2008 Aircraft Icing Research Alliance -

Research Implementation Forum

R&D on Icing Engineering Tools for Regulatory Use

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Outline

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FAA Priorities

Research Needs

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This presentation concentrates on research and development of in-flight engineering tools for improving certification efforts for aircraft icing.

Acknowledgement

I would first like to recognize that significant new capabilities in the development of engineering tools for icing design and certification have taken place over the last 10+ years.

Organizations like NASA, Environment Canada, National Research Council Canada, NCAR, ONERA, DSTL, INTA, Transport Canada, the FAA, and their academic partners have made tremendous gains in the basic science knowledge and the engineering disciplines involved in icing, icing weather, and iced aerodynamics.

Special recognition should go to NASA, University of Illinois at Urbana-Champaign, Wichita State University, Iowa State University, and Mississippi State University for the body of research they have delivered!

Current Developments

Recent R&D work has provided a great deal of evidence about atmospheric icing conditions, ice shape features and iced aerodynamics, icing physics and scaling, and large droplet icing conditions. Technical committees have provided major improvements and standards for facilities (tunnels, tankers, and codes) calibration and performance criteria. Growing international collaboration has leveraged resources to provide expertise, funds, and research assets.

The regulatory agencies and industry have reviewed these improvements and, along with industry experience, have been developing improved guidance material for use of this knowledge to improve means of compliance.

Current Developments

This recent investment into icing R&D has improved aviation safety – how we account for icing effects on aircraft and what to look for during certification.

However

The icing research community is a long way from completing the investigative work needed to understand how ice accretions grow and how to model, develop, validate, and use 3D CFD tools to provide accurate estimates of performance and handling qualities prior to flight testing (for airframe and propulsion systems). 3D iced aerodynamics, steady and unsteady flow – also needs much more work. The facilities capabilities and test techniques are still not adequate for large, multi-component test articles across the range of icing conditions.

Current Developments – Why better tools are needed?

- Winter operations feedback continues to provide areas of concern to flight standards and icing specialists.
- Incidents and accidents continue to happen and provide clues to either what was missed in a certification effort, or what we don't understand:
  - Ice accretion buildup can impact aerodynamic and propulsion performance and aircraft handling qualities in ways not expected or understood.
  - Icing conditions beyond current certification requirements can be encountered potentially resulting in aircraft that are not fully tested for safe operations.

  A number of these events have been examined (CAST, IPHWG, etc.) to help identify changes in icing certification needs.
- New knowledge, new test and measurement techniques, and increased computational speed and efficiency have provided opportunity to improve the accuracy and reliability of engineering tools.
  - These have opened the boundaries to explore micro-physical phenomena

Current Developments – Where we are?

- Engineering tools used for current designs and means of compliance (MOC) for certification for icing:
  - ➢ Rigorous test capabilities, artificial ice shape testing in natural conditions, and historical experience have led to accepted practices for use of engineering tools in certification
  - ➢ Test methods – adequate for 2D and 3D within limited scaling ranges
  - ➢ CFD – adequate for 2D simple airfoil sections and "historically tested" icing conditions.
- Icing facilities have been developed with performance and icing condition testing capabilities that meet needs of many low-speed, component-level current design efforts.
  - ➢ Icing tunnels, engine test cells, and icing tankers are the typical experimental facilities that provide MOC for certification
    - ✓ These are also used, along with flow labs, calibration facilities, and icing research aircraft by researchers to further explore icing physics and scaling, ice growth modeling, iced aerodynamics, and iced flight dynamics

Current Developments – What are the challenges?

- Engineering tools for design and means of compliance need to be developed and validated for:
  - Icing scaling for size/geometry/conditions-limited testing
  - 3D, complex multi-body aircraft components
  - Internal flow, propulsion system analysis
  - Complete aircraft analysis
- Fundamental work needs to be done to develop a comprehensive understanding of the physics underlying ice growth on aerodynamic surfaces: water film transport, roughness and heat transfer, phase change kinetics, three-phase flow, and ice growth modeling.
- Iced aerodynamics research is needed to study the effects of ice contamination on both boundary layer level and far-field flow phenomena, both steady and un-steady.
- New engineering tools need to be developed and validated for Supercooled Large Droplet (SLD) icing and ice crystal engine icing.

