Academic Airframe Icing Perspective

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Introduction

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• What research do we need?
  – 3-D Ice accretion and aerodynamics
  – Systems-based multidisciplinary research

• But first:
  – Some philosophy on university research
  – Some icing research history and lessons learned

• Then to 3-D and multidisciplinary research
Why University Research?

The best university researcher strives to have Impact in many dimensions:
- New discoveries
- Graduate education
- Contribution to society
- Economic development

University researchers think of research in MS and Ph.D “units”

University research can be both applied and fundamental
Basic versus Applied Research

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• Traditional Research Continuum

<table>
<thead>
<tr>
<th>Basic Research</th>
<th>Applied Research</th>
<th>Development</th>
<th>Production and Operation</th>
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• Quadrant Model of Research

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<tr>
<th>Quest for Fundamental Understanding?</th>
<th>Consideration of use?</th>
<th>Pure basic research (Bohr)</th>
<th>Use-inspired research (Pasteur)</th>
<th>Pure applied research (Edison)</th>
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<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
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<td>Pasteur’s Quadrant</td>
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<td>No</td>
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From “Pasteur’s Quadrant” by Donald E. Stokes
NASA/university 2-D iced-airfoil aerodynamics

- Evolving goals as we learned more and motivation changed (1980 – 2008)
  - Understanding of ice accretion effect on lift and drag
  - Support for CFD development and validation
  - Understand iced-airfoil physics
  - Roselawn accident focused us on “use”
  - Aircraft control and more 3-D
  - Effect of airfoil and ice-shape geometry
  - Understanding Re and M effects
  - Ice accretion aero classification and simulation
Aerodynamic Techniques

Initial techniques
- Relatively simple steady RANS
- Simple small-scale experiments with large horn ice at low Re

Current techniques
- 3-D unsteady RANS/LES methods
- Pressure tunnels at near-flight Re and M, multiple ice shapes, advance measurement techniques including PIV
What did we learn from 2-D aerodynamics?

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Process
• Re and M important to understand but low-Re data are valuable and provide a cost-effective research method for many cases
• Flowfield understanding critical in reducing “matrix” and understanding simulation
• Flow separation is key and is always unsteady and 3-D
• Roselawn and considering “use” or application led to more focused and productive research programs

Physics
• An understanding of the basic relationships between airfoil geometry, ice-accretion geometry, and iced-airfoil aerodynamics and aerodynamic performance including control was accomplished with some fundamental understanding of the flow
2-D Icing

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• Ice Accretion Physics
  – Droplet trajectory calculations well understood
  – Basic surface water transport and bulk ice growth is understood
  – LEWICE does a good job within its 2-D validation data set

• Iced-Airfoil Aerodynamics
  – Understand basic flowfield and gross aerodynamics for the four identified ice shape categories
  – Simulation ice shape methods identified and validated
  – RANS does a reasonable job with gross aerodynamics
The 3-D Icing Problem

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- **Ice accretion**
  - 3-D ice accretion have been observed and documented
  - Scallops have been studied, resulting in a foundation of experimental understanding
  - Fundamental processes in 3-D are not understood well enough for reliable models

- **Aerodynamics**
  - Flow separation including shear layer development is the fundamental flow feature and it is 3-D and unsteady
  - RANS insufficient but full 3-D and unsteady cost/resource prohibitive
  - No 3-D experimental data at near-flight Re and M
3-D Ice Accretion

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- **Goals**
  - Understand basic physical processes underlying aircraft icing.
  - Create simplified engineering tools.
  - Understand the accuracy of the engineering tools.

- **What is needed?**
  - Growth mechanisms for complex 3-D accretions (scallops, etc.)
  - Simulation methods for complex 3-D accretions
  - Nonlinear coupled interactions (droplets splashing, surface water transport, impact freezing, etc.)
3-D Ice Accretion (cont.)

Approach

- Understand the basic physical processes underlying aircraft icing:
  - Develop a foundation of understanding based on experiments.
  - Develop detailed physical models which explain the experiments.

- Use icing physics knowledge to help create simplified ice accretion engineering tools.

- Understand the processes which limit the accuracy of the engineering tools.
Example – Surface Physics

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- Basic water transport can be handled using simple models.

- Ice surface roughness can be explained by heat transfer driven instability of the ice surface.

- There is a need to better understand more complex 3-D nonlinear interactions:
  - Growth of complex ice shapes. Nonlinear coupling of droplet impacts, unsteady aerodynamics past complex 3-D ice/water shapes, water transport, and complex ice growth. Coupling to rapid phase transitions when crossing from rime to glaze icing, etc.

- NASA VIST facility and icing physics experiments are important steps to resolve these issues.

Source: Rothmayer, Matheis, Otta, Tsao, Wang
3-D Icing Aerodynamics

• Goals
  – Basic understanding of 3-D iced wing flowfield
  – Simulation methods and a small-scale, low-Re capability
  – Computational methods that accurately predict Clmax and control deflection effects

• What is needed?
  – Iced-wing data at high Reynolds number and flight M
  – Data for code development and validation
  – Unsteady, RANS/LES method development
  – Key features: unsteady separated flow, shear-layer development, transition
3-D Icing Aerodynamics

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- **Approach**
  - Fundamental studies to aid understanding of key flow phenomena
  - Development of advanced CFD methods
  - High-Re data on representative geometries
  - Validation of CFD methods
  - Experimental and computational tools for practical problems
Example – Hybrid RANS/LES

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• Observations
  – RANS, while highly efficient, requires a high degree of phenomenological modeling, which limits its applicability
  – LES, which models fewer of the turbulent scales, is prohibitively expensive in aero boundary layers

• Current general consensus
  – Valid for massively separated flows
  – Problematic for aerodynamically-relevant flows

DES for extruded GLC305/944 ice shape

– Selected time steps show development of characteristic “loop” vortices

• Basic idea
  – Use RANS in regions of attached flow
    • Consistent with modeling the Reynolds stress
  – Use LES in regions of separated flow
    • Consistent with modeling the subgrid stress
  – Implicit zonal boundary
    • Achieved through a dynamically-varying eddy viscosity
Example – Hybrid RANS/LES

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- **DES for extruded GLC305/944 ice shape**
  - Detached Eddy Simulation (DES) (specific form of hybrid RANS/LES)

  *Three-dimensional unsteady flow in separated region*

  *RMS of streamwise velocity fluctuations*

  Source: Mogili, Thompson (MSU), Choo, and Addy (NASA GRC)
• Example – Smart Icing Systems
  – Combined human factors, controls, flight mechanics, and aerodynamics to address icing flight safety system
  – Systems to sense effect of ice accretion on aircraft and operate IPS, provide envelope protection, inform/advise pilot, etc
  – Systems, multidisciplinary approach provides integrated solutions and where needed helps guide new research
Systems-Based Multidisciplinary Research (cont.)

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• **Needed Multidisciplinary Research**
  – Couple ice accretion and ice protection modeling with aerodynamics and control
  – Couple flight mechanics, aerodynamics, sensing and flight mechanics and control
  – Bring atmospheric science and route planning into the problem of SLD protection
  – Include Human Factors and training into the research with flight simulation, ice accretion, and flight dynamics
  – Etc.
Summary

2-D ice accretion and aerodynamics reasonably well understood for engineering applications

To significantly improve our current capabilities we need to understand 3-D

- Important ice accretion physics and modeling not well understood in 3-D
- Aerodynamics unsteady and 3-D especially near stall

Larger systems issues important and require multi-disciplinary team approach