SLD Research at NASA
Numerical Modeling

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AEST - Atmospheric Environment Safety Technologies Project

Airframe Icing Simulation and Engineering Tool Capability

- Develop and demonstrate 3-D capability to simulate and model airframe ice accretion and related aerodynamic performance degradation for current and future aircraft configurations in an expanded icing environment that includes freezing drizzle/rain.

Two Technology Fronts

1. Current and future airframes → swept wing
2. Expanded icing envelope → SLD, freezing drizzle and rain.

Expanded Icing Envelope (SLD)

- Technology Building Blocks:
  1. Experimental SLD Ice Accretion Simulation
  2. Computational SLD Ice Accretion Simulation

Assessment of Simulation Methods
Current Capabilities for SLD Icing Simulation

Courtesy of the

IPHWG – not yet

publicly released

FZDZ – freezing drizzle

FZRA – freezing rain

		Unprotected Areas				Protected Areas					Detection Methods			Air Data Sensors	
		Wing	Tail	Radome	Non-lifting Surfaces (antenna, inlets, external modifications)	Thermal (protected area)	Thermal (Aft of protected area)	Mechanical (protected area)	Mechanical (aft of protected area)	Fluid Freezing Point Depressant	Visual Cues (Reference Surface)	Instrument (position or installation effects)	Instrument (performance)	Instrument (position or installation effects)	Instrument (performance)
FZDZ MVD < 40µm	Icing Tunnels	green	green	*	green	green	green	green	green	green	*	red	green	*	green
	Codes	green	green	yellow	green	**	red	red	red	green	**	green	**	green	red
	Tankers	red	red	red	red	red	red	red	red	red	red	red	red	red	red
FZDZ MVD > 40µm	Icing Tunnels	green	green	*	green	green	yellow	yellow	green	green	*	red	green	*	green
	Codes	green	green	yellow	green	**	yellow	yellow	green	green	**	green	**	green	red
	Tankers	red	red	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow
FZRA MVD < 40µm	Icing Tunnels	yellow	yellow	*	yellow	yellow	yellow	yellow	yellow	green	red	red	red	red	red
	Codes	yellow	yellow	**	yellow	**	yellow	yellow	yellow	yellow	red	red	red	red	red
	Tankers	red	red	red	red	red	red	red	red	red	red	red	red	red	red
FZRA MVD > 40µm	Icing Tunnels	yellow	yellow	*	yellow	yellow	yellow	yellow	yellow	yellow	red	red	red	red	red
	Codes	yellow	yellow	**	yellow	**	yellow	yellow	yellow	yellow	red	red	red	red	red
	Tankers	red	red	red	red	red	red	red	red	red	red	red	red	red	red

LEGEND

Updated FEB 2009

The capability exists today and is suitable to be an element of a MOC

The capability is possible, but has not been demonstrated, or there is limited or no validation.

The capability is unknown, or does not currently exist

* It may be possible to test small scale installation effects, but large scale installations are not currently feasible

** Current 2D capabilities exist with large droplet effects, but limitations exist in the use of 3D codes for simulation of Appendix X effects
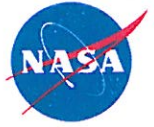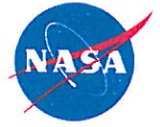
Computational SLD Ice Accretion Simulation

Objective

- Develop and validate computational simulation capability for SLD ice build-up on aircraft surfaces.

Key Steps in Technology Development Roadmap

- Assess current capability for existing data sets.
  - 2D Airfoils
  - 3D Wings
  - More complex geometries
- Identify model weaknesses.
  - Droplet break-up
  - Droplet splashing
  - Droplet re-impingement
  - Ice shape surface motion
  - Variable density modeling

  > Just examples. Others might be identified and/or these may be removed.

- Design experiments to test and/or improve models.
- Implement improved models into simulation capability.
- Compare to experimental ice shapes from tunnel or flight.

Computational SLD Ice Accretion Simulation

Objective

- Develop and validate computational simulation capability for SLD ice build-up on aircraft surfaces.

