Reliability study on avionics: feasibility study to determine mean time between failure (MTBF)

(Versão final após defesa)

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Resumo

No momento presente o mundo enfrenta um aumento na pressão para que os trabalhos se executem de modo mais rápido, melhor e mais barato, exigindo que os engenheiros prevejam com precisão a fiabilidade dos produtos. Nas fases iniciais do processo de *design* do produto, essas previsões precisas contribuirão não só para um produto mais robusto e fiável, mas também reduzirão os custos associados a redesenhar o produto, por exemplo, quando o produto está em fase de manufatura e é encontrado um erro de *design,* ou face a necessidade de melhorar a fiabilidade detetada em sede de utilização.

O número de componentes eletrónicos, equipamentos e sistemas numa aeronave, aumenta com os novos avanços na tecnologia. Por isso é imperativo que os fabricantes destes mesmos equipamentos eletrónicos prevejam com exatidão a probabilidade de falha e o tempo médio entre falhas de cada equipamento/componente.

Para que esta exatidão seja elevada, existem três metodologias: empírica (baseada em *standard*s), mecanismos de falha, e testes acelerados. A metodologia mais comum é a utilização de *standards*. Um dos primeiros *standard* desenvolvidos e mais reconhecido, principalmente na área militar, é o MIL-HDBK-217F, contudo no momento presente de desenvolvimento da tecnologia, encontra-se obsoleto, pois os valores de previsão são aquém da realidade.

Para ultrapassar este problema, um consórcio de empresas da área de aeronáutica e aeroespacial desenvolveu o *standard* FIDES, agrupando as três metodologias para que houvesse uma melhoria significativa na previsão da probabilidade de falha de sistemas. Pelo facto de o *standard* FIDES ser periodicamente atualizado e revisto, faz deste um dos *standard*s mais adaptados e precisos na previsão da probabilidade de falha e tempo médio entre falhas para tecnologias recentes.

Assim sendo, esta dissertação tem por base o *standard* FIDES, conjugando a metodologia descrita para o cálculo da probabilidade de falha de componentes eletrónicos com a informação e dados recolhidos em colaboração com a empresa de manutenção Aeromec, para a realização do estudo do tempo médio entre falhas em quatro circuitos integrados.

O objetivo final deste estudo é estabelecer uma metodologia que permita determinar o tempo médio entre falhas de um componente específico, fornecendo à empresa de manutenção Aeromec um processo relevante, nomeadamente a metodologia implementada, para o cálculo do tempo médio entre falhas dos equipamentos a serem instalados, e, se viável, permitir fazer ajustes aos programas de manutenção das aeronaves sob sua responsabilidade.

A comparação dos resultados obtidos foi realizada através da comparação com um valor estimado para o tempo médio entre falhas dos circuitos integrados estudados por parte da empresa *Flight Data Systems* com o *software* para previsão do tempo médio entre falhas, denominado "*ReliaSoft*".

Com este estudo verificou-se que a previsão do tempo médio entre falhas para os quatro circuitos integrados, realizada recorrendo ao *standard* FIDES, é mais otimista e portanto com um tempo médio entre falhas mais longo do que o *standard* MIL-HDBK-217F, utilizado para a mesma previsão por parte da empresa *Flight Data Systems*.

Podendo isto dever-se a dois fatores: o *standard* MIL-HDBK-217F não ser revisto e atualizado para as novas tecnologias desde 1995, contrariamente ao *standard* FIDES; O perfil de utilização da previsão por parte da empresa *Flight Data Systems* não corresponder exatamente ao perfil de utilização no estudo.

Em trabalhos futuros, o próximo passo será conduzir um estudo do tempo médio entre falhas para um equipamento específico, por exemplo um display primário de voo, recorrendo a metodologia apresentada neste estudo, estimando o tempo médio de falhas de cada componente incorporado no equipamento, para posterior cálculo do tempo médio entre falhas total. Este trabalho poderá ser realizado por parte da Aeromec para avaliar o tempo médio entre falhas para equipamentos a serem instalados em aeronaves a realizar manutenção.

Palavras – Chave

Fiabilidade, Probabilidade de Falha, Tempo Médio Entre Falhas, Previsão de Fiabilidade, Circuitos Integrados, FIDES, MTBF

Resumo alargado

Introdução

Este resumo alargado pretende expor de uma forma concisa o enquadramento desta dissertação e os objetivos a atingir com a realização da mesma. São também referidos os aspetos mais relevantes do caso de estudo, as principais conclusões retiradas durante o seu desenvolvimento e as perspetivas de trabalhos futuros.

Enquadramento da dissertação

Em geral, o mundo de hoje enfrenta um aumento na pressão para executar mais rápido, melhor e mais barato, exigindo que os engenheiros prevejam com precisão a fiabilidade dos produtos. Nas fases iniciais do processo de *design* do produto, essas previsões precisas contribuirão não só para um produto mais robusto e fiável, mas também reduzirão os custos associados a redesenhar o produto, por exemplo, quando o produto está em fase de manufatura e é encontrado um erro de *design*, ou face a necessidade de melhorar a fiabilidade detetada em sede de utilização.

O número de componentes eletrónicos, equipamentos e sistemas numa aeronave, aumenta com os novos avanços na tecnologia. Por isso é imperativo que os fabricantes destes mesmos equipamentos eletrónicos prevejam com exatidão o tempo médio entre falhas de cada equipamento/componente, de modo a evitar remoções prematuras e dessa maneira trabalhos de manutenção adicionais que colocam aeronaves fora de serviço.

Objetivo

O objetivo desta dissertação é, a partir das várias previsões de fiabilidade existentes atualmente, estabelecer uma metodologia que permita determinar o tempo médio entre falhas de um componente específico, impactando a capacidade da empresa de manutenção Aeromec em realizar o cálculo do tempo médio entre falhas dos equipamentos a serem instalados, e, se viável, fazer ajustes aos programas de manutenção das aeronaves sob sua responsabilidade.

Desenvolvimento

Em qualquer aeronave existem diversos equipamentos eletrónicos com diferentes tempos médios entre falhas. É necessário fazer cálculos para prever esse tempo médio, para que a manutenção possa ser feita antes que o equipamento falhe. Esses equipamentos são compostos por componentes, cada um com o próprio tempo médio entre falhas.

Para calcular o tempo médio entre falhas de um equipamento é necessário calcular o tempo médio entre falhas de cada componente. Esta é a melhor maneira de avaliar a fiabilidade de um equipamento eletrónico. Embora o caso de estudo ótimo seja uma previsão do tempo médio entre falhas para um equipamento nas condições reais de operação, contudo, as informações disponíveis para fazer essa avaliação são escassas pois os dados necessários não são disponibilizados por parte dos fabricantes. Assim foram utilizados quatro circuitos integrados para a realização do estudo do tempo médio entre falhas.

O principal *standard* utilizado na indústria eletrónica para previsão do tempo médio entre falhas (*Mean Time Between Failure - MTBF*) é o manual (*Handbook*) militar do departamento de Defesa Americano MIL-HDBK-217F. Contudo, no momento presente de desenvolvimento da tecnologia, encontra-se obsoleto, pois os valores de previsão são aquém da realidade. Em alternativa identificou-se como metodologia de determinação da fiabilidade o *standard* FIDES, que por ser periodicamente atualizado, faz deste um dos *standard*s mais adaptados e precisos na previsão da probabilidade de falha e consequentemente do tempo médio entre falhas para tecnologias recentes.

Assim sendo, esta dissertação tem por base o *standard* FIDES, conjugando a metodologia descrita para o cálculo da probabilidade de falha de componentes eletrónicos com a informação e dados recolhidos em colaboração com a empresa de manutenção Aeromec, para a realização do estudo do tempo médio entre falhas em quatro circuitos integrados.

Principais conclusões

O cálculo do tempo médio entre falhas de um equipamento é essencial para determinar a sua fiabilidade. Quanto maior for este intervalo de tempo mais fiável será o equipamento. Por isso, é imperativo que as previsões seja as mais precisas possíveis.

O conceito de previsão de fiabilidade tem sido empregue para denotar o processo de utilização de modelos matemáticos para estimar a fiabilidade de um sistema/equipamento. Para isto, foram desenvolvidas diferentes abordagens, cada uma com vantagens e desvantagens. Assim, distinguem-se três categorias: empírico (baseada em *standards*), mecanismos de falha e testes acelerados.

Com este estudo, verificou-se que a previsão do tempo médio entre falhas para os quatro circuitos integrados, realizada utilizando o *standard* FIDES, é mais otimista e, portanto, com um tempo médio entre falhas maior/mais longo do que a previsão realizada pela *Flight Data Systems* com o *standard* MIL-HDBK-217F.

Isto pode dever-se a dois fatores: o *standard* MIL-HDBK-217F não ser revisto e atualizado para as novas tecnologias desde 1995, ao contrário do *standard* FIDES; e o perfil de uso na previsão da *Flight Data Systems* não corresponder exatamente ao do *standard* FIDES.

O *standard* FIDES permite que os fatores de multiplicação (fator $\prod_{PM}$. e fator $\prod_{Process}$.) sejam ajustados, aumentando ou diminuindo o seu valor, de acordo com os resultados de uma auditoria ao fabricante do componente/equipamento.

Estes fatores são um dos grandes avanços alcançados pelo *standard,* pois permite que o controlo da qualidade do processo de desenvolvimento, fabricação e manuseamento (*Quality Assurance Level*) seja tomado em conta no cálculo, resultando na fiabilidade intrínseca. Assim sendo, para o mesmo equipamento a operar nas mesmas condições, é possível obter um tempo médio entre falhas diferente.

O perfil de utilização a que o equipamento está sujeito influenciará o seu tempo médio entre falhas, pois as condições operacionais afetam os tipos e níveis de tensão a que o componente está submetido.

Este estudo mostra a importância de realizar uma avaliação da fiabilidade de um sistema/equipamento. Quanto mais próximas as previsões estiverem da realidade, melhor será o planeamento das ações de manutenção necessárias para manter o nível de fiabilidade de uma aeronave, reduzindo o tempo que a mesma precisará de estar em terra para cumprir essas ações.

A comparação dos resultados obtidos foi realizada através da comparação com um valor estimado para o tempo médio entre falhas dos circuitos integrados estudados por parte da empresa *Flight Data Systems* com o *software* para previsão do tempo médio entre falhas, denominado "*ReliaSoft*".

Perspetivas futuras

Em trabalhos futuros, o próximo passo será conduzir um estudo do tempo médio entre falhas para um equipamento específico, por exemplo um display primário de voo, recorrendo a metodologia apresentada neste estudo, estimando o tempo médio de falhas de cada componente incorporado no equipamento, para posterior cálculo do tempo médio entre falhas total.

Este trabalho poderá ser realizado por parte da Aeromec para avaliar o tempo médio entre falhas para equipamentos a serem instalados em aeronaves a realizar manutenção. Para que haja uma maior precisão na previsão do tempo médio entre falhas, a empresa Aeromec deverá conduzir uma auditoria ao fabricante dos equipamentos fornecidos para instalação nas aeronaves, de forma a verificar o nível de garantia de qualidade (*Quality Assurance Level*), assegurando que os fatores de multiplicação presentes nos cálculos sejam o mais correto possíveis.

Abstract

In general, the world faces an increase in the pressure to perform faster, better and cheaper, requiring engineers to predict accurately the reliability of products. In the early stages of the design process, these accurate predictions will contribute not only to a more robust and reliable product, but also will drive down the costs associated with redesigning the equipment/component, for example, when a product is already in production and a design error is found or as the result to improve the reliability obtained from operation.

The number of electronic components, equipment and systems in an airplane increases with the new developments in technology. That is why it is imperative that manufacturer predict the failure rate and the mean time between failure of each equipment/component with the greatest accuracy.

For this accuracy to be fulfilled, there are three methodologies: empirical (based on standards), failure mechanisms, and accelerated/life tests. The most common methodology is the use of standards. The main handbook/standard used in the electronics industry for the prediction of the mean time between failure is the MIL-HDBK-217F. However, at the present moment of technology development, this handbook is obsolete, as the predicted values are far from the reality.

To overcome this problem, several companies from aeronautic and aerospace sector developed a standard called FIDES, which incorporate the three methodologies so that there was a significant improvement in predicting the probability of systems failure. By the fact that this standard is updated periodically and revised, it makes it one of the most suitable and accurate methods of predicting the probability of failure and mean time between failure for recent technologies.

Therefore, this dissertation is based on this standard, using the methodology described alongside with the information and data retrieved in collaboration with Aeromec, for calculating the mean time between failure of electronic components, four integrated circuits.

The final aim of this study is to establish a methodology to predict the mean time between failure of a specific component, giving to Aeromec a relevant process, namely the methodology implemented, to do the calculations for the equipment to be fitted on to an aircraft, and if feasible, then make adjustments to the aircraft maintenance programs under their responsibility.

The comparison of the results obtained was carried out by comparing it with an estimated value for the mean time between failure of the four integrated circuits done by *Flight Data Systems* with the "*ReliaSoft*" reliability prediction software.

With this study it was found that the prediction of the mean time between failure for the four integrated circuits, carried out using the FIDES standard, is more optimistic and therefore with a longer/higher mean time between failure then the prediction made by *Flight Data Systems* with the MIL-HDBK-217F standard.

This may be due to two factors: the MIL-HDBK-217F standard has not been reviewed and updated for new technologies since 1995, contrary to the FIDES standard; and the usage profile in *Flight Data Systems* prediction does not exactly match as the one in FIDES.

For future works, the next step is to conduct a full study to assess the mean time between failure for a specific equipment, for example a primary flight display that has several different components, meaning estimate the mean time between failure for every component incorporated, and then the overall mean time between failure. This work could be done by Aeromec to assess the mean time between failure for the equipment that will be installed in to aircraft in maintenance.

Keywords

Reliability, Failure Rate, Mean Time Between Failure, Reliability Prediction, Integrated Circuits, FIDES, MTBF

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Acronyms List

CAMO	Continuing Airworthiness Management Organisation
COTS	Commercial Off-The-Shelf
DfR	Design for Reliability
EASA	European Aviation Safety Agency
EPRD	Electronic Parts Reliability Data
EWIS	Electrical Wire Interconnection System
FAA	Federal Aviation Administration
λ	Failure Rate
FIT	Failure In Time
IC	Integrated Circuit
MRO	Maintenance, Repair and Overhaul
MTBF	Mean Time Between Failure
NPRD	Non-electronic Parts Reliability Data
PMAR	Portuguese Military Airworthiness Requirements
PoF	Physics of Failure
RAC	Radio Corporation of America
RIAC	Reliability Information Analysis Center
SFAR	Special Federal Aviation Rulemaking
UTE	Union Technique de l'Electricité

Chapter 1 – Introduction

1.1 Motivation

In general, the world faces an increase in the pressure to perform faster, better, and cheaper, requiring engineers to predict accurately the reliability of products. In the early stages of the design process, these accurate predictions will contribute not only to a more robust and reliable product, but also will drive down the costs with redesigning the equipment/component, for example, when a product is already in production and a design error is found or as the result to improve the reliability obtained from operation.

