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CASE STUDY OF THE INSTALLATION OF THE A400M ENGINE CONTROL UNIT

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Abstract.

The integration of the airframe of a turboprop propulsion system entails several challenges. One of them is the ventilation of the engine components and the Engine Control Unit (ECU) is one of them, which require some special attention since it controls the optimal engine performance and its reliable operation.

The integration of the ECU inside the A400M nacelle ventilation bay entailed several challenges due to the overall design requirements derived by the functional and compact integration of multiple systems. The goal was to provide the ECU with the right thermal environment, which is critical to ensure the safe Aircraft Operation.

This paper is an account of how such installation challenges were approached in the A400M Aircraft. The engineering process is described, where CFD codes were extensively used for the analysis of the different alternatives for the equipment installation.

Ground and Flight test campaigns later showed that the proposed selected configuration to optimize the ECU installation was efficient at meeting the requirements.

1. Ventilation system description.

One of the main challenges of the nacelle ventilation system is to provide ventilation airflow through the engine bay on the ground and at low speed, keeping the nacelle equipment at suitable conditions. Further, nacelle ventilation flows reduce the risk of a nacelle fire.

Figure 1 describes schematically the architecture system used to ensure the ventilation of the nacelle bay which houses the engine and all equipment including the ECU. Ventilation flow is energized as it is mixed with the primary engine flow which acts as a pump. This eductor role is to provide entrainment of airflow coming from the nacelle bay area.

Figure 1 also represents the main flows inside the nacelle ventilation bay and the ECU location. The main ventilation scoops and the upper scoops provide all the flow necessary for nacelle ventilation.

The nacelle ventilation analysis requires a Multiphysics approach, where convection, conduction and radiation effects are accounted for, as external and internal flows are fully coupled in the Aerothermal CFD simulations.

In addition ice accretion analyses were also conducted to ascertain that ventilation is ensured under icing conditions.

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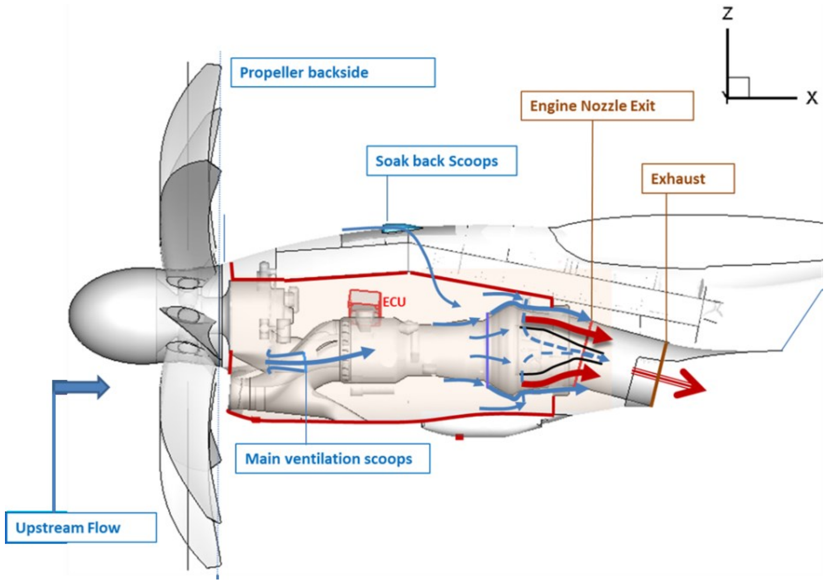

Figure 1: A400 Engine ventilation Architecture.

2. CFD Aerothermal Analysis.

A full 3D model including the wing, the nacelle and the exhaust was studied using the COTS CFD code Fluent.

Figure 2 and Figure 3 show the complete external and internal 3D models respectively. The propeller effects were introduced by means of an actuator disk model with a distribution of radial pressure jump and swirl. The pressure increase was derived from the propeller deck provided by the propeller manufacturer. The engine was modeled using a mass flow boundary condition, where the engine mass flow, the total temperature and the swirl of the combustion gases are imposed. All these values were calculated with the aid of the engine deck. The boundary condition is located at the low pressure turbine exit plane, upstream of the Outlet Guide Vanes. Far field boundary conditions were imposed by means of Riemann invariant Boundary Conditions. It is important to note that for this simulation the radiation and in-plane heat conduction effects of the engine were taken into account.

