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Academic Airframe Icing Perspective

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Airframe Icing Workshop
NASA Glenn
June 9, 2009

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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?

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- 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

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Basic versus Applied Research

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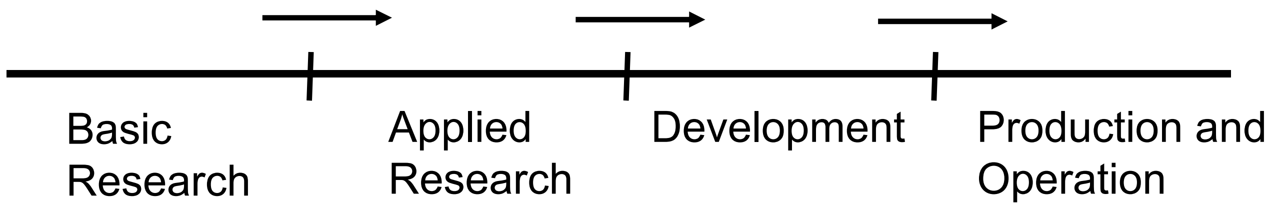
- **Traditional Research Continuum**



- **Quadrant Model of Research**

Consideration of use?

Quest for Fundamental Understanding?	No	Yes
Yes	Pure basic research (Bohr)	Use-inspired research (Pasteur)
No		Pure applied research (Edison)

Pasteur's Quadrant

From "Pasteur's Quadrant" by Donald E. Stokes

2-D Airfoil Icing Aerodynamics

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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

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Aerodynamic Techniques

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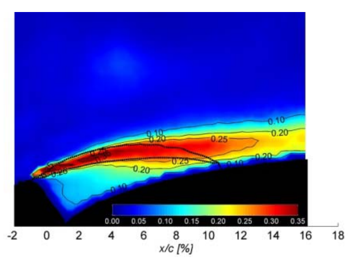
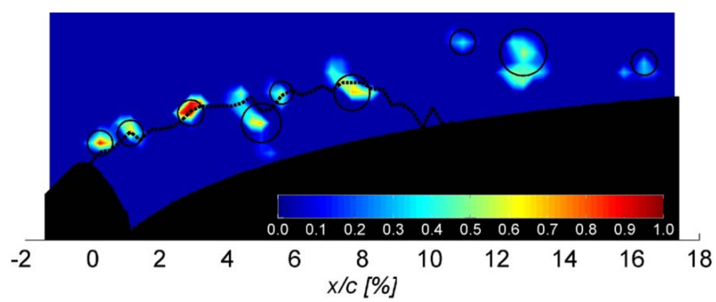
Initial techniques

- 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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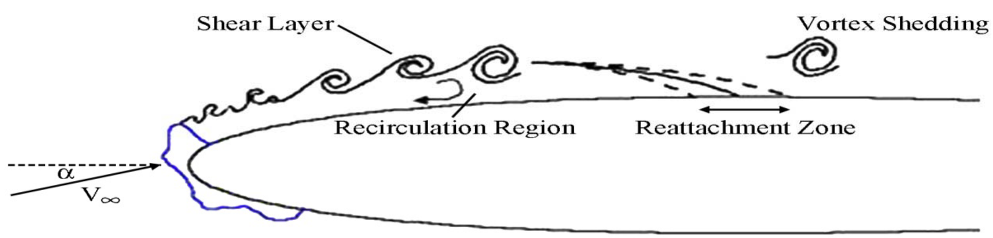
Process

