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Description of an Air-Oil Test Set-Up for ACOC Heat Exchangers Testing

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Abstract

The Air Cooled Oil Cooler (ACOC) heat exchanger is an important element of the lubrication system of aero engines. The aim of the lubrication system is to cool and to lubricate the bearings and gears of the engine to ensure its proper working. The Aero-Thermo-Mechanics department of the Université libre de Bruxelles (ULB) has developed two test set-ups for the characterisation of ACOC prototypes: a low air flow rate set-up for the experimental testing of small scale ACOC prototype and a higher air flow rate set-up for real scales prototypes and more realistic flight conditions. The two test set-ups are complementary and can be used for different test campaigns.

1. Introduction

Reducing the fuel consumption in modern aero engines is a key point for more sustainable air transportation. It has a positive impact on the reduction of green house gases on one side and on the other side it can reduce the operation costs. The reduction of the fuel flow rate and the increase of needs for oil cooling in the aero engines leads to the addition of an Air Cooled Oil Cooler (ACOC) in the oil system. The aim of the oil system is to cool and lubricate the bearings and gears of the aero engines. The aim of the ACOC in this system is to cool the oil with an air flow from the engine to ensure the proper additional cooling of the oil in complement of the Fuel Cooled Oil Cooler (FCOC). Improving the ACOC design to reduce the pressure drop on the air side of the heat exchanger decreases the amount of pressure the fan needs to counteract and thus the power consumed by the fan. It then reduces the fuel consumption of the entire engine. Reducing the pressure drop of the air side of the ACOC heat exchanger leads to better performance of the aero engine.[4,11]

The Aero-Thermo-Mechanics (ATM) department of the Université libre de Bruxelles (ULB) has developed several test set-ups dedicated to the reproduction and study of the oil system of the aero engines. A first oil and air mixed test set-up with the ability to reproduce the pressure variations of in-flight conditions. It was mainly used to test pumps.[8] This test set-up is also the basis of the low air flow rate test set-up presented in the following section of this paper. Another test set-up developed at the ATM department is the breather and separator test bench coupled with the brushseal test set-up.[13,15] It can use two separates lines of air and oil. This set-up also includes an oil pollution loop. Particles can be injected to test the resistance of particular prototypes in a dirty environment. The particles can also be counted. There is also a water test bench that replicates part of the oil system for first prototyping testing. Finally there is the large air flow rate heat exchanger test set-up which involve the biggest air flow line designed in the department.

The second section of this paper is focused on the presentation of the oil system and the ACOC heat exchanger in particular. Then the first test set-up presented is the low air flow rate set-up. It was also the first heat exchanger test bench designed at the ATM department. In the fourth section the large air flow rate test set-up is presented. After the presentation of both test set-up a comparaison between them is made in the fifth section of the paper followed by a conclusion about our test facilities and capabilities.

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2. Oil System and ACOC Heat Exchangers

As mentioned in the introduction the ACOC is an element of the oil system of the aero engine. It is then important to show a brief description of the oil system before entering into the details of the ACOC heat exchangers and the description of the test set-ups.

2.1 Oil System

The objective of the oil system is to provide cooling and lubrication of the bearings and gears in the engine. The oil system is composed of multiple elements such as: a tank, a feed pump, scavenge pumps, filters, injectors, sumps, chips detectors, separators, oil cooler(s) and venting system. The schematic of a typical oil system is shown on the figure 1.

