

Ice Accretion Prediction on Helicopter Rotor Blade in Hover Flight

G. Zanazzi, G. Mingione, A. Pagano, A. Visingardi

CIRA, Italian Aerospace Research Centre, Capua (IT)

and

R. Narducci

BOEING COMPANY, P.O. Box 16858, Philadelphia, PA 19142-0858

**SAE's Aircraft & Engine Icing International Conference
September 24-27, 2007
Seville, Spain**



- Background
- Validation Test Case Description
- Clean Rotor Performance Prediction
- Ice Accretion: 2D Approach
- 3D Effects
- Conclusions

- In 2004, a joint collaboration between CIRA and The Boeing Company was started to establish and validate a procedure to predict the ice accretion and aerodynamic performance degradation on helicopter rotor blades.
- The objective of this collaborative effort is to have a complete understanding of icing effects on rotor performance and to assess a comprehensive methodology to predict the ice formation.
- The goal is to investigate physical phenomena of ice accretion on rotor blades (including performance degradation, ice shedding) both in hover and forward flight.

Army UH-1H Helicopter Hovering in the Icing Cloud



Canadian National Research Council spray rig at Uplands Airport, Ottawa, Canada, winter of 1982-83: Helicopter icing flight test (HIFT) program using a UH-1H aircraft by NASA Lewis Research Center and the US Army

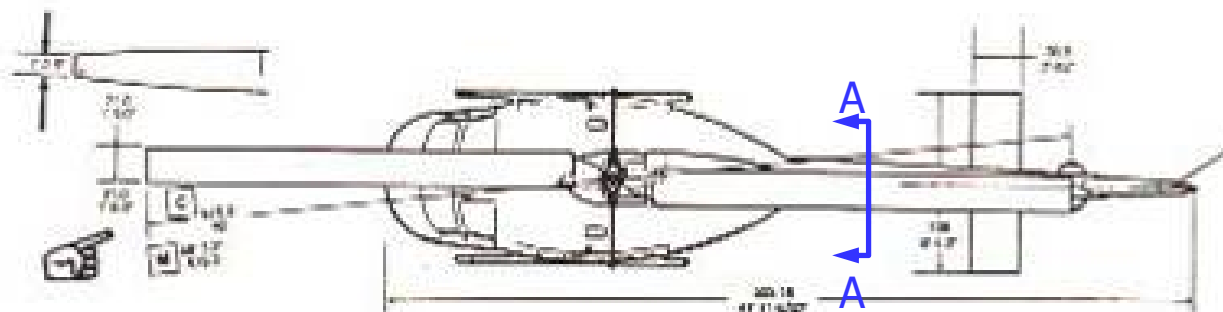
- Shaw, R.J., Richter, G.P., “*The UH-1H Helicopter Icing Flight Test Program: An Overview*,” AIAA-85-0338, 1985
- Lee, J.D., “*Aerodynamic Evaluation of a Helicopter Rotor Blade with Ice Accretion in Hover*,” AIAA-84-0608, 1984
- Lee, J.D., Harding, R., Palko, R.L., “*Documentation of Ice Shapes on the Main Rotor of a UH-1H Helicopter in Hover*,” NASA CR 168332, Lewis Research Center, 1983

Summary of Hover Icing Flight

Section A-A



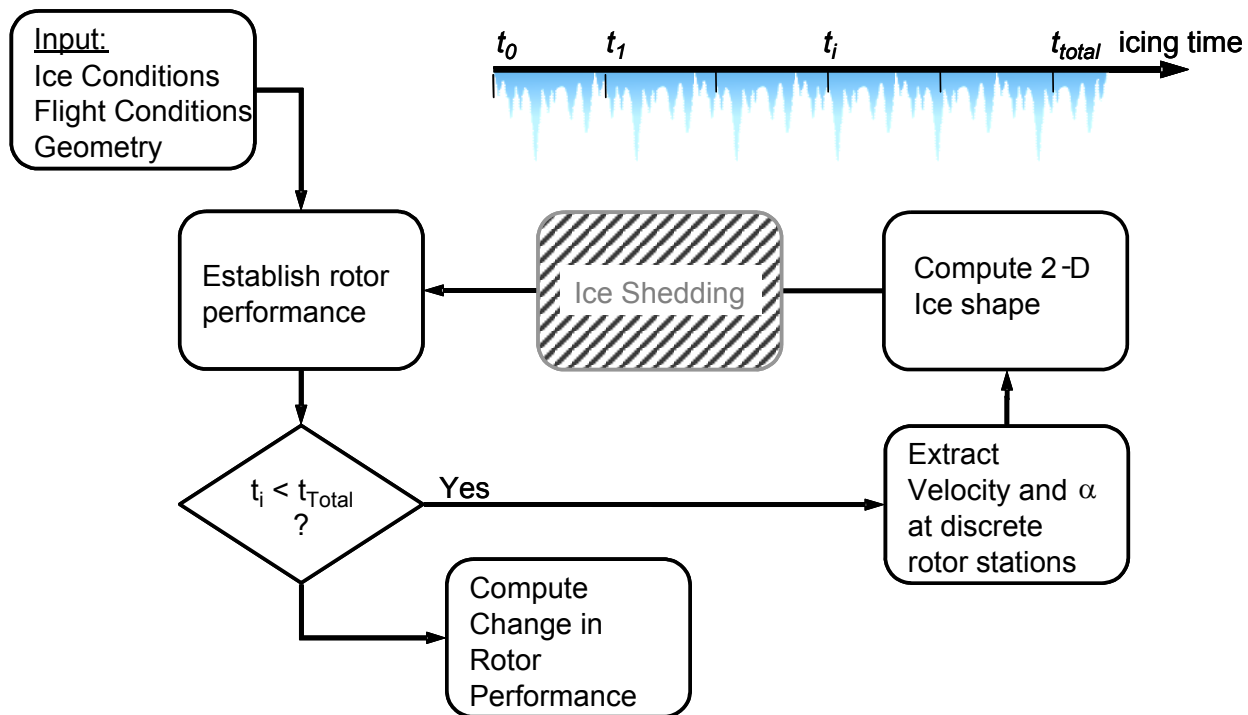
NACA 0012



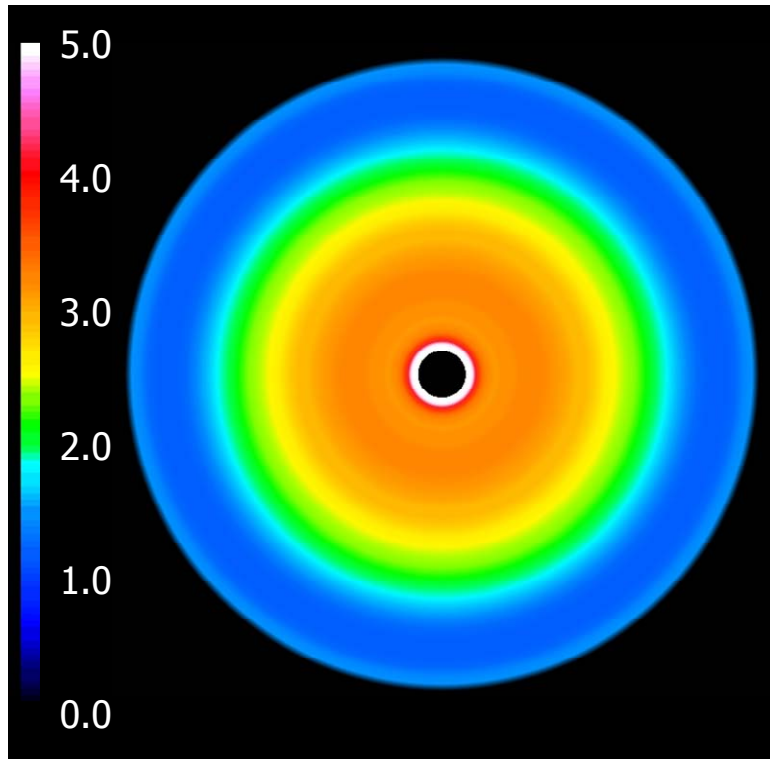
- Chord of 0.533 m.
- The radius is 7.136 m
- Disk Area is equal to 168.11 m²
- Rotational speed of 33.9 rad/sec
- Tip Mach number of about 0.77
- The rotor blade has a linear 10.9° twist along the span
- The maximum gross weight of the UH-1H is about 4300 kg
- $C_T / \sigma = 0.071$

Flight Number	Wind Speed (k)	Gusts	LWC gm/m ³	T Ambient °C	Time min	Ice Extent (r/R)
A	7	Medium	0.4	-12.0	4.5	0.75
B	10	Medium	0.4	-9.5	4.25	0.65
C	6	Medium	0.4	-17.5	4.0	
D	4	Low	0.4	-21.5	6.0	
E	9	Low	0.7	-19.0	3.0	0.92

