GlennICE 2.1 Capabilities and Results

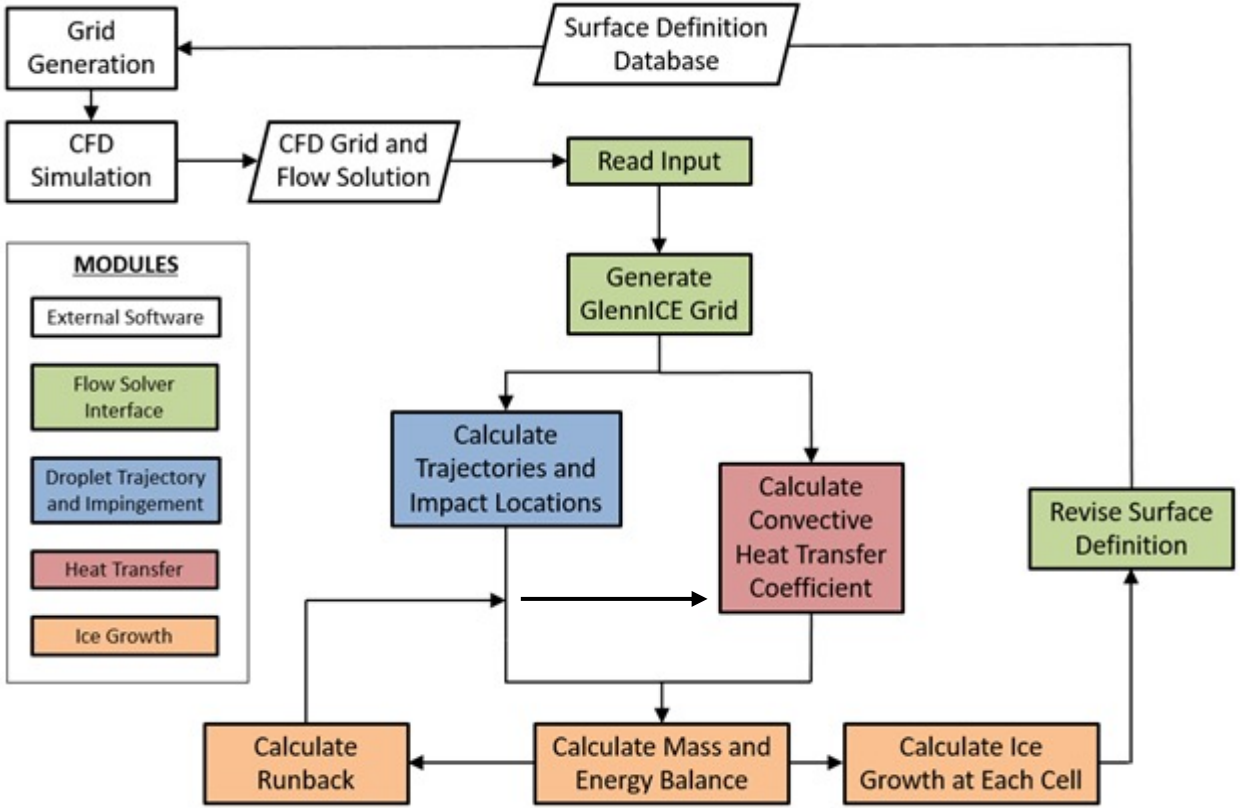
William Wright
HX5, LLC
AIAA Aviation 2022, Jun 27-Jul 1

Co-Authors
David Rigby HX5, LLC
Eric Galloway HX5, LLC
Christopher Porter, NASA GRC

Outline

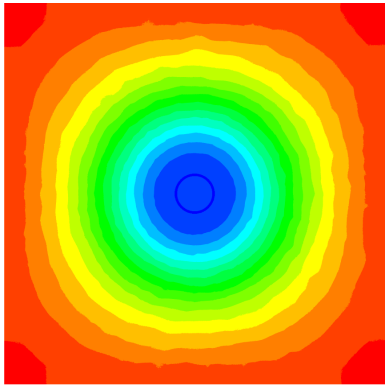
- GlennICE process
  - Flow solver inputs
  - Trajectory calculation and refinement
  - Heat transfer and augmentation
  - Surface water runback
- Results from 1st Ice Prediction Workshop
  - NACA 23012 (Case 252)
  - Swept NACA 0012 (Case 363)
- Conclusions

