Engine Icing Technical Challenges

Joseph P. Veres
Technical Lead, Engine Icing

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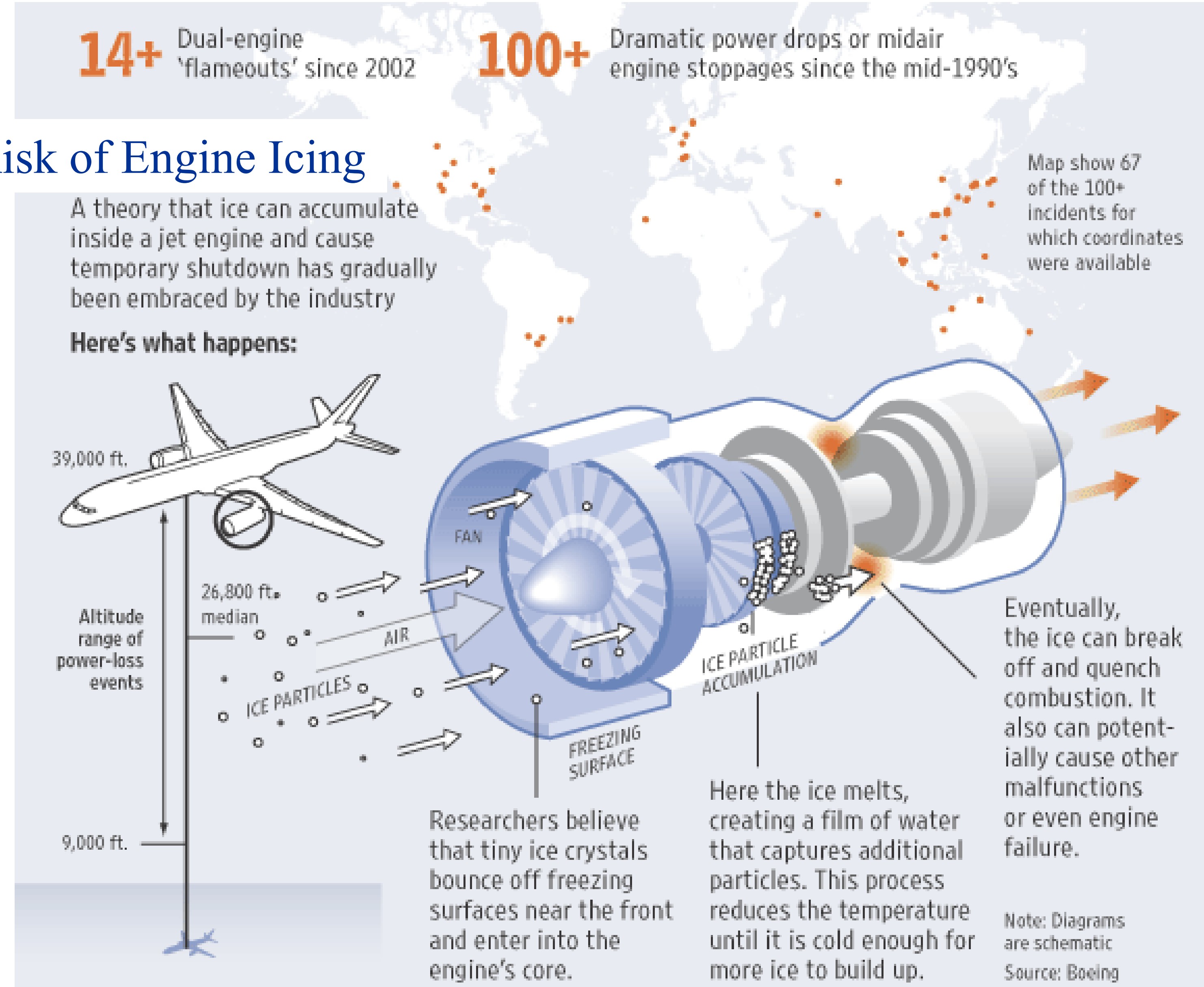
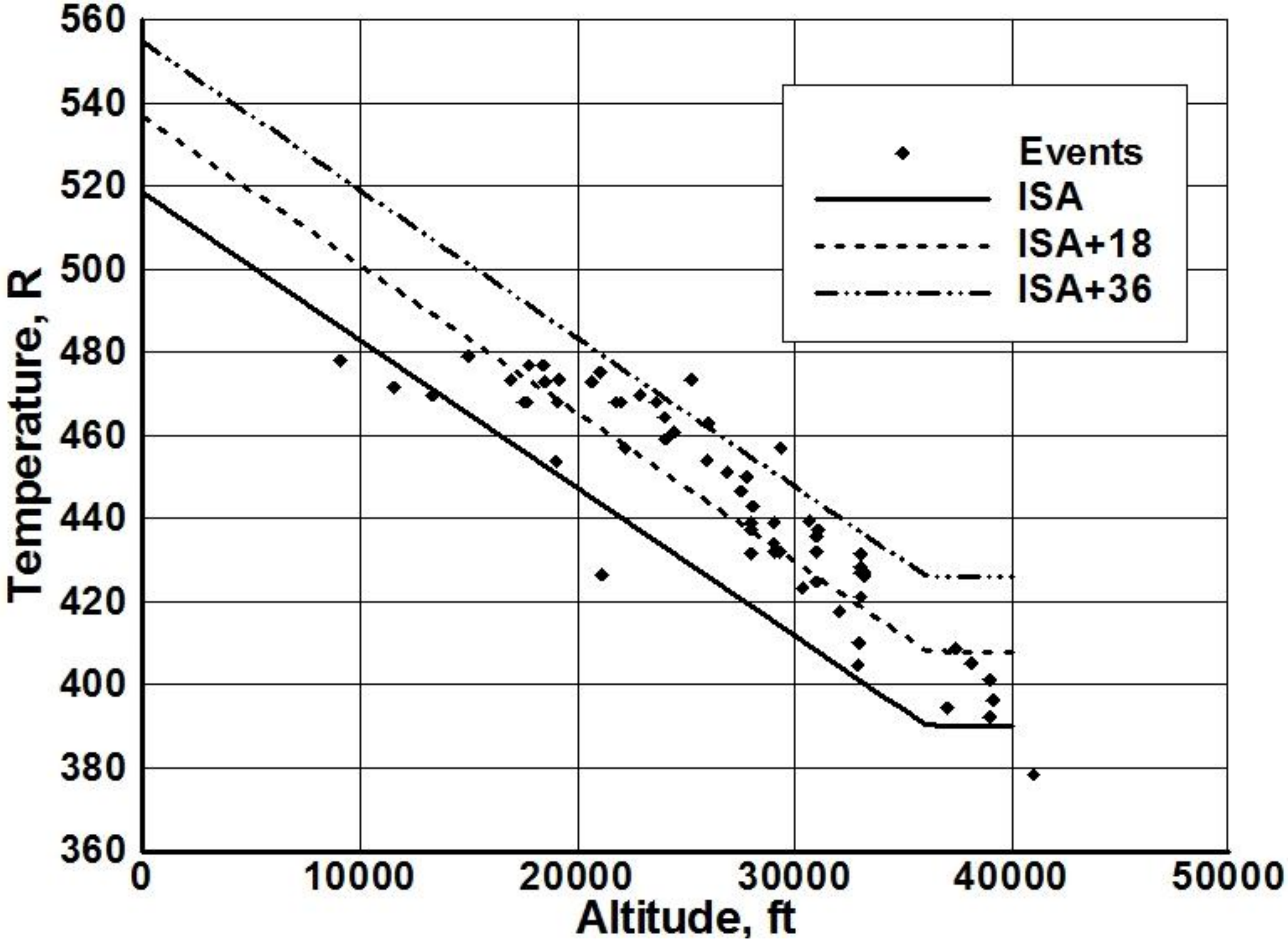
Engine Icing Technical Challenges

