МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

АЕРОКОСМІЧНИЙ ФАКУЛЬТЕТ

КАФЕДРА ПІДТРИМАННЯ ЛЬОТНОЇ ПРИДАТНОСТІ ПОВІТРЯНИХ СУДЕН

ДОПУСТИТИ ДО ЗАХИСТУ

Завідувач кафедри

к.т.н., доцент

___________________О. В. Попов

«_____»__________2021 р.

КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ «МАГІСТР»

ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ

«ТЕХНІЧНЕ ОБСЛУГОВУВАННЯ ТА РЕМОНТ ПОВІТРЯНИХ СУДЕН І АВІАДВИГУНІВ»

Тема:" . Методологічні основи підтримання експлуатаційної надійності паливної системи пасажирського літака великої дальності з двома турбореактивними двигунами"

Виконав: __________ **Тюрін Д. Д.**

Керівник:

к.т.н., доцент _________ **Ругайн О. В.**

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Нормоконтролер: ___________/______________

Київ 2021

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

AIRSPACE FACULTY

Aircraft Airworthiness Continuing Department

DEFENCE PERMITED

The Head of the Department

Ph.D., associate professor

____________ O.V.Popov

«____» __________ 2021

MASTER DEGREE THESIS

(EXPLANOTARY NOTE)

GRADUATE OF EDUCATIONAL DEGREE "MASTER"

FOR EDUCATIONAL AND PROFESSIONAL PROGRAMS "MAINTENANCE AND REPAIR OF AIRCRAFT AND AIRCRAFT ENGINES"

Topic Methodological bases for maintaining the operational reliability of the fuel system of a long-range passenger aircraft with two turbojet engines"

Fulfilled by: __________ **Tiurin D.D.**

Supervisor:

Ph.D., associate professor __________ **Rugain O.V.**

labor precaution:

Ph.D., associate professor __________ **Kovalenko V.V.**

environmental protection:

Ph.D., associate professor __________ **Sanenko T.V.**

Standards Inspector: ____________/__________

Kyiv 2021

NATIONAL AVIATION UNIVERSITY

Airspace Faculty

Aircraft Continuing Airworthiness Department

Educational Degree "Master"

Speciality 272 "Aviation Transport"

Educational and professional programs "Maintenance and repair of aircraft and aircraft engines"

APPROVED BY

The Head of the Department

Ph.D., associate professor

___________ O.V.Popov

“_____”__________2021

Graduation Project Assignment

Tiurin Danylo

1. Topic:**" Methodological bases for maintaining the operational reliability of the fuel system of a long-range passenger aircraft with two turbojet engines"**

approved by the Rector’s order of "11" October 2021 № 2196/CT.

2. Period of accomplishing of the Graduation Project since October 25, 2021 until December 31, 2021.

3. Initial data for the project: searching for data and identifying faults that occur in the hydraulic system and reducing them to maintain the safety of the aircraft.

4. The content of the explanatory note: introduction about activity and principle usage of

aircraft and the uses of other systems and units of the aircraft and the large capacity for energy consumption, especially the hydraulic system that provides systems and mechanisms for aircraft management that determine the safety of the flight.

5. The list of mandatory graphic materials: shows the work of the hydraulic, landing gear parts, marking pipeline, the sensor alarm water sludge. Exhaust systems in the aircraft llustrated material is completed with the help of Microsoft Office.

6. Time and Work Schedule

#	Stages of Graduation Project Completion	Stage Completion Dates	Remarks
1	Task receiving, selection of material	25.10.21– 31.10.21	Done
2	Analytical part, detailed analysis of factors influencing on aircraft operational reliability, serviceability	02.11.21-09.11.21	Done
3	Project part	12.11.21-18.11.21	Done
4	Scientific part	19.11.21-24.11.21	Done
5	Labor precautions	25.11.21-26.11.21	Done
6	Ecology	27.11.21-28.11.21	Done
7	Arrangement of explanatory note	29.11.21-06.12.21	Done
8	Preparing for project defend	13.12.21-20.12.21	Done

7. Advisers on individual sections of the project:

Section	Adviser	Date, Signature	
		Assignment Delivered	Assignment Accepted
Labor precaution	Ph.D., associate professor Konovalova O.V.		
Environmental protection	Ph.D., associate professor Radomska M. M.		

8. Assignment issue date “_____”___________ 2021.

Degree work supervisor: __________ Rugain O.V.

(signature)

Assignment is accepted for fulfillment __________Tiurin.D.

(signature)

ABSTRACT

Explanatory note for diploma work named as “Methodological bases for maintaining the operational reliability of the fuel system of a long-range passenger aircraft with two turbojet engines”:

95 pages, 19 figures, 6 tables, 10 references

Object of study – is optimal method of maintaining the operational reliability of the fuel system of a long-range aircraft with two turbojet engines and its components.

Subject of study – fuel system of Boeing-787 and it’s maintenance methods.

The purpose of the work – to increase the operational reliability and improve some maintenance procedures of the fuel system of chosen aircraft with the implementation of modern technology.

Research method – analytical processing of all regulatory, technical documents, maintenance manuals, Maintenance programme of the operator and statistical data on fuel system failure or malfunction with reported conclusions from national transportation safety board.

The Practical meaning of diploma work results is determined by evaluating the reliability of Boeing-787 fuel system increase, enhancement of some maintenance procedure and technical operation efficiency rise.

Scientific novelty – the main idea is to where it will enhance operational reliability and decrease the maintenance cost of the airplane.

Materials of diploma work are recommended to use during study process and practical activity of design bureau specialists.

FUEL SYSTEM, COMPONENT RELIABILITY, EPOXY TECHNOLOGY, FEEDTHROUGH, REGULATORY DOCUMENTS, MAINTENANCE MANUAL, OPERATION EFFICIENCY.

CONTENT

LIST OF ACCEPTED ABBREVIATIONS, UNITS AND TERMS

AC – aircraft;

DTS – digital twin sensor;

DTT – digital twin technology;

ICAO – International Civil Aviation Organization;

MP – Maintenance programme;

SAA – State Aviation Administration;

APU – auxiliary power unit;

ACARS – aircraft communication addressing and reporting system;

MEL – minimum equipment list;

NTSB – National Transportation Safety Board;

NA – not accessible;

AE – adverse event;

ECS – engine control system;

O/J – override/jettison pumps;

FOHE – fuel/oil heat exchanger;

FMU – fuel metering unit;

EICAS – engine indication and crew alerting system;

FMC – flight management computer;

FDR – flight data recorder;

CDU – control display unit;

CVR – cockpit voice recorder;

QAR – quick access recorder;

FQIS – fuel quantity indication system;

ACMF – aircraft condition monitoring function;

EHM – engine health monitoring;

APM – aircraft performance monitoring;

EASA – European Union Aviation Safety Agency;

FAA – Federal Aviation Administration;

AMM – aircraft maintenance manual;

ELMS – electrical load management system;

AI – artificial intelligence;

FBG – fiber bragg grating;

OSA – optical spectrum analyser;

AWG – arrayed waveguide grating;

WDM – wavelength division multiplexing;

EDG – Echelle diffractive grating;

PIC – photonic integrated circuit;

AE – acoustic emission;

$R(t)$ – reliability;

t – continuous operating hours/cycles between diagnostics;

$\varphi(t)$ – constant failure rate;

e – exponential function;

$Q(t)$ – probability of failure;

S_i – possible state of aircraft;

η – degree of adverse factors;

K_d – laboriousness coefficient;

$\lambda(t)$ – failure rate;

H_y – differential pressure on the seal;

μ – coefficient of slot seal flow;

Q – fluid leakage;

T_m – coefficient of variation;

h_g – the efficiency of the boos pump.

INTRODUCTION

Nowadays every aircraft which is operated involves large amount of systems to maintain normal operating conditions. Ensuring aircraft systems reliability and durability is a direct way to provide safety in flight, maintenance department of aviation company is ordered to supply this necessity. Normally, each modern company or operator has own Maintenance programme (MP), methods, instructions, technologies and procedures which are distinctly approved according to manufacturer's regulatory documents and consequently due to International Civil Aviation Organization (ICAO) or State Aviation Administration (SAA) requirements.

Modern aircraft carries the newest scientific and technological decisions, this approach needs to improve aircraft efficiency permanently. On the other hand, maintenance methodology is needed to chase the technology step close enough, Aviation authority requirements should be chased in the same way.

Given work purpose is obtained to study a long-range twin turbojet aircraft fuel system, investigate ways and approaches for maximizing reliability during flight operations.

Fuel system on every modern AC is a complicated complex of interconnected subsystems. Every part which provide fuel delivery is required appropriate maintenance and defined level of reliability. Developing of fuel system efficiency is achieved by rapid growth of the aviation industry (before the COVID-19 quarantine), technologies, appropriate competition between aircraft manufactures all around the world, including Boeing company and Airbus, eternal wishes of designers to reveal new trends and new solutions in aircraft manufacturing.

As a definition of an aircraft always includes an engine or engines, the problem of fuel system and its safety operations should be monitored during all aircraft operations. Fuel supplies engine, Auxiliary power unit, used to maintain appropriate eight and balance conditions to provide aircraft stability and controllability. On some aircraft types it is also used as a coolant liquid, for instance, in air conditioning system or to cool the oil.

Though the fuel supply is so important and complicated, should be applied specific approach to maintain its operation ability. Manufacturer, operator, technical staff have to be aware of all of the regulations, technical documentation and maintenance procedure strictly. Only in this way it is possible to keep airworthiness condition permanently. Moreover, the operator has to have relevant and efficient maintenance department. Finally, the problem of new methodological bases for maintaining the operational reliability of the fuel system is very important.

The development of scientific and technological progress in civil aviation sets targets to further improvement of safety and reliability of AC. As was mentioned before the development of scientific and technological progress in civil aviation sets targets for further improvement of safety and reliability of AC. Hence, this development needs involving of new solutions which can propose something new, more practicable or flexible due to tasks of the present day.

All in all, if the operator will be possible to monitor all data, condition and any failures of fuel system and its components continuously via satellites with implementation of digital twin technology (DTT) it will definitely increase operational reliability.

In this diploma I would like to propose the implementation of epoxy wire feedthrough installed in a fuel pump on the example of Boeing-787 based on the results of the analysis of reliability of the units of the fuel system, statistical data about their failure, maintenance manuals, technical documentation, procedures, and malfunctions.

Realization of epoxy wire feedthrough will definitely increase the operational reliability, safety margin and to find out new methodological bases during maintenance works. All in all, it helps to reduce maintenance cost, time, and improve efficiency of the maintenance department of any airline.

CHAPTER 1: The analysis of failures of 787 family

1.1 The concept of reliability

Every person which takes part in aircraft operations would operate that type of aircraft which don`t need the attention at all. Every incident, every failure needs to be repaired as soon as aircraft is so expensive during operations and maintenance, it is necessary to produce enough reliable product.

Reliability assessments and their processes have been implemented only recently in complex aircraft programs. Nowadays in new complex aircraft programs, reliability as a property of aviation product helps to solve huge amount of problems. Reliability decides the next problems:

- to lower the life cycle cost of the product;

- to enhance aircraft\system availability;

- to enhance the design for aftermarket services;

-to inherently improve safety through the improvement of the aircraft/system failure rate;

- to increase customer satisfaction.

The reliability assessment process on complex aircraft program, starts at the concept phase and supports the program throughout all its stages. A systematic reliability analysis of existing and future technical systems is a paramount precondition to lower the program risks and increase the operational efficiency of the system.

So, and now it is necessary to understand what is reliability. Due to american literature the reliability is "…the measure of the probability of successful performance of the system over a period of time". Quantitative reliability is generally defined as the probability that an item (component, equipment or system) will operate without failure for a stated period of time under specified conditions [1].

Reliability and risk assessment methods are both employed in safety studies to identify the various combinations of faults which can lead to reduced safety. Reliability assessment should be carried out during every stage of the project. A formal reliability program is essential on all projects of any size or importance. The reliability program should begin at the earliest stage in a project and must be defined in outline before the concept design phase starts [2].

Reliability - the property of the aircraft to keep in time in the established the limits of the values of all parameters characterizing the ability to perform flight missions in design modes and operating conditions, technical maintenance, repairs, storage and transportation. Thus, reliability is a complex property of an aircraft and consists of a combination of properties: reliability, maintainability, durability and preservation.

Reliability - the property of an aircraft to continuously maintain its operational state during the flight mission execution time.

Reliability indicators are quantitative characteristics. one or more properties that make up the reliability of the object. In the first the case, the indicators are called single, in the second complex. Indicators reliability are among the most important concepts of the theory of reliability.

The main indicator of non-failure operation is the probability of failure-free operation, i.e. the probability that within a given operating time not a single refusal. This indicator is determined on the assumption that at the initial moment time (the moment of the beginning of the calculation of operating time) the object is in workable condition.

Reliability, where safety is not an issue, is relatively straightforward. It has direct influence on company`s cash flow and image because an unreliable aircraft flies less than its intended utilization and causes many disruptions affecting availability. In many cases, the reliability program can be cancelled or significantly reduced due to budget constraints or the program running overbudget. In this case, it should be noted that any add-on reliability features after the aircraft enters service will always be significantly more expensive and in some cases might not get to the intended reliability improvement.

Great amount of emphasis is based upon the failure rate or Mean Time Between Failures of a component of system analyzed to describe its reliability. There does exist two main methods to determine the component reliability:

- Analytical by component count

- Historical by means of accumulated inservice experience and lessons learned

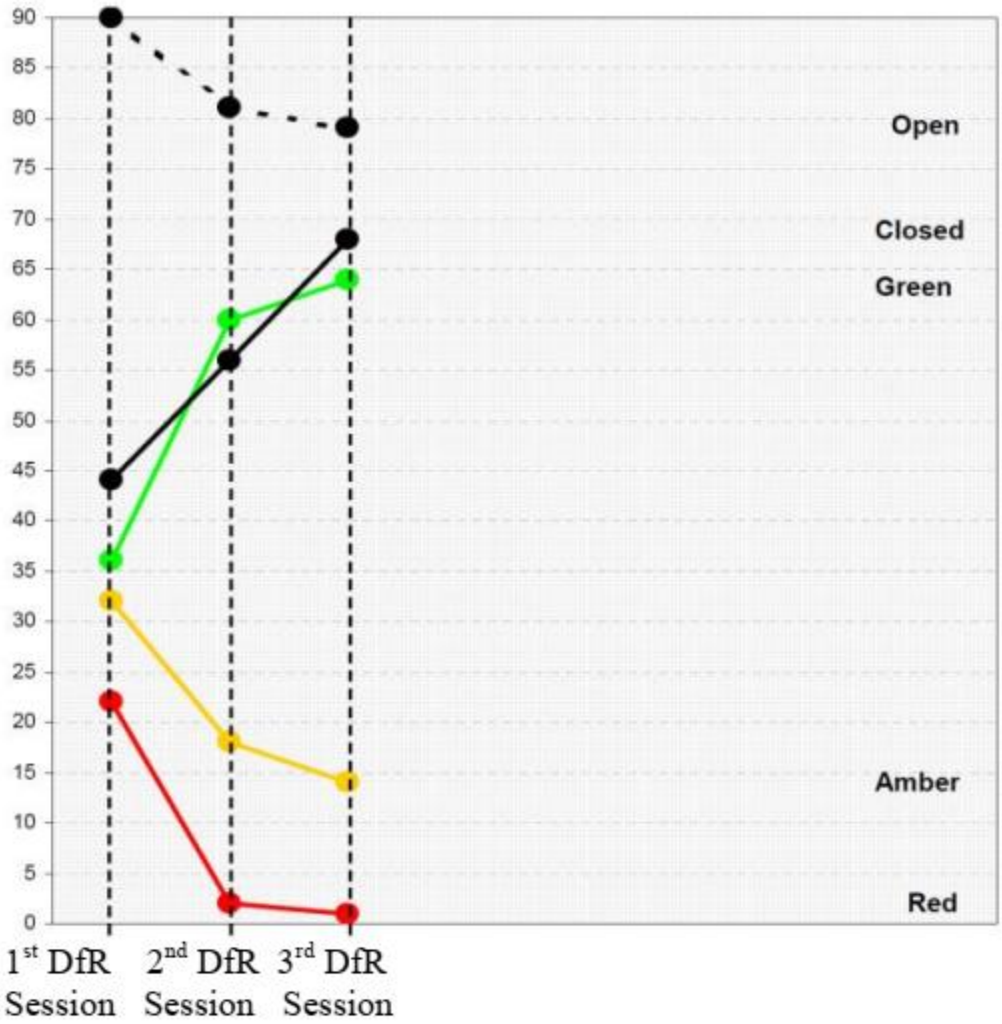

Figure 1. Example of a reliability monitor status

The color markings description:

1. Black: Reliability risk closed. Mitigation has been completed and/or traceable documentation is available.

2. Green: Reliability mitigation has been planned and agreed, target dates are being achieved. Many reliability risks identified require the successful completion of program

development tests or specific dedicated test in order to be closed (specified in the reliability monitor)

3. Amber: Reliability mitigation has been planned, the plan is not yet agreed; or its adequacy to mitigate the reliability risk is not assured; or the plan is behind schedule, not impacting major program milestones.

4. Red: Reliability mitigation has not been planned; or the plan is significantly behind schedule, impacting major program milestones

Whilst design for reliability has been documented and suggested for a long time, it is only in recent complex aircraft programs, that it has been implemented effectively. This is the result of a cultural change within the aerospace community, which places a lot of emphasis on improving the product life cycle cost and subsequently the business case model (for both the Original Equipment Manufacturer and the operator).

As shown in Figure 3 below (describing the product timeline for an engine application), design for reliability activities should start at the concept phase and support the product development beyond its entry into service.

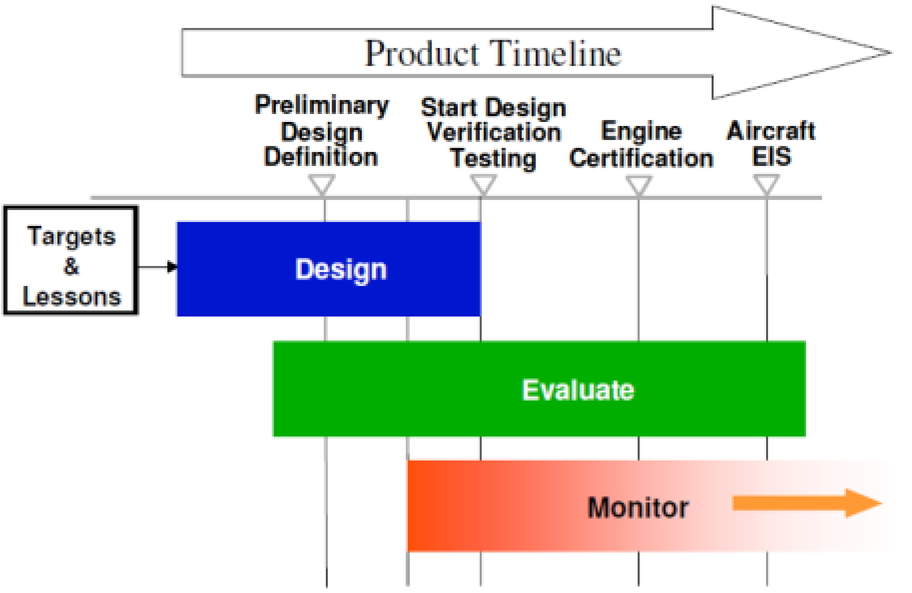

Figure 2. Overview of the design for reliability timeline .

The benefits of such a process on safety, availability and aftermarket services are numerous and summarized in the body of this report. In order to obtain a mature, robust and reliable product at entry into service, it is essential that all parties involved in the design and development of the product (design engineers, system specialists, project engineers, validation engineers and vendors/suppliers…), are made aware of the importance of the DfR process and how to design and develop the product to meet the reliability and aftermarket requirements. The design for reliability process discussed is detailed enough to enable any reliability engineer with good experience to adopt it and it can be applied to any other industry, including that of space.

1.2 Turbojet engine principle of operation theory

In case to provide thrust all aircraft engines work by impating rearward momentum to one or more streams of gas, this gas is the reaction gas and such engines are known collectively as reaction engines.