Key Steps in Technology Development Roadmap

- Water Film Flow, Roughness, & Heat Transfer
    - Define test objectives, conditions, measurements and model(s).
    - Develop diagnostic techniques (film thickness, velocity, shear, etc.).
    - Identify experimental facilities.
    - Conduct experiments.
    - Modify/update models in software.

Computational SLD Ice Accretion Simulation

Objective

- Develop and validate computational simulation capability for SLD ice build-up on aircraft surfaces.

Planning Questions

- How do we answer the "Wright challenge" (Show me where its wrong.)?
  - Do we need more SLD impingement data (different speeds, MVDs, more geometries — multi-element, 3D, etc.)?
  - If we can "calibrate" SLD impingement, do we need to be concerned with droplet dynamics (break up, splashing, etc.) and other potential "model weaknesses" on previous slide?
- Can we identify current model weaknesses, or fundamental experiments to ascertain? This would allow for specifics in roadmap.
- Is there research required on the computational methods themselves, i.e., "numerical" experiments.

Computational SLD Ice Accretion Simulation

Technology Development Roadmap

National Aeronautics and Space Administration
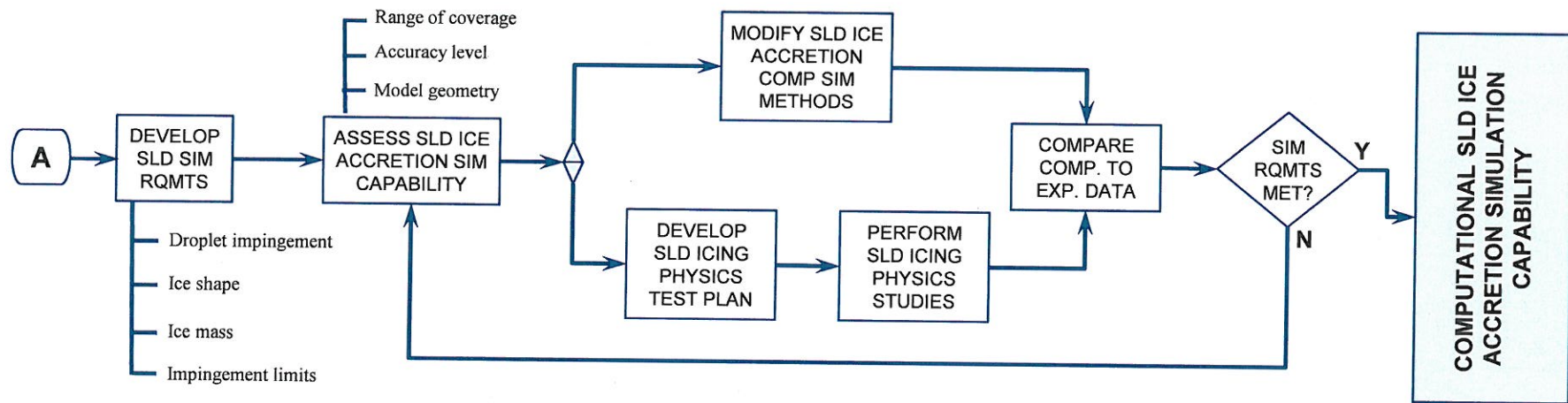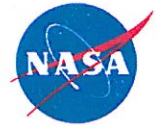
Current Activities

www.nasa.gov   8

LEWICE3D/TRAJMC3D
Version 2.2 Completed

Objectives:

- Modify LEWICE/TRAJCM3D ice accretion software to allow Super Cooled Large Droplet (SLD) and High Ice Water Content (HIWC) analysis.

- Predict rate ice will accrete due to SLD conditions with splashing and rate which crystals will impinge due to bouncing. Assessed SLD model against SLD data from Wichita State University Impingement database.

Results:

- SLD splashing, droplet breakup and ice crystal bouncing physics were added to the LEWICE3D/TRAJMC3D software.

