Small Airframe Manufacturer’s Icing Perspective
Agenda

- Background/Perspective
- Icing Effects & Mitigation
- Icing Certification
- New Technologies
- Summary and Recommendations
Background/Perspective
Product Line

- Cessna currently offer ten models with FIKI* approval
  - Two models offer equipment for inadvertent icing

*FIKI = Certification for Flight Into Known Icing
## Aircraft Size/Technology

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>MTOW</th>
<th>Certified Ceiling</th>
<th>Max Cruise Speed</th>
<th>Wing Stabilizer</th>
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<tbody>
<tr>
<td>Citation X</td>
<td>36,100 lbs</td>
<td>51000 ft</td>
<td>525 KTAS</td>
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<td>Citation XLS+</td>
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<td>Citation CJ4</td>
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<td>Citation CJ3</td>
<td>13,870 lbs</td>
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<td>417 KTAS</td>
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<tr>
<td>Citation CJ2+</td>
<td>12,500 lbs</td>
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<td>418 KTAS</td>
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<tr>
<td>Citation CJ1+</td>
<td>10,700 lbs</td>
<td>41000 ft</td>
<td>389 KTAS</td>
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<tr>
<td>Citation Mustang</td>
<td>8,645 lbs</td>
<td></td>
<td>340 KTAS</td>
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<tr>
<td>Grand Caravan</td>
<td>8,750 lbs</td>
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<td>Caravan 675</td>
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<tr>
<td>400 Corvalis TT</td>
<td>3,600 lbs</td>
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<td>235 KTAS</td>
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<td>350 Corvalis</td>
<td>3,400 lbs</td>
<td>18000 ft</td>
<td>191 KTAS</td>
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</tbody>
</table>
Trends

Available Aircraft Performance
Available Energy for Icing Systems

Business Jets
Transport & Regional Jets
Business Turboprops
Regional Turboprops
Pistons

Service Ceiling

High Speed Cruise (KTAS)

FIKI = Certification for Flight Into Known Icing
Characteristics of Small Aircraft

- Small leading edges have high water collection rates
  - Increases local water catch rates
  - Increases relative size of ice shapes (w/ respect to chord)
- Typically unpowered flight controls
- Majority are fixed leading edges

Citation Mustang
43.2 ft wingspan

Citation X
63.9 ft wingspan

737 Next Gen
117.4 ft wingspan
Protected Areas

- Small aircraft typically protect a much larger percentage of the airframe.
- Large proportion of available energy is required for ice protection.
- Protected areas provide the majority of aerodynamic effect on small aircraft.
Icing Effects/Mitigation
Icing Effects on Small Aircraft

- Scale effects limit the ability of small aircraft to operate unrestricted in icing
- Performance effects can be significant
- Current ice protection technology can not protect against “severe” icing
- Severe conditions require
  - Avoidance
  - Monitoring
  - Identification and exit

FAA Aeronautical Information Manual: Severe - The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate flight diversion is necessary.
Risk Mitigation

DESIGN
- Aerodynamic Configuration
- Airframe Ice Protection Systems
- Engine Ice Protection Systems
- Air Data Sensors
- Stall Warning/Protection
- System Safety Aspects

CERTIFICATION
- Validation of aircraft performance & handling qualities (w/ ice shapes)
- Validation of ice protection system performance
- Validation of Operating procedures and Limitations
- Validation of Abnormal & Emergency procedures

OPERATION
- Training
- Preflight planning/exit strategies
- Adherence to operating limitations and procedures
- Avoidance and exit from severe icing
Icing Certification
Current Icing Certification

- Icing certification has taken an increasing role in mitigating icing risk
  - Small aircraft standards amended in 1993
  - Large aircraft standards amended in 2007
  - FAA Guidance/Policy continues to evolve
- As part of certification, extensive flight testing is performed with artificial ice shapes
  - Natural icing is typically a validation of the results of the artificial ice shape testing
- Artificial ice shapes provide the data used to develop performance information, operating procedures and limitations
NASA’s Connection to Certification

- Most small aircraft manufacturers rely heavily on NASA developed simulation tools
- LEWICE 2D/3D are the primary ice accretion codes in use for certification
  - Primarily used for unprotected ice shapes
- LEWICE is also used to provide collection efficiencies and impingement limits that are used in designing protection systems
  - Water catch distributions are also used as input to heat and mass transfer analysis
- NASA IRT is often used for developing protected area ice shapes for certification
Conservative versus Accurate