From Newtons laws of motion we know that force is equal to change in momentum, thus thrust, F*n* for a jet engine can be written as follows, know as the general thrust equation [5]:

$$F_{n=(}M_a+M_f)V_e-M_aV_0$$

$$F_n = (m_a + m_f)V_e - m_a V_0,$$

Where

m_{air}	is the mass flow rate of the air passing through the engine
m_{fuel}	is the mass flow rate of fuel entering the combustion chamber
V_e	is the velocity of the exhaust stream (= V7)
V_0	is the free stream velocity of the air coming in to the engine, same as the true airspeed of the aircraft

Since _ $m_{air} >> m_{fuel}$ we can make the simplification that the mass flow rate entering the engine is the same as the mass flow rate exiting the engine, and from there we get a simple expression for the propulsive efficiency, ηp, which is the ratio between the work done on the aircraft compared to the kinetic energy imparted to the air stream flowing through the engine:

$$\eta_p = 2V_0/(V_0 + V_e) = 2/((V_e/V_0)+1))$$

From this the conclusion can be made that the highest efficiency is achieved when the velocity of the exhaust is nearly the same as that of the aircraft, shown in fig. 2. Using a larger mass flow rate instead of higher exhaust velocities is therefor preferable. Depending on the range of speeds an aircraft is designed to operate in the preferred engine type varies, with slow aircraft the choice is propellers, followed by high-bypass turbofan and then progressively lower bypass ratios as the speed increases. [5]

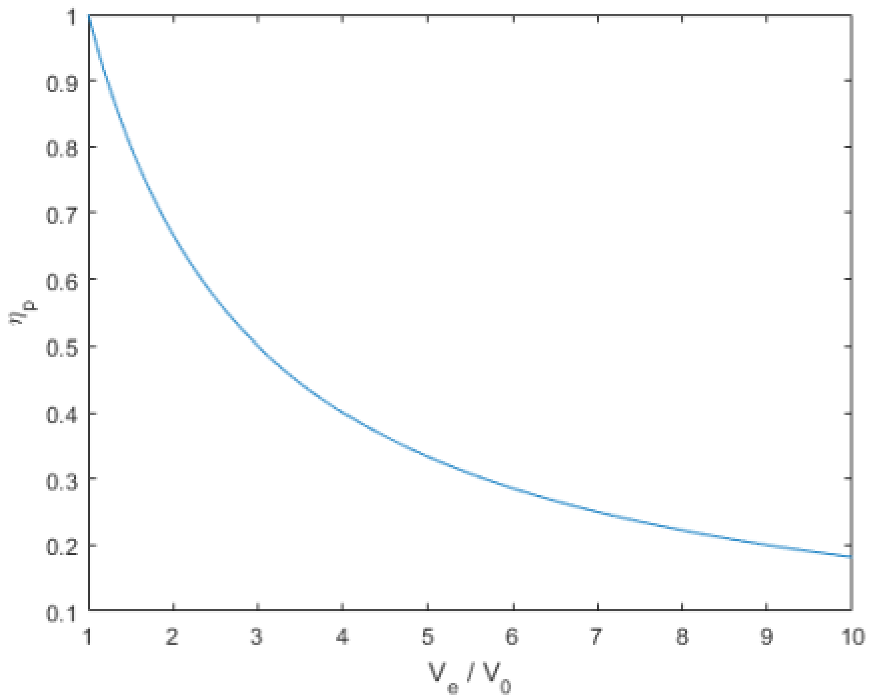

Figure 3. Propulsive energy as a function of V_e/V_0

Therefore heat after combustion is used to propel the air rearwards. Thermodynamic cycle could describe an ideal case of jet engine operation. Every turbojet engine has five main design areas: diffuser, compressor, combustion chamber, turbine, nozzle. Schematic view is presented. Due to scheme we may observe the zeroth station. It is far enough up stream before the intake that ambient conditions apply.

Diffuser is located between area 1 and 2, in this zone stream slows down and the pressure rises. The region between 2 and 3 is the compressor, where energy is added to the flow, idealized as an adiabatic process where the pressure and the temperature increases and the volume decreases. Between station 3 and 4 the combustion takes place, heat is added and the volume and the entropy increases and the temperature reaches its peak. Between station 4 and 5 is the turbine, where the pressure and the temperature decreases and the volume increases while the air flows through the turbine, converting heat to mechanical work.

Finally, area from 5 to 6, the air goes through the nozzle back to ambient pressure during acceleration.

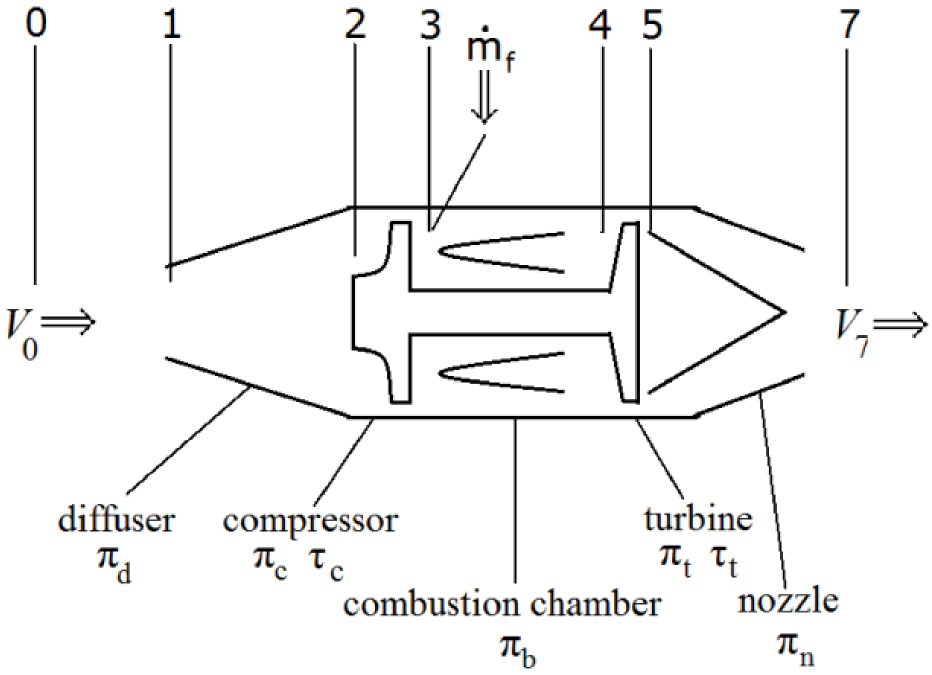

Figure 4. A schematic view of turbojet engine

We will use a number of approximations and idealizations to describe the flow and its thermodynamic features. We assume frictionless and inviscous flow to avoid fluid losses. Now let's remind us the equation for ideal gas:

$$p/\rho = RT .$$

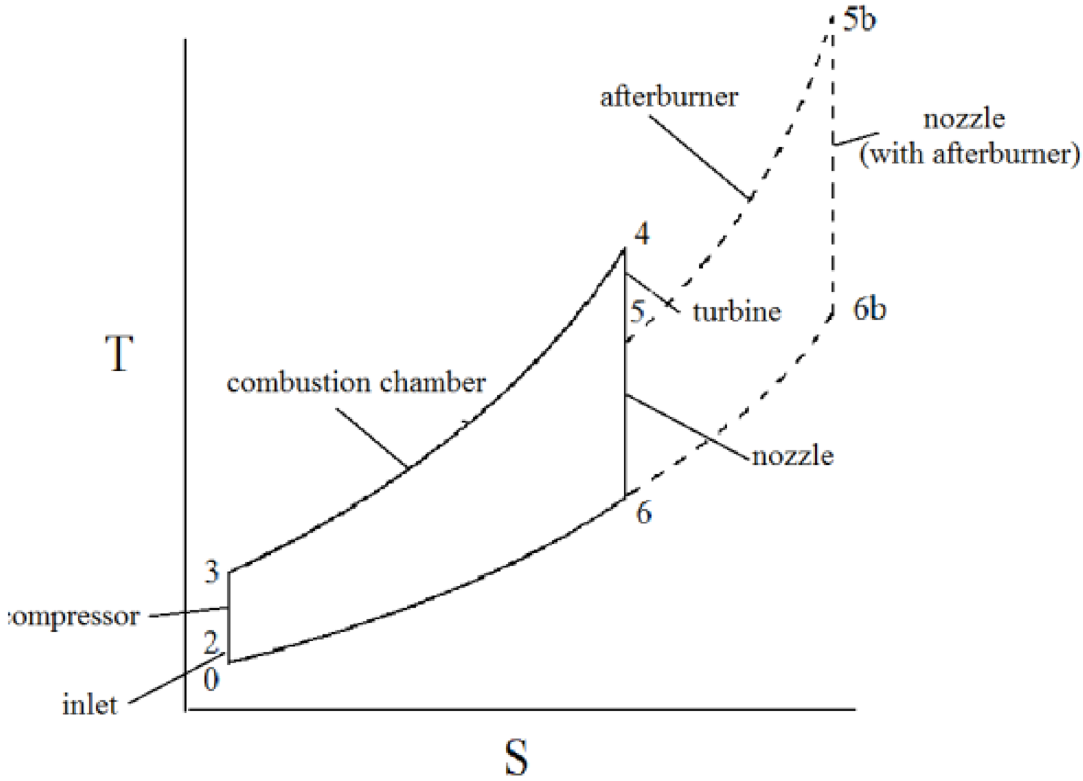

Figure 5. Ideal Brayton cycle for Turbojet

The ideal open Brayton cycle consists of 4 processes, isentropic compression, isobaric heat addition and isentropic expansion and then an isobaric heat rejection between exit and inlet. We can see these relationships:

Work done by compressor:

$$E_{W,}\, c = m_a\,(h_{03} - h_{02})\ (3)$$

Work done on turbine:

$$E_{W,}\, t = (m_a + m_f)(h_{04} - h_{05})(4)$$

Heat added to system during combustion:

$$Q_{in} = (m_a + m_f)h_{04} - m_a h_{03} \quad (5)$$

Heat rejected from the system in the gas stream:

$$Q_{out} = (m_a + m_f)h_{06} - m_a h_{00} \quad (6)$$

The work done by the gas on the turbine is in a turbo jet only used to drive the compressor and various auxiliaries. The energy left in the gas stream after the turbine and how that is converted to propulsive force is what is of interest in this context.

Using conservation of energy, assuming that the change in potential energy due to elevation is negligible and assuming conservation of mass (neglecting fuel flow since $m_{air} >> m_{fuel}$)

$$q_{out} + 1/2(V_6^2 - V_0^2) = q_{in} + (e_{W,c} - e_{W,t}) \quad (7)$$

Using the thrust equation from the previous section, eq 1, the kinetic energy term can be written as (8)

$$V_6^2 - V_0^2 = (V_6 - V_0)(V_6 + V_0) = (V_6 + V_0)(F_n/m)^{\cdot}$$

Assuming e W,in − e W,out = 0, since in the ideal case no work is done by the shaft, gives an expression for thrust

$$F_n = [(q_{in} - q_{out})]\,(m/V_{avg}) \quad (9)$$

Define the over all efficiency of the engine, the ratio of work done by the exiting stream to the rate of heat added

$$\eta_0 = F_n V_0 / m q_{in} = (V_0 / V_{avg})(1 - (q_{in}/q_{out})) \quad (10)$$

Propulsive efficiency, eq 2 can be rewritten as $\eta_p = V_0/V_{avg}$, thus overall efficiency can be stated as a product of propulsive and thermal efficiency, $\eta_0 = \eta_p \eta_{th}$, where thermal efficiency is defined as

$$\eta_{th} = 1 - (q_{out}/q_{in}) = 1 - ((h_{06} - h_{00})/(h_{04} - h_{03} \quad (11)$$

Both heat in and heat out are constant pressure processes, approximating constant specific heat $C_p = C_{p,avg}$, equation 11 becomes

$$\eta_{th} = 1 - C_p(T_{06} - T_{00})/C_p(T_{04} - T_{03}) \quad (12)$$

Compression and expansion is assumed to be isentropic and we assume polytropic gas. And $P_{03} = P_{04}$ and $P_{06} = P_{06}$ so

$$T_{03}/T_{00} = (P_{03}/P_{00})^{((\gamma-1)/\gamma)} = (P_{04}/P_{06})^{((\gamma-1)/\gamma))}$$

Substitution then gives

$$\eta_{th} = 1 - (1/\pi_0)^{((\gamma-1)/\gamma)} \quad (13)$$

where $\pi_o = P_{03}/P_{00} = P_{04}/P_{06}$ is the overall pressure ratio of the engine. As fuel efficiency is directly related to thermal efficiency, as high a pressure ratio, and temperature ratio as possible is desired. [6] [7]

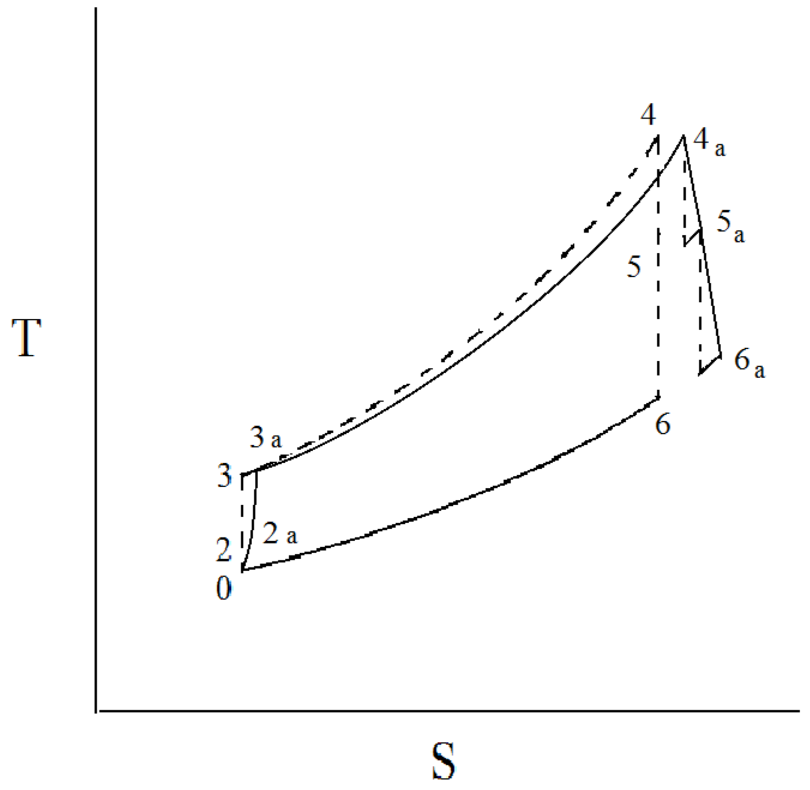

Figure 6. Actual Brayton cycle

In the actual cycle there are a number of differences with regard to the ideal case. Compression and expansion is not isentropic, and there are pressure losses along the whole path that the air takes in the engine. The isentropic efficiency for the compressor and turbine is an expression for the differences between the ideal case and the actual case, a meassure of how much of the theoretically available heat that is converted to work on the rotor in the case of the turbine, and for compressors how much of the mechanial work done by the rotor leads to increase in energy of the gas.

$$\eta_t = e_{W,t,actual} / e_{W,t,ideal} = (h_{04} - h_{05,a}) / (h_{04} - h_{05}) \quad (14)$$

$$\eta_c = e_{W,c,ideal} / e_{W,c,actual} = (h_{03} - h_{02}) / (h_{03,a} - h_{02})$$

There are two types of turbines and compressors which are used in jet engines and power turbines: axial and radial/centrifugal. There rotating mechanical part exchanges energy on a continuous flow of air. Both are designed with two main parts, a rotating and a static part.

The rotating part, rotor, transfers kinetic energy to/from the fluid. In the the static part, stator, the kinetic energy is converted to pressure by redirecting the flow and by increasing the flow area to slow the fluid down. Or vice versa, to convert pressure to kinetic energy. Each pair of rotor and stator is called a stage and are compounded in order to achieve greater pressure differentials. In axial compressors, the pressure rise per stage is usually in the range 1.1:1 to 1.4:1, whereas centrifugal regularly operate around 3:1 and in extreme cases up to 12:1. The stages are usually compounded and some designs use a mixture of radial and axial. In high performance applications, such as in modern aircraft engines, many stages are used to achieve total pressure ratios of up to 40:1 . For turbines the axial type is almost exclusively used as the pressure differential needed is lower, and isentropic efficiency is more important. [3]

Performance prediction for compressors and turbines

Using a model of simple one dimensional flow, a way to describe the gas stream is to use three basic equations. These are derived from conservation of mass, conservation of momentum and conservation of energy.

The mass of the gas is conserved, with the fluid seen as a continuum this can be formulated as:

$$m=\rho AV \quad (16)$$

where

m	is the mass flow rate of the fluid
ρ	is the fluid density
A	is the cross sectional area of the passage
V	is the velocity of the fluid

Conservation of momentum, or more specifically conservation of angular momentum can be formulated in what's known as Euler's turbine equation, or the momentum equa- tion. The change in angular momentum on the fluid stream passing over the rotor is

equal to the torque from the rotor. This can be written as:

$$\tau = \dot{m}\,(r_1 V_{\theta,1} - r_2 V_{\theta,2}) \quad (18)$$

the product of the torque and the angular velocity is the rate of energy transfer

$$\tau\omega = \dot{m}\,(r_{1\omega} V_{\theta,1} - r_{2\omega} V_{\theta,2}) \quad (19)$$

so the specific work, e_W, can be written as

$$e_W = U_1 V_{\theta,1} - U_2 V_{\theta,2} \quad (20)$$

where U_1 and U_2 is the tangential velocity of the rotor, blade velocity, at respective radii. Note the sign, by convention work done by the fluid is defined as positive, so for a compressor this expression would be negative.

In the case of an axial rotor, the blade velocity is constant from inlet to outlet, $U_1 = U_2$, so

$$e_W = U(v_{\theta,1} - V_{\theta,2}) \quad (21)$$

And for the case of a centrifugal compressor with no pre-whirl, the incoming flow has no tangential component, $v_{\theta,1} = 0$, so

$$e_W = -U_2 V_{\theta,2} \quad (22)$$

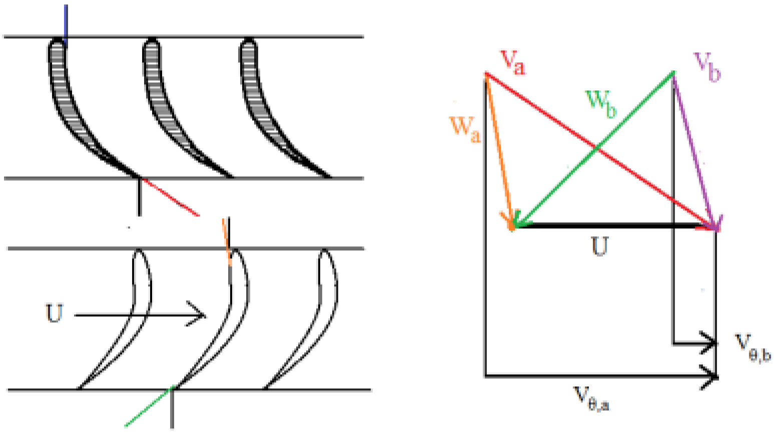

Figure 7: Velocity triangles for axial turbine. W is the relative stream velocity

Combustion chamber

In the combustion chamber is where the combustion takes place. Here, heat is added to the jet engine in the Brayton Cycle. Compressed air flows from the compressor into the chamber and ignites after being mixed with the fuel. The efficiency of the combustion is given by

$$\eta_{combust} = \Delta h_{actual}\ \Delta h_{theoretical=}((m_a + m_f)h_3 - m_a h_2)/\ m_f\ (LHV_f)$$

m_{air}	mass flow of gas
m_{fuel}	mass flow of fuel
h_3	enthalpy of gas after combustor
h_2	enthalpy of gas before combustor
LHV	fuel heating value

The actual change of enthalpy in the chamber is given by Δh_{actual} and is divided by the theoretical change of enthalpy, $\Delta h_{theoretical}$, given by the energy added by the fuel. For this formula we assume an adiabatic process where no heat flows through the boundary of the chamber $\Delta Q = 0$.

The efficiency given is to see how much of the fuel that takes part in the combustion. Fuel that is unburned is wasted and therefore reduces the efficiency. A major problem in maintaining a high efficiency is loss of pressure. In an ideal Brayton cycle the pressure is kept at a constant level through the combustion chamber. But with pressure losses from such things as wall friction, turbulence and heat loss, it is not possible. There are three stages in the combustion chamber. The recirculation zone, the burning zone and the dilution zone. Here the fuel gets, respectively, evaporated and partially burned, and then completely burned, and last mixed with bypass air to provide proper cooling. About 25% to 35% of the incoming air is entered directly into the flame tube, where the combustion takes place. The rest of the air is bypassed and used for cooling of the housing and to keep a steady flame. An important part of the chamber is the diffuser, located before the liner, which is used to slow the compressed air down to a speed better suited for combustion. In addition to the diffuser the bypassed air is also used to create turbulence in the liner which also slows the flow. [8]

Figure 8 shows how the velocity of the gas relates to the fuel-air ratio, this shows the important of velocity for a good combustion and also that there is an upper limit. A high velocity and a high fuel-air ratio will give a rich blowout. Which means that oxy- gen is displaced by fuel, which lowers the temperature of the flame and in some cases distinguishes it. A lean blowout is where not enough fuel is given to the flame and could also cause it to be distinguished, this is also used for lowering the engine RPM. The peak velocity and optimal fuel-air ratio gives the best combustion.

Fuel-air ratio when burning propane, which is the fuel chosen for this project, is approximately 1 kg propane per 12 m^3 of air.

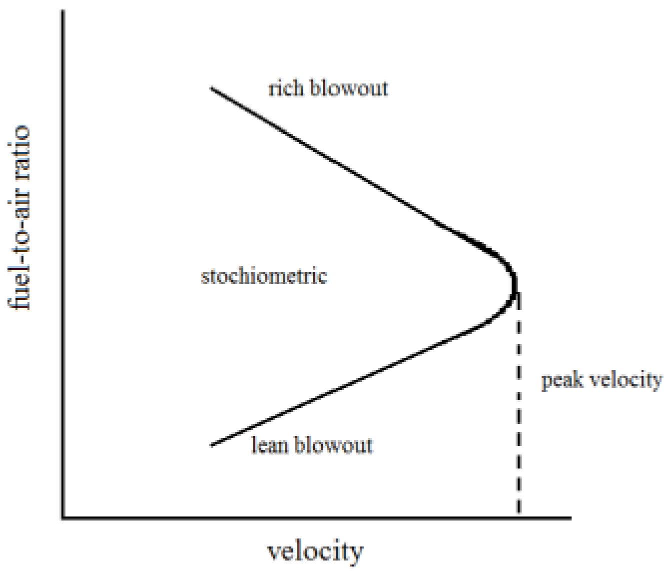

Figure 8. Fuel-air ratio vs velocity

Different from an internal combustion engine, in which ignition is needed at every cycle, the jet engine works with a continuous flow. The igniter needs only to create a spark at the start-up. Once the air and fuel-mixture has been ignited the combustion will be self-sustained. There are three different types of combustion chambers used in aircrafts. Annular, can and can-annular, as shown in cross-section in figure 9. All three types have the same function, to increase the temperature of the high-pressure gas. The combustion chamber used for this project is the annular combustion chamber.