Reference 1 describes in detail the model used for the configuration analysis.

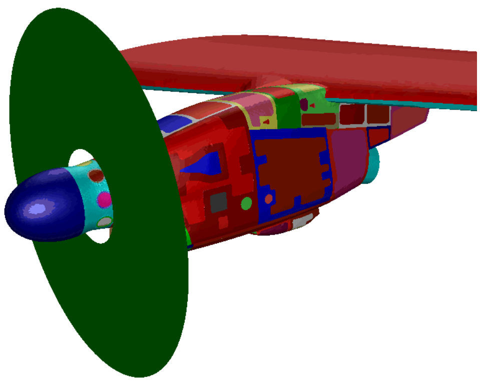

Figure 2: Computational ventilation model. External CFD domain.

The computational domain was meshed with a conformal tetrahedral mesh, except inside the nacelle ventilation bay where the velocities are very small, and prisms were extruded. The total mesh size is roughly $6 \cdot 10^6$ cells. The k-ω Shear Stress Transport (SST) turbulence model was used and a second order spatial discretization scheme was used for all equations. From all the available algorithms in Fluent version 6.3 to solve the Reynolds averaged Navier-Stokes Equations, the implicit pressure based coupled solver was selected with segregated energy, turbulence, conduction and radiation.

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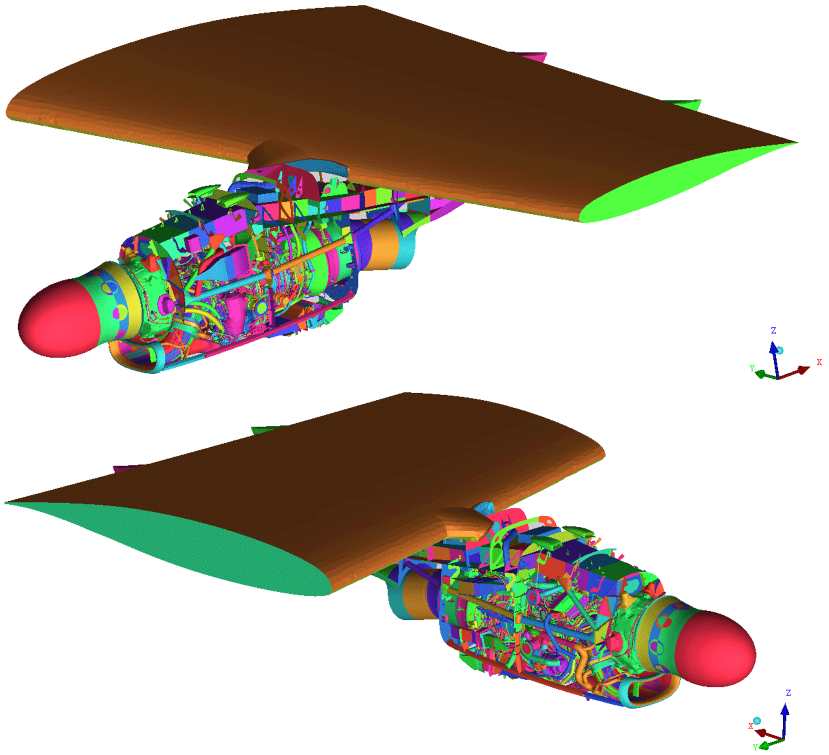

Figure 3: Computational ventilation model. Internal CFD domain.

Figure 4 show the ECU domain case for the baseline case.

Main Boundary condition is the heat power load generated by the all the electronic equipment inside the ECU.