FAA Priorities (through 2010): for Research Related to Improved Engineering Tools for Means of Compliance

1. Reduce accidents during flight in Supercooled Large Droplet, glaciated, and mixed-phase icing conditions:
    A. Engine powerloss and damage from high altitude ice crystal ingestion
    B. New rulemaking for performance and handling in SLD
2. Reduce accidents during flight in Appendix C icing conditions
3. Propeller icing effects on safe flight *(priority for funding still unresolved)*

FAA Priorities: Reduced Accidents During Flight in Glaciated, Mixed-phase and SLD Icing Conditions

What research is needed?

- Glaciated, mixed-phase, and SLD research needed to support the Aviation Rulemaking Advisory Committee (ARAC) recommended rulemaking
  - Develop and validate means of compliance
  - Get mixed-phased icing conditions measurements
  - Provide regulatory guidance

FAA Priorities: Reduced Accidents During Flight in Appendix C Icing Conditions

What research is needed?

- Validate and enhance icing simulation methods used as means of compliance for flight in icing approvals
- Investigate critical ice shapes
- Provide guidance for certification of ice protection systems.

FAA Priorities: Propeller Icing Effects on Safe Flight

Why is research needed?

- Turboprop powered airplane accident investigations have indicated loss of control resulting from insufficient acceleration in airspeed during stall warning recovery, and drag that cannot be accounted for by airframe ice accretions.

What research is needed?

- Provide certification guidance for determining the effects of propeller icing on propeller efficiency and resulting effects on airplane handling and performance, including use of testing and analytical methods.

FAAPriorities*: Rotorcraft Icing

* <u>*Did not receive approval for new funding start this FY:*</u>

- Assessment of and guidance for use of analytic methods for evaluation of rotor ice accretion, runback ice, and shed ice for new certifications of rotorcraft for flight in icing conditions

What research is needed?

- Assess new analytical methods to determine acceptable means of compliance
  - for evaluating rotor ice accretion on thermally protected rotor blades, and
  - for evaluating rotor ice shedding
- Obtain data and information on the capabilities of the analytical methods for developing guidance on their use as certification means of compliance.

FAA Priorities: Next Steps

So far, only one of the FAA priorities for improvements in engineering tools to support means of compliance has arrived at a point in the new rulemaking process where the Aviation Rulemaking Advisory Committee is providing feedback on next steps:

SLD, Mixed-phase, and Glaciated Icing Conditions

Research Needs – Feedback to the FAA Priority for SLD, Mixed-phase, and Glaciated Icing Conditions Based on the *New Rulemaking* Process

- In response to FAA tasking, during November 2005, ARAC recommended proposed 14 CFR Parts 25 and 33 rulemaking to the FAA with a strong recommendation to continue funding efforts for development and validation of icing simulation methods (analytical, experimental, and testing).
- ARAC requested that the IPHWG conduct a Phase IV review of the research status regarding engineering tools capability for MOC prior to issuance of the proposed rulemaking as a NPRM. The Phase IV review is on-going.
- Research identified in the SLD technology roadmap is feasible but *still* requires significant investments, coordination, and commitment by the FAA, Transport Canada, NASA, other Canadian federal research agencies and other worldwide research organizations.

Research Needs – FAA Priorities: Feedback for SLD, Mixed-phase, and Glaciated Icing Conditions Based on ***New Rulemaking***

The “bottom line” here is:

- ARAC has requested that the capability to address the means of compliance for the new rulemaking for SLD, mixed-phase, and glaciated icing conditions should be examined and determined to be adequate at some confidence level prior to initiating any new rulemaking.
- The engineering tools that have been researched and developed need to be evaluated for their application as means of compliance.