The Risk of Engine Icing



Engine Icing Events Reported

Most engine icing events occurred at engine inlet conditions that are warmer than ISA standard atmosphere and at a variety of altitude operating conditions of the vehicle trajectory



Engine Icing Research Elements and Technical Challenges

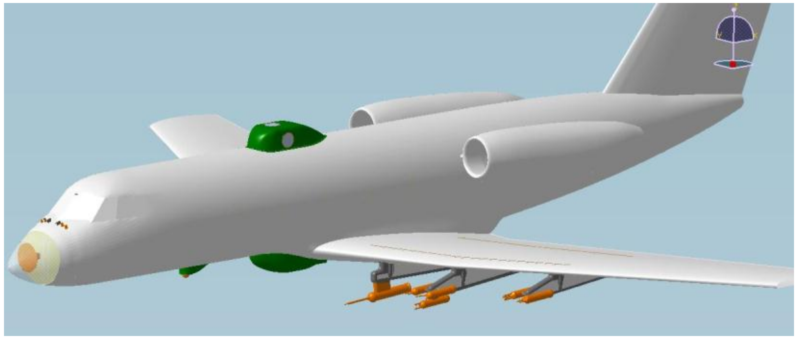
High Ice Water Content Flight Campaign: This project focuses on obtaining a benchmark database of atmospheric conditions by characterizing the ice/water content of clouds having high concentrations of ice crystals. A heavily instrumented aircraft will be flown into deep convective clouds to measure the cloud properties, namely the ice water content and ice crystal particle size and shape.

Engine Icing Performance Simulation: This effort will develop a modeling and simulation tool to estimate the flow field in the fan and low pressure compressor of a turbine engine throughout the complete flight trajectory. The tool consists of an engine thermodynamic cycle code, coupled to a compressor flow analysis code. The detailed fluid conditions including pressure and temperature are estimated in each blade row. These will be used as BCs in the ice accretion model to estimate ice accretion efficiency and rate.

Engine Ice Accretion Simulation: This effort is focused on developing an ice accretion model which will work in conjunction with the engine performance and compressor flow field estimation code. The accretion will be able to assess the compressor's susceptibility to ice accretion in any of the blade rows, at any flight condition along the vehicle trajectory.

Propulsion System Laboratory Modifications: The addition of a spray bar will provide full scale, ground-based engine testing with a cloud of ice crystals sprayed into the engine inlet at simulated altitude operating conditions of pressure and temperature.

