

Design and Analysis Tools

presented by Mark Potapczuk

Nov. 13, 2000

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Icing Branch

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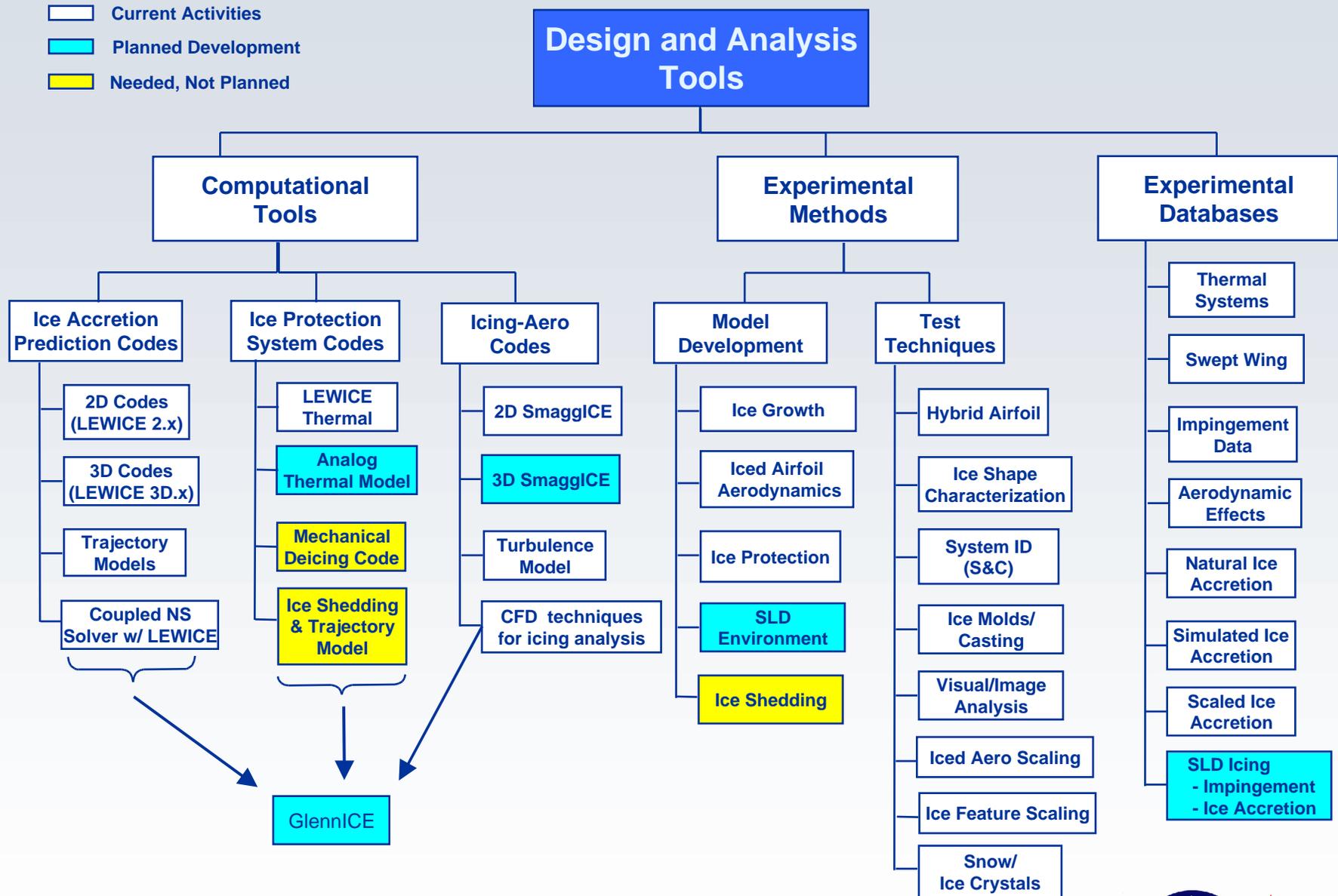


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Overview

- **Structure**
- **Description**
- **Elements**
 - **Computational Tools**
 - **Experimental Methods**
 - **Experimental Databases**
- **Concluding Remarks**



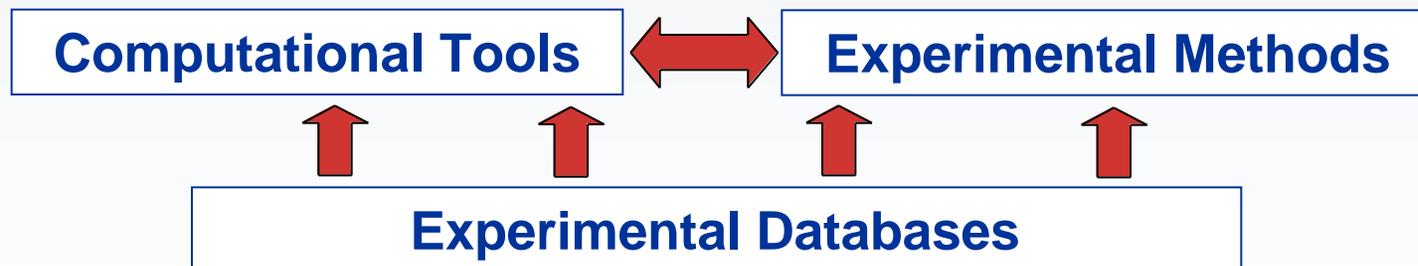


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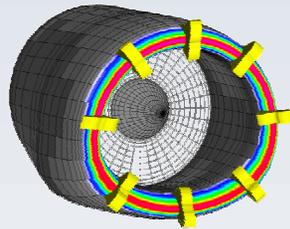
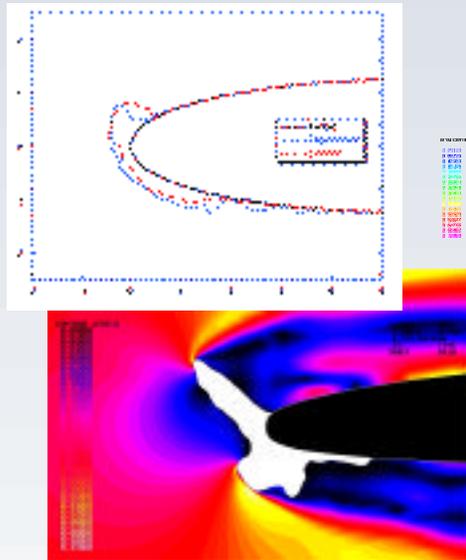
Description

The Icing Branch has a comprehensive, multi-disciplinary research effort aimed at development of Design and Analysis Tools that can aid aircraft manufacturers, sub-system manufacturers, certification authorities, the military, and other government agencies in assessing the behavior of aircraft systems in an icing environment. These tools consist of computational and experimental simulation methods that are validated, robust, and well documented. In addition, these tools are supported through the creation of extensive databases used for validation, correlation, and similitude.