Figure 9: Cross-section of can, annular and can-annular type combustion chamber.

Can and can-annular work in similar ways. The combustion takes place in several cans, placed symmetrically around the shaft. The difference lies in the forming casing. The can-annular has a more evenly structure, keeping the cans together. While the can type is kept together by a ring-type structure.

The annular combustion chamber is the most common type. It is the most efficient of the three and has the simplest structure.

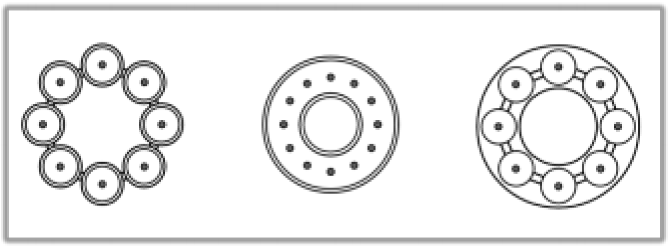

Figure 9. Cross-section of can, annular and can-annular type combustion chamber

1.3 Failures analysis

The first Dreamliner was delivered to customer in September 2011, therefore we cannot obtain objective analysis of fuel system reliability. Nowadays two the most major incidents connected to fuel system failure will be considered shortly next.

During analysis of events associated with the Boeing 787 Dreamliner from November 2011 till January 2016 occurred 22 incident due to different malfunctions. Only one incident connected with a fuel system occurred during this time (excluding one incident when two fuel filters were not installed due to maintenance staff carelessness).

Table 1.1 Events associated with the Boeing 787 Dreamliner, November 2011 - January 2013

Date	System	Component	Failure mode	Event description	Airline
November 2011	Landing gear	Hydraulic valve	Failure to open/close	The ANA-operator flight had to make a second attempt at landing using alternate extension backup, after a faulty hydraulic valve could not deploy the landing wheel.	All Nippon Airways Registration (ANA) JA801A
February 2012	Fuselage	Stiffening rods	De-lamination	Stiffening rods/shear ties used to connect the fuselage skeleton with the skins had delaminated from the skins	All Dreamliner Aircraft
July 2012	Engine ancillary	Gearbox	Corrosion	ANA grounded five of its 11 Dreamliners,	ANA

	system			due to corrosion of parts of the gearbox used to drive ancillary systems in the Rolls Royce Trent 1000 engine.	
July 2012	GEnx engine	Fan shaft	Fracture	One of the shafts that connect the fan and the booster to the low-pressure turbine of the dual-shaft GEnx engine fractured at the rear end of the threads where the retaining nut is assembled. This occurred during pre-delivery taxi test.	Pre-delivery
September 2012 Engine ancillary	Engine ancillary system	Hydraulic system	Leak	ANA aborted flight from Okayama Airport after detecting smoke-like emission due to misting of oil dripping from hydraulic pump on the hot engine	ANA: JA801A
December 2012	Control system	Electrical panel	Alarm	Aircraft headed from Houston to Newark, emergency-landed in New Orleans after a	United Airlines - Registration N26902;

				false alarm indicated generator failure. Short circuiting on an electrical panel was found to be the cause of the false alarm. The same problems were reported in one of the Qatar Airways aircraft and another United Airlines aircraft in the same month.	Qatar - Registration A7-BCA
December 2012	Engine ancillary system	Fuel system	Leak	FAA ordered an inspection into improperly installed fuel line connectors after finding that it could result in leaks leading to fuel exhaustion, thermal runaway, engine power loss or shutdown.	All Boeing Dreamliners
January 2013	Li-ion battery system	Battery	Smoke	Heavy smoke was found emitting from the electronic equipment bay in the aft cabin of a parked aircraft at Logan	Japan Airlines Registration: JA829J

				International Airport, Boston. The smoke was attributed to the thermal runaway caused by internal short circuiting of one of the APU Li-ion battery cells.	
January 2013	Li-ion battery system	Battery	Smoke	The flight on its way to Tokyo from Yamaguchi Ube Airport received an Engine Indicating and Crew Alerting System (EICAS) message reporting battery failure accompanied by an unusual smell in the cockpit. Battery heating and thermal runaway were reported to be the probable causes for smoke.	ANA: JA804A
September 18 2013	Engine ancillary system	Fuel system	Alarm	The flight powered by two Rolls-Royse Trent 1000-67B	Registration: SP-LRB

				turbofan engines experienced a maintenance status message “ENG FUEL FILTER R” on its way from Beijing to Warsaw Chopin Airport. Later on, a maintenance investigation found that the fuel filter in the right engine had not been installed. Further examination revealed that the fuel filter was not installed in the left engine as well.	
September 19 2013	Engine ancillary system	Fuel system	Alarm	Following the SP-LRB, this flight was checked the next day to reveal that there were no fuel filters installed in this aircraft too.	LOT Polish Airlines Registration: SP-LRC

During this investigation it became clear that the most dangerous failures connected to fuel system of Dreamliner occured further.

The Australian Transport Safety Bureau (ATSB) has today revealed the outcome of its investigation into the “uncommanded engine shutdown”

During a flight from Singapore to Perth on October 11, 2018, a Scoot Boeing 787-9, registration 9V-OJE, suffered a problem with an engine that caused it to shut down. Around two hours into the flight, the aircraft's crew received two status messages "indicating abnormalities within the right engine." At 46km (28.6miles) north of Perth Airport, the crew became aware that the right engine, a Rolls-Royce Trent 1000, was responding slowly to commands.

During the aircraft's descent, the engine's performance continued to deteriorate and, while passing through 9,000 feet, the aircraft developed "severe thrust asymmetry." Soon afterward, the engine shut down. The ATSB report says that the crew had followed appropriate procedures and, because of the proximity of the airport, decided not to attempt to restart the engine.

The crew landed the plane safely with the one operational engine. After a visual inspection of the aircraft by emergency services, it was cleared to taxi to the gate. The passengers disembarked normally via the airbridge. There were no resulting injuries, and the aircraft was undamaged.

The subsequent investigation into the incident by the ATSB and Rolls-Royce found that an inlet filter had been blocked by debris from worn bearings in the secondary high-pressure fuel pump, which had restricted the flow of fuel. Rolls-Royce discovered that the secondary HP pump-driven gear bearings were heavily worn, with evidence of scoring and missing material.

After the crew of another Scoot 787 received similar maintenance messages in November 2018, wear was also found on the secondary HP pump journal bearings. Rolls-Royce monitored the Trent 1000 engines of Scoot's 787 fleet. Five more events involved messages generated by inlet filters being blocked by fuel pump debris.

Between late 2018 and early 2019, Rolls-Royce determined that Scoot's fleet was "particularly susceptible to low-life wear in the journal bearings of the secondary high-pressure fuel pump." The ATSB report says, “The Rolls-Royce investigation identified various potential factors that might have contributed to low life journal wear, including the fleet’s operation, maintenance, fuel quality, or pump design and construction.

“It also considered factors in addition to those listed above but, due to the number of variables, was unable to identify which might have been dominant with respect to the pump bearing wear.”

As a result of the incident, Rolls-Royce has updated its Fault Isolation Manual for the Trent 1000 to instruct all operators to remove the fuel pump and hydro-mechanical unit when maintenance messages are received about the fuel metering valve not being in the commanded position.

Rolls-Royce is also monitoring maintenance messages and looking into the possibility of using flight data to detect fuel pump journal wear before its effects on valve operation become apparent.

The official report of Australian Transport Safety Bureua describing situation with 9V-OJE:

"The ATSB determined that following a series of engine status and alert messages, 9V-OJE experienced an uncommanded engine shutdown while on descent into Perth, before landing safely using the operational engine.

Based on a review of the flight data and an examination of engine components by Rolls-Royce, the engine shutdown was due to debris from worn journal bearings in the engine’s secondary high-pressure fuel pump blocking an inlet filter for the fuel metering valve servo assembly. This prevented the valve from delivering sufficient fuel to the engine.

Rolls-Royce also determined that, between late 2018 and early 2019, the operator’s fleet of 787 aircraft had been particularly susceptible to low-life wear in the journal bearings of the secondary high-pressure fuel pump. It identified a number of potential factors that led to the component wear but, due to the number of variables, a single/dominant reason could not be established.

What has been done as a result

Rolls-Royce updated its Fault Isolation Manual to instruct all operators to remove the fuel pump and hydro-mechanical unit in the event of a maintenance message regarding the fuel metering valve not being in the commanded position. Rolls-Royce is also monitoring maintenance messages and investigating the possibility of using flight data to detect fuel pump journal wear before its effects on valve operation become apparent.

Safety message

This occurrence highlights the importance of flight crew being familiar with emergency procedures, so that the appropriate corrective action can be taken quickly and effectively. In this case, the flight crew worked effectively to assess the situation, and took appropriate action to minimise risk in accordance with the operator's flight crew operations manual.

This occurrence also shows that positively identifying the factors contributing to technical failures can be difficult and time consuming. However, manufacturers and operators can implement interim risk mitigation measures, as was the case here."
So the main reason of fuel blockage was the ice droplet with the fuel pump defect. In total, it`s not correct to develop the maintenance basis as Rolls-Royse company began to reset the old type pump. And the new one nowadays with appropriate maintenance level has enough reliability condition.
On 29 March 2019 the No 1 General Electric GEnx-1B engine of Jetstar Airways Boeing 787-8 VH-VKJ, flying from Cairns, Australia to Osaka Kansai International, Japan, fell below idle during the descent at an altitude of about 16,000 ft for 8 seconds. The No 2 engine then fell below idle too for 81 seconds. The aircraft safely landed at Kansai International less than 30 minutes later.

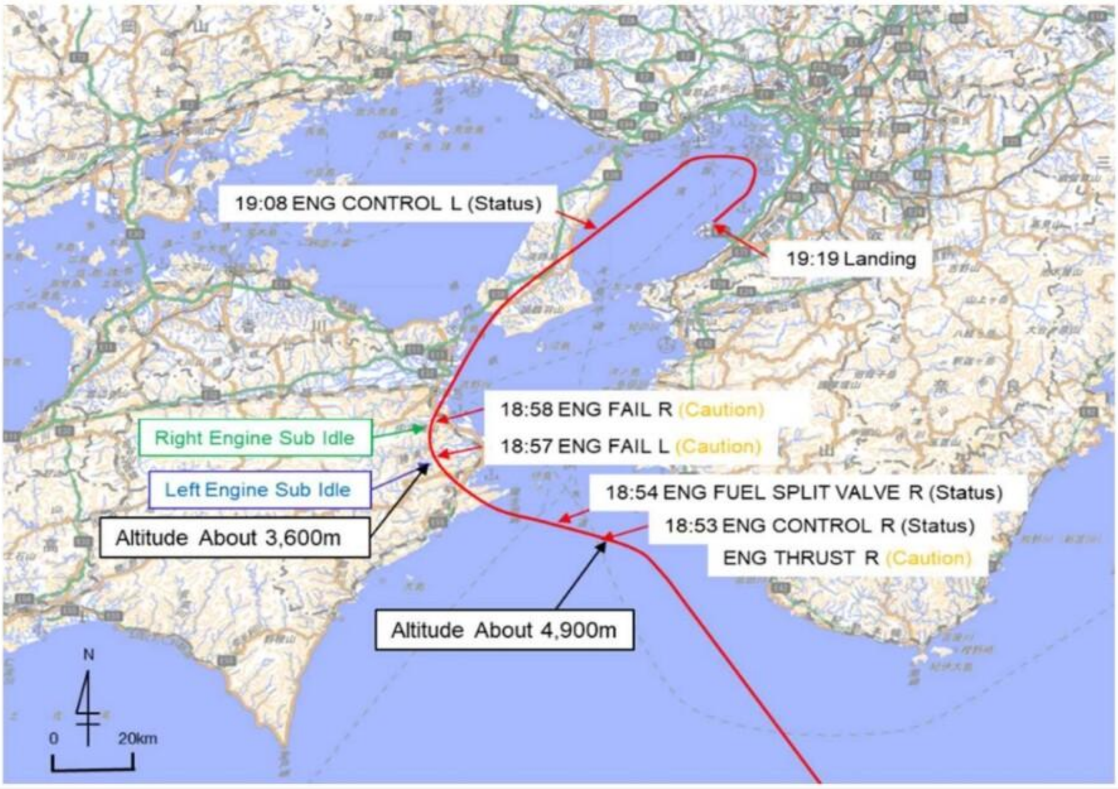

Figure 10. Jetstar Airways Boeing 787-8 VH-VKJ GEnx-1B Engine Incident Approaching Kansai

The Japan Transport Safety Board (JTSB) explain in their safety investigation report (issued 25 June 2020) that engine rpm oscillations had been recorded during the incident.

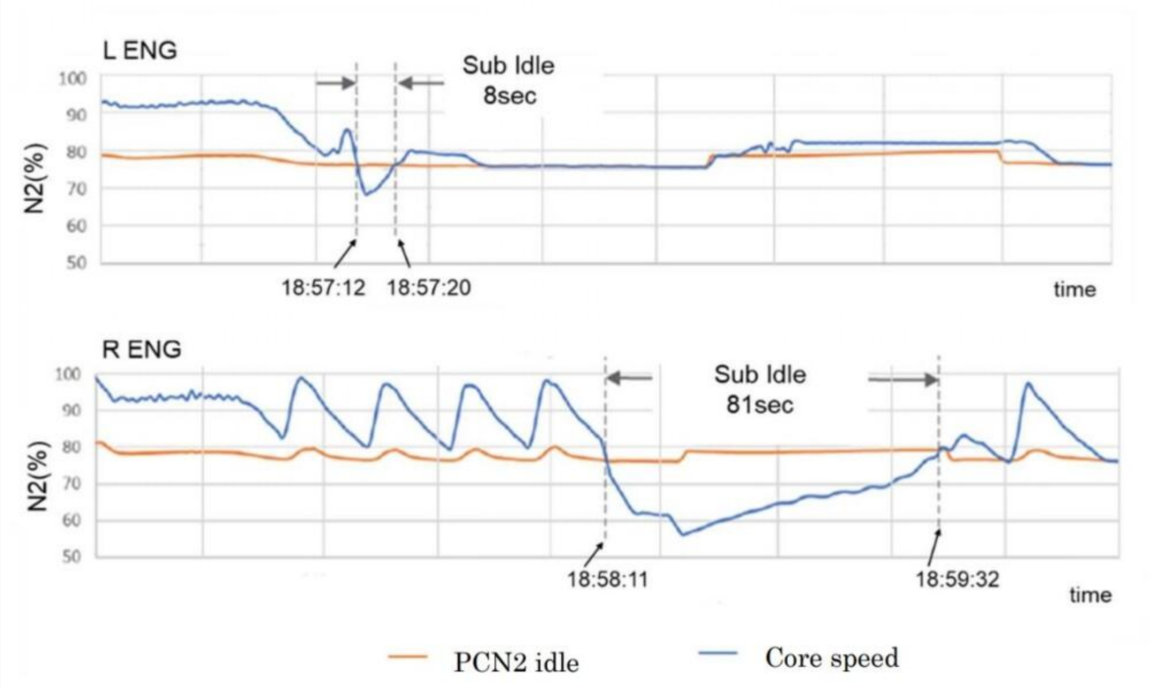

Figure 11. Jetstar Airways Boeing 787-8 VH-VKJ GEnx-1B Engine Speed Oscillations for No1/Left and No2/Right

In fact oscillations had been recorded by the FDR since a fuel biocide treatment had occurred on 27 March 2019. However, these oscillations had been so small as not to have been noticed until the descent on 29 March 2019 when "ENG FAIL L" and "ENG FAIL R" EICAS messages also appeared. During the subsequent investigation…

….a residue, primarily composed of magnesium salts was observed in multiple locations (fuel filter, fuel metering valve [FMV] spool, fuel splitting valve [FSV] spool, variable bleed valve [VBV] spool and high pressure turbine [HPT] active clearance control [ACC spool]).

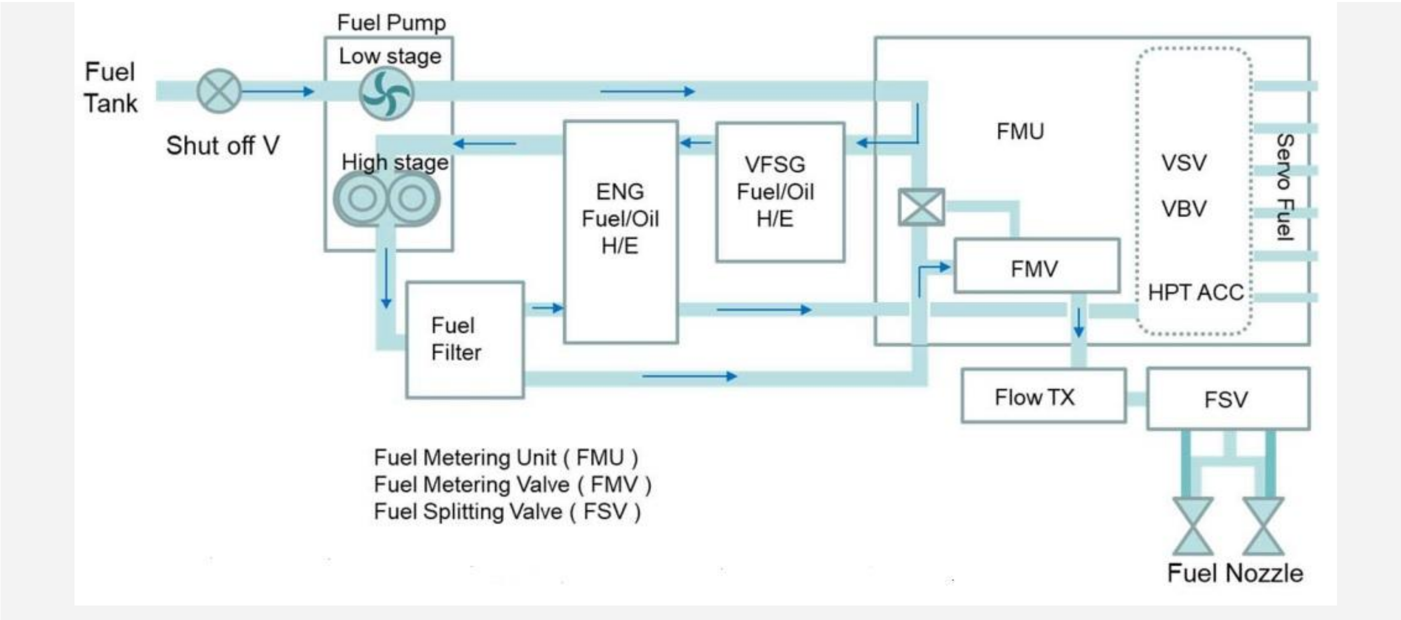

Figure 14.GE GEnx-1B Fuel System

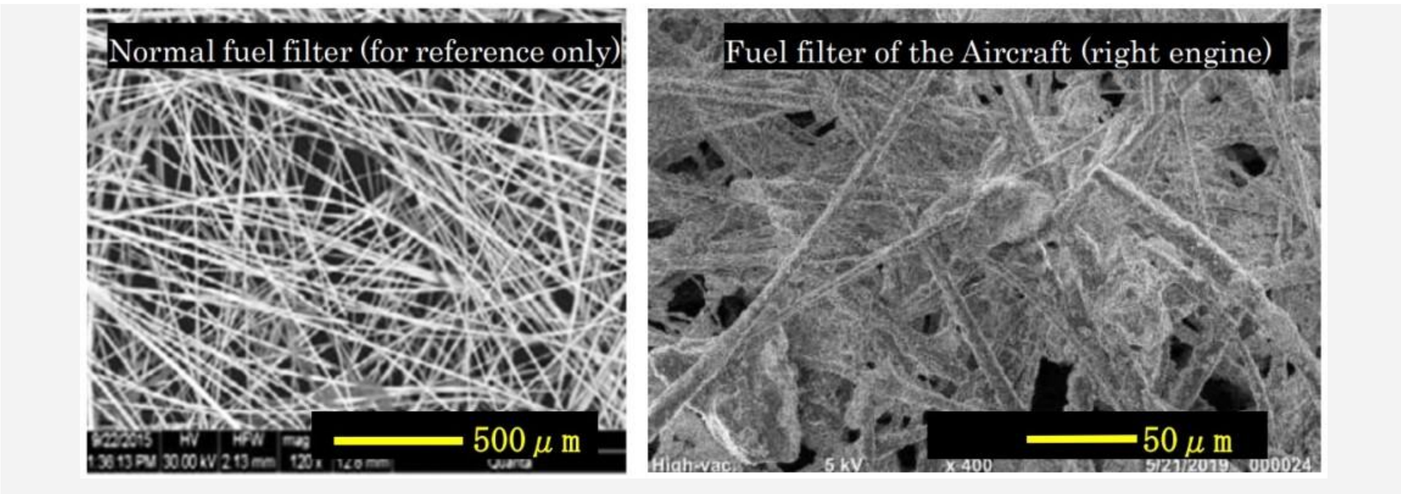

Figure 13 Jetstar Airways Boeing 787-8 VH-VKJ GEnx-1B Fuel Filter Residue

Testing showed that up to 320 times more force was needed to move the control servos with the residue.

