2ND AIAA ICE PREDICTION WORKSHOP

IPW

ESTABLISHED 2019

Glenn Icing Computational Environment (GlennICE) Results and Analysis

International Conference on Icing of Aircraft, Engines and Structures

Thomas A. Ozoroski
NASA Glenn Research Center

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Overview

Introduction:

- GlennICE is a fully three-dimensional single-shot ice accretion post processing software being developed at NASA Glenn Research Center
- For the workshop, we chose to analyze just the CRM-65 Mid-Span model
  - Cases 1.1, 1.2, and 1.3
- Within the analysis of the workshop cases, issues with some of the ice shapes generated by GlennICE were identified
- Goal is to discuss discrepancies within the results and what is causing them in 3D

Outline:

- Discussion of GlennICE
- How the 3D cases were run
- What the issues with the 3D cases were
- 2D Infinite Sweep analysis
- Comparison to experimental ice shapes
- Moving Forward

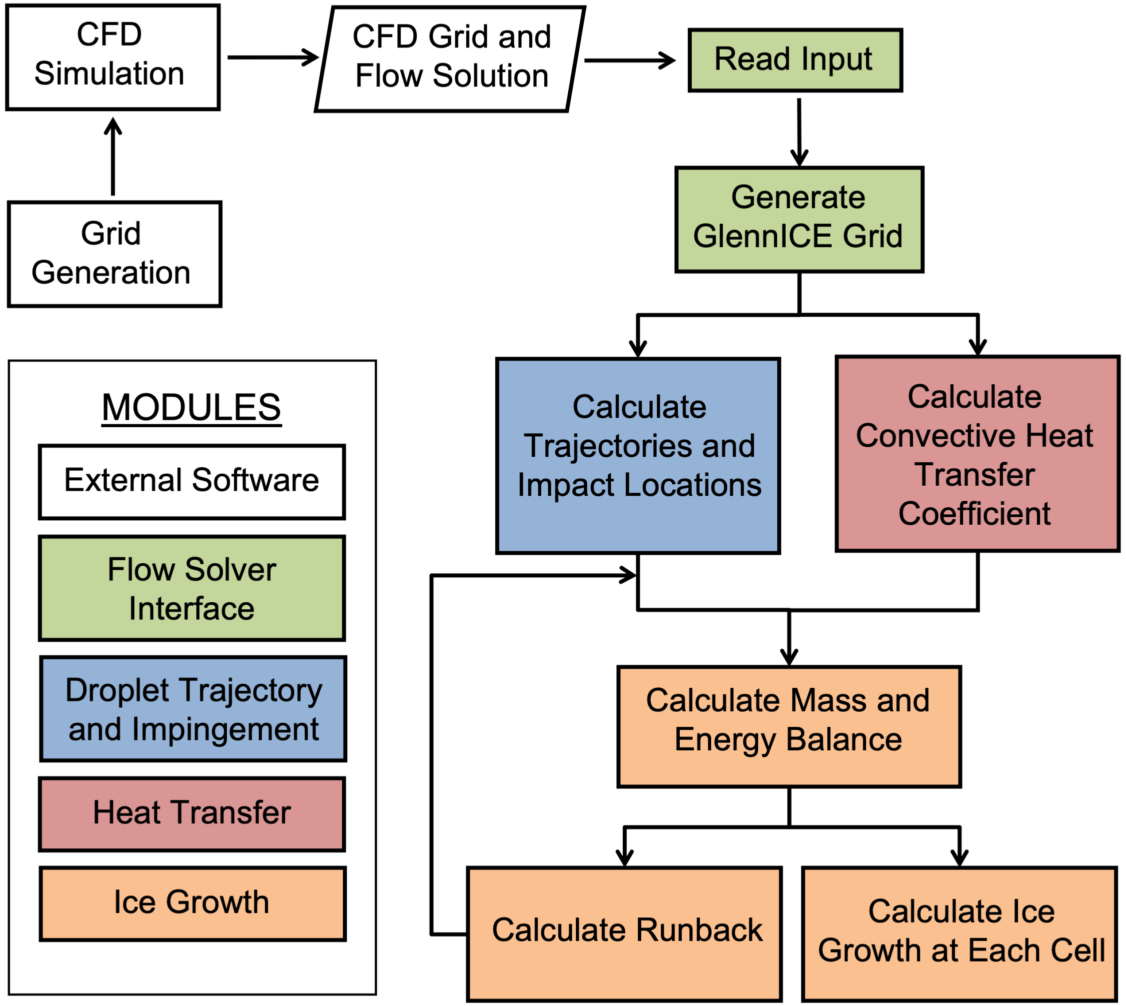
GlennICE Background

- CFD post-processing ice accretion solver being developed at NASA Glenn
- Currently solves for a fully 3D ice accretion in a single shot
- Lagrangian trajectory routine utilizing a provided CFD velocity field
- Leverages the Dormand-Prince method to solve the ODEs with an adaptive time stepping scheme [1]
- Impingement computed from a streamtube based per trajectory finite area approach with automatic impingement refinement
- Utilizes the Messinger model to calculate the amount of frozen water on the surface per discrete cell [2]
- Migration of unfrozen water between surface cells occurs based upon surface shear vectors
- After the per element ice shape is solved for, an extrusion of the ice shape is conducted to generate a 3D computational ice shape

