Fault Analysis Methodology and Maintenance Improvement

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Abstract

Both in civil and private aviation, a strict control of costs is key for economically viable and lucrative operations. Also, there is a demand for increasingly higher levels of safety that can translate into more operational costs. As a consequence, a balance between both costs and safety is necessary and can be achieved via efficient Aircraft Maintenance Plans. The evolution of technology has aided in the close monitoring of relevant operational aircraft parameters, contributing to the efficiency of its maintenance. As an example, some faults can be irrelevant for the operation and be undetected, but when combined with other faults (or if repeated over time) they can indicate possible impending failures and the need for additional maintenance. One software that is used to store and analyse this data is the Computerized Aircraft Maintenance Program (CAMP). In this work, a methodology was implemented to analyse failures on NetJets' fleets of aircraft, namely the Cessna Latitude and the Bombardier Challenger 350. It focused on understanding the failure modes on the analysed systems and on the risks for the operation. Furthermore, and as implemented in a real aviation scenario, the risk critical items were further investigated, determining possible causes of failure, as well as plausible solutions to prevent their recurrence. It was expected that the implementation of the methodology would result in more efficient plans, with custom tasks, reducing costs in the long term. It is concluded that the impact of manufacturing failures is relevant, as items can be faulty from factory and not able to be prevented via maintenance. Also, based on the Pareto's idea, it is noticed that the failures that most contribute to disruptions in operation are related with the Engine Fuel and Control Systems. Furthermore, using the Failure Mode, Effects and Criticality Analysis, the criticality of the fleets is compared: the higher Risk Priority Number values of the Challenger 350's components make it the most critical of both fleets. Ultimately, two Engineering Orders were produced to improve the preventive maintenance plans, alongside four new component developments by the manufacturers to reduce the number of unscheduled events related with faulty items.
Keywords: Aircraft, Failures, Maintenance, Methodology, Risk

1. Introduction

The evolution of the world's economy has a strong impact on the profitability of airlines, which focus on air transport.

Several economical scenarios influence the air transport sector, for instance: if there is an economic recession, there are less travelers willing to spend money flying, whereas if there is an economic boom there is a growth in the sector.

The growth of the air transport sector is perceived as an increase on the number of passengers, as well as on the evolution of globalisation, with an increase on the number of hours flown. This can lead to a higher number of aviation incidents or accidents.

As such, an increase in aviation safety levels must follow, with novel aircraft, in conjunction with tighter schedules of preventive maintenance or even with the evolution of predictive maintenance [1].

A downside to an increase of maintenance are the costs, being of the most importance to reach a balance between the risk of incidents and the costs associated with their prevention.

To decrease the costs, there must be an efficient management of the maintenance plans, with a correct scheduling of the preventive maintenance actions, reducing downtime of aircraft and therefore the associated costs [2] [3].

Complementing, analysis of operational failures can lead to highly customized plans, reducing the occurrence of unscheduled events and promoting a good balance between corrective and preventive maintenance actions [4], as seen on Figure 1.

Based on this principle of reducing the impact of Maintenance costs in an airline, the motivation of implementing a methodology that allows for the analysis of operational failures on NetJets Transportes Aéreos arises, leading to more efficient and customized maintenance strategies and possibly reducing long term costs.

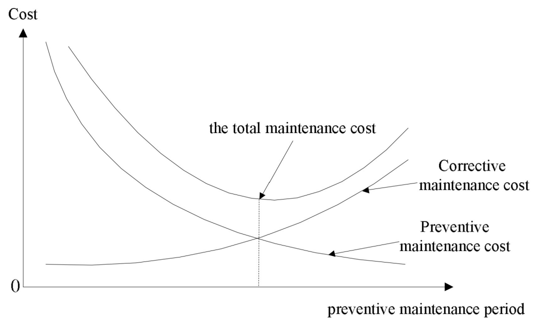

Figure 1: Preventive and Corrective Actions Balance [4].

2. Background

2.1. Mean Time Between Failure

The Mean Time Between Failure (MTBF) is the average of times of failure of a certain component (or components in a certain sample) [5].

Considering the useful life models (constant failure rate λ), the MTBF can be calculated by inverting the failure rate [5]:

$$MTBF = \lambda^{-1} \tag{1}$$

As the components are replaceable, the failure rate of a certain component is calculated by dividing the total number of failures (ΔN_f) by the total service time in which those failures occurred [5].