The number of electronic components, equipment and systems in an airplane increases with the new developments in technology. So, it is imperative that the manufacturers accurately predict the mean time between failure (MTBF).

There are several methods to do these predictions, empirical methods (based on standards), physics of failure methods (the mechanisms that lead to the failure of the asset) and life testing methods.

All are essential to do the most accurate predictions of an asset useful life period, but the most credible approach to the prediction of an asset reliability is utilizing an internationally accepted reliability databases and reliability prediction methods (standards) [1]. These methods predict the MTBF or the reciprocal function, the failure rate (λ).

The failure rate of an asset (component or system) is defined by the number of failure which occur per unit of time, at a given age. Experience shows that the MTBF will increase (failure rate will decrease) at the beginning of the lifetime, stabilizes during a long period and decrease until the end (failure rate will increase). The period in which the MTBF is constant corresponds to the useful life period [2].

Reliability electronic guides are used to calculate the reliability of electronic systems. These predictive reliability calculations propose, for each component, values for their rate of failure, which are adjusted by factors depending on their application and environment, quality in construction, as well as multiple types of stresses they are subject to [2]. The predictive reliability calculation guide widely used in the electronics industry is MIL-HDBK-217F which has not been updated for 25 years [2].

However, since the 2000s, the design and technology of electronic component has improved and the reliability of the components has increased [2]. The failure rate calculations provided by these guides no longer correspond to field return data [2]. That is why in January 2004 the French Ministry of Defense encouraged the consortium of French companies to propose the FIDES predictive reliability guide. This manual is updated periodically [2].

In every electronic component information book, the failure rate and the MTBF tends to be presented, so the customer can assess and chose the component that fits better in their system/product.

1.2 Objective

The objective of this dissertation is, starting from the various reliability predictions currently existing, to establish a methodology to predict the MTBF of a specific component.

This will enable Aeromec to have a relevant process, namely the calculations for the equipment to be fitted on to an aircraft, and if feasible, then make adjustments to the aircraft maintenance programmes under their responsibility.

1.3 Scope of the dissertation

With the objective in mind, this research intends to derive the state of the art of the methods uses in the aeronautic industry on how to accurately predict the reliability of any item that is put on an airplane.

It is also considered the case of study would be a MTBF calculation for a specific equipment, such as a Flight Management System or a Flight Data Recorder or other electronic equipment fitted on an aircraft.

1.4 Methodology

To conduct the study and calculations for the λ, and later the MTBF it will be used the most recent version, available on the FIDES website at the time, the “FIDES guide 2009 Edition A September 2010 Reliability Methodology for Electronic Systems” with the aid of the FIDES experimentation tool - “FIDES ExperTool” - to present the final results.

The λ for integrated circuits has been decreasing over the decades and consequently the MTBF increasing. The prediction of MTBF done by this study should be similar or better to the predictions made by a company, in the real world, with a reliability software to predict the MTBF. So this will be the criteria for comparing the results.

1.5 Work limits

The biggest limitation of this work is related to the quantity of the information available, presented next.

Since the method used to conduct the study needed some parameters that are not available, such as the quality and technical control over manufacturing of the asset and the quality and technical control over the development, manufacturing and usage process for the product containing the asset, it will be used a default value defined from literature.

Also the life usage profile is not accurate as it would be in a real life application because of the lack of information, so a default profile will be used defined from literature.

Moreover, due to information shortage, this dissertation will focus on the MTBF calculation of four different Integrated Circuits (IC), which are components in many electronic equipment on an aircraft, and not for one whole equipment.

1.6 Structure

This dissertation is divided in five chapters:

- In the current chapter, first chapter, the author expresses his motivation to perform this dissertation. It also includes the objective, methodology and work limits. In this chapter, the scope of work is presented. Last, it contains the structure of the thesis.
- The second has a brief presentation of OMNI Aviation Group and Aeromec in terms of history, Aeromec operations in the market, and how the reliability is handled.
- The third chapter focus on the history of reliability in aviation industry, highlighting the most common methods to perform the reliability prediction of an asset.
- The fourth introduces the case of study with the data information, the methodology of work used to conduct the reliability prediction and the results (MTBF).
- In the fifth chapter, the last one, it is presented the main conclusions of this dissertation and indications of future work.

Chapter 2 – Aeromec

2.1 History

2.1.1 OMNI Aviation Group

In 1988 OMNI Aviation Group (logo in Figure 1) was founded as a private Portuguese aviation group. It started as a single-contract, single-client seasonal provider of aviation business. Over the years, the group as expanded into a major aviation company, playing a huge role in the national aviation sector.

Now, eight companies form the group. Having 65 aircraft (fixed and rotary wing) it provides scheduled and non-scheduled airline operations, leasing, medical operations (evacuation and rescue). It also has a training center for pilots and maintenance technicians, consulting, executive handling, aircraft management, and has its own maintenance subsidiary unit, Aeromec.

Figure 1 – OMNI Aviation Group logo

2.1.2 Aeromec

Founded in 1991 as the maintenance company branch of OMNI Aviation Group, Aeromec (logo in Figure 2) has evolved over the years responding to the strict demand requirements of the aviation industry, building a solid reputation and offering today customized maintenance, repair and overhaul (MRO) solutions for the Commercial, Business, Helicopter and Defence Aviation Markets, with enhanced focus on Customer Support, Compliance, Safety, Innovation and continuous improvement [3].

Figure 2 – Aeromec logo

2.2 Operation

Despite being headquartered in Oeiras, it operates its MRO services from a hangar at Cascais Airfield in Tires, shown in Figure 3.

Figure 3 – Aeromec hangar (Portuguese Air Force (PTAF) Falcon 50) [4]

Aeromec operates several MRO services in many types of airplanes, which includes [5]:

- Commercial Aviation (Line Maintenance):
  - Airbus A320 Family;
  - Boeing 737 NG.
- Business and Regional Aviation (Line and Base Maintenance):
  - Beech 200 / 1900;
  - ATR 42 / 72;
  - Learjet 40 / 45;
  - Falcon 50 / 900.
- Helicopters (All levels of inspections and repair and overhaul):
  - Bell 206 / 212 /222 / 412;
  - S-76A / AS350.
- Defence Aviation:
  - C-130 / P-3 / F-16;
  - C-212 / CN-235 / C-295 / TB 30
- Interior Solutions:
  - Special Mission Aircraft;
  - VIP Interiors;
  - Flight Environment.

- Avionics Equipment Systems:
    - Fire Attack Systems;
    - Spray Systems;
    - Sky Cannon;
    - Aerial Cleaning and De-icing Systems.
- Avionics Upgrades;
- Propellers Repair and Overhaul.

Figure 4 shows Aeromec technicians performing maintenance on an ATR 72.

Figure 4 – Maintenance on an ATR 72-500 from AirEuropa Express

It is also responsible for the engineering and maintenance support of the OMNI Aviation Group fleet.

Aeromec exhibits various certifications and approvals, such as: Approved Maintenance Organisation EASA Part 145, Aircraft Maintenance Organisation (AQAP 2120) Portuguese Ministry of Defence, Quality Management System (NP ISO 9001:2015), Environment Management System (14001:2015), PMAR 145 Approved Maintenance Organisation [6].

2.3 Reliability in the company

Aeromec MRO EASA Part 145 itself does not have a reliability department. In this subject the company is supported by the OMNI Group branch company White Airways that has a CAMO department (Continuing Airworthiness Management Organisation).

To deal with reliability, Aeromec has several personal courses, which includes:

- EWIS (Electrical Wire Interconnection System) training [7]:
  This training was issued as an EASA requirement in the summer of 2008. The origins of the requirement for EWIS Training go back to a number of incidents which have had a catastrophic effect on the industry with instances of in-flight smoke and fire events in which contaminants were ignited by electrical faults which allowed a fire to be sustained and spread. Research has demonstrated that wiring can be harmed by accidental damage when maintenance is being performed on other aircraft systems.

- Human factors training:
  The study of Human Factors is about understanding human behaviour and performance. When applied to aviation operations, Human Factors knowledge is used to optimize the fit between people and the systems in which they work in order to improve safety and performance [8]. This training help to reduce the risk of any one of the "Dirty Dozen" to take place.

- Fuel tank safety training [9]:
  After the TWA flight 800 incident accident investigation the FAA issued Special Federal Aviation Rulemaking (SFAR) 88, set up committees to investigate and issued a number of advisory circulars. Both the FAA and EASA have mandated mandatory Fuel Tanks Safety Training. This training is a requirement of EASA Part 66[1], EASA Part-M[2] and EASA Part-145[3] regulations, which requires that personnel involved in Continued Airworthiness Management and Maintenance of Aircraft Fuel Systems, are given suitable training. Fuel Tank Safety Training includes an understanding of the following:
  In-service maintenance of Fuel Tank Ignition Source, Suppression and Flammability Reduction features, Nitrogen Inerting Systems and safety precautions.

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[1] Part 66 is the aviation regulation which defines the conditions by which a maintenance engineer is able to gain (through a company approval) authorisation to work on, certify and release an aircraft into service after a maintenance operation [12].

[2] Part M concerns specifically the continuing airworthiness of aircraft and aeronautical products, parts and appliances together with the approval of organizations and personnel involved in these tasks [13].

[3] EASA Part 145 is the European standard for the approval of organisations that perform maintenance on aircraft and aircraft components that are registered in EASA Member States [14].

The data which is gathered through the reliability programme is a measure of the effectiveness of the maintenance which is applied to an aircraft [10]. A low incidence of technical findings is one way by which determination can be made that the maintenance is effective [10].

The type of data to be collected should be related to the objectives of the reliability programme and should be such that it enables an overall broad based assessment of the information to be made and also assessments as to whether any action, both to trends and to individual events, is necessary [11].

The following are examples of the normal prime sources [11]:

- Pilots Reports;
- Technical Logs;
- Aircraft Maintenance Access Terminal / On-board;
- Maintenance System readouts;
- Maintenance Worksheets;
- Workshop Reports;
- Reports on Functional Checks;
- Reports on Special Inspections;
- Stores Issues/Reports;
- Air Safety Reports;
- Reports on Technical Delays and Incidents.

The reliability function entails the collation and analysis of technical data derived from the in service activities of the aircraft and its systems and associated components, with the primary purpose being to monitor the failure level and to identify poor performance typically as a result of breaching alert levels [10].

Such a process may involve [11]:

- Comparisons of operational reliability with established or allocated standards;
- Analysis and interpretation of trends;
- The evaluation of repetitive defects;
- Confidence testing of expected and achieved results;
- Studies of life-bands and survival characteristics;
- Reliability predictions.

The information processed is used to identify failure trends on fleets, and in so doing to develop corrective actions to ensure they can continue to operate in a safe, punctual, reliable and efficient manner [10].

The corrective actions shall correct any reduction in reliability revealed by the programme and could take the form of [11]:

- Changes to maintenance, operational procedures or techniques;
- Maintenance changes involving inspection frequency and content, function checks, overhaul requirements and time limits, which will require amendment of the scheduled maintenance periods or tasks in the approved maintenance programme. This may include escalation or de-escalation of tasks, addition, modification or deletion of tasks;
- Amendments to approved manuals (e.g. maintenance manual, crew manual);
- Initiation of modifications;
- Special inspections of fleet campaigns;
- Spares provisioning;
- Staff training;
- Manpower and equipment planning.

This is achieved through the continued airworthiness management processes in place within the Reliability and Engineering departments, and observing compliance with the company CAMO department and applicable regulations [10].

Chapter 3 – Reliability and estimation methods

3.1 Reliability

Reliability is the characteristic of an asset (component, system or aircraft) expressed by the probability that it will perform a required function in a stated environment for a stated period of time [15].

It can also be defined as the function of probability of performing without failure [15].

With this respect an asset from a reliability perspective has two conditions [15]:

- Reliable: If it follows an expected law or behaviour. It performs the function for what was designed;
- Unreliable: If it does not follow an expected law or behaviour; It does not perform the function for what was designed.

There are four elements that integrate the reliability:

- Function – The purpose of the asset;
- Conditions – The environment in which the asset will operate;
- Failure – Defines what will be the malfunction of the asset;
- Time – The life span of the asset in which it must perform the purpose for which it was built for.

With regard to failure frequency, some may occur regularly, at average intervals measured in months, weeks or even days (or in the case of aircraft measured in flight hours, cycles, calendar or a combination). Others may be extremely improbable, with mean time between occurrences can be measured eventually in millions of years [16].

After 1930, there was an increase in airplane fatal accidents. With this, governmental and international agencies have been promoting over the decades several directives, safety protocols, procedures, reliability estimations and maintenance strategies that have considerably reduced faults, failures and aircraft crashes, to the point that in 2015, only four fatalities occurred during 37 million flights [17].

This led to establish the concept of Design for Reliability (DfR) in the Aviation industry. This is the process of considering in the design process the reliability into products. This is done through a number of techniques, methods and instruments utilized within the design phase of every product or service to optimize the probability that the asset can satisfy reliability requirements [17].

According to Harry and Schroeder [18]: “If reliability is taken care of at the design phase, the final cost of the product does not go up. If a reliability problem is detected during engineering, the cost of the product goes up by a factor of 10. If the problem is caught in the production phase, the cost of the product increases by a factor of 100 or more”.

Reliability is the focus at the design stage so that engineers can obtain an excellent product and consequently generate a system with high probability of mission without failure, meaning that reliability at the operational stage will be maximized [17].

During the DfR the persons involved are typically [19]:

- Component engineers who manage the component library;
- Systems engineers who set up the system constraints for an assembly and operation;
- Layout engineers who are assigned with computer-aided design (CAD) responsibilities;
- Manufacturing engineers who are responsible for design for manufacturability and assembly;
- Test engineers who establish environmental stress screening and in-circuit test parameters;
- Reliability engineers who focus on statistical techniques and environmental testing.

In today’s competitive market, having systems with reliability higher than competitors is one of the key factors for success. To obtain high product reliability, consideration of reliability issues should be integrated from the very beginning of the design phase. This leads to the concept of reliability prediction.

Historically, this term has been used to denote the process of applying mathematical models and component data for the purpose of estimating the field reliability of a system, before failure data are available for the system.

However, the objective of reliability prediction is not limited to predicting whether or not reliability goals, such as MTBF, can be reached [17].

