Anti-Ice Simulation
Pitot Tubes

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- The Company
- Ice Protection Enginering
- Anti-Ice Simulation
- R&D Project
- Pitot Tubes

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The Company

- The Aero-Thermal Solutions for Industry, ATS4i, is a company that provides engineering solutions to both users or developers of thermal and fluid flow equipments, systems or processes. The projects are tailored to fit to user needs and made to comply with performance or regulation requirements of pressure, temperature, flow, heat transfer , combustion, stress, strain, vibration and control.
- ATS4i has experience in designing, testing and simulating:
  - ✓ Aircraft Ice Protection
  - ✓ Aircraft ECS - Bleed and Air Conditioning
  - ✓ Aerospace systems
  - ✓ Combustion Equipments and Processes
  - ✓ Power generation
  - ✓ Thermal process/equipments

Ice Protection Experience

- ATS4i engineers have experience:
  - ✓ Design, Test and Certification of Pitot, TAT probes, Pitot Stand-By and Static Ports of Embraer ERJ145/140/135 jet aircraft;
  - ✓ Thermal Analysis of Embraer ERJ 145 wing anti-ice;
  - ✓ Thermal Analysis of Embraer 170 and 190 wing/slat anti-ice;
  - ✓ Dynamics and Control of Embraer 190 bleed and wing/slat anti-ice systems;
  - ✓ Testing in NASA Icing Research Tunnel (multiple entries) of Embraer 190 slat anti-ice;
  - ✓ Natural Icing campaign of Embraer 190 (several flights);
  - ✓ Certification of Smart Probes (TAT, AOA and Pitot's) of Embraer 190;
  - ✓ Design and Testing of wing fence ice protection for Embraer 190;
  - ✓ Whole development and certification phase of Embraer 170 and 190.
  - ✓ Wind tunnel design and Laser (LDA) anemometry measurements
  - ✓ Temperature, heat flux and concentrations measurements
- Team: Guilherme da Silva, Ph.D. (14 years aero ECS and ice protection), Marcos Arima, Ph.D. (12 years, testing and CFD), Francisco Sousa (40 years, thermal engineering and testing)

Simulation Applied to System Development

- Conceptual studies
- Pre-design including interfaces with structural, aerodynamic performance, powerplant and fuel tank areas
- System development (PDR, CDR)
- System certification
- Support to in-service difficulties solution

Anti-ice Simulation Main Objectives

- Support feasibility studies and technology selection;
- Define system requirements (performance, control, logic)
- Support partners/suppliers selection and follow-up
- Select critical anti-ice operational cases based on system thermal performance and its design margins;
- Size equipment and design system at critical points;
- Evaluate performance in aircraft icing operational envelope including those points not tested in flight or tunnel;
- Provide data or simplified models to bleed and powerplant systems;
- Support tunnel and in-flight tests campaign definition;
- Support system logic and control developments.

Simulation Main Results Required

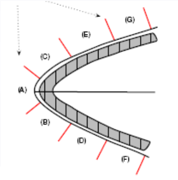
- To check anti-ice system thermal performance, for example:
  - ✓ *IMPINGEMENT MAX. LIMITS [m]*
  - ✓ *TOTAL WATER CATCH [kg/(m*s)]*
  - ✓ *REMAINING ICE/WATER [kg/(m*s)]*
  - ✓ *ANTI-ICE AVERAGE POWER DENSITY [W/m2]*
  - ✓ *FREEZING POSITION [m]*
- To check design margins of anti-ice system thermal performance, for example:
  - ✓ *Impingement limits compared with protected area limits*
  - ✓ *Remaining water compared with total catch*
  - ✓ *Anti-ice average power density compared with full evaporative requirement*
  - ✓ *Freezing position compared with protected area limits*
  - ✓ *Highest temperature compared with material/structural temperature limits*

Summary of Anti-ice Simulation Strategies

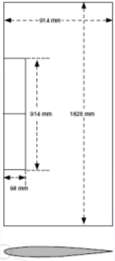
- Traditional (no CFD code used)
  - ✓ 2D Potencial or Full Potencial Flow Solution
  - ✓ 2D Lagrangian water trajectories and impingement
  - ✓ Boundary-layer solved by integral (1D) or differential methods (2D)
  - ✓ Runback Water film and rivulets (1D) model
  - ✓ Piccolo flow distribution solution (manifold)
  - ✓ Anti-ice system heating:
    - 1D or 2D electrical heaters distribution or
    - Piccolo jets heat transfer coefficient by semi-empirical correlations.

