# SLD Research at NASA
## *Basic Research*

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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)

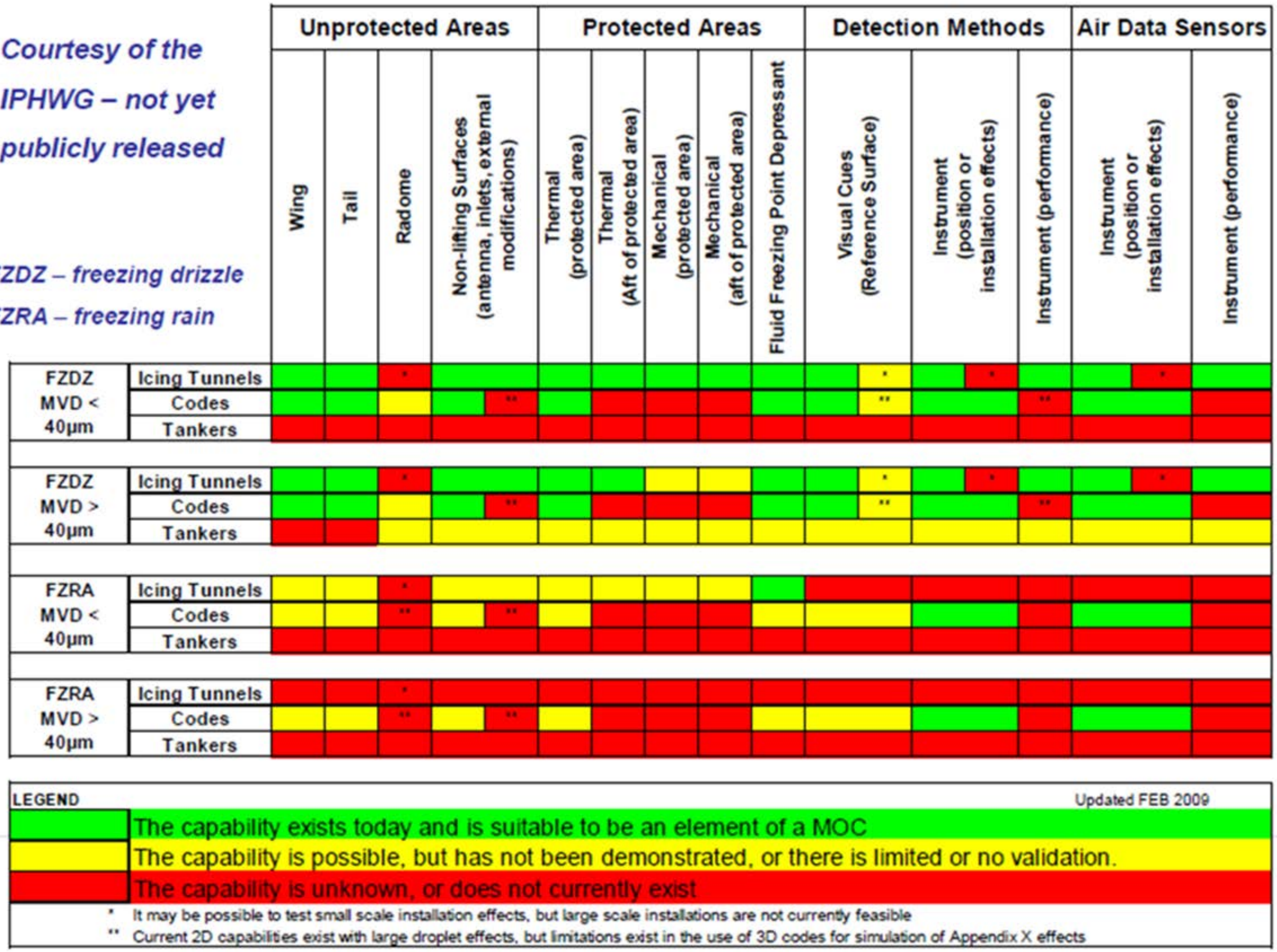
- Technology Building Blocks:
  1. Experimental SLD Ice Accretion Simulation
  2. Computational SLD Ice Accretion Simulation

# Assessment of Simulation Methods
# Current Capabilities for SLD Icing Simulation

*Courtesy of the IPHWG – not yet publicly released*

*FZDZ – freezing drizzle*

*FZRA – freezing rain*



# Experimental SLD Ice Accretion Simulation

## Objective

- Develop and demonstrate experimental simulation capability for SLD ice build-up on aircraft surfaces.