When the prototype of a product is available, lab technicians perform a series of tests to obtain more accurate reliability predictions. Accurate prediction of the reliability of any asset, requires knowledge of many aspects such as: components, design, manufacturing process and conditions in which it will operate.

In this respect, different approaches have been developed. Each approach has its unique advantages and disadvantages. Among these approaches, three main categories are often used within military and commercial environments [17]:

- Empirical (standards based);
- Physics of failure and;
- Life testing.

To determine reliability, there are various standards, such as MIL-HDBK-217, Bellcore/Telcordia, RDF 2000 and China 299B, which are widely used for reliability prediction of electronic products.

The physics of failure methods are based on root-cause analysis of failure mechanisms, failure modes and stresses.

This approach is based upon an understanding of the physical properties of the materials, operation processes and technologies used in the production. The life testing methods are used to determine reliability by testing a relatively large number of samples at their specified operation stresses or higher stresses and using statistical models to analyse data [17].

Additionally, component databases such as NPRD (Non-electronic Parts Reliability Data) and EPRD (Electronic Parts Reliability Data) are often used in conjunction with the Reliability Prediction standards to augment prediction analyses. The NPRD and EPRD databases include failure data on a wide range of electrical components and electromechanical parts and assemblies [21].

Next sections address each of the reliability approaches.

3.2 Empirical (Standards Based) prediction methods

Empirical prediction methods are based on models developed from statistical curve fitting of historical failure data. These methods tend to present good estimates of reliability for similar or slightly modified parts to those that gave data for the statistical curve in the models.

The variables used in the reliability calculation formulas to calculate component failure rates vary, to include data such as device ratings, temperatures, operating parameters, and environmental conditions [21]. Some parameters can be modified to incorporate engineering knowledge about the part/component in question. The assumption is made that system or equipment failure causes are inherently linked to components whose failures are independent of each other [17].

There are many different empirical methods that have been created for specific applications. Table 1 lists some of the most important standard predictions methods available. In the following sections it will be described the most commonly used.

Table 1 – Prediction standards for empirical methods with last update

Prediction Method	**Market**	**Last Update**
MIL-HDBK-217F	Military	1995
Bellcore/Telcordia	Telecom	2016
Siemens SN29500	Siemens Products	2013
China 299B	Chinese Military	2006
PRISM (217 Plus)	Military/Commercial	2016

3.2.1 MIL-HDBK-217 reliability prediction standard

The first handbook on reliability prediction, the "Reliability Stress Analysis for Electronic Equipment" or TR-1100, was released by Radio Corporation of America (RCA)[4]. The handbook presented some important mathematical models for estimating the electronic component failure rates and was the predecessor of what would become the standard and a mandatory requirement for reliability prediction in the decades to come, MIL-HDBK-217 [22].

The MIL-HDBK-217's official name is *Military Handbook: Reliability Prediction of Electronic Equipment*. It was originally developed and published for use by the Department of Defense of the United States of America, in 1961. Probably, it's the most internationally recognized prediction method. The latest version is MIL-HDBK-217F, which was released in 1991 and had two revisions: Notice 1 in 1992 and Notice 2 in 1995.

This handbook consists primarily of two sections: Parts Count and Part Stress.

The Part Count Section is useful in early design stages when not all operating parameters are known, as this does not require as many parameters input for analysis compared to the Part Stress predictions. So, for the parameters that are unknown, it is assumed typical operating conditions, called reference conditions, like device complexity, ambient temperature, electrical stresses, operation mode and environment.

These analyses can be used as an estimation technique, obtaining early failure rate assessments, but since the parts may not operate under de reference conditions, the real

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[4] RCA was a major American electronics and communications company founded in 1919 by General Electric Company.

operating conditions may result in a different MTBF (or the reciprocal function, failure rates). So these are not as accurate as Part Stress analyses.

Therefore, the Part Stress methods are used after the product design is finalized, because it requires the specific part's complexity, electric stress levels, environment factors, etc.

The equations, the variables, and the data parameters needed vary according to the components. The Part Stress section of MIL-HDBK-217 includes complete details on all the equations and how to assess the variables used in the equations [21].

After its introduction, all reliability predictions were based on this handbook, and all other sources of failure rate, such as those from independent experiments, gradually disappeared. The failure to use these other sources was due to a very important fact: MIL-HDNK-217 was almost always cited as a contractual document, leaving manufacturers of components with the impossibility to use other models or handbooks [22]. Nowadays, many other reliability standards available have their roots in this handbook.

3.2.2 PRISM (217Plus Standard)

The 217Plus™ reliability prediction standard was developed by Quanterion Solutions[5] [21]. Work on 217Plus was started under Department of Defense contracts with the Reliability Analysis Center (RAC) and Reliability Information Analysis Center (RIAC), and was released originally under the name PRISM [21] in 2006. The official 217Plus standard name is *Handbook of 217Plus Reliability Prediction Models* [21].

The failure rate models of 217Plus have their roots in MIL-HDBK-217, but have enhancements to include the effects of operating profiles, cycling factors, and process grades on reliability [21]. After using the equations in the handbook to calculate the failure rate of the system, further analysis can be done at the system level if more data are available, such as test or field data [21]. At the system level, 217Plus can incorporate environmental stresses, operating profile factors, and process grades. If these data are not known, default values are used [21].

As with MIL-HDBK-217, there is a Part Count reliability prediction intended for use in early design stage when all data parameters are not yet finalized, and provides a simpler approach to prediction calculations [21]. The Part Count section of 217Plus includes a number of tables for device failure rates that are based on the combination of the environment and

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[5] Quanterion Solutions Incorporated is small business (based in America) that specializes in high-quality analytical services, products and training in the fields of Alternative Energy, CRBNE and WMD Defence, Cybersecurity, Homeland Defence and Critical Infrastructure Protection, Knowledge Management, Materials Science, Reliability, Maintainability & Quality (RMQ), and Software Design and Development.

operating profile of the system. In this case, a table lookup will provide the failure rates for devices without the need for calculations [21].

3.2.3 Bellcore/Telcordia predictive method

Telcordia Sr-332 is another widely accepted and used reliability prediction standard. Early on, Telcordia was referred to as the Bellcore standard. The full name of the Telcordia standard is *"Reliability Prediction Procedure for Electronic Equipment, Special Report SR-332"*.

Like other prediction methods, Telcordia standard has also been through several updates and revisions, which are designated by the Issue Number [21]. They are:

- Bellcore TR-332 Issue 6 (1997);
- Telcordia SR-332 Issue 1 (2001);
- Telcordia SR-332 Issue 2 (2006);
- Telcordia SR-332 Issue 3 (2011);
- Telcordia SR-332 Issue 4 (2016);

Inside the Telcordia standard there are three methods to predict failure rates [25]:

- **I:** also known as the Black Box method uses the generic failure rates defined by the Bellcore/Telcordia standard.
- **II**: allows to supplement Method I with real data that were obtained from testing.
- **III:** allows to supplement Method I with real data that were obtained from an identical or similar asset operating in the field.

3.2.4 NPRD and EPRD Databases

The NPRD[6] and EPRD[7] include failure data on a wide range of electrical components and electromechanical parts and assemblies [21]. Failure data spans a variety of environments and quality levels, allowing to select components that most accurately reflect the usage [21].

When utilizing NPRD or EPRD databases, there is no equation to be evaluated, and, therefore, no data parameters to enter [21]. Is possible to scan the database of components and select one that matches, or most closely matches, the device that is being modelled [21]. The component or assembly failure rate obtained on field-based failures can then be used in the reliability prediction [21]. The latest versions of these databases,

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[6] NPRD provides historical reliability data on a wide variety of electrical assemblies and electromechanical/mechanical parts and assemblies to aid engineers in estimating the reliability of systems.
[7] EPRD databases contains reliability data on both commercial and military electronic components for use in reliability analyses.

NPRD-2016 and EPRD-2014, can be used alongside the prediction standards and work well together [21].

3.2.5 Discussion of empirical methods

Although empirical prediction standards have been used for many years, it is always wise to use them with caution. The advantages and disadvantages of empirical methods have been discussed a lot in the past three decades. A brief summary is now presented [20]:

Advantages of empirical methods:

- Easy to use and with many of component models;
- Relatively good performance as indicators of inherent reliability;
- Provide an approximation of field failure rates.

Disadvantages of empirical methods:

- A large part of the data used by the traditional models outdated;
- Failure of the components is not always due to component-intrinsic mechanisms but can be caused by the system design;
- The reliability prediction models are based on industry-average values of failure rate, which are neither vendor-specific nor device-specific;
- It is hard to collect trustful field and manufacturing data, which are needed to define the adjustment factors, such as the Pi factors in MIL-HDBK-217.

3.3 Physics of failure methods

Unlike empirical reliability prediction methods, a physics of failure (PoF) approach is based on the understanding of the failure mechanism (root cause of failure processes) and applying the PoF model to the data.

It is based on understanding the [23]:

- relationships between requirements and the physical characteristics of the product (and their variation in the production process);
- interactions of product materials with loads (stresses at conditions of operation) and their influence on product reliability with respect to the use conditions.

Products may change with time by physical mechanisms as a reaction of materials to loads and as material interactions influenced by loads occurring in use. Materials, their interactions, and the stresses acting on them principally determine potentially active mechanisms.

The most known and common used models to predict the reliability are the Arrhenius's equation and the Eyring model, explained next. Also, several models are similar to the standard Eyring model, using the same principles to predict the reliability, this includes [20]:

- Two Temperature/Voltage Model;
- Three Stress Model (Temperature-Voltage-Humidity);
- Corrosion Model;
- Hot Carrier Injection Model;
- Black Model for Electromigration;
- Coffin-Manson Model for Fatigue.

3.3.1 Arrhenius's equation

This law is one of the earliest and most successful acceleration models that predicts how the time-to-failure of a system varies with temperature [20]. This empirically based model is known as the Arrhenius equation [20]. Generally speaking, chemical reactions can be accelerated by increasing the system temperature [20]. Since it is a chemical process, the aging of a capacitor (such as an electrolytic capacitor) is accelerated by increasing the operating temperature [20].

3.3.2 Eyring model

While the Arrhenius model emphasizes the dependency of reactions on temperature, the Eyring model is commonly used for demonstrating the dependency of reactions on stress factors other than temperature, such as those driven from mechanical stress, from humidity or from voltage [20]. According to different PoF mechanisms, one more term (i.e. stress) can be either removed or added to the standard Eyring model [20].

3.3.3 Discussion of physics of failure methods

The PoF approach aims to identify the root cause of the potential failures and set up links between failure mechanisms and the lifetime under specified operation conditions, through the use of stress and damage models [24].

The PoF considers the potential failure mechanisms individually [23]. A given component will have multiple failure mechanisms (i.e. humidity, voltage, temperature, thermal cycling). Their investigation provides the different stress–time relationships [23]. Application of these models enables to design and qualify a product for the intended application. In detail this has to be done on the level of individual product elements, as their design determines materials, imposed stresses and related mechanisms [23].

The system's failure rate is equal to the sum of the failure rates of the components involved. In using the models listed in section 3.3, the model parameters can be determined from the design specifications or operating conditions [20].

In the PoF methodology, the development of an effective physics-based model makes as critical a contribution to an accurate reliability prediction as the identification on the failure mechanisms [24].

The advantages and disadvantages of PoF method have been discussed over the years. A brief summary is presented as follow.

Advantages of physics of failure methods:

- Accurate prediction of wear out using known failure mechanism;
- Modelling of potentials failure mechanisms based on the PoF;
- During the design process, the variability of each design parameter can be determined.

Disadvantages of physics of failure methods:

- Needs detailed component manufacturing information (such as material, process and design data);
- All the failure mechanisms have to be taken into account to make an accurate prediction, and if one is not yet modelled, then this will lead to erroneous MTBF predictions;
- Numerous operational conditions, each with a combination of temperature/vibration/ humidity/power cycling and others stress factors.
- Algorithms typically assume a "perfect design".
- Analysis is complex and is costly to apply;

3.3 Life testing method

3.3.1 Normal usage conditions

With this method a test is conducted on a sufficiently large sample of units operating under normal usage conditions [20]. Times-to-failure are recorded and then analysed with an appropriate statistical distribution in order to estimate reliability metrics such as the B10 life (when 10% of components will fail) [20].

3.3.2 Lab-test conditions

Some manufacturers, like engine manufacturers, test their assets in lab-test conditions. This means that in laboratories they simulate the operational conditions that the asset will withstand.

There are two ways to conduct these lab-tests: the first is to simulate the normal conditions, but because these tests are expensive and need to come to results very fast, they are scaled up to replicate the conditions and wear out over time.

The second is to simulate extreme conditions, which is meant to see how the asset will perform in abnormal conditions, predicting the consequences and the actions that need to be ensured.

3.3.3 Discussion of the life testing method

The life testing method can provide more information about the product than the empirical prediction standards. Therefore, the prediction using this method is usually more accurate, given that enough samples are used in the testing.

When it is necessary to obtain a realistic prediction for the entire system, this method is preferred because the other calculate the failure rate based on predictions of the components alone, assuming there are no interaction failures between the numerous components, that they are independent, which isn´t true because the components are not isolated, they interface between them.

For example if the heat exchanger is not working properly, the engine will fail faster because of the high temperature. Therefore, in order to consider the complexity of the entire system, life tests can be conducted at the system level, treating the system as a "black box," and the system reliability can be predicted based on the obtained failure data [20].

These three methods have been applied to a variety of industries, but, in almost every case, separated from each other. To try to incorporate all three methods, the project FIDES was created. In the next section, this project is presented.

3.4 FIDES

In the year 2000 the French Ministry of Defence, together with eight companies from the fields of aeronautics and defence (Airbus France, Eurocopter, Nexter Electronics, MBDA Missiles Systems, Thales Services, Thales Airborne Systems, Thales Avionics, Thales Underwater Systems), created a study to develop a new reliability assessment method for electronic components taking into consideration COTS (Commercial Off-The-Shelf) and specific parts and the new technologies.

The global aim was to find a replacement to the worldwide reference MIL-HDBK-217F, which was old and had not been revised since 1995. Moreover, the MIL HDBK 217F was considered very pessimistic for COTS components, which are more and more widely used in military and aerospace systems. This leads to the creation of the FIDES Group.

In 2004 was released the first FIDES methodology (FIDES Guide 2004 Edition A) and later in 2010 it was released a new guide (FIDES Guide 2009 September 2010) [26]. Finally, in 2011, the French standardisation organisation UTE (*Union Technique de l'Electricité*) accepted the FIDES Guide 2009 September 2012 and it became the new version of the Standard UTE 80811 January 2011 [26].

The FIDES methodology is based on the physics of failures and supported by the analysis of test data, field returns and existing modelling.

