Development of a Framework for Design Verification Report of UAS:
Proposal of Means of Compliance for Flight Termination System
(Versão final após defesa)

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Resumo

Atualmente, a utilização de veículos aéreos não tripulados, também conhecidos como drones, continua a expandir-se no nosso quotidiano, impulsionada pela sua versatilidade e utilidade em diversas áreas. Estas incluem fotografia aérea e videografia, mapeamento, vigilância, agricultura, transporte de alimentos e bens essenciais, inspeção de infraestruturas, operações de salvamento, entre outras aplicações. Assim, os veículos aéreos não tripulados desempenham um papel significativo no avanço da engenharia e aplicações militares, mas também desempenham um papel fundamental em ações humanitárias, como o transporte de alimentos e medicamentos vitais.

Porém, surge uma crescente preocupação relativa ao uso responsável dos veículos aéreos não tripulados. Questões relacionadas à privacidade, segurança, perda de empregos, impactos ambientais e sociais devem ser cuidadosamente consideradas aquando da adoção desta tecnologia. De modo a mitigar riscos e potenciais efeitos adversos, é necessário que as entidades reguladoras, instituições, partes interessadas, operadores e estados-membros da União Europeia desenvolvam regulamentações que unifiquem e esclareçam o uso de veículos aéreos não tripulados relativamente a essas preocupações.

Daqui surge a necessidade de desenvolvimento de leis para o uso responsável de drones. Contudo, dada a natureza ainda pouco explorada e em constante evolução desta área, é essencial atualizar e aprimorar as regulamentações existentes. Além disso, as partes interessadas devem desempenhar sempre um papel ativo no desenvolvimento das legislações.

Esta dissertação visa contribuir para o desenvolvimento da legislação de veículos aéreos não tripulados, abordando tópicos que ainda suscitam muitas questões. A importância da verificação do projeto deve-se à possibilidade de identificar e corrigir potenciais problemas antes que o veículo aéreo não tripulado entre em produção ou operação, permitindo, essencialmente, identificar falhas de segurança que poderiam causar danos irreversíveis.

É, então, desenvolvida uma metodologia que identifica os passos gerais do processo de verificação do projeto, permitindo a obtenção de uma autorização operacional. Esta é aplicável a qualquer sistema do veículo aéreo não tripulado e pode ser utilizada pela indústria como forma de obter aprovação por parte da autoridade competente. Este fluxograma é elaborado com base em documentos de suporte emitidos pela autoridade competente e visa unificar uma estratégia para a obtenção de uma autorização operacional para operações com um nível específico de integridade e garantia IV.

Ao aplicar-se este fluxograma, surge a necessidade de desenvolver meios de conformidade para o sistema em estudo, sendo este o sistema de terminação de voo. Esta proposta de meios de conformidade serve como uma declaração que viabiliza à autoridade competente emitir uma autorização operacional, permitindo ao aplicante comprovar o desempenho do sistema. Esta proposta de meios de conformidade é desenvolvida tendo em conta documentos já emitidos pela autoridade competente, propondo a inclusão de novos testes e algumas sugestões de adaptações.

A importância de desenvolver meios de conformidade propostos reside na capacidade de apresentar um caminho para a demonstração de conformidade com os requisitos impostos pela entidade competente, permitindo ao aplicante mostrar que os sistemas do veículo aéreo não tripulado se encontram em conformidade com as normas, respeitando as práticas seguras e sustentáveis.

Palavras-chave

Sistemas de Aeronaves Não Tripuladas (UAS); Sistema de Terminação de Voo (FTS); Verificação do Projeto; Categoria Específica; Nível Específico de Integridade e Garantia (SAIL); Meios de Conformidade (MoC); Análise de Risco Operacional (SORA)

Resumo Alargado

Motivação

Mobilidade aérea avançada (AAM) representa uma categoria emergente de veículos aéreos e sistemas de transporte projetados para fornecer serviços de transporte mais rápidos, eficientes e sustentáveis tanto em áreas urbanas quanto rurais. AAM refere-se ao uso de aeronaves, incluindo veículos híbridos e elétricos de descolagem e aterragem vertical (eVTOL), helicópteros híbridos-elétricos e drones que podem transportar passageiros e/ou carga entre centros urbanos, semiurbanos e áreas remotas. O principal objetivo da AAM é reduzir o congestionamento do tráfego, melhorar a conectividade e acessibilidade, e diminuir as emissões de carbono do transporte terrestre. Estes veículos avançados são projetados para voos de curta distância e para descolar e aterrar verticalmente, eliminando a necessidade de pistas e permitindo que operem de *helipads* ou *vertiports* [1].

Veículos aéreos não tripulados (UAVs), também conhecidos como drones, são aeronaves que operam remotamente sem um piloto humano a bordo. Os UAVs podem ser controlados remotamente por um operador humano ou programados para voar autonomamente [2]. No entanto, o uso contínuo de sistemas de aeronaves não tripuladas (UAS) levanta questões sobre a privacidade, segurança e impacto social. Deste modo, a Agência da União Europeia para a Segurança da Aviação (EASA) implementou regulamentações e diretrizes para a operação e uso de UAS que devem ser adotadas pelos estados membros da União Europeia.

Para operar e comercializar com sucesso serviços de UAVs, é essencial cumprir todas as regulamentações estabelecidas pela EASA. Um dos requisitos estabelecidos pela entidade competente é a implementação de sistemas de segurança e emergência eficientes. Entre estes sistemas, o sistema de terminação de voo (FTS) surge como um componente fundamental na prevenção de acidentes e mitigação de riscos. A implementação de sistemas essenciais como o FTS é importante para garantir a segurança da população, propriedades e aeronaves tripuladas durante as operações dos UAVs. Por essa razão, foi escolhido o FTS como o foco central desta dissertação.

O sistema de terminação de voo é um mecanismo de segurança instalado nos UAVs e é projetado para interromper remotamente operações de voo em caso de emergências e garantir a contenção da aeronave. O FTS fornece meios para operadores no solo interromperem rapidamente o voo, e em segurança, no caso de situações incontroláveis ou inseguras [3]. A importância da obtenção de um relatório de verificação do projeto (DVR) para um FTS centra-se em garantir a conformidade, confiabilidade, desempenho e responsabilidade do sistema.

O estudo da presente dissertação tem como objetivo certificar o FTS utilizado no UAS chamado AAMOB, desenvolvido pelo CEiiA em colaboração com o Centro Hospitalar Universitário São João (UHCSJ) e Rangel Logistics Solutions. O AAMOB tem objetivos urbanos e semiurbanos para auxiliar em emergências médicas e pode ser utilizado para transportar bens essenciais médicos (por exemplo, sangue) entre hospitais ou instalações médicas. Algumas características deste UAS já foram estabelecidas, tais como descolagem e aterragem vertical (VTOL), operações para além da linha de vista (BVLOS), configuração de asa fixa e velocidade de cruzeiro igual a 120 km/h.

O AAMOB enquadra-se na categoria específica de operações, devido a fatores como a sua massa máxima à descolagem (MTOM) de aproximadamente 80 kg, características operacionais e riscos operacionais associados.

De acordo com a metodologia de análise de risco operacional (SORA), que avalia os riscos e determina a aceitabilidade de uma operação proposta [4], o AAMOB opera com um nível específico de integridade e garantia (SAIL) IV com base numa análise de risco no solo e no espaço aéreo. O SAIL representa o nível de confiança de que a operação do UAS permanecerá sob controlo [4]. As configurações operacionais introduzem desafios específicos e potenciais riscos associados à presença de áreas povoadas, ao aumento do tráfego aéreo e à necessidade de navegação e coordenação precisas.

Objeto e Objetivo

O objeto selecionado para esta dissertação é o desenvolvimento de uma metodologia geral que pode ser aplicada a qualquer sistema do UAV e que inclui os meios necessários para a demonstração de conformidade com os objetivos de segurança operacional (OSOs) segundo os requisitos regulatórios.

Pretende-se desenvolver uma metodologia flexível que possa ser aplicada não só ao FTS, mas também a outros sistemas (por exemplo, paraquedas). No entanto, quando aplicada especificamente ao FTS, esta metodologia leva à proposta de meios de conformidade (MoC). O MoC consiste num documento com instruções detalhadas e critérios para atender aos requisitos regulatórios, detalhando ações específicas, processos ou métodos que precisam de ser implementados para alcançar a conformidade.

Assim, o primeiro objetivo desta dissertação é o desenvolvimento de uma metodologia que permita a validação do FTS para operações até SAIL IV. O desenvolvimento e implementação desta metodologia permitirá obter validação por parte da autoridade competente, utilizando os meios de conformidade propostos para o FTS, resultando na emissão de um DVR.

Além disso, a proposta do MoC especificamente adaptado para operações em SAIL IV com a contenção representa o segundo objetivo da presente dissertação. O FTS serve como um método para lidar com a contenção do UAS [3].

Metodologia

A metodologia adotada segue uma abordagem conceptual, começando com uma apresentação da motivação para o desenvolvimento da dissertação, bem como o objeto e objetivos.

A pesquisa começa com uma revisão da literatura que ajuda a recolher os conceitos-chave para definir a estrutura da dissertação. Esta revisão foca-se nas definições de AAM e UAS, assim como um estudo intensivo das três categorias de operação: aberta, especifica, e certificada. Posteriormente, é analisada a legislação existente para UAVs e para os seus sistemas. Para alcançar os objetivos propostos da dissertação é necessário compreender o conceito de operações (ConOps) e as características da aeronave para as quais o FTS em estudo foi projetado.

A metodologia SORA consolida todos os conceitos anteriormente mencionados. SORA fornece uma metodologia para criar, avaliar e realizar operações de UAS em segurança dentro da categoria específica de operações. Esta análise de risco consiste numa metodologia para auxiliar tanto os operadores de UAS como a autoridade competente na avaliação da segurança da operação de determinado UAS. Esta serve, também, como um guia para ajudar os operadores de UAS a identificar as medidas de mitigação mais adequadas para reduzir o risco da operação até um nível aceitável [4].

Depois do estudo da metodologia SORA, é possível entender-se o relatório de verificação do projeto. Este consiste num relatório emitido pela EASA que documenta que o projeto do UAS está em conformidade com os objetivos de segurança aplicáveis [5].

A *framework* proposta nos objetivos é desenvolvida, principalmente, com base em *standards* aeronáuticos existentes e documentação de suporte fornecida pela autoridade competente. Quando esta metodologia se encontrar desenvolvida pretende-se aplicá-la a um sistema específico, o FTS.

Após a análise dos *standards* aeronáuticos e da documentação de suporte (por exemplo, o MoC para contenção até operações SAIL II [3]), o estudo avança para o desenvolvimento dos meios de conformidade propostos para a demonstração de conformidade para o FTS, o que representa uma etapa crucial na referida *framework*.

Análise e Resultados

A metodologia desenvolvida para a presente dissertação visa identificar e enumerar os passos necessários para a obtenção de um DVR considerando diversos cenários possíveis. O processo de obtenção desse relatório, aplicável a um sistema, parte ou componente do UAS, assegura a conformidade do projeto com os objetivos de segurança operacional. Este fluxograma é desenvolvido com base em documentos emitidos pela autoridade competente, sendo aplicável a qualquer um dos seguintes casos [6]:

- Quando uma operação é classificada como SAIL IV;
- Meios de mitigação relativos ao projeto quando declarada alta robustez;
- Para a verificação da contenção melhorada conforme definido no SORA quando nenhum MoC é aplicado.

A metodologia em questão pode ser dividida em oito passos. O primeiro passo envolve o estabelecimento do conceito de operações e dos limites operacionais abrangidos pelo UAS em estudo. O segundo passo propõe uma metodologia de análise de risco operacional à autoridade competente ou a execução da metodologia SORA desenvolvida pela EASA, para avaliar a segurança da operação do UAS. Se a autoridade competente concordar com a execução desta análise de risco, é então possível avançar para o próximo passo. Este passo consiste em verificar as condições de aplicabilidade enumeradas acima. Em seguida, é necessário identificar os requisitos para os quais a conformidade com os objetivos de segurança operacional deve ser demonstrada para o sistema, parte, ou componente em estudo. Uma vez identificados os requisitos, é necessário identificar os meios de conformidade ou documentos de suporte (como especificações técnicas ou *standards* industriais) publicados pela autoridade competente que delineiam a metodologia para a demonstração de conformidade. Geralmente, essa demonstração ocorre através de revisões do projeto, cálculos, análises, testes de laboratório, testes de solo, testes de voo, entre outros. O sexto passo consiste em propor um programa de verificação do projeto, que compreende uma lista dos meios de conformidade propostos ou previamente identificados como sendo úteis para a demonstração de conformidade, juntamente com outros documentos relevantes. Aqui, são identificados procedimentos, datas, testes, avaliações e outros elementos fundamentais para a demonstração de conformidade com os OSOs técnicos. Se a autoridade competente concordar com este programa, o processo avança para a execução das atividades de verificação iniciando, assim, o processo de verificação do projeto. As atividades de verificação incluem avaliações, análises, testes, etc., e os resultados devem ser documentados e facultados à autoridade competente. Por fim, se todos os passos anteriores forem cumpridos e aceites pela autoridade competente, a EASA emitirá um relatório de verificação do projeto garantindo a conformidade do sistema, parte ou componente com os requisitos identificados.

Surge, portanto, a necessidade de propor meios de conformidade para operações em SAIL IV para o FTS, uma vez que estes ainda não foram desenvolvidos pela autoridade competente. Este MoC proposto foi desenvolvido tendo por base o MoC estabelecido para a contenção para operações em SAIL II emitido pela EASA. As principais diferenças identificadas entre os meios de conformidade propostos para SAIL IV e aqueles já existentes para operações em SAIL II, ambos referentes à contenção, são as seguintes:

- Para operações em SAIL IV, a probabilidade do UAS sair do volume operacional por hora de voo é de 10^{-5}, e a probabilidade do UAS sair da *ground risk buffer* e entrar na área adjacente por hora de voo é de 10^{-7};

- O número de ativações necessárias para cada teste é modificado, exigindo agora 100 ativações por teste (100 para os testes de bancada, 100 para os testes de integração no solo após a instalação do FTS no UAS e 100 para os testes de voo);
- Propõe-se a inclusão de um novo teste na campanha de testes, denominado *Power Cut-Off Test*;
- Sugere-se também a alteração do tempo de latência entre a ativação do sistema e o sinal enviado pelo piloto remoto, passando este a ser considerado de 5 segundos;
- Realização de uma avaliação de segurança conforme o *standard* ED-280, que inclui a realização de uma FHA seguindo o *standard* ED-279, bem como a realização de uma avaliação do projeto e da instalação segundo o *standard* ASTM F3309-21.

A necessidade de se realizar uma análise de segurança, bem como o aumento do número de testes, advém do aumento do nível de garantia declarado para operações em SAIL IV.

Conclusões

Em suma, os objetivos da presente dissertação foram alcançados permitindo explorar a temática da mobilidade aérea avançada e a legislação atual aplicada aos veículos aéreos não tripulados.

A importância da realização desta dissertação reside na sua contribuição para o desenvolvimento da legislação dos UAVs, reconhecendo a necessidade de equilibrar os potenciais benefícios associados a estas tecnologias inovadoras. Assim, as regulamentações existentes visam unificar leis, tentando mitigar riscos e eliminar eventuais perigos associados ao uso de UAVs.

Em face à necessidade de estabelecer meios de conformidade para operações em SAIL IV, uma vez que estes ainda não foram estabelecidos pela autoridade competente, a metodologia desenvolvida visa preencher essa lacuna. Deste modo, os meios de conformidade propostos representam um passo importante na demonstração de conformidade com os requisitos identificados para a contenção em operações SAIL IV.

Abstract

Nowadays, the use of unmanned aerial vehicles, also known as drones, continues to expand in our daily lives, due to their versatility and practicality across various domains. These include aerial photography and videography, mapping, surveillance, agriculture, food and essential goods delivery, infrastructure inspection, and search and rescue operations, among other applications. Unmanned aerial vehicles play a significant role not only in advancing engineering and military applications but also hold a critical function in humanitarian efforts, such as the transport of food and medical supplies.

However, there is a growing concern regarding the responsible use of unmanned aerial vehicles. Issues related to privacy, safety, job displacement, and environmental and social impacts must be carefully considered when adopting this technology. To address these concerns and mitigate associated risks, regulatory entities, stakeholders, operators, and European Union Member States must collaborate in developing regulations that unify and clarify the use of unmanned aerial vehicles.

From this need arises the demand for the development of laws for the responsible use of drones. Yet, given the relatively unexplored and constantly evolving nature of this field, it becomes essential to update and enhance existing regulations. Additionally, stakeholders must actively participate in the development of legislation.

This dissertation aims to contribute to the evolution of legislation for unmanned aerial vehicles, addressing topics that still raise many questions. The importance of design verification lies in its capacity to identify and correct potential issues before unmanned aerial vehicles enter into production or operation, enabling the identification of safety failures that could lead to irreversible damage.

Consequently, a methodology is developed to outline the general steps of the design verification process, facilitating the obtainment of operational authorisation. This methodology is adaptable to any unmanned aerial vehicle system and can be employed by the industry to obtain approval from the competent authority. The framework is developed based on supporting documents issued by the competent authority and aims to unify a strategy for obtaining operational authorisation for operations with a specific assurance and integrity level IV.

The application of this framework underscores the need to establish means of compliance for the system under study, namely the Flight Termination System. This proposed means of compliance serves as a declaration that enables the competent authority to issue operational authorisation, allowing the applicant to substantiate the system's performance. This proposal for means of compliance is developed taking into account documents previously issued by the competent authority, suggesting the inclusion of new tests and offering recommendations for adaptations.

The importance of developing these proposed means of compliance lies in its ability to present a path for demonstrating compliance with the requirements imposed by the competent authority. It allows the applicant to demonstrate that systems comply with standards, adhering to safe and sustainable practices.

Keywords

Unmanned Aircraft Systems (UAS); Flight Termination System (FTS); Design Verification; Specific Category; Specific Assurance and Integrity Level (SAIL); Means of Compliance (MoC); Specific Operations Risk Assessment (SORA)

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List of Acronyms

AAM	Advanced Air Mobility
AC	Advisory Circular
AEC	Airspace Encounter Category
AEH	Airborne Electronic Hardware
AGL	Above Ground Level
AMC	Acceptable Means of Compliance
ANAC	Autoridade Nacional da Aviação Civil
ANSP	Air Navigation Service Provider
ARC	Air Risk Class
ATM	Air Traffic Management
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CAGR	Compound Annual Growth Rate
CEiiA	Centre of Engineering and Product Development
CNS	Communication, Navigation, and Surveillance
ConOps	Concept of Operations
CS	Certification Specification
CU	Command Unit
DAA	Detect and Avoid
DAL	Development Assurance Level
DVP	Design Verification Programme
DVR	Design Verification Report
EASA	European Union Aviation Safety Agency
EU	European Union
eVTOL	electric Vertical Take-Off and Landing
FAA	Federal Aviation Administration
FH	Flight Hour
FHA	Functional Hazard Assessment
FMEA	Failure Modes and Effects Analysis
FTS	Flight Termination System
GM	Guidance Material
GRC	Ground Risk Class
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
LTU	Lift/Thrust Unit
LUC	Light UAS Operator Certificate
MoC	Means of Compliance

MTOM	Maximum Take-Off Mass
NAA	National Aviation Authority
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
OSO	Operational Safety Objective
PANS	Procedures for Air Navigation Services
PAV	Personal Aerial Vehicle
PDRA	Predefined Risk Assessment
R&D	Research and Development
RID	Remote Identification
RPAS	Remotely Piloted Aircraft System
RTC	Restricted Type Certificate
SAA	See and Avoid
SAIL	Specific Assurance and Integrity Level
SARPs	Standards and Recommended Practices
SC	Special Condition
SDSP	Supplemental Data Service Provider
SORA	Specific Operations Risk Assessment
STS	Standard Scenario
sUAS	small Unmanned Aircraft System
SW	Software
TC	Type certificate
TLOS	Target Level of Safety
TMPR	Tactical Mitigation Performance Requirement
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
UHCSJ	University Hospital Center of São João
USSs	UAS Service Suppliers
UTM	UAS Traffic Management
VLOS	Visual Line of Sight
VTOL	Vertical Take-Off and Landing

Chapter 1

Introduction

1.1 Motivation

Advanced Air Mobility (AAM) represents an emerging aerial vehicles category and transportation systems designed to provide faster, more efficient, and sustainable transportation services in both urban and rural areas. AAM refers to the use of aircraft, including electric Vertical Take-Off and Landing (eVTOL) vehicles, hybrid-electric helicopters, and autonomous drones that can carry passengers and cargo between urban centers, suburbs, and remote areas. The primary goal of AAM is to reduce traffic congestion, improve connectivity and accessibility, and reduce carbon emissions from ground transportation. These advanced vehicles are designed for short-haul flights and to take-off and land vertically, eliminating the need for runways and enabling them to operate from helipads or vertiports [1].

