Introduction

Mike Bragg
University of Illinois at Urbana-Champaign

Smart Icing Systems
NASA Review
June 19-20, 2001
Outline

Background
Objective
Smart Icing System solution
Timeline and research review
Schedule of the presentations
Illinois Icing Research

Iced Airfoil Aerodynamics
- AGATE residual ice and scaling study
- Sensing ice-induced separation and flow unsteadiness
- Iced airfoil aerodynamics of critical ice shapes
- Airfoil sensitivity to intercycle and SLD ice accretions
- Computational and experimental techniques
- Unsteady iced flowfields near maximum lift

Ice Accretion Physics
- Turbulence measurements in icing conditions
- Hybrid model design for ice accretion scaling
- Influence of roughness on ice accretion
- Computational modeling of icing test facilities

Smart Icing Systems
- Interdisciplinary research for flight safety
Aircraft Icing Accidents

Accidents

- Air Florida - takeoff accident - performance and S&C.
- United Express Jetstream - tail stall - longitudinal S&C.
- Roselawn ATR - roll upset - lateral S&C.

Common Features

- Ice accretion.
- Aerodynamic effect leads to degradation in performance and handling qualities.
- Pilot is unaware of the full effect of ice on aircraft.
- Accident occurs.
ATR 72 Roselawn Accident

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Pilot’s Perspective

Steve Green (ALPA) UIUC April 29, 1999

• When operating in icing conditions the flight crew should:
  – Monitor airspeed, rate of climb, fuel flow, SAT/TAT, cloud formation
  – Monitor aerodynamic surfaces, or representative surfaces for ice accretion
  – Allow some specified quantity of ice to build prior to operating the ice protection system
  – Determine whether the ice protection system is adequately clearing ice
  – Develop and update an opinion as to whether the icing conditions may adversely affect the safety of flight
Pilot’s Perspective (cont)

Steve Green (ALPA) UIUC April 29, 1999

• Safe Operation in Icing
  • Provide pilot with aerodynamic monitoring (proximity to $C_L$ divergences)
  • The pilot must have reliably correlated data, measured in real time, with which to infer the proximity of divergences in $C_L$ or $C_h$ in a timely manner.
Goal

- To improve the safety of aircraft operating in icing conditions.

Objective

- To develop a human-centered automated system, to characterize icing effects, operate the IPS, provide envelope protection and control adaptation.

Approach

- An interdisciplinary, systems approach is used to conduct the research in aerodynamics, flight mechanics, controls and human factors. Flight simulation and flight testing are used to develop the concept and validate the methods.
Defenses in Depth

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Accident Trajectory

No Accident
New Aircraft Icing Encounter Model

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Ice Accretion

Ice Protection System (IPS)

Pilot / Automation

Aircraft Dynamics

Ice Management System (IMS)

Information

Pilot Input

Envelope Protection

Control Adaptation

Primary IPS Operation

Ice Accretion Sensors

Advisory

Ice Effects
IMS Functional Model
SIS Development Strategy

• Incorporate Human Factors input throughout process
• Focus on technology and tools, not specifics of the IMS for a given aircraft
• Focus on icing effect characterization years 1 and 2
• Use flight simulator as system integrator with emphasis in later years of project
• Conduct envelope protection and control adaptation research years 3 and 4
Major Program Changes

- **Added**
  - Analysis of the effect of atmospheric effects
  - Flight test
- **Delayed**
  - Envelope protection research
  - Nonlinear aircraft model
  - CFD analysis of iced aircraft
- **Eliminated**
  - Construction of wind tunnel models and testing
IMS Development

- IMS development progressing in stages.
- First simple model presented at Reno 2000 used neural net to predict icing level from two dynamic characterization inputs.
- A more sophisticated neural net using dynamic and steady state characterization inputs as well as some sensor inputs presented Reno 2001.
- Nondimensional ID, improved neural networks, and envelope protection analysis presented here.
NASA/University of Illinois Smart Icing Systems Program

Technology Development

Systems Identification

Human Factors

IMS Decision Making

Piloted Flight Simulator Systems Integration

Flight Test

\[ \eta_{\text{ice}}, \text{icing rate, ice location} \]

\[ M_\alpha, M_\delta, \Delta C_d, T \]
Faculty and Students

**Aerodynamics, Propulsion and Flight Mechanics**
- Profs. Mike Bragg (AAE) and Eric Loth (AAE)
- Sam Lee, Andy Broeren, Jason Merret, Kishwar Hossain, Ed Whalen
- Leia Blumenthal, Chris LaMarre, (AAE)

**Control and Sensor Integration**
- Profs. Tamer Basar (ECE/CSL), Bill Perkins (ECE/CSL), Petros Voulgaris (AAE/CSL)
- James Melody (ECE/CSL), Vikrant Sharma (AAE/CSL), Paul Pawola (ECE/CSL)
- Evgeniy Sklyanskiy (AAE)

**Human Factors:**
- Profs. Nadine Sarter (OSU), Chris Wickens (ARL)
- John McGuirl (OSU)

**Flight Simulation:**
- Prof. Michael Selig (AAE)
- Bipin Sehgal, Rob Deters (AAE)
SMART ICING SYSTEMS
Research Organization

Core Technologies

- Aerodynamics and Propulsion
- Flight Mechanics
- Control and Sensor Integration
- Human Factors/Cognitive Engineering
- Aircraft Icing Technology

IMS Functions

- Characterize Icing Effects
- Operate and Monitor IPS
- Envelope Protection
- Adaptive Control