GlennICE Process

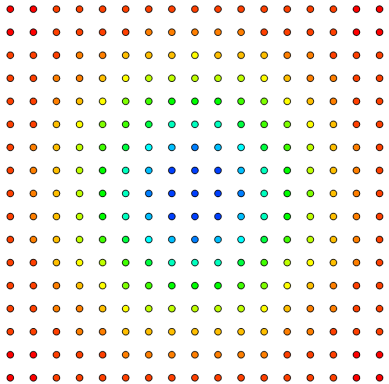


Adaptive Refinement Problem

- The minimum wall distance of each trajectory can be stored at the seed point that led to that trajectory.
- The seed points are co-planar, and therefore the computational problem being solved is now two-dimensional.
- The problem is a minimum search on a discretized two-dimensional data set.
- The sink behavior of the problem is leveraged in the minimum search.



The two-dimensional minimum wall distance solution.



Data available at a given iteration.

McClain Roughness

- $R_q = t_r 0.7(1 - C_p)\eta \left(0.34 + \Delta T_{oS}^{2/3} exp\left[-\frac{\Delta T_{oS}}{2.25}\right]\right)$ (roughness)
- $t_r = min\left[\frac{LWC * V_\infty * t * \beta}{\rho_{ice}}, t_{r,max}\right]$ ($t_{r,max}$ is user-defined)
- $htc_{augmented} = htc\left(1 + A\frac{R_q}{0.001}\right)$
- Since roughness is proportional to augmentation (A), A and $t_{r,max}$ are not independent parameters

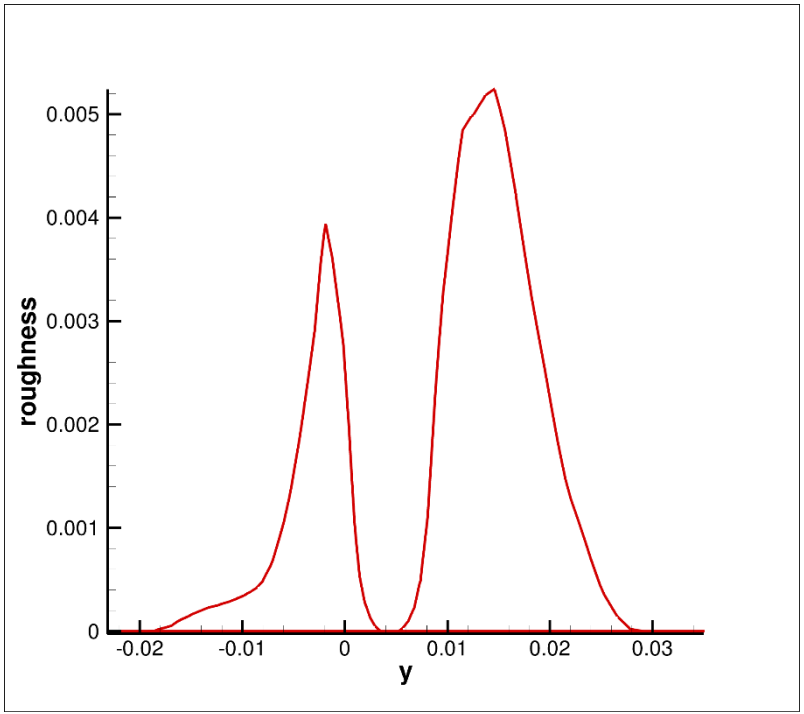
Iteration for Roughness Augmentation

- Roughness depends on freezing fraction
- Freezing fraction depends on heat transfer coefficient
- Heat transfer coefficient depends on roughness