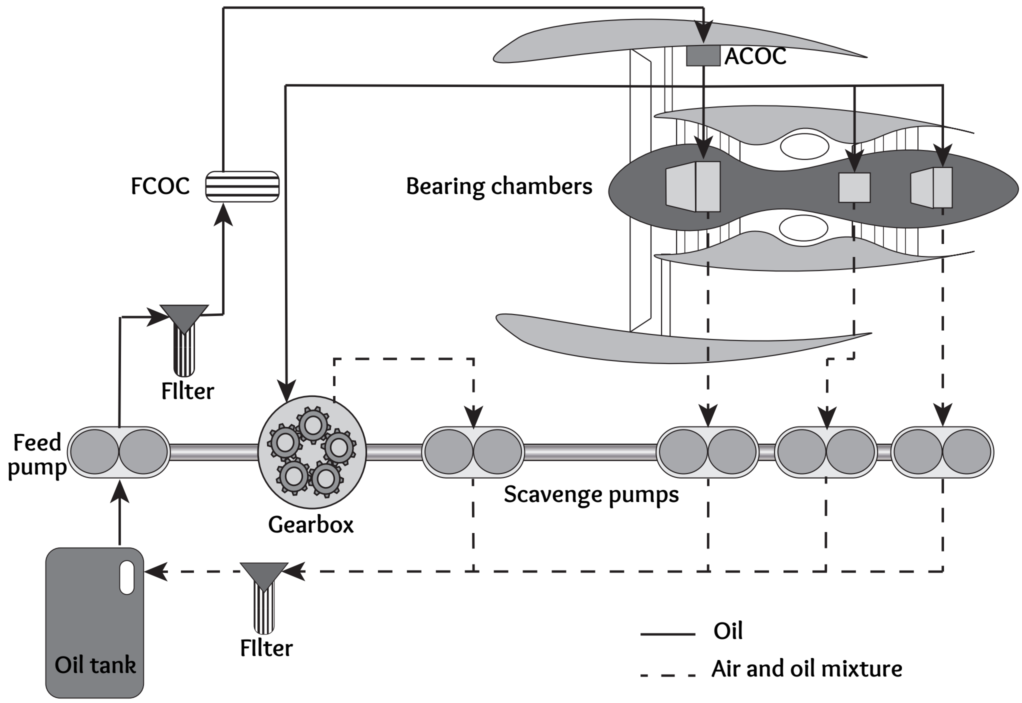

Figure 1: Schematics of the Oil System

The oil is stored in the tank. Then it is passing through the feed pump which deliver the oil to every bearing chambers and gearboxes in the system. The oil is flowing through a filter to remove any possible particles from the pump then it passes inside the FCOC to cool the oil in an heat exchange with the fuel. As there is a limitation of the temperature of the fuel at the outlet of the heat exchanger to avoid auto-ignition of the fuel in new engines there is an additional need of oil cooling.[6,18] This additional cooling is done through an ACOC heat exchanger. The extra cooling of the oil is performed through a heat exchange with the air coming from the secondary flow of the reactor.
After the two heat exchangers the oil is cold and can thus be injected in the different bearing chambers shown in the schematic 1. Inside the bearing chambers there is also compressed air coming from the compressor stage of the engine. This pressurised air is used to ensure a correct sealing of the bearing chambers.
Therefore the fluid flowing through the different scavenge pump is a mixture of air and oil as shown on the schematics. There is one scavenge pump per bearing chamber and per gearbox present in the engine. The mixture of air and oil is then returned to the tank by the scavenge pumps and passing through another filter. Inside the tank there is a separation system to ensure that the oil going back to the feed pump is free of the air. And the air is passing through a venting system to remove the oil droplets inside the air flow before it is sent back to the atmosphere.[9,12,17,19]
The configuration shown in the schematics is called the hot tank configuration because the oil stored in the tank is not already cooled by the heat exchangers because there are after the feed pump in the circuit.

Another configuration exists it is called the cold tank. In this other version the heat exchangers are placed after the scavenge pumps. In this case there is a mixture of air and oil flowing inside the FCOC and the ACOC.[3,7,10] But this cold tank configuration is not the configuration on which the ATM department is working.