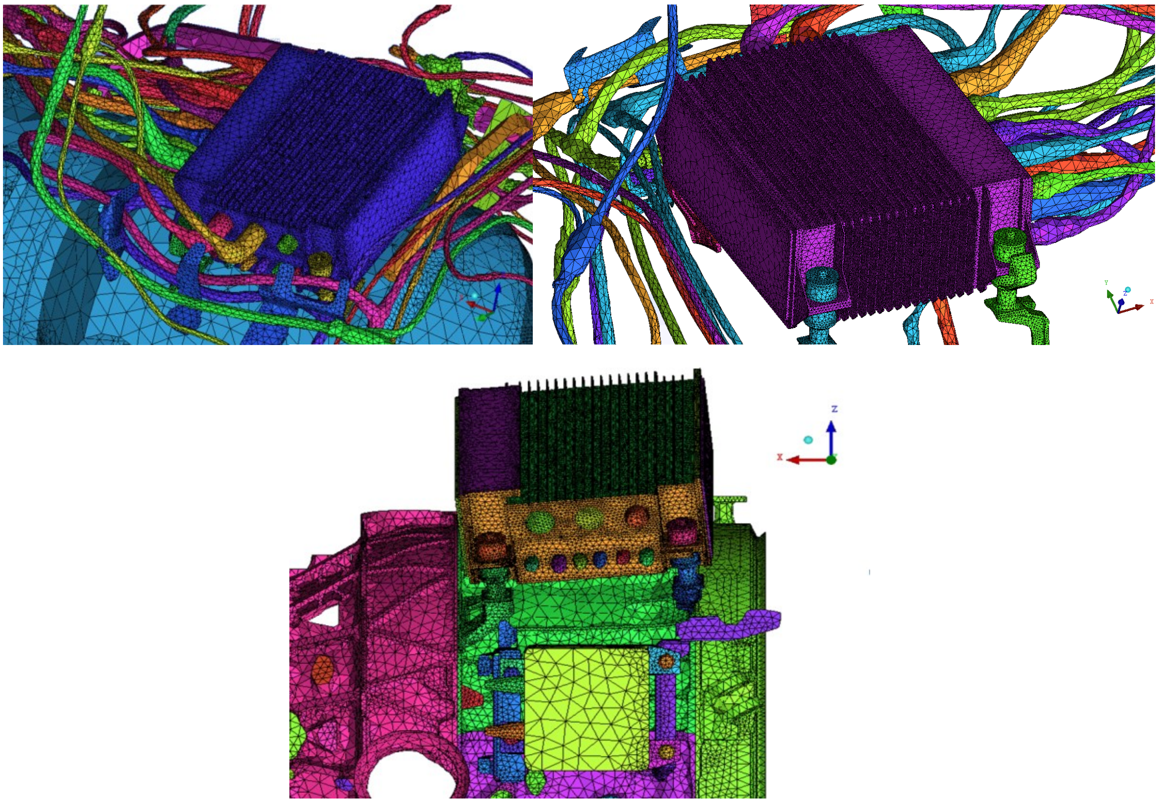

Figure 4: Computational ventilation model. ECU domain mesh. Baseline configuration.

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3. Analysis of ECU venting configurations.

Several equipments are housed inside the nacelle and the complexity of this layout gives place to many geometrical and installation constraints. Different ventilation configurations were investigated: from the conventional installation of the dedicated scoops and NACA inlets as well as fan forced ventilation or the implementation of dedicated ducts. The final configuration has been selected taking into different requirements:

1. Improve the ECU cooling.
2. Reduce the installation cost: e.g. Parasitic drag account
3. Account for ice accretion effects.
4. Respect installation constraints.

Initially, the following configurations were analysed:

1. Baseline.
2. Baseline + Dedicated intakes.
    a. Baseline + Dedicated NACA (flush) intakes.
    b. Baseline + Dedicated scoop intakes.
3. Baseline + Dedicated duct.
    a. Single diffuser.
    b. Double diffuser.
4. Baseline + Dedicated duct with fan.

3.1 Baseline configuration.

The Baseline configuration is represented by the ECU equipment mounted on the engine, where the heat exchange between the surrounded environment and the ECU is done by means of natural convection. See Figure 1 and Figure 4. Available existing data showed that there was a significant risk of not meeting the ECU requirements.

3.2. Baseline + Dedicated NACA flush intakes.

Figure 4 shows the analyzed configuration, where two lateral NACA intake, sized in accordance with existing cowling limits constraints, would not meet the equipment cooling requirements. The intake size necessary to cool down the ECU largely exceeded the existing cowling constraints.