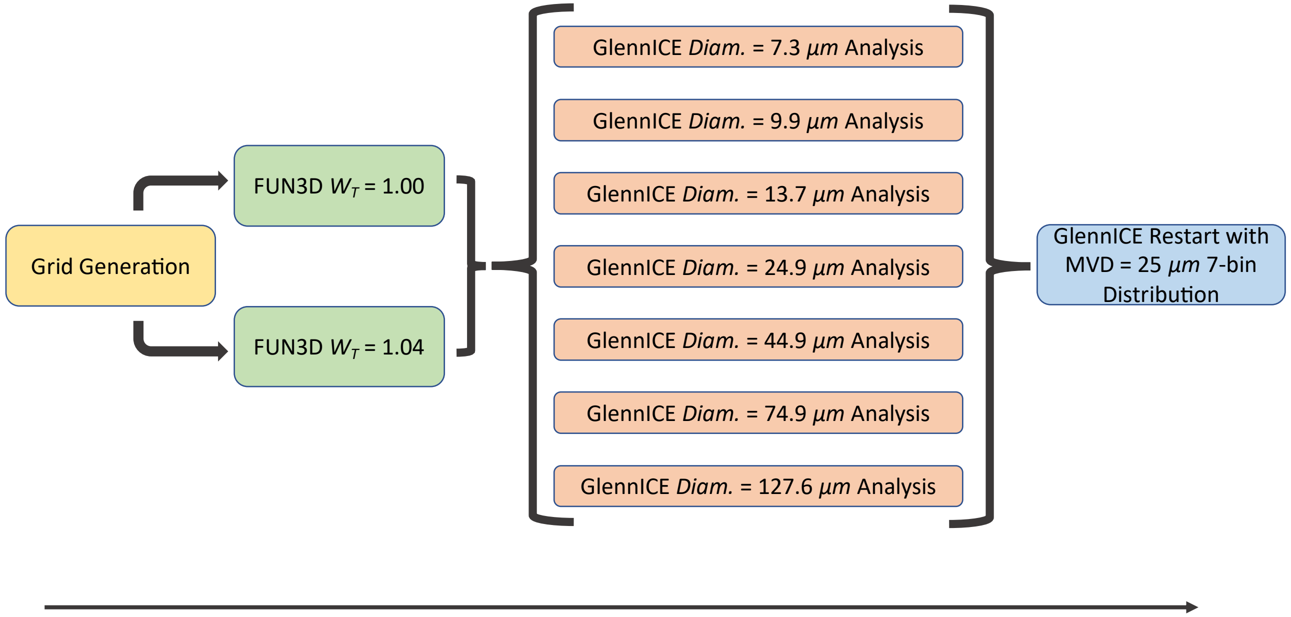
Roughness Modeling Within GlennICE

- Roughness is modeled by an empirical correlation derived by McClain et al. [3] and two user defined parameters (UDPs)
  - Model utilizes properties such as surface Cp, MVD, LWC, and icing time
  - UDP 1: Augmentation of the turbulent heat transfer coefficient for increases caused by roughness unseen by dry-air CFD solutions
  - UDP 2: The ideal rime limit defines the distance in meters in which the ice shape is no longer considered roughness
- The empirical roughness model was ‘largely generated’ utilizing 2D ice shapes
  - Unswept 21-in. NACA 0012, the 72-in. NACA 0012, and the HAARP-II models
  - Data from the swept 36-in NACA 0012 was used early on and has been compared to some of the CRM-65 ice shapes
- To date, suggested UDPs for GlennICE by Wright et. al. 2023 have been mostly selected based upon 2D ice shapes [4]
- The correlation applies in 3D, but UDPs are not fully understood for every case in GlennICE
- Demonstration of this will be shown later on in the presentation

