Abstract

This Thesis pretends to satisfy the necessity of the aeronautic company Lufthansa Technik AG, based in Hamburg (Germany), to develop the handling of a compact mobile maintenance tool capable of preserving aircraft engines. In order to achieve it we will work both in the development of a new preservation procedure and well as in the systems and tooling that will be required. We expect that this developed procedure and technology will guarantee the correct preservation of the engines according to the current regulations as well as a time and money spare for the company.

After describing the main units of the company business we make a brief explanation about the aircraft engine function with its most relevant parts and components. We aim to get the reader familiarized to the kind of technology studied.

Following we deepen in the engine preservation, main subject of the project. It is explained what is the process about, in which situations should be applied and reasons for its use: avoid corrosion in particular systems and devices of the engine during long periods of inactivity. It is analysed then which is the State of the Art regarding the current preservation procedures of the company. Such analysis pretends to be the foundations where we will develop the new alternative process.

From the study and knowledge about the operation of certain components it has been determined and described the technical characteristics of several tooling that used together allow a new way of preserving aircraft engines. The election of those tooling is backed up by explanations that may vary depending on the operation of the different components of the engine fuel system.

Finally it is described step by step how to proceed with the new procedure as well as it is commented which are its main characteristics.

The obtained result, compared to what until today has been carried out, shows enormous expectations regarding processing time and cost.

Summary

1. Glossary

AGB - Accessory Gearbox

AMM – Aircraft Maintenance Manual

AMOC - Alternate Method of Compliance

APU - Auxiliary Power Unit

BSV – Burner Staging Valve

CFMI - Commercial Fan Motor International: General Electric & SNECMA

CMDS - Component Maintenance Document System

DEU - Display Electronic Unit

EBT – Earnings before Tax

EEC – Electronic Engine Control

EM – Engine Manual

FMV – Fuel Metering Valve

GPU - Ground Power Unit

HMU – Hydromechanical Unit

HPC - High Pressure Compressor

HPSOV – High Pressure Shutoff Valve

HPT - High Pressure Turbine

HPTACC - High Pressure Turbine Active Clearance Control Systems

IDG – Integrated Drive Generator

LHT - Lufthansa Technik AG

LPC - Low Pressure Compressor

LPT - Low Pressure Turbine

LPTACC - Low Pressure Turbine Active Clearance Control Systems

MEC - Main Engine Control

MRO - Maintenance, Repair and Overhaul

PCR – Pressure Control Return

P&W - Pratt and Whitney

TBV - Transient Bleed Valve

TCC - Turbine Case Cooling

TCS - Total Components Support

TES - Total Engine Support

TGB - Transfer Gearbox

TTS - Total Technical Support

VBV – Variable Bleed Valves

VSV – Variable Stator Vane

2. Preface

2.1. Source of the project

At the moment Lufthansa Technik AG carries out the aircraft engine preservation in two ways: the first is directly executed with the engine hanging from the wing and the second one is carried out on the test bed, once the engine has already been repaired and verified. Either of both operations involves an important expense. Lufthansa Technik AG needs to develop a more cost-efficient alternative compared to these two current procedures. Hence a new possibility rises: in certain circumstances the engines could be preserved on a stand thanks to the development of a mobile machine, saving this way time and money.

2.2. Motivation

The writer of the Thesis, student of Industrial Engineering (ETSEIB), has always considered very interesting the world of aeronautics. So during the summer of 2008 the chance was offered to him of doing his Master Thesis in Lufthansa Technik AG Hamburg Headquarters. Because of the prestige and all the possibilities that this offer brings, the student accepted pleasantly. Lufthansa Technik AG is the world market leader in the Maintenance, Repair and Overhaul (MRO) of commercial aircrafts, their engines and components.

2.3. Previous requirements

The student had to become familiar with how an aircraft engine works, given that he previously lacked of this specific knowledge, so he would be able to carry out the Master Thesis. To do so the student worked during a month in the overhaul shop with the mechanics of the company. There he could learn by asking, observing and working what are the components of an aircraft engine and which are their main characteristics and functions. These new concepts acquired at the beginning of the Thesis let the student work more comfortably and be fully informed about the subject. Knowing all components and systems that integrate an aircraft engine is compulsory for a better understanding and development of the tools and procedures which allow performing his preservation.

3. Introduction

3.1. Project objectives

This Thesis pretends to satisfy the necessity of the aeronautic company Lufthansa Technik AG, based in Hamburg (Germany), to optimize the handling of a compact mobile maintenance machine/tool capable of preserving aircraft engines. This preservation is necessary and mandatory to protect engines from corrosion, inlet of foreign objects or external elements and the weather during long periods of storage or inactivity. Currently there are different procedures to carry out this preservation. Usually it is performed directly on the wing or on a test bed. Nevertheless, the idea is to develop a new methodology which allows doing that with the engines fixed on a stand.

Considering simple applications, tools and handling, the machine will be optimized aiming to minimize both operation times and costs, compared to the procedures which at the moment are carried out by the company. It is essential that the new procedure guarantees the correct preservation of the lube and fuel engine systems avoiding that way the corrosion phenomenon.

3.2. Project reach

In the Thesis it is considered a thorough analysis of both the process and the machine required to achieve this preservation. The company's intention is to put into practice a new methodology, aiming to improve this kind of procedures. Machines, tools, materials and components are thoroughly described as well as the normative and guidelines of the process to assure satisfactory results, always according to the current regulations (EM/AMM). The thesis intention does not lie on the particular design of the elements, but in the identification and layout of the whole, according to the new process requirements. The target is to produce a study about the advantages that this new process can provide, as well as confirm that the new procedure preserves all the systems which might suffer from corrosion.

4. Market study

According to the context in which this thesis is developed, it has not been considered necessary to make a market study. The intention of this Thesis is not to design a mass-produce machine/tool. The target is to satisfy a specific need of the company, therefore there is no need of creating a market competitive product.

5. Company introduction

5.1. Lufthansa Technik AG

“Lufthansa Technik AG (LHT)” was founded in 1994 as a German Lufthansa’s subsidiary company, with the purpose to be a first class technical image for the consortium. The headquarters located in Hamburg, represent the LHT consortium’s main facility with nearly 7.000 workers arranged in 750.000 m^2.

Nowadays LHT is one of the world service leaders in aircraft technical maintenance, repair and overhaul. The service spectrum covers from single orders, providing components (Total Components Support, TCS) and aircraft engine advising (Total Engine Support, TES), to the complete supply of the whole aircraft company (Total Technical Support, TTS). In the customer’s list there are around 530 companies apart from other aviation exploiters from around the world **[1]**. They have nearly 30 branches worldwide. For the costumers it has only one meaning: proximity. Currently it is possible to reach adequate personal help in a particular time zone, benefiting also from the Group’s flexibility and quick response times.

Fig. 5.1. “Lufthansa Technik” Group

5.2. Commercial activities

The six business units of LHT attend more than 530 customers worldwide. These units are divided in Maintenance, Overhaul, Engines Services, Components and Logistics, VIP aircrafts and Landing Gear. The four first areas are described as follows:

5.2.1. Maintenance (WF)

"Lufthansa Technik" carries out maintenance tasks for their customers in every important airport in Germany, apart from more than 50 store facilities worldwide, using Maintenance Bases. The main Maintenance Bases of LHT is located in Frankfurt airport with 3.400 workers and it is on service 365 days a year. Then follow Munich with 400, Berlin with 370 and Düsseldorf with 150 **[1]**.

Mechanic and aircraft electronic technicians, supported by nearly 200 aircraft qualified engineers, are responsible for 200.000 take-offs and landings per year. A vast experience, in combination with these professional staff, allows Lufthansa to achieve the top of the list as a maintenance services provider. .

Notice that there is a difference between maintenance and overhaul. In a maintenance check, which is carried out every 15-21 months (C-Check), the plane remains in scheduled service. In the other hand, in the event of the overhaul, which is carried out at intervals of several years (D-Check), the aircraft must be stored for several weeks and can not keep going with the planning service.

5.2.2. Overhaul (WD)

An overhaul work program, also known as D-Check, usually consist in the external aircraft painting, cabin refurbishing, and addition of electrical and mechanical modifications. Landing gear, landing flaps, engines, all electric and electronic instruments and interior fittings are removed always following a scheduled work. Nowadays the commercial aircrafts have to go to the shop for a general overhaul when they have at least been on service for six years, 15 billion miles or flown more than 30.000 hours.

Complete overhauls are carried out from Airbus and Boeing aircrafts at the Hamburg base. Lufthansa Technik has other branches in Shannon, Budapest, Manila and Beijing where aircraft overhauled is carried out too.

5.2.3. Engines (WT)

Taking into account the service sales volume, the WT department is the biggest of all 6 business units. Figure 5.2 shows the sales volume distribution among the different business units.

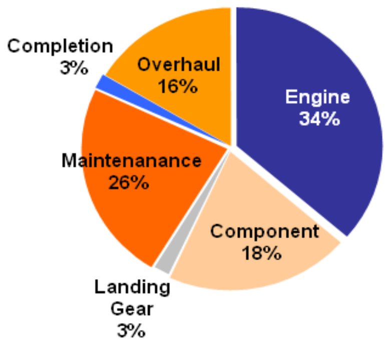

Fig. 5.2. Distribution service sales volume 2008

HAM WT engine department in Hamburg takes care of planning and executing the repair and overhaul processes. Next scheme represents the Engine Business Unit WT organization, duties and competences in Hamburg.

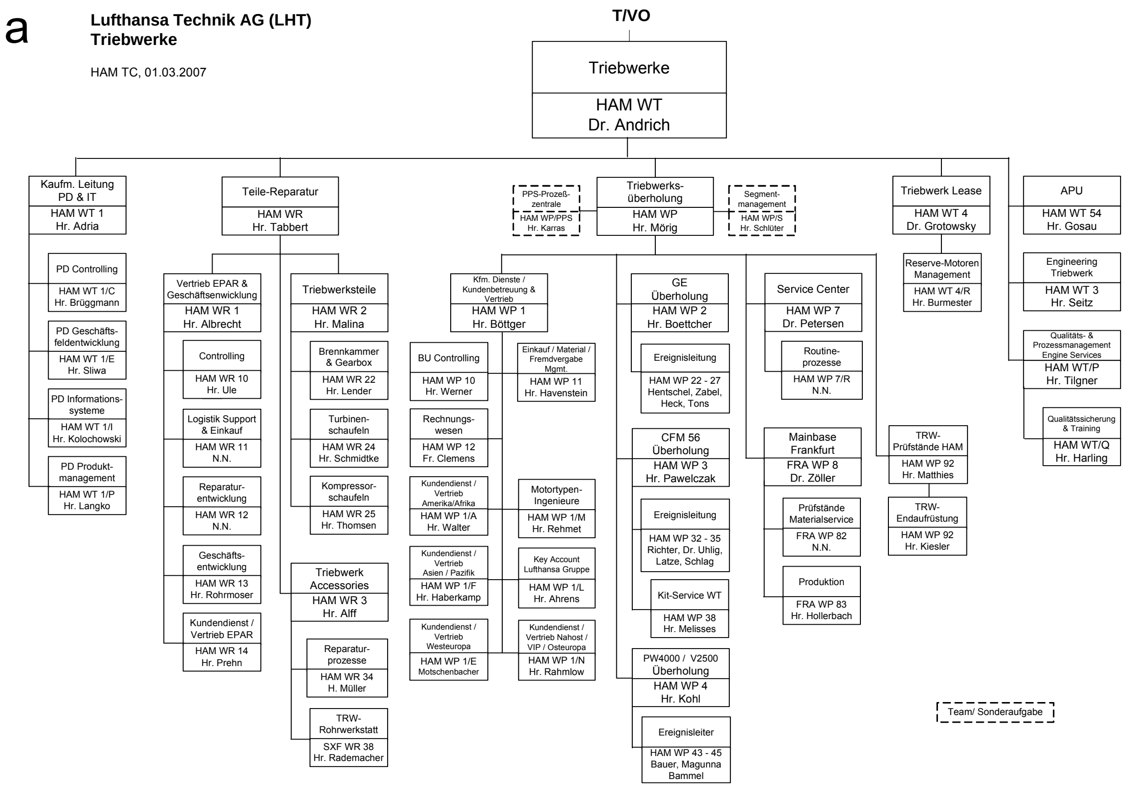

Fig. 5.3. Organization scheme HAM WT

The engine workshop of the Hamburg Base is one of the biggest workshop for commercial aircraft engines overhaul without taking into account the ones located in the USA. However, having vast facilities is not the only reason why 30.000 jet engines have been overhauled at the group. Lufthansa Technik is a repair-development agency and a certified warranty repair station for CFMI, IAE, GE (General Motors), Rolls-Royce and P&W (Pratt and Whitney) engines. This allows the Engine Services Team to develop repair procedures, solving many problems without costly parts replacement. Many times repairing the parts is significantly cheaper than replacing them. That is one of the main reasons why so many costumers trust their planes to the Lufthansa Technik Engine Services.