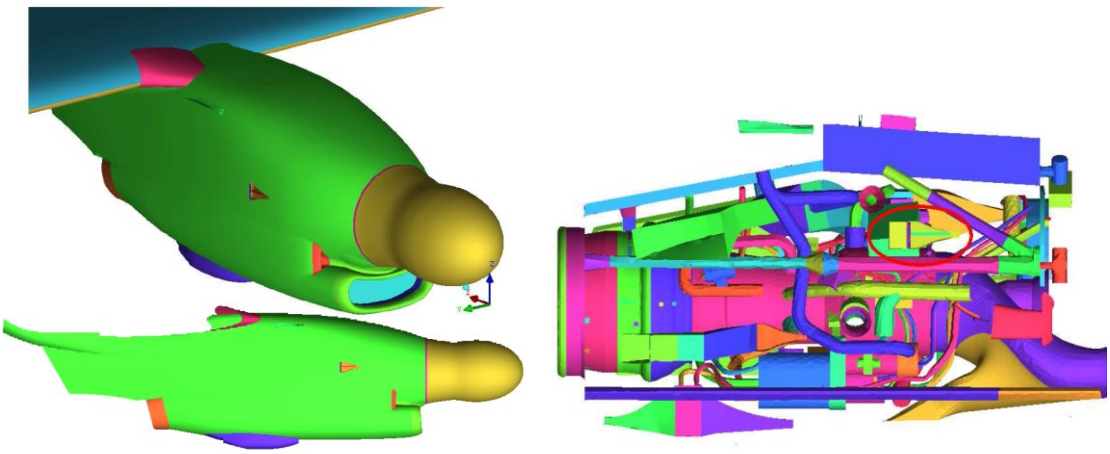

Figure 4: Baseline + Dedicated NACA flush intakes.

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3.3. Baseline + Dedicated scoop intakes.

The analyzed configuration is shown in figure 5. Initial ice accretion analysis showed this intake partially blocked at some operational conditions which could result in some risk of ECU over heat. In addition this configuration entails some cost in terms of A/C parasitic drag. As a consequence, and taking into account the potential advantages of other configurations, it was decided to stop the development of this configuration in favor of those configurations.

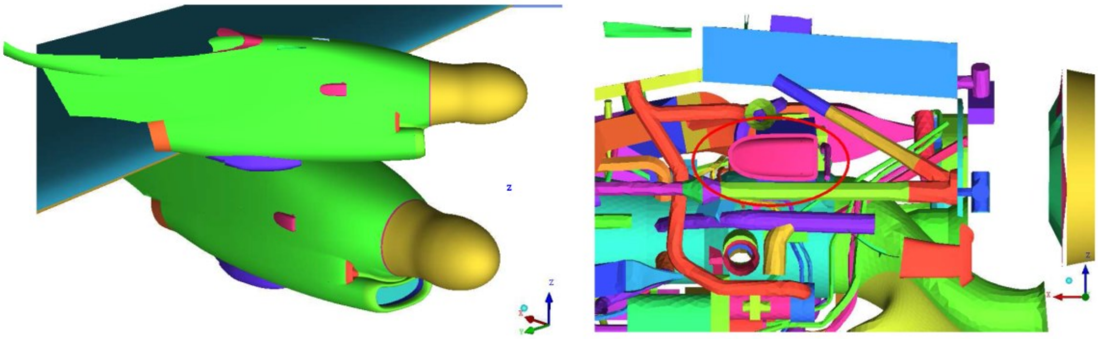

Figure 5: Baseline + Dedicated scoop intakes.

3.4 Baseline + Dedicated duct.

The final solution was to use a pipe to channel part of the main ventilation scoops flow right onto the ECU surface (Figure 6). This solution was the less penalizing one in terms of parasitic drag cost without compromising the ventilation of the other elements housed inside the nacelle ventilation bay, meeting at the same time the equipment environmental requirements.

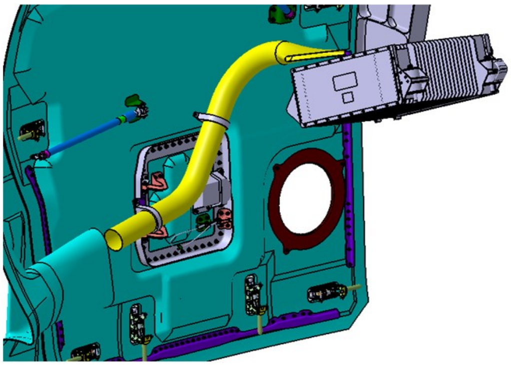

Figure 6. Single diffuser duct installation.

