ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

FLIGHT SAFETY RISK AWARENESS AT FLIGHT TEST ACTIVITIES WITH ANALYTICAL HIERARCHY PROCESS METHOD

M.Sc. THESIS

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

ANALİTİK HİYERARŞİ SÜREÇ YÖNTEMİ İLE UÇUŞ TEST FAALİYETLERİNDE UÇUŞ EMNİYET RİSK FARKINDALIĞI

YÜKSEK LİSANS TEZİ

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To my family,

FOREWORD

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Yusuf AKGÜR
Aerospace Engineer

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ABBREVIATIONS

AC	: Advisory Circular
ACAS	: Airborne Collision Avoidance System
AFM	: Aircraft Flight Manual
AHP	: Analytical Hierarchy Process
AIR	: Aircraft Certification Service
ANS	: Air Navigation Service
ATM	: Air Traffic Management
ATO	: Approved Training Organization
ATS	: Air Traffic Services
CAA	: Civil Aviation Agency
CASA	: Civil Aviation Safety Authority
CFIT	: Controlled Flight into Terrain
CFR	: Code of Federal Regulations
CG	: Center of Gravity
CPL	: Commercial Pilot License
CS	: Certification Standards
DGCA	: Directorate General of Civil Aviation
DOA	: Design Organisations Approval
DT&E	: Development Test and Evaluation
EASA	: European Aviation Safety Agency
ERP	: Emergency Response Plan
ETPS	: The Empire Test Pilot School
FAA	: Federal Aviation Authority
FDM	: Flight Data Monitoring
FSTDs	: Flight Simulation Training Devices
FTE	: Flight Test Engineer
FTI	: Flight Test Instrumentation
FTOM	: Flight Test Operations Manual
ICAO	: The International Civil Aviation Organization
IR	: Instrument Rating

ITPS : International Test Pilot School

LFTE : Lead flight test engineer

LOA : Letter of Authorization

MTOM : Maximum Take-Off Weight

NATO : North Atlantic Treaty Organization

NTPS : National Test Pilot School

OT&E : Operational Testing and Evaluation

PIC : Pilot in Command

PIO : Pilot Induced Oscillations

POA : Production Organisations Approval

SAAB : Sweden Aircraft Industries (Svenska Aeroplan AktieBolaget)

SAG : Safety Action Groups

SMS : Safety Management System

SPI : Safety Performance Indicators

SPT : Safety Performance Targets

SRB : Safety Review Board

SRM : Safety Risk Management

STC : Supplemental Type Certificate

TAWS : Terrain Awareness and Warning System

TC : Type Certificate

TCAS : Traffic Alert and Collision Avoidance System

THA : Test Hazard Analysis

TIA : Type Inspection Authorization

TP : Test Pilots

V_{MCG} : Minimum Containment Ground Speed

V_{MU} : Velocity of Minimum Unstick

SYMBOLS

λ_{max}	: Consistency check value
a_{ij}	: Elements of comparison matrix
b_{ij}	: Elements of normalized matrix
CI	: Consistency Index
CR	: Consistency Ratio
n	: Number of elements
RI	: Random Consistency Index
w_i	: The weight of each risk

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FLIGHT SAFETY RISK AWARENESS AT FLIGHT TEST ACTIVITIES WITH ANALYTICAL HIERARCHY PROCESS METHOD

SUMMARY

In 1903, the Wright brothers succeeded in flying the first manned and propelled heavier-than-air aircraft, which soon led to the birth of aviation and the spread of aircrafts. Aircrafts, which started to be produced for different purposes, have caused many accidents and even deaths in their post-production use and especially in the design development stages. Over the years, various arrangements have been made, international agreements have been signed, and local and international organizations have been established in order to prevent these accidents and deaths and to manage aircraft operations safely.

Annex-19 Safety Management System (SMS), which is the 19th and last annex of the International Civil Aviation Organisation (ICAO) Air Transport rules, is a system for managing the safety risks of organizations carrying out aviation activities and ensuring the effectiveness of safety risk controls, and includes systematic procedures, practices and policies for the management of these risks. Implementation of SMS in organizations carrying out civil aviation activities has started to be made compulsory by relevant local and international authorities.

The studies which aim to prove whether the designed and manufactured aircraft provide the desired performance are called flight tests. Advances in technology, when incorporated into aircraft design processes, have led to the creation of formal requirements and specifications that provide universal benchmarks in aircraft design processes. Parallel to these developments, the aims and applications of flight testing have also matured and become a discipline. Flight tests are high-risk flights since they are carried out with aircraft that have not been certified yet, have low flight hours, and have many unknowns about the nature of the aircraft. For these reasons, within the scope of flight test activities, the risks should be determined in advance, necessary mitigation studies should be carried out and test procedures should be determined.

It is stated in the Flight Test Operational Manuel (FTOM) guide document published by EASA that flight test organizations should improve the SMS. In this document, flight test risk management activities and risk management activities that must be carried out within the scope of SMS are separated. Flight test risk management was held responsible for the management of specific risks specific to each flight test, while SMS risk management was held responsible for operational risks that constitute continuity.

Within the scope of this study, the Analytical Hierarchy Process (AHP) method, which is a hierarchical weighted multi-purpose decision analysis method that combines qualitative and quantitative analysis methods, was used to provide a holistic awareness of flight safety risks in flight test activities. When using the weighting function of the AHP method, the safety risk matrix published by the SMS risk management of the relevant institution is based on and it is aimed to determine how important the risks

are to each other. The values selected from the risk matrix for the risk specific to the flight test and operational risks are multiplied with the coefficients to be determined for each risk level to create a comparison matrix and the weight of each risk is calculated. It is expected that the flight test risk will have the largest share in the weighting to be achieved, and the evaluation of the results in this direction. Providing corrective feedback on the coefficients determined for each risk level, the choice of risk value and the structure of the risk matrix are the gains that can be achieved in addition to flight safety risk awareness.

The use of the safety risk matrix and the values here while calculating the weights of the risks eliminates the subjective evaluation in the AHP method and makes the consistency index 0. However, the method used is subjective due to the structure of the risk matrix, the selected risk values and coefficients. For this reason, the returns to be obtained in line with the outputs of the method will allow these subjective values to change and take their optimum form over time.

This study, which started in line with the definitions in the EASA Part-21 FTOM Guide document, became an example of how Flight Test Risk Management and Safety Management System can work together. As a result, it is aimed to raise awareness of the flight safety risks involved in Flight Test Activities to the relevant flight test team by making use of the weighting feature of the AHP method.

ANALİTİK HİYERARŞİ SÜREÇ YÖNTEMİ İLE UÇUŞ TEST FAALİYETLERİNDE UÇUŞ EMNİYET RİSK FARKINDALIĞI

ÖZET

Uçmak, geçmişten günümüze birçok insan için tutku, gizem ve hatta son derece kutsal bir olgu olarak bile görülmüştür. Uçma hayaline uluşmak için dünyanın farklı yerlerindeki insanlar yüzyıllarca uçmanın yollarını aramış ve en nihayetinde yapılan doğa gözlemleri, matematiğin ve fiziğinde gelişmesiyle birlikte uçuş dinamikleri öğrenilmiştir. 1903'te Wright kardeşler ilk insanlı ve tahrikli havadan ağır uçağı uçurmayı başarması kısa sürede havacılığın doğuşuna ve hava araçlarının yaygınlaşmasına yol açmıştır. Bu araçlar posta taşımacılığından insan taşımacılığına, hobi amaçlı kullanımlardan askeri kullanımlara kadar geniş bir yelpazede kullanılmaya başlanmıştır.

Farklı amaçlar için üretilmeye başlanan hava araçları, üretim sonrası kullanımlarında ve özellikle tasarım geliştirme aşamalarında birçok kazalara ve hatta ölümlere neden olmuştur. Havacılığın ilk yıllarında daha çok teknik sebeplerle yaşanan bu kazalar, teknolojinin gelişip teknik hataların azaltılmasıyla insan faktörleri ve ardından organizasyonel etkiler kaynaklı yaşanmaya başlanmıştır. Yıllar içerisinde bu kaza ve ölümlerin önüne geçebilmek ve hava aracı operasyonlarını emniyetli bir şekilde yönetebilmek için çeşitli düzenlemeler yapılmaya başlanmış, uluslararası anlaşmalar imzalanmış, yerel ve uluslararası kuruluşlar oluşturulmuştur. Hava araçlarının ortaya çıkmaya başladığı ilk günlerde sayfalarla ölçülebilen bu düzenlemeler, günümüzde kitaplarla ölçülebilecek kurallar bütünü ve üzerlerinde çalışılan uzmanlıklar haline gelmiştirler.

Havacılık emniyeti, 1990'ların ortalarında organizasyonel, insani ve teknik faktörleri kapsayan sistematik bir perspektifte ele alınmaya başlanmıştır. Örgüt kültürü ve politikalarının emniyet riski kontrollerinin etkinliği üzerindeki etkileri bu dönemde dikkate alınmaya başlanmış ve "Örgütsel kaza" kavramı ortaya çıkmıştır. Reaktif ve proaktif yöntemler kullanılarak toplanan ve analiz edilen emniyet verileri, kuruluşların belirledikleri risklerini izlemelerini ve ortaya çıkan emniyet eğilimlerini tahmin etmelerini sağlamıştır. Bu gelişmeler, günümüzün emniyet yönetimi yaklaşımının ortaya çıkmasına neden olan temel bilgi ve altyapıyı oluşturmuştur.

Sivil havacılığın uluslararası bağlamda ve küresel ölçekte emniyetli ve düzenli bir şekilde gelişmesini sağlamak ve uçuş emniyetini artırmak amacıyla 1944 yılında Chicago Konvansiyonu'ndan sonra kurulan Uluslararası Sivil Havacılık Örgütü (ICAO) Hava Taşımacılığı kurallarının ayrıntılarının yer aldığı ekler yayınlamıştır. Yaşanılan gelişmeler neticesinde bu eklerin 19. ve sonuncusu olan Emniyet Yönetim Sistemi (SMS) 2013 yılında yayınlanmıştır. Emniyet Yönetim Sistemi, emniyet yönetimine yönelik sistematik ve belgelenmiş bir yaklaşımdır ve genel amacı, kuruluşun iş hedeflerine emniyetli bir şekilde ulaşmasını sağlamaktır.

Ek-19 Emniyet Yönetim Sistemi, havacılık faaliyetleri yürüten kuruluşların emniyet risklerini yönetmeye ve emniyet riski kontrollerinin etkinliğini sağlamaya yönelik bir sistem olup bu risklerin yönetimi için sistematik prosedürler, uygulamalar ve politikalar içerir. İlgili yerel ve uluslararası otoriteler tarafından SMS'nin bu kuruluşlarda uygulatılması zorunlu hale getirilmiştir. Bu kuruluşlar ilk olarak havayolları, hava alanları, hava trafik kontrol üniteleri ve onaylı eğitim kuruluşları olup Avrupa Parlementosunun (EU) 2022/201 numaralı komisyon yönetmeliği gereği sivil hava aracı, motoru, pervaneleri ve parçalarının tasarlayan ve üreten tasarım ve üretim organizasyonları için zorunlu hale gelecektir.

Gün geçtikçe büyümeye devam etmekte olan gerek askeri gerekse sivil havacılığın artan talep ve ihtiyaçları doğrultusunda her yıl farklı kategorilerden binlerce hava aracı gökyüzü ile buluşmaktadır. Üretilmekte olan bu hava araçlarının, özellikle de henüz tasarımı olgunlaşmamış, sivil sertifikaya sahip olacak olanlar ilgili otoriteler tarafından belirlenen birçok spesifikasyona sahip olması ve bunlara olan uyumluluğunun belgelenmesi gerekmektedir. Bu uyum doğrulama faaliyetleri hava aracı ile yapılacak uçuş testlerini de içermektedir. Uçuş testleri henüz sertifiye olmamış, düşük uçuş saatine sahip ve hakkında birçok bilinmezin bulunduğu hava araçları ile icra edildikleri için yüksek riskli uçuşlardır. Bu sebepten uçuş test faaliyetleri kapsamında bu risklerin önceden belirlenip gerekli mitigasyon çalışmalarının yapılması ve test usullerinin belirlenmesi gerekmektedir. Bu faaliyetler Uçuş Test Risk Yönetimi olarak adlandırılmakta olup bu alandaki faaliyetler ilgili kategorideki uçuş test derecesine sahip uçuş test pilotları ve uçuş test mühendisleri tarafından yürütülmektedir.

İlk uçuş denemelerinin başlamasıyla ortaya çıkan uçuş testlerinin amacı, her ne kadar günümüzde askeri uçaklarda kullanılan teknoloji ilkel uçak teknolojisinden uzak olsa da değişmemiştir. Uçuş testi, en basit şekliyle, tasarlanan ve üretilen hava aracının istenilen performansı sağlayıp sağlamadığının kanıtlanması çalışmasıdır. İstenen performans kriteri geçmişte pilotun yaralanmamış veya uçağın hasar görmemiş olması iken, günümüzde genişletilmiş olup ve farklı bir seviyededir. Uçaklarda performans, güvenilirlik, bakım yapılabilirlik vb. konularda iyileştirmeler aranırken, askeri uçaklar açısından ise uçağın her türlü hava koşulunda uçabilmesi ve silah taşıyabilmesi için çeşitli sistemler geliştirilmiştir. Teknolojideki bu gelişmeler, uçak tasarım süreçlerine dahil edildiğinde, uçak tasarım süreçlerinde evrensel ölçütler sağlayacak resmi gereksinimlerin ve spesifikasyonların oluşturulmasına yol açmıştır. Bu gelişmelere paralel olarak uçuş testinin amaç ve uygulamaları da olgunlaşmış ve bir disiplin haline gelmiştir.

Tasarım organizasyonlarının bir parçası olan Uçuş Test faaliyetleri uçuş test organizasyonları tarafından gerçekleştirilmektedir. Uçuş test organizasyonlarının SMS'i geliştirmeleri gerektiği EASA tarafından yayınlanmış olan FTOM kılavuz dokümanında belirtilmiştir. Uçuş test organizasyonunda geliştirilecek SMS'nin eğer var ise kuruluşun SMS'sine entegre olması gerektiği de bu dokümanda belirtilmiştir. Yine bu dokümanda Uçuş Test Risk Yönetim faaliyetleri ile SMS kapsamında yürütülmesi gereken risk yönetim faaliyetleri ayrıştırılmıştır. Uçuş test risk yönetimi her bir uçuş testine özel spesifik risklerin yönetiminden, SMS risk yönetimi ise süreklilik teşkil eden operasyonel risklerden sorumlu tutulmuştur.

Bu çalışma kapsamında uçuş test faaliyetlerindeki uçuş emniyet risklerine bütüncül bir şekilde farkındalık sağlanması için nitel ve nicel analiz yöntemlerini birleştiren, hiyerarşik ağırlıklı çok amaçlı bir karar analizi yöntemi olan AHP metodundan faydalanılmıştır. AHP metodunun ağırlıklandırma fonksiyonu kullanılırken risklerin birbirine göre ne kadar önemli olduklarını ilgili kuruluşun SMS risk yönetimi kapsamında yayınlanmış olan emniyet risk matrisi baz alınmıştır. Uçuş testi özelindeki risk ve operasyonel riskler için risk matrisinden seçilen değerler her bir risk seviyesi için belirlenecek olan katsayılar ile çarpılarak karşılaştırma matrisi oluşturulur ve her bir riskin ağırlığı hesaplanır. Uçuş test riskinin elde edilecek ağırlıklandırma da en büyük paya sahip olması beklenmekte olup bu doğrultuda çıkan sonuçların değerlendirilmesi her bir risk seviyesi için belirlenen katsayılara, risk değeri seçimine ve risk matrisinin yapısına yönelik düzeltici geri dönüşler sağlaması uçuş emniyet risk farkındalığı yanında elde edilebilecek kazanımlardır.

Risklerin ağırlıklıkları hesaplanırken emniyet risk matrisinin ve buradaki değerlerin kullanılması AHP metodundaki sübjektif değerlendirmeyi ortadan kaldırmakta, tutarlılık indeksini 0 yapmaktadır. Ancak kullanılan yöntem risk matrisinin yapısı, seçilen risk değerleri ve katsayılardan dolayı sübjektif olmaktadır. Bu sebeple, metodunun çıktıları doğrultusunda elde edilecek geri dönüşler bu sübjektif değerlerin değişmesine ve zamanla en optimum halini almasına imkan verecektir.

SMS'nin uçuş test faaliyetleri gerçekleştiren kuruluşlara uygulanması halihazırda buralarda yürütülen Uçuş Testi Risk Yönetimi ile benzerlikler göstermektedir ancak birbirinden farklıdırlar. EASA FTOM kılavuz dokümanındaki tanımlar doğrultusunda başlayan bu çalışma, Uçuş Testi Risk Yönetimi ve Emniyet Yönetim Sisteminin birlikte nasıl çalışabileceğinin bir örneği olmuştur. Sonuç olarak, AHP metodunun ağırlıklandırma özelliğinden faydalanılarak ilgili uçuş test ekibine Uçuş Test Faaliyetlerinde yer alan uçuş emniyet riskleri konusunda farkındalık yaratmak amaçlanmaktadır. Farkındalık sağlanmasının yanında, metodunun çıktılarından elde edilecek geri dönüşler uçuş emniyetinin gelişimine de katkı sağlayabilecektir. Zaman geçtikçe bu çalışma ve ortaya çıkacak benzer yeni çalışmalar doğrultusunda uçuş test organizasyonlarında uçuş emniyeti faaliyetleri daha standart hale getirecektir.

1. INTRODUCTION

Flying has been seen as a passion, mystery and even as an extremely sacred phenomenon, as mentioned in Turkish mythology, for many people from past to present. Even so that it was thought the Turk, who believed in the God (Gök Tengri), had to "fly" to go to heaven [1]. It is for these reasons that humanity has sought ways to fly in different parts of the world for centuries, and has achieved this by observing nature and learning laws of nature. In 1638, Hezarfen Ahmet Çelebi flew over the Bosphorus with a pair of wings inspired by birds, in 1783 Montgolfier brothers flew using a hot air balloon which they invented in Paris, and in 1903 the Wright brothers succeeded in flying the first manned and propulsion aircraft that was heavier-than-air. This success of the Wright brothers led to the birth of aviation and widespread use of aircrafts in a short time. These vehicles started to be used in a wide range from postal transportation to human transportation, from hobby uses to military uses.

The adventure, which started with aircrafts, continued with the invention of helicopters, rockets that will carry humanity beyond the Earth, and many other aircraft. These aircrafts, produced for different purposes, caused many accidents and even deaths in their post-production use and especially in the design development stages. Over the years, various regulations have started to be established, international agreements have been signed, and local and international organizations have been established in order to prevent these accidents and deaths and to manage aircraft operations safely. These regulations, which could be measured in pages in the first days when aircrafts began to emerge, have become a book-filled set of rules and a profession to be studied today. When talking about these regulations in aviation, it is mentioned that they are written in blood because the new regulations added are unfortunately created as a result of lessons learned from the accidents usually.

In order to ensure the safe and orderly development of civil aviation in the international context and on a global scale and to improve flight safety the International Civil Aviation Organization (ICAO), which was established in 1944 after the Chicago Convention, has published annexes for the details of the rules of air transport. These annexes are issued in many areas such as Pilot Licensing, Air Traffic Services and Airworthiness. The 19th and latest of these annexes is Safety Management System (SMS), which was published in 2013 [2]. The overarching goal of SMS is to enable the organization to safely fulfill its business objectives through a structured and documented approach to safety management.