- Conservative ice shapes are required for certification
  - With respect to aerodynamic effect
- However, excess conservatism can have unintended consequences
  - Too high of stall speeds adversely affects approach speeds/landing distances
  - Excessive drag can affect performance and climb information
- As such, conservative and accurate ice shapes are an objective
Certification Changes

- Certification ice shapes are transitioning from a single operating point to scenario based shapes
  - Takeoff ice, Final takeoff ice, En route ice, Holding ice, Approach ice, Landing ice, "sandpaper" ice
- Large droplet rulemaking define scenarios for recognition and exit of conditions
  - Requires transitions between Appendix C and Appendix X icing conditions
- Current available version of LEWICE does not address such scenarios
Future Icing Certification

- Draft rulemaking has been proposed for SLD
- Options include:
  - Unrestricted operations
  - Unrestricted in a portion
  - Detect and exit
- Simulation and compliance methods are limited
- Interim methods focus on detect & exit
**IPHWG**  
**Phase IV Review**

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<thead>
<tr>
<th></th>
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<th>Protected Areas</th>
<th>Detection Methods</th>
<th>Air Data Sensors</th>
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<td></td>
<td>Wing</td>
<td>Tail</td>
<td>Radar</td>
<td>Non-lifting Surfaces</td>
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<td><strong>FZDZ</strong> 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 means of compliance, or is readily achievable based on current experience.  
- 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*
# IPHWG

**Phase IV Review**

**Small Aircraft Emphasis Area**

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- Green: The capability exists today and is suitable to be an element of a means of compliance, or is readily achievable based on current experience.
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- Current 2D capabilities exist with large droplet effects, but limitations exist in the use of 3D codes for simulation of Appendix X effects.

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Simulation Efforts

- As illustrated, much work remains to mature SLD simulation methods
- With individual icing tunnel tests on the order of $500k to $1M, no individual manufacturer has the resources to mature simulation methods
- This effort is best accomplished through joint efforts between NASA and industry
  - Benefits flying public by improving safety
  - Conserves limited resources
Balance of Needs

- Much of the funding for icing research appears to have shifted towards engine/ice crystal research
  - This area is less mature than SLD and requires significant research and development
- However, the maturity of the SLD simulation methods will likely have a larger near term impact on icing safety
- Continued development of both the ice crystal and SLD technical areas is recommended
New Technologies
New Technologies

- Continued interest in new technology ice protection systems that balance design parameters
  - Energy requirements
  - Aerodynamic effects
  - Weight
  - Reliability
  - Affordability
- Severe icing detection methods
  - For both Appendix C and SLD
Summary and Recommendations
Summary

- NASA’s simulation tools are essential for aircraft development and certification
- Artificial ice shapes developed using these tools are fundamental to the certification process
- Continued maturation of SLD simulation tools are essential for future certifications
  - Particularly combined effects of SLD with ice protection systems
    - Potential accretions aft of protected areas
Needs/Recommendations

- Atmospheric research that supports a detect and avoid strategy
- Aircraft level simulation of icing effects
  - Current certification standards provide a rigorous evaluation prior to field operations
  - Provides the basis for any aircraft specific training that may be required
- Computational simulation of ice accretions during scenarios
  - Changing icing and aircraft conditions, etc.
  - Aligns LEWICE with current regulatory requirements
Needs/Recommendations (cont.)

- Performance of ice shapes with well defined separation features is fairly consistent with scale
  - Can be readily simulated in scale wind tunnel tests
- Roughness based ice shapes still present challenges with respect to scale
  - Reynolds number issues
- Ability to effectively model roughness based ice shapes is critical for design and certification
  - Improved predictability of full wing stall behavior
  - Ties in with aircraft level simulation of icing effects
Recommendations: NASA’s Role

- Provide technical leadership
  - Roadmaps, consortiums, industry cooperative programs
- Fundamental research to be used in simulation methods
- Continued support of development and certification tools (with focus on SLD)
  - Proactive approach to icing safety
  - Addresses the issue before the aircraft are placed in the field
Questions?