Unmanned Aircraft Vehicles (UAVs), also known as drones, are aerial vehicles designed to operate remotely without an onboard human pilot. UAVs can be controlled remotely by a human operator or can be programmed to fly autonomously. UAVs are used in a wide range of applications, including aerial photography and videography, surveying and mapping, agriculture and forestry, infrastructure inspection and maintenance, search and rescue operations, disaster management and humanitarian aid, military and security operations, and environmental monitoring [2]. They are also being developed for commercial delivery services, such as delivering packages to customers or transporting medical supplies to remote areas, such as Manna Drone Delivery [7] and Zipline Drone Delivery [8].

However, the use of Unmanned Aircraft Systems (UAS) has also raised concerns about privacy, safety, and security. Consequently, the European Union Aviation Safety Agency (EASA) has implemented regulations and guidelines for UAS operation and usage among its Member States in the European Union (EU). Overall, UAS development and deployment will continue to be a subject of great interest and ongoing debate.

Due to its growth potential in the market, examining the UAV from a market study standpoint is becoming increasingly significant. According to the Global Drone Market Report by Drone Industry Insights, the global drone market size is forecast to reach US$55.8 billion by 2030, with the commercial market growing at a 7.8% Compound Annual Growth Rate (CAGR) [9].

To successfully operate and commercialize UAV services, it is essential to comply with all the regulations established by EASA. One of the requirements set forth by EASA is the implementation of efficient safety and emergency systems. Among these systems, the Flight Termination System (FTS) emerges as a pivotal component in preventing accidents and mitigating risks. The deployment of essential systems like the FTS is crucial for ensuring the safety of individuals, properties, and manned aircraft during UAV operations. Consequently, the FTS was chosen as the central focus of this dissertation.

An FTS is a safety mechanism installed on UAVs designed to remotely terminate flight operations in case of emergencies and ensure containment of the aircraft. The FTS provides means for ground operators to quickly and safely stop a UAV flight in the event of an uncontrollable or unsafe situation, such as loss of control or navigation, system malfunction, or unauthorised flight that leads to operation outside the operational volume [3]. The importance of obtaining a Design Verification Report (DVR) for an FTS focuses on ensuring system compliance, reliability, and performance. A properly designed and verified FTS can provide confidence to operators, regulatory agencies, and the public that the UAV is equipped with a system that can safely and reliably terminate flight in an emergency.

The case study presented in this dissertation aims to verify the FTS used in the UAS called AAMOB, developed by CEiiA in partnership with the University Hospital Center of São João (UHCSJ) and Rangel Logistics Solutions. AAMOB has urban and semi-urban objectives to assist in medical emergencies and can be used to transport medical supplies like blood between hospitals or medical facilities. Some of the characteristics of this UAS have already been established, such as Vertical Take-Off and Landing (VTOL), Beyond Visual Line of Sight (BVLOS) capabilities, fixed-wing design, and cruise speed of 120 km/h.

AAMOB falls into the specific category of operations, which is determined by factors such as its Maximum Take-Off Mass (MTOM) of approximately 80 kg, operational characteristics, and associated operational risks.

According to the Specific Operations Risk Assessment (SORA) methodology, which evaluates the risks and determines the acceptability of a proposed operation [4], this UAS operates with a Specific Assurance and Integrity Level (SAIL) IV based on a comprehensive analysis of ground and air risk factors associated with its operations. The SAIL level represents the level of confidence that the UAS operation will remain under control [4]. The operational characteristics introduce specific challenges and potential risks due to the presence of populated areas, increased air traffic, and the need for precise navigation and coordination.

In summary, AAMOB can quickly transport medical supplies, including blood, from one defined point to another (which can be hospitals, medical facilities, or storage facilities). This is particularly important in situations where time is critical since UAS can be faster and more efficient than ground transportation.

1.2 CEiiA

CEiiA is a Centre of Engineering and Product Development that conceives, develops, and produces new technologies, products, and services towards a more sustainable society.

Founded in 1999, CEiiA initially focused on supporting the competitiveness of the Portuguese automotive industry. However, driven by its commitment to innovation and the evolving needs of various industries, CEiiA expanded its scope to encompass other sectors, including aeronautics, urban mobility, automotive, ocean and space [10]. As one of the leading Research & Development (R&D) investors in Portugal, CEiiA plays a crucial role in bridging the gap between cities, industries, and universities.

It is important to highlight some of the most significant projects developed by CEiiA. In the field of unmanned aircraft, one standout project is the TROANTE project, in which CEiiA participated as one of the principal institutions involved. The TROANTE project, initiated in 2016 and completed in 2020, focuses on the development of UAV technology. Its primary objective is to obtain economically advantageous and effective topographic, hydrographic, oceanographic, and direct observation products from geospatial data collected by sensors on board the UAS30. The UAS30 is an aerial unmanned system designed to monitor activities with high economic or strategic value [11].

Regarding aeronautics, CEiiA is also a key partner in the entire development cycle of the new KC-390, the largest aircraft ever produced by EMBRAER. This participation is focused on two primary structures (the elevator and the central fuselage) and the sponson and included activities such as Design, Stress Analysis, Weight Reduction, Manufacturing Support, the production of the First Flight Documentation and Certification Documentation, and the definition and execution of tests [12].

In the field of urban mobility, CEiiA adopts a sustainability-as-a-service model and concentrates on developing emergent technologies and products that enable the creation of new services and business models for carbon-neutral cities, such as AYR – a sustainability acceleration platform to achieve zero carbon. Furthermore, CEiiA has developed mobi.me to connect vehicles and infrastructures, integrate different information systems, and promote sustainability, offering a comprehensive answer to the needs of users, operators, and city authorities. The portfolio of projects also includes initiatives of electric vehicles charging, bike and scooter sharing, and fleet management in Europe and Brazil, with Operation and Control Centres installed in different locations [13].

CEiiA's contributions to the automotive sector are significant as well. CEiiA provides support for product development, from concept and design to pre-series, namely in areas like vehicles exterior, body panels and closures, chassis, interior, and also the electrical part [14]. Notably, the creation of Buddy, a fully electric car aimed at achieving a complete reduction of the carbon footprint, exemplifies the dedication to sustainable transportation solutions.

Within the ocean and space domain, CEiiA has been actively involved in developing a diverse portfolio of projects, from the development of in-situ observation vehicles to remote observation vehicles. The overarching goal is to integrate information into an Earth observation platform. Notable projects in 2021 include ORCA, MAANTA, Astriis, Nautilos, Behyond, Nipimar, Dune, and OceanVision within the ocean domain, and INFANTE, ESA RFA One, MAGAL, AEROS, Viriato, ESA Building Blocks, Caravela, and Magellan within the space domain.

In the ocean domain, the OCEANTECH project, led by Abyssal, deserves special recognition. It aims to develop, produce, and operate a new generation of robotic systems for the sea, connected by an intelligent operations management system.

Lastly, in the space domain, one notable project is Magellan. Led by RFA Portugal in collaboration with CEiiA, the Magellan Research and Development project represents a unique opportunity for Portugal to enter the aerospace industry market, which is currently expanding and recognised for its strategic importance.

The multidisciplinary team supporting this dissertation holds expertise in Advanced Air Mobility as well as solid backgrounds in aircraft development and Smart Mobility. This Business Unit's major objective is to promote the secure adoption of Advanced Air Mobility while coordinating with authorities and strategic partners.

1.3 Object and Objective

The object selected for this dissertation is the development of a general methodology that can be applied to any UAV system and includes the necessary means to demonstrate compliance with safety and design objectives [15] according to regulatory requirements.

The idea is to develop a flexible methodology that can be applied not only to the FTS but also to other systems (for example, parachutes). However, when specifically applied to the FTS, this methodology leads to a Proposed Means of Compliance (MoC). MoC consists of detailed instructions and criteria for meeting regulatory requirements, outlining specific actions, processes, or methods that need to be implemented to achieve compliance. By following the prescribed MoC, organisations can demonstrate compliance with regulatory expectations and meet the necessary safety standards.

As expected, one of the objectives of the dissertation is to develop a methodology that enables the validation of the FTS for operations up to SAIL IV. The SAIL consolidates the ground and air risk analyses and drives the required activities [4].

The development and implementation of the proposed general methodology will aim to obtain validation from the competent authorities by using the proposed MoC for the FTS, leading to the issuance of a DVR.

Furthermore, an additional objective is to propose a MoC specifically tailored for SAIL IV operations with containment. The FTS serves as a method to address the UAS containment. The proposed MoC will allow substantiation of the FTS performance [3].

1.4 Methodology

The methodology adopted follows a conceptual approach. The investigation starts with an extensive literature review, which helps collect the necessary key concepts to define the structure of the dissertation. The review mainly focuses on the definitions of AAM and UAS, as well as an intensive study of the three categories of operation: Open, Specific, and Certified. Subsequently, the existing legislation for UAVs and their systems are analysed. To achieve the dissertation's goals, it is necessary to understand the Concept of Operations (ConOps) and the aircraft characteristics for which the FTS under study is designed.

SORA consolidates all the previously mentioned concepts. SORA provides a framework for creating, assessing, and conducting UAS operations safely in a specific category of operations. It offers a methodology to assist both UAS operators and the competent authority in evaluating whether a UAS operation can be conducted safely. SORA serves as a guide to help UAS operators identify the best-fit mitigation measures to reduce the risk to an acceptable level. Its purpose is to inspire UAS operators and competent authorities and highlight the benefits of a harmonised risk assessment methodology [4].

After understanding the definition and process of SORA, it is possible to study the DVR. It is a report issued by EASA that documents that the UAS design complies with the applicable Operational Safety Objectives (OSOs), including any possible limitations or assumptions the actual drone model needs to operate [5].

The framework for the general methodology is essentially developed based on existing aeronautical standards and supporting documentation provided by the competent authority. Once this methodology is developed, with the aim of its applicability to diverse aircraft systems, the intention is to apply it to a particular system, namely the FTS.

After examination of aeronautical standards and supportive documentation, such as the MoC with containment up to SAIL II operations [3], the study advances to proposing and developing means to demonstrate compliance for the FTS system, which represents a crucial step in the framework.

Finally, the dissertation will provide detailed explanations and conclusions concerning the developed research and ideas for future work in the study area.

The methodology used in this dissertation is presented in the flowchart shown in Figure 1.1.

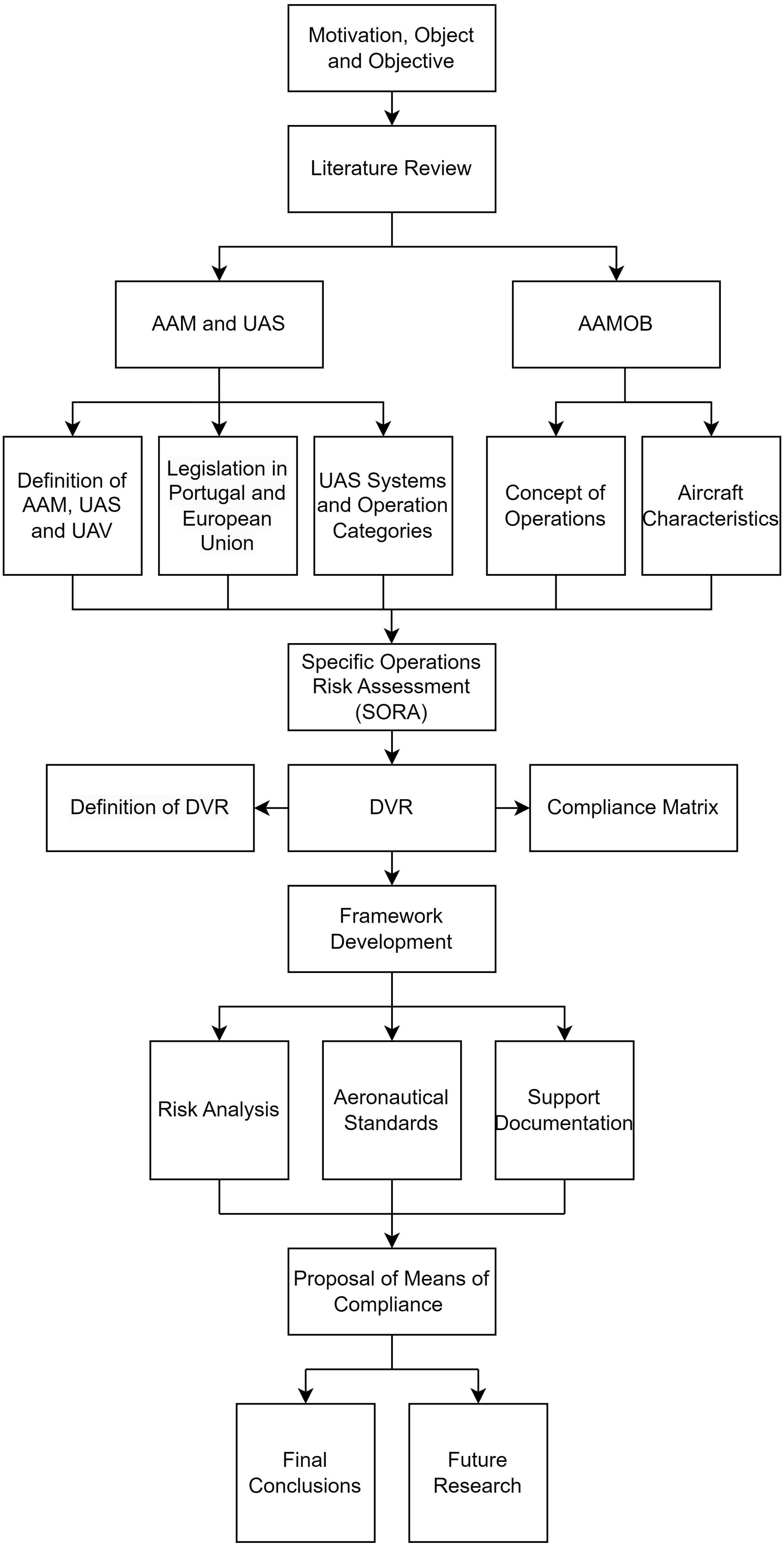

Figure 1.1: Workflow of the dissertation's methodology.

1.5 Dissertation Outline

The structure of this dissertation is divided into five chapters: Introduction, Literature Review, Methodology, Proposal of Means of Compliance for Flight Termination System, and Conclusions.

Chapter 1 is the introduction, which provides a clear overview of the dissertation's motivation, object and objective, methodology, and structure.

Chapter 2 focuses on the literature review, including a study of the literature related to AAM, UAS Regulations, Regulation (EU) 2019/947, Specific Category, and DVR. This chapter also identifies existing standards that contribute to the methodology development and the proposed MoC.

Chapter 3 presents the development of a methodology that enables the demonstration of compliance with safety objectives. This methodology is established to be general and flexible. While adaptable to various applications, the FTS serves as a study case to illustrate the framework's practical application. An integral part of this framework involves the proposal of means of compliance, paving the way for the subsequent chapter.

Chapter 4 applies the methodology developed in the previous chapter to a specific aircraft system, specifically the FTS. It is necessary to propose means to demonstrate compliance with containment for SAIL IV operations since that is a crucial step to obtain a DVR.

Chapter 5 concludes the dissertation with final remarks and suggestions for future work concerning UAS certification, means of compliance, and UAS legislation.

Chapter 2

Literature Review

Chapter 2 provides a thorough literature review that explores key concepts essential for the development of this dissertation. The chapter begins with an overview of Advanced Air Mobility, followed by an in-depth study of existing UAS Regulations, with particular emphasis on Regulation (EU) 2019/947. It is relevant to understand the specific category since the AAMOB falls under this category. Lastly, this chapter encompasses a study of Design Verification Reports, offering valuable insights into their necessity and importance.

2.1 Advanced Air Mobility

2.1.1 Concept and Purpose

AAM is an emerging transportation system that leverages the capabilities of unmanned aircraft, such as eVTOL vehicles, to enable safe and efficient low-altitude operations. This innovative approach allows for the transportation of passengers, cargo, or both between places that were previously underserved or not served at all by traditional aviation [16] [17].

However, by using AAM, numerous expected benefits can positively impact society and the environment. One of the primary advantages of AAM adoption is the potential reduction in pollution [18]. With the increasing focus on environmental sustainability, electric-powered eVTOL aircraft have the advantage of producing zero direct emissions during flight. By transitioning from traditional combustion engines to electric propulsion, AAM has the potential to contribute significantly to reducing carbon emissions and improving air quality in urban areas.

Moreover, AAM can reduce transport costs and increase accessibility [18]. By providing efficient transportation options for short-haul flights, AAM can connect urban centers, suburbs, and remote areas more effectively [1]. This improved connectivity can enhance accessibility for communities that previously had limited transportation options, facilitating economic growth, and increasing mobility for individuals and businesses alike.

AAM also enables a more reliable and resilient supply chain [18]. Due to the use of unmanned aircraft, AAM can help overcome challenges such as traffic congestion and limited infrastructure faced by traditional ground transportation. This flexibility allows for faster and more efficient delivery of goods, enhancing supply chain operations and improving overall logistics.

Despite the numerous benefits, the widespread adoption of AAM is hindered by the lack of regulations in many countries. The absence of clear and consistent regulatory frameworks slows down the progress of businesses and international organisations involved in AAM, as well as poses challenges to ensuring human welfare and safety [18]. Governments and regulatory bodies must work together to develop appropriate regulations that address safety, privacy, and airspace management concerns while fostering innovation and growth in the AAM sector.

To advance AAM implementation on a global scale, the National Aeronautics and Space Administration (NASA), in collaboration with the Federal Aviation Administration (FAA), is spearheading efforts. On a European scale, Drone Strategy 2.0 sets out a vision for the further development of the drone market [19]. These initiatives aim to establish the necessary infrastructure, information architecture, software functions, concepts of operation, and operations management tools for a robust AAM ecosystem [16].

2.1.2 eVTOL Aircraft Architecture and Concept

Air mobility refers to the use of aircraft, including helicopters, tilt-rotors, and eVTOL vehicles, for transporting passengers and cargo. AAM aims to provide a faster, more efficient, and environmentally friendly mode of transportation, especially in congested urban areas. Although AAM technology is still in its early stages, many companies ranging from major aerospace companies to start-ups, as well as standards organisations, are investing in the development of eVTOL vehicles and the associated infrastructure, such as charging stations and landing pads [1].