Description

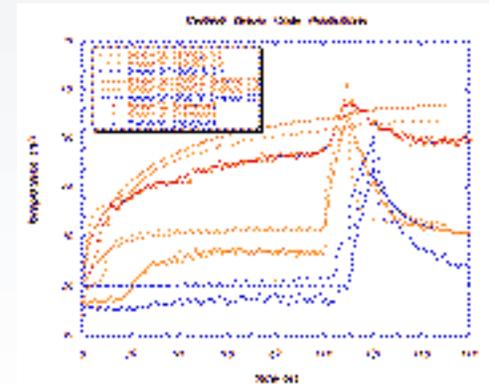
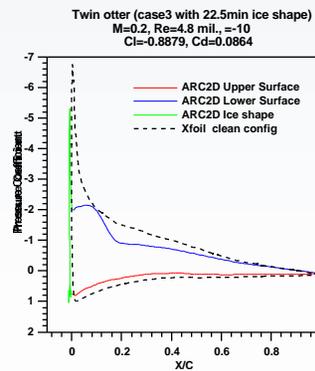
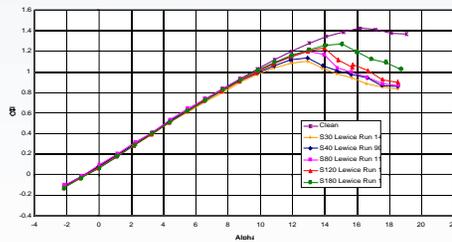
Computational Tools



Experimental Methods



Experimental Databases



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Description

Types of Tools

- Ice Growth Prediction
- Ice Protection System Performance
- Effects of Ice Growth on Aerodynamics and Performance
- Simulation of Icing Conditions

Disciplines

- Aerodynamics
- Thermodynamics
- Heat Transfer
- Turbulence Modeling
- Roughness
- Phase Change
- Grid Generation
- CFD
- Instrumentation
 - Optical
 - Thermal
 - Pressure
 - Forces

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Design and Analysis Tools - Computational Tools



- ***Goal***

Develop validated tools for predicting ice growth, ice protection system behavior, and the effects of ice contamination for design, analysis, and certification

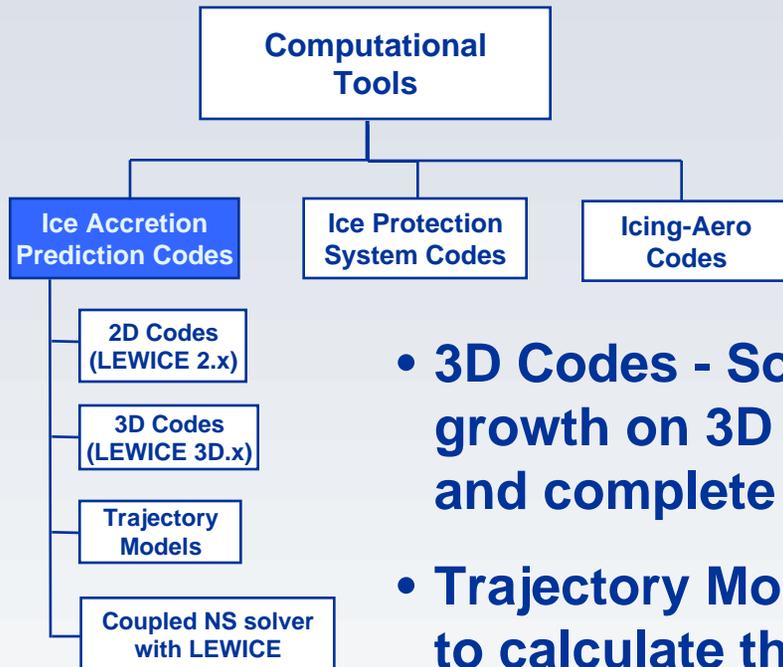
- ***Approach***

Improve current ice accretion and ice protection system prediction methods to allow use of codes for design and certification over a broad range of icing conditions, aircraft geometries, and flow conditions. Ensure codes are accurate, robust, fast, and easy to use.



Design and Analysis Tools - Computational Tools

Ice Accretion Codes



- Current Activities
- Planned Development
- Needed, Not Planned

- **2D Codes** - Software used to predict ice shape growth on 2D surfaces such as airfoils and engine inlet lips

- **3D Codes** - Software used to predict ice shape growth on 3D surfaces such as wings, fuselage, and complete engine inlets

- **Trajectory Models** - Software subsystems used to calculate the paths of super-cooled water droplets. Can include determination of droplet break-up and splashing

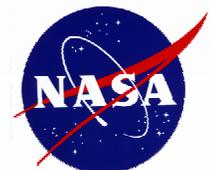
- **Coupled NS solver with LEWICE** - Software for 2D ice shape predictions at high AOA and high Mach number

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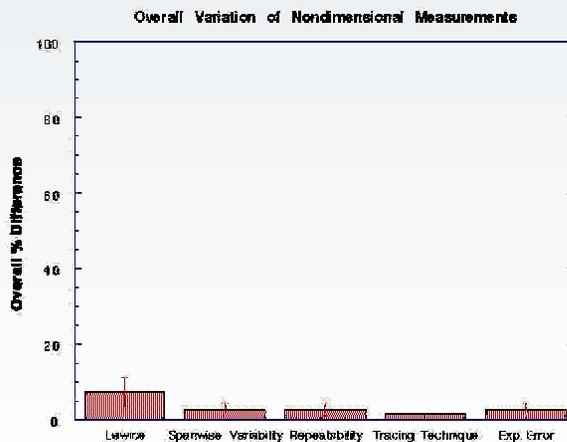
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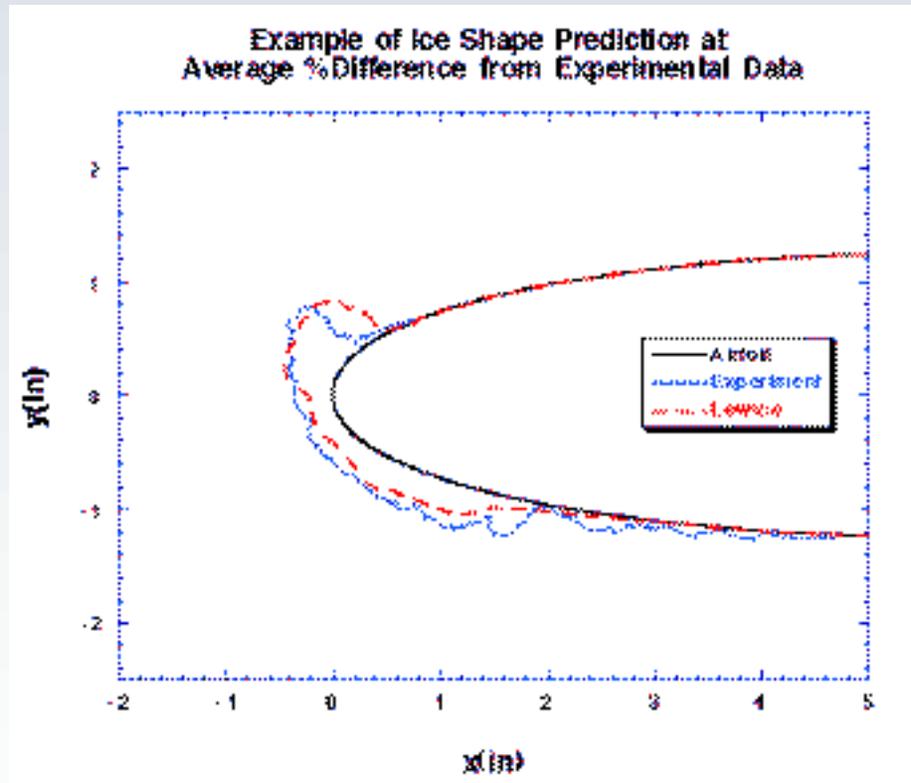
2D Ice Accretion Codes