Running GlennICE



GlennICE Programmatic Diagram



Workshop Applied Process Diagram

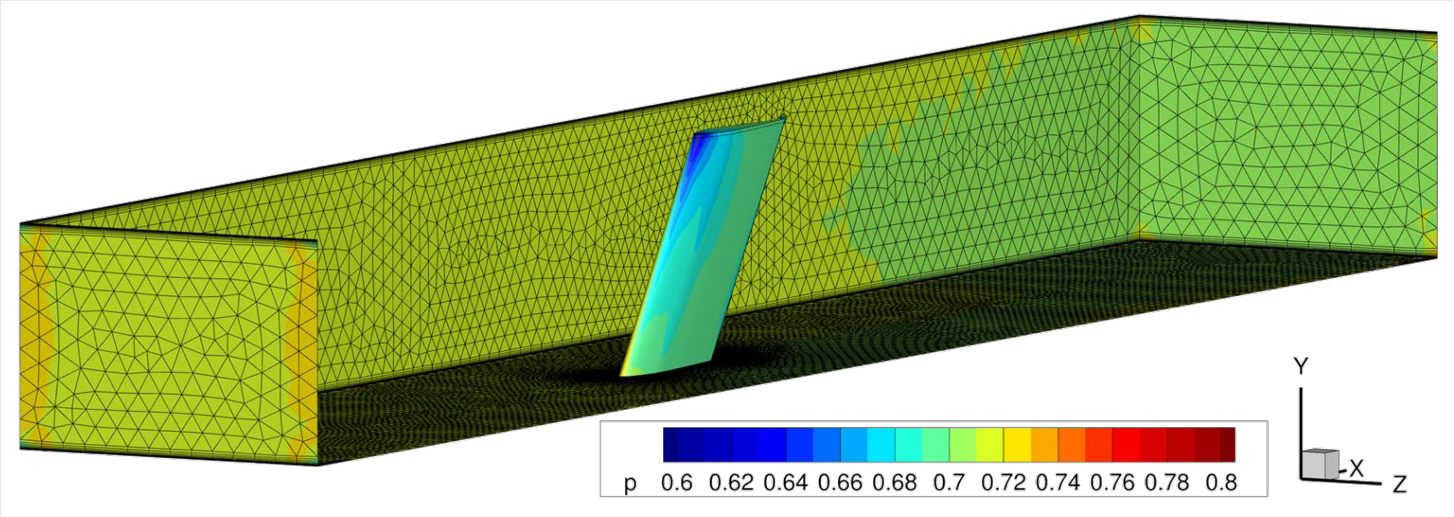
Analysis of the CRM-65 Mid-Span Model - Case 1.2

Geometry: With-Gap CRM-65 Mid-Span
Grid: Workshop Provided Unstructured
CFD Solver: FUN3D v14.0
Turbulence Model: SA-neg
Wall Temps (W_T): 0.97, 1.04
Mach Number: Matched at Pitot Tube

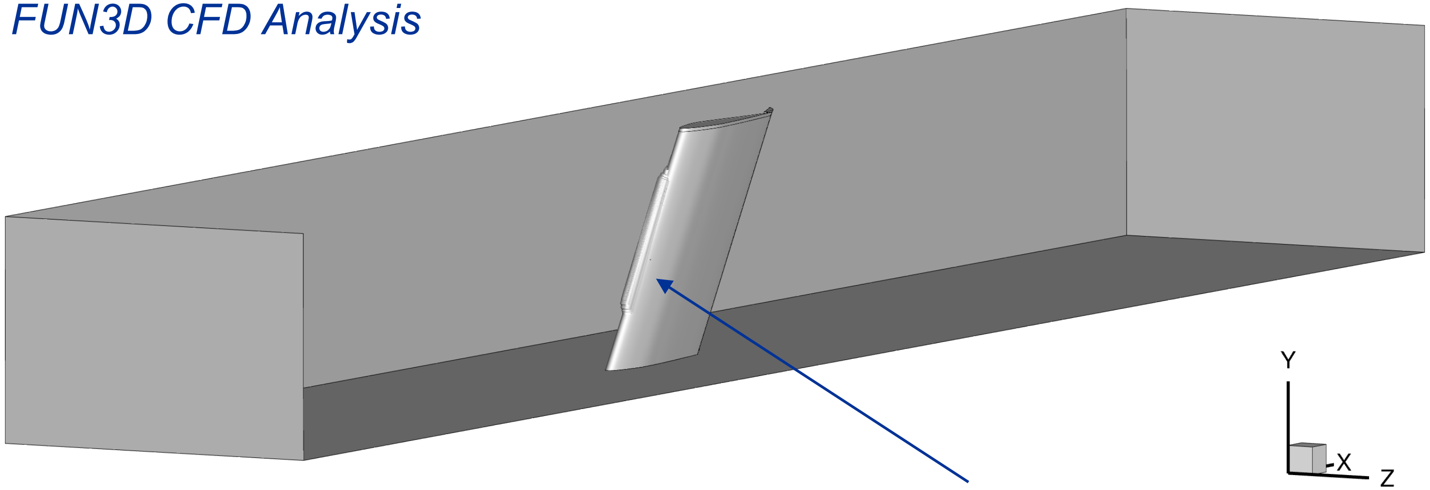
Icing Solver: GlennICE - v3.1.0
Augmentation: HTC = 3, IRL = 0.004*m*
Ice Density: ρ_{ice} = 450 kg/m^3
Particle Release Domain: 0.41 m - 1.41 m
MVD Distribution: IRT 7-bin 25*μm* provided

- We ran our CFD analyses
- We ran our GlennICE analyses
- We have generated our 3D ice shapes

What do they look like?