Supported Engine Types

CFM International:
CFM56-3, CFM56-5A, -5B, -5C, CFM56-7
General Electric:
CF6-50, CF6-80 C2, GE 90
Pratt & Whitney:
PW4000, JT9D, JT9D 7R4
International Aero Engines:
V2500-A5, V2500-D5
Rolls-Royce:
RB 211-524, Trent 500, Trent 700

Fig. 5.4. Supported engine types

In order to keep in the lead on engine overhaul matters, recently LHT inaugurated at the Hamburg base a new engine overhaul centre focused exclusively to CFM56 engines, extending this way their production capability in Germany. Nearly 50 million € have been invested in the new building. Hamburg's annual capability for overhauls will increase from the present 320 to over 400 engines **[1]**.

5.2.4. Components and Logistics (WG)

The WG Business Unit is the responsible of replacement parts supply for both the company and external clients. In the aircraft industry world a lack of replacements could mean great economic losses. Therefore, logistics cannot be considered as the mere transport of a parcel between two points.

The WG Unit will take care of storing the spare part worldwide for its customers as well as determining, planning and coordinating the needed shippings at all times, depending on the customers' needs. The spare parts can be structure components, hydraulic machinery, pneumatic replacements, electronic cockpit components, etc…

With more than 40 years experience in the logistic field, Lufthansa Technik is one of the best repair agencies of commercial aircrafts. This experience is represented in three main points **[1]**:

1- To have the capability to repair all aircraft components.

2- To have an exclusive and precise distribution management.

3- To have a complete inventory and logistical setup to ship components anywhere in the world as soon as possible, without delays.

5.3. Financial figures

The demonstration of Lufthansa's leadership and evolution can be observed in the following table **[1]**. The results are self-speaking:

		2007	2006
Revenue	thousands of euros	3,571,272	3,415,315
Result from operating activities	thousands of euros	312,347	263,306
Earnings before tax (EBT)	thousands of euros	287,473	242,461
Operating result	thousands of euros	292,766	248,039
Investments	thousands of euros	194,030	110,553
Depreciation on assets	thousands of euros	83,180	76,336
Balance sheet total	thousands of euros	2,539,190	2,382,278
Employees (year average)	Average for the year	18,733	18,089
Personnel costs	thousands of euros	992,233	922,031

Fig. 5.5. Financial data Lufthansa Technik

6. Operation Fundamentals of an aircraft engine

In order to familiarize the reader with the sort of technology discussed in this Project, it is convenient to explain roughly the basic principles of an aircraft engine operation, as well as some parts and systems. The components described in the following sections of this chapter are more likely to experience corrosion; therefore these are the ones to study.

6.1. Physical principle of a turbofan engine

Aircrafts thrust in based in the momentum that the engines generate when accelerating great air masses. The impulse $\vec{I}$ is obtained multiplying the mass “m” times the speed “c”:

$$\vec{I} = m \cdot c \qquad \text{(Ec. 6.1)}$$

the units are $[N]$.

The conservation of the momentum, regardless external forces, combined with the Third Law of Newton (action-reaction) explains the jet propulsion. According to this law, to every action force corresponds another equal force with opposite direction. Hence, the air mass that exits the engine with a certain acceleration applies a force of the same magnitude and opposite direction that will push the aircraft forwards. The air mass exits at a higher speed than it enters while the aircraft moves along. Hence, in these circumstances the thrust generated by the turbofan depends on the difference between the exiting and the entering airflow energy.

$$F_t = \dot{m}_L \cdot (c_E - c_0) \qquad \text{(Ec. 6.2)}$$

with F_t: Thrust [N]

$\dot{m}_L$: Airflow $[kg \cdot s^{-1}]$

c_E: Exit airflow’s velocity $[m \cdot s^{-1}]$

c_0: Entry airflow’s velocity $[m \cdot s^{-1}]$

An aircraft engine consists of these main components: fan, low pressure compressor (LPC), high pressure compressor (HPC), combustion chamber, high pressure turbine (HPT) and finally the low pressure turbine (LPT). Figure 6.1 shows the structure of a Pratt & Whitney PW4000 engine.

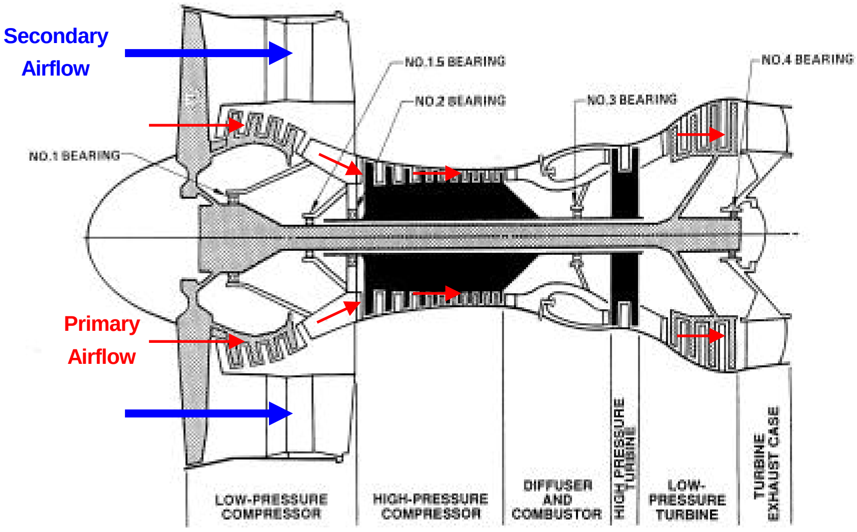

Fig. 6.1. Turbofan engine PW4000

The turbofan engines consist of at least 2 coaxial shafts (n1 and n2) and a first big compressor stage, called fan, which is activated thanks to a particular turbine stage. The fan, the LPC and the LPT have a common shaft, the n1. El n2, designed to spin at very high revolutions, is controlled by the HPC and HPT.

The primary airflow is focused and compressed through the low and high pressure compressor thanks to a series of blades and variable vanes stages. This compressed airflow is then ready to get in to the combustion chamber with the combustible, which is injected through the fuel nozzles. The air and combustible mix combusts generating a series of gases that are expelled via the HPT and the LPT at a great speed. The big energy of these exhaust gases allows the turbine to achieve high revolutions, which are transferred al fan to the fan by the n2. Hence the fan spins at the same rate as the turbine absorbing that way immense air amounts. This great absorbed airflow known as secondary airflow is responsible of generating most of the thrust that allows the aircraft to travel.

Hence we can appreciate that the main advantage of a first fan stage engine is an increase of the volume of absorbed air:

$$F_t = \dot{m}_I \cdot (c_1 - c_0) + \dot{m}_{II} \cdot (c_2 - c_0) \qquad \text{(Ec. 6.3)}$$

with F_t: Thrust [N]

$\dot{m}_I$: Primary airflow $[kg \cdot s^{-1}]$

$\dot{m}_{II}$: Secondary airflow $[kg \cdot s^{-1}]$

c_0: Entry airflow's velocity $[m \cdot s^{-1}]$

c_1: Exhaust gases velocity $[m \cdot s^{-1}]$

c_2: After fun airflow's velocity $[m \cdot s^{-1}]$

6.2. Engine fuel distribution system CFM56-7

Every single component described later belongs to the engine fuel distribution system. They are the ones that are most likely to show corrosion in the overhaul shop visits, and therefore the ones to be studied in this project. In the other hand the components of the engine lubrication system do not show this problem presumably because their conservation process happens to be easier.

Now follows the description of a CFM56-5B/-7 engine fuel system, with its most relevant parts as well. We considered important to adopt a particular kind of engine in order to be used as a general example for the explanations. The reason is that despite there are different engines produced by different companies, the engine fuel system always follows the same working principals, it is constituted by almost the same components, and when not there is normally an analog one with the same role or it has simply another name. In further sections we will refer to those small differences in order to ease reader's comprehension.

6.2.1. Fuel system presentation

The fuel comes from the aircraft and flows through the as follows: Low Pressure pump, IDG Oil cooler, Main Fuel/Oil Heat Exchanger, Fuel Filter, High Pressure Pump, Wash Filter, Hydromechanical Unit, Fuel Flow Transmitter, Fuel Nozzle Filter, Burner Staging Valve, Fuel Nozzles. Figure 6.2 shows the scheme of those components for a better comprehension of the whole path of the fuel through the engine **[2]**:

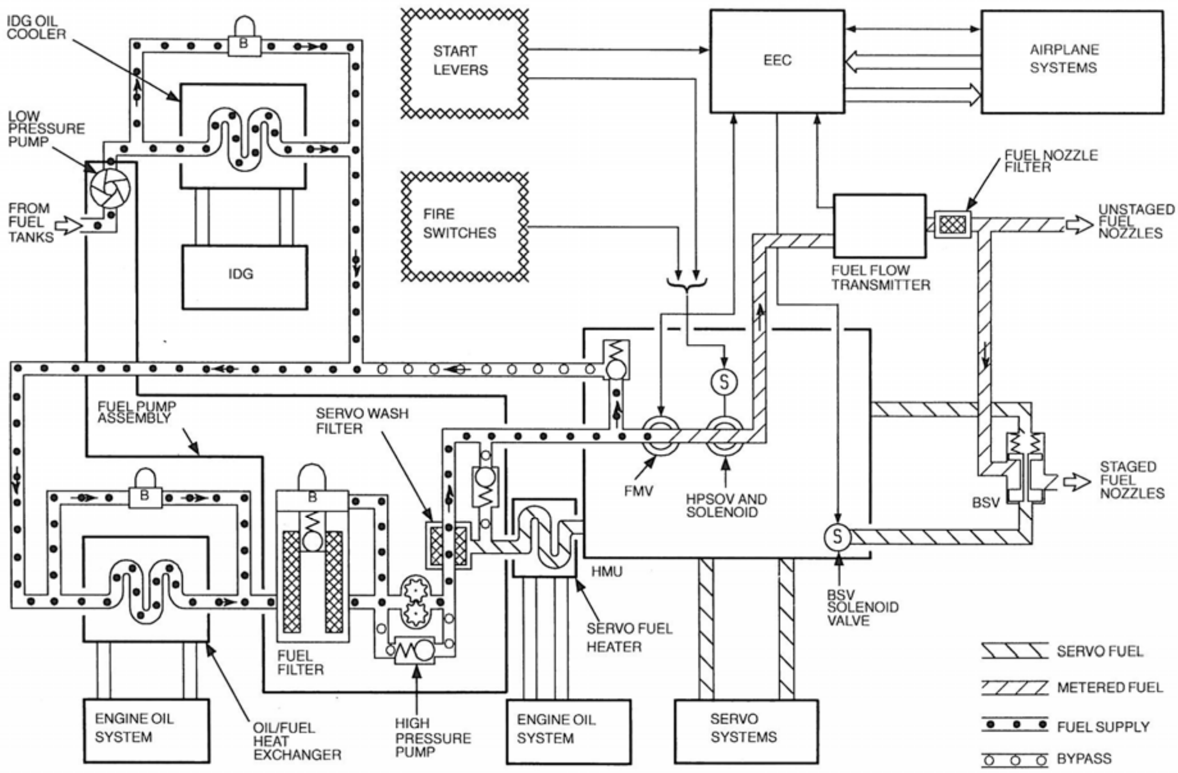

Fig. 6.2. Fuel and Control System Schematic

The excess of fuel travels back through the HMU bypass valve to the Main Fuel/Oil Heat Exchanger. Fuel can go back again from there to the main flow when pushed again by the HP Pump.

6.2.2. Fuel distribution components

- **Fuel Pump:** consists of a low pressure stage and a high pressure stage. Both are activated by the shaft n2 through the Accessory Gearbox. Hence the provided pressure depends completely on the shaft n2 revolutions.

  All the fuel pumped by the HP stage must previously go through the fuel filter inside the pump. The explanation is obvious: the fuel going to the fuel nozzles must be completely filtered with no chips. Also there is a HP Stage Relief Valve within so exit pressure can be limited to a maximum of 1160 PSI.

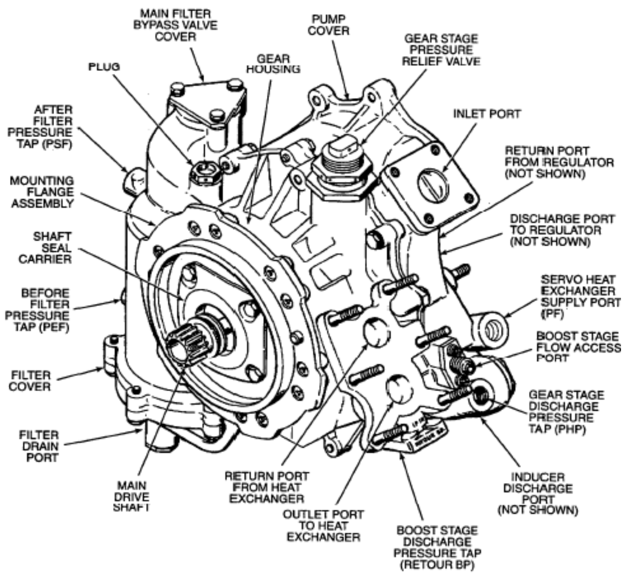

Fig. 6.3. Fuel Pump

- **Hydromechanical Unit (HMU):** it is a machine which calculates and regulates the fuel amount and controls the hydraulic pressure processes as well. The HMU transforms the electric signals coming from the Electronic Engine Control (EEC) into hydraulic control signals, which adjust the position of the Servo Valves through torque motors (see fig. 6.4.). Regarding the fuel regulation, the way it works is considered half electric half hydraulic. Hence the HMU controls the following systems: Fuel Metering valve (FMV), VBV/VSV, HPTACC/LPTACC, TBV and BSV.