Following the announcement of Annex-19 by ICAO, the SMS has been started to be implemented by various organizations in the aviation sector, based on the basic four principles (Safety Policy, Safety Risk Management, Safety Assurance and Safety Promotion) accepted by national and international aviation authorities. To give an example, the European Aviation Safety Agency (EASA), which is followed closely by the DGCA (Directorate General of Civil Aviation) started to obligate SMS into approved training organizations, commercial operators and non-commercial operators of complex motor-powered aircraft. Furthermore, EASA plans to put practice SMS into to maintenance, design and production organizations [3]. In summary, as Blake (2014) mentioned, regulators have made significant progress in recent years to implement ICAO's SMS into airlines, albeit as a required or recommended practice. More recently the regulators are seeking to implement SMS into the aircraft manufacturing and aircraft maintenance domains.

Unlike airlines, aviation companies such as Boeing, Airbus, TUSAŞ, which have design and production activities, have a more complex structure and many fields consisting of different engineering disciplines. In particular, the regulations for companies which develop civil aircrafts must comply with in order to prove and certify the airworthiness of the vehicles they produce are specified in EASA Part-21 which regulates the approval of aircraft design and production organisations and the certification of aircraft Products, Parts and Appliance [4].

1.1 Purpose of Thesis

A company that is subject to Part-21 due to the civil aircraft they produce has simply design, production, maintenance and flight test activities. When it comes to the implementation of the SMS in these organisations, it should be applied in a broad perspective, covering these four areas. Flight Test Operations Manual (FTOM) guide, which is a guide document on how flight test activities should be carried out, has been published by EASA. This document is intended to assist approved Design

Organisations (DOA) and Production Organisations (POA) in the production of a FTOM. EASA Part-21 requires that the flight test organisation to develop an SMS. But also indicate if company SMS exists, the flight test organisation should be integrated with the company SMS [5].

In addition to the fact that the flight itself has many risks, flight test activities have more than these, some risks of their own, and the management of these risks is very important for the safe execution of flight tests. For the management of these risks, the FTOM guide document separate the flight test risk management and safety management.

The safety management implemented by SMS is a continuous and strategic system that includes incident reporting, research, trend analysis and the like. Flight test risk management is not the same as safety management but it complements safety management. The flight test risk management process is established to manage hazards directly related to flight test activities and certain flight tests. To make it clear, there are continuous risks in flight tests as well as in all flights such as CFIT (Controlled Flight into Terrain), bird strike, mid-air collision etc. These continuous flight risks would be managed under the SMS. However, there may introduce specific risks associated with that particular flight test in a flight test. For example, a minimum control speed test presents a risk of loss of directional control. This resulting risk will only be valid for aircraft with that activity. The risk level to be calculated in this scenario will be decided by the characteristics of the aircraft doing the test. There can also be some flights that a risk managed by the SMS could be greatly increased by the flight test and such cases the associated flight risks should be managed under the flight test risk management [5].

In addition to the FTOM guidance document, FAA ORDER 4040.26C Annex-C also distinguishes between flight test risks and other risks in the risk management process. In this document minimum control air speed is again given the as example of flight test. Furthermore, it has been established that the risk associated with specific flight test methodologies is superior than the hazard involved with operational flying. And once again, but in a different way, The operational hazards connected with flying a test aircraft, which arise from the aircraft's configuration or the environment in which it is flown, as well as the hazardous conditions that may lead to these risks, must be considered. [6]. Boing UK also mentioned about this topic in its Test and Evaluation methodology as generic and test risks [7].

In conclusion, when the relevant documents are examined, it is understood that the risks related to the subject to be tested directly in the flight test activities should be evaluated, and the operational risks arising only from the flight should be addressed separately from the flight test. Of course, the risks related to the subject to be tested need to be given more important and priority attention, but operational risks need to be aware of and followed. In this thesis, it is aimed to provide this awareness by making use of the analytical hierarchy process method. In order to better understand the method to be used, the analytical hierarchy process will be explained after a wide literature review in the next step. In the literature review, the titles of Safety Management System, Flight Test Activities and Flight Test Safety are discussed in detail.

2. LITERATURE REVIEW

2.1 Safety Management System (SMS)

Safety, in its simplest form, can be defined as a state in which or a place is safe and not in hazard or at risk [8]. In terms of aviation, it is said that safety is always the number one priority and it has special importance. The most recent of the 19 documents, which are the annexes of the Chicago Convention, containing the international aviation standards managed by ICAO, is Annex 19 adopted in 2013 and is called Safety Management System (SMS). SMS itself is an indication of the importance given to safety in aviation and ICAO defines SMS as follows: "A systematic approach to managing safety, including the necessary organizational structures, accountability, responsibilities, policies and procedures" [9]. As it can be understood from the definition of ICAO, the meaning of safety in aviation has become more specific and it is mentioned that safety has control and acceptable levels. As such, managing safety in aviation is an important task. Similar to other management functions, safety management entails planning, organizing, communicating and providing direction.

2.1.1 Historical Background and Evaluation of SMS

The SMS is unlikely to start as a result of a particular event at a particular time. Rather, it has been the result of an evolutionary process with a lot of combining of ideas from other management and scientific domains and a lot of sharing of information within the air safety community [10]. In the wake of the Three Mile Island and Chernobyl disasters, it is highlighted for the need for a systemic risk management approach that is predictive, proactive, non-punitive, repeatable, has top management accountability and focuses on a safety culture, all of which have become cornerstones of the SMS philosophy and architecture [3]. Other domains adopted the theory as SMS was established and institutionalized, such as the maritime industry [11] and railway firms in 2001 under Transport Canada [12].

In the mid-1990s, the SMS ideology was noticed by the FAA and other aviation regulators around the world. Instead of pursuing the decades-old reactive approach of largely mitigating after an incident or accident investigation, benefit of SMS as a methodology that could apparently forecast the possibility of a risk occurrence and make proactive improvements is recognized by the authorities. Despite the fact that the reactive technique for increasing safety has been proven to be beneficial, there was still a need for a method or system that could help uncover latent situations that could lead to accidents before they happened for the aviation industry. In order to support the implementation of this new approach to the management of safety, the ICAO Safety Management System (SMS) program was launched in 2004 [13].

In order to better understand the development of SMS in aviation, it is necessary to examine how safety has developed in aviation and the prevailing understandings over the years. The early pioneers of aviation had little regulation, practical experience, and engineering knowledge to guide them in safety. Advances in technology, operational experience and regulations in aviation activities have contributed significantly to aviation safety. Then, a second stage was started for aviation safety, with the introduction of human factors that focus on individual and team performance which reduce accidents. While human factors focus only on the person, the operational and organizational context is not taken into account, and as a result, a safety understanding has developed to include them as well. These developments in aviation safety can be divided into four periods historically: the technical era, the human factors era, the organizational era and the total era.

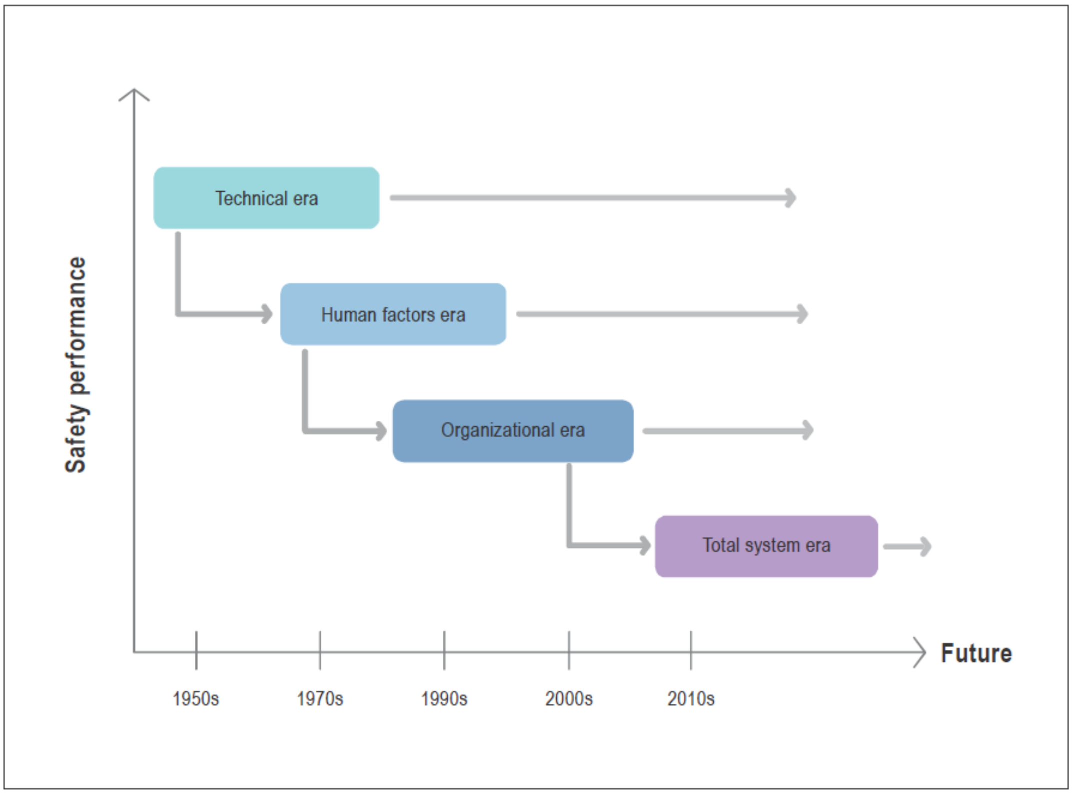

Figure 2.1 : The evaluation of aviation safety [14].

From the beginning of the 1900s, when the first aircraft was invented, to the end of the 1960s, technical factors were the most important causes of safety deficiencies in aviation, and investigation and elimination of deficiencies caused by technical factors took place in the focus of safety improvement studies. As a result of the developments in aviation technology with the coming of the 1950s, a gradual decrease occurred in accident-crash rates, and in parallel with this, compliance with regulations and surveillance issues began to be focused on in safety studies.

By the early 1970s, there was a significant decrease in aviation accidents with the development of technological advancement and aviation regulations and then the focus of aviation safety shifted to the human factors. In this period, when subjects such as the human-machine interface were started to be studied, human factors focused only on the person, while the operational and organizational context was not taken into account.

Safety began to be addressed in a systematic perspective in the mid-1990s, encompassing organizational, human, and technical factors. The effects of organizational culture and policies on the effectiveness of safety risk controls began to be taken into account in this period, and the concept of “Organizational accident” emerged. In addition, safety data collected and analyzed using reactive and proactive methods enabled organizations to monitor their identified risks and to anticipate emerging safety trends. These developments formed the basic knowledge and infrastructure that led to the emergence of today's approach to safety management.

Since the beginning of the 21st century, many countries and service providers (an organization that provides services in civil aviation) have not only assimilated the safety approaches of previous periods, but have reached a higher level of safety maturity than these approaches. These countries and service providers have started to see positive results of safety management by implementing the State Safety Program (SSP) and Safety Management System (SMS).

2.1.2 SMS Framework

Annex 19, published by ICAO, provides a framework for how SMS should be in service providers, their implementation and maintenance. Regardless of the size or complexity of the service provider, the aspects of this established framework are totally valid. However, the only thing that is specific here is the framework, how the implementation will be depends on the organization and its activities and should be adapted to the organization. The ICAO SMS framework consists of the following four components and twelve elements as shown in the table 2.1 [14]:

Table 2.1 : Components and elements of the ICAO SMS framework.

COMPONENTS	ELEMENT
1. Safety policy and objectives	1.1 Management commitment
	1.2 Safety accountability and responsibilities
	1.3 Appointment of key safety personnel
	1.4 Coordination of emergency response planning
	1.5 SMS documentation
2. Safety risk management	2.1 Hazard identification
	2.2 Safety risk assessment and mitigation
3. Safety assurance	3.1 Safety performance monitoring and measurement
	3.2 The management of change
	3.3 Continous improvement of the SMS
4. Safety promotion	4.1 Training and education
	4.2 Safety communication

2.1.2.1 Safety Policy and Objectives

The first component of the SMS framework, safety policy and objectives, focuses on creating an environment in which safety management can be effective. Safety policy consists of setting goals, standards, and assigning responsibilities, and is also where management communicates the organization's commitment to safety performance to its employees.

<u>a) Management Commitment</u>

Senior management and the responsible manager should endorse the safety policy in a way that makes management's active support for the policy evident to the rest of the company. In this way, it is ensured that other employees are more serious and aware of safety. In line with this, it is the responsibility of management to disseminate the safety policy throughout the organization so that all employees are aware of it and are working in compliance with it. This policy should include relate to the safety reporting system to encourage employees to report safety incidents or issues, as well as advise them of the disciplinary policy that will be enforced in the event of reported safety incidents or difficulties. Including safety data and safety information in this policy, as well as issues related to the protection of reporters, will have a positive impact on the reporting culture.

<u>b) Safety accountability and responsibilities</u>

Alongside the policy, in order to specify what it wants to achieve in terms of safety results, the service provider should set safety objectives. Safety policy and safety objectives should be reviewed periodically to ensure they remain current. The Responsible Manager is the individual who sets and promotes safety as a key business value, as well as the safety policy and objectives, designated by the service provider. The Accountable Executive must be at a level in the organization with the authority to take action to ensure that the SMS is effective.

<u>c) Appointment of key safety personnel</u>

For an SMS to be implemented and work well, a qualified person or persons must be appointed to serve the role of safety manager. For the delivery of the SMS and the delivery of safety services to other departments in the organization, the person performing the safety manager position is accountable to the responsible manager. In a service provider organization, the SMS's top safety committee is referred to as the

Safety Review Board (SRB) and is made up of the safety manager, who attend in an advisory capacity, responsible manager and senior executives. The SRB is a high-level advisory body that oversees safety policies, resource allocation, and organizational performance. Managers and front-line staff make form Safety Action Groups (SAGs), which are managed by a designated manager and deal with specific implementation challenges in accordance with the strategies set by the SRB.

d) Coordination of emergency response planning

Coordination of emergency response planning refers to the planning of activities that take place within a limited period of time during an unscheduled aviation operational emergency. For handling aviation emergencies, crises, or accidents, an emergency response plan (ERP) is an important part of a service provider's safety risk management strategy. The ERP's overall goal is to keep operations safe and get them back to normal as quickly as possible. It should handle foreseeable emergencies indicated through SMS and contain mitigation measures, processes, and controls to successfully manage aviation emergencies. The ERP should specify what steps responsible individuals should take in the event of an emergency and be immediately accessible to the required key personnel as well as coordinating external organizations.

e) SMS documentation

A high-level "SMS manual" that describes the service provider's SMS policies, processes, and procedures to facilitate the organization's internal management, communication, and maintenance of the SMS should be included in SMS documents containing a system description that provides the SMS boundaries. This material should be modified and created to address day-to-day safety management operations in a way that all employees can understand. In addition, operational records confirming the existence and ongoing functioning of the SMS must be compiled and maintained. The SMS guide can be a standalone document or can be integrated with other corporate documents (or documents) provided by the service provider. When specifics of the organization's SMS operations are already covered in existing documentation, cross-referencing is adequate. It would be more meaningful for the SMS Manuel to reference other documents, especially in large organizations where complex and multiple aviation activities are carried out together.

2.1.2.2 Safety Risk Management

The Safety Risk Management (SRM) process systematically identifies hazards that exist with regards to the delivery of their products or administrations. Hazards can be the consequence of frameworks lacking in design, technical functionality, human interface, or cooperation with different cycles and frameworks, or they can result from the unsuccess of existing process to adjust to changes in the service provider's operating environment. Cautious investigation of these variables can frequently distinguish possible hazards anytime in the activity or business lifecycle. Safety risk assessments and mitigations must be reviewed on a regular basis to ensure that they are still effective. Figure 2.2 gives an outline of the hazard identification and safety risk management process for a service provider.

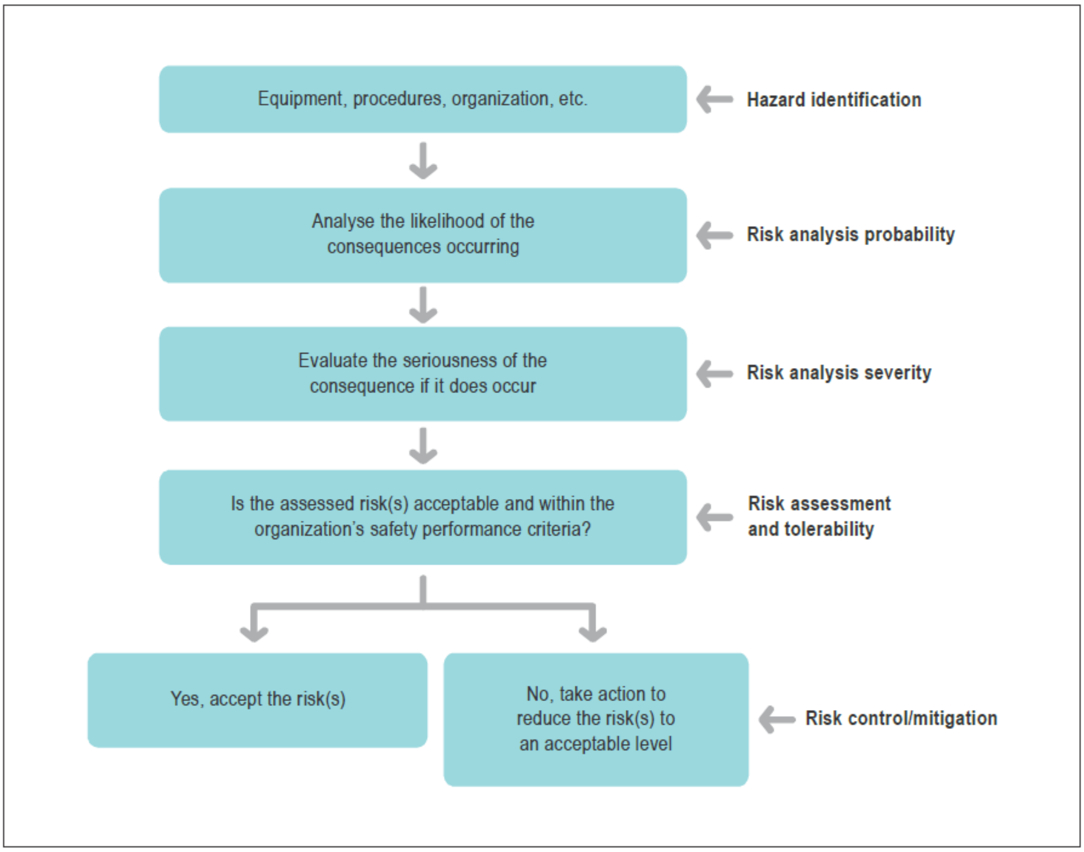

Figure 2.2 : Hazard identification and risk management process [14].

a) Hazard identification

A hazard is a condition or object – always present – with the potential of causing injuries to personnel, damage to equipment or structures, loss of material, or a reduction of ability to perform a prescribed function during transportation operations [15]. The service provider must design and maintain a formal process for identifying hazards that may affect aviation safety in all areas of operations and activities, including equipment, facilities, and systems, as the first step in the SRM process. It is advantageous to the safety of the operation to identify and control any aviation safety hazard. Additionally, essential to consider the hazards might exist because of SMS interacts with outside entities.

In order to identify hazard, several sources can be used and this sources can be internal or external to the organization. Normal operations monitoring, automated monitoring systems, voluntary and mandatory safety reporting systems, audits, feedback from training and service provider safety investigations are some examples of the internal sources. Aviation accident reports, state mandatory and voluntary safety reporting systems, state oversight audits, third-party audits, trade associations and information exchange systems are some examples of the external sources.

b) Safety risk assessment and mitigation

The organization that implemented SMS must design a safety risk assessment model and procedures that will allow for a consistent and methodical approach to the assessment of safety hazards. In order to determine what safety risks are acceptable or unacceptable and which action has priority, the model should include a method. In order to better understand this process, it is important to understand some definitions well. The potential outcomes of the hazard identified in the previous step are the consequences. And the safety risk is the quantification – expressed in terms of predicted probability and severity – of the potential consequence(s) of a hazard taking as reference the worst foreseeable (but credible) situation [2]. An important point of consideration is the fact that safety risk does not exist in the physical world; only hazards do. Hazards are identified and analyzed; safety risk is evaluated. Safety risk is an alphanumeric index that "puts a number" to the potential consequences of hazards [15].