High Ice Water Content Flight Campaign: Tom Ratvasky



This project focuses on making measurements of the atmosphere in clouds of the type that have been correlated with engine power loss. An heavily instrumented aircraft with state-of-the-art instrumentation will be flown into deep convective clouds to measure the cloud properties, the ice water content and ice crystal particle size and shape. The new improved instrumentation will address issues encountered by traditional instrumentation. The outcome of this research is to have a suite of instruments that set a new state-of-the-art for measuring cloud properties and meet the sensing requirements for high ice water content environments.

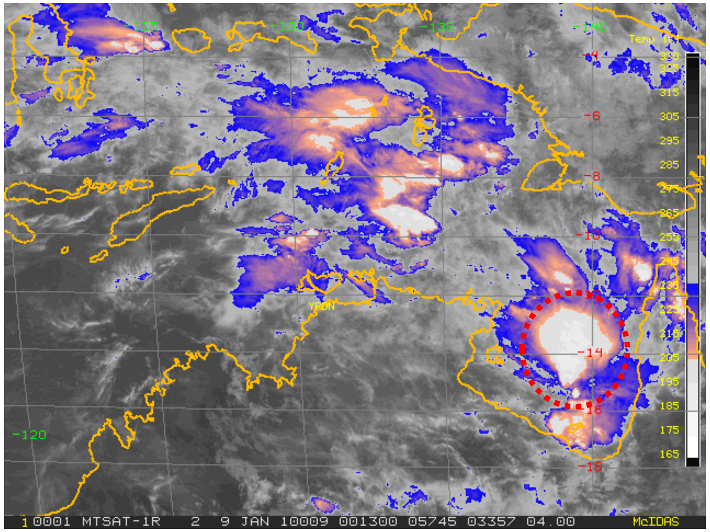
Advanced Instrumentation Features:

- **Resistance to ice particles shattering on spectrometer probe tips and subsequent measurement of shattered artifacts.**
- **Elimination of the under-sampling of ice water content due to mass loss on hot-wire water content probes and saturation limits.**
- **Resistance to electro-static buildup and discharge that can disable instrument electronics, and to condensation buildup in instruments in a tropical environment.**

Environment Characterization- Flight Campaign

Conduct a HIWC flight campaign to acquire a benchmark database on the atmospheric environment that causes engine and air data sensor failures that threatens air transportation safety today. The data will be used to mitigate the threat in the following ways:

1) **Set new design and certification standards for engines and sensors to operate within this environment**
2) **Develop data base for engine ice modeling and simulation**
3) **Guide future experimental activities for means of compliance and fundamental ice growth studies**
4) **Develop HIWC detection methods and advanced instrumentation (onboard; ground-based, space-based) and weather diagnostic/forecast tools to enable threat avoidance**
5) **Understand the fundamental cloud microphysical processes that cause High IWC to occur and by doing so improve the ability to forecast or detect it**



Engine Icing Performance Simulation: Phil Jorgenson

The objective of this task is to develop a modeling and simulation tool to estimate the flow field and flow conditions in each blade row of the fan and low pressure compressor (LPC) in the engine. This capability provides the boundary conditions required for the ice accretion model.

The Numerical Propulsion System Simulation code (NPSS) is used for the thermodynamic cycle analysis. A compressor flow analysis code (COMDES) has been coupled to, and runs concurrently with, the NPSS code such that the two codes provide a higher fidelity component-level simulation of the compression system at all flight conditions along a vehicle flight trajectory. This coupled capability eliminates the need for LPC characteristic maps.

The coupled NPSS-COMDES analysis tool was executed on the notional engine throughout a commercial aircraft flight trajectory from 10000 ft to 39000 ft, including two cruise conditions and descent from 39000 ft at 10% of maximum thrust. The effects of ice blockage were simulated by parametrically varying the blockage at the stator row where a key static temperature was reached.

The detailed blade-row by blade-row flow field in the fan and LPC is provided to the GlennICE and LEWICE accretion models as boundary conditions for estimation of ice accretion location, accretion rate and particle trajectory analysis.

Compressor Flow field Simulation & Ice Accretion Through Flight Trajectory

NPSS Model of Engine
0-D Engine system performance to establish compressor BC's at altitude operating conditions through trajectory

Shaft Rotational Speed
Inlet Pressure
Inlet Temperature

Pressure ratio, overall
Efficiency, overall

Compressor Flow Analysis
Flow analysis of Fan & LPC to determine blade row by blade row performance through the flight trajectory
(1D: COMDES, 2D: HT0300)

