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TECHNOLOGIES INT.

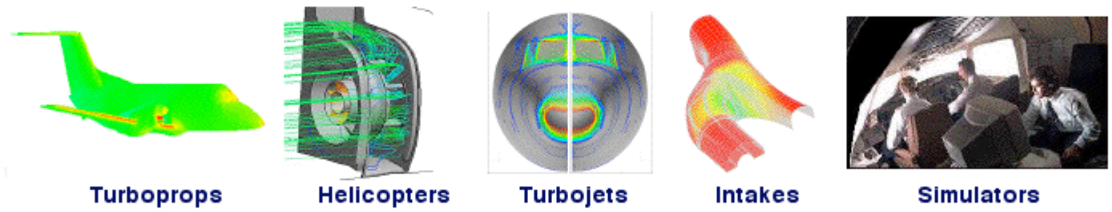
Frequently Asked Questions

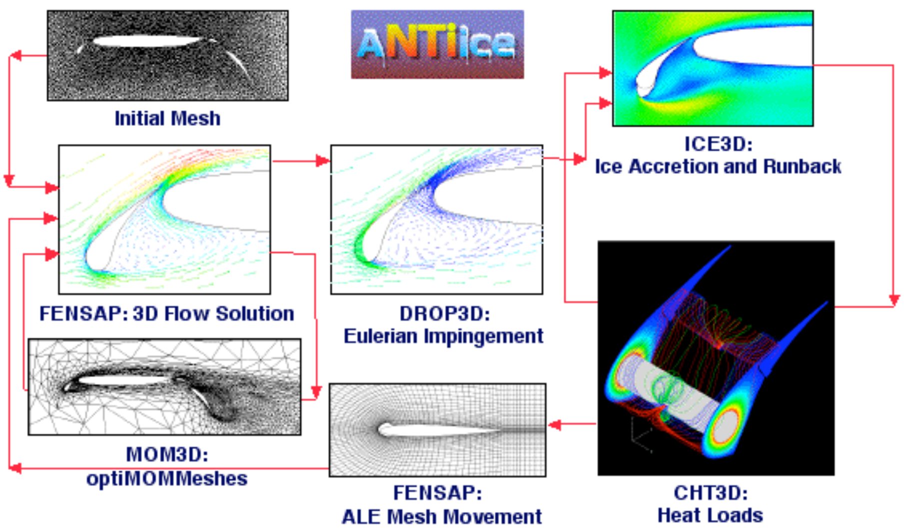
In-flight Icing Simulation via FENSAP-ICE

NTI Aid-in-certification Services

Question 1: What is FENSAP-ICE?

FENSAP-ICE is an integrated 3D software "system" for the simulation in-flight icing analysis of aircraft, rotorcraft, UAVs, jet engines, instruments and appendages. FENSAP-ICE is comprised of 4 modules, driven through a common advanced graphical environment. Each module is offered as standalone interfaced to *your own* CFD software, or as part of the FENSAP-ICE system.





The 4 interconnected modules of FENSAP-ICE are:

- FENSAP for the 3D CFD of clean or contaminated components. Besides CAD fidelity (mesh generation can start from a CAD system description of the component) and accounting for compressibility, viscosity, turbulence and three-dimensionality, FENSAP has numerical features minimizing user intervention, such as mesh movement to follow ice shapes, and mesh optimization (OptiGrid) to get very accurate CFD results.

- DROP3D for 3D droplet impingement based on an Eulerian model, dispensing with the Lagrangian method of tracking individual particles. DROP3D is a one-shot calculation approach for any simple or complex geometry, including multi-element wings, (complete) aircraft, rotorcraft, nacelles, jet engines, instruments, etc.

- ICE3D for 3D ice accretion and water runback based on partial differential equations.

- CHT3D for 3-D Conjugate Heat Transfer analysis of bleed-air and electro-thermal, anti-/de-icing IPS: modeling heat transfer in the flow and ice, through the metal skin(s), and inside the wing, with no empiricism at any interface.

Question 2: Does FENSAP-ICE have any export control?

No, unlike the NASA and ONERA and other national labs software, which are export controlled, FENSAP-ICE is freely commercially available.

Question 3: What is the structure of the FENSAP-ICE system?

The FENSAP-ICE system is fully GUI-driven. The graphical environment includes file browsing and management through a directory and file tree, multi-domain and multi-solver manager with visual support for convergence monitoring.

Question 4: What type of computer hardware is needed?

FENSAP-ICE supports HP-UX, HP-IA, SUN-SOLARIS, IBM-AIX, Linux (32/64 bits), Windows (32/64 bits) environments. FENSAP-ICE is efficiently parallelized for distributed memory clusters.

