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National Aeronautics and Space Administration

Icing Simulation

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Outline

- LEWICE
  - Version 3.2.2 Status
  - Current Development
- LEWICE3D
  - Version 2 Status
  - Current Development

LEWICE Major Applications

- General application is the determination of amount and location of ice accretion on an aircraft.
- Used to determine water loading on aircraft surfaces so that the size and location of the ice protection system can be determined.
- Used to design and analyze hot air and electro-thermal ice protection systems.
- Used to determine ice shapes for FAA failed ice protection system test. These ice shapes are built and attached to aircraft by manufacturers for flight tests to insure that the aircraft can still fly with ice resulting from a failed ice protection system.

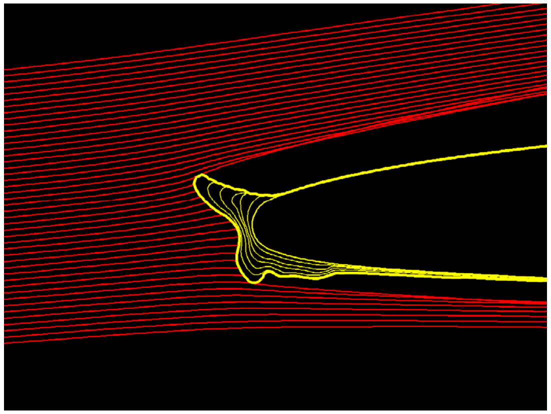
LEWICE 3.2.2 Methodology

- Flow Solver
  - Uses Hess-Smith 2D potential panel code or 2D Navier-Stokes flow solver to determine flow field about surface
- Droplet Trajectories
  - Calculate water droplet trajectories from some upstream location until impact on the surface or until body is bypassed using 4^{th} order predictor-corrector method
- Water Collection
  - Determine water droplet impact location pattern between impingement limits
- Heat Transfer
  - Perform quasi-steady analysis of control volume mass and energy balance in time stepping routine using integral boundary layer method with roughness effects
- Ice Growth
  - Ice growth calculated using scheme based on Messinger Model. Density correlations used to convert ice growth mass into volume
- Iterate
  - With new ice shape, iterate entire routine

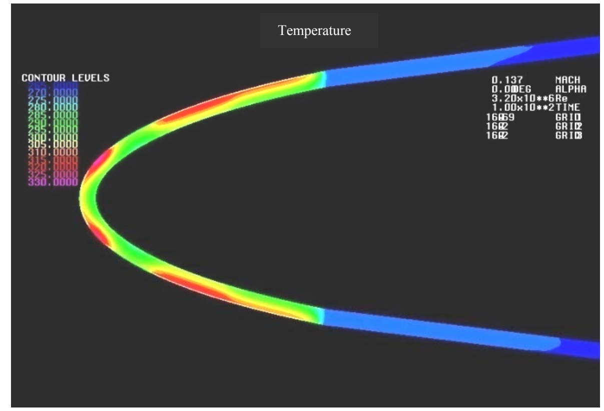
LEWICE Version 3.2.2

- Version 3.2.2 released September 2005
- Version 3.2.2 features
  - Analysis of Hot air and electro-thermal ice protection systems
  - SLD droplet splashing model
  - Droplet breakup model
- Approximations
  - Multi-time step
  - Flow calculated using 2D panel code or 2D Navier-Stokes flow solver
  - Messinger quasi-steady control volume icing model
  - Heat transfer calculated using integral boundary layer algorithm with roughness effects.
  - Surface water loading generated from trajectories calculated from free-stream to surface.

