Academic Airframe Icing Perspective

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Airframe Icing Workshop
NASA Glenn
June 9, 2009
Introduction

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

• Traditional Research Continuum

Basic Research  Applied Research  Development  Production and Operation

• Quadrant Model of Research

Consideration of use?

<table>
<thead>
<tr>
<th>Quest for Fundamental Understanding?</th>
<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
<td>No</td>
<td>Pure basic research (Bohr)</td>
<td>Use-inspired research (Pasteur)</td>
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<tr>
<td>Yes</td>
<td>Pure applied research (Edison)</td>
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From “Pasteur’s Quadrant” by Donald E. Stokes
2-D Airfoil Icing 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?

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

• **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

**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

• 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

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

DES for extruded GLC305/944 ice shape

– Selected time steps show development of characteristic “loop” vortices
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)
Systems-based Multidisciplinary Research

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