SLD Research at NASA

Numerical Modeling

Mark Potapczuk

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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

<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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</thead>
<tbody>
<tr>
<td></td>
<td>Wing</td>
<td>Tail</td>
<td>Radome</td>
<td>Non-lifting Surfaces (external modifications)</td>
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<tr>
<td>FZDZ MVD &lt; 40μm</td>
<td>Icing Tunnels</td>
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**LEGEND**

- The capability exists today and is suitable to be an element of a MOG.
- 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**

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

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

- Range of coverage
- Accuracy level
- Model geometry

- MODIFY SLD ICE ACCRETION COMP SIM METHODS

- DEVELOP SLD ICING PHYSICS TEST PLAN
- PERFORM SLD ICING PHYSICS STUDIES
- COMPARE COMP. TO EXP. DATA

- SIM ROMTS MET?

- DEVELOP SLD SIM ROMTS
- ASSESS SLD ICE ACCRETION SIM CAPABILITY

- Droplet impingement
- Ice shape
- Ice mass
- Impingement limits
Current Activities
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 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.
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.

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

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

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Droplet Breakup Results
Weber Number vs. Distance from Airfoil

Run 072011.14C droplet #1, droplet diameter = 1062 µm, airfoil chord = 0.710 m, airfoil velocity = 90 m/sec

Weber Number vs. Distance from Airfoil

\[ We = \frac{\rho_{\text{air}} \cdot V_{\text{slip}}^2 \cdot D}{\sigma_{w/a}} \]
Typical Splashing Results
GLC305 AOA=6, MVD=92

Maximum Beta

Lower Impingement Limit

10% Limits

Upper Impingement Limit

Collection Efficiency

\( \Phi < 0.8 \)

\( \Phi > 0.6 \)

www.nasa.gov
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?