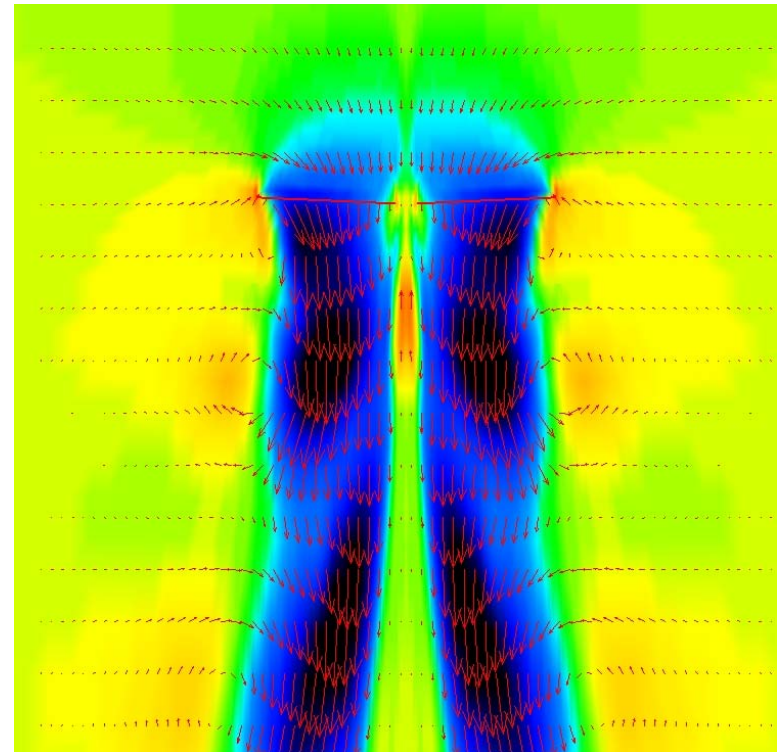
UH-1H Helicopter ice accretion



Isolated Rotor Analysis using Overflow's Momentum Source Rotor Model

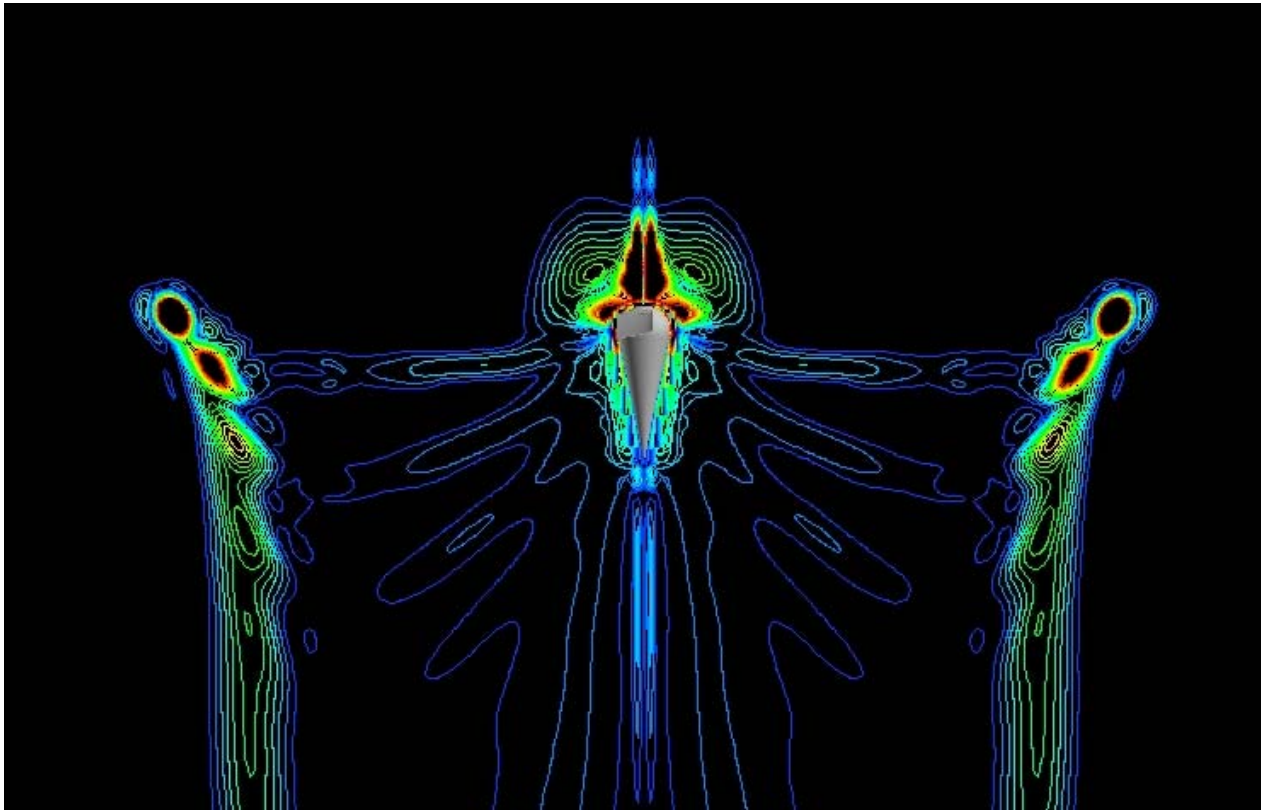


Angle of Attack



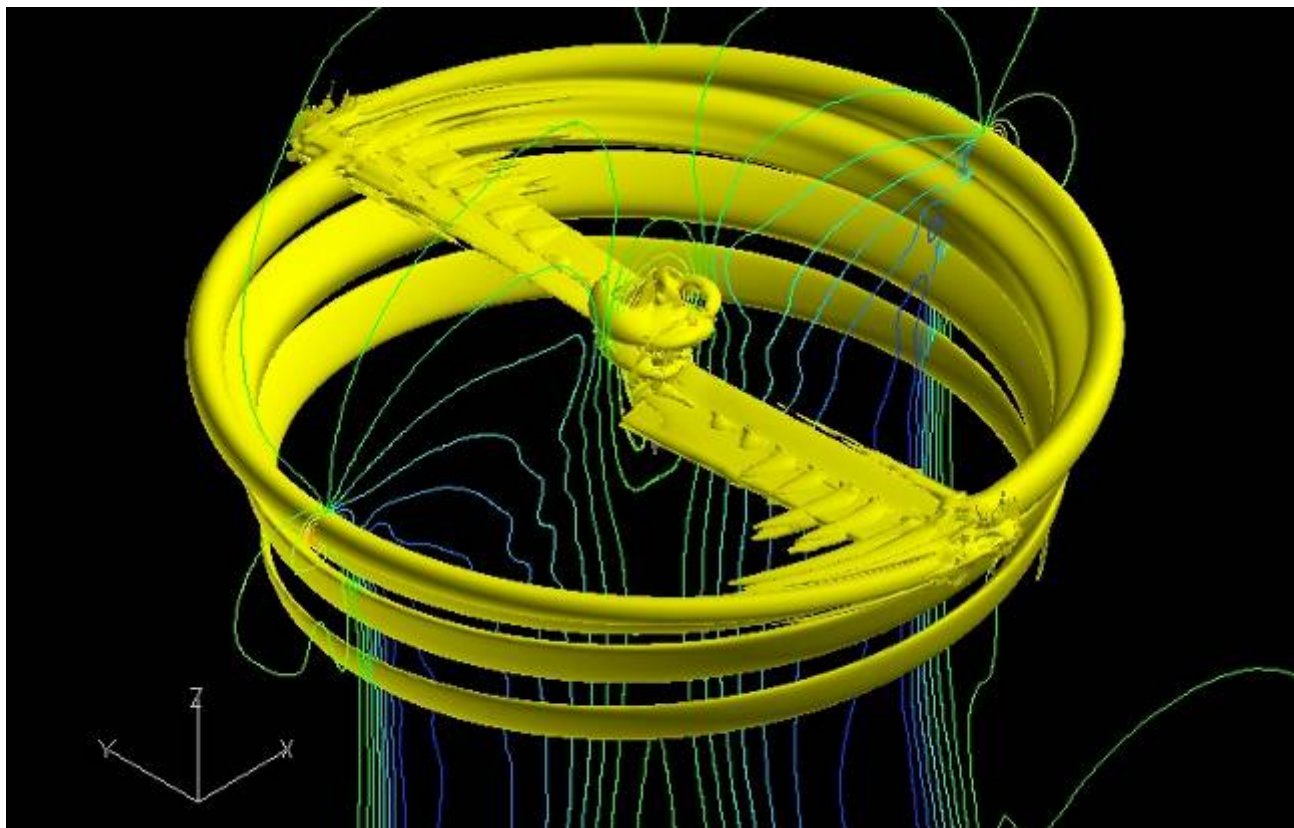
Downward Momentum &
In-plane Velocity Vectors