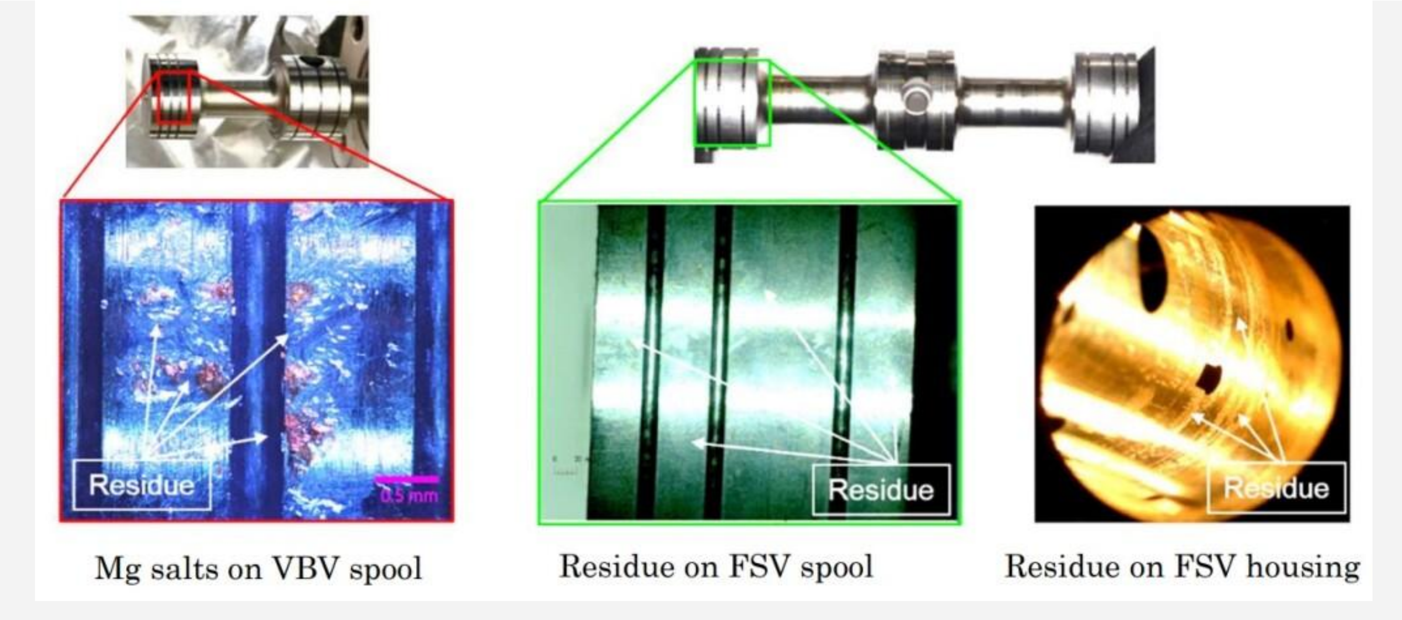

Figure 14 Jetstar Airways Boeing 787-8 VH-VKJ GEnx-1B Spool's Contaminated with Magnesium Salts

The JTSB therefore concluded that when fuel pressure was low when descending at flight idle, "the FMV spool and FSV spool had restricted freedom of movement" and that the engines had dropped below idle due to the FSV sticking.

JTSB say:

It is probable that biocide treatment inside fuel tanks conducted two days before the serious incident was involved in the accumulation of [the] residue…because the composition of the residue were similar to the Kathon FP1.5.

Biocide treatment is used to prevent microbial growth that can cause corrosion and damage fuel and engine systems.

The Aircraft [had been] ferried to Auckland International Airport, New Zealand to borrow facilities of other company to conduct biocide treatment inside all three fuel tanks (left, center and right) because the Operator did not have their own facilities.

…biocide treatment is conducted by connecting biocide treatment cart to a certain position of fueling hose to mix biocide with fuel for loading into fuel tank. AMM stipulates that biocide of either Kathon FP1.5 or Biobor JF is used, and the Operator used Kathon FP1.5.

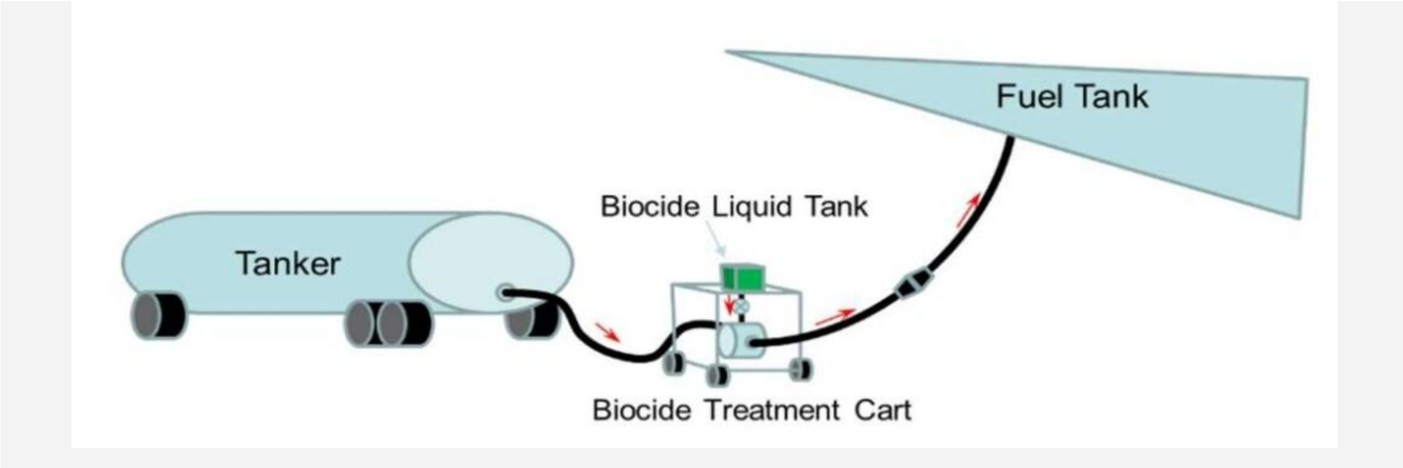

Figure 15. Biocide Treatment

Kathon FP1.5 (MIL-S-53021A) composition is: Glycol: 90.0%, Water: 5.85%, Magnesium salts: 2.65%, 5-Chloro-2-Methyl-4-Isothiazolin-3-one: 1.15% and 2-Methyl-4-Isothiazoliln-3-one: 0.35%. The magnesium salts contained in Kathon FP 1.5 are insoluble in fuel but will dissolve into water if a water phase is present in the fuel.

When Kathon FP1.5 is used, biocide and fuel are loaded to make concentration ratio inside fuel tank 100 ppm (parts per million) by volume. Therefore, in the event that fuel remains in aircraft, fuel and biocide to be loaded require adjustments to obtain a higher concentration ratio for loading into aircraft so that the final concentration ratio inside the tank can be 100 ppm. After completing fuel loading, biocide treatment is completed by soaking fuel for 12 to 24 hours keeping concentration ratio inside fuel tank at 100 ppm.

The certifying staff involved had not recorded details of the biocide quantity added. JTSB comment that “It is desirable to keep these records because they are considered to be important for traceability of maintenance work.”. JTSB determines that the actual concentration was 250 ppm in the left tank and about 285 ppm in the right tank. There was fuel at a lower dosage in the centre tank but it appears that mixing if biocide through the fuel system was not sufficiently rapid to ensure the outer tanks were diluted.

JTSB version of the probable cause was next:

"In this serious incident, it is highly probable that, when the Aircraft was descending for landing, there occurred oscillation in rpm of each engine causing both engines to temporarily fall below idle at separate times because residue primarily composed of magnesium salts accumulated in spools impeded movement of spools that involved in fuel metering of both engines. As for the higher accumulation of residue primarily composed magnesium salts in spools, it is somewhat likely that the fuel with a higher concentration ratio of biocide, which was loaded in the biocide treatment two days before the serious incident, did not mix evenly with the remaining fuel in wing tanks, and was fed to the engines."

Safety Actions

1. The Operator suspended biocide treatment using Kathon FP1.5 inside fuel tanks of the same type of aircraft. The Operator is reviewing maintenance procedures that occur infrequently, to identify task- specific training opportunities for maintenance personnel based on AMM.

2. GE issued service bulletin (SB) for aircraft equipped with GEnx engine to notify operators to suspend biocide treatment using Kathon FP1.5. (SB 73– 0086 R00 ENGINE FUEL AND CONTROL – GENERAL (73-00-00) – SUSPENSION OF THE USE OF KATHON FP 1.5 BIOCIDE TREATMENT ISSUED SEP/30/2019)

3. Boeing deleted biocide treatment procedures using Kathon FP1.5 from the AMM of the same type of aircraft equipped with GEnx engine following SB issued by the design and manufacturer of the engine. The design and manufacturer of the aircraft also updated the AMM for all models of aircraft to explicitly describe the maximum allowable biocide concentration ratio and to record calculation of biocide amount and the amount used.

4. After receiving multiple reports of similar cases using Kathon FP1.5, the Federal Aviation Administration (FAA) issued SPECIAL AIRWORTHINESS INFORMATION BULLETIN and the European Union Aviation Safety Agency (EASA) issued Safety Information Bulletin (SIB No.: 2020-06 Issued: 20 March 2020 Use of DuPont Kathon FP 1.5 Biocide） to notify operators, repair stations, aircraft and engine manufacturers regarding the use of Kathon FP1.5. In addition, the Civil Aviation Safety Authority (CASA) issued AIRWORTHINESS BULLETIN (AWB 28-018 Issue 1 – 26 March 2020 Suspending Use of

Kathon Biocide for Treating Micro-biological Growth in Aviation Fuel) to strongly recommend to suspend the use of Kathon FP1.5 for biocide treatment.

Conclusion to part 1

Every aircraft from Cessna 172 to Antonov 225 unique and technological complicated product. Manufacturer`s aim to develop aircraft which could operate with maximal efficiency and without failures duping operations. Every Manufacturer understands that every failure hits the credibility of a company.

Concerning B787, we give a report to ourselves that it is revolutionary new type of aircraft with a number of applied innovations. On the other hand, we have the aircraft with relatively small history of failures.

Returning to the topic of our investigation, we have only 3 failures which connected to real weaknesses of fuel system. Incident with 9V-OJE showed, n my opinion, the most dangerous failure of the fuel pump. Returning to this incident Rolls-Royse company admitted defective design of the pump and began to install the new one. New problems with pump didn`t occure during further operations of Dreamliner.

Biocide treatment on VH-VKJ wasn`t connected to any defective design decisions. Investigation of this accident defined that magnesium salts accumulated in spools which reduced fuel flow throughput. Investigation said that higher concentration of biocide was loaded and didn`t mix with fuel properly. Therefore we cannot consider this event as defect in design as soon as technical staff probably checked it inappropriately.

Report also described incident with removed fuel filters which makes us remind the problem with technical staff qualifications and personal qualities.

To summarize this chapter I would like to describe B787 as highly reliable aircraft. Of course, it is not enough objective evaluation due to short story of operation (it is only 10 years in the 2021) so we can describe the Dreamliner as an aircraft which on stage of "post-certification development period".

CHAPTER 2: 787 FUEL SYSTEM WORK AND THE WAY FOR DEVELOPING

2.1 787 Fuel system design

The fuel distribution system supplies fuel from the fuel tanks to the engine combustion system.

- Distribution system components pressurize and filter the fuel for delivery to the combustor

1. The main fuel distribution components are:

- Main fuel pump (MFP)
- Fuel filter
- Fuel metering unit (FMU) which also is part of fuel control
- Fuel split valve (FSV)
- Fuel nozzles.

2. Supply fuel goes into the main fuel pump (MFP) and the through its centrifugal boost element.
3. The pressurized fuel goes from the boost element goes from the pump into the FMU.
4. A jet pump in the FMU causes an increased output pressure when mixed with the fuel bypass flow the FMU fuel by-pass valve.
5. From the FOHEs, the fuel goes back into the HP gear element to the MFP and then trough the fuel filter.
6. Most of the fuel flows from the fuel filter to the FMU.

- Some of the fuel goes through the servo fuel heater and then to the FMU to give power to give power to servos, actuators, and valves.

7. The FMU splits its inlet fuel flow into FMU bypass flow and metered flow from the combustor.
8. The FMU bypass flow is mixed in the jet pump with the flow from the MFP boost pump.

- The jet pump increases the flow of the fuel through the fuel the FOHEs for more cooling for VFSGs during engine start.

9. The metered fuel for combustion goes through the fuel metering valve and the high pressure shutoff valve (HPSOV) in the FMU.

- It then goes through the fuel flow meter and the flow split valve (FSV).

10. The FSV sets the percentage of flow that goes to the pilot primary/main manifold and the percentage of flow that goes to the pilot secondary manifold.

11. The fuel then goes to the fuel nozzles in the combustor.

These are the engine fuel and control distibution system components:

- Main fuel supply hose
- Main fuel pump
- Main fuel pump strainer
- Fuel system assembly
- Flow split valve (FSV)
- Fuel nozzles

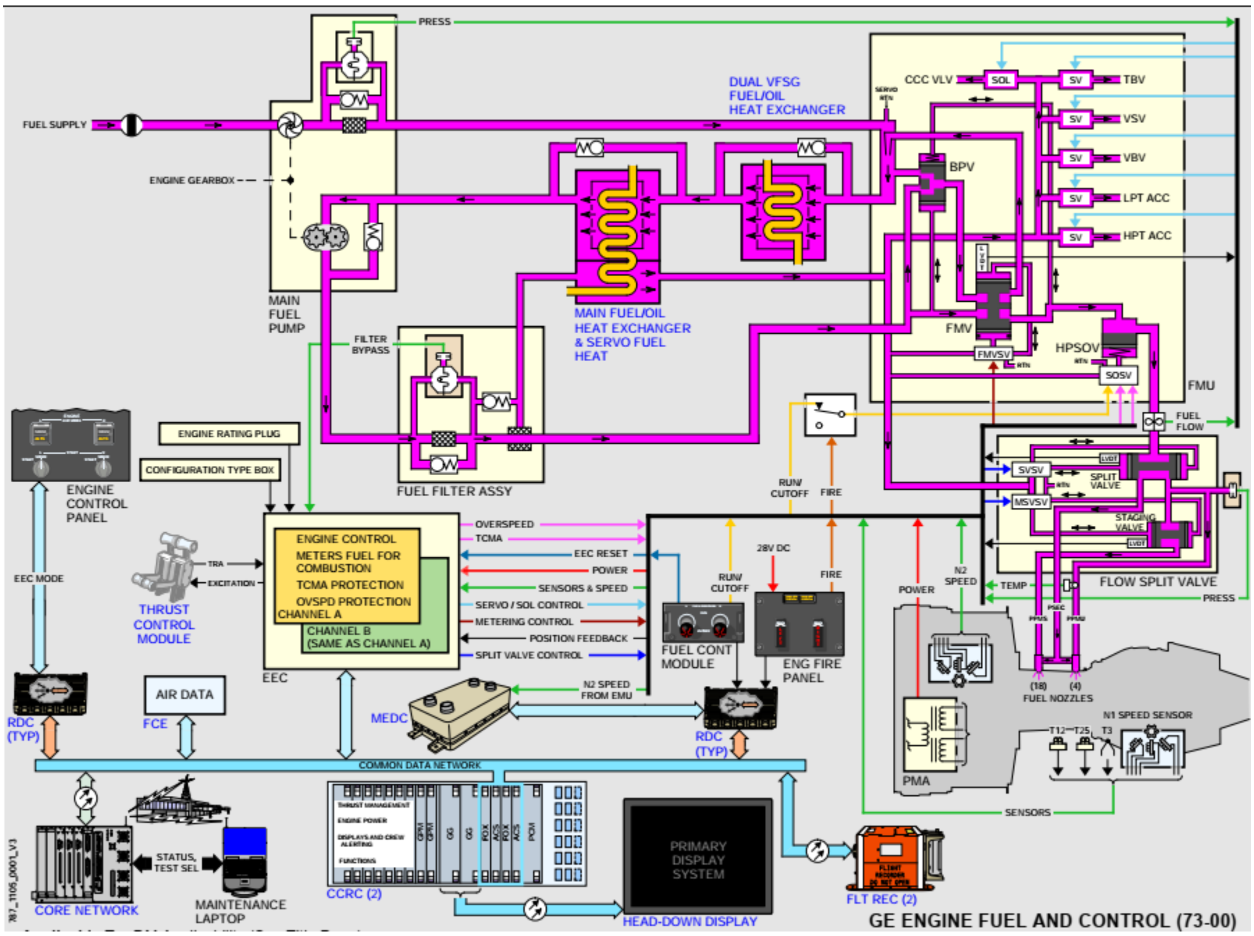

Figure 16. B787 Engine Fuel and Control principle scheme

System description

The engine fuel feed system supplies fuel from the main and center fuel tanks. Fuel from the tanks goes through the main fuel supply hose to the engine main fuel pump (MFP). A centrifugal boost element goes to the fuel metering unit. A centrifugal boost in the pump pressurizes the fuel. The fuel is then filtered through the MFP strainer.

The pressurized fuel from the boost element goes to the fuel metering unit (FMU). The FMU has a jet pump that increases the exit pressure of the boost fuel. The jet pump uses motive force from the FMU bypass fuel to increase the pressure. The fuel from the FMU goes through the variable frequency starter generator (VFSG) fuel/oil heat exchanger (FOHE) and the main fuel/oil heat exchanger (MFOHE).

The fuel then goes back to the pump and into the high pressure gear element of the MFP. From the high pressure gear element, the fuel is filtered through the fuel filter element.

Downstream of the fuel filter, a small quantity of fuel goes through the filter servo wash screen element and into the servo fuel loop of the MFOHE. This fuel then goes to the FMU as servo fuel for the fuel powered engine valves and actuators. The remaining fuel leaves the filter and goes to the FMU where it is split into metered fuel for combustion and bypass fuel. The bypass fuel is mixed with the flow coming from the MFP boost pump jet pump then returned to the MFP gear element.

The metered fuel flow for combustion goes through the EEC controlled fuel metering valve (FMV) in the FMU. The fuel is metered and then goes through the fuel flow meter (FFM) and then to the flow split valve (FSV). The FSV sets the percentage of fuel and acts as a flow distributor to give a schedule modulation fuel pressure to the 22 fuel nozzles. The nozzles send the fuel to the combustor at the correct rate for the commanded power settings of the engine.

Main Fuel Pump

1. The main fuel pump (MFP) provides:

- Sufficient fuel flow and pressure to meet engine burn flow requirements
- Servo fuel flow pressure to all fuel powered valves and actuators to the engine.

2. The MFP has 2 pump elements to pressurize the fuel:

- Low pressure centrifugal boost pump element
- High pressure gear pump element.

3. The low pressure centrifugal boost element increases fuel pressure and sends the fuel in this order to:

- Low pressure fuel strainer with bypass and differential pressure sensing
- Fuel metering system (FMU)
- Variable frequency starter generator (VFSG) fuel/oil heat exchanger
- Main fuel/oil heat exchanger (MFOHE)
- Back to the MFP.

4. The high pressure element is a positive displacement, gear-type pump.

- It sends through the filter assembly to the fuel metering system (FMU).

5. A relief valve prevents system over-pressure.
6. A strainer assembly filters the fuel before it goes to the MFOHE.
7. The MFP is driven by a shaft from the accessory gearbox (AGB).

- It is on the fuel adaptor pad, on the right side aft face of the AGB.

Purpose

The main fuel pump (MFP) pressurizes the fuel from the airplane fuel tanks.

The main fuel pump is shaft-driven by the AGB. When the core engine turns, the MFP supplies fuel pressure and flow. The MFP has 2 pump stages. The boost-stage is a centrifugal-type pump and the main stage is a gear-type positive displacement pump. Fuel from the airplane tanks flows to the inlet side of the centrifugal boost pump. A relief valve prevents system over-pressure.

The MFP fuel flow is filtered through a strainer and filter assembly. The pump has an inlet drain plug. You remove this plug to get access to the strainer between the 2 pump stages and to drain fuel from the pump.

AMM

The main fuel pump weight is 50 lbs (22.7 kgs).

- Special equipment must be used when you remove and install the pump.

The main fuel pump attaches to the aft, right face of the main gearbox. The fuel filter assembly attaches to the main fuel pump.

