Computational Aerodynamic Analysis of Three-dimensional Ice Shapes on a NACA 23012 Airfoil

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Overview

• Background
• Motivation
  – Ice Accretion Shapes
  – Workflow
• Approach
  – Grid Generation
  – CFD
• Results
• Future Work
Background

Lift Coefficient, $C_l$

Drag Coefficient, $C_d$

Angle of Attack, deg

Clean

Runback

Glaze

Rime

Clean

Runback

Glaze

Rime

Clean
Background

- To-date CFD analysis has been performed on, 2D cross-sections, 3D extrusions of 2D cross-sections, and 3D ice shapes generated by ice accretion codes.
Motivation

• Complex 3D ice shape geometry data can now be collected
  – In-situ laser scans of ice accretion shapes
  – CAT scans have also been performed
  – Complete ice shape documentation, including surface roughness elements

• How good is good enough?
  – What level of ice shape detail must be simulated by ice accretion codes?
  – Detailed analysis of the aerodynamics and heat transfer mechanisms at the ice-liquid-air interface can shed light on the parameters of importance
Ice Accretion Shapes

• Types of ice accretion
  – Rime
Ice Accretion Shapes

- Types of ice accretion
  - Glaze
Workflow:

1. Ice Shape Scanned in IRT
2. Ice Shape Processed with Geomagic
3. Ice Shape Grid Built in Pointwise
4. Aerodynamic Analysis with NCC
5. Plotting and Visualization with Tecplot
Approach (Grid Generation)

Geomagic

Commercial software used to create watertight surface from scanned point cloud data

Approach (Grid Generation)

Pointwise

Commercial software used to import ice shape geometry data and create grid for CFD analysis

1. Import Geometry
   • Database
   • Surface Grid
Approach (Grid Generation)

Pointwise
1. Import Geometry
2. Create Surface Grid - Rime
Approach (Grid Generation)

**Pointwise**

1. Import Geometry
2. Create Surface Grid - Horn
Approach (Grid Generation)

**Pointwise**

1. Import Geometry
2. Create Surface Grid
3. Create Volume Grid - Rime
Approach (Grid Generation)

**Pointwise**
1. Import Geometry
2. Create Surface Grid
3. Create Volume Grid - Horn
Approach (Grid Generation)

**Pointwise**
1. Import Geometry
2. Create Surface Grid
3. Create Volume Grid
4. Refinement
# Statistics of Initial Grids

<table>
<thead>
<tr>
<th>Ice Shape Geometry</th>
<th>Chord length (in)</th>
<th>Span length (in)</th>
<th>Grid Type</th>
<th>Volume grid cell count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean</td>
<td>-</td>
<td>18</td>
<td>12</td>
<td>Structured</td>
</tr>
<tr>
<td>Rime</td>
<td>ED1966</td>
<td>18</td>
<td>6</td>
<td>Unstructured</td>
</tr>
<tr>
<td>Glaze</td>
<td>ED1978</td>
<td>18</td>
<td>6</td>
<td>Unstructured</td>
</tr>
</tbody>
</table>

National Combustion Code (NCC)

• **Solver**
  - Finite-volume
  - Explicit, four-stage Runge-Kutta integration algorithm
  - RANS, URANS

• **Turbulence**
  - $k - \epsilon$ model
  - higher order, non-linear method
  - Partially Resolved Numerical Simulation (PRNS)

• **Parallel Computing**
  - Parallel Virtual Machine (PVM)
  - Message Passing Interface (MPI)

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Domain Conditions

• Boundary Conditions
  – Velocity Inlet
  – Pressure Outlet
  – No-slip Airfoil Wall
  – Periodic Side Walls

• Freestream Conditions
  \( M = 0.10, 0.18 \)
  \( \text{Re} = 1.0 \times 10^6, 1.8 \times 10^6 \)
  \( P_\infty = 98,595 \ [\text{Pa}] \)
  \( T_\infty = 294.3 \ [\text{K}] \)
  \( \alpha = 0^\circ \text{ to } 10^\circ \)
Clean Wing (M=0.10 @ 0°)
Clean Wing (M=0.10 @ 0°)
Clean Wing \((M=0.10 \ @ \ 0^\circ)\)
Other CFD Solvers

![Graph showing Pressure Coefficient, \(C_T\), vs. Normalized Chord, \((x/c)\)]
Clean Wing (M=0.10 @ 0°)
Other CFD Solvers
Clean Wing $C_L$ Curve (M=0.10)
ED1966 Wing (M=0.10 @ 0°)
Rime Shape
ED1966 Wing (M=0.10 @ 0°)
Rime Shape

![Diagram of Pressure Coefficient vs Normalized Chord](image-url)
ED1966 Wing Lift Coefficient Results

Rime Shape

- Results suggest that viscous effects play a role for the rime ice case, consistent with expectations.

- Results from a single instantaneous pressure profile, used in the computation, need to be replaced with time averaged and spatially integrated results.
ED1978 Wing (M=0.18 @ 0°)
Glaze shape
ED1978 Wing (M=0.18 @ 0°)
Glaze Shape
Future Work

• Detailed examination of solutions
  – Both ice shapes (ED1966 and ED1978)
    ▪ Variations in flow field results across the span
    ▪ Time averaging of unsteady results
    ▪ Spatial integration across the span
    ▪ Grid resolution studies
    ▪ Turbulence models
  – Glaze ice shape (ED1978)
    ▪ Investigate cause of pressure fluctuations near leading edge

• Parametric study of mesh quality
  – Establish minimum amount of grid points along airfoil surface

• Perform detailed analysis of ice surface roughness region

• Develop post-processing modules for NCC to calculate standard external aerodynamic parameters
Thank You!

Questions?