Ice Shape Tracing; Validation Database



Ice Shape Comparison Results Comp. vs. Exp.



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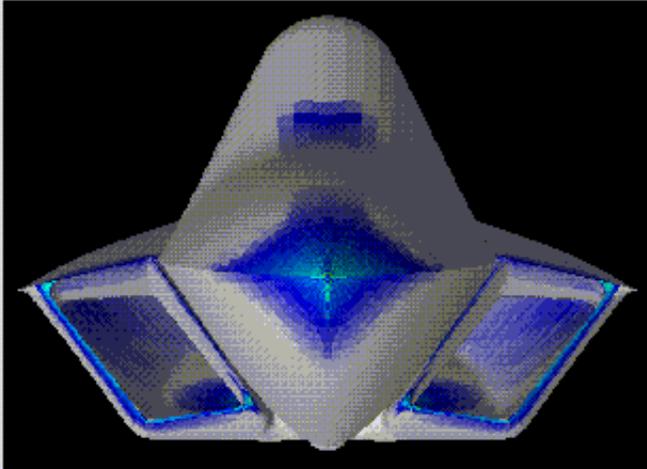


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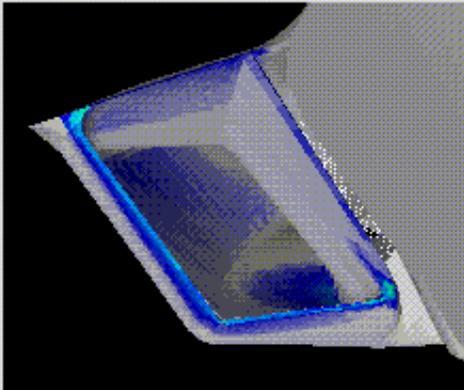
Design and Analysis Tools - Computational Tools

3D Ice Accretion Codes

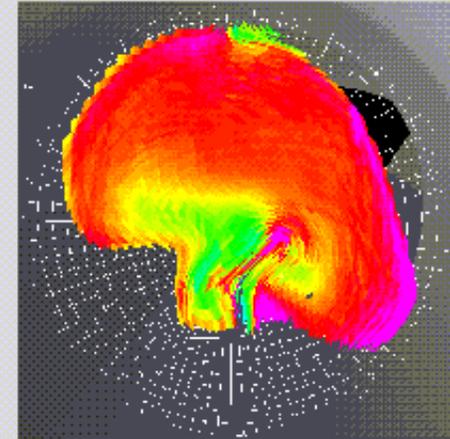
F22 FOREBODY



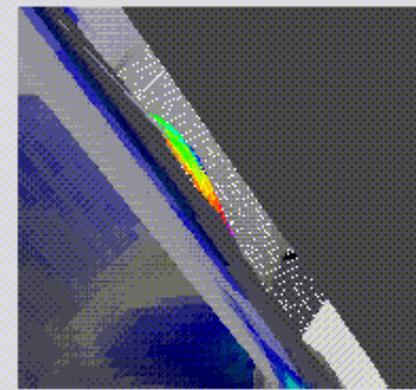
INLET



COMPRESSOR FACE



AUXILIARY INLET



BETA CONTOURS

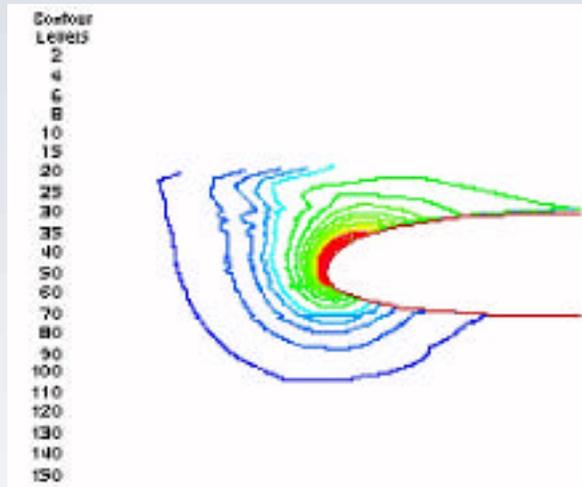
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0.79412
0.88235
0.97059
1.05882
1.14706
1.23529
1.32353
1.41176
1.50000

AAOA; 0 degrees
Mach Number; .3
Reynolds Number; 170687
Drop Size; 40 μm

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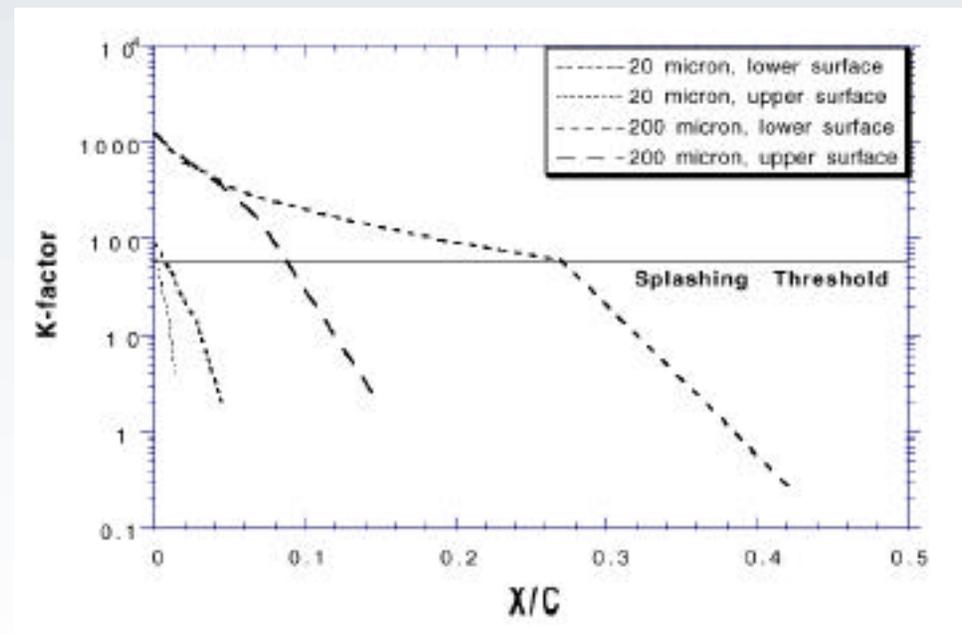
Trajectory Models