Isolated Rotor Analysis using Overflow's Discrete Blade Steady Hover Capability



Flight E, Rotor Speed = 33.9 rad/sec, $T_\infty = 254.15$ K, Collective = 7.5°

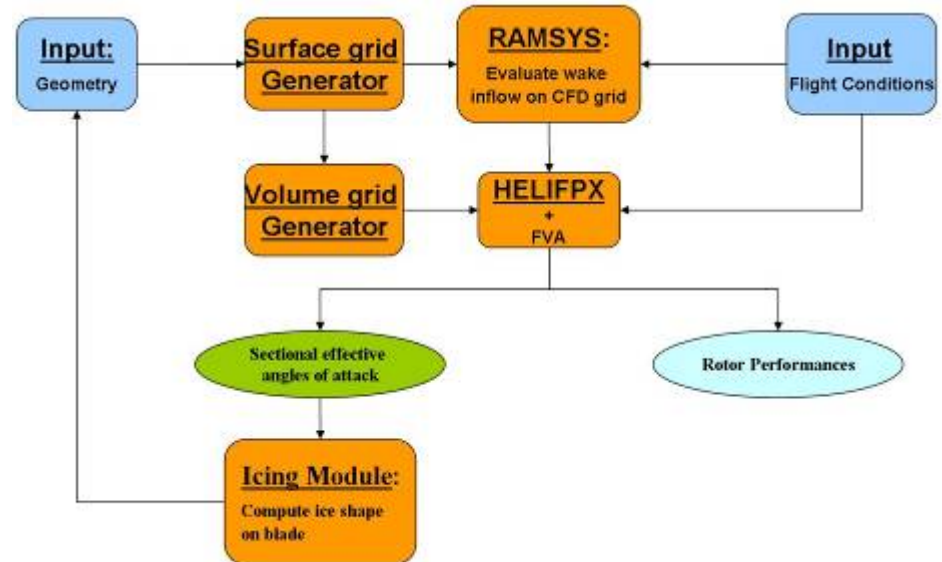
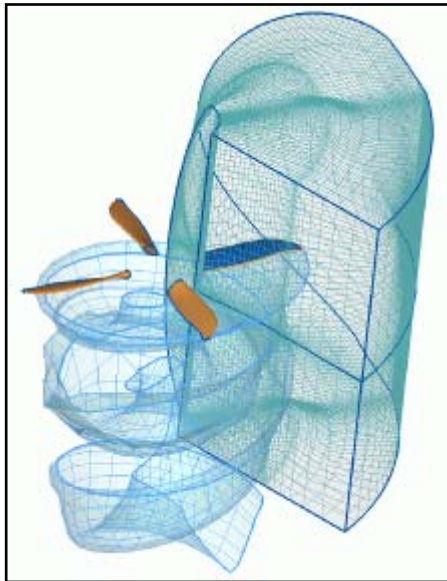
Isolated Rotor Analysis using Overflow's Discrete Blade Steady Hover Capability



Flight E, Rotor Speed = 33.9 rad/sec, $T_{\infty} = 254.15$ K, Collective = 7.5°

HELIFPX-RAMSYS : CIRA Aerodynamic Computation

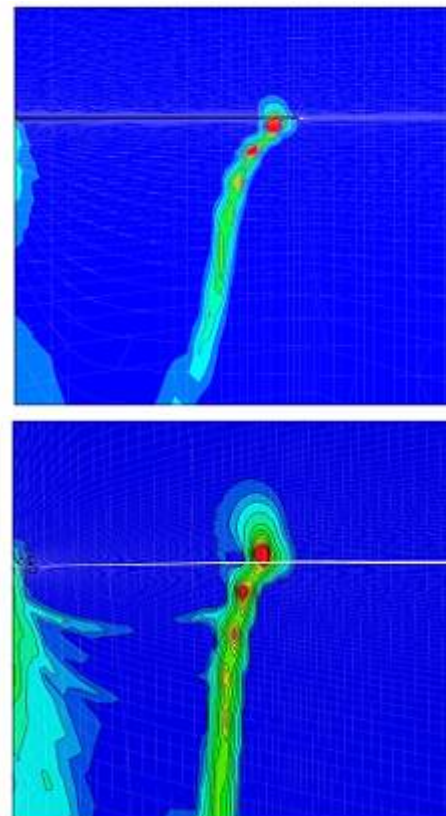
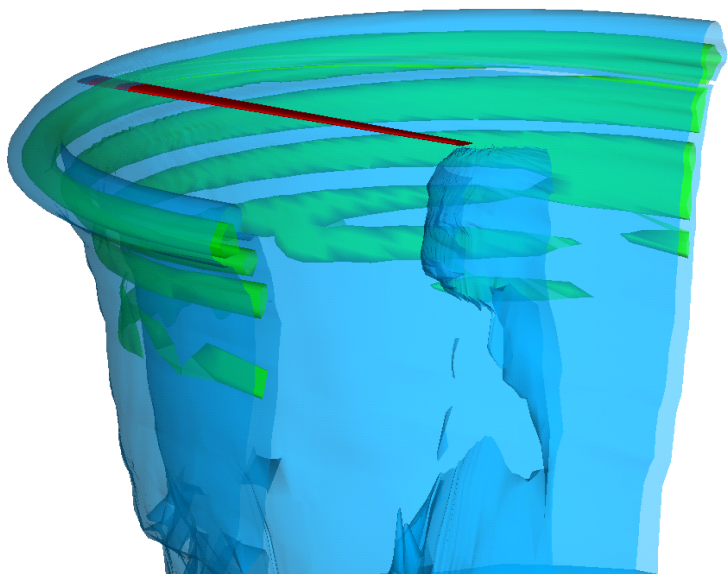
- HELIFPX is a CFD code based on a FP method which is corrected for entropy and vorticity and coupled to a boundary layer model based on “defect formulation”
- RAMSYS is an unsteady, free-wake code based on a BEM method for multi-body configurations
- A HELIFPX-RAMSYS coupling procedure based on the “Field Velocity Approach” is applied



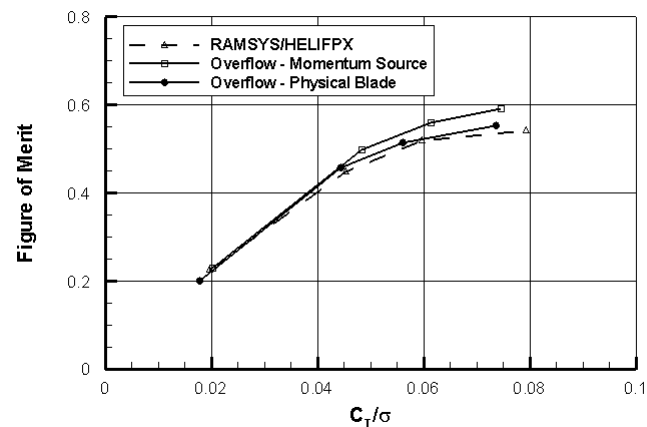
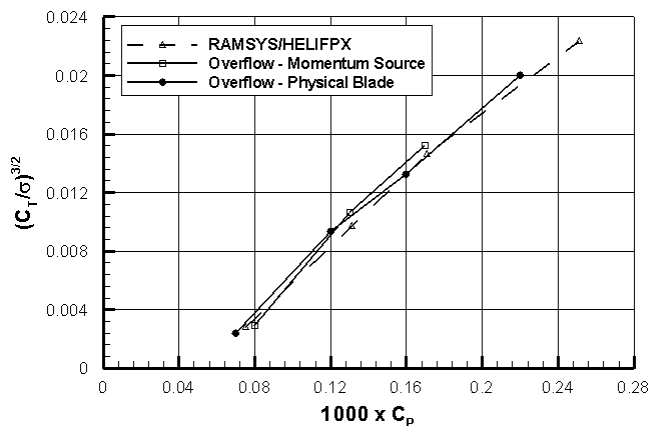
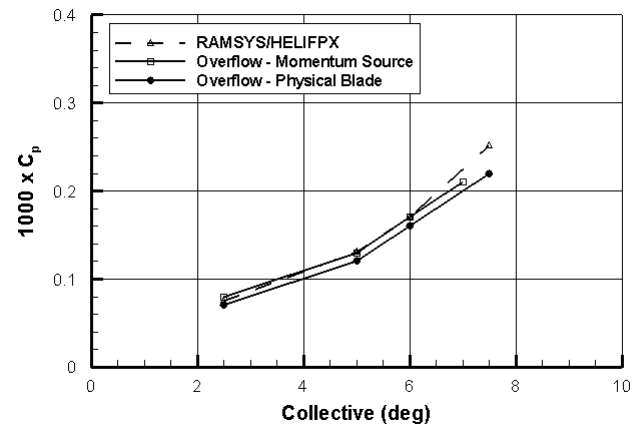
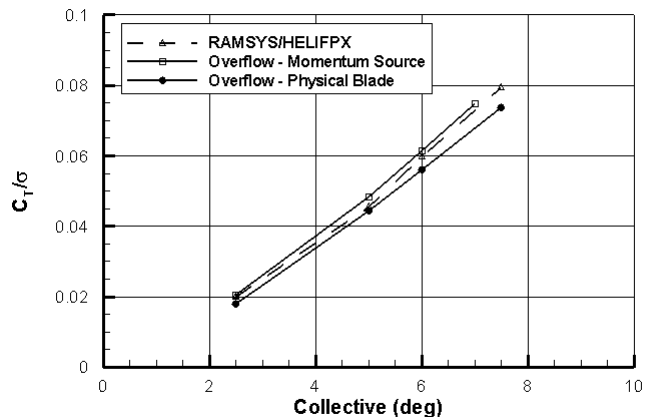
- RAMSYS evaluates on all the CFD grid nodes the velocity induced by the whole configuration and wake system with the exception of the main blade and its near wake
- HELIFPX adds its own grid velocity field to the RAMSYS induced velocity field