- 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



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2-D Icing

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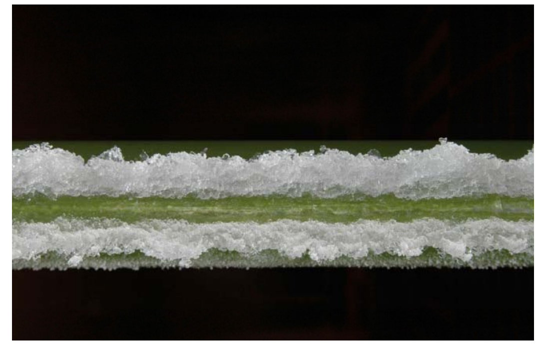
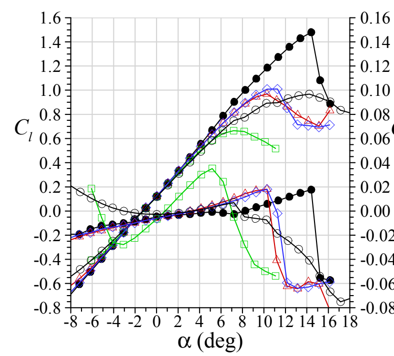
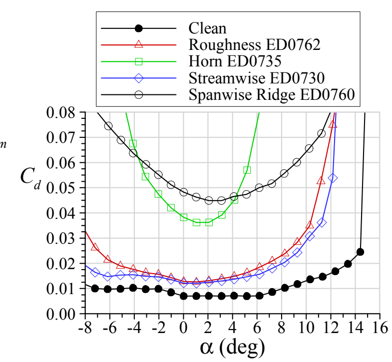
- **Ice Accretion Physics**
  - Droplet trajectory calculations well understood
  - Basic surface water transport and bulk ice growth is understood
  - LEWICE does a good job within its 2-D validation data set



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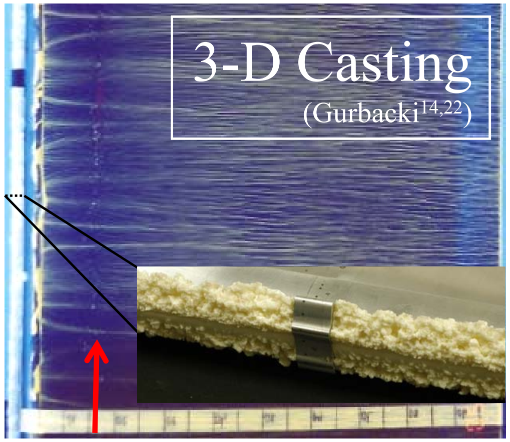
- **Ice accretion**
  - 3-D ice accretion have been observed and documented
  - Scallops have been studied, resulting in a foundation of experimental understanding
  - Fundamental processes in 3-D are not understood well enough for reliable models
- **Aerodynamics**
  - Flow separation including shear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

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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.

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Example – Surface Physics

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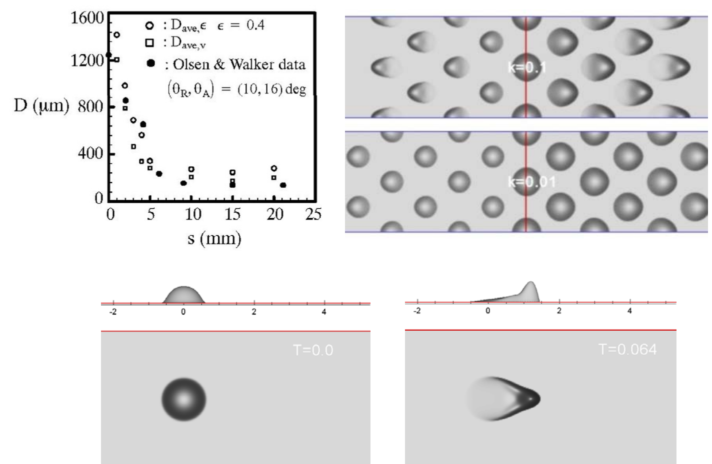
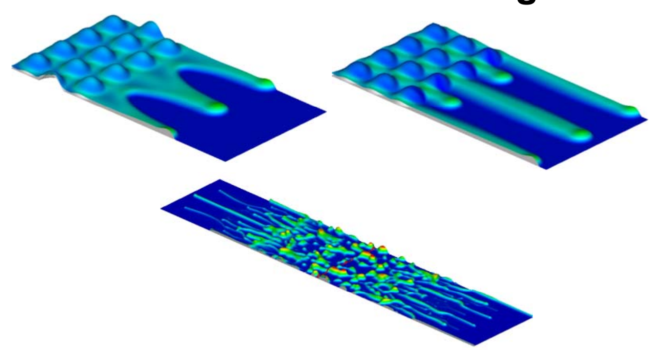
- Basic water transport can be handled using simple models.
- Ice surface roughness can be explained by heat transfer driven instability of the ice surface.
- There is a need to better understand more complex 3-D nonlinear interactions:
  - Growth of complex ice shapes. Nonlinear coupling of droplet 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.

