > Cooler section static surfaces
- > Forward booster/IP stages for “classical” icing
- > Deeper into primary flowpath stages for “crystal” icing
- > Sensors
- > Bleed systems



SLD Accretion

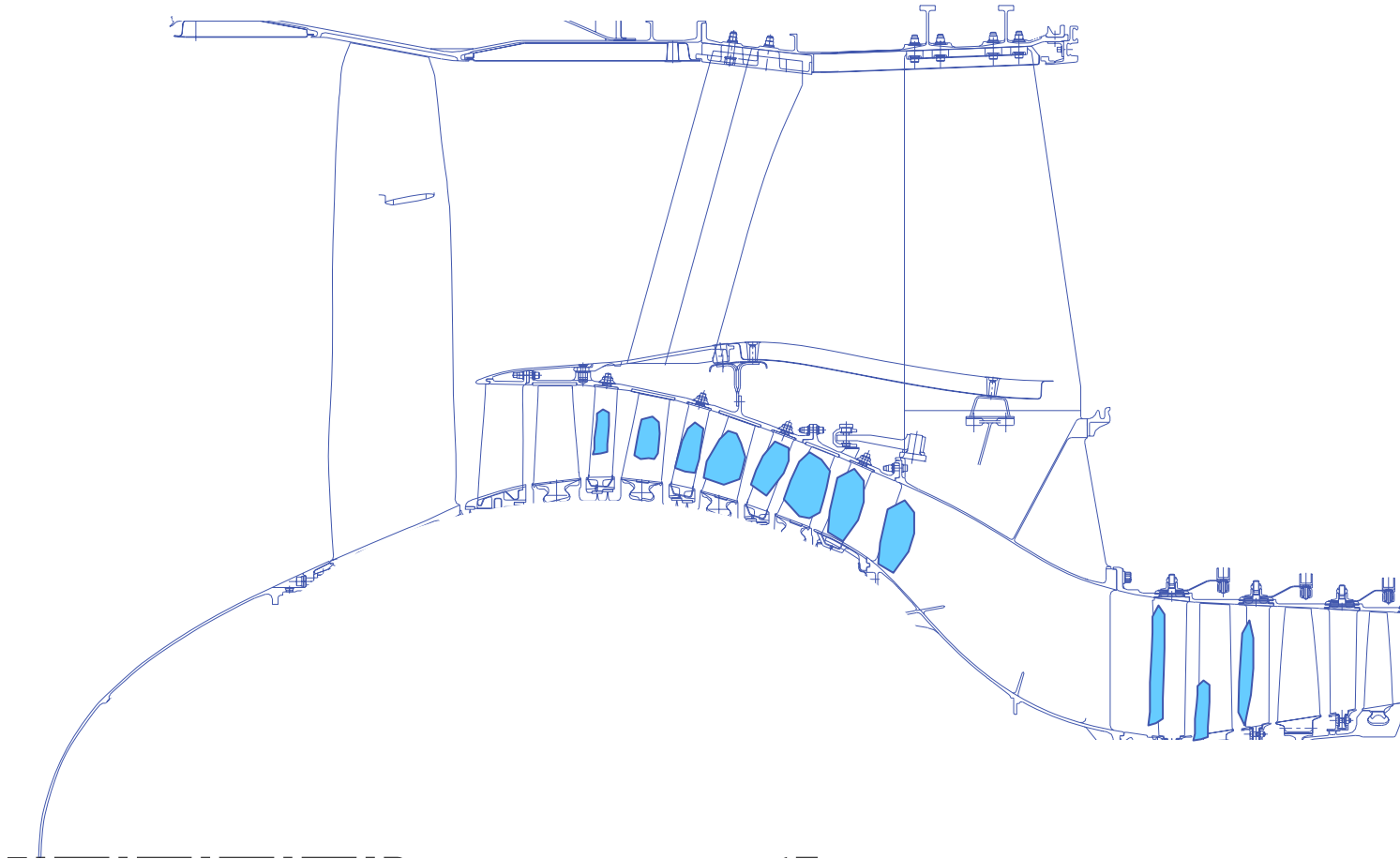
Spinner ice, although interesting, is usually benign in effect on engine