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2.2 ACOC Heat Exchangers

ACOC heat exchangers are often plate-fin type heat exchangers. A schematic of a typical ACOC geometry is shown in figure 2. It can be seen from the schematic that the oil is flowing through the plates and the air flow is passing between the fins. The presence of the fin enhances the heat exchange capabilities on the air side compared to simple plate heat exchangers. The dimension and thickness of the fins can vary between the different plate and fin heat exchangers. The oil flow pattern inside the plate can be much more complex than the simple version shown on the drawing. It can include labyrinth path for some models.[1,2,5,14,16]

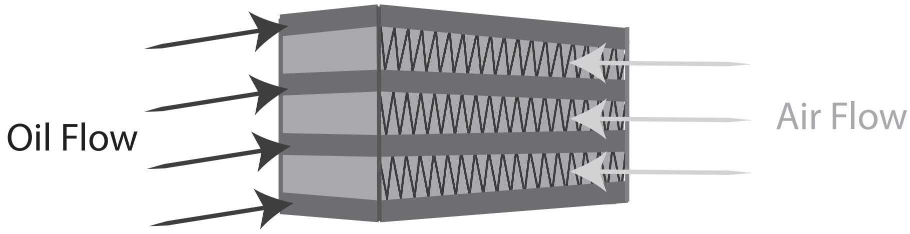

Figure 2: Schematics of an ACOC

3. Low Air Flow Rate Test Set-Up

After the introduction about the context of the research at the ATM department, the brief description of the oil system and the ACOC heat exchanger in itself the first designed test-up can be introduced. It is a low air flow flow rate set-up that was designed for small-scale ACOC prototypes manufactured by the Additive Layer Manufacturing (ALM) technics. The objectif of the test set-up is to measure the pressure drop on the air line and on the oil line between the outlets and the inlets of the ACOC as well as the heat transfer between the two sides of the heat exchanger. A first paper about this test bench has already been presented in a previous conference.[20]

This section of the paper is divided in three main parts: the summary of the capabilities of the test set-up on the air side and the oil side, the working principle of the set-up and the hydraulic schematic of the set-up. The comparison between this set-up and the large air flow rate set-up is then performed in the dedicated subsection after the presentation of the large air flow rate set-up.

3.1 Capabilities

The test set-up can reach different air flow rates and oil flow rate independently of the temperature. The range of proper working of the bench is listed in the table 3 and in the table 4. The control precision of the oil flow rate is around 10 l/h and control on the oil temperature is about 3°C. On the air side the control precision is of 3-5 g/s for the flow rate and 5°C for the control of the temperature at the inlet of the ACOC.

Table 1: Oil Side

	Range	**Unit**
Flow rate	200 - 2800	l/h
Temperature Inlet ACOC	30 - 140	°C

Table 2: Air Side

	Range	**Unit**
Flow rate	30 - 240	g/s
Temperature Inlet ACOC	30 - 100	°C

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3.2 Working Principle

The working principle of the small air flow rate test set-up is to create the air flow rate from a blow-down system. There is a 40 bar compressor filling an air tank. The tank is then open to let the air flow inside the circuit with a pressure regulation to ensure a relative pressure inside the pipes of maximum 5 bar. The oil side is a closed loop flow. The oil flow conditions and the air flow conditions can be set and controlled independently relative to each other.

3.3 Hydraulic Schematic

The hydraulic schematic of the test set-up is presented in the figure 3. The oil line is on the right sight of the schematic. In the oil circuit there is a tank open to the atmosphere during the tests. This tank can also be closed and pressurised or depressurised to simulate flight conditions but it was never used in the performed test campaigns. The pressure inside the tank is measured by an absolute pressure sensor. The oil is then flowing through the pump. It is a volumetric gear pump able to impose directly the required flow rate independently of the pressure inside the circuit. It can create a surpressure of maximum 10 bar. The pressure inside the oil circuit is not controlled it is imposed by all the pressure losses from the elements of the circuit and the ACOC prototype in particular. A pressure control could be added if there was any need of it for a further test campaign.