HELIFPX-RAMSYS : CIRA Aerodynamic Computation

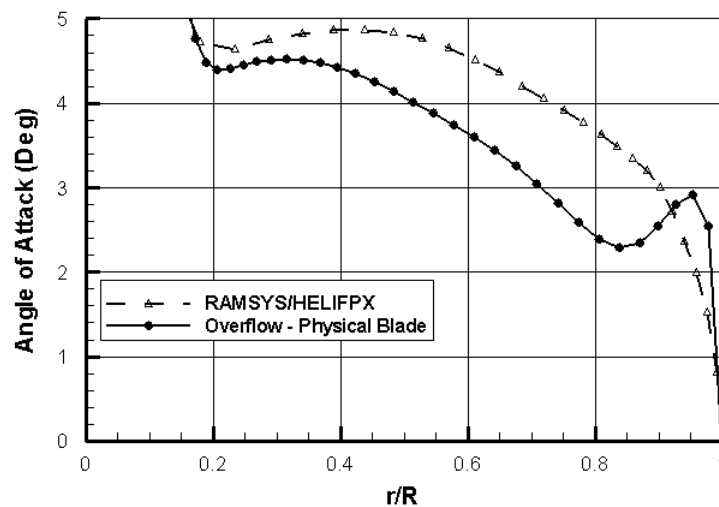
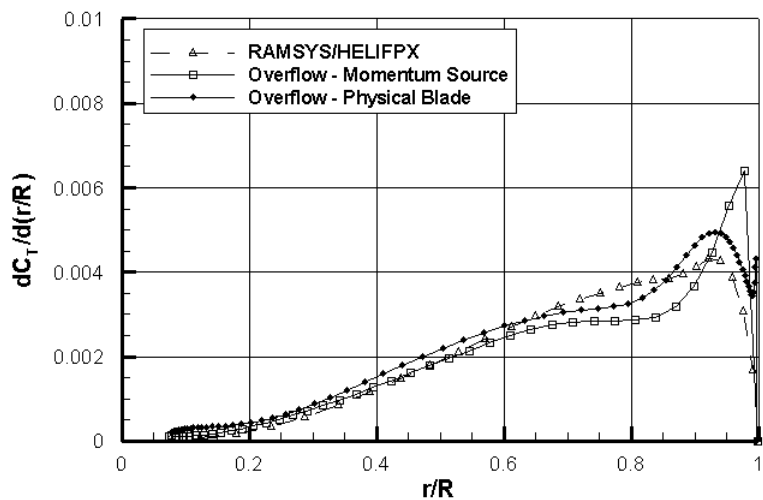
- Blade Element Model calculation of vorticity at 7.5° collective angle.



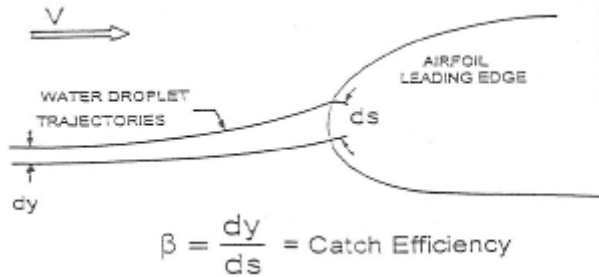
- A contour plot of vorticity cut through two vertical planes, $\psi=0^\circ$ (top) and $\psi=45^\circ$ (bottom), of an HELIFPX solution of an isolated UH-1H rotor at 7.5°



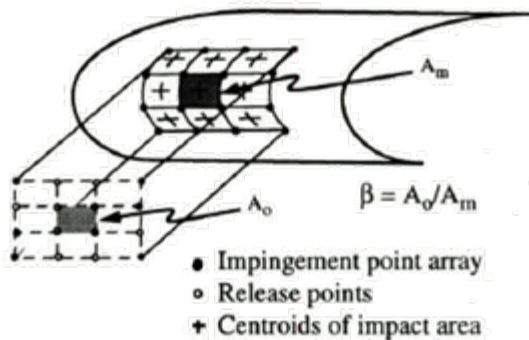
Flight E, Rotor Speed = 33.9 rad/sec, $T_\infty = 254.15$ K



Flight E, Rotor Speed = 33.9 rad/sec, $T_\infty = 254.15$ K, Collective = 7.5°

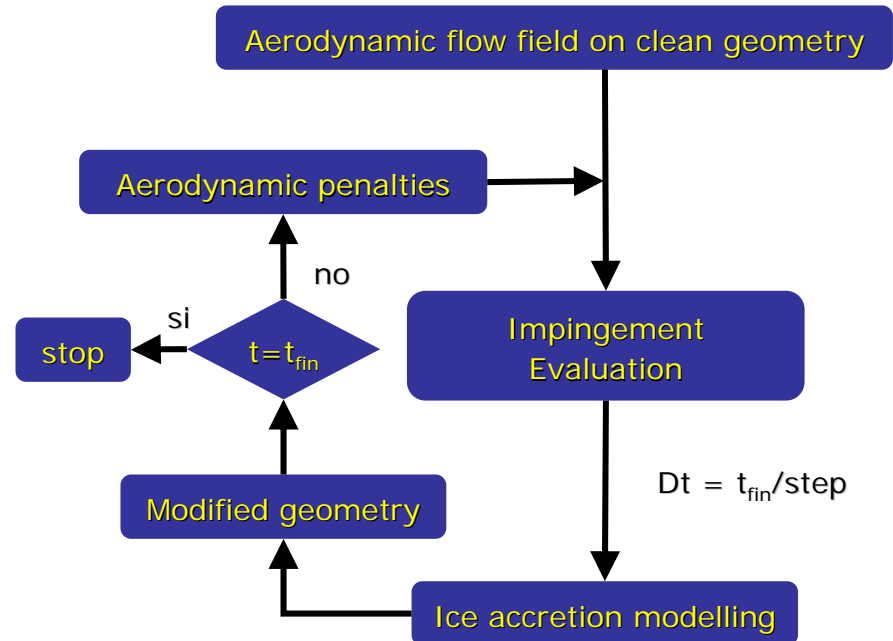


2D Geometry



3D Geometry

MULTI-ICE / LEWICE Procedure

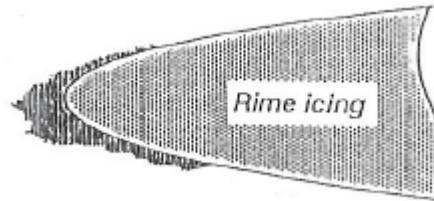


Type of Ice

Rime Ice Condition

- Low temperature
- Low airspeed
- Small droplets
- Low liquid water content

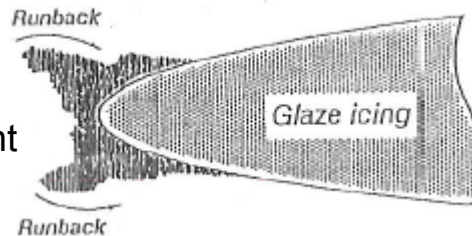
➡ Droplets freeze on impact: $F = 1$



Glaze Ice Condition

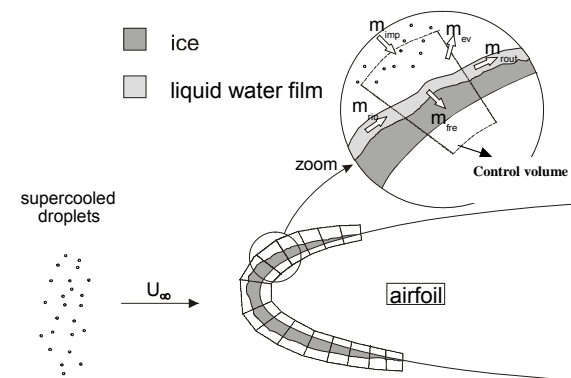
- Temperature near freezing point
- High airspeed
- Large droplets
- High liquid water content

➡ Runback water: $F < 1$



Messinger Model

- A continuous water film covers the surface.
- Simple estimation of run-back as a result of mass and thermal balance.
- The freezing fraction F mainly depends on heat transfer convection and solidification heat latent contribution.



