Validation of 3D Ice Accretion Codes

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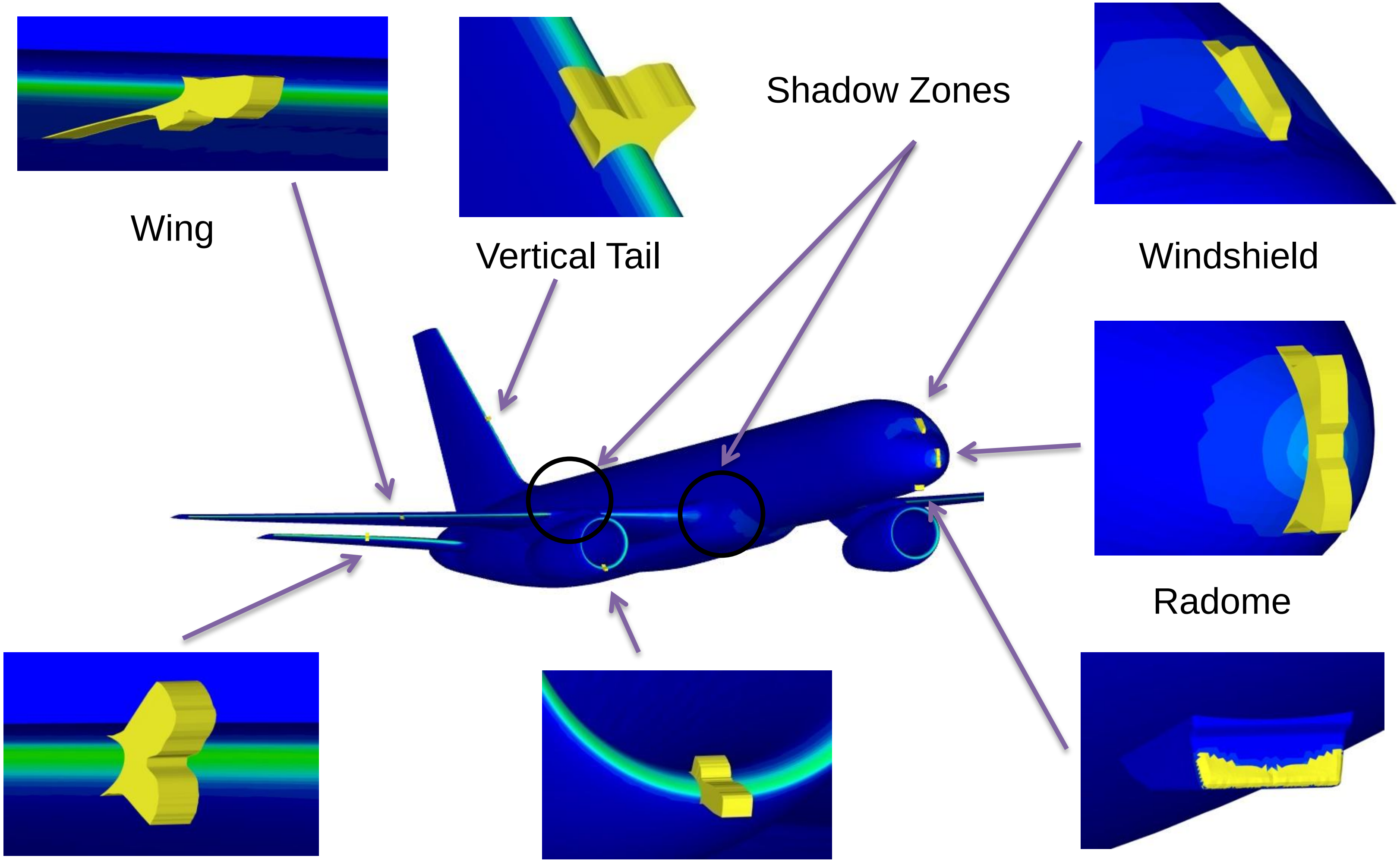
Outline

- Classes of Problems
- Code Elements
- Elements of Accuracy
- Types of Data Bases Available

Common Areas of Analysis For External Airframe Icing



Other Problems of Interests

- High-Lift systems
- Spinners
- Engine, Wing, Sensor Struts
- Vortex Generators, Vortilons
- Engine and APU Ducting
- Propellers
- Internal Guide Vanes
- Compressor Rotors and Stators
- FOD Analysis For Shed Ice
- Sensor Design and Performance (speed, temperature, icing)
- Instrument and Sensor Cloud Correction

Elements of 3D Icing Tools

- Grid Generators
- Flow Solvers
- Collection Efficiency Analysis
- Convective Heat Transfer Analysis
  - Roughness Effects
  - Transition Effects
- Surface Mass, Momentum and Energy Balances
  - Runback Modeling
  - Evaporation
  - Splashing
- Surface Addition Models
  - Ice growth
  - Ice Density

Elements Of Accuracy

The ice accretion process is a non-linear process with high sensitivity to flow, particle transport, convective heat transfer, and surface film dynamics. Each of these processes must be modeled accurately to generate an accurate ice shape.