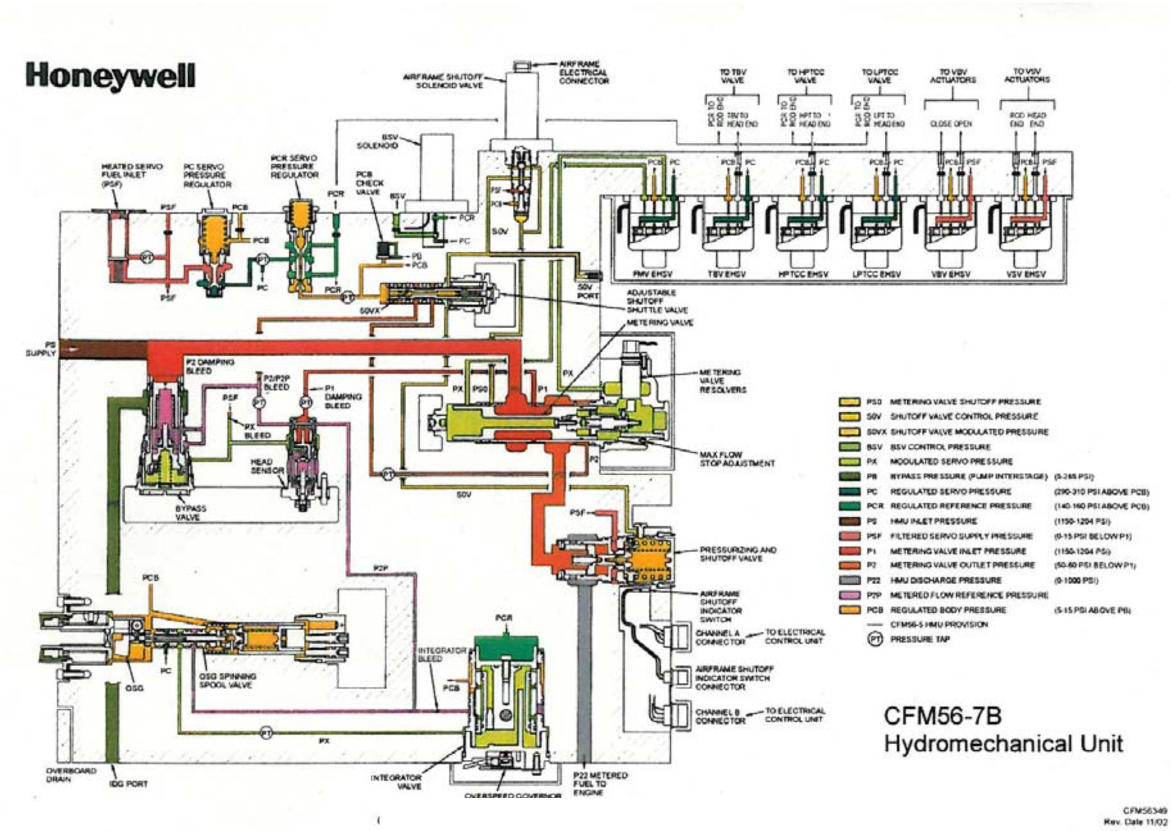

Fig. 6.4. HMU schematic

The metering valve (FMV) controls the rate of fuel flow to the engine for all conditions of operation and the **High Pressure Shutoff Valve (HPSOV)**, which is installed downstream of the FMV, opens and closes to let metered fuel flow to the fuel spray nozzles. This **HPSOV** valve is a hydraulic valve controlled by a solenoid and its functions are:

- To supply sufficient High Pressure fuel for engine start.
- To stop the flow of fuel to the fuel spray nozzles.

Metered fuel from the metering valve flows to the Shutoff valve. The SOV is in the closed position for an initial engine start. As the metered flow pressure increases, it moves the SOV piston (against spring load) and starts to open. Then the HP fuel pressure increases to a level which is sufficient for the operation of the fuel spray nozzles. Then the SOV opens fully.

The ECC is connected through the lane A and lane B receptacles to the torque motor in the SOV servo valve. The EEC can energize the torque motor automatically to cause an engine shutdown. Also the flight crew can operate the Master Lever switch in the cockpit to energize the torque motor and cause an engine shutdown.

When a fuel Shutoff signal is given, the torque motor in the SOV servo valve moves its flapper lever so that the intermediate pressure increases to HP. Then the HP and the springs in the HPSOV move the piston to close the Shutoff valve and at the same time the metering valve piston moves to minimum position.

In the HMU there is also a by-pass, called PCR, within as the fuel pump exit pressure can be limited.

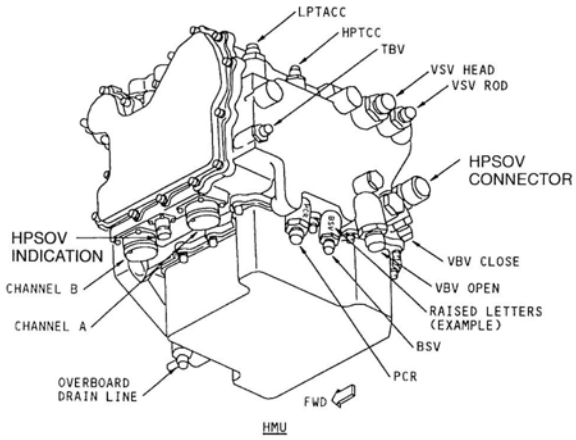

Fig. 6.5. Hydromechanical Unit

- **Variable Bleed Valve System (VBV):** this system lets a part of the low pressure compressor discharge air go to the secondary airflow. The VBV system keeps too unwanted material (such as water or gravel) out of the HPC during the thrust reverser operation in the landing. These actions are carried out with a VBV actuator, which uses HMU servo fuel pressure to move the bleed doors in the necessary position at the precise instant.

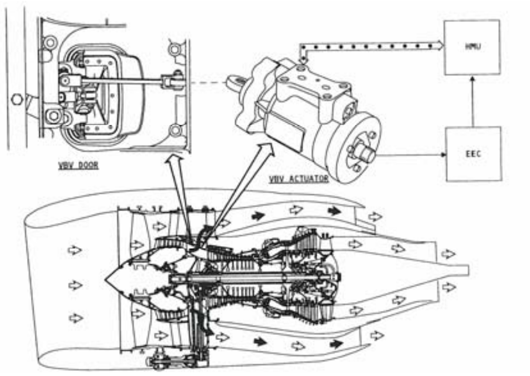

Fig. 6.6. Variable Bleed Valve System Schematic

- **Variable Stator Vane System (VSV):** it is the system in charge of orienting the inlet guide vanes of the HPC. This orientation changes aim to regulate the amount and the direction of the air that circulates through the primary airflow depending on the n2 revolutions. Exactly as in the VBV system, vanes movement happens thanks to actuators (VSV actuators), which uses HMU servo fuel pressure too.

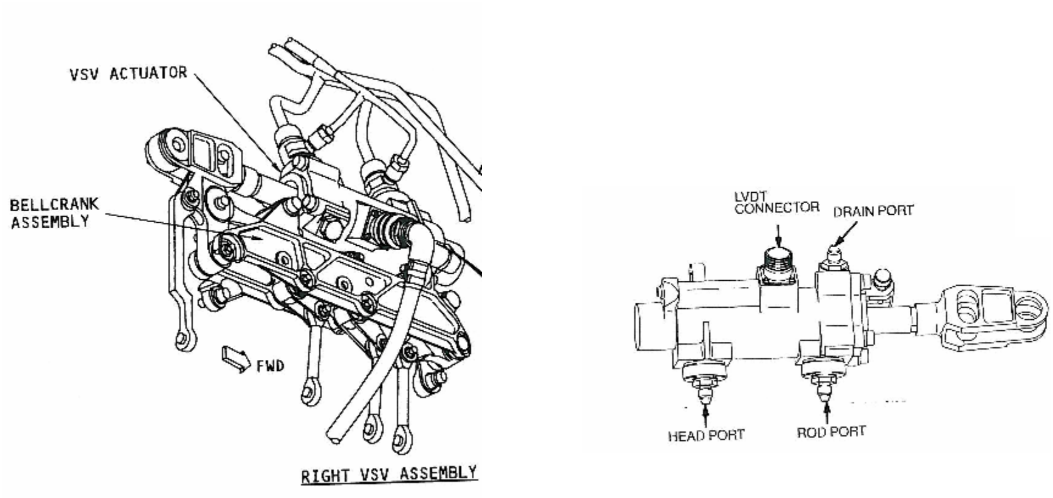

Fig. 6.7. Variable Stator Vane System Schematic

- **Transient Bleed Valve System (TBV):** this system controls the quantity of the HPC 9th stage bleed air goes into the stage 1 LPT nozzles. This process is carried out with the Transient Bleed Valve, which is a butterfly valve that operates with HMU servo fuel pressure actuator. It has two positions: open and closed.

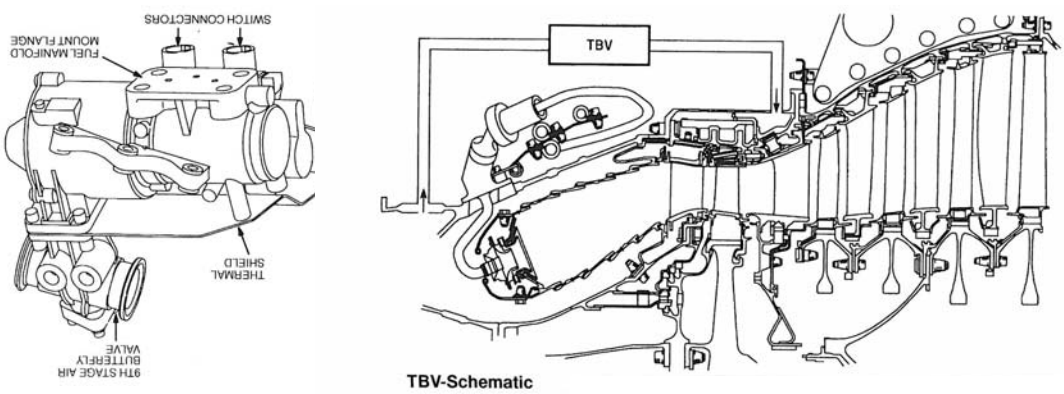

Fig. 6.8. TBV and location.

- **LPTACC and HPTACC systems:** they are systems which cool down LPT and HPT case adequately, whether air coming from the fan or air from cooler stages in the HPC (usually from 4th and 9th although it depends on the model). After the fuel combustion it reaches temperatures beyond 1000 ºC, so it is required to refrigerate both the high and the low turbine. Control of those systems is carried out with several butterfly valves, spread in the engine, which are moved by HMU servo fuel pressure actuators.

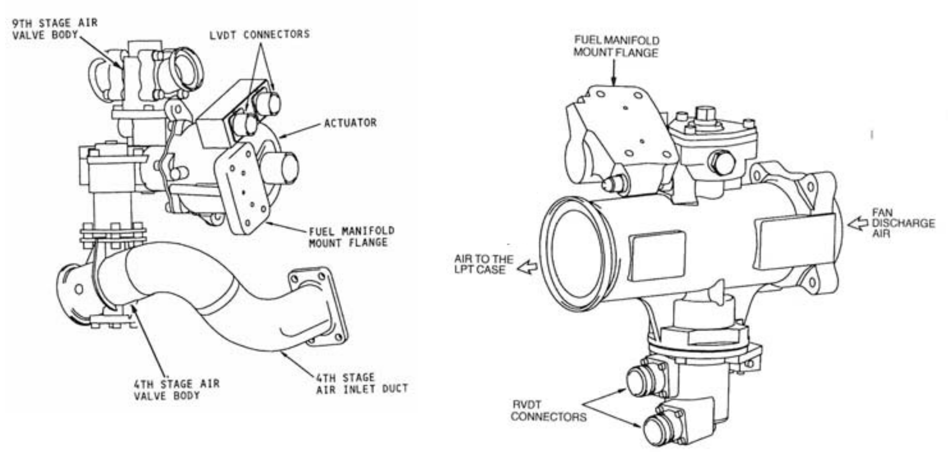

Fig. 6.9. HPTACC and LPTACC systems

- **Fuel flow transmitter:** this machine supplies fuel flow data through the EEC to a computer located in the airplane, the Display Electronics Unit (DEUs). The EECs calculate the fuel flow rate and the DEUs calculate fuel used.