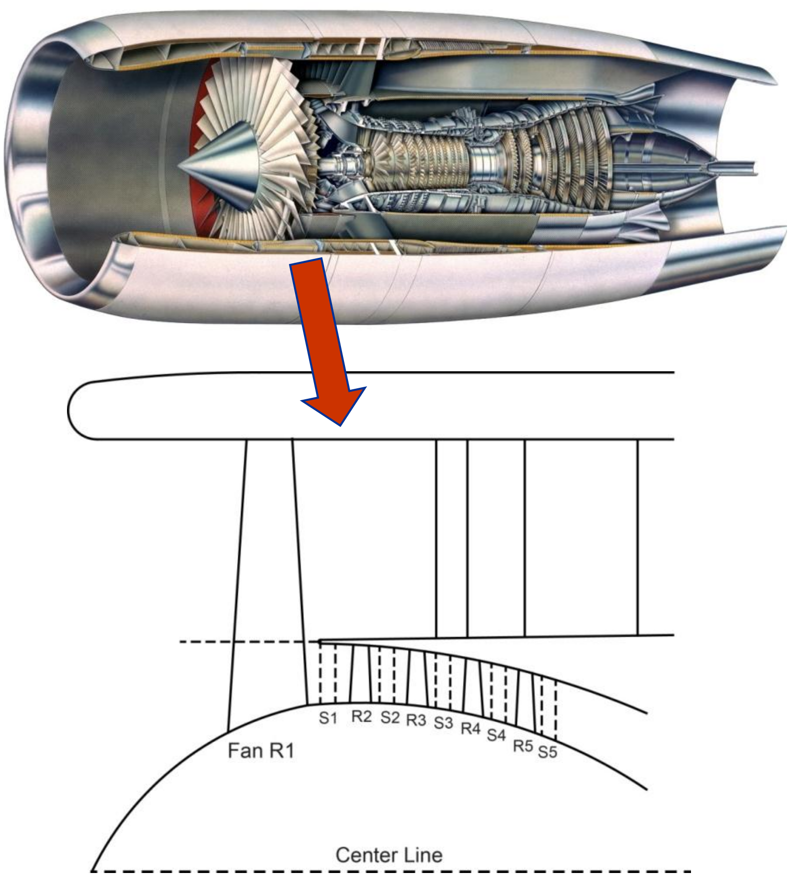
Ice Accretion Model
Estimate of the onset of icing location and rate of ice accretion in the fan & LPC along the flight trajectory
2D: GlennICE, 3D: LEWICE3D

Flow field: blade row by blade row fluid conditions: static and total pressure, Temperature, velocity triangles

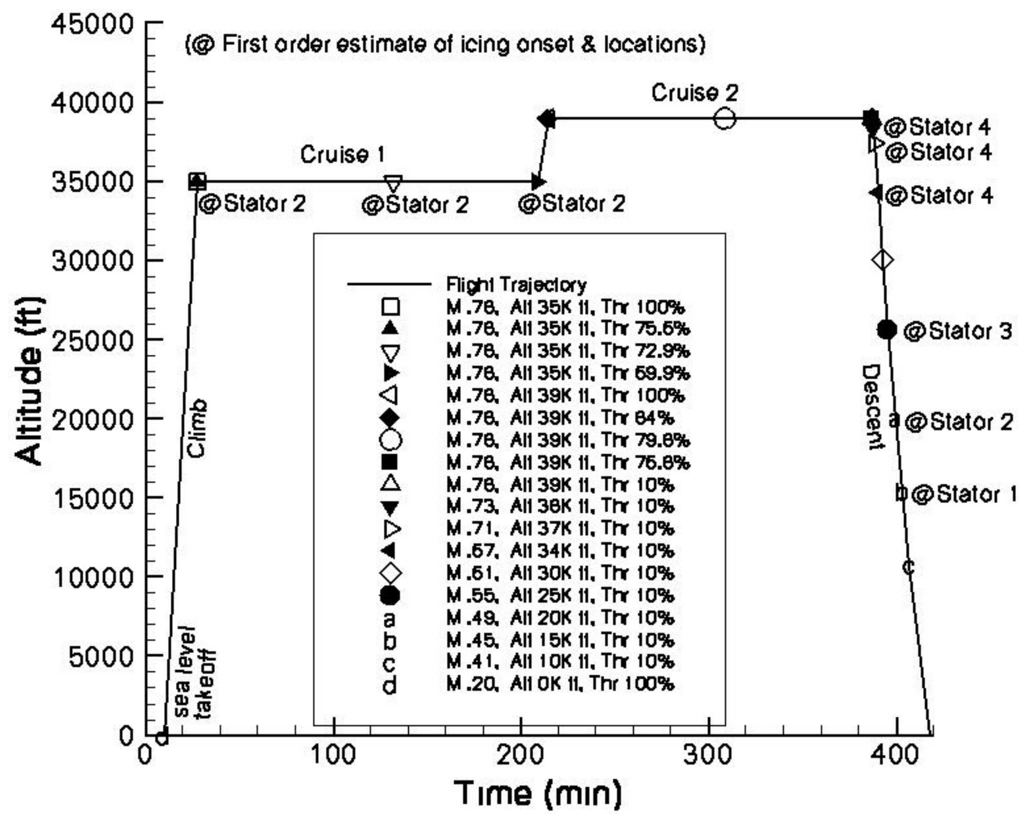
Engine Icing Performance Simulation

Flow Field Through Fan-Core and Low Pressure Compressor Estimated Blade-Row by Blade-Row Through Flight Trajectory