This methodology covers elementary electronic components, electronic modules and subassemblies with well-defined functions [27]. The coverage of component families is not fully exhaustive [27]. However, it is sufficient to allow a representative assessment of the reliability in almost all cases [27]. It also applies to COTS (for which it was originally developed) and also to specific assets whose technical characteristics match those described in the FIDES guide [27].

The FIDES methodology models cover failures whose origins are intrinsic (asset technology or manufacturing and distribution quality) and extrinsic (equipment specification and design, selection of the procurement route, equipment production and integration) to the assets [28].

The methodology takes the following into account [28]:

- Failures resulting from development or manufacture errors;
- Over stresses (electrical, mechanical, thermal) linked to the application and not listed as such by the user (the occurrence of the overstress remains hidden).

It applies to all domains using electronics, including: Aeronautics, Space, Naval, Military, Automotive and others.

3.5 Choosing the reliability prediction method

There are several aspects to consider when selecting a Reliability Prediction method to use for analyses. Often it may not be possible to choose, there may be contractual requirements or may be set by the systems integrator. For example, many military and defence-based contracts will require to use MIL-HDBK-217 [21].

In non-military applications, such as commercial industries including telecom, medical devices, and consumer electronics, Telcordia is often the prediction standard used.

3.5.1 Factors to consider in choosing a reliability prediction method

One significant factor to consider when determining which standard to use is the environments and part types supported [21]. For example, MIL-HDBK-217 and 217Plus both support a broad list of environments, whereas Telcordia supports a smaller set of environments, which does not include military environments such as aircraft and naval [21]. Also, the types of parts supported in each reliability prediction standards varies, so it can be ideal to select the reliability prediction standard which supports the types of parts included in the asset design [21].

To do a more complete coverage of the possibilities, it can be used more than one model and analysis [21]. Unless it is a contractual requirement to use a specific standard, the selection of the reliability prediction standard should be based on the particular needs related to the design in question [21]. Or, one of the reliability standards may be more commonly used in your industry [21]. Or, you may review the standards to determine which one includes the environments and components best matching your design [21].

Choosing the right method is not easy because there are numerous factors to take in account: environment conditions, costs/time consumed in getting the prediction, listed parts, more or less conservative predictions; and to get a real reliability prediction it is difficult for the reason that the working conditions are not always constant, they change through the life span of the asset and in some cases may occur an event that can shorten its life span.

From the methods above, different ones are used in different corporation environments, some are used in telecommunications (Telcordia), others in daily products and in aviation. Particularly in aviation industries, the MIL-HDBK-217F and the FIDES are the most used. Since Airbus and Eurocopter were two of the founder companies of FIDES, it is right to assume that this methodology is the one used in their reliability programme. In cases of aviation for defence purpose, the MIL-HDBK-217F is the most common method used.

To predict the equipment/component MTBF, it is conducted a study to predict the λ and then the MTBF is calculated by just doing the reciprocal function of λ.

Summing up, there are three distinct approaches on how to conduct the reliability prediction of an asset: standards, based on statistics curves, physics of failure, based on the mechanisms that lead to the failure of the asset, and life-tests, based on tests in the real operation conditions.

Each of these have their own advantages and disadvantages. Some are more easy to use or less time/money consuming or less conservative than others. No one is absolute flawless, because many factors will influence the life span of an asset.

So it is imperative that companies output of their reliability prediction is as accurate as possible, and find ways to do this prediction.

Chapter 4 – MTBF calculation

4.1 Case of study

In any aircraft there are several types of electronic equipment with different MTBF. It is necessary to make calculations to predict this MTBF, so maintenance can be done before it fails. These equipment are made up of components, each with its own MTBF.

To calculate the MTBF of one equipment, it is required to calculate the MTBF of every component in it. This is the best way to assess the reliability of a piece of electronic equipment. Although the best case of study is a prediction of MTBF for one equipment in the real operational conditions, the information available to do this assessment is short.

Pursuant to the above considerations, it was decided to study only four components parts of an electronic equipment. It will be assessed the reliability of four different Integrated Circuits (IC), predicting their MTBF.

4.2 FIDES: MTBF calculation methodology

All information about the FIDES methodology for the MTBF prediction was retrieved from the FIDES guide 2009 Edition A September 2010 Reliability Methodology for Electronic Systems [29].

The FIDES reliability approach is based on the consideration of three concepts. These concepts are considered for the entire life cycle from the product specification phase until the operation and maintenance phase.

The three concepts are:

- Technology: covers the technology for the item itself and also for its integration into the product.
- Process: considers all practices and the state of art from the product specification until its replacement.
- Use: takes in account of usage constraints defined by the product design and by operation at the final user.

Applying the FIDES method consists of the following operations [2]:

- Establishing the life usage profile;

- Entering the data for each component of the bill of materials (type, load rate, dissipated power, etc.);
- Setting the $\prod_{PM^{\cdot}}$ factor (manufacturer quality);
- Setting the $\prod_{Process^{\cdot}}$ factor (quality of the assembly process);
- Setting the $\prod_{induced^{\cdot}}$ factor which depends on the $\prod_{Placement^{\cdot}}$, $\prod_{application^{\cdot}}$, $\prod_{ruggedising^{\cdot}}$ factors and the sensitivity coefficient.

Once the failure rate of each component is calculated, the global failure rate of the electronic system is obtained by adding the failure rates of each component and the circuits or subsets [2].

Then an extra calculation is needed to determine the MTBF, by doing the reciprocal function of λ.

4.2.1 General model

The FIDES general reliability model for an item is based on the following equation:

$$\lambda = \left(\sum_{Physical\_contribution^{\cdot}}\right) \times \left(\prod_{Process\_contribution^{\cdot}}\right) \text{ (1)}$$

Where:

- λ is the item failure rate.
- $\sum_{Physical\_contribution^{\cdot}}$ represents a mainly additive construction term comprising physical and technological contributing factors to reliability.
- $\prod_{Process\_contribution^{\cdot}}$ represents a multiplication term that represents the impact of the development, production and operation process on reliability.

In practice, this equation becomes:

$$\lambda = \lambda_{Physical} \times \prod_{PM^{\cdot}} \times \prod_{Process^{\cdot}} \text{ (2)}$$

Where:

- $\lambda_{Physical}$ represents the physical contribution;
- $\prod_{PM^{\cdot}}$ (PM for Part Manufacturing) represents the quality and technical control over manufacturing of the item;
- $\prod_{Process^{\cdot}}$ represents the quality and technical control over the development, manufacturing and usage process for the product containing the item.

The contribution of the $\prod_{PM^{\cdot}}$ and the $\prod_{Process^{\cdot}}$ factors, in this study, are discussed in the subsection 4.3.3 Default values.

The physical contributing factor is itself broken-down into different sub-contributing factors based on the following model:

$$\lambda_{Physical} = \left[\sum\nolimits_{Physical\_Contributions}(\lambda_0 \times \prod\nolimits_{acceleration\cdot})\right] \times \prod\nolimits_{induced\cdot} \quad (3)$$

Where:

- The term between brackets represents the contribution of normal stresses;
- λ_0 is the basic failure rate of the item;
- $\prod_{acceleration\cdot}$ Is an acceleration factor translating the sensitivity to usage conditions;
- $\prod_{induced\cdot}$ represents the contribution of induced factors (also called overstresses) inherent to an application field.

The first factor (λ_0) is broken-down for each physical stress related to each item. Also the $\prod_{acceleration\cdot}$ factor is separated into each type of physical stress.

Last the $\prod_{induced\cdot}$ factor is broken-down considering its origin.

Regarding the $\prod_{acceleration\cdot}$ factor, it is divided in six different families of physical stress, being:

- Thermal: $\prod_{Thermal\cdot}$
- Electrical: $\prod_{Electrical\cdot}$
- Temperature cycling: $\prod_{TCy\cdot}$
- Mechanical: $\prod_{Mechanical\cdot}$
- Humidity: $\prod_{RH\cdot}$
- Chemical: $\prod_{Chemical\cdot}$

The induced factors considered, for the $\prod_{induced\cdot}$ factor, are of mechanical (MOS), electrical (EOS) and thermal (TOS) origin. These factors are calculated for each flight phase in the life usage profile.

This factor is calculated through the following formulation:

$$\prod\nolimits_{induced-i\cdot} = \left(\prod\nolimits_{placement-i\cdot} \times \prod\nolimits_{application-i\cdot} \times \prod\nolimits_{ruggedising-i\cdot}\right)^{0{,}511 \times Ln(C_{sensibility})} \quad (4)$$

Where:

- $\prod_{placement-i\cdot}$ represents the influence of the item placement in the equipment or the system. Placement refers to the position of the item or the function in which it is integrated (particularly whether or not it is interfaced);

- $\prod_{application-i\cdot}$ represents the influence of the usage environment for application of the product containing the item. The factor is variable depending on the life usage profile phase of flight.
- $\prod_{ruggedising-i\cdot}$ represents the influence of the policy for taking account of overstresses in the product development;
- $C_{sensibility}$ represents the influence of sensitivity to overstresses inherent to the item technology considered;
- i is the index of the flight phase considered.

The contribution of all factors associated with the $\prod_{induced-i\cdot}$, in this study, are discussed in the subsection 4.3.3 Default values.

4.2.2 Integrated circuits model

The general model for this family follows the same as in the equation (2) and the physical contribution described in equation (3) is broken down in the following:

$$\lambda_{Physical} = \sum_i^{Phases} \left(\frac{t_{anual}}{8760}\right)_i \times \begin{pmatrix} \lambda_{0\_\mathrm{TH}} \times \prod_{\mathrm{Thermal}\cdot} \\ + \lambda_{0\_\mathrm{TCyCase}} \times \prod_{\mathrm{TCyCase}\cdot} \\ + \lambda_{0\_\mathrm{TCySolder\ joints}} \times \prod_{\mathrm{TCySolder\ joints}\cdot} \\ + \lambda_{0\_\mathrm{RH}} \times \prod_{\mathrm{RH}\cdot} \\ + \lambda_{0\_\mathrm{Mech}} \times \prod_{\mathrm{Mech}\cdot} \end{pmatrix}_i \times \left(\prod_{\mathrm{Induced}\cdot}\right)_i$$

(5)

Where the basic failure rates for the different physical stresses are obtained by the following equation:

$$\lambda_{0\_\mathrm{Stress}} = e^{-a} \times \mathrm{Np}^{b} \quad (6)$$

Where:

- a and b are the constants that depend on the package type and number of pins given by the table in the Annex A.
- Np is the number of pins on the package.

The basic failure rate associated with the chip is also presented in the Annex A.

The equations to calculate the $\prod_{\cdot}$ factors, which contribute to physical stresses, are displayed in the Annex A.

To have the intended result, the MTBF, the equation (7) is applied.

$$\mathrm{MTBF} = {}^{1}/_{\lambda} \quad (7)$$

4.3 Data collection

4.3.1 Integrated circuits

To conduct this study, four different IC were used to assess the MTBF from each.

The first page of the datasheet of each IC is presented in Annex B and the main parameters, relevant to the calculations, are exposed in the next table (Table 2).

In the datasheet of the IC with the name TC7MB3253FK, it is indicated that the package is the type VSSOP, meaning Very Thin Shrink Small Outline Package, which is not define in the FIDES methodology. Instead, it will be used the type TSSOP, meaning Thin Shrink Small Outlines Package.

The type of chip in all of the IC from the PHILIPS COMPONENTS brand was assumed Digital Circuit since the type is not specified in the datasheet.

Table 2 – Relevant parameters from IC

Brand	Part Number	Package (Typical Name)	Type of Chip	Number of Pins
TOSHIBA	TC7MB3253FK	TSSOP (VSSOP)	Digital Circuit	16
PHILIPS COMPONENTS	100164Y	CERPACK	Digital Circuit	24
PHILIPS COMPONENTS	100164A	PLCC	Digital Circuit	28
TOSHIBA	TC3W01F	SOP	Digital Circuit	8

4.3.2 Default values

Setting $\prod_{PM\cdot}$:

The $\prod_{PM\cdot}$ factor represents the item quality level from the manufacturing (Quality Assurance Level). The ranking depends on the certification level of the supplier. It also uses an additional rating of the buyer's past experience with the supplier. The various ratings are rolled into the Part Grade variable. Determining this variable requires input from the user in each of the areas of interest (up to five) for each component. The equation (8) gives the factor result to be applied.

$$\prod_{PM\cdot} = e^{\delta_1 (1-Part\_Grade)-\alpha_1} \quad (8)$$

The variation range of the $\prod_{PM}$.factor varies from 0.5 (supplier better than the state of the art) to 2 (the worst case).

Since these criteria are not available to be assessed, a default value for the factor will be used.

A default value of 1.7 is used for active components and 1.6 for other components, COTS boards and various subassemblies.

Setting $\prod_{Process^{\cdot}}$:

The $\prod_{Process^{\cdot}}$ factor has the purpose to globally evaluate the maturity of the manufacturer on control over his reliability engineering process. It covers all processes from specification to field operation and maintenance. A set of questions is provided in order to audit the product developer's processes. The result is a process grade that fits into the equation (9). The δ_2 is a correlation factor that determines the range of the process factor multiplier and has been set to 2.079 by FIDES developers.

$$\prod_{Process^{\cdot}} = e^{\delta_2\,(1-Process\_Grade)} \quad (9)$$

Likewise the factor above, this factor cannot be estimated. So a default value will be assumed in the calculations.

The variation range of this factor is from 1 (for the best process) to 8 (for the worst process). The value of 4.0 is suggested and will be used.

Setting $\prod_{Placement^{\cdot}}$:

The contribution associated with the $\prod_{Placement^{\cdot}}$ factor is described in the following table (Table 3):

Table 3 – Contribution associated with the $\prod_{Placement^{\cdot}}$ factor

	$\prod_{Placement^{\cdot}}$
Digital non-interface function	1.0
Digital interface function	1.6
Analogue low non-interface function	1.3
Analogue low level interface function	2.0
Analogue power non-interface function	1.6
Analogue power interface function	2.5

All four IC were considered as having a $\prod_{Placement^{\cdot}}$ factor of 1.6, corresponding to have an interface digital function.

Setting $\prod_{application}$.:

The contribution associated with the $\prod_{application}$. factor is evaluated by a series of criteria (user type, user qualification level, system mobility, product manipulation, type of electrical network, product exposure to human activity, product exposure to machine disturbances and product exposure to the weather), with different weights, which fits into an equation, giving the result for each phase of flight. As it is not possible to rate every aspect, the factor for each flight phase will be the suggested in the last column of the life usage profiles table (Table 4 and Table 6).

Setting $\prod_{tuggedising-i}$.:

The contribution associated with $\prod_{ruggedising-i}$. factor is also not possible to be checked out. The suggested value will be used, being 1.7.