Research Needs – FAA Priorities: Ice Crystal R&D

- Engineering tools R&D related to ice crystal effects on turbine engines
  - Development of instrumentation to measure high ice water content (HIWC) environments
  - Development/modification of instrumentation suite and research aircraft preparations for NASA S-3 Viking aircraft field campaigns for ice crystal environment characterization
  - Characterization of HIWC conditions – field campaigns, data analyses, and evaluation of mixed-phase/glaciated icing conditions for a standard
  - Investigations to understand ice crystal formation mechanisms for turbojet engines and develop modeling techniques: single blade, cascade, and rotating rig tests

Research Needs for

Fundamental Studies and general engineering tools R&D:

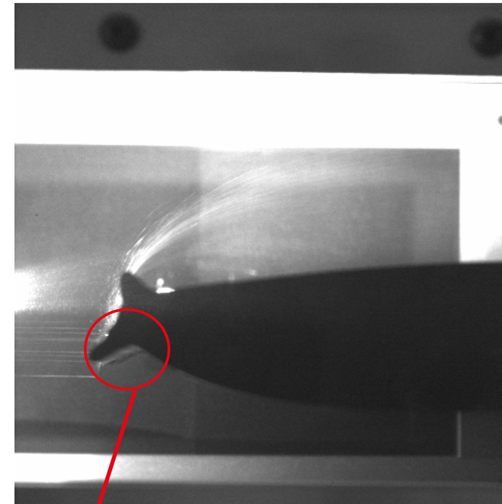
- *Experimental methods*
- *Ice accretion modeling*
- *CFD*
- *Facilities Development*

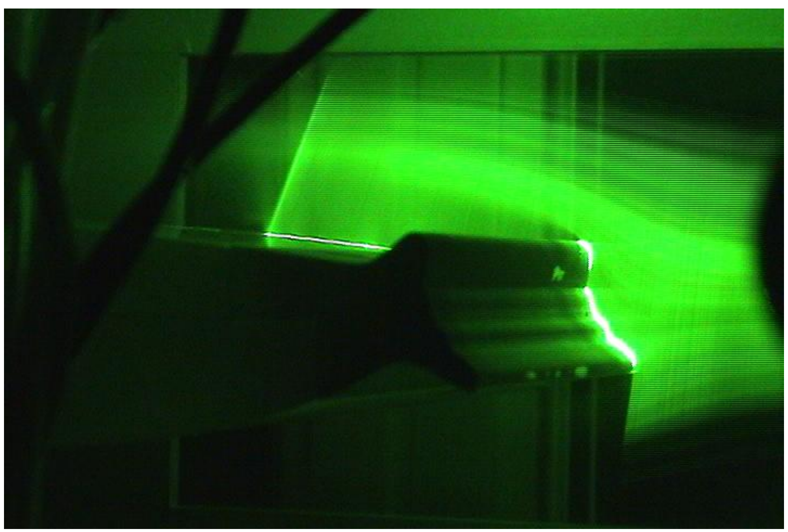
These research needs will support all icing conditions.

Research Needs – Experimental Methods (1/3)

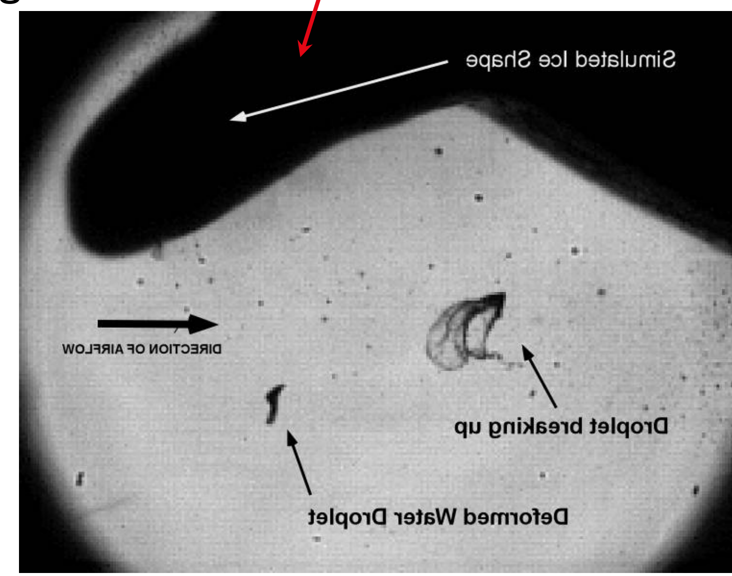
Advanced Measurement Techniques

- Fluid-thermal measurements in the region near the ice/water/air interface
- Non-intrusive liquid water and droplet diameter measurement methods for regions upstream and surrounding test targets
- Unsteady, high-speed velocity measurements in the entire flow surrounding the iced geometry
- Automated ice shape measurement techniques