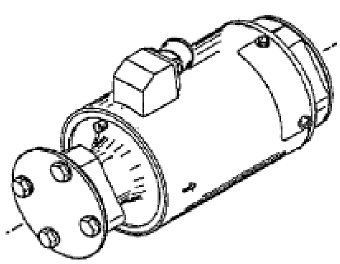

Fig. 6.10. Fuel Flow Transmitter

6.3. Engine fuel distribution analogies with others aircraft engines

Now follows a small table in order to identify the different parts and names which the other engines are constituted **[3], [4], [5]**. Notice that almost all the main function remains the same:

Engine Type	***Part Name***	***CFM56 Part Name***	***Main Function***
PW4000	Fuel Metering Unit	Hydromechanical Unit (HMU)	Remain the same
	Boost stage out (Fuel pump)	LP Pump (Fuel Pump)	Remain the same
	Main stage (Fuel pump)	HP Pump (Fuel Pump)	Remain the same
	Turbine case cooling (TCC)	LPTACC system	Air cooling from the LPC stage to the HPT and LPT case
CF6	Main Engine Control (MEC)	Hydromechanical Unit (HMU)	Remain the same
V2500	Fuel Metering Unit	Hydromechanical Unit (HMU)	Remain the same
	Fuel Flow Meter	Fuel Flow Transmitter	Remain the same
	LPC Bleed Master Actuator	Variable Stator Vane System	Air-bleed from the LPC stage to the fan duct

Figure 6.11. Name differences between engine types

7. Preservation

The preservation is a necessary procedure to protect the aircraft engine against corrosion, liquid and debris entering the engine and atmospheric conditions during period of storage. It is also recommended for installed engines on inoperative aircraft or an engine not to be operated for more than 30 days.

The procedure recommended for preservation of the engine will vary depending upon the duration of inactivity and if the engine is operable or non-operable. Notice that engines which can be started are considered operable and engines that for any reason cannot be started are considered non-operable. The procedure developed in this Thesis will allow preservation of engines in either condition.

In the AMM the preservation procedure is based upon the following schedule **[6]**:

a) Up to 30 days

b) Up to 90 days

c) 30 days to 1 year

d) Indefinite

The preservation procedure schedule in this Thesis will be the third option, “30 days to 1 year”. The reason is that most of the engines which have to visit the overhaul shop remain there during a period of more than 3 months. During this time, the engine must be preserved to assure the correct protection against corrosion.

Engine preservation is a flexible program that should be implemented to satisfy particular weather and storage conditions involved. For example, engines exposed to high humidity and large temperatures changes, especially if it is near a salt water area, requires more attention than those engines stores in drier climates.

It is also very important plan in advance a program to implement the preservation renewal requirements and to monitor regularly to assure that the required action is implemented prior to the expiration of the preservation period. Notice that engines cannot be preserved and placed into storage and forgotten, a viable plan must be defined and then implemented. There is no restriction on the number of times the preservation procedure can be renewed, as long as it is accomplished every year.

Once defined preservation and its characteristics next we explain and give examples of possible consequences in case they are not applied, or what is the same, the formation of corrosion.

7.1. Corrosion

Corrosion means the breaking down of essential properties in a material due to chemical reactions with its surroundings. In the most common use of the word, this means a loss of electrons of metals reacting with water and oxygen. Most structural alloys corrode merely from exposure to moisture in the air. Corrosion can be concentrated locally to form a pit or crack, or it can extend across a wide area to produce general deterioration **[7]**.

According to the definition of corrosion and the encouraging factors, it can be established that a performing engine eliminates itself both internal and external humidity in some level, thanks to the combustion heat. In the other hand, the lubrication oil that circulates through the engine creates a protective layer over the surface of the lubrication system components.

Therefore as soon as an engine ceases activity those protections against corrosion, inherent to its activity, disappear and preservation becomes an alternative.

The principle of preservation consists in forcing circulation of corrosion preventive oil through the fuel and lubrication systems, so they create a protective layer against corrosion as they flow **[8]**. These preventive substances come from petroleum and create a layer similar to wax over the metal. There are several kinds depending on the different specifications, so they adapt to the different needs of aviation. Despite those preventive substances act as humidity isolators they cannot cope with excessive levels of humidity and will eventually decompose so corrosion would start. They could also end up dry because the oil base might evaporate gradually. This allows humidity to contact the metal and encourage corrosion. Hence when an engine is stored in an envelope or container some kind of dehydrating agent must be used (desiccant bags) so humidity can be removed from the air surrounding the engine.

The appearance of corrosion causes for example that: valves cannot open or close, actuators remain still or they do not move properly, small particles of the parts are released and end up flowing with the fuel until the fuel nozzles...

So to finish with the explanation and in order to justify the importance of engine preservation it is adequate to illustrate a few examples of corrosion in some fuel system parts. In Figs.7.1, 7.2, 7.3 and 7.4 it can be appreciated the appearance of HMU parts that have not been preserved correctly:

Figure 7.1. Corrosion's HMU part

Figure 7.2. Corrosion's HMU shaft

Figure 7.3. Corrosion's HMU port

Figure 7.4. Corrosion's HMU valve

7.2. Procedure engine on wing (AMM)

Once explained corrosion phenomenon and defined preservation as a way to avoid it, we pretend to thoroughly describe the operation in order to achieve it

In this section the preservation procedure is explained according to the Aircraft Maintenance Manual (AMM), which is with the engine on wing. This is one of the two procedures that currently are carried out to preserve the engines.

This is the procedure used to preserve the CFM engines. As in the previous chapter, we took as example a CFM engine. All engines regardless the manufacturers have a very similar process. We are interested in the general concept and not the small details of particular models. Operation related with oil system preservation will be omitted for already explained reasons.

This preservation procedure must be applied prior to an engine return to shop **[6]**:

1. First of all disconnect the fuel pump inlet tube (see fig. 6.3.) and let the fuel drain into a container.

2. Install a temporary line to the fuel pump inlet tube. This line will supply fuel system corrosion preventive oil from the “oil pressurized servicing cart” to the fuel pump, at 50 psi (344738 Pa) maximum pressure. See figure 7.5..

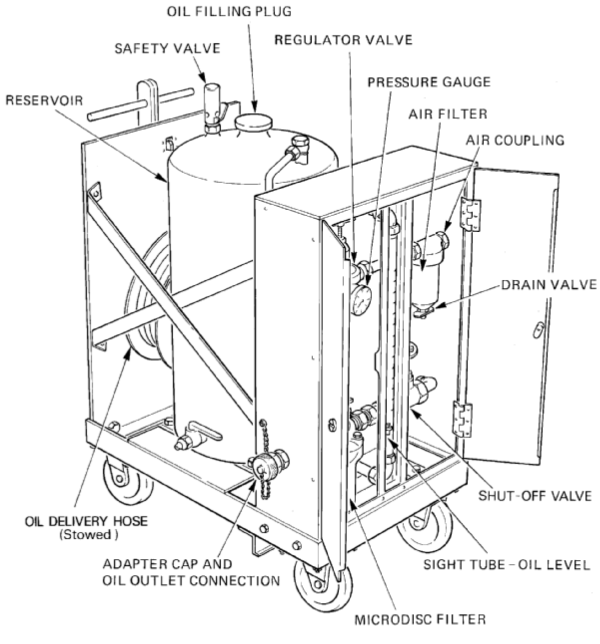

Figure 7.5. Oil pressurized servicing cart

3. Then disconnect the line from the Pressure Control Return (PCR) port on the HMU.
4. Install a temporary hose drain line from the HMU PCR port and put the hose to drain in a container.
5. Start the “oil pressurized servicing cart” to supply the fuel pump inlet (the oil is necessary to lubricate the fuel pump and the HMU to prevent damage).
6. Do a dry motoring check for 30 seconds. This dry motoring check is a task which makes sure that the engine will turn freely and the instruments operate correctly. It is also carried out to dry the remaining fuel that can collect in the combustion chamber or the lower section of the turbine casing.
7. Stop to motor the engine and let it to coast down. It is necessary continue introducing the preservation fluid under a low pressure when the dry motoring is finished and make sure that the preservation fluid fills correctly the fuel circuit.
8. Stop the “oil servicing cart” to cut off the preservation fluid at the fuel pump inlet.
9. Remove the temporary drain line from the Pressure Control Return port on the HMU and reconnect the PCR line to the PCR port.
10. Do again a dry motoring check for 30 seconds. After this dry motoring, the preservation fluid fills the fuel circuit up to the HPSOV (see fig. 6.2.).
11. Do a wet motoring for 5 seconds or until the sprayed preservation fluid comes out of the engine exhaust nozzle as a spray. This job is necessary for maintenance check where you must turn the engine and have fuel flow without ignition. This motoring opens the HPSOV and let the preservation fluid to exit the rear of the engine through the fuel spray nozzles (see fig 6.2.). Move the Master Lever to OFF and do the engine motoring for 60 seconds.
12. Stop to motor the engine. Permit the engine to coast down.
13. Remove the temporary oil supply line from the fuel pump inlet tube.
14. Assure that the VBV (see fig 6.6.) doors are closed.
15. Install “vapor barrier film” on all open areas. Install caps or plugs on all open engine areas, such as pipes and accessory pads.
16. Put desiccant on either sides of the engine.
17. Put a waterproof shipping cover on the engine to cover full engine.

18. Finally put a tag on the engine to show that the engine is under preservation.

7.2.1. Procedure characteristics

I would like to point out some aspects of the whole process. In this preservation the fuel system will be fully preserved. However it is achieved without starting the engine so it is a process without ignition. The dry and wet motoring are carried out with a ground power plant which supplies a high-pressured airflow to turn the n2 shaft. Another characteristic of this process is the use of an oil pressurized servicing cart to provide the engine preventive oil with the required pressure. Despite the engine is “on wing” the preventive oil supply will not be done using the airplane wing pumps.

I would like to place emphasis on how important is the fact of allowing the opening of the FMV and HPSOV and let the preservation fluid to exit the rear of the engine through the fuel spray nozzles. It is fundamental to open that servo valves to let the preservation fluid to flow through the components (see fig 6.2.). The electric signals that allow this HMU valves regulation come directly from the EEC and are sent from the cockpit (Master Lever), so in this case the signals are generated directly from the airplane. In the new process that we achieve to develop, electric signals that allow the valves to open will not be sent from the airplane, so we must find another way.

Finally, the great disadvantage of this process lays on the need of its performance with the engine on the airplane wing. Direct consequence of this is that the whole plane must stay on the ground for about 14 hours until the process is complete and the engines are replaced with new ones. Nowadays it is not allowed to preserve engines inside a hangar because Environment Authorities consider that the gases that come out of the engine exhaust nozzle as a spray are health threatening for the workers (toxic) and flammable. Therefore the plane has to be placed on a save spot outside, in a well ventilated area, in order to perform this operation and then return back to the hangar, increasing the operation time.

In the aeronautic world, a plane is producing when it is flying, hence anything that stops that means loss of profit for the company. Lots of time would be saved if they only replaced the engines before preserving first the old ones. If preservation was done on a stand, the plane could retake its activity without having to wait for the current engines to be preserved.

7.3. Procedure engine in test bed (EM)

7.3.1. Engine Manual preservation procedure

This is the alternative to preserve engines, in the test bed. In this situation the engine is already removed from the aircraft, which will require to do the preservation according to the engine manual (EM) instead of the AMM as it was in the previous situation.

In the EM there is a procedure where the actions to be taken to preserve a removed engine are explained. This procedure has been used until a few years ago. Afterwards a new technology was developed (AMOC) which allowed to carry out the procedure on a test bed in another way.

The procedure previously used is **[9]**:

1. Install a temporary line to the fuel pump. The line will supply fuel system corrosion preventive oil at 50 psig (344738 Pa) maxim pressure.
2. Disconnect the line from the PCR port on the HMU.
3. Install a temporary drain line from the PCR port to a container.
4. Motor the engine as follows:
    a. Let the engine be stable at the maximum motoring rpm and monitor these items making sure that:
        i. There is a positive indication of oil pressure (the oil is necessary to lubricate the fuel pump and the HMU to prevent damage).
        ii. N2 indication is approximately 4000rpm.
        iii. The VSV are closed.
        iv. The VBV are open.
        v. There is no leakage from the oil system tubes or components
    b. Make sure there is an indication of fuel flow as follows:
        i. Set the Master Lever to ON for a maximum 15 seconds.
        ii. Monitor the fuel flow indicator for a positive indication.

iii. Set the Master Lever OFF (then the fuel flow indication must decrease to 0).

c. Continue to dry-motor the engine for 60 seconds to remove the fuel from the combustor.

d. Stop motoring the engine and permit it to coast down.

5. Remove the temporary drain line from the PCR port on the HMU.

6. Motor the engine to 20% N2. Move the Master Lever to ON for 5 seconds. Move the Master Lever to OFF and motor for 60 seconds. Then stop the motoring and permit the engine to coast down.

7. Remove the temporary oil supply line from the fuel pump inlet. Install a cap or cover on the fuel inlet to the pump.

8. Install a “vapor barrier film” on all open areas. Install caps or plugs on all open engine areas, such as pipes and accessory pads.