Weber number for
1000 micron droplet



Threshold for droplet break-up
based on Weber number ($We = 10$)

Threshold for droplet splashing
at an airfoil leading edge



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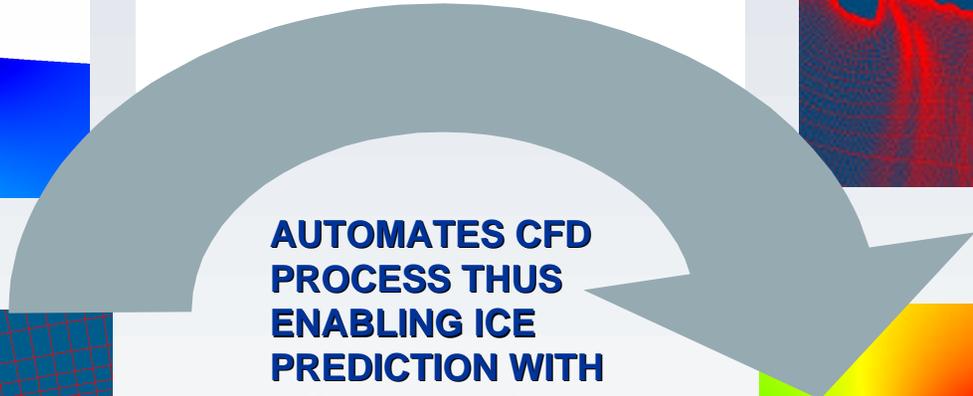
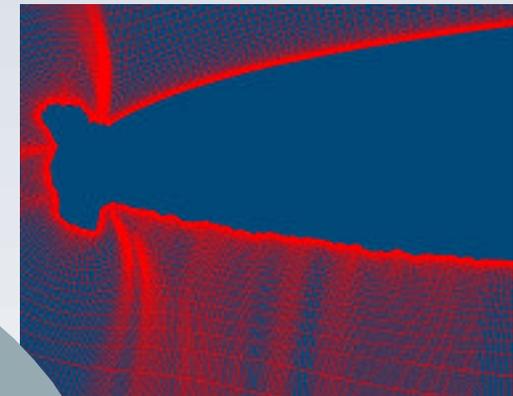
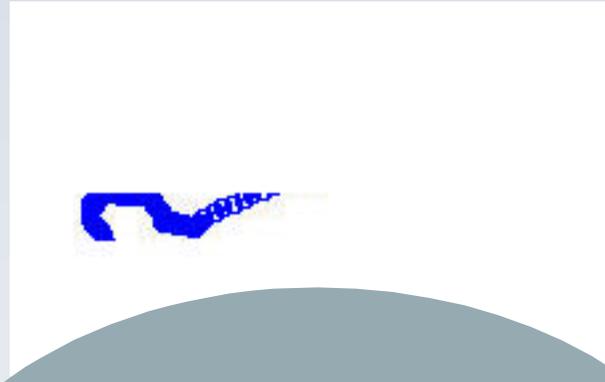
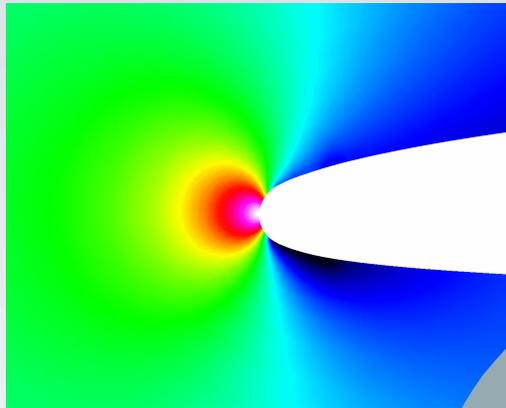
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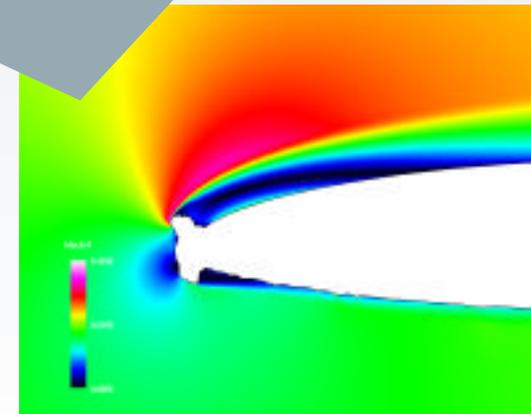
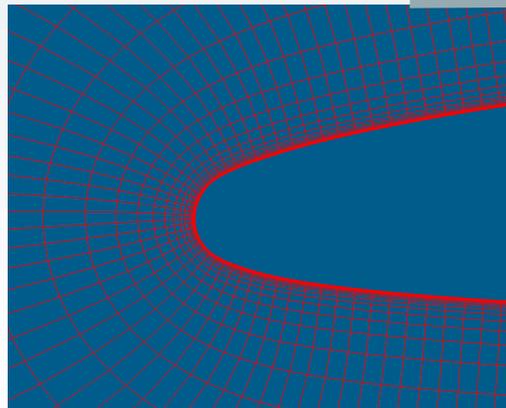
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Design and Analysis Tools - Computational Tools