The vehicle mostly considered for AAM operations is an eVTOL aircraft capable of carrying passengers and air cargo with a limited capacity. Like any other flying platform with humans on board and flying over human living areas, the establishment of a highly reliable and intelligent system of Communication, Navigation, and Surveillance (CNS) is crucial to ensure safe operations and avoid life-threatening accidents. In future scenarios involving autonomous and BVLOS flights, the reliability and robustness of the communication link between the AAM vehicle and ground control stations is the key factor in safe AAM operations. One of the significant challenges for AAM connectivity is the need for secure and reliable communication networks capable of handling the vast amounts of data generated by these vehicles while the AAM vehicle flies through controlled and uncontrolled airspace. When operating in controlled airspace, effective communication with ground-based Air Traffic Management (ATM) entities is essential to adhere to instructions and maintain safe operations.[1].

In terms of eVTOL aircraft architecture, EASA has established specific guidelines through its Special Condition (SC) for small-category VTOL aircraft, which identify two distinct characteristics shared by eVTOL aircraft. These include VTOL capability and a distributed electric propulsion system. The implementation of a distributed electric propulsion system simplifies the propulsion systems for both vertical lift and forward thrust modes, eliminating the need for complex jet engines or thrust vectoring mechanisms typically used in conventional VTOL aircraft. In line with the nomenclature outlined in the EASA SC-VTOL guidelines, these propulsion units are referred to as lift/thrust units (LTUs) [20].

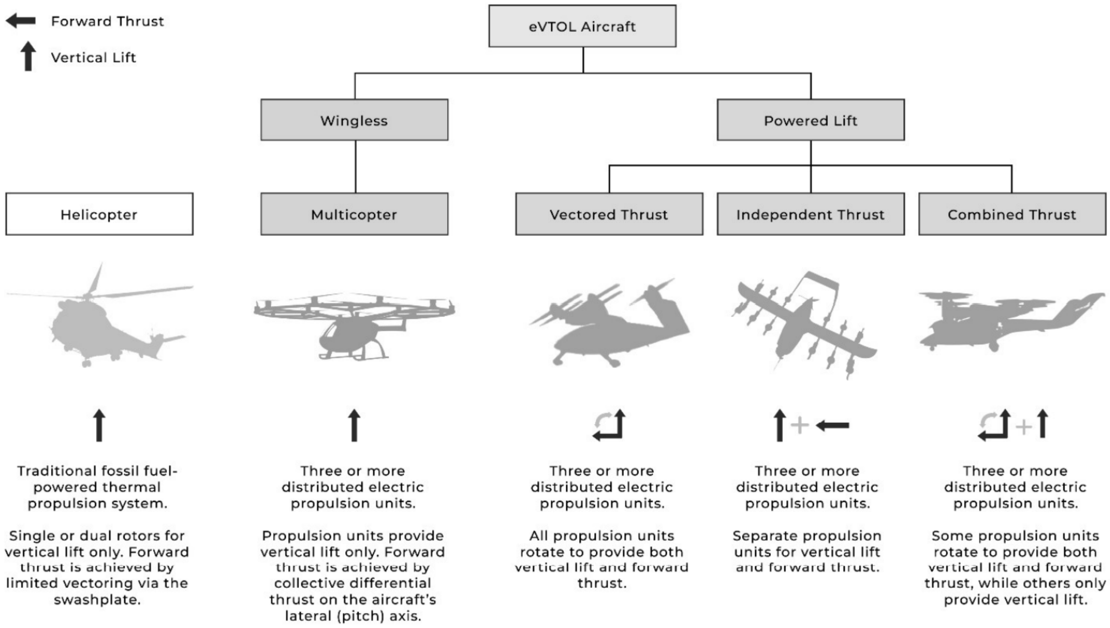

Figure 2.1: Propulsion architectures of eVTOL aircraft [20].

All eVTOL aircraft can take-off and land vertically, eliminating the need for a traditional runway. However, it is important to note that only powered lift aircraft use wings (see Figure 2.1). This design feature enables them to achieve cruising speeds comparable to conventional fixed-wing aircraft, and operate at higher altitudes than wingless eVTOL aircraft and helicopters. This extra ability of powered lift aircraft naturally presents opportunities to carry out more extended-range missions more efficiently than the wingless type. Consequently, powered lift aircraft offer greater flexibility to aircraft designers in terms of cruise speed, payload capacity, and range, surpassing the capabilities of wingless eVTOL aircraft. However, the advantages of powered lift aircraft come at the cost of increased complexity in both design and operation [20].

Wingless eVTOL aircraft rely on the thrust generated by their LTUs for both vertical lift and forward flight. One prevalent subtype within the wingless architecture is the multicopter, as indicated in Figure 2.1. Multicopters are equipped with multiple LTUs that provide vertical lift, similar to helicopters. Nevertheless, their flight characteristics remain closer to a helicopter than a fixed-wing aircraft. Many proposed multicopter concepts are designed mainly for use in air taxi services and emergency services. However, a distinct subclass within the multicopter architecture is the Personal Aerial Vehicle (PAV). Although technically possessing a multicopter design, PAVs distinguish themselves in terms of carrying capacity. PAVs are typically single-seat eVTOL aircraft intended for personal use, and some concepts even offer a ground-based transport mode in addition to flight mode [20].

In conclusion, eVTOL aircraft offer a promising solution to address the pressing issue of carbon emissions in the aviation sector, as they have a significantly lower environmental impact compared to traditional aircraft. Given the urgency of combating climate change, the expansion of AAM contributes to reducing this global problem and offers a way for a more sustainable and greener future for air transportation.

2.1.3 Infrastructure and Ecosystem

AAM infrastructure enables and supports a range of applications, including passenger transportation, cargo delivery, infrastructure inspection, and precision agriculture using UAS in the low-altitude National Airspace System (NAS). The increasing demand for these use cases is expected to result in millions of daily operations in the coming years, exceeding the capacity of the traditional human-centered NAS. Therefore, a digital and flexible transportation framework is being developed to coordinate among the new NAS users (the AAM users) and existing NAS users and manage unmanned air traffic. This framework, known as the AAM architecture, aims to integrate UAVs into U-space, ensuring their safety and security from environmental risks [16].

Figure 2.2 provides an overview of the primary stakeholders and components of the AAM architecture, illustrating their contextual linkages and functions. It is considered two types of UAVs or AAM aircraft in this architecture. The first one is the eVTOL, which has been developed to transport people and cargo across local, regional, inter-city, and urban spaces. The second one is the drone or small Unmanned Aircraft System (sUAS), which has already been used to transport small packages quickly and effectively. These vehicles boast innovative designs and capabilities, primarily operating at altitudes less than 400 ft (120 m) above ground level (AGL) in uncontrolled airspace [16].

Vertiports serve as hubs and provide the necessary infrastructure for eVTOL take-off and landing, recharging, maintenance, and storage. These vertiports can be an airport, heliport, rooftop setup, or custom configuration based on the location and type of application. The design and capabilities of vertiports are essential for ensuring the safety, efficiency, and sustainability of AAM, making them a vital component of the future of air mobility and transportation as a whole [16] [21].

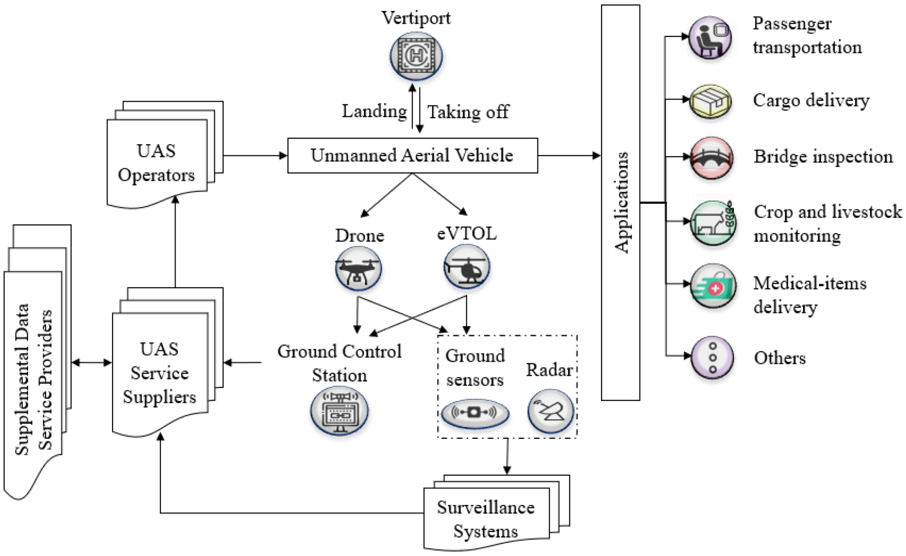

Figure 2.2: AAM architecture [16].

To ensure safe and efficient management of UAS traffic, the AAM architecture is designed based on the principles of data sharing through a distributed information network, supported by a set of protocols and functions. The architecture aims to develop a UAS Traffic Management (UTM) system that enables seamless coordination and communication among various stakeholders involved in AAM operations.

UTM serves as a dedicated traffic management ecosystem for uncontrolled operations that is separate from, but complementary to, the existing ATM system. UTM pretends to identify services, responsibilities, information architecture, data exchange protocols, software functions, infrastructure, and performance requirements for enabling the management of low altitude uncontrolled drone operations [22].

Similar to vertiports, UTM is a critical tool for effectively managing the increasing number of eVTOL and drone operations in shared and segregated airspace. It serves as a platform that facilitates the involvement of stakeholders, including drone operators, National Aviation Authorities (NAA), Air Navigation Service Providers (ANSP), and traditional ATM entities. Through UTM, these stakeholders can determine and communicate real-time airspace status, ensuring the safe integration and operation of drones of all sizes. The UTM system also encompasses various functionalities and protocols that govern the exchange and processing of data. These include functions such as registration, strategic deconfliction, monitoring and alerting, tactical deconfliction, and remote identification [21].

Ground control stations are important in monitoring and tracking UAVs within the UTM system. These stations receive and analyse essential telemetry data from the UAVs, including their position, velocity, flight intent, and remote identification (RID). This data is transmitted through a reliable radio frequency link to ensure real-time monitoring and control [16].

The data collected from ground control stations and surveillance systems are routed to UAS Service Suppliers (USSs), which play a crucial role in facilitating the safe and efficient use of airspace by assisting UAS operators in meeting UTM operational requirements. USSs serve as a communication link between authorities and drone operators, offering tools and services to monitor the airspace, execute missions safely, and store operational data. In a given geographical area, multiple USSs can operate together, creating a network that facilitates information sharing and enhances situational awareness. This shared information includes flight plans, flight status, and aircraft location [23].

USSs support operations planning, intent sharing, strategic and tactical deconfliction, conformance monitoring, RID, airspace authorisation, airspace management functions, and management of off-nominal situations. USSs facilitate authorised UTM stakeholders in discovering active USSs and accessing available services within the USS Network. They enable vehicle owners to register UAS-related data and facilitate USS registration. To ensure data security, USSs also offer message security services, safeguarding the exchange of data only among authorised users [23].

Supplemental Data Service Providers (SDSPs) complement USSs by offering advanced flight support services, including topographical and obstacle data, specialized meteorological data, surveillance, and constraint information [16].

UAS operators rely on USSs to obtain necessary approvals, advisories, and UTM services. These services enable operators to effectively manage their fleet of UAVs for various applications, including passenger transportation and cargo delivery, agriculture and livestock monitoring, medical items delivery, and more.

2.1.4 Environmental Impact and Sustainability

AAM operations can have various environmental impacts, including weather, noise, visual pollution, and land use considerations [24].

Weather conditions present specific challenges for AAM operations due to the smaller size of aircraft and their increased sensitivity to weather phenomena. Low-level flight over urban areas can introduce operational complexities, making it essential to assess the suitability of different aircraft and propulsion systems across a range of weather conditions. Electric aircraft currently have greater temperature limitations, which could impact aircraft range and payload capabilities [24].

Mitigating noise is another important consideration in AAM operations. According to [24], there are two ways the FAA mitigates noise: 1) addressing the noise source itself (e.g., by developing quieter aircraft) and 2) implementing land use planning strategies. In areas where people reside within zones with higher noise levels, specific mitigation measures might be necessary to reduce noise disturbances and ensure community wellbeing.

Visual pollution is also a factor that needs to be taken into account. The FAA includes visual impacts in its environmental review processes, evaluating the effects of aircraft lighting and vertiport infrastructure on the surrounding community. Minimising visual pollution and preserving the aesthetic integrity of the environment are essential aspects of sustainable AAM development [24].

Regarding land and privacy considerations, it is important to protect the public from intrusive surveillance activities involving cameras, sensors, and other monitoring technologies [24]. Respecting privacy rights and addressing any potential land use conflicts is vital for fostering public acceptance of AAM operations.

Despite these challenges, electric propulsion systems, a defining feature of AAM vehicles, offer significant advantages over conventional combustion engines. These systems dramatically reduce pollutants, lower noise levels, and enhance overall efficiency, contributing to a cleaner and more sustainable aviation industry. AAM vehicles seamlessly transition between ground and air operations by utilizing electric motors for vertical takeoff and landing, facilitated by their lift and push capabilities [25].

The implementation of AAM is foreseen to not only benefit the people and economy but also ensure environmental sustainability. AAM can reduce congestion by providing an additional transportation option, leading to faster and more efficient commuting, particularly in densely populated urban areas. With electric propulsion systems, AAM vehicles produce lower emissions compared to conventional aircraft or ground vehicles powered by fossil fuels. This can significantly contribute to reducing air pollution and greenhouse gas emissions, combating climate change and improving local air quality [25].

Improved connectivity is another key advantage of AAM. By providing efficient and convenient transportation options, especially for areas with limited infrastructure, AAM can enhance regional connectivity. It enables faster travel between cities and regions, opening up new opportunities for business, tourism, and emergency response [25].

Autonomous flight systems in AAM vehicles enhance safety by reducing the risk of human error. These systems incorporate advanced collision avoidance technologies and real-time monitoring to ensure safe operations [25]. By leveraging automation, AAM vehicles can achieve a high level of safety and reliability, instilling confidence in passengers and stakeholders.

In conclusion, the implementation of AAM brings diverse benefits that not only enhance transportation efficiency but also make significant contributions to building a more sustainable and resilient future.

2.1.5 Public Perception and Acceptance

In recent years, the presence of civil UAVs has increased significantly, capturing attention in the media and becoming part of everyday life. However, public acceptance of UAVs still seems limited, with acceptance rates typically hovering around 50% [26]. Given the anticipated growth in drone numbers, understanding and addressing public acceptance becomes crucial for the widespread use of civil drones.

Promoting widespread public acceptance is essential for facilitating the dissemination of new technologies. Conversely, concerns among residents regarding the integration of UAVs into their daily environment can pose potential barriers to the further proliferation of civil UAVs, particularly in urban areas. As AAM services begin to expand on a global scale, the attention is now focused on the potential development of AAM driven by business plans and competition. From food or parcel delivery to e-scooter services, the public has experienced certain downsides to deregulation in daily life, and some fear that similar issues may arise in the air. Therefore, regulations for AAM are needed to guide the process, and many institutions are in the process of formulating conditions and requirements for AAM services [26].

Several factors influence the public attitude towards UAVs, including the acceptance of specific UAV applications and general concerns related to civil UAVs. Of particular importance are concerned noise pollution, which can have a significant impact on public perception and acceptance [26]. Understanding these factors and addressing the associated concerns is vital in shaping public opinion and paving the way for the successful integration of AAM into society.

According to Eißfeldt et al. [26], the German Aerospace Center conducted, in 2018, a study to understand the public acceptance of civilian drones. The researchers conducted computer-assisted telephone interviews as the methodology for data collection and obtained responses from 832 participants.

The study revealed that the overall attitude towards drones was slightly more favorable, with 49% of respondents indicating a rather positive attitude. Conversely, 43% expressed a rather negative attitude, and approximately 8% remained undecided. Additionally, participants were asked about their specific concerns related to the use of civil drones. The concerns were presented in random order to avoid any bias. The study identified seven main areas of concern related to civil drones: misuse for criminal purposes, privacy concerns, accidents (liability, insurance, transport safety, damages, and injuries), animal welfare, and noise. Figure 2.3 illustrates the seven social acceptance factors collected by German Aerospace Center.

The primary concern surrounding civil drones is their potential for misuse in criminal activities. Some of the greatest fears and concerns regarding drones include unauthorised people that may exploit drones for various illegal purposes. These include transporting drugs, conducting surveillance for illicit activities, hacking the drone-pilot link and stealing the data, and even engaging in acts of terrorism such as transporting explosives or chemicals or access to restricted areas [27].

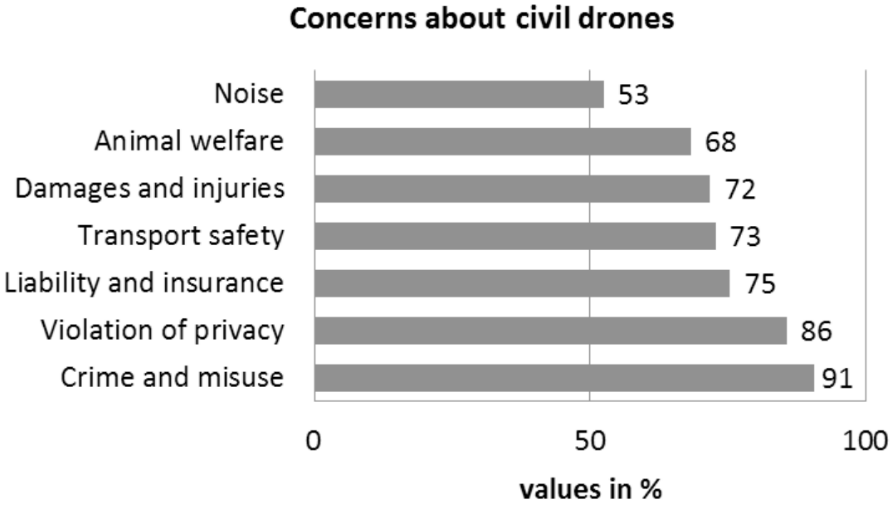

Figure 2.3: Concerns about civil drones [26].

The second issue associated with the use of civil drones is privacy. The ability of drones to capture high-resolution images and videos raises concerns about the invasion of personal privacy. Unauthorised aerial surveillance, especially when conducted in residential areas or public spaces, can infringe upon individuals' right to privacy. Striking a balance between the benefits of drone technology and safeguarding personal privacy is essential to address these concerns. Incidents such as acquiring information (espionage, paparazzi) and financial profit (blackmail, smuggling) have been identified as the main motivations and types of incidents credited as the main culprits in drone incidents. The lack of privacy caused by drones is attributed to the anonymity of their flights, since the drone pilot cannot be easily identified, making accountability and enforcement of legal regulation difficult. Furthermore, the flights have a purpose unknown to the public, and data, including photos and recordings, could be collected without consent [27].

Accidents involving civil drones pose additional challenges and risks. Accidents can occur due to technical failures, human error, or even collisions with other aircraft or objects. Liability concerns regarding the legal rights and duties of drone use are common and unsettling. The flight of drones over private property is a concern for the public, especially non-users of drones. This is due to the inability to determine the purpose of the flight, the possibility of irresponsible behavior, and potential damage. Therefore, some suggestions to ensure the proper use of drones and to have registration are mandatory liability insurance, training, registration for different types and uses of drones, identification of drone use by brands online availability of drones' geolocation, and specific state authority for drones [27].

Considering animal welfare, drones can also displace animals from preferred habitats, reducing access to resources and potentially resulting in changes in migration patterns [28].