## Key Steps in Technology Development Roadmap

- Assess current experimental simulation capabilities (both test methods and facilities) for freezing drizzle and freezing rain throughout the community
- Develop strategy for addressing gaps in the capabilities (can we organize by test methods and facilities?)
  - Advocate for new facilities
  - Identify modifications for current facilities (larger drop sizes, lower LWC)
  - Develop techniques using current facilities (tunnels, test rigs, tankers)
  - Identify the uses of scaling and extend scaling methods
- Implement changes in the facilities
- Improve test methods
- Calibrate facilities
- Check against requirements

# Experimental SLD Ice Accretion Simulation

## Objective

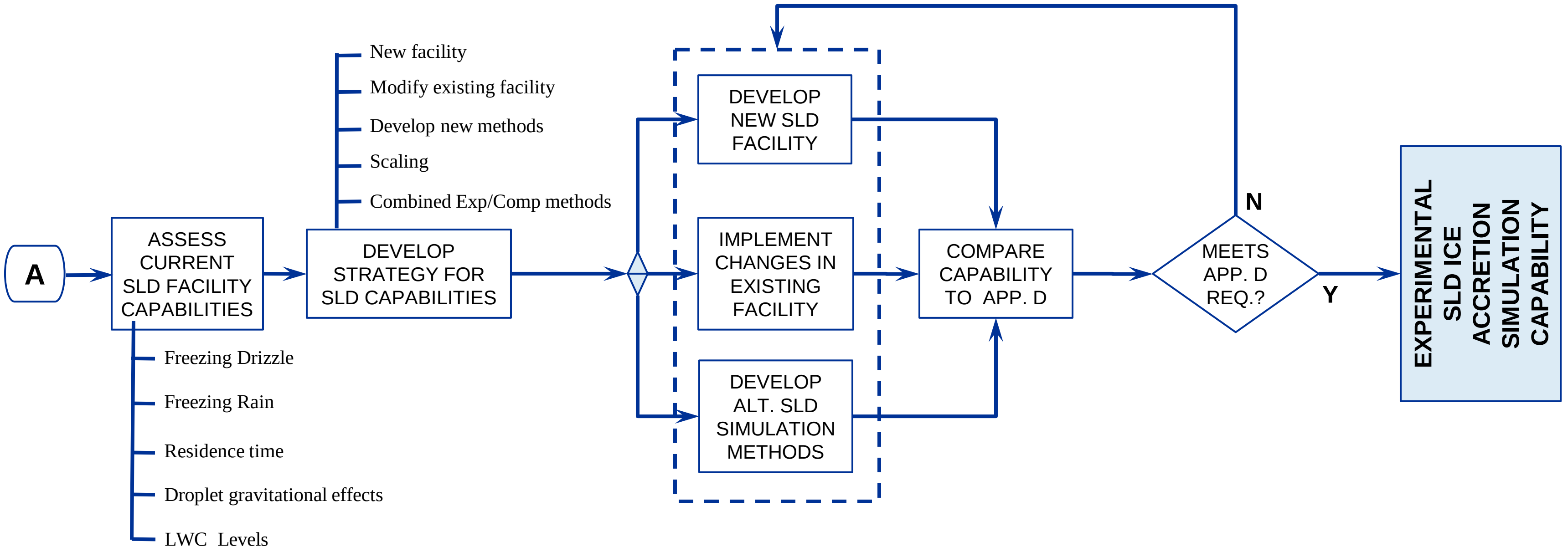
- Develop and demonstrate experimental simulation capability for SLD ice build-up on aircraft surfaces.