Coupled Navier/Stokes Solver with LEWICE



**AUTOMATES CFD
PROCESS THUS
ENABLING ICE
PREDICTION WITH
N/S METHODS**



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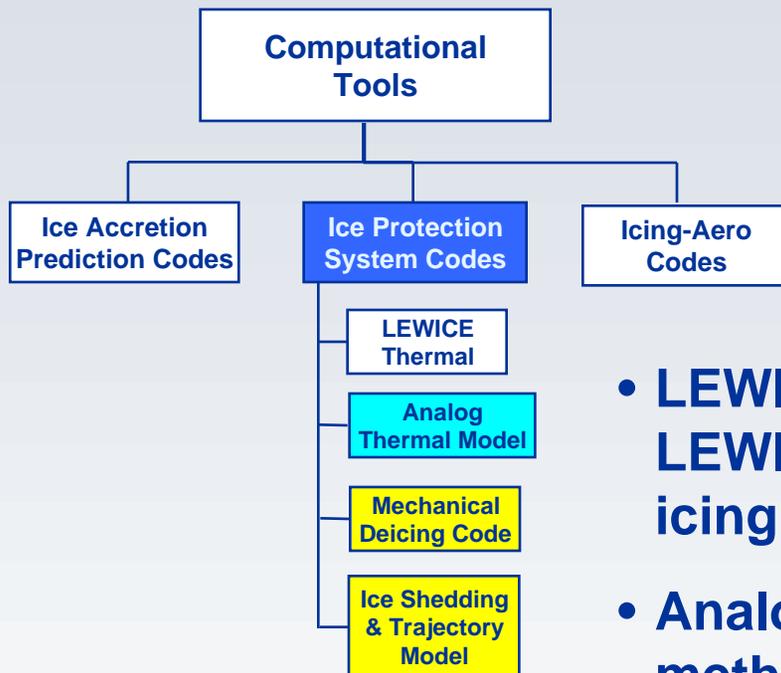
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Design and Analysis Tools - Computational Tools

Ice Protection System Codes



-  Current Activities
-  Planned Development
-  Needed, Not Planned

- **LEWICE Thermal** - Modules added to LEWICE used to simulate thermal anti-icing and de-icing systems
- **Analog Thermal Model** - Circuit analysis methods used to generate first order approximation to thermal IPS behavior
- **Mechanical De-Icing Code** and an **Ice Shedding Model** are desirable tools; no current plans for development

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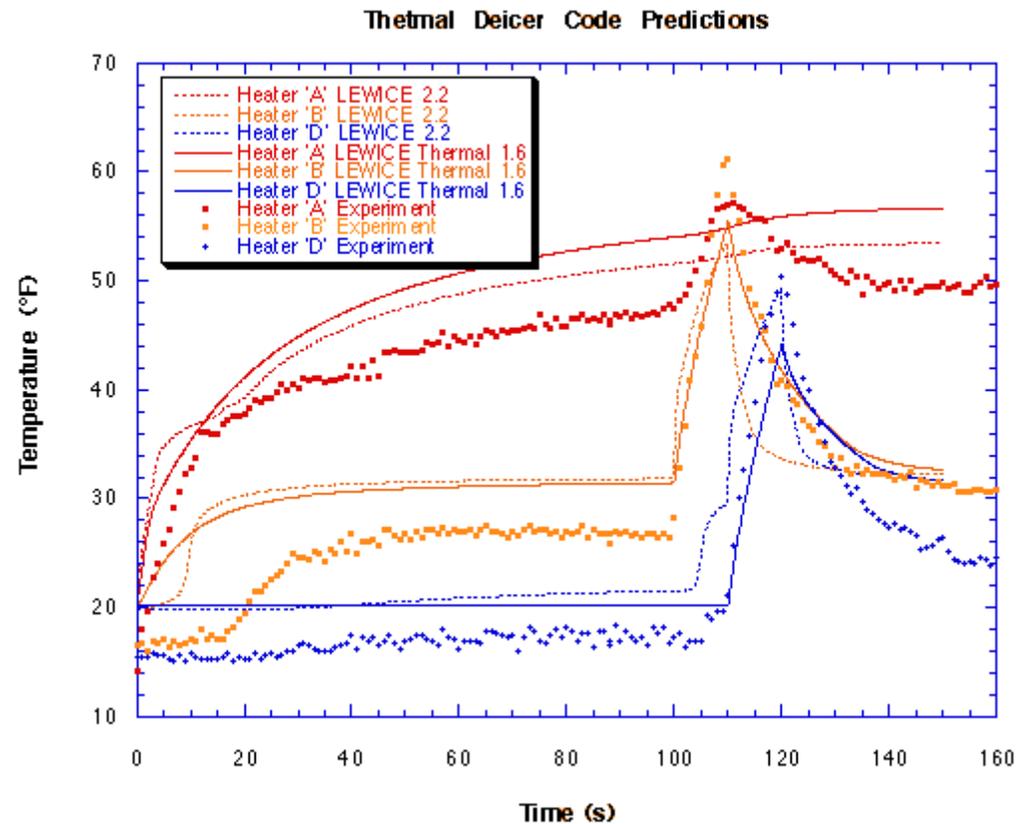
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Design and Analysis Tools - Computational Tools

LEWICE Thermal

Comparison of LEWICE 2.2 with LEWICE Thermal 1.6 and with Experiment

LEWICE 2.2 will include the modules needed for analysis of thermal ice protection systems



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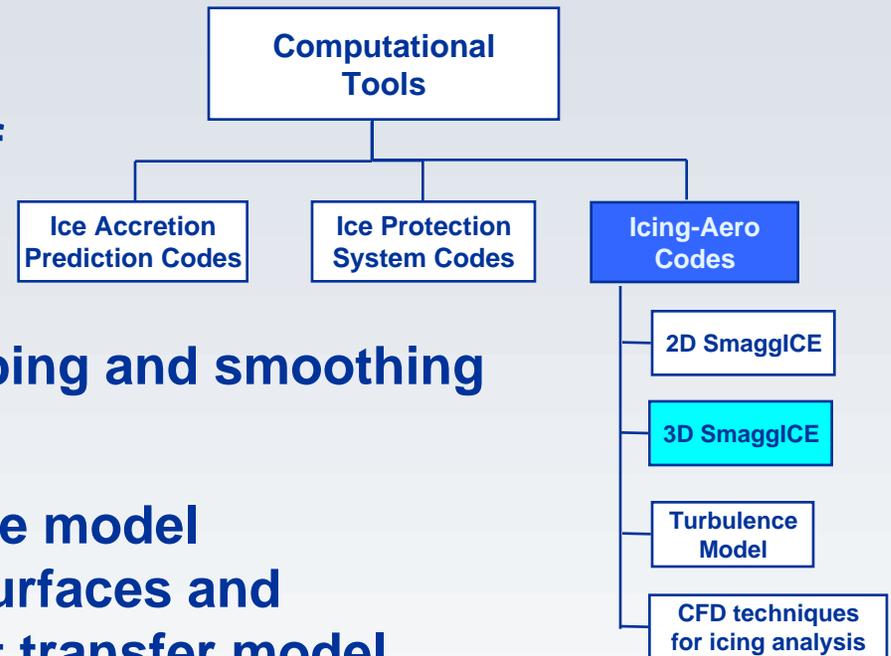


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Design and Analysis Tools - Computational Tools