9. Put desiccant on either sides of the engine.

10. Put a waterproof shipping cover on the engine to cover full engine.

11. Finally put a tag on the engine to show that the engine is under preservation.

We considered convenient to indicate which was the previous process because of two reasons: First because it is the foundation where the new used technology is based (AMOC). Despite this new modern process is quite different to the previous one, it had to comply with the requirements and to obtain the results established by the EM in order to achieve a correct preservation. Second because it is the procedure established in the EM that helped the author of this thesis to develop the system to preserve the engines in shipping stands. The current way of working on the test bed is quite different to the one that we aim to develop, but in the other hand, the one explained in the EM shows steps that are useful as guidance for the shipping storage procedure.

7.3.2. Alternate Method of Compliance (AMOC)

Currently the process used by Lufthansa Technick AG to preserve an engine on the test bed (fig. 7.6.) has been simplified thanks to the development and use of a preservation tooling that consists on pumps and lines. This system, known as Alternate Method of Compliance (AMOC) aims to provide the engine with preventive oil through a temporary line connected into the fuel feed port.

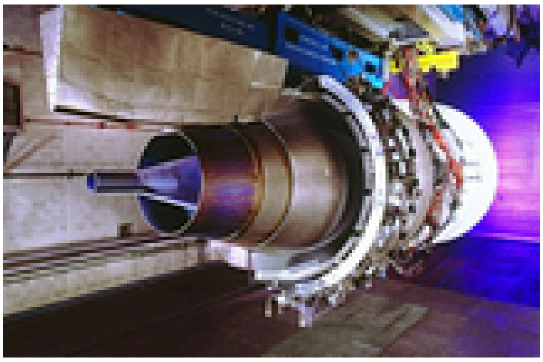

Figure 7.6. Test Bed

This preservation tooling is divided in two parts: one located in the set up shop and the other in the test bed. However they belong to the same system. In the set up shop there is a suction tube connected to a barrel (with preventive oil) and a pressure control pump, regulated with variable by-passes, which has two 100 micrometer filters, before and after the pump. The system continues inside the test bed, where it is located the main fuel line with an anti-return valve and a magnetic valve, which is connected into the fuel feed port.

Apart of this tooling to pump “preventive oil”, in the side of the test bed is installed a fuel line, with a magnetic valve too, to supply fuel. Both this line and the preservation oil line can be connected or disconnected into the fuel feed port of the engine thanks to a commutation device.

As we explained previously, the principle of preservation lays on forcing the circulation of corrosion preventive oil through the fuel system, in order to produce a protective layer in on the components against corrosion as it flows. In this case we achieve this using the preventive oil as combustible while the engine is on.

At the beginning of the procedure, the magnetic valve of the preservation tooling is closed. In the other hand the fuel line magnetic valve is open and allows filling fuel into the engine to start it. With the engine in idle condition (working with fuel) the magnetic valve of the fuel line is close from the measurable room at the same time that the magnetic valve of the preservation tooling is opened. From that moment on the engine keeps on working for about 40 seconds in idle condition using the preventive oil as combustible. The required pressure from the oil (25 psi ≈ 172369 Pa) is achieved via a electric pump that works at 220/380V, which spins at 1390 rev/min. The preservation fluid is contained in the setup room in a barrel ready for use and shows combustion characteristics very similar to the usual fuel. During this whole process there is no need of interrupting the engine activity anytime. After 40 seconds the engine is switched off, letting it stop spinning on its own.

7.3.3. Procedure characteristics (AMOC)

In this preservation the fuel system will be fully preserved too like in the AMM, however it is achieved with starting the engine, with ignition.

Another characteristic is that the preventive oil provision’s is carried out with a fixed pump and lines system in the test bed instead with a pressurized servicing cart.

The opening of the FMV and HPSOV is controlled via the measure room. From there it can simulate and send exactly the same electric signals as you would send from an aircraft, so through the EEC all components can be controlled as well as the servo valves.

One of the greatest disadvantages of this process lays on the need of its performance with the engine in the test bed. Usually this kind of facilities is used to check that the engines leaving the overhaul shop are working properly, not to carry out preservations. This way Lufthansa Technik guarantees that the engines have been checked up correctly and that they are fit to go back in service after being thoroughly tested.

Problem appears when we pretend to carry out a preservation on the test bed, because it is necessary to configure and adjust all the AMOC systems depending on the engine model. All this setup requires time and generally forces to reset the setup after the previous configuration to carry on with the check tasks already planned. Hence when an engine has to be preserved sporadically on the test bed, the work chain planned to test the engines is strongly affected, which generates delays in the delivery of the engines to the customers.

8. Shipping stand preservation

So far we have described what corrosion is and witches are the two processes that Lufthansa Technik AG performs in order to avoid it. The intention of explaining and providing detail about both processes lays not only on the knowledge about the current State of the Art of the reader but also on the fact that those processes constitute the foundations in order to develop the new process to preserve engines in a shipping stand. The study of both processes allowed the student to acquire interesting concepts about the engine preservation, which later on were useful as a base to develop altogether with the engineers and mechanics at the Lufthansa Hamburg Base a new preservation procedure.

During this study it was observed that there are some irreplaceable elements such as: a corrosion engine preventive oil supply unit or tooling (max ≈ 345 KPa) with temporary lines, electric signals that allow the FMV and HPSOV regulation and the way to motor the engine (with or without ignition).

8.1. Engine preservation unit

As discussed previously it was noticed that the way that the preventive oil was supposed to be provided in order to preserve the engines had to be chosen. Since the preservation process is expected to be carried out in the workshop it is required to have available a mobile oil provider that allows placing it close to the shipping stand of the engine to be preserved.

During the development of the new preservation procedure, we considered as a good solution to have a engine preservation unit. Based on the already used oil servicing cart we designed a similar mobile tooling to supply corrosion preventive oil wherever it might be needed.

8.1.1. Engine preservation unit technical characteristics

The engine preservation unit consists on some basic elements such as: a deposit to store the preventive oil, a pump with its hydraulic circuit and a wheeled metallic structure where we attach all those parts.

Regarding the deposit, it was considered enough with a 60 litres one to content the well-known corrosion preventive oil.

In the other hand, regarding the kind of pump to be used, we chose a compressed-air-powered double-diaphragm. It is a kind of diaphragm pump where the movement of its parts is caused by the action of the compressed air provided by a compressor. The pressure increase happens due to the push of certain membranes that modify the volume of the chamber increasing and decreasing it alternatively. The liquid moves from the less-pressured area to the more-pressured one **[10]**.

One of the advantages is a very simple, fast and easy-to-replace-components maintenance. Due to the resistance to corrosion of those pumps and since there is no need to fill the vacuum column with liquid in order to make them work, these components are very popular in industry to move almost all kind of liquids like acids, petrol derivates, paints, etc...

This kind of pump is perfect to be used at the workshop since we have air compressors available designed to perform several overhaul tasks with the adequate pressure. This way the engine preventive oil pump could be used without requiring a specific electrical supply.

To assure the correct work of the pump it was required to design a simple hydraulic system with a primary line, a secondary or drain line and a pressure system for the pump. Next figure shows the pump pressure system:

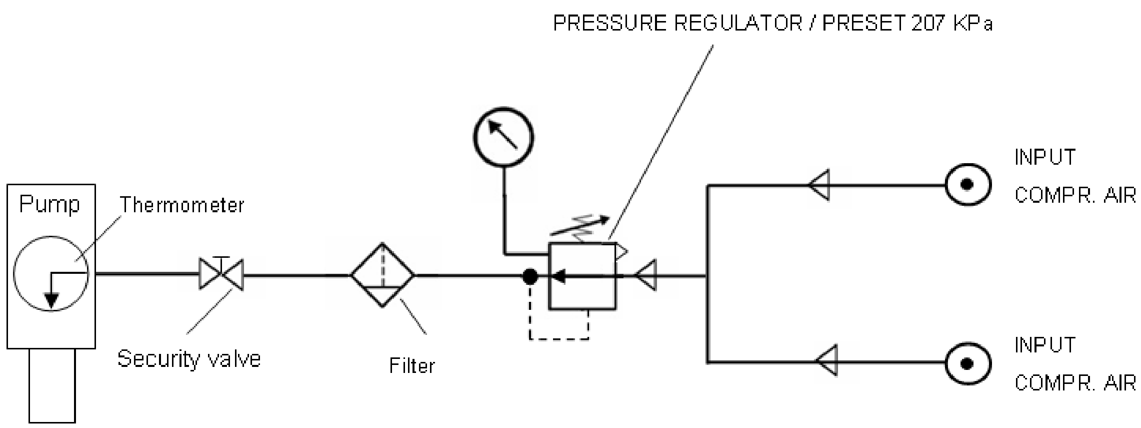

Figure 8.1. Air pressure feed system schematic

Concerning the primary line, it has a manometer to visualize the fluid pressure, a thermometer to check the oil temperature, a pressure relief, an oil filter, a two-positions valve (1.- return to tank or 2.- preservation) and a security valve. The schematic representation would be as follows:

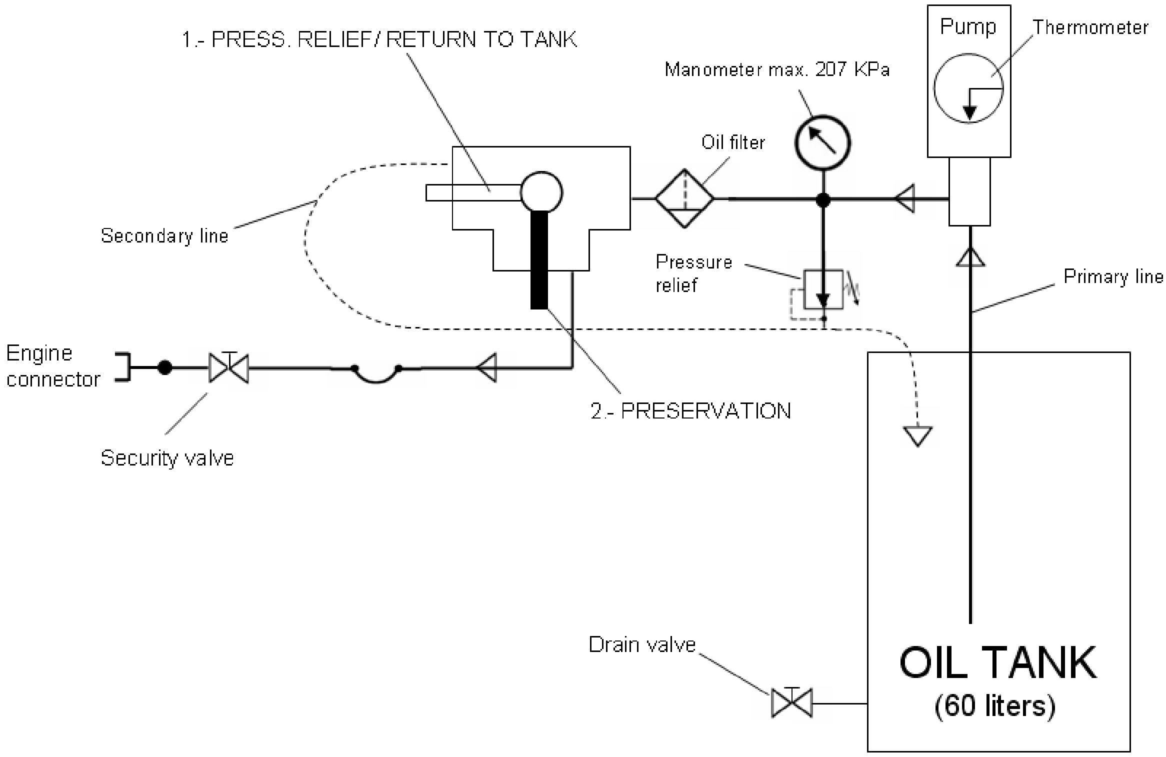

Figure 8.2. Hydraulic system schematic

Finally the characteristics of the metallic structure to hold all those components are pretty simple for their design is not really relevant. It consists on a flat base of 1x1 m^2 with four little wheels where the oil tank would be placed. Using screwed fixations and welding the hydraulic system could be installed directly over the superior surface of the oil tank so we can use the side surfaces to hold other elements such as the air compressed and oil hoses.