For the purpose of ensuring used SRM tools are suitable for the service provider's operating environment, they may need to be reviewed and customized periodically. As the SMS in the organization matures, the service provider may find more sophisticated approaches that better reflect the necessities of their operation. On account of unavailability of data, safety risk assessments sometimes need to utilize subjective data rather than quantitative data. The user can represent the safety risk(s) associated with the identified hazard in a quantitative format by using the safety risk matrix.The use of the safety risk matrix allows for direct magnitude comparison between identified safety risks. Where quantitative evidence is unavailable, a qualitative safety risk evaluation criterion such as "likely" or "unlikely" may be ascribed to each detected safety risk. Suitable safety risk controls can be executed after safety risks have been assessed. When the hazard control has been concurred and carried out, the safety performance ought to be monitored to guarantee the effectiveness of the safety risk control. This is important to verify the integrity, productivity and viability of the new safety risk controls under operational circumstances.

The Risk Management process consist basically 5 steps, as shown in the figure 2.2: Hazard Identification, Risk Analysis Probability, Risk Analysis Severity, Risk Assessment and Tolerability, Risk Control/Mitigation.

STEP 1: Hazard identification is the first and most important step of the risk management process. Identification of the hazard's precise components, accurate evaluation of the potential result(s), including magnitude, and successful mitigation of the potential consequence are all made possible by properly labeling the hazard (s). The simplest and most effective way to discern between hazards and consequences is to look at their definitions: Hazards are in the present; consequences, on the other hand, are prospective results and so belong in the future [14].

STEP 2: First, the probability of a prospective result is assessed, followed by the severity. Because safety management is primarily concerned with high likelihood/low consequence occurrences, safety risk evaluation and indexing under safety management focuses on lowering the higher probability, as lowering the [lower] severity is difficult – if not impossible – in transportation operations [14]. In order to determine the probability and consequences of potential outcomes, similar tables are used, although there are variations according to the needs of an organization. These tables generally consist of five levels of probabilities and five levels of severity and there may be more or less levels depending on the needs and activities of the organization. For instance, the criterions in order to determine severity and probability of a hazard used by SAAB (Svenska Aeroplan AktieBolaget), Sweden Aircraft Industries [16] in its flight test safety risk management, and a practical guide about SRM published by Civil Aviation Safety Authority (CASA) [17] are as below:

Table 2.2 : SAAB probability determination criterion.

PROBABILITY LEVELS	DEFINITIONS
OFTEN	Happens every test sortie.
SOMETIMES	Count on it happening several times; however, not in every sortie.
SELDOM	Maybe it won't happen, but it cannot be totally ignored.
VERY SELDOM	It is very probable that it won't happen; seldom if we do not expose ourselves too much.
IMPROBABLE	We are certain it won't happen, and we are probably right.

Table 2.3 : SAAB's severity determination criterion.

SEVERITY LEVELS	DEFINITIONS
CATASTROPHE	Malfunction/condition that seriously reduces the aircraft's function, handling qualities and/or the pilot's capability to such a degree that continued safe flight and landing is not possible, with total loss of material, death and serious damage to the environment as a result.
CRITICAL	Malfunction/condition that reduces aircraft function, handling qualities and/or pilot capability to such a degree that serious personal injury, severe damage to material or great environmental damage can result.
MARGINAL	Malfunction/condition that degrades aircraft function and handling qualities in a way that is familiar, and at a level that the pilot can handle, but can lead to minor personal injury, minor damage to material, minor damage to the environment.
NEGLIGIBLE	Malfunction/condition that does not degrade aircraft function and handling qualities or does not noticeably increase the workload on the pilot.

Table 2.4 : CASA's probability determination criterion.

LEVEL	LIKELIHOOD	DESCRIPTOR
5	Almost Certain	Imminent-is expected to occur in most circumstances
4	Likely	Once in the next month, will probably occur in most circumstances
3	Possible	Once in the next 12 months, might occur at some time
2	Unlikely	Once in the next 1-5 years, could occur at some ime
1	Rare	Once in the next 10 years-may occur only in exceptional circumstances

Table 2.5 : CASA's severity determination criterion.

LEVEL	SEVERITY/ CONSEQUENCE	DESCRIPTOR
5	Severe	Catastrophic(at least one fatality, huge financial loss)
4	Major	Major (extensive injuries to on or more people, major financial loss
3	Moderate	Moderate (medical treatment required, high financial loss)
2	Minor	Minor (first aid treatment at the workplace, medium financial loss)
1	Negligible	Insignificant (no injuries, low financial loss)

As can be seen from the tables, organizations make probability and severity classifications in line with their own needs. While both organizations use five levels of probability determination, SAAB uses four levels and CASA suggests five levels for severity determination.

STEP 3: During the risk assessment phase, a value is found on the risk matrix according to the probability and severity levels determined. The risk matrix here consists of the product of probability and severity values and is categorized according to the magnitude of the resulting values. These categories will provide guidance on what the next steps will be. The risk matrices formed in line with the probability and severity tables and the risk levels on these matrices used by SAAB and CASA are as follows:

Table 2.6 : SAAB's safety risk matrix.

	Often	Sometimes	Seldom	Very Seldom	Improbable
CATASTROPHE	24	20	16	12	8
CRITICAL	18	15	12	9	6
MARGINAL	12	10	8	6	4
NEGLIGIBLE	6	5	4	3	2

Table 2.7 : SAAB's safety risk levels.

RISK INDEX	ASSESSMENT	REQUIREMENT
16 - 24	High risk test	Doubtful whether testing can be conducted. Further reviews must be taken regarding additional mitigating risk reduction actions or altered test methods.
9 - 15	Medium risk test	No special requirements. The test is managed in accordance with normal routines with authorised personnel, telemetry and test pilots.
2 - 8	Low risk test	Can be conducted without telemetry, and with low formal requirements on the test plan, etc.

Table 2.8 : CASA's safety risk matrix.

	Negligible 1	Sometimes 2	Seldom 3	Very Seldom 4	Improbable 5
Almost Certain 5	6	7	8	9	10
Likely 4	5	6	7	8	9
Possible 3	4	5	6	7	8
Unlikely 2	3	4	5	6	7
Rare 1	2	3	4	5	6

Table 2.9 : CASA's safety risk levels.

RISK INDEX	ASSESSMENT	REQUIREMENT
> 7	Extreme risk	Detailed treatment plan required
6 to 7	High risk	Needs senior management attention and treatment plan as approriate
4 to 5	Medium risk	Manager-level attention and monitoring as appropriate
< 4	Low risk	Manage by local-level procedurs

When the matrices used by SAAB flight tests and published by CASA as a guide are analyzed, it is seen that the matrix of SAAB makes a 3-level risk classification as low, medium and high, and the matrix used is 4x5. CAA, on the other hand, makes a 4-level risk classification as low, medium, high and extreme high, and uses a 5x5 matrix. In addition, the multiplier values in the matrix used by SAAB are in the range of 2-24. When looking at the guide matrix of CAA, the multiplier values are in the range of 2-10. In both, a high multiplier value indicates a high risk level. Although the matrices used, the values and which values will be at which risk level are different, basically the desired point is the same.

STEP 4: As a result of the risk value and level found in the previous step, whether this risk is acceptable or not, and if it is unacceptable, actions to reduce the level, severity, probability or both of the risk are taken to reduce the risk to an acceptable level.

2.1.2.3 Safety Assurance

Safety Assurance consists of the processes and activities performed to determine whether the SMS is functioning in accordance with expectations and requirements. In addition, Safety assurance includes the continuous monitoring of all processes and operation area of the service provider in order to detect changes or deviations in the system that cause the emergence of new risks or adversely affect existing risk controls.

a) Safety performance monitoring and measurement

It can be stated that the monitoring and measurement of safety performance generally consists of a combination of internal audit processes and the creation and monitoring of safety performance indicators (SPI). One of the tools that enable the evaluation of the effectiveness of the entire SMS is the "internal audit" processes. While internal audits evaluate the effectiveness of the SMS, they also allow areas of potential improvement opportunity to be identified.

The safety performance of the service provider must be verified with reference to the safety performance indicators and safety performance targets (SPT), which are the supporting elements of the safety objectives of the enterprise. SPIs, specific to each service provider and linked to their current safety objectives, are used to survey the overall performance of the service provider's operational safety performance and SMS. SPIs are based on the analysis of data and information from a variety of sources, including data from the reporting system. The process of monitoring and measuring safety performance holistically includes selected SPIs as well as their associated SPTs and alert levels.

It is also important to evaluate the validity of safety risk controls, as the predicted results are not always achieved during the implementation phase. In this way, it can be understood whether the right safety risk control has been chosen and, if necessary, even the conclusion that a different safety risk control strategy should be applied.

b) The management of change

Change management is a structured approach to move employees and organizations from an existing state to a desired new state. Opportune change management helps to ensure that this can be done without adversely affecting employees or having other undesirable consequences. Changes can modify the effectiveness of existing safety risk controls. Therefore, hazards that may arise during changes should be identified and the associated safety risks assessed and controlled, as defined in the entity's current hazard identification and safety risk management procedures. Some examples of changes mentioned in ICAO's SMS Manual are as follows [14]:

- introduction of new technology or equipment;
- changes in the operating environment;
- changes in key personnel;
- significant changes in staffing levels;
- changes in safety regulatory requirements;
- significant restructuring of the organization; and
- physical changes (new facility or base, aerodrome layout changes etc.).

c) Continuous improvement of the SMS

The service provider is responsible for monitoring and evaluating the SMS processes in order to maintain and continuously improve the holistic effectiveness of the safety management system. SMS effectiveness should not be determined exclusively by SPIs, but various methods should be used to measure the effectiveness of SMS, such as internal and external audits, assessments, monitoring of incidents, safety surveys, management reviews, and lessons learned from incidents and reports. As a result, safety performance monitoring and internal audit processes contribute to the service provider's ability to continually improve safety performance. Ongoing monitoring of the SMS, safety risk controls, and supporting systems provides assurance to the service provider and state that safety management processes are meeting desired safety objectives.

2.1.2.4 Safety Promotion

The Safety Promotion is intended to provide employees with a comprehensive understanding of their safety obligations, as well as familiarity with the company's safety rules and standards, reporting procedures, and risk controls. If there is active involvement from operational leaders, clear lines of communication between up and down and colleagues in the organization, vigilance, and assurance that employees know that safety is an important part of their job performance, the organization will have an effective SMS to aid decision making at all levels.

a) Training and education

The service provider is responsible for developing and maintaining a safety training program to ensure that its personnel are trained and competent to perform their SMS duties. In this direction, the scope of the SMS trainings offered to each employee must be proportional to their function in the SMS, and the safety manager is responsible for ensuring that the organization has an acceptable safety training program in place. Initial and recurrent trainings requirements should be included in the training program in order to maintain competencies.

b) Safety communication

The organization's SMS objectives and procedures should be communicated by the service provider to all relevant personnel. A communication strategy should be established to improve safety communication, and depending on this strategy, various channels such as safety news, announcements, bulletins, briefings or training courses can be used to deliver messages effectively to those concerned. In addition, the safety manager should ensure that lessons acquired from incident investigations, historical cases or experiences from internal or external sources are implemented. An important point in safety communication is that safety promotion activities should continue to be performed throughout the SMS lifecycle, not just at the beginning of the SMS implementation.

2.1.3 SMS Obligations

ICAO Annex 19 requires states to implement a safety management system for service providers under their jurisdiction [2]. These service providers are:

- Approved training organizations that are exposed to safety risks associated with aircraft operations during their activities in accordance with Annex-1;
- Aircraft or helicopter operators authorized to engage in international commercial air transport in accordance with the relevant parts of Annex-6;
- Approved maintenance organizations providing services to aircraft or helicopter operators engaged in international commercial air transport in accordance with the relevant parts of Annex-6;
- Organizations responsible for the type design or manufacture of aircraft, engines or propellers within the scope of Annex-8;
- Air traffic services (ATS) providers in accordance with Annex-11; and
- Operators of airports certified in accordance with Annex 14, Volume I.

In this context, how the requirements described in the 2.1.2 subsection of the service providers that need to have a safety management system will be established depends on the regulatory framework of the state. States should provide guidance to their respective service providers on how to develop and implement SMS. The gap analysis in ICAO Doc9859 chapter 9 [14] is a guide on this subject. This guide provides a good plan with milestones and timelines for SMS implementation.

In the document Order.8000.369C [18] published by the United States Federal Aviation Administration (FAA), it is written that the SMS must be complied with by lines of business and staff offices of air traffic organization, aviation safety, airports, commercial space transportation, next generation air transportation system, and security and hazardous materials safety. Similarly, the SHT-SMS [19] instruction published by Turkey's civil aviation authority, DGCA, regulates the procedures and principles regarding the implementation of the safety management system in commercial air transport enterprises, type rating training organizations, flight training organizations and approved maintenance organizations, design and production organizations.

Mandatory reporting is one of the applications that governments make obligatory for the relevant service providers within the scope of SMS. Events that pose a serious hazard to aviation safety and fit into the defined categories must be reported using reporting systems, according to European Parliament regulation (EU) No 376/2014 [20]. Examples of aforementioned aviation safety occurrences and service provider groups responsible for reporting them are specified in the relevant regulation as in Appendix-A.

DGCA in parallel with the regulation of the Council of Europe, has listed aviation safety-related incidents that must be reported by the relevant service providers in the Republic of Turkey in the SHT-OLAY [21] instruction it has published.

On the official website of EASA [22] it is written that there are SMS rules enforced in accordance with the requirements of ICAO Annex-19 in the domain of aviation, excluding airworthiness. The domains here are initial and continuing airworthiness, aircrew, air operations, air traffic management/air navigation services, and aerodromes. The same concepts applied in other aviation domains will be developed into phase II with the published RMT.0251 "Embodiment of safety management system requirements" [23] with the rule maker (EU) Commission Regulations No 1321/2014 and 748/2012. Once the phase II published, SMS requirements, relevant authority oversight and management system requirements for EASA Part-21 approved design organizations, approved production organizations and EASA Part-145 approved maintenance organizations will be introduced by EASA.

According to the commission regulation (EU) 2022/201 [24] published in the Official Journal of the European Union recently, approved design and production organizations producing civil aircraft, engines, propellers and parts will be required to fulfill the safety management system requirements. Currently, these organizations fulfill some of the requirements of the safety management system, but do not cover all the requirements. Missing elements must be added to existing requirements and meet all requirements. It is also written in this regulation that a sufficient transition period will be provided for approved design organizations to ensure their compliance with the new rules and procedures.

2.2 Flight Testing

Flight testing emerged with the start of the first flight trials. Although the technology used in military aircraft today is far from the technology of primitive aircraft, the purpose of the flight test has not changed. Flight testing, in its simplest form, is the study of proving whether the designed and manufactured aircraft can provide the desired performance. While the criterion of desired performance was that the pilot was not injured or the aircraft was not damaged in the past, it is expanded and at a different level today. While seeking improvements in performance, reliability, maintainability, etc. in aircraft, various systems have been developed to enable the aircraft to fly in all weather conditions and to carry weapons in terms of military aircraft. The technology, which will provide the desired improvements in the performance of aircraft, is realized rapidly, especially with the advances in the 21st century. These advances in technology, when incorporated into aircraft design processes, have led to the establishment of formal requirements and specifications that will provide universal benchmarks in aircraft design processes. In parallel with these developments, the purpose and applications of flight test have matured and become a discipline.

After the first controlled powered flight, a comprehensive database was formed as a result of the developments experienced over the years in fundamental subjects of aviation such as aerodynamics, aerospace structures and material science. Thanks to this database, while designing a new aircraft, wind tunnels, propulsion test stands, mathematical models and simulations were started to be used. In line with these developments, the necessity of flight test can be questioned. However, for many reasons, flight testing is necessary even if all developments occur. The main reasons for this are as follows as Appleford (2005) [25] stated:

It is not impossible to test the conditions that aircraft will be in while flying on the ground, but it is not practical either (e.g., testing fuel system on the range of acceleration forces would be impossible on the ground).

Certain flight conditions (e.g., the flow field round an aircraft carrier) may not be well defined enough to be simulated.

Except for the simplest systems, aircrafts are made up of exceedingly complex systems, and flight testing is the only opportunity to explore the integrated interactions of these systems.

Despite all the technological developments, there are inconsistencies between the characteristics of an aircraft in real flight and the calculations made and ground-based tests. Therefore, flight test is essential to increase the accuracy of the models and simulations, which are becoming more important day by day in the development and certification processes.

For these reasons, the expected performance from the aircraft in real flight under operationally representative (when potentially limiting conditions can be approached in a controlled and incremental manner with significant parameters monitored through appropriate test instrumentation) can be obtained by flight tests.

2.2.1 Civil and Military Flight Test

The route to be followed in the execution of the flight tests of the aircraft to be developed depends on the purpose for which the aircraft was produced. Flight test programs consist of two types, depending on whether the aircraft is used for military or commercial purposes. However, in the flight tests of aircraft to be used for military purposes, it may be applied in the program as well as for commercial purposes. This is because commercial aircraft have more requirements, so it is more inclusive.

a) Civil Aircraft Flight Test

Commercial flight tests are performed to meet the applicable safety and performance requirements of national or international authorized certification agencies. There are many organizations in this sense in the world, DGCA in Turkey, EASA in the European Union, FAA in the United States and Civil Aviation Agency (CAA) in the United Kingdom can be given as examples. These civil aviation authorities are not concerned with the commercial success of these commercial aircraft, but with the safety of these vehicles and the pilots' accurate reporting on the performance of the aircraft. Civil aviation authorities are generally not involved in flight tests until the manufacturer has completed their development on the aircraft and is ready for certification.

b) Military Aircraft Flight Test

In military aircraft programs, governments contract with the manufacturer of these vehicles to design and manufacture aircraft with features that can perform the desired tasks. In this case, governments are the customers of the aircraft, unlike commercial aircraft, and they have a direct share in fulfilling the capabilities expected from the aircraft. Because the performance requirements of the aircraft are documented in the characteristics of the aircraft, the details of the flight test program and many other requirements are specified in the statement of work. In military aircraft projects, the government is more involved in the flight testing of the aircraft, as it funds the program. The final stage of flight test activities is operational tests. At this stage, the aircraft has completed all development and certification activities, and its design has been frozen. In these projects, a test team is appointed by the state to perform operational tests and confirm that this aircraft is suitable.