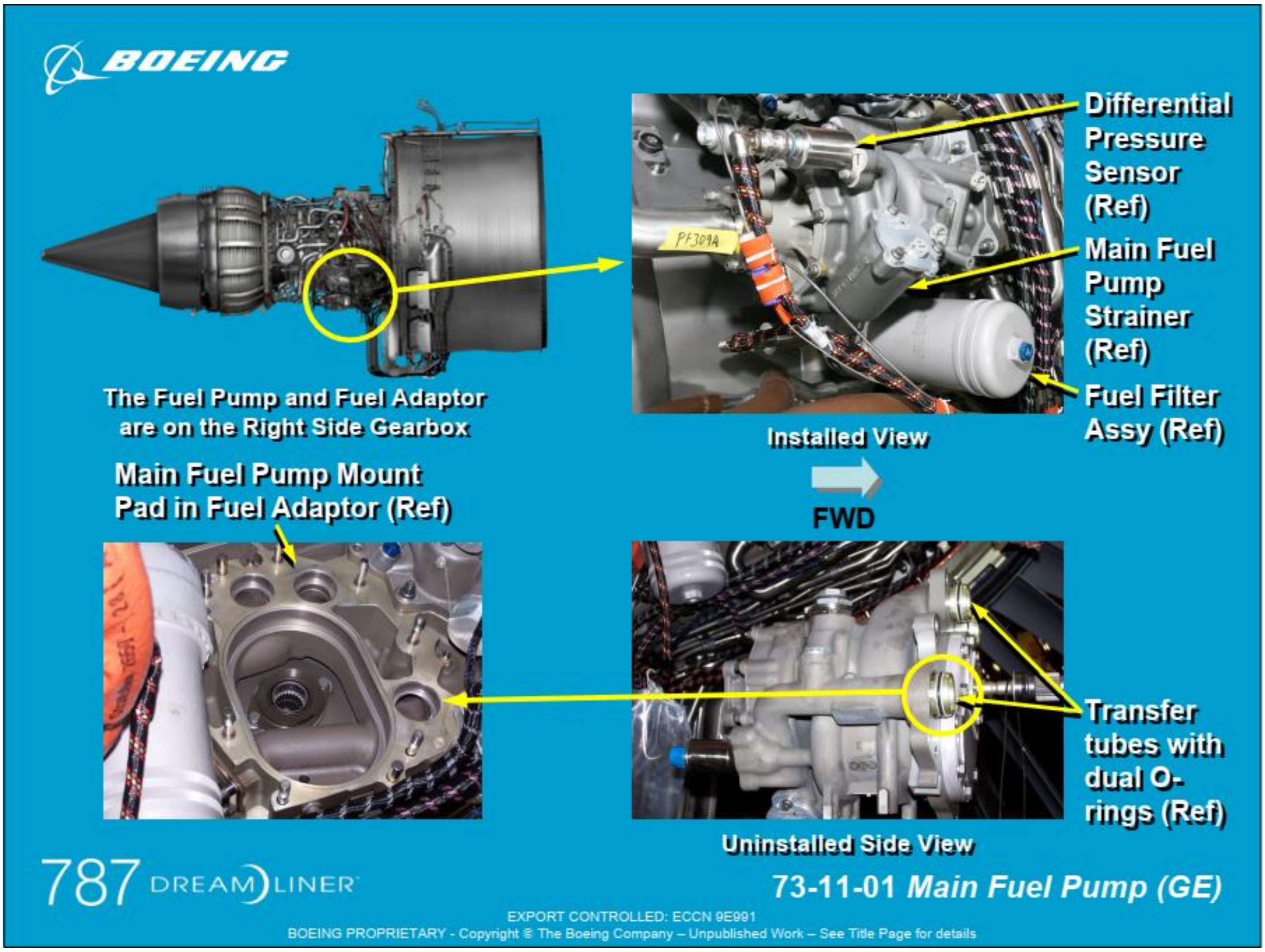

Figure 17. GEnx Engine Main Fuel pump

Main fuel pump strainer

1. From the low pressure centrifugal boost pump element, the fuel goes to the main fuel pump strainer assembly.

- The strainer filters the fuel before it goes to the MFOHE.

2. The strainer has a bypass valve and differential pressure sensor.

- The differential pressure sensor gives an indication when the fuel strainer is almost to a bypass condition.

3. The interstage fuel strainer filters the main fuel pump (MFP) fuel that comes from the boost stage and goes to the high pressure gear stage.
4. The strainer stops particles that could contaminate the high pressure stage of the positive displacement pump.

5. The interstage strainer differential pressure sensor measures the difference in pressure upstream and downstream the MFP boost stage strainer filter for maintenance fault monitoring.
6. When the MFP strainer differential pressure sensor shows that the fuel filter is almost bypassed, the switch closes and an amber EICAS advisory message, ENG FUEL STRAINER L/R, shows.

The main fuel pump strainer filters the main fuel pump fuel that comes from the boost stage and goes to the high pressure gear stage.
Physical Description
The main fuel pump strainer is a metal mesh and includes a differential bypass indication. The EEC monitors the bypass indication. When the MFP strainer differential pressure sensor shows that the fuel filter is almost to a bypass condition, the switch closes. This causes an amber EICAS advisory message, ENG FUEL STRAINER L/R.

The main fuel pump strainer is on the bottom right side of the main fuel pump. Access to the strainer is through a cover on the pump housing.

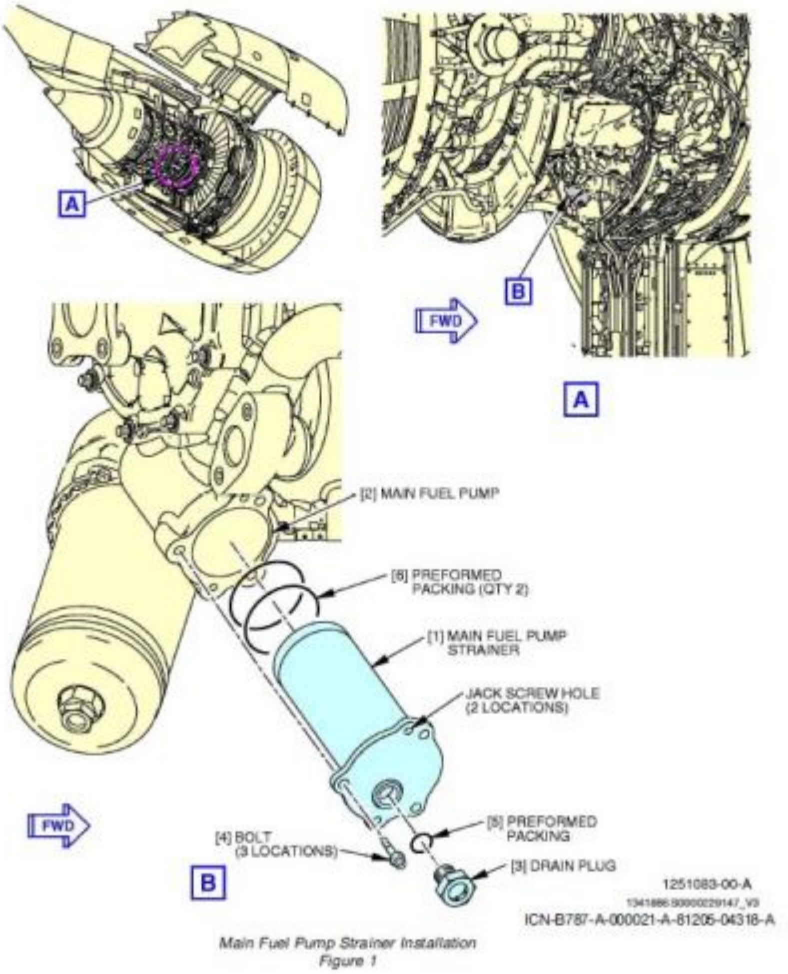

Figure 18. Installation of Main Fuel Pump Strainer

Fuel Filter Assembly

1. The fuel filter assembly removes contaminants from the fuel.
- It has a removable filter bowl and a disposable filter element.
2. A differential pressure sensor is on the fuel filter housing.
- At high power, the electronic engine control (EEC) uses the pressure signal to detect a filter clog condition.
3. The fuel filter assembly also has a bypass valve. - This valve opens if the filter element clogs.
4. From the main fuel pump (MFP), the high pressure fuel goes to the fuel filter. 5. From the filter, most of the fuel goes to the fuel metering unit (FMU).

6. Some of the fuel goes through the servo fuel heater section of the main fuel/ oil heat exchanger (FOHE).

- This heated fuel goes to the FMU to power servos, actuators, and valves.

7. The fuel filter assembly is on the fuel adaptor.

- The fuel adapter is on the aft face of the accessory gearbox (AGB), at the 6:00 position.

Purpose

The fuel filter removes contamination from the fuel after it flows through the main fuel pump.

The filter has a differential pressure sensor to supply electronic system monitoring data to the electronic engine control (EEC). The fuel filter bypass valve opens when the filter element plugs with contamination. The servo wash screen is downstream from the filter element. A small quantity of fuel flows across the wash screen to the servo loop of the main servo fuel (MSF) nozzle control fuel oil heat exchanger (FOHE). This is the servo filtered fuel. The servo filtered fuel flow goes from the wash screen in the filter assembly to the fuel management unit (FMU) for power to servo actuators and valves. The wash screen includes a high differential pressure bypass valve.

You remove the filter housing to change or examine the filter element. You can remove the filter assembly as a unit.

Physical Description

The fuel filter assembly has these parts: - Housing

- Filter element
- Bypass valve
- Servo wash screen.

The filter has a differential pressure sensor to supply electronic system monitoring data to the electronic engine control (EEC). The fuel filter bypass valve opens when the filter element plugs with contamination. The servo wash screen is downstream from the filter element. A small quantity of fuel flows across the wash screen to the servo loop of the main servo fuel (MSF) nozzle control fuel oil heat exchanger (FOHE). This is the servo filtered

fuel. The servo filtered fuel flow goes from the wash screen in the filter assembly to the fuel management unit (FMU) for power to servo actuators and valves. The wash screen includes a high differential pressure bypass valve.

You remove the filter housing to change or examine the filter element. You can remove the filter assembly as a unit.

Physical Description

The fuel filter assembly has these parts: - Housing

- Filter element
- Bypass valve
- Servo wash screen.

AMM

The filter mounts by a ratchet type lock tab.

There is drain plug on the bottom of filter housing.

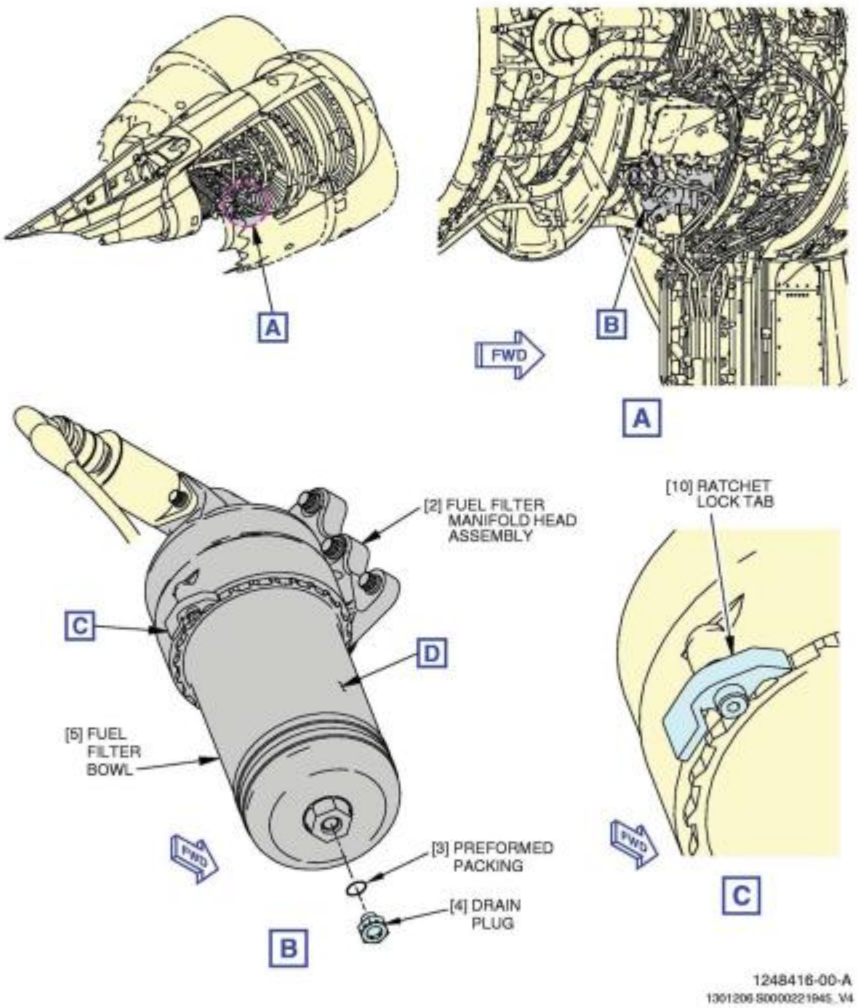

Figure 19. Fuel Filter Assembly Installation

Fuel Metering Unit

1. The fuel metering unit (FMU) is on the fuel adaptor on the accessory gearbox (AGB).

- It controls and distributes the correct amount of fuel necessary for combustion.

2. The FMU also supplies servo fuel as muscle fuel pressure to move actuators and valves in the engine air system.

3. It is an electronically controlled hydro-mechanical unit. The FMU is controlled by commands from the electronic engine control (EEC).

4. The EEC monitors feedback from engine and airplane sensors to calculate the correct combustor fuel flow. Electrical signals go to control these FMU internal components:

- Fuel metering valve (FMV)
- High pressure shutoff valve (HPSOV) - Electro-hydraulic servo valves (EHSV) - Bypass valve (BPV).

5. The FMV is a servo valve inside the FMU with position feedback to the EEC from a dual-channel linear variable differential transformer (LVDT).

6. The HPSOV, also referred to as the pressurizing shutoff valve (PSOV), is a spring-biased, servo operated valve with a primary function to control the engine shutdown.

7. The HPSOV's secondary function is to provide sufficient fuel pressure at low pressure conditions to maintain sufficient force margins for the FMU internal EHSVs to operate the fuel powered actuators.

8. The EHSVs receive electrical commands that controls fuel flow to move the FMV and HPSOV spools.

9. The bypass valve has an internal spool valve controlled by servo pressure from both sides of the FMU.

10. There is an EEC commanded electronic over-speed function which also controls the HPSOV.

11. The FMU also has a thrust control malfunction accommodation (TCMA) function that is also commanded by the EEC for HPSOV control.

Purpose

The fuel metering unit (FMU) supplies the correct quantity of fuel necessary for combustion. The FMU also supplies servo fuel for valves and actuators and it supplies the fuel shutoff function.

Physical Description

The FMU has these valves to control and supply fuel: - Fuel metering valve (FMV)

- High pressure shutoff valve (HPSOV)
- Electro-hydraulic servo valves (EHSV).
- Bypass valve.

The FMU gets control signals from the electronic engine control (EEC). The EEC monitors data from engine and airplane sensors and calculates the necessary combustor fuel flow. This data goes to the FMU. The FMU changes the signals to fuel flow rate with an internal servo valve. The servo valve controls the fuel flow to move the fuel metering valve in the FMU. A dual- channel linear variable differential transformer (LVDT) gives FMV position feedback to the EEC.

The FMU also supplies servo fuel to these valves and actuators: - Variable bleed valves (VBV)

- Variable stator vanes (VSV)
- High pressure turbine active clearance control (HPTACC)
- Low pressure turbine active clearance control (LPTACC) - Transient bleed valve (TBV)
- Fuel nozzle controller (FNC) servo valves.

The FMU supplies an engine shutdown function that uses a shutoff solenoid to control the HPSOV.

The FMU includes a thrust control malfunction accommodation (TCMA) EHSV that is controlled by the EEC. The TCMA decreases fuel flow to a safe level when there is a signal from the EEC.

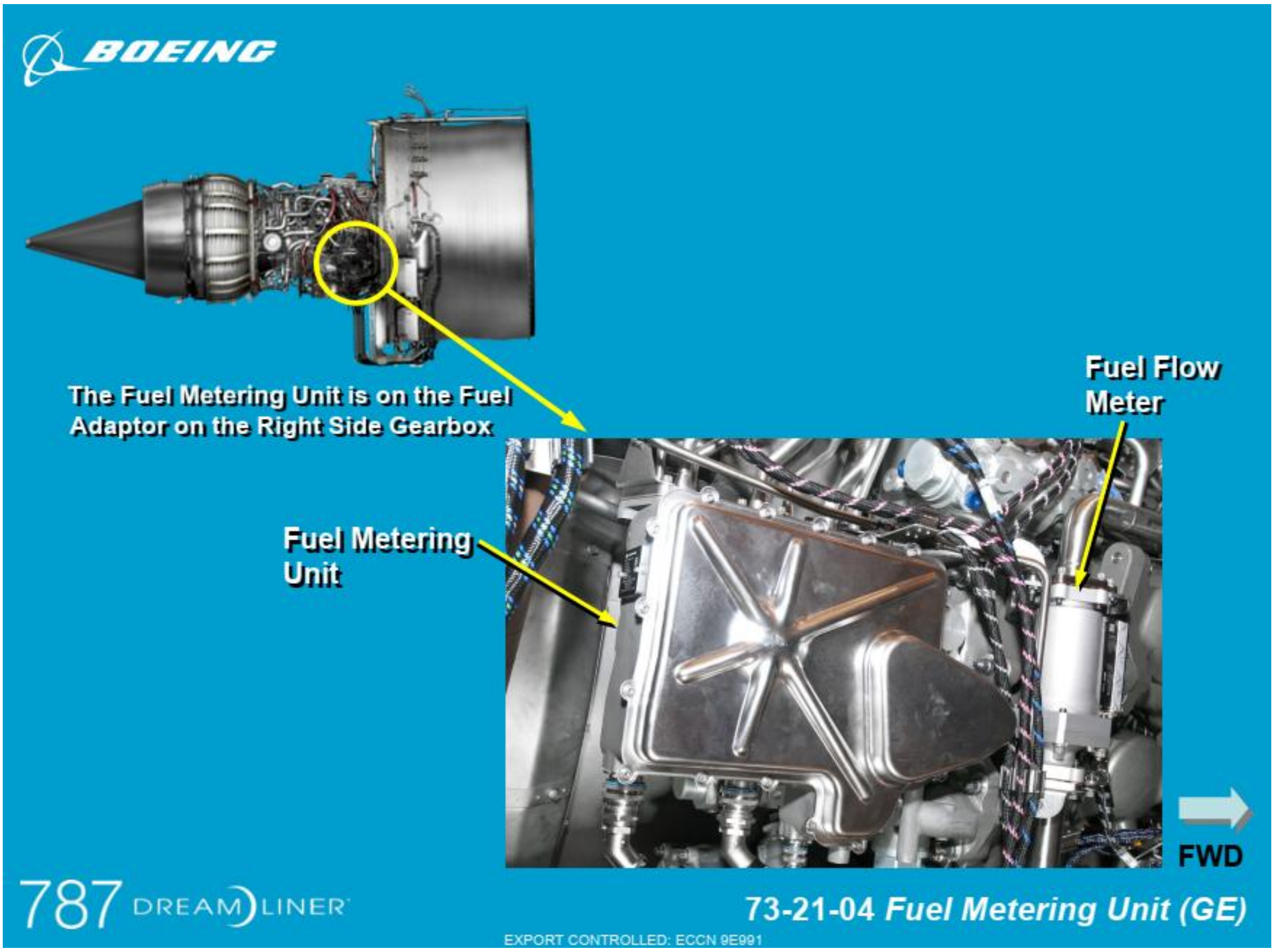

Figure 20. Fuel Metering Unit

Flow Split Valve

1. The flow split valve (FSV) is an EEC controlled servo operated valve.
2. The FSV provides the correct amount to fuel to all 22 fuel nozzles at all thrust levels.
3. The FSV contains 2 internal valves: - Split valve
- Main staging valve.
4. Each valve provides fuel to a dedicated fuel nozzle output orifice.
5. Each valve uses a linear variable differential transformer (LVDT) to provide position feedback to the EEC.
6. The split valve supplies fuel to 3 manifold circuits.
- Pilot primary and main unstaged (PPMU) gives fuel to the 4 fuel nozzles near the engine igniters.
- Pilot primary and main staged (PPMS) gives fuel to the other 18 fuel

nozzles.

- Pilot secondary (PSEC) gives fuel to each of the fuel nozzles.
- The split valve decreases fuel output to the PSEC as thrust increases.

7. The main staging valve provides fuel to 18 of the 22 fuel nozzles. - The valve increases fuel output as thrust increases.
8. Using 2 output orifices for fuel, the valves change the fuel spray pattern at each nozzle.

- The adjusted spray pattern improves engine efficiency.

9. The FSV is located on the fuel adaptor on the accessory gearbox.

The flow split valve (FSV) controls fuel flow at the correct pressure to the 22 fuel nozzles. Fuel goes from the main fuel pump (MFP) to the fuel metering unit (FMU) and the fuel flow meter before going to the FSV and then finally to the fuel nozzles.

The FSV is controlled by the electronic engine control (EEC). The EEC monitors inputs from the thrust resolver angle (TRA) of the thrust levers and feedback from engine and airframe sensors. The EEC uses this data to make adjustments through the FSV servo valves for each of 3 manifold circuits that go to the fuel nozzles.

The FSV has ports for these fuel manifold circuits: - Pilot primary and main unstaged (PPMU)

- Pilot primary and main staged (PPMS)
- Pilot secondary (PSEC).

The pilot primary and main unstaged fuel goes to the 4 enrichment fuel nozzles. The pilot primary and main staged fuel goes to the other 18 fuel nozzles. The pilot secondary is staged fuel and goes to each of the 22 fuel nozzles.

The FSV has 2 internal electro-hydraulic servo valves (EHSV). The 2 valves are the fuel splitting valve (EHSV 1) and the main staging valve (EHSV 2). Each valve has a linear variable differential transformer (LVDT) that gives feedback to the EEC.