FUN3D CFD Analysis

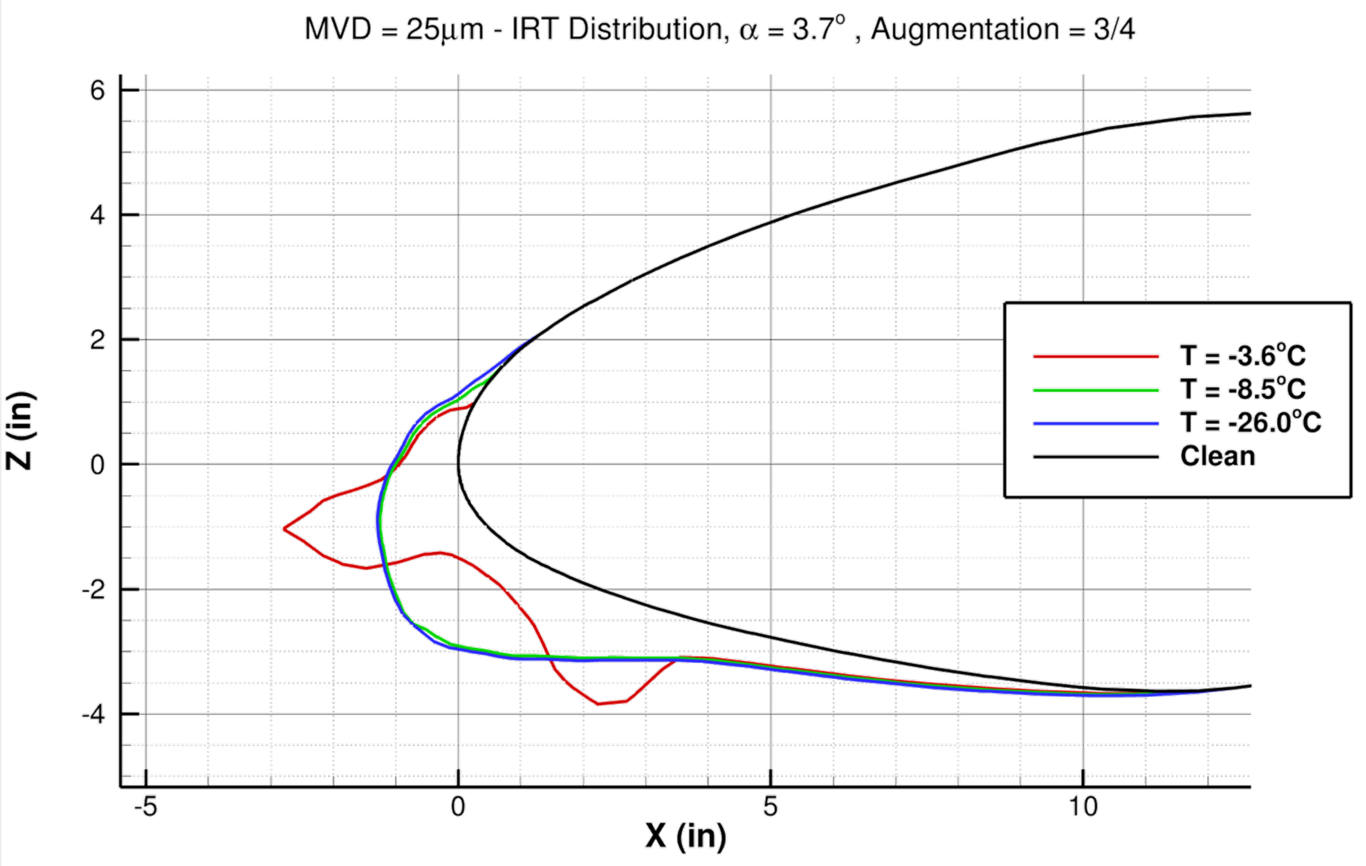


GlennICE Analysis

3D Ice Shape Results

What Happened?

- Why does T_s = -8.5°C look rime?
- Too much augmentation is occurring causing more trajectories to freeze on impact
- This results in us computing more of a rime ice shape instead of glaze ice shape
  - We have no horns being generated
- Has not been seen previously due to limited analyses to date on highly swept 3D wings
- We would expect there to be no augmentation on the attachment line
  - But we see large augmentation values present
- Believed to track back to the 1-Cp term within the roughness correlation



Extracted a slice perpendicular to the leading edge at Y = 36 in

2D Infinite Sweep Theory

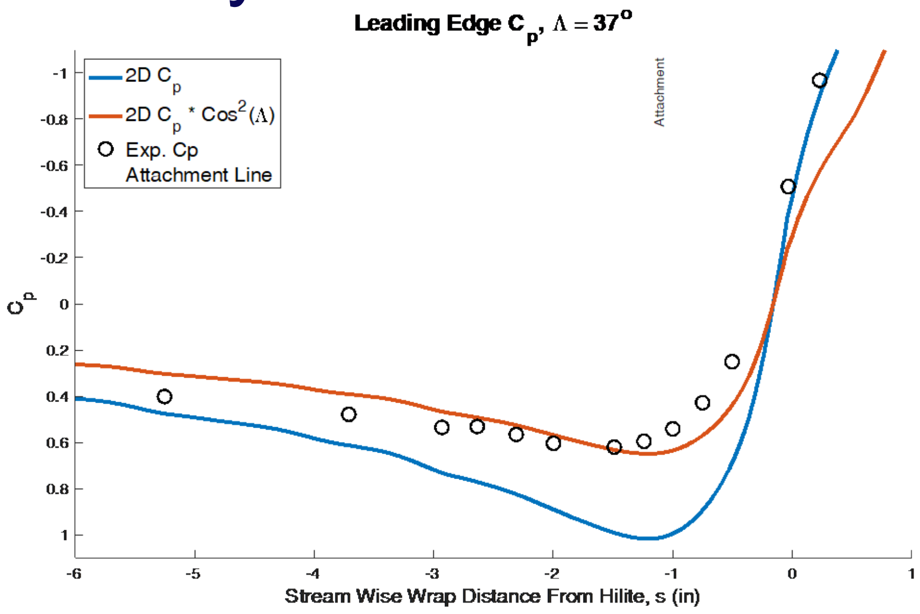
- Various 2D results have previously shown good agreement to experiment
- The roughness model has produced good results in 2D and appropriate shapes
- Can isolate the influence of sweep angle on the GlennICE results by conducting a 2D infinite sweep analysis
- Adjust velocity to account for sweep by:

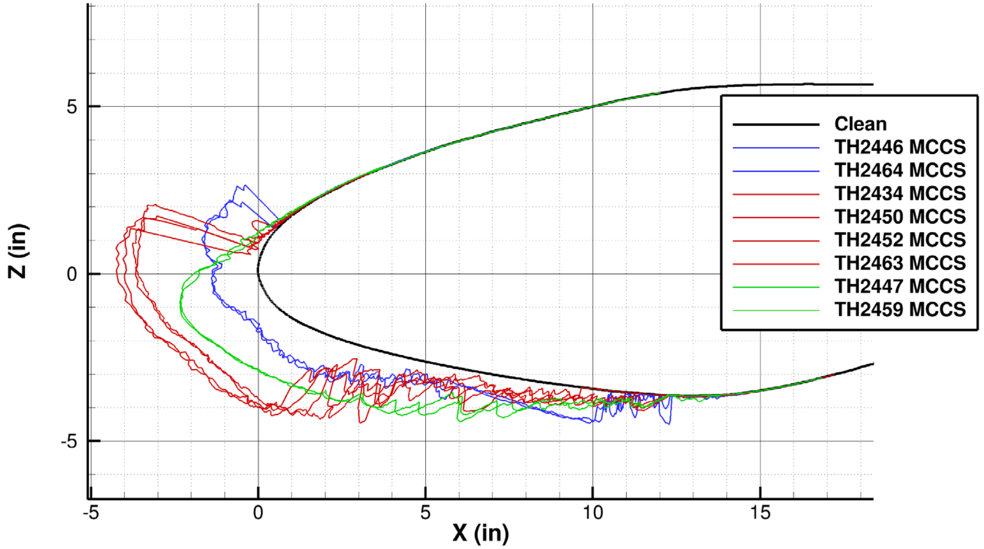
$$V_n = V_\infty * cos(\Lambda)$$

- Adjust the incoming temperature to account for sweep by:

$$T_{n,s} = T_{s,f} + \frac{V_\infty^2}{2C_p} sin^2(\Lambda)$$

- We match attachment line within the margin, but we don't attempt to perfectly match Cp distribution
- Our main goal is to determine whether the 3D sweep angle is a larger influence on GlennICE ice shapes than previously thought