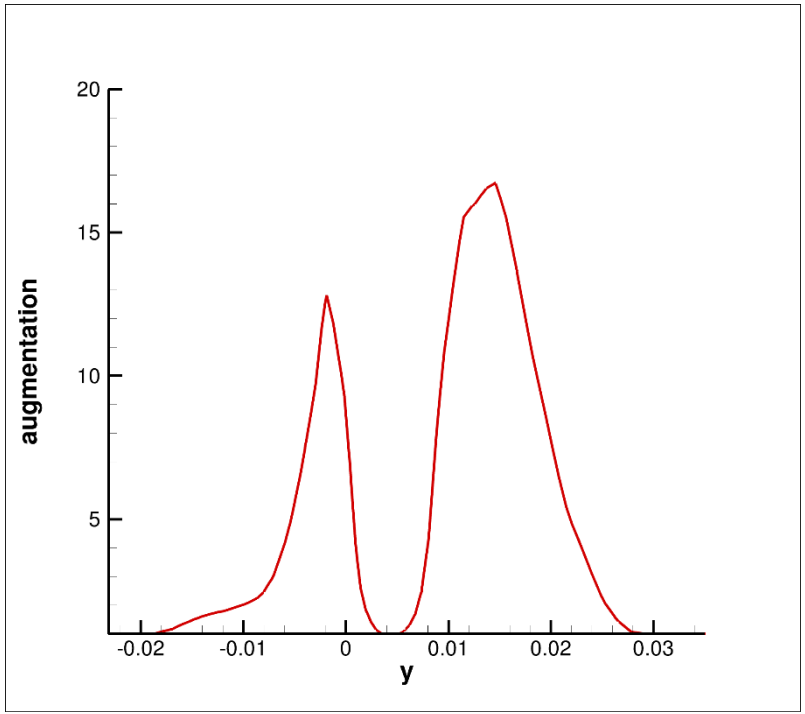
- Iteration is performed for convergence

Heat Transfer Augmentation

R_q



Augmentation=$(1+A*R_q/0.001)$

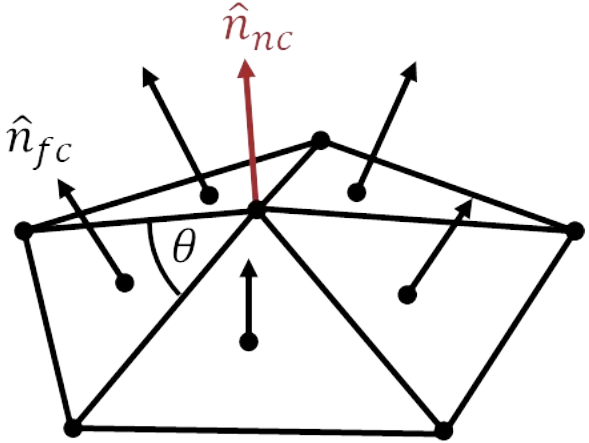


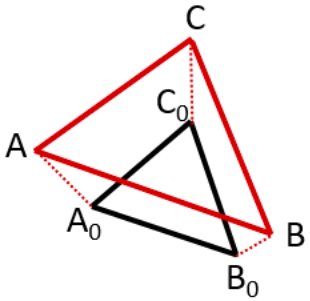
Surface Water Runback

- Iteration 1 - energy balance performed on each face
  - Runback mass to next face computed
- Iteration 2 - water flows into face and freezes if there is enough left-over energy
- Iteration is continued until there is no more runback mass
- GlennICE iterates for roughness, then iterates for runback

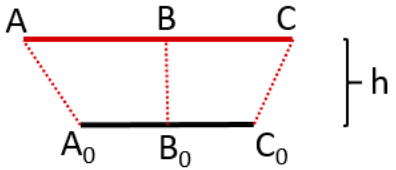
Ice Growth

- Surface is deflected normal to surface
- Cubic equation is solved at each face for ice height that conserves mass