- LEWICE3D/TRAJMC3D results were compared to SLD data from the Wichita State University Impingement database for several geometries. Comparisons were good for the all of the cases except the multi-element wing where LEWICE3D over-predicted collection efficiency on the main element and flap. This is thought to be due to deficiencies in the flow model.

- Delivered Version 2.2. of the TRAJMC3D software to Boeing Company and is currently available to the public.
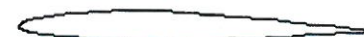
Image & profile of swept wing tip.
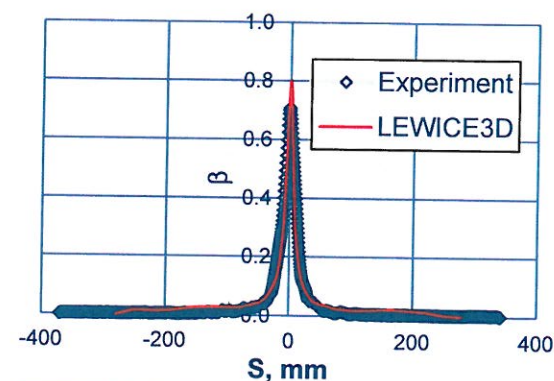
Collection Efficiency
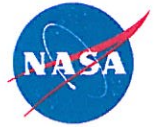
Robust Mesh Generation for Aircraft Icing Applications

Objective:

- To facilitate grid-based ice accretion simulations on realistic, three-dimensional configurations

Key Technology:

- Automated meshing with surface/volume mesh deformation

Approach:

- Adapt/develop meshing tools for
  - volume preserving surface mesh evolution
  - volume mesh deformation
  - mesh quality improvement
- Emphasize automation, efficiency, and robustness

Project Status:

- Basic toolset for evolution/deformation is complete
- Verification and validation is ongoing.
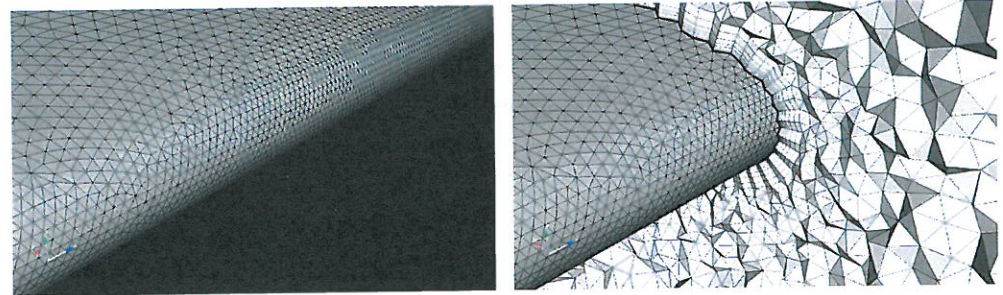
Initial surface and volume meshes

Step 1. Compute flow solution
Step 2. Compute ice accretion rates (LEWICE3D)
Step 3. Evolve surface and deform volume mesh
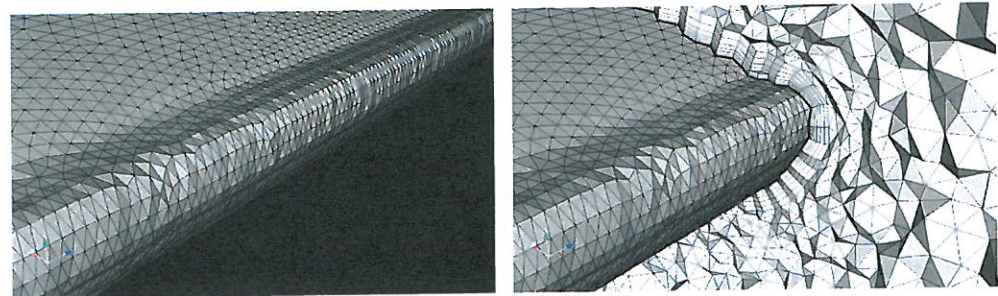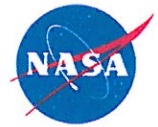
Deformed surface and volume meshes