2.2.2 Flight Test Types

Flight tests can be of different types for the purposes of a particular program. Flight tests are carried out for scientific research, development of new technologies, experimental, evaluation of operational performance or, when necessary (especially for civil aircraft), for airworthiness certifications [26]. In addition to these, flight tests are also carried out to verify compliance with the design performance standards of the airframe produced in an approved type (production flight), to test the new systems installed (system flight test) and to test the aircraft after maintenance (post-maintenance flight test). Whatever type of flight test is to be performed, as Alfrod (1999) [27] states, any modification to the aircraft can lead to disastrous results if it is not adequately tested. Scientific Research, Experimental Flight Test, Developmental Test and Evaluation, Operational Test and Evaluation, Airworthiness Certification flight tests are explained within the scope of this study.

a) Scientific Research Test

Although wind tunnels and computational fluid dynamics simulations are used to gain scientific knowledge about flight, high-quality scientific research is only possible with real flight. In the results obtained from wind tunnels, there are always facility impacts like downstream pressure gradients in the test section, wall boundary layer effects, test section occlusion, turbulence intensity level, model size limits, Mach and/or Reynolds scaling insufficiency, and so on. Wind tunnels and their limitations are discussed in studies "Measurement in Fluid Mechanics" by Tavoularis (2005) [28] and "Low-Speed Wind Tunnel Testing" by Barlow (1999) [29]. Similarly, their modeling is limited in computational fluid dynamics simulations. Their capacity to describe viscous, unstable separated flows is restricted, especially when the model is large (like an entire plane). Limitations on computational aerodynamics are contained in Cummings (2015) [30] "Applied Computational Aerodynamics" study. Turbulence modeling strategies, time-accurate solutions and system resolution always need some kind of validation. Therefore, experiments in flight are the ultimate evidence of scientific ideas about flight.

b) Experimental Flight Test

Experimental flight tests with the use of newly developed flight technologies aim to expand existing flight capabilities. These cutting-edge aircraft, developed to demonstrate new technologies or advanced concepts, are classified as X-planes. There are numerous flight research programs in this area, particularly those run by the US Government, and the Bell XS-1 was the first aircraft in this elite product line (Miller 2001) [31]. After a period of dedicated flight testing, many of these X-planes became successful production flight vehicles.

The X-wing project, which is being studied to improve the forward flight speed of helicopters, is an interesting example for this type of test flight. The Sikorsky S-72 shown in Figure 2.3 is a mix of fixed-wing aircraft and conventional rotorcraft. After taking off from the ground like a conventional helicopter, this aircraft switches from vertical flight to horizontal flight by stopping its rotors. This innovative aircraft paved the way for the Sikorsky S-97 Raider or Airbus RACER program helicopters used today [27].

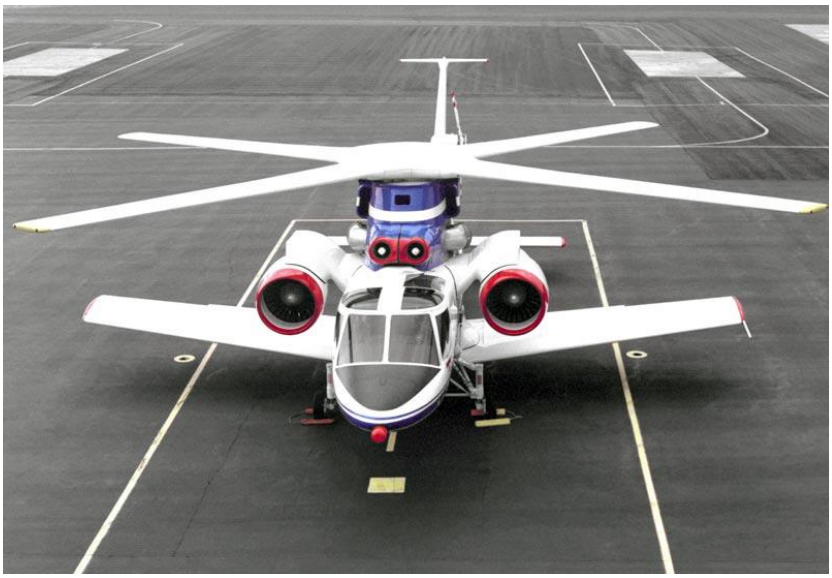

Figure 2.3 : Sikorsky S-72X [32].

c) Developmental Test and Evaluation

Significant time and effort is spent on development test and evaluation (DT&E) flight tests. This type of flying test necessitates a thorough examination of an aircraft's flight characteristics, as well as the evaluation of the aircraft's performance, stability, and handling characteristics. Evaluation of new software and weapons to be used in the aircraft is also included in this type. These flight tests are used to determine if an aircraft meets performance standards and to spot flaws in new systems. Flight test pilots are frequently involved in test planning early in the design cycle, and they push the system's performance limitations. For example, the separation properties of a new weapon system designed for an aircraft, its compatibility with the aircraft system in various flight conditions, and the evaluation of flutter flight characteristics will be evaluated by the test pilot.

d) Operational Test and Evaluation

Evaluation of the conditions that an aircraft's performance will meet during its operations is carried out by Operational Testing and Evaluation (OT&E). It is ensured that the aircraft is tested under different conditions such as rain and snow, which may be caused by precipitation, or runway due to altitude differences. In addition, the robustness and reliability of the aircraft system under a wide variety of weather conditions such as hot, cold and icing conditions are evaluated by aircraft manufacturers.

e) Airworthiness Certification Test

Airworthiness certification is the process of proving that an aircraft complies with approved design objectives and is capable of safe operation. A certificate of airworthiness is issued to an applicant who submits reports documenting airworthiness for a new aircraft type by civil aviation authorities such as FAA and the EASA. This certification process can be a long process, including flight tests, to show the aircraft's compliance with performance and safety standards.

In the United States, the FAA's regulatory authority for certifying the airworthiness of aircraft is Title 14, Part I, Subpart C of the Code of Federal Regulations (CFR), part 23 for light aircraft, part 25 for transportation aircraft, parts 27 and 29 for rotorcrafts. Similarly, in the European Union there are certification standards (CS) provided by EASA. These are CS-23 for light aircraft, CS-25 for transportation aircraft, CS-27 and

CS-29 for rotorcrafts. Both authorities have flight testing chapter in their regulations. For example, for light aircraft, Subpart B 14 CFR §23.2100 is included in the FAA document, while it is also included in the EASA document as of CS-23 Subpart B CS 23.2100 article.

Published by both authorities to the relevant aircraft category, these standards detail the safety flight standards that must be met in order for an aircraft to be certified as airworthy and organize them into broad performance criteria and flight characteristics categories. The weight and center of gravity position of the aircraft, the stall speed of the aircraft under various operating situations, takeoff performance, climb performance, glide performance, and landing distance required are all performance parameters.

For instance, the flight characteristics for certification in part 23 include demonstrations that:

- The aircraft is controllable and maneuverable;
- The aircraft can be trimmed in flight;
- The aircraft has static and dynamic longitudinal, lateral, and directional stability;
- The aircraft has controllable stall characteristics in all maneuvers and that sufficient stall warning is provided;
- Spins are recoverable;
- The aircraft has controllable ground handling characteristics; and
- Vibration and buffeting do not interfere with control of the aircraft or cause excessive fatigue.

Many aircraft in flight today are certified under older versions of relevant regulations. It is therefore important to be familiar with historical approaches to airworthiness certification. Kimberlin's (2003) "Flight Testing of Fixed-Wing Aircraft" [33] provides a good summary of these old regulations and how antique airplanes still fly under the airworthiness certificates issued under the old regulations.

2.2.3 Flight Test Process

The Flight Test Process basically consists of three stages: Flight Test Planning, Flight Test Execution and Flight Test Reporting. However, before the planning of flight tests, flight test requirements need to be determined while the aircraft is still in the design phase or even before it. Determination of Flight Test Requirements can only be added for newly developed aircraft as the fourth and first step of the process.

a) Flight Test Requirements Determination

In the projects carried out within the scope of the newly developed aircraft, the flight test team should be involved in this process to determine the flight test requirements, together with the determination of the needs and requirements of the project. The flight test team should take part in determining the operational concept and support strategies, in order to provide technical inputs before and after the design. Before the start of the contract or design activities of the projects, studies should be started within the scope of flight test schedule and workforce planning. Some of the issues to be determined by the Flight Test team at this stage are:

- Determination of flight test types to be performed within the scope of the project,
- Determining the scope of Certification & Qualification,
- Similarities of the project to previous flight test activities,
- Determining the telemetry and flight test facility needs of the project,
- Determining the training and equipment needs of the flight test team,
- Determination of flight test areas
- Determining how to do data analysis,
- Determining the Research Reference Flight Test needs,
- Determining the need for the number of prototypes / simulators / iron bird of the project,
- Anticipating flight test instrumentation needs,

covered during this period.

b) Flight Test Planning

The allocation and organization of resources is done during the planning phase to validate each flight test target to be achieved during the aircraft's flight test campaign. To enhance test efficiency and success, it is required to develop excellent testing methodology on how to execute tests to achieve each goal. This needs considerable collaboration and discussion with all necessary testing-related technical disciplines. According to Pavlock (2013) [34], the content of the flight test plan, which is a documented systematic method, is as follows:

- Purpose and scope of the test;
- Number of flights needed to accomplish each objective;
- Duration of each flight;
- Flight path;
- Required flight maneuvers and test point acceptance criteria;
- Test configurations;
- Test conditions;
- Risk reduction techniques;
- Data collection, including measurements, data rate, and format type;
- Data-gathering and reduction methods to evaluate test results during and/or post-flight.

In order to obtain the data needed to verify the success of the flight test and the target(s), determination of appropriate flight maneuvers, which are often determined by the focus of the mission, test point conditions and test point acceptance criteria are the most important factors at the planning stage. The handling quality and performance of an aircraft are the two focal points of flight testing.

Performance flight tests include instrumentation of engine pressure, engine rpm, fuel flow, total fuel and aircraft altitude, and are performed to obtain aircraft information such as range, speed, drag. Climb and descent rate performance, take-off and landing time and distance measurements, cruise performance are just a few examples of these tests [35].

Handling quality tests, on the other hand, are performed to determine the stability and control characteristics of the aircraft, along with the aircraft's response to an external disturbance or flight control input throughout the aircraft's flight range. Handling quality includes the airworthiness of the aircraft as a result of the characteristics of the aircraft and the input techniques of the pilot operating the aircraft. For this reason, these tests require an aircraft equipped with flight test instrumentation that includes data records on flight control positions and forces, linear accelerations, airspeed, altitude, angle of attack, and side shift [36].

Test point conditions such as control surface configuration, aircraft condition, air constraints, airspeed, and aerodynamic loads define necessary prerequisites prior to each test point. In order to achieve efficient flight test and obtain the desired data, appropriate conditions must be determined, but also to produce the correct data, the limits within which the test should also be determined. These limits assist flight test engineers and flight test pilots in deciding whether a test point has been successfully completed or if repetition is necessary.

The first draft of the flight test plan, which outlines the most effective, efficient and safe way to verify the target(s), should be used as a guide during development, but information from the flight environment may differ from the initial knowledge, so it needs to be flexible. The results of the flight test may be better or worse than expected. Changes, such as removing, adding, duplicating, or changing the scope of test points, are required in this situation. All changes to the test plan must be identified, negotiated, documented, and approved to ensure that the test's safety and success are not jeopardized.

c) Flight Test Execution

Although the flight test plan includes information on the tests to be carried out extensively, the test team should be given a more defined mission plan to design and communicate.These documents are flight test cards that outline a particular sequence of events in a logical, efficient and safe way to perform the flight test. The contents of the flight test card are basically as follows [34]:

- Identification of test aircraft;
- Test card revision and card numbers;
- Test objective;

- Aircraft and test point configuration description; and
- Test maneuvers and test point acceptance criteria.

Approved test cards are reviewed in preflight briefing which is a coordination meeting where all test participants review the objectives, scope, procedures and requirements of the flight test. These briefings discuss test point maneuvers, procedures to be followed in the event of an emergency, and the hazards involved in this test. If an error is detected in the test plan during the briefing, consideration should be given to whether the test will continue. If the test can be continued with minor corrections after the evaluation, the relevant changes are noted on the test card and the flight is started. If considerable changes are in question, the flight test should be postponed until all technical disciplines have completed an adequate and comprehensive review, ensuring that the mission's safety and success are not jeopardized. Since the preflight briefings are the last step before the flight, the decisions and the evaluations be made here have great importance. Because of this feature, these briefings can be seen as the last major safety barrier before the flight.

Most of the flight tests are carried out by transmitting the data obtained through the telemetry of the flight test instrumentation systems attached to the aircraft, to a ground-based control room instantly. The necessary data for the success and safety of the flight are monitored in here. The team performing the flight test consists of the test pilot in the test aircraft, the test coordinator in the control room and personnel from the relevant technical disciplines. If necessary, a chase aircraft and its pilot who fly close to the test aircraft from a safe distance and observe the test aircraft can be included in this team.

After the completion of the flight test, another important evaluation, debriefings, is made. In debriefings, issues such as what is good during the test flight, unexpected situations, how much of the test points have been completed, and areas for improvement are discussed in the perspective of efficiency, success and safety. Debriefings can serve as a first indicator that more data analysis is needed to guarantee that no abnormalities are present, unless they are clearly recognized in real time during testing. In case of unacceptable or unexplained results obtained from the test performed, it may be necessary to make the decision to postpone the new tests to be performed. The choice to continue with flight testing should be based on both technical and risk management considerations, with safety being the most important factor [34].

d) Flight Test Reporting

Flight test datasets are the principal result of flight tests. Long before the actual flight test, the requirements for this data are developed in accordance with the flight test objectives. To evaluate data requirements, a thorough understanding of quality, bandwidth, and potential data reduction options is required. These collected data must be transformed into a format that allows for data analysis and reporting in order to be useful.

The data obtained as a result of the flight test is analyzed and the compatibility of the results with the predicted test results is evaluated first. In addition, data analysis is also used to understand whether additional flights are required and whether the current approach is safe. An update to the estimation tools should be considered when the results differ from those predicted. If a design update is required to acquire relevant or accurate data, model updates are critical to the design's success.

The summary of the mission performed in the flight test along with the data analysis and all critical information related to the test should be documented in the flight test reports. Through this documentation, flight test reports provide a historical record of what has occurred, allowing future reference to test results, techniques and procedures. In addition, thanks to these documentation, lessons are learned from the mistakes made and it contributes to the success of the next tests. The number of flight test accidents has decreased over the years, and the success here is partly due to the flight test community sharing ideas and lessons learned [34]. Flight test reports should be written in a way that is clear, not too detailed, but comprehensive and concise. The aim here is to present the findings that will enable someone else to obtain the same or very similar results specified in the flight report when someone else performs the same test under similar conditions.

2.2.4 Flight Test Team

Although the structure of the flight test team varies according to the size and complexity of the organization carrying out the flight test activities, there are some roles in all flight test organizations in general. The first two of these are flight test engineers (FTE) and flight test pilots/experimental test pilots. Although the leader of the flight test team is usually a flight test engineer, flight test pilots can also fulfill this task. Flight test instrumentation (FTI) engineer and telemetry engineers may be other members of the test team, as well as many roles such as instrumentation system technicians, aircraft maintenance workers, quality/product assurance inspectors. In addition, engineers from various disciplines will also be part of the team, who will support the testing of their own special systems and analyze the data obtained.

a) Flight Test Engineers (FTE)

Flight test engineer's responsibilities are the planning, execution, analysis and reporting of test flights. They also manage the preparation of test plans with the test pilots to ensure that the objectives of the flight test activities are met and to find deficiencies at an early stage. FTEs ensure that maneuvers or flight conditions planned for testing are safe and within the approved flight plan, and they often conduct flight test briefings. LFTEs are flight test engineers who are assigned to an aircraft to conduct flight tests or support the pilot in the operation of the aircraft and its systems during flight testing. As a part of the flight test crew, LFTEs have unique responsibilities and privileges, including operating test aircraft systems either directly or through dedicated flight test instruments.

b) Test Pilots (TP)

The responsibilities of the test pilot are operating the test aircraft, ensuring that the maneuvers or flight conditions planned for the test are safe and within the approved flight plan, as well as the tasks defined during the development studies of these aircraft, training activities, etc. Test pilots work in coordination with relevant FTEs and product engineers to complete the flight test process in a safe, effective and efficient manner. Test pilots take an active role in the preparation of test plans in coordination with FTEs. Their flight experience is utilized in the early stages to ensure that the objectives of flight test activities are achieved. Before the flight test, they conduct pre-flight briefings in which all crew members and experts participate and FTEs are adjusted. Test pilots make effort to provide qualitative and quantitative feedback during and after test flights and then together with FTEs, they prepare flight test reports.

c) Telemetry Engineers

Telemetry Engineers are responsible for design, installation, maintenance and operation of the telemetry system and they ensure required telemetry configuration is set and ready for each flight test activity.

d) Flight Test Instrumentation (FTI) Engineers

Flight test instrumentation engineers are responsible for designing FTI Systems to gather the parameters and they ensure required FTI configuration is set and ready in each flight test activity.

e) Management

Another member of the flight test team is management, who can be found at various levels of flight test. Whether or not they directly participate in flight test activities, managers have responsibilities for the safe execution of flight test activities [37]. A risk management-based supervisor position, project guidance, and a non-intrusive senior manager would be the most useful inputs they can provide. At the same time, taking measures to reduce the pressure on the flight test phase while the related aircraft project continues is an important issue that the management can provide.

2.2.5 Flight Test Categories and Corresponding Crew Composition

The flight crew who will perform the flight test activities with an aircraft that to be certified or to be carried out already has a certificate must have certain qualifications. These qualifications are determined by civil aviation rules and EASA Part-21 Annex XII [38]. EASA CS-23 (for aircraft with a maximum take-off weight (MTOM) of 2000 kg or more), CS-25, CS-27, CS-29 or equivalent airworthiness codes (such as the FAA's CFR Codes) defines the requirements of aircraft in the certification process. In order to be able to test aircraft performance, systems, handling characteristics and compliance with the relevant Certification Specifications (CS's), the test team which will perform flight tests must know some skills, theoretical knowledge and special techniques. As a result of flight test training and special experience that the test team have, the test team must accomplish followings according to Timurkaynak (2020) [39]:

- Safely perform systematic and comprehensive flight envelope exploration;
- Acquire specific skills and abilities for some particularly difficult tests;

- Mitigate risks by anticipating potentially hazardous situations, and by applying methods that permit the safest flight possible in these situations;
- Understand the relevant CSs; and
- Learn methods to assess whether the aircraft or its systems comply with these regulations.

Flight Test categories are used to understand the proficiency levels of pilot, flight crew and flight test engineers specified in EASA PART – FCL [40] or FAA 14 CFR Part 61 [41] for flight testing. The required qualifications specified in Part-FCL or 14 CFR Part 61 for all flight tests, not only for certification tests, can be taken into account by the companies performing these activities. These documents serve as guidelines for minimizing unsafe situations and incidents during flight.

There are four main flight test categories listed in EASA Part-21 [38] and are defined as in Appendix-B.

The followings can be given as examples for category-1 flight tests:

- Velocity of Minimum Unstick (V_{MU}) determination, minimum containment ground speed (V_{MCG}) determination, spinning and initial stalling tests for fixed-wing aircraft.
- Encountering unexpected and hazardous flight characteristics during the flight.
- In a situation where one or more parameters in aircraft handling and performance which are altitude, attitudes, weights, center of gravity (CG), speed/Mach, stalls, temperature, engine and aerofoil performance are getting close to the actual limits of the aircraft envelope.
- Where new systems used on the aircraft significantly affect the performance or handling of the aircraft.

In Category-2 tests, the flight test envelope of the aircraft is already opened, its attitude is sufficiently safe and does not have unsafe flight characteristics. The followings can be given as examples for category-2 flight tests:

- Function and reliability flights.
- All-engines-operating climb performance.

- Static stability demonstration.
- Cruise performance.

Situations that require the aircraft to be operated outside of standard operational procedures, such as testing of warning systems (Terrain Awareness and Warning System (TAWS), Airborne Collision Avoidance System (ACAS) and etc.), or autopilot systems.

Category-3 test flights are also called production flights in general, and the behavior of the aircraft is known since the type certificate of the aircraft that will perform the test flights in this category is approved. They are carried out on new aircraft that already have a type certificate to check that the systems are working properly and are in compliance with the certified type.

During the manufacturing flight tests of a new aircraft, unexpected problems can occur that are not documented in the aircraft flight manual (AFM). As a result, it is thought that extra training should be required. It should be emphasized that in order for a production flight test to be designated Category 3, a type certificate (TC) or supplemental type certificate (STC) must have been issued. Any flight, including production flight tests, will be classified as Category 1, 2, or 4 until a TC or STC is awarded [39].