While the issue of noise was the least-mentioned concern, it still stood out among respondents, with 53% of participants citing it in the study conducted by Eißfeldt et al. [26]. Noise pollution poses a significant challenge when operating eVTOL aircraft in urban areas. The continuous operation of these aircraft, along with frequent take-offs and landings in densely populated regions has the potential to disrupt the peaceful environment of residential neighborhoods and adversely affect the quality of life for residents.

2.2 UAS Regulations

2.2.1 Scope and Purpose

UAS have rapidly become popular in many applications. However, ensuring the safe operation of UAS is paramount to mitigate potential risks associated with this technology. In response to this necessity, UAS regulators within the EU have dedicated significant efforts to establish a legal framework for UAS operations. The primary objective is to adapt to the evolving capabilities of UAS technology and minimise the risks of property damage and, most importantly, human injury [29].

Conducting flight missions with a high level of safety is one of the main problems in UAS-based applications. Achieving a safe UAS operation can be complex and challenging due to the need to coordinate multiple factors, including the identification of barriers and obstacles present in the operation scenes. However, it is imperative to minimise the risks that may arise during the operation time and influence other airspace users, bystanders, and property on the ground. That legislation should provide clear technical and operational definitions to address common problems encountered during flight missions [30].

The importance of UAS regulations is demonstrated by their function in preserving public safety and minimising potential harm. While allowing for the continuous advancement and application of UAS technology, these laws seek to establish standards and limitations that promote responsible UAS operation. UAS regulation helps to reduce the dangers involved with UAS operations and promote the safe integration of drones into the current airspace systems by establishing a framework for operational standards, licensing, and airspace limits.

In conclusion, UAS regulations are essential for encouraging the safe and responsible use of drones. They give rise to a legal framework that handles practical issues, guarantees public security, and safeguards privacy rights. Drones operators can help ensure the safe and long-term integration of UAS technology into our society.

2.2.2 Development of UAS Regulations

2.2.2.1 Global UAS Regulations

When dealing with UAS regulations at a global scale, the International Civil Aviation Organisation (ICAO) takes center stage as the specialized agency of the United Nations. To ensure uniformity and safety across nations, ICAO is responsible for establishing global rules and guidelines for UAS operations.

ICAO has released significant documents related to UAS operations. In 2011, ICAO Circular 328 on UAS was published as an early discussion document outlining ICAO's understanding of UAS technology and its expected approach to the establishment of regulations [31].

Additionally, the Manual on Remotely Piloted Aircraft Systems (RPAS) 1^{st} Edition (Document 10019 [32]), published in 2015, provides information relevant to the introduction of RPAS into non-segregated airspace and at aerodromes. However, it specifically addresses the operation of RPAS under Instrument Flight Rules (IFR) in controlled airspace between 500 feet and flight level 600, whereas at the time of writing much UAS activity falls outside of this specification [31].

Recognising that Doc 10019 does not address the majority of UAS activity, ICAO has developed a regulatory framework specifically for UAS operating outside of the IFR International arena. This involved a review of existing UAS regulations across various States to identify commonalities and best practices consistent with the ICAO aviation framework. The outcomes of this activity are the ICAO Model UAS Regulations, consisting of Parts 101, 102, and 149. These model regulations, accompanied by companion Advisory Circulars (ACs), serve as a template for Member States to implement or supplement their existing UAS regulations. These regulations and ACs are intended to be a living document and will evolve as the industry matures, providing States and regulators with internationally harmonised material based on the latest developments [33].

The ICAO Model UAS Regulations, issued in 2020, cover different aspects of UAS operations. Part 101 focuses on general provisions, establishing a foundational framework for UAS operations. AC 101 provides guidance associated with rule 101, offering additional clarity and interpretation. Part 102 focuses on the certification of UAS personnel, defining the requirements and procedures for certifying individuals involved in UAS operations. AC 102 complements the certification process with guidance related to rule 102. Lastly, the airworthiness of UAS is covered in Part 149, which also outlines the standards and requirements for guaranteeing the dependable operation of UAS [33].

Many States that had not previously published UAS regulations are now adopting these model regulations as they prepare their national frameworks. However, the Model Regulations allow States flexibility in determining specific parameter values. Therefore, while there may be structural commonality, there could be differences in the specifics of the regulations [31]. To assist States in implementing these Model Regulations, ICAO has recently released an Implementation Package (iPack), which includes a program of training and guidance.

ICAO has also issued numerous Standards and Recommended Practices (SARPs), Procedures for Air Navigation Services (PANS) documents, circulars, and guidance materials that cover various aspects of UAS operations. Today, with over 12,000 SARPs across the 19 Annexes[1] and six PANS to the Convention, ICAO remains committed to continuously managing and evolving these documents in line with the latest developments and innovations in the aviation industry. The establishment and maintenance of international SARPs and PANS are integral to ICAO's mission and role as they ensure global harmonisation and safety in aviation practices [34].

Another crucial organisation in global regulations is the Joint Authorities for Rulemaking on Unmanned Systems (JARUS). JARUS consists of an international group of aviation regulatory experts who collaborate to recommend a unified set of technical, safety, and operational requirements for all aspects related to the safe operation of UAS. The organisation comprises regulatory experts from 63 countries, including the EASA and EUROCONTROL, who actively contribute to the development of JARUS work products. JARUS publications[2] serve as valuable resources for Member States and aviation stakeholders [31].

One of the most important and influential documents published by JARUS is the Certification Specifications for Unmanned Aircraft Systems (CS-UAS) issued in 2019. This document provides recommendations for Member States to use in developing their own national legislation concerning certification specifications for UAS. It represents the culmination of best practices and procedures derived from prior UAS approvals [35]. The CS-UAS document serves as the foundation for EASA in issuing its regulations related to UAS operations. By using the recommendations presented in the CS-UAS, States can align their national regulations with internationally recognised standards, contributing to the harmonisation of UAS operations and enhancing safety across the industry.

2.2.2.2 EU UAS Regulations

Concerning European Union regulations, the EASA plays a leading role in developing and implementing rules. Established in 2002, EASA has become a dynamic and central organisation dedicated to aviation safety and environmental protection in Europe. As an independent and neutral body, EASA is vital for instilling confidence in safe air operations across Europe by proposing, formulating, and enforcing rules, standards, and guidance; by certifying aircraft, parts, and equipment. EASA's primary objective is to ensure a high

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[1] Annexes 1,2,6,7,8,10,11,12,14 e 19 are particularly relevant to UAS regulations.

[2] JARUS publications are available at `http://jarus-rpas.org/publications/`.

level of aviation safety within the EU. To achieve this, EASA harmonises regulations and standards across Member States, promoting a consistent approach to safety in aviation operations, including UAS operations [36].

EASA has published two specific regulations for UAS: Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 and Commission Implementing Regulation (EU) 2019/947 of 24 May 2019. The first regulation focuses on UAS and third-country operators of UAS, while the second regulation addresses the rules and procedures for the operation of unmanned aircraft [37] [38].

Both of these documents have undergone subsequent amendments. The Regulation (EU) 2019/945 is amended by Commission Delegated Regulation (EU) 2020/1058 [37]. The Regulation (EU) 2019/947 is amended by Commission Implementing Regulation (EU) 2020/639, Commission Implementing Regulation (EU) 2020/746, Commission Implementing Regulation (EU) 2021/1166, and Commission Implementing Regulations (EU) 2022/425 [38].

To provide further guidance, EASA has also developed Acceptable Means of Compliance (AMC) and Guidance Material (GM) for the Regulation (EU) 2019/947 and the Part-UAS regulations.

In addition, EASA has published the Easy Access Rules for UAS, which consolidate and present the rules and procedures for the operation of unmanned aircraft in a user-friendly format. This publication includes Regulation (EU) 2019/947, along with the related AMC and GM, as well as Regulation (EU) 2019/945. The Easy Access Rules provide convenient navigation features through links and bookmarks, making it easier for stakeholders to access and understand the regulations [39].

2.2.2.3 National UAS Regulations

Autoridade Nacional da Aviação Civil (ANAC) is the regulatory body responsible for civil aviation safety in Portugal. Its primary objective is to ensure the safety, security, and efficiency of aerial operations within Portuguese airspace. ANAC accomplishes this by establishing and enforcing regulations, rules, and standards that govern various aspects of civil aviation [40].

ANAC is also responsible for issuing licenses and certifications to aviation personnel and organisations. It grants licenses to pilots, air traffic controllers, and other aviation professionals, ensuring that they meet the required standards and qualifications [41]. By doing so, ANAC contributes to maintaining a highly trained and skilled workforce in the aviation industry. Furthermore, ANAC certifies airlines, airports, and maintenance organisations, verifying their compliance with prescribed safety and operational regulations.

Regarding the operation of UAS in Portugal, ANAC oversees and implements EU Regulation 2019/947. Under this regulation, UAS operators obtain authorisation from their state of registry to conduct operations within the EU [42].

Moreover, ANAC has introduced its own regulations to address UAS operations within Portuguese airspace. These include Regulation (ANAC) 1093/2016, issued on 14 December 2016, and Regulation (ANAC) 372/2023, published on 23 March 2023. These regulations outline the specific conditions and requirements for the safe and responsible operation of UAS within Portugal [42].

ANAC is committed to continuously monitoring and updating its regulations to adapt to the evolving aviation landscape. By doing so, it remains at the forefront of industry advancements and maintains regulatory practices aligned with international standards.

2.3 Regulation (EU) 2019/947

2.3.1 Scope and Purpose

Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 establishes detailed provisions for the operation of UAS, including the roles and responsibilities of personnel involved in these operations, such as remote pilots and organisations [43]. The regulation aims to increase the level of UAS operations-related safety across Europe and promote harmonisation within the European market. It covers various aspects, including UAS operations, operator requirements, and remote crew competencies [44].

One of the primary goals of this regulation is to establish a common set of rules and standards for UAS operations and ensure the safe integration of UAS into the airspace while addressing safety, security, and privacy concerns. The regulation seeks to create a level playing field for UAS operators and provide clear guidelines for UAS manufacturers, operators, and competent authorities.

The regulatory framework adopts a risk-based approach, considering factors like weight, specifications, and the intended operation of the drone, rather than distinguishing between private and commercial UAS operations. Regulation (EU) 2019/947, which is applicable since 31 December 2020 in all EU Member States, has defined three categories of operations: the open, the specific, and the certified [45]. Each category corresponds to a particular level of risk and is subject to different limitations and requirements. The risk assessment considers the technical characteristics of the UAS (e.g., MTOM), operational aspects (e.g., maximum operating altitude), and the competencies of the remote crew [44].

Overall, Regulation (EU) 2019/947 establishes guidelines for UAS operations in the EU, which all Member States must follow.

2.3.2 Amendment

Regulation (EU) 2019/947 underwent its first amendment through Regulation 2020/639, which introduced several significant changes. The amendment aimed to enhance the clarity and specificity of the regulation by introducing 11 new definitions [43].

One significant adjustment made by this amendment was the provision enabling holders of Light UAS Operator Certificate (LUC) to engage in cross-border operations, facilitating seamless UAS operations across national boundaries. Recognising the importance of visibility and differentiating UAS from manned aircraft during night operations, the amendment mandated turning on a green flashing light on the unmanned aircraft [43].

The amendment also described in more detail the responsibilities of the UAS operator in the specific category concerning record keeping. These include maintaining records for personnel, their qualification, and the UAS operations performed, including unusual technical or operational occurrences [43].

Furthermore, the amendment introduced two new standard scenarios for UAS operations falling under the specific category. These scenarios, namely STS-01-VLOS over a controlled ground area in a populated environment and STS-02-BVLOS with airspace observers over a controlled ground area in a sparsely populated environment, provided standardized guidelines for conducting UAS operations in specific situations [43].

The second amendment was made by Regulation 2020/746. The COVID-19 pandemic's effects on the aviation industry, including the emerging UAS sector, inspired the development of this document [43].

Regulation 2021/1166 made the third change to this regulation. It recognised that certain harmonised standards applicable to UAS classes C5 and C6 would not be available as expected. As a result, the application dates for these standards were postponed to provide stakeholders with sufficient time to comply with the updated standards once they become available [43].

The fourth amendment to this regulation was made by Regulation 2022/425. It acknowledged that some of the harmonised standards for UAS classes C0 to C6, necessary for open category operations or under standard scenarios, as well as direct remote identification, would not be available until mid-2023 [43].

2.3.3 Definitions

Some relevant definitions from Regulation (EU) 2019/947 that will be important to the development of this dissertation are [38]:

1. Unmanned Aircraft System Operator (UAS Operator) refers to any legal or natural person who operates or intends to operate one or more UAS.

2. Assemblies of people describes gatherings where individuals are unable to move freely due to the density of people present. The concept of assemblies of people is based on an objective criterion, considering the limitation of movement to mitigate the consequences of an out-of-control unmanned aircraft. Although specifying a precise number of people at which a group turns into an assembly is challenging due to variations.

3. Standard scenario denotes a specific type of UAS operation within the specific category. Standard scenarios involve a predefined list of mitigating measures that satisfy the competent authority.

4. Visual Line of Sight (VLOS) operation requires the remote pilot to maintain continuous unaided visual contact with the unmanned aircraft. This enables the remote pilot to control the flight path and avoid collisions with other aircraft, people, and obstacles.

5. Beyond Visual Line of Sight (BVLOS) operation means a type of UAS operation conducted without continuous unaided visual contact between the remote pilot and the unmanned aircraft.

6. Dangerous good refers to articles or substances that have the potential to pose a hazard to health, safety, property, or the environment in the event of an incident or accident. These hazardous materials are carried as payload by unmanned aircraft and include diverse substances, notably explosives, gases, flammable liquids and solids, oxidizing agents, organic peroxides, toxic and infectious substances, and radioactive and corrosive substances.

7. Direct remote identification involves a system that broadcasts information about an unmanned aircraft in operation, including its marking, without requiring physical access to the unmanned aircraft.

8. Follow-me mode means an operational mode of UAS in which the unmanned aircraft continuously tracks and follows the remote pilot within a predefined radius.

9. Geo-awareness entails a functionality that uses data provided by Member States to detect potential violations of airspace restrictions or limitations. When that breaches are detected, the system notifies the remote pilot, enabling them to take immediate and effective action to prevent any unauthorised entry into restricted airspace.

10. Autonomous operation refers to a situation where an unmanned aircraft operates without the remote pilot's ability to intervene. It excludes flight phases where the remote pilot can intervene through emergency procedures or when there is a loss of command-and-control connection. An autonomous operation

11. Uninvolved persons means individuals who are neither participating in the UAS operation nor aware of the instructions and safety precautions provided by the UAS operator.

12. Controlled ground area denotes an area on the surface of the earth where the UAS operator ensures that only involved persons are present. The controlled ground area encompasses the flight geography area, contingency area, and ground risk buffer.
13. Flight geography refers to the spatial and temporal definition of the airspace volume(s) where the UAS operator plans to conduct operations following normal procedures.
14. Flight geography area represents the projection of the flight geography on the earth's surface.
15. Contingency volume is the airspace volume outside the flight geography where contingency procedures are implemented.
16. Contingency area corresponds to the projection of the contingency volume on the earth's surface.
17. Operational volume is formed by the integration of the flight geography and the contingency volume. It encompasses the airspace where the UAS operator conducts their operations.
18. Ground risk buffer refers to an area on the earth's surface surrounding the operational volume. Its purpose is to minimise the risk to third parties on the ground if the unmanned aircraft deviates or exits the operational volume. The ground risk buffer is specifically designated to enhance safety measures and mitigate potential hazards to individuals or property on the surface.

2.3.4 Categories of UAS Operations

All EU Member States are governed by Regulation (EU) 2019/947, which addresses the majority of civil drone activities and assesses their associated levels of risk. As previously mentioned, it establishes three categories of operations: open, specific, and certified.

2.3.4.1 Open Category

The open category is designed for lower-risk civil drone operations, prioritising safety while ensuring compliance with relevant requirements. Unlike other categories, the open category does not require authorisation from the competent authority or declaration from the UAS operator, as the operational risks involved are considered low [46].

Operations shall be classified as UAS operations in the open category where the following requirements[3] are met [38]:

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[3] These requirements are listed in Article 4 of Regulation (EU) 2019/947 of 24 May 2019.

- The unmanned aircraft has a MTOM of less than 25 kg;
- The remote pilot ensures that the unmanned aircraft is kept at a safe distance from people and that it is not flown over assemblies of people;
- The remote pilot keeps the unmanned aircraft in VLOS at all times except when flying in follow-me mode or when using an unmanned aircraft observer;
- During flight, the unmanned aircraft is maintained within 120 meters from the closest point of the surface of the earth, except when overflying an obstacle;
- During flight, the unmanned aircraft does not carry dangerous goods and does not drop any material.

Flight BVLOS, overflight of assembly of people, interference with manned aviation traffic, dropping materials, and interference or flying near emergency response services are strictly forbidden in the open category.

From an operational perspective, the open category is subdivided into three subcategories: A1, A2, and A3. These subcategories are determined based on the distance of the operation from people and entail different restrictions regarding UAS weight and pilot certification. Remote pilots operating in these subcategories can choose to obtain an A1/A3 license and/or an A2 license. The A2 license is suitable for UAS flights closer to infrastructure and people compared to A1/A3 license. The A1/A3 license is granted upon successful completion of online training, while A2 remote pilot license requires a pilot certificate of competency [45].

Subcategory A1 permits flights over people but not over assemblies of people. In this subcategory, UAS operations must comply with requirements that ensure a minimal risk of severe injuries to people on the ground or damage to manned aircraft, without necessitating specific remote pilot competence or strict operational limitations [47]. The UAS weight qualifying for this subcategory is up to 500 gr.

Subcategory A2 allows operations close to people. UAS operating under this subcategory must comply with requirements that mitigate the risk of several injuries to people on the ground or damage to manned aircraft. Furthermore, these UAS must be operated by registered operators and equipped with geofencing and electronic identification systems [47]. The UAS weight to fall under this subcategory ranges from 500 gr to 2 kg, inclusive.

Subcategory A3 enables flights conducted far from people. UAS operating under this subcategory must meet requirements that include technical mitigations, such as geofencing and electronic identification systems. These operations pose a higher risk of several injuries to people on the ground or damage to manned aircraft and must be conducted by registered operators with advanced competence levels [47]. The UAS weight for qualification under this subcategory ranges from 2 kg to 25 kg, inclusive.

Furthermore, the open category is also divided into five classes (C0, C1, C2, C3, and C4) based on various UAS factors such as size, weight (including payload), speed, and additional requirements. The most important characteristics of these classes are presented in Table 2.1.

Table 2.1: UAS classes according to technical properties and operational requirements. Adapted from: [29].

Subcategory	Class	MTOM	Velocity	Max. AGL	Pilot Registration Needed
A1 Fly over people	C0	<250 g	max 19 m/s	120 m	No (except if equipped with a camera)
	C1	<900 g	max 19 m/s	120 m	Yes
A2 Fly close to people	C2	<4 kg	-	120 m	Yes
A3 Fly far from people	C3	<25 kg	-	120 m	Yes
	C4	<25 kg	-	-	

2.3.4.2 Specific Category

The specific category pertains to more high-risk civil drone operations, which prioritise safety through the acquisition of operational authorisation from the national competent authority before commencing any operations. To obtain this authorisation, the drone operator must perform a risk assessment. The assessment will determine the specific requirements needed to ensure the safe operation of the civil drone(s) unless the operator already possesses a LUC with the relevant privileges [46].

The specific category of UAS operations applies to drone operations that exceed the operational limitations set for the open category. However, if an operation poses an even higher level of risk, it must be conducted under the certified category. Examples of UAS operations within the specific category include [48]:

- Operating a UAS in BVLOS;
- Operating drones with MTOM greater than 25 kg;
- Flying at altitudes exceeding 120 meters AGL;
- Using a drone to release or drop material during flight;
- Operating drones in urban environments with an MTOM greater than 4kg or without a class identification label.