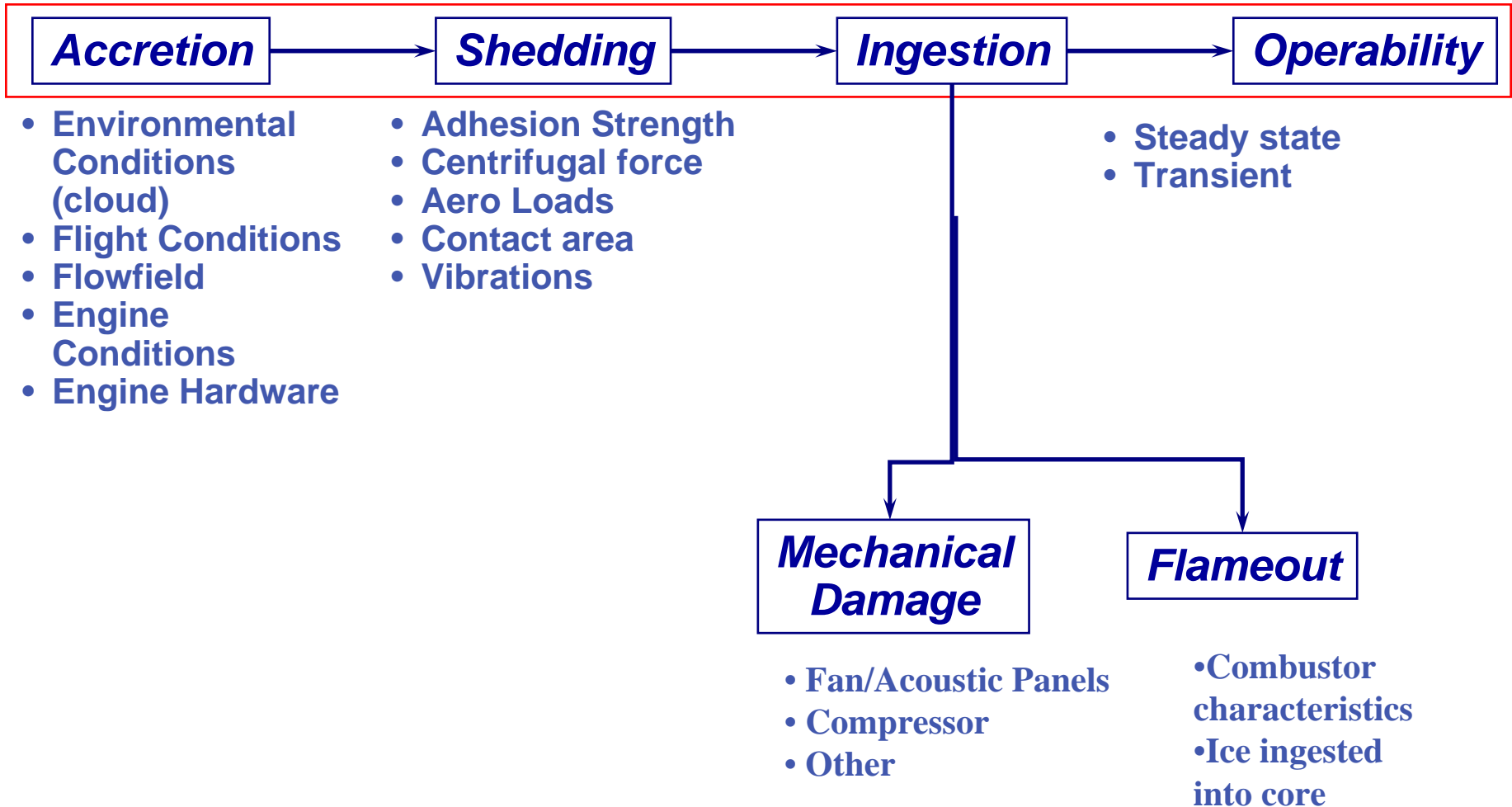
Supercooled Droplet Accretion Locations – fan/ogv's