The aerodynamic code

Douglas Hess-Smith

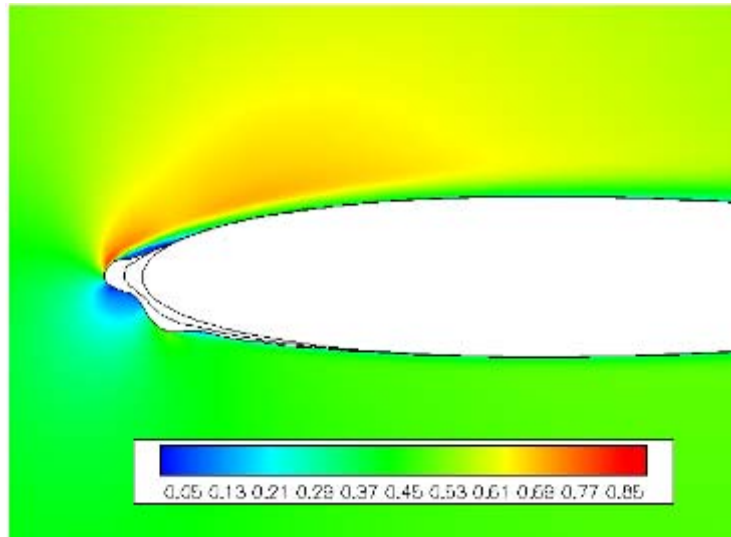
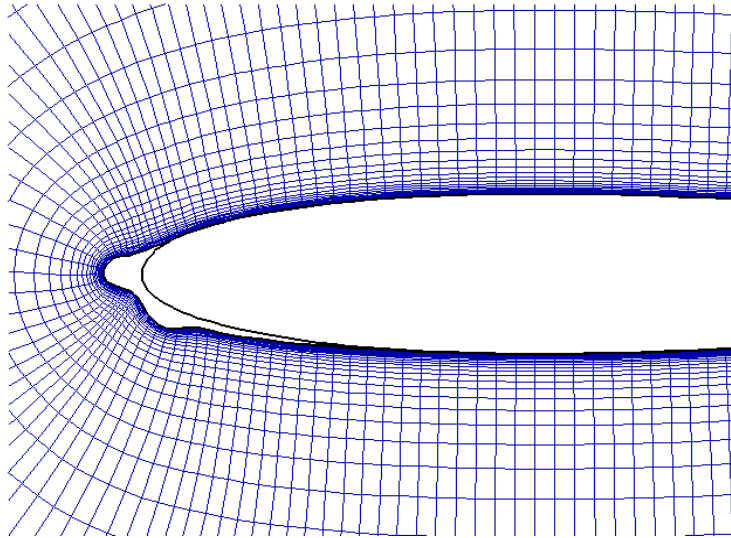
- Potential Panel Method
- Sources and Vortices distributed on the surface

ZEN

- CIRA developed RANS code
- Multi-block structured grids
- Finite volume formulation
- 2nd order cell-centered
- Second and fourth order artificial dissipation
- Multistage Runge-Kutta
- Local time stepping
- Implicit residual averaging
- Multi-grid method
- Dual Time Stepping

CFL3D

- NASA developed RANS code.
- Structured finite volume flux difference splitting scheme
- Roe's third-order upwind

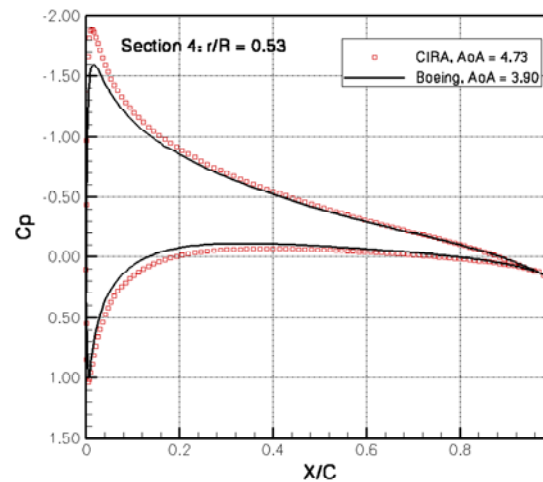
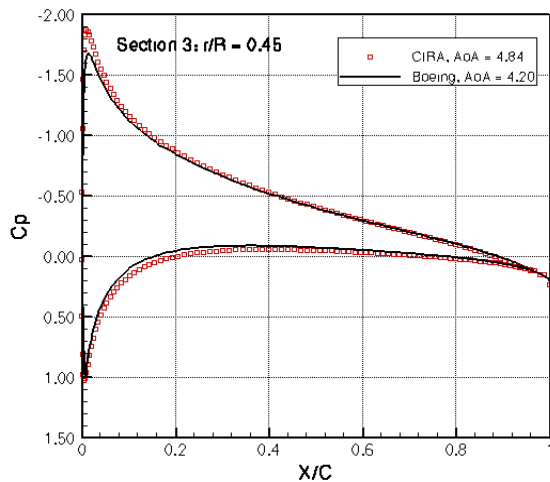
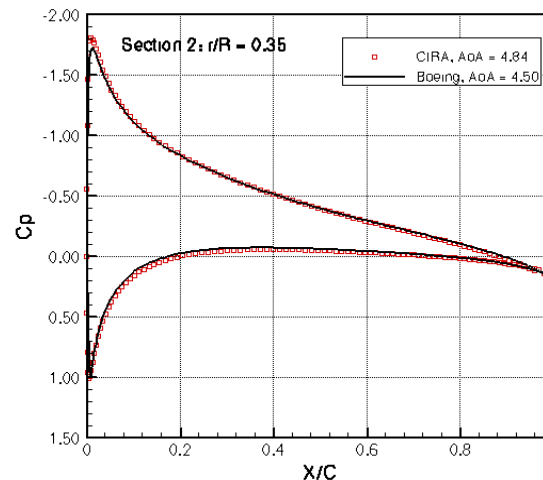
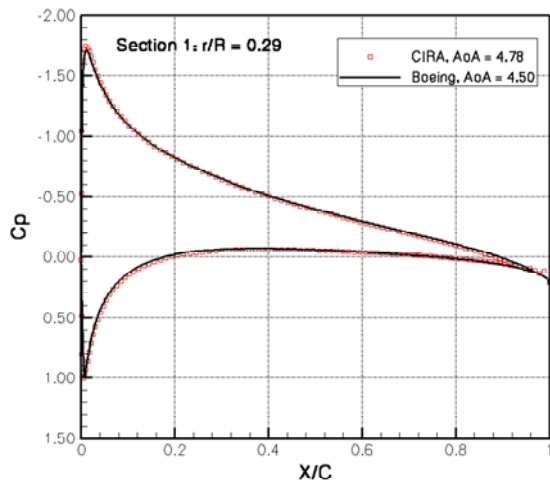


CIRA /Boeing RANS Simulation:

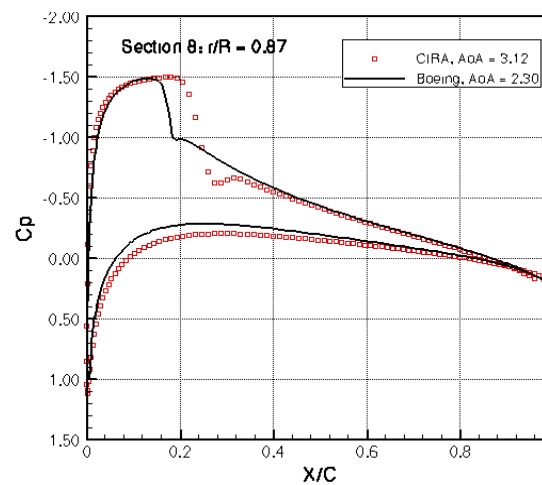
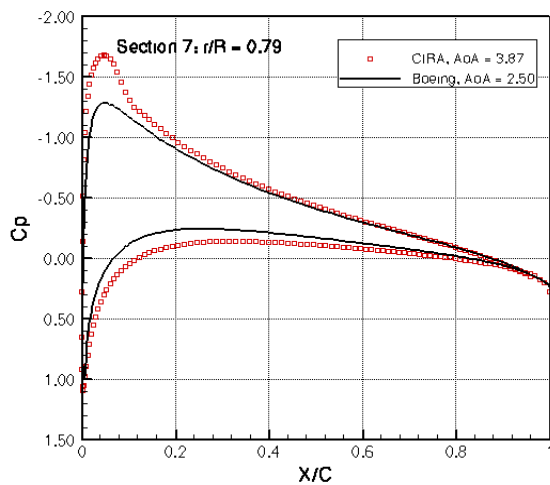
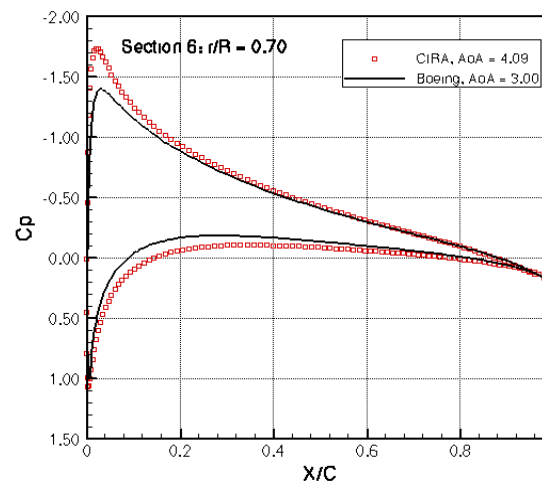
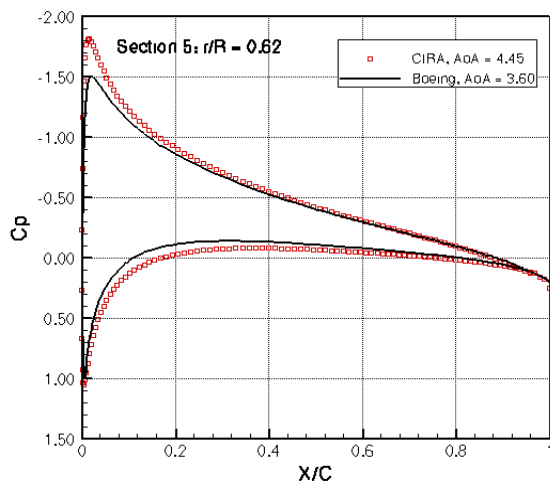
- ZEN and CFL3D code
- Automatic mesh generator
- Interpolated curve
- Structured C-type grid
- Y^+ close to 1.
- $K-\omega$ Turbulence Model.

