UNIVERSIDADE DA BEIRA INTERIOR
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Optimization of the LCF coefficients to be applied on RTM322-02/8 Mk250 engines in case of Manual Download

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All over this years, many people have positively influenced me to achieve this moment.

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Resumo

O principal objetivo deste trabalho consiste, através da análise e interpretação da performance dos motores RTM322 e do espectro de missões realizadas pelas aeronaves EH101 da Força Aérea Portuguesa, em ser capaz de otimizar os coeficientes que são usados para o cálculo de cada LCF (*Low Cycle Fatigue*), sempre que seja necessário um *download* manual.

O processo de otimização destes valores consistirá, no estudo do comportamento do desempenho dos motores, para operações em voo e no solo separadamente, e comparação com as consequências que os *downloads* manuais têm em todos os componentes dos motores controlados por limite de vida.

Através desta otimização será possível, para além do ganho em matéria de limite de vida dos componentes do motor, mas também para que o valor a pagar por cada ciclo esteja de acordo com os reais valores que são consumidos pelo motor, caso no futuro se decida pela assinatura de um contrato de suporte de motores com a Turbomeca, *Global Support Package* (GSP), o que implicará custos relacionados com os ciclos do motor.

Este método vai permitir a obtenção de quatro níveis de risco para cada valor de LCF, cada um com o seu correspondente ganho, através do qual a Força Aérea Portuguesa poderá decidir aplicar tendo em consideração os seus próprios critérios de aeronavegabilidade.

Palavras-Chave

RTM322, ciclos do motor, níveis de risco, otimização, helicópteros EH101, Motor *Turbo-shaft*

Resumo Alargado

Com a realização deste trabalho foi possível confirmar que alguns pressupostos relativamente à operação e performance dos motores são corretos, bem como munir a Força Aérea Portuguesa de fatos e valores que lhe permitam otimizar o consumo de ciclos dos componentes dos motores RTM322, que equipam os helicópteros EH101, sempre que se torne necessário a utilização do *download* manual como ferramenta de obtenção de dados.

Para a obtenção dos dados iniciais que serviriam de amostra para os cálculos e comparações a efetuar ao longo do trabalho, tornou-se necessário recorrer ao auxílio da AW, nomeadamente do engenheiro informático que é responsável pelo suporte à PGS, visto as bases de dados da própria PGS não terem disponível toda a informação necessária à concretização deste trabalho. Esta situação, nomeadamente a necessidade de recorrer a *backups* realizados pela AW, uma das grandes limitações deste software.

Com este trabalho torna-se possível verificar que os erros despoletados em qual uma das fazes de *download* da informação da aeronave para a PGS, influenciam negativamente os valores de ciclos acumulados pelos componentes dos motores bem como da existência de inúmeros tipos de erros, desconhecidos até ao momento, que ao longo dos últimos 10 anos de operação das aeronaves têm vindo a adulterar a informação disponível na PGS.

Inicialmente foi necessário verificar se a variante da aeronave e a posição em que os motores se encontram instalados na mesma eram fatores determinantes na performance dos motores. Para tal foi necessário numa primeira etapa dividir a informação recolhida em dois tipos distintos de operação: operação no solo e em voo; esta divisão é essencial tendo em consideração que o próprio fabricante do motor diferencia os mesmos tipos de operação.

Após a verificação dos pressupostos anteriores foi utilizado um método comparativo definido em patamares de risco/ganho de forma e possibilitar, em primeiro lugar a verificação de que realmente existe margem de otimização e por fim fornecendo a possibilidade à PtAF de optar, com base nos resultado obtidos, do patamar de risco/ganho que melhor se adequa aos seus próprio critérios de segurança.

Abstract

The main objective of this work is to, by the analysis and interpretation of the RTM322 engines performance and the usage spectrum of the Portuguese Airforce EH101 operations, be able to optimise the values that are used for the LCFs calculations, every time a manual download is needed.

The process to optimise this values, will consist on the study of the engines performance behaviour, separately on flight and ground operations, and compare it with the consequences that manual downloads have on all engine life components.

This optimisation will allow, not only to gain in a matter of engine components life limit but also to not pay for cycle consumption than the engines, in reality, are not consuming, if in the future is decided to go through the sign of an engine support contract, called by Turbomeca as Global support Package (GSP), which could imply some cycle related costs.

This method will allow to obtain four risk levels for each LCF values, each one with it correspondent gain, from which Portuguese Air Force will be able to decide to apply considering their own airworthiness authority criteria.

Keywords

RTM322, engine cycles, Risk levels, optimization, EH101 Helicopters, Turbo-shaft Engine

Contents

Acknowledgments .... **iii**

Resumo .... **v**

Resumo Alargado .... **vii**

Abstract .... **ix**

Contents .... **xi**

List of Figures .... **xiii**

List of Tables .... **xv**

List of Graphics .... **xvii**

List of Acronyms .... **xix**

1 Introduction **1**

1.1. Objective 1
1.2. Context and Motivation 2
1.3. EH101 Aircraft 3
1.3.1. EH101 Program 3
1.3.2. Aircraft Management System (AMS) 4
1.3.3. Health and Usage Monitoring System (HUMS) 5

2 RTM322-02/8 MK250 Engine **7**

2.1. Engine Description 7
2.2. Engine Modules 8

3 Problem in Study **13**

3.1. Data Download System 13
3.2. Manual Downloads Consequences on RTM322 Engine 15
3.2.1. LCF manual counting 15
3.3. Study Case Data 19
3.3.1. PGS download data 19
3.3.2. Engine Data gathering 19
3.3.3. Data Sample Optimization 20

4 Data Sample Analysis **25**

4.1. Flight operations vs Ground Operations 25
4.2. Analysis Method 27
4.2.1. Step One – Engine Comparison 27
4.2.2. Step Two – Aircraft Comparison 30
4.2.3. Step Three - Manual and Automatic LCF Comparison 31
4.2.4. Step Four – Optimization Method 38

5 Results **41**

5.1. Flight Operation Results 41

5.1.1. Risk Level's LCF Values Calculation/Interpretation 41
5.1.2. Risk Level's Gain Calculation 44
5.2. Ground Operation Results 46
5.2.1. Risk Level's LCF Values Calculation 46
5.2.2. Risk Level's Gain Calculation 53
6 Conclusions and Future Works 57
6.1. Conclusions 57
6.2. Future Works 58
7 Bibliografia 59
Appendix A 61
Appendix B 67

List of Figures

Figure 1 – AMS architecture [2] 4
Figure 2 – data transfer process [2] 5
Figure 3 – RTM322-02/8 Mk250 [3] 7
Figure 4 – Engine Modules [4] 8
Figure 5 – Core Module (M00 – M01 + M02) [4] 9
Figure 6 – Module 3 (M03) [4] 9
Figure 7 – Module 4 (M04) [4] 10
Figure 8 – Module 5 (M05) [4] 11
Figure 9 – Module 6 (M06) [4] 11
Figure 10 – Engine Electronic Control Unit (EECU) [4] 12
Figure 11 – SIGOP database example [8] 25

List of Tables

Table 1 – LCF by RTM322 components [7] 16
Table 2 – Ground Operation LCF (appendix A) 16
Table 3 – LCF Ground Operations Values (work proposes) 17
Table 4 – Partial Cycles Description (appendix A) 17
Table 5 – LCF calculation Formulas (work proposes) 18
Table 6 – Resume of Engine Data (01JAN14 and 31DEC15) [7] 19
Table 7 – Sample and Population Comparison [7] 20
Table 8 – Data Sample Errors [7] 21
Table 9 - Sample and Population Comparison without errors [7] 22
Table 10 - Aircraft A, B and C LCF Comparison (Start=1 vs Start>1) Flight Operations 23
Table 11 - Aircraft A, B and C LCF Comparison (Start=1 vs Start>1) Ground Operations 23
Table 12 – Total Ground and Flight Operations Downloads 26
Table 13 - Aircraft C Manual and Automatic LCF comparison (Flight) 32
Table 14 – Automatic and Manual average LCF comparison (Flight) 33
Table 15 – LCF average values (ground operations) 33
Table 16 - Aircraft C (Eng1 and Eng3) Manual and Automatic LCF comparison (Ground) 36
Table 17 – Eng1 and Eng3 Automatic and Manual average LCF comparison (Ground) 36
Table 18 - Aircraft C (Eng2) Manual and Automatic LCF comparison (Ground) 38
Table 19 – Eng2 Automatic and Manual average LCF comparison (Ground) 38
Table 20 – LCF average values (flight operations) 38
Table 21 – Engine 1 and 3 LCF average values (Ground operations) 39
Table 22 - Engine 2 LCF average values (Ground operations) 39
Table 23 – Risk Levels 40
Table 24 – Risk Level's Values (flight operations) 41
Table 25 - Risk Level's corrected Values (flight operations) 44
Table 26 – Aircraft C/Engine1 Manual and Risk Levels cumulative values comparison (flight operations) 44
Table 27 – Aircraft C/Engine1 Gain for 100% Manual Downloads (flight operations) 45
Table 28 - Aircraft C/Engine1 Gain for 10.4% Manual Downloads (flight operations) 45
Table 29 - Aircraft C/Engine1 Gain for 16.4% Manual Downloads (flight operations) 45
Table 30 – Engines 1 and 3 Risk Level's Values (ground operations) 46
Table 31 – Engine 1 and 3 Risk Level's corrected Values (ground operations) 49
Table 32 – Engine 2 Risk Level's Values (ground operations) 50
Table 33 - Engine 2 Risk Level's corrected Values (ground operations) 53
Table 34 - Aircraft C/Engine1 Manual and Risk Levels cumulative values comparison (ground operations) 53
Table 35 - Aircraft C/Engine1 Gain for 100% Manual Downloads (ground operations) 54
Table 36 - Aircraft C/Engine1 Gain for 10.4% Manual Downloads (ground operations) 54

Table 37 - Aircraft C/Engine1 Gain for 16.4% Manual Downloads (ground operations) 54
Table 38 - Aircraft C/Engine2 Manual and Risk Levels cumulative values comparison (ground operations)... 55
Table 39 - Aircraft C/Engine2 Gain for 100% Manual Downloads (ground operations) 55
Table 40 - Aircraft C/Engine2 Gain for 10.4% Manual Downloads (ground operations) 55
Table 41 - Aircraft C/Engine2 Gain for 16.4% Manual Downloads (ground operations) 56

List of Graphics

Graphic 1 - defence expenses evolution between 2002-2014 at current prices [1]................2
Graphic 2 - defence expenses evolution between 2002-2014 in % of GNP [1] 3
Graphic 3 - Manual Downloads evolution over time 14
Graphic 4 - Manual Downloads evolution over time counting, between Jan2014 and Dec2015, with the new error found... 14
Graphic 5 - Manual Downloads evolution over time counting with the new error found since the beginning of the fleet 15
Graphic 6 – Aircraft A/Engine 1 LCF Comparison (Start=1 vs Start>1).............................. 22
Graphic 7 - Aircraft A LCF Engine Comparison (Flight)... 27
Graphic 8 - Aircraft A LCF Engine Comparison (Ground)... 28
Graphic 9 - Aircraft B LCF Engine Comparison (Flight)... 28
Graphic 10 - Aircraft B LCF Engine Comparison (Ground) 29
Graphic 11 - Aircraft C LCF Engine Comparison (Flight) 29
Graphic 12 - Aircraft C LCF Engine Comparison (Ground) 29
Graphic 13 – Aircraft LCF average values comparison (flight) 30
Graphic 14 - Aircraft LCF average values comparison (ground) 30
Graphic 15 - Aircraft C/Engine 1 - LCF1 Aut vs Man (Flight) 31
Graphic 16 - Aircraft C/Engine 1 – LCF2 Aut vs Man (Flight) 31
Graphic 17 - Aircraft C/Engine 1 – LCF3 Aut vs Man (Flight) 32
Graphic 18 - Aircraft C/Engine 1 – LCF4 Aut vs Man (Flight) 32
Graphic 19 - Aircraft C/Engine 1 – LCF1 Aut vs Man (Ground) 34
Graphic 20 - Aircraft C/Engine 1 – LCF2 Aut vs Man (Ground) 34
Graphic 21 - Aircraft C/Engine 1 – LCF3 Aut vs Man (Ground) 35
Graphic 22 - Aircraft C/Engine 1 – LCF4 Aut vs Man (Ground) 35
Graphic 23 - Aircraft C/Engine 2 – LCF1 Aut vs Man (Ground) 36
Graphic 24 - Aircraft C/Engine 2 – LCF2 Aut vs Man (Ground) 37
Graphic 25 - Aircraft C/Engine 2 – LCF3 Aut vs Man (Ground) 37
Graphic 26 - Aircraft C/Engine 2 – LCF4 Aut vs Man (Ground) 37
Graphic 27 – Aircraft C/Engine 1 LCF1 Risk Levels Comparison (flight operations).............. 42
Graphic 28 - Aircraft C/Engine 1 LCF2 Risk Levels Comparison (flight operations).............. 42
Graphic 29 - Aircraft C/Engine 1 LCF4 Risk Levels Comparison (flight operations).............. 43
Graphic 30 - Aircraft C/Engine 1 LCF3 Risk Levels Comparison (flight operations).............. 43
Graphic 31 - Aircraft C/Engine 1 LCF1 Risk Levels Comparison (ground operations)............ 47
Graphic 32 - Aircraft C/Engine 1 LCF1 Risk Levels Comparison (ground operations)............ 47
Graphic 33 - Aircraft C/Engine 1 LCF 2 Risk Levels Comparison (ground operations) 48
Graphic 34 - Aircraft C/Engine 1 LCF3 Risk Levels Comparison (ground operations)............ 48
Graphic 35 - Aircraft C/Engine 1 LCF4 Risk Levels Comparison (ground operations)............ 49
Graphic 36 - Aircraft C/Engine 2 LCF1 Risk Levels Comparison (ground operations)............ 51

Graphic 37 - Aircraft C/Engine 2 LCF2 Risk Levels Comparison (ground operations)............ 51
Graphic 38 - Aircraft C/Engine 2 LCF3 Risk Levels Comparison (ground operations)............ 52
Graphic 39 - Aircraft C/Engine 2 LCF4 Risk Levels Comparison (ground operations)............ 52

List of Acronyms

AGB	Accessory Gearbox
AMS	Aircraft Management System
ASMC	Aircraft System Management Computers
ATA	Aircraft Time of Arrival
ATD	Aircraft Time of Departure
AW	Agusta-Westland
CSAR	Combat Search and Rescue
DCSI	Direção de Comunicações e Sistemas de Informação
DEFLOC	Locação de Equipamentos de Defesa, S.A.
EECU	Engine Electronic Control Unit
FADEC	Full Authority Digital Engine Control
FISS	Full In Service Support
GI	Ground Idle
GNP	Gross National Product
GSP	Global Support Package
HCF	High Cycle Fatigue
HPT	High Pressure Turbine
HUMS	Health and Usage Monitoring System
IPS	Inlet Particle Separator
LCF	Low Cycle Fatigue
MGB	Main Gear Box
MPOG	Minimum Pitch On Ground
MNT	Maintenance Operations (flight and ground)
NATO	North Atlantic Treaty Organization
NDT	Non Destructive Technics
Nf	Power Turbine Speed
NgC	Corrected Gas Generator Speed
OEI	One Engine Inoperative
PCMCIA	Personal Computer Memory Card International Association
PGS	Portuguese Ground Station
PtAF	Portuguese Air Force
RAF	Royal Air Force
RR	Rolls-Royce
SAR	Search and Rescue
SIFICAP	Maritime Vigilance
SIGOP	Sistema Integrado de Gestão Operacional
TM	Turbomeca
TMF	Thermo-Mechanical Fatigue

1 Introduction

The PtAF have in operation, since 2005, 12 helicopters EH101 from the Anglo-Italian Company Agusta-Westland (AW). The first flight of these helicopter prototype occur in October 1987. 10 years later the Royal Air Force (RAF) was the first operator to receive an operational EH101 aircraft.

Being a very advanced aircraft for that time, the EH101 is equipped with a series of sensors and avionics systems that integrated by the Aircraft Management System (AMS) make it possible to record almost every data of the flight allowing a posterior analysis by the Maintenance Management Software (Portuguese Ground Station – PGS).

One of the technologies implemented within the PGS is the Health and Usage Monitoring System (HUMS). This system analyse the raw data collected by the AMS with the objective of permitting a close control of the aircraft and its critical components. From the various components analysed by HUMS this work will focus on part dedicated to the RTM322-02/8 MK250 engines.

1.1. Objective

The objective of this work is to, taking in consideration the engine related data collected by the aircraft and the typical flights performed by the 751 squadron, obtain an optimized values of the LCF coefficients to apply every time the data download between the aircraft and PGS fails.

First of all, will be need to analyse the data available in PGS and collect a reasonable sample of engine data within and stablish the best period of time that suites the objectives of the work. To make the better correlation between the flight data and the typical flights, it is imperative to stipulate witch are this typical flights and this is possible with the indispensable help of the 751 squadron, being them the ones that operate the aircraft.

After that, it is indispensable to get to know the RTM322 engine and its components as also the aircraft available data that is critical for the adequate and continuous operation of the engines. It is also pertinent to try to understand the reasons that led the automatic downloads to fail, forcing to perform manual downloads and consequently the use of the LCF coefficients to calculate the cycles consumed by the engines components on that flight.

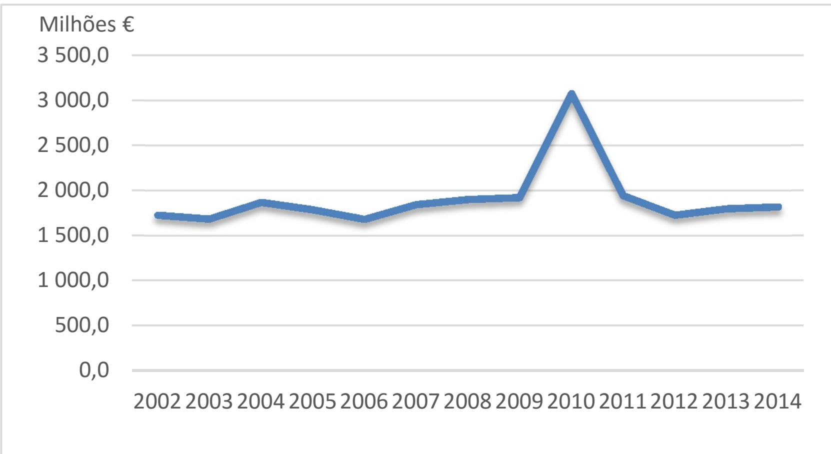
The final phase of this work, will be the data analysis and using statistic methods calculate optimized coefficients related to the current utilization of the aircraft by the PtAF witch will culminate with a list of conclusions and recommendations with the objective of optimize the engine components consumed life and reduce the costs of a future engine maintenance contract.

1.2. Context and Motivation

The severe economic and financial crisis that hit the Euro Zone since 2008, dictate Portugal to ask for a financial assistance program, signed in May 2011. In consequence of that, and putting aside the previous measures taken since 2010 focusing the rationalization of the expenses on all the defence institutions, the previous government conceived, in 2013, a new plan, *Defesa 2020* of restrictions and rationalization of the budget spent on defence.

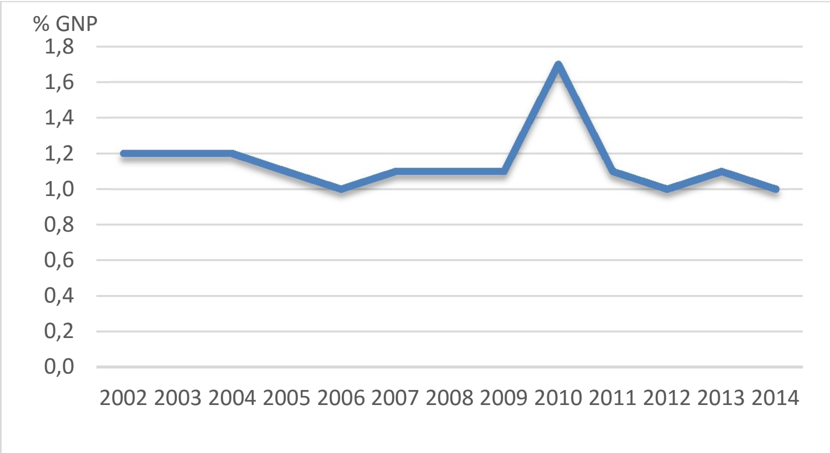
This new situation of restriction and rationalization on the defence budget, it is not only a problem for small countries like Portugal. With effect, all over the world, with particular incidence on the so called western countries, the decrease of defence budgets is a reality that is leading the North Atlantic Treaty Organization (NATO) and the European Union (EU) to develop new mutual defence politics centralized on mutual cooperation and sharing of resources. This kind of politics tend to led small countries like Portugal to disinvest on essential capabilities of national strategic value.

In the concrete example of Portugal, in terms of defence expenses (Graphic 1), the evolution has been practically constant since the beginning of the century, exception made in 2010 (3.079.8 M€), consequence of the extraordinary accounting respected to the acquisition of the two new submarines for the Portuguese Navy.



Graphic 1 - defence expenses evolution between 2002-2014 at current prices [1]

In the same context, the relative weight of the defence expenses, in percentage of the GNP, have been, also practically constant, exception made, as seen previously, the year 2010 for the same reasons. The defence expenses swing between 1.0% and 1.3% of the GNP, having the *Defesa 2020* plan the goal of 1.1% of GNP expend on the defence area (Graphic 2).



Graphic 2 - defence expenses evolution between 2002-2014 in % of GNP [1]

This contextualization leads to the main goal of this work, the reduction of maintenance cost and life limit consumption by optimise the LCF coefficients that are applied on the RTM322 components every time a manual download is required.

1.3. EH101 Aircraft

1.3.1. EH101 Program

In the middle of the 90s, with intention of improvement of the Search and Rescue (SAR) and maritime vigilance capabilities the Portuguese Government started a procedure to replace the fleet of SA330 Puma Helicopters.

The main reasons for that replacement were:

- The SA 330 fleet would achieve, in 2002, the life limit for operation. Adding to this fact that the helicopter couldn't preform night missions, neither had the required range to guarantee the SAR missions on all the area of Portuguese responsibility because it could only reach the 200 mile of operational range, half of EH101's.
- With the incorporation, within NATO partners, of new weapon systems with wide range and all weather condition capabilities, was urgent to equip the PtAF with similar assets allowing the recovery of friendly combatants in all operation area of National interest.
- By International agreements, Portugal is responsible to provide SAR service in both *Lisboa* and *Santa Maria* Flight Information Regions (5.600.000Km^2). With this area, 35 times the area of Continental Portugal, most of the responsibility it is attributed to the PtAF.

To overcome this reasons and after 3 public tenders it was granted to the EH Industries (now Agusta-Westland International Limited), the supply of 12 EH101 Merlin Helicopter in 3 variants:

- 6 aircrafts on Search and Rescue (SAR) variant;
- 2 aircrafts on Maritime Vigilance (SIFICAP) variant;
- 4 aircrafts on Combat Search and Rescue (CSAR) variant;

1.3.2. Aircraft Management System (AMS)

The EH101 aircraft has incorporated five main avionics subsystems, responsible for areas such as, flight control, communications, navigation, visual information and aircraft management. From this subsystems, the AMS is considered the most important, because of it many responsibility of integrate and manage all the electronic information produced by the aircraft (Figure 1).

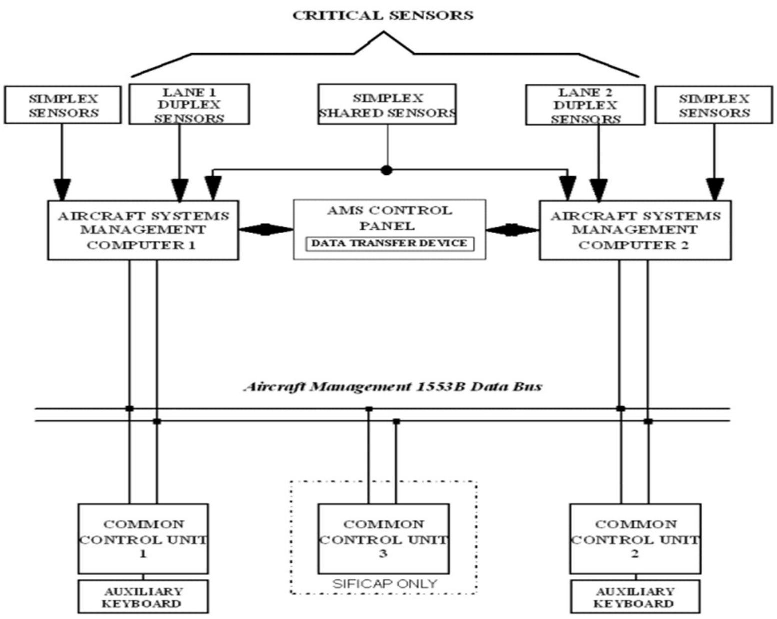


Figure 1 – AMS architecture [2]

Such importance come from the main characteristics of this system, which allows a permanent control of most equipment integrity and functioning, as also the processing of all avionics and navigation operations. The main AMS areas of interaction extend through aircraft and components integrity, HUMS, aircraft performance and the management of systems, such as, navigation, communications, alerts and cockpit displays.

The AMS function like a "nervous system" of the aircraft, processing the analogic signals generated by the aircraft's sensors and converting them to digital signals. All this processing is performed by the two Aircraft System Management Computers (ASMC), one of which function as a master while the other is in hot standby, providing redundancy to the system. The choice of the master computer can be made automatically or manually by the pilot choice. One of the most innovative characteristics of this system was the possibility of download all the data processed by the AMS, providing this way all the useful information to the aircraft management and maintenance or the other way around updating limited programs to the aircraft system. This is possible through the Data Transfer Device (DTD) that is integrated with the AMS (Figure 2).

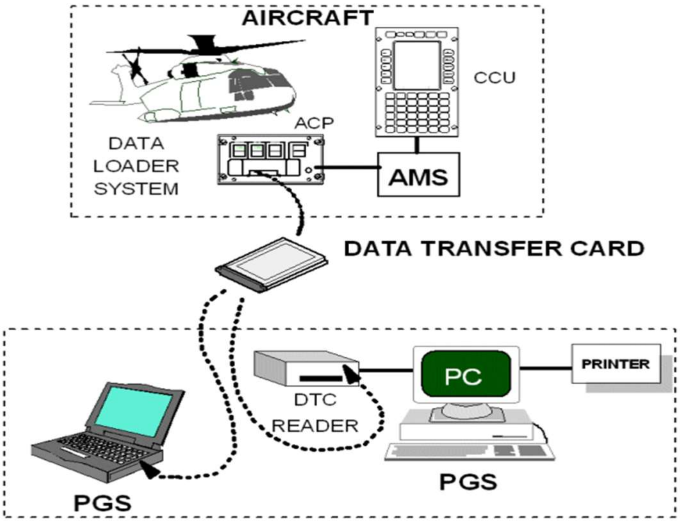


Figure 2 – data transfer process [2]

1.3.3. Health and Usage Monitoring System (HUMS)

For the main objective of this work, it will just be focus a small part of HUMS that is responsible for control the engine performance rates and also its components life. This subsystem allows the AMS to detect any values that are over or under the limits stipulated by the manufacturer. The Engine-HUMS, as it is called, is divided in two parts:

- Engine Health Stateboard – Records the faults that happed and also the data referent to the parameters analyzed;
- Engine Usage Stateboard – Is responsible for recording the specific flight parameters and the cycle values for each engine component.