## Planning Questions

- What experimental capabilities (test methods and facilities) are available to perform freezing drizzle and freezing rain testing?
  - What are the limitations for validation data if freezing drizzle and freezing rain capabilities are unavailable?
  - How do we create validation databases for computational simulations of SLD icing?
  - Is tanker testing the only viable method for SLD simulation?
  - Does flight testing provide the only means for SLD computational validation data?
- What icing physics experiments should be conducted for computational model development?
  - What test methods and facilities are available for the icing physics experiments?
- Is a facility for SLD conditions needed and what should its characteristics and capabilities be?

# Experimental SLD Ice Accretion Simulation

## Technology Development Roadmap



# Icing Facility Survey

Facilities with the ***potential*** to do SLD simulation:

## Freezing Drizzle

NASA IRT

NRC AIWT

CIRA IWT

Univ. of Alberta IWT

Luan Phan Wind Tunnel

DGA S1 tunnel

## Freezing Rain

NASA IRT

CIRA IWT

Univ. of Alberta IWT

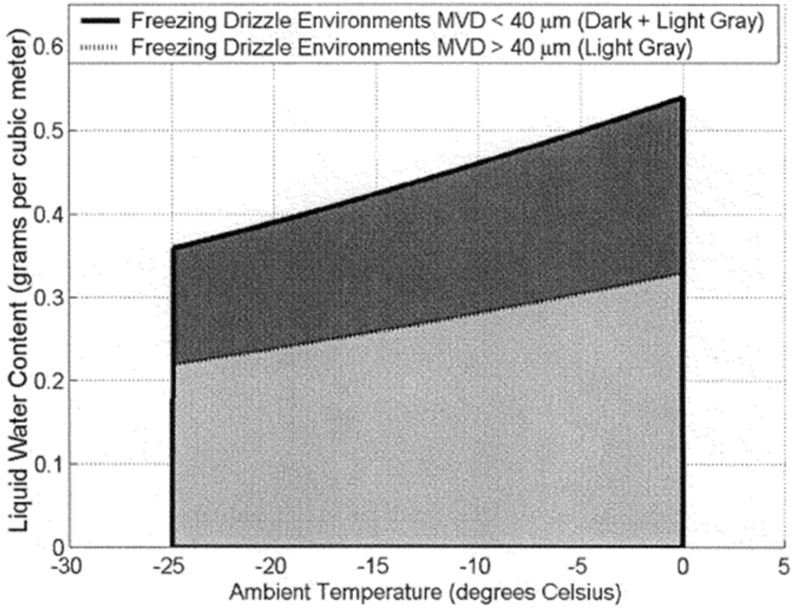
DGA S1 tunnel

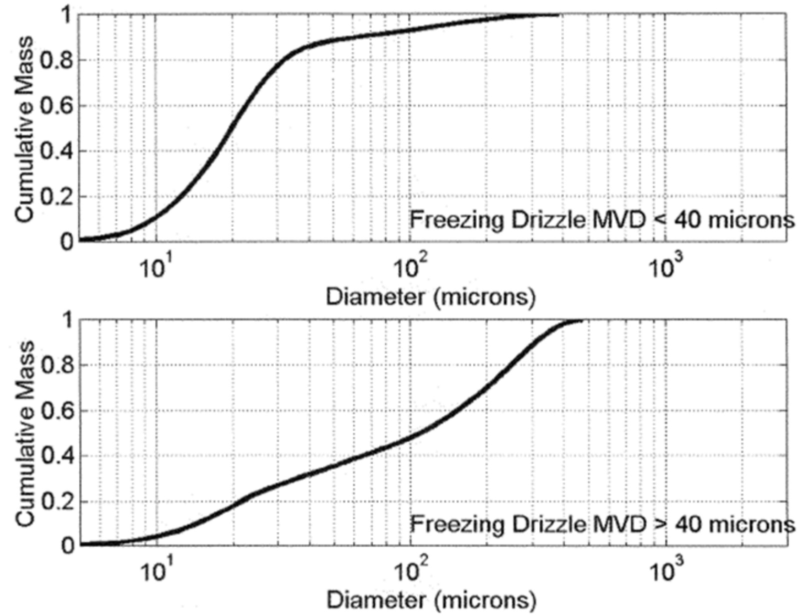
# SLD Icing Facility Study

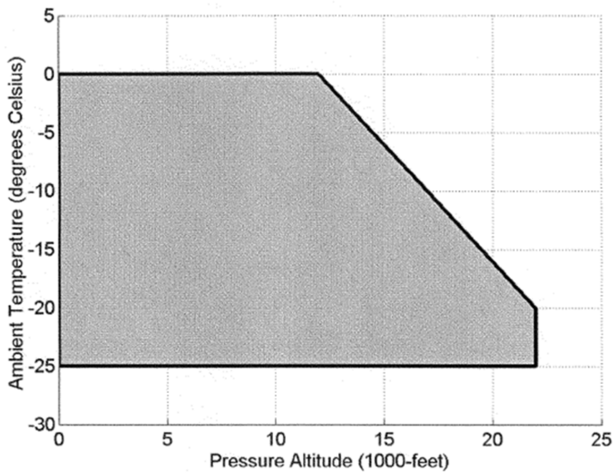
## Objective

Develop some concepts for a facility that can produce Supercooled Large Droplet (SLD) icing conditions representative of the SLD environment for the purposes of simulating those conditions, investigating the physics of SLD ice accretion, and providing data for computational icing simulation validation