Question 5: Is it possible to use another CFD code instead of FENSAP?

It is possible to use any CFD code within the FENSAP-ICE system. FENSAP-ICE is currently interfaced with FENSAP, FLUENT and CFX. But NTI can develop any interface to convert the grid and solution to a format legible by FENSAP-ICE.

It is possible to use any post-processing software within the FENSAP-ICE system. FENSAP-ICE is currently interfaced with FieldView and Ensight. If you already have a visualization code, we can provide a converter to its format.

Question 6: Is it possible to run the modules of FENSAP-ICE simultaneously?

It depends on the problem to be solved but it is possible to run multiple DROP3D solutions for a given droplet distribution, or ICE3D solutions simultaneously once the flow solution is obtained.

If runs of the modules are unrelated, it is possible to run all of them concurrently through the graphical environment, since all modules are licensed separately.

The general ice accretion problem being, by its very nature, sequential: flow solution, droplet impingement, followed by ice accretion, such sequential calculations can be launched directly through the GUI.

Question 7: What are limitations on collection efficiency for complex shapes?

Unlike Lagrangian approaches, FENSAP-ICE's unique Eulerian approach captures the collection efficiency distribution on all solid surfaces of a 3D model at once, without any need to seed or to track particles. The complexity of the object is thus immaterial: the code is fully 3D, with ABSOLUTELY no geometric restrictions.

Question 8: Can FENSAP-ICE determine shadow zones?

Yes, FENSAP-ICE can determine them with great ease and with no extra effort. Remember that the code solves for water concentration, so it gives it everywhere. One has just to visualize the results in order to see the shadow zones.

Question 9: Can FENSAP-ICE analyze electro-thermal and hot air IPS?

Yes, FENSAP-ICE can analyze both systems, in anti- and de-icing modes.

Question 10: Can all analyses (aero + icing) needed for the design of a new aircraft be carried out using FENSAP-ICE?

Yes, absolutely. Think of FENSAP-ICE as an advanced icing code that can do CFD, as opposed to a CFD code that attempts to do icing. FENSAP-ICE is a complete (aerodynamics + in-flight icing) *system*. By using FENSAP-ICE, aero design and in-flight icing protection become synchronous exercises. Think of all the grids and flow solutions that have already been generated for aero analysis. Once that effort is made, icing is just an incremental step.

Question 11: Can FENSAP-ICE determine the effects on stall speed and characteristics of minor amounts of rime ice?

Yes, FENSAP-ICE can determine the effects of small ice quantities such as inter-cycle or residual ice on airfoils and wings. It can simulate sandgrain roughness as well, with or without ice accretion. Experience has shown that the performance degradation can be very strong depending on the location of the ice. In cases where the small ice shape corresponds with the suction peak of the wing, the stall speed can be increased dramatically. In case this is in front of an aileron section, the effect can be even more dramatic.

Question 12: What are aircraft sections to which FENSAP-ICE is applicable?

"All" aircraft, rotorcraft and engine sections of the following Table, and more. For example, FENSAP-TURBO can give impingement an dicing results deep inside mulstistage jet engines .

Systems	
Complete Aircraft	Turbofan
	Turboprop
	Helicopter
Airfoil	Single Element
	High-lift
Wing Surface	Swept
	Twisted
Winglet	
Empennage	Vertical Stabilizer
	Horizontal Stabilizer
Canard	
Nacelle	
Pylon	
Wing-Nacelle-Pylon System	
Engine	
Detectors, Probes	
Fuselage Components	
Radome	
Propeller	Blades
	Spinner
Helicopter Rotor	Main
	Tail

Question 13: Has FENSAP-ICE been compared to test data?

Indeed, extensively. NTI has analyzed airfoils in the NACA 4-digit series and 5-digit series, as well as proprietary airfoils, for impingement and ice accretion. Several examples of 3D calculations and validations have also been documented. These are available, upon request, to customers.

Most of the work we have conducted on comparison to tests, in particular for performance degradation of aircraft and engine components, is, however, customer proprietary and as per their request cannot be divulged. As you can appreciate, performance of aircraft in icing is a highly sensitive area. Your own organization would probably refuse to divulge data even if it worked with NTI. Right?

Nevertheless, we have extensively compared the predictions of FENSAP-ICE with available open literature data and our comparisons are interspersed in the publications listed on our web site.

We are quite unique in the fact that client confidence has been demonstrated through joint scientific publications on icing. We have published technical papers with important industrial partners such as Bell Helicopter Textron, Bombardier Aerospace, CAE, Meteorological Services Canada, Northrop Grumman, AVIC1 and Mitsubishi.