Regarding the connection between the engine preservation unit and the engine, it will be carried out directly in the fuel inlet hose in order to supply the preventive oil through the fuel pump. As it has been verified in the preservation procedures described along this thesis this is the way the connection has to be done to supply the engine with oil. Therefore the engine connector of the preventive unit (see fig. 8.2) will be plugged directly to the fuel inlet hose. Depending on the situation, the connection can be done at the very beginning of the fuel inlet hose or else in a point closer to the fuel pump. The following pictures both possible connection options are shown:

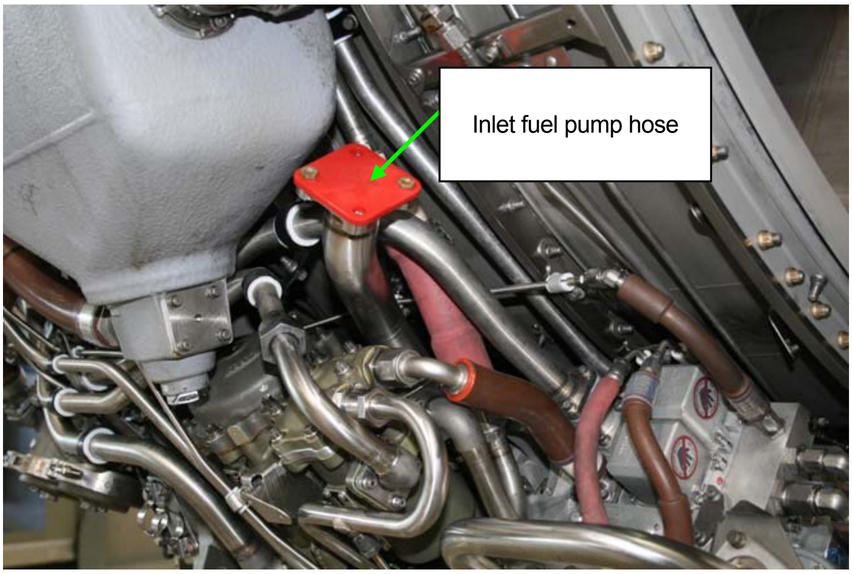

Fig. 8.3. Possible inlet fuel connection point CFM56-5A

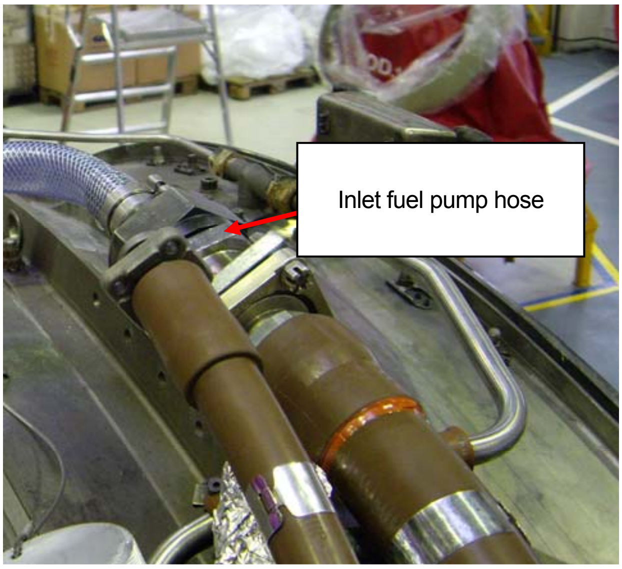

Fig. 8.4. Possible inlet fuel connection point CFM56-5A

In the other hand to avoid the preventive oil from reaching the fuel nozzles we expect to disconnect the main fuel hose just after the fuel flow transmitter (see fig 6.2). Once disconnected we expect to connect a temporary drain line to a suitable container to let drain the preventive oil (see fig 8.5):

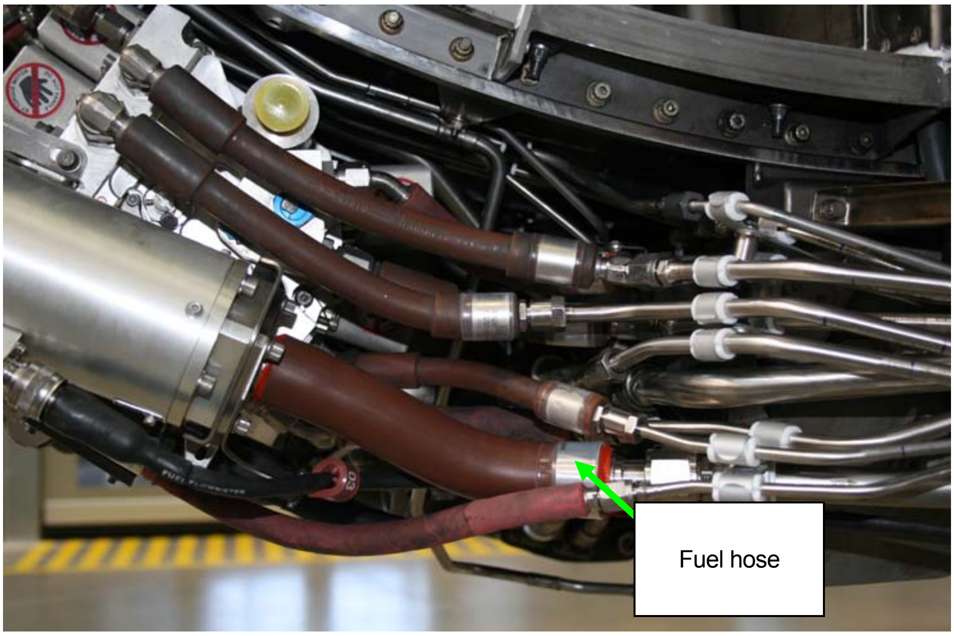

Fig. 8.5. Fuel hose disconnection point CFM56-5A

8.2. Electric motor

The need of the preservation on a shipping stand inside the workshop implies that the new process carries out the preservation without ignition and without coming out any gases of the engine exhaust nozzle as a spray for they are toxic. Hence, if motoring is required, we will need to have some kind of machine that manages to spin the n2 but without ignition.

Currently it is being used the ground power unit (GPU) or the auxiliary power unit (APU) to do this kind of motoring. The GPU is a big mobile tooling able to provide a great airflow at high pressure while the APU is an air-pressure generator placed at the back of the aircraft used normally to start the engine. Those high-pressured air masses are conducted through a line until the starter which starts turning with these airflows. This fan, called starter, has a shaft directly connected to the accessory gear box (see fig. 8.6.) which transfers its rotation to for example the fuel pump, the HMU and the n2 shaft among other components.

Initially it was considered to keep the use of a GPU, used until now in any preservation carried out with the engine on wing (AAM). However, due to the great dimensions that this tooling presents an alternative was required. Since the objective of the GPU is to transmit a certain r.p.m. to elements such as the fuel pump, the HMU and the n2 through the accessory and transfer gearbox (see fig. 8.6.), an electric motor was thought to be able to perform the same task.

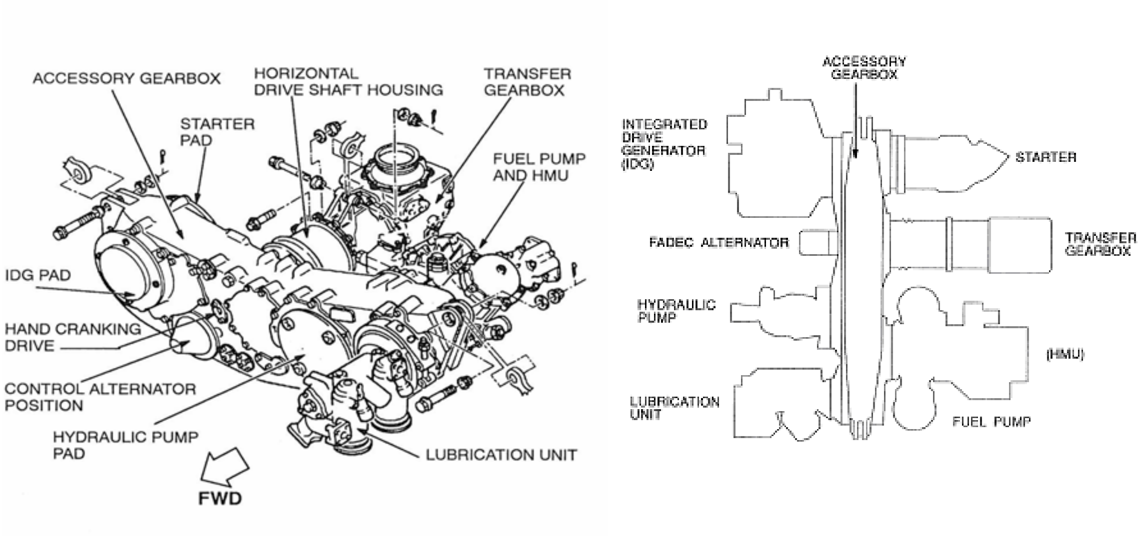

Figure 8.6. View of AGB arrangement of the accessories CFM56-5A

The process would consist in connecting, using adapters (mechanized parts), the spin axis of the electromotor to the accessory gearbox, performing the transmission through the starter port (see fig 8.7. and 8.8.). This way and helped by a motor controller the electric motor would start and the rpm would increase slowly.

Fig. 8.7. Starter pad front view CFM56-5A

Fig. 8.8. Starter pad side view CFM56-5A

Depending on the pumping pressure desired for the fuel pump to move the preventive oil through the fuel components, a particular level of rpm will be required in the accessory gearbox transmission. Hence we need keep in mind which is the transmission ratio between the accessory gearbox and the fuel pump.

The gear ratio is the relationship between the number of teeth "z" on two gears that are meshed:

$$\frac{\omega_s}{\omega_{fp}} = \frac{-z_{fp}}{z_s} \qquad \text{(Ec. 8.1)}$$

ω_s : Entry angular velocity $[rpm]$

ω_{fp} : Exit angular velocity $[rpm]$

z_s : Teeth number entry gear

z_{fp} : Teeth number exit gear

- The minus sign represents the inversion of the rotation way.

From this expression it can be easily calculated the transmission ratio between the starter and the fuel pump. We only need to know the number of teeth on each gear (fig. 8.9.) **[2]**:

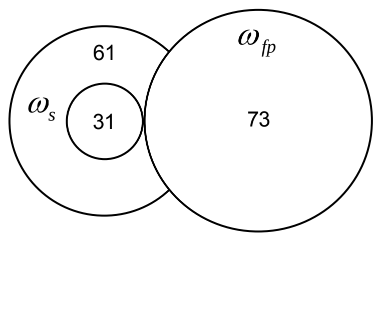

Figure 8.9. Teeth number gears schematic CFM56-3

$$\frac{\omega_s}{\omega_{fp}} = \frac{-z_{fp}}{z_s} \longrightarrow \omega_{fp} = -\omega_s \times \frac{z_s}{z_{fp}} \longrightarrow \boxed{\omega_{fp} = -\omega_s \times \frac{31}{73}}$$

With the transmission ratio (1:0,42) we only have to find the minimum amount of revolutions that the fuel pump needs to spin so the adequate pressure can be achieved in order to successfully carry out the new procedure.

8.2.1. Fuel pump calibration

As explained at section “6.2.2 Fuel distribution components” the HPSOV has several functional characteristics that demand a specific pressure in order to open it.

According to data from the Argo-Tech company, which is in charge of the production of the fuel pump for the aircraft engines CFM56, the minimum sufficient pressure to open de HPSOV for the operation of the fuel spray nozzles is **[11]**:

Table 104. Fuel Pump Calibration

Para-graph	Shaft Speed rpm	Discharge Pressure psig or (kPa gage) Required	Actual	Discharge Flow gpm or (phr) or [l/min] Required	Actual	Filter Inlet Pressure psig or (kPa gage)	Filter Outlet Pressure psig or (kPa gage)	Heat Exchanger Pressure Drop psid or (kPa)	Bypass Flow gpm or (phr) or [l/min]	Boost Stage Discharge Pressure psig or (kPa gage) Req	Act
9E(1)	625 ±10	305 ±5 (2103 ±34.5)		5.0 min (1689) [16.72]					0.0		
9E(2)	3850 ±25	500 ±5 (2896 ±34.5)							0.0		
9E(3)	6250 ±30	420 ±5 (2896 ±34.5)		68.0 max (22.656) [223.3]					0.0		
9E(4)	6250 ±30	1145 ±10 (6895 ±69)		59.0 min (16.896) [166.6]					0.0		
9E(5)	6250 ±30	1075 ±5 (5895 ±34.5)		36.8 ±0.5 (10.560 ±192) [104.1 ±1.9]						(NOTE 4)	

9F Seal drain leakage
Collected fluid volume:__________cm³
Elapsed sampling time:__________minutes
Average leakage rate:__________cm³/min (0.1 cm³/min maximum)
Other external leakage:__________pass __________fail
(No other visually discernable leakage permitted)

NOTE: 1. At the beginning of each test run, set inlet pressure to 30 ±5 psig (207 ±34 kPa gage) before starting pump. Accelerate pump from 0 to 3000 RPM within 20 to 30 seconds with pump discharge valve wide open, then complete speed-pressure schedule.
2. Pump inlet pressure 29 ±2 psig (200 ±14 kPa gage).
3. Pump inlet temperature 80° ±20°F (27° ±11.1°C).
4. Calculate boost stage pressure rise by subtracting pump inlet pressure from actual boost stage discharge pressure [114 psid (786 kPa) minimum].

Figure 8.10. Fuel pump calibration CFM56- 5B, -5C

At the table it can be appreciated that the minimum required pressure is about 2100 KPa and that it is achieved with a shaft speed of around 625 rpm. So we already know the revolutions that we must spin the fuel pump to achieve the sufficient pressure in order to open the HPSOV. The attached table gives us also some other interesting details such as the inlet fuel pump pressure (207±34 KPa) so the necessary pressure required for the engine preservation unit is confirmed.