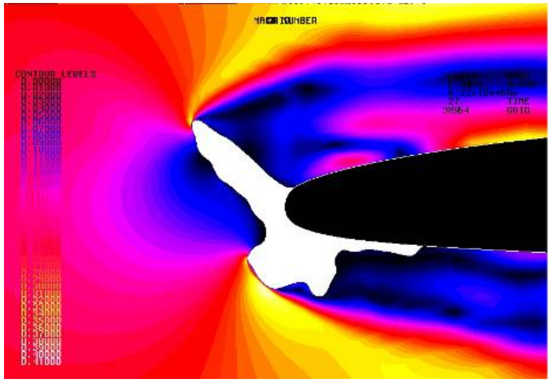


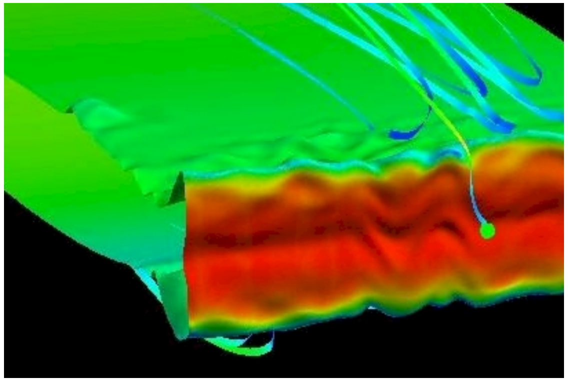
Images from NASA Glenn DrIFT

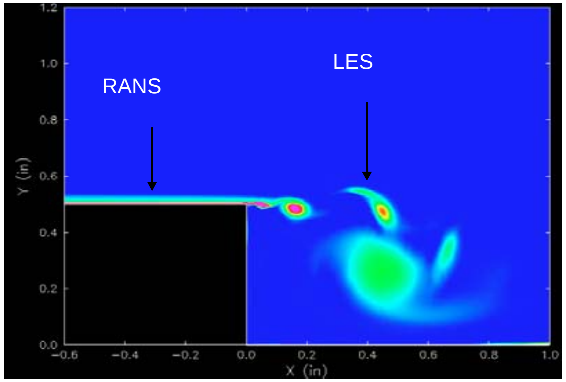


Research Needs – Experimental Methods (2/3)

- Iced Aircraft CFD Modeling - near-stall condition flow field research
  - Regions containing vortex shedding, vortex interaction from several regions of interest, flow separation and reattachment, separation bubble reattachment unsteadiness, and extended regions of boundary layer transition





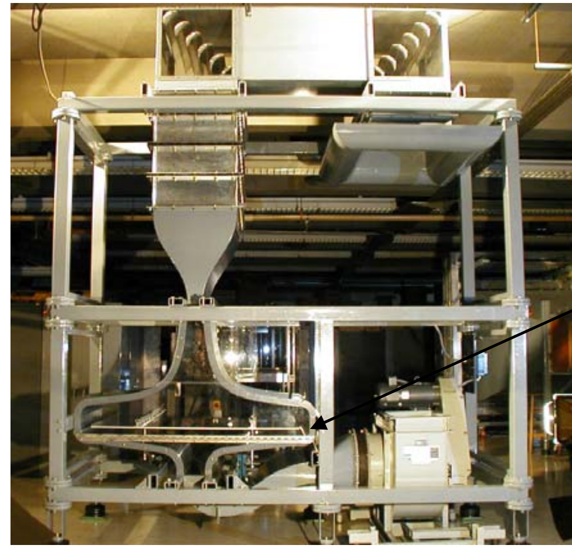


Images courtesy of NASA

Research Needs – Experimental Methods (3/3)