- **Flow Field**
  - The flow field must be modeled accurately. Differences in local angles-of-attack of as little as 2 degrees can cause significant difference in impingement, heat transfer and the resulting ice shape.
  - Grid models must be properly resolved to generate accurate particle transport and surface mass, momentum and energy balances (20-50 surface elements in impingement region)
- **Collection Efficiency**
  - Collection efficiency must be resolved accurately. Sufficient volume and surface grid resolution must be provided along particle path to transport particles accurately.
  - For complex surfaces with multiple impact regions along particle paths (e.g. multi-element wings, ducts, fuselage mounted pods) distributions may be required to resolve drop size effects.
  - Diffusion and stability effects for complex particle paths must be quantified and controlled before confidence can be placed in Eulerian drop transport methods.
  - SLD conditions require splashing models to account for the large mass loss observed in impingement experiments (~30%).

Elements Of Accuracy cont.

- **Convective Heat Transfer**
    - The calculation of accurate convective heat transfer remains the most critical element in obtaining accurate mixed and glaze ice shapes. The modeling of transition and roughness are key components in the calculation convective heat transfer. The size and location of ice horns are directly related to transition location and the magnitude of roughness. Roughness and transition models have been tuned to generate good agreement over a range of icing conditions for the Integral Boundary Layer techniques used in the LEWICE programs. Navier-Stokes code based methods used for generating convective heat transfer must employ transition models, roughness models and have sufficient grid points in the boundary layer before confidence can be placed in these methods to generate accurate heat transfer. That is generating heat transfer from fully turbulent boundary layers without roughness effects or simple multipliers is not an acceptable method for determining heat transfer for ice shapes.
- **Surface Film Dynamics**
    - Film models must accurately predict the transport of water on the surface especially for glaze ice shapes where it is known that a large amount of water is transported from the stagnation region to the horn region.

Elements Of Accuracy cont.

- **Ice Addition**
  - Accurate ice density models are crucial in generating iced surfaces especially for swept wings where overall ice densities can be less than 20 percent of the standard un-swept densities resulting in ice shapes that are 5 times larger.
  - Radius of curvature should be accounted for in ice addition or added mass can be much larger than that desired.
- **User Experience**
  - 3D icing analysis tools do not represent a mature technology. This requires that the user be sufficiently proficient to access the quality of their solutions (e.g. reasonableness of flow, heat transfer or collection efficiency, ice shape).
  - New users at a minimum should be proficient in the used of 3D grid generation and flow solver technology. This is not always the case.
  - New users must introduced to topics related to icing physics such as: heat transfer, droplet transport, convection heat transfer, transition, roughness, ice types such as rime, mixed, glaze and scalloped, critical ice shapes, droplet distributions, splashing and shadow zones. It can take years to master these topics.
  - It can take a month for a new user to generate a reasonable first 3D analysis.
  - It can take 3-5 years to become moderately proficient and 5-10 to become an expert with these tools.

Validation Data

- **Flow Solution**
  - Lift, Drag
  - Pressure Distribution
  - Boundary Layer Velocity Profiles
- **Collection Efficiency Methods**
  - Surface Water Catch (NASA/WSU Impingement Test Data)
  - Surface Water Catch (Rime Ice Shapes)
  - Particle Velocity Measurements
- **Convective Heat Transfer**
  - Heat Transfer Measurements
- **Surface Film Dynamics**
  - Surface Film Measurements
  - Droplet Splashing Measurements
- **Ice Shape Data**
  - Tracings, Castings, and 3D Scans
  - Ice Density Shape Density Measurements

Conclusions

- Aircraft Icing involves many classes of problems each of which can require different solution techniques and validation data. A piece-wise approach whereby tools are certified for a certain class of problems and validated against an appropriate set of data seems the most reasonable.
- A relatively large amount of validation data exists for both flow and droplet impingement for common problems of interest (wings, inlets, ice shapes).
- There is a dearth of data for 3D convective heat transfer which is the arguably the most important factor in accurate glaze ice shape prediction.
- Very little publicly available 3D ice shape data exists. Access to company proprietary ice shape data would greatly expand the size and diversity of the data base. This is probably the only path by which near term (~5 years) 3D code validation could occur.