Crystal accretion locations – booster/IPC static hardware/HPC forward stages



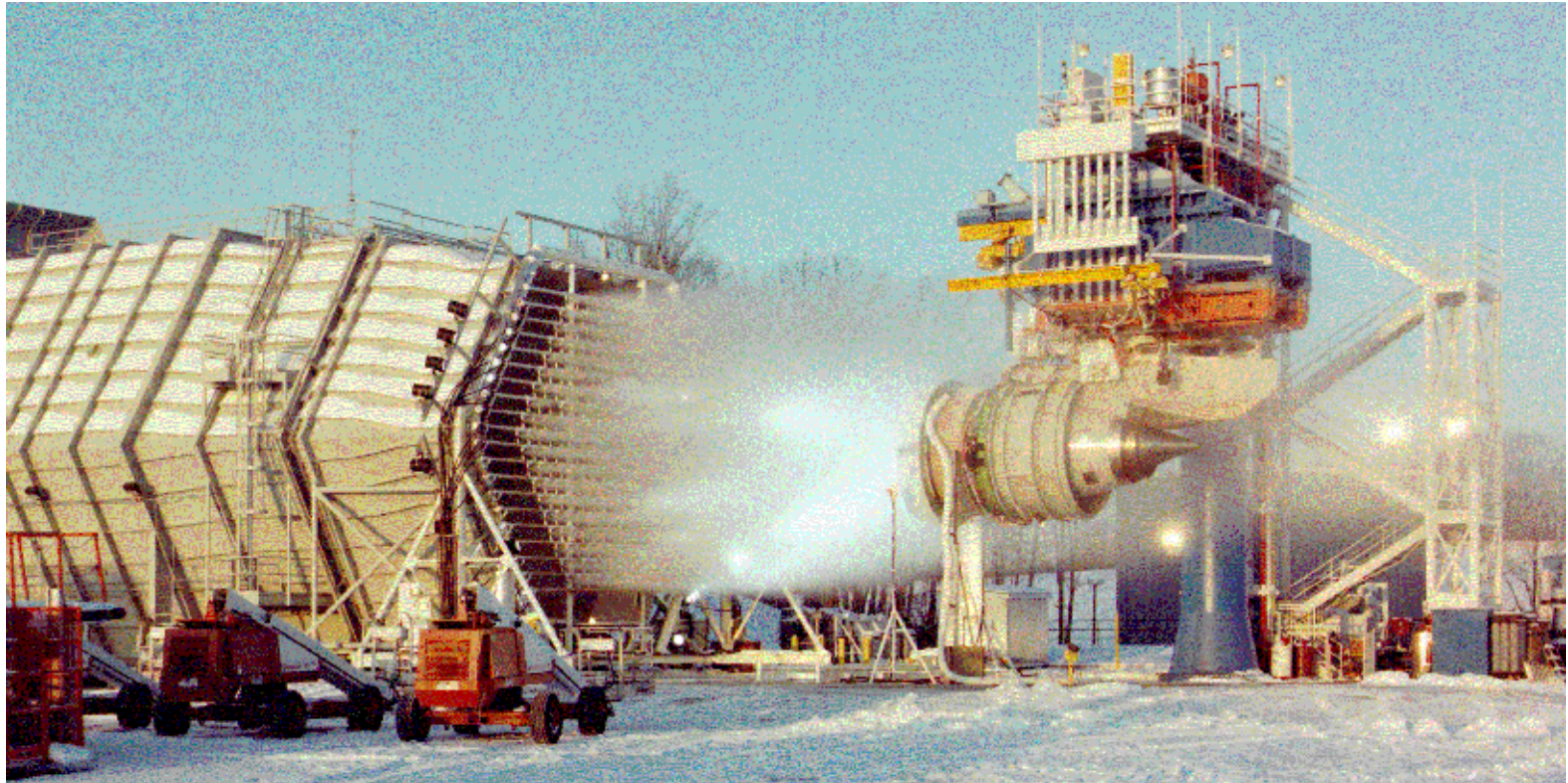
Engine Icing Considerations - Overview

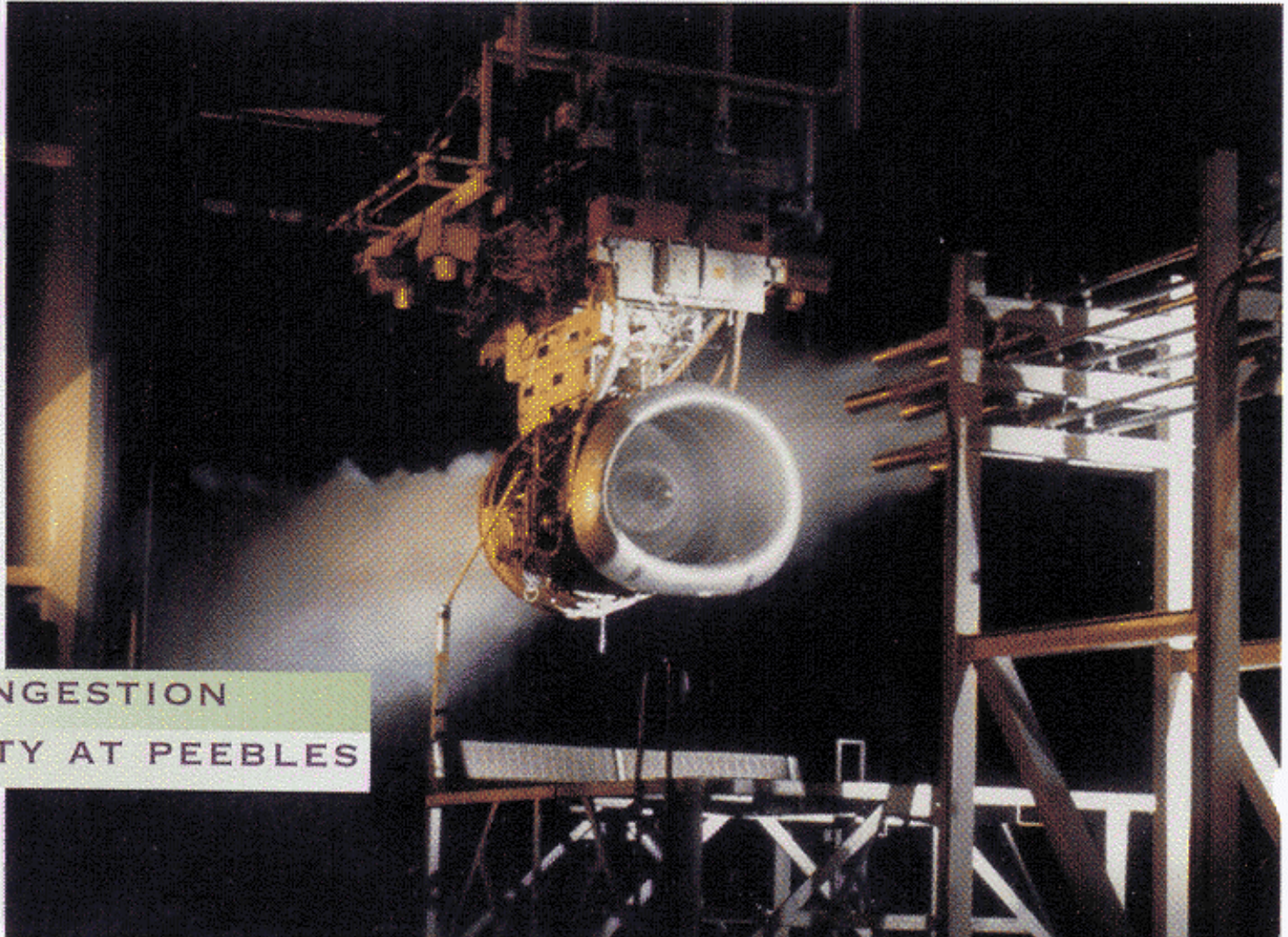


Engine Icing Considerations - Design

- > Analyze accretion/shedding zones throughout the flight envelope in icing atmospheres
- > Ruggedize blades & ice impact zones
- > Design components to minimize accretion, shedding and associated effects.
- > Design operability bleed schedules to remove shed ice
- > Define operability margins to account for shedding
- > Anti-ice or de-ice surfaces
- > Perform tests to show capability