In the specific category, all drone operators need to register themselves. If the operator is already registered, for example, because they operate a drone in the open category, there is no need to register again, even for operations in the specific category. UAS operators must register themselves in the Member State where they reside, while legal entities need to register in the Member State where they have their principal place of business. Third-country operators without a principal place of business in an EASA Member State need to register in the first EASA Member State in which they perform an operation [48].

Obtaining an operating license in the specific category requires a risk assessment that must be reviewed by the competent authority. This assessment goes beyond a simple declaration. According to Regulation (EU) 2019/947, an operational risk assessment should include, but is not limited to (a) a description of UAS operation, (b) a proposal for maintaining operational safety, (c) identification of ground and air risks to uninvolved persons and objects, (d) measures for risk mitigation, (e) technical characteristics of the UAS, and (f) competencies of the personnel. SORA methodology, developed by JARUS, can be applied to conduct the operational risk assessment and safely carry out UAS operations [29].

SORA is a methodology used to classify the risk associated with a drone flight in the specific category of operations and identify mitigations and safety objectives. It assists operators in identifying operational limitations, establishing training objectives for essential personnel involved in the operation (e.g., remote pilots, observers, maintainers, etc.), determining technical requirements for the drone, and developing appropriate operational procedures to be included in the operator manual [49].

Further information about the specific category of operations will be provided in Section 2.4.

2.3.4.3 Certified Category

The certified category of UAS operations is specifically designed for operations with a high level of risk to guarantee the highest level of safety. This category encompasses drone flights with passengers on board, such as air taxis. In terms of safety measures, the approach taken for certified UAS operations closely resembles the standards employed in manned aviation [50].

Several requirements must be satisfied to maintain the highest safety standards. Firstly, a thorough certification process for the UAS itself is required, which includes obtaining a Type Certificate (TC) and a certificate of airworthiness. Additionally, the UAS operator must obtain air operator approval issued by the competent authority. Lastly, the remote pilot is required to possess a pilot license. However, as technology advances, the expectation is that drones will become increasingly automated, with the potential for fully autonomous operations without the need for a remote pilot's intervention [46] [50].

Operations are classified in the certified category when the operation is conducted in any of the following conditions [43]:

- Over assemblies of people;
- Involves the transport of people;

- Involves the carriage of dangerous goods, with high-risk potential for third parties in the event of an accident.

UAS operations are classified as certified when the competent authority, based on the risk assessment, considers that the inherent risks associated with the operation cannot be sufficiently mitigated without certifying the UAS, the UAS operator, and, where applicable, licensing the remote pilot [43].

It is important to note that facilitating operations in the certified category necessitates substantial amendments to existing aviation regulations. This undertaking represents a big task that requires careful consideration and implementation. EASA decided to conduct this activity in multiple phases and to address the first three types of operation [50].

Operations type 1 involves international flights of certified cargo drones conducted in IFR conditions within airspace classes A-C. These flights include take-offs and landings at aerodromes under the purview of the EASA [50].

Operations type 2 pertains to drone operations in both urban and rural areas, using predefined routes in airspaces where U-space services are provided. These operations encompass unmanned drones engaged in transporting passengers or cargo [50].

Operations type 3 are similar to operations type 2, but with an important distinction: it involves an aircraft with a pilot on board. Initially, this category covers the initial air taxi operations where a pilot is physically present on board. Subsequently, in the second phase, the aircraft transition to being remotely piloted, falling under the classification of operations type 2 [50].

2.3.5 Operational Limitations

As mentioned earlier, the open category is considered low-risk for UAS operations and requires operating the UAS within VLOS conditions, where pilots must maintain continuous visual contact with the UAS. However, relying on VLOS operations may not be suitable for certain UAS applications. For example, monitoring issues in dense forest research may not always be feasible with direct visual contact with UAS. On the other hand, BVLOS operations are a significant aspect of the drone operation. BVLOS allows UAS to operate beyond the pilot's direct visual range, enabling them to cover long distances and large areas, resulting in time and cost reductions. However, current regulations still impose limitations on BVLOS operations, and efforts are being made by EU regulators to develop and adopt clear rules for such operations [30].

To better understand the potential of VLOS and BVLOS operations, Figure 2.4 provides a comparison of typical applications. One can see that the UAS market is increasingly adopting BVLOS techniques to enhance UAS functionalities and enable new commercial services for first responders, package delivery, and more. However, the decision to conduct a VLOS or BVLOS operation depends on various factors, including safety, security, time, cost, and others. These factors influence the selection of the appropriate operation category for UAS operations [30].

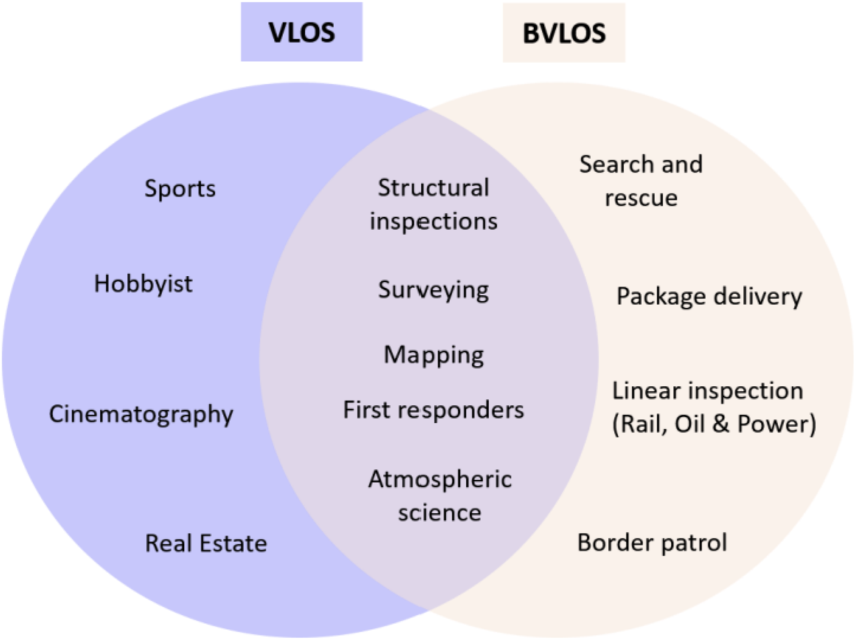

Figure 2.4: VLOS and BVLOS based typical applications [30].

In this context, UAS flights in the specific and certified categories are permitted under BVLOS conditions. While this may appear as a practical solution to overcome VLOS limitations, it also introduces additional processes that lead to more administrative and bureaucratic complexities, which has somewhat discouraged flights in these categories [30].

Since operational limitations are the main criteria of most UAV regulations, some countries have defined horizontal distances to people and property, or so-called no-fly zones, which need to be taken into account. One prominent example of a no-fly zone is the vicinity of aerodromes, airports, and airstrips. Due to the substantial risk, UAS pose to manned aircraft, flying in controlled airspace and near areas of aircraft take-off and landing is generally prohibited. However, in certain cases, a special authorisation may be granted on an individual basis. Another significant operational limitation mandates a safe distance between the UAS and uninvolved people, property, and vessels present in the surrounding area, emphasizing the need to ensure the safety of all parties not directly involved in the UAS flight [51].

2.4 UAS Operations in the Specific Category

2.4.1 Authorisation of Specific Category Operations

When a UAS operator intends to conduct an operation that does not fall within the open category, it automatically falls under the specific category. This occurs when at least one of the general criteria listed in Article 4 of the Regulation (EU) 2019/947, mentioned in Section 2.3.4.1, is not met, or when the detailed criteria for an open subcategory are not satisfied.

The authorisation process for operations within the specific category is based on a risk evaluation, which determines whether a declaration from the competent authority is sufficient or if an application for operational authorisation is required [52]. These operations within the specific category can be classified into three pillars, as illustrated in Figure 2.5.

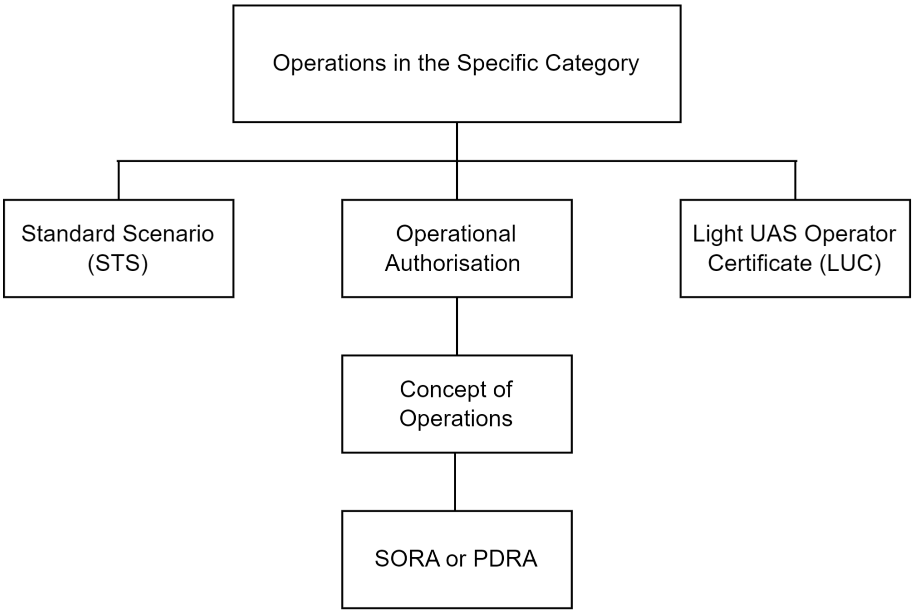

Figure 2.5: Operation types in the specific category [45].

A standard scenario (STS) refers to a type of UAS operation for which a precise set of mitigating measures has been identified. In such cases, operators can declare their intention to apply these mitigating measures during the execution of the operation, satisfying the competent authority [45].

To obtain operational authorisation within the specific category, operators must apply to the competent authority by conducting a risk assessment and proposing adequate mitigating measures. The competent authority evaluates the proposed operation and assesses the associated risks. Once the competent authority determines that the operational risks are acceptable and properly mitigated, they will issue the operational authorisation [45]. This authorisation grants UAS operators permission to conduct the specified operations within the specific category.

When a UAS operation meets specific operational characterizations described in a catalog, the associated risks can be addressed and mitigated through a Predefined Risk Assessment (PDRA). However, if the PDRA is not applicable or sufficient, the SORA must be conducted to assess and mitigate the risks associated with the operation [45]. It is important to note that while PDRA is verified through an authorisation process, a declaration is sufficient for STS.

LUC provides an alternative pathway for obtaining authorisation. Instead of focusing on individual operations, it is an organisational approval certificate that grants the organisation the privilege to self-authorise operations within specified limits. The LUC is issued by a national authority and is awarded to an organisation that can demonstrate its operating experience and has a mature organisational management system capable of assessing operational risks independently. According to instructions provided by EASA, once an organisation obtains a LUC, it gains several privileges. It can operate under STS without the need for a declaration, self-authorise PDRA operations without an application, and self-authorise allowed operations using the SORA process. These privileges can significantly benefit drone operators, especially when dealing with a high number of required authorisations for a variety of operations [52].

2.4.2 Specific Operations Risk Assessment (SORA)

When conducting an operation that is not covered by an STS or a PDRA, applicants must perform a risk assessment, identify mitigations and comply with safety objectives. To facilitate this process, EASA has developed the SORA methodology [49].

SORA, published by EASA as an AMC to Article 11 to Regulation (EU) 2019/947 [4], serves as both a methodology and guidance for UAS risk analysis and assessment to ensure an equivalent level of safety as in manned aviation. It facilitates the authorisation of operations outside the PDRA or STS categories through an iterative procedure that systematically identifies risks associated with complex UAS operations. The concept of SORA was originated by JARUS and has been adapted and accepted for use in Europe to meet the requirements of EU regulations [4].

To understand the SORA process, it is important to introduce the concept of robustness. Each risk mitigation or OSO can be demonstrated at different levels of robustness. The SORA process establishes three levels of robustness: low, medium, and high, corresponding to the level of risk involved. The designation of robustness is determined by evaluating the level of integrity (i.e., safety gain) provided by each mitigation, and the level of assurance (i.e., method of proof) that verifies the claimed safety gain has been achieved [4].

A low level of assurance is characterized by the applicant simply declaring that the required level of integrity has been achieved. A medium level of assurance is achieved by providing supporting evidence, such as testing or proof of experience, to demonstrate that the required level of integrity has been attained. A high level of assurance is attained when an independent third party verifies that the achieved integrity is acceptable. Table 2.2 provides guidance in determining the level of robustness based on the level of integrity and the level of assurance [4].

Table 2.2: Determination of robustness level [4].

	Low assurance	**Medium assurance**	**High assurance**
Low integrity	Low robustness	Low robustness	Low robustness
Medium integrity	Low robustness	Medium robustness	Medium robustness
High integrity	Low robustness	Medium robustness	High robustness

For example, the overall robustness will be considered low if an applicant demonstrates a medium level of integrity with a low level of assurance. In simple terms, the robustness will always be determined by the lower level between integrity and assurance [4].

The SORA methodology follows a systematic approach to analyse the proposed ConOps and establish a sufficient level of confidence in the operation's ability to be conducted with an acceptable level of risk. SORA is supported by ten steps, as illustrated in Figure 2.6. This methodology addresses the risks associated with both ground and air components of UAS operations and provides applicable mitigations to reduce these risks. It defines OSOs that must be achieved with a designated level of robustness based on specific levels of risk for both ground and air. The outcome of the SORA process is the determination that the proposed ConOps can be executed with an acceptable level of risk [4].

The following is a general explanation of the different steps of SORA [4] [53]:

- Step 1 - ConOps description: This initial step involves collecting and presenting relevant technical, operational, and system information regarding the intended use of the UAS in the operation.
- Step 2 - Determination of the UAS intrinsic Ground Risk Class (GRC): The intrinsic GRC refers to the risk of a person being struck by a UAS (in the event of loss of control with a reasonable assumption of safety). This parameter is influenced by factors such as UAS characteristics (e.g., MTOM, speed, etc.), flight conduct, and ground zone characteristics. The GRC is quantitatively assessed on a scale of one to ten, representing varying levels of risk (from lowest to highest).
- Step 3 - Final GRC determination: Mitigation measures are implemented to reduce the intrinsic GRC to a level equal to or less than 7, enabling the continuation of the SORA process.
- Step 4 - Determination of the initial Air Risk Class (ARC): The initial ARC pertains to the risk associated with a mid-air collision between the UAS and a manned aircraft. The ARC is determined based on the applicable Airspace Encounter Category (AEC),

which is determined by the type of airspace in which the operation takes place. The ARC is qualitatively assessed at four levels (from lowest to highest risk): ARC-a, ARC-b, ARC-c, and ARC-d.

- Step 5 - Application of the strategic mitigations to determine the final ARC: Strategic mitigations are implemented to reduce the initial ARC by demonstrating a lower risk of collision with manned aircraft within the operational airspace compared to that indicated by the AEC. The result of these mitigations is referred to as the residual ARC.

- Step 6 - Tactical Mitigation Performance Requirement (TMPR) and robustness levels: Tactical mitigations in the form of technical requirements are applied to further reduce the residual ARC. These mitigations must be demonstrated with a specified level of robustness. Tactical mitigations will take the form of either See and Avoid (SAA) for VLOS operations and Detect and Avoid (DAA) for BVLOS operations.

- Step 7 - SAIL determination: The SAIL parameter consolidates the ground and air risk analyses, drives the required activities, and indicates the level of confidence in maintaining control of the UAS operation. This parameter is determined based on the final GRC value and the residual ARC obtained in steps 3 and 6, respectively. The SAIL is quantitatively assessed on a scale of one to six, representing varying levels of risk (from lowest to highest). Section 2.4.3 explains how to determine the SAIL level.

- Step 8 - Identification of OSOs: OSOs are requirements necessary to ensure the safety and feasibility of a UAS operation. These requirements are divided into 24 OSOs, each with specific robustness levels depending on the SAIL level. The OSOs cover areas such as technical issues with the UAS (OSOs 1-10), deterioration of external systems supporting UAS operations (OSOs 11-13), human error (OSOs 14-20), and adverse operating conditions (OSOs 21-24).

- Step 9 - Adjacent area/airspace considerations: This step focuses on evaluating the risk posed by a loss of control of the operation, leading to infringement of adjacent areas on the ground and/or adjacent airspace. The characteristics of the adjacent airspace/area are taken into account to determine the level of containment that the operator must ensure to mitigate the risk.

- Step 10 - Comprehensive safety portfolio: In the final step, the UAS operator prepares a safety report that includes the risk assessment findings and supporting evidence. This report is then submitted to the appropriate regulatory authority to obtain operational authorisation for the proposed UAS operation.

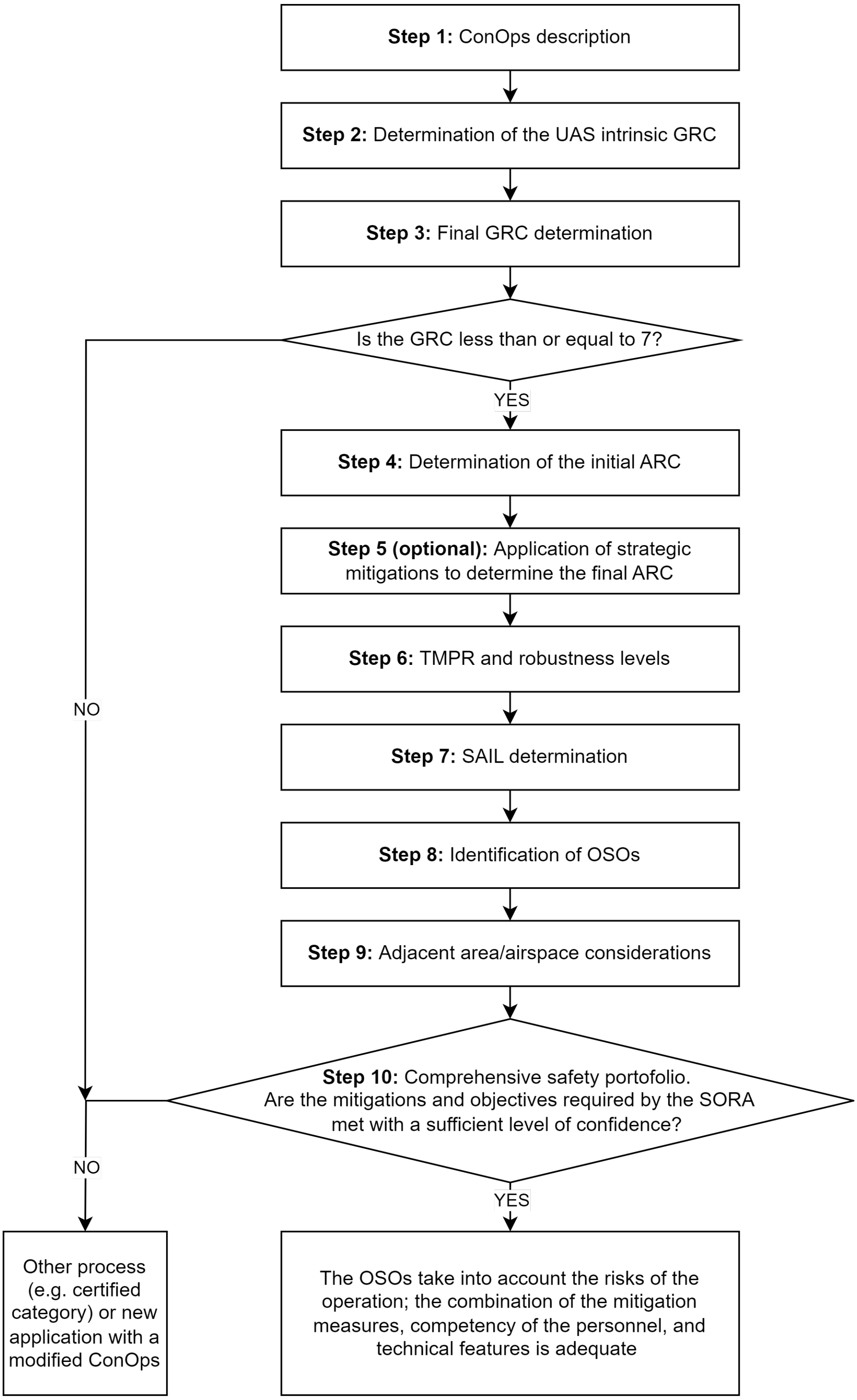

Figure 2.6: The SORA process [4].