All this data is provided by several sensors spread through the engine allowing the recording of Speed, Torque and Temperature in specific areas of each engine.

2 RTM322-02/8 MK250 Engine

2.1. Engine Description

In 1992 was delivered the first RTM322 engine to power the Royal Navy EH101 helicopter. This engine is the result of a joint-venture between the English Rolls-Royce (RR) and the French Turbomeca (TM). Since then more than 1500 engines have been manufactured and equips several helicopters from the EH101 to the English Apache. In 2014 Turbomeca acquired the Rolls-Royce share of the engine and is now the sole manufacture and maintainer of this type of engine allowing the company to gain strength on this segment of market.

The RTM332 (Figure 3) is free turbine turboshaft engine with forward coaxial drive shaft. One of the key features of this engine is it modularity (Figure 4), allowing a simpler module change comparatively to other engines on this spectrum. The engine is composed by 6 modules: M01 – Compressor; M02 – Combustion Chamber and High Pressure Turbine (HPT) – the aggregation of this two modules is called Module 0 or M00 (Figure 5); M03 – Power Turbine (PT); M04 – Power Output Shaft; M05 – Accessory Gearbox (AGB); M06 – Inlet Particle Separator (IPS). The entire engine control is processed by the Engine Electronic Control Unit allowing an increment on engine performance on every condition.

Figure 3 – RTM322-02/8 Mk250 [3]

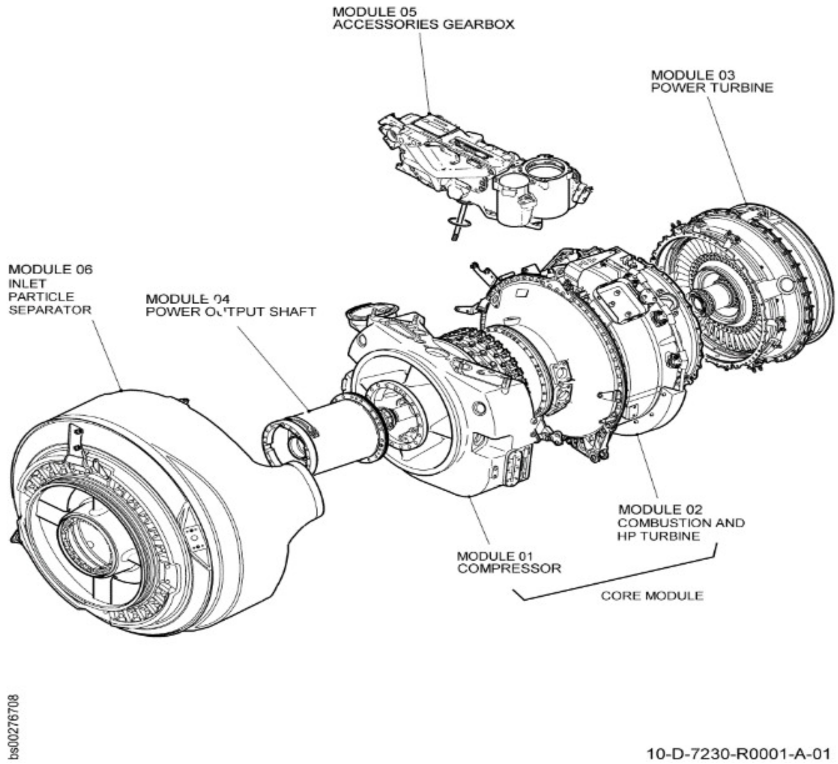


Figure 4 – Engine Modules [4]

2.2. Engine Modules

a) M01 – The RTM322 compressor module is composed by 3 stage axial compressor and a single stage centrifugal compressor. In total on this section the air is compressed on a rate of 15.3. Within M01 module there are 5 components with life limit [5] controlled on cycle consumption, 3 of them part of the axial compressor and with 4570 cycle of life limit and the remaining 2 components integrated on the centrifugal compressor with a life restricted to 3030 and 3780 cycles.

b) M02 – This module e composed by the combustion chamber and 2 stages of high pressure turbine. On the first part of M02 the air is divided in two, one that will mixture with the fuel and feed the combustion and the remaining air will be used to cool down that area. The gas that is generated on the combustion chamber is directed to the high pressure turbine first stage. The HPT is responsible for the transformation of the flow energy into mechanical energy, which power will be used to drive the compressor since it is connected to the HPT by the same axis. In this module case there are 6 components controlled by cycles [5]. With life limit of 3000 – 5 components - and 3180 – 1 component.

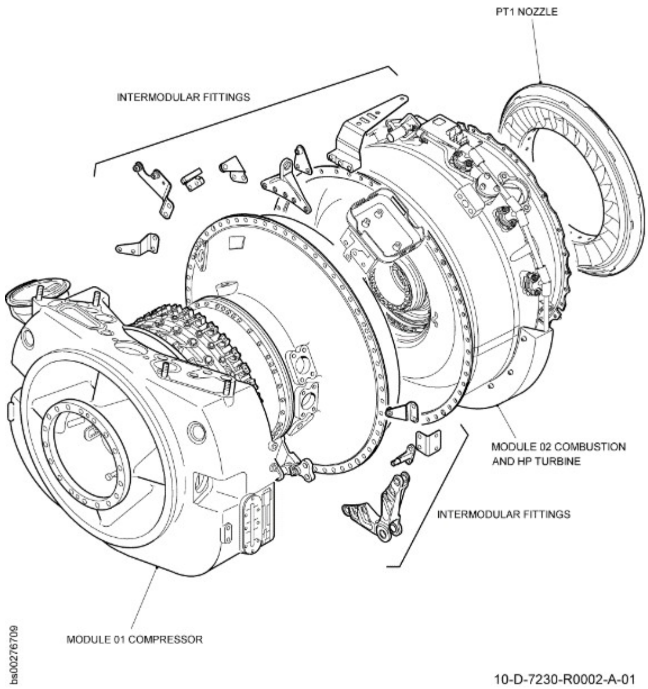


Figure 5 – Core Module (M00 – M01 + M02) [4]

c) M03 (Figure 6) – On the power turbine, the air flow energy is also converted into mechanical energy but in this case this energy is transferred to the power output shaft (M04). Within M03 we can find 3 life limited components, all restricted to 4240 cycles [5].

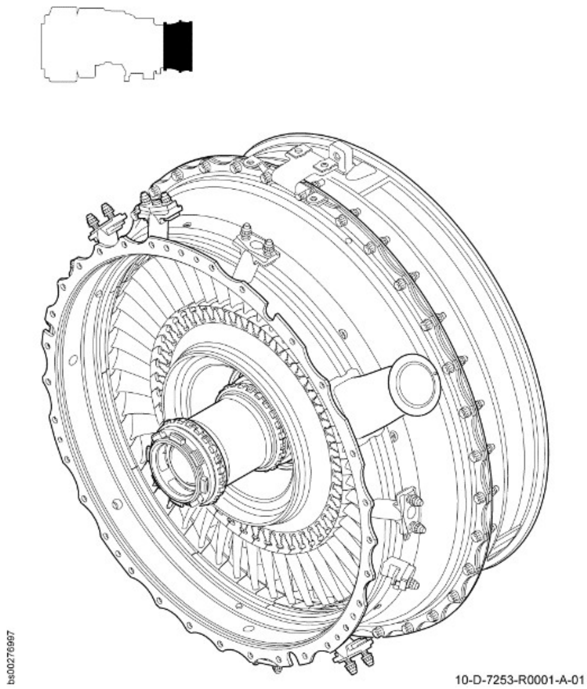


Figure 6 – Module 3 (M03) [4]

d) M04 (Figure 7) – This module is responsible to transmit the power generated on the PT to the aircraft gearing system. To guarantee the system integrity the shaft has to rotate at constant velocity being this feature achieved by the EECU control of the engine.

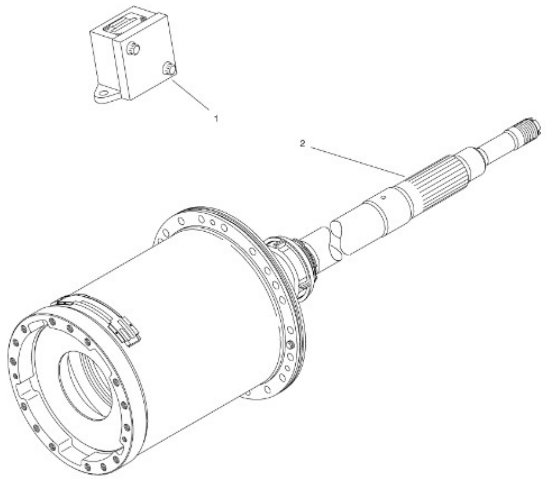


Figure 7 – Module 4 (M04) [4]

e) M05 (Figure 8) – The engine AGB incorporate several components with huge importance on the engine operation. Some of this components are:

- High/Low pressure fuel pumps;
- Oil Pump;
- Alternator;
- Oil/Fuel filters;

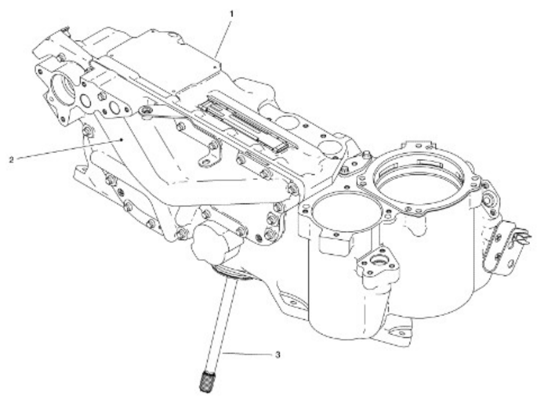


Figure 8 – Module 5 (M05) [4]

f) M06 (Figure 9) – It is on this module that the air that enters on the engine air intake is filtered from particles that could damage the internal components. By this way the wear and tear of the internal components is reduced.

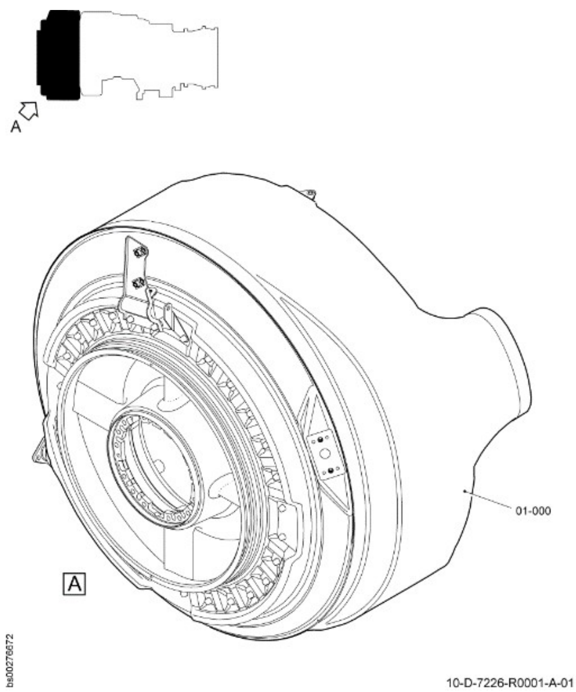


Figure 9 – Module 6 (M06) [4]

Other key component that was already mentioned above is the EECU (Figure 10). The RTM322 engine is controlled by the Full Authority Digital Engine Control (FADEC) that is inserted in the EECU. This component is nothing more than a control unity that allows to optimize the engine performance. With this kind of individual control of the engine it is possible to distribute the torque through the 3 engines equally on normal operation. This characteristic allows also, in case of engine failure, that the 2 other engines distribute the torque between them to continue to power the aircraft.

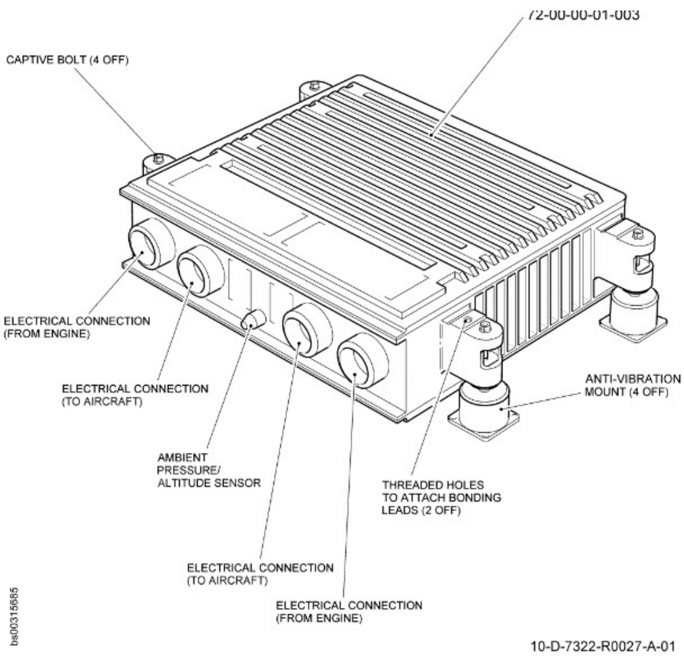


Figure 10 – Engine Electronic Control Unit (EECU) [4]

3 Problem in Study

3.1. Data Download System

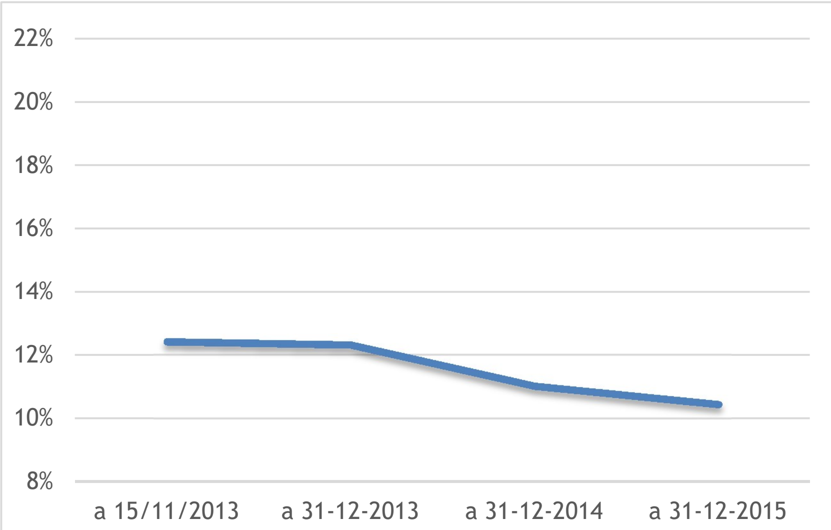
The data download system, as already discussed on paragraph 1.3.2, is an important feature that allows all data recorded on flight to be uploaded to the software used for the record and control of all maintenance tasks. In the specific case of the PtAF, this software is the Portuguese Ground Station (PGS).

Even being such advanced system for its time, when was developed, as all digital systems it has some problems that lead to failure of the download on several occasions over the past 12 years. In 2013 it was estimated in 13.5% the number of downloads had to been made on Manual mode. This situation triggered an investigation to find out the main reasons for this huge percentage, leading to the conclusion that mostly it have been a mishandling of the download procedure, but was also found that the system also has its owns problems.

As was concluded, the automatic download, could fail for many reasons on several stages of the process, such as:

- Mishandling of the download procedure;
- The ASMC fail to record the data during the flight;
- The data fail to download to the PCMCIA card;
- Fail to upload the data to PGS;

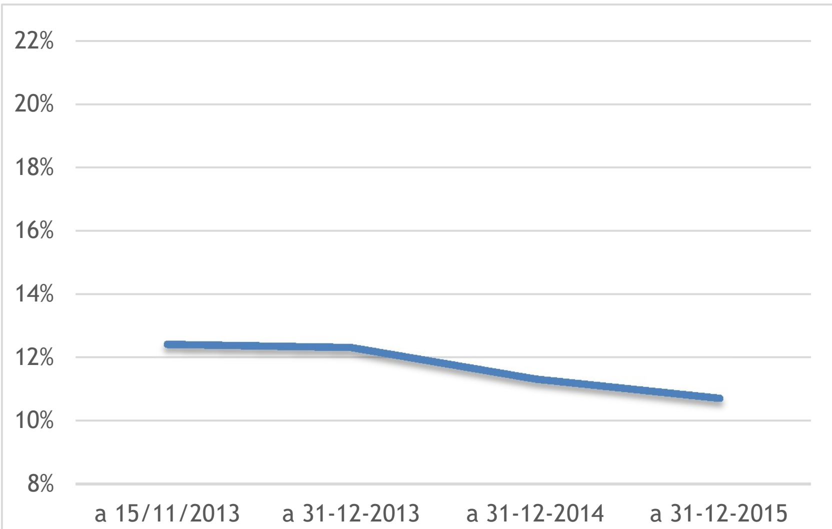
After getting this conclusions and with the objective of reducing the number of manual downloads, was implemented a technical instruction that helped to decrease the percentage of manual downloads from 12.4%, at the time of the investigation, to 10.4% today (Graphic 3).



Graphic 3 - Manual Downloads evolution over time

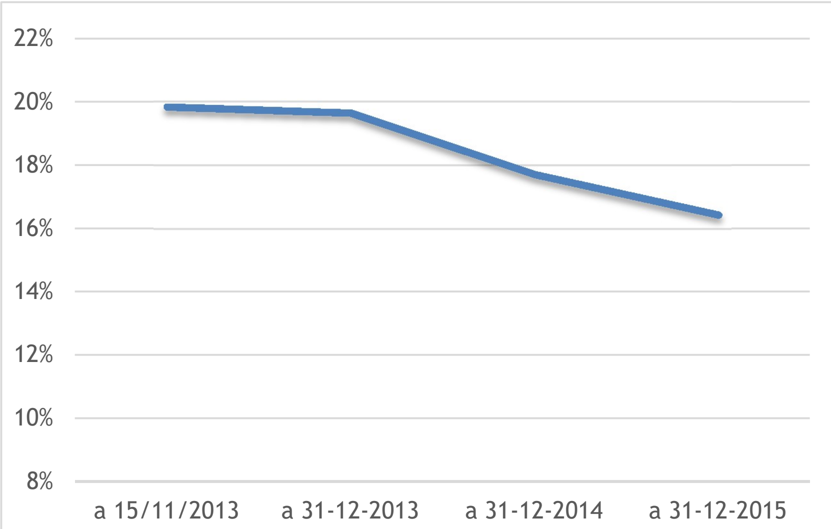
Even with this considerable decrease on the number of manual downloads performed, there have been done 82 of these downloads since the technical instruction is in place and the number will imperatively increase over the years because of the obsolescence of the ASMC and the discovery of new PGS related errors that obligate to perform manual downloads.

During the preliminary analysis of the data, on witch this work will focus, was found a new error on automatic downloads. Some engine starts were not counted and this will imply in future that for similar cases a manual download will be performed. Between January 2014 and December 2015 were detected 54 of this cases, which if discovered before will have translated into a slowdown on the manual downloads decrease (Graphic 4).



Graphic 4 - Manual Downloads evolution over time counting, between Jan2014 and Dec2015, with the new error found

If instead, the counting takes in consideration all the similar cases since the beginning of the aircraft fleet, 615, it implies a considerable increment on the total percentage of Manual Downloads, from 10.4% (Graphic 3) to 16.4% (Graphic 5).



Graphic 5 - Manual Downloads evolution over time counting with the new error found since the beginning of the fleet

3.2. Manual Downloads Consequences on RTM322 Engine

The RTM322 engine component's life is controlled by cycles called Life Cycle Fatigue (LCF). This control in the case of PtAF EH101's is performed on the PGS, with the data recorded by the aircraft on each flight. With this assumption every time that occurs a flight, the data is record and afterwards uploaded to the PGS populating a series of data bases including the ones related to engines.

When an error occurs, such the ones explained on point 2.1, it is necessary to perform a manual download. In this case all the metrics related to the engines have to be inputted manually. Is possible to obtain some of this metrics from the aircraft computer, but other, specifically the LCF it is not.

3.2.1. LCF manual counting

As explained before, some engine components have their life controlled by fatigue cycles. In what to fatigue concerns are recognized three forms, thermo-mechanical fatigue (TMF), high cycle fatigue (HCF) and low cycle fatigue (LCF) [6]. Usually, in the case of turbine engines, is applied the LCF and the TMF. This two forms of fatigue are related to large temperatures which leads to significant thermal expansions and contractions as also mechanical strains changes related to the centrifugal loads that the engine is subject as speed changes.

In the case of RTM322, the PGS records 4 independent cycle values that are distributed by the 3 main engine modules, M01, M02 and M03, as shown in Table 1, which are called life cycle factors (LCF). To avoid misunderstanding between the low cycle fatigue and the initial life cycle factors, for the remaining of this work the LCF initial refer to the life cycle factors.

Table 1 – LCF by RTM322 components [7]

	Module
LCF1	M01 – Centrifugal Compressor
LCF2	M01 – Axial Compressor
LCF3	M02 – Gas Generator
LCF4	M03 – Power Turbine

According to the engine manufacturer, Turbomeca, the component cycles can be counted manually, while the AMS system was being certified and also every time an automatic download fails to record or download the engine related metrics. To apply the manual cycle counting there is a worksheet, 05-50-15-00A-284A-A Life Cycle Counts – Special Irregular Inspections (appendix A), which gives the formulas and the procedure to do so, for every LCF and differently for flight or ground operations.

a) In the case of ground operations, according to appendix A, the cycles for each LCF should be counted according to Table 2:

Table 2 – Ground Operation LCF (appendix A)

	Start -> GI -> Shutdown	Start -> MPOG -> Shutdown
LCF1	0.3	0.5
LCF2	0.3	0.5
LCF3	0.3	0.5
LCF4	0.5	1.0

For the purposes of this work, considering that all ground operations, performed by the 751 squadron, imply the controls to go to MPOG, this will be used for all the ground operations related calculus of the LCF values presented on Table 3

Table 3 – LCF Ground Operations Values (present work proposal)

	Ground Operations
LCF1	0.5
LCF2	0.5
LCF3	0.5
LCF4	1.0

b) In the case of flight operations, the cycle counting is much more complex because partial cycles also have to be counted. A partial cycle, according to Turbomeca, is “a sequence of engine operation procedures related to a power/speed decrease followed up by a large increase without engine shutdown”. There are two different types of partial cycles that can be used on the calculation of LCF as seen in Table 4 below:

Table 4 – Partial Cycles Description (appendix A)

<table>
<tr><th></th><th>Partial Cycle 1 (n1)</th><th>Partial Cycle 2 (n2)</th></tr>
<tr><td>LCF1</td><td rowspan="3">OEI not selected - select GI -> reselect Flight Mode</td><td rowspan="3">OEI selected - NgC decreases below 90% and then increases more than 10%</td></tr>
<tr><td>LCF2</td></tr>
<tr><td>LCF3</td></tr>
<tr><td>LCF4</td><td>Each time Nf is more than 109% and then goes back to below 109%</td><td>Each time Nf goes to less than 90% and then goes back to more than 90%</td></tr>
</table>

Taking the information verted in Table 3 in consideration, each LCF has a specific formula to obtain the final count of cycles:

- LCF1:

$$LCF1 = C + (n1 * 0.7) + (n2 * 1.1) \qquad (1)$$

C=1.5 – when OEI has not been selected on the engine between the Start and the Shutdown;

C=2.0 – when OEI has been selected on the engine between the Start and the Shutdown;

- LCF2:

$$LCF2 = C + (n1 * 0.3) + (n2 * 0.3) \qquad (2)$$

C=1.3 – when OEI has not been selected on the engine between the Start and the Shutdown;

C=1.4 – when OEI has been selected on the engine between the Start and the Shutdown;

- LCF3:

$$LCF3 = C + (n1 * 0.4) + (n2 * 0.5) \qquad (3)$$

C=1.2 – when OEI has not been selected on the engine between the Start and the Shutdown;

C=1.3 – when OEI has been selected on the engine between the Start and the Shutdown;

- LCF4:

$$LCF4 = C + (n1 * 0.3) + (n2 * 0.2) \qquad (4)$$

C=1.5 – when Nf <= 109%;

C=1.9 – when Nf > 109%;

Until this moment the partial cycles haven't been counted for the manual calculation of LCF values. For this reason and for the purposes of this work, the partial cycles will be despised. So the LCF calculations will be done according to the following table (Table 5):

Table 5 – LCF calculation Formulas (work proposes)

	OEI not selected	OEI selected
LCF1	nº Starts*1.5	nº Starts*2.0
LCF2	nº Starts*1.3	nº Starts*1.4
LCF3	nº Starts*1.2	nº Starts*1,3
	Nf <= 109%	Nf > 109%
LCF4	nº Starts*1.5	nº Starts*1.9

3.3. Study Case Data

3.3.1. PGS download data

As discussed in the sub-chapter 1.3.2 the aircraft AMS is responsible for the integration of every onboard system. Only with this kind of system integration is possible for the aircraft computers to record every single data from both the individual components and the aircraft sensors. The amount of information available for download is incredible huge which obligates the PGS to only keep online a small percentage of all the data, normally a period of more or less fifteen days.

To prevent the loss of all the aircraft history data, the Portuguese Airforce's Communications and Informatics Systems Directorate (DCSI) is responsible for making periodic backups of all PGS data.

In 2014, during the implementation of some engine metrics corrections, were encounter some difficulties to gather the information required to fulfill that task. Fortunately this time, with the help of AW's PGS support engineer, was possible to retrieve the amount of engine information considered ideal for achieving the objective of this work.

3.3.2. Engine Data gathering

To achieve the main goal of this work, was requested to AW's PGS support engineer the backup of the engine related data from a two year period, between 1st of January 2014 and 31st of December 2015, for all the twelve aircrafts that composes the EH101 fleet.

As is possible to verify on Table 6, that the amount of engine information gathered on that period of time is huge. In total were recorded 2059 downloads, distributed between the twelve aircrafts. Considering that each aircraft have 3 engines this leads to 6170 lines of data corresponding to a total of 11656 engine hours.

Table 6 – Resume of Engine Data (01JAN14 and 31DEC15) [7]

Nº Downloads	Nº Lines of Data	Total Engine Hours
2059	6177	11656

A sample of this data was retrieved following the criteria below:

a) One aircraft from each variant:

At this point it was not possible to determine if the type of variant could have impact on the engine cycle rate consumption, considering that each variant have different kinds of equipment on board changing the weight of the aircraft. Choosing an aircraft of each variant, which by themselves, as described further below, corresponds to one third of all data, allows to compare the results and verify if the type of variant is an important factor;

b) Aircrafts which engines with higher value of cumulative hours:

From each variant was chose the aircraft with higher value of accumulative engine hours, making possible to get a substantial amount of data representative of all the fleet.

Taking in consideration this criteria, was retrieved, from all da data collected, the data of the aircraft from each variant which have the higher engine hour's cumulative value. Because the relation between the aircrafts tail number and the data collected is sensitive information, for this work proposes, the aircrafts will be named as Aircraft A (SAR variant), Aircraft B (SIFICAP variant) and Aircraft C (CSAR variant).

On Table 7, below, it is summarized the information gathered from the sample of aircrafts comparatively to the main population (Table 6):

Table 7 – Sample and Population Comparison [7]

	Nº Downloads	Nº Lines of Data	Total Engine Hours
Aircraft A	223	669	1342
Aircraft B	190	570	1095
Aircraft C	285	855	1427
Total	698	2094	3864
% from Population	33.90%	33.90%	33.15%

From the data presented on Table 7 is possible to verify that Aircrafts A, B and C represent, for all the three categories (nº of downloads, nº of lines of data and total engine hours), one third of all data collected for the stipulated period of time. With the results of this comparison is possible to affirm that this sample is representative of the population, for this work purpose.

