Development and Conception of a test bench to help the reparation of Thrust Reversers

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Abstract

This thesis aims to design and develop a test bench to the reparation of the Thrust Reversers of the CFM56-5B engine. Currently, the Thrust Reverser is fixed in the engine workshop and its operation is only tested when it is mounted on the wing, because it was considered that the repair made at the workshop was sufficient. The maintenance and checking on the wing are made through the AMM. It was found, however, that this type of maintenance was not sufficient. Having seen the potential that the maintenance of Thrust Reversers presents, TAP decided to invest in the development of equipment for reparation and test of Thrust Reversers.

Keywords: Thrust Reverser, test bench, TAP

1. Introduction

This paper is on the development and conception of a test bench to help the reparation of Thrust Reversers.

The aircraft is one of the most important means of transport in existence. One of the components of the aircraft is the Thrust Reverser which is used to brake, besides the brakes and spoilers. Due to its frequent use, the components wear, which leads to the need for repair and maintenance. In order to ensure the proper functioning of this system, it is necessary to make verification testing and validation of components in order to guarantee security in the various stages of use. TAP Engine Maintenance workshop carries out the repair and maintenance of engines and Thrust Reversers of the aircraft fleet of TAP.

2. Aerostructures

The turbojet and turbofan aircraft type have a fuselage, wings, tail, propulsion system, braking system and monitoring systems. Since the TR is a component that embraces the engine, one will present the components that make up this system (nacelle), shown in figure 1.

![Figure 1 – Nacelle components. [1]](image)

The pylon is the component that connects the assembly to the airplane wing. The structure consists of the cowl inlet (rollover that allows air to enter), the cowl fan (rollover protecting the fan), TR which involves the engine and deflects
the air bypass and exhaust (nozzle and cone).

The Jet propulsion is a direct application of Newton’s 3rd Law which states that “for every force acting on a body, there is an opposing force in the same direction and intensity”, that is, for all forces there is always a reaction force. In the case of propulsion, the "body" of which are being exerted forces is the air passing through the reactor, resulting in its acceleration. The force needed to cause the air acceleration has, therefore, a direction opposite reaction force that will be responsible for the movement, this force is called thrust.

In a turbofan, the engine core is made of a fan, a low pressure compressor (booster) upstream and an additional turbine downstream. The impulse is then achieved by combining the high exhaust velocity, from burning fuel with a flow in a duct after the fan, shown in figure 2.

![Turbofan engine scheme.][1]

Of the air flow which is admitted to the fan, a small portion proceeds to the core (=20%), primary flow, providing oxygen for combustion to occur, which is responsible for generating thermal power, and supplying air to the cooling circuits of the reactor.

The turbines are responsible for performing the conversion of the thermal power to mechanical power, so that the compressors and the fan can move. In the particular case of a turbofan shaft, double Low Pressure Turbine (LPT) moves the fan and the low pressure compressor via an inner shaft (N1 rotational speed) and the High Pressure Turbine (LPT) is then responsible for transmitting movement to the High Pressure Compressor (HPC) making use of an outer shaft (rotational speed N2) surrounding the inner shaft.

The remaining air, which represents the remaining 80% of the total flow is called secondary air flow or bypass. The bypass ratio is the relationship between the secondary flow that bypasses the core and the primary flow passing through the core. In the case of the CFM56-5B engine, the bypass ratio is 5.5:1 to 6:1, the secondary air flow is 5.5 to 6 times higher than the flow rate of primary air. Currently relationships can be achieved up to 11 to 1.

The turbofan increases its momentum by increasing the mass flow rate through the bypass. Moreover, this secondary flow is used to cool gases leaving the turbine, reducing the thermal differential output and reduced noise of the aircraft.

3. Breaking systems / Reverse Thrust

After crossing a certain distance, the aircraft needs to land. The complete landing of an aircraft is to land, lead the aircraft to a low speed (taxi speed) and its complete stop. However, most of the commercial jet engines continue to produce forward thrust even when they are inactive, acting contrary to the deceleration of the aircraft. The landing brakes and the spoilers of modern aircraft are sufficient under normal circumstances, but for safety reasons, and to reduce tensions on the brakes, another deceleration method is needed: the Thrust Reverser.