When fuel goes to the FSV from the FMU, it first goes to the fuel splitting valve. Fuel from the splitting valve is then split out to the 3 manifolds. One manifold is the PPMU that goes to the 4 enrichment nozzles. The second manifold is the PSEC that goes to each of the 22 fuel nozzles. The third manifold goes through the main staging valve as PPMS fuel to the 18 nozzles.

The FMU sends metered fuel to the FSV. The EEC controls the position of the split valve and the main staging valve in the FSV. When the metered fuel from the FMU changes, valves in the FSV control the quantity of fuel available at each fuel nozzle. The metered fuel flow changes give:

- Decreased fuel pressure changes in the combustion chamber - Decreased temperature variations
- Decreased emissions
- Improve fuel consumption.

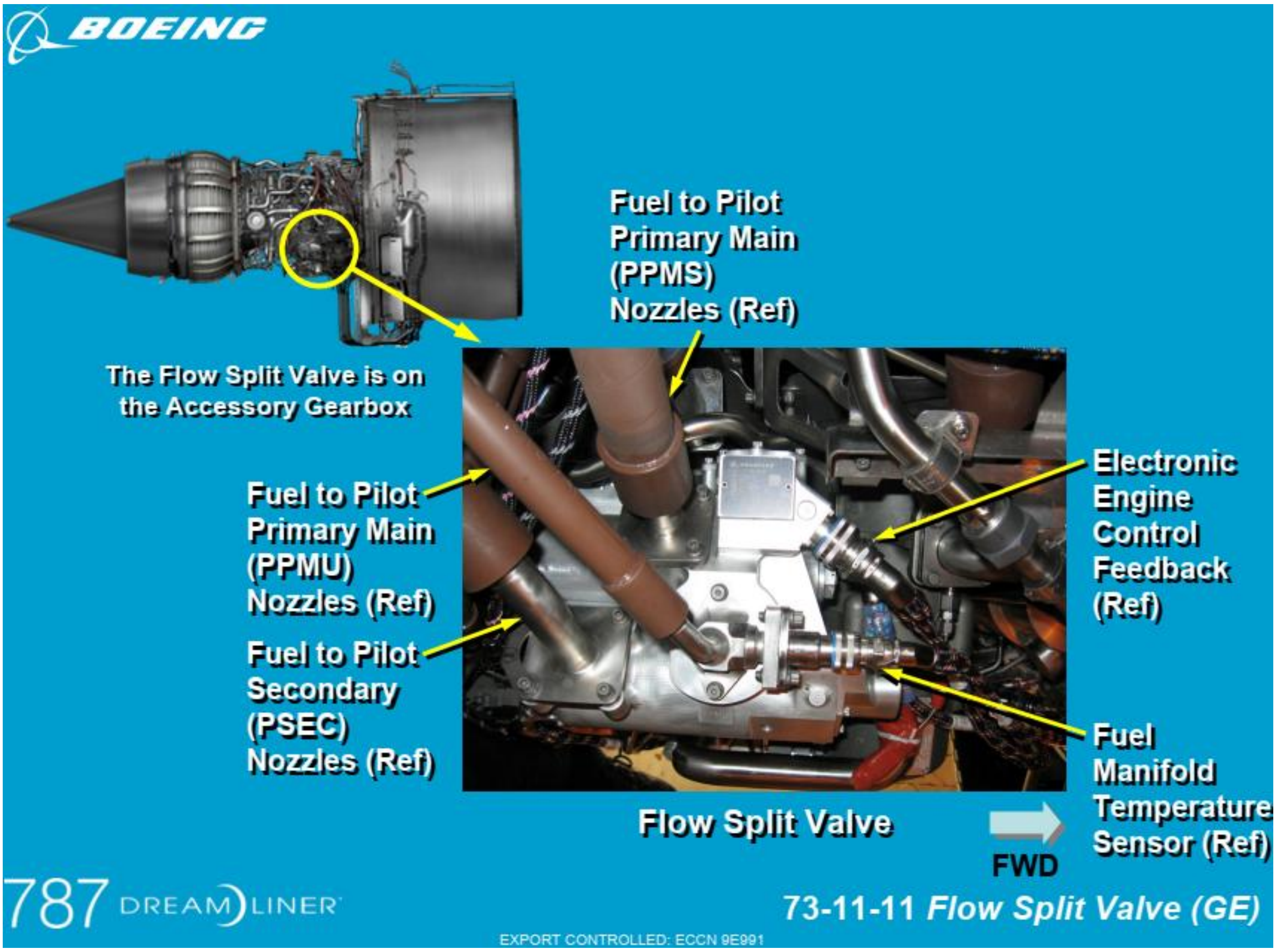

Figure 21. Fuel Split Valve

Fuel Nozzle

1. The flow split valve (FSV) supplies fuel pressure and flow distribution to the

twin-annular premixing swirler (TAPS) fuel nozzles. The TAPS fuel nozzles decrease pilot nozzle output while they increase main fuel nozzle output.

- This improves the shape of fuel burn patterns and increases the efficiency of the engine.

2. There are 22 fuel nozzles that distribute metered, atomized fuel to the combustion chamber.
3. The fuel nozzles are set at equal spaces around the circumference of the combustor.

- Fuel nozzles have position numbers in a clockwise sequence, looking forward.
- Fuel nozzle number 1 is at the 12:00 position

4. The fuel nozzles are a twin-annular premixing swirler (TAPS) design. This gives the fuel nozzles 3 fuel supply circuits - pilot primary, pilot secondary, and main.
5. Fuel goes into the fuel nozzle at 2 locations: - Pilot primary/main fuel tube

- Pilot secondary fuel tube.

6. Each nozzle has 3 internal fuel circuits with pressure actuated valves. - Each circuit provides fuel flow to a separate output at each nozzle.

- The valves separate fuel and send it to the pilot primary and pilot secondary circuits.
- The third fuel circuit at each nozzle provides fuel to the circumferential main fuel flow circuit.

7. The pilot secondary fuel tube sends fuel to the pilot secondary nozzle output of 22 fuel nozzles.
8. The pilot primary/main fuel tube nozzle input sends fuel to the main flow and pilot primary output of each fuel nozzle.

9. Pilot secondary and main flow fuel flow output of the fuel nozzles is staged. The flow can be changed to increase main flow output from the nozzles while decreasing the fuel flow to the pilot secondary output.
10. Pilot primary flow is not staged, or controlled.

- There are 4 fuel nozzles connected to the pilot primary output. - These nozzles are near engine ignitors.

11. Fuel staging in the combustor provides a controlled, uniform flame cup and decreased heat on the combustor and high pressure turbine (HPT) nozzle components.

12. The pilot flow circuit provides rich burn for stability and operability.
13. The nozzles mount on the combustion case with 4 bolts and a seal assembly.

Purpose

The fuel nozzles supply atomized fuel into the combustion chamber. Physical Description There are 22 fuel spray nozzles at equal distances around the combustion chamber outer case. Each nozzle attaches with 4 bolts to the case. There are 18 normal flow nozzles and 4 enrichment nozzles. The enrichment nozzles are 17, 18, 19, and 20. Each is identified with a blue band.

Fuel is delivered to the fuel nozzles at the correct pressure and rate by the flow split valve (FSV). There are 3 manifolds that go from the FSV to the fuel nozzles.

These are the manifolds:

- Pilot primary and main unstaged (PPMU) - Pilot primary and main staged (PPMS)
- Pilot secondary staged (PSEC).

Fuel goes out of the nozzles through one of 3 orifices: - Pilot primary

- Pilot secondary
- Main.

The fuel is atomized with high pressure airflow from the high pressure compressor (HPC). There are air swirlers for the pilot fuel flows and the main fuel flow.

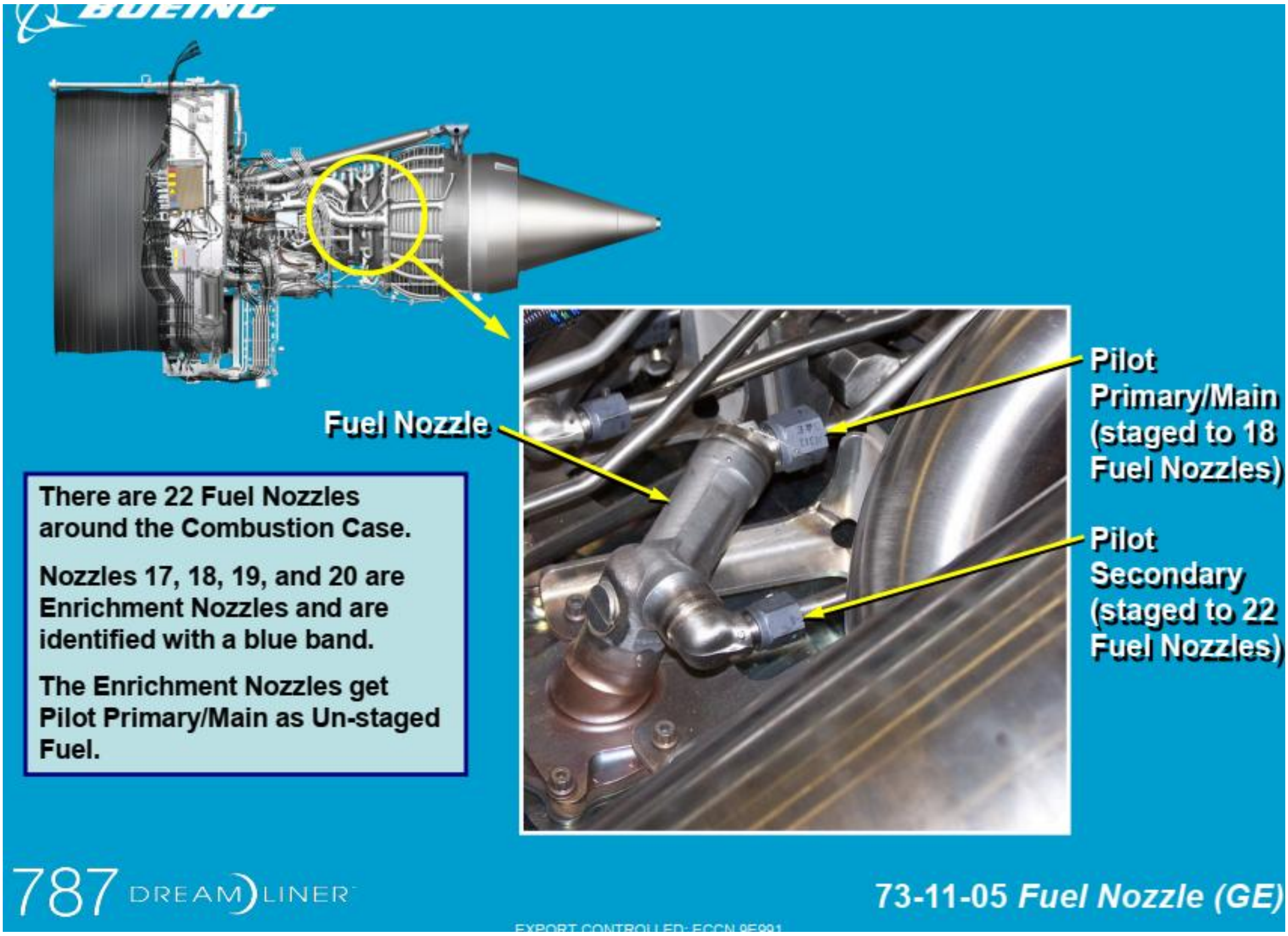

Figure 22. Fuel Nozzle

Fuel Control

1. The fuel control system sets the engine power level in relation to the mode set by the flight crew.

Components and Interfaces

The fuel control system has these components: - Electronic engine control (EEC)

- Fuel metering unit (FMU)
- T12 sensor
- Configuration type box
- Control alternator stator and rotor
- Engine rating plug

- Main engine data concentrator (MEDC) (Chapter 26) - Fuel filter differential pressure sensor
- T25 Sensor
- Fuel manifold pressure sensor
- Fuel pressure sensor
- EEC electrical harness.

The fuel control system has an interface with these systems: - Fuel distribution system (73-11)
- Fuel flow indicating system
- Engine controls
- Engine fuel feed system
- Electrical power generator drive system
- Common core system

System Description

The EEC is the primary component in the fuel control system. This is a 2- channel computer system, channel A and channel B.

The EEC electrical harness is the connection between the engine sensors, actuators, engine control electronics and the airplane.

For power, the EEC uses the control alternator stator and rotor component as the primary power source. Airplane power is a secondary power source.

The EEC receives inputs from the common data network (CDN) and from these components:
- Configuration type box - Engine rating plug
- Engine sensors
- Thrust control module.

These engine sensors give data to the EEC to monitor and to control engine operation:
- T12 sensor
- T25 sensor
- T3 sensor

- N1 speed sensor
- N2 speed sensor
- Fuel filter differential pressure sensor - T48 (EGT) probes and harnesses
- Fuel manifold pressure sensor - Fuel pressure sensor.

The EEC uses thrust resolver angle and the inputs to calculate the correct fuel flow and control the engine airflow.

For control, the EEC operates these FMU components: - Fuel metering valve (FMV)
- High pressure shutoff valve (HPSOV)
- Servo valves.

The FMV controls the rate of fuel flow to the combustor for all conditions.

The HPSOV opens and lets fuel flow to the flow split valve (FSV).

The EEC operates the servo valves to control engine airflow.

From the FMV, fuel goes to the FSV. The EEC controls the FSV and sets the correct delta pressure for the fuel nozzles.

Engine sensors also give data to the MEDC. The MEDC receives and multiplexes the sensor data. The MEDC transmits the multiplexed signal to the common core system (CCS). For more data on the MEDC, see Chapter 26.

The EEC uses N1 to calculate thrust. The EEC controls thrust in 3 modes: - Normal
- Soft alternate (reversionary)
- Hard alternate (reversionary).

When the EEC is in the soft or hard alternate mode, the thrust calculations are less accurate. The EEC goes into the soft alternate mode automatically. You push the EEC mode switch to put the EEC in the hard alternate mode.

Electronic Engine Control

1. The electronic engine control (EEC) is a 2-channel digital electronic control component.
2. It controls the engine systems based on throttle resolver angle (TRA) signals.
3. The EEC also uses inputs from sensors and probes and data from the common core

system (CCS) and CCS propulsion system software.

4. Each channel processes this data and does calculations and comparisons to data stored in EEC memory.

5. There is a cross-channel data link (CCDL) that lets the 2 channels exchange data internally.

6. At engine start, the EEC goes through an initialization process.

7. One channel is selected to be the channel in control (active channel). - The other channel is in standby.

- The channel in control is determined after initialization and fault
crosschecks.
- The channel in control changes at each engine start.

8. The channel in control controls the engine valves, actuators, and solenoids either directly or with fuel signals to the fuel metering valve (servo fuel).

9. The EEC controls these valves for thrust control and engine protection: - Transient bleed valve

- Variable bypass valves
- Variable stator vanes
- Low and high pressure turbine clearance control valves - Core compartment cooling valve.

10. The EEC controls all engine functions after power-up.

- When all parameters are in the correct range, the EEC lets the ignition
- It shuts the engine down when parameters are not in the correct range (more covered in lesson ATA 74/80).

11. The EEC continually monitors all engine parameters during engine operation and flight.

12. The EEC is air cooled.

Student Notes

System Description Section (SDS)

Purpose

The electronic engine control (EEC) controls the engine operation. The EEC monitors inputs from the engine and airplane systems, the engine limits, and environmental conditions and uses these inputs for control. The primary functions of the EEC are thrust control, fault monitoring, and maintenance testing.

General Description

The EEC is a dual channel processor (channel A and channel B). The channels are the same and each can control the engine. Only 1 channel at a time operates the engine. This channel is called the channel in control or active channel. The other channel is in standby. The EEC processes thrust lever position command, engine signals, and airplane data received from the common data network (CDN). This data is used to calculate the necessary fuel flow and correct engine airflow. The EEC channel in control adjusts engine valves, actuators, and solenoids to supply the fuel and air necessary to give the correct thrust.

The EEC gets power from the PMA when N2 gets to 8% rotor speed. The PMA drive is from the accessory gear box. The PMA has separate coils for each EEC channel. The EEC also gets 115v ac airplane power. Airplane power is used for EEC maintenance, back-up power, and engine start.

circuit energize.

- There is no flight deck igniter control.
- It shuts the engine down when parameters are not in the correct range

11. The EEC continually monitors all engine parameters during engine operation and flight.
12. The EEC is air cooled.

Purpose

The electronic engine control (EEC) controls the engine operation. The EEC monitors inputs from the engine and airplane systems, the engine limits, and environmental conditions and uses these inputs for control. The primary functions of the EEC are thrust control, fault monitoring, and maintenance testing.

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solenoids to supply the fuel and air necessary to give the correct thrust.

The EEC gets power from the PMA when N2 gets to 8% rotor speed. The PMA drive is from the accessory gear box. The PMA has separate coils for each EEC channel. The EEC also gets 115v ac airplane power. Airplane power is used for EEC maintenance, back-up power, and engine start.

circuit energize.

- There is no flight deck igniter control.

The EEC interfaces with these components on the engine: - Engine rating plug

- T12 sensor
- T25 sensor
- T3 sensor
- N1 speed sensor
- N2 speed sensor
- Fuel metering unit (FMU)
- Flow split valve (FSV)
- Fuel system filter and pressure sensors
- Variable stator vane (VSV) actuators
- Variable bleed valves (VBV) actuators
- High pressure turbine active clearance control (HPTACC) valve - Low pressure turbine active clearance control (LPTACC) valve - Core compartment cooling (CCC) valve
- CCC temperature sensor
- Engine oil level/temperature sensor
- Engine oil system filter and pressure sensors
- Debris monitoring system (DMS) system
- Ignition system.

The basic functions that the EEC uses to control engine operation are fuel flow, VSVs , and VBVs.

For engine control, the EEC operates these components: - Fuel metering valve (FMV)

- High pressure shutoff valve (HPSOV)
- Servo valves in the FMU.

The EEC electrical harness is the connection between the engine sensors, actuators, engine control electronics, and the airplane.

The EEC communicates with the airplane over the CDN. The CDN uses the ARINC 664 digital data bus. Each EEC channel has a bi-directional duplex CDN end-system. This system communicates with the CDN A and B domains. You can load data to the EEC from on-board the airplane on the CDN from the airplane crew information system (CIS).

Engine rating and engine N1 thrust data goes to the EEC from the engine rating plug. Engine serial number and hardware configuration data is from the engine configuration box. These components are attached on the engine and connect to the EEC. The EEC gets airplane model data from the CDN.

The EEC is at the 10:00 position on the aft fan case on 4 shock mounted fittings. There are connections for electrical cables on the forward and bottom faces. There are also fittings for pressure sense inputs. It has ground handling brackets to help with removal and installation.

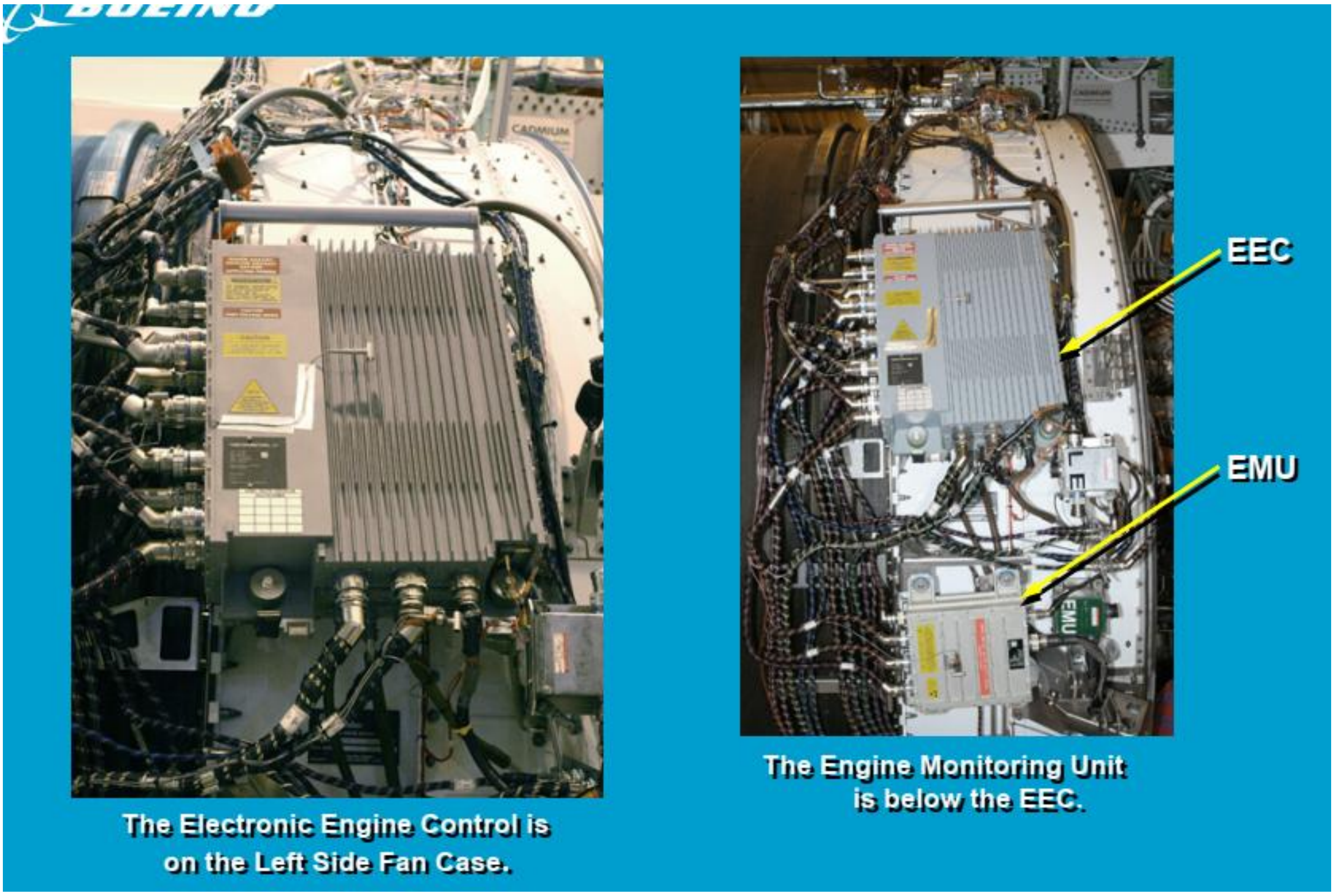

Figure 23. Electronic Engine Control and Electronic Monitoring Unit

Configuration Type Box

1. The configuration type box provides this data to the EEC:
- Engine serial number
- Engine monitoring
- High pressure turbine active clearance control (HPT ACC) adjustment - Engine hardware configuration.
2. It has an electronic memory and is reprogrammable.
3. The configuration type box has 2 channels with separate connectors for output to both EEC channels.
4. The EEC reads the data stream at power-up, and validates the data received.
5. After the contents of the configuration type box are read, the data is copied to non-volatile memory (NVM) if valid.
6. The NVM values are used during initialization of the EEC.
7. The configuration type box is on fan hub frame at the 9:00 position and connects to the EEC.