The oil flow rate is then measured by a turbine flowmeter. The temperature of the oil is measured inside this flowmeter to take into account the impact of the temperature on the viscosity of the oil. The measured oil flow rate is a volumetric flow rate. The oil flow is then going inside the ACOC heat exchanger. There are multiple sensors at the oil inlet and outlet of the prototype. At the inlet of the heat exchanger there is a temperature measurement performed with a 1/10 DIN PT100 probe to ensure a good precision. There is also an absolute pressure measurement and a differential pressure measurement between the oil inlet and outlet of the ACOC. The position of the sensors on the oil line is called P4. There is a similar position at the oil outlet of the ACOC named P5. There is also a temperature measurement and an absolute pressure measurement. The temperature probes are then used to calculate the heat transfer between the oil side and the air side of the ACOC heat exchanger.
After the outlet of the ACOC there is a filter with the possibility to filter the oil from particles coming from the tested prototypes or from items inside the oil flow. It is a safety measure to protect the different elements inside the oil circuit specially the pump and the ACOC heat exchanger. A 5 micron or a 22 micron filter can be inserted inside the filter casing in the circuit. During the different test campaigns only a 22 micron filter has been used but it could easily be change inside the circuit. The oil is then passing through the oil heater. It is composed of electric resistances inserted inside the oil flow. It is this oil heater that can control the oil temperature at the inlet of the ACOC prototype using a regulation system implemented inside the control program of the test set-up. The oil heater is really useful to re-warm the oil coming from the ACOC to ensure a constant temperature of the oil inside the circuit even when the ACOC is cooling the oil.

The air line of the test set-up is shown on the left side of the figure 3. It is an open loop circuit. The air is compressed by a 40 bar compressor and stored inside an air tank. When the test are started the air line is then open and the air stored in the tank is flowing in the rest of the circuit to the ACOC prototype. There is first a pressure regulator to decrease the pressure of the air flow from 40 bar to between 1 and 5 bar relatives. It is controlled manually at the beginning of the test session but can be changed during the tests. Then the air is flowing through a volumetric flowmeter. The measured volumetric flow rate is then converted into a mass flow rate using an absolute pressure sensor and a temperature sensor. It is a PT100 probe. The pressure and temperature measurement can be used to compute the density of the air flow. The temperature can vary a lot during a test session and subzero temperature can be reached in case of important diminution of pressure between the air tank and the line after the pressure regulator.

After the flowmeter there is a regulation valve (V3 on the schematic). It allows precise control of the air flow rate inside the ACOC prototype. A variation of 3-4 g/s in the air flow rate is possible through this valve. There is also a pressure relief valve for safety inside the circuit. If there is more pressure than 5.5 bar then the pressure relief valve is opened to prevent an excess of pressure in the pipings. After this the air flow is entering the air heater. There are electrical resistances inserted inside the air flow to heat the air. The temperature control is performed through a PID regulation. The temperature of the air entering the ACOC is in general 40°C during the test campaigns. There are three pitot tubes present in the air line. Two are at the air inlet of the ACOC prototype and one at the outlet.

The pitot tubes are at fixed positions inside the air flow. Both pitot tubes can measure the static and dynamic pressure and are also equipped with thermocouples. The absolute pressure and the temperature are measure at a first position near the inlet of the ACOC at the position P1. At the position P2 there is also a differential pressure sensor

