Installation issues of a small turboshaft engine into a light helicopter

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ABSTRACT

The ESPOSA project develops and integrates novel design and manufacturing technologies for a range of small gas turbine engines up to approximately 1.000 kW (SL ISA) to provide aircraft manufacturers with a better choice of modern propulsion units. It also deals with engine related systems that contribute to overall propulsion unit efficiency, safety and pilot workload reduction. Through the newly developed design tools and methodologies for the engine/aircraft integration, the project also contributes to the improved readiness for new gas turbine engines installation into small aircraft.
ESPOSA[1] is a FP7 Level 2 research project intended to study the applicability of small gas turbine engines on aircraft. Three applications have been selected to receive the 200 HP-rated TP/TS100 turboshaft[2] engine of PBS, two fixed wing aircraft and one rotorcraft. This paper is related to the helicopter application of the TS100 turboshaft version into the Belgian B250 Winner Helico.
In this paper, all aspects related to design and installation of a new turboshaft into a small helicopter are tackled, from the support of the engine on the helicopter structure (chassis or airframe), the transmission system including the tail rotor, the cooling of the engine and of its lubrication oil, the air intake equipped with IBF (Inlet Barrier Filters) and the exhaust pipes to the fuel system or the controls. The integration of all these aspects and components in the helicopter is also detailed. Two examples are the full integration of the complete engine into the rear fuselage of the helicopter and CFD computations of the air flow in a first geometry of the "double ear" intake.

Keywords: rotorcraft, small turboshaft, integrated design, engine airframe, air intake, IBF filter.

[1] ESPOSA means Efficient Systems and PrOpulsion for Small Aircraft.

[2] 200 HP is the derated power in SLS ISA conditions required for the B250 helicopter.

1. INTRODUCTION

The ESPOSA project is aimed at the development of technologies necessary for application of small gas turbine engines as the primary power plant on general aviation airplanes and light helicopters. The developed solutions in the area of the engine and its related systems are focused on cost reduction, environment protection and reduction of workload to flight crew.

Within the objectives of the ESPOSA project, the plan is the verification of developed technologies on flying demonstrators. The demonstrator in Aircraft Configuration (ACC) designated HE1 refers to the installation of 1 x BE1 engine (shaft power 200 HP in SLS ISA conditions, model TS100) with a constant-speed main rotor, in a turboshaft configuration, inside the fuselage of the light and low cost helicopter B150 (Figure 1). This will lead to the TS100-equipped B250 helicopter of the ESPOSA project (Figure 2).

The installation of the BE1 engine on the HE1 aircraft is planned on the tube chassis in the rear area, maintaining as much as possible the existing steel tube chassis of the T62-equipped B150 and modifying as less as possible the position the helicopter centre of gravity compared with the originally approved B150 helicopter with the DGAC certification when using the T62-T32 gas turbine.

Figure 3 shows a cross section of the B250 ACC HE1 helicopter with some details of the engine support and of the whole propulsion chain installed in the rear fuselage bay of the helicopter.

Figure 1 - ACC HE1: TS100 in helicopter configuration on the B150 aircraft – Side rear view

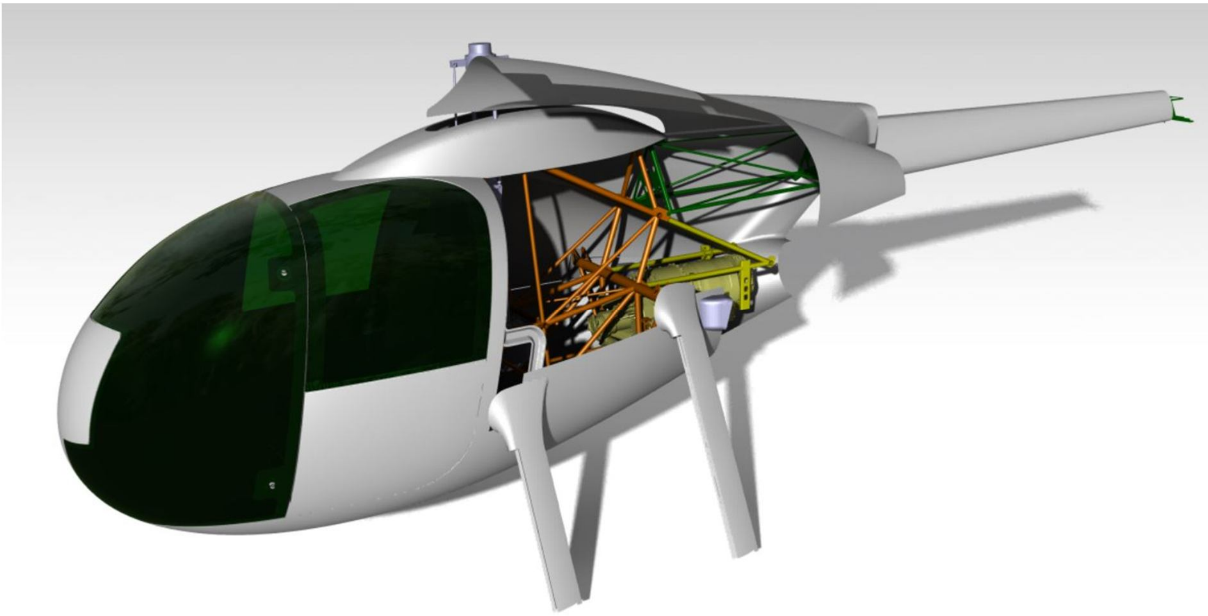


Figure 2 - ACC HE1: TS100 in helicopter configuration on the B250 aircraft – Side view