Peebles Icing Facility

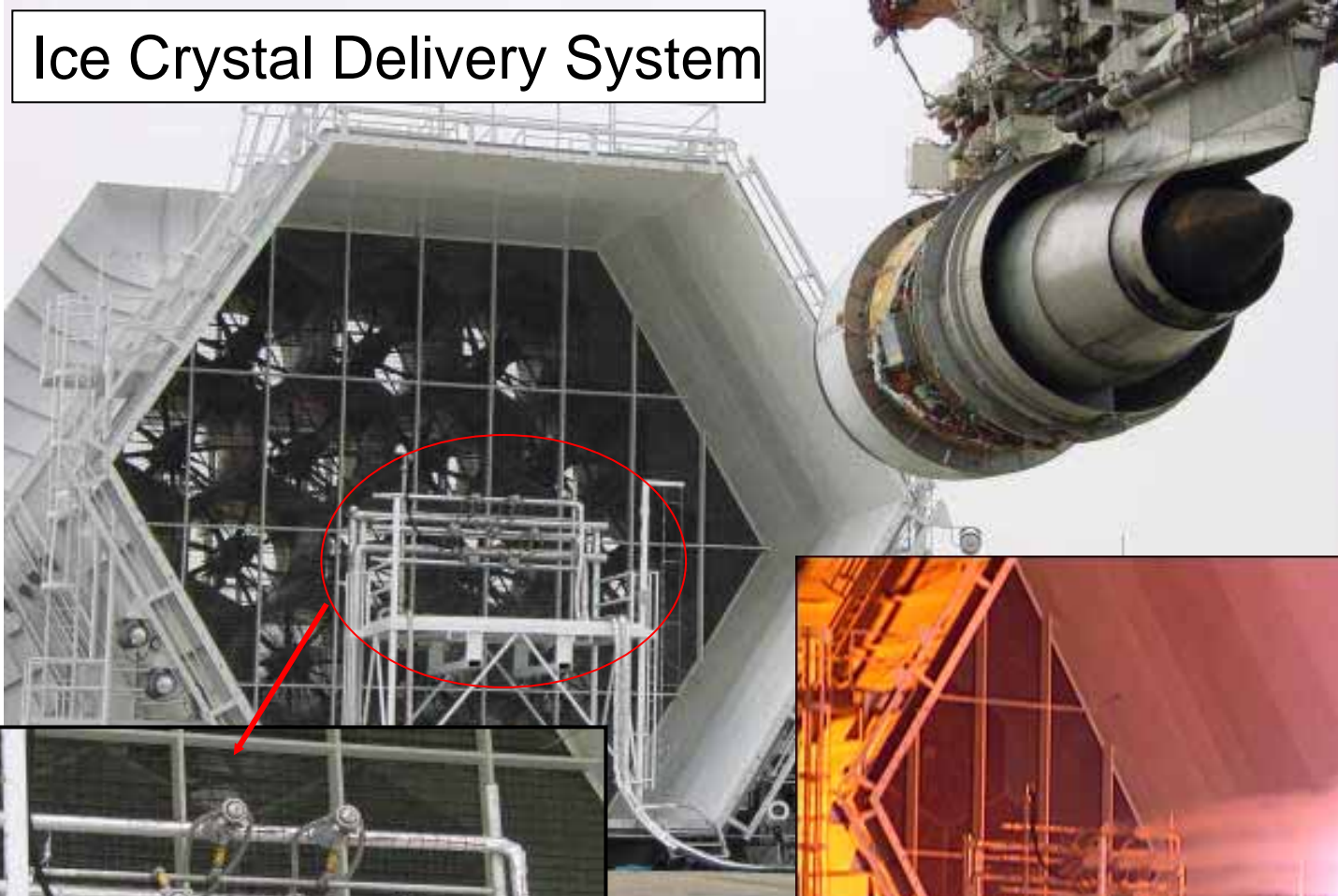




HAIL INGESTION
FACILITY AT PEEBLES

Simulated Ice Crystal Testing

Ice Crystal Delivery System



The Record

- > **Current icing regulation (Far33.68) has been in use for over 30 years**
 - Rulemaking committee used extensive data from 40's,50's to define FAR25 AppC atmospheres over 40 years ago
 - Industry experience & cert. history in AC20-73 and now AC20-147 have defined standard test points which, along with other manufacturer defined 'critical points' have given an excellent service record
 - The recent rulemaking committee, originally for SLD, collected manufacturers event data for 13+ years which included over 200 million flights – relatively few events have occurred.
 - New atmosphere for ice crystals will close perceived gaps

The Challenges - Opportunities for Research

> Atmospheric threat

- Instrumentation
- IWC / LWC
- Particle size / structure / distribution
- Duration

> Mixed-phase / glaciated accretion process

- Code development & validation
- Facility and Instrumentation Challenges

> Shedding / Dynamics of ice release

- Rotating and stationary surfaces
 - centrifugal vs adhesion for rotating; drag vs fracture for stationary
- Adhesion properties
 - function of temperature, material, ice type etc.
 - ice shear strength
 - liquid interface effects