The SORA methodology described above is based on SORA version 2.0. However, an updated version, namely version 2.5, has been developed by JARUS and is currently undergoing review for publication.

2.4.3 Specific Assurance and Integrity Level (SAIL)

The SAIL parameter consolidates the ground and air risk analyses and drives the required activities. It serves as a measure of confidence level in maintaining control over the UAS operation. The SAIL is not a quantitative value, but rather encompasses the following elements [4]:

- Compliance with specific OSOs;
- Description of the activities that might support compliance with those OSOs;
- Evidence that indicates that the objectives have been satisfied.

The SAIL associated with the proposed ConOps can be derived after determining the final GRC and the residual ARC.

2.4.3.1 Ground Risk Class Determination

The GRC is defined as the risk associated with a person being hit by a drone in the event of a loss of UAS control, assuming a reasonable level of safety. To determine the GRC, several factors need to be considered, including aircraft characteristics (weight and dimensions), the specific flight area, and knowledge of the intended operational scenario [4].

Table 2.3 illustrates how to determine the intrinsic GRC. This value is determined based on the intersection of the relevant operational scenario and the maximum dimension of the UAS that defines the lethal area. In cases where there is a discrepancy between the maximum UAS dimension and the expected kinetic energy, the applicant must justify the chosen column [4].

Table 2.3: Determination of the intrinsic GRC [4].

Intrinsic UAS Ground Risk Class				
Max UAS characteristics dimension	1 m	3 m	8 m	> 8 m
Typical kinetic energy expected	< 700 J	< 34 kJ	< 1084 kJ	> 1084 kJ
Operational scenarios				
VLOS/BVLOS over controlled ground area	1	2	3	4
VLOS over a sparsely populated area	2	3	4	5
BVLOS over a sparsely populated area	3	4	5	6
VLOS over a populated area	4	5	6	8
BVLOS over a populated area	5	6	8	10
VLOS over an assembly of people	7			
BVLOS over an assembly of people	8			

Once the intrinsic GRC has been determined, mitigations must be implemented to reduce the risk and obtain the value of the final GRC. At this stage, it is important to analyse the concept of robustness within the SORA methodology. The robustness of the mitigation measures refers to the level of integrity provided by each mitigation measure and the level of assurance attained through validation methods [54]. The levels of robustness are outlined in Table 2.2.

Depending on the robustness values of the implemented mitigations, the GRC value can be reduced, leading to the determination of the final GRC. However, the final GRC cannot be lower than the minimum value indicated in the resulting column of Table 2.3.

Table 2.4 provides a list of potential mitigations along with their corresponding relative correction factors. A positive value indicates an increase in the GRC, while a negative value indicates a decrease in the GRC [4].

Table 2.4: Mitigations for final GRC determination [4].

		Robustness		
Mitigation Sequence	**Mitigations for Ground Risk**	**Low/None**	**Medium**	**High**
1	M1-Strategic mitigations for ground risk	0: None -1: Low	-2	-4
2	M2-Effects of ground impact are reduced	0	-1	-2
3	M3-An emergency response plan is in place, the UAS operator is validated and effective	1	0	-1

2.4.3.2 Air Risk Class Determination

Apart from assessing ground risks, the SORA methodology also considers the risk of collision in the air based on the defined airspace in the ConOps where the UAS will operate. This assessment is referred to as the ARC, which is the classification according to the ratio in which a drone can meet a manned aircraft in a typical airspace [54].

To determine the initial ARC, SORA provides a framework that takes into account the predefined airspace specified in the ConOps. As shown in Figure 2.7, the airspace is divided into 13 aggregated collision risk categories. These categories are characterized based on factors such as altitude, controlled versus uncontrolled airspace airport/heliport versus non-airport/non-heliport environments, airspace over urban versus rural areas, and typical versus atypical airspace [4].

To assign the appropriate ARC for a type of UAS operation, applicants should refer to the decision tree presented in Figure 2.7. It is important to note that ARC-a generally denotes airspace where the risk of a collision between a UAS and a manned aircraft is considered acceptable without the need for tactical mitigation. On the other hand, ARC-b, ARC-c, and ARC-d represent volumes of airspace with increasing risk of a collision between a UAS and a manned aircraft [4].

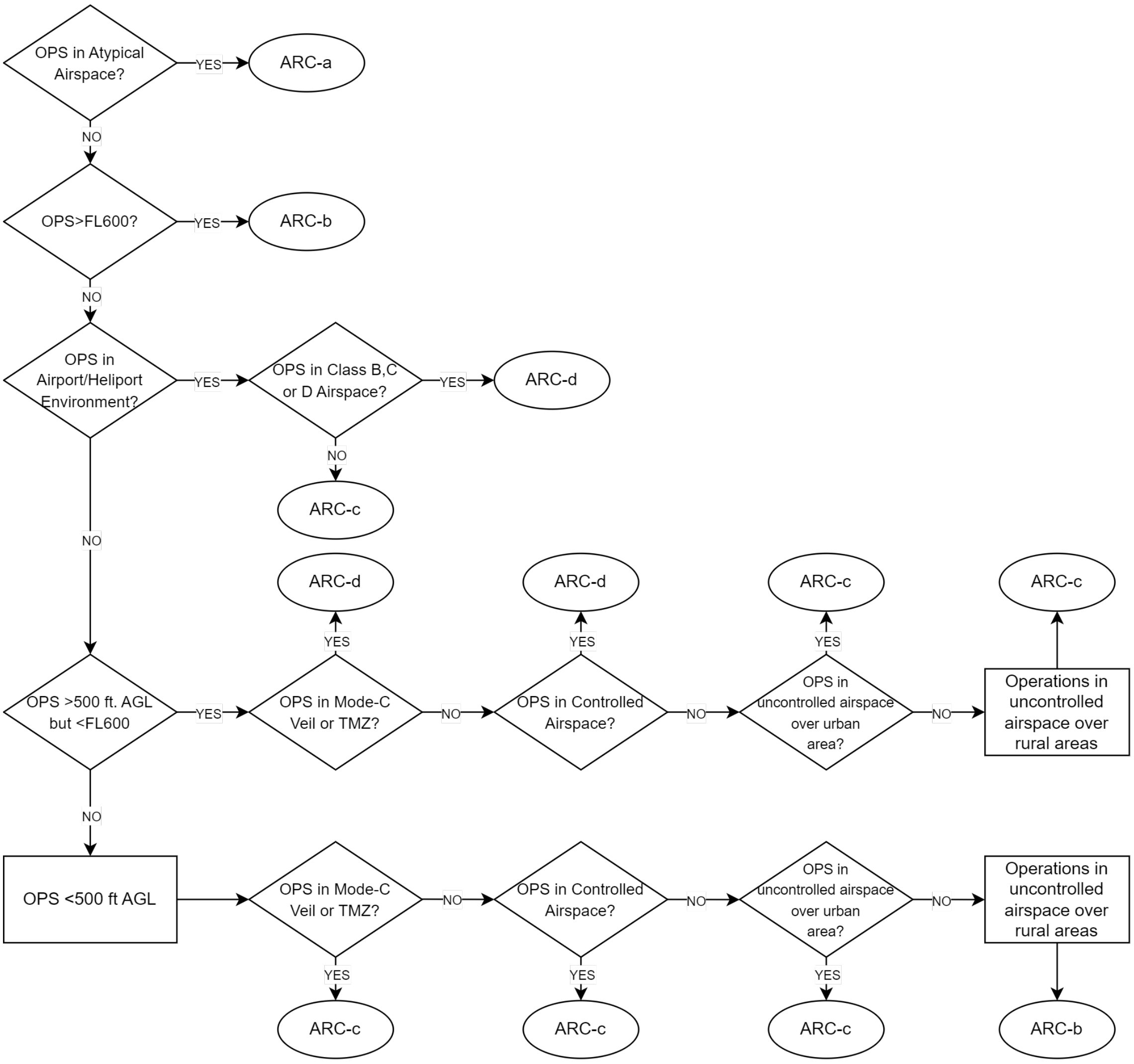

Figure 2.7: ARC assignment process [4].

Once the initial ARC has been determined, strategic mitigations can be implemented to reduce the initial ARC and determine the residual ARC (this step is optional). If the applicant believes that the initially assigned ARC is too high for the specific operational volume, strategic mitigations can be applied [4]. These mitigations may involve adjustments made before the operation, such as the timing and duration of the flight. Additionally, regulatory limitations, such as maximum altitude and flight distance restrictions, can also contribute to reducing the ARC

Furthermore, tactical mitigations can be employed to further mitigate the risk of air collisions. These mitigations are implemented by the pilot and their team during the flight, such as SAA and communication with ANSP services [54].

However, if the applicant determines that the initial ARC assignment aligns appropriately with the conditions in the local operational volume, then the assigned ARC becomes the residual ARC [4], requiring no further adjustment.

2.4.3.3 SAIL Determination

Once the final GRC and residual ARC values have been calculated, it is now possible to determine the SAIL.

The SAIL is an index ranging from one to six that indicates the level of assurance and integrity of the mitigation measures to be implemented, representing their robustness [54]. The assignment of the SAIL for a particular ConOps is determined using Table 2.5.

A low SAIL value corresponds to operations with low risk, indicating a lower level of robustness required for the mitigation measures. Conversely, a higher SAIL value indicates a higher level of robustness needed, as the associated operation carries a higher level of risk [54].

Table 2.5: SAIL determination [4].

SAIL determination				
	Residual ARC			
Final GRC	**a**	**b**	**c**	**d**
≤2	I	II	IV	VI
3	II	II	IV	VI
4	III	III	IV	VI
5	IV	IV	IV	VI
6	V	V	V	VI
7	VI	VI	VI	VI
>7	Category C operation			

2.5 Design Verification Report

2.5.1 Scope and Purpose

After completing the SORA process, the operator determines the SAIL, corresponding to the intrinsic risk level of the operation, and identifies the required level of robustness for demonstrating compliance with the OSOs [5]. Furthermore, the application of guidelines for design-related OSOs depends on the assigned SAIL level.

For SAIL I, II, and III operations, the operator can choose to use a drone that either carries a class identification label or has a declaration of compliance with the technical OSOs. However, in cases where compliance with technical mitigations (M2) and enhanced containment is required, the NAA may mandate the use of a drone assessed by EASA through a design verification report [5].

In the case of SAIL V and VI operations classified as high-risk, the use of a drone with a TC, according to Part 21 (Regulation (EU) 748/2012), is mandatory [5].

For SAIL IV operations, a more suitable, simplified, and flexible alternative is available, known as the design verification report. This option provides a comprehensive assessment of the drone's design compliance [5].

The DVR is a report issued by EASA to ensure that the UAS design complies with the relevant OSOs. The DVR outlines any crucial limitations or assumptions necessary for the safe operation of the specific drone model. It is important to note that the DVR is not a TC and is recognised exclusively within EASA Member States [5].

To initiate the DVR process, drone manufacturers must submit an application form provided by EASA. A pre-application meeting is then conducted by EASA, where manufacturers are expected to provide a description of their planned operations, along with timelines and schedules for design verification, certification, and market entry. During this meeting, EASA experts may offer valuable guidance to the manufacturer, who can then decide whether to proceed with the application or postpone it [5].

Upon successful completion of the pre-application meeting, EASA experts collaborate with the manufacturer to establish the applicable requirements derived from the Special Conditions for Light-UAS Medium Risk. The manufacturer assembles the necessary documentation to demonstrate compliance with these requirements, which is then submitted to EASA. After a thorough evaluation of the documentation, EASA issues the DVR [5].

When operators apply for operational authorisation using a drone for which EASA has issued a DVR suitable for their intended operation, they can effectively demonstrate compliance with the design-related OSOs through the DVR. The DVR should encompass the following elements [5]:

- Clear references to applicable documents provided by the manufacturer;
- Identification of the suitable SAIL, Ground and Air Risk classes, the operational environment, etc., specific to the drone design;
- Precise conditions and limitations under which the design is expected to perform adequately. This may include factors such as minimum ground/air buffers, population density limits, radio frequency environment considerations, and specific aspects regarding continuing airworthiness, etc.

2.5.2 Special Conditions for Light-UAS Medium Risk

With the introduction of Special Conditions for Light-UAS, EASA has established a legal framework focusing on medium-risk operations within the specific category. This Special Conditions (SC) provide general requirements that serve as a basis for more specific standardization efforts incorporating quantitative requirements, parameters, and testing methods.

The SC for Light-UAS specify the application of the framework to UAS meeting the following criteria [55]:

- Not intended for transporting humans;
- Operated with the intervention of a remote pilot or autonomously;
- Have an MTOM up to 600 kg;
- Operated in the specific category of operations, medium risk.

The term 'medium risk' is used here to refer to operations classified as SAIL III and IV. Although voluntary certification for SAIL III and IV operations is possible, the competent authority may still require EASA validation of UAS and/or its components' compliance with the design-related OSOs [55].

For manufacturers and operators, the SC aim to facilitate the use of UAS. Manufacturers can declare conformity with these requirements, and operators can use such declarations in their risk assessments to simplify the evaluation process. EASA further states that the special conditions will eventually be transformed into certification specifications, enabling certification bodies to assess and certify UAS compliance with these requirements in the future [56].

Regarding UAS systems (Light-UAS.2510 Equipment, Systems and Installation), the SC establishes that the design and installation of these systems, when considered separately or in relation to other systems, must adhere to the following principles [55]:

1. Minimise hazards in the event of a probable[4] failure[5];
2. Ensure that a catastrophic failure condition will not result from any single failure;
3. If the SAIL is IV, provide means for detecting, alerting, and managing any failure or combination of failures that could lead to a hazard[6].

Additionally, the SC emphasizes the need to minimise hazards resulting from the operation of equipment and systems not covered by Light-UAS.2500 [55].

In terms of containment (Light-UAS.2511 Containment), it is explicit that no probable failure of the UAS or any external system supporting the operation must result in operations beyond the defined operational volume. Conversely, when the risk associated with adjacent ground areas or adjacent airspace is significantly higher than the risk associated with the operational volume including the ground buffer [55]:

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[4] The term 'probable' refers to occurrences anticipated to happen one or more times during the entire system/operational life of an item.

[5] The term 'failure' refers to an occurrence that affects the operation of a part or element, rendering it unable to function as intended. Errors may cause failures but are not considered failures themselves.

[6] The term 'hazard' refers to a failure condition that relates to major, hazardous, or catastrophic consequences.

1. The probability of leaving the operational volume must be demonstrated to be acceptable with respect to the risk posed by a loss of containment;
2. No single failure of the UAS or any external system supporting the operation must result in operations outside the ground risk buffer;
3. Software and airborne electronic hardware, which, if faulty, could lead directly to operations outside the ground risk buffer must be developed to a standard or methodology accepted by EASA.

2.5.3 EASA Guidelines for Design Approvals

Guidelines on Design Verification for UAS operated in the specific category is a document issued by EASA in August 2023. These guidelines are essential for ensuring that UAS operating in the specific category and classified in SAIL IV meet the required design and safety standards.

This publication marks the second installment from EASA concerning design verification. The inaugural release, dating back to March 2021, pertains to operations classified in SAIL III and IV. The present document, conversely, exclusively addresses operations within SAIL IV.

The process for design verification depends on the level of risk associated with the operation. When the UAS is used in high-risk operations (SAIL V and VI according to SORA), EASA will issue a TC. In medium-risk operations (SAIL III and IV according to SORA), a more proportionate approach is applied, resulting in the issuance of a DVR. The guidelines describe the procedure for applying to EASA to obtain a DVR [57].

This document elucidates the verification processes and procedures to demonstrate compliance with applicable regulations and requirements. It underscores that when an operation is classified as SAIL IV, the national competent authority should mandate an EASA design verification of the UAS. This requirement also applies to mitigation means linked with design when claimed at high robustness, and for verifying the enhanced containment function as presently defined by SORA when no declarative MoC can be applied. Importantly, these guidelines apply to any design verification project [6].

Moreover, although not mandatory, manufacturers of UAS used for SAIL IV operations may opt to apply for a TC or a Restricted Type Certificate (RTC) according to Regulation (EU) 748/2012 (Part 21) [6].

The guidelines specify that the scope of design verification can encompass one or more of the following points [6]:

- The full design of the UAS for its compliance with design-related OSOs outlined in the SORA process, aimed at achieving the required level of robustness for the applicable SAIL;

- The mitigation means linked with the design;
- The enhanced containment function;
- Parts installed on a UAS contributing to the safety performance[7].

In cases of a more limited design verification scope for specific functions/features, the verification process will be confined to elements necessary for demonstrating compliance with specific paragraphs (i.e., Light-UAS.2511 for enhanced containment and Light-UAS.2512 for mitigation means). For instance, if the aim is to verify compliance with enhanced containment requirements and the UAS boasts an independent stand-alone FTS, the DVR might be restricted to that system. Conversely, if containment functionality is deeply integrated into the UAS architecture, the investigation could encompass other UAS functions and equipment crucial for the proper operation of the containment function [6].

The provision of design verification service in the specific category unfolds across three phases: Application, Design Verification Process, and issuance of a Design Verification Report.

During the initial phase, agreement on the design verification basis is reached early in the process. Subsequently, the applicant conducts noise measurements following appropriate procedures, reporting these levels to EASA. EASA has already issued Guidelines on Noise Measurement of Unmanned Aircraft Systems Lighter than 600 kg Operating in the Specific Category (Low and Medium Risk) [58]. Familiarity with the Design Verification Programme (DVP) is also expected from the applicant. The DVP serves as a document facilitating the management and control of evolving UAS design and the applicant's compliance demonstration process. The applicant proposes their DVP, including the MoCs. Upon EASA's approval, the applicant conducts verification activities (appraisals, analyses, tests, etc.) and documents them accordingly [6].

EASA evaluates the application, and upon acceptance, enters the design verification phase. The DVR is issued to the applicant, who holds the responsibility of retaining pertinent design information, drawings, and test reports to ensure continued airworthiness and the continued validity of the DVR. The applicant must demonstrate compliance with the design verification basis and applicable environmental protection provisions, proposing means (MoCs) for demonstrating this compliance [6].

The proposed DVP must include the MoCs. Each MoC proposal should encompass at least the following [6]:

- The specific design objective to be achieved;

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[7] Parts installed on the UAS will initially be evaluated only within the frame of a full design verification project.

- The planned activities and their schedule;
- Relevant parameters and their rationale;
- References to industrial standards, airworthiness specifications, or other GM/AMC (if applicable);
- Pass/fail criteria.