Question 14: Has NTI taken part in major international exercises to compare ice accretion codes?

Typically, comparisons at such marathon test meetings (the last one having taken pace in Capua in 2000) are only for ice shapes; the icing community believing that this may be the extent of capability of CFD.

That, in NTI's opinion, is absolutely no longer true, as algorithms have tremendously improved and computer speed has accelerated by 2 million times (yes, 2 million!) in 20 years.

NTI thus does not like to mix apples and oranges: FENSAP-ICE is a *second-generation* complete 3D icing "*system*" that goes way beyond ice accretion; its claim to fame being accuracy, 3D realism and integration within aerodynamic design.

NTI also feels that, at these meetings codes, are being asked to regurgitate 2D test cases for which they were well prepared and for which organizations have conducted hundreds of tests to get correlations.

Finally, let us consider the following scientific argument. To obtain ice shapes 3 steps are needed: flow (CFD), droplet impingement and limits (extent of water impinging), and then accretion (water runback and heat transfer). All 3 steps involve possible inaccuracies. Moreover, all codes do not use the same class of CFD; some use panel methods (inviscid, incompressible), while others use Euler or Navier-Stokes. For droplets, most codes seed particles (accuracy depends on density of particle seeding), while others like FENSAP use an Eulerian method. So, if and when ice shapes are different at end: how can one determine the source of discrepancy? And which one is right? We hope you see the dilemma and the futility of such truncated exercises.

Question 15: What advantages does FENSAP-ICE have over other codes?

Let us only cite the most important ones:

- It is fully 3D, not quasi-3D and not only 2D
- It is a complete integrated system (flow, impingement, accretion, heat loads)
- It uses one grid for all four modules
- It requires no remeshing when ice forms
- It is based on partial differential equations
- It is a one-shot scheme:
  - It gives impingement at once, everywhere
  - It gives the shadow zones
- It gives more accurate impingement limits than panel-based methods
- It handles adjacent rotating-stationary components (rotors, propellers, engines)
- It is compatible with modern aero codes:
  - One can do aero + icing from start
  - One can use aero grids and flow and do icing in an incremental way
- It allows thoroughly exploring the combined aerodynamic + icing envelopes
- It is developed by a large team of specialists: advances are rapid

Question 16: Yes, but we have been using other codes and built a track record with the certification agencies: why should we change this?

If your interest is only 2D, you can continue using these codes. FENSAP-ICE is built for truly 3D problems and cannot give the quick and dirty answers of 2D codes.

However, if your interest is 3D, FENSAP-ICE has no parallel. It is the most advanced and only commercial code that can handle all aspects of in-flight icing, as a "system".

Just to put your mind at ease, and perhaps the certification authorities too, the models used in FENSAP-ICE are essentially identical to the other well-known national labs codes. The main difference is that they are expressed in terms of partial differential equations, and in three dimensions. This means that if FENSAP-ICE is used to solve a truly 2D problem, and one uses a "very coarse" grid, you will obtain the same results as the other 2D codes. So, when the results are different, it is not because the model is different, it is only because you are using a finer grain representation of it: better.

Finally, some companies' rationale could be: "why wet the appetite of certification authorities when it is not mandated to use expensive 3D simulations"? Most forward-looking companies consider certification requirements to be baseline or minimum ones and are interested in going beyond them, for safety and for a reality check. Moreover, once adopted, a 3D simulation mindset is different: any money a company spends on 3D simulation will directly result in from 5- to 10-fold savings in testing costs, shorter certification time, reduced post-certification problems, and elimination of potential incidents or accidents.

Question 17: Can you provide ice shapes for flight tests in dry air?

Yes, we can provide this information in the form of 3-D ice shapes as opposed to the traditional 2-D sections for flight tests in dry air. We can give examples of customers for whom NTI has calculated 3D ice shapes, and the aircraft has been certified following a very short test campaign.

Question 18: Do you support natural flight tests?

One of the most challenging phases is the natural icing flight campaign to gain certification for flight into known-icing. Aircraft manufacturers fly their new aircraft and/or systems into clouds, targeting specific combinations of temperature, liquid water content and droplets' size. Such conditions can be rather elusive and the time, energy and costs involved in finding, staying within, and documenting them, can be quite significant.

NTI has teamed up with Ben BERNSTEIN and Leading Edge Atmospherics (LEA), renown for making this rather daunting task more simple, efficient and safe. LEA has more than a decade of experience guiding a wide variety of aircraft safely into (and out of) icing conditions over the United States, Canada and Europe. These aircraft have included helicopters, small through large turboprops, business jets and large jets.