Isometric View

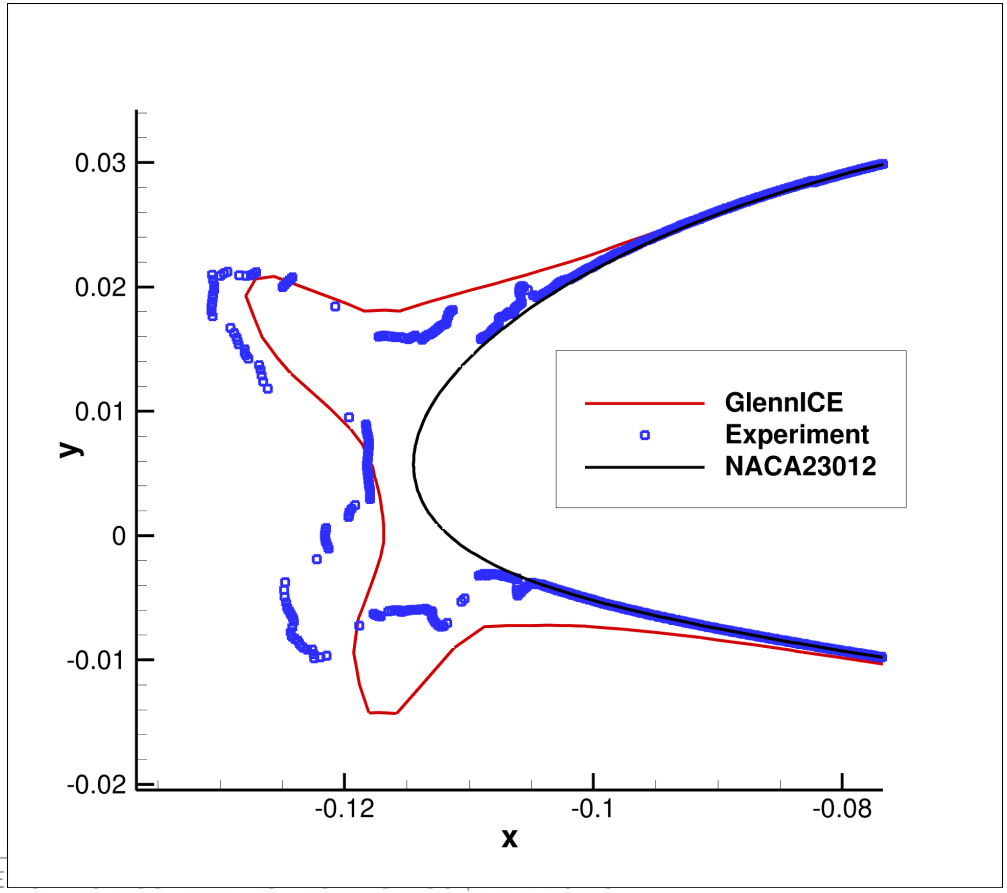


Side View

Ice Prediction Workshop Cases

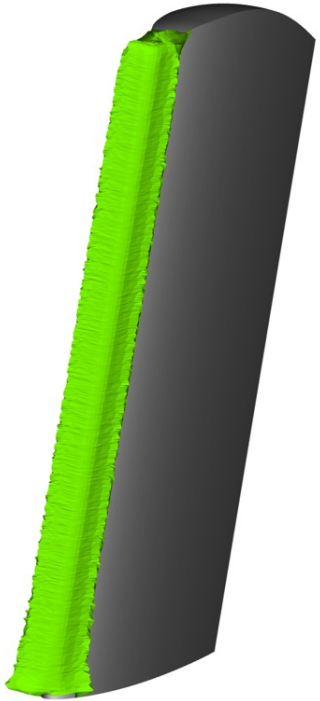
- Case 252
  - NACA 23012 straight wing
  - V=103 m/s, AOA=2°, T=260.7 K, LWC=1.63 g/m^3, t=398 s
  - MVD=21.5 (bimodal distribution)
- Case 363
  - NACA0012 wing 30° sweep
  - V=115 m/s, AOA=0°, T=263 K, LWC=0.5 g/m^3, t=1062 s
  - MVD=20.5 (7 bin distribution)
  - Ice Density = 200 and 300 kg/m^3
    - Experiment result is MCCS – Ice densities chosen to match