Finally, the third phase entails the issuance of a DVR. The result of the design verification process is an EASA document, referred to as the design verification report, affirming EASA's contentment with the verified compliance demonstration provided by the applicant. The DVR encompasses limitations, conditions, or assumptions defining its validity [6].

Additionally, these guidelines also provide guidance for developing means of compliance, presented as an Annex. This supplementary guidance intends to illustrate EASA's expectations regarding the proposal of means of compliance within the context of a Design Verification Project [6].

2.5.4 Compliance Matrix for Design Verification Projects

The compliance matrix is a spreadsheet, based on SC Light-UAS, and is meant for use by the applicants and EASA within design verification projects. EASA has defined the SC Light-UAS based on a range of sources, including CSs and the SORA.

To establish the foundation for design verification projects, the specifications of SC Light-UAS Medium Risk, as adopted by EASA in December 2020, serve as the basis. The compliance matrix encompasses all the specifications outlined in the SC Light-UAS and establishes links between each specification and the corresponding SORA elements (OSOs, step 9, Mitigation Means M2). These links are crucial in determining the level of robustness required for the MoC to be proposed by the applicant in the design verification project [59].

The MoC can be identified and proposed based on existing standards, which can be tailored and adapted by the applicant to suit the specific project requirements. In cases where specific standards are unavailable, the applicant has the flexibility to propose alternative means of compliance without direct reference to such standards [59].

2.5.5 Means of Compliance with Light-UAS.2510

The means of compliance with Light-UAS.2510, released by EASA in June 2023, addresses equipment, systems, and installations. This document outlines an accepted means for demonstrating compliance with the requirements outlined in Light-UAS.2510 of Special

Conditions for Light-UAS Medium Risk (see Section 2.5.2). These means are intended to supplement the engineering and operational judgment that should underlie any demonstration of compliance [60].

This MoC is applicable to UAS intended for SAIL IV operations and is relevant to the installed equipment and systems, in addition to specific system requirements. It covers the complete UAS, which is comprised of the unmanned aircraft and the remote control equipment (command unit) [60].

The primary goal of Light-UAS.2510 is to ensure a satisfactory level of safety for equipment and systems when integrated into the UAS. Light-UAS.2510 requirement stipulates that the equipment and systems identified in Light-UAS.2500 when considered separately and in relation to other systems, must be designed and installed in a manner that minimises hazards in the event of a likely failure. It should be reasonably expected that a single failure will not result in a fatality. Furthermore, for SAIL IV operations, there must be means for detecting, alerting, and managing failures or combinations thereof that could lead to hazards. The subsequent Safety Objectives are applicable to medium-risk UAS (SAIL IV) [60]:

1. Failure conditions leading to the loss of control of the operation are not probable;
2. Failure conditions leading to the loss of control of the operation will not result from a single failure;
3. Functions, systems, equipment, and items whose development error(s) could directly result in the loss of control of operation should be developed to DAL C.

Development Assurance encompasses planned and methodical actions used to confirm with a satisfactory level of confidence, that errors in requirements, design, and implementation have been identified and rectified, ensuring compliance with the applicable certification basis. Development Assurance Level (DAL) refers to the rigor level of development assurance tasks necessary to demonstrate conformity with the provisions of Light-UAS.2500 and Light-UAS.2510 [60].

The subsequent portions of this MoC detail how to demonstrate compliance with the outlined safety objectives.

2.5.6 Means of Compliance with Light-UAS.2511

The means of compliance with Light-UAS.2511 Containment, issued by EASA in May 2022, is a significant document that pertains to operations up to SAIL II. It serves as a formal declaration to the relevant regulatory authority responsible for granting operational authorisation. This document primarily focuses on containment, specifically addressing the FTS within UAS. It offers a streamlined approach for UAS operators to demonstrate

FTS performance compliance through a simplified design checklist and a series of tests [3].

It is important to notice that this MoC does not address the design of the specific UAS concerning their probability of leaving the operational volume. However, it provides a logic according to which a maximum probability can be determined based on SAIL. This MoC's foundation on a specific FTS design facilitates a straightforward calculation of the maximum probability of leaving the ground buffer [3].

This MoC defines a concise set of prescriptions that allow, when successfully demonstrated, reasonably ensure that the probability of FTS failure is below 10^{-2}/Flight Hour (FH) ($P_{FTSfail}$<10^{-2}/FH). This, when considered in conjunction with the UAS performance (as represented by the SAIL) and a design checklist ensuring proper FTS segregation from the UAS, allows for an estimation of the probability per flight hour that the UAS might leave the ground risk buffer and enter in adjacent areas/volumes[8] [3].

To ensure the adequate performance of the FTS, the MoC outlines a set of verification tests. These include bench tests, ground integration tests after FTS installation on the UAS, flight tests, and end-to-end activation tests [3].

Additionally, this MoC offers valuable guidance concerning the necessary inclusions in the UAS flight manual. It also provides recommendations for establishing maintenance instructions, ensuring the FTS functions as intended throughout the life of the installed system [3].

2.6 Conclusion

In conclusion, this chapter has provided an overview of the concept of AAM and the global, European, and national regulations in place to harmonise the impact of drones on our airspace and society.

Furthermore, an analysis of the EASA documents was made, primarily focusing on those relevant to the specific category of operations and for obtaining a DVR. EASA's stance in this endeavor is evident through its ongoing efforts to develop and update guidelines and regulations, ensuring that UAS operations remain safe and harmonised throughout the EU.

As technology continues to advance, it is crucial that stakeholders, including regulators, industry players, and operators, collaborate to strike a balance between innovation and safety. The documents and regulations discussed in the present chapter provide a solid foundation for achieving this objective.

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[8] Existing the ground risk buffer is typically associated with an imminent crash in adjacent areas or, in rare and extreme instances, a potential collision with manned aircraft.

Chapter 3

Methodology

This chapter outlines the methodology used in developing the means of compliance with the FTS for operations in SAIL IV. The methodology presented here comprises a versatile framework that can be effectively applied to any UAS system, providing a clear path to obtain a DVR. Consequently, this framework delineates the steps and procedures for achieving a successful DVR. In light of this, the chapter is divided into three distinct sections: Purpose of the Framework, Framework Development, and Conclusion. The first section elucidates the framework's purpose, utility, and applicability. The second section illustrates the framework development process.

3.1 Purpose of the Framework

The purpose of this framework is to systematically outline the steps to obtain a DVR, taking into account a range of potential scenarios. Illustrated in Figure 3.1, this framework serves as a comprehensive methodology that the industry can adopt to identify the required and necessary steps to obtain a DVR issued by EASA.

This framework's development is firmly rooted in the Guidelines on Design Verification for UAS operated in the specific category, detailed in Section 2.5.3. Consequently, it adheres to the constraints outlined in that document. Concerning the applicability of the framework, it aligns with the same criteria as the guidelines. As a result, an EASA DVR is required (and thus the framework is to be applied) in the following circumstances [6]:

- If an operation is classified as SAIL IV;
- Mitigation means linked with design when claimed at high robustness;
- For the verification of the enhanced containment as currently defined by SORA when no declarative MoC can be applied.

It is important to note that meeting any one of the above three points is sufficient for the framework's application. However, an operation may fall under one or more of these criteria and still be encompassed by the framework.

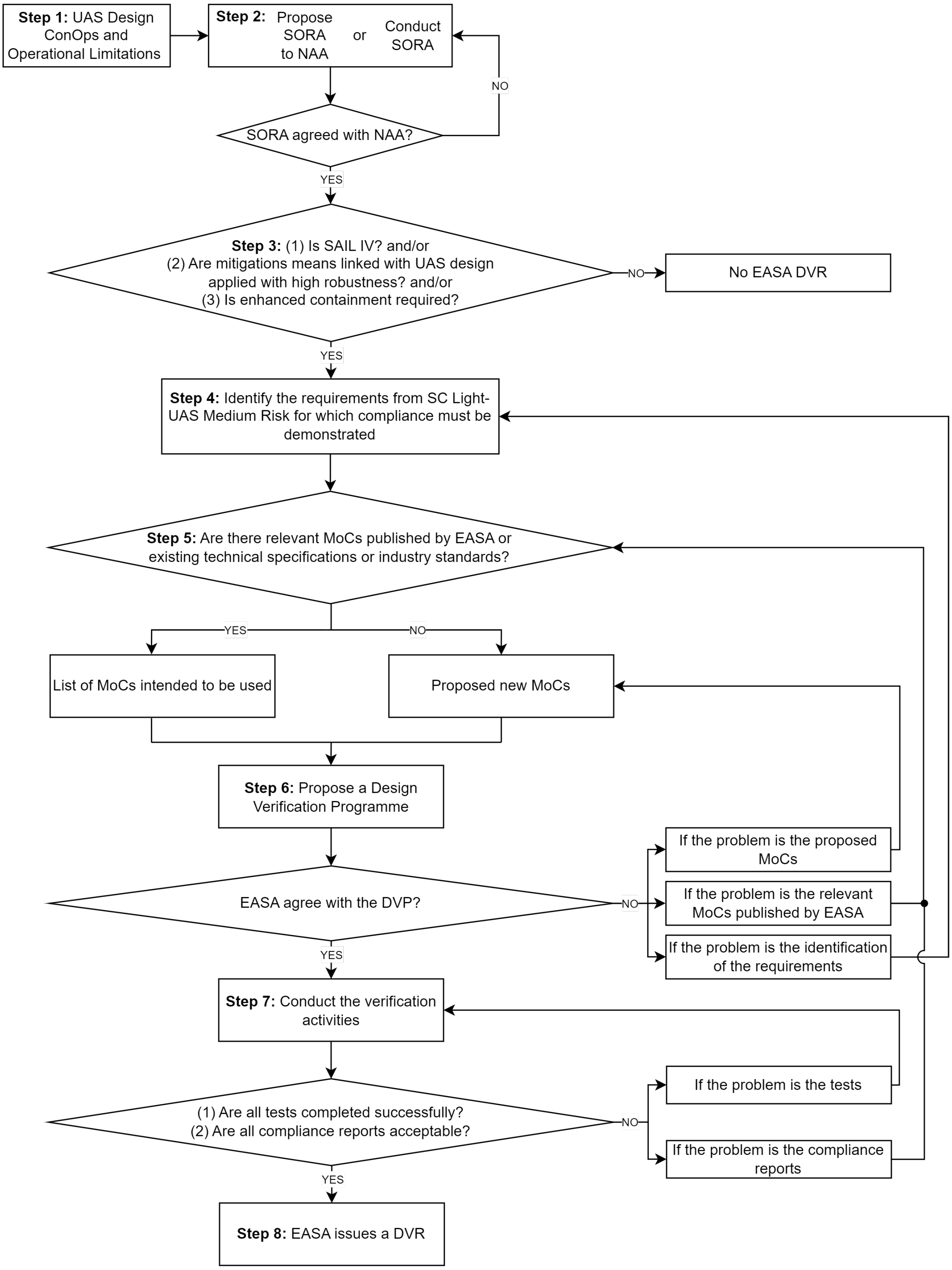

Figure 3.1: Design verification process.

Within the scope of this dissertation, the importance of this framework lies in the imperative need to adhere to this flowchart. It serves as a guide to formulate the required MoC for certifying the FTS for SAIL IV operations. Thus, the intention is to systematically follow all these steps and apply them to the FTS under study.

3.2 Framework Development

As previously mentioned, the framework was developed based on the document issued by EASA, known as the Guidelines on Design Verification for UAS operated in the specific category, which has been analysed in the previous chapter. The primary objective of this document is to guide applicants seeking design approval from EASA. According to these guidelines, any natural or legal person with access to the relevant design and technical data, enabling them to demonstrate compliance with the applicable technical requirements is eligible to apply for a DVR [6].

First and foremost, it is essential to understand how the design verification process works in a general context. Obtaining a DVR is never solely the responsibility of the applicant; it is a collaborative effort with EASA.

In a general sense, the process of obtaining a DVR begins with the applicant submitting a presentation to EASA, providing an overview of the system. Subsequently, a familiarization meeting occurs, where the applicant's technicians and EASA experts come together. Following this, the MoC is defined. A series of meetings take place for EASA to ensure a thorough understanding of the system and the applicant's comprehension of the expectations outlined in the MoCs. Following interactions between the applicant and EASA, the applicant submits the Design Verification Programme (DVP), which includes references to compliance activities and documents. EASA reviews the DVP and provides feedback. Once the DVP is agreed by EASA, the applicant proceeds with testing and the preparation of final compliance documents, which are sent to EASA upon completion. EASA reviews these final compliance documents and offers further comments. Once a consensus is reached, EASA issues the DVR.

In conclusion, as per the guidelines, the process of obtaining a DVR can be essentially divided into three distinct phases. The first phase is the Application phase, during which the applicant proposes their DVP. Once accepted by EASA, the second phase starts, known as the Design Verification Process. In this phase, the applicant applies the DVP, which involves conducting the tests proposed in the DVP, as well as quantitative and qualitative assessments. If applicable, EASA may investigate the correct installation of tactical mitigation means (following manufacturer instructions), their safe system integration, and pilot interface [6]. Following the design verification process, the third phase begins, culminating in the issuance of a DVR, indicating EASA's satisfaction with the verified compliance demonstration provided by the applicant.

Therefore, the steps required to achieve the targets of these three phases outlined in the guidelines have been organised into a flowchart, presented in Figure 3.1. This framework serves as the roadmap for obtaining a DVR for any UAS system, part, or component. It is important to note that the specific compliance requirements will vary from one system to another. As a result, the framework is versatile and adaptable, as different systems require different sets of requirements.

Then, the following explanation provides details for each of the framework's steps, considering various decision scenarios.

Step 1: UAS Design ConOps and Operational Limitations

The framework initiates with the establishment of the UAS design ConOps and the identification of operational limitations. The last one includes, for example, maximum operating altitudes, flight duration, payload capacities, and any other constraints that impact the UAS's operational capabilities.

In this phase, it is crucial to understand how the UAS is intended to be used. It involves defining the typical operational scenarios, including the specific missions or tasks the UAS is designed to perform.

It is also relevant to consider the environmental conditions under which the UAS is intended to operate. It can encompass various factors, such as day and night operations, adverse weather conditions, and temperature ranges. Clearly defining these conditions is vital for ensuring safe and effective UAS operation.

Another critical aspect involves the assessment of risk mitigation means. It entails determining whether the UAS relies on ground-based or air-based risk mitigation means to enhance safety during operations.

It is also necessary to identify if the enhanced containment would be required. Enhanced containment refers to strategies and technologies employed to prevent or mitigate potential hazards in case of system failure or unexpected events.

Furthermore, the delineation of buffers and corridors is of utmost importance. The dimensions of these zones, within which the UAS will operate, are indispensable parameters for ensuring safe separation from other airspace users and potential obstacles.

In conclusion, this initial step is distinct for every UAS since the aircraft ConOps is never the same.

Step 2: Propose SORA to NAA or Conduct SORA

The second step stays around the SORA process. Consequently, it is essential to develop a representative SORA for the typical operation [6]. The framework provides two distinct pathways to accomplish this objective.

The first approach entails the proposition of a risk analysis methodology, effectively presenting a SORA to the NAA. If the competent authority approves this proposed SORA, the process of obtaining a DVR will proceed, advancing to the next step. However, in the event of a negative response, signifying the competent authority's disapproval of the proposed SORA, it becomes necessary to revisit this step and formulate a new SORA.

Alternatively, the second option involves the conduct of the SORA process established by

EASA, which outlines how to design, evaluate, and execute UAS operations safely [38]. Within this scenario, it remains imperative for the competent authority to endorse the results derived from this risk analysis. Upon completing all the steps of the SORA, the applicant must submit a copy of the risk assessment to the NAA for review, as well as a detailed description of the design and configurations to be verified [6].

Similar to the previous option, if the NAA concurs with the execution of the SORA, the process proceeds to the next step. Conversely, if not, the SORA process necessitates a review and execution.

Step 3: Verify the applicability conditions

Once the SORA has been correctly executed and the NAA has approved its execution, it is then possible to verify whether the applicability conditions for this framework apply to the UAS under study, as the SAIL of the operation, mitigation means, and verified of enhanced containment are already known.

These conditions have been listed in Section 3.1 and can be summarised in three key points: whether the UAS operation is a SAIL IV operation, if mitigation means are linked with design when claimed at high robustness, and if verification of enhanced containment as currently defined by SORA is needed when no declarative MoC can be applied [6].

As stated before, this framework becomes applicable if one or more of these conditions are pertinent to the specific UAS operation under study. If any of the conditions mentioned above are applied, the process of obtaining a DVR moves on, following the prescribed flowchart.

However, if none of the conditions listed apply to the UAS in question, it becomes unfeasible to use this framework because the DVR is only required for the listed cases.

Step 4: Identify the requirements from SC Light-UAS Medium Risk for which compliance must be demonstrated

After confirming the applicability conditions are met, it means that the process outlined in the framework can advance.

This leads to the next step, which involves determining the design verification basis. Establishing the design verification basis should commence by referencing the SC Light-UAS and identifying applicable requirements based on the scope of the ConOps and risk assessment. Subsequently, the design verification basis may encompass one or more of the following aspects [6]:

- The full design of the UAS for its compliance with design-related OSOs as defined in the SORA process, meeting the required level of robustness for the applicable SAIL;
- Mitigation means linked with the design;

- Enhanced containment function;
- Parts installed on a UAS contributing to its safety performance.

As outlined in the guidelines, it is imperative to demonstrate compliance not only with the requirements specified in SC Light-UAS but also with the recommended OSOs outlined in the SORA process. These OSOs have a historical track record of ensuring the safety of UAS operations, drawing upon the collective expertise of numerous professionals, rendering them a dependable starting point for defining the necessary safety objectives for a particular operation. It is important to note that competent authorities issuing operational authorisations may establish additional OSOs for a given SAIL and its associated level of robustness [38].

For obtaining a DVR, the manufacturer's perspective is the primary focus since it pertains to the technical aspects of the UAS. The OSOs deriving from the SORA contain sections designated for manufacturers, while others are intended for UAS operators. Therefore, in formulating the design verification basis, it is critical to identify the parts of OSOs tailored to manufacturers and incorporate them into the compliance requirements.

This step should be addressed early in the process to ensure a clear and well-defined path toward obtaining the DVR.

Step 5: Identify the relevant MoCs published by EASA or existing technical specifications or industry standards

After identifying the requirements for which compliance should be demonstrated to obtain the DVR, it is essential to enumerate existing relevant documents. These documents may include MoCs published by EASA, existing technical specifications, and industry standards.

It is already known that the applicant's responsibility consists of demonstrating compliance with the design verification basis (as defined in step 4) and proposing the means (MoCs) through which this compliance will be achieved. For each element of the design verification basis applicant needs to provide a MoC.

Given that SC Light-UAS is objective-based, these MoCs must effectively accomplish the following [6]:

- Clearly describe how the SC Light-UAS paragraph applies to the UAS configuration;
- Specify concrete UAS design-related auditable or measurable specifications;
- Define the methodology for demonstrating compliance with this data, which includes design review, calculations, analysis, laboratory tests, ground tests, flight tests, and other applicable methods.

Therefore, if there are indeed important documents published by EASA that cover these points, it is essential to compile a list of these MoCs intended to be used and provide that list to EASA.

However, in scenarios where there are no EASA-published documents applicable to the specific case under consideration (for example, if the SAIL of the operation falls outside the scope of existing MoCs), it becomes imperative to propose new MoCs. These proposed MoCs should include, in each case, the following points [6]:

- Clearly articulate the design objective to be achieved;
- Specify the activities to be carried out and outline their scheduling;
- Define the relevant parameters and their rationale;
- Provide references to industrial standards, airworthiness specifications, or other applicable guidance material or acceptable means of compliance;
- Establish the pass/fail criteria.