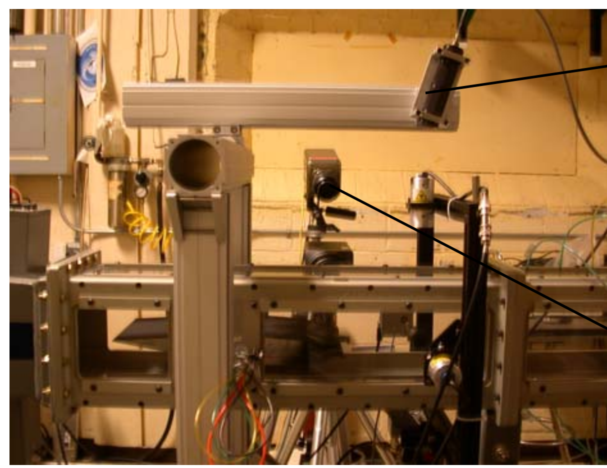
Microphysical Studies

- Multi-phase region at the ice surface: water film thickness and velocity, the ice surface topology, detailed airflow temperatures and velocities



Physics Flow Laboratory - at NASA Glenn

Experimental site



Laser sheet source

NASA Glenn DrIFT

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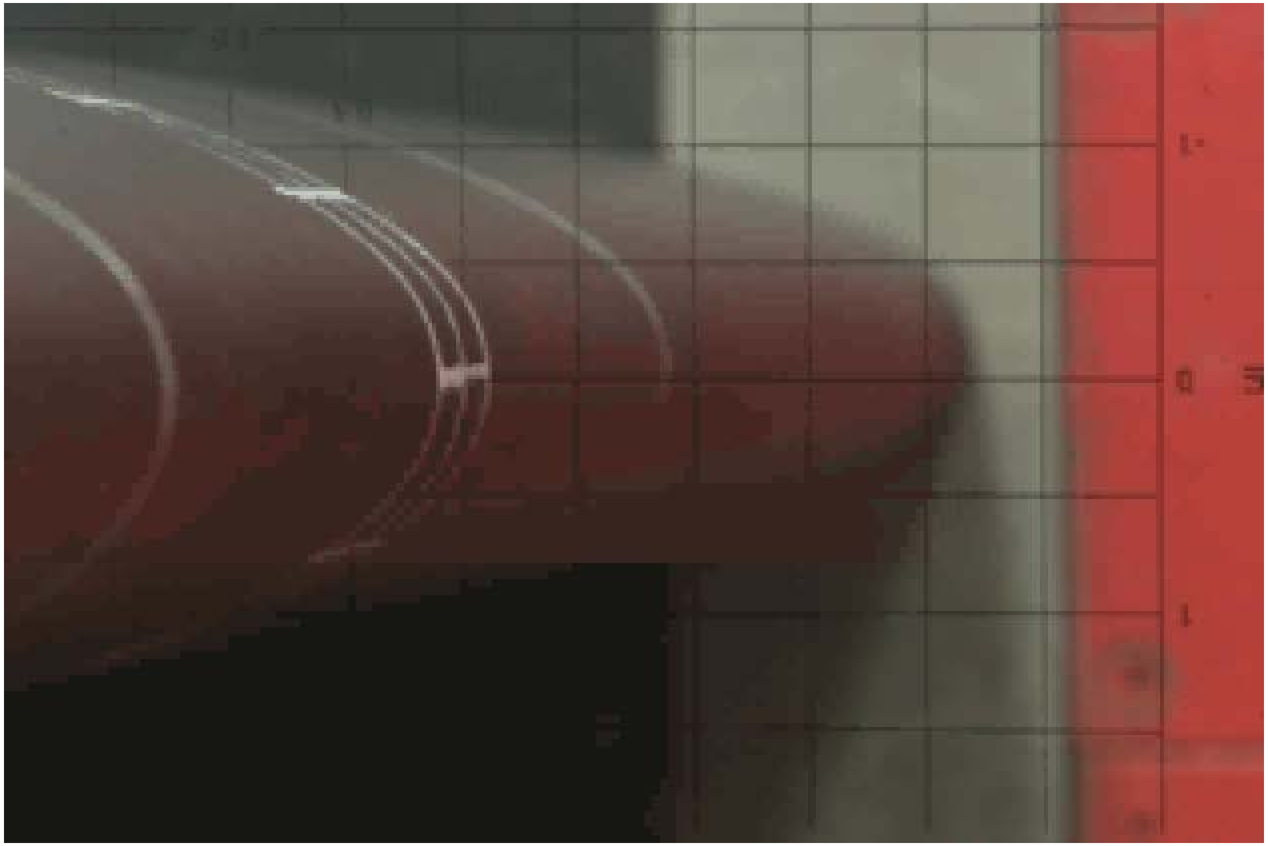
Research Needs – Ice Accretion Modeling (1/2)