3.3.3. Data Sample Optimization

On sub-paragraph 2.1 was explained the way that the data download system works and the consequences of using manual downloads every time of an automatic fail. During the current life of the fleet were identified numerous errors that have as corrective measures, the obligation to perform manual download every time the error occurs.

During the analysis of the data from aircrafts A, B and C were identified five new type of data errors (Table 8) that were unknown until now. This errors, all of them on automatic downloads that apparently went well, have adverse consequences on the engine metrics counting leading to incorrectness on all engine metrics cumulative values.

Table 8 – Data Sample Errors [7]

Type	Discarded Download	Aircraft A	Aircraft B	Aircraft C	Total
1	Without engine Data (at least 1 engine)	5	4	4	13
2	Without engine Cycles (at least 1 engine)	4	2	0	6
3	Without engine Starts (at least 1 engine)	4	6	10	20
4	Automatic Download with manual cycle values (at least 1 engine)	5	0	0	5
5	Without SIGOP mission correspondence	5	6	20	31
	Total Download errors	23	18	34	75

Each type of error have different consequences on the engine cumulative metrics:

a) Type 1 – on this type of error there is no information on all the metrics (engine hours, starts and cycles, of one or more of the 3 engines;

b) Type 2 – the only metric missing in this case is the engine cycles, affecting the cumulative value of this metric and consequently the life of engine cycle controlled components;

c) Type 3 – a download that doesn't record the metric starts doesn't have influence on the life limit of engine components, but at long term will have consequences when some metrics comparisons could be needed for further investigations;

d) Type 4 – in this case the download is registered as automatic but the engine metrics were told to be inserted manually;

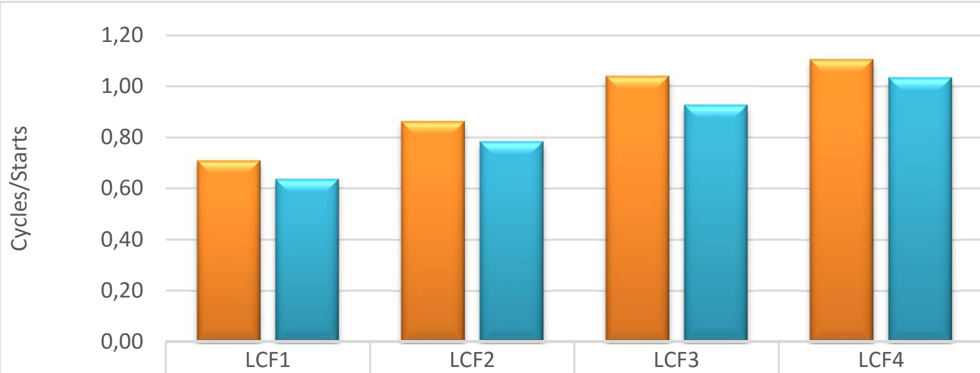
e) Type 5 – further bellow on this work, will be discussed the need to separate flight operations downloads and ground operations' ones. The data retrieved from downloads without a SIGOP correspondence couldn't be used for the purposes of this work because it will not be able to differentiate them between flight and ground operations.

After the filtering of the sample data, to remove the kind of errors that were found, a considerable amount of engine information are still available, approximately 30% of all the population gathered (Table 9).

Table 9 - Sample and Population Comparison without errors [7]

	Nº Downloads	Nº Lines of Data	Total Engine Hours
Aircraft A	200	600	1271
Aircraft B	172	516	1003
Aircraft C	251	753	1371
Total	623	1869	3645
% from Population	30.26%	30.26%	31.27%

The next and final step on getting the most appropriated and flawless data sample is to exclude downloads with 2 or more starts. As pointed in sub-paragraph 2.2.1, In order to obtain the LCF values by manual counting, it is needed to multiply the coefficients on Table 4, by the number of starts that happened for each engine on each flight. This decision on exclude, from the sample, downloads with equal or more than 2 starts was made taking in consideration the results as the illustrated on Graphic 6.



	LCF1	LCF2	LCF3	LCF4
Start = 1	0,71	0,86	1,04	1,11
Start >= 1	0,64	0,78	0,93	1,03

Graphic 6 – Aircraft A/Engine 1 LCF Comparison (Start=1 vs Start>1)

From the example illustrated on Graphic 6, it possible to clearly see that there is a considerable difference on the values of cycle/start between the cases when the value of starts is always equal to one and the ones where that value can also be more than one start. If the number of starts were independent of the value of the cycle, the two bars (orange and blue) should be equal because the values for cycle/start would be the same. This happens for all the 3 engines on the three aircrafts for both flight operation (Table 10) and ground operations (Table 11) (this difference flight vs ground will be explained further below on this work).

Table 10 - Aircraft A, B and C LCF Comparison (Start=1 vs Start>1) Flight Operations

	Engine 1		Engine 2		Engine 3	
Aircraft A	Start = 1	Start >=1	Start = 1	Start >1	Start = 1	Start >=1
LCF1	0.71	0.64	0.75	0.69	0.75	0.69
LCF2	0.86	0.78	0.88	0.83	0.86	0.79
LCF3	1.04	0.93	1.08	0.98	1.05	0.94
LCF4	1.11	1.03	1.11	1.05	1.11	1.05
Aircraft B	Start = 1	Start >=1	Start = 1	Start >=1	Start = 1	Start >=1
LCF1	0.78	0.66	0.84	0.75	0.79	0.69
LCF2	0.90	0.78	0.93	0.86	0.91	0.81
LCF3	1.08	0.93	1.13	1.03	1.12	0.98
LCF4	1.09	1.00	1.10	1.03	1.10	1.03
Aircraft C	Start = 1	Start >=1	Start = 1	Start >=1	Start = 1	Start >=1
LCF1	0.75	0.63	0.79	0.71	0.77	0.67
LCF2	0.88	0.76	0.90	0.84	0.89	0.79
LCF3	1.04	0.89	1.08	0.99	1.07	0.94
LCF4	1.08	0.99	1.08	1.03	1.08	1.02

Table 11 - Aircraft A, B and C LCF Comparison (Start=1 vs Start>1) Ground Operations

	Engine 1		Engine 2		Engine 3	
Aircraft A	Start = 1	Start >=1	Start = 1	Start >1	Start = 1	Start >=1
LCF1	0.08	0.06	0.38	0.34	0.09	0.08
LCF2	0.28	0.24	0.62	0.56	0.30	0.26
LCF3	0.39	0.34	0.71	0.64	0.41	0.35
LCF4	1.03	0.91	1.06	0.96	1.03	0.91
Aircraft B	Start = 1	Start >=1	Start = 1	Start >=1	Start = 1	Start >=1
LCF1	0.09	0.07	0.40	0.34	0.10	0.09
LCF2	0.30	0.24	0.66	0.56	0.32	0.28
LCF3	0.41	0.33	0.75	0.64	0.43	0.37
LCF4	1.08	0.83	1.10	0.93	1.04	0.97
Aircraft C	Start = 1	Start >=1	Start = 1	Start >=1	Start = 1	Start >=1
LCF1	0.10	0.09	0.39	0.37	0.10	0.10
LCF2	0.32	0.29	0.64	0.60	0.33	0.30
LCF3	0.43	0.39	0.72	0.68	0.44	0.39
LCF4	1.04	0.94	1.04	0.95	1.03	0.93

Taking this in consideration and for the purpose of this work, it will only be used downloads wherein the starts delta value is equal to one.

4 Data Sample Analysis

4.1. Flight operations vs Ground Operations

In sub-paragraph 3.2.1 was explained that, taking in consideration the TM worksheet about manual cycle counting, to obtain the value for each manual LCF, the number of starts of each engine should be multiplied by the correspondent coefficient presented on Table 3, for ground operations and Table 5, for flight operation.

Taking the description above in consideration it was needed to sub-divide the, already flawless data sample, in flight and ground operation's data that so it would be possible to apply the TM work sheet and optimise the coefficients.

The PGS data, individually, doesn't identify if a download is related to a flight or ground operation. In order to get this relation another database had to be used, SIGOP.

SIGOP is a software in which all operational records are made by the pilots. As exemplified below (Figure 11) those information are so various, as which squadron is refer to (*UNID AÉREA*), the mission type (*Airtask MOD* and *TIPO-MOD*), how many aircrafts were involved and their tail numbers (*Aeronaves Nº* and *Nº CAUDA)* and flight start and end time (ATD and ATA), among others.

UNID BASE	UNID AÉREA	DEST	AIRTASK	AIRTASK	AIRTASK	AIRTASK	AIRTASK	AERONAVES
UNID BASE	UNID AÉREA	DEST	NºSEQ	Nº	DATA	MOD	Tipo MOD	Nº
BA6	751		2	xxxx	02/jan	AMOV	OPER	2
BA6	751		2	xxxx	02/jan	AMOV	OPER	2
BA6	751		5	xxxx	07/mar	AQUAL	TRU	5
BA6	751		2	xxxx	22/abr	AMOV	OPER	2

AERONAVES	AERONAVES	TROÇO			CÓDIGOS	CÓDIGOS
TIPO	NºCAUDA	Nº	ATD	ATA	BENEF	ESTAT
EH101	xxxx	2	15:00	19:10	FA	xxxx
EH101	xxxx	1	08:10	13:25	FA	xxxx
EH101	xxxx	1	14:00	14:55	FA	xxxx
EH101	xxxx	2	14:55	18:10	FA	xxxx

Figure 11 – SIGOP database example [8]

With the useful help of the 751st Squadron was possible to gather all SIGOP information for the same period of time of the PGS sample. After that it was needed to compare every single SIGOP record with its PGS correspondent download, what should be easy to make on perfect circumstances, but in this case it was not.

First of all PGS records different times for different purposes:

a) Flight Time : PGS records the flight time metric taking in consideration the inputs from the wait on wheels sensors, which means that this metric start to count as soon as the aircraft wheels leave the ground until touch down again;

b) Operational Hours: In this case, PGS consider the interval between the start and stop of the aircraft rotor as value for this metric;

c) Engine Hours: This metric is really not one but three separated metrics, Engine hours 1, 2 and 3, each of them matches to one of the three aircraft engines. Their value is calculated as the interval between engine start and shutdown and so, each one of the three metrics will be different in every flight considering that each engine starts and shutdowns at different times from one another;

Considering the three PGS's time related metrics above, at first view, would be easier to find out which one would be related to SIGOP information record by the pilot but it is not the case. Pilots consider their flight time as the interval between the current times in which the aircraft start to operate until it stops, in values multiple of 5 minutes.

This differences in the interpretation of the real flight time metric, have made the work of comparing SIGOP and PGS data incredible hard and time costly but not impossible. So in order to achieve that objective there was the need to overlap another factor that contributed for the difficulty to separate flight from ground operations, the fact that the pilots register all maintenance operations, both the ones that the aircraft flown and the ones that were strictly on the ground with the same type of operation, MNT.

The first step was to look line by line the SIGOP data and find the correspondent PGS download. After that and knowing which download have flight time associated to, again with the useful help of AW software supporter engineer, was possible to divide the data for each aircraft, A, B and C, on theirs flight and ground operations downloads (Table 12).

Table 12 – Total Ground and Flight Operations Downloads

	Total Flight Operations Downloads			Total Ground Operations Downloads		
	Engine 1	Engine2	Engine 3	Engine 1	Engine2	Engine 3
Aircraft A	130	128	128	29	29	29
Aircraft B	123	127	127	19	20	21
Aircraft C	163	162	167	40	42	42

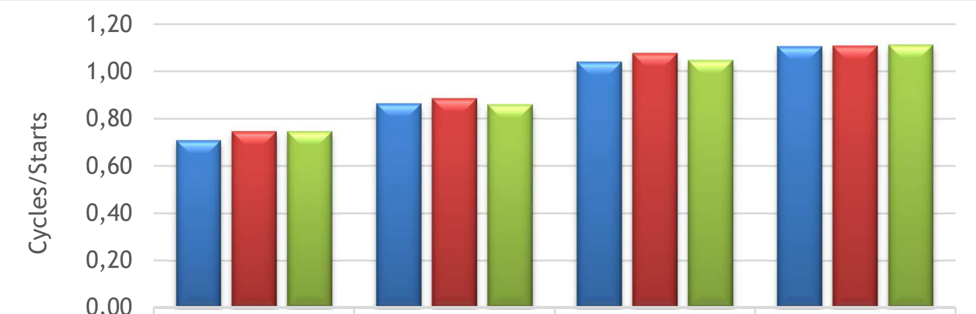
4.2. Analysis Method

As explained in sub-chapter 4.1, was needed to divide flight operations from ground ones, in order to be in accordance to TM worksheet principles. So with the data sample already filtered from errors and only with downloads in which the engine only performed one start, it was possible to analyse the 4 LCF cumulative values for the 3 engines of each aircraft.

4.2.1. Step One – Engine Comparison

As first step each aircraft have to be analysed independently engine by engine, in order to understand if the LCF cycle consumption is similar for all the 3 engines. To do so, were calculated the average LCF's values for each engine and compared between the three of them:

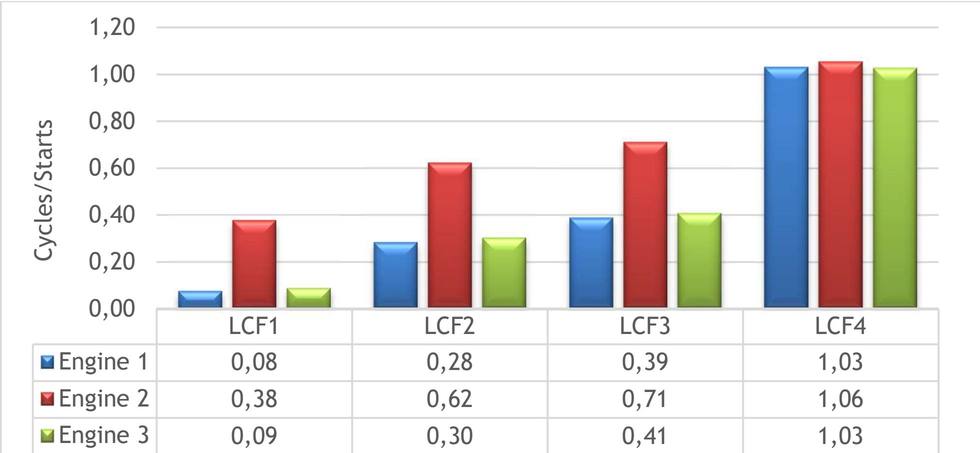
a) Aircraft A – In case of this aircraft as is possible to understand by the graphic below (Graphic 7), the difference between the average LCF consumption values of the three engines is small enough to be discarded in what to flight operations is related.



	LCF1	LCF2	LCF3	LCF4
Engine 1	0,71	0,86	1,04	1,11
Engine 2	0,75	0,88	1,08	1,11
Engine 3	0,75	0,86	1,05	1,11

Graphic 7 - Aircraft A LCF Engine Comparison (Flight)

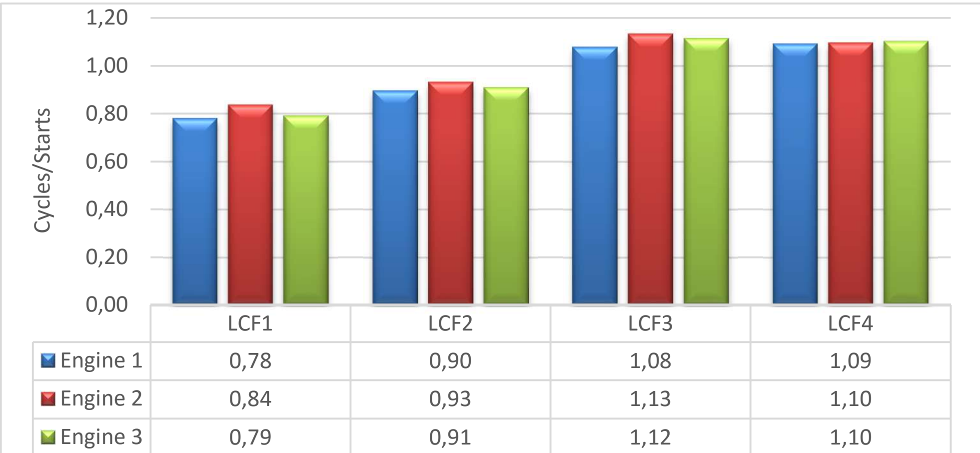
In what to ground operations is concerned, this situation is not verified. In this case there is incredible differences between the average values for engine 2 and both engines 1 and 3 (Graphic 8). The reasons for this kind of values will be discussed further along this work.



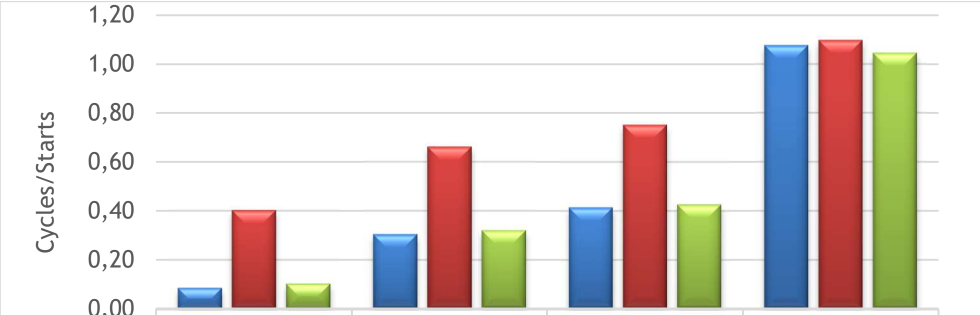
Graphic 8 - Aircraft A LCF Engine Comparison (Ground)

In a small conclusion, for aircraft A, in flight operations, the engine position have no influence in the cycle consumption. On another hand, in ground operations there is a significant differences on those values and so, for ground operations the engine position may influence cycle consumption.

b) Aircraft B – The results for this aircraft (Graphic 9 and Graphic 10) are in all similar to the ones reached for Aircraft A:



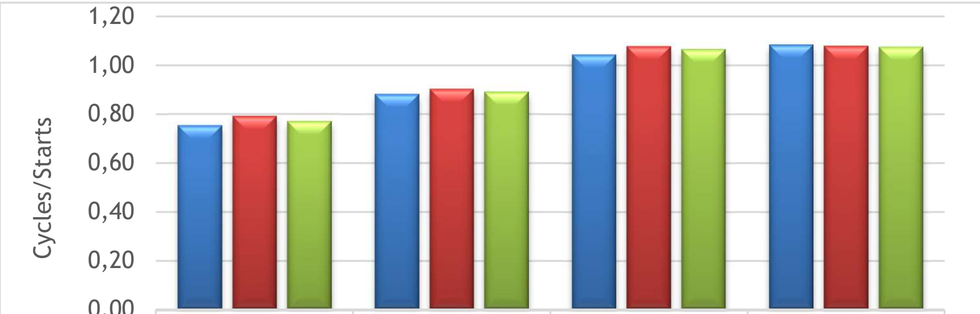
Graphic 9 - Aircraft B LCF Engine Comparison (Flight)



	LCF1	LCF2	LCF3	LCF4
Engine 1	0,09	0,30	0,41	1,08
Engine 2	0,40	0,66	0,75	1,10
Engine 3	0,10	0,32	0,43	1,04

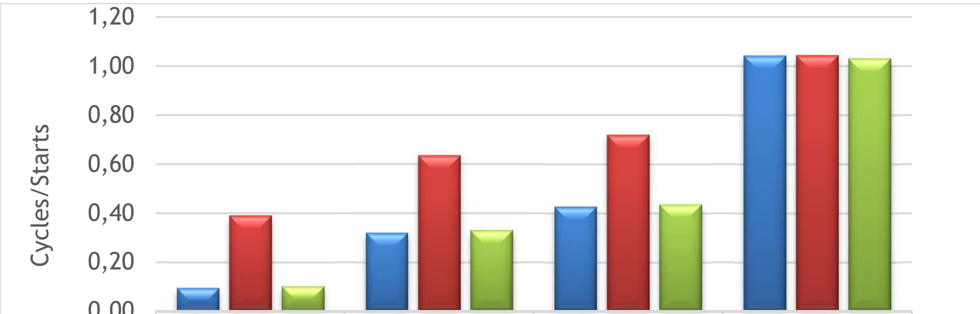
Graphic 10 - Aircraft B LCF Engine Comparison (Ground)

c) Aircraft C – The results for this aircraft (Graphic 11 and Graphic 12) are in all similar to the ones reached for the other two aircrafts in study:



	LCF1	LCF2	LCF3	LCF4
Engine 1	0,75	0,88	1,04	1,08
Engine 2	0,79	0,90	1,08	1,08
Engine 3	0,77	0,89	1,07	1,08

Graphic 11 - Aircraft C LCF Engine Comparison (Flight)



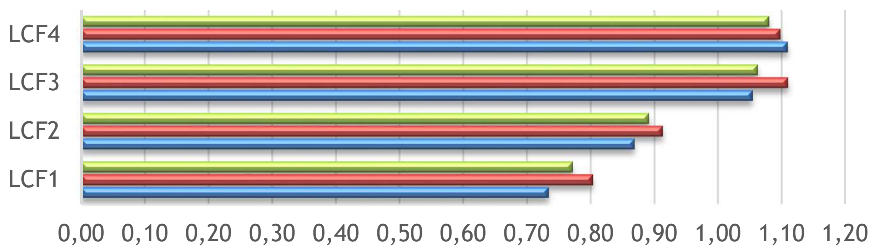
	LCF1	LCF2	LCF3	LCF4
Engine 1	0,10	0,32	0,43	1,04
Engine 2	0,39	0,64	0,72	1,04
Engine 3	0,10	0,33	0,44	1,03

Graphic 12 - Aircraft C LCF Engine Comparison (Ground)

4.2.2. Step Two – Aircraft Comparison

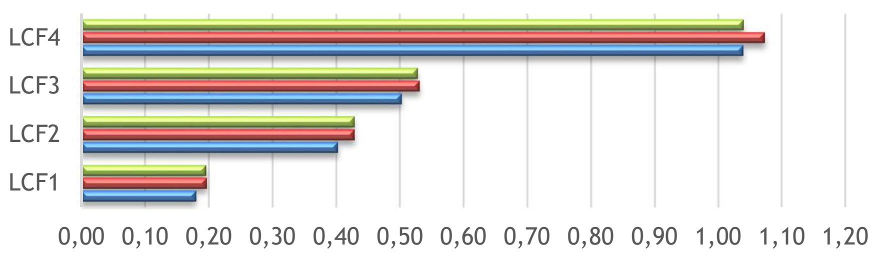
On this second step, the objective is to compare the results of the LCF's average values from each aircraft with the values of the other two aircrafts in order to identify if the variant type is a factor on the engine performance. In a similar way to step 1, with the average values for each aircraft's LCF already calculated, the three aircrafts were compared, as is possible to verify on Graphic 13 and Graphic 14.

Contrary to the results achieved in step one, although the aircraft B values for LCF1, 2 and 3 are higher than on aircraft A and B, the values for each variant are similar and less than 0.1 cycles/start of difference.



	LCF1	LCF2	LCF3	LCF4
Aircraft C	0,77	0,89	1,06	1,08
Aircraft B	0,80	0,91	1,11	1,10
Aircraft A	0,73	0,87	1,05	1,11

Graphic 13 – Aircraft LCF average values comparison (flight)



	LCF1	LCF2	LCF3	LCF4
Aircraft C	0,20	0,43	0,53	1,04
Aircraft B	0,20	0,43	0,53	1,07
Aircraft A	0,18	0,40	0,50	1,04

Graphic 14 - Aircraft LCF average values comparison (ground)

According to the results above, is possible to determine that, on both, flight and ground operations, the aircraft variant is independent from the performance of the engines.

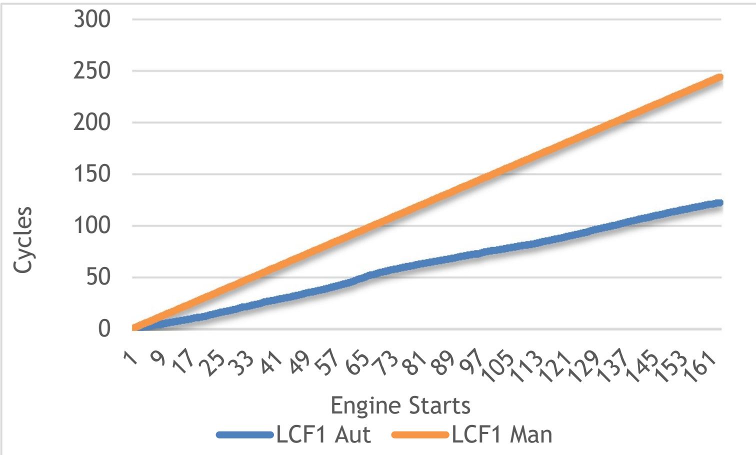
4.2.3. Step Three - Manual and Automatic LCF Comparison

To make possible the achievement of this work goal, it is needed to confirm that the EH101 fleet operation spectrum is less severe than the general one, for what the manual counting of the LCF values, presented on TM worksheet (appendix A) where estimated.

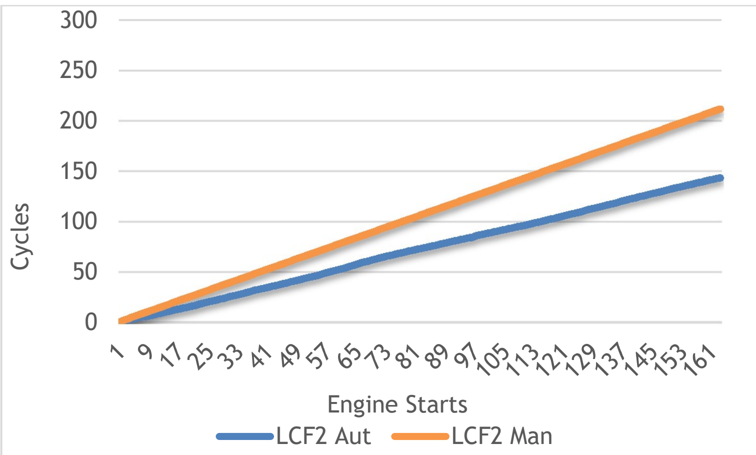
Considering the presuppositions verified on step 1 and 2, and the sample optimization explained on sub-paragraph 3.3.3, where calculated, for each individual engine and aircraft, the cumulative automatic LCF values on time lapsed graphics by the cumulative number of starts. In an opposing way were also calculated for the same downloads the cumulative LCF values but this time simulating that all the downloads where manual (Table 3)

In order to have an example in this work discussion and considering that the engine performance is independent from the aircraft's variant, the following graphics will refer only to engine 1 from aircraft C, since is the aircraft with more downloads of the sample. On appendix B is possible to consult the graphics and the summarized results for the three aircrafts.