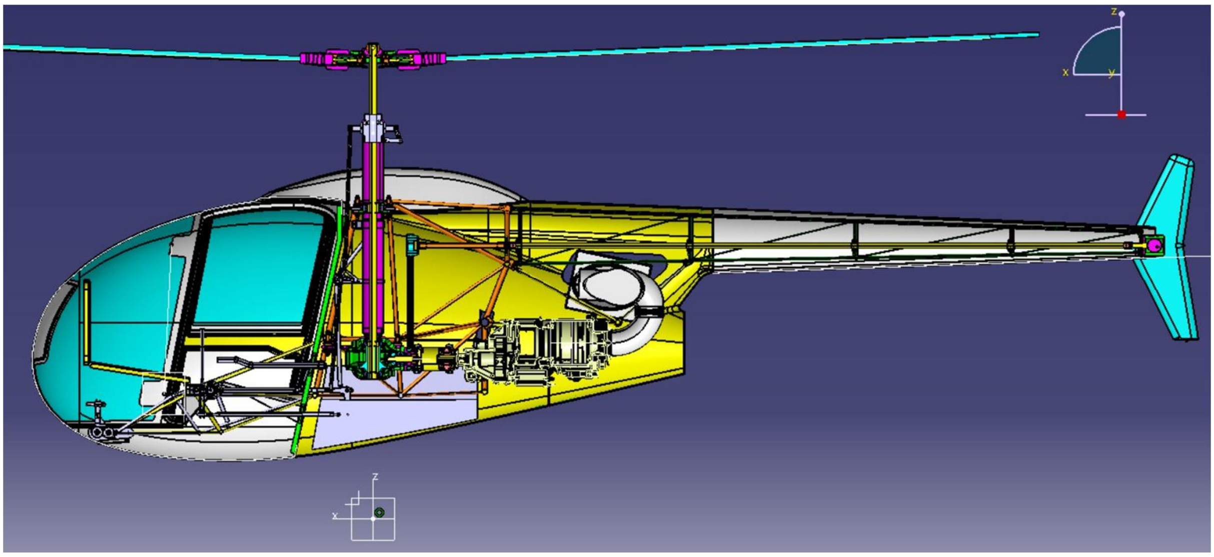


Figure 3 - ACC HE1: TS100 in helicopter configuration on B250 aircraft – Cross section with IBF filters

2. AIRCRAFT DESCRIPTION

For the ACC HE1 flying demonstrator of the ESPOSA project, the following aircraft status and operation envelope are defined and planned:

- Experimental helicopter category (in France, special DGAC certification), for development flight test program with an airworthiness and basic performance verification with approximately 30 flying hours each, 60 flying hours in total;

- Flying demonstrator to be built (B250 prototype);

- Flight allowance of the French DGAC to be achieved on the base of a compliance substantiation program for agreed CNSK certification basis in a scope to be agreed with the responsible French airworthiness authority;

  Operational limitations within the flight envelope altitude limits, with ambient temperature limitations of +45°C down to -15°C and a minimum flight crew of one pilot;

- Weather operating capability VFR Day/Night is allowed and Flight In Known Icing (FIKI) is not allowed;

  Note:

  > *CS-VLR.903 regulation requires the engine to meet the specifications of appendix B "Engines" of the CS-VLR regulation that does not require any specific measure against icing except for the fuel system.*
  > *The B250 helicopter is only operated in non-icing flight conditions as written in its airworthiness requirements Aircraft Certification Plan (ACP) introduced at the level of the French DGAC authority.*
  > *These operational limitations are also written in the Engine Certification Plan (ECP) of the TS100 in the B250 rotorcraft.*

- Surface type on which operation may be conducted: paved and unpaved surface.

2.1 Airframe specifications

Three airframe elements must be redesigned with a view on the new TS100 engine integration: the chassis as engine support but also the fuselage with its different fixed and mobile cowlings, and the tail boom containing the tail rotor shaft that brings the requested rotation movement and power at the level of the tail rotor gearbox.

The full composite fuselage is built of carbon / epoxy composite sheets with some steel fittings at the connections between the fixed and mobile assemblies. This fuselage will be described in a later version of this document as well as the production process employed in the fuselage modification.

The stainless steel chassis / frame for the engine mount is made using TIG (Tungsten Inert Gas) tube welding.

2.2 Components of power plant installation

The engine data are based of the engine producer document "PP-52 Installation Manual Turboshaft Engine TS100ZA", issued in August 2013.

The installation comprises:

1. Engine unit with built-in gear box
2. Air intake
3. Hot gas exhaust
4. Power transmission chain towards the helicopter main and tail rotors.

Supplemented with following components or connections to the airplane systems:

1. Engine mount
2. Oil system
3. Fuel system (w. fuel/oil drainage tank)
4. Electrical system (w. engine built-in electrical system and external accessories)
5. Power plant control & monitoring
6. Fire protection.

2.2.1. Power plant installation - General layout

The general layout of the TS100 engine – chassis – fuselage integration is shown on Figures 4, 5 and 6 (with also the servicing doors shown).

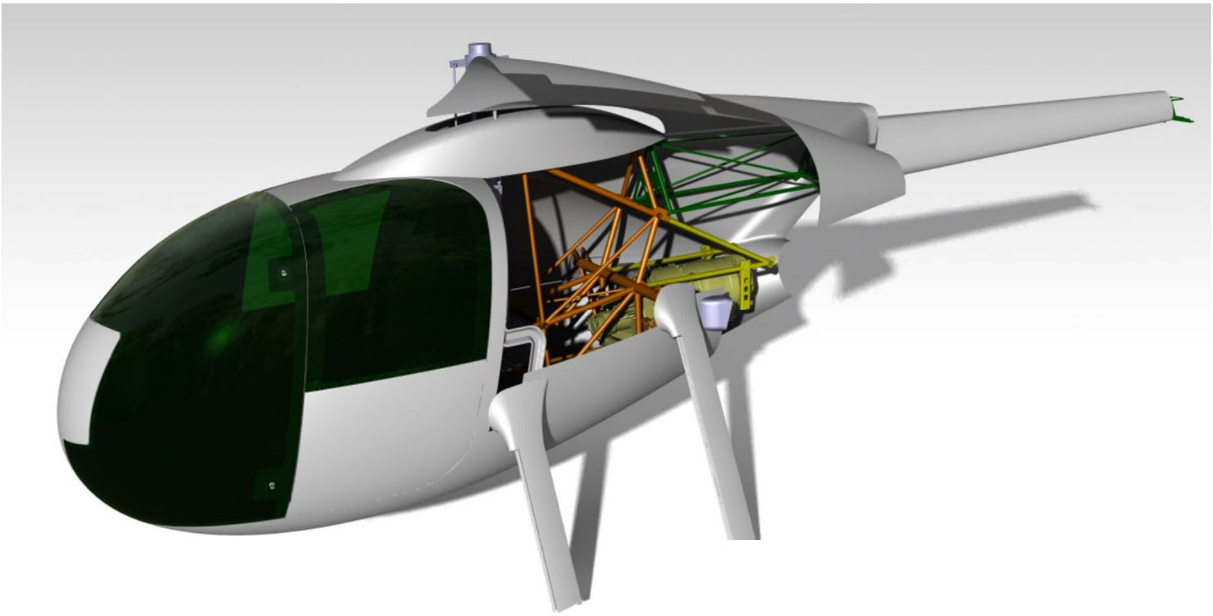


Figure 4 – Detailed Catia view of the TS100 engine – main helicopter gearbox – chassis – fuselage B250 integration