Water bead runback



Rivulet interaction with roughness



Source: Rothmayer, Matheis, Otta, Tsao, Wang

3-D Icing Aerodynamics

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- **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

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3-D Icing Aerodynamics

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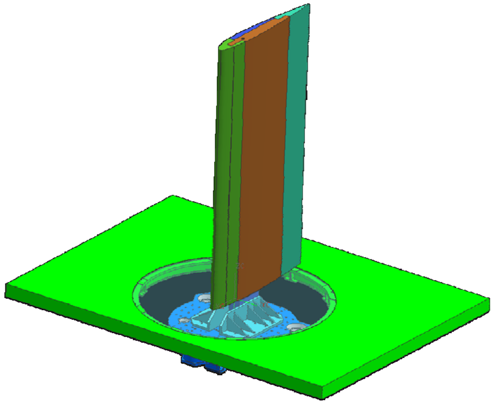
- **Approach**
  - Fundamental studies to aid understanding of key flow phenomena
  - Development of advanced CFD methods
  - High-Re data on representative geometries
  - Validation of CFD methods
  - Experimental and computational tools for practical problems



Example – Hybrid RANS/LES

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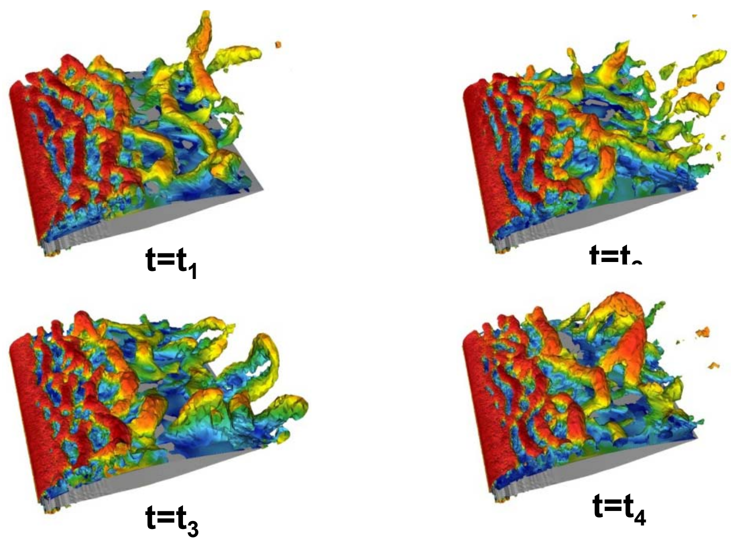
- **Observations**
  - RANS, while highly efficient, requires a high degree of phenomenological modeling, which limits its applicability
  - LES, which models fewer of the turbulent scales, is prohibitively expensive in aero boundary layers
- **Current general consensus**
  - Valid for massively separated flows
  - Problematic for aerodynamically-relevant flows