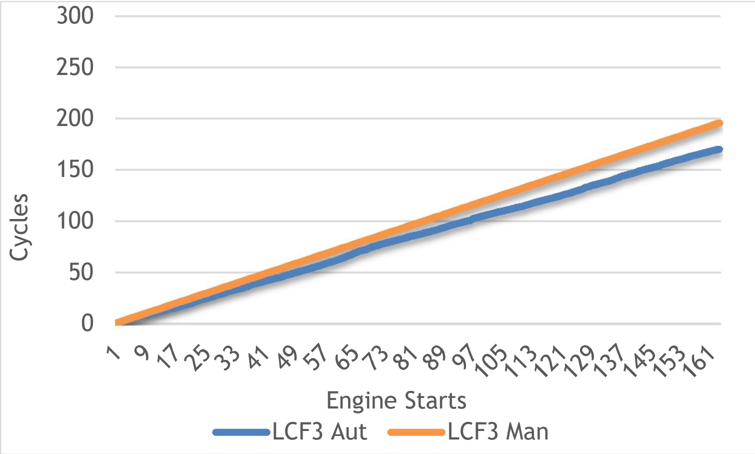
a) Flight Operations:



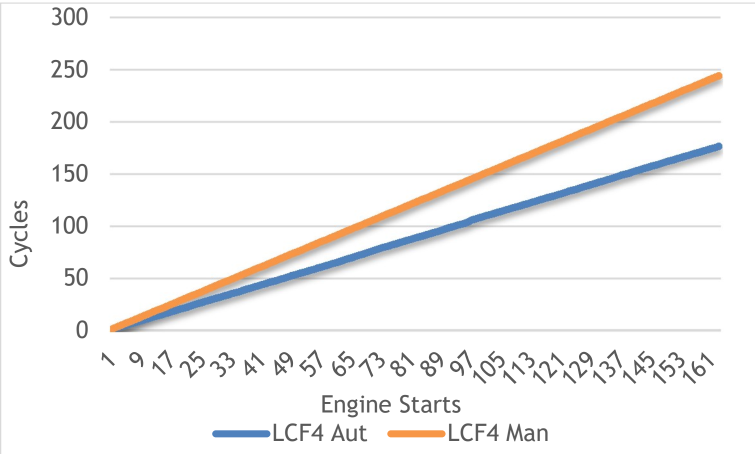
Graphic 15 - Aircraft C/Engine 1 - LCF1 Aut vs Man (Flight)



Graphic 16 - Aircraft C/Engine 1 – LCF2 Aut vs Man (Flight)



Graphic 17 - Aircraft C/Engine 1 – LCF3 Aut vs Man (Flight)



Graphic 18 - Aircraft C/Engine 1 – LCF4 Aut vs Man (Flight)

The values for the three engines are summarize on Table 13. On Table 14 are presented the average values for the 3 aircrafts. From both results is possible to conclude that in fact manual cycle counting is severely penalizing the final cumulative LCF values. In average the manual counting have values between 97% (LCF1) to 12% (LCF3) higher than the correspondent automatic cumulative value. This is result of the difference between the operational spectrum for which the TM worksheet coefficients (Table 5) where calculated and the Portuguese Air Force operational usage of the aircrafts.

Table 13 - Aircraft C Manual and Automatic LCF comparison (Flight)

		Total AUT	Total MAN	MAN-AUT	Average
LCF1	Engine 1	122.77	244.5	121.73	119.48
	Engine 2	128.23	243.0	114.77	
	Engine 3	128.58	250.5	121.92	
LCF2	Engine 1	143.63	211.9	68.27	67.00
	Engine 2	146.30	210.6	64.30	
	Engine 3	148.67	217.1	68.43	

LCF3	Engine 1	170.20	195.6	25.40	22.54
	Engine 2	174.57	194.4	19.83	
	Engine 3	178.01	200.4	22.39	
LCF4	Engine 1	176.72	244.5	67.78	68.92
	Engine 2	174.86	243.0	68.14	
	Engine 3	179.67	250.5	70.83	

Table 14 – Automatic and Manual average LCF comparison (Flight)

	Aircraft A	Aircraft B	Aircraft C	Average
LCF1	109%	87%	94%	97%
LCF2	50%	42%	46%	46%
LCF3	14%	8%	13%	12%
LCF4	35%	37%	39%	37%

This results and conclusions justify the main objective of this work, to optimise the LCF coefficients presented on TM worksheet to the PtAF aircrafts real operations.

b) Ground Operation:

As previous conclude on step 1 and 2, on ground operations the LCF counting is dependent on the engine positions. So, in this case, there is the need to understand each engine by their self.

By the interpretation of the values on Table 15 is possible to conclude that for engine 1 and 3 all the average LCF's values are similar but on engine 2 the values of LCF1, 2 and 3 are incredible higher (values in orange colour).

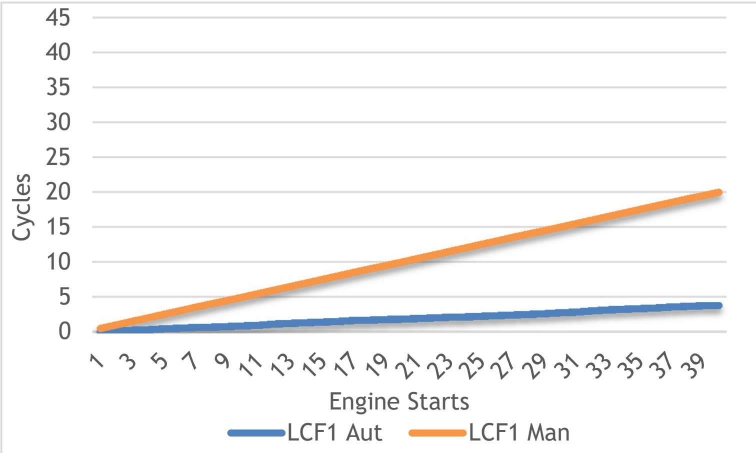
Table 15 – LCF average values (ground operations)

		LCF1	LCF2	LCF3	LCF4
Engine 1)	Aircraft A	0.08	0.28	0.39	1.03
	Aircraft B	0.09	0.30	0.41	1.08
	Aircraft C	0.10	0.32	0.43	1.04
Engine 2	Aircraft A	0.38	0.62	0.71	1.06
	Aircraft B	0.40	0.66	0.75	1.10
	Aircraft C	0.39	0.64	0.72	1.04
Engine 3	Aircraft A	0.09	0.30	0.41	1.03
	Aircraft B	0.10	0.32	0.43	1.04
	Aircraft C	0.10	0.33	0.44	1.03

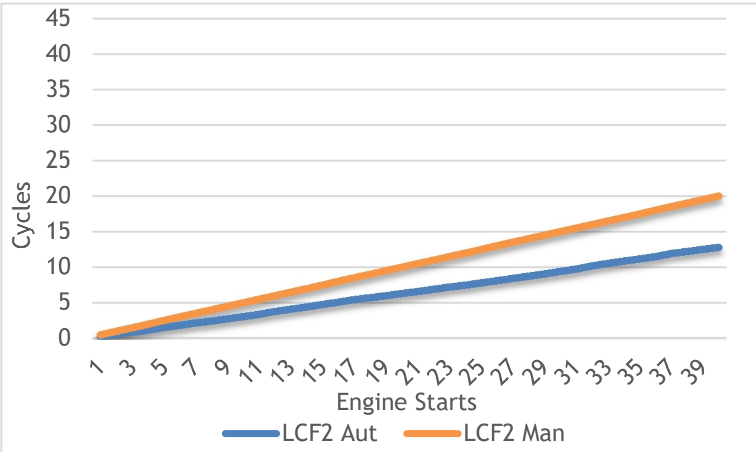
This situation is consequence both from aircraft conception and engine start procedure. By conception engine 2 shaft is always engaged on the aircraft Main Gear Box (MGB). This characteristic adding the factor that by procedure engine 1 and 3 are only engaged to the MGB at a rotor speed of 102%, makes engine 2, by itself, always responsible for the initial rotation of the rotors until the other engines could be also engaged. All this factors turns the performance of the engine installed on position two more severe than the engines on the other two positions.

So for the proposes of finding average LCF values for operations on the ground and considering that engine 1 and 3 have similar performances, it will be used has example the engine 1 and engine 2 data of aircraft C (the 3 aircrafts' graphics and values are presented on appendix B).

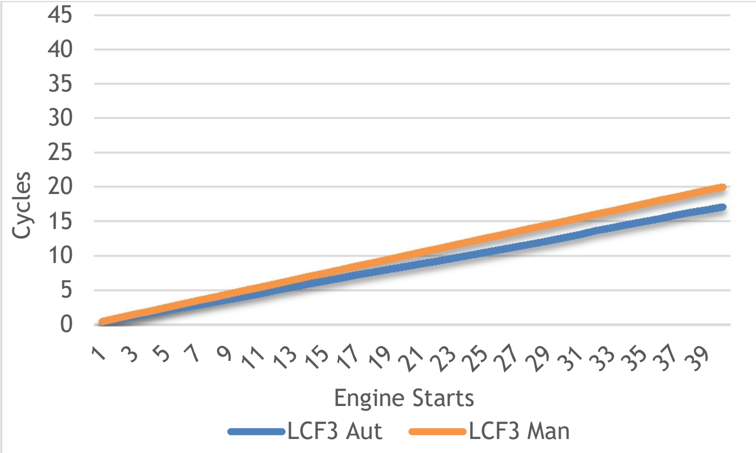
- Average values for engine 1 and 3:



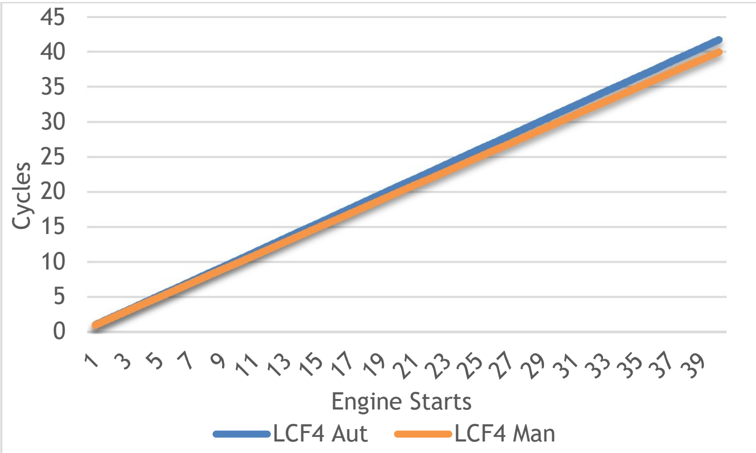
Graphic 19 - Aircraft C/Engine 1 – LCF1 Aut vs Man (Ground)



Graphic 20 - Aircraft C/Engine 1 – LCF2 Aut vs Man (Ground)



Graphic 21 - Aircraft C/Engine 1 – LCF3 Aut vs Man (Ground)



Graphic 22 - Aircraft C/Engine 1 – LCF4 Aut vs Man (Ground)

The values for engines 1 and 3 are summarize on Table 16. On

Table 17 presents the average values for the 3 aircrafts. From this partial results is possible to conclude that, without considering engine 2 results, the values for manual counting are much higher than the ones automatically calculated by the aircraft. This difference is even more evident than on the flight operations LCF1, 2 and 3 values. For the first time an automatic value was found to be higher the correspondent manual, this is the case of LCF4.

This paradigm change is the result of the type of operation and the charge that is put on each engine. In the ground, the main rotor rotates freely without any charge on it, so it is normal that the power turbine (M03), that is responsible to transfer the engine power into rotary movement of the main gear box works on the maximum profile and have a cycle consumption similar or even higher than the manual coefficients. The differences between M01/M02 and M03 indicates that for Ground operations, in the case of engine 1 and 3, it is needed the intake of less amount of air to achieve the maximum performance of the engine.

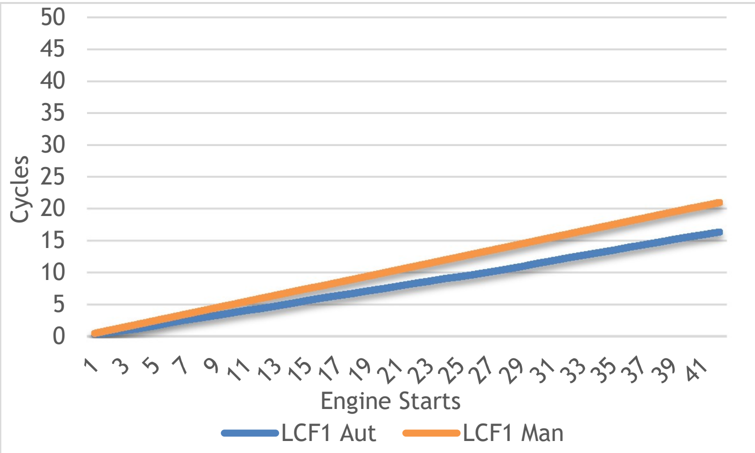
Table 16 - Aircraft C (Eng1 and Eng3) Manual and Automatic LCF comparison (Ground)

		Total AUT	Total MAN	MAN-AUT	Average
LCF1	Engine 1	3.81	20	16.19	16
	Engine 3	4.31	21	16.69	
LCF2	Engine 1	12.80	20	7.20	7
	Engine 3	13.87	21	7.13	
LCF3	Engine 1	17.08	20	2.92	3
	Engine 3	18.33	21	2.67	
LCF4	Engine 1	41.71	40	-1.71	-2
	Engine 3	43.30	42	-1.30	

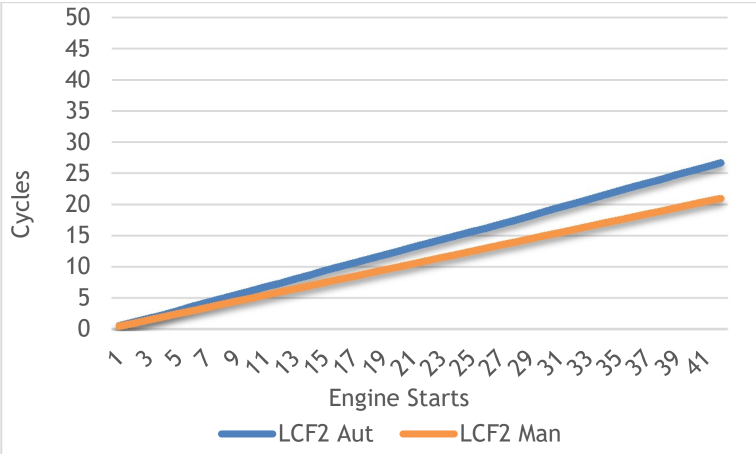
Table 17 – Eng1 and Eng3 Automatic and Manual average LCF comparison (Ground)

	Aircraft A ENG1+ENG3	Aircraft B ENG1+ENG3	Aircraft C ENG1+ENG3	Average
LCF1	514%	437%	406%	452%
LCF2	71%	60%	54%	62%
LCF3	26%	19%	16%	20%
LCF4	-3%	-6%	-4%	-4%

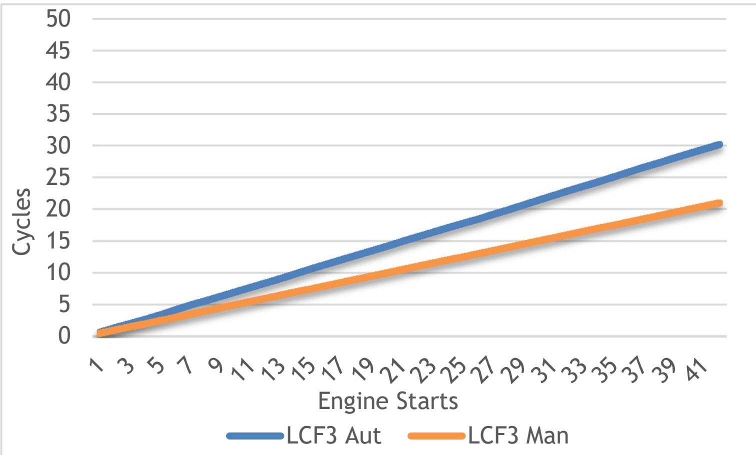
- Average values for engine 2:



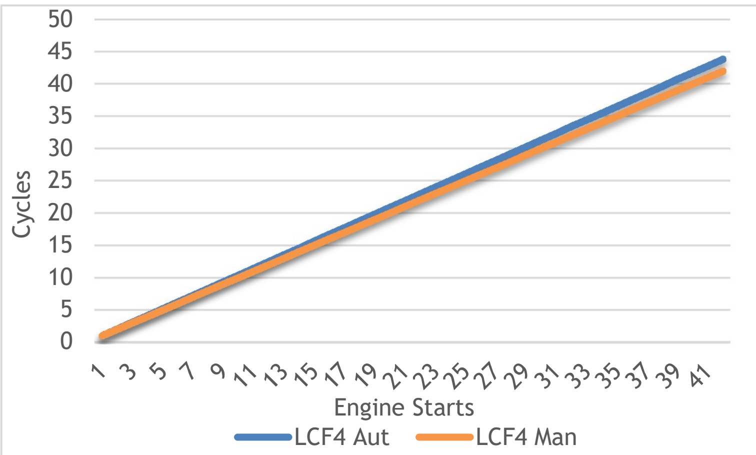
Graphic 23 - Aircraft C/Engine 2 – LCF1 Aut vs Man (Ground)



Graphic 24 - Aircraft C/Engine 2 – LCF2 Aut vs Man (Ground)



Graphic 25 - Aircraft C/Engine 2 – LCF3 Aut vs Man (Ground)



Graphic 26 - Aircraft C/Engine 2 – LCF4 Aut vs Man (Ground)

The change in the paradigm, which was referred above, is clearly evident in the case of engine 2. In this case the LCF2, 3 and 4 automatic values are all higher than the correspondent manual values (Table 18 and Table 19). This is verified because, as already explain, engine 2 is, by itself, the engine that launch the rotors, so it is in full charge since it is started until the shutdown.

Table 18 - Aircraft C (Eng2) Manual and Automatic LCF comparison (Ground)

	Total AUT	Total MAN	MAN-AUT
LCF1	16,36	21	4,64
LCF2	26,68	21	-5,68
LCF3	30,21	21	-9,21
LCF4	43,83	42	-1,83

Table 19 – Eng2 Automatic and Manual average LCF comparison (Ground)

	Aircraft A	Aircraft B	Aircraft C	Average
LCF1	33%	24%	28%	28%
LCF2	-20%	-24%	-21%	-22%
LCF3	-30%	-33%	-30%	-31%
LCF4	-5%	-9%	-4%	-6%

4.2.4. Step Four – Optimization Method

The main objective of this work is to obtain optimized values for the LCF manual counting taking in consideration the type of operation that the PtAF EH101 fleet is subjected every day. As it was concluded in 4.2.1, 4.2.2 and 4.2.3 this optimization have to be done for flight and ground operations separately. To do so is was needed to obtain LCF values independent from the variant type and engine position, in the case of flight operations and, values only independent from the variant type in what to ground operations have concern.

a) For flight operations will be assumed as values for the engine's LCF optimization the average values of the 3 aircrafts individual average values (Table 12).

$$LCF\alpha * = \frac{(A^1\alpha + B^2\alpha + C^3\alpha)}{3} \qquad (5)$$

Table 20 – LCF average values (flight operations)

LCF1	LCF2	LCF3	LCF4
0.77	0.89	1.08	1.10

* LCF number
[1] Aircraft A average value (Eng1+Eng2+Eng3)
[2] Aircraft B average value (Eng1+Eng2+Eng3)
[3] Aircraft C average value (Eng1+Eng2+Eng3)

b) For ground operations the LCF values were calculated in the same way than on flight operations, but in this case they have to be obtain separately to be used on engine 1/engine 3 (Table 21) and engine 2 (Table 22).

$$LCF\alpha *= \frac{(A^4\alpha + B^5\alpha + C^6\alpha)}{3} \qquad (6)$$

Table 21 – Engine 1 and 3 LCF average values (Ground operations)

LCF1	LCF2	LCF3	LCF4
0.09	0.31	0.42	1.04

$$LCF\alpha *= \frac{(A^7\alpha + B^8\alpha + C^9\alpha)}{3} \qquad (7)$$

Table 22 - Engine 2 LCF average values (Ground operations)

LCF1	LCF2	LCF3	LCF4
0.39	0.64	0.72	1.06

Now that were obtained suitable LCF values representative of the fleet operation, will be possible to start with the optimization process.

Optimization is present on every aspect of our lives, from manufacturers that aim to reach a maximization of the processes efficiency, the Nature itself which is always optimizing energy consumption, to the performance optimization that is seek by engineers [9]. This last type of optimization is the one that this work is aiming to achieve.

In 4.2.3 was possible to see that in general for all aircrafts/engines the manual LCF values were much higher comparatively to the automatic ones, which are calculated taking in consideration the real operations of the aircrafts. Taking this fact in consideration and also knowing that engine's life limited components are controlled in cycles (2.2), each time a manual download is required this will

[*] LCF number
[4] Aircraft A average value (Eng1+Eng3)
[5] Aircraft B average value (Eng1+Eng3)
[6] Aircraft C average value (Eng1+Eng3)

[7] Aircraft A average value (Eng2)
[8] Aircraft B average value (Eng2)
[9] Aircraft C average value (Eng2)

increment a cycle value that is incredibly higher than the one that each component really have operated. This situation not only incredibly diminish the life of the engine, leading to an overall sooner than expected, but also in case of the signing of a contract for engines support based in cycle cost, every time a manual download is performed with the current LCF coefficients, the price paid will be higher than what should be on an automatic download.

The optimization that this work is looking for is based on a Risk vs Gain basis. In this case is understandable as more or less Risk, the choosing, as ideal values, the ones more or less approximated to the average values. On another hand, assuming more risk leads to an increase on the gain that is possible to achieve.

Considering the risk vs gain concept and having the PtAF the engineer authority to decide based on this concept, was decided not to get, as final results, unique optimized values but 4 levels of risk with the correspondent gain for each one in comparison to the coefficients provided by TM.

To allow a suitable and sustained decision by the PtAF, on which risk level will accept to operate, the levels were distributed on an interval of 10% of each other, starting on level 1 with the average values incremented on 5%, this means that the levels will be composed by the values calculated accord to Table 23.

Table 23 – Risk Levels

Level 1	average values + 5%
Level 2	average values + 15%
Level 3	average values + 25%
Level 4	average values + 35%

5 Results

In this chapter, will be determined and discussed the main results of this work, where the values for each one of the risk levels are obtained considering the method proposed in sub-chapter 4.2. Again and as already determined the results will be divided taking as base each type of aircraft operation. The following results will allow to verify, alert and comprehend the following:

- Conclude If the LCF coefficients from TM worksheet can be adjusted to the Portuguese usage of their aircrafts.
- Alert for the differences already identified between engine 1/3 LCF values and engine's two, in ground operations and possible solutions to prevent it.
- Will permit PtAF, within its own airworthiness' authority, to choose which risk level suits best on their own safety parameters.

5.1. Flight Operation Results

5.1.1. Risk Level's LCF Values Calculation/Interpretation

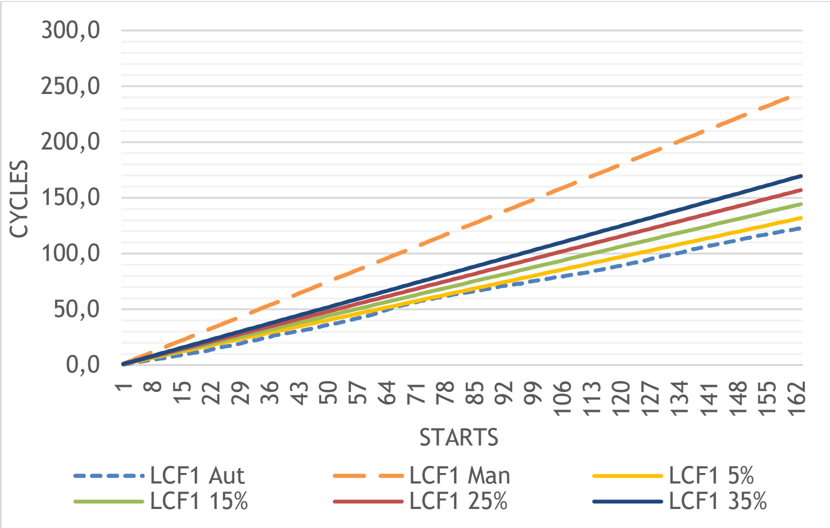
Taking Table 23 as base to the calculations of Risk Levels' LCF values was possible to get, for the flight operations, the results represented on Table 24. From this results, at first view, is easy to identify which values are higher that the manual ones, meaning that those should be discarded. This situation happen only in LCF3 values for risk levels 2, 3 and 4.

Table 24 – Risk Level's Values (flight operations)

	LCF1	LCF2	LCF3	LCF4
MAN coefficients[10]	1.50	1.30	1.20	1.50
Average AUT[11]	0.77	0.89	1.08	1.10
Level 1	0.81	0.93	1.13	1.15
Level 2	0.89	1.02	1.24	1.26
Level 3	0.96	1.11	1.35	1.37
Level 4	1.04	1.20	1.45	1.48

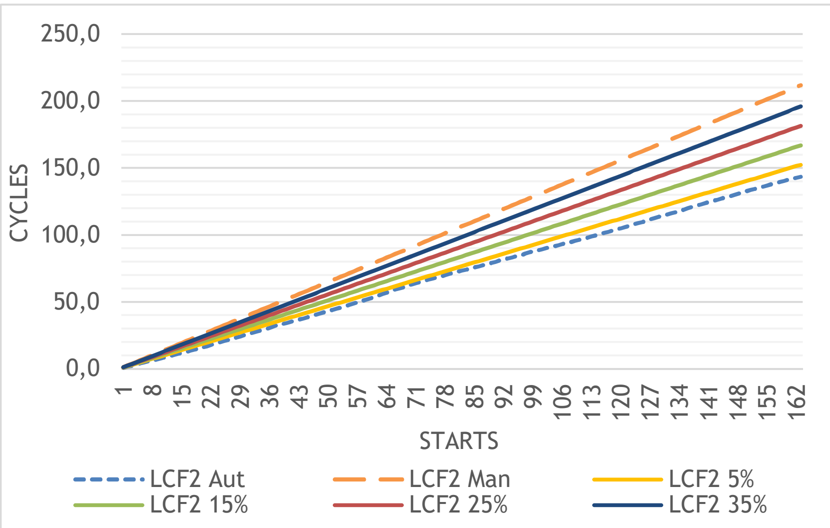
[10] Table 5 – LCF calculation Formulas (work proposes)
[11] Table 20 – LCF average values (flight operations)

This results are easier to understand when seen graphically:

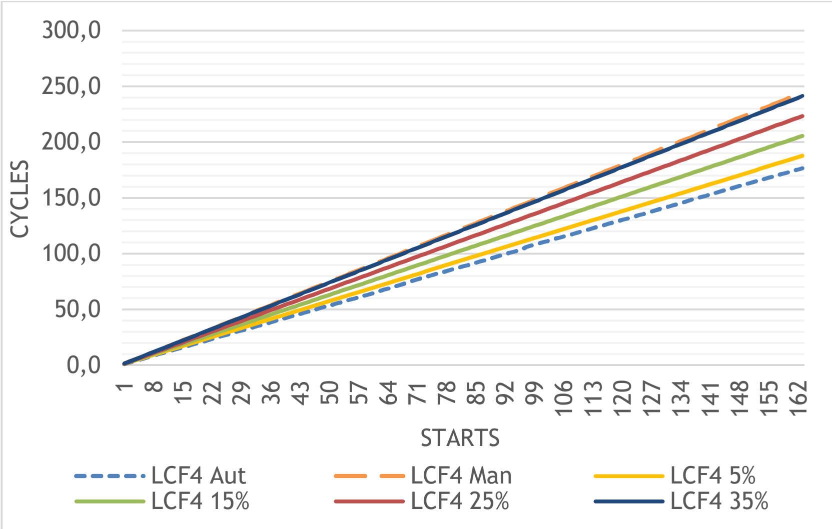


Graphic 27 – Aircraft C/Engine 1 LCF1 Risk Levels Comparison (flight operations)

For the LCF1 values (Graphic 27), by comparison, all risk level leads to cumulative values within the interval between the automatic and the manual ones, considering the same data range. The same is also verifiable in the case of LCF2 and LCF4 (Graphic 28/Graphic 29).