Section	r/R	r [m]	AoA (Boeing)	AoA (CIRA)	Mach
1	0.292	2.13	4.50	4.78	0.227
2	0.354	2.60	4.50	4.84	0.275
3	0.454	3.32	4.20	4.84	0.353
4	0.533	3.90	3.90	4.73	0.414
5	0.617	4.51	3.60	4.45	0.479
6	0.700	5.12	3.00	4.09	0.544
7	0.788	5.76	2.50	3.67	0.612
8	0.871	6.37	2.30	3.12	0.676

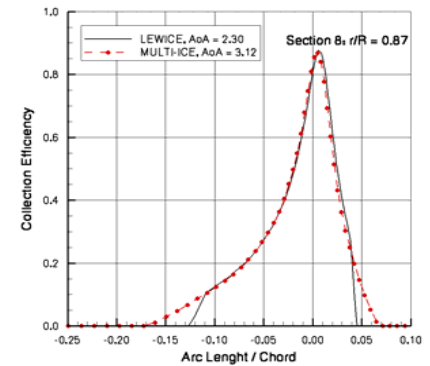
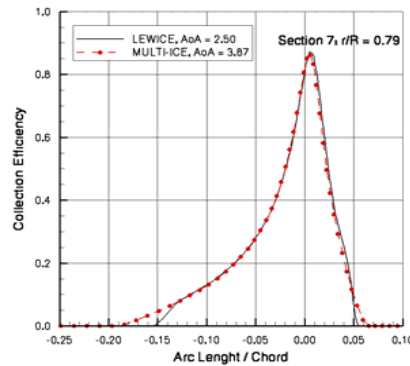
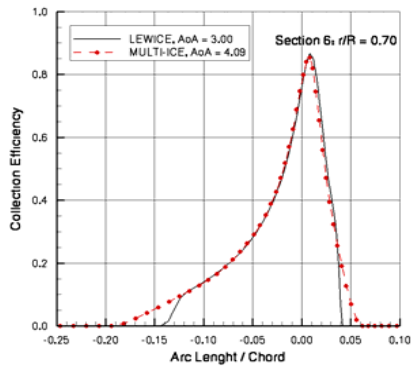
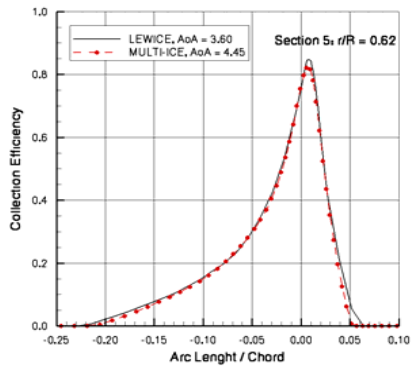
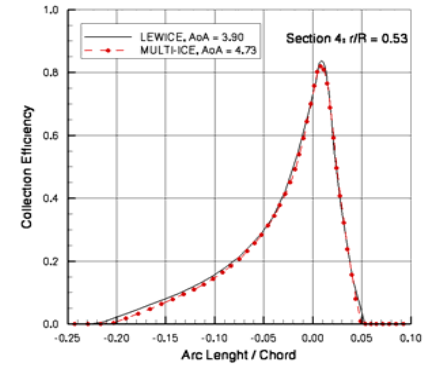
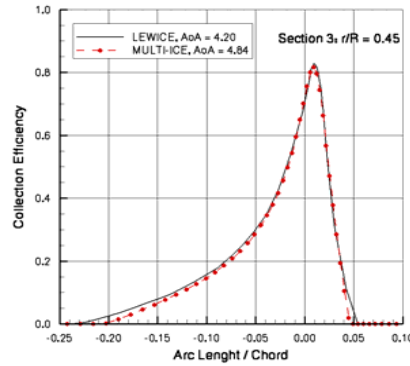
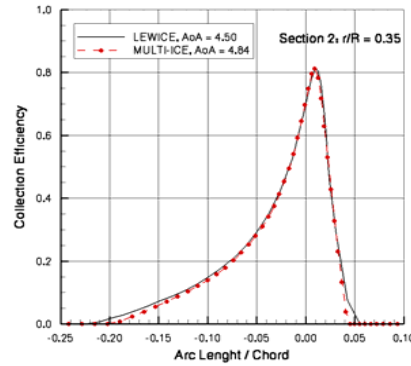
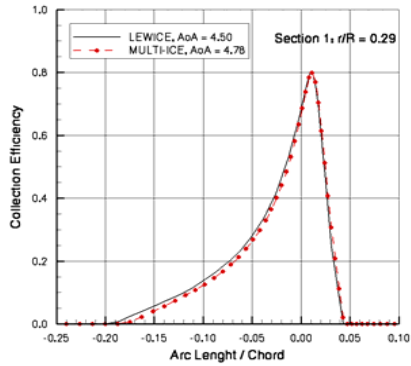
Pressure Coefficient Comparison on Clean Configuration