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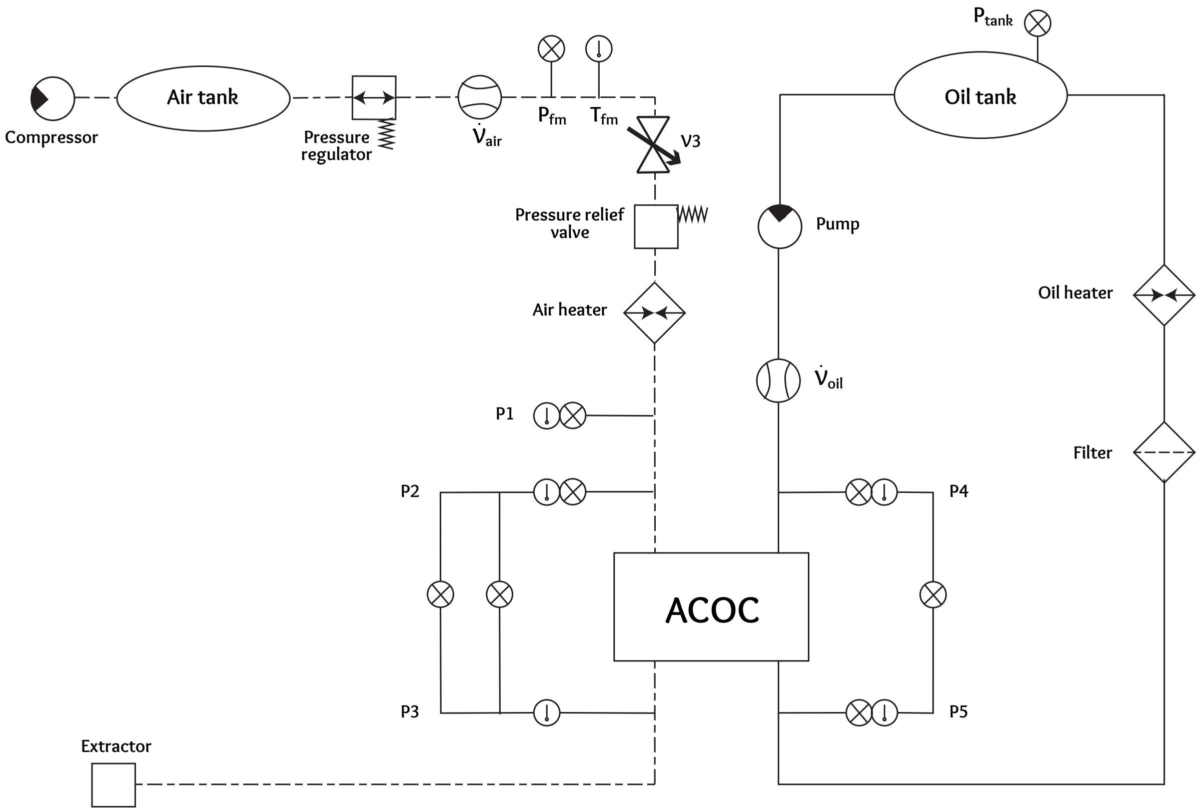

Figure 3: Hydraulic Schematic of the Low Air Flow Rate Set-up

on both the static pressure and the dynamic pressure between the inlet (P2) and the outlet P3. The temperature is also measure at the P3 position at the outlet of the ACOC. The temperature measurements are then used to compute the heat transfer between the air side and the oil side of the ACOC heat exchanger. The air is then returned to the atmosphere through the vent system of the bench.

4. Large Air Flow Rate Test Set-Up

The large air flow rate test set-up was designed after the low are flow rate set-up. The aim was to enhance the amount of air flowing through the heat exchanger to be closer to the real flight conditions and perform test on more mature prototypes. The bench can reach higher mass flow rate but with less surpressure available. The advantages and disadvantages of this set-up compared to the previous test set-up are developed in the comparison section of this paper. The structure of this section is similar to the structure of the previous section.

4.1 Capabilities

The test set-up can also reach different air flow rates and oil flow rate independently of the temperature. The range of proper working of the bench is listed in the table 3 and in the table 4. The control precision of the oil flow rate is around 10 l/h and control on the oil temperature is about 3°C. On the air side the control precision is of 5-10 g/s for the flow rate and 5°C for the control of the temperature at the inlet of the ACOC.

4.2 Working Principle

The main difference in the working principle of this set-up compared to the previous one is the continuous operation. Since the compressor is directly creating the air flow and no more filling a tank the air line can be operate continuously.

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Table 3: Oil Side

	Range	Unit
Flow rate	200 - 2000	l/h
Temperature Inlet ACOC	30 - 180	°C

Table 4: Air Side

	Range	Unit
Flow rate	15 - 650	g/s
Temperature Inlet ACOC	45 - 100	°C

It increases the efficiency of the bench but also the quality of the measurement because it is easy to stabilise at the required flow rate and perform a long measurement without running out of air. The oil side is really similar to the previous version although it is much simpler without the possibility of controlling the pressure of the oil tank.