The use of all the default values may result in a reduction of the accuracy of the final results.

4.3.3 Life usage profile

The life usage profile describes the type and level of the physical stresses that will be applied on components during their operational life, having a direct effect on $\lambda_{Physical}$ [2]. In the case of an activity which occurs periodically, a corresponding mean operational activity can be defined [2]. For this reason, the FIDES methodology is applied to one calendar year (8,760 h) of operational activity [2].

The physics of failure laws are often expressed relative to a level of physical stress, which is considered independent of time [2]. When the level of stress evolves with time, the life usage profile is split into flight phases in which the level of stress is constant [2].

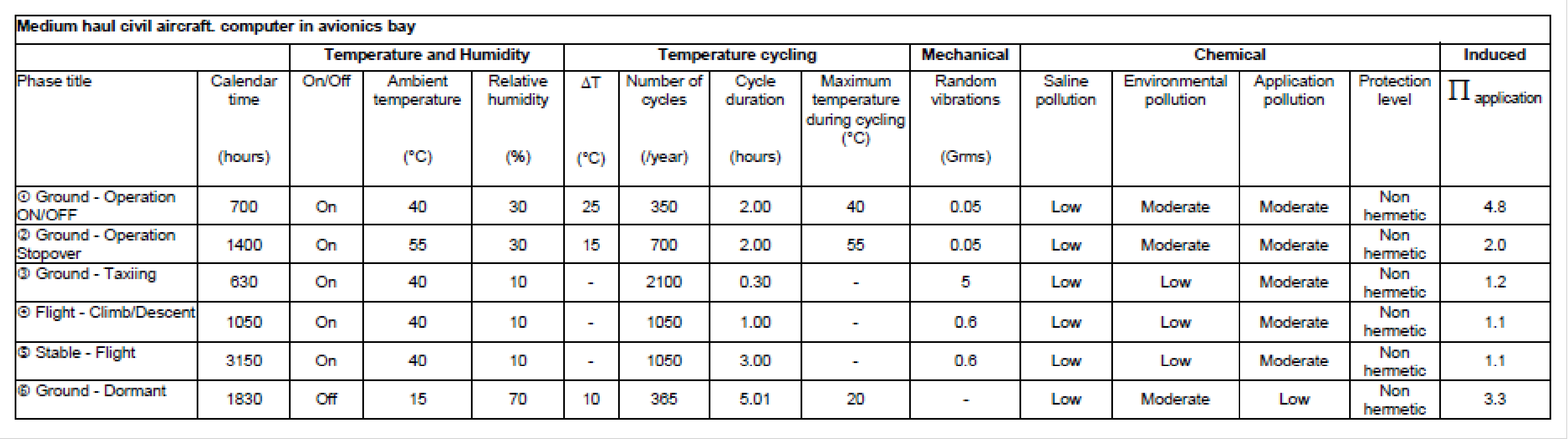
By breaking down the life usage profile into flight phases in which the validity of the physics of failure laws is respected, the level of every physical stress can be set for each of these phases of flight, and the predicted failure rate of the system calculated [2].

From the statements above, it is clear that the life usage profile of a component will affect its reliability due to the different types of stress it will be submitted and the environmental conditions during its operation.

As it is not possible to determine the exact life usage profile of the component because it can change on a daily basis, it will be assumed two life usage profiles from the FIDES methodology.

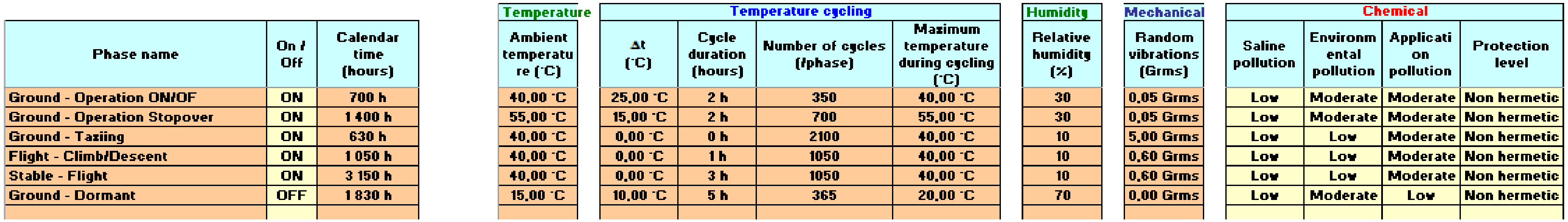
The life usage profile assumed is presented in the Table 4, corresponding to “Life usage profile of equipment (in avionics bay) mounted in a medium haul civil aircraft”. The Table 5 shows this life usage profile on “FIDES ExperTool”. All the parameters considered are explained in the Annex C.

Table 4 – Life usage profile of equipment (in avionics bay) mounted in a medium haul civil aircraft [29]



Medium haul civil aircraft. computer in avionics bay														
		Temperature and Humidity			**Temperature cycling**				**Mechanical**	**Chemical**				**Induced**
Phase title	Calendar time (hours)	On/Off	Ambient temperature (°C)	Relative humidity (%)	ΔT (°C)	Number of cycles (/year)	Cycle duration (hours)	Maximum temperature during cycling (°C)	Random vibrations (Grms)	Saline pollution	Environmental pollution	Application pollution	Protection level	$\Pi_{application}$
① Ground - Operation ON/OFF	700	On	40	30	25	350	2.00	40	0.05	Low	Moderate	Moderate	Non hermetic	4.8
② Ground - Operation Stopover	1400	On	55	30	15	700	2.00	55	0.05	Low	Moderate	Moderate	Non hermetic	2.0
③ Ground - Taxiing	630	On	40	10	-	2100	0.30	-	5	Low	Low	Moderate	Non hermetic	1.2
④ Flight - Climb/Descent	1050	On	40	10	-	1050	1.00	-	0.6	Low	Low	Moderate	Non hermetic	1.1
⑤ Stable - Flight	3150	On	40	10	-	1050	3.00	-	0.6	Low	Low	Moderate	Non hermetic	1.1
⑥ Ground - Dormant	1830	Off	15	70	10	365	5.01	20	-	Low	Moderate	Low	Non hermetic	3.3

Table 5 – Life usage profile of equipment (in avionics bay) mounted in a medium haul civil aircraft on “FIDES ExperTool”



			Temperature	**Temperature cycling**				**Humidity**	**Mechanical**	**Chemical**			
Phase name	**On / Off**	**Calendar time (hours)**	**Ambient temperature (°C)**	**Δt (°C)**	**Cycle duration (hours)**	**Number of cycles (/phase)**	**Maximum temperature during cycling (°C)**	**Relative humidity (%)**	**Random vibrations (Grms)**	**Saline pollution**	**Environmental pollution**	**Application pollution**	**Protection level**
Ground - Operation ON/OF	ON	700 h	40,00 °C	25,00 °C	2 h	350	40,00 °C	30	0,05 Grms	Low	Moderate	Moderate	Non hermetic
Ground - Operation Stopover	ON	1 400 h	55,00 °C	15,00 °C	2 h	700	55,00 °C	30	0,05 Grms	Low	Moderate	Moderate	Non hermetic
Ground - Taxiing	ON	630 h	40,00 °C	0,00 °C	0 h	2100	40,00 °C	10	5,00 Grms	Low	Low	Moderate	Non hermetic
Flight - Climb/Descent	ON	1 050 h	40,00 °C	0,00 °C	1 h	1050	40,00 °C	10	0,60 Grms	Low	Low	Moderate	Non hermetic
Stable - Flight	ON	3 150 h	40,00 °C	0,00 °C	3 h	1050	40,00 °C	10	0,60 Grms	Low	Low	Moderate	Non hermetic
Ground - Dormant	OFF	1 830 h	15,00 °C	10,00 °C	5 h	365	20,00 °C	70	0,00 Grms	Low	Moderate	Low	Non hermetic

4.4 Results

The results were obtained by inputs (life usage profile, all five multiplication factors - $\prod_{PM}$·, $\prod_{Process}$·, $\prod_{tuggedising-i}$·, $\prod_{Placement}$·, $\prod_{application}$· and specific to the IC) into the Excel workbook template and later computing in the software (Figure 5) from the “FIDES ExperTool”. The Excel workbook template and the software were obtained from the FIDES website.

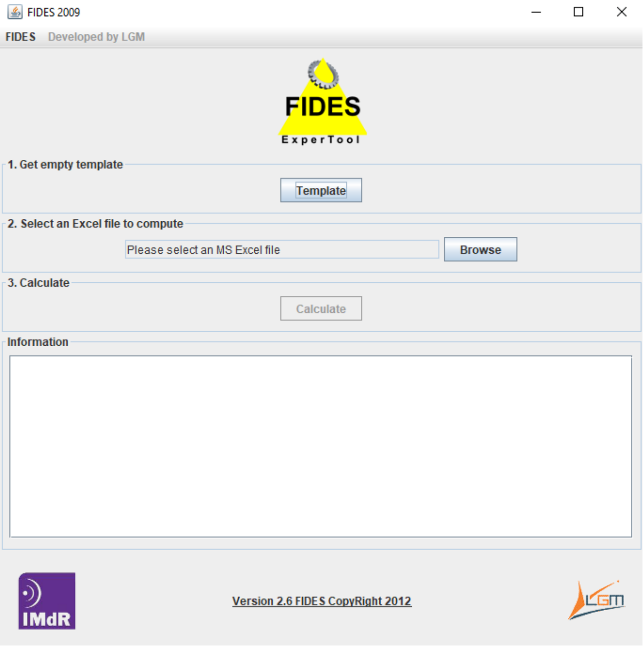


Figure 5 – FIDES calculation software

The MTBF from the different IC is presented in the Table 6.

It is possible to see the contribution from the several phases of flight of the life usage profile to the λ. This is presented by graphical means in the Annex D.

Table 6 – FIDES predicted MTBF

Part Number	**MTBF** [10^6 hours]
TC7MB3253FK	75.1
100164Y	74.6
100164A	74.1
TC3W01F	75.5

4.5 Discussion of results and comparison process

4.5.1 Comparison process

As described in chapter 1, the comparison criteria requires that the MTBF to be similar or better to the predictions made by a company with a reliable reliability prediction software. The company *Flight Data Systems* provided the reliability prediction for the MTBF with the aid of the *“ReliaSoft Lambda Predict”* reliability prediction software.

The prediction made by *Flight Data Systems* used the MIL-HDBK-217F reliability prediction standard. On doing so, the life usage profile model used was the *“Airborne Inhabited Cargo”,* and the values used as input to the software were the following:

- Global variables:
    - Ambient temp: 40 °C;
    - Case Temp: 55 °C;
    - Package Type: Non Hermetic;
    - Quality: Commercial/Unknown.

- PHILIPS COMPONENTS 100164Y:
    - Number of pins = active pins: 24;
    - Production years: 30 (products age);
    - Number of gates: 21;
    - Technology: TTL.

- PHILIPS COMPONENTS 100164A:
    - Number of pins = active pins: 28;
    - Production years: 30 (products age);
    - Number of gates: 21;
    - Technology: TTL.

- TOSHIBA TC7MB3253FK:
    - Number of pins = active pins: 16;
    - Production years: 20;
    - Number of gates: 22;
    - Technology: Bipolar CMOS.

- TOSHIBA TC3W01F:
    - Number of pins = active pins: 8;
    - Production years: 20;
    - Number of Gates: 8;
    - Technology: Low Power Schottky TTL.

With these inputs, the obtained predictions for the MTBF are the described in figure 6.

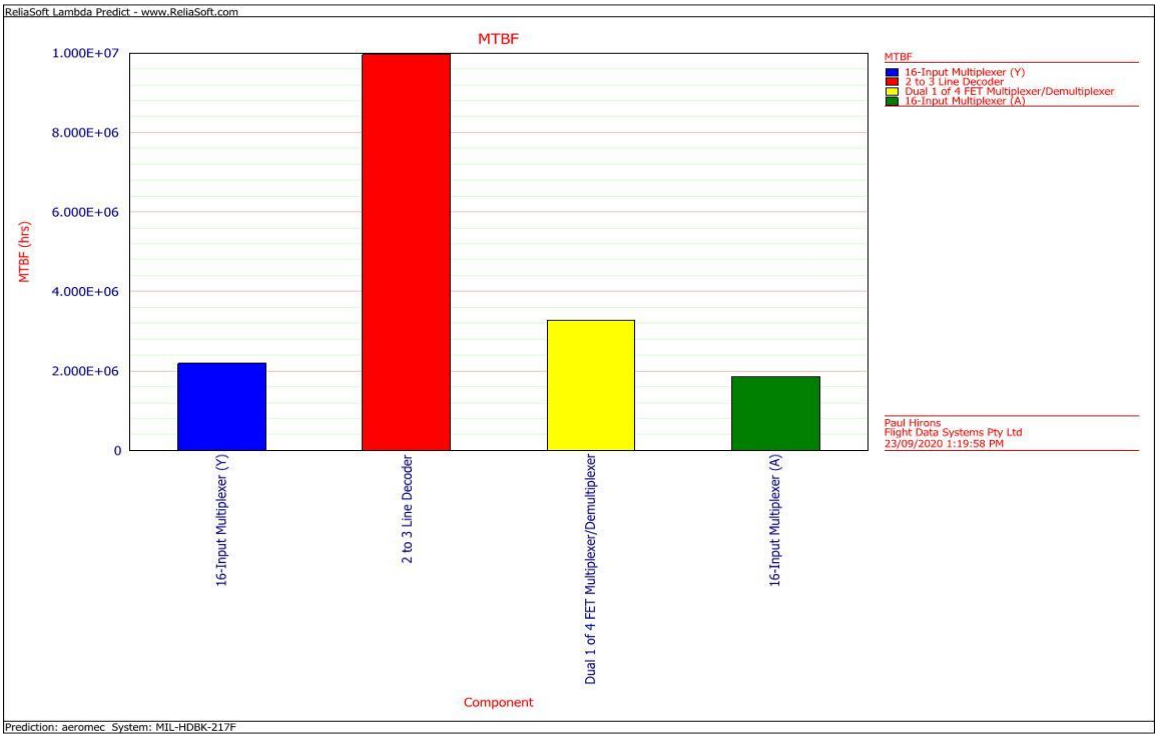


Figure 6 – MTBF prediction by *Flight Data Systems*

4.5.2 Discussion of results

Comparing the results obtained by *Flight Data Systems* to the results of this study, shown in Table 7, it is possible to see that the FIDES predictions are more optimistic and therefore with higher MTBF than the predictions from the MIL-HDBK-217F standard. This can be due to the MIL-HDBK-217F standard being obsolete and not updated since 1995, as the predicted values do not correspond to the reality, and by opposition the FIDES being updated and revised periodically, as the latest update was in 2010. Also because the life usage profile was not the same as in this study.