40K Thrust Engine

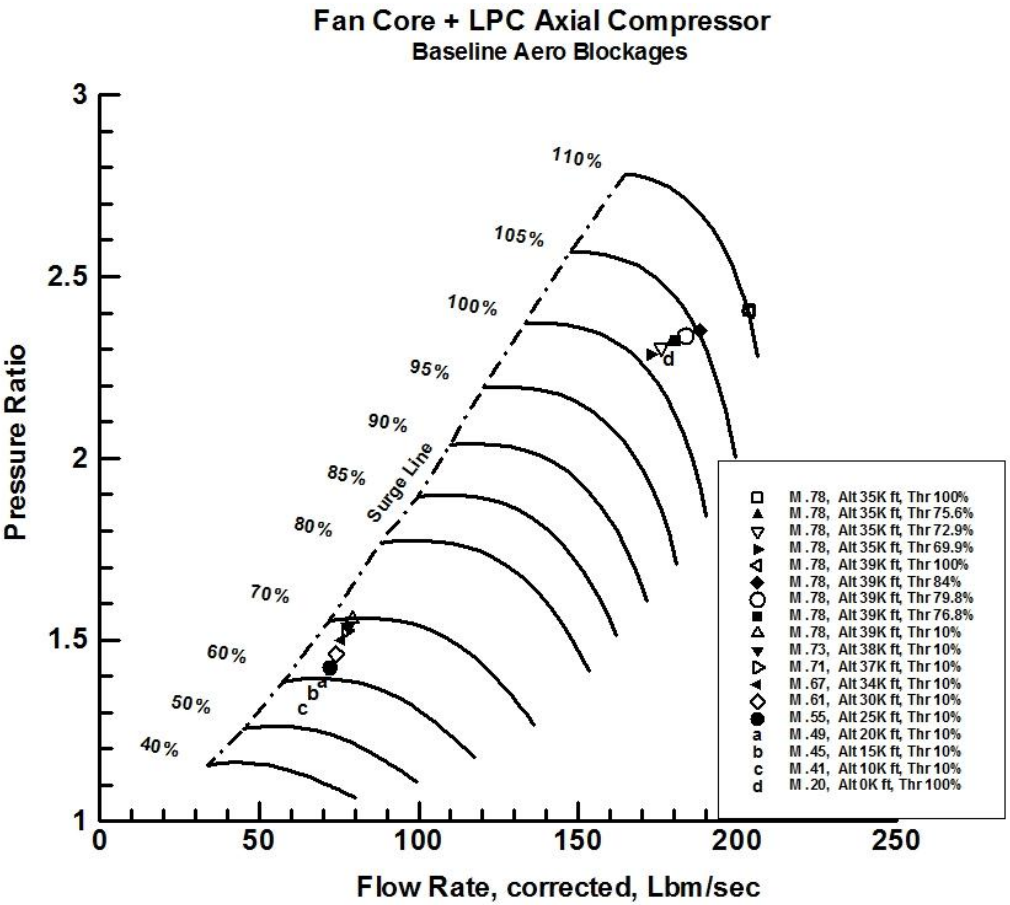


Fan and Low Pressure Compressor

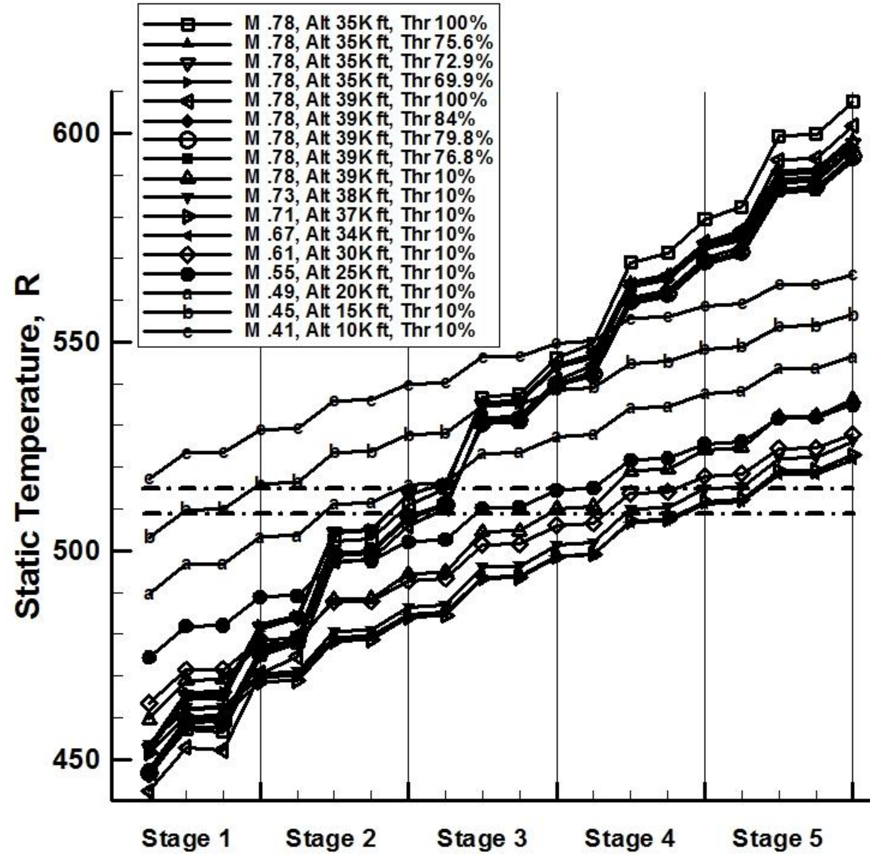


Vehicle Flight Trajectory

Engine Performance Simulation Through Vehicle Flight Trajectory



Overall Pressure Ratio of Fan Core & LPC



Static Temperatures in Each Stage Blade-Row by Blade-Row

Modeling and Simulation – Fan and LPC Performance in an Engine System Environment