Pressure Coefficient Comparison on Clean Configuration

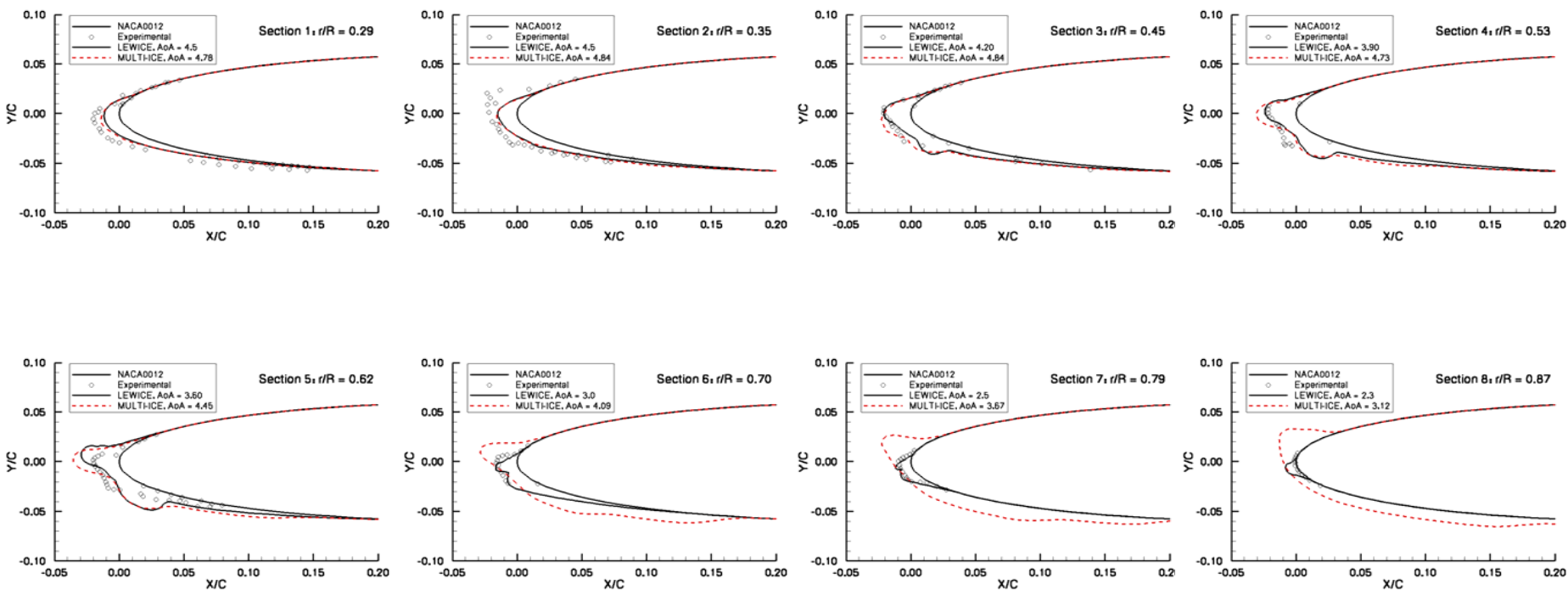


Collection Efficiency



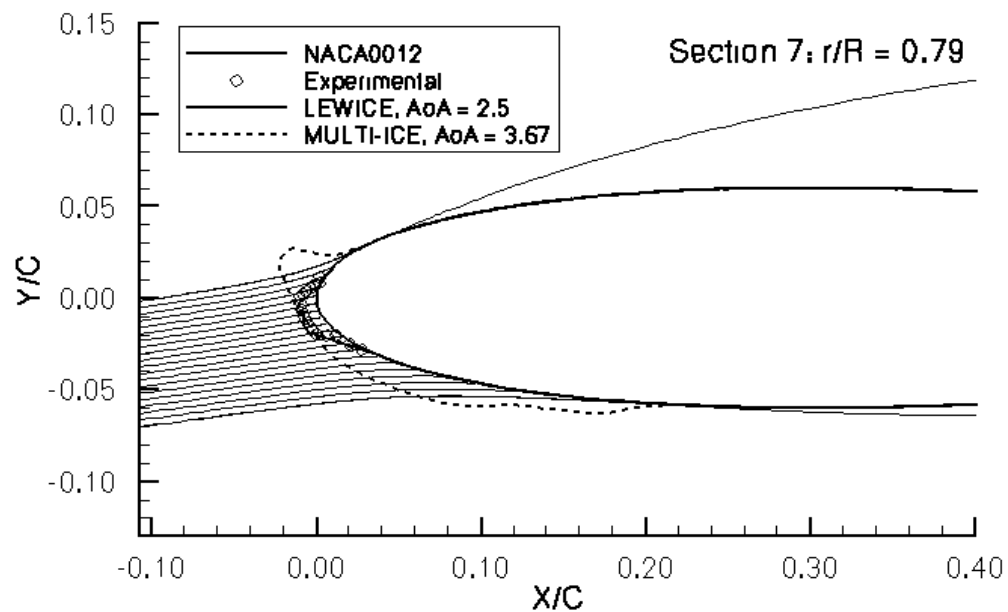
Flight E, Rotor Speed = 33.9 rad/sec, $T_{\infty} = 254.15$ K
 LWC = 0.7 g/m³, MVD = 30 μ m, Spray = 3 min

Ice Accretion Prediction



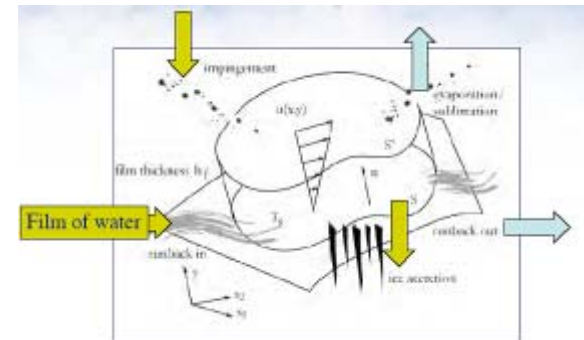
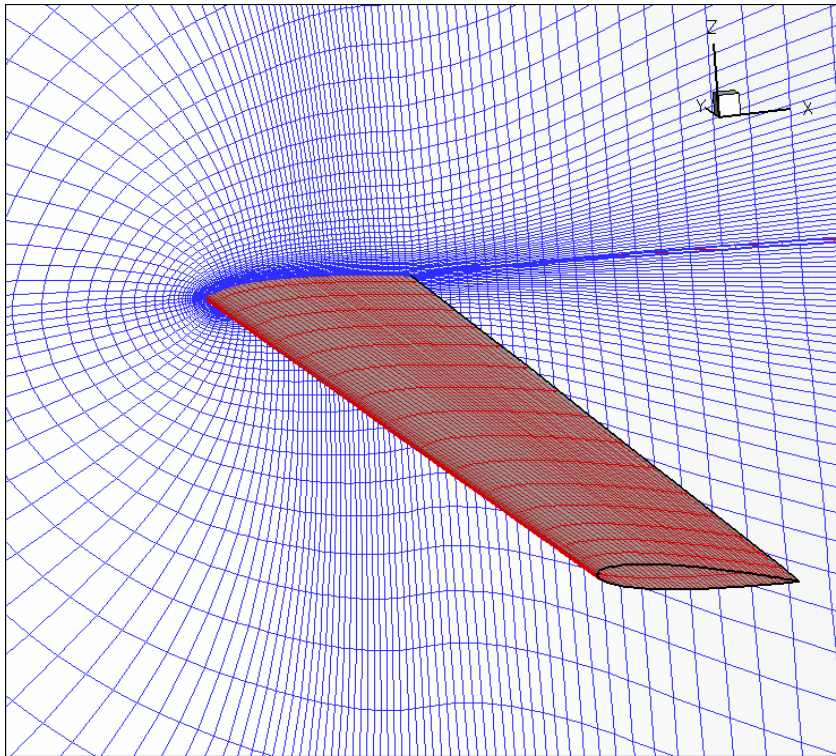
Flight E, Rotor Speed = 33.9 rad/sec, $T_{\infty} = 254.15$ K
 LWC = 0.7 g/m³, MVD = 30 μ m, Spray = 3 min

Ice Accretion Prediction



Flight E, Rotor Speed = 33.9 rad/sec, $T_{\infty} = 254.15$ K
 LWC = 0.7 g/m³, MVD = 30 μ m, Spray = 3 min

- Similar approach 2D/3D ice accretion model
- Classical Lagrangian approach and Messinger model
- Heat transfer coefficient by using an integral-boundary layer calculation method.
- The runback direction is assumed to follow the inviscid surface streamlines.



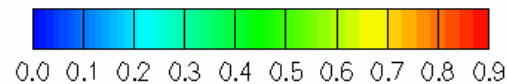
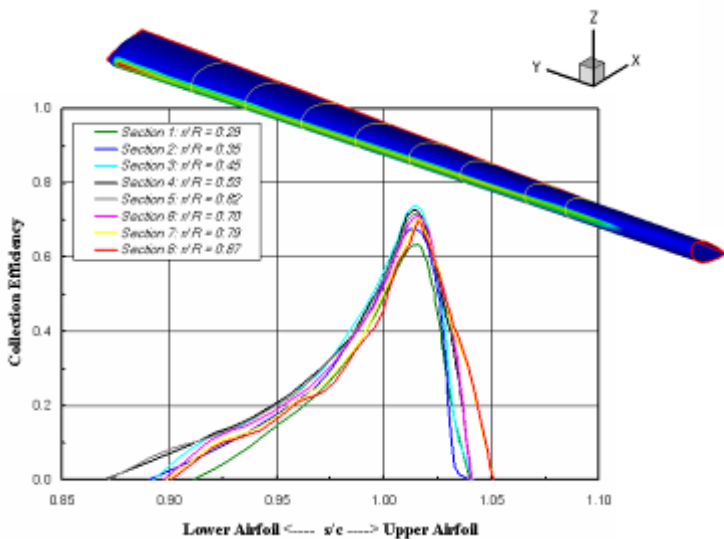
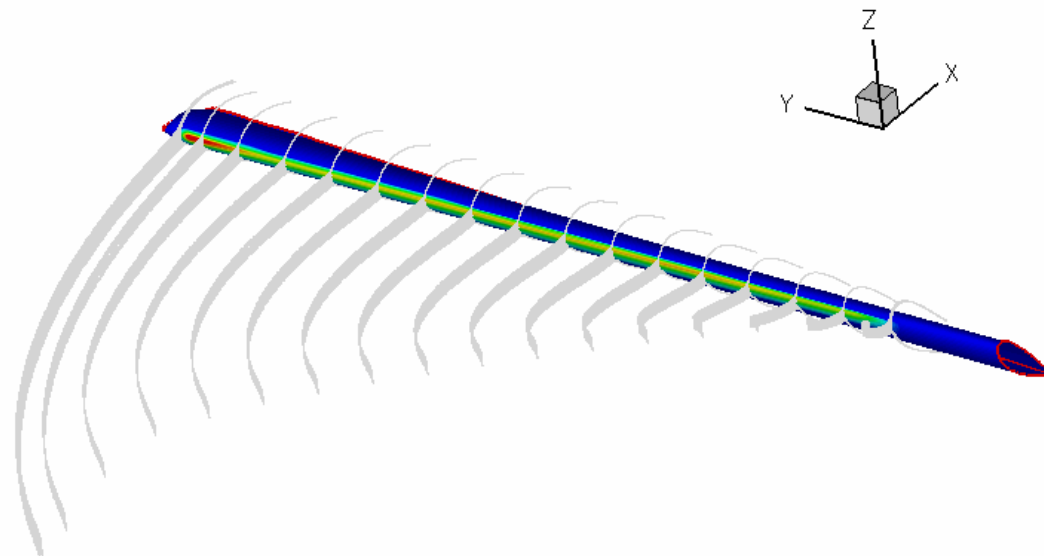
- Heat Balance

$$\dot{Q}_{conv} + \dot{Q}_{es} + \dot{Q}_{imp} + \dot{Q}_{rbi} + \dot{Q}_{kin} = 0$$