In this work, the total service time of a component is a result of the number of years in service (Y), the average aircraft flying hours per year ($\overline{FH}$) and the number of aircraft in the fleet ($N_{A/C}$).

As such, the MTBF can be obtained by dividing the total operational experience time by the number of failures occurred [5] [6]:

$$MTBF = Y \times \overline{FH} \times N_{A/C} \times \Delta N_f^{-1} \tag{2}$$

2.2. Risk Analysis

A Risk Analysis relies on understanding the hazards to the operation upon failure of selected components. The Failure Mode, Effects and Criticality Analysis (FMECA) is used to prioritize the risk of failures.

Upon selection of the failure modes, these can be rated according to three different features [7]:

– *Detection (D):* the probability of detecting a failure previous to realizing its effect;

– *Severity (S):* the possible consequence of the failure to the operation;

– *Occurrence (O):* the frequency or probability of occurring a failure (mostly related with MTBF).

The Detection, Severity and Occurrence are each assigned with a number from 1 to 10 [7] [8] .

With a combination of these three factors, a Risk Priority Number (RPN) can be calculated [8]:

$$RPN = D \times S \times O$$

As such, several items can be compared via their respective RPNs, as the numbers are dimensionless: the higher the RPN, the higher the consequences to the operation [8].

3. Methodology

The methodology consists of several steps, so that there is a systematic approach to any possible study, as follows:

Step 1 – Fleets and Main System Selection: the aircraft fleets and major sections of each fleet shall be selected to be analysed (for example, fleet of Cessna Latitude and engine section);

Step 2 – Data Collection and Categorization: all data related with failures of the selected section shall be compiled, as well as organized according to parameters that will support the study later on (Corrective Action as an example of a parameter);

Step 3 – Decision Making and Pareto Analysis: to focus the investigation on important subsystems, the exclusion of those that don't contribute to a certain amount of the total failures is essential; also, this will reduce the workload and time consumed on further steps;

Step 4 – Data Analysis: understand all items that caused failures on each subsystem, how many failures occurred as well as the respective corrective actions taken;

Step 5 – Risk Analysis and Critical Items Selection: each item that failed is assessed on the values of Detection, Severity and Occurrence, with consequential calculus of the Risk Priority Number; the critical items (with highest values of RPN) shall be selected for further analysis; the number of items selected depends on the available timeframe of the project;

Step 6 – Critical Item Analysis and Potential Solution Finding: in each selected critical item, all events shall be analysed, as well as detecting related tasks on the maintenance plans; furthermore, possible solutions shall be drawn (either via maintenance tasks or the manufacturer); cost analysis on new (or improved) maintenance tasks shall also be performed.

4. Results & Discussion

At first, the fleets and systems to be analysed were selected based on the preferences of NetJets.

As an Engine Health Monitoring system was to be used (namely, CAMP), this implied that the fleets selected were the Cessna Citation Latitude and the Bombardier Challenger 350 (or CH350). The corresponding engines are the *Pratt and Whitney's PW306D1* and the *Honeywell's HTF7350*.

In order to have all data regarding failures from both engines, it was necessary to build a sheet with important categories for the posterior analysis, as:

– Date;
– Aircraft Registration;
– Reported Failure;
– Corrective Action;
– Engine Flight Hours;
– Work Order Type;
– Failure Category;
– Corrective Action Category;
– CAMP Fault Codes Prior to Failure;
– Number of CAMP Fault Codes;
– Relation of Failure with CAMP Fault Codes.

4.1. Latitude

Being based on the ATA 100 Chapters and the Latitude's Engine Maintenance Manual (EMM) [9], the Failure Categories and Subcategories for this fleet were defined, as on Table 1.

Category	Subcategory
Bleed Air	Engine Bleed Valves
	Anti-Ice System
Engine Fuel and Control	Fuel System
	Fuel Filter
	ECTM No Transmit
	Engine Dispatch Limited
Engine Indicating	Incorrect Engine Temperature
Exhaust	Thrust Reversers
Fire Protection	Fire Detector Warnings
Ignition	Engine No Start
	Auxiliary Power Unit No Start
	Engine Ignition
Oil	Oil Pressure
	Oil Filter
Structural Damage	Foreign Objects / Birdstrike
	Internal / External Damage
	Engine Vibration
	Corrosion

Table 1: Latitude's Failure Categories and Subcategories.