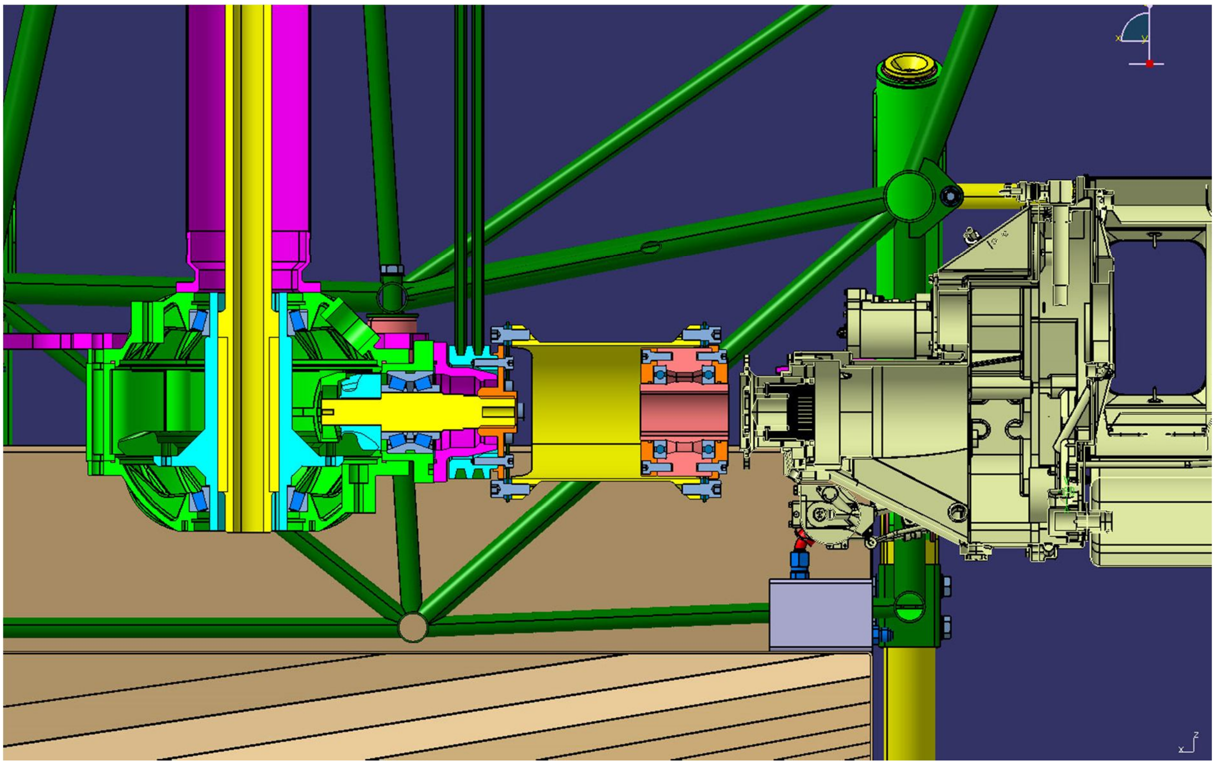


Figure 5 – Detailed Catia view of the
TS100 engine – main helicopter gearbox – chassis B250 integration

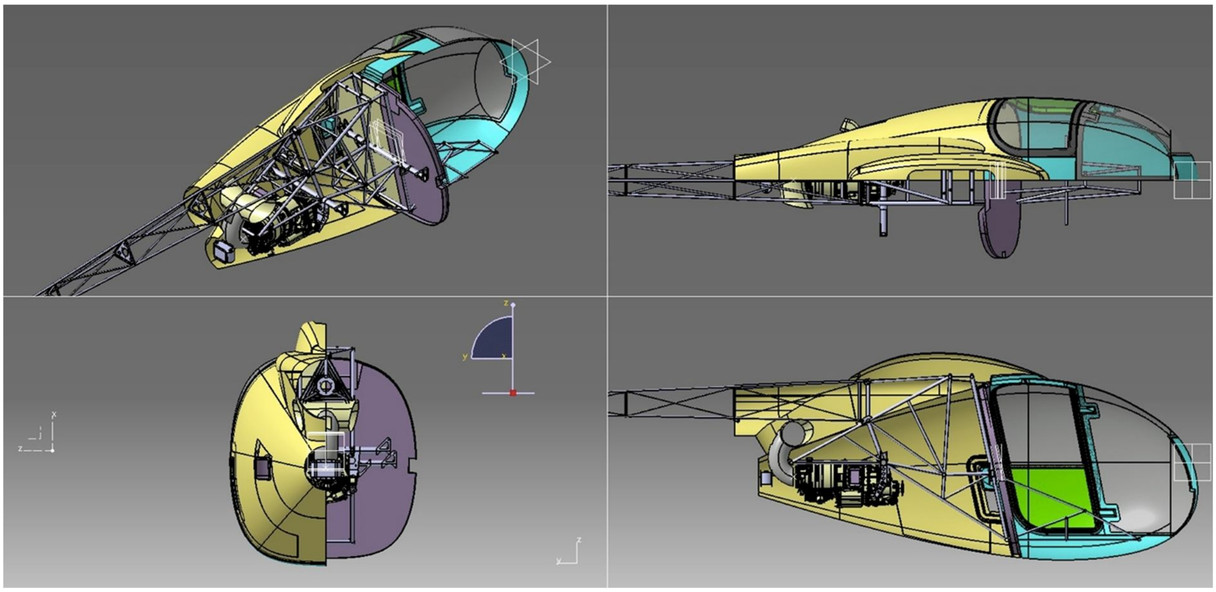


Figure 6 – B250 complete fuselage / engine nacelle

2.2.2. Air intake

The components of the air intake are to be built of composite materials in a conventional wet lamination process. At this stage of the project, the EC reviewers recommended a particle separator or another type of filter for the air intake channel. The proposed solution is a quickly removable inlet barrier filter (IBF) that is permanently mounted on the engine/helicopter. The air intake design including two IBF is shown, integrated with the TS100 and in the B250, on Figures 7 and 8. It is a double ear intake merging into a single channel towards the compressor face. On this single channel a by-pass door in case of blockage of the filters has been installed at the front of the intake channel.