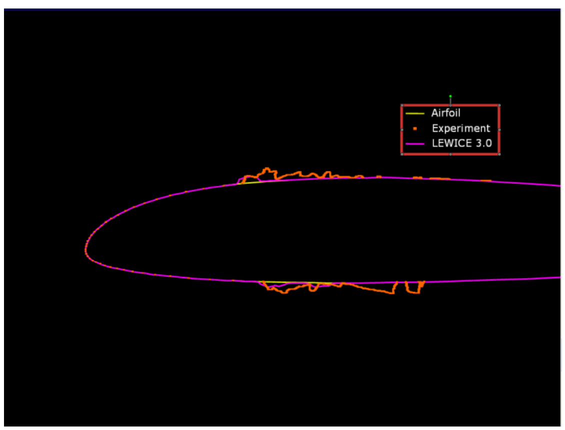
LEWICE – 2D Icing Tool



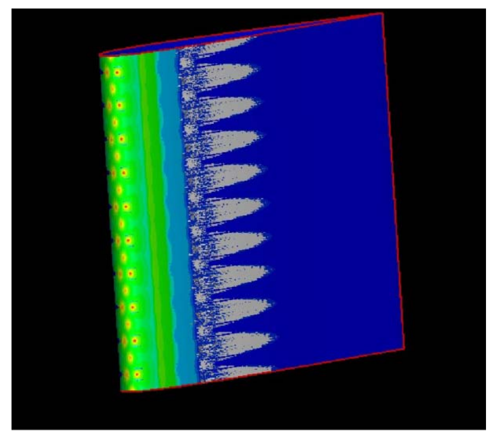
Droplet Trajectory and Ice Shape Prediction



Electro-Thermal System Performance



Residual Ice Prediction



Bleed Air System Performance

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Current LEWICE Development

- Mixed phase capability
  - Surface energy balance with ice instead of super-cooled water
- Particle energy balance
  - Evaporation (super-cooled drops)
  - Sublimation (ice particles)
- Automated multi-time step ice accretion using unstructured Navier-Stokes (FUN2D)

LEWICE3D Major Applications

- General application is the determination of amount and location of ice accretion on an aircraft.
- Used to determine water loading on aircraft surfaces so that the size and location of the ice protection system can be determined.
- Used to determine ice shapes for FAA failed ice protection system test. These ice shapes are built and attached to aircraft by manufacturers for flight tests to insure that the aircraft can still fly with ice resulting from a failed ice protection system.
- Used to determine location of icing sensors (don’t want to put a sensor in a position where there is no ice).
- Used to determine corrections for cloud measurement instruments (e.g. droplet size probes, liquid water content probes) on an aircraft (the aircraft causes a flow disturbance the result of which is that an instrument mounted on the aircraft will not read the correct free stream cloud properties).

LEWICE3D Methodology

- Flow Solver
  - User supplies grid based flow solution. LEWICE3D can handle multi-block structured grids, “VSAERO” type structured grids, adaptive cartesian grids (ICEGRID/PATCHGRID), and unstructured grids
- Droplet Trajectories
  - Trajectories are calculated using 4th order Adams-type predictor-corrector method developed by Hillyer Norment.
- Water Collection
  - Collection efficiencies for simple 2D or 3D regions can be calculated using a modified LEWICE2D scheme.
  - Collection efficiencies for complex regions are calculated using a quadtree area based collection efficiency method.
- Heat Transfer
  - Perform quasi-steady analysis of control volume mass and energy using integral boundary layer method with roughness effects using 3D strip approach.
- Ice Growth
  - Ice growth calculated using modified LEWICE2D scheme based on Messinger Model. Ice Density model with additions for “scalloped” ice shapes.

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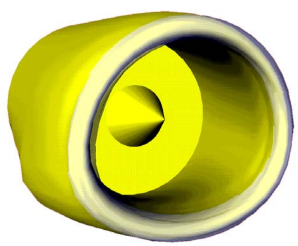
LEWICE 3D Version 2