Confirmation of Geometry Match of 2D and 3D

Analysis of the 2D CRM-65 Mid-Span Model - Case 1.2

Geometry: 2D - CRM-65 Mid-Span

Grid: Y+ = 1, 1-cell wide 2D grid

CFD Solver: FUN3D v14.0

Turbulence Model: SA-neg

Wall Temps (W_T): 1.00, 1.04

Mach Number: M = 0.205 Freestream

Angles: α = 3.7°, δ = 25°

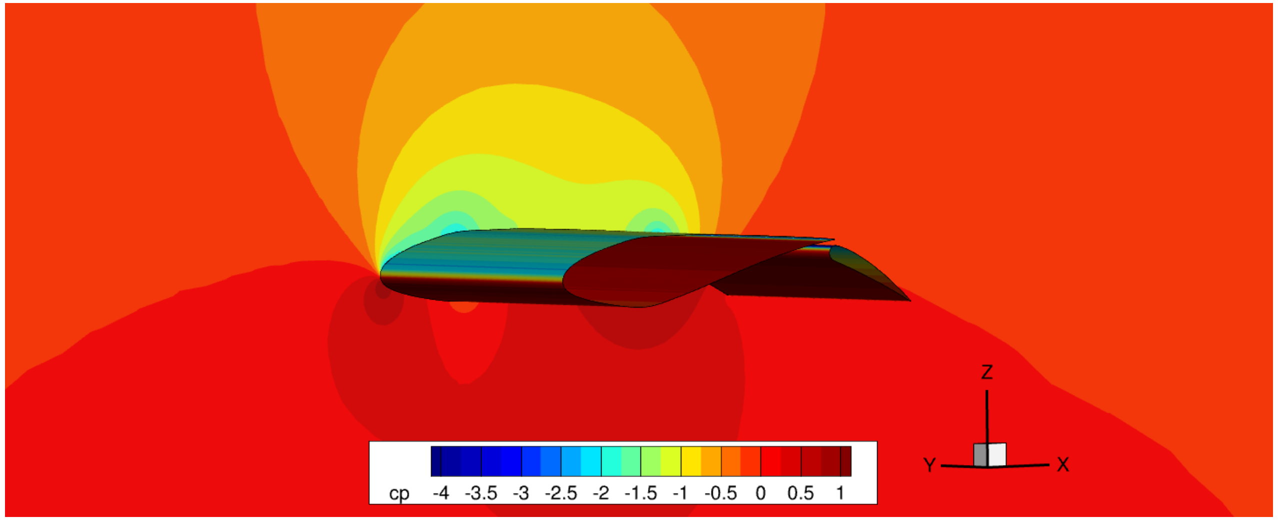
Icing Solver: GlennICE - v3.1.0

Augmentation: HTC = 3, IRL = 0.004m

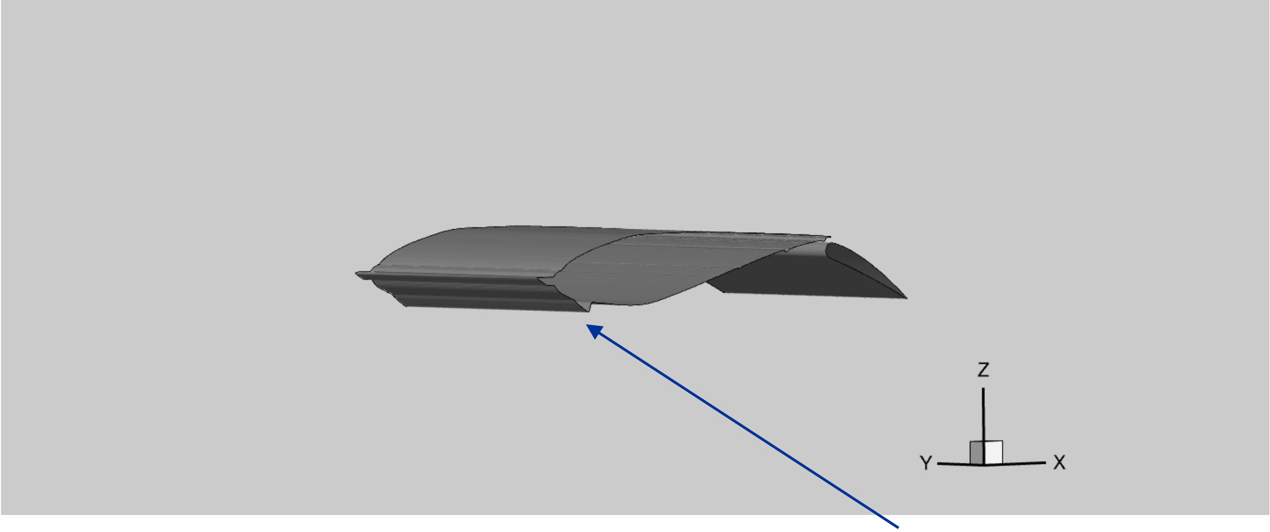
Ice Density: ρ_{ice} = 450 kg/m^3

MVD Distribution: IRT 7-bin 25μm provided

Do the 2D infinite sweep ice shapes look more reasonable?