Forced ventilation is achieved by capturing the right amount of ventilation flow coming into the nacelle from a ventilation scoop. This concept results in negligible penalties in parasitic drag.
Two configurations were analyzed:

a. Ventilation on the upper side of the ECU. Single duct diffuser as shown in Figure 6.
b. Ventilation on both, the upper and the lower sides of the ECU. Double duct diffuser. Figure 7.

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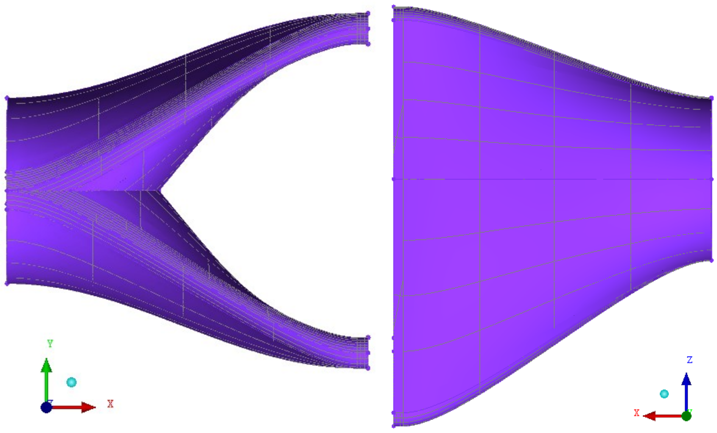

Figure 7. Double diffuser duct installation (upper and side view).

3.5. Baseline + Dedicated duct + Fan.

Figure 8 shows a further configuration: the inclusion of a fan inside the duct. Initial analysis showed that, in order to achieve some significant increase of ECU ventilation flow, a significant amount of electric power was required, introducing at the same time, more complexity with the addition of an active system. Hence, this configuration was ruled out.

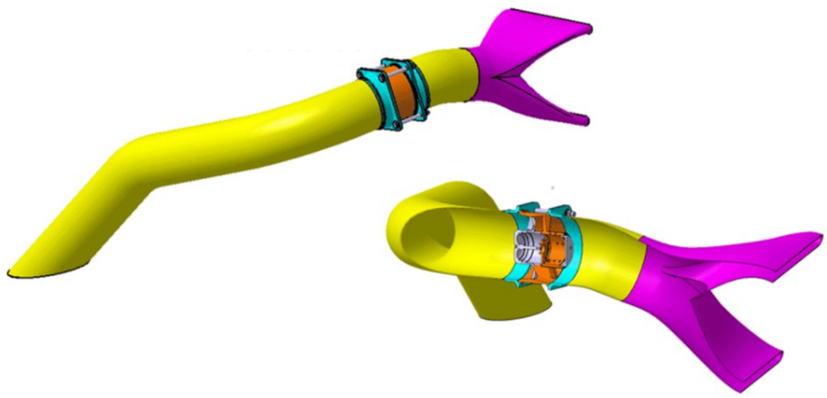

Figure 8. Fan inside the Double diffuser duct installation.

4. Analysis of duct configurations.

In accordance with the previous arguments, from the previous configurations, the following ones were analysed in more detail:

- Baseline configuration.
- Single duct diffuser.
- Double duct diffuser.

Figure 9 shows elements of the mesh domain for the single diffuser duct installation. Figure 10 shows the mesh domain for the double diffuser case.

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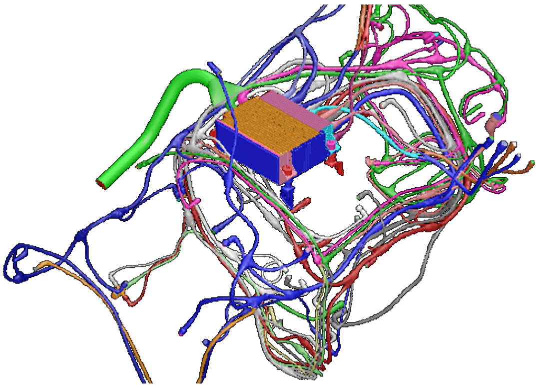

Figure 9. Mesh Domain: Single diffuser duct installation.