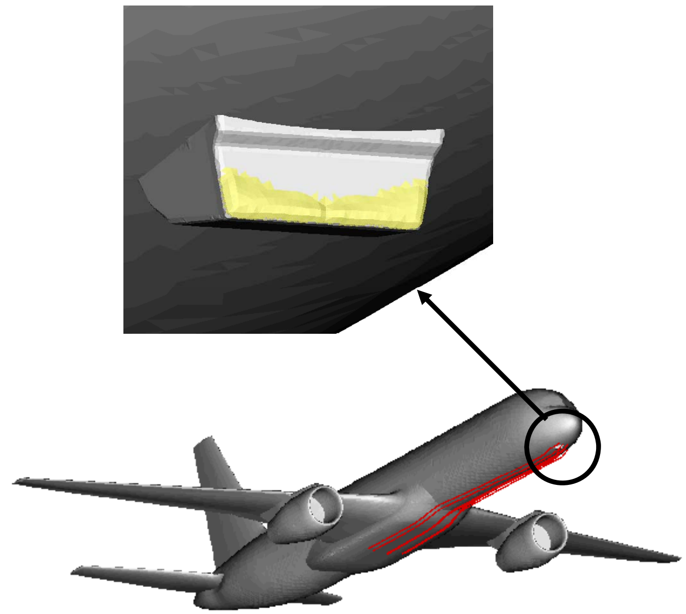
- Version 2 Released March 2007
- Version 2 Features
  - Automated most users inputs
  - Roughness model incorporated
  - Ice density model for scallop ice shapes
  - Variable area collection efficiency method installed which reduces calculation times and insures convergence
  - Dynamic memory allocation and OpenMP and MPI parallelization has been incorporated to optimize memory and speed on modern computers.
- Approximations
  - Single time step
  - Ice shapes calculated along 3D strips
  - Steady or time averaged flow solutions required
  - Grid based application requires user supplied 3D flow solutions on structured, or unstructured grids
  - Messinger quasi-steady control volume icing model
  - Heat transfer calculated using integral boundary layer algorithm with roughness effects
  - Surface water loading generated from trajectories calculated from upstream to surface

LEWICE3D - 3D Icing Tool

Version 2 of the LEWICE 3D ice accretion computational tool calculates water and ice accretion on complex aircraft surfaces



Boeing 737-300 Inlet

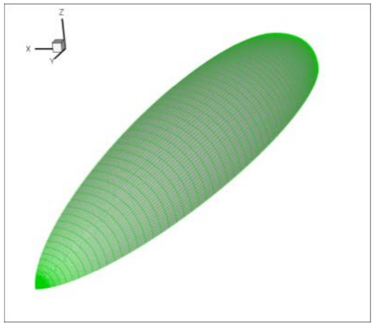


Boeing 757 with FLIR Pod

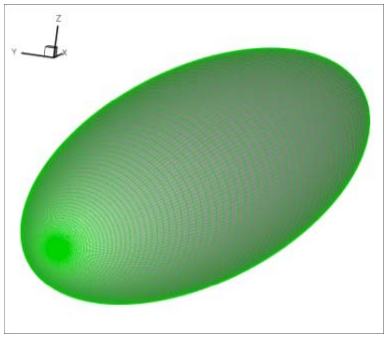
Current LEWICE3D Development
(LEWICE3D Version 3)

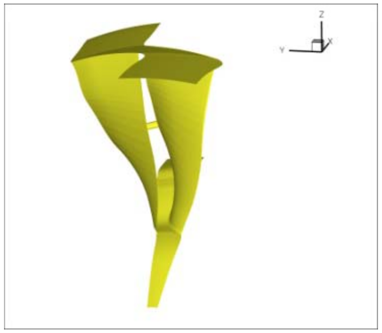
- A grid block transformation scheme which allows the input of grids in arbitrary reference frames, the use of mirror planes, and grids with relative velocities has been developed.
- A simple ice crystal and sand particle bouncing scheme has been included.
- Added an SLD splashing model based on that developed by William Wright for the LEWICE 3.2.2 software.
- A new area based collection efficiency algorithm will be incorporated which calculates trajectories from inflow block boundaries to outflow block boundaries. This method will be used for calculating and passing collection efficiency data between blade rows for turbo-machinery calculations.