Considering that the electric motor transmission will not act directly on the fuel pump but on the AGB instead, into the starter port, it is only necessary to apply the transmission ratio between those two components to achieve the adequate revolutions for the electric motor. So the result is:

$$\omega_{fp} = -\omega_s \times \frac{31}{73} \longrightarrow \omega_s = -\omega_{fp} \times \frac{73}{31}$$

$$\omega_s = 625 \times \frac{73}{31} = 1471{,}77 \approx 1472 \text{ rpm}$$

$$\omega_s = \omega_e$$

ω_e: Electromotor angular velocity $[rpm]$

$$\boxed{\omega_e \geq 1472 \text{ rpm}}$$

Now we just need to find an electric motor with the needed characteristics to comply with the studied requirements.

8.2.2. Electric motor technical characteristics

Due to the existing conditions where the electric engine will have to work, the choice of poly-phase electric motor was made. These kinds of engines present a high torque as well as a great performance. Precisely it was decided that an induction engine can be the simplest solution, due to their rugged construction, absence of brushes and the ability to control the speed of the motor.

Notice that we work with the "preventive oil" which is a flammable liquid, so we must to meet the requirements of equipments in an environment with an explosive atmosphere. The ATEX 95 equipment directive 94/9/EC, regulates the equipment and protective systems intended for use in potentially explosive atmospheres.

Our preservation procedure can be considerate like an "Effective ignition source". It is a term defined in the European ATEX directive as an event which, in combination with sufficient oxygen and fuel in gas, mist, vapor or dust form, can cause an explosion.

Hence the chosen engine will have to be manufactured regarding the mechanical, thermical and electrical requirements of the new classification. The manufacturer will need also a Quality System certified by an authorised official body

To continue with the motor choice, the synchronous speed can be calculated as follows:

$$n_s = \frac{60 \cdot f}{p} \qquad \text{(Ec. 8.2)}$$

n_s : Synchronous speed $[rpm]$

f : Frequency $[Hz]$

p : Pair of poles

Hence if it is necessary to achieve a speed of 1472 rpm and the net frequency is 380V/50 Hz:

$$n_s = \frac{60 \cdot f}{p} \longrightarrow p = \frac{60 \cdot f}{n_s}$$

$$p = \frac{60 \cdot 50}{1472} \leq 2 \text{ pair of poles}$$

We only need to know which is the minimum starting momentum that the electric engine must produce to move all the required load. With the engine on a shipping stand the mechanics found out empirically which was the adequate momentum on the started port that allows to mover the engine to make the oil flow through the components. The momentum was approximately 22,37 Nm.

Hence we have already all the data in order to select the adequate motor to perform the explained duty. The chosen motor must comply the following:

- Minimum nominal speed.............1500 rpm.
- Pair of poles...................................≤ 2
- Starting torque..............................22,37 Nm.

8.3. False fuel metering valve signals

Once solved the hydraulic way to open the HPSOV, the last obstacle that appears when developing this new preservation procedure lays on how to control the electric work of the FMV and the HPSOV since we have neither an aircraft nor a test bed to produce electric signals.

To fix this problem we will use an electronic control unit capable of producing an electric signal that excites the torque motors of the FMV and the HPSOV. The idea is to fake the signals simulating the ones that initially should be sent by the EEC. As in the test bed, we pretend to send electric signals that let us control the engine torque of the FMV and the HPSOV despite having no plane.

8.3.1. Electronic control unit

Regarding the FMV, the control unit operation is based in particular signals that usually are sent by the EEC to open or close that valve. Checking the CFM56 engines CMDS we notice the following table **[12]**:

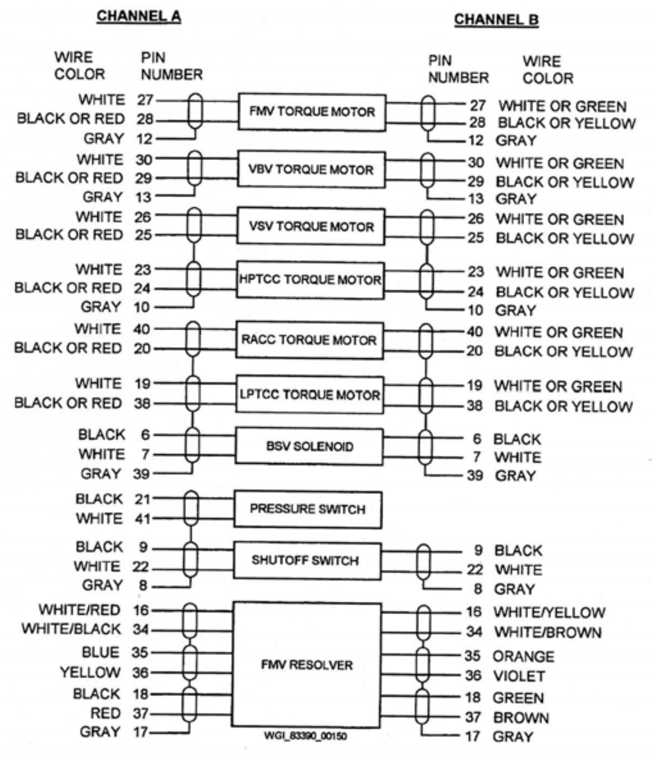

Figure 8.11. EEC channel functions

Speaking about this table, notice that pin 27 and 28 control the engine torque of the FMV, allowing to regulate its activity. In table 8.11. there are two channels A and B for the same functions so they are redundant for security purposes. In case one fails the other one can keep on controlling the components functions without risking the engine performance.

In the other hand, regarding the HPSOV control there are some differences. The command to shut down or to let it open can come from a magnetic latching solenoid, powered by an airframe signal or from the ECC through the fuel metering system. When the upper coil of the solenoid is energized, the magnetic latch force is overcome and the solenoid plunger retracts to a new magnetically latched position. These actions are carried out to operate the HPSOV. Hence the control unit has the task of regulating the magnetically latched position.

This device can be considered as a rectifier capable of broadcasting particular signals since it convert 230V/50Hz A/C in 24V C/C. Its mechanism is simple and it manipulated with only three switches **[13]**:

- Energizing Switch ON/OFF.
- Toggle switch CH. B FMV: opens or closes the FMV through the Channel B FMV. The FMV position is shown by a red LED (valve closed - 10°) and a green LED (valve open – 70°).
- Toggle switch HP SHUTOFF SOLENOID: opens or closes the Shutoff Solenoid. A red LED means closed and a green LED means opened.

The maneuver circuit is as shown:

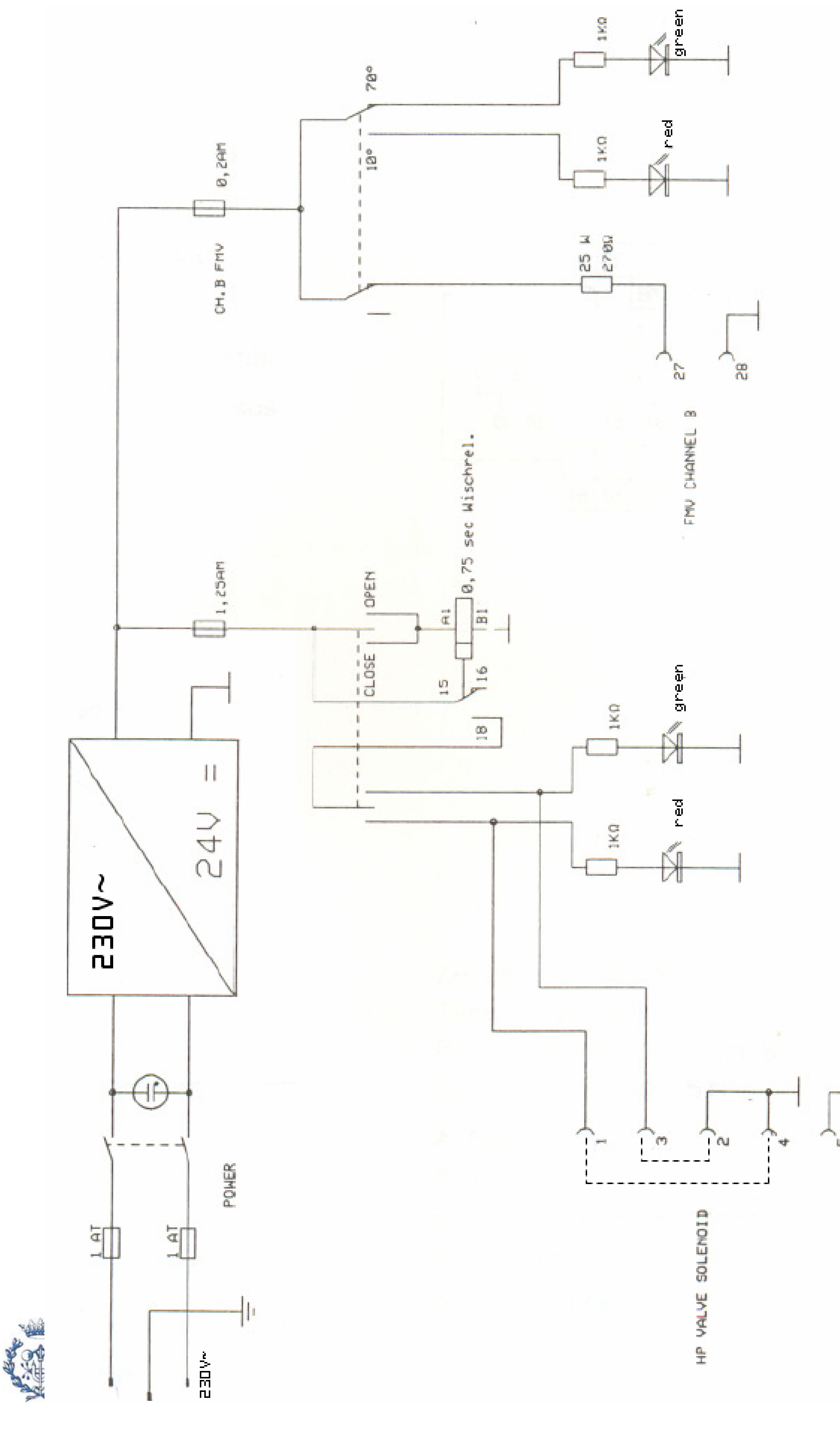

Figure 8.12. Maneuver circuit

FMV connection is carried out connecting the control unit FMV Channel B cable to the HMU Channel B connector (see fig. 6.4). The signals sent show the following characteristics:

- Maximal current FMV 70°..................+90mA
- Minimal current FMV 10°...................+0mA

Combination of those signals applied to the adequate channels allows controlling the movement of the FMV. Channel 27 moves the FMV torque motor in a + way and Channel 28 in a – way (see fig. 8.12.).

In the other hand HPSOV connection is carried out plugging the control unit HP shutoff valve solenoid cable to the HMU Airframe shutoff solenoid connector (see fig. 6.4). The signals sent show the following characteristics:

- Nominal voltage solenoid supply………………………..24 V
- Nominal current solenoid supply………………………...1A

According to schematic 8.7. notice that:

- Connector 1: HP valve close solenoid +
- Connector 2: HP valve close solenoid -
- Connector 3: HP valve open solenoid +
- Connector 4: HP valve open solenoid -
- Connector 5: Ground/Mass

Thanks to the fleeting relay adjustable (see fig. 8.12.) we can configure the excitation times of the SOV solenoid to open or close the HPSOV.

Let us see then how the new process would look like after the explanation of the tooling and the simple handling that will be required.

8.4. Procedure CFM56 engines installed on shipping stands

This is the new alternative procedure to preserve engines. In this situation the engine is installed on a shipping stand.

All engines regardless the manufacturers will have a very similar process. We are interested in the general concept and not the small details of particular models.

So finally the procedure is described as follows:

<u>**WARNING**</u>**:** make sure there is a safety perimeter around the engine and that fire extinguishing equipment is at hand.

1. Remove the starter if is not already removed and connect the electric motor in the AGB starter pad using a suitable mechanic adapter. (See fig. 8.6., 8.7. and 8.8.).

2. Put a container, suitable for fuel, under the fuel filter drain plug.

3. Remove the fuel filter drain plug and allow the fuel to drain off.

4. Remove and discard O-ring from the drain plug.

5. Install a new O-ring lightly coated with CP5070 vaseline, on the drain plug.

6. Torque the drain plug to 5-6,5 Nm and safety with CP8001 Safety wire 0,8mm.

7. Connect the flexible temporary line from the preservation unit to the fuel pump inlet line (see fig. 8.3. and 8.4.). Torque the engine connector to 5-6,5 Nm (see fig. 8.2.). This line will supply CP5066 “fuel system corrosion preventive oil” at 207 KPa maximum pressure.

8. Disconnect the PCR line from the port on the HMU. (See fig. 6.5.).

9. Connect a temporary drain line from the PCR port and from the disconnected line to a 40 liter container suitable for fuel.