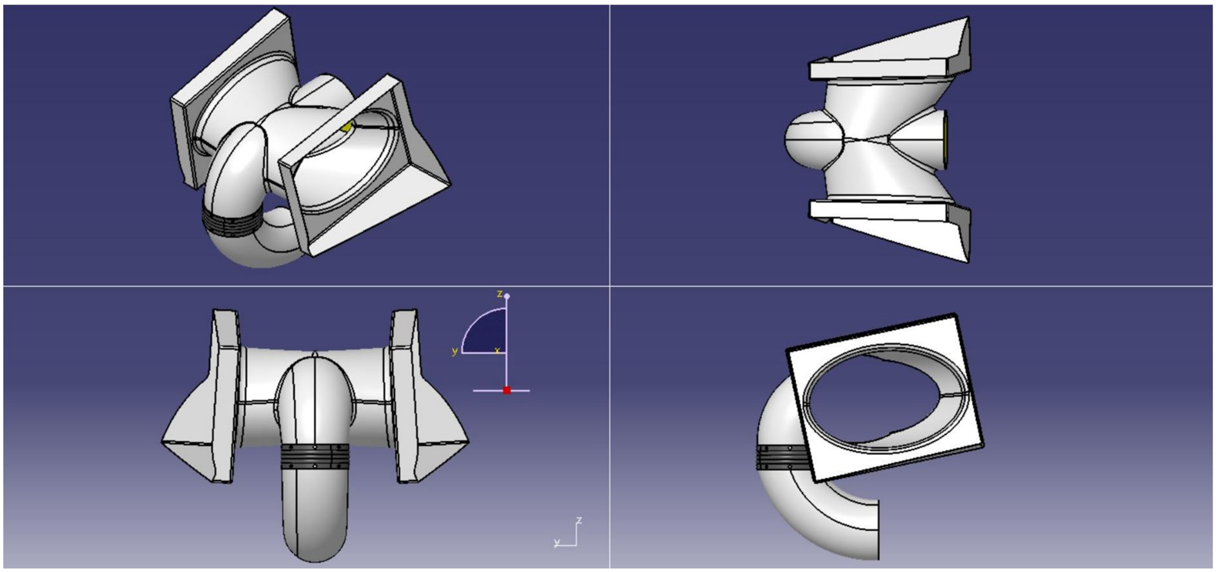


Figure 7 – B250 air intake with IBF and by-pass door

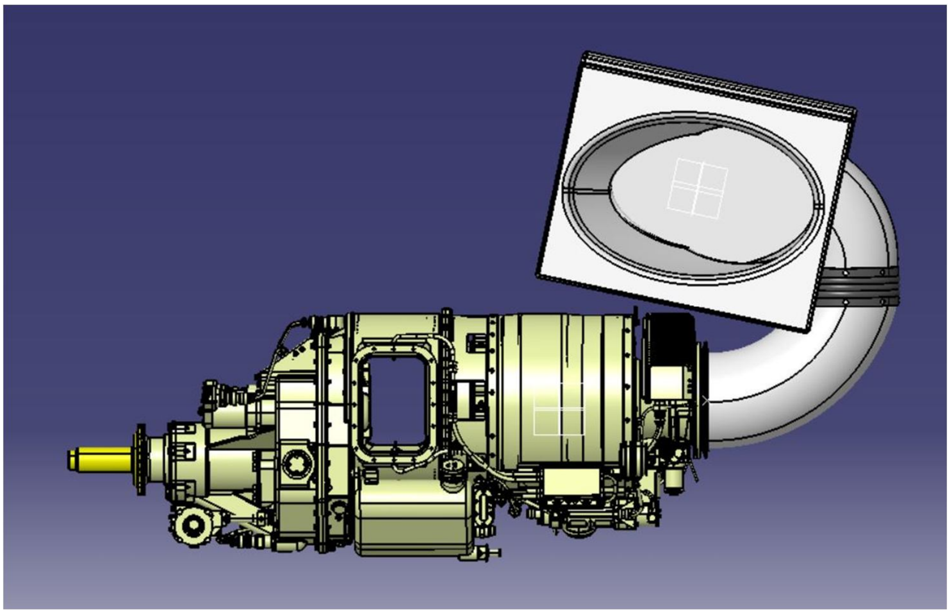


Figure 8 – B250 air intake with IBF integrated with the TS100

The IBFs are installed between the skin of the helicopter and the entrance lips of each „ear” of the intake. The IBF needs to be selected in products that are already available on the market. The IBF from Donaldson Aerospace mounted on the Bell 205 helicopter has been selected. This filter has standard dimensions and is delivered with a mounting frame.

On this IBF equipped air intake, flow computations have been done in order to check the flow velocity in any section of the intake in different flight conditions and configurations of the intake (no filter blocked, 1 filter blocked or 2 filters blocked), the pressure loss through the intake and the uniformity of the flow at the entrance of the compressor. A special report on the design of this intake and the related CFD computations has been written and could be delivered on request.

2.2.3 Engine mount

The TS100 engine mounting and dismounting from the helicopter airframe is made of four anchoring points. This has requested a first complete redesign of the existing B150 chassis as well as an adapted connection/support of the chassis to the tail boom. Engine mount frame is built of stainless steel tubes (25CrMo4 steel) assembled with a TIG welding process. All this new chassis assembly has been designed in Catia with the requested structural calculations of all tubes and metal connecting plates.

After comments received from the ESPOSA review team as well as due to the integration needs of the new air intake and of the IBFs, a complete redesign of the chassis took place. The tail boom has also been replaced by a truss structure making the whole structure stiffer and also slightly lighter. The fuselage skin (including access doors for servicing and maintenance) has also be positioned on the integrated chassis-trussed tail structure, air intake and exhaust nozzles. This is shown on Figure 9.