Regarding the contributions for the λ, and consequently for the MTBF, by each flight phase of the life usage profile, it is possible to perceive, in annex D, the phases of flight that have greater contribution for the final result.

Table 7 – Comparison between FIDES predicted MTBF and MIL-HDBK-217F predicted MTBF

Part Number	**MTBF FIDES** [10^6 hours]	**MTBF MIL-HDBK-217F** [10^6 hours]
TC7MB3253FK	75.1	2.3
100164Y	74.6	10.0
100164A	74.1	3.3
TC3W01F	75.5	1.9

For all the IC, the contribution from each phase of flight is similar and in the same order of contribution, with the main contribution coming from the Ground - Operation Stopover, and the least from the Ground – Dormant.

In the next chapter it will be presented the conclusions and future work.

Chapter 5 – Conclusions and future work

5.1 Conclusions

This work was aimed at research the different methodologies used by the electronics industry to accurately predict the MTBF. Then using one of them, the FIDES methodology, predict the MTBF of one electronic component, four integrated circuits.

The calculation of the MTBF of an equipment is essential to determine its reliability. The higher the MTBF of an equipment is the more reliable it will be. This will have an impact on reducing the time that an aircraft needs to be grounded to perform MRO services. Therefore it is imperative to have the most accurate prediction with respect to the reliability calculations.

With the result of this work, Aeromec will have a relevant process on how to predict the MTBF of equipment that will be installed in the aircraft.

Reliability prediction has been employed to denote the process of use mathematical models to estimate the reliability of a system. Different approaches have been developed, each with advantages and disadvantages. Three main categories are used to distinguish them, empirical (standard based), physics of failure and life testing.

The empirical prediction methods are based on models developed using historical failure data. The main handbook/standard used is the MIL-HDBK-217F. However, at the present moment of technology development, this handbook is obsolete, as the predicted values do not correspond to the reality.

The physics of failure methods is based on understanding the failure mechanism and applying the models created. Several models were created, with the most common used being the Arrhenius's law and Eyring model.

The life testing method conduct trials on a large sample of units under normal operating conditions and with all the data collected, it is conducted an analysis to estimate the reliability.

In 2004 a consortium of eight companies developed a new reliability methodology, called FIDES, to calculate the failure rate of an equipment/component. This methodology tries to encompass the three main categories above, being based on the physics of failures and supported by the analysis of test data, field returns and existing modelling. The fact that

FIDES methodology is periodically updated and revised makes it adapted to the new technologies.

The FIDES is based on three concepts: Technology - which covers the technology inherent to the item; Process – all practices and state of art from the product specification; and Use – covers the usage constraints (product design and operation from the final user).

To apply this methodology, it is necessary to establish the life utilisation profile, enter the data for each component and setting several multiplication factors according with several criteria. These data are then gathered on an Excel workbook provided by the FIDES group to implement its prediction method.

After this has been done, a software set up by the FIDES group does all the calculations based on the Excel workbook input, giving the results by phase of flight, component and type of stress.

The validation of the results obtained was carried out by comparing them with an estimated value for the MTBF of the four integrated circuits done by *Flight Data Systems* with the "*ReliaSoft*" reliability prediction software.

With this study it was found that the prediction of the MTBF for the four integrated circuits, carried out using the FIDES standard, is more optimistic and therefore with a longer/higher MTBF then the prediction made by *Flight Data Systems* with the MIL-HDBK-217F standard.

This may be due to two factors: the MIL-HDBK-217F standard has not been reviewed and updated for new technologies since 1995, contrary to the FIDES standard; and the usage profile in *Flight Data Systems* prediction does not exactly match as the one in FIDES.

The life usage profile to which the equipment is subject will influence its MTBF, as the operating conditions will affect the types/levels of stress to which the component is subjected (thermal, electrical, temperature cycling, mechanical, humidity and chemical).

The FIDES standard allows the multiplication factors (factor $\prod_{\boldsymbol{PM}}$. and factor $\prod_{\boldsymbol{Process}}$.) to be adjusted, increasing or decreasing their value, according to the results of an audit to the component/equipment manufacturer.

These factors are one of the major breakthrough by this standard, as it allows the quality control of development, manufacturing and handling process (Quality Assurance Level) to be taken into account in the calculations, resulting in the intrinsic reliability. Therefore, for the same equipment, operating under the same conditions, it is possible to obtain a different MTBF.

This study shows how important is to conduct an assessment of the reliability of a component/equipment. The closer the predictions are to reality, the better will be to plan the maintenance actions needed to maintain the level of reliability of an aircraft.

5.2 Future work

For future works, the next step is to conduct a full study to assess the MTBF for a specific equipment, for example a primary flight display that has several different components, meaning to estimate the MTBF for every component incorporated, and then the overall MTBF.

This work could be done by Aeromec to assess the MTBF for the equipment that will be installed in the aircraft. To better assess this value, the company should audit the manufacturers of equipment to check the Quality Assurance Level and ensure that the multiplication factors present in the calculations are correctly calculated, increasing the accuracy of the prediction.

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Annexes

Annex A – Constants and Multiplication Factors for the Basic Failure Rate

Constants for the basic failure rates associated with package [29]

Typical name	Description	Np	λ_{0RH}		λ_{0TCy_Case}		$\lambda_{0TCy\_Solder\ joints}$		$\lambda_{0\ mechanical}$	
			a	b	a	b	a	b	a	b
PDIP. TO116	Plastic Dual In line Package	8 to 68	5.88	0.94	9.85	1.35	8.24	1.35	12.85	1.35
CERDIP. CDIP	Ceramic Dual-In-Line Package	8 to 20 >20 to 48	λ_{0RH}=0		6.77	1.35	5.16 4.47	1.35 1.35	8.38 7.69	1.35 1.35
PQFP	Plastic Quad Flatpack. L lead	44 to 240 >240 to 304	11.16	1.76	12.41	1.46	10.80 10.11	1.46 1.46	14.71 14.02	1.46 1.46
SQFP TQFP. VQFP. LQFP	Plastic Shrink (thickness) Quad Flatpack. L lead Plastic Thin Quad Flatpack. L lead	32 to 120 >120 to 208	7.75	1.13	8.57	0.73	6.96 5.57	0.73 0.73	11.57 10.18	0.73 0.73
Power QFP (RQFP. HQFP. PowerQuad. EdQuad...)	Plastic Quad Flatpack with heat sink. L lead	160 to 240 >240 to 304	14.17	2.41	15.11	1.96	13.50 12.81	1.96 1.96	17.41 16.72	1.96 1.96
CERPACK		20 to 56	λ_{0RH}=0		12.41	1.46	10.80	1.46	14.02	1.46
CQFP. Cerquad	Ceramic Quad Flat Pack	64 to 132 >132 to 256	λ_{0RH}=0		12.41	1.46	10.80 9.19	1.46 1.46	14.02 12.41	1.46 1.46
PLCC	Plastic Leaded Chip Carrier J-Lead	20 to 52 >52 to 84	9.36	1.74	18.52	3.15	16.91 15.52	3.15 3.15	21.11 19.72	3.15 3.15
J-CLCC	J-Lead Ceramic Leaded Chip Carrier	4 to 32 44 52 68 84	λ_{0RH}=0		8.07	0.93	6.46 5.77 5.36 4.85 4.38	0.93	9.68 8.99 8.58 8.07 7.6	0.93
CLCC	Ceramic Leadless Chip Carrier	4 20 32 44 52 68 84	λ_{0RH}=0		8.07	0.93	5.07 4.51 4.38 4.26 4.26 4.16 4.16	0.93	8.07 7.51 7.38 7.26 7.26 7.15 7.15	0.93
SOJ	Plastic Small Outlines. J-Lead	24 to 44	4.31	0.86	8.36	1.39	6.75	1.39	11.36	1.39
SO. SOP. SOL. SOIC. SOW	Plastic Small Outlines. L lead	8 to 14 16 to 18 20 to 28 32	8.23	1.17	13.36	2.18	11.75 11.06 10.36 10.14	2.18 2.18 2.18 2.18	16.36 15.66 14.97 14.75	2.18 2.18 2.18 2.18
TSOP I TSOP II	Thin Small Outlines. leads on small edges. L lead Thin Small Outlines. leads on long edges. L lead	5 to 16 >16 to 32 >32 to 44 >44 to 56	6.21	0.97	9.05	0.76	7.44 6.05 5.83 5.36	0.76 0.76 0.76 0.76	12.05 10.66 10.44 9.97	0.76 0.76 0.76 0.76
SSOP. VSOP. QSOP	Plastic Shrink (pitch) Small Outlines. L lead	16 to 64	11.95	2.23	16.28	2.60	14.67	2.60	19.28	2.60
TSSOP. MSOP. µSO. µMAX. TVSOP	Thin Shrink Small Outlines. L lead	8 to 28 >28 to 48 56 64	11.57	2.22	15.56	2.66	13.95 13.21 12.56 12.16	2.66 2.66 2.66 2.66	18.56 17.86 17.17 16.76	2,66 2,66 2,66 2,66
QFN. DFN. MLF	Quad Flat No lead (package without lead)	8-24 28-56 64-72	8.97	1.14	11.2	1.21	8.12 7.90 7.71	1.14	11.34 11.12 10.93	1,21
PBGA CSP BT 0.8 and 0.75 mm	Plastic Ball Grid Array with solder ball pitch = 0.8 mm and 0.75 mm	48 to 384	9.7	1.50	12.13	1.49	9.13	1.49	12.82	1,49
PBGA flex 0.8 mm	Plastic Ball Grid Array with solder ball pitch = 0.8 mm and 0.75 mm	48 to 288	9.7	1.50	12.13	1.49	8.57	1.49	12.26	1,49
PBGA BT 1.00 mm	Plastic Ball Grid Array with solder ball pitch = 1.0 mm	64 to 1156	6.2	0.81	10.89	1.00	7.67	1.00	11.36	1,00
PBGA 1.27mm	Plastic Ball Grid Array. with solder ball pitch = 1.27 mm	119 to 352 >352 to 432 >432 to 729	6.87	0.90	10.36	0.93	7.36 7.14 6.67	0.93 0.93 0.93	11.05 10.83 10.36	0,93 0,93 0,93

Typical name	Description	Np	λ_{0RH}		λ_{0TCy_Case}		$\lambda_{0TCy\_Solder\ joints}$		$\lambda_{0\ mechanical}$	
			a	b	a	b	a	b	a	b
Power BGA (TBGA SBGA...)	Tape BGA. PBGA with heat sink. die top down pitch=1.27 mm Super BGA. PBGA with heat sink. die top down Pitch=1.27 mm	256 to 352 >352 to 956	9.44	1.31	15.73	1.68	12.73 12.33	1.68 1.68	16.42 16.02	1,68 1,68
CBGA	Ceramic Ball Grid Array	255 to 1156	11.78	1.72	15.37	1.87	11.56	1.87	14.56	1,87
DBGA	Dimpled BGA	255 to 1156	11.78	1.72	15.37	1.87	12.15	1.87	15.15	1,87
CI CGA	Ceramic Land GA + interposer. Ceramic column GA	255 to 1156	11.78	1.72	15.37	1.87	11.81	1.87	14.81	1,87
CPGA	Ceramic Pin Grid Array	68 to 250 >250 to 655	$\lambda_{0RH}=0$		8.07	0.93	5.77 4.85	0.93 0.93	8.76 7.85	0.93 0.93

Basic failure rates associated with the chip [29]

Type	λ_{0TH}
FPGA, CPLD, FPGA Antifuse, PAL	0.166
Analogue and Hybrid circuit (MOS, bipolar, BiCMOS)	0.123
Microprocessor, Microcontroller, DSP	0.075
Flash, EEPROM, EPROM	0.060
SRAM	0.055
DRAM	0.047
Digital circuit (MOS, bipolar, BiCMOS)	0.021

Factors contributing to physical stresses [29]

$\Pi_{Thermal\_}$	In an operating phase: $e^{11604 \times 0.7 \times \left[\frac{1}{293} - \frac{1}{(T_{j-component} + 273)}\right]}$ In a non-operating phase: $\Pi_{Thermal = 0}$
Π_{TCy} *Case*	$\left(\frac{12 \times N_{annual-cy}}{t_{annual}}\right) \times \left(\frac{\Delta T_{cycling}}{20}\right)^{4} \times e^{1414 \times \left[\frac{1}{313} - \frac{1}{(T_{max-cycling} + 273)}\right]}$
Π_{TCy} *Solder joints*	$\left(\frac{12 \times N_{annual-cy}}{t_{annual}}\right) \times \left(\frac{\min(\theta_{cy},2)}{2}\right)^{\frac{1}{3}} \times \left(\frac{\Delta T_{cycling}}{20}\right)^{1,9} \times e^{1414 \times \left[\frac{1}{313} - \frac{1}{(T_{max-cycling} + 273)}\right]}$
Π_{Mech}	$\left(\frac{G_{RMS}}{0.5}\right)^{1.5}$
Π_{RH}	$\left(\frac{RH_{ambient}}{70}\right)^{4,4} \times e^{11604 \times 0.9 \times \left[\frac{1}{293} - \frac{1}{(T_{board-ambient} + 273)}\right]}$ In operating phase: $\Pi_{RH} = 0$

Information about the life profile [29]