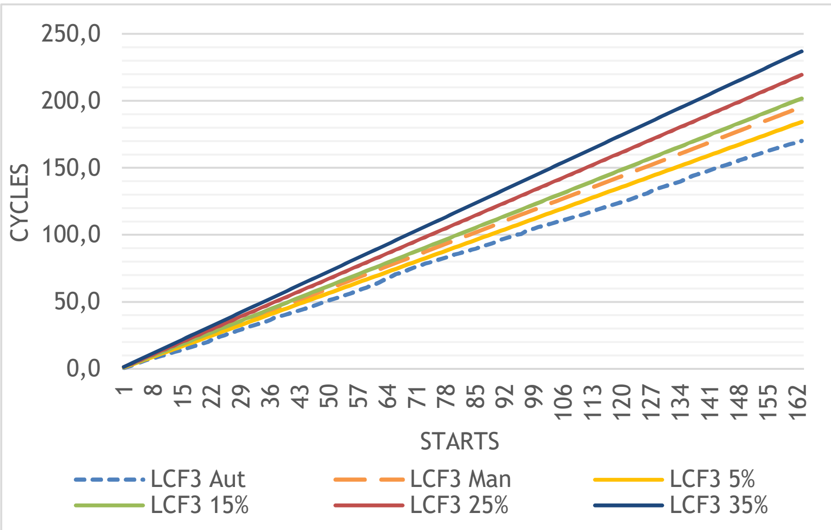


Graphic 28 - Aircraft C/Engine 1 LCF2 Risk Levels Comparison (flight operations)



Graphic 29 - Aircraft C/Engine 1 LCF4 Risk Levels Comparison (flight operations)

In contrast to the results for LCF1,2 and 4 and as already identified from the interpretaion of the results on Table 24, in the case of LCF3 values (Graphic 30) only the cumulative results representing the Level1 stays between the manual and the automatic ones.



Graphic 30 - Aircraft C/Engine 1 LCF3 Risk Levels Comparison (flight operations)

Considering the results' interpretations above, the Levels 2, 3 and 4 values for LCF3 will be replaced with the same value of Level 1, which is the only level in which was possible to obtain a useful value within the criteria that was choose. This change leads to an update Table 24 values (see Table 25)

Table 25 - Risk Level's corrected Values (flight operations)

	LCF1	LCF2	LCF3	LCF4
MAN coefficients[12]	1.50	1.30	1.20	1.50
Average AUT[13]	0.77	0.89	1.08	1.10
Level 1	0.81	0.93	1.13	1.15
Level 2	0.89	1.02	1.13	1.26
Level 3	0.96	1.11	1.13	1.37
Level 4	1.04	1.20	1.13	1.48

5.1.2. Risk Level's Gain Calculation

Now that correct and usable values were obtained for each risk level, is possible, in comparison to the manual values, to determine the correspondent gain on each case.

To achieve this goal, the cumulative values that are represented on the graphics above (Graphic 27, Graphic 28, Graphic 29 and Graphic 30) were retrieved and are exemplified on Table 26:

Table 26 – Aircraft C/Engine1 Manual and Risk Levels cumulative values comparison (flight operations)

	MAN	Level 1	Level 2	Level 3	Level 4
LCF1	244.5	131.8	144.3	156.9	169.4
LCF2	211.9	152.4	166.9	181.4	195.9
LCF3	195.6	184.3	184.3	184.3	184.3
LCF4	244.5	187.7	205.5	223.4	241.s3

Taking in consideration the values on the Table 26, is now possible to calculate the final difference (Gain) between each Risk level value and the manual one (Table 27):

[12] Table 5 – LCF calculation Formulas (work proposes)
[13] Table 20 – LCF average values (flight operations)

Table 27 – Aircraft C/Engine1 Gain for 100% Manual Downloads (flight operations)

	Level 1 Gain	Level 2 Gain	Level 3 Gain	Level 4 Gain
LCF1	112.7	100.2	87.6	75.1
LCF2	59.5	45.0	30.5	16.0
LCF3	11.3	11.3	11.3	11.3
LCF4	56.8	39.0	21.1	3.2
Total	240.4	195.5	150.6	105.6

The gain that is represented on Table 27 was obtained considering that, for the same range of starts values, each automatic download was replaced by a manual one, which means that manual downloads are 100% of all downloads. On chapter 3 is described that currently the manual download tax is about 10.4% of all downloads and if we considered the error described also on the same chapter, which would lead to an increase on manual downloads, the manual download tax increase to 16.4%. Taking this taxes values in consideration and applying it to Table 26's calculated values it is possible to estimate the real gain values for each level, considering the 2 year period represented on the sample data (Table 28/Table 29).

Table 28 - Aircraft C/Engine1 Gain for 10.4% Manual Downloads (flight operations)

	Level 1 Gain	Level 2 Gain	Level 3 Gain	Level 4 Gain
LCF1	11..7	10.4	9.1	7.8
LCF2	6.2	4.7	3.2	1.7
LCF3	1.2	1.2	1.2	1.2
LCF4	5.9	4.1	2.2	0.3
Total	25.0	20.3	15.7	11.0

Table 29 - Aircraft C/Engine1 Gain for 16.4% Manual Downloads (flight operations)

	Level 1 Gain	Level 2 Gain	Level 3 Gain	Level 4 Gain
LCF1	18.5	16.4	14.4	12.3
LCF2	9.8	7.4	5.0	2.6
LCF3	1.9	1.9	1.9	1.9
LCF4	9.3	6.4	3.5	0.5
Total	39.4	32.1	24.7	17.3

From the results above, for both manual download taxes, is possible to conclude that on every risk level there is gain to obtain by using its values, comparatively to the manual ones present on TM worksheet.

5.2. Ground Operation Results

5.2.1. Risk Level's LCF Values Calculation

In what to ground operations is concerned, based on the aspects described on page 27 of this work, the calculation of the results had to be made separately for engines 1/3 and engine 2.

a) Engine 1 and 3 application:

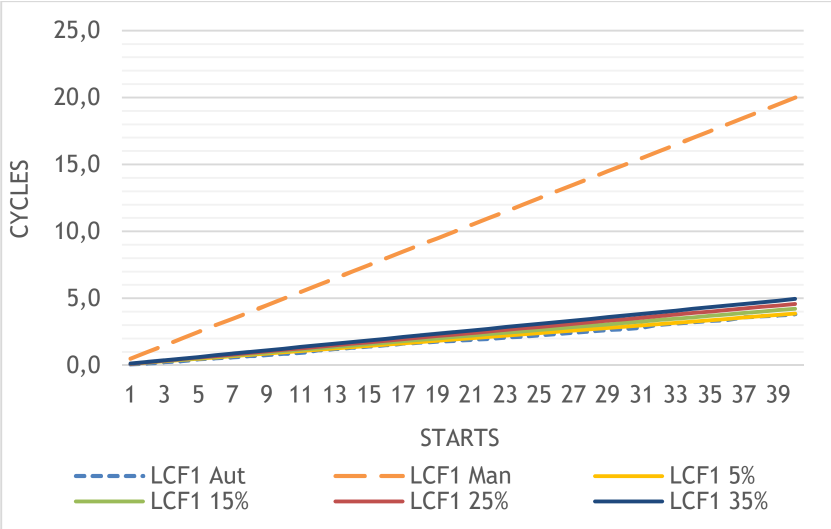
Table 30 – Engines 1 and 3 Risk Level's Values (ground operations)

	LCF1	LCF2	LCF3	LCF4
MAN coefficients[14]	0.50	0.50	0.50	1.00
Average AUT[15]	0.09	0.31	0.42	1.04
Level 1	0.10	0.33	0.44	1.09
Level 2	0.11	0.36	0.48	1.19
Level 3	0.11	0.39	0.53	1.30
Level 4	0.12	0.42	0.57	1.40

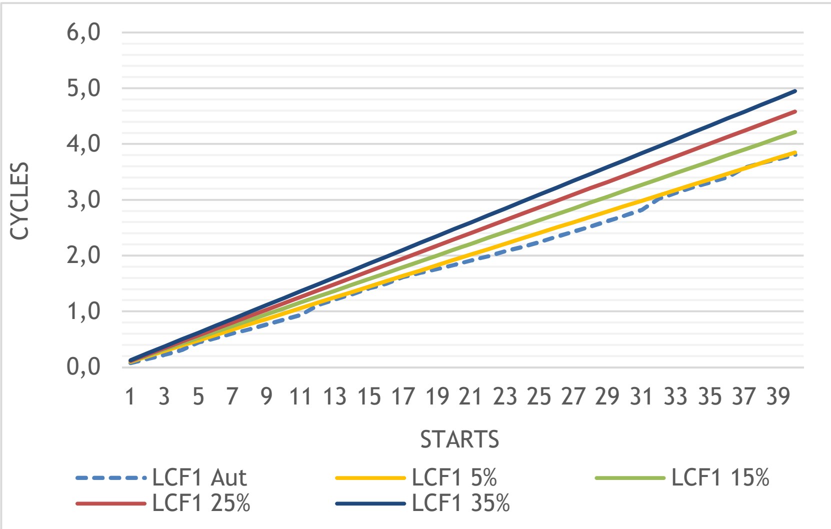
Using the same method and criteria, as on flight operations' calculations, was possible to get the results for the risk level's LCF values that are applicable on Engines 1 and 3 (Table 30), this time on ground operations. At first view of these results, it is possible to conclude right away that exists namely, on the calculated values LCF3 and LCF4, values that are higher to the manual ones because of which they will be discarded.

The graphics below (LCF1 - Graphic 31/Graphic 32; LCF2 - Graphic 33; LCF3 - Graphic 34; LCF4 - Graphic 35) were produced, In order to better understand the implications that those new values have on the same data range that was choose as sample for this work.

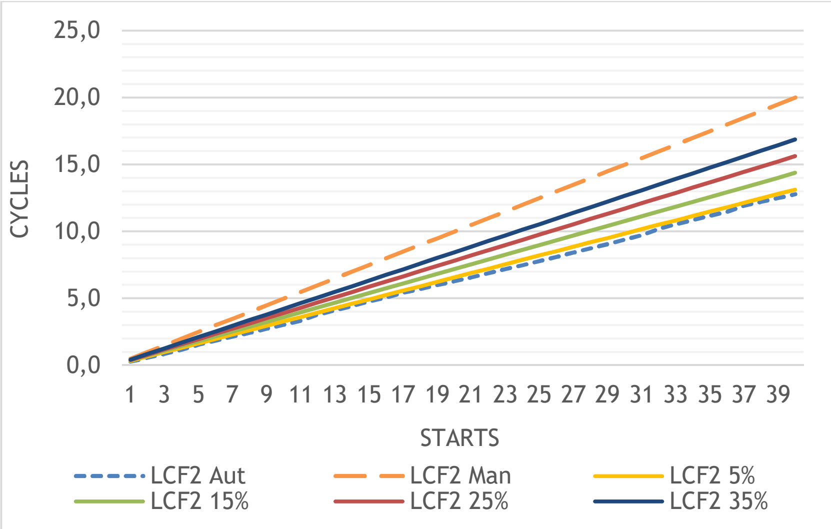
[14] Table 3 – LCF Ground Operations Values (present work proposal)
[15] Table 21 – Engine 1 and 3 LCF average values (Ground operations)



Graphic 31 - Aircraft C/Engine 1 LCF1 Risk Levels Comparison (ground operations)

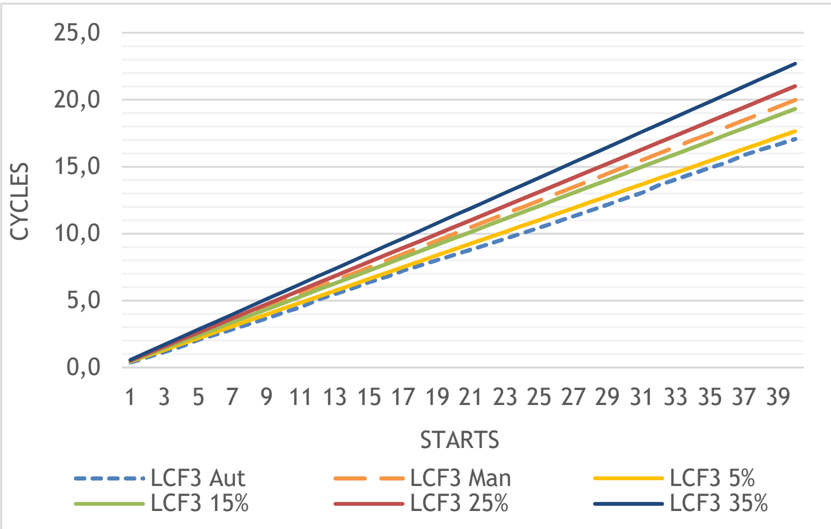


Graphic 32 - Aircraft C/Engine 1 LCF1 Risk Levels Comparison (ground operations)



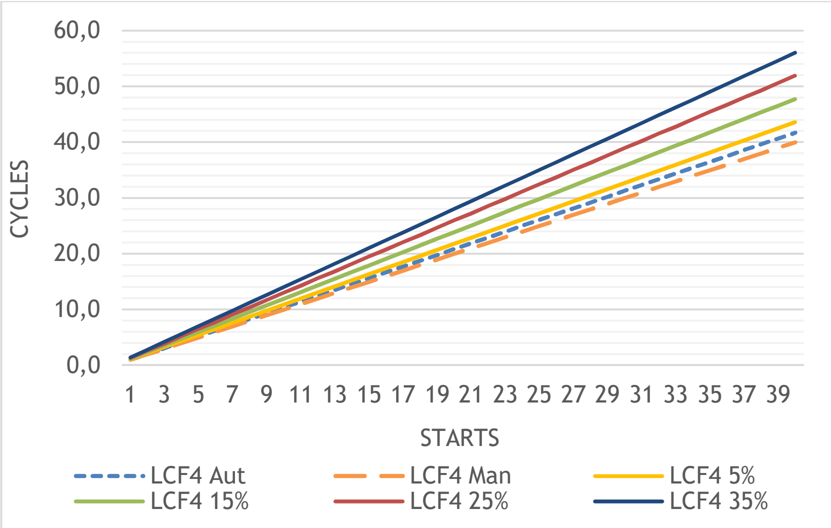
Graphic 33 - Aircraft C/Engine 1 LCF 2 Risk Levels Comparison (ground operations)

In the case of LCF 1 and 2 graphics is possible to see that all risk levels cumulative values are within the interval comprise between the automatic and manual ones.



Graphic 34 - Aircraft C/Engine 1 LCF3 Risk Levels Comparison (ground operations)

Differently from LCF1 and 2 results, only the values for levels 1 and 2 can be used to optimise the manual downloads LCF3 coefficients.



Graphic 35 - Aircraft C/Engine 1 LCF4 Risk Levels Comparison (ground operations)

LCF4 risk level results, as previous described, cannot be used in the intended way proposed on this work because for this specific case the automatic average value is higher than the manual one but closer to it, which means that, for the operation in the ground, the engine power turbine module operates closer to the limits for which was design for.

Taking in consideration all the results above and in a similar way as it was applied on the flight operations case, this higher values will be replaced, in the case of LCF3' by the same value that was calculated for lever 2 and for LFC4's values, in which all levels' values are higher than manual ones, was decided to replaced them by the average automatic value for that LCF. This will leads to an update on Table 30 values (Table 31).

Table 31 – Engine 1 and 3 Risk Level's corrected Values (ground operations)

	LCF1	LCF2	LCF3	LCF4
MAN coefficients[16]	0.50	0.50	0.50	1.00
Average AUT[17]	0.09	0.31	0.42	1.04
Level 1	0.10	0.33	0.44	1.04
Level 2	0.11	0.36	0.48	1.04
Level 3	0.11	0.39	0.48	1.04
Level 4	0.12	0.42	0.48	1.04

[16] Table 3 – LCF Ground Operations Values (present work proposal)
[17] Table 21 – Engine 1 and 3 LCF average values (Ground operations)

The previous decision was made, in what LCF4's values is concerned, because for the first time in this work results, the automatic average values are higher than the manual ones. This situation happens for the reasons explained previous when manual and automatic values were compared.

b) Engine 2 application:

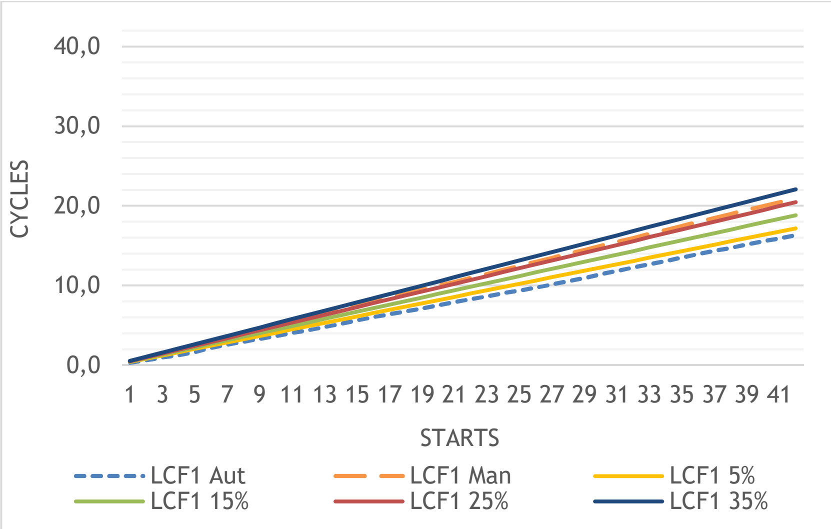
Table 32 – Engine 2 Risk Level's Values (ground operations)

	LCF1	LCF2	LCF3	LCF4
MAN coefficients[18]	0.50	0.50	0.50	1.00
Average AUT[19]	0.39	0.64	0.72	1.06
Level 1	0.41	0.67	0.76	1.11
Level 2	0.45	0.73	0.83	1.21
Level 3	0.49	0.79	0.90	1.32
Level 4	0.53	0.86	0.97	1.42

The results for engine 2 were calculated considering the same method that have already been applied on the obtainment of the previous results above.

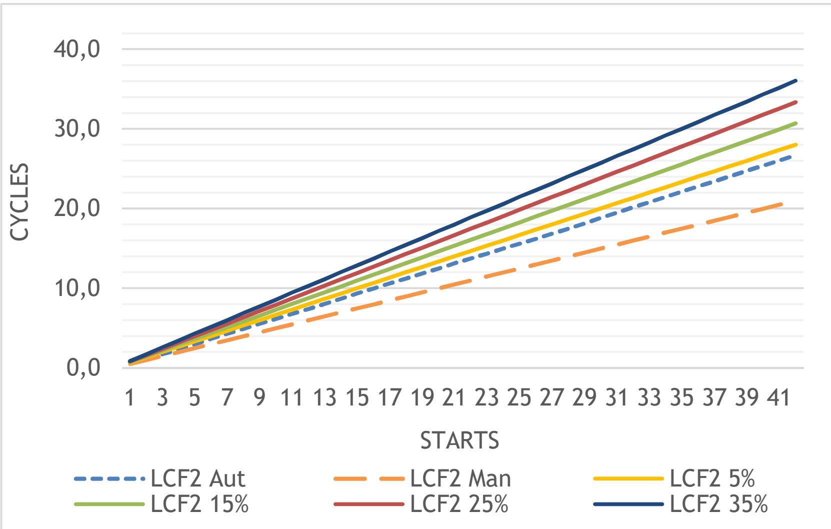
The increased quantity of values in red on Table 32 was already expected considering, as explained before, that by aircraft design and engines start procedure, engine two is subject to higher load especially on the engine start. Because of that only the axial compressor have an average automatic value lower than the correspondent manual one. This situation is easily understood by the analysis of each LCF's graphics below.

[18] Table 3 – LCF Ground Operations Values (present work proposal)
[19] Table 22 - Engine 2 LCF average values (Ground operations)

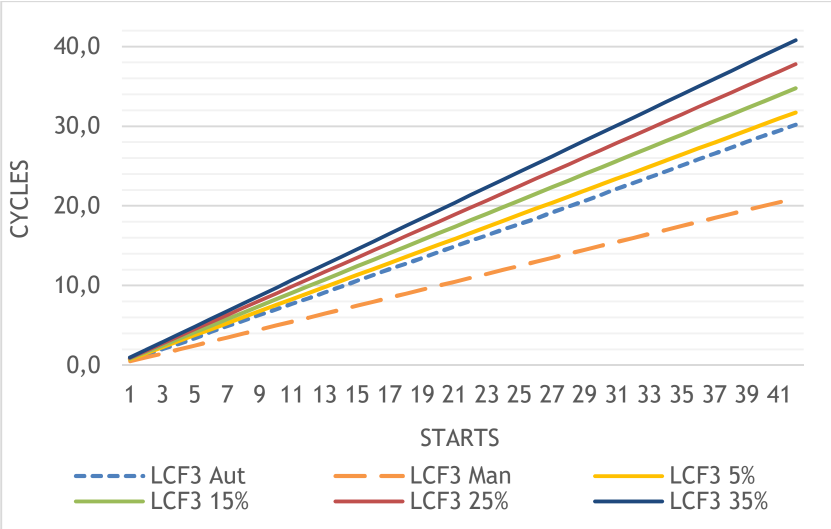


Graphic 36 - Aircraft C/Engine 2 LCF1 Risk Levels Comparison (ground operations)

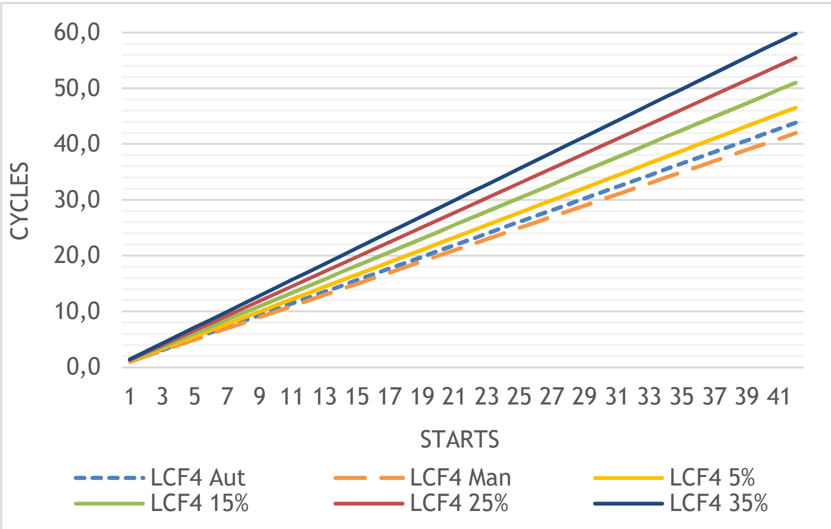
The axial compressor module, in which LCF1 values are related to (Graphic 36), is the one that don't operates near to it design limits. This is easily verified, considering that only one of the risk levels' values (level 4) is out of the interval formed by the manual and automatic ones. This turns the LCF value optimisable.



Graphic 37 - Aircraft C/Engine 2 LCF2 Risk Levels Comparison (ground operations)



Graphic 38 - Aircraft C/Engine 2 LCF3 Risk Levels Comparison (ground operations)



Graphic 39 - Aircraft C/Engine 2 LCF4 Risk Levels Comparison (ground operations)

On another hand, considering the graphics for LCF2 (Graphic 37), LCF3 (Graphic 38) and LCF4 (Graphic 39), for those LCFs the automatic values, as described before, are higher than the manual coefficients available on TM worksheet.

Considering all this new information, there is the need to update Table 32 with the values that are useful for this work purpose. So, for LCF 2, 3 and 4, the level's values were replaced by the automatic average correspondent values. In the case of LCF1, only level 4 value was needed to be replaced with the lower level value (Table 33).

Table 33 - Engine 2 Risk Level's corrected Values (ground operations)

	LCF1	LCF2	LCF3	LCF4
MAN coefficients[20]	0.50	0.50	0.50	1.00
Average AUT[21]	0.39	0.64	0.72	1.06
Level 1	0.41	0.64	0.72	1.06
Level 2	0.45	0.64	0.72	1.06
Level 3	0.49	0.64	0.72	1.06
Level 4	0.49	0.64	0.72	1.06

5.2.2. Risk Level's Gain Calculation

To determine the gain related to each risk level values, taking in consideration that those values where already corrected on Table 31 and Table 33 for engine 1/3 and engine 2 correspondently, it will be needed to gather from all graphics above the cumulative manual and risk level's values.

a) Engine 1 and 3 application

Knowing that engine 1 and 3 have similar performances over ground operations, engine 1 from aircraft C will be used to exemplify the gain associated to each risk level.

Table 34 - Aircraft C/Engine1 Manual and Risk Levels cumulative values comparison (ground operations)

	MAN	Level 1	Level 2	Level 3	Level 4
LCF1	20.0	3.8	4.2	4.6	4.9
LCF2	20.0	13.1	14.4	15.6	16.9
LCF3	20.0	17.6	19.3	19.3	19.3
LCF4	40.0	40.0	40.0	40.0	40.0

Taking in consideration the values on the Table 34, is now possible to calculate the final difference (Gain) between each Risk level value and the manual one (Table 35).

[20] Table 3 – LCF Ground Operations Values (present work proposal)
[21] Table 22 - Engine 2 LCF average values (Ground operations)

Table 35 - Aircraft C/Engine1 Gain for 100% Manual Downloads (ground operations)

	Level 1 Gain	Level 2 Gain	Level 3 Gain	Level 4 Gain
LCF1	16.2	15.8	15.4	15.1
LCF2	6.9	5.6	4.4	3.1
LCF3	2.4	0.7	0.7	0.7
LCF4	0.0	0.0	0.0	0.0
Total	25.4	22.1	20.5	18.9

The gain values represented on Table 35 were obtained considering that all downloads, during the two years period of time, were manual. Although, again from chapter 3 explanation, the download current tax is it about 10.4% of all downloads and if we consider the error found during the data analysis, this tax grows to 16.4%.

Considering this taxes, the gain results will be as represented on Table 36 (for a 10.4% tax) and Table 37 (for a 16.4% tax).

Table 36 - Aircraft C/Engine1 Gain for 10.4% Manual Downloads (ground operations)

	Level 1 Gain	Level 2 Gain	Level 3 Gain	Level 4 Gain
LCF1	1.7	1.6	1.6	1.6
LCF2	0.7	0.6	0.5	0.3
LCF3	0.2	0.1	0.1	0.1
LCF4	0.0	0.0	0.0	0.0
Total	2.6	2.3	2.1	2.0

Table 37 - Aircraft C/Engine1 Gain for 16.4% Manual Downloads (ground operations)

	Level 1 Gain	Level 2 Gain	Level 3 Gain	Level 4 Gain
LCF1	2.6	2.6	2.5	2.5
LCF2	1.1	0.9	0.7	0.5
LCF3	0.4	0.1	0.1	0.1
LCF4	0.0	0.0	0.0	0.0
Total	4.2	3.6	3.4	3.1

b) Engine 2 application

Similar method and criteria was applied to engine 2 related gain values. First of all by gathering, from Graphic 36, Graphic 37, Graphic 38 and Graphic 39, the cumulative values for the manual and each risk level (Table 38) and then by calculating for a manual download taxes of 100% (Table 39), 10.4% (Table 40) and finally for a tax of 16.4% (Table 41).