Test flights flown after cabin conversion, telephone installation and new radio equipment installation, etc. can be given as examples of category-4 flights. In its simplest form, category-4 test flights are flights made after changes that do not affect the behavior of the aircraft.

- Those flights which are not included in Category-2 and
- all that is required is a proper operating test. and

There's no need to fly the plane outside of the AFM's restrictions.

Flights after the arrangement of the guidance/warning systems for these two items are also included in the category-4.

In line with the information given above, flight test categories can be summarized as in the table below:

Table 2.10 : Flight test categories [39].

FLIGHT TEST CATEGORIES	TEST PURPOSE (in general)	TC/STC ISSUE of TYPE	MODIFICATION of CERTIFIED TYPE
Category 1	Initial flights of a new type	NO	YES (if there is a TC/STC issued before)
Category 2	Test of a not yet approved modification	NO	YES (if there is a TC/STC issued before)
Category 3	Production tests	NO	NO
Category 4	Test of a not yet approved but non-significant modification (in the same envelope limit) like a repeated test	YES	NO

For each flight test category in the table above, there are some competences and experience levels that test pilots and flight test engineers should have. These requirements are defined in EASA Part-21 Annex II [38] as in the table below:

Table 2.11 : Flight test competence levels.

	Flight Test Categories			
Aircraft	1	2	3	4
CS-23 commuter or aircraft having a design diving speed (md) above 0.6 or a maximum celling above 7260m (250000ft), CS-25, CS-27, CS-29 or equivalent airworthiness codes	Competence level 3	Competence level 3	Competence level 3	Competence level 3
Other CS-23 with an MTOM of or above 2000 kg	Competence level 3	Competence level 3	Competence level 3	Competence level 3

In the flight test rating of PART-FCL.820 [40], assessments of the requirements for these competences are specified as in Appendix-C.

Under the FCL.820 regulation heading, some requirements for test pilots and flight test engineers who already have a flight test rating are specified in (c) and (e). But in (d), there are the requirements for test pilots and flight test engineers who will receive this rating for the first time as in Appendix-C.

One of the trainings received at the ATO is the Risk/Safety management course as stated in the regulation. This is an important point because risk/safety management is not available in most of the other ratings and licenses in the EASA Part-FCL document. The importance of providing safety and risk awareness in flight test activities to flight test pilots and engineers by EASA can be understood with this regulation in Part-FCL.

Competence level requirements are defined in the EASA Part-21 document [4] for pilots and flight test engineers, respectively, as in Appendix-D.

The organization's flight operations manual should describe all competency and experience for Lead flight test engineers (LFTEs) and other flight test engineers. Flight test engineers shall have experience and training commensurate with the duties assigned to them as crew members. Minimum ground flight training hours and course schedules for pilots and LFTEs are described in EASA Part-ORA [42] and summarized in Part-21.

The characteristics of an ATO suitable for providing flight test training for pilot licenses, related authorizations and certificates are specified by EASA in the Part-ORA document. The requirements relate to the organization's application, personnel, record keeping, training program, manuals, trainer aircraft and flight simulation training devices (FSTDs), training areas. There are many ATOs approved by EASA or FAA and their own national certification authorities, such as ETPS (The Empire Test Pilot School), ITPS (International Test Pilot School), NTPS (National Test Pilot School), etc.

2.3 Flight Test Safety

A safe flight is a top priority for all aircraft operations. If the flight activity in question is a flight test, safety becomes higher priority. Because flight tests are flights where a new system is tested on an aircraft or a new aircraft design is tested completely, and they can bring many unforeseen hazards. Regulations on the management of risks and safety in flight test activities have been published by the relevant authorities. In accordance with the (EU) 2022/201 [24] regulation published by the European Union

Commission, it is required to create a flight test operations manual that defines the policies and procedures of the organization that will carry out flight test activities. One of the topics that should be covered in this handbook is the availability of a policy on methodologies for risk and safety management.

EASA has published a guide document that will help organizations engaged in flight test activities to create a must-have flight test operation manual [5]. In line with EASA's European Aviation Safety plans, it enables authorities and organizations to establish a management that will ensure the management of safety in a systematic and proactive way that takes into account the potential hazards and associated risks before aviation accidents occur. In the guide document, it is stated that the way to provide this management can be done with SMS published by ICAO and flight test organizations should develop SMS in accordance with EASA Part-21. If there is an SMS in the company in which the organization currently performing flight test activities is located, the SMS of the flight test organization must be integrated into the SMS of the company.

In the process of performing flight test activities, there is flight test risk management and it complements safety management, but the two are not the same. Safety management within the scope of SMS is a continuous and strategic process that includes processes such as occurrence reporting, investigations and trend analysis. On the other hand, flight test risk management addresses the hazards related to each flight test directly related to that flight test. In all flight activities, including test flights, risks such as bird strike, mid-air collision and CFIT are continuous risks and should be managed within the scope of SMS. In particular, the risks that may be encountered during the flight test should be handled within the scope of flight test risk management. For example, in the minimum control speed test, there is a risk of loss of directional control, which may lead to the loss of the aircraft. This risk is valid only for this test, and the determined risk level is specific only to the aircraft performing the test. On another aircraft where the minimum control speed is to be tested, this risk may be at a different level. In some cases, an SMS-managed risk can be significantly increased by flight testing. In flight tests where such situations are experienced, these risks should be managed within the scope of flight test risk management. For example, in a flight where TAWS (Terrain Awareness Warning System) is tested, the CFIT risk normally managed by SMS is covered by flight test risk management.

In line with the standard definitions in the ICAO SMS handbook, the organization should define the risk levels as it determines and determine the risk approval levels within the organization and present it to in the FTOM.

Similar to what is written in the safety risk management title (2.1.2.2.), the following steps should be followed in risk management as recommended in the FTOM guide document:

- Identification of test points;
- List of potential causes of the hazards for individual test points;
- Subjective risk assessment of each hazard (likelihood vs severity);
- Identifying applicable mitigations;
- Determining the overall risk level for each flight.

While conducting risk analysis, it may be useful to examine case studies prepared for flight test hazards, as in FAA Order 4040 [6], but it is recommended to determine the hazard by brainstorming by the team beforehand. Otherwise, direct reference will limit the hazard identification. Organizations are advised in the FTOM guideline document that it should be determined how the risk assessments made should be recorded, planned and included in the flight briefing processes.

2.3.1 Flight Test Risk Management

There are many resources on flight test risk management, but the FAA Order 4040.26C [6] document, which is also referenced in the FTOM guide document, covers the process in detail. This document sets out the flight test risk management program requirements by the FAA Aircraft Certification Service (AIR) and is designed to complement FAA Order 8040.4, Safety Risk Management. The FAA expects everyone participating in certification flight test activities to comply with all elements of this document. FAA Order 4040.26C Appendix-C contains detailed information about the flight test risk management process. This appendix contains basic information about risk management and explains how risk management should be done at every stage of the flight test. Here are the basic principles of risk management:

a. Accept no unnecessary risks.

b. Reduce risks to an acceptable level.

c. Manage risks as early in a project as possible

d. Risk Management acceptance should be made at the appropriate level.

e. Focus on test-related risk.

f. Review all plans.

g. Utilize all available resources.

h. Allow time for critical thinking.

The flight test risk management process can be examined in three steps: prior to the flight testing, during the flight testing and after the flight testing.

a) Prior to the flight testing:

1. The resulting risks associated with certain flight test techniques often result in a higher risk than those associated with operational flight. The test methods defined in the test plan will be included, but the hazards and hazardous situations that may arise due to other factors such as the flying environment and aircraft configuration should be taken into account.
2. Hazards related to test techniques must be identified, but there may be more than one hazard depending on the techniques to be applied. In such cases, all hazards should be identified.
3. The causes of all hazards identified in the previous step should be determined.
4. The potential effects of all identified hazards should be determined.

The probability of the occurring of each identified hazards and the severity levels of the negative consequences that these hazards may cause should be tried to be estimated. After the probability and severity levels are determined, a risk assessment matrix similar to the one below in FAA.Order.4040.26C Appendix C should be created and risk levels should be determined over this matrix.

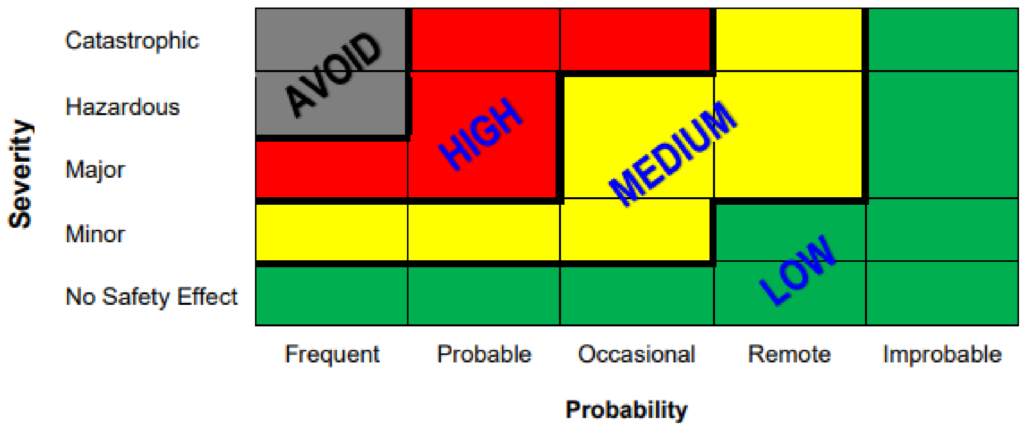

Figure 2.4 : FAA's flight test safety risk assessment matrix template.

A similar matrix is included in the Appendix-C section of the Advisory Circular (AC) 21-47 v1.1 [37] document published by the Australian Government Civil Aviation Safety Agency (CASA) on flight test safety and is as follows.

Hazard Outcome Category	Subjective Probability of Occurrence			
	Probable	Possible	Unlikely	Remote
Catastrophic	UNACCEPTABLE	HIGH	Medium	Low
Critical	HIGH	HIGH	Medium	Low
Marginal	Medium	Medium	Medium	Low
Acceptable	Low	Low	Low	Low

Figure 2.5 : CASA's flight test safety risk assessment matrix.

The definitions of risk levels in Figure 2.5 are given as follows:

- Unacceptable Risk: Tests or activities that pose a significant risk to personnel, equipment or property and that take place after all possible precautions have been taken. The acceptance of this level of risk should not be authorised.
- High Risk: Tests or activities that pose a significant risk to personnel, equipment or property and that take place after all possible precautions have been taken. Acceptance of this level of risk is not normally allowed, but if the decision to continue the activity is taken, it can only be authorised by highest level after all the mitigations have been implemented. However, it is recommended that flight test crews make their own decisions in line with the risks they will encounter. High speed tests above $V_{NE}/V_{MO}/M_{MO}$, V_{MCA} tests at low altitude, autopilot malfunction tests at low altitudes, spin testing,

autorotation testing, inflight thrust reverser deployments and pilot induced oscillations (PIO) testing are given as examples of tests in this category [37].

- Medium Risk: Tests or activities that present a greater-than-expected risk to personnel, equipment or property during routine flight operations. Aerobatic manoeuvres, Low speed and high speed stability and control, role rate, TAWS, any tests involving low altitude operations, Traffic Alert and Collision Avoidance System (TCAS) using airborne target and engine out operations at low altitude tests are given as examples of tests in this category [6].
- Low Risk: Tests or activities that pose no greater risk to personnel, equipment or property than are encountered during routine flight operations. High altitude airspeed calibrations and climb performance/speed power are given as examples of tests in this category [37].

When figure 2.4 and figure 2.5 matrices are examined, both have 4 risk levels, but the number of probability and severity levels is 5 in figure 2.4 and 4 in figure 2.5. Among these matrices, which are a guide for flight test risk management, suitable matrices or matrices of different sizes to be determined by the company can be used. There is no single correct matrix used to perform a flight test risk assessment, the main purpose being to identify risk levels, risk approval authorities and the probability and severity levels that make up the risk matrix. Many factors should be taken into account when making a risk assessment. Some of these factors are:

− Design maturity.

− Specific aircraft limitations.

− Test techniques and workloads.

− Gross weight and center of gravity.

− Environmental conditions (weather, airport conditions, illuminance, wind conditions, etc.).

− Proficiency, familiarity and currency of the test team about the test aircraft.

− Past experience, computer models or presence of simulator.

1. Steps to mitigate hazards should be identified and controllers that mitigate risks should be developed. Mitigations, which are actions to minimize the causes of

hazards, should aim to reduce the likelihood or severity of a hazard or cause, or both.

2. If a hazardous situation arises despite the mitigation measures taken, emergency procedures should be defined to reduce the effects of the consequences. Despite all this, if undesirable situations cannot be prevented as a result of hazardous situations, the focus should be on the protection of the flight crew.

3. Testing procedures and techniques should be reviewed to determine if there are safer alternatives, especially for newly established test techniques. Records of past flight test techniques, preliminary tests to be made in the simulator and the creation of additional test points are examples of improvements that can be made in this regard.

4. The last stage of the risk assessment made before the flight test is the documentation of the risk management studies and their review by the relevant departments, persons and authorities. Risk assessments made in line with risk management are also called Test Hazard Analysis (THA) and there are examples of THA in Table E.1, Table E.2 and Table E.3. The way in which the risk assessments are documented is not limited to these examples in Appendix-E, but different ways can be followed. The aim is to document the work done within the scope of risk management studies and then communicate the details in a simple, clear and unambiguous manner to test teams and those who accept the Type Inspection Authorization (TIA) or Letter of Authorization (LOA) risk. The review phase can be achieved through the distribution of this documented work to the relevant stakeholders or by convening the SRB which has been detailed in 2.1.2.1. Safety Policy and Objectives. Lastly, Acceptance of the risk management plan will be documented on the TIA and/or LOA.

b) During the Flight Testing Process:

1. Pre-flight briefing checklists that effectively cover the safety aspects of testing should be used correctly during flight.

2. The configuration/suitability of the aircraft to be tested must be maintained for safe operation. Where necessary, flight test personnel should contact the relevant quality assurance representative or alternatively designated

airworthiness representative prior to flight to confirm the aircraft's suitability through a form.

3. Continuous risk assessment should be performed by checking the accuracy of the factors contributing to the risk. Consideration should be given to the assessment of operational risks that may contribute to flight test risk, such as unscheduled weather. If at any time it is decided that the identified risk is insufficient, the flight should be stopped and the risk reassessed.
4. Procedures should be developed for changes that can be made to the test profile due to unusual circumstances or operational considerations. The changes to be made in the test plan are within the scope of the previously approved risk management plan, if there is no increase in risk and the test team members agree, permission should be given.

c) After Completion of Flight Testing:

1. Post-flight briefings should be conducted after the test flight is completed, where the test is discussed, reviewed and documented about how well the test was done, how successful it was, or what went unexpectedly during the test. Post-flight briefings are critical to flight testing.
2. There are many lessons learned during the flight testing process. These lessons should be passed on to others by the relevant flight testers as they can contribute to the safer realization of future flight test projects.

Ground and flight test personnel, program management, engineers with expertise in related fields, and representatives of departments in the organization that have input into flight test activities should be among the participants of this event. Lessons learned, difficulties encountered during tests, effectiveness of test planning, risk assessments are some of the topics that can be discussed at this event.

2.3.2 Operational Flight Risks

Along with the risks specific to the flight test of flight test activities, there are continuous risks, or in other words, operational risks, which have a lower risk level but are present in all flights due to the nature of the flight and mentioned in the FTOM document. Operational risks have a more important place especially during the flights of certified like routine operations in airlines. As explained in detail in the previous section, test flights, by their nature, bring many unknowns and therefore high risks. However, as in all flights, there are operational risks as well as test-related risks in test flights. Along with flight test risks, these risks should be determined and awareness should be created. Unlike flight test risks, these risks should be monitored continuously, and actions should be taken when necessary, as these risks may be exposed in all flight activities, not specific to the test. It is written in the FTOM guide document that the monitoring and risk assessment of these risks in flight test organizations should be systematically handled by the SMS, which is expected to be in the relevant organization.

When considering operational risks, the conditions of the time of flight should be evaluated also before the flight. For example, Boeing provides the management of operational risks in flight test activities by evaluating the conditions of that day for each flight. While making this risk assessment, the following factors are effective, including but not limited to [7]:

- Show time;
- Planned duty day;
- Planned take-off and duration;
- Non-standard shift patterns;
- Flight planning time;
- Complexity/Test Risk;
- Crew composition;
- Crew qualification and training;
- Recency;
- Operating area;
- Departure/Arrival weather;
- Type of flying, i.e., VFR, VMC, IFR, IMC; and
- Intangible considerations.

When considering these and similar factors within the scope of operational risk assessment, a point to be considered is that the flight should not be continued when the factors included here may cause the aircraft to go into the flight envelope or if there is a situation that conflicts with the relevant procedures. To give an example for better understanding, planning a night flight with an aircraft that is not yet equipped to perform a night flight is not within the scope of risk assessment. Such a planning would be a direct flight stop and no flight would take place. Similarly, the fact that a pilot who does not have a CAT-1 test pilot license is included in the flight crew that will perform the CAT-1 test flight cannot be the subject of risk assessment, this would be a violation of the rule and prevent the flight.

When the factors that can be considered during the operational risk assessment are examined, it is seen that one of the items included here is the Test Risk. From this point of view, before starting the test flight, it is necessary to consider conditions of that day, in a more general term, operational risks, as well as the test risk as a result of the flight test risk assessment prepared for the test flight.

Safety-related data from internal and external sources are used to monitor operational risks. These data can be defined as any deviation from what is expected, defined as an undesired event, which may result in personal injury or property damage. Systemic analysis of undesirable events acts as a signal that makes it possible to improve the organization's risk prevention mechanisms [43]. Some examples given by EUROCOPTER for undesirable events that may be encountered during flight operations and the risks resulting from these events are in Table F.1.

In the task force reports published by the CAA, seven operational risks are mentioned [44], similar to the risks that may occur as a result of undesirable events in Table X. These risks are: Loss of Control, Runway Overrun or Excursion, CFIT, Runway Incursion and Ground Collision, Airborne Conflict, Ground Handling Operations and Airborne and Post-Crash Fire. Operational risks related to the flight are not limited to the examples given, but different operational risks can be defined as a result of the hazard identification and risk assessment processes in line with what is explained in the 2.1.2.2 "Safety Risk Management" section. The followings are examples of hazard sources that can be used in hazard identification in the operational risk management process [43]:

- Natural hazards like earthquakes, volcanic phenomena, etc.
- Environmental hazards like cyclones, snow or sand storms, etc.

- Technological hazards which are related to the aircraft design, their maintenance, their operation, etc.
- Organizational hazards which are related to the company itself, to its operating manner.
- Human hazards which are related to training, competence, job culture, etc.

Two kinds of sources, internal and external, can be mentioned in the identification of hazards and in the determination of undesirable events in the same direction. Internal sources include incident report analyses, organization voluntary event reports, flight data analyses of flight data monitoring (FDM) programs, safety audit reports, safety indicator follow-ups, and so on. External sources include information exchange with other companies, subscription to an incident/accident data bank, study of reports from national and international organizations, analysis of manufacturer recommendations, study of accident reports from various Air Accident Investigation Boards, and so on.

3. METHODOLOGY

While it contains many risks arising from the nature of flight in all flight operations, in flight test activities, the tested aircraft carries more risks since it is in the development phase and the characteristics of the tested systems and aircraft have not been fully determined. Risks involved in flight test activities as defined in EASA's FTOM document, there are risks specific to the flight test to be carried out and continuous risks arising from the flight operation. In the pre-flight briefings held before the flight during the flight test process, the flight test risks are mentioned and the flight crew is raised awareness. The Analytical Hierarchy Process (AHP) method will be used within the scope of this study in order to bring a holistic flight safety risk awareness to the flight crew, which will include not only flight test risks but also operational risks. The matrices used in risk management will be used while creating the decision matrix of the AHP method, which will be detailed in the next section.