FUN3D CFD Analysis

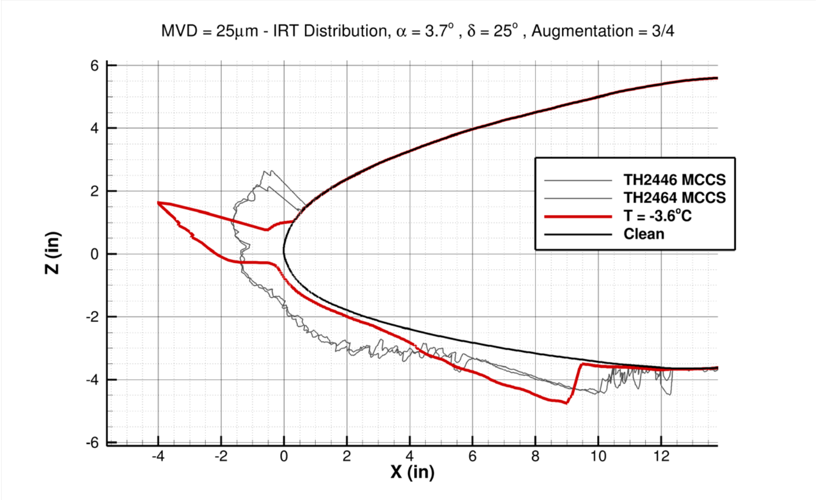


GlennICE Analysis

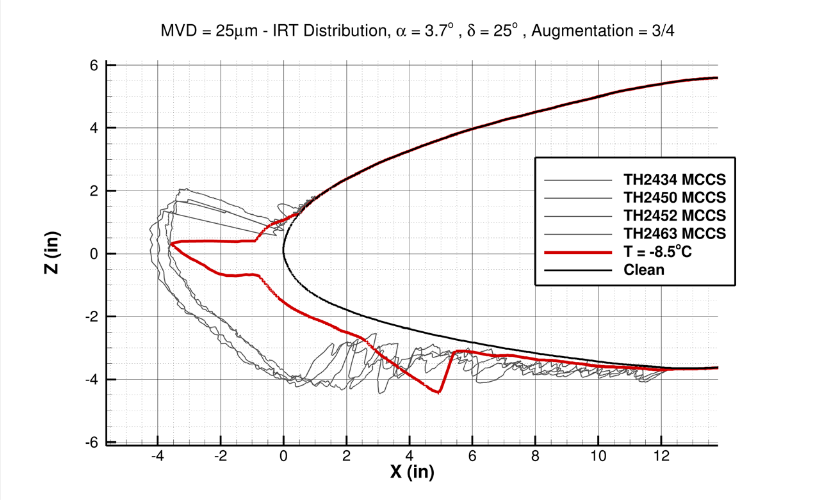
Ice shape

2D Infinite Sweep Icing Results

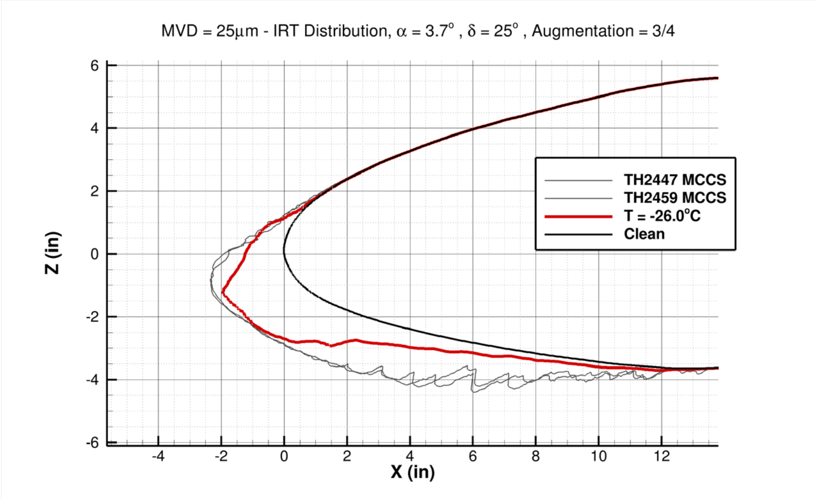
- For glaze conditions, the 2D infinite sweep does not produce similar results as the fully 3D analysis
- The T_s = -8.5 °C case is no longer rime as is with 3D and produces horns
- The T_s = -26.0 °C case is similar to the 3D, as expected
- This confirms that the issue stems from roughness augmentation discrepancies for a 3D swept wing configuration
  - No rime shapes generated under glaze conditions in 2D
  - The roughness augmentation worked as desired
  - Again, the goal was not to perfectly match the experiment, but to show swept wing effects