4. Thrust Reverser

On an aircraft with a jet engine, a simple and efficient method of braking is to reverse the direction of engine exhaust flow jet and use the engine power to slow itself. There is a set of Thrust Reversers on each engine A320.
Each set consists of two halves which are hinged at the top of the pylon and locked together on top of the split line. Moreover, the assembly is also embedded in the end of the fan structure. This system works only together, that is, it cannot deflect the air only from one side. Thus, the Thrust Reverser is a temporary deviation in the engine exhaust system of an aircraft so that the produced exhaust gases are directed forward instead of going backward. This acts contrary to the displacement forward of the aircraft, providing deceleration. Ideally, the reversed exhaust flow should be directed to the straight ahead. However, for aerodynamic reasons, this is not possible, and an angle of 45° is used, resulting in a less efficient solution, shown in figures 3 and 4.

The Thrust Reverser is triggered manually. First the engine controls (throttle) are put in idle, the TR command (throttle) is pushed up and, when all necessary conditions for landing are satisfied, the throttle is placed at maximum, so the engine produces the maximum thrust in order to brake.

The Thrust Reverser is designed to be used only on the ground and works in four modes: stow, deploy, disabled and manual. In stow mode, the reversing system acts as an aerodynamic structure to store and secure the aircraft engine and its components. The reverser also acts as a conduit that provides a streamlined flow path and an outlet of the engine fan to the exhaust gas system. In the deploy mode, the reverser changes the direction of the exhaust air flow to the engine to obtain the thrust inversion. This reverse of thrust causes a braking effect which slows the aircraft.

In order to actuate the Thrust Reverser one must meet the following requirements: all wheels must be on the ground to ensure the touchdown, all wheels must be spinning fast enough to keep up with the aircraft, the aircraft must be moving slowly enough and throttles must be in the correct position.

The initial deceleration provided by the reverse pulse may reduce the braking force and landing distance of a quarter or more. However, the regulations require that an aircraft must be able to land on a runway without the use of Thrust Reverser.

Once the aircraft's speed has slowed down, the Thrust Reverser is turned off to prevent that the reverse air current throws debris into the intake air in the front of the engine and causes damage by external objects. The need to use the Thrust Reverser is most evident in scenarios involving bad weather, where factors such as snow or rain on the track reduces the efficiency of the brakes and in emergencies such as canceled takeoffs.

The amount of generated thrust and power are proportional to the speed of the aircraft, making thrust reverse more efficient at high speeds. For maximum efficiency, it must operate quickly after the landing. Figure 5 shows the percentage of reverse thrust (in % of impulse created) due to engine power (% of power level in rpm) for a target bucket.
Thrust Reverser type. It is important to notice that the higher inversion pulse (at about 60% of the momentum created) is made at the maximum engine power (100%), it is not possible to use all the engine power for braking.

5. Types of Thrust Reversers

Figure 5 – Reverse Thrust due to engine power. [3]

There are five Thrust Reverser systems in common use: Target Bucket, Clam-Shell, Coldstream Pneumatic (Translating Cowl), Coldstream Hydraulic (Pivoting Doors) and Coldstream Electric.

The Target Bucket system uses a set of structures that resemble a bucket which are hydraulically actuated to reverse the flow of hot gas to the exhaust outlet. During normal operation, these ports form a converging-diverging nozzle end to the motor, shown in figure 6.

Figure 6 – Target bucket system (closed and open). [3]

The Clam-Shell system operates pneumatically and is located between the turbine and the exhaust nozzle. When the system is activated, the ports which resemble shells rotate to open and close the conduits normal output, so that the thrust is directed forward. In a turbojet engines, this system is less efficient than the Target Bucket system, since the Clam-Shell system only uses the flow of air from the turbine which is not as hot as the exhaust gases, shown in figure 7.