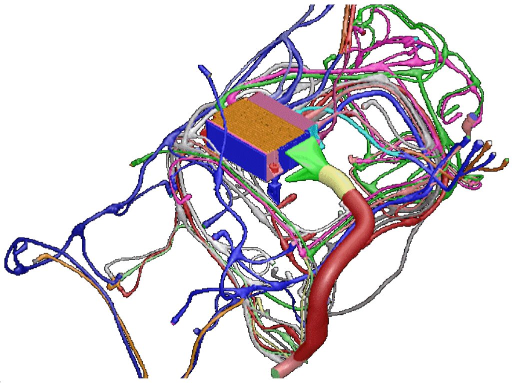

Figure 10. Mesh Domain: Double diffuser duct installation.

For the analysis of the thermal performance of the cooling alternatives, a full CFD aerothermal computation was conducted on a characteristic hot flight condition:

- Low level Flight: Mach=0.25, 4000 ft, ISA+25

Figure 11, Figure 12 and Figure 13 show temperature maps on the ECU surface. The introduction of one diffuser reduces the ECU temperature (figure 12). The effect of the double diffuser cooling both, the upper and lower ECU sides reduces dramatically the ECU temperature (Figure 13).

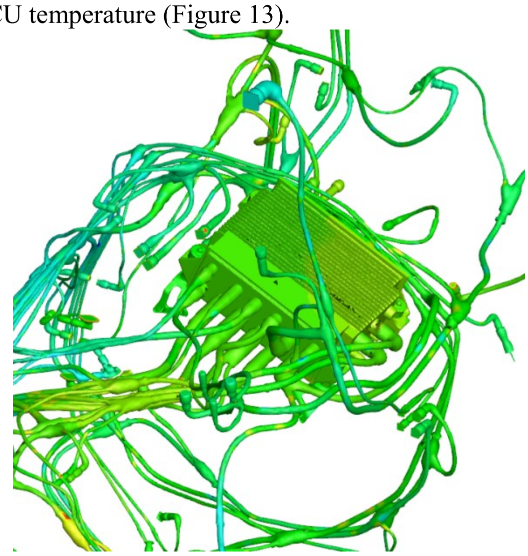

Figure 11. Baseline Configuration : ECU Temperature map

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Figure 12. Single diffuser configuration: ECU Temperature map

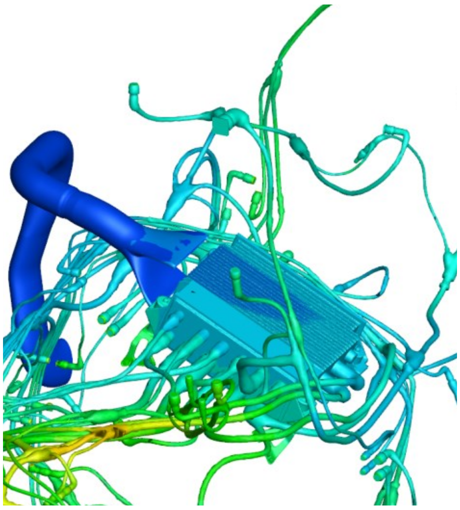

Figure 13. Double Diffuser configuration: ECU Temperature map

Figure 14 and figure 15 show the cooling flow pattern from the diffusers and how surface flow is guided along the ECU cooling fins.