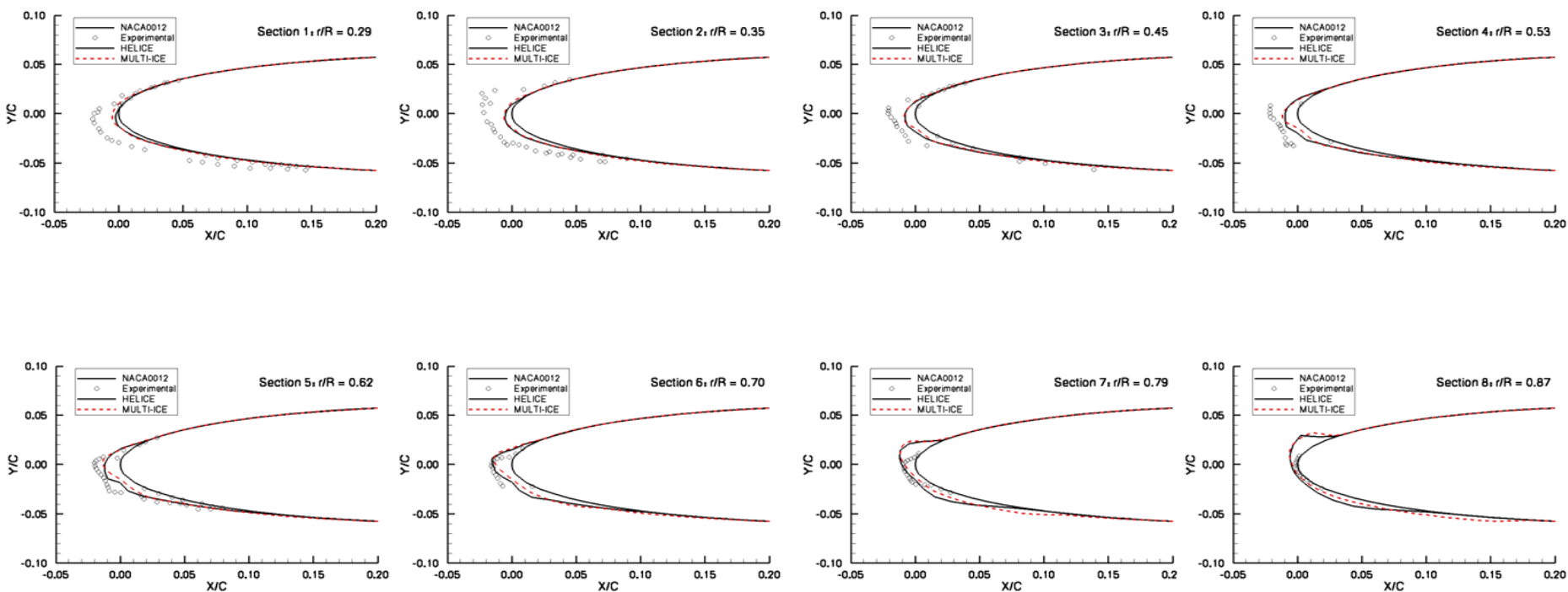
- Mass Balance

$$\dot{m}_{rbi} + \dot{m}_{imp} - \dot{m}_i - \dot{m}_{es} = \dot{m}_{rbo}$$

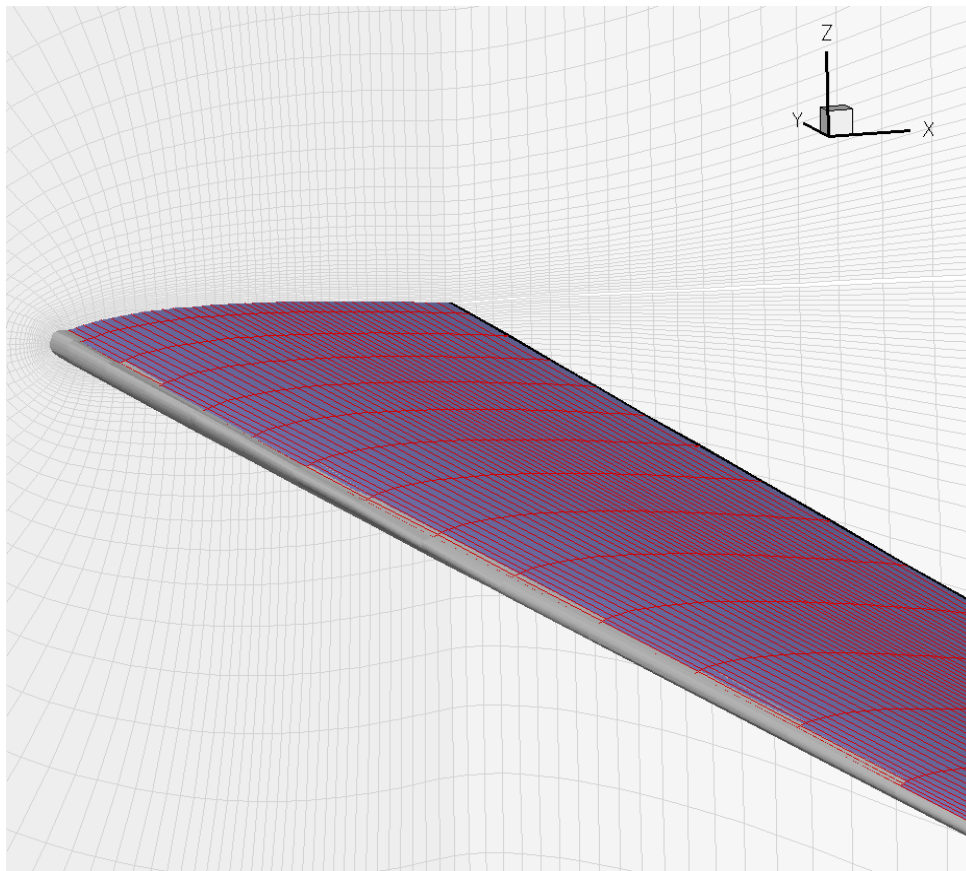
3D Collection Efficiency



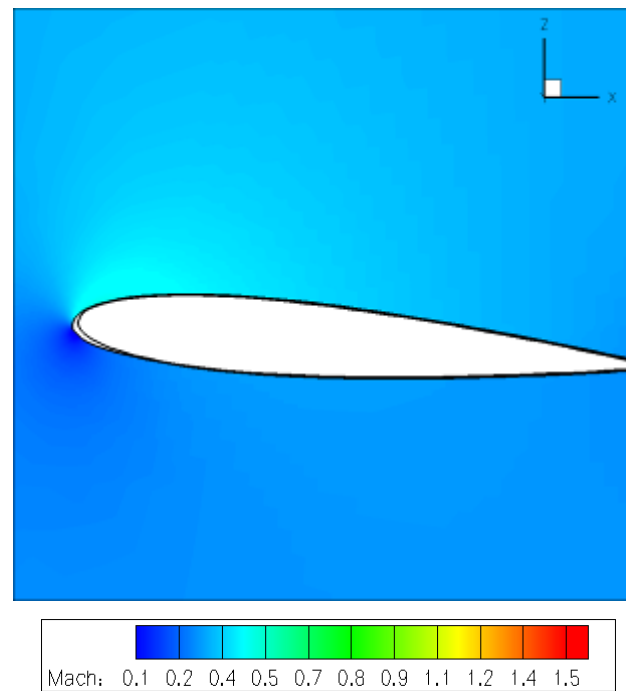
Ice Accretion Prediction



Flight E, Rotor Speed = 33.9 rad/sec, $T_{\infty} = 254.15$ K
 LWC = 0.7 g/m³, MVD = 30 μ m, Spray = 3 min



Ice shape along spanwise sections



Flight E, Rotor Speed = 33.9 rad/sec, $T_{\infty} = 254.15$ K
 LWC = 0.7 g/m³, MVD = 30 μ m, Spray = 3 min

- The NASA Lewis Research Center and US Army HILT program is being utilized to benchmark our prediction tools.
- Though aerodynamic prediction methods for a rotor in hover differ, there is no stand-out better method to feed into ice accretion prediction tools. A rotor in hover can be segmented into sections, with each section handled by 2D analysis.
- Generally good predictions are obtained inboard (rime ice and low compressibility). Additional investigation need the outboard sections (glaze is more challenging) and compressibility and ice erosion have bigger effects.
- Results for the first minute are shown for the three-dimensional ice accretion. A general good agreement with the two-dimensional approach is detected.
- 3D simulation provides better and more direct approach to predict ice accretion on rotors blade

- Include ice shedding phenomena on the computations.
- Perform ice accretion simulation in forward flight condition.