> Engine Design

- Preference to design for ice tolerance without anti/de-icing or coatings
- Potential for efficient thermal anti/de-icing and durable ice-phobic surfaces

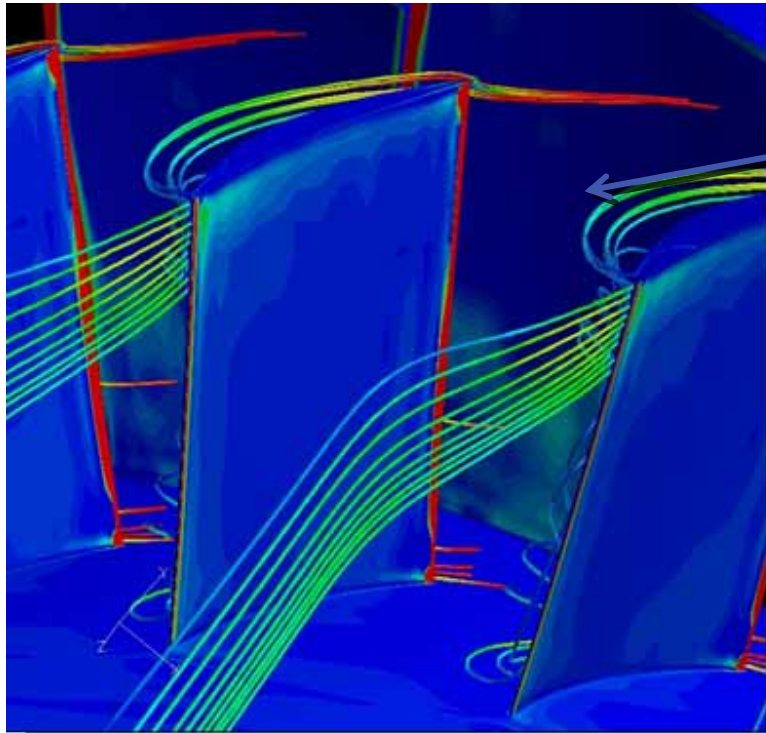
International Industry Working Group

4 different tasks have been defined in 'Technology Research Plan' :

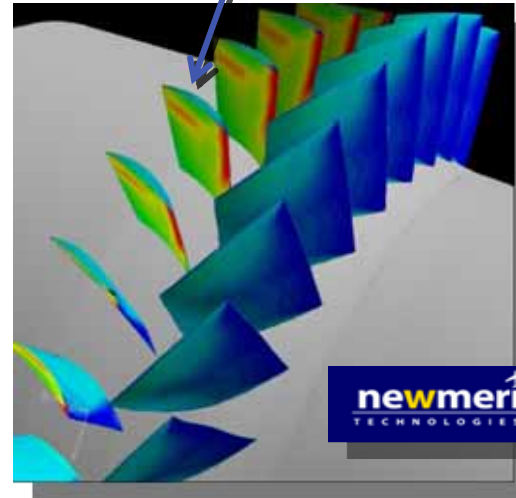
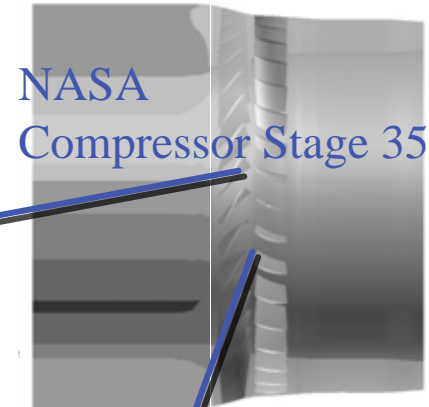
- > Task 1: Improved instrumentation to measure atmosphere**
- > Task 2: Flight trials to characterize atmosphere (understand particle size, concentration and extent)**
- > Task 3: Fundamental physics of ice accretion and shedding**
- > Task 4: Test methods and facilities**

TASK 3 - Codes are being developed – LEWICE – NASA TSIICE from Trebor Systems FENSAP-ICE

Unsteady Droplet Impingement in a Compressor Stage



Collection efficiency on stator blades & droplet trajectories



Where next ?