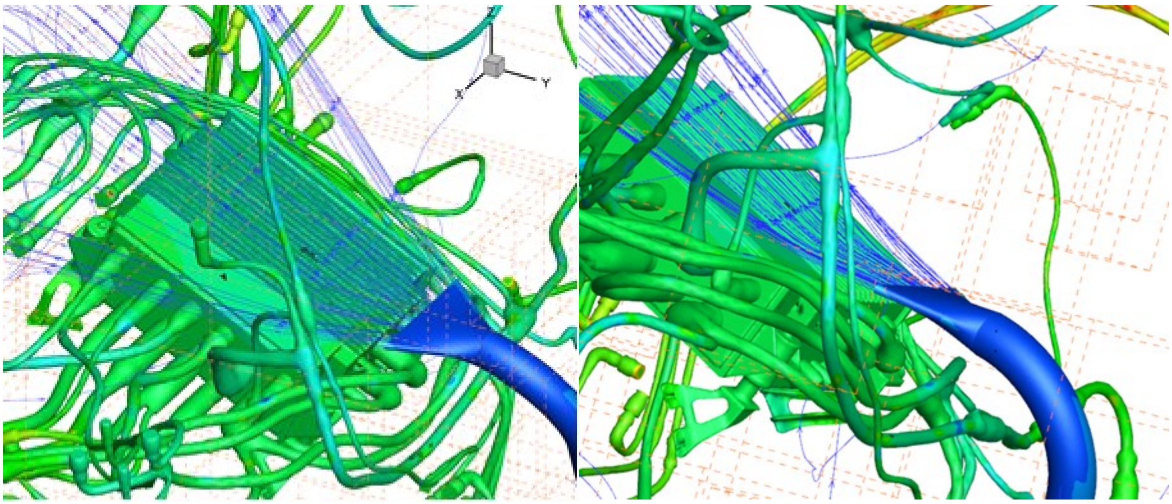

Figure 14. Single diffuser configuration: Cooling Flow Streamlines

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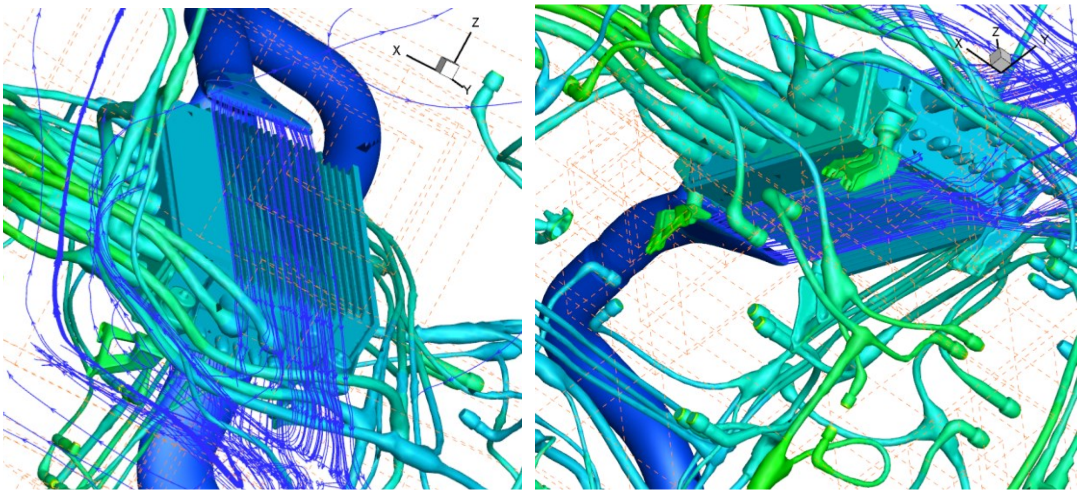

Figure 15. Double diffuser configuration: Cooling Flow Streamlines

The following table summarizes the benefits in ECU temperature in terms of the average static temperature on the ECU wet surface

Configuration	Delta T (respect the Baseline Configuration)
Single duct diffuser	-15ºC
Double duct diffuser	-26ºC

Based on the above data, the duct equipped with the double diffuser was selected as the final cooling configuration of the ECU equipment. FT results demonstrated that the solution reached by means of numerical analysis was compliant with the system cooling requirements. The double duct diffuser configuration mitigates any risk of ECU overheat at the A/C flight envelope.

The analysis of the effect of ice accretion at the entry of the double diffuser entry on nacelle ventilation was conducted- Particularly, a holding condition characterized by a long exposure time to icing conditions was selected. For this condition the ANSYS CFX CFD code has been used to analyze the aerodynamic flow field and the FENSAP-Ice code for the analysis of the water catch and ice accretion. The result of this analysis was that even in the most critical icing conditions the double duct was able to provide the required ventilation flow to the ECU.

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5. Conclusions.

The implemented design consisting of a dedicated duct which channel some of the entry ventilation flow on the ECU surface has eliminated any ECU overheat risk on the A/C flight envelope. The following design characteristics are met:

- Passive solution.
- No penalties in terms of A/C parasitic Drag.
- Ice accretion is not a threat for ECU ventilation.
- All installation constraints are respected. No interference with other elements inside the nacelle

Extensive CFD analysis has been able to provide the proof-of-concept to go ahead with the final development on A/C hardware. Flight test campaigns have finally proved the validity of the configuration.

References.

[1] RTO Applied Vehicle Technology. Fully Coupled Aero-Thermal Modeling of Aircraft Powerplant Installations with COTS Tools. RTO AVT-178-2010.