There is a total of 117 events concerning all categories, with these not contributing evenly for the total. For example, the Engine Fuel and Control System Failures correspond to over 30% of the total amount of events, whereas the Fire Protection System Failures contribute with less than 2%.

Due to a review from the Maintenance Team (MT) from NetJets, the *Engine Condition Trend Monitoring (ECTM) No Transmit* Subcategory as well as the *Structural Damage* Category were excluded from further analysis, leaving a total of 96 events.

With Pareto's idea [10] in mind, that a high number of failures is caused by a small number of causes, a consensus was reached in order to select which Categories were to be detailed afterwards: those that didn't contribute to at least 10% of the 96 events were to be excluded. As such, the *Bleed Air System*, *Engine Indicating System* and *Fire Protection System* Failure Categories were left out of the scope of the study.

To further understand the failures, it was required to analyse the components or items that lead to those failures, as well as the possible consequences for the operation. For that, all the components that failed were discretized, followed by the number of occurrences, an RPN analysis and also plausible mitigation actions based on the corrective actions performed upon failure.

The ranking of the components based on their RPN number can be seen on Table 2.

Component	D	S	O	RPN
T/R Control Valve	5	5	8	200
EEC Electrical Connectors	5	3	9	135
FFIB Switch	5	3	9	135
T/R Control Valve Connectors	5	5	4	100
EEC	5	3	6	90
Oil System Seals	4	3	6	72
Fuel Filter	4	3	4	48
Generator Control Unit	4	3	4	48
Oil Bypass Switch	5	2	4	40
Spark Ignitor	5	2	4	40
Starter Generator	5	2	4	40
Start Switch	5	2	4	40
Oil Level	2	2	9	36
T/R Doors	1	2	4	8

Table 2: Latitude's Components RPN Ranking.

Due to time constraints, only three components were selected for further investigation, corresponding to the highest values of RPN: the *Thrust Reverser (T/R) Control Valves*, the *Electronic Engine Control (EEC) Electrical Connectors* and the *Fuel Filter Impending Bypass (FFIB) Switches*.

4.1.1. Thrust Reverser Control Valves

Among the several types of thrust reversers, the Cessna Latitude has a *bucket type*, similar to the one displayed (deployed) on Figure 2. Its deployment (and stowage) is dependent on the electrical input that reaches the T/R Control Valve.

Figure 2: Deployed Bucket Type Thrust Reverser.

At NetJets Europe (NJE), there were 5 events related with a replacement of the control valves. Being a reduced number, data from NetJets Aviation (NJA) was added. Out of a total of 40 replacements, there are 31 different valve Serial Numbers (S/N), all with the same Part Number (P/N).

Out of the 31 different valves, 18 (58%) have a S/N of the form *8xy*. Out of these 18, 11 valves (61% of the *8xy* series) were ultimately removed, no longer being in service. The remaining 7 valves (39%) are still in use, although being overhauled at least once. The data suggests an issue affecting specific serial numbers, with manufacturing errors or faulty batches being probable causes.

Regarding the type of events leading to replacements, out of the 40 events, 23 (58%) were related with inspections. The remaining 17 (42%) were unscheduled events where the plane had to be grounded, a high number for a system whose failures can have dangerous outcomes.

In addition, 12 out of the 17 (71%) concerned valves that did not complete 800 Flight Hours (FH) of operation (average of 623FH). As such, even if the possible failures could be prevented, tasks would not be efficient as they would not be coincident with any existent scheduled maintenance.

As no other information was known, the manufacturer was informed of the failures. Two malfunctions on the valves were later discovered as being the cause of the failures, as such:

– a bent spring guide internal to the control valve (*vd.* Figure 3);

– an incomplete drill depth on the supply pressure channel.

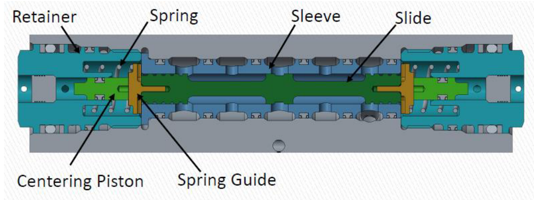

Figure 3: Control Valve Schematics and Spring Guide Location.

Replacement was required for the affected valves, corresponding to 79 different serial numbers. As such, a Service Bulletin was issued for that effect, occurring during the next maintenance opportunities.