Case 252 (NACA23012)



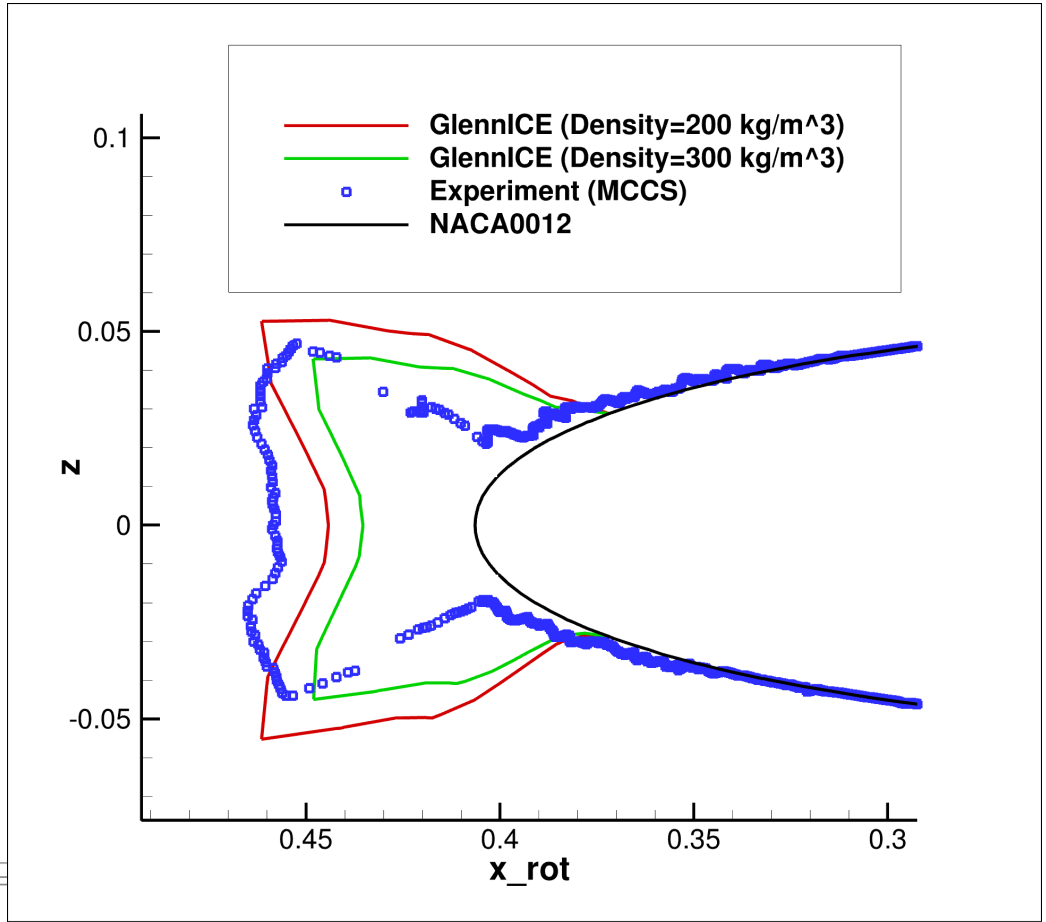
Case 363 Full Span View

Experiment



GlennICE
Ice Density =
300 kg/m^3

Case 363 MCCS (Swept NACA0012)



Conclusions

- GlennICE produces full 3D iced geometries that could be remeshed
  - Robust method for finding particles that hit a surface
  - Heat transfer based on roughness
  - Water runback based on Shear Stress
- Results show good comparison to experiment
  - Improved void density model needed for scalloped ice shapes

Acknowledgements

- The authors would like to acknowledge the support of the Advanced Air Transport Technology project for support for this research effort.