Grid Block Transformation and Mirroring Scheme

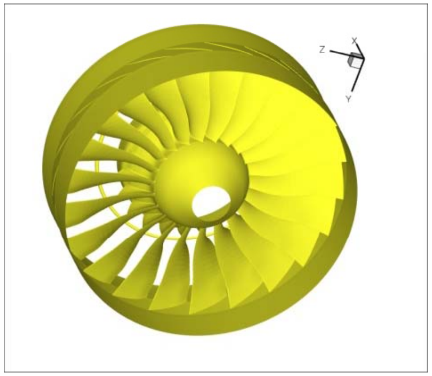


Rotation and Symmetry Plane Mirroring





Radial Mirroring with Relative Velocities



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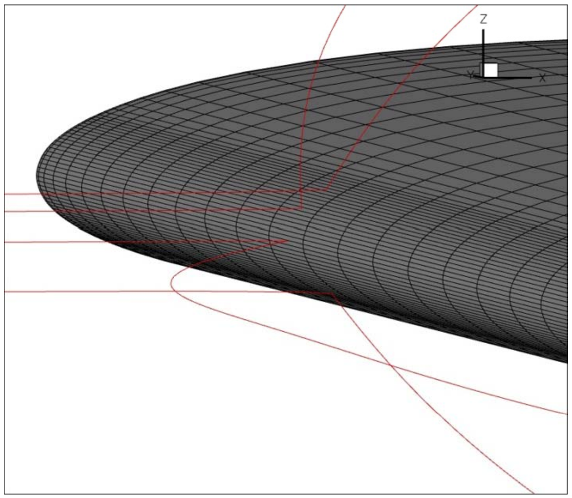
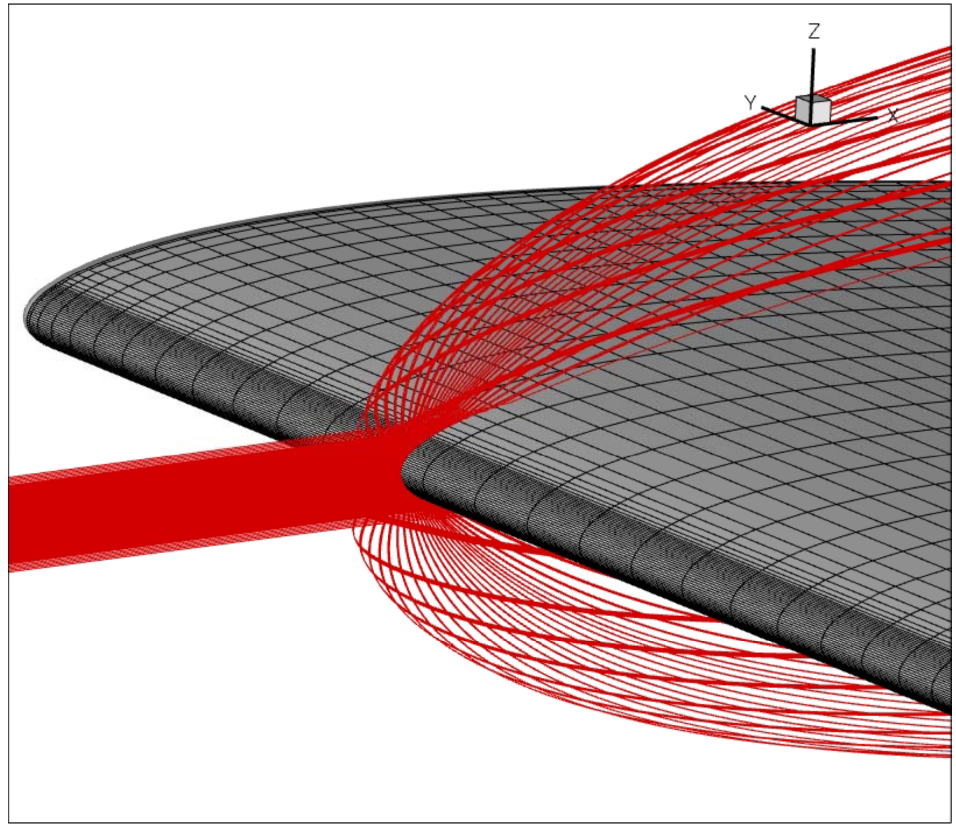
Particle Reflection Model For Bouncing Sand and Ice Crystals