Purpose

The engine configuration type box gives engine serial number and engine hardware configuration to the electronic engine control (EEC).

Physical Description

The configuration type box has isolated connectors for output to the 2 EEC channels. A single stream of serial data is supplied by the configuration type box to the EEC. The EEC monitors the data continuously to give fault detection during operation. The configuration type box memory can be reprogrammed.

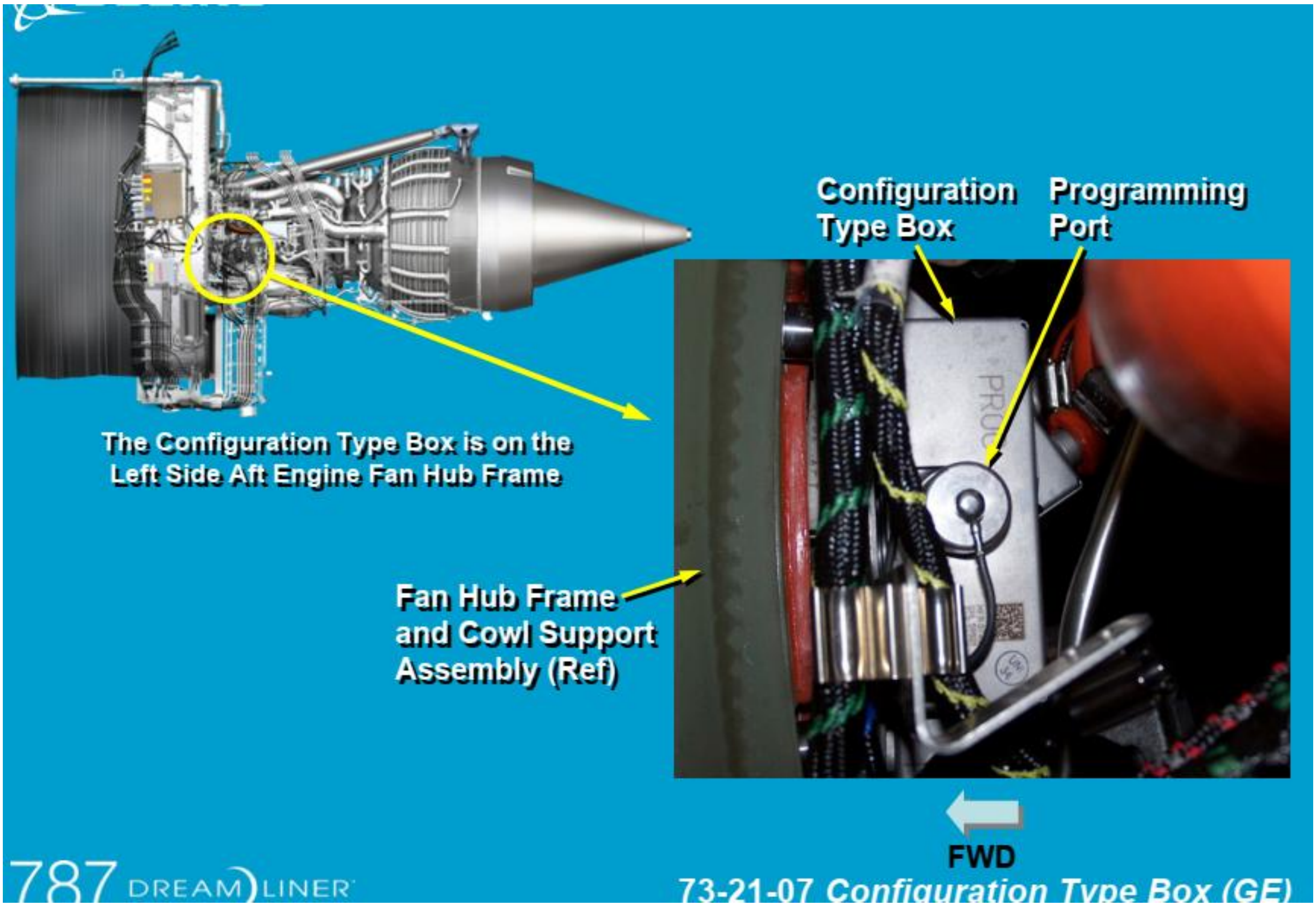

Figure 24. Configuration Type Box

2.2 Impoving fuel pump design

Every decision about design that deals with the operation of an in-tank fuel pump, the way you seal seal the pump housing may come the first one .Poor sealing allows liquid fuel to work proper way into the housing that have to corrode the electronics and potentially can cause fire. It`s surprising how these seals important and a lot of self-contained fuel delivery systems still contain o-ring assemblies to seal the power and signal passes fuel pump housing.

The o-ring materials that resists fuels tend to be costly.

With long-term exposure to gasoline, diesel, jet fuel and liquid propane many elastomers are not able to resist stagnation. Today used grease are not competitive with common fuels therefore o-ring materials needs to be greased for sure to prevent from cracking and leaking prematurally.

Disadvantages from a manufacturability standpoint are making to o-ring seals bad. Firstly, o-ring seals usually needs components as jam nuts or snap rings which locates on fuel pump cap. Then you need to install o-rings with high quality and very clean prior to the first installation or in other way they will create a leakage at the first sign of pressure contamination, surfaces imperfections on feedthrough or fuelpump cap.

Dual o-ring housings are a common way to alleviate issues with dirty or poor quality o-rings, but it needs additional cost and lengthens the seal pump.

O-rings need a huge amount of high-touch installation labor and addition checks for quality which drives even more expensive and lengthens time for delivering.

To seal fuel pump wiring more effectively needed to use of exopy-based feedthrough technology. Epoxies are more effective in this field - not only the best-of-class resistance to all common fuels and chemicals. To use epoxies isn`t new investigation. Nowadays more than a million fuel pump feedthroughs are used for all kinds of automotive, commercial aviation, aerospace, heavy equipment, recreational vehicle and small engine applications.

New approach is how the epoxy is being applied. In the past, many of these epoxy wire feedthroughs were delivered as separate assemblies that would then require assembly into the fuel pump cap or housing. Today, epoxy feedthroughs can often be integrated into fuel pump itself through a direct casting process.

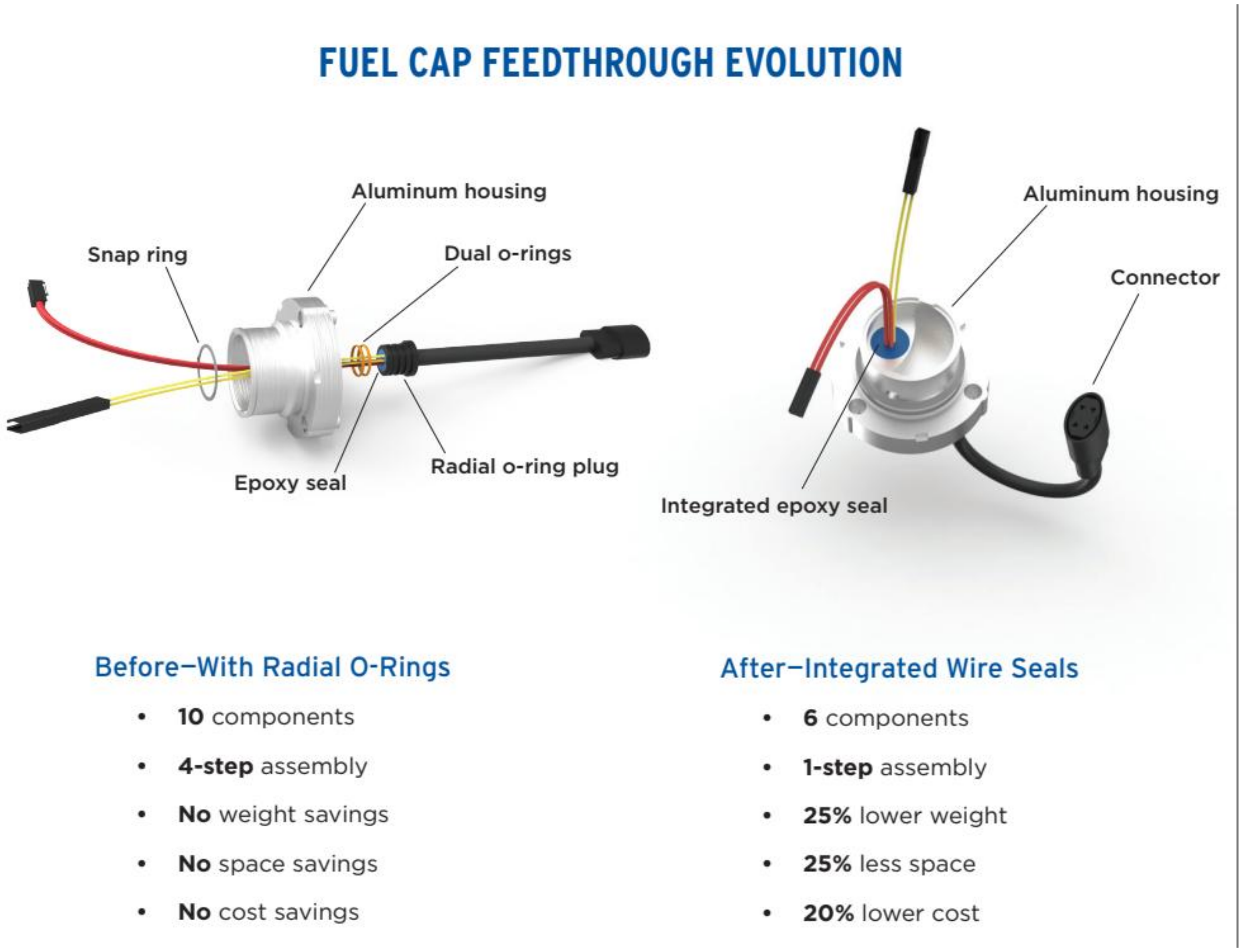

Figure 25. Epoxy wire feedthrough

Direct casting is presented next: the epoxy feedthrough is casted into an opening in fuel pump housing - usually the cap. It sounds simple but process consists of a number of difficult engineering difficulties. To provide successfully epoxy formation, for example, you need to have the right balance of flow and mechanical properties to satisfy both the manufacturability and end-use requirements. Also the design of the feedtrough and its opening needs to be optimized to provide a strong mechanical connection between the epoxy and the pump housing material - typically aluminium of other metal in high-performance pumps. In particular, the design has to accommodate differences in the coefficient of thermal expansion (CTE) of the epoxy and the metal.

As soon as these challenges have been met, the resulting feedthrough creates a true hermetic seal around any wires goes trough the pump housing. The Douglas Electrical Components company designed and manufactured integrated wire feedthroughs that withstand fuel pressure up to 2,250 psi for liquid propane (LP) systems while offering true hermetic sealing with leak rates better than $1/10^{-8}$ ccHe/sec. Numerous tests demonstrates that fact that this feedthroughs also withstands long term exposure without shrinking or cracking to ethanol, gasoline, diesel, jet fuels and LP. They pass a battery of rigorous tests, including:

- Thermal cycling from -40 to 130ºC
- Salt fog exposure
- Thermal cycling from -40 to 130ºC
- Vibration to IAW MIL-STD-810G
- Burst testing to and above 2,000psi

A common o-ring assembly used in fuel pump consists of not only the o-ring itself but also a snap ring or other retaining component . Not only do these components add extra materials cost, they also add labor cost for the assembly. Also failed o-rings add additional costs in form of recalls and reworks. As practice showed, integrated epoxy feedthrough have an 20% lower installed cost based on the component and labor savings.

Reducing a number of extraneous components, the integrated wire feedthrough additionally save space and weight comparing with traditionally o-ring wiring seals. In most fuel pump designs, the weight and space savings can be as much as 25%.

2.3 Evaluating of the wire feedthrough realibility

The operating time for failure of the the integrated wire feedthrough , obtained on the basis of the collection and analysis of statistical data during testing and from working cycles already mounted on other systems, is:

t_i = {0,57; 0,82; 0,93; 1,08; 1,21; 2,22; 3,80; 4,14; 6,72; 8,0}, m = 10;

Estimated coefficient of variation of data v = 0,4;

Limit relative error d = 0,15;

Trust probability q = 0,85;

Number of degrees of freedom K = 1.

The law of distribution of the integrated wire feedthrough operating time for failure – Weibull, the law of distribution of elimination time of the integrated wire feedthrough - normal.

We calculate the actual value of the coefficient of variation and the limiting relative error:

$$T_m = \frac{\sum_{i=1}^{m} t_i}{m} \qquad (2.1)$$

$$T_m = \frac{(1,77+2,02+3,63+5,08+7,21+10,22+12,80+14,14+16,72+18,0)}{10} = 9,159$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{m} \left(t_i - T_m\right)^2}{m-1}} \qquad (2.2)$$

$$\sigma = \sqrt{\frac{(1,77-9,159)^2+(2,02-9,159)^2+(3,63-9,159)^2+(5,08-9,159)^2+}{10-1}}$$

$$\overline{\frac{+(7,21-9,159)^2+(10,22-9,159)^2+(12,80-9,159)^2+(14,14-9,159)^2+}{}}$$

$$\overline{\frac{+(16,72-9,159)^2+(18,0-9,159}{}} = 6,065$$

$$\nu = \frac{\sigma}{T_m} \tag{2.3}$$

$$\nu = \frac{6,065}{9,159} = 0,662$$

$$d = max\left\{\frac{T_m - T_{mi}}{T_m}; \frac{T_{ma} - T_m}{T_m}\right\} \tag{2.4}$$

$$d = max\left\{\frac{9,159-1,77}{9,159}; \frac{18-9,159}{9,159}\right\} = max\{0,807;\ 0,965\} = 0,965$$

Since the coefficient of variation $\nu = 0,662$ less than the specified (0,7), and $d_{\max}$ = 0,965 > 0,2, then we accept the final value of the test volume N = 40.

Taking into account the fact that there are the integrated wire feedthrough on the airplane, the number of observed AC should be at least 20.

Estimate of the Weibull distribution parameters

To estimate the parameters of the Weibull distribution *a* and *b*, we use the method of successive approximations:

$$A = \frac{\sum_{i=1}^{m} \ln t_i}{m} \tag{2.5}$$

$$A = \frac{\ln(1,77)+\ln(2,02)+\ln(3,63)+\ln(5,08)+\ln(7,21)+\ln(10,22)+\ln(12,80)+}{10}$$

$$\frac{+\ln(14,14)+\ln(16,72)+\ln(18,0)}{} = \frac{19,394}{10} = 1,939$$

The initial approximation of the parameter *b*:

$$b_0 = \frac{m+1}{(A - \ln t_i)\cdot(0,23\cdot m + 3,71)} \qquad (2.6)$$

$$b_0 = \frac{10+1}{(1,939 - \ln(1,77))\cdot(0,23\cdot 10 + 3,71)} = 1,338$$

On $k+1$ step we compute the approximation b_{k+1}:

$$b_{k+1} = \left(\frac{\sum_{i=1}^{m} t_i^{b_k} \ln t_i + (N-m)\cdot t_m^{b_k}\cdot \ln t_m}{\sum_{i=1}^{m} t_i^{b_k} + (N-m)\cdot t_m^{b_k}} - A \right)^{-1} \qquad (2.7)$$

Process of calculation b_k is carried out until condition is satisfied:

$$\left| \frac{b_{k+1} - b_k}{b_k} \right| < 0,001 \qquad (2.8)$$

$$b_1 = \left(\frac{\sum_{i=1}^{10} t_i^{1,338} \ln t_i + 30\cdot 18^{1,338} \ln 18}{\sum_{i=1}^{10} t_i^{1,338} + 30\cdot 18^{1,338}} - 1,939 \right)^{-1} = \left(\frac{533,616 + 4146,003}{211,651 + 1434,418} - 1,939 \right)^{-1} = 1,106$$

$$\left| \frac{1,106 - 1,338}{1,338} \right| = 0,173 > 0,001$$

$$b_2 = \left(\frac{\sum_{i=1}^{10} t_i^{1,106} \ln t_i + 30\cdot 18^{1,106} \ln 18}{\sum_{i=1}^{10} t_i^{1,106} + 30\cdot 18^{1,106}} - 1,939 \right)^{-1} =$$

$$= \left(\frac{292,245 + 2120,344}{118,704 + 733,589} - 1,939 \right)^{-1} = 1,121$$

$$\left| \frac{1,121 - 1,106}{1,106} \right| = 0,014 > 0,001$$

$$b_3 = \left(\frac{\sum_{i=1}^{10} t_i^{1,121} \ln t_i + 30 \cdot 18^{1,121} \ln 18}{\sum_{i=1}^{10} t_i^{1,121} + 30 \cdot 18^{1,121}} - 1,939 \right)^{-1} =$$

$$= \left(\frac{303,772 + 2214,295}{123,173 + 766,093} - 1,939 \right)^{-1} = 1,120$$

$$\left| \frac{1,120 - 1,121}{1,121} \right| = 0,00089 < 0,001$$

Using the method of successive approximations, we determined $b_3 = 1,120$.

$$a = \frac{\left(\sum_{i=1}^{m} t_i^b + (N-m) \cdot t_m^b \right)^{\frac{1}{b}}}{m} \qquad (2.9)$$

$$a = \frac{\left(\sum_{i=1}^{10} t_i^{1,120} + 30 \cdot 18^{1,120} \right)^{\frac{1}{1,120}}}{10} = 42,852$$

Thus, the Weibull distribution parameters:

a = 42,852

b = 1,120

Evaluation of reliability indicators

Assessment of reliability indicators of the integral section:

a) mean time between failures

$$\overline{T} = a \cdot \Gamma \left(1 + \frac{1}{b} \right) \qquad (2.10)$$

$$\overline{T} = 42,852 \cdot \Gamma \left(1 + \frac{1}{1,120} \right) = 42,852 \cdot 0,96177 = 42,214$$

b) probability of failure-free operation

$$P(t) = e^{-\left(\frac{t}{a} \right)^b} \qquad (2.11)$$

$$P(t) = e^{-\left(\frac{9,159}{42,852}\right)^{1,12}} = 0,837$$

c) probability of failure

$$q(t) = 1 - P(t) \tag{2.12}$$

$$q(t) = 1 - 0,837 = 0,163$$

d) failure rate

$$\lambda(t) = \frac{b}{a} \cdot \left(\frac{t}{a}\right)^{b-1} \tag{2.13}$$

$$\lambda(t) = \frac{1,120}{42,852} \cdot \left(\frac{9,159}{42,852}\right)^{1,12-1} = 0,022$$

In order to collect data on the reliability of the integrated wire feedthrough, a surveillance plan is chosen, involving unlimited monitoring of 60 integrated wire feedthrough (20 AC).

According to the data obtained during the implementation of the observation plan, it is determined that the time between failures of the integrated wire feedthrough has a Weibull distribution with parameters:

a = 42,852

b = 1,120

The obtained values of the distribution parameters allowed us to estimate the probability of failure of the sensors and the mean time between failures:

$\overline{T} = 42,214$

$q(t) =$ 0,163

Thus it can be seen that the failures of the integrated wire feedthrough occur periodically, most often the electrical part fails. Therefore, it is necessary to develop a procedure for replacing the sensor, which allows reducing the labor capacity and the time of servicing the fuel system of the Boeing-787 in different modifications.

CONCLUSION TO PART 2

B787 is a highly technological and revolutionary aircraft. Failures statistics shows us that 787 type has no evident weaknesses connecting to the fuel system design. Li-on batteries affecting on its weight but this problem is not going to be disccussed.

Applying of epoxy feedthrough previously discussed is the perspective way to achieve new level of reliability. High resistance to a large number of modern chemicals and fuels ensures the operator that the fuel pump would provide reliable operation during its lifecycle.