NTI-LEA work closely with pilots and flight test engineers to get the icing conditions that they need for certification. We examine historical weather data to determine optimal locations for the operations base to help maximize the opportunity to find the desired conditions. Working with the program, we put the icing weather into pilot terms, helping customers to plan flight routes effectively to make the most of sampling opportunities, and to determine critical escape routes that may be needed to maintain safety.

Question 19: Do you generally recommend flight behind tankers and ice tunnel tests?

We would recommend extensive CFD analyses to highlight critical conditions in terms of performance penalties or handling characteristics. Icing tunnel testing could then be conducted to confirm a small number of critical test items in a reduced test matrix, for cost-effectiveness.

The risks are totally mitigated by this approach so that, for the final demonstration, flight tests can be undertaken with confidence. Tanker tests are expensive, only qualitative and inaccurate not only because only parts of the aircraft are exposed but also because of the non-natural icing conditions. Therefore, tanker tests should not be needed. Of course, this approach has to be in agreement with the airworthiness authorities beforehand.

In all the cases NTI has been involved in, the modeling and simulation approach has been considered very comprehensive, safe and was accepted by the FAA or JAA. The compliance plan would reflect the recommended strategy.

Question 20: Do you have a DER who can approve flight test data?

NTI has associated consultants (former personnel of the FAA and JAA) with extensive experience in this area. NTI would have specific information available when it discussed your specific applications.

Question 21: What are the steps in NTI's icing protection design?

The first step is to establish an icing and flight condition matrix. It is obtained by combining the aircraft or rotorcraft flight envelope with the icing envelope of Appendix C and additional airworthiness guidance material. Then, we examine the matrix to identify critical conditions for a given type of ice protection system on a certain aircraft component. For example, critical conditions for a pneumatic deicer are very different than those or an electro-thermal system. At this stage, it may be possible to establish pass/fail criteria for performance of the components or systems.

Here is, for example, a roadmap that we have used with aircraft customers. Although it may not directly apply to your exact needs, it gives you an idea of the thoroughness with which we have served our clients, based on some widespread mistakes we have noticed in the design of aircraft that we have been asked to investigate after accidents:

1. Define or request all 3D wing and empennage geometry and all sectional geometry of the vehicle.

2. Define flight performance data for all normal and extreme phases of flight, such as true air speed (TAS), fuselage angle of attack, local geometric angle of attack, spanwise lift distribution, aircraft weights (maximum, minimum, intermediate), c.g. limits (aft, forward), configurations (i.e. flaps, ailerons, landing gear position), availability of excess power for the proper operation of the deicing or anti-icing system, trimmed and transient flight conditions.

3. Define the most critical cases for *impingement, accretion and handling qualities*. It must be remembered that worst-case impingement (high speed, low AoA) does not correspond to worst-case performance (low speed, high AoA). Some of the critical parameters from an icing point of view that have to be considered for each characteristic airfoil section include:

    - True air speed
    - Local aerodynamic angle of attack
    - Droplet size
    - Total and static temperature (for possible runback effect)
    - Altitude (air density)
    - Airfoil chord
    - Leading edge sweep
    - LWC and duration of flight in icing
    - Load factor
    - Compressibility
    - Reynolds number
    - Effect of flaps

Assuming that the type of ice protection systems for each aircraft component to cover are chosen, we can concurrently start generating CAD geometry for the components to analyze. We could decide to analyze the complete external aircraft for the design of the wing and tail ice protection simultaneously. The next step is to generate a mesh for each calculation domain.

For unprotected components, we obtain an accurate flow solution, using FENSAP.

The air solution is then used to calculate droplet impingement on all surfaces using DROP3D. This determines the mass flow of water impinging on each point of the geometry.

Ice is grown on each unprotected surface using ICE3D.

The final step is to assess the performance degradation using FENSAP again.

This cycle can be repeated for several ice layers if required. Remeshing may not be necessary because FENSAP-ICE includes ALE (Arbitrary Lagrangian-Eulerian) mesh movement.

For protected components, the analysis process varies depending on the type of protection. For example, for pneumatic deicers, the analysis is similar to unprotected components for the calculation of inter-cycle ice and associated performance degradation. For hot air or electro-thermal ice protection, the calculation involves a multi-domain problem. The physical phenomena in each domain, whether it is conduction only, or conduction with phase change, or Reynolds-averaged Navier-Stokes for fluid domains, are solved iteratively in each domain. Heat fluxes are transmitted through domain interfaces in a conservative fashion and not only pure geometrical interpolation for non-matching grids.