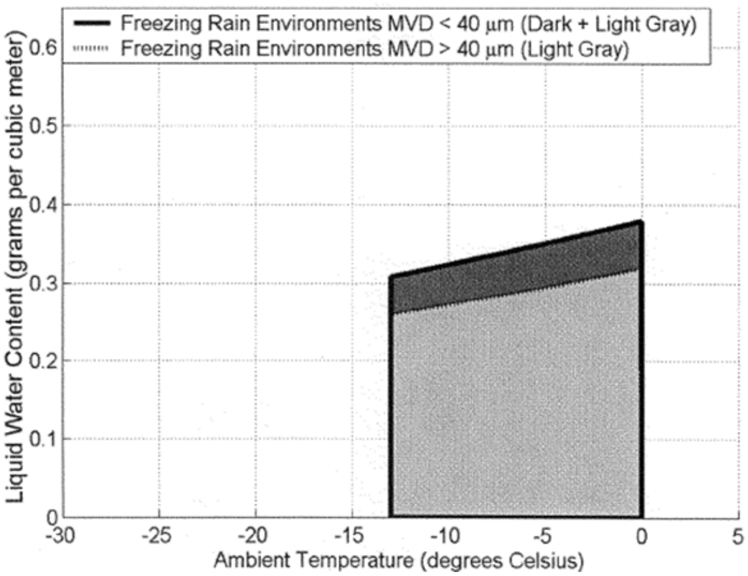
# Appendix O – Freezing Drizzle

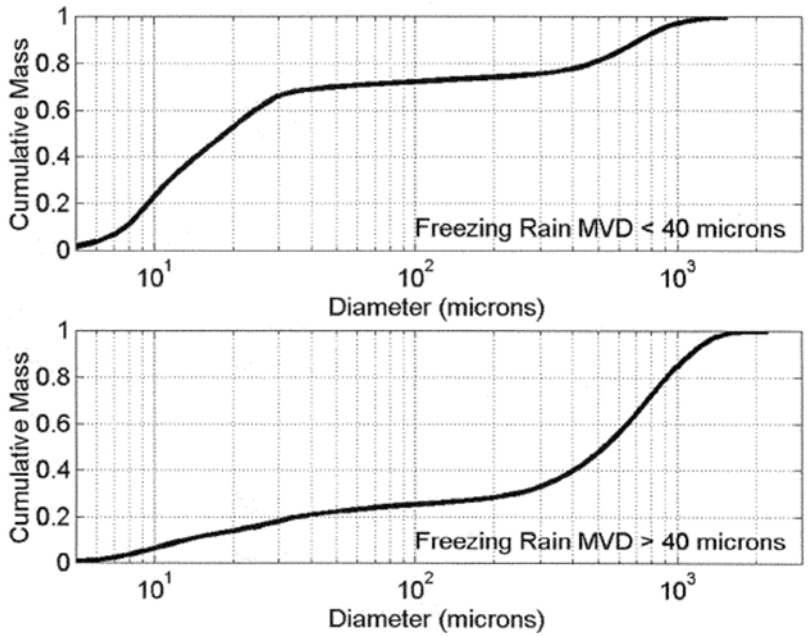


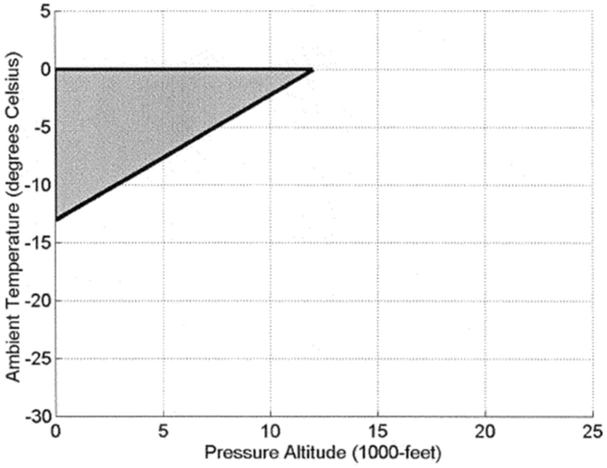



# Appendix O – Freezing Rain



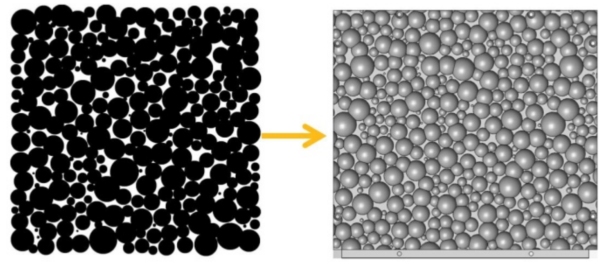



# Nominal SLD Icing Simulation Requirements

| SLD regime | Temperature Range (°C) | MVD Range (μm) | Max. Drop Diam. (μm) | LWC Range ($g/m^3$) |
|---|---|---|---|---|
| Freezing Drizzle | -25 to 0 | 40 to 120 | 400 to 500 | 0.22 to 0.55 |
| Freezing Rain | -13 to 0 | 17 to 550 | 1500 to 2200 | 0.27 to 0.37 |