Icing Aero Codes

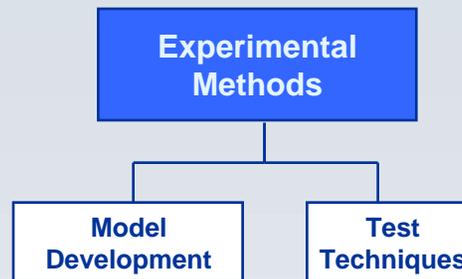
- 2D SmagglICE - Ice shape probing and smoothing for 2D geometries; allows analysis of geometric features and grid generation for aero analysis
- 3D SmagglICE - Ice shape probing and smoothing for 3D geometries
- Turbulence Model - Turbulence model development for rough iced surfaces and separated flow; improved heat transfer model
- CFD techniques for icing analysis - Adaptation of state of the art CFD methods to address aerodynamic features relevant to iced aircraft



□ Current Activities
■ Planned Development
■ Needed, Not Planned



Design and Analysis Tools - Experimental Methods



- **Goal**

Develop validated experimental methods for simulating the elements of an icing encounter

Develop test techniques for use in icing research and certification

- **Approach**

Improve current capabilities and develop innovative methods

- Quantify ice feature characteristics
- Measure the effects of iced aircraft performance
- Evaluate ice protection system behavior
- Improve knowledge of ice accretion physics

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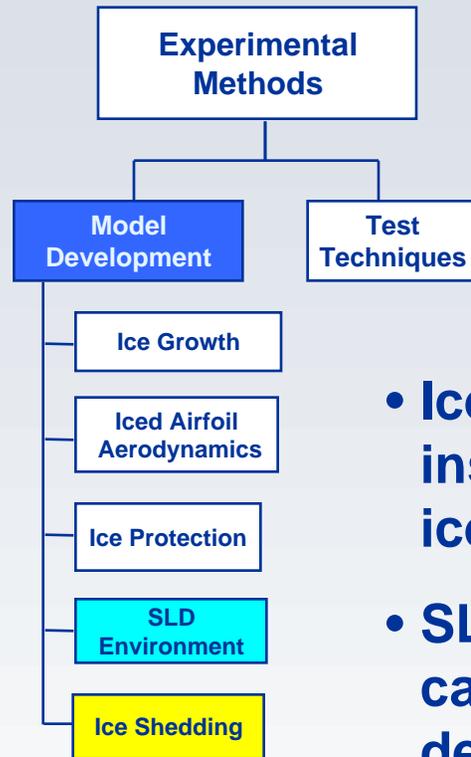
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Design and Analysis Tools - Experimental Methods



- Current Activities
- Planned Development
- Needed, Not Planned

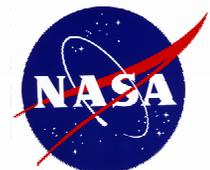
- **Ice Growth** - Investigations into ice growth physics
- **Iced Airfoil Aerodynamics** - Specialized testing methods for examination of aerodynamics
- **Ice Protection** - Testing methods and instrumentation development to allow evaluation of ice protection systems
- **SLD Environment** - Modification of tunnel capabilities needed to simulate SLD icing cloud; development of instrumentation capable of measuring droplet size and LWC
- **Ice Shedding** - Methods for simulation of ice shedding, trajectory tracking, and shed particle size measurement

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Design and Analysis Tools - Experimental Methods

Ice Protection



NASA Glenn has a long history of supporting the development of innovative ice protection systems

The Icing Branch has been equally innovative in developing methods to examine and quantify the performance of candidate ice protection systems



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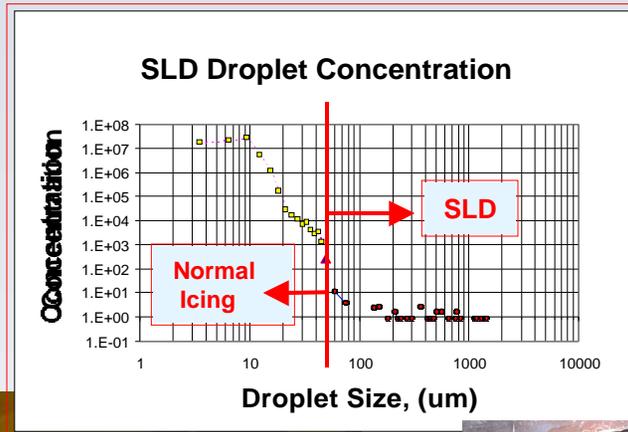
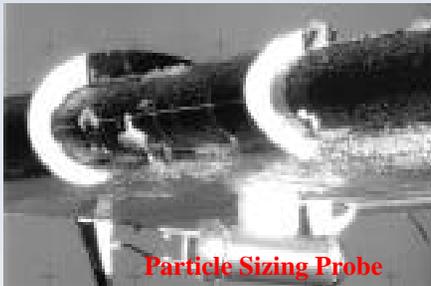
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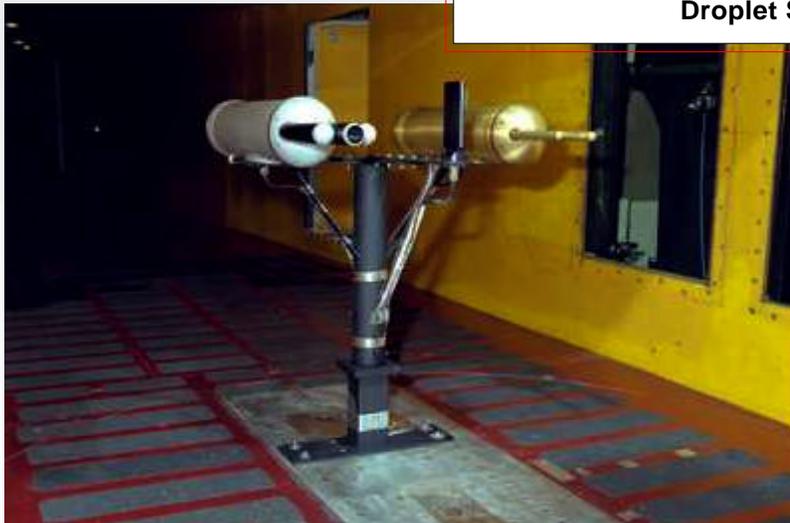
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Design and Analysis Tools - Experimental Methods

SLD Environment



Activities directed at expanding the capability of the IRT to simulate SLD conditions



Joint NASA/AES Icing Cloud Instrumentation tests in the NASA Glenn Icing Research Tunnel