4.3 Hydraulic Schematic

The hydraulic schematic of the large air flow rate set-up is shown in the figure 4. The oil circuit is on the right side of the schematic. The oil circuit is really similar to the one of the previous test set-up but is simplified. The oil capacity is reduced in quantity of oil inside the tank but also on the maximum flow rate. There is no pressure regulation of the tank which is simply open to the atmosphere. Then the oil is passing through a pump and to a flowmeter to measure the oil volumetric flow rate. There are the same type of sensors at the inlet and at the outlet of the ACOC heat exchanger. One absolute pressure sensor at the inlet of the prototype (P7) and a temperature probe.

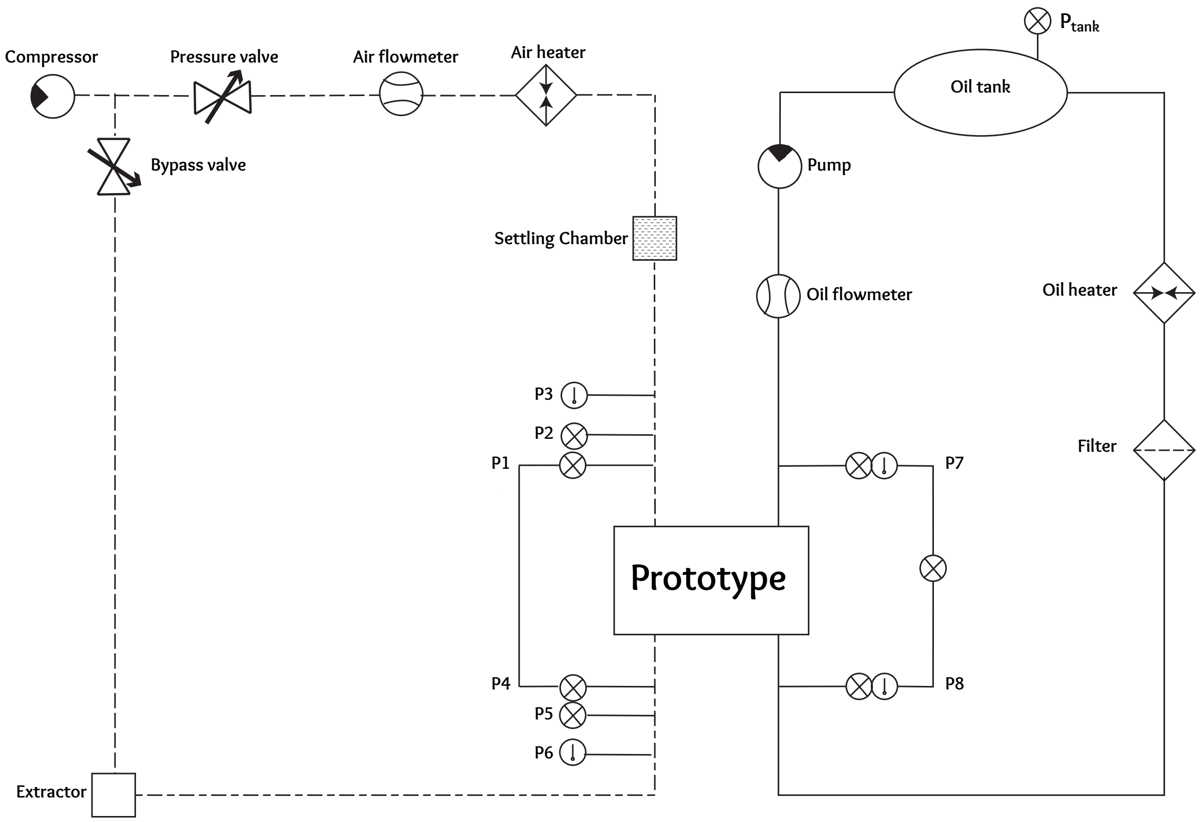

Figure 4: Hydraulic Schematic of the Large Air Flow Rate Set-up

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Another absolute pressure sensor at the outlet of the heat exchanger (P8) coupled with a temperature probe. There is also a differential pressure measurement between the inlet and the outlet to determine more precisely the pressure drop on the oil side of the prototype. There is also a filter in the circuit to protect the different elements form the particules. Specially some residual particules coming from the ALM manufacturing of the prototypes. The oil heater is this time coupled with the oil tank. There are electrical resistance inside the tank to warm up the oil. The temperature of the oil is kept relatively constant even when the air flow rate is cooling the oil.