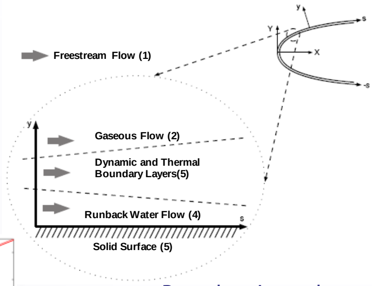
ATS4i in-house 2D Anti-ice Simulation

Power Density of Electro-thermal Anti-ice System

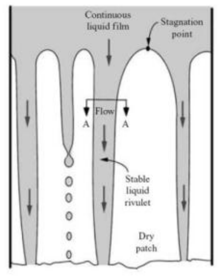


External Flow Solution By Potencial Codes

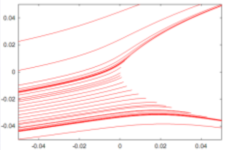




Runback Film and Rivulets Model



Internal Heat Transfer by correlations if hot air type

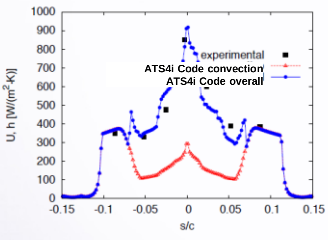


Boundary Layer by Integral or Differential Methods

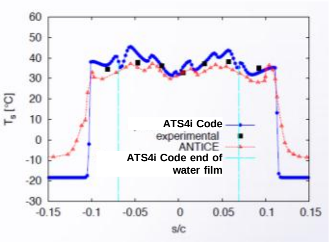
Lagrangian 2D Impingement

ATS4i in-house 2D Anti-ice Simulation - Typical Results

Heat Transfer Coefficient



Airfoil Surface Temperatures



caso	$\dot{q}_{tot}$ kW	$\overline{q''}_{tot}$ kW/m²	$\overline{q''}_{agua}$ kW/m²	$\dot{q}_{req}$ kW	$\overline{q''}_{req}$ kW/m²	$\dot{q}_{req}/\dot{q}_{tot}$ %	$\Delta\dot{q}_{req}$ %	$\Delta\dot{q}_{evap}$ %
22A diferencial	3, 2	16, 4	33, 5	1, 6	36, 8	49, 3	102, 8	142, 7
22A integral	3, 3	16, 7	33, 5	1, 6	35, 3	49, 2	103, 3	157, 5
67A diferencial	4, 7	23, 8	26, 7	3, 8	30, 9	81, 2	23, 1	75, 6
67A integral	4, 7	24, 0	26, 1	3, 6	25, 8	75, 5	32, 4	80, 5
67B diferencial	2, 1	10, 4	10, 3	2, 4	11, 9	116, 4	−14, 1	−19, 1
67B integral	2, 1	10, 4	10, 5	2, 5	12, 8	121, 7	−17, 9	−19, 1

Total and Density of Power Margins

	Upper Surface				LowerSurface			
Caso	s_r mm	s_{imp} mm	s_{prot} mm	s_r/s_{prot} %	s_r mm	s_{imp} mm	s_{prot} mm	s_r/s_{prot} %
22A diferencial	22, 2	24, 4	103, 3	21, 5	−21, 1	−26, 0	−93, 6	22, 6
22A integral	22, 9	24, 7	103, 3	22, 1	−22, 9	−26, 5	−93, 6	24, 4
67A diferencial	62, 6	33, 7	103, 3	60, 6	−60, 4	−33, 7	−93, 6	64, 6
67A integral	70, 2	33, 7	103, 3	68, 0	−67, 7	−33, 7	−93, 6	72, 4
67B diferencial	105, 6	35, 1	103, 3	102, 2	−94, 9	−35, 1	−93, 6	101, 4
67B integral	103, 4	35, 1	103, 3	100, 2	−92, 7	−35, 1	−93, 6	99, 1

Ice/Water Remaining Margins

Summary of Anti-ice Simulation Strategies (II)

- With CFD codes
  - ✓ CFD Flow 3D Solution by RANS;
  - ✓ CFD Eulerian dispersed phase or lagrangian;
  - ✓ CFD to solve also momentum and heat transfer around airfoil or body;
  - ✓ External code to solve "quasi-3D" by 2D sections (xz planes normal to leading edge) along span (y axis):
    - Runback water model;
    - mass transfer (evaporation) effects;
  - ✓ CFD to solve piccolo flow distribution along its length
  - ✓ Anti-ice system heating:
    - 1D or 2D electrical heaters placement in CFD model or
    - Piccolo jets heat transfer coefficient by CFD solution inside D-Bay.