Research needed to de-construct ice growth stages into micro-physical phenomena from roughness to ice feathers to ice shape ⟶ new physical models, improved CFD tools

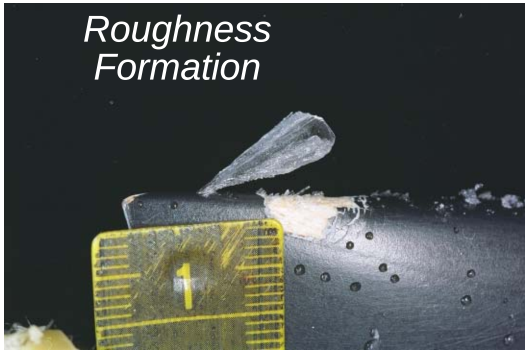


Movie

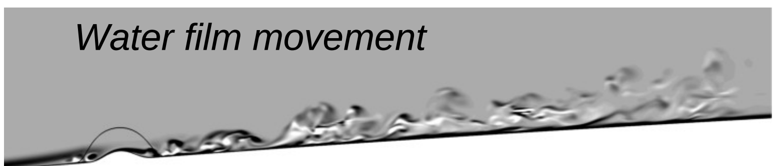
IRT Test –

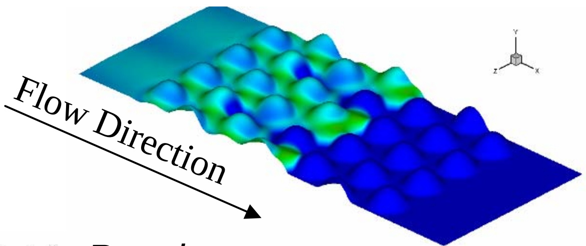
ice shape growth

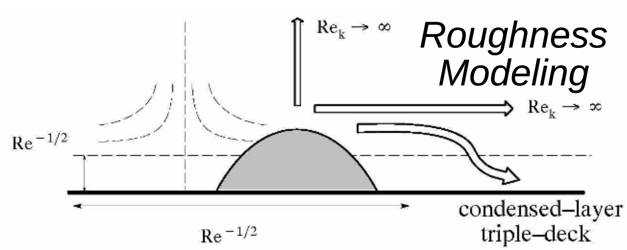
Research Needs – Ice Accretion Modeling (2/2)



Feather growth

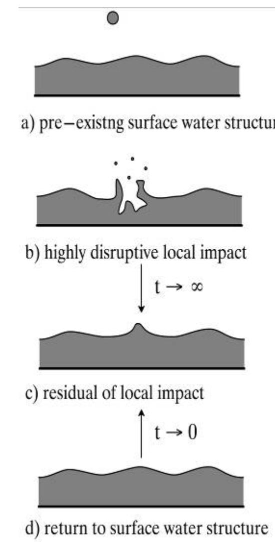






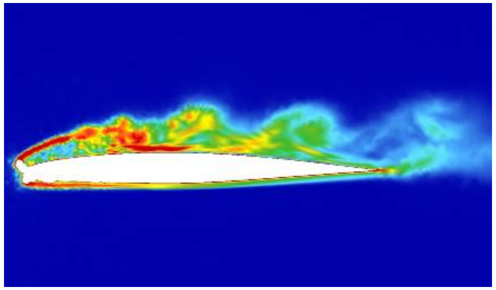
Examine the physics of ice accretion to understand:

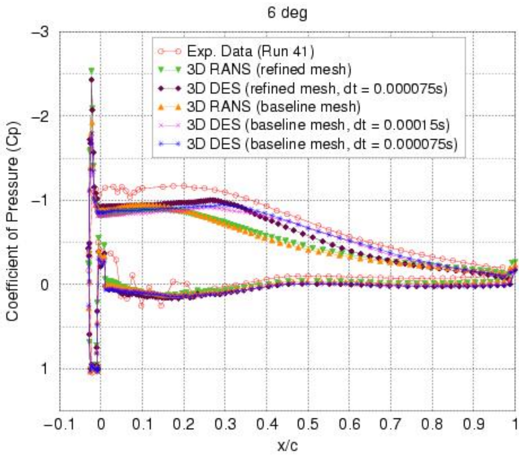
- Droplet impact dynamics (splashing, break-up, re-impingement)
- Surface water transport
- Heat transfer
- Roughness formation
- Phase change kinetics
- Scallop ice (swept wing) shape formation