Figure 7 – Clam-Shell system (closed and open). [3]

In the Coldstream systems, ports in the bypass duct are used to redirect air which is accelerated by the fan section, but does not pass through the combustion chamber (called air bypass) providing reverse thrust. The cold stream system can be activated electrically, pneumatically or hydraulically, shown in figure 8.

Figure 8 – Coldstream system (closed and open). [3]

The cold stream system is known for its structural integrality, practicality and versatility. This system can be heavy and difficult to integrate into nacelles that house large motors. It is this system that is used in aircraft of TAP and will be analyzed. In the case of the CFM56-5B system is hydraulic.

6. TR hydraulically driven (Pivoting Doors)

This is the type of TR that will be used and for which the test bench was developed, shown in figure 9.
Before the system operates, the sensors must verify that all operating conditions are being met and inform the ECU (Electronic Control Unit). If all conditions are verified, the ECU sends a signal to open the SOV (Shut Off Valve). The SOV is a 3/2 valve that provides fluid to the HCU (Hydraulic Control Unit) from the hydraulic system of the aircraft. The electrical power is supplied to the SOV via the electrical power of the fan box.

The opening command / closing of the SOV is provided by logical command aircraft, completely independent of the basic structure of the Thrust Reverser.

The HCU controls the flow of hydraulic fluid and is mounted on the top front of the Thrust Reverser structure right. HCU has the following functions: supply pressure to the hydraulic system (by pressurizing valve) regulating the speed stop of doors pivoting (acting as flow limiter), supplying fluid to the latches (via solenoid directional valve) and fluid supply to the actuators of the pivoting doors (through the directional valve).

During the opening phase, before the actuators are driven, it is necessary that the hydraulic latches are unlocked. This is done through one of the exits from the HCU. There are four locks, one for each pivoting door. The latches hold the doors during closing mode and are located beside the actuators on the front structure of the Thrust Reverser. The latches are unlocked hydraulically, mechanically locked and are connected in series so that the actuators advance only when all of the latches are unlocked.

Once the latches are open, the HCU receives a signal and opens an outlet for the fluid to operate the actuators. There are four hydraulic actuators mounted on the front frame through hinges, one by pivoting door. These hydraulic actuators have four different functions: opening and closing of the door, ensuring a secondary locking in the closed position and ensure that the door rotation speed decreases at the end of the opening phase. The actuator is mechanically locked in the closed position by an inner gripper device.

This action is sufficient to actuate the switch (deploy switch) issuing the alert in the cockpit. The actuators are connected to the pivoting doors. There are two pivoting doors installed on each half of the Thrust Reverser and each rotates about a fixed axis in the following positions: 3h, 9h, the upper structure and lower structure.

When the Thrust Reverser is in open mode, the four revolving doors redirect the air flow forward. As disadvantage, this system is not entirely leak proof.

The top half of each Thrust Reverser has a beam with three joints (hinge beam). The joints connect half of the pylon by hinges. The bottom half of the door is secured with six hinges. In closed mode, each revolving door is locked on the front of the frame to ensure that does not move. When pivoting doors reach the end of the course these moving the lever of the opening switches (deploy switch) that sends a signal to the junction box and the ECU stating that the doors are open.

The door opening position is sensed by two Thrust Reverser deploy switches, one for the two doors on the right side and the other one to the two ports on the left side. They are located between the corresponding ports in beams aimed at 3 h and 9 h. It is a limit switch, which only tells if the door is open or not. Any opening switches are electrically connected in series to ensure that in the event of failure, a door will not be opened.
anymore. The doors only open if the signal is valid in the two switches, namely, the four ports. This information appears in the cockpit through a green light.

In case of closing, the stow switch indicates to the ECU that the pivoting door is closed. It is also a limit switch and, therefore, only tells if the door is closed or not. There are four individual switches on the Thrust Reverser, one per port. These switches are connected in parallel so if there is a failure of a door locking it does not prevent the other doors to close.