4.1.2. EEC Electrical Connectors

The EEC is a digital computer that receives multiple flight condition inputs (as air temperature or throttle lever position) via electrical connectors.

The EEC and corresponding connectors are mounted inside the engine nacelle (housing that holds and protects the engine). In here, these are subjected to massive vibrations, as well as to environmental agents (dust and moisture) that can escape into the EEC's protected area. As such, the connectors can be negatively affected.

At NJE, a total of 9 events related with the EEC Electrical Connectors were registered. Being a reduced number of events, NJA's data was added. As such, in only a year, NJA registered 61 events related with the connectors.

All the corrective actions performed (either on NJE or NJA) are based on the EMM [9] and consist of a cleaning of the connectors. This was highly effective in the short term, but in the long term the faults would appear again.

This data indicates that a preventive maintenance task can be effective while the manufacturer does not find a permanent solution for the failures. As such, an Engineering Order (EO) was drafted.

In first place, the recurrence of the tasks is to be defined, being important to schedule the tasks to be performed coincidentally with other maintenance procedures.

As most failure events occurred in the interval between 967.3FH and 1833.7FH, it was decided that a recurrence of 800FH was the best option.

Next, it is important to define the scope of the EO. As there are several connectors, it is relevant to assess which bring more risk to the operation.

As seen on Table 3, the EEC and P1/T1 Line Replaceable Units (LRU) are responsible for 81% of failure events, whereas the Engine Diagnostic Unit (EDU) and the Bleed-Off Valve (BOV) Solenoid are only responsible for 19%.

Applying Pareto's idea [10], the electrical connectors corresponding to the first two LRUs were included in the EO's tasks.

LRU	Connectors	Distrib.
EEC	P1; P2; P4; P5	56%
P1/T1	P22; P23	25%
EDU	P36; J36	12.5%
BOV Solenoid	P13; P14	6.5%

Table 3: LRUs, Connectors and Distribution of Events.

Finally, the resources to perform these tasks need to be defined. These are related with the time consumed in performing the tasks, as well as the costs associated.

Upon contact, a Service Center determined that the EO would require a total of 5 hours per aircraft: 2 hours per engine to clean the EEC and P1/T1 electrical connectors; and 1 hour of functional checks afterwards.

Regarding the costs and taking into account the average man-hour value, the EO would cost 465€ per aircraft, yearly totaling 7440€.

4.1.3. Fuel Filter Impending Bypass Switches

Current turbine engines make use of fuel systems in which there is a fuel filter. Due to the mesh size used, it is prone to blockages. To prevent a total cutoff of fuel supply to the engine, with subsequent shutdown, a relief valve is installed, acting as a bypass. The opening of the valve physically activates the FFIB Switch (*vd.* Figure 4), signaling the crew to a possible filter failure.

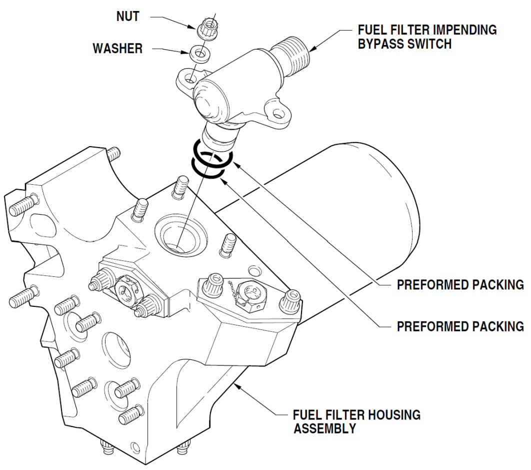

Figure 4: Latitude's FFIB Switch Schematics [9].

At NJE, there were 7 events related with a replacement of the FFIB Switch. Being a relatively reduced number, data from NJA was added. A total of 169 removals were registered, with the following information:

– there were 26 removals in 2017, 32 in 2018, 41 in 2019 and 61 in 2020;

– all switches have the same P/N 30B3500-03;

– only 1 FFIB Switch (corresponding to 1 S/N) was overhauled;

– there is no direct correlation between a group of S/N and failure.

In first place, the growing number of removals per year indicates that the significance of these unscheduled events has been growing with time.

In second place, the fact that all switches have the same P/N, but variable S/N, might indicate a baseline manufacturing issue with all switches rather than simply a faulty batch.