3.1 Analytical Hierarchy Process (AHP) Method

AHP is a hierarchical weight decision making method proposed by the American operations researcher Satie in the early 1970s by integrating network system theory and multi-objective evaluation method [45]. AHP is a multi-objective decision analysis method that combines qualitative and quantitative analysis methods. With the complex problem, the main ideas of the method are divided into several layers and several factors, because to make two important degrees of comparative judgment between two indicators. While forming the judgment matrix, the largest calculated eigenvalues and the corresponding eigenvectors of the judgment matrix can give different weights and importance, for the selection of the best solution which provides the decision basis. In summary, a hierarchical structure model is established, the weight index is calculated, and the best solution is sought in order to be able to make the final decisions of practical problems with the AHP method. Because of its simple structure and easy application, the AHP method can be used in many fields, including safety science.

The AHP method implementation can be explained in four steps [46]:

1. First, a hierarchical problem model is created that must be determined upon, with the goal at the top of the hierarchy. Criteria and sub-criteria are at the bottom of the model, while alternatives are at the top. This structure is depicted in Figure 3.1.

2. Using the Saaty relative importance scale, the decision maker's preferences are compared in pairs of building elements at each level of the hierarchy. The scale used consists of 9 levels corresponding to numerical values in the range of 1 to 9, including 5 levels and 4 sub-levels. The intensity of each level is described verbally as in table 3.1.

Table 3.1 : Saaty scale.

IMPORTANCE	DEFINITION	EXPLANATION
1	Equally important	Both elements have wqual contribution in the objective
3	Moderately important	Moderate advantage of the one element compared to the other
5	Strong important	Strong favoring of one element compared to the other
7	Very strong and proven importance	One element is strongly favored and has domination in practice, compared to the other element
9	Extreme importance	One element is favored in comparison with the other, based on strongly proved evidences and facts.
2,4,6,8	Inter - values	

3. Evaluations of relative importance to elements at each level of the hierarchical structure are applied to calculate local criteria, sub-criteria and alternatives. The alternatives' general priorities are then summarized. The total priority of each alternative is determined by adding the local priorities weighted by the weights of higher-level parts.

4. A sensitivity analysis is carried out.

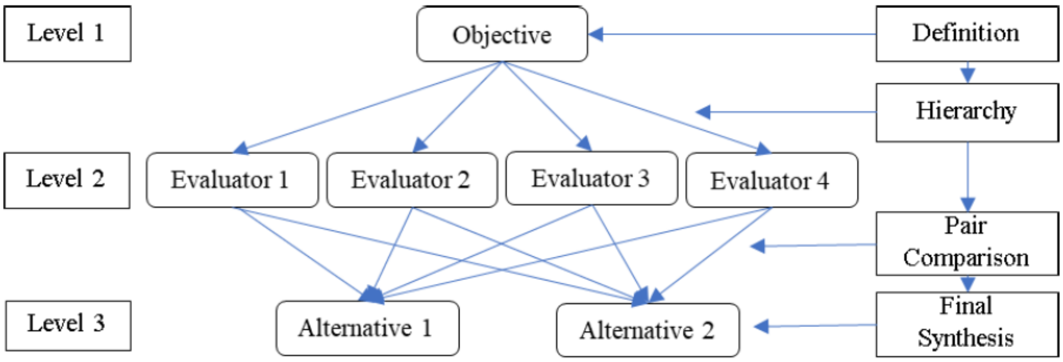

Figure 3.1 : Analytical hierarchy structure [47].

<u>Mathematical Model of AHP</u>

Matrix A of size nxm is created for the comparison results for the number of n elements compared.

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{1nm} \end{bmatrix} \quad (1)$$

The ratio between the elements of the matrix, that is, the criteria being compared, is expressed by the formula:

$$a_{ij} = w_i / w_j \quad (2)$$

If element A is n times more important than element B, element B is 1/n times more important than element A. Which can be shown as:

$$a_{ij} = 1 / a_{ji} \quad (3)$$

In order to obtain a normalized matrix B = $[b_{ij}]$, the elements of the matrix B are calculated as:

$$b_{ij} = a_{ij} / \left(\sum_{i=1}^{n} a_{ij} \right) \quad (4)$$

The calculation of the weights i.e. eigenvector w = $[w_i]$ form the normalized matrix B is performed by calculating the arithmetic mean for each row of the matrix according to the formula:

$$w_i = \left(\sum_{j=1}^{n} b_{ij} \right) / n \quad (5)$$

Consistency of the Comparison Matrix

Consistency refers to a consistent judgment of the decision maker regarding pairwise comparisons. Mathematically comparison matrix A is consistent if $a_{ij}.a_{jk} = a_{jk}$ for all i, j and k.

A reasonable degree of inconsistency is expected and tolerated, because human judgment is involved in the creation of these matrices. For this reason, it is unusual for all comparison matrices to be consistent.

For comparison matrix A, a quantifiable measure is developed to determine whether the level of consistency is reasonable. If matrix A is perfectly consistent, a normalized matrix C is produced in which all columns are the same.

$$C = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_1/w_n \\ \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{bmatrix} \quad (6)$$

The original comparison matrix A can be determined from C by dividing the elements of column i by w_i :

$$A = \begin{bmatrix} 1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & 1 & \dots & w_1/w_n \\ \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_2 & \dots & 1 \end{bmatrix} \quad (7)$$

The resulting ratio comparisons are illustrated as follows:

$$\begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_1/w_n \\ \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_3 \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_3 \end{bmatrix}$$

The matrix is multiplied by w on the right to get the n x w term. Briefly, given that w is the column vector of the relative weights w_i, i=1,2,…,n, A is consistent if:

$$Aw = nw \quad (8)$$

Where A is not consistent, the relative weight w_i is approximated by the average of the n elements of row i in the normalized matrix C. Letting $\bar{w}$ be the computed average vector, it can be shown that

$$A\ \bar{w} = \lambda_{max}\ \bar{w}\ ,\ \lambda_{max} \geq n \qquad (9)$$

In this case, it can be concluded that the closer λ_{max} is to n, the more consistent the comparison matrix A will be. The consistency ratio is calculated with AHP based on this observation as:

$$CR = CI / RI \qquad (10)$$

Where CI is consistency index of A and is calculated as:

$$CI = (\lambda_{max} - n) / (n-1) \qquad (11)$$

Whereas RI is the Random consistency index of A. The RI value is taken according to the corresponding matrix row number value "n" in table 3.2.

Table 3.2 : Random consistency index [46].

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,52	0,89	1,11	1,25	1,35	1,4	1,45	1,49

If $CR \leq 0.1$ the level of inconsistency is acceptable. In cases where this condition is not met, the inconsistency is high and the decision maker may need to re-estimate the elements of A to obtain better consistency. The value of the i^{th} equation is computed as:

$$\sum_{j=1}^{n} a_{ij}\ \bar{w} = \lambda_{max}\ \bar{w}_i\ ,\ i = 1,2,\ldots n \qquad (12)$$

Given $\sum_{i=1}^{n}\ \bar{w} = 1$ it is obtained

$$\sum_{i=1}^{n}\ (\sum_{j=1}^{n} a_{ij}\ \bar{w}) = \lambda_{max} \sum_{i=1}^{n}\ \bar{w}_i = \lambda_{max} \qquad (13)$$

This means that the value of λmax can be determined by first computing the column vector A $\bar{w}$ and then summing its elements.

3.2 Weighting of Risks with the AHP Method

As the AHP method is used in many fields, there are various studies on its use in aviation, more specifically in the field of aviation safety. Weishi Chen's (2016) [47]

"Safety performance monitoring and measurement of the civil aviation unit" study and Junfeng's (2018) [48] "Aviation Maintenance Quality Management with Fuzzy Ambiguous Analytical Hierarchy Process with Different Weights" are two of the examples that can be given. In this study, the weighting feature of the AHP method will be used and no further steps will be taken to make a decision with the AHP method, because there is no situation that requires decision making. The aim is to determine how significant the flight test-specific risk involved in flight test activities and the ongoing risks arising from the nature of flight are relative to each other.

The main element to be taken as a basis in determining this is the safety risk matrix published by the SMS organization within the company or used by the flight test organization if there is no SMS organization. This matrix will be equal to the product of the severity of a hazard on the occurrence of the risk and the probability that the hazard will cause an undesirable situation. The fact that this product, which is a dimensionless number, is essential in determining the risk levels for the method to be used, according to the size of the result. In some matrices used for risk management, the product of probability and severity may not give a value. For example, probability levels can be expressed with numbers as 1,2,3,4,5, while severity levels can be represented with letters as A,B,C,D,E. As a result of the multiplication, values such as 5A, 3C, 1E are formed. Within the scope of this study, the values to be included in the risk matrix must represent a number. No matter what form of representation is currently used, both probability and severity levels must be numbers, and their product must naturally be a number and take place in the matrix. The determination of risk levels should also consist of corresponding levels for a certain value range. The ratios of the values in this matrix will be used instead of the Saaty scale (Table 3.1) in the AHP method.

The flight test-specific risk and the value of this risk in the risk matrix used by the flight test organization are included in the flight test risk management studies, and a risk value should be determined in the risk matrix in the same way for continuous risks. However, since operational risks will be handled within the scope of SMS and they should be reviewed periodically, their values in the risk matrix may change. Operational risks are reviewed at regular intervals in line with information from sources such as reports, flight data, and external notifications, and they are updated if necessary. Which continuous risk will be effective for that day's flight is a matter to be decided by the flight test team within the context of the time, location and other external factors of the flight. As a result, the criterion to be used to compare the indicators in the AHP method will be the ratio of the matrix values of the relevant flight test risk and the selected continuous risks, but the level of the risk will also affect this ratio. This ratio will change according to how many risk levels are in the risk matrix used, and each increasing risk level will be multiplied by a fixed number compared to the previous one. For example, in the SAAB Safety Risk matrix in table 2.6, there are 3 levels of risk as low, medium and high. Accordingly, if an assessed risk is at a low level, for example, it will be multiplied by 0.5 when using the AHP method, and if this constant value is multiplied by 2 while moving to a higher value, the product value will be 1 for medium risks and 2 for high risks. The values determined here are subjective and the important thing is that they are chosen in a way that draws logical conclusions and increases at the rate determined according to the risk levels. The purpose of multiplying the relevant risk value with a fixed coefficient according to the risk levels is to ensure that more attention is paid to the higher level of risk. When all steps are completed and the weights of the risks are found with the AHP method, it is displayed with a pie chart to create flight safety risk awareness in pre-flight briefings.

In summary, if the steps are listed:

1. A matrix including probability, severity and risk levels is created by the SMS unit of the company where the flight test activities are carried out, so that the whole company can make a safety risk assessment, including flight test activities. If company SMS is not yet available, the SMS function for the flight is carried out by the flight test organization.
2. A number should be determined for each probability and severity value in the created matrix, and the risk levels are determined according to the value ranges in the matrix formed as a result of their multiplication.
3. The risk level and value included in the risk assessment prepared within the scope of flight test risk management in the relevant test flight are noted.
4. Which of the operational risks monitored by the SMS are expected to be exist in the conditions of the time when the relevant test flight will take place are

determined by the flight test engineers, and the current risk levels and values are noted.

5. Each risk is multiplied by the coefficient determined according to the risk level as a parameter of the decision matrix created within the scope of the AHP method and placed in the matrix.
6. With the AHP method, a decision matrix is created in such a way that the relative evaluations of each parameter, which are flight test and operational risks, their corresponding values in the risk matrix and the ratio of the result obtained as a result of their multiplication with the determined coefficient, relative to each other.
7. After the decision matrix is created, the weight of each risk is found by performing the calculations in the AHP method.
8. The values found are converted into pie charts and presented at the pre-flight briefing to increase the awareness of the flight test team and especially the flight crew.

4. ILLUSTRATION OF THE MODEL

As a result of the literature review, the AHP model and the examination of the weighting function of this model, this section will include case studies on how the model will be constructed and how the results will be. First of all, a risk assessment for a flight test, operational risks likely to be encountered during this flight test, and finally a risk matrix to be used while evaluating these risks should be determined. In the first scenario to be constructed, the "Spin" test, which is included in the Certification Specification (CS-23) [49] document published by EASA for normal category airplanes, will be performed. The spin maneuver is a special category of stall that results in autorotation (rolling without command) about the airplane's longitudinal axis and a shallow, rotating, downward path centered approximately on a vertical axis. In these tests, which will be carried out to determine the spin characteristic, there is a risk of "Loss of Control" as it is a situation that the aircraft and the pilot will have difficulty. These tests pose a “High” level of risk as stated in Advisory Circular (AC) 21-47 v1.1.

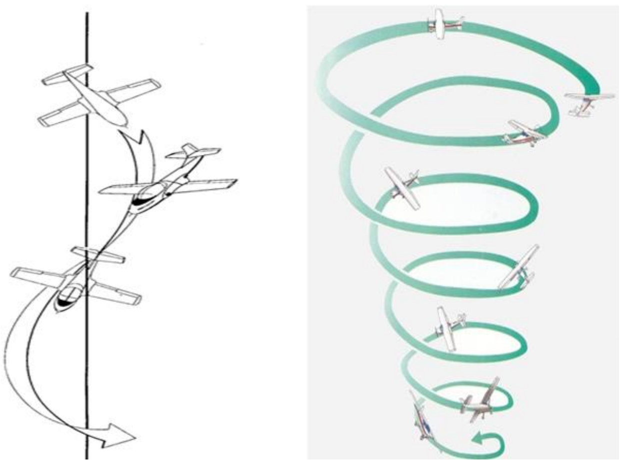

Figure 4.1 : Spin maneuver and spiral instability [50].

In addition to this test risk, let's consider 5 operational risks that may arise from the flight operation itself and the nature. These risks may include: Ground Accident, Icing Condition, Near Miss, Runway Excursion and Bird Strike. In a flight with a high risk level such as a spin test, the risk arising from this test itself is, of course, the most important issue to be considered and studied. However, taking into account the risks that may arise as a result of the flight operation, as well as the risk arising from the spin test, will create an awareness for the crews that will perform the flight, especially if there have been events which triggered these risks recently.

Together with the spin test risk and operational risks, in total there are 6 flight safety risks in the scenario that was designed. A risk matrix is used to determine the levels of these risks. Let SAAB's safety risk matrix in table 2.6 be used to determine these risk levels. The risk arising from the spin test can be chosen as "20", corresponding to the "High" level as mentioned above. It is not possible to make such an assessment for operational risks, because the levels of these risks may change as a result of safety data such as reporting, case studies and trend analysis. It can be commented that these risks do not generally appear at very high levels, and in cases where they do occur, the frequency of occurrence of these events has increased and it will be necessary to reduce them to low levels again by taking the necessary precautions. Let the risk levels be determined as follows, using the same risk matrix for the identified operational risks:

- Ground Accident, 8 – Low Level
- Icing Condition, 6 – Low Level
- Near Miss, 3 – Low Level
- Runway Excursion, 9 – Medium Level
- Bird Strike, 10 – Medium Level

After determining the levels and values of all risks, the comparison matrix in the AHP method is created. While creating this matrix, the relative importance of the risks will be calculated using the values determined in the risk matrix. However, these values will not be used directly and will be multiplied by a coefficient determined for each level in the risk matrix. This coefficient will increase as the level of risk increases and will increase the weighting of high-level risk and thus attract more attention to these risks. Let these values be initially determined as 0,5, 1 and 2 for low, medium and high level, respectively. In other words, the coefficient at each risk level will be 2 times the previous level. The risk values are multiplied by the relevant coefficient according to their level and the comparison matrix is created in accordance with the formulas (1), (2) and (3).

The resulting comparison matrix is as follows:

Table 4.1 : Comparison matrix for scenario 1.

Comparison Matrix		Loss of Control (Spin Test)	Ground Accident	Icing Condition	Near miss	Runway Excursion	Bird Strike
		20x2=40	8x0.5=4	6x0.5=3	3x0.5= 1.5	9x1=9	10x1= 10
Loss of Control (Spin Test)	20x2 =40	1	10	13,333	26,667	4,444	4
Ground Accident	8x0.5 =4	0,1	1	1,333	2,667	0,444	0,4
Icing Condition	6x0.5 =3	0,075	0,75	1	2	0,333	0,3
Near miss	3x0.5 =1.5	0,0375	0,375	0,5	1	0,167	0,15
Runway Excursion	9x1 =9	0,2250	2,25	3	6	1	0,9
Bird Strike	10x1 =10	0,25	2,5	3,333	6,667	1,111	1
$\sum_{i=1}^{n} a_{ij}$		1,688	16,875	22,5	45	7,5	1,35

After the comparison matrix is obtained, the normalized matrix and the weight of each risk with the values obtained from the normalized matrix are found. The formulas used to calculate the normalized matrix from the comparison matrix and then the weighting are:

- $b_{ij} = a_{ij} / (\sum_{i=1}^{n} a_{ij})$; elements of normalized matrix
- $w_i = (\sum_{j=1}^{n} b_{ij}) / n$; the weight of each risk

The resulting normalized matrix is as follows:

Table 4.2 : Normalized matrix for scenario 1.

Normalized Matrix	Loss of Control (Spin Test)	Ground Accid.	Icing Cond.	Near miss	Runway Excurs.	Bird Strike	w_i	λ_{max}
Loss of Control (Spin Test)	0,593	0,593	0,593	0,593	0,593	0,593	0,593	3,556
Ground Accident	0,0593	0,0593	0,0593	0,0593	0,0593	0,0593	0,059	0,356
Icing Condition	0,0444	0,0444	0,0444	0,0444	0,0444	0,0444	0,044	0,267
Near miss	0,0222	0,0222	0,0222	0,0222	0,0222	0,0222	0,022	0,133
Runway Excursion	0,1333	0,1333	0,1333	0,1333	0,1333	0,1333	0,133	0,8
Bird Strike	0,1481	0,1481	0,1481	0,1481	0,1481	0,1481	0,148	0,889

Here, in addition to the normalized matrix and weighting, the λ_{max} value is calculated. The λ_{max} value is a value that will be used to check the consistency of the results obtained.

Consistency rate (CR) of the created matrix is found with the ratio of CR = CI/RI.

RI is a random consistency index and is taken from table 3.2 according to the number of elements. In the scenario constructed, it is taken as RI=1.25, where there are 6 elements. The CI consistency index is found as follows:

$$CI = (\sum\lambda_{max} – n) / (n-1)$$

The $\sum\lambda_{max}$ value is found as 6 as a result of the sum of the values in the above table. The value “n” is the number of elements which is also 6. CI is calculated as 0 thus CR is becoming 0 too. Conditions with a CR value of ≤ 0.1 indicate that the comparison matrix is consistent. A value of 0 indicates that a fully consistent matrix has been created. In case the created matrix is consistent, it should be provided in the equation (8).