# Heat Transfer from Surfaces with Realistic Ice Accretion Roughness



Simulator output SolidWorks model

## Objective

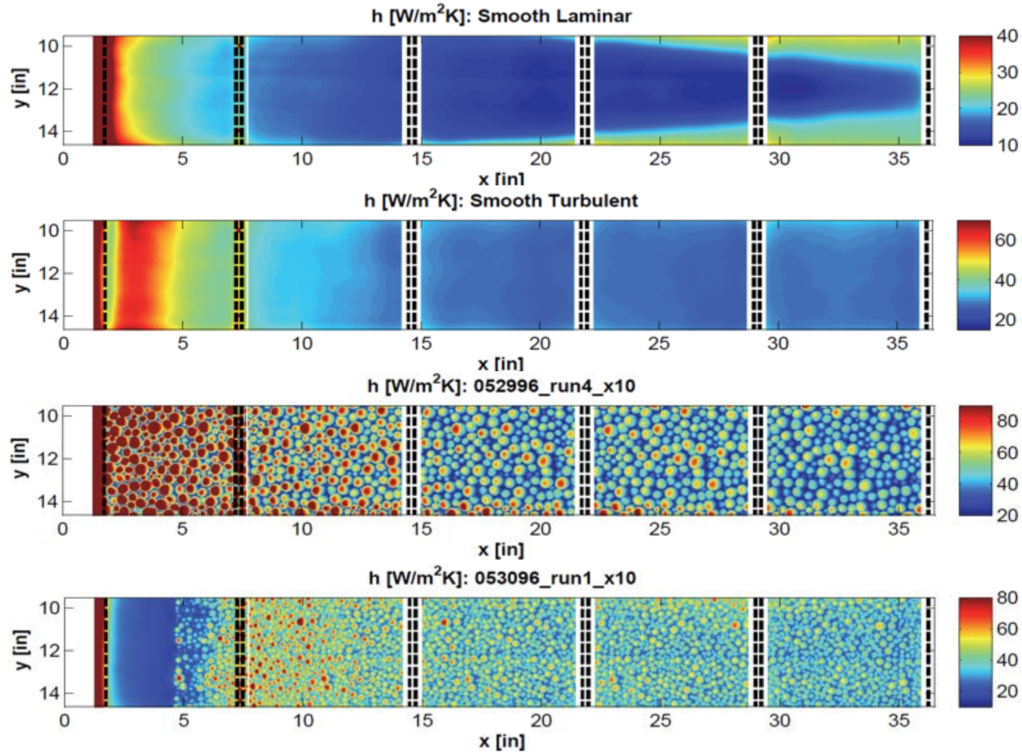
- Develop better predictions of convective heat transfer during SLD icing process
- Use surfaces with realistic short-duration ice accretion roughness characteristics

## Approach

- Use droplet simulator to produce random droplet/bead distributions
- Create surfaces with 3-D printer
- Measure steady-state convection using infrared techniques