Table 38 - Aircraft C/Engine2 Manual and Risk Levels cumulative values comparison (ground operations)

	MAN	Level 1	Level 2	Level 3	Level 4
LCF1	21.0	17.2	18.8	20.4	20.4
LCF2	21.0	26.7	26.7	26.7	26.7
LCF3	21.0	30.2	30.2	30.2	30.2
LCF4	42.0	43.8	43.8	43.8	43.8

Table 39 - Aircraft C/Engine2 Gain for 100% Manual Downloads (ground operations)

	Level 1 Gain	Level 2 Gain	Level 3 Gain	Level 4 Gain
LCF1	3.8	2.2	0.6	0.6
LCF2	-5.7	-5.7	-5.7	-5.7
LCF3	-9.2	-9.2	-9.2	-9.2
LCF4	-1.8	-1.8	-1.8	-1.8
Total	-12.9	-14.5	-16.2	-16.2

Table 40 - Aircraft C/Engine2 Gain for 10.4% Manual Downloads (ground operations)

	Level 1 Gain	Level 2 Gain	Level 3 Gain	Level 4 Gain
LCF1	0.4	0.2	0.1	0.1
LCF2	-0.6	-0.6	-0.6	-0.6
LCF3	-1.0	-1.0	-1.0	-1.0
LCF4	-0.2	-0.2	-0.2	-0.2
Total	-1.3	-1.5	-1.7	-1.7

Table 41 - Aircraft C/Engine2 Gain for 16.4% Manual Downloads (ground operations)

	Level 1 Gain	Level 2 Gain	Level 3 Gain	Level 4 Gain
LCF1	0.6	0.4	0.1	0.1
LCF2	-0.9	-0.9	-0.9	-0.9
LCF3	-1.5	-1.5	-1.5	-1.5
LCF4	-0.3	-0.3	-0.3	-0.3
Total	-2.1	-2.4	-2.7	-2.7

The results obtained for ground operations are very different than the ones for flight. First of all the need to separate engine 1/3 from engine 2, consequence of the aircraft design and engine start procedure, leaded to the calculation of different LCF values to be use differently on those engines. This fact won't probably suit, operationally, the needs of the squadron.

Contrarily, also, to flight operation results, some of the gain values calculated are negative, this means that in the case of those LCF there is no applicable optimization available because the automatic values are already higher than the manual ones.

6 Conclusions and Future Works

6.1. Conclusions

First of all, is very important to refer that not only the objective of this work was accomplish as also other new information, unknown until now, was discovered during the realization of this work. With this work was possible to define new optimised LCF cycle values, distributed between 4 different risk levels, allowing the PtAF to use them according to their own safety parameters.

With this work, it was identified that on flight operations the aircraft variant and the engine position is not a factor on engine performance allowing the calculation of optimized LCF cycle values to be used on every single manual download in which flight operations is concerned, independently of its position and aircraft variant.

On other hand, for ground operations, the results where a little troubled. From the information obtain from ground operations downloads was possible to exclude the aircraft variant as a factor but, contrary to flight operation results, the engine position has an incredible impact on the engine performance. The engine that is installed on position nº2 has almost the twice cycle consumption the nº1 and 3 engines. This situation is consequence of two different characteristics: aircraft conception – by conception the engines positioned on position nº2 are at all time engaged on the aircraft main gear box which makes the nº2 engine always subjected to additional load since it starts to shut down; Engine start procedure – by procedure the engines positioned on positions 1 and 3 are only engaged to the aircraft main gearbox at a rotor speed of 102% which make the engine in position 2 the one that has, by itself, to turn the rotor to that speed, until the work force can be distributed by all the three engines.

This situation leads to different optimized cycle values to be used differently on engine 1/3 and engine 2.

Operationally the use of different values per engine will be very hard to implement. Adding to this the fact that on ground operation the automatic values are, in case of engine 1/3's LCF5, higher than the manual ones and on engine 2 only LCF1 automatic value is lower than the manual's, is turns the optimization of the LCF cycle values for ground operation hard to concretize.

To conclude the PtAF has now the tools to optimize the LCF cycle values to be used every time a flight operation related manual download is needed, allowing an increment on the engine components life and also in budget gain if in the future is decided to sign any contract in which will be required to pay for flight cycle consumption.

6.2. Future Works

Once that during this work were explained several limitations and errors found on PGS's data bases, procedures and as also hardware related, it is possible to refer some recommended works to be realized in the future.

First of all, considering the difficulties to obtain any data older than 1 month without the help of AW's PGS supporter engineer and that all engine related issues are not included on the FISS contract, would be useful to, in collaboration with PtAF DCIS, elaborate a user friendly software which could compiled all the engine related information since 2004 and allow its day by day consultation without the need to resort to AW agreement.

In order to be possible in the future to successfully compare the total data retrieved from SIGOP with the data record on PGS, through each download, is recommended an update of the SIGOP software and a change on the pilot data record procedure, in a way on which can allow the maintenance operations to be recorded separately on flight and ground activities.

On chapter 3 (3.3.3) were described some data errors that were unknown until now and have incredible impact on the cumulative metrics values. It is possible that, similar to this new errors, many others could exist and been impacting the final values for each engine and aircraft components without being notice. In order to identify this situations would be very useful to make an investigation, download by download, on a two year sample, but this time covering all aircraft components.

Today the only way to prevent this download errors is to stop the automatic downloads and obligate to perform a manual one. This way to react is incrementing the number of manual downloads, which is expect to increase in the near future, having, as described during this work, a negative impact on the cumulative cycle values. To prevent this type of reaction, would be useful, in collaboration with DEFLOC and AW, to identify the hardware and software upgrades that are needed in comparison with the positive budget and impact that this upgrades would bring to the EH101 fleet.

7 Bibliography

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Appendix A

SAFRAN

NATO UNCLASSIFIED

Status

DMC: 10-D-05-50-15-00A-284A-A
Title: Life Cycle Counts - Special Irregular Inspections
Issue number: 002(status)
Issue date: 2014-06-02
Language: sx (US)

Security classification: UNCLASSIFIED
Responsible partner company: F0228
Originator: F0228
Applicability: EH101 RTM322 MK250 (02/8)
Quality assurance status: First verification: Table top
Reason for updating: Status changed

DMC: 05-50-15-00A-284A-A
Applicability: 02/8 MK250-01

Issue date: 2014-06-02
Page: 1/5

Life Cycle Counts - Special Irregular Inspections

References:

Data Module/Technical Publication
– 05-10-00-00A-000A-A

Preliminary Requirements

Required Conditions

None

Support Equipment

None

Supplies

None

Spares

None

Safety

WARNING

COUNT AND RECORD THE CYCLES USED, IN THE ENGINE RECORDS. THIS PROCEDURE IS MANDATORY AND THE OPERATOR MUST DO THIS. FAILURE TO COUNT CYCLES (OR ERRORS MADE WHEN YOU COUNT OR RECORD CYCLES) MAY AFFECT COMPONENT RELIABILITY AND AFFECT FLIGHT SAFETY.

CAUTION

IF AN ENGINE OR MODULE IS RETURNED TO A REPAIR CENTRE AND CYCLE COUNTS HAVE NOT BEEN RECORDED IN THE DOCUMENTATION, ALL LIFE LIMITED PARTS WILL BE REPLACED.

NOTE 1

This data module gives the instructions to manually record the life cycle counts for the power plant. The Aircraft Management System (AMS) will automatically record the life cycle counts, but it is not approved at this time. Thus, you must record the life cycle counts manually.

NOTE 2

You must also use these instructions to manually record the life cycle counts if (after approval) the AMS becomes unserviceable.

Procedure

1. Introduction

Cycle counts are related to the flight or ground running profile.

The number of cycles used between a start, flight and subsequent shut down of an engine is equal to one complete cycle and possibly one or more partial cycles. Less cycles are used when ground running only than are used during a flight.

NOTE 3

Cycle count algorithms for the engine parts shown below are different when complete cycles and partial cycles are used.

- ***The compressor axial stages***
- ***The compressor centrifugal impeller assembly***
- ***The gas generator turbine (combustion and HP turbine module)***
- ***The power turbine module.***

1.1. A complete cycle is a sequence of engine operation procedures that include a start (up to Ground Idle (GI)). Usually (but not always) followed by a large power/speed increase and then an engine shutdown.

1.2. A partial cycle is a sequence of engine operation procedures related to a power/speed decrease followed up by a large increase without engine shutdown.

1.2.1. There are two types of partial cycles used in the calculation of the life cycle counts for the engine parts shown below: (Refer to (see step 1.2.1.1.) and (see step 1.2.1.2.)).

- The compressor axial stage
- The compressor centrifugal impeller assembly
- The gas generator turbine

1.2.1.1. Partial cycle 1: While in normal flight mode (One Engine Inoperative (OEI) not selected by the EECU on the engine), selection of Ground Idle (GI) followed by a reselection of flight mode.

1.2.1.2. Partial cycle 2: While in maximum contingency flight mode (One Engine Inoperative (OEI) selected by the EECU on the engine), Ng decrease down to NgC less than 90%, followed by a large power increase (+ 10%NgC).

1.2.2. There are two types of partial cycles used in the calculation of the life cycle counts for the power turbine module (Refer to (see step 1.2.2.1.) and (see step 1.2.2.1.)).

1.2.2.1. Partial cycle 1: Each time the Nf is more than 109% and then goes back to an Nf of less than 109%.

1.2.2.2. Partial cycle 2: Each time the Nf goes to less than 90% and then goes back to an Nf of more than 90%.

2. Manual life cycle counts procedure - Ground running (Not flight).

The cyclic counts in (see step 2.1.) and (see step 2.2.) should be used for ground runs only (for example, ground runs for maintenance or to dry the engine after a compressor wash).

2.1. Engine start to ground idle and shutdown.

Use 0.3 cycles for the engine critical parts shown below (Refer to (Refer to 05-10-00-00A-000A-A)):

- The compressor axial stages
- The compressor centrifugal impeller assembly
- The gas generator turbine.

Use 0.5 cycles for the power turbine module critical parts (Refer to (Refer to 05-10-00-00A-000A-A)).

2.2. Engine start to MPOG and shutdown.

Use 0.5 cycles for the engine critical parts shown below (Refer to (Refer to 05-10-00-00A-000A-A)):

- The compressor axial stages
- The compressor centrifugal impeller assembly
- The gas generator turbine.

Use 1.0 cycle for the power turbine module critical parts (Refer to (Refer to 05-10-00-00A-000A-A)).

3. Manual life cycle counts procedure (Flight).

3.1. Compressor axial stage cycles - to be applied to the compressor module (M01) axial stage critical parts (Refer to (Refer to 05-10-00-00A-000A-A)).
The total cycle used (C1) for the axial stages between a start and a subsequent shutdown is calculated as follows: C1 = C + (n1 x 0.7) + (n2 x 1.1)

- C: Complete cycle (Refer to (see step 1.1.)) used:
  - When maximum contingency (OEI) mode has not been selected on the engine between the start and the shutdown: C=1.5
  - When maximum contingency (OEI) mode has been selected on the engine between the start and the shutdown: C=2.0
- n1: number of partial cycle 1 (Refer to (see step 1.2.1.1.))
- n2: number of partial cycle 2 (Refer to (see step 1.2.1.2.)).

3.2. Compressor centrifugal impeller assembly cycles - to be applied to the compressor module (M01) centrifugal impeller and impeller cover critical parts (Refer to (Refer to 05-10-00-00A-000A-A)).
The total cycle used (C2) for the centrifugal impeller assembly between a start and a subsequent shutdown is calculated as follows: C2 = C + (n1 x 0.3) + (n2 x 0.3)

- C: Complete cycle (Refer to (see step 1.1.)) used:
  - When maximum contingency (OEI) mode has not been selected on the engine between the start and the shutdown: C=1.3
  - When maximum contingency (OEI) mode has been selected on the engine between the start and the shutdown: C=1.4
- n1: number of partial cycle 1 (Refer to (see step 1.2.1.1.))
- n2: number of partial cycle 2 (Refer to (see step 1.2.1.2.)).

3.3. Gas generator turbine cycles - to be applied to all the combustion and HP turbine module (M02) critical parts (Refer to (Refer to 05-10-00-00A-000A-A)).
The total cycle used (C3) for the gas generator turbine between a start and a subsequent shutdown is calculated as follows: C3 = C + (n1 x 0.4) + (n2 x 0.5)

- C: Complete cycle (Refer to (see step 1.1.)) used:
  - When maximum contingency (OEI) mode has not been selected on the engine between the start and the shutdown: C=1.2
  - When maximum contingency (OEI) mode has been selected on the engine between the start and the shutdown: C=1.3
- n1: number of partial cycle 1 (Refer to (see step 1.2.1.1.))
- n2: number of partial cycle 2 (Refer to (see step 1.2.1.2.)).

3.4. Power turbine cycles - to be applied to all the power turbine (M03) critical parts (Refer to (Refer to 05-10-00-00A-000A-A)).
The total cycle used (C4) for the power turbine between a start and a subsequent shutdown is calculated as follows: C4 = C + (n1 x 0.3) + (n2 x 0.2). The partial cycles used for the power turbine are related to the changes of Nf speed from the normal operating conditions.

- C: Complete cycle (Refer to (see step 1.1.)) used:

- When maximum power turbine speed is less than or the same as 109% Nf during flight: C=1.5
- When maximum power turbine speed is more than 109% Nf during flight: C=1.9

- n1: number of partial cycle 1 (Refer to (see step 1.2.2.1.))
- n2: number of partial cycle 2 (Refer to (see step 1.2.2.2.)).

4. Record the life cycles after the last flight of the day as follows:

4.1. Record the number of used cycles (complete cycles and (if applicable) partial cycles) done by the following parts since they were last recorded :
- Compressor axial stages
- Compressor centrifugal impeller assembly
- Gas generator turbine
- Power turbine.

4.2. Calculate and record the total number of used cycles (complete cycles and (if applicable) partial cycles) done by the compressor axial stages. Since the compressor module (M01) is new and (if applicable) since replacement of a critical part.

4.3. Calculate and record the total number of used cycles (complete cycles and (if applicable) partial cycles) done by the compressor centrifugal impeller assembly. Since the compressor module (M01) is new and (if applicable) since replacement of a critical part.

4.4. Calculate and record the total number of used cycles (complete cycles and (if applicable) partial cycles) done by the gas generator turbine. Since the combustion and HP turbine module (M02) is new and (if applicable) since replacement of a critical part.

4.5. Calculate and record the total number of used cycles (complete cycles and (if applicable) partial cycles) done by the power turbine. Since the power turbine (M03) is new and (if applicable) since replacement of a critical part.

CAUTION

IT IS NECESSARY THAT A LIFE LIMIT PART BE REMOVED FROM SERVICE AS SOON AS IT HAS GOT TO ITS APPROVED IN SERVICE LIFE LIMIT. IF YOU DO NOT DO THIS YOU COULD AFFECT FLIGHT SAFETY.

4.6. Make sure that each life limited part has not got to its life limit.

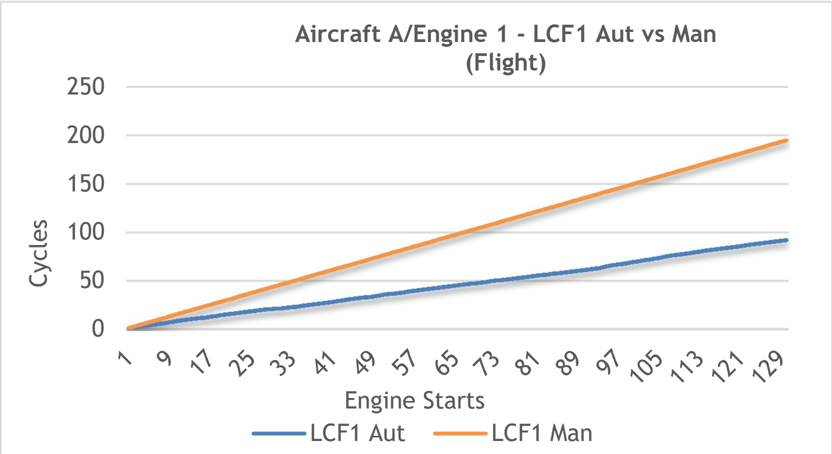
5. When you remove a module, record the number of cycles used on the modules log card.

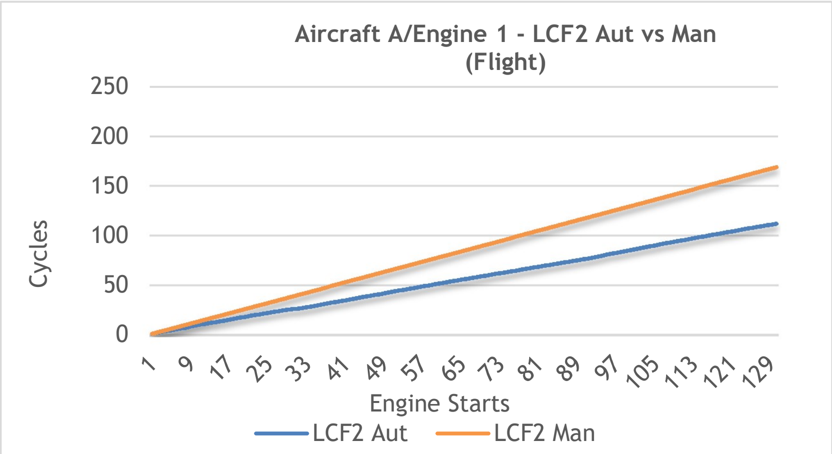
***** End of data module *****

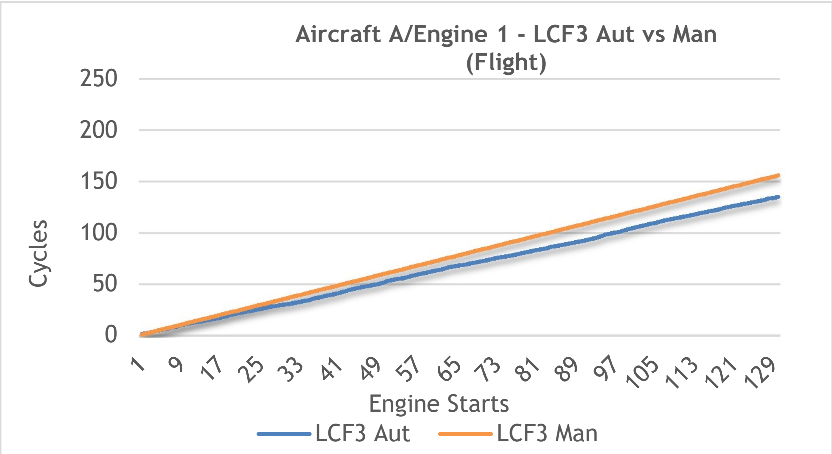
Appendix B

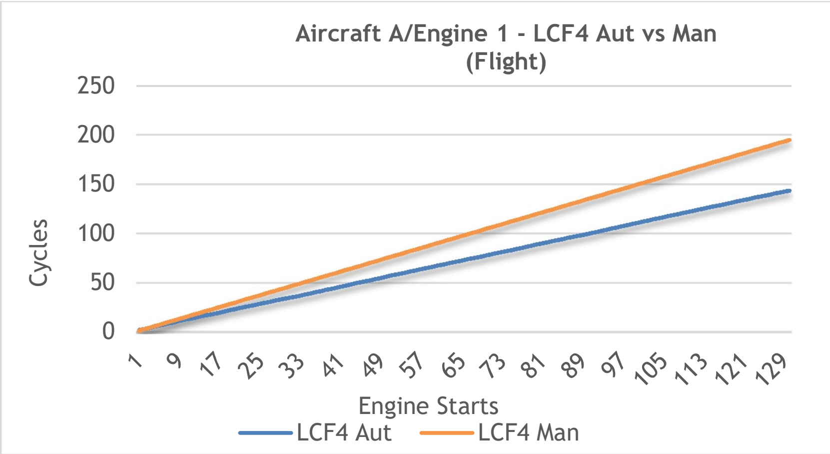
Aircraft A

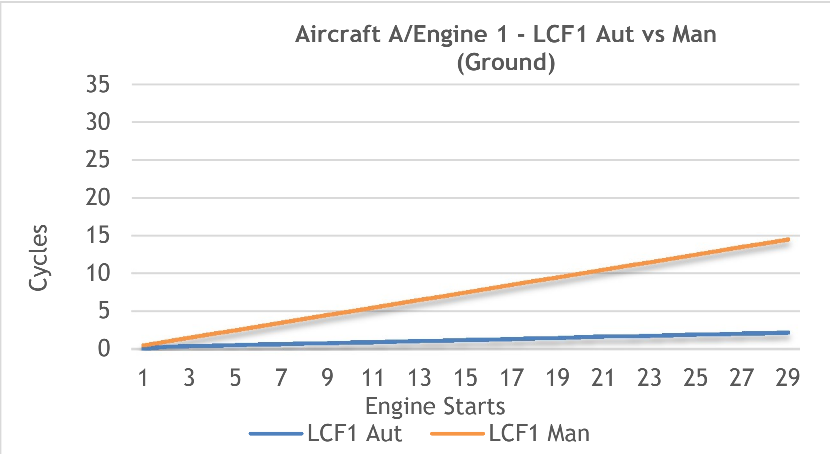
Engine1:

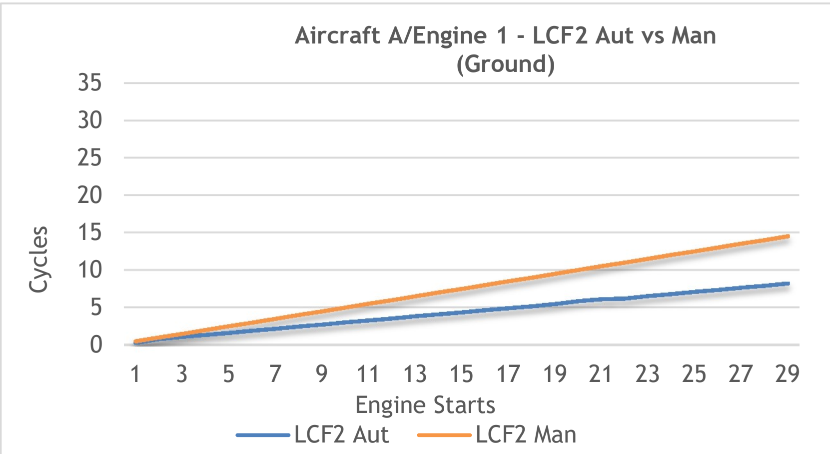


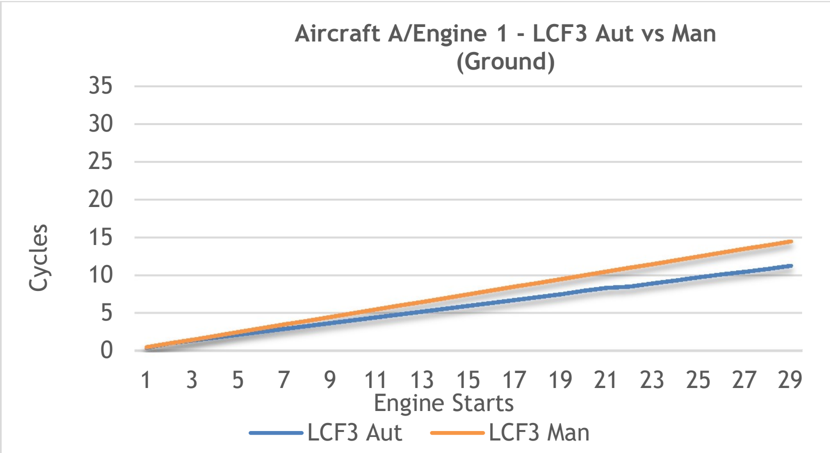


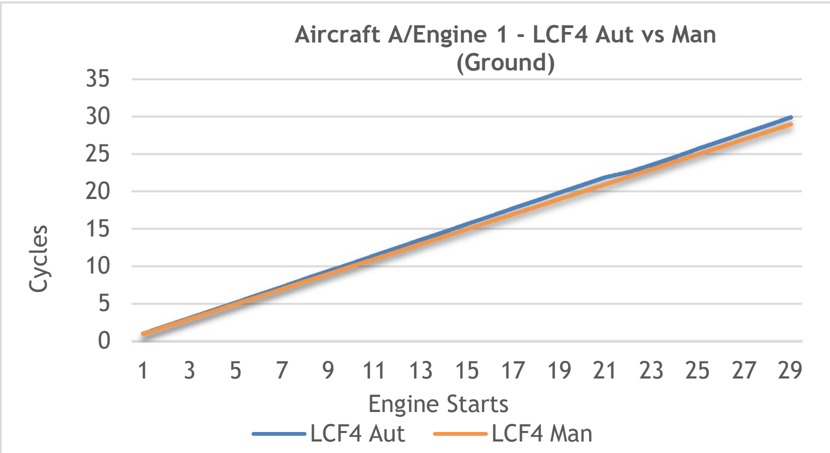



Aircraft A/Engine 1 - LCF4 Aut vs Man (Flight)
Cycles
250
200
150
100
50
0
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129
Engine Starts
LCF4 Aut
LCF4 Man

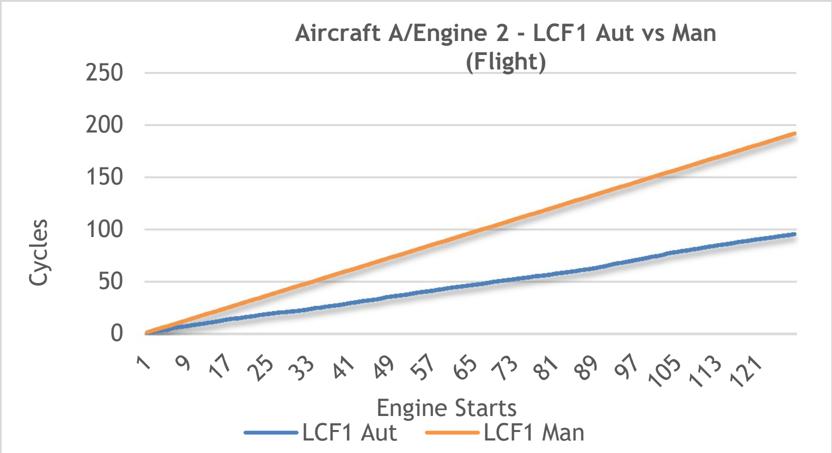

Aircraft A/Engine 1 - LCF1 Aut vs Man (Ground)
Cycles
35
30
25
20
15
10
5
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Engine Starts
LCF1 Aut
LCF1 Man

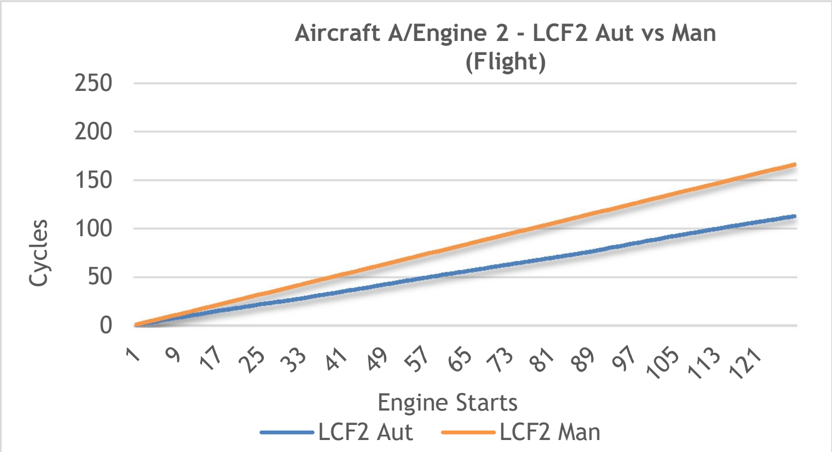

Aircraft A/Engine 1 - LCF2 Aut vs Man (Ground)
Cycles
35
30
25
20
15
10
5
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Engine Starts
LCF2 Aut
LCF2 Man