Summary of Anti-ice Simulation Strategies (III)

- 2D-3D Blend Type
  - ✓ Any combination of Traditional and Recent simulation strategies;
  - ✓ The use of one or other software depends on codes robustness and user application requirements;
  - ✓ The softwares are mixed by scripting, command line and also flow engine/optimization software packages;
  - ✓ The Blend strategy is commonly found in current industry practice since the Traditional is becaming outdated and Recent are not validated, not available or not well integrated;

Proposed Anti-ice Simulation for UFRJ Research

- WHAT:
  - ✓ *To implement a fully integrated and validated CFD solution*
  - ✓ *To add runback water model and its phase change to CFD;*

- WHY:
  - ✓ *The need to have a 3D simulation of anti-ice system thermal performance (Piccolo D-bay compartment, pitot, antennas, radomes, multi-body wings, windshield…)*
  - ✓ *There is no major CFD commercial package that has 3D solution:*
    - LEWICE3D – export restricted and it is icing not anti-icing;

Proposed Anti-ice Simulation Development Cycle for UFRJ

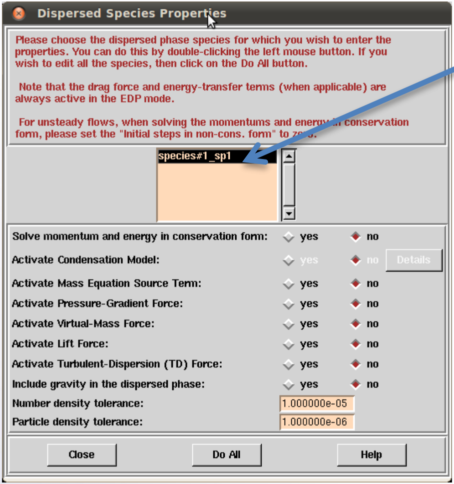
➢ HOW: Joint Development

- ✓ *To define code requirements*
- ✓ *To develop code:*
- ✓ *To verify and validate code*
- ✓ *To document the code*
- ✓ *To support the users*

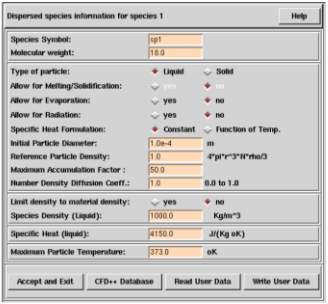
Preliminary Pitot CFD Demonstration for UFRJ

- Initial simulation to demonstrate CFD++ capabilities
- Icing condition → no standard or regulation defined
- Geometry and mesh developed by UFRJ → generic pitot
- **Objective**: Assess the impingement pattern on pitot surface to help Eng. Brito (UFRJ) in his PhD thesis with geometry he is already using
- Flow Conditions:
  - *Air - U=50 m/s, T=-10 C*
  - *Water LWC=0.5 g/m3, MVD=20e-6 m*
  - *Adiabatic surface (no heat transfer simulated in this case, only flow)*

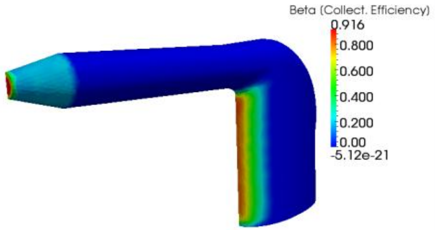
CFD++ Configuration



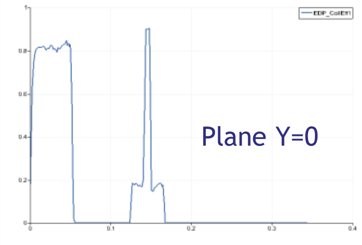
Double click here to define MVD and LWD and other parameters of the model such as Drag law, gravity force direction and others….