The opening and closing switches are dual, meaning that they have two cells (A and B), each dedicated to an ECU channel. It is considered a fail-safe system, in the case of one of the channel fails, the information always comes to the ECU by the other channel.

The electrical junction box of the Thrust Reverser transmits control signals and feedback between the ECU and Thrust Reverser components. It is a prefabricated unit having electrical connections for the connection of the channels "A" and "B" and the ECU

Opening mechanisms serve to maintain the Thrust Reverser doors open for service and repair. When the system is in closed mode, the doors pivoting part of the outer cowl establishes a streamlined outer contour for the air leaving the fan, reducing friction. The inner cowl creates the inner contour for the air leaving the fan and the outside of the motor housing. Both have a structure in honeycomb with insulating surfaces of sound.

7. Test benches

The solution is the development of a test bench based on the Thrust Reversers maintenance manual from Goodrich Company, see figure 10.

The development of the test stand depends on three parts which are interconnected: structure, hydraulic system and electrical system. The test bench should be able to test each half individually. The most common situation that exists in the maintenance workshop is to test one half. This is because the half that is good remains in the airplane and the half which is defective is replaced by another equivalent (the same model TR), while it is being repaired. Then, it may leave the workshop. This solution reduces the time that the aircraft is stopped for maintenance.

The weight of the components of the right half of the TR is heavier than the left half due to the components that constitute and differ from one half to the other: the mass of the right side is 198 kg and the mass of the left side is 186 kg. The test bench must have a free area to allow the movement of technicians to wire the electrical system, hydraulic system and assemble the pieces.

The test bench must allow the mounting of a TR CFM56-5B model, the dimensions of encumbrance are: Length of 2005 mm, Width of 1010 mm, Height of 2100 mm and Pylon width of 530 mm. Furthermore, it should be high enough to allow access by the technicians for the installation of locks on the supports below, see figure 11.
In order to construct a test bench with a reduced cost, it was decided to build it with materials available in the materials warehouse of TAP. The hydraulic fluid used shall be NSA-307-110 Type 4 which is the fluid used in aircraft and advised by Goodrich for the test. The test bench must have enough lightness to be transported by a forklift. During normal operation, the test bench is welded to the floor so that there is no oscillation of the components. Because the TR is a component with high complexity and due to the fact that the manufacturer, Goodrich, do not provide the CAD drawings of the components, a simplified model of the TR was used. Since the aim of the project is the analysis of the structure behavior when subjected to the weight of the TR, a simplified way is the application of the distributed weight along a plate to simulate the TR. The modeling and analysis were done in Solidworks. The connection is made by pins. The pins are made of AISI 321 steel and have a diameter of 12 mm.

It should be taken into account the width of the pylon is 530 mm, that is, the distance between the center of the hole of the hinges on the right side and left side, so that the TR stay firmly seated. The material which was chosen for the construction of the hinges system and the structure of the test bench was AISI 4130 steel. This steel was chosen because of its availability in the TAP material warehouse and because it presents a high yield stress and allows the structure to support the load that is imposed.

When the TR set is mounted on the aircraft, the system latches connect the two halves below. This system consists of a hook on the right side and a locking system on the left side, allowing the TR to hold down to the engine.

In the case of the test bench, it should be noted that each half of the TR should be fitted individually. The solution passes through the replication of the fitting system. In the case of the side that has a hook, the test bench has a docking system and in the side with the locking system, the test bench has a hook. Despite this simple solution one should take into account the offset from the hinge of approximately 115 mm at the top, on each side, since the value of the pylon 530 mm spacing corresponds to the situation in which the bases have no spacing between them.

The latch system is also made of AISI 4130 steel, for the same reasons hinges system. The system also uses 12 mm pins made of steel AISI 321 for the placement of the docking latches are convenient and easy to perform.

8. Development of Hydraulic System

The main purpose of the bench is to test each half separately TR. As mentioned above, the HCU, which is located on the right, controls both sides. The right side is considered the master and the left side is considered the slave. For this reason, the test bench should be adapted to each case: only the right half
(with HCU) and only left half (without HCU).