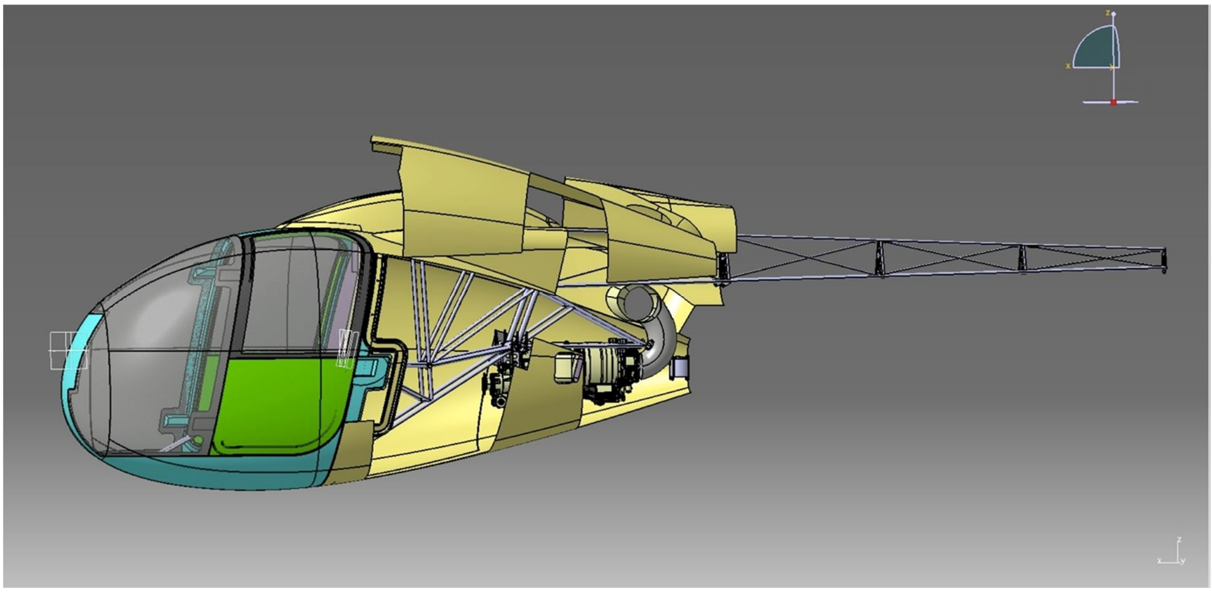


Figure 9 – B250 engine support structure with trussed tail boom and open fuselage (with access doors)

In addition to the strength requirements, the design must ensure resistance of structure (including composite elements) against fire and high temperature - in case of fire in the engine compartment. Therefore a blanket made of Diatex is put on top of the fuel tank (in the B250 helicopter, it is positioned under the main helicopter gearbox).

2.2.4. Engine nacelle / Helicopter fuselage

The TS100 engine is in fact located in a rather large (rear) nacelle under the main rotor. This nacelle is partly made of fixed elements and partly of movable elements / doors that give access to the different components that are inside the engine nacelle (Figures 9 and 10), i.e. the engine itself, the air-oil coolers, the main helicopter gearbox, the belt towards the tail rotor shaft, the freewheel, …

Access demands

The design must ensure access to servicing / inspection area of particular systems.

<u>Oil system</u>

- Gearbox oil filter
- Engine core oil filter
- Oil tank plug for oil filling – difficult access!
- Gearbox oil outlet
- Oil tank outlet
- Core regulation valve
- Gearbox regulation valve
- Oil level indicator – visual contact
- Fuel/oil drainage tank

It must also allow helicopter gearbox servicing, including the belt towards the tail rotor shaft, and complete TS100 engine servicing.

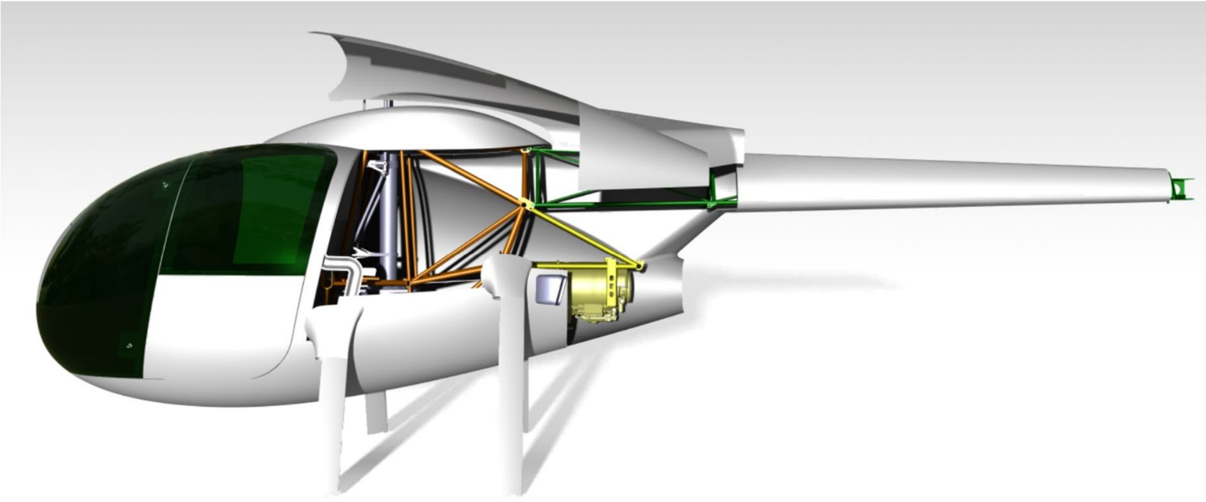


Figure 10 – B250 engine nacelle / helicopter rear fuselage with B250 chassis

2.2.5. Engine ventilation / cooling

The design ensures ventilation of engine compartment to prevent accumulation of hot air, gases and vapours, and heat protection of composite parts/ systems against expected temperatures that are expected on engine external surface (Figure 11). The rear fuselage has a top opening to all main rotor downwash to enter into the rear fuselage cavity and an exit opening at its right-hand extremity.

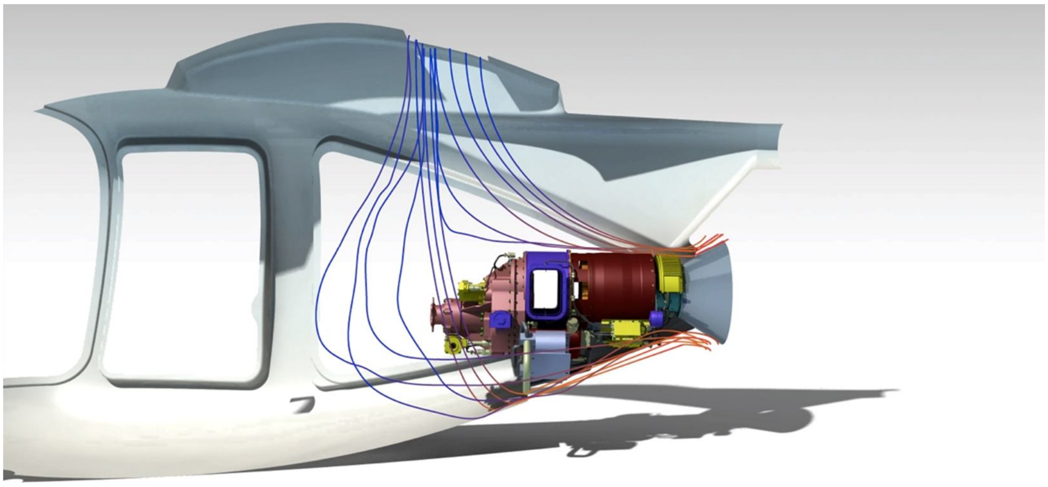


Figure 11 - Engine nacelle ventilation – working principle (side view)

A solution using an electrically-driven fan to increase the mass flow rate through the ACOC could also be envisaged.