As no other information was known, the manufacturer was informed of the failures. At first, some preliminary conclusions were reached: there was a contamination on the switches' contacts, leading to two changes:

– a *physical change*, with the replacement of the connecting gasket (or seal) for a better one;

– a *procedural change*, by changing the hand balm of the workers that worked on the switches.

The test switches with the changes continued to fail. A new non-specified contamination was discovered, leading to a development of a fully new switch.

The faulty switch was *normally closed*, with the switch's circuit always closed (with permanent physical contact between switch and circuit). This permanent contact was deemed the source of the faults.

As such, the new switch required less contact time to overcome the malfunctions. A *normally open* switch was developed, with an added inverter to emulate a closed circuit on the on-board computer.

A Service Bulletin was then issued, requiring the replacement of all old P/N switches for the new P/N. Thus far, no failures have been reported regarding the new FFIB Switches.

4.2. Challenger 350

Being based on the ATA 100 Chapters and the CH350's EMM [11], the Failure Categories and Subcategories for this fleet were defined, and can be seen on Table 4.

There is a total of 103 events concerning all categories, with these not contributing evenly for the total. For example, the Engine Fuel and Control System Failures correspond to over 35% of the total amount of events, whereas the Engine Indicating System Failures contribute with less than 2%.

Category	Subcategory
Bleed Air	Bleed Fault
	Anti-Ice System
Engine Fuel and Control	FADEC Memory
	FADEC Fail Message
	Short Time Dispatch
Engine Indicating	Engine Fluctuations
Hydraulic Power	Hydraulic System
Ignition	Engine No Start
	Power Faults
Oil	Oil Chip Message
	Oil Pressure
Structural Damage	Foreign Objects / Birdstrike
	Internal / External Damage
	Corrosion

Table 4: CH350's Failure Categories and Subcategories.

Due to a review from the MT from NetJets, the *Full Authority Digital Engine Control (FADEC) Memory* and *Oil Chip Message* Subcategories, as the *Structural Damage* Category were excluded from further analysis, leaving a total of 82 events.

With Pareto's idea [10] in mind, and similarly to what occurred was used on the Latitude fleet, a consensus was reached in order to exclude from further analysis those that didn't contribute to at least 10% of the 82 events. As such, the *Ignition System* and the *Engine Indicating System* Failure Categories were left out of the scope of the study.

Component	D	S	O	RPN
Anti-Ice Valve	5	5	8	200
Oil Pump	5	3	9	135
Engine Driven Hydraulic Pump	5	3	9	135
Hydraulic Pump Filter	5	5	4	100
Oil System Seals	5	3	6	90
EEC	4	3	6	72
Engine Control Unit	4	3	4	48
Bleed Air Leak Detector	4	3	4	48
Output Signal Sensor	5	2	4	40
Oil Level	2	2	9	36

Table 5: CH350's Components RPN Ranking.

To further understand the failures, it was required to analyse the components or items that lead to those failures, as well as the possible consequences for the operation. For that, all the components that failed were discretized, followed by the number of occurrences, an RPN analysis and also plausible mitigation actions based on the corrective actions performed upon failure.

The ranking of the components based on their RPN number can be seen on Table 5.

Due to time constraints, only three components were selected for further investigation, corresponding to the highest values of RPN: the *Anti-Ice (A/I) Valves*, the *Oil Pumps* and the *Engine Driven Hydraulic Pumps (EDHP)*.

4.2.1. Anti-Ice Valves

Ice on the wing and engine of an aircraft can be a severe problem. The anti-icing systems are designed to prevent the formation of ice on surfaces of the aircraft whenever icing conditions are detected.

In turbine-powered aircraft, heated bleed air from the engine is directed to the cowlings or wings via ducts, over the course of which are valves to regulate the flow. The Challenger 350's Engine Anti-Ice Valve is depicted in Figure 5.

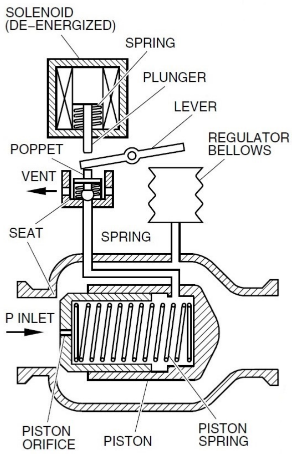

Figure 5: CH350's Anti-Ice Valve Cut Schematics [11].