When it is testing only the right side, the operating mode of the hydraulic system is similar to the assembly due to the presence of the HCU. For this reason, only must make the following changes to the system:

1) Connection of the latches, which are made in series, will not be made to the left side. The two latches on the right are connected to each other and the connection that would be made on the left side is made to the right side, closing the TR hydraulic circuit.

2) No connection is made to the actuators on the left. Under normal conditions, the connection of the actuators is made in parallel to act simultaneously. In this case, only the right side actuators are connected.

3) To test the left side, the solution involves the purchase of individual components that simulate the operation of the HCU. Two distributors valves would be used, one for the latches and one for the actuators, in order to guarantee the proper functioning of the system and safety during the process.

The only disadvantage is that it is a less compact, it would have to make more connections between components. The main advantage is the price, since these simpler components make up more than in a more complex unit.

According to the Goodrich manual hydraulic power unit must: provide a 3000 psi pressure (206 bar) to the system, work with fluid type NSA-307110 Type 4, have a reservoir of 50 L and maximum advance time of 2 s actuators. From this information, one can calculate the remaining system parameters, such as pump volumetric flow rate and power, obtained by:

\[ V_p = A \times v = 6,861 \times 10^{-4} \text{m}^3/\text{s} = 10,9 \text{gpm} \]

\[ P_B = \frac{\rho g H_B V_B}{\eta} = 21,04W \]

The choice of the hydraulic power group was made using companies specializing in hydraulic equipment. Of the several companies contacted, the Movicon control company responded to the contact and suggested a hydraulic power group with the following characteristics: a deposit of 70 L, fixed charge pump: 47 L / min, pressure up to 210 bar and a pump with a three-phase electric motor of 11 kW, shown in figure 12.

![Figure 12 – Hydraulic power unit.][2]

9. Development of the Electrical System

The TR is controlled through a system called ECU, with receives and sends information to and from the TR. The ECU is one of several units of the aircraft that have microprocessors that control the various components. The ECU sends and receives 28 V DC signals via two channels A and B for the TR. The use of an analogue of DC 28V due to historical reasons, because the batteries used for aircraft operated with 28 V DC.

The use of a channel A and a channel B is considered a fail safe system, or these two independent channels receive and accurately emit the same information between the ECU and RT in case one fails, the other one remaining operational.

The test bench must meet the following requirements: work with a 28 V DC voltage, must have an amber light for when the TR is in stow, a green light when the TR is in deploy, a red light (On / Off system, system between stow and}

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[2]: Image of the hydraulic power unit.
deploy, shut-off solenoid valve actuated, deploy solenoid valve actuated, pressure actuated switch, the selected channel), must simulate the right side of the test (with HCU and without TR junction box) and left (without HCU and with TR junction box) and allow the use of independent electric cables.

A simple electrical circuit scheme was developed to control the TR.

Based on the circuit diagram, it is taken as the simplification that only the lamps consume most of the power supplied to the system, since the relays and valves consume very little power compared to the lamps. For this calculation, it is considered the most extreme situation: all lit lamps. This is an extreme case and it will never happen, because taking the example of channel test A: When referring to this channel lamp comes on, the lamp of the channel B must necessarily be deleted.

\[ P = NUI = 8.96 \text{W} \]

In addition to the aforementioned components, the following components must be used: 3 DPST relays: allow direct electric current as the electrical signal sent to the reel, 1 cam switch with two positions: for the test bench test system A or B, depending on the selection of the position, 1 rotary switch with 3 positions: to enable select stow, deploy or off system, plugs to enable connection to the mains terminal equipment with electrical functions and electric cables to connect between components, shown in figure 13.

10. Conclusion

One may conclude the test bench fulfills all the structural, electrical and hydraulic requirements. It is possible to test each side of the TR individually.

All the theoretical calculation process, choice of materials and cost analysis culminated in a viable project and can be continued.

The test bench adds value to the Engine Maintenance Workshop of TAP.

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References

[1] ATA 78, TAP


