Low-Reynolds Number Aerodynamics of an 8.9% Scale Semispan Swept Wing for Assessment of Icing Effects

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Introduction

- Development and use of 3D icing simulation tools.
- Lack of ice accretion and aerodynamic data for large-scale, swept wing geometries.
- Aerodynamic understanding important for evaluating efficacy of 3D icing simulation tools.
- Multi-faceted research effort called SUNSET II.
Introduction

Aerodynamic understanding important for evaluating efficacy of 3D icing simulation tools.

• Low-Reynolds number \((Re \leq 2.4 \times 10^6)\) aerodynamic test campaigns.

• The artificial ice shapes were developed based upon a series of ice-accretion tests in the NASA Icing Research Tunnel.
  − High fidelity and low fidelity

• Higher-Reynolds number (up to \(Re \approx 12 \times 10^6\)) aerodynamic test campaigns.
Objectives and Approach

Objectives
• Perform experimental and computational assessment of clean-wing aerodynamics, model installation and simulation of small ice roughness.

Approach
• Perform aerodynamic testing with 8.9% scale semispan swept wing model of CRM65 at low-Reynolds number.
• Perform 3D RANS simulations of clean wing fully turbulent and with free transition.
• Parametric study of model-mounting configurations.
• Investigate techniques for simulating small ice roughness.
Common Research Model (CRM)

- Commercial transport class configuration.
- Contemporary transonic supercritical wing design.
- Publically available and otherwise unrestricted for world-wide distribution.
- A 65% scale CRM was selected as the full-scale, reference swept-wing geometry for this research.
- CRM65 size airplane is comparable to Boeing 757.
Experimental Methodology

- Aerodynamic testing performed at Wichita State University Beech Wind Tunnel.
- Test section size 7-ft x 10-ft.
- 8.9%-scale semispan model of CRM65 geometry.
- Reynolds numbers = 0.8, 1.6 and 2.4×10^6
- Corresponding Mach numbers = 0.09, 0.18 and 0.27.
- Measure surface pressure - $C_P$.
- Mini-tuft and surface-oil flow visualization.
Model Mounting Configurations

- Circular Splitter Plate
- Rectangular Splitter Plate
- Streamlined Shroud
- Wing
- Circular Shroud
- Seam for splitter plate removal
Model Mounting Configurations

- Effect of model mounting on aerodynamic performance at $Re = 2.4 \times 10^6$, $M = 0.27$. 

![Graph showing CL and CD vs. angle of attack for different model configurations.](graphics)
Model Mounting Configurations

- Surface pressure distribution at $y/b = 0.44$, $\alpha = 13.2$ deg., $Re = 2.4 \times 10^6$, $M = 0.27$. 

![Graph showing pressure distribution with different configurations]
Clean Model Aerodynamics

- Effect of Reynolds and Mach number on clean wing configuration.
Clean Model Aerodynamics

- Surface pressure distribution at $Re = 1.6 \times 10^6$, $M = 0.18$. 

\[
\alpha = 9.0 \text{ deg.}
\]

\[
\alpha = 11.1 \text{ deg.}
\]
Clean Model Aerodynamics

- Mini-tuft and surface-oil flow visualization at $\alpha = 11.1$ deg., and $Re = 1.6 \times 10^6$, $M = 0.18$. 
Clean Model Aerodynamics

- Surface-pressure distribution and mini-tuft flow visualization at $\alpha = 13.6$ deg., and $Re = 1.6 \times 10^6$, $M = 0.18$. 

![Diagram showing pressure distribution and flow visualization](image-url)
Clean Model Aerodynamics

- Surface-pressure distribution and mini-tuft flow visualization at $\alpha = 14.1$ deg., and $Re = 1.6 \times 10^6$, $M = 0.18$. 

$\alpha = 14.1$ deg.
Clean Model Aerodynamics

- Surface-pressure distribution animation at $Re = 1.6 \times 10^6$, $M = 0.18$. 

\[ \alpha = 9.0 \text{ deg.} \]
CFD Simulation Methodology

- CFD simulation included the wing and splitter plate, no shroud.
  - Test-section floor included as symmetry plane.
- Chimera overset grid based upon ONERA methodology.
  - Wing: \( \sim 9.4 \times 10^6 \) cells
  - Splitter: \( \sim 6.5 \times 10^6 \) cells
  - Collar grid: \( \sim 0.65 \times 10^6 \) cells
- ONERA elsA solver for 3D compressible RANS equations.
- One equation Spalart-Allmaras turbulence model.
- Free-transition model criteria based upon free-stream turbulence intensity of 0.11% \( (N_T = 8) \) corresponding to WSU wind tunnel.
CFD Simulation Comparison

- Clean wing performance at $Re = 1.6 \times 10^6$, $M = 0.18$. 

![Graph showing comparison between WSU Experiment, CFD Turbulent, and CFD Transition (N = 8).]
CFD Simulation Comparison

- Surface oil flow visualization and transition location at $\alpha = 0$ deg. and $Re = 1.6 \times 10^6$, $M = 0.18$. 

![CFD Simulation Comparison Image]
CFD Simulation Comparison

- Surface pressure distribution at $\alpha = 13.1$ deg. and $Re = 1.6 \times 10^6$, $M = 0.18$. 

![Graphs showing CFD simulation comparison with experiment data at y/b = 0.28 and y/b = 0.84.](image)
Roughness Simulation Methodology

- Full-span artificial ice shapes were bolted to the wing leading edge.
- Artificial ice shapes were made using rapid-prototype manufacturing (RPM).
- Small ice roughness was simulated with regular pattern of hemispheres in the RPM shape.
- Aerodynamic results were compared to carborundum grit of equivalent size applied to the clean leading edge.
Roughness Simulation Comparison

- Aerodynamic performance at $Re = 1.6 \times 10^6$, $M = 0.18$. 

![Graph showing aerodynamic performance with different roughness conditions](image-url)
Summary

- Experimental and computational study of 8.9% scale CRM65 semispan wing at \( Re = 0.8, 1.6 \) and \( 2.4 \times 10^6 \) and \( M = 0.09, 0.18 \) and \( 0.27 \).
- Four different model mounting configurations were investigated.
  - Circular splitter plate and streamlined shroud selected for further work.
- A detailed study of clean wing aerodynamics was performed:
  - For all \( Re \) and \( M \) conditions, the flow over the outboard sections of the wing separated as the wing stalled with the inboard sections near the root maintaining attached flow.
  - This behavior was captured for 3D RANS CFD simulations with free transition model, with opposite results for fully turbulent simulations.
- Artificial ice roughness simulated with hemispherical patterns in RPM shapes generated aerodynamic effects equivalent to similar size carborundum grit roughness.
  - Size of RPM-based hemispherical roughness limited to height = 0.010 inches due to manufacturing limitations.
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