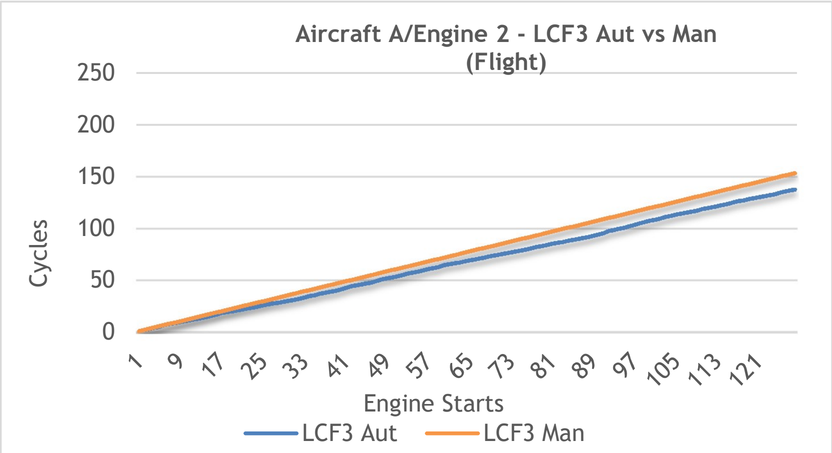

Aircraft A/Engine 1 - LCF3 Aut vs Man (Ground)
Cycles
35
30
25
20
15
10
5
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Engine Starts
LCF3 Aut
LCF3 Man

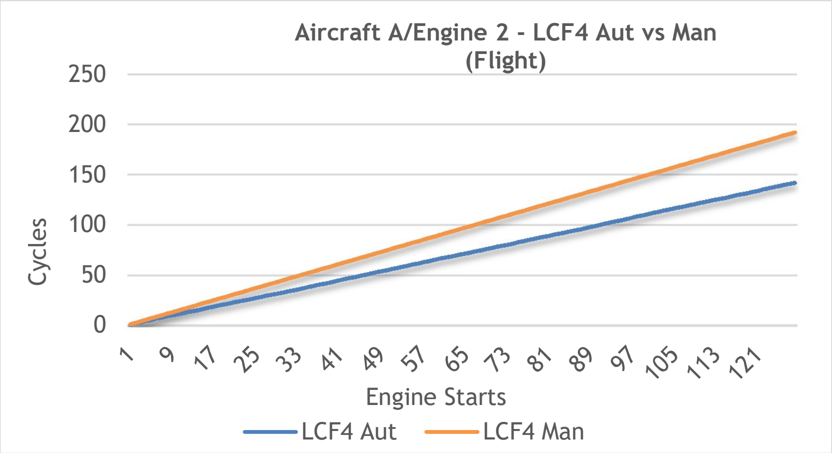

Aircraft A/Engine 1 - LCF4 Aut vs Man (Ground)
Cycles
35
30
25
20
15
10
5
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Engine Starts
LCF4 Aut
LCF4 Man

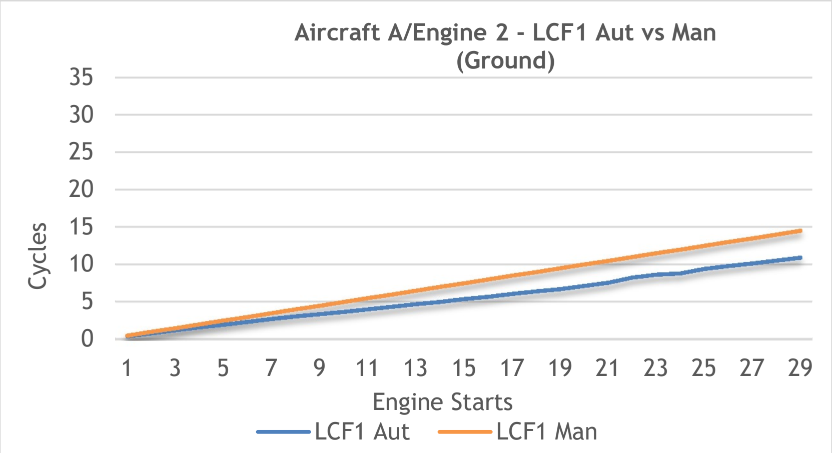
Engine2:

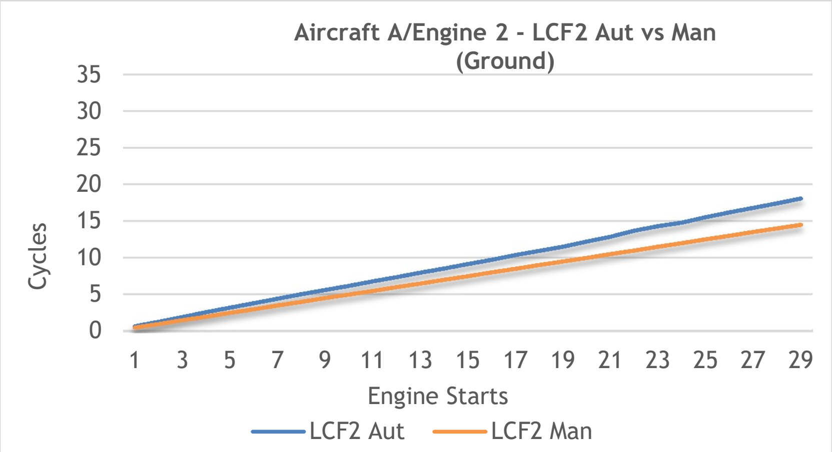

Aircraft A/Engine 2 - LCF1 Aut vs Man (Flight)
Cycles
250
200
150
100
50
0
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121
Engine Starts
LCF1 Aut
LCF1 Man

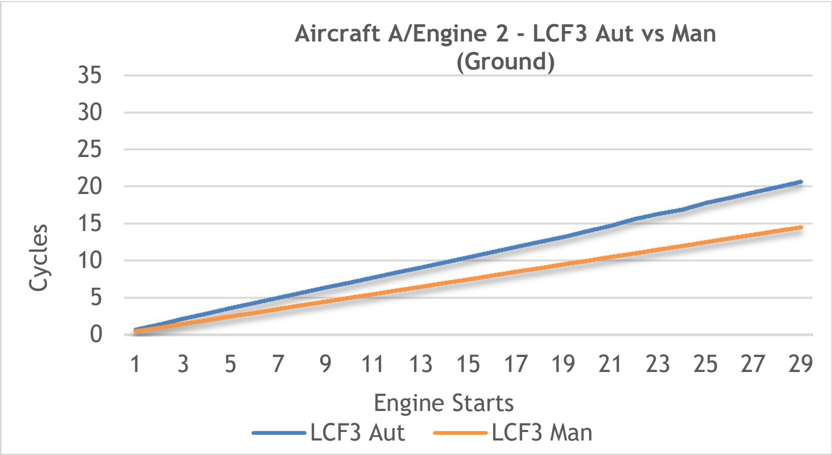

Aircraft A/Engine 2 - LCF2 Aut vs Man (Flight)
Cycles
250
200
150
100
50
0
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121
Engine Starts
LCF2 Aut
LCF2 Man

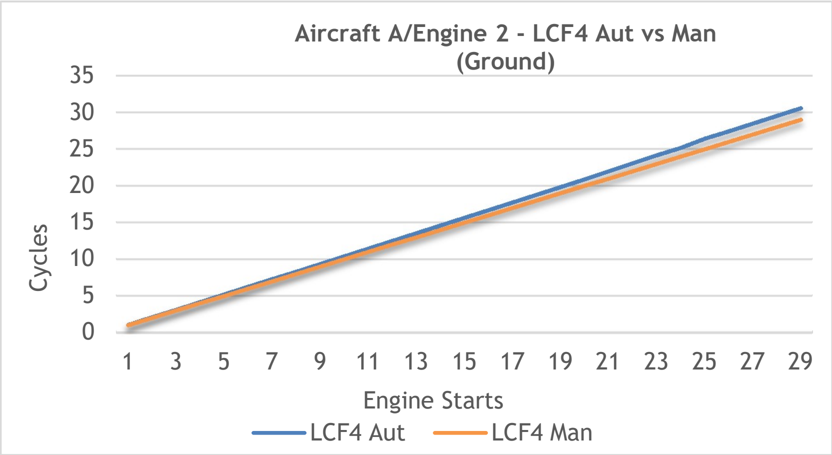

Aircraft A/Engine 2 - LCF3 Aut vs Man (Flight)
Cycles
250
200
150
100
50
0
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121
Engine Starts
LCF3 Aut
LCF3 Man


Aircraft A/Engine 2 - LCF4 Aut vs Man (Flight)
Cycles
250
200
150
100
50
0
1
9
17
25
33
41
49
57
65
73
81
89
97
105
113
121
Engine Starts
LCF4 Aut
LCF4 Man

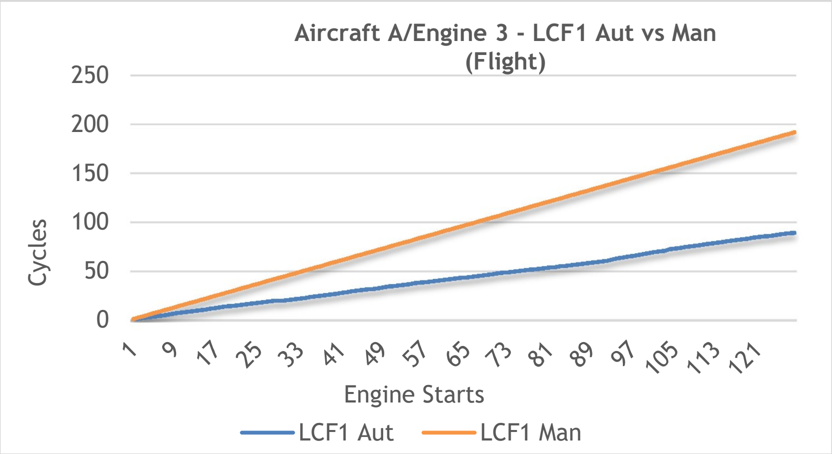

Aircraft A/Engine 2 - LCF1 Aut vs Man (Ground)
Cycles
35
30
25
20
15
10
5
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
Engine Starts
LCF1 Aut
LCF1 Man

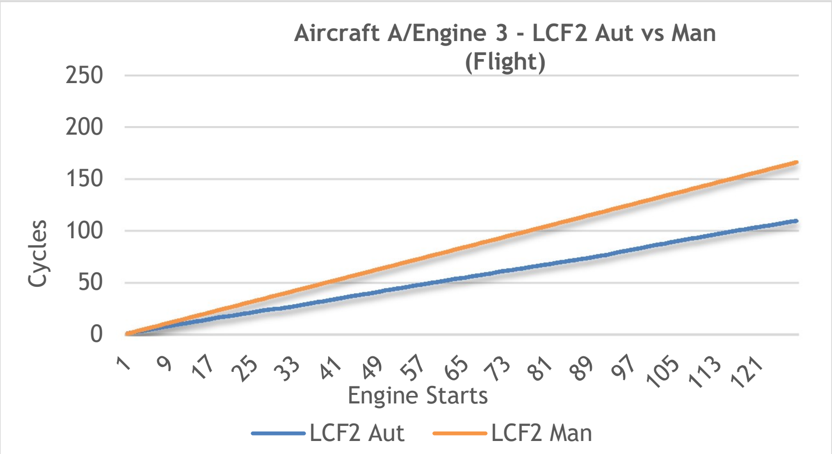

Aircraft A/Engine 2 - LCF2 Aut vs Man (Ground)
Cycles
35
30
25
20
15
10
5
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
Engine Starts
LCF2 Aut
LCF2 Man

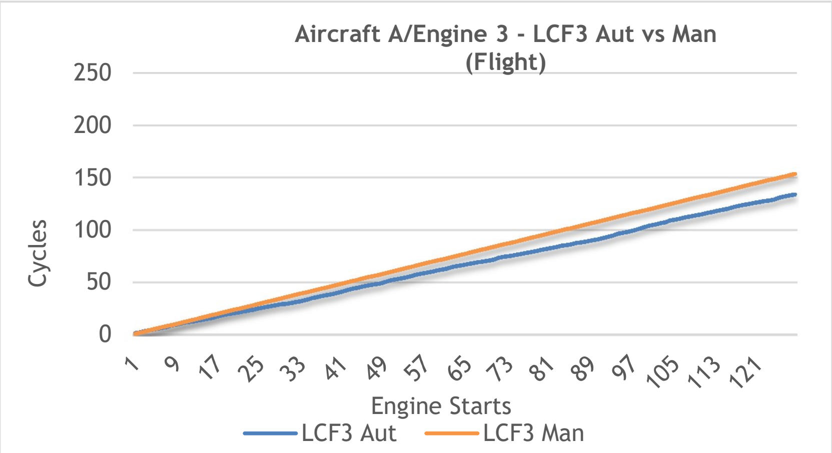

Aircraft A/Engine 2 - LCF3 Aut vs Man (Ground)
Cycles
35
30
25
20
15
10
5
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Engine Starts
LCF3 Aut
LCF3 Man

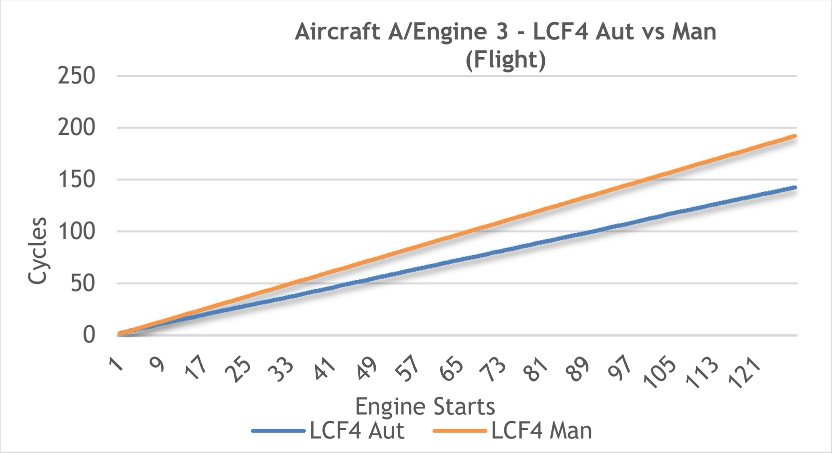

Aircraft A/Engine 2 - LCF4 Aut vs Man (Ground)
Cycles
35
30
25
20
15
10
5
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Engine Starts
LCF4 Aut
LCF4 Man

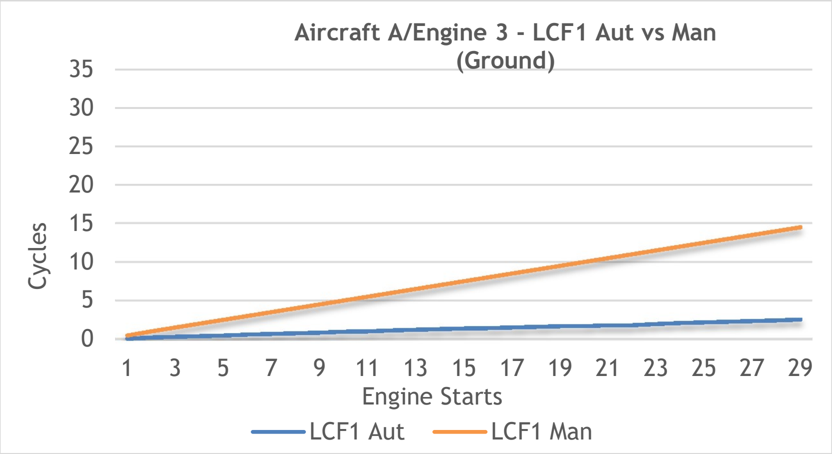
Engine3:

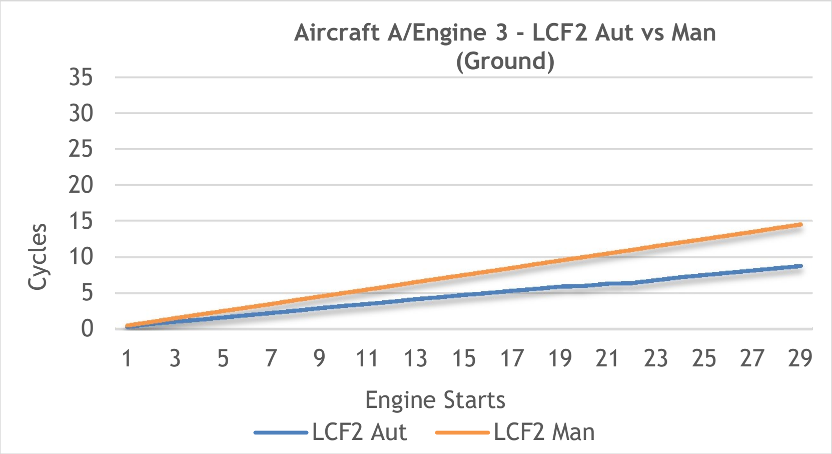

Aircraft A/Engine 3 - LCF1 Aut vs Man
(Flight)
250
200
150
100
50
0
Cycles
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121
Engine Starts
LCF1 Aut
LCF1 Man

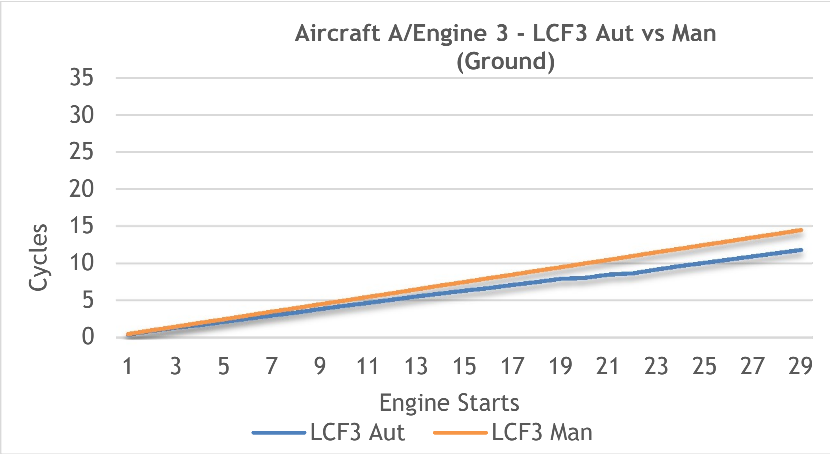

Aircraft A/Engine 3 - LCF2 Aut vs Man
(Flight)
250
200
150
100
50
0
Cycles
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121
Engine Starts
LCF2 Aut
LCF2 Man

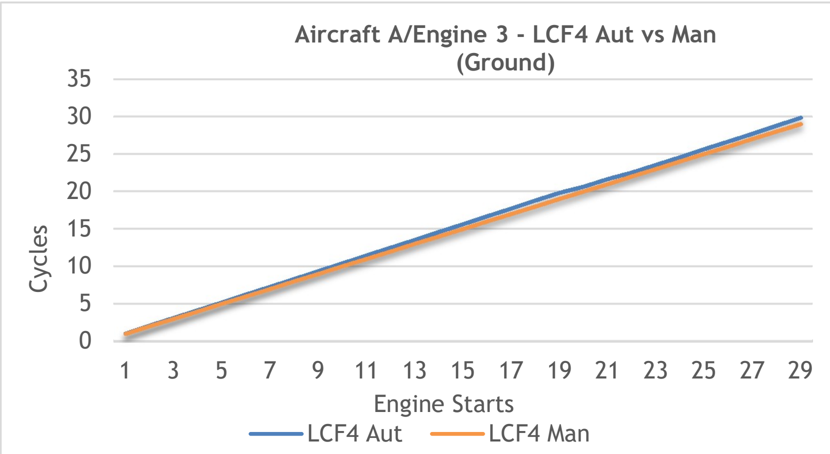

Aircraft A/Engine 3 - LCF3 Aut vs Man
(Flight)
250
200
150
100
50
0
Cycles
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121
Engine Starts
LCF3 Aut
LCF3 Man


Aircraft A/Engine 3 - LCF4 Aut vs Man (Flight)
Cycles
250
200
150
100
50
0
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121
Engine Starts
LCF4 Aut
LCF4 Man


Aircraft A/Engine 3 - LCF1 Aut vs Man (Ground)
Cycles
35
30
25
20
15
10
5
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Engine Starts
LCF1 Aut
LCF1 Man

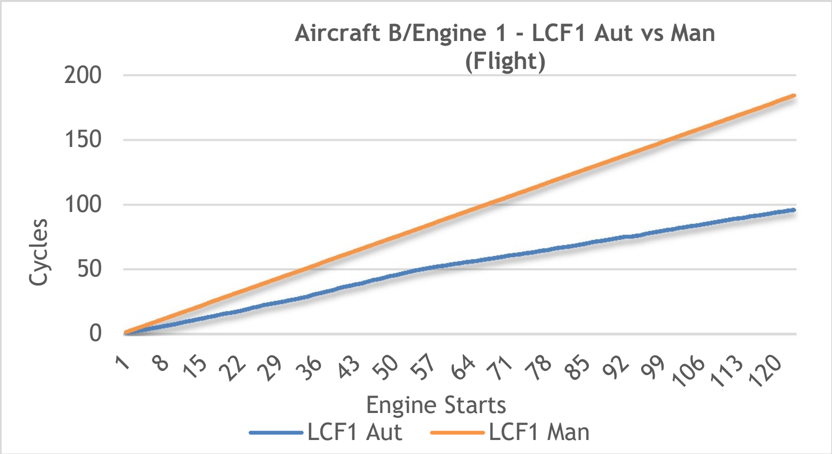

Aircraft A/Engine 3 - LCF2 Aut vs Man (Ground)
Cycles
35
30
25
20
15
10
5
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Engine Starts
LCF2 Aut
LCF2 Man

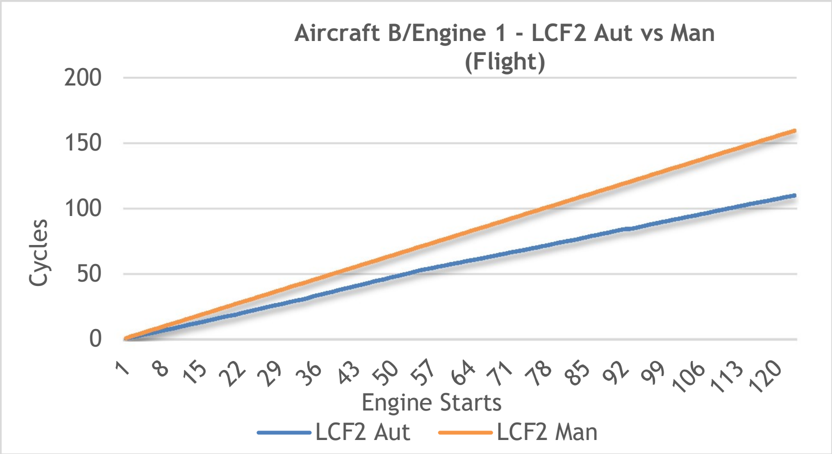

Aircraft A/Engine 3 - LCF3 Aut vs Man (Ground)
Cycles
0
5
10
15
20
25
30
35
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Engine Starts
LCF3 Aut
LCF3 Man

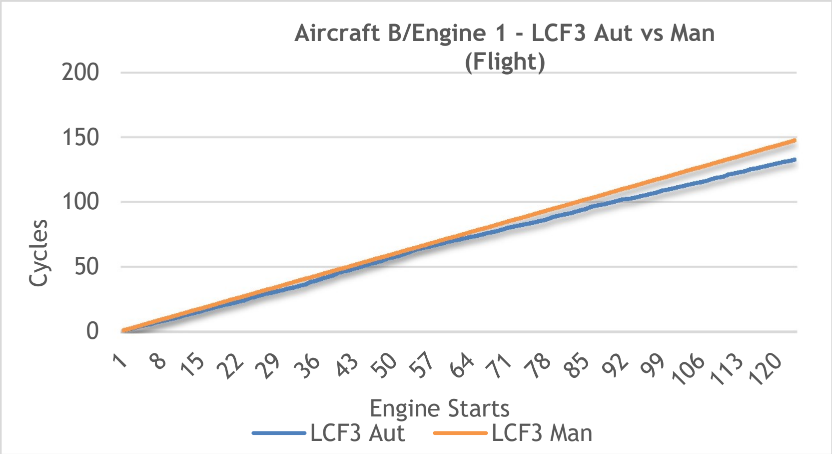

Aircraft A/Engine 3 - LCF4 Aut vs Man (Ground)
Cycles
0
5
10
15
20
25
30
35
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Engine Starts
LCF4 Aut
LCF4 Man

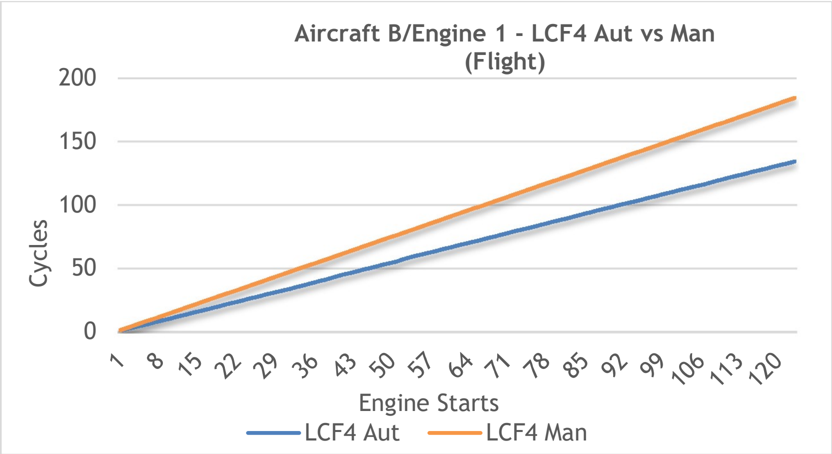
Aircraft B

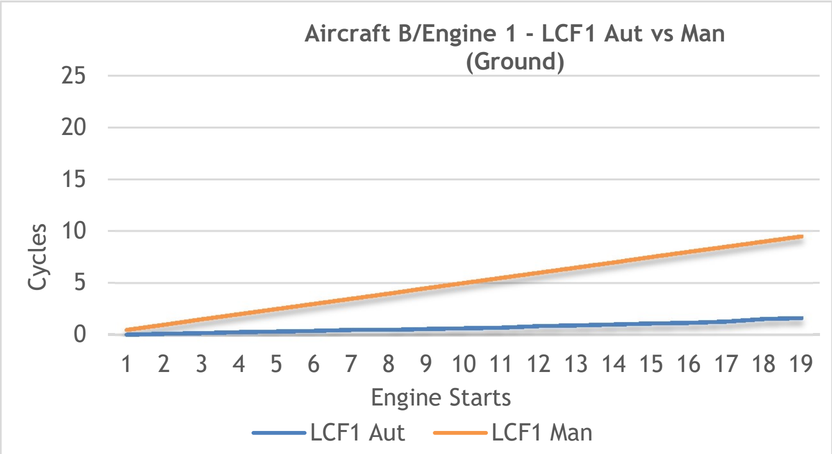
Engine1:

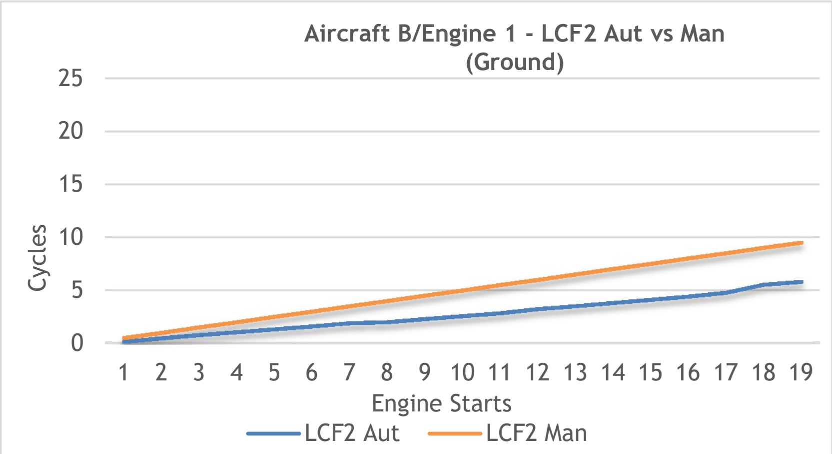


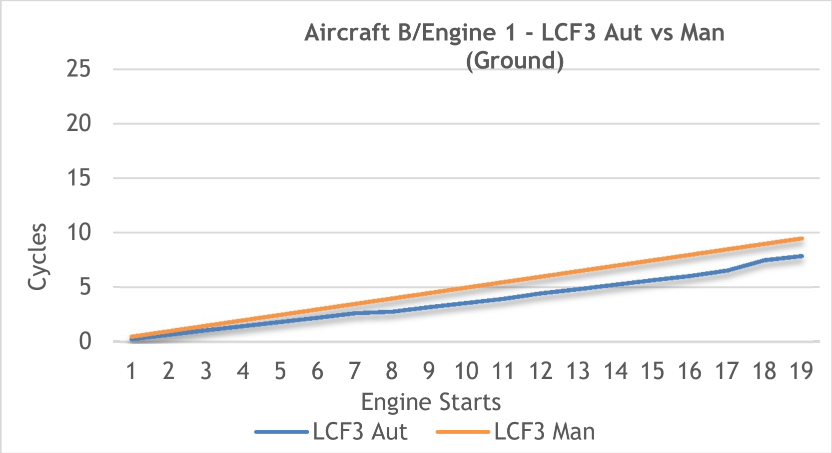


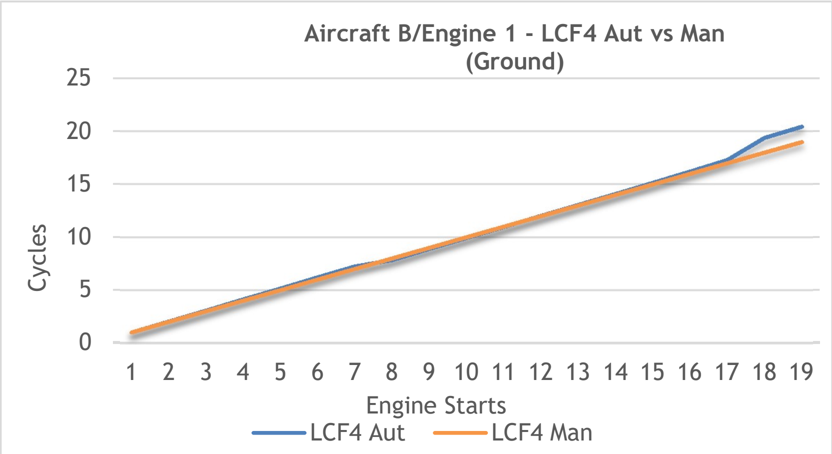



Aircraft B/Engine 1 - LCF4 Aut vs Man (Flight)
Cycles
0
50
100
150
200
Engine Starts
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120
LCF4 Aut
LCF4 Man

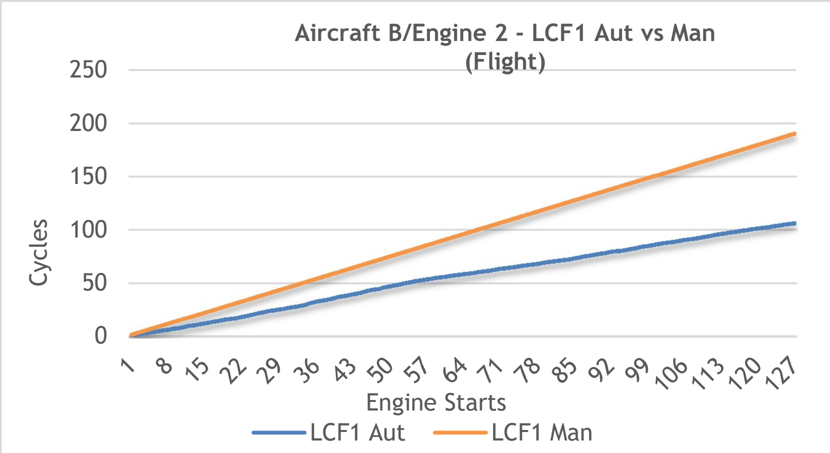

Aircraft B/Engine 1 - LCF1 Aut vs Man (Ground)
Cycles
0
5
10
15
20
25
Engine Starts
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
LCF1 Aut
LCF1 Man

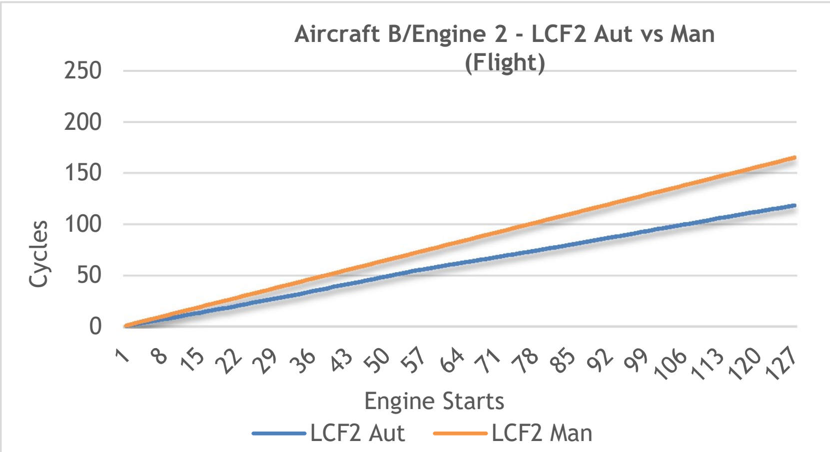

Aircraft B/Engine 1 - LCF2 Aut vs Man (Ground)
Cycles
0
5
10
15
20
25
Engine Starts
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
LCF2 Aut
LCF2 Man

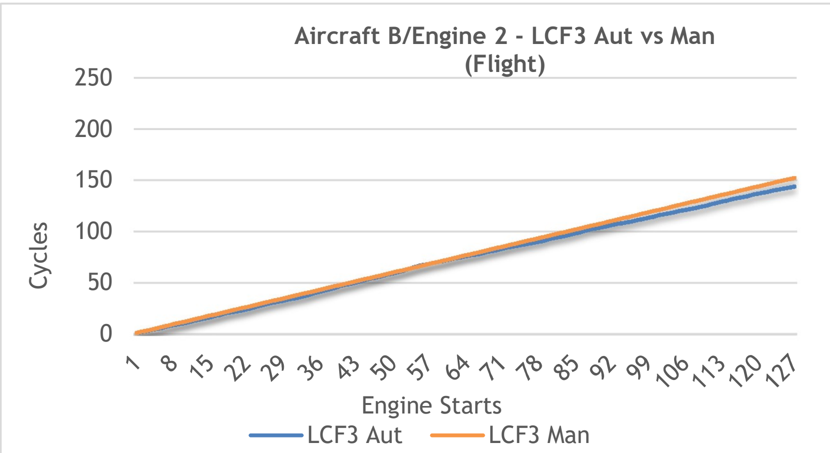

Aircraft B/Engine 1 - LCF3 Aut vs Man (Ground)
Cycles
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Engine Starts
LCF3 Aut
LCF3 Man

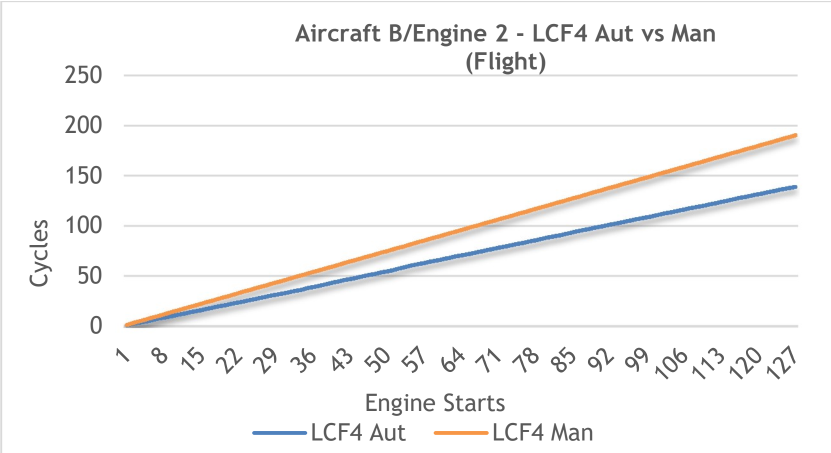

Aircraft B/Engine 1 - LCF4 Aut vs Man (Ground)
Cycles
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Engine Starts
LCF4 Aut
LCF4 Man

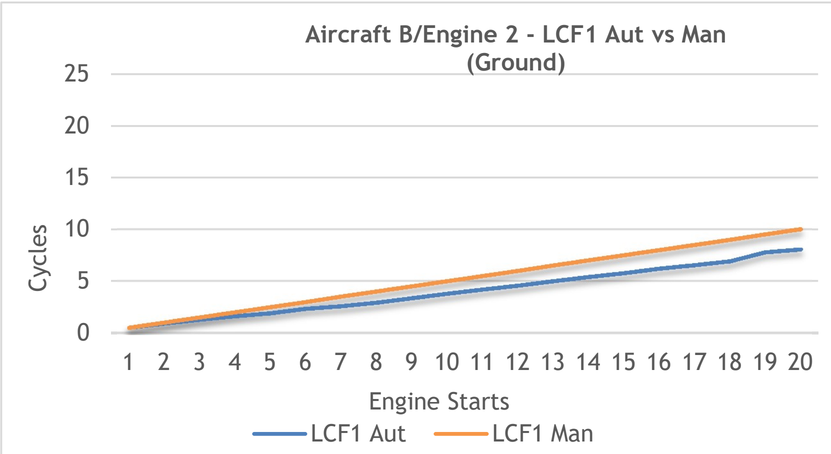
Engine2:

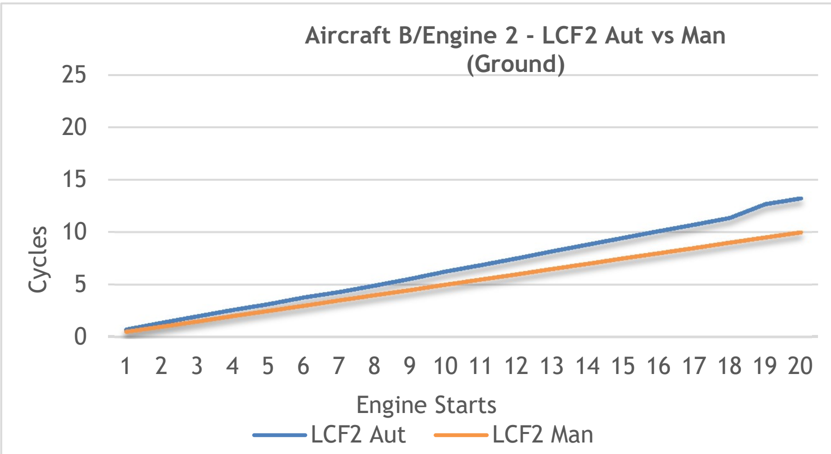

Aircraft B/Engine 2 - LCF1 Aut vs Man
(Flight)
250
200
150
100
50
0
Cycles
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
106
113
120
127
Engine Starts
LCF1 Aut
LCF1 Man

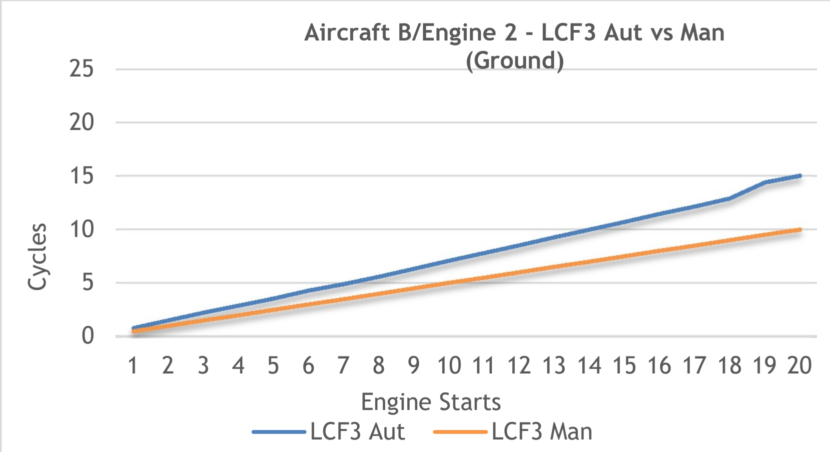

Aircraft B/Engine 2 - LCF2 Aut vs Man
(Flight)
250
200
150
100
50
0
Cycles
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
106
113
120
127
Engine Starts
LCF2 Aut
LCF2 Man

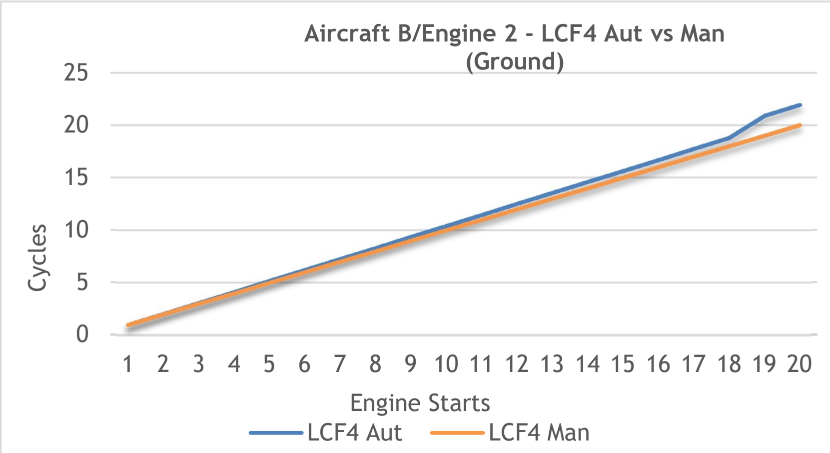

Aircraft B/Engine 2 - LCF3 Aut vs Man
(Flight)
250
200
150
100
50
0
Cycles
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
106
113
120
127
Engine Starts
LCF3 Aut
LCF3 Man


Aircraft B/Engine 2 - LCF4 Aut vs Man (Flight)
250
200
150
100
50
0
Cycles
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127
Engine Starts
LCF4 Aut
LCF4 Man

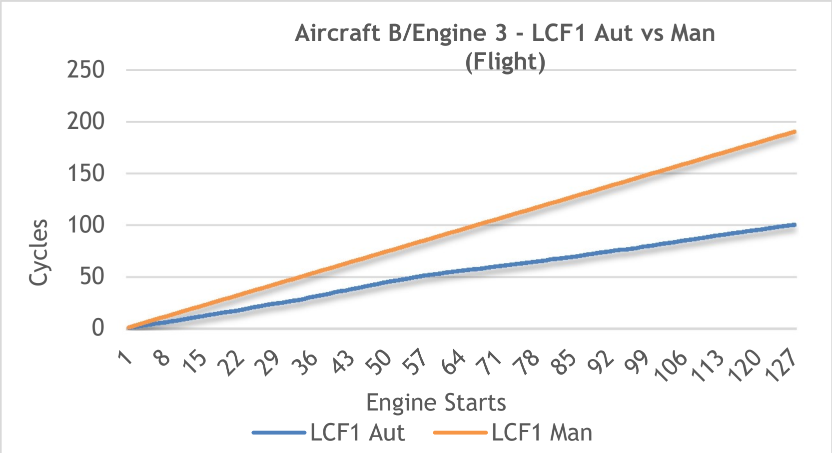

Aircraft B/Engine 2 - LCF1 Aut vs Man (Ground)
25
20
15
10
5
0
Cycles
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Engine Starts
LCF1 Aut
LCF1 Man

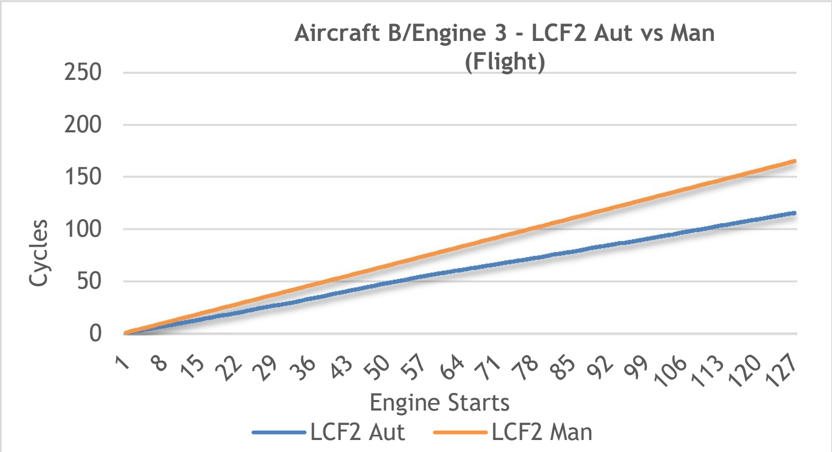

Aircraft B/Engine 2 - LCF2 Aut vs Man (Ground)
25
20
15
10
5
0
Cycles
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Engine Starts
LCF2 Aut
LCF2 Man

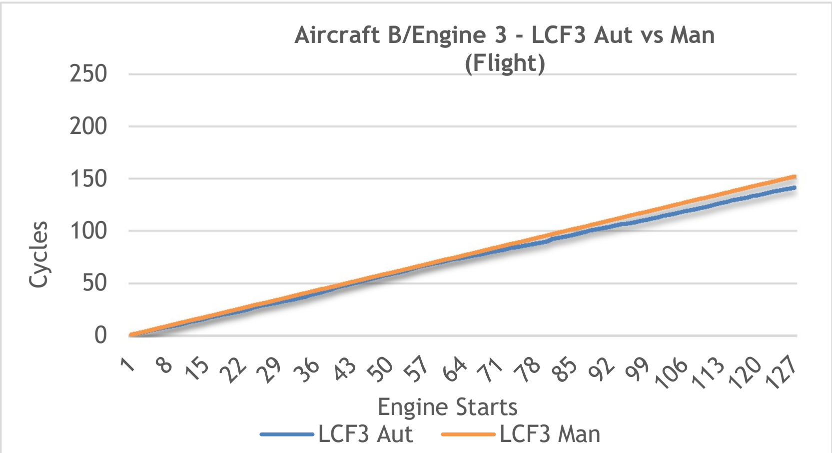

Aircraft B/Engine 2 - LCF3 Aut vs Man (Ground)
Cycles
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Engine Starts
LCF3 Aut
LCF3 Man

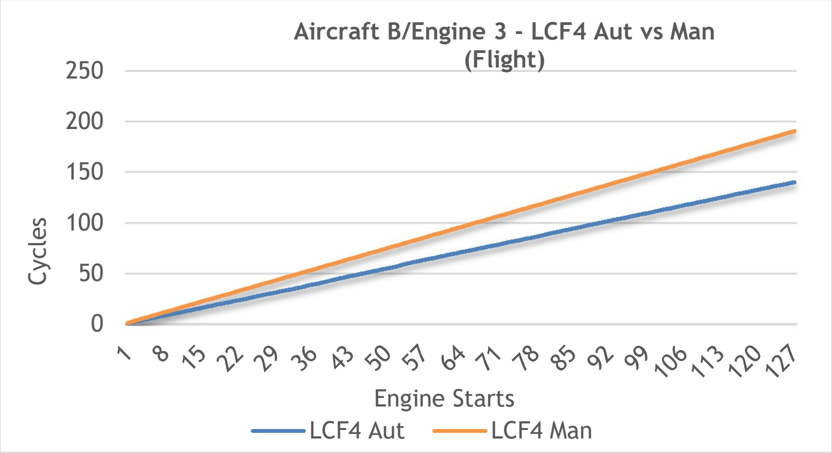

Aircraft B/Engine 2 - LCF4 Aut vs Man (Ground)
Cycles
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Engine Starts
LCF4 Aut
LCF4 Man

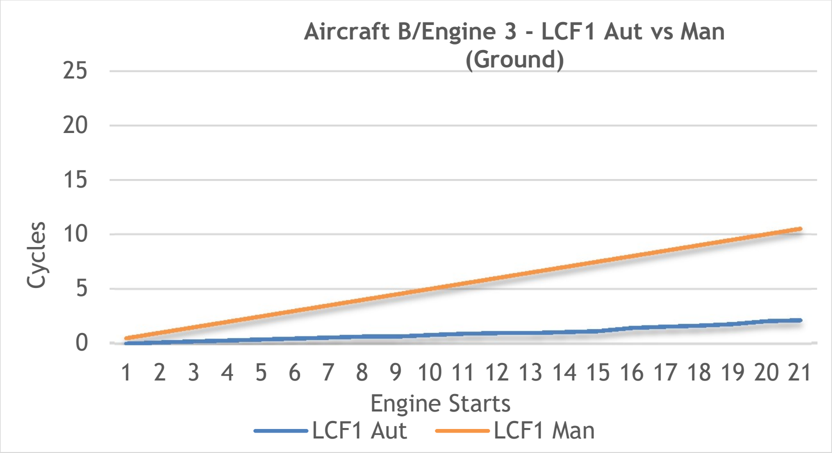
Engine3:

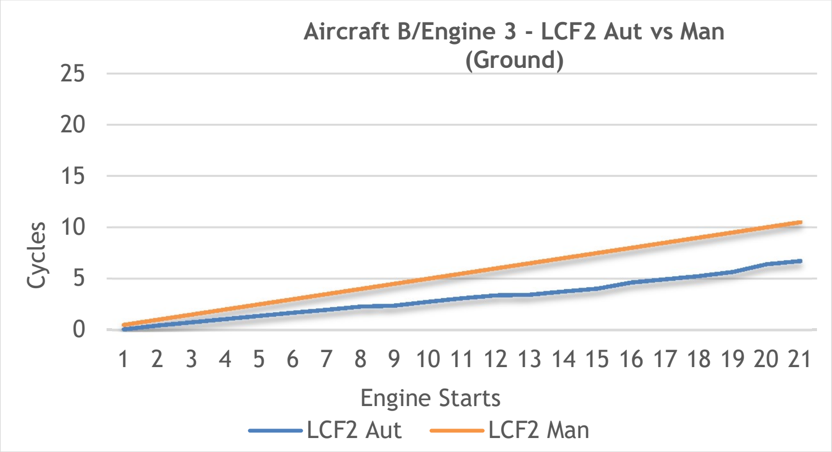

Aircraft B/Engine 3 - LCF1 Aut vs Man
(Flight)
250
200
150
100
50
0
Cycles
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127
Engine Starts
LCF1 Aut
LCF1 Man

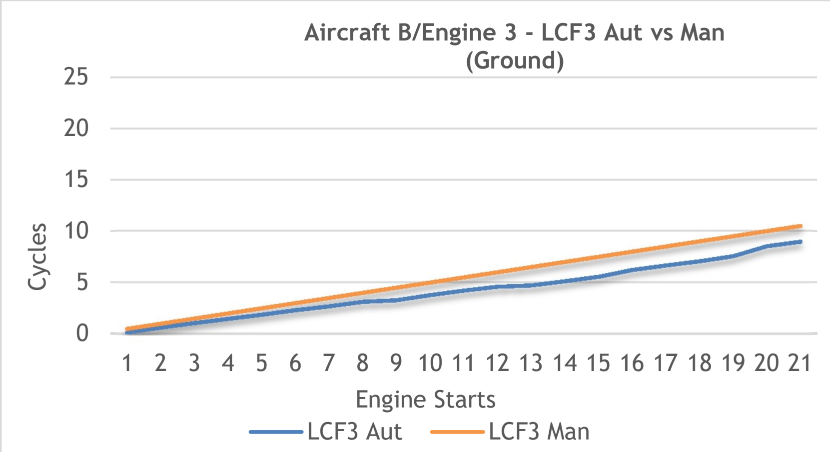

Aircraft B/Engine 3 - LCF2 Aut vs Man
(Flight)
250
200
150
100
50
0
Cycles
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127
Engine Starts
LCF2 Aut
LCF2 Man

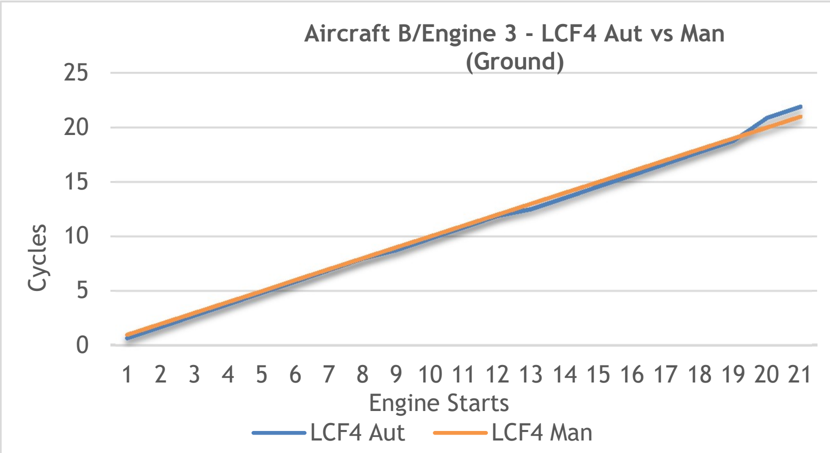

Aircraft B/Engine 3 - LCF3 Aut vs Man
(Flight)
250
200
150
100
50
0
Cycles
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127
Engine Starts
LCF3 Aut
LCF3 Man


Aircraft B/Engine 3 - LCF4 Aut vs Man (Flight)
Cycles
250
200
150
100
50
0
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127
Engine Starts
LCF4 Aut
LCF4 Man


Aircraft B/Engine 3 - LCF1 Aut vs Man (Ground)
Cycles
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Engine Starts
LCF1 Aut
LCF1 Man


Aircraft B/Engine 3 - LCF2 Aut vs Man (Ground)
Cycles
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Engine Starts
LCF2 Aut
LCF2 Man


Aircraft B/Engine 3 - LCF3 Aut vs Man (Ground)
Cycles
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Engine Starts
LCF3 Aut
LCF3 Man


Aircraft B/Engine 3 - LCF4 Aut vs Man (Ground)
Cycles
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Engine Starts
LCF4 Aut
LCF4 Man