FENSAP-ICE-TURBO™

Imagine an engine test facility and a high-altitude test cell on your desktop
FENSAP-ICE-TURBO™ enables in-flight icing simulation and certification of jet engines “as installed on the aircraft”

About FENSAP-ICE-TURBO

FENSAP-ICE-TURBO is the first system specifically developed to simulate all aspects of in-flight icing for jet engines.

FENSAP-ICE-TURBO is custom tailored to the needs of jet engine manufacturers, meeting the requirements of Appendix C, Appendix D (Ice Crystals) and Appendix O (SLD).

FENSAP-ICE-TURBO’s integrated approach is a leap forward into 21st century CFD technology, opening a new era in the design and certification of ice protection of jet engines.

FENSAP-ICE-TURBO has no geometric limitations and is applicable to all internal and external components of the jet engine, from the tip of the center cone to the combustor inlet.

FENSAP-ICE-TURBO can analyze the external flow and icing over the aircraft, with engines installed and running. Detect and solve icing and installation problems before the aircraft design cycle is completed.

FENSAP-ICE-TURBO’s 4 modules simulate, with great precision:
- Airflow (CFD)
- Droplets and ice crystals impingement limits
- Ice shapes
- Anti- and de-icing heat loads
- Aerodynamic degradation (CFD)

An advanced Graphical User Interface (GUI) links the four modules seamlessly.

FENSAP-ICE-TURBO accepts grids generated by most commercial mesh generation software. Grids can be structured or unstructured-hybrid (hexahedral, tetrahedral, pyramid and prism elements). The same grid is used by the 4 modules, therefore the CFD aero grids can be re-used to analyze the effects of icing. FENSAP-ICE-TURBO’s technology therefore permits the analysis of aero and icing simultaneously: no other existing system does that!

FENSAP-ICE-TURBO also accepts airflow results from most commercial CFD codes, seamlessly integrating into the engine development cycle.

FENSAP-ICE-TURBO can output data to most commercial data visualization packages.

FENSAP-ICE-TURBO runs on most computer platforms, from PCs to clusters.

Current FENSAP-ICE users can upgrade to FENSAP-ICE-TURBO with the addition of a moderately priced module.
FENSAP-ICE-TURBO™ accurately models multi-phase flows in multi-stage jet engines

Overview of the System

FENSAP-TURBO supports any number of blade rows.

Sequential and staggered arrangements are allowed.

The process of coupling the inflow/outflow boundary surface pairs that form the interfaces between rows is automatic.

Each rotating component can have its own rotational speed, enabling the simulation of multi-spool configurations.

Each module is designed to reduce the work needed to configure various components of the turbomachine.

The easy-to-use Graphical User Interface greatly simplifies the set-up of multistage icing calculations.
FENSAP-ICE-TURBO™ accurately computes heat fluxes and shear stresses for icing calculations

AIRFLOW
FENSAP-TURBO Module

FENSAP-TURBO is the RANS flow solver, capable of seamlessly handling stationary and rotating periodic components and computing shear stresses and heat fluxes with the high accuracy required by ice accretion simulation.

It is based on a high-precision Finite Element formulation.

It can support hexahedral, tetrahedral, prismatic and pyramidal elements.

Exchange of information between rows is carried out by pitch-averaging algorithms.

Ice roughness can be simulated with no special grid treatment.

Powerful ALE algorithms deform the mesh during the growth of ice, “without remeshing.”

Extended Icing Data, a proprietary technology of NTI, can extract additional features from the flow solution to improve the simulation of ice accretion in the higher enthalpy range, where the stagnation temperature is very close to the freezing temperature. EID also supports other commercial flow solvers.
**FENSAP-ICE-TURBO™** meets the requirements of Appendix C, Appendix D and Appendix O; all in a single system

**LIQUID WATER/ICE CRYSTALS**  
**DROP3D-TURBO Module**

DROP3D-TURBO solves the Eulerian particle transport equations, be they for droplets and/or ice crystals, to provide, in a single calculation, a complete picture of the water catch on all wall surfaces of all rows of a turbomachine.

DROP3D can handle monodispersed particles, user-defined, or Langmuir distributions as required by Appendix C of the FAA certification regulations, as well as Supercooled Large Droplets (SLD) and Ice Crystals, as proposed in the upcoming FAA Appendix O and Appendix D icing certification guidelines.

DROP3D-TURBO can handle multi-row geometries, using the same grids as the airflow solver and exchanges information between rows through pitch-averaging algorithms.

DROP3D-TURBO is interfaced with several commercial CFD solvers.

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Particle paths in a fan row, showing the radial migration of droplets caused by the centrifugal and Coriolis forces

Differences in droplets and ice crystals impingement characteristics on a fan blade section

SLD droplet breakup zones in the stator and IGV passages

LWC distribution in a turbofan, showing the shadow zones created by the blades, the rotor tip leakage and the pitch averaging
FENSAP-ICE-TURBO™ computes 3D ice accretion on the same grid used for the airflow and water impingement

ICE ACCRETION
ICE3D-TURBO Module

ICE3D-TURBO simultaneously computes the 3D water film flow, ice formation and growth on all the solid surfaces of all rows, using the shear stresses and heat fluxes computed by the airflow solver (FENSAP-TURBO), and the water impingement computed by DROP3D-TURBO.

The effects of the centrifugal and Coriolis forces are fully accounted for in the water film transport equation.

ICE3D-TURBO automatically averages the water catch, shear stress and heat flux in the tangential direction to account for the movement of the rotating components.

ICE3D-TURBO takes full advantage of EID, a proprietary technology of NTI, to simulate the effect of rising stagnation temperature in the turbomachine, which may eventually reach and pass the freezing temperature, leading to partial ice coverage on the blades.

Multi-shot ice accretion is supported, with ALE mesh displacement or with remeshing. Sliding surfaces can be defined to allow the mesh displaced by the ice accretion to slide over surfaces that accrete little or no ice, such as at hub and shroud, and prevent the severe mesh distortion that would otherwise occur.
FENSAP-ICE-TURBO™ precise heating performance analysis for complex hot-air and electro-thermal ice protection systems

CONJUGATE HEAT TRANSFER
CHT3D-TURBO Module

CHT3D-TURBO simulates the complex flow and thermal phenomena within hot-air or electro-thermal Ice Protection Systems (IPS) to determine their effectiveness.

CHT3D-TURBO handles dry- or wet-air simulations and offers a range of airflow/solid domain coupling options, from simple constant convective heat flux coefficients all the way to full RANS simulations with roughness.

There is no limit on the number of interfaces that can be defined.

There is no limit on the number of material layers that can be simulated. Each material can have its own constant or thermally varying properties.

CHT3D-TURBO supports multiple-connected domains for the cold external and hot internal flows, to improve the stability and convergence of the simulation. Dry zones can be defined to reduce the complexity of the simulation, without compromising its accuracy.

- Heat flux distribution on the external surface of a heated engine center cone rotating at 4,000 rpm (wet-air CHT simulation)
- Water film and ice accumulation on an engine center cone (heating off), clearly showing the transition from glaze to rime ice
- Water film on the external surface and temperature distribution on the internal surface of a heated engine center cone (incomplete evaporation, no ice)

Temperature distribution inside the center cone and circumferential cuts of the helical wakes of the hot air orifices
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