On the left side of the schematics shown in figure 4 there is the air line of the test set-up. The main part of this line is the compressor which is able to deliver a flow rate of maximum 650 g/s at a surpressure of 1,1 bar. Since the minimal rotation speed of the compressor is still delivering in average 100 g/s which is not the minimum air flow rate required for the test campaigns a by-pass has been introduced inside the air line of the test set-up. To reach the minimal air flow rate around 15 - 20 g/s the compressor is set at its minimal rotation speed and the rest of the flow rate control is performed through the control of the by-pass valve. The excess of air flow is directly ejected at the outlet of the compressor without going through the flowmeter and the ACOC prototype. In addition to this by-pass valve there is also a pressure valve in the main air line to be able to increase the pressure at the inlet of the prototype if a particular pressure must be reached. This valve can also be installed at the outlet of the prototype to simulate an increase of counter-pressure behind the ACOC.

The air flowmeter is a mass flowmeter so there is no need to measure the temperature and the pressure around the flowmeter to convert a volumetric flow rate like on the low air flow rate set-up. After the flowmeter there is the air heater. There are electric resistances inserted inside the air flow. The activation of those resistance can increase the flow temperature. The maximum reached temperature was 100°C but higher temperatures could be reached if needed for other applications. The control of the air flow temperature is performed through a PID regulation on the control program of the test set-up. After the flow has been conditioned by acting on the amount of air flow rate, its pressure and its temperature the flow can be settled and guided properly inside the prototype inlet section. The settling chamber has the same shape and cross-section than the test veins containing all the measurement probes before and after the prototype. It is also the same section as a part of the prototypes. Its role is to reduce the turbulences inside the test veins and the prototype and also to redirect the flow before entering the prototype. It is composed of 3 honey combs and 3 metallic grids to kill the vortices. The velocity profile at the end of the settling chamber has been measured to ensure that it is correctly centered inside the test veins.

The test veins around the prototypes are equipped with different sensors. There are two temperature probes one at the inlet of the prototype and the other one at the outlet of the prototype. Both are 1/10 DIN PT100 to ensure a good precision on the temperature measurements. Those values are used to compute the heat exchange between the oil side and the air side of the ACOC as for the previous test set-up. The temperature measurement are represented in the schematics by the positions P3 and P6. There is also a static pressure measured at the inlet and at the outlet of the prototype marked as P2 and P5. It is a point on the wall of the test veins. Then there are two multiple pitot tubes with seven entry each that are inserted at the location P1 and P4. Those pitot tubes can only measure the dynamic pressure. It is very useful to measure the velocity profile because the seven pins are dimensioned to be equally spaced on the total height of the prototype cross-section as shown on the figure 5.

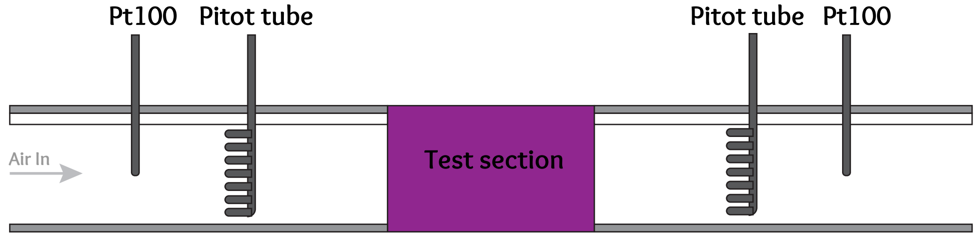

Figure 5: Test Veins Cross-section

The different air pressures are measured with a pressure scanner with 16 entries. This sensor has been selected because

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of its precision and because it reduces the number of sensors required since all the measured pressure are in the same range. The precision of the sensor is enough therefore there is no use of a differential pressure measurement between the inlet and the outlet of the prototype. After the test veins and the measurements the section of the piping is increased to reduce the speed at the outlet of the test set-up and reduce the noise produced by the set-up.