3. FLOW AT THE EXIT OF THE AIR INTAKE

The focus of this task is on evaluating the main characteristics of a turbulent flow in the air intake of the turboshaft. The analysis is carried on using CFD (Computational Fluid Dynamics) analysis as an aid to mechanical design process. A series of simulations on the air intake was conducted in order to the search a reliable prediction of its fluid dynamic phenomena. A future confirmation of experimental data appears to be fundamental to give a sort of reliability of data obtained and it is so recommended. The adopted air intake mesh is presented on Figure 12.

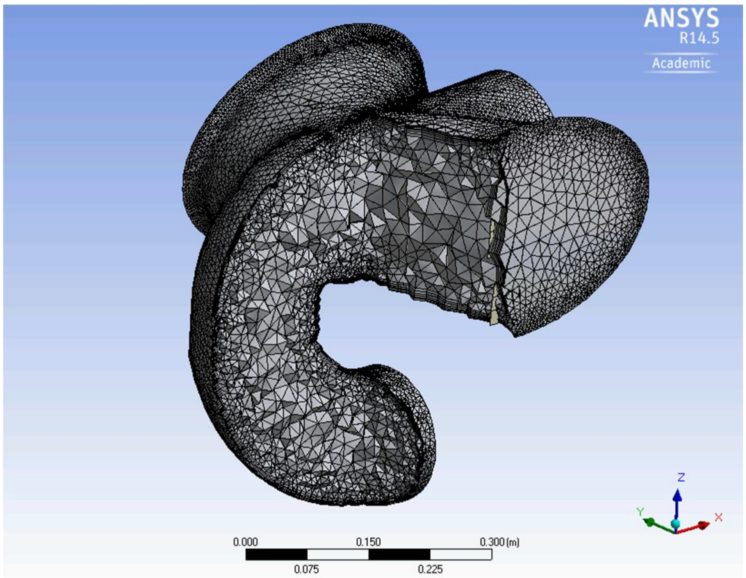


Figure 12 – Adopted CFD mesh

Simulations are first done with a normal air aspiration through the air intake. This is the case in which the aspiration of the entire mass of air passes through the two lateral inputs and the by pass passage is fully closed. The simulation, conducted with the k-epsilon model in standard wall function, shows the static pressure field on Figure 13.

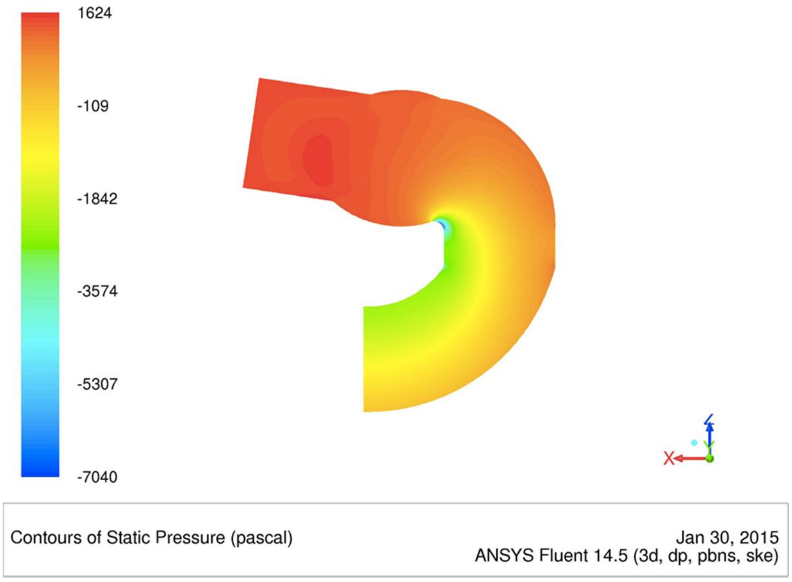


Figure 13 – Pressure field in the air intake

Moreover, the air intake must keep the distortion criteria DC_{60} (or the DC_{120}) acceptable at the outlet for different operating conditions. Here an estimation of this value is reported following the equation:

$$DC_{60} = (P_{60min} – P_i)/q$$

where P_{60min} is the mean total pressure in one 60-degrees segment, minimum value of all segments, P_i is the mean value of total pressure in outlet surface and q the mean value of dynamic pressure.

$$DC_{60} = -0.847$$
$$DC_{120} = -0.607$$

This value of the DC_{60} parameter is particularly high. This can be justified by the fact that a significant direction change of the flow is present in the geometry. Effects of induced pre-rotation were not compiled with the current simulation. That could increase the flow turbulence and give a more uniform flow at the outlet. Testing will deliver the final outlet flow view.