Planned:

- **Coupling of the NPSS-COMDES codes to the GlennICE code.**
- **Add wet-bulb temperature distribution estimation to the COMDES compressor flow analysis code.**
- **Higher fidelity 2-D Euler empirical model of compression system with and without ice blockage to determine the overall and blade-row by blade-row performance of compression system due to span-wise variation of additional blockage.**
- **Investigate 3-D CFD analysis code for analyzing the effects of blockage due to ice accretion. Investigate coupling of ice accretion model with 3-D compressor analysis code.**
- **Investigate 3-D CFD with conjugate heat transfer to analyze ice accretion on compressor stator vanes and assess potential mitigation options**

Engine Icing Accretion Simulation: William Wright

This effort is focused on developing GlennICE, a two-dimensional ice accretion estimation model. This model works in conjunction with the intermediate-fidelity engine/compressor flow code to assess susceptibility to ice accretion in the fan or the low pressure compressor stator blade rows at any engine operating condition through the vehicle flight trajectory.

- **A capability for modeling ice crystals and mixed phase icing has been added to GlennICE.**
- **Modifications have been made to the particle trajectory algorithm and energy balance to model this behavior.**
- **A preliminary model for multiphase ice accretion was developed for GlennICE. An analysis of typical ice crystal inputs showed that one-way coupling could be used in the icing model.**
- **The effects of temperature change, phase change and sublimation of the ice crystal were added to the ice/water particle trajectory model.**
- **Non-spherical ice crystal capability was also added.**

<u>Planned:</u> Improvement of the accretion code to work in 3-D to utilize tangential components of velocity as boundary conditions from the compressor flow analysis code

Engine Icing Accretion Simulation

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0-D Engine system performance to establish compressor BC's at altitude operating conditions through trajectory

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Inlet Temperature

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2D: GlennICE, 3D: LEWICE3D

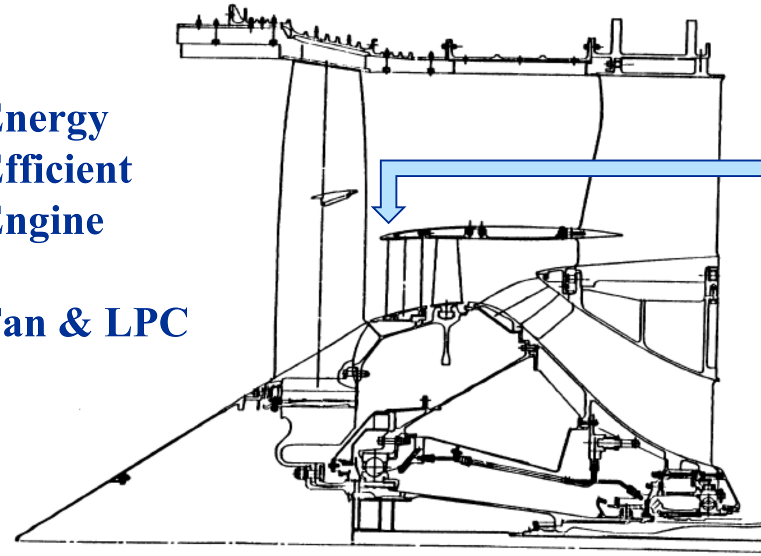
Flow field: blade row by blade row fluid conditions: static and total pressure, Temperature, velocity triangles

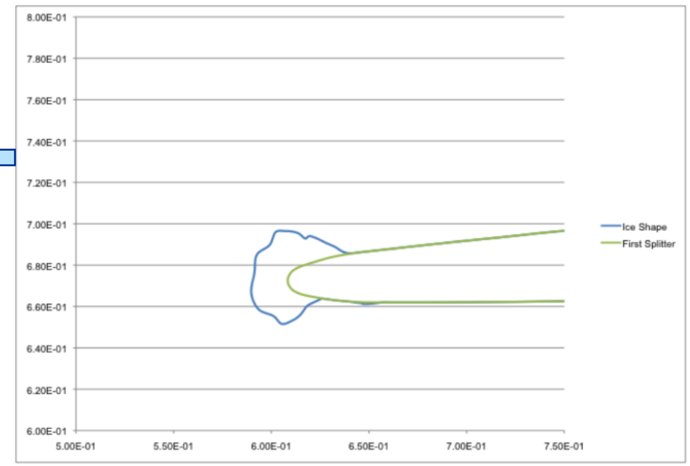
Engine Icing Accretion Simulation: GlennICE

Blade-row by blade-row fluid conditions (pressures, temperatures) from engine – compressor model are used as BCs in GlennICE accretion model