Visualization and post-processing are conducted to extract useful data such as forces and moments, droplet collection efficiency distribution or mass of ice accreted. These quantities can then be compared with the initial pass/fail criteria.

After the initial analyses, design changes may be required if the system is predicted to perform below expectations. Optimization of the components or systems may be conducted through additional analyses. For example, we may be interested in minimizing bleed air requirements for hot air systems or electrical output to minimize generator size for electro-thermal systems. We may change pneumatic boot coverage if it is insufficient.

At this stage, we can look at different scenarios, if required, that may not be in the icing regulations. For example, we could look at different aircraft maneuvers after an icing encounter to ensure that adequate stability and control margin remains despite ice accretion.

Finally, once all analyses are completed, we can settle on a test matrix for demonstration of compliance. Because of the thoroughness of the analyses, the risks associated with certification are totally mitigated by the complex 3D computations as opposed to the traditional 2D geometries.

Question 22: Has FENSAP-ICE been used in certification?

Certification remains a case-by-case situation in which a complement of CFD/Icing Tunnel/Tanker Testing/Flight Testing is used to demonstrate compliance. In that vein, NTI's software has been used in the certification of:

- Wide-body jets
- Regional jets
- Business jets
- Turboprops
- UAVs
- Light-medium twin helicopters
- Tiltrotor aircraft
- Test aircraft
- Military transport
- Jet engines
- Nacelles

Question 23: Does the FAA, EASA, TC or other certification authorities approve FENSAP-ICE?

The answer to that question must be given in two parts. First, NO ICING CODE (*no matter what anyone makes you believe*) HAS BEEN OFFICIALLY APPROVED. Certification still remains a case-by-case situation in which a complement of CFD/Icing Tunnel/Tanker Testing/Flight Testing is used to demonstrate compliance.

The best reading material to show this is the final document from the SAE ARP-5903 from the AC-9C committee on icing codes. It shows the great conservatism of the community of developers who, for the most, had not been able to step away from 2D, although all are currently trying. In reality, companies have been successfully using 3D for a decade and in that way integrated their aerodynamic and icing departments in an efficient concurrent way, rather than as two solitudes.

NTI has made presentations of FENSAP-ICE to the FAA personnel in Atlantic City and to EASA in Köln where several ACOs from European countries attended.

A document, "NTI's Certification Capabilities", is available upon request.

Question 24: Name industries that have used NTI's software/services

Aircraft	Airbus, EADS, TAI, RUAG, Bombardier, Embraer, AVIC1, Mitsubishi, Kawasaki, Fuji, Lockheed Martin
Rotorcraft	Bell Helicopter, Boeing Helicopter, Sikorsky, Eurocopter, Agusta Westland
Engines	Williams International, Snecma, GE Aviation, Rolls-Royce, Pratt & Whitney
Optronics	Thales, Transport Canada, Meteo France, Meteorological Services Canada

Question 25: The novelty of NTI's Eulerian impingement code, DROP3D is wearing off, and many commercial and national lab codes now offer the same formulation

We are flattered as we believe imitation is the best compliment and advertising for NTI. Those who were denigrating 3D as being expensive are now trying to catch up, those who swore by the advantages of the Lagrangian formulation are now racing to do an Eulerian one. Etc. What does this all mean? Simply, that they are playing "Join the Leader".

Please remember one thing: most of them are doing 101 models, and icing is one of them. NTI does icing, period.

Now, more specifically: are there any differences?.......................Indeed.

They are all using our pioneering Eulerian formulation that was published in 1998. After 10 years of operation would you believe for a minute that NTI has not vastly improved it own formulation? It has, but it no longer publishes how it should be done.

NTI can do impingement on adjoining rotating and stationary components.

NTI can do impingement on aircraft, rotorcraft and jet engines: with essentially the same code.

Same for icing. Eventually someone will have a 3D ice accretion code. NTI is already ahead as it has an unsteady ice accretion technology that no one else has.

NTI has an analytical roughness model that no one else has. NTI does not need to run hundreds of tests to correlate roughness: it "predicts" it. Do multishots? Devine how to space them out in time? Why? : use NTI's fully unsteady technology.

NTI is the only organization that can do Supercooled Large Droplets impingement more accurately via an Eulerian formulation, as was vividly demonstrated at the NASA-ONERA SLD Workshop in Arizona in 2006.

Newmerical Technologies International (NTI) develops and markets advanced CFD software and offers flow simulation services in the aerospace, architectural, automotive and marine markets.

NTI is an acknowledged leader for in-flight icing simulation and related services.

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