10. Apply and keep a pressurized oil supply to the fuel pump inlet at 207 KPa. To do it set the two positions main valve in position “2.- preservation”. (See fig. 8.2.)

11. Start the electric motor and dry motor the engine at maximum speed for two minutes.

12. Stop the electric motor and let the engine to coast down.

13. If the fan rotor did not turn during motoring, protect your hands with heavy gloves and rotate the fan rotor CCW (forward looking aft) two complete turns.

14. Stop the preservation unit to cut off the preservation fluid at the fuel pump inlet.

15. Remove the temporary drain line from the PCR port of the HMU.

16. Reinstall the line from the PCR to the HMU.

17. Disconnect the J6 harness on the HMU side and any harness that is connected to the SOV connector on the HMU side.

18. Connect the electronic control unit to the HMU. Make sure the energizing switch is set to OFF. First connect the FMV Channel B wire to the HMU Channel B connector. Then connect the HP shutoff valve solenoid wire to the HMU Airframe shutoff solenoid connector. (See fig. 6.4.).

19. Remove the fuel hose (see fig. 8.5.) and connect a drain line to a 60 liter container suitable for corrosion preventive oil CP5066.

20. Set the energizing switch to ON and energize the FMV. Use the electronic control unit to supply 24V, 90mA maximum current to the HMU J6 connector.

21. Set the HP SHUTOFF SOLENOID switch on electronic control unit, to open the SOV (24V, 1A).

22. Restart the engine preservation unit to supply the fuel pump inlet.

23. Start again the electric motor to motor the engine at minimum motoring speed to achieve the necessary pressure to move the SOV piston (≈1500rpm).

24. Make sure CP5066 corrosion preventive oil comes out to the drain container.

25. Set the energize switch to OFF and continue motoring for two minutes.

26. Stop the electric motor and allow the engine to coast down.

27. If the fan rotor did not turn during motoring, protect your hands with heavy gloves and rotate the fan rotor CCW (forward looking aft) two complete turns.

28. Set the main valve to the “1.- return to tank” position and stop the engine preservation unit. (See fig. 8.2.).

29. Remove the temporary oil supply line from the fuel pump inlet line.

30. Install the cover or a cap on the fuel pump line.

31. Seal inlet and exhaust openings with CP2160 vapor barrier film and safety with tape. Seal all engine openings with caps or plugs.

32. Put CP2098 Desiccant Bags. Do not put it in contact with engine hardware.

33. Cover the entire engine with waterproof protective covering and attach tightly.

34. Attach a tag to the engine to warn that the fuel system has been preserved with preventive oil. Include the date of preservation.

8.4.1. Procedure characteristics

I would like to point out some aspects of this new procedure. In this preservation the fuel system will be fully preserved with the exception of the fuel nozzles. Authorities consider that the gases that come out of the engine exhaust nozzle as a spray are health threatening for the workers (toxic) and flammable. Therefore in order to perform this preservation in the workshop we must to keep the preventive oil in liquid state.

The preservation is achieved without starting the engine so it is a process without ignition. Another shared characteristic with the AMM procedure is the use of an oil pressurized servicing cart (engine preservation unit) to provide the engine preventive oil with the required pressure.

I have placed emphasis during all the Thesis on how important is the fact of allowing the opening of the FMV and HPSOV and let the preservation fluid to fill correctly the fuel circuit. The electric signals, that allow this HMU valves regulation, come in this case directly from an engine control unit.

The HPSOV presents also a specific requirement; it needs a minimum pressure to be opened. In this new procedure we have achieved this pressure thanks to an electric motor. The electric motor solution allows achieving the necessary pressure to open the HPSOV and moving all the essential mechanical components to carry out the preservation.

9. Estimate

In this section we expect to justify the viability and cost-benefit ratio of the whole shipping stand procedure. Financial costs are not considered since the investment is so little that there is no need to ask for a loan to any external bank or building society.

9.1. Estimate required tooling

In order to elaborate this estimate we assumed some suppositions:

- Estimate required tooling: in order to determine the price of the engine preservation unit we checked in some online catalogs for each one of the components in order to obtain approximate costs. For the electric engine we checked straight away one that satisfies all the calculated requirements (for more information please check Annex C). Concerning the electronic control unit the cost information was provided the company Lufthansa Technik AG itself. Maintenance costs of all tooling were considered nil.

Tooling description	***Unit price (€/u)***	***Units***	***Cost***
Engine preservation unit			1645,47
- Air pressure regulator	129	1	129
- Air filter	43,5	1	43,5
- Air security valve	80,95	1	80,95
- Compressed-air double-diaphragm pump	484	1	484
- Oil Tank	89,99	1	89,99
- Manometer	21,50	1	21,50
- Thermometer	24,95	1	24,95
- Pressure oil relief	10,99	1	10,99
- Oil filter	13,99	1	13,99
- Two-positions valve	371	1	371
- Oil security valve	69,95	1	69,95
- Lines and connectors	150	1	150
- Structure with wheels	112	1	112
- Drain valve	43,65	1	43,65
Electric motor	355	1	355
Electronic control unit	436	1	436
	TOTAL COST:		**2436,47€**

Figure 9.1. Estimate required tooling

9.2. Estimate supply costs.

- Estimate supply costs: regarding the fuel system preservation procedure we only need to count the cost of the corrosion preventive oil. In the other hand to preserve the lubrication system is necessary to mix the aircraft oil tank with at least 5% of Lubrication System Corrosion Preventive oil or, as an alternative, 7 percent Corrosion Preventive Additive by volume **[6]**.

Speaking about electric and air supply (for the pump to work) the cost is so low than can be ignored. The tooling required to carry out this process are the same ones used daily at the workshop, so they do not involve any extra cost. Hence, altogether the costs would be:

Material Info	***Price***	***Quantity***	***Cost (€)***
Corrosion preventive oil (Mobil Avrex S Turbo 256)	4,27 (€/l)	60 (l)	256,44
Corrosion Preventive Additive (Brayco 599 GE D50TF6-S1 Rust Preventive Concentrate for Synthetic Turbine Oil)	94,75 (€/l)	22x0,07 (l)	145,91
Dessicant bags (Silica gel)	4,54 (€/kg)	16 (kg)	72,72
		TOTAL COST:	**475,07**

Figure 9.2. Estimate supply costs

9.3. Account

- Account: retrieving all data we are now able to evaluate the expenses account. We cannot forget that since it is not a chain process or production the cost of the tooling investment would be too high if calculated for only one preservation. In my opinion I would just ignore this cost since we are speaking about such a company as Lufthansa Technik AG and the long-term cost for it would be nil. However another option would be to establish an estimate number of preserved engines per year, an estimate number of year to amortize the tooling and from that point calculate how much each preservation would be.

According to our company data we can estimate that we would manage to preserve about 200 engines per year. If we expect to amortize it in one year:

Item	**Description**	**Costs**
Staff (3 mechanics)	3 x (16 €/h x 32 hours)	1536€
Supply		475,07€
Recovery (1 year)	2436,47 / 200	12,18€

TOTAL EXPENSES …………..……………………..……………………….2023,25€

5% PROFIT OF TOTAL EXPENSES…………………………………………..101,16€

ACCOUNT……………………………………………………………………..2124,41€

Figure 9.3. Account

With the new procedures fully developed each preservation on a shipping stand would be about 2124,41 € taking roughly 32 hours with three mechanics to be carried out.

10. Environmental degradation study

The study of the Environmental Impact is focused on the waste materials management, the life-span of the tooling and the energy consumption required carrying out this new preservation procedure.

10.1. Waste materials

The raw material used in this process is made of: Corrosion preventive oil (Mobil Avrex S Turbo 256) and corrosion preventive additive (Brayco 599 GE D50TF6-S1 Rust Preventive Concentrate for Synthetic Turbine Oil).

Both products are recyclable, hence once placed in a suitable container they will be picked up and processed by the adequate recycling specialized companies which will deal with them.

The remains of fuel extracted during the initial part of the process will be also place in a suitable container in order to be picked up and processed as well by a waste management company.

10.2. Life-span end of the tooling and recycling

The electronic control unit is constituted by electronic components which are not very easy to recycle. The most of them are plastic and silicates, very complicated to be reused. Also it has some minor components such as lead, arsenic or mercury – very toxic – which should be properly processed. Hence an electronic components recycling company should take care of picking those up and process those electronic components for a proper recycling.

The rest of the tooling used in this process is made basically of 100% recyclable materials, since most of them are metals. Should the life-span of the engine preservation unit and the electric motor end, an adequate company will separate the components depending on the process required to be recycled.

10.3. Energy consumption

The engine preservation unit works using compressed air, hence its electrical consumption is almost insignificant. It uses indirectly the energy required to compress the air used afterwards.

I the other hand, the electric motor estimated power is between 2 and 3 Kw.

Finally the electronic control unit has also such a low consumption that it can be ignored, industrially wise speaking.

Just notice that obviously every energy consumption, even the smallest, implies previous greenhouse effect gasses emissions. However in this project electric consumption is not something really remarkable.

10.4. Environmental characteristics of the new procedure

In the procedure engine on wing (AMM) during the wet motoring, the sprayed preservation fluid comes out of the engine exhaust nozzle as a spray. The direct consequences are a loss of air quality and the chance of breathing issues among the workers.

In the other process that is being carried out so far – preservation of the test bed – it implies the engine ignition. Direct consequences are: emission of greenhouse effect gasses and emission of volatile and non-volatile nanometre-sized particles that affect the air quality. The following table shows the value of those emissions **[14]**:

Fabricante de la serie/modelo	modo	potencia	flujo de combustible (kg/min)	índice de emisión (kg/1000 kg de combustible)				
				TOG	CO	NO	SO2*	PM
JT8D-17R Pratt & Whitney.	Despegue	100%	85.02	0.21	0.95	25.30	0.54	-
	Ascenso	85%	66.18	0.27	1.03	17.60	0.54	-
	Aproximación	30%	22.53	0.53	2.54	8.40	0.54	-
	Carreteo	7%	9.30	0.95	9.43	3.30	0.54	-
PW4152 Pratt & Whitney	Despegue	100%	130.62	0.13	0.12	26.90	0.54	-
	Ascenso	85%	107.10	0.16	0.17	22.70	0.54	-
	Aproximación	30%	35.58	0.15	1.09	11.10	0.54	-

Figure 10.1. Aircraft engine's emissions

With the new process we remove both contaminating effects of both current processed, since the engine preventive oil remains liquid. This way it does neither burn nor become part of the air becoming sprayed particles.

Another relevant environmental improvement is that since ignition is not required, removed completely the acoustic pollution, which is becoming at the airports a greater problem every day.

Conclusions

Highlight first of all the relevance that the study of the State of the Art regarding the current preservation procedures as well as the study of the operation of certain fuel system components. Without this ground this project would not have been possible.

Watching at the results, despite some theoretical aspects that would still need to be tested in reality; we can affirm that we were successful in configuring a new preservation procedure that allows decreasing operation times (the procedure is supposed to take 30 minutes and the whole operations about 32 hours). According to what it is explained it is no longer required to preserve the engine when it is off wing on the test bed, or while it is on wing, installed on the aircraft. Both methods mean high costs for reasons already explained through the project.

In order to make the developed procedure come true in an efficient way it must first be approved by qualified professionals from the WT department at Lufthansa Technik AG. However the engineers cooperating in the development of this new maintenance tool used for cool preservation were optimistic and according to them the process will comply with current regulations and will be used in a near future.

Anyway this project is no more than a proposal of the development of a maintenance tool for cold preservation, hence it could be that only a part of it could be executed or that it might require modifications.

I would like to remark that all calculations, technical details and suppositions done and used to carry out this project have been according to the engines manufactured by the company CFMI – Commercial Fan Motor International: General Electric & SNECMA. What we want to point out is that despite what we developed could be applied to other aircraft engines, in any case it would require considering the characteristics of each model and what states in their manuals.

Finally point out that the development of this project forced the student to study constantly several components of an aircraft engine, which after seven months have flourished in really valuable knowledge in aeronautical engineering.

Gratitude

First of all I would like to thank Lufthansa Technik AG the chance I was given of doing my Thesis at their Hamburg base. From the very beginning all my colleagues, mechanics or engineers, showed huge hospitality easing dramatically my integration. Considering I was in another country, I was facing a new language and I was joining what for me was a completely new company I cannot thank enough all those people who somehow tried to make me feel as comfortable as possible, definitely as just another one:

In second place I would like to thank my parents the unconditional support that they always gave me and of course all the economical sponsoring as a student. Important mention deserves also my brother for reasons we both known.

Thanks also to all my university friends whom I have studied with and who helped me through difficult times.

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Finally as a sign of gratitude I would like to mention with name and surname the people who made possible that I was able to enjoy such a constructive and positive experience. Starting with my tutor in Lufthansa Technik: **Jörg Rehmet**, Georg Barke, Bernd Westphal, Jürgen Barsuhn, York Schilling, Lena Scholle, Jens Schoensee, Manfred Chinitzky, Carsten Hoose and Joseph Rosenblatt.

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