When the valve receives a command input to close at higher inlet pressure, the regulator *bellows* moves the lever, placing the control section poppet near the seat.

The assessment performed of the valves is as follows:

– the 18 A/I Valves removed all have the same P/N WBA3020G103-005;

– there are no A/I Valves reinstalled, all being discarded after removal, implying that all valves have different S/N;

– there is no direct correlation between a group of S/N (for instance, a batch) and failure, with a great diversity of the S/N.

No other information regarding the repairs or causes of failure was known, therefore the manufacturer was contacted. The investigation demonstrated problems with inner parts of the valve, namely with the bellows.

With the thermal expansion and contraction, the bellows material becomes brittle and damaged. This has an effect on the control section airflow, causing the valves to malfunction.

The manufacturer decided to create a new valve, with a new P/N. Whenever the new P/N is available, the valves will be replaced according to the manufacturers' guidelines.

4.2.2. Oil Pumps

In an aircraft, the oil system is vital for maintaining a continuous flow of oil to the jet engine. The engine-driven pressure oil pump is responsible for delivering the oil to the engine components.

The CH350's oil pumps have a gerotor design, with a pair of toothed rotors, as seen on Figure 6. While the outer rotor has a circular profile, the inner has a related coupled trochoid profile.

In theory, contacts between both rotors should be *simultaneous at all teeth*, but there are unavoidable gaps and clearances in a real profile. These cause *volumetric losses* and therefore a *variation of pressure in gerotor pump chambers* [12].

Figure 6: CH350's Oil Pump Component Breakdown.

At NJE, there were 11 events of oil pump failure, regarding two different part numbers:

– 4 older events relative to a *P/N-3*;

– 7 recent events relative to a *P/N-5*.

The existence of two P/N demonstrates that an attempt was performed by the manufacturer to stop the failure events. The *P/N-5* had minor design changes compared to the *P/N-3*, namely an increased spring tension of the internal components. This kept the subparts closer together, thus reducing the gaps and clearances and, consequently, pressure variations.

As the *P/N-5* continued to fail, the manufacturer continued to seek possible manufacturing defects on both pumps *P/N-3* and *P/N-5*. There were contaminants discovered present on the pumps, rich in Silicon, Oxygen and Aluminum. These were consistent with two known factors:

– the sand from which the mold of the pump was built with;

– the glass and sand particles from the jet blast used for cleaning purposes.

As such, a new pump, *P/N-6*, was developed. It further reduced the internal movement of the pump by reducing the gaps and clearances, and added a new section of pressure relief, similar to one already being in use in the industry (the Airbus A350's Auxiliary Power Unit pump).

This new design fully eliminated the radial forces of the discharge pressure by routing the flow of fluid through eccentric rings and wear plates instead of through the body and came of the pump.

In addition, new manufacturing techniques were used so that contamination of the pumps doesn't occur.

Full fleet replacement of the pumps for the new *P/N-6* is undergoing. Thus far, and after a few inspections performed, those in service don't have any registered failures until September 2020.

One unscheduled event related with a *P/N-6* pump has been detected in October 2020, possibly indicating that not all problems were solved with this new pump.

4.2.3. Engine Driven Hydraulic Pumps

In most jet engine aircraft, the control surfaces, as well as the landing gear and flaps, are powered by the Hydraulic Systems. These use fluid and pressure to operate the surfaces, with the help of an Engine Driven Hydraulic Pump.

In order to develop a more robust investigation, data relative to the EDHP's failures from NJA and NJE was analysed. As the total of events is relatively elevated, only the factual analysis of the data will be detailed. As such:

– there is a total of 62 events, resulting in 58 replacements (removal and installation) of the EDHP;

– the 58 removed EDHP all have the same P/N 51160-06;

– only 1 EDHP (corresponding to 1 S/N) was overhauled and reinstalled after a first removal, with all others being discarded;

– 17 events occurred during flight and 41 were detected whilst the aircraft was still grounded.

Out of the 58 events that lead to the removal of EDHPs, the main reason for the failure events are leak events, with a total of 45 leakages. A real leak of the CH350's EDHP is shown on Figure 7.

Figure 7: CH350's EDHP Leak.

Most failure events occurred in the interval 952 and 3658 Engine Flight Hours (EngFH), empirically implying that a possible preventive maintenance task should take place in this interval. As such, an EO was prepared.