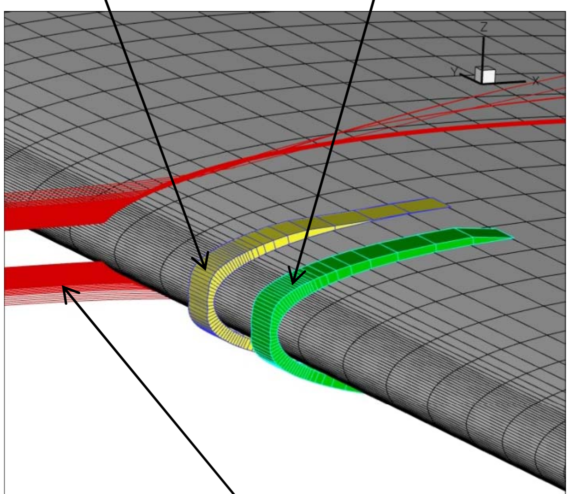


SLD Splashing Model Based On Wrights LEWICE 3.2 Model

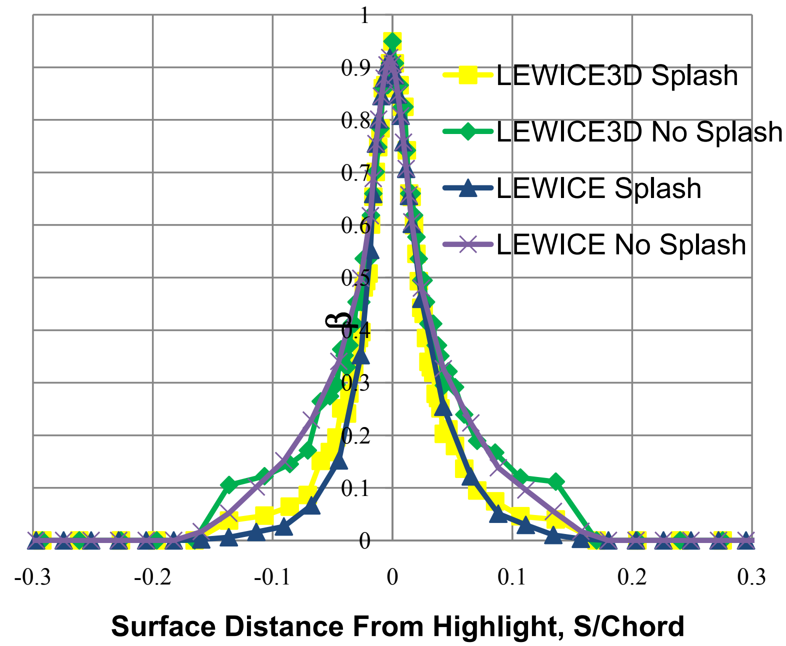
(NACA 0012; MVD=160 Microns; V=87 m/s)

Ice Shape
With Splashing

Ice Shape
No Splashing



Splashing Droplet Trajectories



Future LEWICE3D Validation Requirements

- Ice accretion data for 3-dimensional configurations needs to be generated to validate icing calculations (e.g., swept wings, radomes, inlets, etc.). The available data for validation is limited and most of it is proprietary.
- Ice crystal and sand rebound models need to be validated. Some data exists for sand but no data exists for ice crystals.
- A more sophisticated SLD splashing model and more detailed experimental splashing data needs to be generated to handle complex configurations such as multi-element wings with multiple impingement regions. The current model has been tuned to match data for simple configurations with single leading edge impingement regions. The current model approximates the splashed water from a droplet impact as a single drop which has limited accuracy for predicting the location of secondary impact zones.