## Status

- Preliminary measurements completed with constant flux
- Starting varying flux and accelerating flow measurements



# Ice Shape and Roughness Evaluation

## Objective

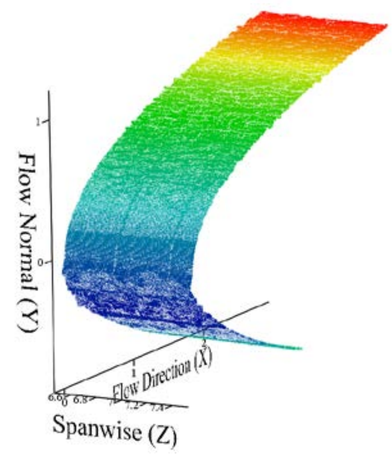
- Develop method to evaluate variations in roughness properties on “wrapped” surfaces from 3-D ice scans

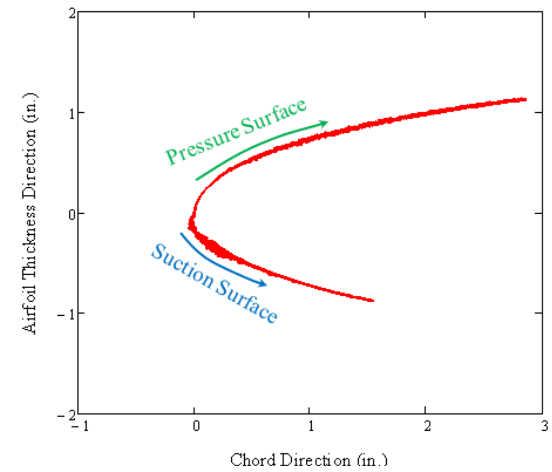
## Approach

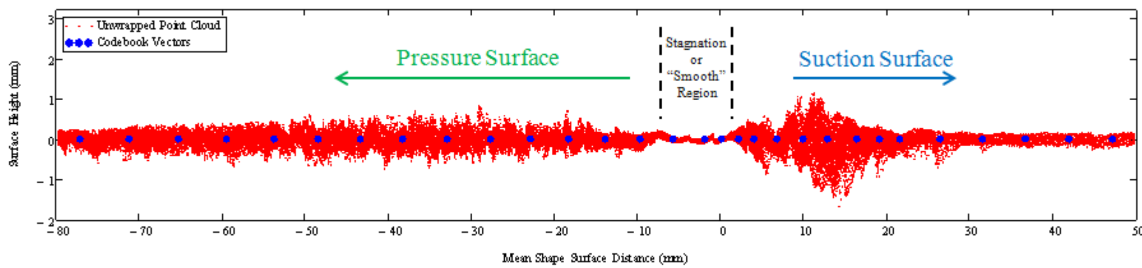
- Employ Self-Organizing Map approach
- Combine with multi-dimensional statistics approach

