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

<table>
<thead>
<tr>
<th></th>
<th>Unprotected Areas</th>
<th>Protected Areas</th>
<th>Detection Methods</th>
<th>Air Data Sensors</th>
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<tbody>
<tr>
<td></td>
<td>Wing</td>
<td>Tail</td>
<td>Radome</td>
<td>Non-lifting Surfaces</td>
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<tr>
<td>FZDZ – freezing drizzle</td>
<td>Icing Tunnels</td>
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<td>FZDZ MVD &lt; 40μm</td>
<td>Codes</td>
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<td></td>
<td>Tankers</td>
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**LEGEND**
- 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

Updated FEB 2009
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

A. Assess Current SLD Facility Capabilities
   - Freezing Drizzle
   - Freezing Rain
   - Residence time
   - Droplet gravitational effects
   - LWC Levels

B. Develop Strategy for SLD Capabilities
   - New facility
   - Modify existing facility
   - Develop new methods
   - Scaling
   - Combined Exp/Comp methods

C. Develop New SLD Facility
D. Implement Changes in Existing Facility
E. Develop Alt. SLD Simulation Methods
F. Compare Capability to App. D
   - MEETS APP. D REQ.?
     - Y
     - N

G. Experimental SLD Ice Accretion Simulation Capability
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
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

[Graphs and diagrams related to freezing drizzle phenomena]
Appendix O – Freezing Rain
# Nominal SLD Icing Simulation Requirements

<table>
<thead>
<tr>
<th>SLD regime</th>
<th>Temperature Range (°C)</th>
<th>MVD Range (µm)</th>
<th>Max. Drop Diam. (µm)</th>
<th>LWC Range (g/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freezing Drizzle</td>
<td>-25 to 0</td>
<td>40 to 120</td>
<td>400 to 500</td>
<td>0.22 to 0.55</td>
</tr>
<tr>
<td>Freezing Rain</td>
<td>-13 to 0</td>
<td>17 to 550</td>
<td>1500 to 2200</td>
<td>0.27 to 0.37</td>
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</table>
Heat Transfer from Surfaces with Realistic Ice Accretion Roughness

 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 multidimensional 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

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.

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

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.

SLD Droplet Experimental Research

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?