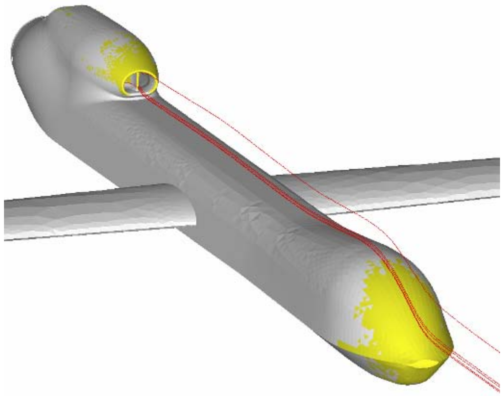
Research Needs – Iced CFD Studies

1.) Ice feature effects, identification of critical ice shapes



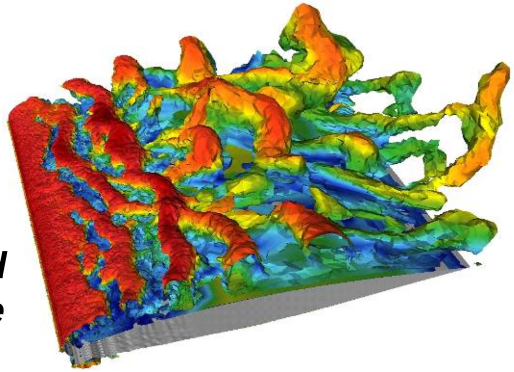


3.) CFD modeling for 3D surfaces

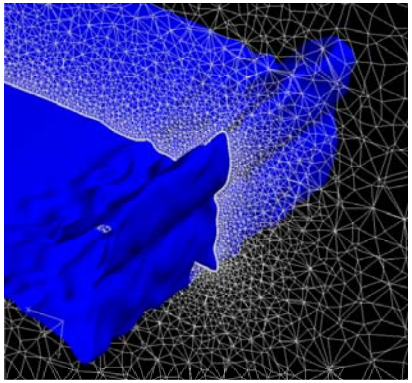


2.) Turbulence modeling and time dependent/ adaptive gridding for icing topology

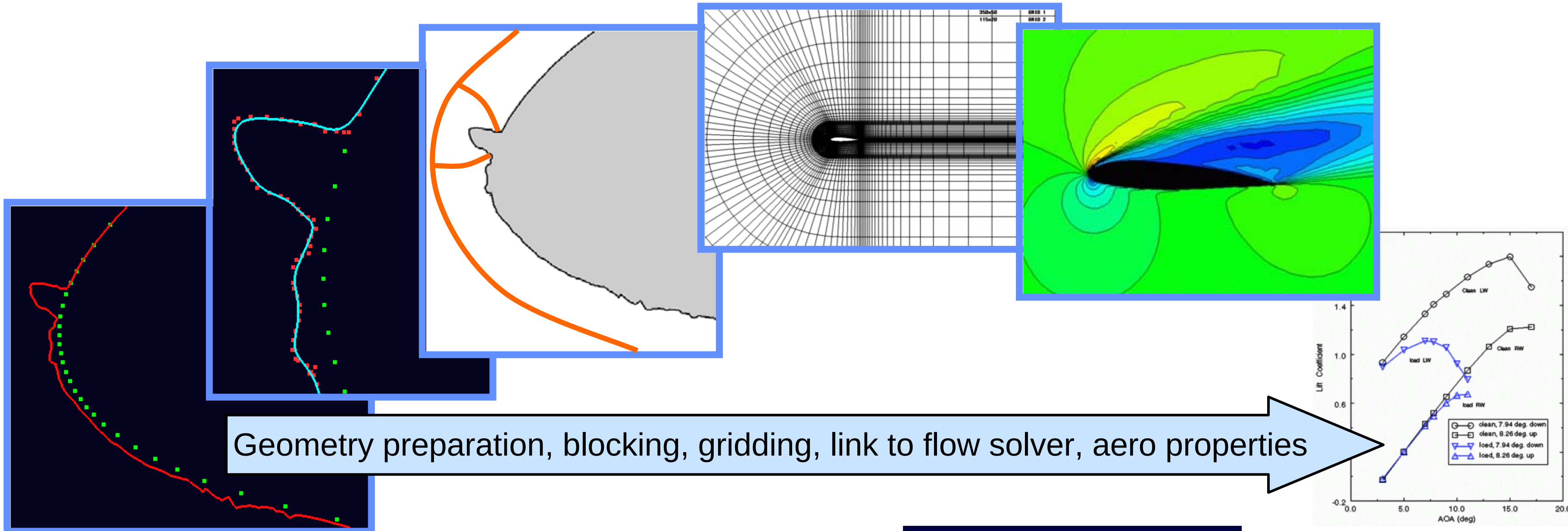
Turbulence generation behind a leading edge ice shape