In addition, it should`ve be said that as epoxy feedthrough so effective technology, given innovation makes wire lifecycle more safe. Remembering that aviation products become more electrical from year to year, epoxy feedthrough would find its applying not only onboard of Dreamliner family.

CHAPTER 3: LABOUR PRECAUTION

3.1 Factors influencing safety during repairing of B787 Dreamliner

Every operation with aircraft should be done in accordance with aviation authorities requirements. Maintenance operations are not an exception. In Ukraine such a document is «Actions of safety features at working places during maintenance procedures» (ССБТ. ГОСТ 12.0.230.2-2015). The next hazardous things could take part:

- edges with sharp angles with different roughness;
- insufficient delivery of natural light;
- developing of shock wave (explosion, vapors from flammable fluids);
- highly positioned AC parts with complicated access to them;
- high level of static electricity;
- presence of hazardous chemical components that are residuals or the main part in percentage of fuel and lubricants;
- real danger for inadvertently slip (due to icing, humidification at high level of the surfaces of AC, ladders and coverings of parking places);
- tools and materials for maintenance of AC which can fall and damage structural parts of the aircraft likely stabilizer, fuselage frame and when at height conducting the maintenance using mechanized lifts;
- any part of the constructions (production tools and equipment, side staircases or simple stairs).
- increased of dust and gas contamination in the service area;
- harmful products of engine exhaust gases and liquids with hazardous content from vessels and AC pipelines what experience pressure loads;
- non-regulated noise, vibrations;
- dimmed lightning places where maintenance procedures conducting;
- decreased or even increased values of temperatures of any AC, material surfaces and different tools;

- self-driven machinery, vehicles of special demands and purposes for other vehicles.

3.2 Precautionary measures to reduce hazardous influencing during operation on the fuel system

Using a special metodology basis is aimed in reduction hazardous influences on a working place. Hygienic standards in the parameters of the microclimate in the working area are given in Interstate standard due to ГОСТ 12.0.230.2-2015 («General sanitary and hygienic requirements for the air of the working area»). Working area should extend at least for up to 2 m above the floor or ground, where all maintenance procedures were planned to conducted. Permanent jobs is considered, that job when we can make an assessment more than half of whole time, or more than 2 hours continuously.

To prevent the hazards during repairing (or significantly reduce this influence), technical staff needs to operate with amount of precautions:

- when working on caissons-tanks, portable explosion-proof lamps with a voltage of 28 V;
- for the removal of static electricity in the hangar and in the parking lot of the AC installed wells, for grounding AC;
- in order to reduce the influence of noise from running engines, when it is necessary to check the tightness of the fuel system, it is envisaged to use anti-noise headphones;
- in order to reduce toxic fumes of fuel (the maximum permissible concentration is 300 mg/m^3), when working in fuel tanks, mandatory use of personal protective equipment of respiratory organs;
- in works related to open fuel volumes, special silicate ointments are used to protect open parts of the body;
- when working on high-lying parts of the power plant, tools and equipment are located on the staircases in the sorts, so that they do not fall and injure maintenance personnel;
- for eliminating of the increased pollution, stands are periodically cleaned of dirt, ice, snow, and also the using of specially designed footwear is obligatory;

- system of ventilation of the AC hangar uses the circulation of warm dry air in the winter and cold in the summer;
- briefing conducting for drivers special transport with basic traffic rules and access to the AC;
- the speed of movement of special vehicles and self-propelled vehicles in the parking areas and on the platform should be no more than 20 km / h. At the entrance to the serviced AC, before reaching it - 10 m the driver is obliged to stop the car and start the approach at a speed of no more than 5 km / h under the direction of the official currently responsible for the AC;
- for the maneuvering of special vehicles there are one-way gates with a width of 3.5 m;
- to reduce the dustiness of the working area in the open area, it is envisaged to use special machines that clean the soil with a strong stream of water, in enclosed spaces, the use of natural and forced ventilation;
- on the platform, in the hangar there are sources of artificial lighting.

3.3 Calculation of ventilation of a hangar for B787 servicing

Hangars are used to service the fuel conditioning system. Since the fuel is less harmful to human health, the evaporator should be equipped with ventilation.

The amount of fresh air required to dilute harmful emissions to an acceptable concentration is calculated using the formula: $Q = 3600 \cdot \mu \cdot A \cdot \sqrt{\frac{2 \cdot g}{\gamma_н}} \cdot H$ [m^3/hour], (4.1)

where μ = 1 - Supply air flow coefficient for rectangular opening;

A – area of supply air holes, m^2;

g = 10,81 – acceleration of gravity, m/c^2;

$\gamma_н$ = 9,25 – specific gravity of air, N/m^3;

H - thermal head, Pa.

To obtain some measurements data of the area of the supply holes we should determine the overall space of the hangar.

Hangar area is determined like digit based on the geometric dimensions of the AC

- Length of AC L = 51 m;

- Wingspan Lк = 34 m.

Distance between AC to the wall of the hangar should be at least - 6 m for special vehicle corridors and stairs. The distance between the extreme points of the wings must be at least - 10 m.

Area according to data of intake openings:

$$A = 2 \cdot 2 \cdot 25 = 100 \text{ (m}^2\text{)}.$$

Obtained area:

$$S = a \cdot b\,(\mathrm{m}^2), \qquad (4.2)$$

$$S = 80 \cdot 90 = 7200\,(\mathrm{m}^2).$$

Sizing holes dimensions $2 \times 2\text{м}$; Number of holes 29.

The thermal head is generated in the chamber due to the difference in the specific weight of the air at the bottom and at the top of the room.

$$H = h \cdot (\gamma_Н - \gamma_в)\,[\mathrm{Pa}], \qquad (4.3)$$

Where h - height between the centers of the fence and the outlet, m;

$\gamma_н$, $\gamma_в$ - specific gravity of air inside and outside the room, N/m^3.

$\gamma_н = 12,25$ *N/m*^{3},
$\gamma_в = 12,23$ *N/m*^{3},
$h = 25$ *m.*

Then the heat head:

$$H = 25 \cdot (12,25 - 12,23),$$

$$H = 0,5(\mathrm{Pa}).$$

$$Q = 3600 \cdot 1 \cdot 100 \cdot \sqrt{\frac{2.9,8}{12,25} \cdot 0,5}\ ,$$

$$Q = 250452\ \left(\mathrm{m}^3/\mathrm{h}\right).$$

Having obtained the required pressure and efficiency of the fan, we chose the fan. with the following features:

$H = 0,5$ *Pa*,
$\eta = 0,55\%$,

$Q = 250452$ *m*^{3}*/h*.

Selection of the fan motor.

Statistical power of the electric motor is represented by the formula:

$$N = \frac{H \times Q \times B}{3600 \times 102 \times \square} \ [\text{kW}], \tag{4.4}$$

where B = 3,1 - coefficient of power.

$$N = \frac{0{,}5 \cdot 240452 \cdot 3{,}1}{3400 \cdot 122 \cdot 0{,}55} = 8{,}7$$

Optimizing features of the fan blades to the corresponding motor with rated power with a safety margin about 5 %:

$$N \quad = 8{,}7$$

It gives us a such conclusion that calculated ventilation parameters of the determined hangar ensures that maintenance personnel are performing safely in maintenance of the two of Boeing-787 AC fuel systems.

3.4 Fire protection

"Instruction of labor safety rules for maintenance and current repair of aviation equipment" describes the fire safety in the next way:

- involvement of electrical equipment concerned with the main task of fire and explosion risks in accordance with the requirements of the "Rules for the installation of electrical installations».
- fire protection provides: compartments for luggage hold, the use of fire extinguishing means and appropriate types of fire equipment tools, application of automatic fire alarm and fire extinguishing systems
- technological processes automatization and hazards risks avoiding connected with work combustible substances using of fireproof materials for cabin crew and passenger cabin equipment;
- pressurized compartments including ambient air probably gives cooling of both the engine parts and the aggregates inside of them, comprising the possibility of removing and minimizing the quantity from fuel vapors.

CONCLUSION TO PART 3

Detailed analysis of hazards on work places gave us a concept how to improve maintenance of fuel system through improving safety coefficient during operations.

Permanent evolution of the approaches to aviation personnel training, developing new regulation basis and applying new technologies lead to improving labour safety on new level.

CHAPTER 4: ENVIROMENTAL PROTECTION

4.1 Ukrainian requirements for environmental protection

The Law on Economic Independence of Ukraine mentions these main objectives of economic independence, security achievements, and the creation of healthy and safe living and working conditions. The Law on Enterprises of Ukraine stipulates that all enterprises are obliged to take environmental measures in a timely manner. Companies are responsible for maintaining requirements and standards for nature conservation, the rational use of natural resources and restoration.

Part VII "Environmental Security" of the Declaration on the Sovereignty of the State of Ukraine declares that Ukraine has the right to prohibit the construction or suspension of enterprises, establishments, plants and establishments that pose a threat to environmental safety. Ukraine cares about the environmental safety of its citizens.

Ukrainian Environmental Protection Law has some main principles:

- ensuring environment safety for humans, their life and health;
- use of "green" materials to reduce polluting influence;
- mandatory compliance with environmental standards, norms and restrictions on the use of natural resources.

Big influence on environmental safety has local public organizations which permanently monitor pollution status. This groups react quickly and, as the main resource of authority, environmental situation couldn`t become rapidly ugly.

Also in Ukraine exists such a ecological passports for the companies. Company may have bonuses while ensuring its "green" politics.

4.2 B787 operation influence on the environment

Present time requirements for environmental protection becomes more strict from year to year. Aircraft manufacturer should to comply with this states. We do not discuss influences during the process of manufacturing, nevertheless, the effect is colossal. This work is going to describe gas turbine engine emission influence on the environment.

Gas turbine engine exhaust components include the following main components: carbon monoxide, hydrocarbons (methane CH_4, acetylene C_2H_2, ethane C_2H_6, ethylene C_2H_4, propane C_3H_8, benzene C_6H_6, toluene $C_6H_5CH_3$, etc.), nitric oxide, alkaline oxide, aldehyde, aldehyde $CH_2 = CH = CHB$, acetaldehyde (CH_3CH, etc.), sulfur oxides, soot (smoke lamps visible behind engine nozzles), benzopyrene.

One minute operation of turbojet engine releases 2-4 mg of carcinogens into the atmosphere, mainly benzopyrene. ICAO regulations permit draining fuels, so the manufacturer should investigate a design with this requirements.

The quantitative emission characteristics of AE is an emission index, which shows how many grams of a substance are released into the air when 1 kg of fuel is burned.

Amount of carbon monoxide and hydrocarbons in AE emissions is possible to be calculated only from complete combustion. For small temperatures and air pressure in combustion chamber the combustion completeness is minimal. Low gas mode decreases the fuel injection, therefore, stagnates combustion quality.

Other problem - noise index of the aircraft. ICAO regulations regulate noise level which aircraft should produce. There are special power plants and vehicles

The fan is the main source of engine noise.

Rotational noise and helix are the key contributors to propeller noise.

Through long-term development in the field of science and technology, an artificial electromagnetic field was created. Its main source is the transmitters of radars, radio navigation and broadcasting stations. It is possible to trace the effect on the human body of the emitted electromagnetic radiation by these devices.

Biomedical studies have revealed a significant degree of exposure to strong electromagnetic fields, which, in turn, depends on the frequency range, radiation intensity, nature and duration of exposure.

It is safe to say that the economic activity of airlines, associated with the maintenance of air conditioners, contributes to the deterioration of environmental conditions.

As a result of such actions on aprons, in parking lots, as well as in hangars and large airports, up to 40 tons of hydrocarbons, solar, organic and mineral detergents, and phenols get into the soil per hour. The reason for this effect on the soil is the loss of fuels and lubricants when charging with alternating current. At the same time, flammable lubricants are not only poured into the soil, but also applied with air.

It is safe to say that the amount of losses should be reduced in order to further minimize damage to the soil and atmosphere.

4.2 Evaluation of the emission index for GEnx-1B series

In direct relation to the concentration of CO and C_XNx in the flue gases of an AC engine, the characteristics of its combustion chamber (value of the combustion coefficient) of the engine are determined. Thus, the process of maximum fuel combustion in the engine is observed in the design mode, that is, in the takeoff (maximum engine thrust mode).

Modern engines in the above mode burn out almost completely, which is not possible to apply in practice. In all other modes, low rates are observed, i.e. combustion efficiency is low, the engine emits incomplete combustion products (CO, C_XNx, etc.) into the atmosphere, thus increasing air pollution.

The values of NO_X concentration in the flue gases of an AC engine are directly dependent on the temperature of the mixture in the combustion chamber (the higher NOX is formed) and on the maximum (up to 2500-3000 K) take-off mode and power. the mixture stays in the combustion chamber longer. NOX), which occurs at low aircraft speeds.

Peak NOX emissions occur during engine take-off and related modes such as AC start and climb. Thus, depending on the engine operating mode and the duration of operation in this mode, the amount of engine emissions in the airport area depends. Along the territory of the airport, space indicators are taken with a height of 100 m, and the airfield is limited in size.

Table 4.1 – GEnx-1B series engine running time in operating modes

Name of the engine operating mode	Thrust, $\bar{N}$e	Duration of the regime *t*, minutes
Running, warming up, taxiing	0,07	2
End of Table 5.1.		
Takeoff	1	0,7
Set of the height of 1000 m	0,85	2,2

Approach for landing	0,3	4
Taxiing after landing	0,07	6

Table – 4.2 Standard emission data for engine emissions GEnx-1B series

Harmful substances	CO	C_xH_y	NO_x
Kin, (kg subs. / kg of fuel) for the engine GE-90	0,035	0,015	0,005

Table – 4.3 Table of the mass emission rate of the ingredient under the appropriate engine operating conditions

Mass emission rate, kg sub. / h	Engine operating mode		
	Takeoff	Cruising	Nominal
WCO	2,65	2,4	2,4
WCH	0,5	0,55	0,5
WNO	3,5	2	2,5

Engine specifications:

N_e = 2500 h.p. = 1850 kW; N_{cr}= 1300 kW; $C_{sp.lg}$ = 0,025 кg / kW·h

From table 5.2:

T_{og} = 2 min = 0,367 (h) ;

T_{1fl} = 0,7 min = 0,0117 (h);

T_{2fl} = 2,2 min = 0,0367 (h);

$T_{3fl} = 4$ min = 0,067 (h);

Then $G_{fg} = 0{,}069 \cdot 378 \cdot 0{,}033 = 0{,}86$(kg).

Determine the mass of each ingredient that thrown out by the engine when working on the ground:

$M_{CO} = 0{,}035 \cdot 0{,}86 = 0{,}03$ (kg);

$M_{CH} = 0{,}015 \cdot 0{,}86 = 0{,}013$ (kg);

$M_{NO} = 0{,}005 \cdot 0{,}86 = 0{,}0043$ (kg);

$M_{COto} = 2{,}65 \cdot 0{,}01 + 2{,}4 \cdot 0{,}0367 + 2{,}4 \cdot 0{,}1 = 0{,}35$ (kg);

$M_{CHto} = 0{,}5 \cdot 0{,}01 + 0{,}55 \cdot 0{,}0367 + 0{,}5 \cdot 0{,}1 = 0{,}075$ (kg);

$M_{NOto} = 3{,}5 \cdot 0{,}01 + 2 \cdot 0{,}0367 + 2{,}5 \cdot 0{,}1 = 0{,}358$ (kg).

Calculating mass emission in the terminal area:

$M_{CO} = 0{,}03 + 0{,}35 = 0{,}38$ (kg);

$M_{CH} = 0{,}013 + 0{,}075 = 0{,}088$ (kg);

$M_{NO} = 0{,}0043 + 0{,}358 = 0{,}362$ (kg).

ICAO standards on the emission control parameter for AC engines are currently:

$M_{CO}/Ne = 0{,}56$ g / kW; $M_{CH}/Ne = 0{,}2$ g / kW; $M_{NO}/Ne = 0{,}8$ g / kW;

$M_{CO}/Ne = 380/1850 = 0{,}23 < 0{,}56$ g / kW;

$M_{CH}/Ne = 88/1850 = 0{,}08 < 0{,}2$ g / kW;

$M_{NO}/Ne = 362/1850 = 0{,}2 < 0{,}8$ g / kW.

According to the values obtained, it follows that the engine emission does not exceed the established ICAO norms.

Conclusion to part 4

The way we described in the previous part, it becomes clear that GE-series meets the ICAO requirement fully. The controlled emission parameters of carbon monoxide CO, a mixture of hydrocarbon compounds C_xN_x, and nitrogen oxide NO_x are within the ICAO standard limits, and their values are very small compared to the limit values. Based on the above, it can be concluded that the engine meets the ICAO emission standards.

From year to year aviation authorities make ecological requirements more strict. Of course, aviation industry needs to find new decisions permanently. On the other hand, ecolocgical tasks make the progress move further and in 20 years we would observe aircraft with reduced fuel consumption by 20% with the parallel reduction in fuel emissions level.

GENERAL CONCLUSIONS

1. The analysis of the operational characteristics of the Boeing 787 fuel system shows that the fuel system must be reliable, meet the highest requirements for production and maintenance. Analyzed statistical data on Boeing-787 fuel system failures and malfunctions. Dreamliner family has not rapid deffective parts; fuel pump which were damaged during pumps selfdestruction made Rolls-Royse company to fix this thickness.

2. As soon as the 787 family is highly electrical product, wires and huge amount of electrical connections needs to exist in proper way. Improving pumps by epoxy feedthroughs in its housings allows to hold the wires out of fuel and other chemical parts.

3. Applying epoxy wire feedthrough into a fuel pump allows to save space, use smaller number of installation components. This technology saves weight and space which always be actual as aviation industry permanently finds ways to reduce operating weight of an AC. Wire feedthrough technology occurs cheaper and, therefore, I assume a great future to this technology.

4. Damage to the maze seal of the centrifugal fan has a significant impact not only on power consumption but also on the production level. Improving abrasion-resistant seals is important not only to improve current efficiency and capacity, but also to keep them at a more critical level. Head and efficiency are reduced during damaged maze seals [15]. The performance curve is shifted down and to the left, reducing compressor capacity and limiting pump output.

5. Based on the analysis of hazardous and noxious industrial factors occurring during the maintenance of the AC fuel system, measures have been developed to improve the safety during maintenance and operation, in addition to short-term maintenance of the Boeing-787 AC. .

6. AC-mounted engines comply with ICAO standards for all parameters. Due to the growing impact of the artificial environment, its protection is the most pressing and multifaceted issue. In recent years, environmental issues have become more and more important. It is gradually becoming a global issue, and it is becoming more and more acute.

7. Most people agree that lip seals need to be removed regularly for unknown reasons, but engineers should always look at the picture. It is known that all applications for the use of lip seals are already over, but new options have emerged for users who know the reliability and energy. Unfortunately, the lip seal does not meet the expectations of most intermediate pump users. It makes no difference that the lipstick is in the cassette configuration.

References

1. J D Andrews and T R Moss (2002). Reliability and Risk Assessment. Second Edition. Professional Engineering Publishing. pp02-04

2. W Wong (2002). How Did That Happen? Engineering Safety and Reliability. Professional Engineering Publishing. pp148-154

3. Simon Fahlström, Rikard Pihl-Roos Design and construction of a simple turbojet engine September 2016 TE Munns and RM Kent, ‘Structural Health monitoring degradation mechanism and system requirements’, 19th proc. of Digital Avionics Systems Conf. DASC, Philadelphia, USA, 2000.

4. PM Pawar and R Ganguli, ‘Helicopter rotor health monitoring – a review’, Proceedings of IMechE Vol. 221 Part G: J. Aerospace Engineering, 2007.

5. ‘A Review of Structural Health Monitoring Literature: 1996-2001’, Los Alamos National Laboratory Report, LA-13976-MS, 2003.

6. C Boller and M Buderath, ‘Fatigue in aero structures—where structural health monitoring can contribute to complex subject’, Phil. Trans. R. Soc. A, Vol 365, pp 561–587, 2007.

7. E Taylor, ‘Structural monitoring system, keeping aircraft out of the hangar’, Australian aviation, July 2008.

8. H Stehmeier and H Speckmann, ‘Comparative Vacuum Monitoring (CVM) Monitoring of fatigue cracking in aircraft structures’, 2nd European Workshop on Structural Health Monitoring, Munich/Germany, July 7 - 9, 2004.

9. RD Finlayson et al, ‘Health Monitoring of Aerospace Structures with Acoustic Emission and Acousto-Ultrasonics’, 15th conf. of WCNDT, Rome, 2000.

10. H Pfeiffer and M Wevers, ‘Aircraft Integrated Structural Health Assessment – Structural Health Monitoring and its implementation within the European project AISHA’, EU Project Meeting on Aircraft Integrated Structural Health Assessment (AISHA), Leuven, Belgium, June 2007.

11. VK Varadan and VV Varadan, ‘Wireless Remotely Readable and Programmable Microsensors and MEMS for Health Monitoring of Aircraft Structures’, in ”Structural Health Monitoring”, pp. 96–105, CRC Press, 1999.

12. UIA AMM.pdf.

13. Andrew Harrison (2006). DESIGN FOR SERVICE– HARMONISING PRODUCT DESIGN WITH A SERVICES STRATEG . ASME Turbo Expo 2006: Power for Land, Sea and Air. May 8-11, 2006, Barcelona, Spain.

14. https://www.boeing.com/commercial/aeromagazine/articles/2012_q3/2/

15. Driss Ouedghiri, Stuart Baskcomb: Design for Reliability in Aviation (A must to improve Life Cycle Cost, Safety and Availability)