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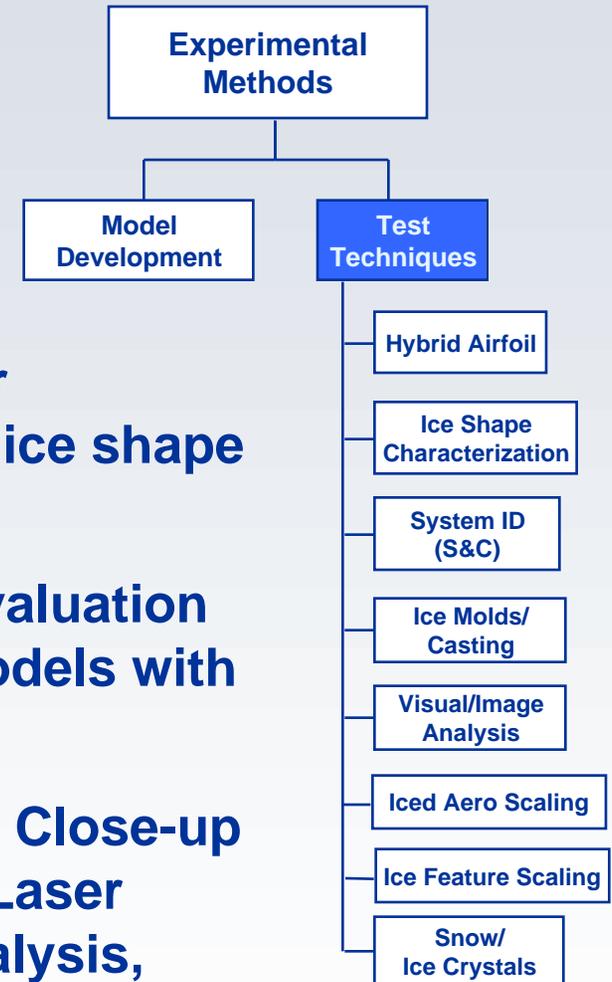
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Design and Analysis Tools - Experimental Methods

- **Hybrid Airfoil** - Use of full scale leading edge and truncated after-body to avoid scaling of icing conditions
- **Ice Shape Characterization** - Methods for recording, quantifying, and reproducing ice shape geometries
- **System ID (S&C)** - Test techniques for evaluation of stability and control derivatives on models with artificial ice shapes
- **Visual / Image Analysis** - High Res Stills, Close-up Photos, High Speed Video, IR cameras, Laser sheet / PIV, Stereo Photogrammetric Analysis, Shed Ice size analysis



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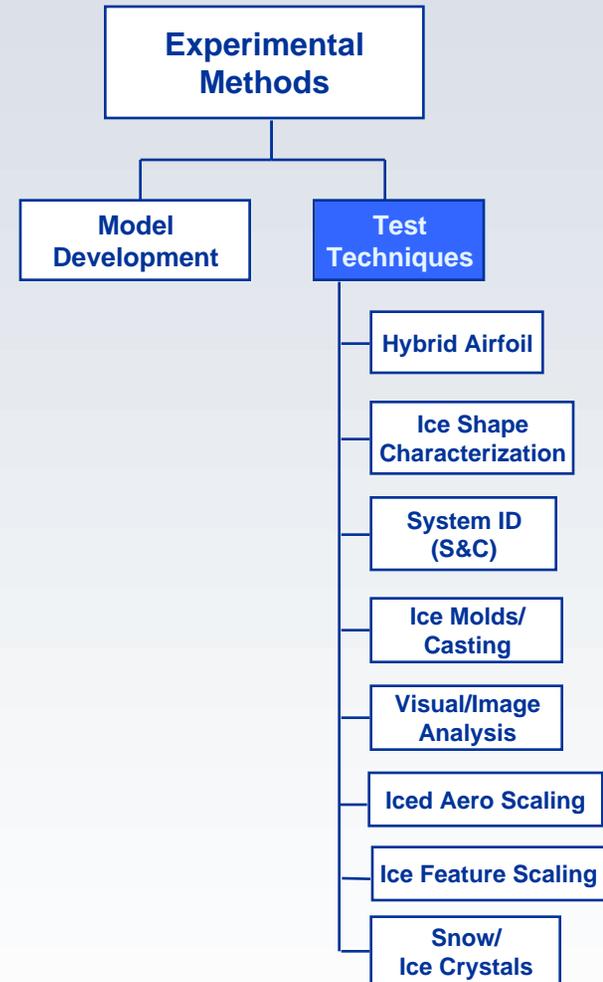
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Design and Analysis Tools - Experimental Methods

- **Ice Molds/Casting** – Methods for recording and reproducing accurate representations of 3D ice shapes
- **Iced Aero Scaling** - Allows use of smaller, low-speed aero facilities
- **Ice Feature Scaling** - Model/droplet scaling methods, expands tunnel cloud simulation
- **Snow/Ice Crystals** - Methods for generation of mixed phase icing through an SBIR



Design and Analysis Tools - Experimental Methods

Hybrid Airfoil

Develop “Icing” Scale Model Design Technique

- *Design model with full scale leading edge, truncated aft-body and trailing edge device*
- *Use integrated computational method*
 - *match circulation and droplet impingement*
- *Build model and test in IRT*

Reference model



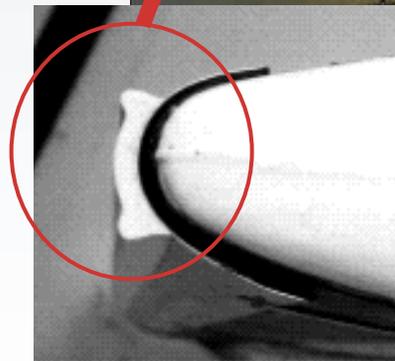
Hybrid model



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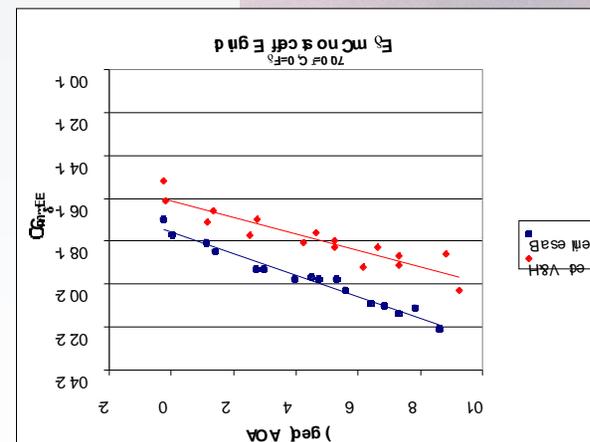
System ID (S&C)

System Identification techniques applied to iced aircraft to determine the degradation in stability & control