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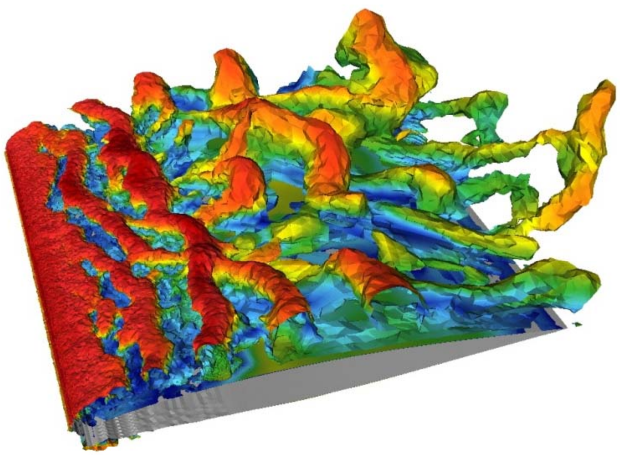
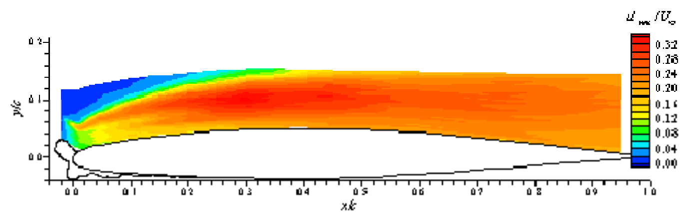
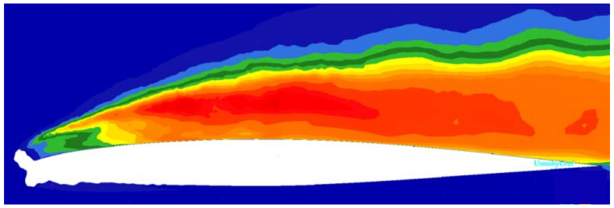
- **DES for extruded GLC305/944 ice shape**
  - Detached Eddy Simulation (DES) (specific form of hybrid RANS/LES)



Three-dimensional unsteady flow in separated region



Experimental data



DES results

RMS of streamwise velocity fluctuations

Source: Mogili, Thompson (MSU), Choo, and Addy (NASA GRC)

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Systems-based Multidisciplinary Research

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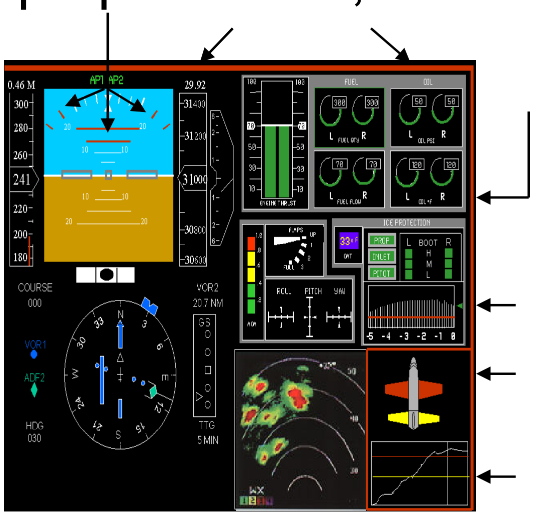
- **Example – Smart Icing Systems**
  - Combined human factors, controls, flight mechanics, and aerodynamics to address icing flight safety system
  - Systems to sense effect of ice accretion on aircraft and operate IPS, provide envelope protection, inform/advise pilot, etc
  - Systems, multidisciplinary approach provides integrated solutions and where needed helps guide new research



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Systems-Based Multidisciplinary Research (cont.)

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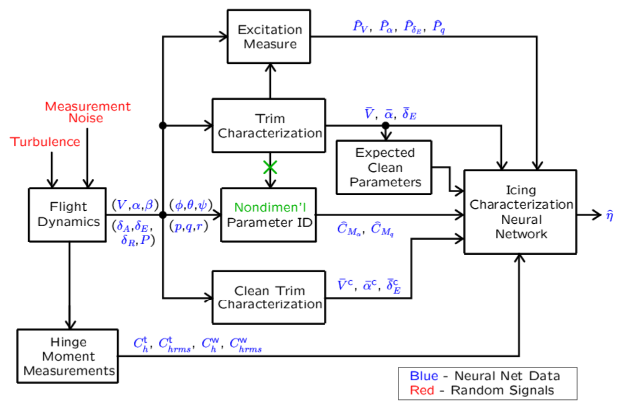
- **Needed Multidisciplinary Research**
  - Couple ice accretion and ice protection modeling with aerodynamics and control
  - Couple flight mechanics, aerodynamics, sensing and flight mechanics and control
  - Bring atmospheric science and route planning into the problem of SLD protection
  - Include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



Summary

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- 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