Energy Efficient Engine

Fan & LPC



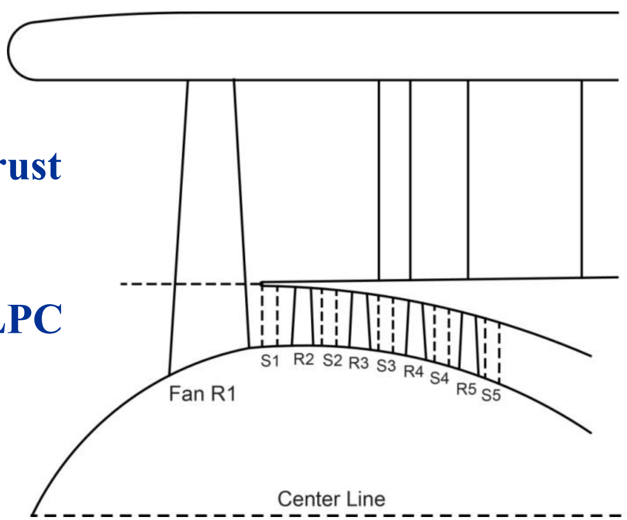


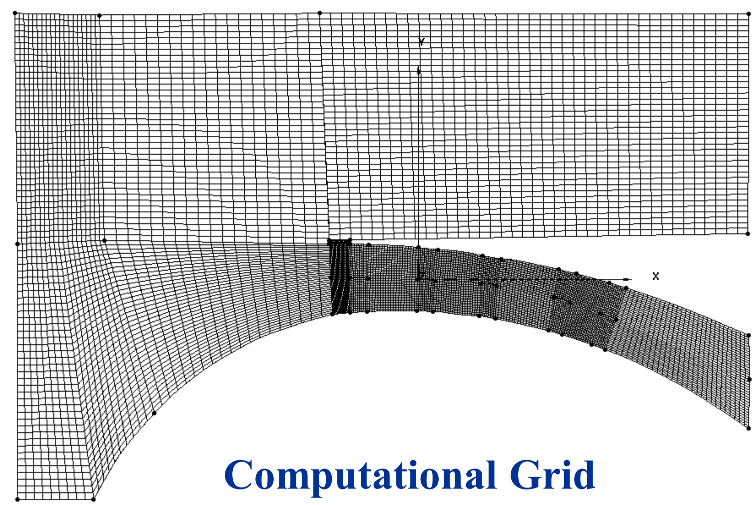
Accretion on first splitter

Present Status

40K Thrust Engine

Fan & LPC



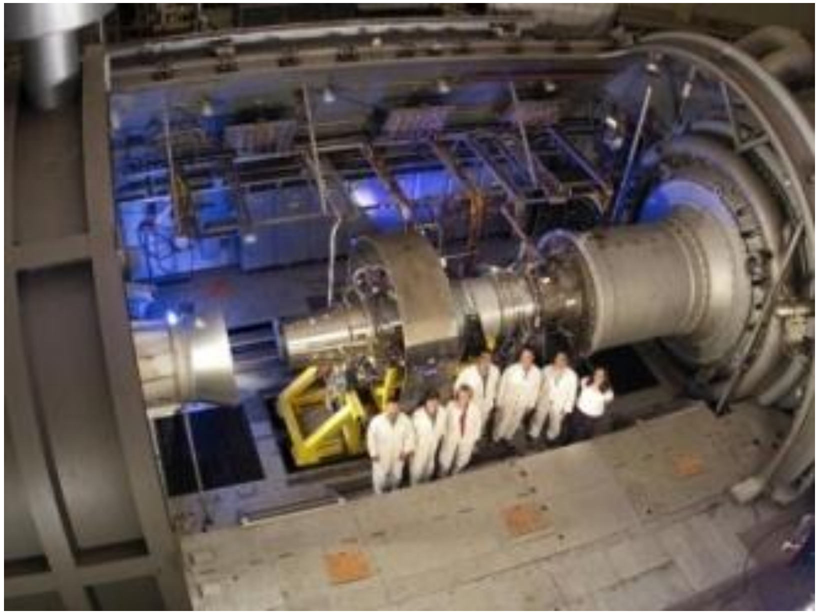


Computational Grid

Planned

Propulsion Systems Laboratory Engine Icing Modifications: Tom Hoffmann

NASA PSL is one of the Nation's Premier Direct Connect Altitude Simulation Facilities for Full-Scale Gas Turbine Engine and Propulsion System Testing

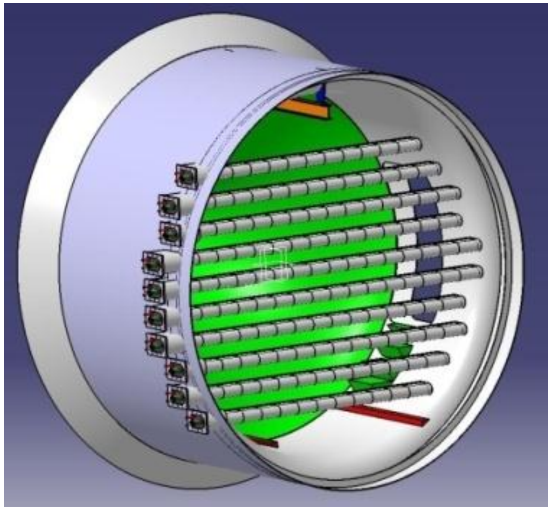


A spray bar is being installed into the PSL to provide an ice crystal cloud near the engine inlet. This will provide the capability of full scale, ground-based engine testing with ice crystal ingestion at pressures and temperatures similar to those encountered at altitude operation. The facility can simulate altitude operating conditions up to 40,000 ft with inlet temperatures down to -60 F and ice crystal cloud sprayed into the engine inlet at the rate of 9 grams/m^3. It is anticipated that this facility will sufficiently reproduce the conditions experienced by an engine in flight through a cloud containing high concentrations of ice crystals. If the ice cloud results in accretion inside the compression system, it is expected to result in reduced compressor and engine performance.