As it is very broad, a more discretized approach was taken, analysing the events that occurred at every interval of 400 EngFH. It is also important to state that events prior to 800 EngFH were considered Infant Mortality (I.M.).

Afterwards, to correctly assess a timing for a maintenance task to be scheduled, the cumulative Table 6 was constructed. It represents the number of events that could be missed (and therefore cause an unscheduled event) if a maintenance task was performed at a given time.

To be stated that the percentages of *Missed Events* is obtained by taking into consideration all 58 events, whilst the percentages of the *Missed Events without (w/o) I.M* is obtained considering only 47 events.

Recurrence	**Missed Events**		**Missed w/o I.M.**	
1200 EngFH	13	22%	2	4%
1600 EngFH	19	33%	8	17%
2000 EngFH	26	45%	15	32%
2400 EngFH	31	53%	20	43%
Total Events	58	100%	47	81%

Table 6: Cumulative Missed Events on the EDHP.

When analysing the data, some conclusions are drawn, as follows:

– if task performed at every 1200 EngFH, a very small percentage of possible events would be missed; highly effective, but economically expensive, as the number of yearly tasks would increase in 25%.

– if task performed at every 2000 EngFH, possibly a very high number of events would be missed, leading to questionings regarding the reasons for preventive maintenance to be performed.

As such, a trade-off between the number of inspections and of possible missed unscheduled events is necessary. Therefore, the recurrence of the maintenance task is set at 1600 EngFH, with roughly 17% of events possibly missed.

To select the maintenance task, information regarding the EDHP's assembly is necessary. The EDHP is closed, therefore only a General Visual Inspection (GVI) can be performed. If failure is found, a Detailed Inspection shall be carried out to determine if the item is safe for operation; if unsafe, a replacement of the EDHP is mandatory.

Finally, the resources to perform these tasks need to be defined. These are related with the time consumed in performing the tasks, as well as the costs associated.

Upon contact, a Service Center determined that the EO would require a total of 2.5 hours per aircraft: 30 minutes per engine for access gain; and 45 minutes per engine for the GVI.

Regarding the costs and taking into account the average man-hour value, the EO would cost 233€ per aircraft, totaling 2796€ at every two years.

5. Conclusions

This work demonstrates the benefit of applying theoretical decision making processes to analyse the occurrence of failures, instead of a simple empirical analysis.

An average of 110 failures per fleet was compiled. These were mainly a result of malfunctions with the Engine Fuel and Control System as well as the Oil System.

The usage of the Pareto's idea was useful in reducing the number of events possibly under investigation. The systems that didn't contribute to a minimum percentage of failure events were excluded, with an average reduction of 12% in events to be assessed.

The Risk Analysis, based on the RPN, allowed a good understanding of the importance of each component or item to the Netjets operation. As such, the most critical components of both fleets, per order of RPN, are as follows:

– Anti-Ice Valve (CH350);
– Oil Pump (CH350);
– Engine Driven Hydraulic Pump (CH350);
– Thrust Reverser Control Valve (Latitude);
– EEC Electrical Connectors (Latitude);
– FFIB Switch (Latitude).

Comparing both fleets, it is concluded that the Challenger 350 has failures with a higher risk for the operation than the Latitude, as the Top-3 Critical Items belong to the Challenger 350.

Several solutions for the failures were achieved. It can be concluded that not all solutions for failures are maintenance tasks, as some components may suffer from manufacturing errors or can be poorly manufactured for the location they are installed in.

Regarding the critical items, the following was achieved:

– the Anti-Ice Valve bellows became damaged due to thermal expansions and contractions a new valve is under development by the manufacturer;

– foreign debris were discovered on the failing Oil Pumps, due to manufacturing errors; new pumps were developed with different manufacturing techniques and with a new pressure relief section;

– a general visual inspection on the Engine Driven Hydraulic Pump is possible to prevent unscheduled failure events; if precursor of failure is found, replacement is mandatory;

– a faulty batch of Thrust Reverser Control Valves was discovered due to a bent spring guide and an incomplete drill depth; affected valves are undergoing replacement;

– the EEC Electrical Connectors are prone to contamination; a recurrent cleaning maintenance task is possible to prevent unscheduled events;

– permanent contact of the Fuel Filter Impending Bypass Switches was found to be a cause for the failures; also, contaminants were found on the switches; new switch was developed to minimize contacts; switches undergoing replacement.

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