Systems Integration

- Flight Simulation
- Flight Test
SIS Schedule

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Federal Fiscal Year

98  99  00  01  02  03

Concept Development  CRI Funding

SIS Core Technologies / IMS research

Icing Encounter Flight Simulator

Systems Study  Flight test

♦ Preliminary IMS Methods  ♦ IMS Demo  ♦

June 2001
# Meeting Schedule

**Smart Icing Systems Review, June 19-20, 2001**

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<thead>
<tr>
<th>Time</th>
<th>Event Description</th>
<th>Location</th>
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<tbody>
<tr>
<td><strong>Tuesday June 19:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>9:00 am – 9:45 am</strong></td>
<td><strong>Introductions</strong></td>
<td><strong>B02 CSRL</strong></td>
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<tr>
<td>9:00 am – 9:05 am</td>
<td>Welcome</td>
<td>Bond</td>
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<tr>
<td>9:05 am – 9:35 am</td>
<td>Smart Icing Systems Overview</td>
<td>Bragg</td>
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<tr>
<td><strong>9:45 am – 11:00 am</strong></td>
<td><strong>Aerodynamics and Flight Mechanics</strong></td>
<td><strong>B02 CSRL</strong></td>
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<tr>
<td>9:35 am – 10:20 am</td>
<td>Assessing Atmospheric Effects on Icing Characterization</td>
<td>Merret</td>
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<tr>
<td>10:20 am – 10:30 am</td>
<td>Break</td>
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<tr>
<td>10:30 am – 11:00 am</td>
<td>Envelope Protection</td>
<td>Hossain</td>
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<tr>
<td><strong>11:00 am – 1:30 pm</strong></td>
<td><strong>Flight Controls and Sensors</strong></td>
<td><strong>B02 CSRL</strong></td>
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<tr>
<td>11:00 am – 11:45 am</td>
<td>ID and Characterization with Nondimensional Derivatives</td>
<td>Melody</td>
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<tr>
<td><strong>11:45 noon – 1:00 pm</strong></td>
<td><strong>Lunch</strong></td>
<td><strong>301 CSRL</strong></td>
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<tr>
<td>12:30 pm – 12:45 pm</td>
<td>College Summary</td>
<td>Vojak</td>
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<tr>
<td>1:00 pm – 1:30 pm</td>
<td>Autopilot Studies</td>
<td>Voulgaris</td>
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<tr>
<td><strong>1:30 pm – 3:15 pm</strong></td>
<td><strong>Human Factors</strong></td>
<td><strong>B02 CSRL</strong></td>
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<tr>
<td>1:30 pm – 2:00 pm</td>
<td>The IMS as a Decision Support Tool</td>
<td>Sarter</td>
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<tr>
<td>2:00 pm – 2:30 pm</td>
<td>Visual and Tactile Cues for Presenting In-flight Information</td>
<td>McGuirl</td>
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<tr>
<td>2:30 pm – 3:00 pm</td>
<td>Overview of IMS Interface and Planned Human Factors Activities</td>
<td>Sarter</td>
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<tr>
<td>3:00 pm – 3:15 pm</td>
<td>Break</td>
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<tr>
<td><strong>3:15 pm – 4:15 pm</strong></td>
<td><strong>Flight Simulation</strong></td>
<td><strong>B02 CSRL</strong></td>
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<tr>
<td>3:15 pm – 3:45 pm</td>
<td>IMS Integration and Software Development</td>
<td>Sehgal</td>
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<tr>
<td>3:45 pm – 4:15 pm</td>
<td>Twin Otter Model and Validation</td>
<td>Deters</td>
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<tr>
<td><strong>6:30 pm – 8:30 pm</strong></td>
<td><strong>Reception</strong></td>
<td><strong>Bragg Residence</strong></td>
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**6:30 pm – 8:30 pm**

Reception

Bragg Residence
### Wednesday June 20:

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<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Speaker</th>
<th>Room</th>
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<tr>
<td>8:30 am – 9:00 am</td>
<td>Flight Simulation Demonstration</td>
<td>Selig</td>
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<tr>
<td>9:00 am – 10:30 am</td>
<td>Twin Otter Flight Test Analysis</td>
<td>BR02 CSRL</td>
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<tr>
<td>9:00 am – 9:15 am</td>
<td>Flight Test Objectives and Plan</td>
<td>Bragg</td>
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<tr>
<td>9:15 am – 9:45 am</td>
<td>Analysis of Quasi-Steady Data</td>
<td>Lee</td>
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<td>9:45 am – 10:00 am</td>
<td>Break</td>
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<tr>
<td>10:00 am – 10:30 am</td>
<td>ID and Characterization with Flight Test Data</td>
<td>Melody</td>
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<tr>
<td>10:30 am – 11:00 am</td>
<td>Future Plans</td>
<td>BR02 CSRL</td>
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<tr>
<td>11:00 am – 11:30 am</td>
<td>Open Discussion</td>
<td>BR02 CSRL</td>
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<tr>
<td>11:30 am – 1:00 pm</td>
<td>Lunch</td>
<td>301 CSRL</td>
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<tr>
<td>1:00 pm – 2:00 pm</td>
<td>Government Meeting</td>
<td>469 CSRL</td>
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<td>2:00 pm – 2:15 pm</td>
<td>Break</td>
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<tr>
<td>2:15 pm – 3:30 pm</td>
<td>Review of SIS Research</td>
<td>469 CSRL</td>
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