5. Comparaison of the Two Set-Ups

The objective of this section is to compare the two test set-ups. Both set-ups have advantages and disadvantages and are suitable for different applications. They are complementary.

5.1 Low Air Flow Rate Set-up

The main advantage of the low air flow rate set-up is its oil circuit. The set-up is implemented to be a part of a more complex oil test bench therefore the oil circuit can easily be adapted to every oil configuration needed. There is a possibility to control the pressure inside the tank to put the complete oil circuit in pressure or to depressurised it to mach different flight conditions. There is also a possibility to add a control of the pressure inside the oil flow if needed for some tests. The oil flow rate can easily be changed as there is multiple pumps available in the test bench. Therefore there is a possibility to reach around 5000 or 7000 l/h if needed. The temperature of the oil flow can also be increased up to 200°C if needed. The oil temperature was only reduced during the tests campaigns because of the ACOC prototype. Thus if a complex oil circuit is needed to fulfill the requirements of the test campaigns the low are flow rate set-up is the best of our experimental set-up.

The main disadvantage of the low air flow rate set-up is its maximum air flow rate. It is only of 250 g/s which is not close to the real conditions of an ACOC heat exchanger. It is far from the required air velocities inside the prototype. The other main disadvantage of this set-up is the time of testing. If the air flow rate is around 250 g/s there is less than 10 minutes of test with the current tank. And the time needed to fill up the air tank is around 7 to 8 hours. It means that it is only possible to run tests twice a day which is not suitable for long test campaigns. Another limitation is the precision of the temperature sensors inside the air flow. It is thermocouples and not PT100 probes therefore the precision is reduced. The advantage of the thermocouples is that they are imbedded in the pitot tubes which gives the temperature of the flow at the exact same location of the measurement of the pressure. But the precision could be better using also complementary PT100 probes.

5.2 Large Air Flow Rate Set-up

The main advantage of the large air flow rate set-up is its available air flow range. It can be used for small air flow rate with a minimum of around 15 g/s and at the same time reach maximum values of 650 g/s. The pressure inside the air line can be tuned to fulfill the requirement until it stays below a surpressure of 1,1 bar. The air temperature can reach more than 100°C and can be controlled precisely. The settling chamber ensure a good quality of the flow entering the test section. It was not controlled in the low air flow rate set-up. Another advantage is the high precision on the temperature measurements in the air flow and also on the pressure measurement. The flowmeter is directly giving the mass flow rate which also improve the precision on the heat transfert.

The main disadvantage is the oil line of this set-up. It is not flexible because it comes from a mobil oil bench associated with the air line. It is smaller than the oil circuit on the low air flow rate set-up because it is design to be transportable. It cannot be modified or improved easily. Thus the large air flow rate set-up is a good solution if the air flow rate is important and if the oil circuit is not complex.

6. Test Methodology

The test methodology implemented on both set-up is quite similar. The idea is to first reach the oil flow conditions and then control the air flow conditions. The reason the oil flow conditions are reached first is simple in fact reaching the correct oil temperature takes time. For both test set-up stabilising the temperature around 120°C takes around 1h30. When the temperature is stabilised the oil flow rate is also stabilised at the required value. Then the air line is open.

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The required flow rate and temperature are stabilised at the same time. When every measurement is within the test campaign tolerance the test can be recorded.

7. Conclusions

The two developed test set-up are able to properly perform test campaigns on ACOC heat exchangers. The precision and the repeatability of the set-ups have been proved during the first test campaigns. The flow conditions can easily be stabilised in both test benches and maintained during a test run. Both a complementary test set-up with a best performance in the oil circuit for the low air flow rate set-up and a best performance in the air line for the large air flow rate set-up. Those set-ups are flexibles and could be used to perform other experimental campaigns on different types of prototypes requiring an air line and an oil line. Both circuit can also be operated separately so for example only using the air line.

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