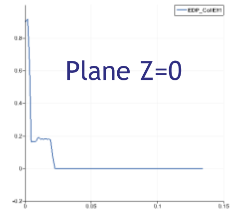


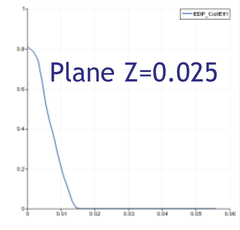
Collection Efficiency Results



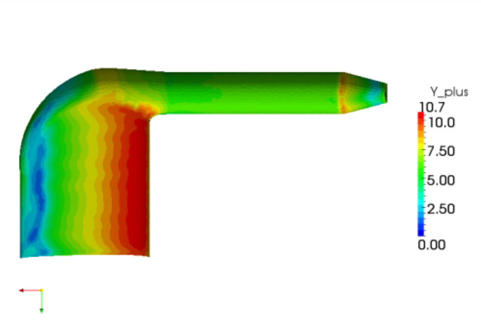
Collection Efficiency on Surface

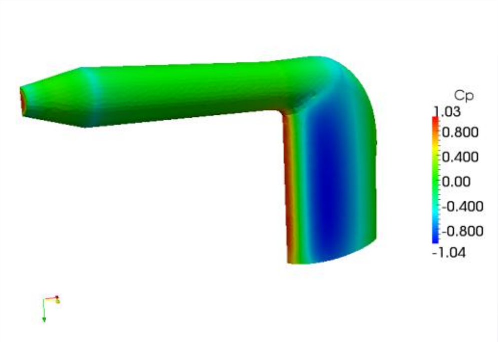




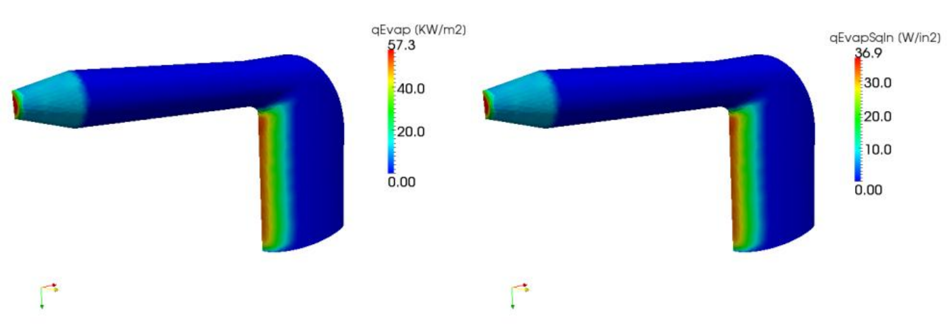


Y^+ and Cp Results





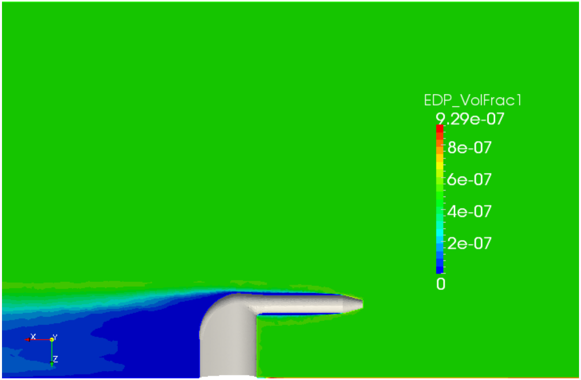
Evaporation Heat Flux Results



Full Evaporative Average Heat Flux Demanded → 4.03 KW/m^2 or 2.6 W/in^2
Full Evaporative Peak Heat Flux Demanded → 57.3 KW/m^2 or 36.9 W/in^2

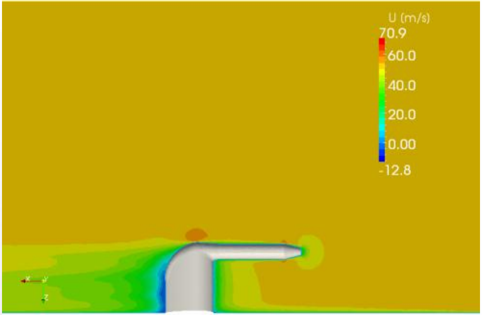
Power Measured = 0.092 kW → Power Density Available = 15.4 KW/m^2 and 10 W/in^2

EDP Volume Fraction



Local LWC may be higher or lower than Freestream LWC due Installation effects

U and W Velocities



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