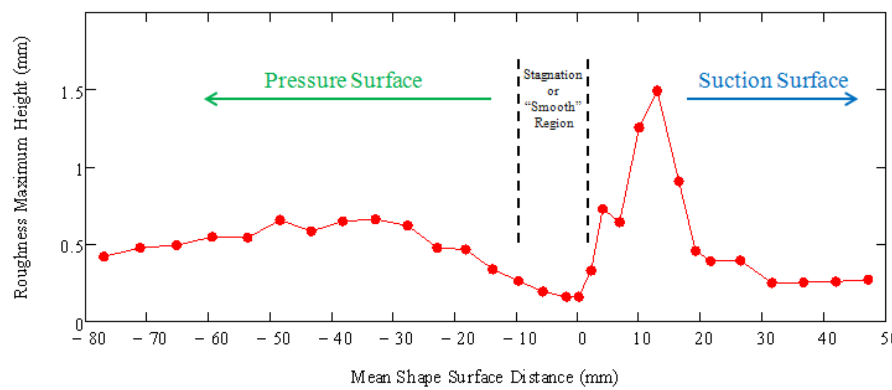
## Status

- In use to evaluate roughness variations in SLD icing conditions
- In validation stage using comparisons to archival roughness measurements
- Developing methods to automate process



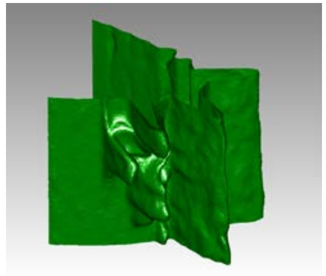



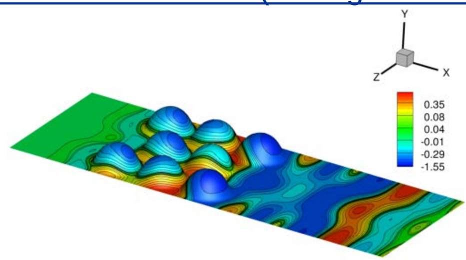
# 3D Runback Prediction

Goal: compute runback on complex 3D glaze ice shapes of the form →

(Source: Potapczuk, NASA Glenn )

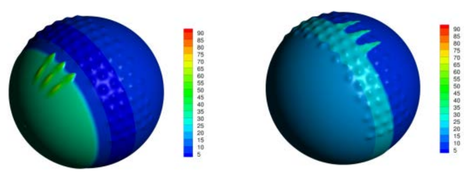


Sub-Grid Model Film Thickness (Strong Interaction Theory )




Preliminary Covariant Mass Transport Model Test on Sphere

$$\rho\left\{\frac{\partial}{\partial t}\left(\sqrt{g}\,\delta\right)+\frac{\partial}{\partial x^{\alpha}}\left(\sqrt{g}\,g^{\alpha\kappa}E_{\kappa}\right)\right\} = \sqrt{g}\left(LWC\,\beta V_{\infty}-\dot{m}_{L}-\dot{m}_{U}\right)$$



## Objective:

- Develop a model to predict fully 3D water runback for LEWICE 3D.