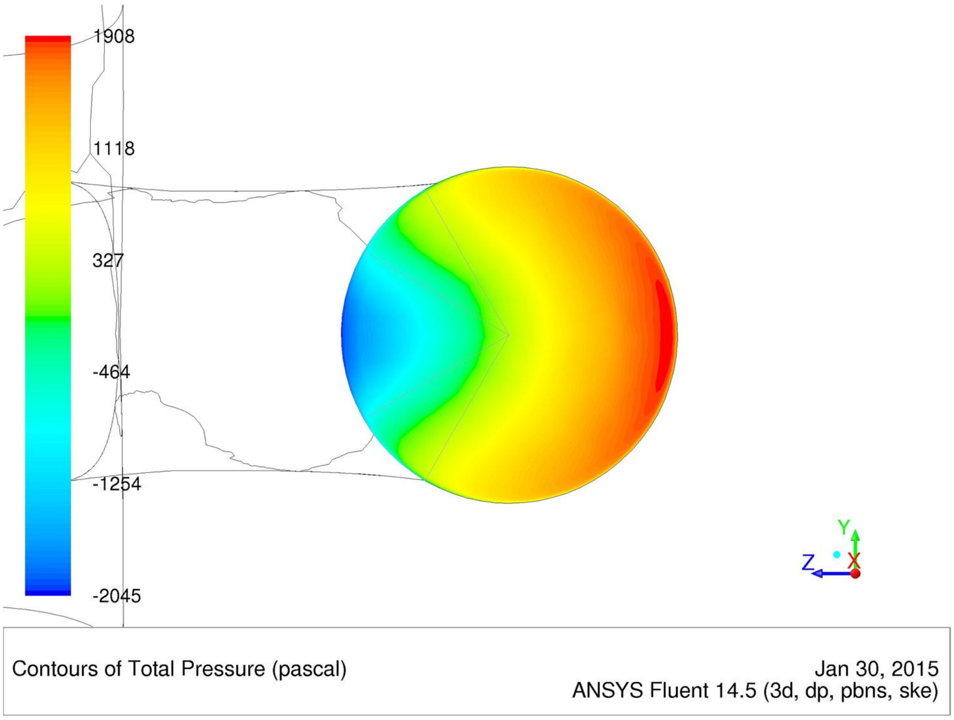


Figure 14 – Total pressure contours at the outlet of the intake

4. ENGINE OIL COOLING AND AIR-OIL COOLER POSITION

A preliminary study has been conducted on the best position for the air-oil heat exchanger (HE or cooler or ACOC) in order to increase the air mass flow rate passing through the exchanger. Three different positions suggested by the manufacturer (Figures 15, 16 and 17) are considered. From Table 1, instead, it can be argued that the best position is surely the aft body one. From a more detailed analysis, it seems that this location can be useful also for an easier maintenance. It can be added that when the HE is positioned under the electronic control system, the temperature plume can in some manner reach some parts of the engine and compromise the functionalities of these parts. This is another consideration that has driven to choose the lower exit as the best zone where the HE should be put.

Table 1 Mass flow rates in the heat exchanger for its rear and more advanced position

HE position	**Velocity [m/s]**	**Roof Mass flow rate [kg/s]**	**HE mass flow rate [kg/s]**
1	**7**	**1.97**	**0.001**
2	**7**	**1.97**	**0.005**
3	**7**	**1.97**	**0.02**