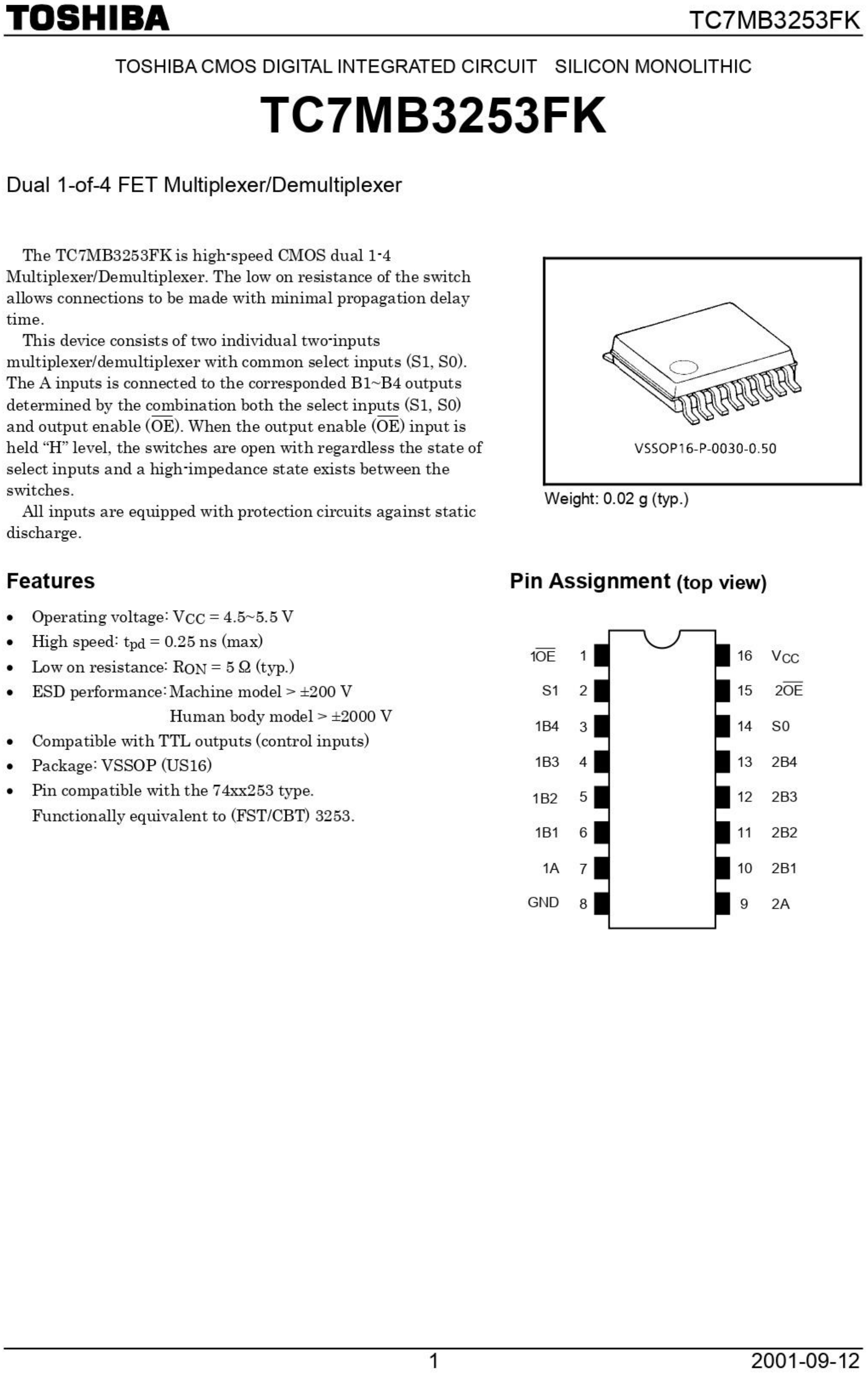
t_{annual}: time associated with each phase over a year (hours)
$RH_{ambient}$: humidity associated with a phase (%)
$T_{board-ambient}$: average board temperature during a phase (°C)
$\Delta T_{cycling}$: amplitude of variation associated with a cycling phase (°C)
$T_{max-cycling}$: maximum board temperature during a cycling phase (°C)
$N_{annual-cy}$: number of cycles associated with each cycling phase over a year (cycles)
θ_{cy}: cycle duration (hours)
Grms: vibration amplitude associated with each random vibration phase (Grms)

Information about the application [29]

$T_{J\_component}$: component junction temperature during an operating phase (°C)
$T_{J\_component} = T_{ambient} + R_{JA} \cdot P_{dissipated}$
$P_{dissipated}$: power dissipated by the component during the phase (W)

Annex B – Integrated Circuit Datasheet

Toshiba TC7MB3253FK datasheet [30]



TOSHIBA TC7MB3253FK

TOSHIBA CMOS DIGITAL INTEGRATED CIRCUIT SILICON MONOLITHIC

TC7MB3253FK

Dual 1-of-4 FET Multiplexer/Demultiplexer

The TC7MB3253FK is high-speed CMOS dual 1-4 Multiplexer/Demultiplexer. The low on resistance of the switch allows connections to be made with minimal propagation delay time.

This device consists of two individual two-inputs multiplexer/demultiplexer with common select inputs (S1, S0). The A inputs is connected to the corresponded B1~B4 outputs determined by the combination both the select inputs (S1, S0) and output enable ($\overline{OE}$). When the output enable ($\overline{OE}$) input is held "H" level, the switches are open with regardless the state of select inputs and a high-impedance state exists between the switches.

All inputs are equipped with protection circuits against static discharge.

Weight: 0.02 g (typ.)

Features

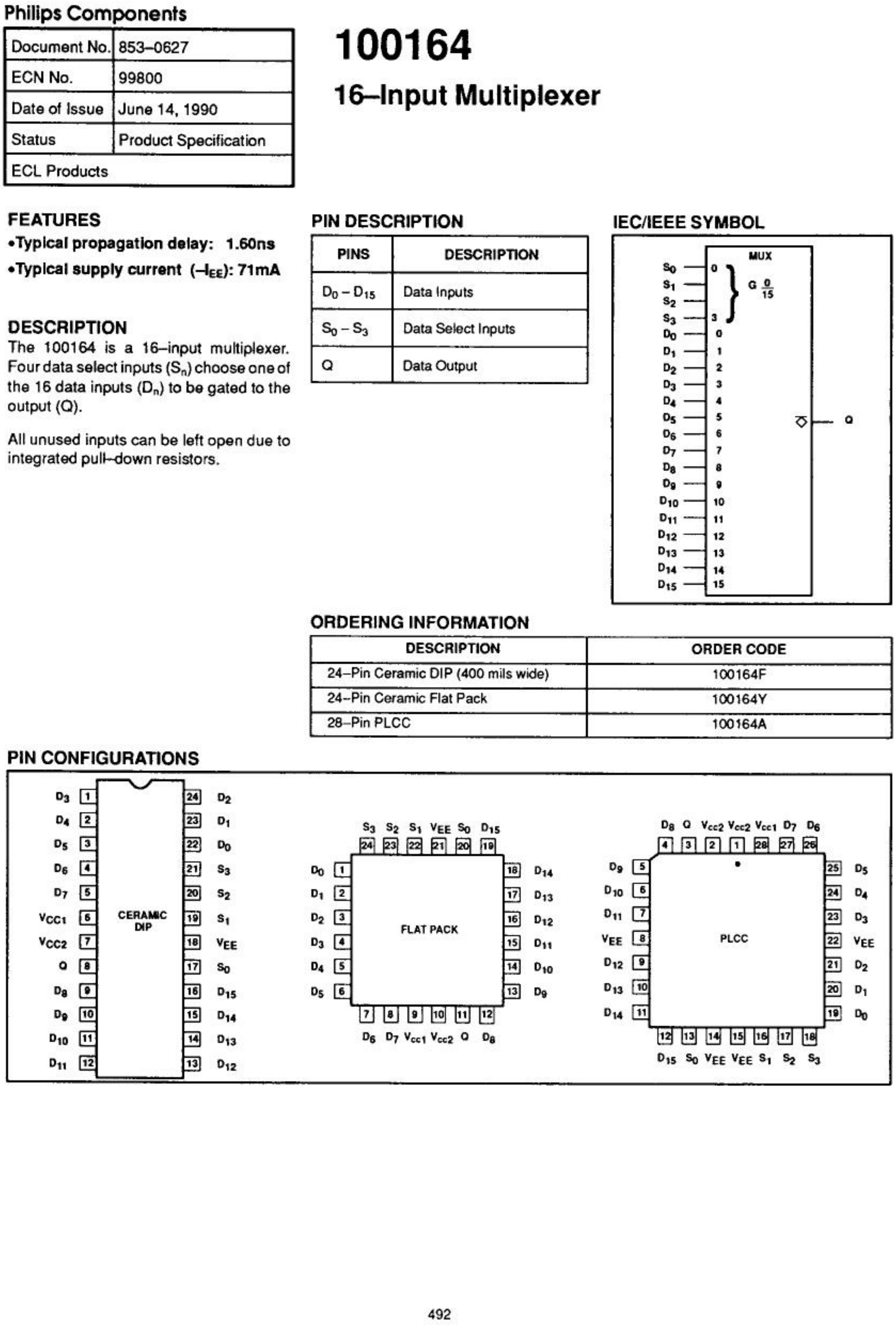
- Operating voltage: V_{CC} = 4.5~5.5 V
- High speed: t_{pd} = 0.25 ns (max)
- Low on resistance: R_{ON} = 5 Ω (typ.)
- ESD performance: Machine model > ±200 V
  Human body model > ±2000 V
- Compatible with TTL outputs (control inputs)
- Package: VSSOP (US16)
- Pin compatible with the 74xx253 type.
  Functionally equivalent to (FST/CBT) 3253.

Pin Assignment (top view)

Signal	Pin	Pin	Signal
$1\overline{OE}$	1	16	V_{CC}
S1	2	15	$2\overline{OE}$
1B4	3	14	S0
1B3	4	13	2B4
1B2	5	12	2B3
1B1	6	11	2B2
1A	7	10	2B1
GND	8	9	2A

1 2001-09-12

Philips Components 100164-F & 100164-A datasheet [31]



Philips Components

Document No.	853–0627
ECN No.	99800
Date of Issue	June 14, 1990
Status	Product Specification
ECL Products	

100164

16–Input Multiplexer

FEATURES

- **Typical propagation delay: 1.60ns**
- **Typical supply current ($-I_{EE}$): 71mA**

DESCRIPTION

The 100164 is a 16–input multiplexer. Four data select inputs (S_n) choose one of the 16 data inputs (D_n) to be gated to the output (Q).

All unused inputs can be left open due to integrated pull–down resistors.

PIN DESCRIPTION

PINS	DESCRIPTION
$D_0 - D_{15}$	Data Inputs
$S_0 - S_3$	Data Select Inputs
Q	Data Output

IEC/IEEE SYMBOL

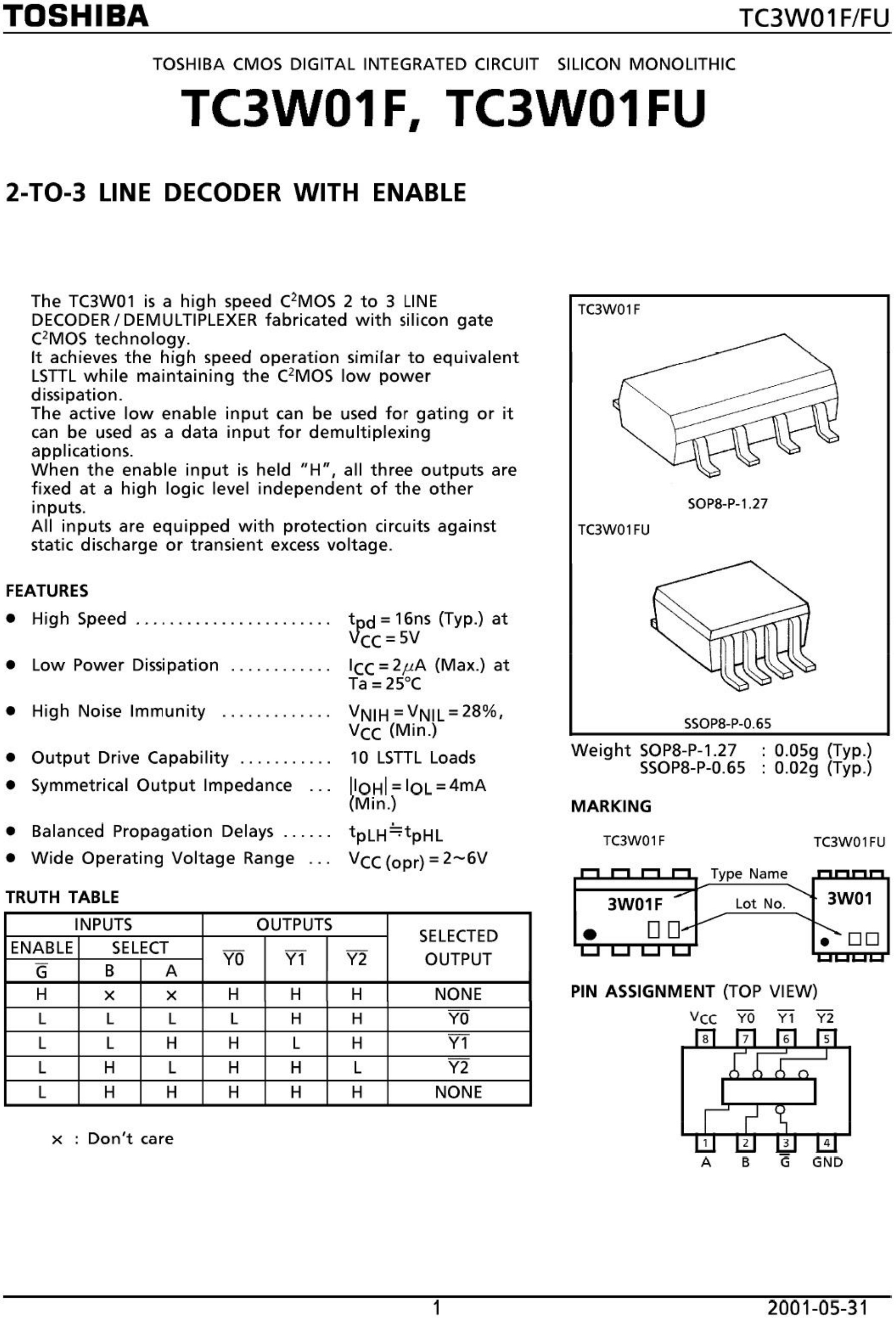
ORDERING INFORMATION

DESCRIPTION	ORDER CODE
24–Pin Ceramic DIP (400 mils wide)	100164F
24–Pin Ceramic Flat Pack	100164Y
28–Pin PLCC	100164A

PIN CONFIGURATIONS

492

Toshiba TC3W01F datasheet [32]



TOSHIBA TC3W01F/FU

TOSHIBA CMOS DIGITAL INTEGRATED CIRCUIT SILICON MONOLITHIC

TC3W01F, TC3W01FU

2-TO-3 LINE DECODER WITH ENABLE

The TC3W01 is a high speed C^2MOS 2 to 3 LINE DECODER / DEMULTIPLEXER fabricated with silicon gate C^2MOS technology.
It achieves the high speed operation similar to equivalent LSTTL while maintaining the C^2MOS low power dissipation.
The active low enable input can be used for gating or it can be used as a data input for demultiplexing applications.
When the enable input is held "H", all three outputs are fixed at a high logic level independent of the other inputs.
All inputs are equipped with protection circuits against static discharge or transient excess voltage.

Weight SOP8-P-1.27 : 0.05g (Typ.)
SSOP8-P-0.65 : 0.02g (Typ.)