Propulsion Systems Laboratory Engine Icing Modifications

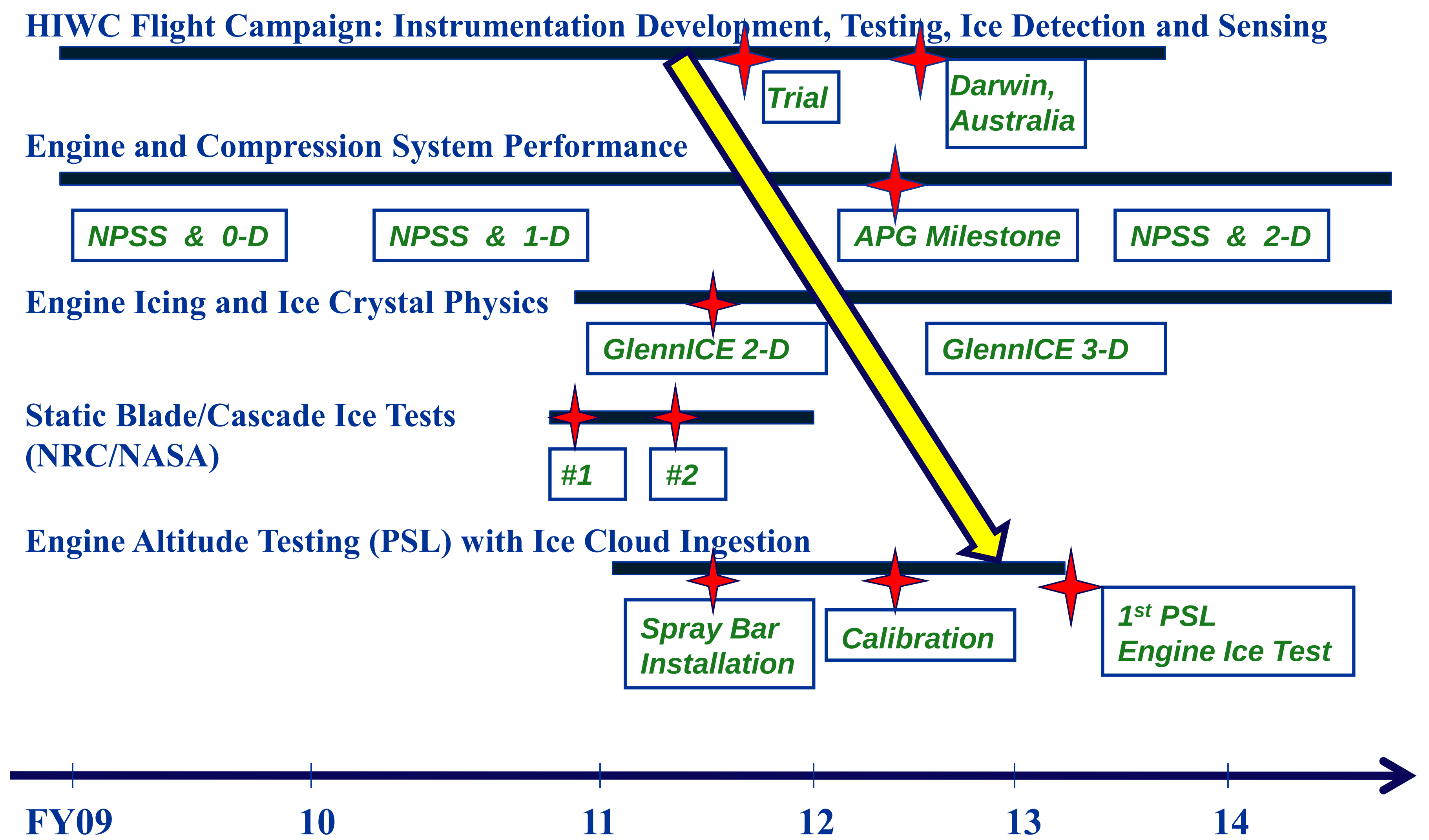
The PSL altitude test facility has been modified to enable testing of an engine while ingesting an ice crystal cloud. By collaboration with industry partners, an engine will be tested in 2013 at a range of simulated altitude conditions to investigate ice accretion.

Spray Bars Create Ice Crystal Cloud at Engine Inlet



The iced engine test data obtained will support the development of engine ice accretion simulation tools, and consequently, methodologies to avoid engine icing.

Engine Icing Roadmap



Summary / Conclusions

Flight campaign to take atmospheric data is on schedule

Engine and compressor flow analysis models on schedule

Ice accretion model is being worked to accept BCs from compressor blade row flow field analysis

NRC testing yielded valuable validation data for accretion code

Spray bars to generate ice crystals ahead of engine is being installed into PSL altitude test facility