Thompson, et. al., "Discrete Surface Evolution and Mesh Deformation for Aircraft Icing Applications," 2013 AIAA ASE Conference
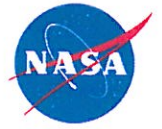
Modeling Improvements Required
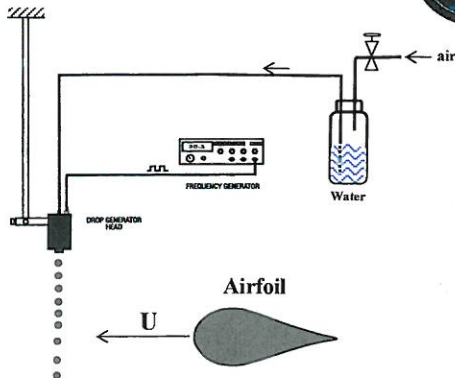
SLD Modeling Improvements Required

- Droplet break-up
- Droplet splashing
- Droplet re-impingement
- Ice shape surface motion

SLD Droplet Experimental Research

Rotating Arm Rig

Conceptual View of Experiment

Objective

- Measure deformation and breakup of water droplets approaching leading edge (LE) of airfoil.

Approach

- Airfoil on a rotating arm, velocities 50-90 m/s

- Droplets fall along airfoil path, diameters 200-2000 µm

- High speed imaging capture droplet deformation

- Three airfoils of same geometry and chords of 0.210, 0.470 and 0.710 m

- Obtain droplet displacement, velocity, acceleration, Reynolds Number, Weber Number, Bond Number, vertical and horizontal deformation, and distance from LE where breakup begins

Project Status

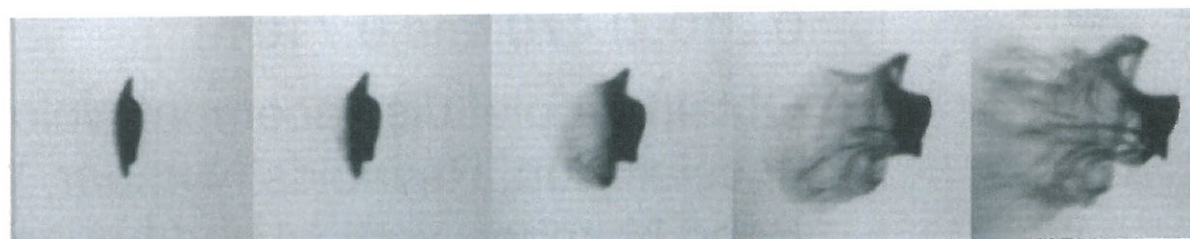- Several tests completed; latest test conducted at INTA, Oct. 2012
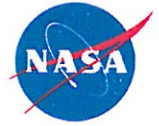
Droplet Breakup Results

Run 072011.14B.1 droplet #1, droplet diameter = 1032 µm, airfoil chord = 0.710 m, airfoil velocity = 90 m/sec
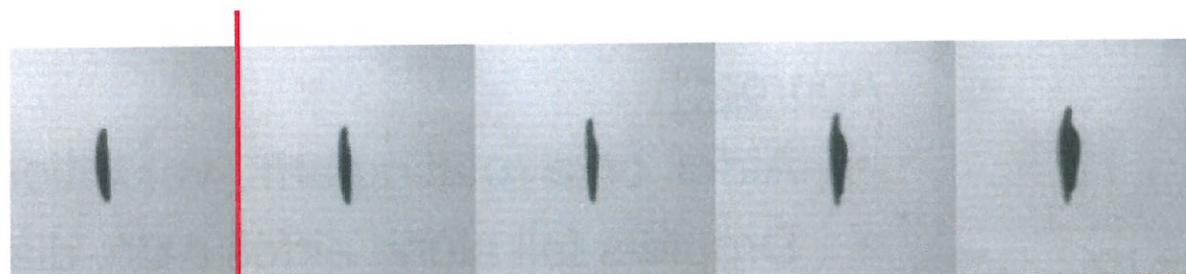
Frame #	190	194	198	203	205
Time (µsec)	2520	2573	2627	2653	2720
x-distance (mm)	32	28	23	17	15