## Approach:

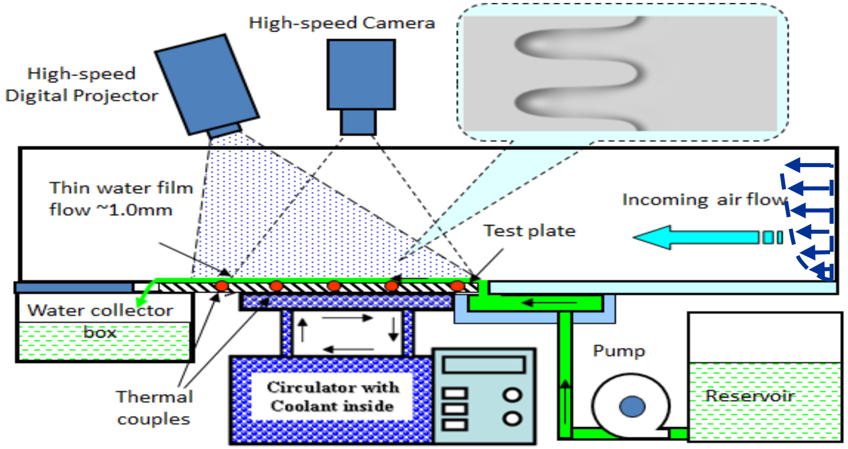
- Develop a covariant/tensor mass transport model.
- Develop sub-grid models based on air/water strong-interaction theory.
- Integrate the models into LEWICE 3D and validate.

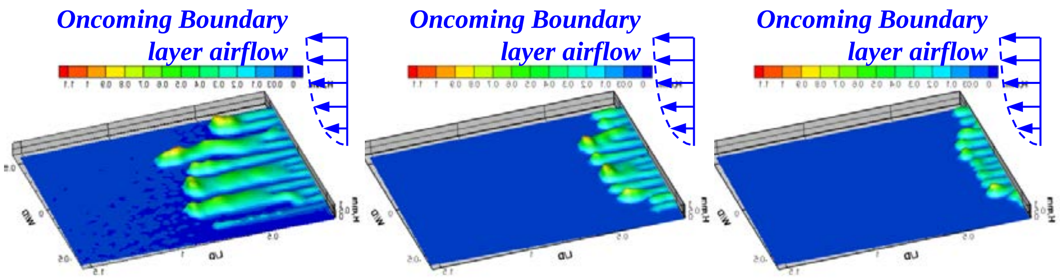
## Project Status:

- Tensor formulation developed, along with simple preliminary tests.
- Preliminary algorithms developed for strong-interaction sub-grid models.

Rothmayer A.P., and Hu, H., 2013, “Linearized solutions of three-dimensional condensed layer films,” to appear, 5th AIAA Atmospheric and Space Environments Conference.

# 3D Runback Models for Surface Water Transport (Experimental Work)




(c). $t=t_0+2.0s$ (b). $t=t_0+1.0s$ (a). $t=t_0$

***Snap shots of wind–driven water film/rivulet flows over a test plate***

## Objectives:

- Quantify the transient behavior of wind-driven water film/rivulet flows over ice accreting surfaces to guide 3D water runback model development.

## Approach:

- Develop a non-intrusive technique to achieve time-resolved thickness distribution measurements of surface water film/rivulet flows.
- Conduct comprehensive wind tunnel experiments.

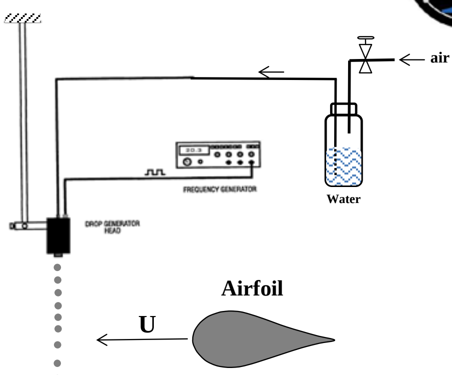
## Project Status :

- Develop a novel digital image project (DIP) technique.
- Quantify wind-driven thin water film/rivulet flows in both dry and wetted conditions.

Zhang K, Zhang S, Rothmayer A, Hu H, 2013, “Development of a Digital Image Projection Technique to Measure Wind-Driven Water Film Flows”, AIAA-2013-0247; 51st AIAA Aerospace Sciences Meeting and Aerospace Exposition, 07 - 10 January 2013, Grapevine, Texas, USA.

# 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

# Thank you for your attention.
# Questions?