When the values are replaced and necessary calculations are done:

$$\begin{bmatrix} 1,0000 & 10,0000 & 13,3333 & 26,6667 & 4,4444 & 4,0000 \\ 0,1000 & 1,0000 & 1,3333 & 2,6667 & 0,4444 & 0,4000 \\ 0,0750 & 0,7500 & 1,0000 & 2,0000 & 0,3333 & 0,3000 \\ 0,0375 & 0,3750 & 0,5000 & 1,0000 & 0,1667 & 0,1500 \\ 0,2250 & 2,2500 & 3,0000 & 6,0000 & 1,0000 & 0,9000 \\ 0,2500 & 2,5000 & 3,3333 & 6,6667 & 1,1111 & 1,0000 \end{bmatrix} . \begin{bmatrix} 0,5926 \\ 0,0593 \\ 0,0444 \\ 0,0222 \\ 0,1333 \\ 0,1481 \end{bmatrix} = \begin{bmatrix} 0,5926 \\ 0,0593 \\ 0,0444 \\ 0,0222 \\ 0,1333 \\ 0,1481 \end{bmatrix} . 6$$

$$\begin{bmatrix} 3,556 \\ 0,356 \\ 0,267 \\ 0,133 \\ 0,800 \\ 0,889 \end{bmatrix} .= \begin{bmatrix} 3,556 \\ 0,356 \\ 0,267 \\ 0,133 \\ 0,800 \\ 0,889 \end{bmatrix} \quad \text{equality is achieved}$$

It is almost impossible to come across in the AHP method when the consistency ratio is 0 and the equality above is achieved. The main factor in obtaining this result is not using a subjective comparison of the values determined in the comparison matrix, but using the ratios of the risks whose values are determined through a risk matrix. In this case, the subjective part is the risk matrix used, the value chosen on this risk matrix for each risk and the coefficients determined for each level. In line with the weightings obtained as a result of the AHP method, these subjective situations may be questioned and re-evaluated.

The resulting weightings are shown in the pie chart as follows:

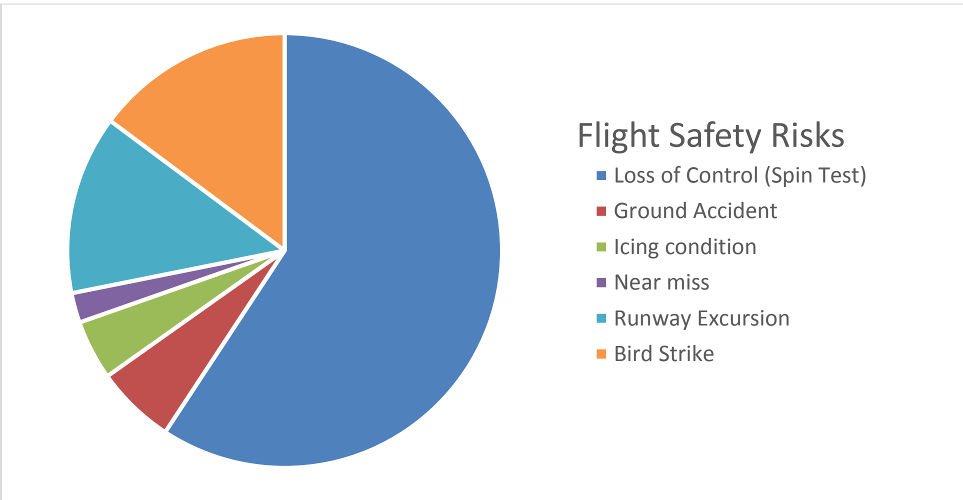

Figure 4.2 : Pie chart of risks weight distributions for scenario 1.

When the above graph is examined, it is seen that the risk originating from the spin test has the largest share, as expected. Bird Strike and Runway Excursion risks follow this risk in terms of share, respectively. In this case, it can be inferred that there has been a bird strike event recently, that the bird density has increased in the region where the tests were carried out. Moreover, there may have been reports of increase in bird density in the region where the tests were carried out. Similarly, there may have been events that will lead the aircraft to go off the runway. In this way, the flight crew gains awareness of the current status of operational risks and the extent of these risks, as well as the current flight test to be carried out and the risks posed by this test. As for other risks, it can be interpreted that necessary precautions have been taken since they have a very small share, or that the frequency of events that will trigger these risks has decreased. Although they have small shares, the purpose of showing these risks is that there is more than one operational risk besides the flight test risk and that these risks can be encountered even if the level is low. Because the flight itself carries risks and as long as the flight activities are carried out, the risks can never be completely eliminated.

If we replace the 0.5, 1 and 2 coefficients determined for a risk level with 0.2, 0.6 and 1.8, respectively, in the scenario that has been constructed, the consistency will not change and the distribution of the new weights obtained will be as follows:

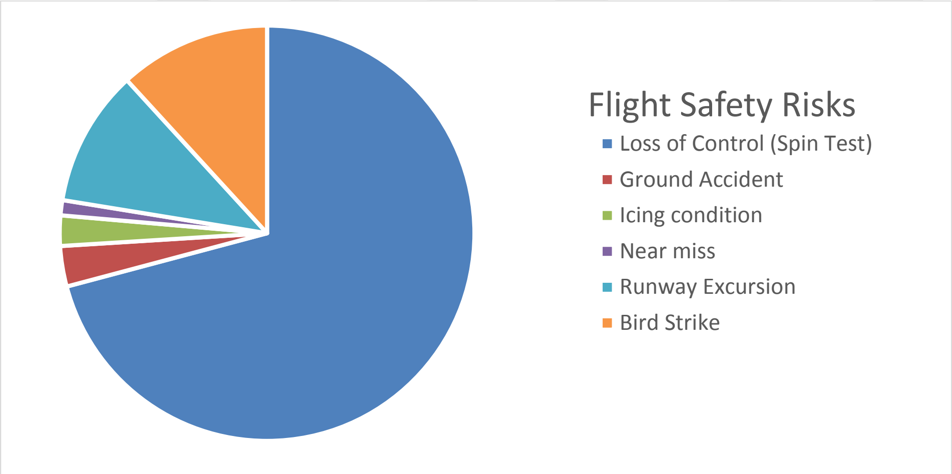

Figure 4.3 : Pie chart of risks weight distributions for scenario 1 with different coefficient.

When the above graph is analyzed, it is seen that while the share of high-level risk increases, the share of lower-level risks decreases. The main reason for this is to triple the ratio between the coefficients. Although the comments made for the previous distribution remain valid in this distribution, it can be concluded that it is desired to draw more attention to the risk arising from the flight test.

Let's create a second scenario using the same risk matrix, this time with a test flight selected in such a way that the flight test risk is not high, but medium. Considering a flight where the Roll Rate of the aircraft will be tested, this flight will have a medium level of risk, as shown in table A.3, and may result in Structural Failure in the worst case. In addition to this test risk, let's consider 5 operational risks that may arise from the flight operation. These risks may include: Hard Landing, Turbulence, Near Miss, Runway Excursion and CFIT. For the determined operational risks and test risk, the risk matrix used in the previous scenario and the risk levels can be determined as follows:

- Structural Failure (Roll Rate), 15 – Medium Level
- Hard Landing, 8 – Low Level
- Turbulence, 5 – Low Level
- Near Miss, 3 – Low Level
- Runway Excursion, 8 – Low Level
- CFIT, 10 – Medium Level

After determining the levels and values of all risks, the new comparison matrix is created as in the previous scenario, using the coefficients of 0.5, 1 and 2 for the low, medium and high level, respectively.

Table 4.3 : Comparison matrix for scenario 2.

Comparison Matrix		Structural Failure (Roll Rate)	Hard Land.	Turbu.	Near miss	Runway Excursion	CFIT
		15x2=30	8x0.5=4	5x0.5=2.5	3x0.5= 1.5	8x0.5=4	10x1= 10
Structural Failure (Roll Rate)	15x2 =30	1	3,75	6	10	3,75	1,5
Hard Landing	8x0.5 =4	0,267	1	1,6	2,667	1	0,4
Turbulance	5x0.5 =2.5	0,167	0,625	1	1,667	0,625	0,25
Near miss	3x0.5 =1.5	0,1	0,375	0,6	1	0,375	0,15
Runway Excursion	8x0.5 =4	0,267	1	1,6	2,667	1	0,4
CFIT	10x1 =10	0,667	2,5	4	6,667	2,5	1
$\sum_{i=1}^{n} a_{ij}$		2,467	9,25	14,8	24,67	9,25	3,7

After the comparison matrix is obtained, the normalized matrix and the weight of each risk with the values obtained from the normalized matrix are found.

Table 4.4 : Normalized matrix for scenario 2.

Normalized Matrix	Struct. Failure (Roll Rate)	Hard Landing	Turbu.	Near miss	Runway Excurs.	CFIT	w_i	λ_{max}
Structural Failure (Roll Rate)	0,405	0,405	0,405	0,405	0,405	0,405	0,405	2,432
Hard Landing	0,108	0,108	0,108	0,108	0,108	0,108	0,108	0,648
Turbulance	0,0676	0,0676	0,0676	0,0676	0,0676	0,0676	0,0676	0,405
Near miss	0,0405	0,0405	0,0405	0,0405	0,0405	0,0405	0,0405	0,243
Runway Excursion	0,1081	0,1081	0,1081	0,1081	0,1081	0,1081	0,1081	0,648
CFIT	0,2703	0,2703	0,2703	0,2703	0,2703	0,2703	0,2703	1,621

There is no need to calculate consistency again in this scenario, because again a risk matrix-based ratio was made and no subjective evaluation included. The resulting weightings will be displayed in the pie chart as follows:

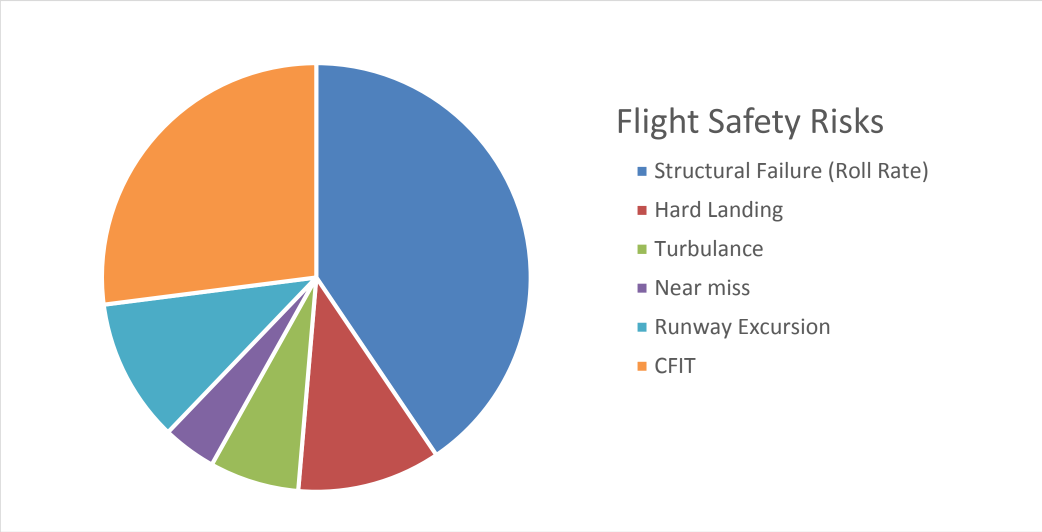

Figure 4.4 : Pie chart of risks weight distributions for scenario 2.

When the above graph is examined, it is seen that the flight test risk still has the largest share, but the CFIT operational risk has a share almost as much as the flight test risk. The main reason for this is that both are at a moderate risk level. Similar to the comments made for Bird Strike and Runway Excursion risks in the first scenario, the reason for the CFIT risk to be moderate can be the recent occurrence of undesirable events that may cause CFIT risk. Considering the low-level risks, it is seen that they have a larger share compared to the previous scenario. If the result in this scenario is not logical for the flight test organization, first of all, it may be necessary to change the coefficients determined for each risk level, if there is no logical distribution again, change the risk level selections by reviewing, and if this does not yield any results, the risk matrix and risk levels may need to be revised.

Let's create a third and final scenario with a different matrix but using the same risks and coefficient in the first scenario. The matrix to be used is the CASA safety risk matrix in table 2.8. Unlike the SAAB matrix, this matrix is in 5x5 format instead of 4x5 and has 4 risk levels instead of 3. The coefficient to be used for the fourth risk level, Extreme risk level, will be twice the previous level, i.e. 4. Although it is not exactly the level and values determined for the test and operational risks in the first scenario, in this scenario it will be as follows when it is tried to be selected close to the ones in the first scenario:

- Loss of Control (Spin Test), 9 – Extreme Level
- Ground Accident, 5 – Medium Level
- Icing Condition, 5 – Medium Level
- Near Miss, 3 – Low Level
- Runway Excursion, 6 – High Level
- Bird Strike, 6 – High Level

After determining the levels and values of all risks, the new comparison matrix is created as in the previous scenarios, using the coefficients of 0.5, 1, 2 and 4 for the low, medium and high level, respectively.

Table 4.5 : Comparison matrix for scenario 3.

Comparison Matrix		Loss of Control (Spin Test)	Ground Accident	Icing Condition	Near miss	Runway Excursion	Bird Strike
		9x4=36	5x1=5	5x1=5	3x0.5= 1.5	6x2=12	6x2=12
Loss of Control (Spin Test)	9x4 =36	1	7,2	7,2	24	3	2,571
Ground Accident	5x1 =5	0,1389	1	1	3,333	0,4167	0,357
Icing Condition	5x1 =5	0,1389	1	1	3,333	0,4167	0,357
Near miss	3x0.5 =1.5	0,0417	0,3	0,3	1	0,125	0,107
Runway Excursion	6x2 =12	0,3333	2,4	2,4	8	1	0,857
Bird Strike	6x2 =12	0,3889	2,8	2,8	9,333	1,1667	1
$\sum_{i=1}^{n} a_{ij}$		2,042	14,7	14,7	49	6,125	5,25

After the comparison matrix is obtained, the normalized matrix and the weight of each risk with the values obtained from the normalized matrix are found.

Table 4.6 : Normalized matrix for scenario 3.

Normalized Matrix	Loss of Control (Spin Test)	Ground Accid.	Icing Cond.	Near miss	Runway Excurs.	Bird Strike	w_i	λ_{max}
Loss of Control (Spin Test)	0,4898	0,4898	0,4898	0,4898	0,4898	0,4898	0,4898	2,93877
Ground Accident	0,0680	0,0680	0,0680	0,0680	0,0680	0,0680	0,0680	0,40816
Icing Condition	0,0680	0,0680	0,0680	0,0680	0,0680	0,0680	0,0680	0,40816
Near miss	0,0204	0,0204	0,0204	0,0204	0,0204	0,0204	0,0204	0,12244
Runway Excursion	0,1633	0,1633	0,1633	0,1633	0,1633	0,1633	0,1633	0,97959
Bird Strike	0,1905	0,1905	0,1905	0,1905	0,1905	0,1905	0,1905	1,14285

Consistency calculation is not necessary due to the reasons explained in the previous scenarios. The resulting weightings will be displayed in the pie chart as follows:

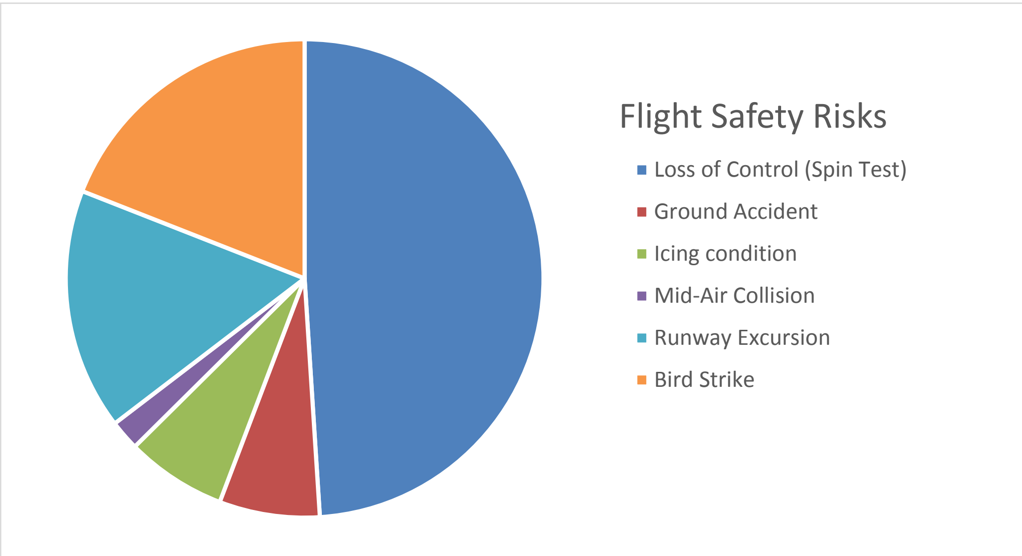

Figure 4.5 : Pie chart of risks weight distributions for scenario 3.

When the above graph is examined, it is seen that the flight test risk has the largest share, but it has a smaller share compared to the graph obtained by using the SAAB safety matrix. The most important reasons for this are that there are 4 levels of risk in the matrix of CASA, Bird Strike and Runway Excursion risks are at a higher level than the previous one, and the area determined for the low risk level in the matrix is very limited, so the number of risks that can take place at this level is low. In addition, the fact that the values at each risk level do not vary, and that there are 10 different values in total for the whole matrix, caused the flight test risk to have a relatively small share. In order to increase the share of flight test risk for this scenario, first of all the coefficients can be selected again with a larger ratio between them. In addition, the matrix can rebuild to increase the area for low and medium risk.

5. CONCLUSIONS AND RECOMMENDATIONS

The Annex-19 Safety Management System, published by ICAO in 2013, has been gradually implemented by all aviation stakeholders by the relevant authorities. Companies that carry out aircraft design and production activities do not have an SMS operating obligation yet, but as of 2025, according to the decision taken in the European Parliament, it will become mandatory for these organizations as well. This decision, which will be enforced by the EASA, will be put into practice by taking the example of the national aviation agencies of countries outside of Europe.

The process until the aircraft's type design and repair designs, part/device approvals, design/production organization approvals and related certificates are obtained, in short, pre-airworthiness is handled in Part-21 regulations published by EASA and FAA. Flight test activities are included under the title of design organizations (Subpart J) of this regulation, and the FTOM guide document on how these activities should be carried out has been published. Under the section of safety and risk management in the FTOM document, it is written that flight test specific risks should be evaluated with flight test risk management, and continuous/operational risks arising from the flight itself should be evaluated within the scope of SMS.

Within the scope of this study, it is aimed to raise awareness of the relevant crew before the flight by showing all the flight safety risks during the flight test execution by using the AHP method and the risk matrix used in the evaluation of flight safety risks. The use of the safety risk matrix and the values here while calculating the weights of the risks eliminates the subjective evaluation in the AHP method and makes the consistency index 0. However, the method used is subjective due to the structure of the risk matrix, the selected risk values and coefficients. Some conditions and points to be considered in order for the method to be applied and to give more realistic and accurate results are as follows:

• It is necessary to have a numerical value for each probability-severity factor in the risk matrix to be used and to determine the risk levels.

• Using the value selected for flight test risk, not the value reduced after necessary reductions, will provide more meaningful results if preventive and corrective reductions are not made, using the risk value it will have.

• It is necessary to define operational flight risks, choose an appropriate value in the risk matrix used, and determine which of these risks are likely to be encountered for each flight test.

• Effective monitoring of operational risks within the scope of SMS risk management and updating the levels of these risks (if necessary) periodically are also required as part of the requirements of the SMS.

• The effective functioning of the SMS within the institution will contribute to the achievement of healthier results by increasing the safety reporting and safety data sharing.

When the risk distributions in the sample flight test scenarios in this study are examined, it is seen that the risk arising from the flight test has the largest share in all scenarios. This result is due to the fact that the level of risks arising from the selected flight test is higher than the operational risks. When a flight test with a lower risk level is selected, it is likely that the flight test risk will have a similar share to the operational risks. However, even in such a situation, the flight test risk should be handled as a priority and given more importance. In any scenario, the flight test risk will always be the one that needs the most attention, while the share of operational risks will increase or decrease according to the risk level of the flight test. Rather than emphasizing the size of the operational risks in the total risk, it would be beneficial to show them together with the flight test risk in terms of raising awareness. The size of the operational risks in the total risk will of course enable a comparison among themselves.

Aside from the fact that the risks arising from the flight test are the main risk, when the share of operational risks in the graph is examined, some indicators can be found as to whether an effective safety management system is operated in the organization. If the levels of operational risks remain at the same level throughout a period of time, it may be an indication that these risks are not reviewed or no action is taken to reduce the levels of operational risks other than low risk levels. It is unlikely that even if all operational risks have been reviewed, they may have remained at the same level or no safety data may have been received that could change the level of operational risks.