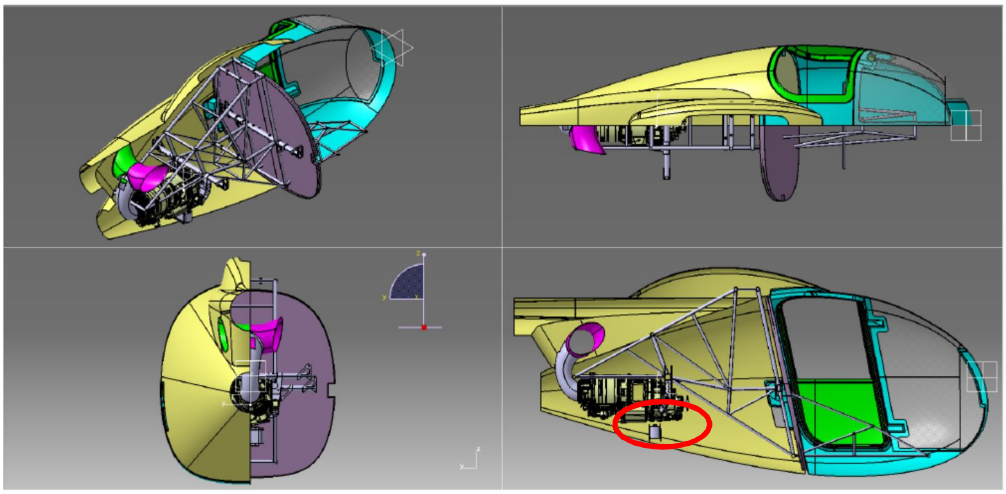


Figure 15 - 1st heat exchanger position

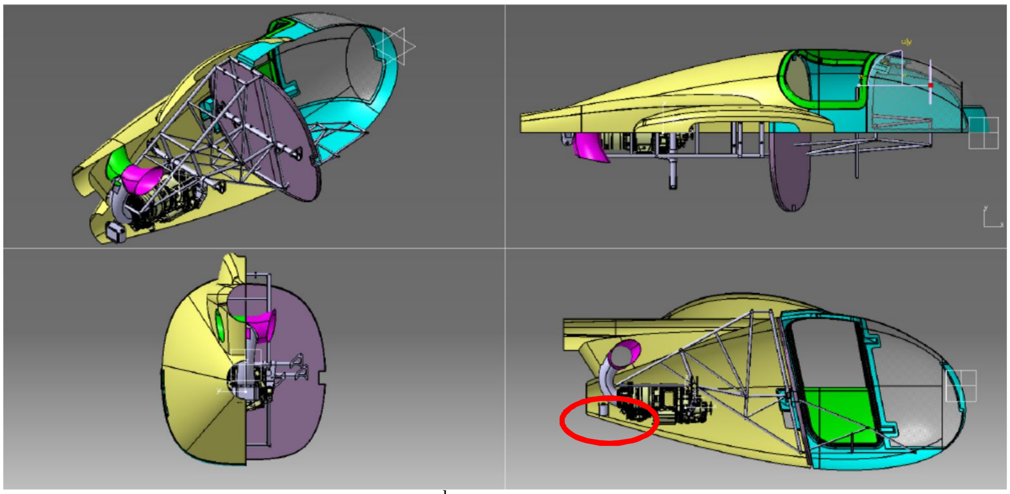


Figure 16 - 2nd heat exchanger position

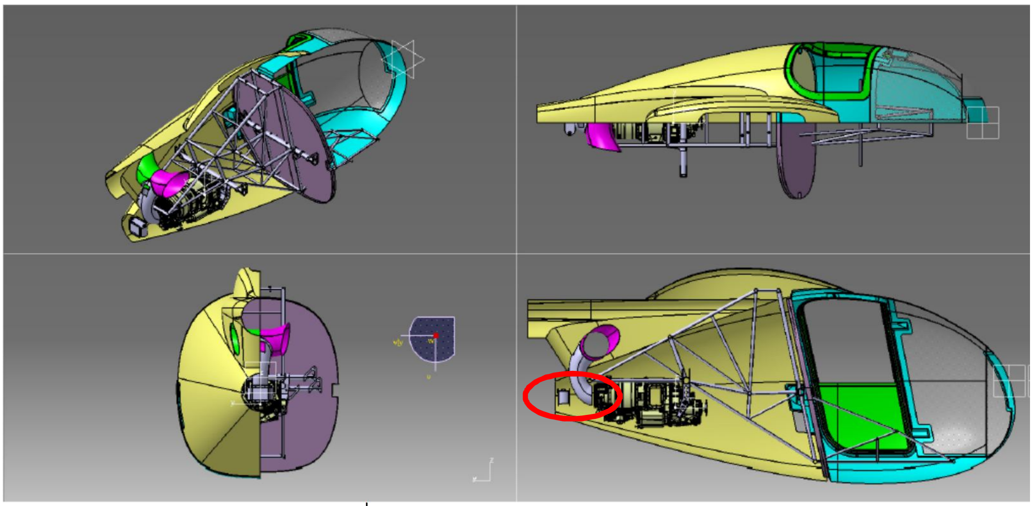
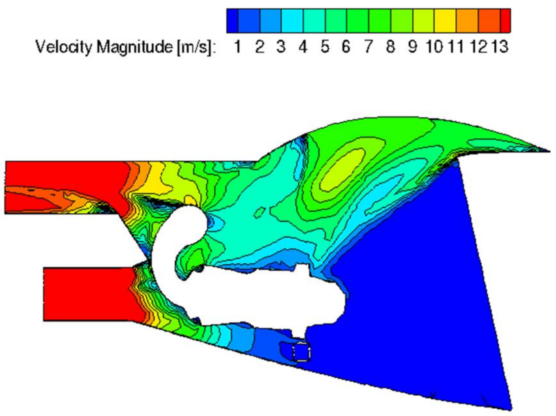
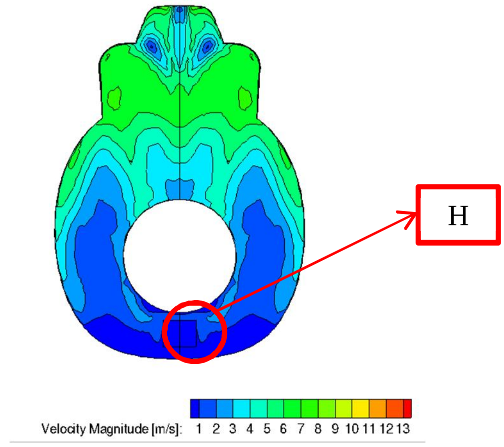


Figure 17 - 3rd heat exchanger position (best position)

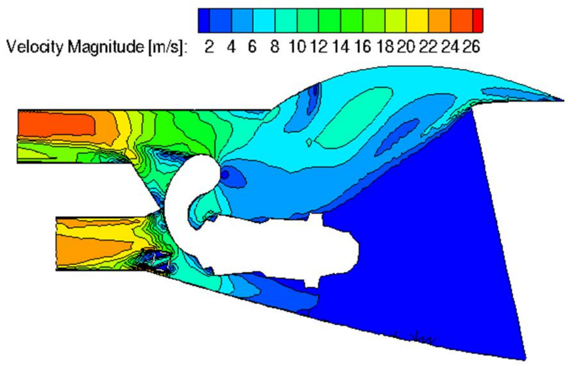
Figure 18 shows velocity fields inside the engine vane on the symmetry plane and in frontal view. Velocity magnitude is greater in the case where the HE is located near the lower exit of the case.



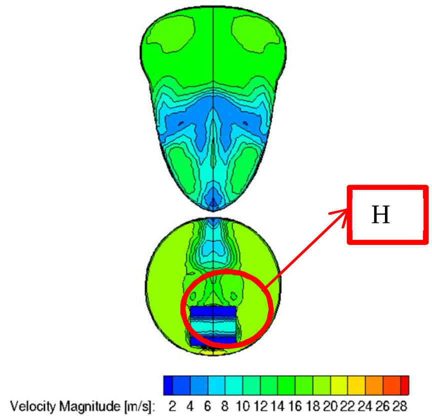
HE Position 1: Symmetry plane



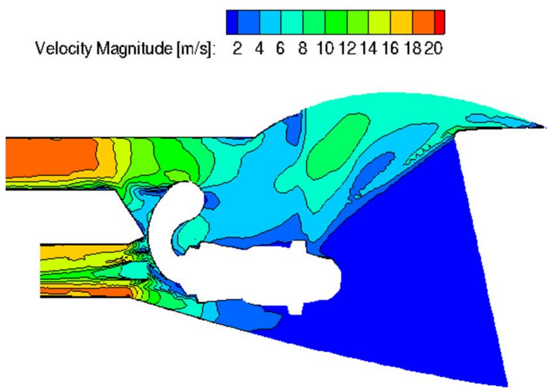
HE Position 1: Frontal view section



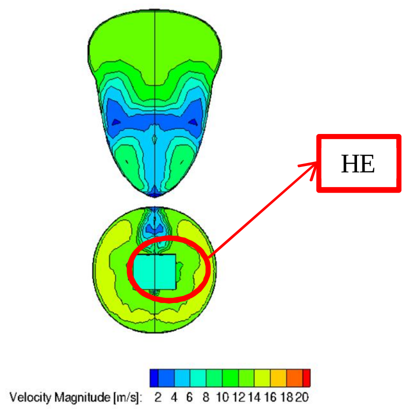
HE Position 2. Symmetry plane



HE Position 2: Frontal view section



HE Position 3: Symmetry plane



HE Position 3: Frontal view section

Figure 18 - Velocity contours related to 3 positions of the heat exchanger

5. CONCLUSIONS AND FUTURE WORK

A few issues related with the integration of a small turboshaft engine into a light helicopter have been presented.

A number of flow field numerical simulations have also been performed in order to achieve a parametric design of the oil heat exchanger position and to compute the mass flow rate inside a light helicopter engine fuselage and inside its air intake.

For the air intake, the normal flow field with the flow going through the lateral openings shows to be acceptable even if the distortion index DC60 or DC120 still looks to be a bit high.

For the oil cooler, the flow condition taken into consideration is the ground idle where the flow comes from above through an opening in the roof under the main rotor. Clear conclusion appears for the design process with the identification of the best position for the cooler and the sizing of the top opening in the helicopter roof.

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