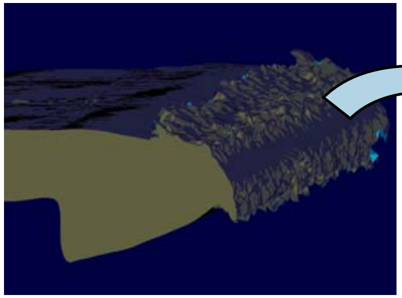
4.) Roughness effects (unsteady, multi-scale)

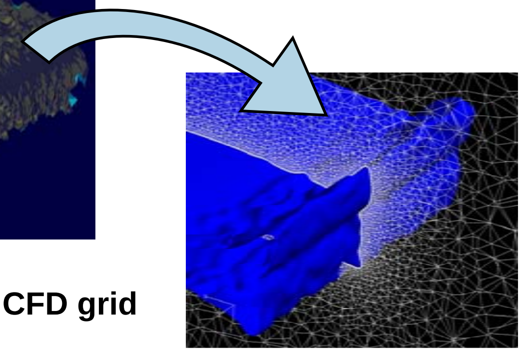


Research Needs – Iced Aircraft CFD Modeling



- Ice feature effects
- Identification of critical ice shapes
- Surface modeling and grid generation
- Turbulence modeling and multi-phase flow
- Time dependent/adaptive gridding
- CFD modeling for 3D surfaces
- Roughness effects (unsteady, multi-scale)
- 3D particle tracking through unsteady/separated flow





Scanned solid to CFD grid

Research Needs – Facilities & Instrumentation

- Develop ground facilities simulation and test methods:
  - Large droplet (freezing rain) simulation
  - Ice crystal simulation
  - Engine testing for ice crystal conditions – design and means of compliance
  - Validation databases for CFD tools: 3D airfoils, SLD conditions, etc.
- Instrumentation
  - High ice water content – research quality instrumentation for flight and ground facilities
  - SLD liquid water content probe

Conclusions

- Icing safety continues to be an area of high interest (included in the NTSB Top 10 Most-wanted). Improvements are still needed in basic science, CFD development, facilities capabilities, experimental methods, and ice aerodynamics.
- Engineering tools R&D is critical to continued improvements in aviation safety and to allow the FAA and other regulatory agencies the ability to provide improvements in guidance for better means of compliance.
- Substantial research investments are still needed to support more accurate and reliable means of compliance.

Observations

- The national levels of funding for icing in general, and specifically for new R&D on fundamental studies to improve knowledge on icing physics, iced aerodynamics, and develop better engineering tools is going down.
- Resource costs for testing, validation, and new highly specialized instrumentation and equipment are going up.
- In order to continue to make aviation safety improvements in icing and pursue better compliance, and guidance development, *more aggressive pursuit* of international collaboration and coordination is needed.

AIRA can play a role here!

We need to develop collaborative partnerships to bring together industry (engine and airframe manufacturers), research organizations, and academia to pursue airframe and engine icing R&D. No single group has expertise and resources to develop simulation capabilities, development of computational tools, and experimental test methods for design and means of compliance.

Thank You

Any Questions