T_s = -3.6 °C



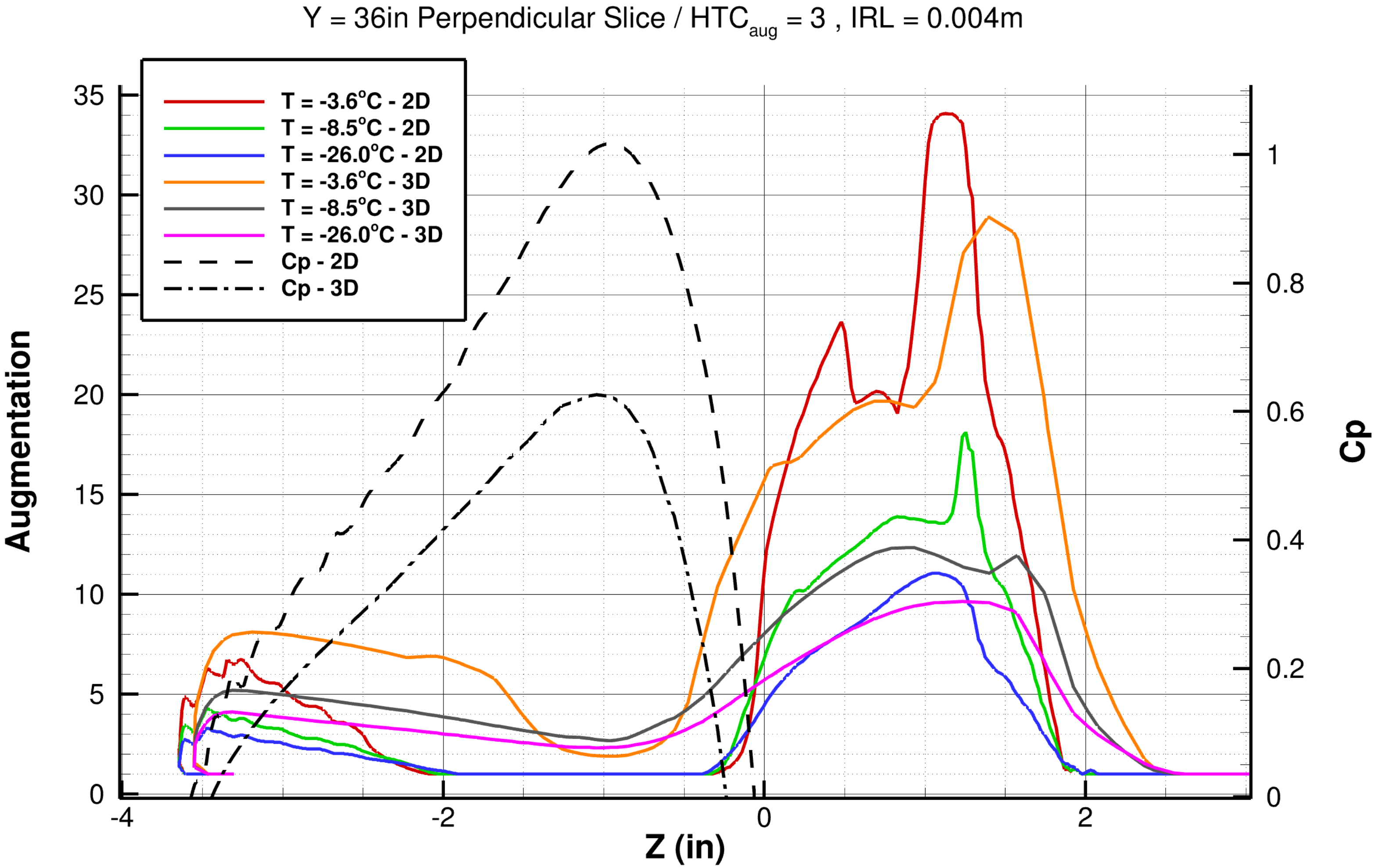
T_s = -8.5 °C



T_s = -26.0 °C

2D and 3D Augmentation Comparison

- Can be seen that with 2D, where Cp reaches a value of 1 at stagnation, we get no augmentation occurring
- In 3D, Cp never reaches a value of 1 at stagnation due to sweep and we get augmentation
- Adjustments to the 1-Cp term could likely correct for sweep and non-stagnating leading edges
- Possibly adjust the correlative relationship with HTC but not roughness
- Multiple options will need to be considered



Conclusions

- We presented an analysis of 3D augmentation shortcomings for highly swept wings
  - Some glaze temperatures are producing rime ice shapes in 3D
  - UDPs from a 2D ice shape comparison are currently ineffective for 3D swept wings
- A 2D infinitely swept wing produces appropriate ice shapes with the augmentation parameters
- We currently have too much augmentation occurring on the leading edge of 3D swept wings
  - Could trace back discrepancies to the 1-Cp term in the roughness correlation
- Our understanding of the effect of sweep on roughness augmentation within GlennICE needs to be expanded
- An adjustment to our implementation of roughness augmentation is necessary
  - In 3D, there is roughness on the leading edge, so eliminating it is ineffective
  - Should we adjust the use of 1-Cp to account for sweep angle?
  - Should we adjust the relationship to HTC only and not roughness?

Moving Forward

- Currently investigating approaches to improve augmentation on 3D swept wings
  - Through adjustments to roughness correlation
  - Through adjustments to HTC and roughness in GlennICE
  - Has to be an encompassing investigation with multiple adjustments being considered
- An analysis of varying sweep angle with our roughness augmentation is being conducted
  - Looking to investigate how our results change when sweep angle is increased
- Suggested McClain augmentation parameters for GlennICE will be adjusted for fully 3D flows with varying sweep angles as was done for 2D flows
- More updates and changes are to come with improvements to results anticipated for the IPW2 AIAA summary report
- Subsequent improvements will be released in upcoming version of GlennICE

Acknowledgments

- The IPW2 working group for their efforts in generating grids, selecting cases, and generating analysis scripts
- NASA's Advanced Supercomputing Division (NAS) for the computing resources needed to obtain the results presented
- The current GlennICE development team members: Zaid Sabri, Eric Galloway, Christopher Porter, Dave Rigby, William Wright, and Mark Potapczuk
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Questions?

GlennICE v3.2 Available Soon to U.S. Nationals Through the NASA Software Catalogue

Free To Download At: https://software.nasa.gov/

References

[1] D. J. Prince, “A family of embedded runge-kutta formulae,” Journal of Computational and Applied Mathematics, vol. 6, pp. 19–26, 1980.

[2] T. G. Myers, “Extension to the messinger model for aircraft icing,” AIAA Journal, vol. 39, no. 2, pp. 211–218, 2001.

[3] S. T. McClain, M. M. Vargas, J.-C. Tsao, and A. P. Broeren, “A model for ice accretion roughness evolution and spatial variations,” AIAA AVIATION 2021 FORUM, 2021.

[4] W. B. Wright, T. A. Ozoroski, D. L. Rigby, “Roughness Parameter Optimization of the McClain Model in GlennICE,” SAE Internal Conference on Icing of Aircraft, Engines, and Structures, 2023.

Backup Slides

2D Icing Results

- MVD sweep results
- Contains combined distribution as well
- 2D Infinite Sweep Theory results