Frame #	207	209	212	215	218
Time (µsec)	2747	2773	2813	2853	2893
x-distance (mm)	13	11	8	5	2

Droplet Breakup Results
Weber Number vs. Distance from Airfol

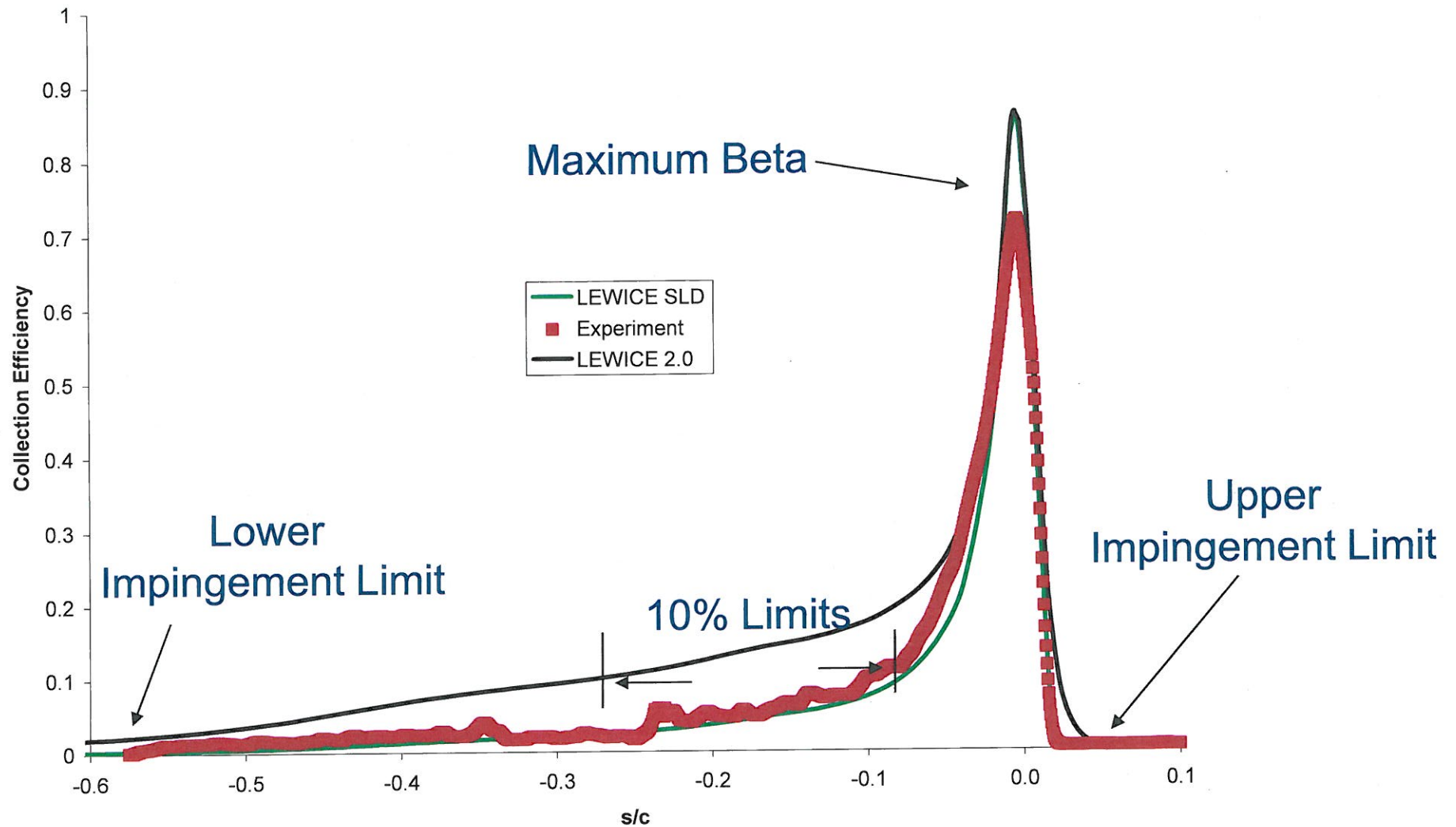**Run 072011.14C droplet #1, droplet diameter = 1062 μm, airfoil chord = 0.710 m, airfoil velocity = 90 m/sec**
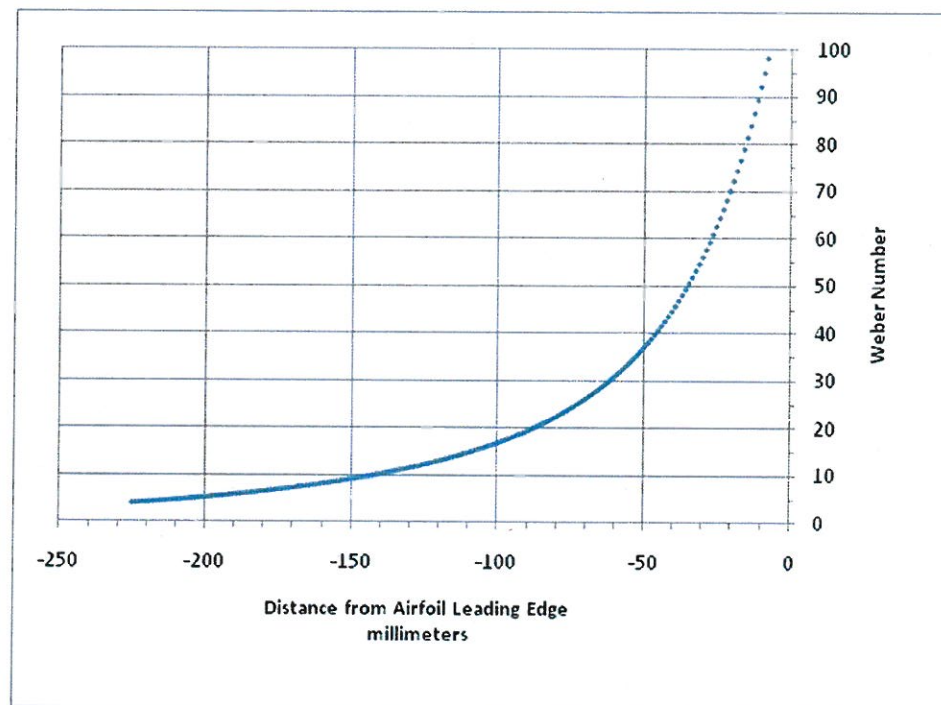
$$We = \frac{\rho_{air} \cdot V_{slip}^{2} \cdot D}{\sigma_{w/a}}$$
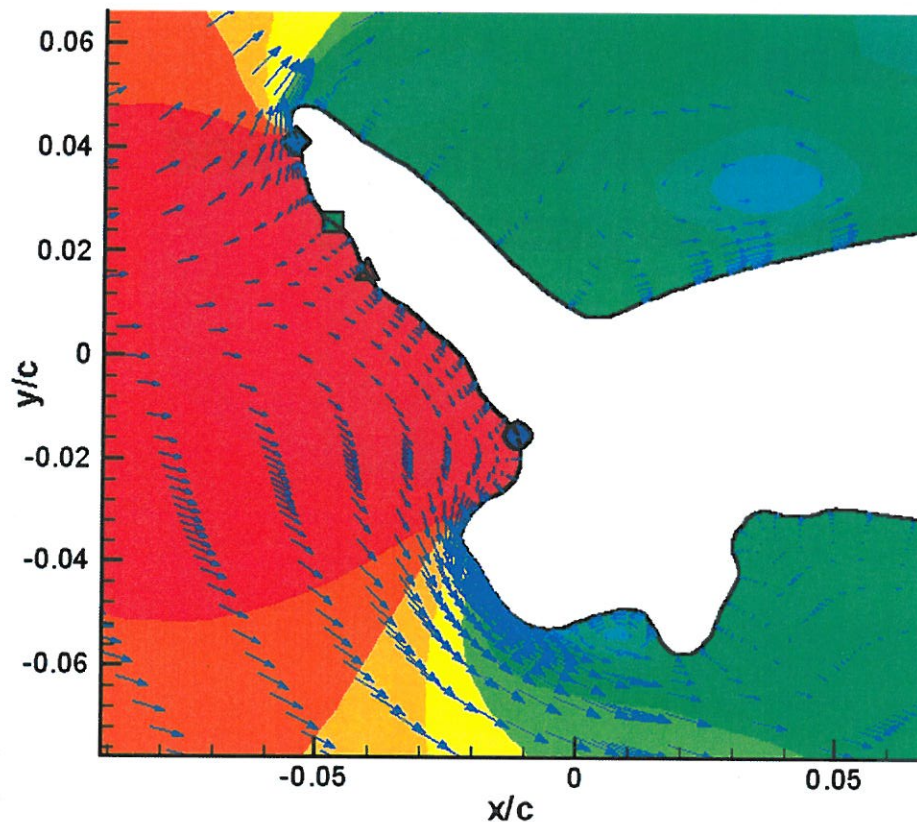
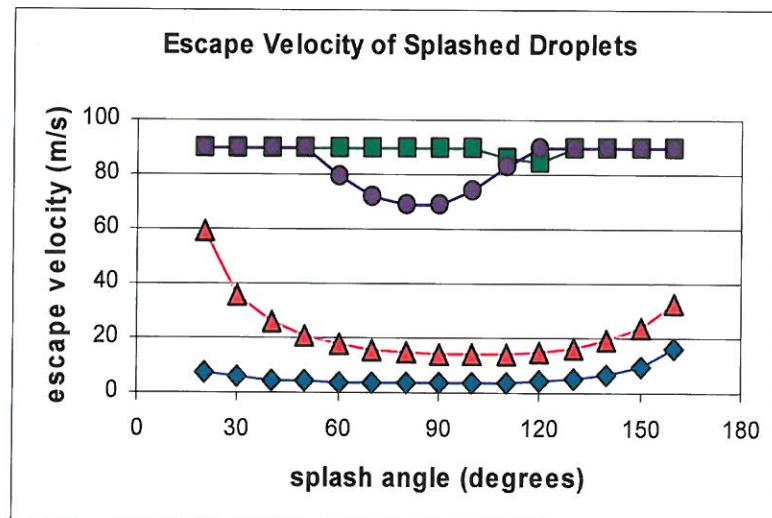# Typical Splashing Results

GLC305 AOA=6, MVD=92

Escape Velocity of Splashed Droplets on an Iced Airfoil

Impact Locations and Flow Solution

**Escape Velocity of Splashed Droplets**

Airfoil: GLC-305
Splash Droplet Diameter: 5 µm
Free Stream Velocity: 90 m/s

Ice Shape Surface Motion

- Most SLD encounters are at warm temperatures
- SLD ice shapes have been observed to slide on the surface in icing tunnel testing
- This ice shape motion is not well documented and the parameters under which it may occur are unknown
- No numerical models are available
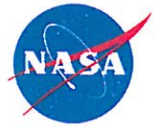
Validation Data Requirements

- ## Ice Shapes
  - Significant database available for freezing drizzle conditions
  - Freezing rain ice shapes are needed for further validation of current codes
  - 3D ice shape measurements are starting to become available
  - Ice shape mass values should be collected for comparison to numerical results

- ## Collection Efficiency
  - A small database is available over a limited range of SLD conditions
  - A greater range of droplet sizes and airspeeds are needed to improve numerical modeling of SLD
  - A new data collection method is needed that provides information on direct impingement, splashing, and re-impingement

Thank you for your attention.
Questions?