Ideally, as a result of reports, notifications and other safety data obtained, the levels of operational risks are changed depending on their probabilities, and the risks that are outside the low level are reduced to a low level by reducing their effects or probability with the actions to be taken. Therefore, unlike flight test risks, operational risks are dynamic and changing over time.

By applying the method described in this thesis, all risks in flight test activities are examined by the relevant flight test team before the flight and their awareness is provided. With this method, results can be obtained that not only raise the awareness of the team, but also question the functionality of the safety management in the organization. Updating the risk management processes in the organization by giving feedback to the risk management process with the outputs of the method, it can be concluded that the safety data are insufficient and scarce, and may lead to their duplication and increase in number. As a result, this study is an example of the applications of SMS in flight test organizations, and after the obligation of SMS to be present in approved aircraft design and production organizations, new applications like this study will emerge and become more standardized.

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APPENDICES

APPENDIX A

Article 3

Subject matter and scope

1. This Regulation lays down rules on:

(a) the reporting of occurrences which endanger or which, if not corrected or addressed, would endanger an aircraft, its occupants, any other person, equipment or installation affecting aircraft operations; and the reporting of other relevant safety-related information in that context;

(b) analysis and follow-up action in respect of reported occurrences and other safety-related information;

(c) the protection of aviation professionals;

(d) appropriate use collected safety information;

(e) the integration of information into the European Central Repository; and

(f) the dissemination of anonymised information to interested parties for the purpose of providing such parties with the information they need in order to improve aviation safety.

2. This Regulation applies to occurrences and other safety-related information involving civil aircraft, with the exception of aircraft referred to in Annex II to Regulation (EC) No 216/2008. Member States may decide to apply this Regulation also to occurrences and other safety-related information involving the aircraft referred to in Annex II to that Regulation.

Article 4

Mandatory reporting

1. Occurrences which may represent a significant risk to aviation safety and which fall into the following categories shall be reported by the persons listed in paragraph 6 through the mandatory occurrence reporting systems pursuant to this Article:

(a) occurrences related to the operation of the aircraft, such as:

- (i) collision-related occurrences;
- (ii) take-off and landing-related occurrences;
- (iii) fuel-related occurrences;
- (iv) in-flight occurrences;
- (v) communication-related occurrences;
- (vi) occurrences related to injury, emergencies and other critical situations;
- (vii) crew incapacitation and other crew-related occurrences;
- (viii) meteorological conditions or security-related occurrences;

(b) occurrences related to technical conditions, maintenance and repair of aircraft, such as:

- (i) structural defects;
- (ii) system malfunctions;
- (iii) maintenance and repair problems;
- (iv) propulsion problems (including engines, propellers and rotor systems) and auxiliary power unit problems;

(c) occurrences related to air navigation services and facilities, such as:

- (i) collisions, near collisions or potential for collisions;
- (ii) specific occurrences of air traffic management and air navigation services (ATM/ANS);
- (iii) ATM/ANS operational occurrences;

APPENDIX B

Appendix XII — Categories of flight tests and associated flight test crew qualifications

Regulation (EU) No 748/2012

A. General

This Appendix establishes the qualifications necessary for flight crew involved in the conduct of flight tests for aircraft certified or to be certified in accordance with CS-23 for aircraft with a maximum take-off mass (MTOM) of or above 2 000 kg, CS-25, CS-27, CS-29 or equivalent airworthiness codes.

B. Definitions

1. 'Flight test engineer' means any engineer involved in flight test operations either on the ground or in flight.

2. 'Lead flight test engineer' means a flight test engineer assigned for duties in an aircraft for the purpose of conducting flight tests or assisting the pilot in the operation of the aircraft and its systems during flight test activities.

3. 'Flight tests' mean:

   3.1. flights for the development phase of a new design (aircraft, propulsion systems, parts and appliances);

   3.2. flights to demonstrate compliance to certification basis or conformity to type design;

   3.3. flights intended to experiment new design concepts, requiring unconventional manoeuvres or profiles for which it could be possible to exit the already approved envelope of the aircraft;

   3.4. flight test training flights.

C. Categories of flight tests

1. General

   The descriptions below address the flights performed by design and production organisations under Annex I (Part 21).

2. Scope

   If more than one aircraft is involved in a test, each individual aircraft flight shall be assessed under this Appendix to determine if it is a flight test and when appropriate, its category.

   The flights referred to in point (6)(B)(3) are the only flights that belong to the scope of this Appendix.

3. Categories of flight tests

   Flights tests include the following four categories:

   3.1. Category One (1)

      (a) Initial flight(s) of a new type of aircraft or of an aircraft of which flight or handling characteristics may have been significantly modified;

      (b) Flights during which it can be envisaged to potentially encounter flight characteristics significantly different from those already known;

(c) Flights to investigate novel or unusual aircraft design features or techniques;

(d) Flights to determine or expand the flight envelope;

(e) Flights to determine the regulatory performances, flight characteristics and handling qualities when flight envelope limits are approached;

(f) Flight test training for Category 1 flight tests.

3.2. Category Two (2)

(a) Flights not classified as Category 1 on an aircraft whose type is not yet certified;

(b) Flights not classified Category 1 on an aircraft of an already certified type, after embodiment of a not yet approved modification and which:

(i) require an assessment of the general behaviour of the aircraft; or

(ii) require an assessment of basic crew procedures, when a new or modified system is operating or is needed; or

(iii) are required to intentionally fly outside of the limitations of the currently approved operational envelope, but within the investigated flight envelope.

(c) Flight test training for Category 2 flight tests.

3.3. Category Three (3)

Flights performed for the issuance of statement of conformity for a new-built aircraft which do not require flying outside of the limitations of the type certificate or the aircraft flight manual.

3.4. Category Four (4)

Flights not classified as Category 1 or 2 on an aircraft of an already certified type, in case of an embodiment of a not yet approved design change.

APPENDIX C

AMC2 FCL.815 Mountain rating

ED Decision 2011/016/R

SKILL TEST AND PROFICIENCY CHECK

The skill test for the issue or the proficiency check for the revalidation or renewal of a mountain rating should contain the following elements:

(a) oral examination

This part should be done before the flight and should cover all the relevant parts of the theoretical knowledge. At least one question for each of the following sections should be asked:

(1) specific equipment for a mountain flight (personal and aircraft);

(2) rules of the mountain flight.

If the oral examination reveals a lack in theoretical knowledge, the flight test should not be done and the skill test is failed.

(b) practical skill test

During the flight test, two sites different from the departure airport should be used for recognition, approach, landing and take-off. For the mountain rating ski or the extension from wheel to ski, one of the two different sites should be a glacier.

FCL.820 Flight test rating

Regulation (EU) 2016/539

(a) Holders of a pilot licence for aeroplanes or helicopters shall only act as PIC in category 1 or 2 flight tests, as defined in Part-21, when they hold a flight test rating.

(b) The obligation to hold a flight test rating established in (a) shall only apply to flight tests conducted on:

(1) helicopters certificated or to be certificated in accordance with the standards of CS-27 or CS-29 or equivalent airworthiness codes; or

(2) aeroplanes certificated or to be certificated in accordance with:

(i) the standards of CS-25 or equivalent airworthiness codes; or

(ii) the standards of CS-23 or equivalent airworthiness codes, except for aeroplanes with an maximum take-off mass of less than 2 000 kg.

(c) The privileges of the holder of a flight test rating are to, within the relevant aircraft category:

(1) in the case of a category 1 flight test rating, conduct all categories of flight tests, as defined in Part-21, either as PIC or co-pilot;

(2) in the case of a category 2 flight test rating:

(i) conduct category 1 flight tests, as defined in Part-21:

— as a co-pilot, or

— as PIC, in the case of aeroplanes referred to in (b)(2)(ii), except for those within the commuter category or having a design diving speed above 0,6 mach or a maximum ceiling above 25 000 feet;

(ii) conduct all other categories of flight tests, as defined in Part-21, either as PIC or co-pilot;

(3) conduct flights without a type or class rating as defined in Subpart H, except that the flight test rating shall not be used for commercial air transport operations.

(d) Applicants for the first issue of a flight test rating shall:

(1) hold at least a CPL and an IR in the appropriate aircraft category;

(2) have completed at least 1 000 hours of flight time in the appropriate aircraft category, of which at least 400 hours as PIC;

(3) have completed a training course at an ATO appropriate to the intended aircraft and category of flights. The training shall cover at least the following subjects:

— Performance,

— Stability and control/Handling qualities,

— Systems,

— Test management,

— Risk/Safety management.

(e) The privileges of holders of a flight test rating may be extended to another category of flight test and another category of aircraft when they have completed an additional course of training at an ATO.

AMC1 FCL.820 Flight test rating

ED Decision 2020/005/R

TRAINING COURSE

GENERAL

(a) Competency-based training:

(1) Training courses for the flight test rating should be competency-based. The training programme should follow as much as possible the syllabus outlined below, but may be adapted taking into account the previous experience, skill and theoretical knowledge level of the applicants.

(2) It should also be recognised that the syllabi below assume that suitable flight test experience will be gained subsequent to attendance at the course. Should the applicant be significantly experienced already, then consideration should be made of that experience and it is possible that course content might be reduced in areas where that experience has been obtained.

(3) Furthermore, it should be noted that flight test ratings are specific to both a certain category of aircraft (aeroplanes or helicopters) and to a certain category of flight test (category 1 or 2). Therefore, holders of a flight test rating wishing to extend their privileges to further categories of aircraft or to further categories of flight test (this is only relevant for holders of a category 2 flight test rating since the category one flight test rating includes the privileges for category 2 test flights) should not be requested to undertake the same course as an 'ab-initio' applicant. In these cases, the ATO should develop specific 'bridge courses' taking into account the same principles mentioned above.

(4) To allow proper consideration of the applicant's previous experience, a pre-entry assessment of the applicant's skills should be undertaken, on the basis of which the ATO

APPENDIX D

D. Competence and experience of pilots and lead flight test engineers

1. General

Pilots and lead flight test engineers shall have the competences and experience specified in the following table.

	Categories of flight tests			
Aircraft	1	2	3	4
CS-23 commuter or aircraft having a design diving speed (Md) above 0.6 or a maximum ceiling above 7 260 m (25 000 ft), CS-25, CS-27, CS-29 or equivalent airworthiness codes	Competence level 1	Competence level 2	Competence level 3	Competence level 4
Other CS-23 with an MTOM of or above 2 000 kg	Competence level 2	Competence level 2	Competence level 3	Competence level 4

1.1 Competence level 1:

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1.1.1 Pilots shall comply with the requirements of Annex I (Part-FCL) to Commission Regulation (EU) No 1178/2011 of 3 November 2011[1].

1.1.2 Lead flight test engineer shall have:

(a) satisfactorily completed a Competence level 1 training course; and

(b) a minimum of 100 hours of flight experience, including flight test training.

1.2 Competence level 2:

1.2.1 Pilots shall comply with the requirements of Annex I (Part-FCL) to Commission Regulation (EU) No 1178/2011 of 3 November 2011.

1.2.2 The lead flight test engineer shall have:

(a) satisfactorily completed a Competence level 1 or level 2 training course; and

(b) a minimum of 50 hours of flight experience, including flight test training.

The competence level 1 or level 2 training courses for Lead flight test engineer shall cover at least the following subjects:

(i) Performance;

(ii) Stability and control/handling qualities;

(iii) Systems;

(iv) Test management; and

(v) Risk/safety management.

1.3 Competence level 3:

1.3.1 Pilot(s) shall hold a valid licence appropriate to the category of aircraft under test, issued in accordance with Part-FCL and hold a Commercial Pilot Licence (CPL) as a minimum. In addition, the pilot-in-command shall:

(a) hold a flight test rating, or;

(b) have at least 1 000 hours of flight experience as pilot-in-command on aircraft having similar complexity and characteristics, and

(c) have participated, for each class or type of aircraft, in all flights that are part of the programme leading to the issuance of the individual certificate of airworthiness of at least five aircraft;

1.3.2 Lead flight test engineer shall:

(a) satisfy Competence level 1 or level 2, or;

(b) have gained a significant amount of flight experience relevant to the task; and

[1] Commission Regulation (EU) No 1178/2011 of 3 November 2011 laying down technical requirements and administrative procedures related to civil aviation aircrew pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council (OJ L 311, 25.11.2011, p.1).

(c) have participated in all flights that are part of the programme leading to the issuance of the individual certificate of airworthiness of at least five aircraft.

1.4 Competence level 4:

1.4.1 Pilot(s) shall hold a valid licence appropriate to the category of aircraft under test, issued in accordance with Part-FCL and hold a CPL as a minimum. The pilot-in-command shall hold a flight test rating or have at least 1 000 hours as pilot-in-command on aircraft having similar complexity and characteristics.

1.4.2 Competence and experience for lead flight test engineers is defined in the flight test operations manual.

APPENDIX E

RISK MANAGEMENT							
Hazard	**Cause**	**Effect**	**Probability**[1]	**Severity**[2]	**Risk**[3]	**Mitigation**	**Emer Proc**[4]
Describe "what might happen to adversely affect the safety of the test?" *Example: Loss of control*	Describe the "what might cause that hazard to happen?". *Example: Poor technique. Unexpected air vehicle response. Wind gradient or shear*	Describe the effect of the hazard *Example: Ground impact, loss of crew/ aircraft*	Describe the chances of the hazard occurring. *Example: Occasional*	Describe severity of the consequences if the hazard occurs *Example: Catastrophic*	State the overall risk. *Example: High*	Describe how the risk is minimized. Include all pertinent factors. *Example (partial):* *1. The pilots must be familiar with the aircraft's handling characteristics at low-speed, high AOA, and stall departure recovery techniques.* *2. Pre-flight briefing to include engine failure procedures, the quick-start procedure, along with ditching procedures.* *3. Lat-Dir handling qualities and stall characteristics testing completed.* *4. etc.*	Describe what will be done IF the hazard occurs to reduce the severity. *Example: Reduce AOA, increase speed, and retard throttle as necessary to maintain directional control, etc.*

Table E.1 : Sample risk management plan in table format [6].

Hazard Number: 1
Test Plan: Aero 1
Flight Test Technique: V_{MCA} Static.
Hazard: Loss of control.
Cause: Low altitude stall.
Effect: Ground impact, Loss of aircraft and crew.

Risk Assessment					
Catastrophic	Avoid	High	High	Medium	Low
Hazardous	Avoid	High	Medium	Medium	Low
Major	High	High	Medium	Medium	Low
Minor	Medium	Medium	Medium	Low	Low
No Safety Effect	Low	Low	Low	Low	Low
Severity / Probability	**Frequent**	**Probable**	**Occasional**	**Remote**	**Improbable**

Mitigations and Minimizing Procedures:

1. The pilots must be familiar with the aircraft's handling characteristics at low-speed, high angle-of-attack, and stall departure recovery techniques.
2. Monitor structural loads real-time.
3. Pre-flight briefing to include engine failure procedures, the quick-start procedure, along with ditching procedures (if over water).
4. Directional control handling qualities testing and Light / Aft stall characteristics will be completed prior to any V_{MCA} tests.
5. Entry altitude should be a minimum of xxxx ft AGL.
6. Spin-chute (if installed) must be operational and pilot familiar with its operation.
7. Minimum crew only.
8. etc.

Emergency Procedures: Reduce angle-of-attack, increase airspeed and retard throttle as necessary to maintain directional control.

Weather Requirement and/or Flight Conditions: VMC, no clouds below.

Minimum Essential Aircrew: **YES** NO | ***Parachutes Required:*** **YES** NO

RISK:	LOW	MEDIUM	**HIGH**	AVOID

Table E.2 : Sample risk management plan in one-page-per-hazard format [6].

Ser.	Event	Hazard	Worst Effect/ Probability	Initial Risk Level	Minimisation Procedures	Corrective Action	Minimisation / Corrective Effect	Residual Risk Level
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
1	SHSS	Structural failure due to excessive sideslip loads.	Catastrophic/ Unlikely	Medium	Confirm aircraft β limit with applicant and observe this limit during tests. Apply and remove pedal deflection in slow, smooth manner.	If β limit exceeded statically, release pedal slowly and smoothly.	Probability reduced to remote.	Low
2	Roll Rate	Structural failure after exceeding aircraft limits.	Catastrophic/ Unlikely	Medium	Discuss roll characteristics with applicant test pilot prior to tests. Centralise skid ball during testing. Knock-it-off (KIO) if control reversal or significant stick force lightening experienced. Build up by Half then Full Aileron Clean then Takeoff then Landing configuration. V_A or V_{FE} – 20% Minimum altitude during roll testing 2000 ft AO.	Loss of Control (LOC) recovery technique. Simultaneously: • Select engine to Idle • Centralise controls • Maintain neutral aileron until V_S+5kts • Retract flaps at pilot's discretion • Recover from dive.	Probability of aircraft damage reduced to remote.	Low

Table E.3 : Hazard analysis risk management matrix [37].

APPENDIX F

SERIOUS
UNACCEPTABLE
UNACCEPTABLE+

No.	Identification of Undesirable Events (UE)	EU1 - CFIT	EU2 - Crash after loss of control in flight	EU3 - Collision in flight	EU4 - Collision on ground	EU5 - Runway excursion	EU6 - Damage/injuries in flight	EU7 - Damage/injuries on ground
UE01	Non-stabilized approach	X	X			X	X	
UE02	Incorrect weight/center of gravity determination and insertion of these data in the FMS		X			X	X	
UE03	Incursions on runways				X	X		X
UE04	Incident associated with icing conditions or deicing procedures		X				X	
UE05	Hazardous phenomena encountered (thunderstorms, strong winds, wind shear, hailstorms, fog, etc.)		X			X	X	
UE06	Failure of a single engine on multi-engined aircraft (failure, no fuel left, etc.)		X			X	X	
UE07	Flight path deviation "en route"	X		X			X	X
UE08	Loss of (IFR/IFR or special IFR/VFR) separation in flight			X			X	
UE09	Unsuitable action of the flight crew (FH, regulation)	X	X	X	X	X	X	X
UE10	Failure of ground/onboard interfaces	X		X			X	
UE11	Events associated with contaminated runway					X		X
UE12	Aircraft system failure (other than engine failure)	X	X	X	X	X	X	X
UE13	Fire, smoke, accidental contact of an oxidizer with a source of ignition		X				X	X
UE14	Events associated with work/maintenance operations/dimensions on the helipad	X			X	X		X
UE15	Events associated with an incident in maintenance	X	X	X	X	X	X	X
UE16	Critical aircraft damage not detected before flight	X	X	X	X	X	X	X
UE17	Failure of a single engine on single-engined aircraft (failure, no fuel left, etc.)		X			X	X	X
UE18	Malfunctioning of the communication system (ATC/aircraft, aircraft/ground team, etc.)			X	X			X
UE19	Obstacle unknown to the flight crew, likely to produce interference with the flight path	X			X		X	
UE20	Bird strike		X				X	X
UE21	Inadvertent entry in IMC, loss of visual reference in flight		X	X			X	
UE22	Exceedance of weight limitation and centre-of-gravity position affecting the controllability		X				X	

Table F.1 : Undesirable Events [43].

CURRICULUM VITAE

Name Surname : Yusuf AKGÜR

EDUCATION :

- **B.Sc.** : 2018, Istanbul Technical University, Faculty of Aeronautics and Astronautics, Astronautical Engineering
- **B.Sc.** : 2021, Anadolu University, Faculty of Business Administration, Aviation Management

PROFESSIONAL EXPERIENCE AND REWARDS:

- Between 2018-2021, his career is started as a flight safety specialist at Turkish Airlines A.O.
- In 2021, he started to work as a safety management system engineer at Turkish Aerospace Industries, and he still continues to do so.