S&C Ice Shape

- Derived from in-flight photos and ADS-4
- Used in previous S&C flight tests



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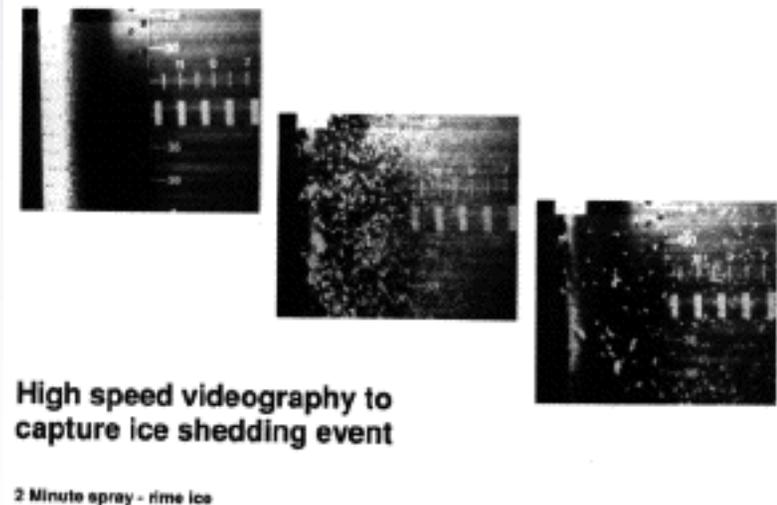
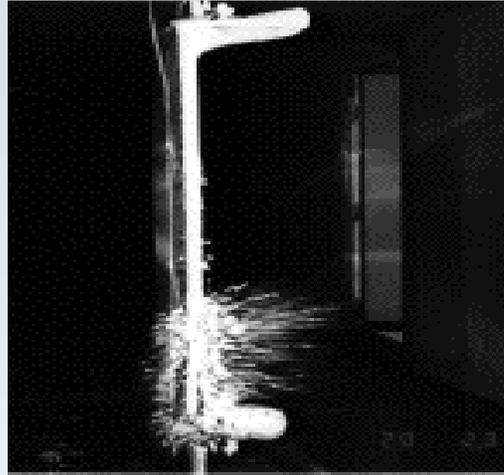


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Design and Analysis Tools - Experimental Methods

Visual / Image Analysis

Still Photography
- deicing system
expelling ice from
leading edge of
engine inlet



Other methods include:

- High resolution and close-up still photography for ice shape characterization
- IR Imaging for thermal analysis
- Laser sheet flow visualization
- Stereo imaging for ice shape quantification
- Particle Image Velocimetry for analysis of iced airfoil aerodynamics and nozzle spray plumes

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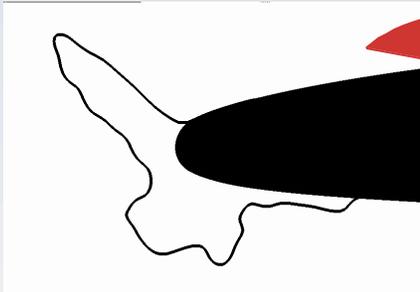


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Design and Analysis Tools - Experimental Methods

Iced Aerodynamic Scaling

Ice shapes from LEWICE



Sub-scale Model in
WSU 7'x10' Wind Tunnel



Full-scale Model in NASA-
ARC 40'x80' Wind Tunnel



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Design and Analysis Tools - Experimental Methods

Ice Feature Scaling

- Ice feature scaling is required due to limitations on facility size and range of icing conditions produced
- Scaling laws indicate that 18 separate parameters must match for complete similitude
- Research is directed at determining what reasonable subset of parameters must be matched to preserve ice shape geometries



12" chord NACA0012



36" chord NACA0012

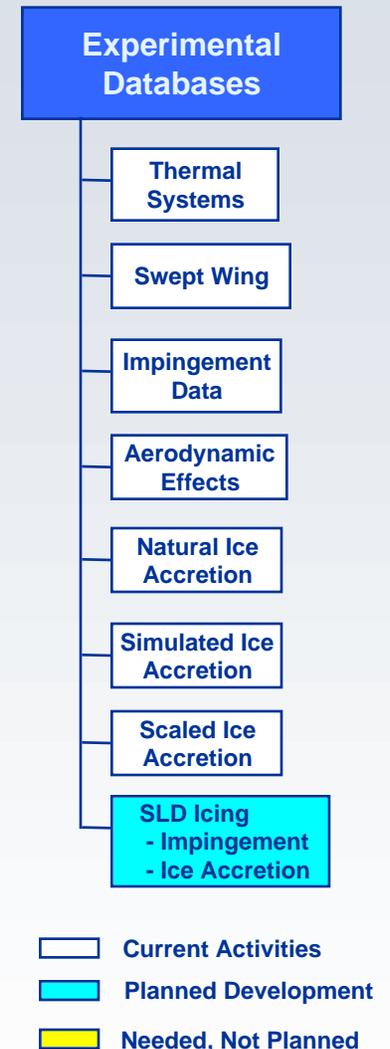
Design and Analysis Tools - Experimental Databases

- **Goal**

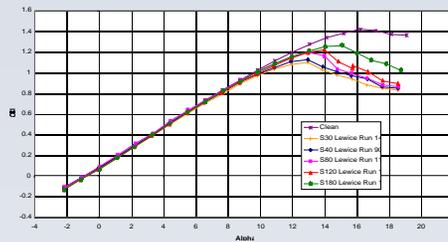
Develop databases for use in code validation, aircraft response modeling, facilities development, and similitude analysis for aircraft design

- **Approach**

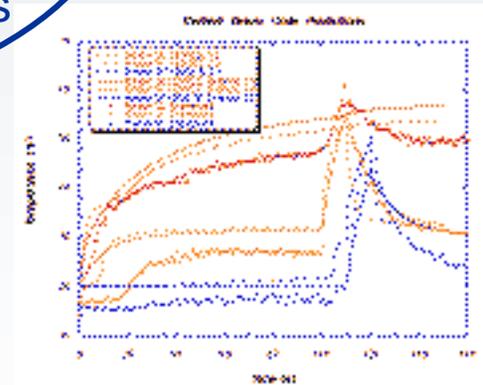
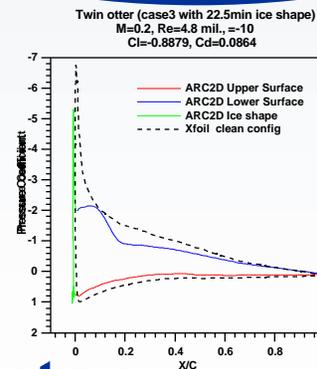
- Create “benchmark” quality public databases
- Evaluate ice protection system behavior
- Measure the effects of ice on aircraft performance
- Improve knowledge on natural ice growth
- Extend current icing scaling capabilities to a broader range of icing conditions
- Expand understanding of exceedance conditions



Design and Analysis Tools - Experimental Databases



- Enhance understanding of icing
- Publicly available
- Validate computational and experimental simulation methods



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Design and Analysis Tools - Concluding Remarks

- Computational and Experimental tools aimed at aiding in design, analysis, and certification for flight in icing
- Comprehensive, multi-disciplinary program structured to provide the information required to create the right tools
- Development of an extensive database of publicly available information allowing industry, government, and academia to create innovative solutions to the icing problems of today and tomorrow