FEATURES

● High Speed	t_{pd} = 16ns (Typ.) at V_{CC} = 5V
● Low Power Dissipation	$I_{CC} = 2\mu A$ (Max.) at Ta = 25°C
● High Noise Immunity	$V_{NIH} = V_{NIL} = 28\%$, V_{CC} (Min.)
● Output Drive Capability	10 LSTTL Loads
● Symmetrical Output Impedance	$\lvert I_{OH}\rvert = I_{OL} = 4mA$ (Min.)
● Balanced Propagation Delays	$t_{pLH} \fallingdotseq t_{pHL}$
● Wide Operating Voltage Range	$V_{CC\,(opr)} = 2\sim6V$

MARKING

TRUTH TABLE

INPUTS			OUTPUTS			SELECTED OUTPUT
ENABLE	SELECT					
$\overline{G}$	B	A	$\overline{Y0}$	$\overline{Y1}$	$\overline{Y2}$	
H	×	×	H	H	H	NONE
L	L	L	L	H	H	$\overline{Y0}$
L	L	H	H	L	H	$\overline{Y1}$
L	H	L	H	H	L	$\overline{Y2}$
L	H	H	H	H	H	NONE

× : Don't care

PIN ASSIGNMENT (TOP VIEW)

1 2001-05-31

Annex C - Life usage profile of equipment (in avionics bay) mounted in a medium haul civil aircraft

1. Description of the profile as a number and duration of cycles [29]

1.1 Profile

The "typical" life usage profile of an equipment (in avionics bay) mounted on a medium haul civil aircraft is composed of the following phases of flight:

- Operating phase on the ground when switching ON and OFF;
- Operating phase on the ground during stopovers (with the equipment remaining in the ON position);
- Taxiing phase (between the moment at which the aircraft leaves the boarding zone and the moment at which the aircraft is ready to takeoff);
- Flight phase, during takeoff (climb) and landing (descent);
- Stable flight phase (cruising speed);
- Non-operating phase on the ground: the equipment is on the OFF position (daily switching off and maintenance phases);
- It is assumed that a medium / long haul civil aircraft is operated at a daily rate of 3 flights per day with 2 intermediate stopovers (no or little change in time zones).

This type of aircraft is average in service for 350 days per year, the remaining time possibly waiting on standby or in scheduled maintenance.

1.2 "Ground-Operation-ON/OFF" phase

The preparation time for the first flight of the day from when the aircraft is switched off after the last flight of the day (duration of the "Ground-Operation-ON/OFF" phase) is assumed to be 2 hours. This duration includes the first embarking and the last disembarking of the plane that takes place in parallel with service activities related to operation of the aircraft.

With 1 daily cycle, the total duration of the phase is 700 hours per year (2 x 350).

1.3 "Ground-Operation-Stopover" phase

The average duration of this phase (Turn Around Time) is assumed to be 2 hours (disembarking, cleaning, catering, reembarking).

With 2 cycles per day (between 3 flights), the total number of cycles is 700 per year (2 x 350). The total duration of the phase is 1400 hours per year (2 x 700).

1.4 "Ground-Taxiing" phase

The average taxiing duration is assumed to be 0.30 hours.

With a taxiing phase before and after each flight, the number of cycles is 6 per day, namely 2100 per year (2 x 3 x 350). The total duration of the phase is 630 hours per year (2100 x 0.30).

1.5 "Flight-Climb/Descent" phase

The duration of the "Flight-Climb/Descent" phase is assumed to be 1 hour/flight.

With 3 flights per day, the number of cycles is 1050 per year (3 x 350). The total duration of the phase is 1050 hours per year (1050 x 1).

1.6 "Stable flight" phase

The total duration of the average flight is assumed to be 4 hours, including 3 hours of "Stable flight".

With 3 flights per day, the number of cycles is 1050 per year (3 x 350). The total duration of the phase is 3150 hours per year (1050 x 3).

1.7 "Ground-Dormant" phase

This phase includes daily stops and the 15 days per year not in operation for which no special phase was created in this example.

The total duration of the phases of flight is 1830 hours per year, so that the total duration of all phases of flight is equal to 8760 hours per year (in other words 24 x 365). In this case, the cycle duration is 5.01 hours (1830 / 365).

2. Profiles characterisation

2.1 ON / OFF

For the most usual equipment in the avionics bay, it is assumed that the equipment is OFF during the "Ground-Dormant" phase and ON during all other phases.

2.2 Temperature profile and cycle

The basic temperature cycle is day/night cycle during the "Ground-Dormant" phase. The ambient temperature is assumed to be 15°C with a cycling Delta T of 10°C and a maximum cycling temperature of 20°C (therefore the temperature varies between 10°C at night and 20°C during the day).

When the avionics bay is powered, the ventilation is started up. The transient phase from the beginning of start up (during which the computers start to warm up while ventilation has not reached its full efficiency) is neglected (furthermore, computers can start in a cold or warm ambient temperature before regulation takes place).

The internal temperature rise in the equipment is assumed to be 15°C (ambient temperature of components relative to the ambient temperature outside the equipment).

Furthermore, considering the effect of ventilation, the ambient temperature selected for the "Ground-Operation-ON/OFF" phase is equal to 40°C, which represents a cycling ΔT of 25°C relative to the ambient temperature in the "Ground-Dormant" phase (15°C). The maximum cycling temperature is equal to the ambient temperature (when ON).

The temperature is assumed to be constant for all the "Ground-Operation-ON/OFF" "Taxiing", "Climb/Descent" and "Stable-Flight" phases. The selected ambient temperature is 40°C, which represents a cycling Delta T of 0°C relative to the ambient temperature in the "Ground-Operation-ON/OFF" phase. The maximum cycling temperature is equal to the ambient temperature.

For the "Ground-Operation-Stopover" phase, it is assumed that there is a loss of efficiency in the temperature regulation caused by the aircraft doors being opened (passenger cabin and avionics bay). The ambient temperature considered (also the maximum cycling temperature) is 55°C, which represents a cycling Delta T of 15°C relative to the ambient temperature during the "Ground-Operation-ON/OFF", "Taxiing", "Flight-Climb/Descent" and "Stable-Flight" phases.

2.3 Humidity

When the equipment is OFF ("Ground-Dormant" phase), the average humidity is assumed to be of about 70%.

When the equipment is ON on the ground with the aircraft doors open ("Ground-Operation-ON/OFF" and "Ground-Operation-Stopover" phases), it is assumed that the internal temperature rise causes the relative humidity to change to 30%.

When the equipment is ON in flight ("Flight-Climb/Descent" and "Stable-Flight" phases or ON on the ground with the aircraft doors closed ("Ground-Taxiing" phase), it is assumed that the relative humidity drops to a level of about 10% (very dry air due to the ventilation system).

2.4 Vibration

The vibration stress level is assumed to be zero during the "Ground-Dormant" phase. The vibration stress level is assumed to be very low during the "Ground-Operation- ON/OFF" and "Ground-Operation-Stopover" phases: 0.05 GRMS.

The vibration stress during the "Taxiing" phase is assumed to 5 GRMS.

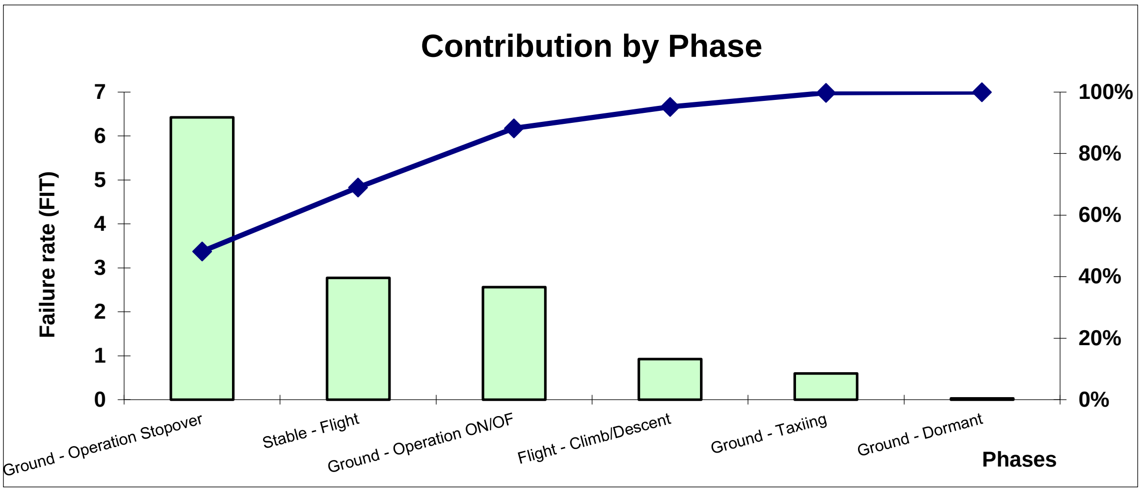
The vibration stress during the "Climb/Descent flight" and "Stable-Flight" phases is assumed to be 0.6 GRMS.

2.5 Chemical

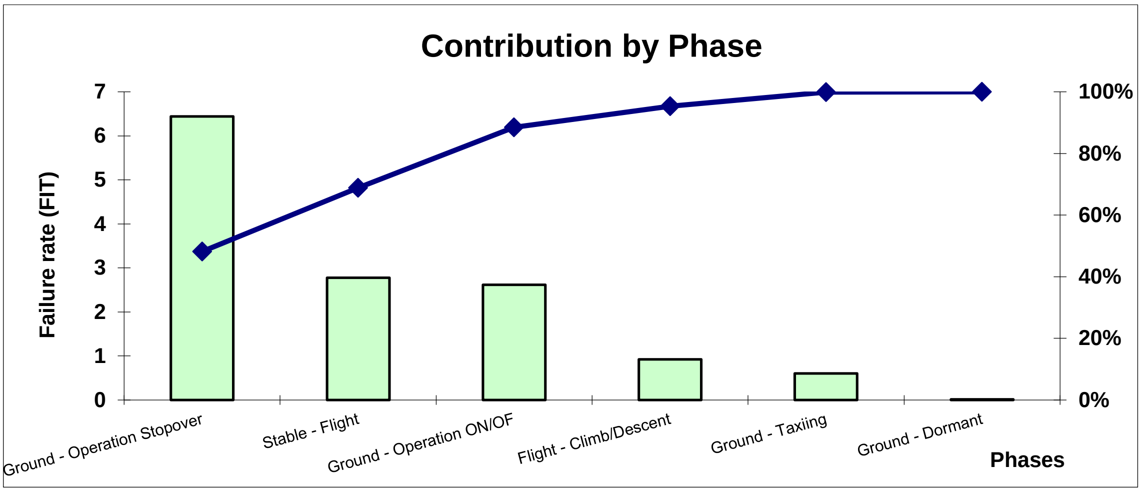
The impact of the "environmental pollution" factor comes into play at the time that the aircraft is on the ground during the "Ground-Operation-ON/OFF", "Ground-Operation-Stopover" and "Ground-Dormant" phases. In these cases, the equipment can be directly subject to the outside environment in an airport type environment.

Concerning application pollution, only the "Ground-Dormant" phase might require action by persons close to equipment compartments.

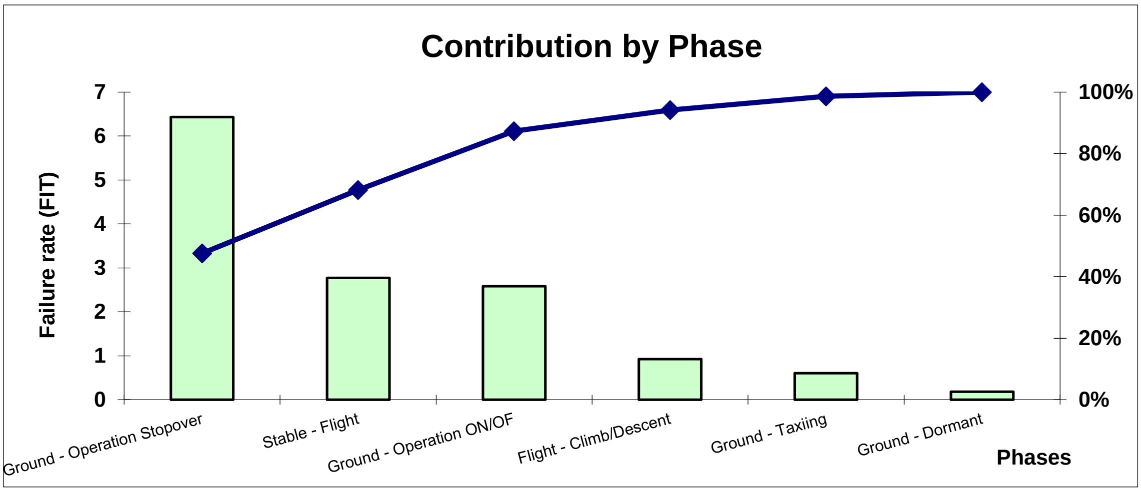
Annex D – Contribution by flight phase for λ graph



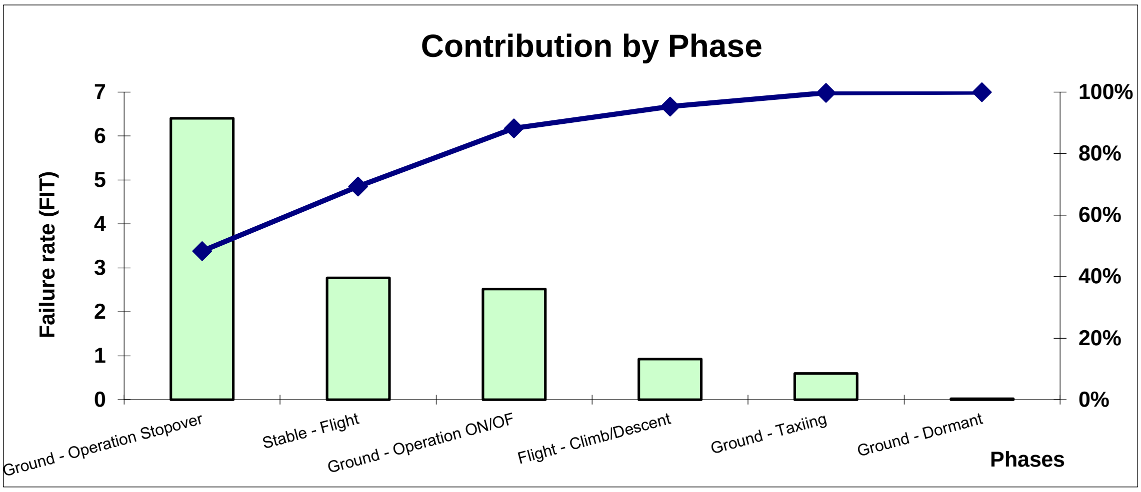
Toshiba TC7MB3253FK



Philips Components 100164Y



Philips Components 100164A



Toshiba TC3W01F