In practice terms, these MoCs should elucidate the safety objectives derived from the design verification basis, enabling EASA Certification Experts to assess the adequacy of the proposed MoC and understand how the applicant intends to demonstrate compliance with these requirements that define the design verification basis [6].

It is important to note that the agreement of EASA with these proposed MoCs is of utmost importance. In cases where EASA disagrees with the proposed MoCs, it will be necessary to restart the process of proposing new MoCs.

Conversely, if EASA agrees with the proposed MoCs, the process outlined in Figure 3.1 continues to progress along its established path.

Step 6: Propose a Design Verification Programme
The next step involves the development and submission of a DVP to EASA for compliance demonstration. This program includes a list of proposed MoCs and relevant compliance documents. The DVP serves as a crucial document that facilitates the management and control of the evolving UAS design by the applicant and EASA, as well as the process of compliance demonstration by the applicant.

In summary, the DVP is a program where the applicant outlines the procedures, dates, tests, appraisals, and other pertinent elements intended to demonstrate compliance with the proposed MoCs. Consequently, the proposed DVP should encompass the entire list of MoCs intended to be used, and the applicant should provide detailed information about them in separate documents when deemed necessary.

Once the DVP is complete, the applicant will propose its DVP to EASA. There are two potential outcomes: EASA may accept or reject the proposed DVP.

If EASA provides a favorable response and approves the proposed program, the process proceeds to step 7, marking a significant advancement.

Conversely, if the response from EASA is negative, signifying disagreement with the proposed program, it becomes essential to identify the reasons for this discordance. There are three conceivable scenarios in which EASA may dissent from the program:

1. EASA may disagree with the identified requirements from SC Light-UAS for which compliance must be demonstrated. In such cases, a revisit to step 4 of the framework is necessary to reevaluate and redefine the requirements encompassing the UAS system or component under examination;
2. If EASA disagrees with the list of MoCs that the applicant has provided, specifically those already published by EASA, a thorough review of this list is imperative, along with any necessary adjustments to align with EASA's requirements;
3. In situations where EASA identifies issues or inconsistencies within the new proposed MoCs that hinder its effectiveness, further revisions and clarifications may be required before progressing to the next step in the framework. Thus, it is necessary to return to step 5 of the framework.

Step 7: Conduct the verification activities

Once EASA approves the DVP, the applicant proceeds to implement it, initiating the design verification process. During this phase, the applicant executes various verification activities, including appraisals, analyses, tests, etc. It is important to note that these activities must be conducted precisely as outlined in the DVP, following all proposed compliance demonstration procedures meticulously.

Upon completing all verification activities, the applicant must thoroughly document them. This documentation serves as evidence for EASA to assess whether all tests were successfully executed and if all compliance reports meet the required standards.

If the response to both of these questions is affirmative, indicating that all tests were completed successfully and the compliance reports are acceptable, EASA approves the design verification process, moving on to the final step of the framework.

However, in the event of a negative response, where EASA disagrees with the execution of the verification activities, two potential scenarios may arise for this discordance:

1. If the issue pertains to the tests themselves or their execution, the applicant must revisit this step, ensuring that test execution aligns with the agreed-upon procedures

with EASA. In case a problem arises from the results obtained during verification activities, the applicant must repeat the verification activities accordingly.

2. If the problem primarily lies within the compliance reports, the framework requires a return to step 5, as presented in Figure 3.1, to initiate the entire process from that point. That involves identifying issues and inconsistencies in the proposed MoCs and proposing new ones.

Step 8: EASA issues a DVR

The final step within this framework culminates in EASA issuing the DVR.

After the design verification process, EASA issues a Design Verification Report. This report serves as a formal declaration of EASA's satisfaction with the applicant's successful demonstration of compliance. The DVR contains relevant information, including any associated limitations, conditions, or assumptions that define its validity. These conditions are inherently tied to the type of operation and are detailed within the SORA submitted in support of the application. They are a direct outcome of the UAS design verification process [6].

As for the content of the DVR, it encompasses references to pertinent documents from the manufacturer, the suitable SAIL, GRC and ARC, as well as conditions and limitations under which the design is expected to perform adequately. This may include factors such as minimum ground/air buffers, population density limits, RF environment considerations, and others.

In terms of accessibility, the DVR can be used by the holder, allowing any operator to use verified designs within EASA Member States. If the UAS operation is under the conditions defined by EASA, there is no necessity for additional EASA involvement. It becomes the UAS operator's responsibility to demonstrate compliance to NAA with all remaining OSOs.

Regarding the cost of the DVR, it is billed on an hourly basis, with charges based solely on the actual time expended on the project. The scope of EASA verification, determined by the ConOps and SAIL, can vary significantly. Limited assessments may result in lower costs, while more complex projects require dedicated evaluations billed at hourly rates. However, the fees are not expected to exceed 180 hours, except in cases of exceptionally complex projects.

3.3 Conclusion

In conclusion, the development of the proposed framework was successfully achieved, aligning with the Guidelines on Design Verification for UAS operated in the specific category. This framework offers a systematic and structured approach for manufacturers seeking to obtain a DVR from EASA.

From defining the ConOps and identifying operational limitations to developing a DVP and successfully conducting design verification activities, each step is indispensable to ensure that the UAS complies with the required safety standards.

This framework represents a roadmap, offering guidance through the intricate process of compliance verification and ensuring the safety and reliability of UAS operations. However, the following chapter will involve the implementation of the framework and an in-depth analysis of its outcomes.

Chapter 4

Proposal of Means of Compliance for Flight Termination System

Chapter 4 is dedicated to the practical application of the previously developed framework, demonstrating its effectiveness and validity. It results in the development of means of compliance up to SAIL IV operations, which has not yet been developed by EASA for containment requirements. This chapter is divided into four sections: Scope and Purpose, Application of the Framework, Proposal of Means of Compliance with Light-UAS.2511, and Conclusion. The first section introduces the FTS system. The second section applies the developed framework to the system, where the identification of the requirements is needed. After this, a new MoC is proposed to demonstrate compliance with the Light-UAS.2511 requirement. This proposed MoC is organised into eight segments: scope and general approach, the applicability of this MoC, design checklist general requirements, compliance evidence, test campaign, flight manual, maintenance instructions, and prescription for ground risk buffer definition. This document intends to demonstrate and elucidate the methodology for achieving compliance with containment and with the corresponding levels of integrity and assurance for SAIL IV operations.

4.1 Scope and Purpose

The FTS is specifically designed to ensure the safe termination of an aircraft's flight in the event of emergencies or potential hazards. It is important to note that the FTS represents an emergency measure, not a contingency measure. In contrast to contingency measures, which aim to guide a UAS back within its originally planned flight geography, the FTS's purpose is to prevent an out-of-control UAS from veering into adjacent areas with unpredictable trajectories. Instead, it ensures the controlled termination of the UAS's flight, containing any crash or debris within the designated ground risk buffer [3].

The importance of this study lies in the development of proposed means of compliance suitable for a general FTS intended for SAIL IV operations. However, as detailed in the upcoming section that covers all the requirements for which the FTS needs to demonstrate compliance, the MoC will be specifically tailored to meet the Light-UAS.2511 requirement.

The study aims to introduce new perspectives on achieving compliance with the requirements outlined in Light-UAS.2511 from Special Conditions for Light-UAS Medium Risk, with the overarching goal of contributing to the advancement of UAS legislation.

4.2 Application of the Framework

To obtain a DVR from EASA validating the intended FTS, a series of steps described in the previous chapter and outlined in the framework presented in Figure 3.1 must be followed. Thus, the framework will be applied to the FTS under study designed for SAIL IV operations.

Step 1: In the initial step, where the definition of the UAS design ConOps and operational limitations are required, it is important to note that, in the current study case, the UAS is designed to operate over a populated area or controlled airspace. The ConOps must provide pertinent technical, operational, and system information essential for assessing the risks associated with the intended UAS operation [4].

Step 2: Moving on to step 2, involving the conduct of the SORA methodology, the risk level identified for the specific operation is categorised as SAIL IV. This classification stems from the UAS's intention to operate in environments with high population density or over a controlled airspace, resulting in a SAIL IV which applies OSO#5 at a high level of robustness.

Step 3: In the third step, where applicability conditions are verified, it is evident that the system under study meets two essential requirements: the operation is classified as SAIL IV, and aims the verification of the enhanced containment as currently defined by SORA when no declarative MoC can be applied.

Step 4: Once the operator confirms the applicability conditions, the following step becomes crucial. This step entails identifying the specific requirements from the Special Conditions for Light-UAS Medium Risk, which the FTS must comply with to meet the necessary standards.

The document published by EASA, titled Special Conditions for Light-UAS Medium Risk (Section 2.5.2), lays out airworthiness specifications for UAS operated in the specific category. These SC establish precise airworthiness standards for obtaining a type certificate and making revisions to this certificate for UAS which is designed for operation within the specific category with a demonstrated medium-risk profile [55].

Using [55] to identify the requirements for which compliance must be demonstrated, the following requirements were identified:

1. **Light-UAS.2510 Equipment, Systems, and Installation**
    (a) The equipment and systems identified in CS-Light UAS.2500, considered separately and in relation to other systems, must be designed and installed such that:
        (1) hazards are minimised in the event of a probable failure;
        (2) it can be reasonably expected that a catastrophic failure condition will not

    result from any single failure; and
    3. if the SAIL is IV, a means for detection, alerting, and management of any failure or combination thereof, which would lead to a hazard, is available.
  - (b) Any hazard which may be caused by the operation of equipment and systems not covered by Light-UAS.2500 must be minimised.

2. **Light-UAS.2511 Containment**
   - (a) No probable failure of the UAS or any external system supporting the operation must lead to operation outside the operational volume.
   - (b) When the risk associated with the adjacent areas on ground or adjacent airspace is significantly higher than the risk associated with the operational volume including the ground buffer:
     - (1) the probability of leaving the operational volume must be demonstrated to be acceptable with respect to the risk posed by a loss of containment;
     - (2) no single failure of the UAS or of any external system supporting the operation must lead to its operation outside the ground risk buffer; and
     - (3) software and airborne electronic hardware whose development error(s) could directly lead to operations outside the ground risk buffer must be developed to a standard or methodology accepted by the Agency.

3. **Subpart G - Remote Crew Interface and other Information**
   - (a) Light-UAS.2600 Command Unit Integration
   - (b) Light-UAS.2602 Command Unit
   - (c) Light-UAS.2605 Command Unit and operation information
   - (d) Light-UAS.2610 Instrument markings, control markings, and placards
   - (e) Light-UAS.2615 Flight, navigation, and thrust/lift/power system instruments
   - (f) Light-UAS.2620 Flight Manual
   - (g) Light-UAS.2625 Instructions for Continued Airworthiness (ICA)

4. **Subpart H - C2 Link**
   - (a) Light-UAS.2710 General Requirements
   - (b) Light-UAS.2715 C2 Link Performances
   - (c) Light-UAS.2720 C2 Link Performance monitoring
   - (d) Light-UAS.2730 C2 Link Security

In conclusion, the requirements for the FTS are outlined in Subpart F (Light-UAS.2510 and Light-2511), Subpart G (Light-UAS.2600, Light-UAS.2602, Light-UAS.2605, Light-UAS.2610, Light-UAS.2615, Light-UAS.2620, Light-UAS.2625), and Subpart H (Light-UAS.2710, Light-UAS.2715, Light-UAS.2720, Light-UAS.2730) from the SC Light-UAS Medium Risk.

However, only the requirements for Light-UAS.2510 and Light-UAS.2511 have been identified for further study. This selection is based on the FTS being subject to multiple airworthiness standards, necessitating the need to focus and streamline the study's requirements.

Step 5: The following step consists of identifying the relevant MoCs published by EASA or existing technical specifications or industry standards, taking into account the previously identified requirements.

For the Light-UAS.2510 requirement, a dedicated MoC has been established for SAIL IV operations, as outlined in Section 2.5.5. Consequently, it will only be necessary to apply these means of compliance to demonstrate that the system complies with both EASA-defined requirements and prevailing aeronautical standards.

For Light-UAS.2511 requirement, and as discussed in Section 2.5.6, EASA has already established means of compliance for UAS operating in the specific category, classified up to SAIL II according to SORA methodology. However, due to the increasing integration of UAVs into various aspects of daily life, there is a growing demand to create MoCs tailored to higher-risk operations.

Since an EASA document has already been established to validate FTS for low-risk operations regarding the Light-UAS.2511 requirement, the following section aims to develop a new document specifically for medium-risk operations. The framework has allowed the identification of the need to propose means of compliance for obtaining a DVR for the FTS in operations classified as SAIL IV.

Step 6: In this step, a DVP is developed, listing MoCs and essential documents for demonstrating compliance. This list includes the developed MoC presented in the following section, along with previously enumerated MoCs.

Step 7: This involves conducting compliance verification activities. Tests identified in the proposed MoC with Light-UAS.2511 for SAIL IV operations should be performed. Safety assessments, as well as Design and Installation Appraisal, must also be conducted.

Step 8: After completing the preceding steps, EASA issues a DVR. This document serves as a formal declaration of EASA's satisfaction with the applicant's successful demonstration of compliance.

As expected, the framework demonstrates significant utility in delineating the process for obtaining a DVR. It has allowed the identification of the imperative need to propose means of compliance with the Light-UAS.2511 requirement, a document that has not yet been developed or issued by the competent authority.

4.3 Proposal of Means of Compliance with Light-UAS.2511

4.3.1 Scope and General Approach

As previously indicated, it is necessary to demonstrate compliance with the specified requirements for the FTS. Consequently, it will be essential to calculate the probability of failure per flight hour of the installed FTS ($P_{FTS(fails)}$) by considering both the probability per flight hour of the UAS exiting the operational volume ($P_{UAexitOV}$) and the probability per flight hour that the UAS may leave the ground risk buffer and exit in adjacent areas/volumes ($P_{UAexitGB}$). Based on the existing MoC for containment up to SAIL II operations, the general equation that correlates the probability that the UAS would exit the ground risk buffer and enter adjacent areas is:

$$P_{UAexitGB} = P_{UAexitOV} \times P_{FTS(fails)} \quad (4.1)$$

In the event of a loss of control, the FTS is triggered to ensure that the crash remains confined within the ground risk buffer. As per this MoC, the FTS is segregated from the UAS architecture, meaning it is isolated from the UAS flight control system and any other component of the architecture whose failure could potentially induce a loss of control, unless such failure would only lead to a crash within the operational volume or ground risk buffer [3]. This segregation gives rise to the previous equation.

By restructuring the equation 4.1 concerning the probability of failure per flight hour of the installed FTS, then:

$$P_{FTS(fails)} = \frac{P_{UAexitGB}}{P_{UAexitOV}} \quad (4.2)$$

Finding the missing values presented in the equation 4.2 is essential to continue the development of this MoC. The following sections explain how it was possible to obtain the addressed values.

4.3.1.1 Probability of the UAS leaving the operational volume per flight hour

By SORA 2.0, the UAS is designed to standards that are considered adequate by the competent authority and/or in accordance with a means of compliance that is acceptable to that authority such that the probability of the UAS leaving the operational volume should be less than 10^{-4}/FH with a high level of integrity. However, the probability of the UAS leaving the operational volume is calculated by the probability of loss of control [38].

SORA 2.5 is the latest version of the SORA methodology, seeking to make the safety standards more accurate to the feedback JARUS has received since the 2019 publication of SORA 2.0. The update improves and simplifies the current version of the framework, making it easier for UAS operators to understand and comply with the requirements. Despite SORA 2.5 is currently open for public consultation, it is a proposed methodology with a high probability of eventual implementation.

In the context of SORA 2.5, a collaborative initiative among aviation experts has culminated in the establishment of a relationship between the SAIL objective levels of robustness and the expected maximum probability of loss of control. This concerted effort unfolded through the JARUS WG-SRM panel, with experts pooling their insights to formulate robustness requirements, which address the operational, organisational, personnel, and technical threat barriers, designed to be implemented and effectively reduce the probability that an operation loses control [61].

Subsequently, the probability of loss of control per flight hour is determined by the SAIL of the operation. Table 4.1 is a representation of the correlation between SAIL and the maximum expected rate (λ_{LOC}) of a loss of control event, ensuring compliance with the Target Level of Safety (TLOS) [61].

Table 4.1: Mapping between SAIL and maximum acceptable Operation Failure Rate [61].

SAIL Level	**I**	**II**	**III**	**IV**	**V**	**VI**
Operation failure rate, λ_{LOC} **(Probability of loss of control per flight hour)**	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}

For SAIL IV operations, the aircraft must meet a probability of loss of control lower than 10^{-4} ($\lambda_{LOC} < 10^{-4}$/FH).

However, it is considered that a loss of control may result in either a crash within the operational volume or an attempt to exit the operational volume. Without specific analysis of the UAS design, it can be assumed that the probability of a loss of control leading to an exit from the operational volume is at least 10 times smaller than the probability of it resulting in a crash within the operational volume [3].

In practice, this assertion makes sense because, in the majority of malfunction instances, the drone tends to descend within the operational volume. Various scenarios can happen, such as the drone falling directly to the ground or flying over and falling still within the operational volume, considering that it generally tends to descend inward. Therefore for a SAIL IV operation, $P_{UAexitOV} < 10^{-5}$/FH.

4.3.1.2 Probability of the UAS exit the ground risk buffer and enter adjacent areas per flight hour

To quantitatively assess the safety of unmanned operations, it is necessary to establish an acceptable level of safety. Following SORA 2.5, this is expressed as a Target Level of Safety (TLOS). This TLOS is based on manned general aviation third-party ground risk, as calculated by [61]:

$$TLOS = \lambda_{LOC} \times N_{people} \times P_{fatality|impact} \quad (4.3)$$

Where TLOS is measured in expected third-party ground fatalities per flight hour, representing the permissible fatality rate in occurrences per hour; λ_{LOC} represents the loss of control rate of the operation; N_{people} is the expected number of people affected by the aircraft in the event of a loss of control, and $P_{fatality|impact}$ denotes the probability of a fatal injury to a person given they have been impacted by the aircraft [61].

However, by multiplying the number of people affected by the aircraft in the event of a loss of control by the probability of a fatal injury to a person affected by the aircraft, the total number of fatalities resulting from the event ($N_{fatality}$) can be derived. Therefore, the previous equation can be summarised as:

$$TLOS = \lambda_{LOC} \times N_{fatality} \quad (4.4)$$

In accordance with the requirements identified for containment, if the risk associated with the adjacent areas on the ground or adjacent airspace is significantly higher than the risk associated with the operational volume including the ground buffer, then the probability of leaving the operational volume must be demonstrated to be acceptable with respect to the risk posed by a loss of control [55].

To satisfy this requirement, the risk associated with adjacent ground areas or adjacent airspace must be equal to or lower than the risk linked to the operational volume. Only under these conditions is it considered that the risk of the UAS exiting the operational volume is acceptable.

The TLOS is the safety target for the operation and must be met in normal operation conditions and in cases of fly away in the adjacent area. Then, can be deduced that the TLOS in adjacent areas ($TLOS_{AA}$) should be less than the TLOS in operational volume ($TLOS_{OV}$). This consistency ensures that the UAS leaving the operational volume is deemed acceptable.

$$TLOS_{AA} < TLOS_{OV} \quad (4.5)$$

Applying equation 4.4 to the operational volume:

$$TLOS_{OV} = \lambda_{LOC} \times N_{fatality|OV} \quad (4.6)$$

Regarding adjacent areas, a loss of control event in adjacent areas corresponds to an instance where the operation exits the ground risk buffer, as the aircraft would otherwise remain within it. Therefore, it is assumed that the loss of control rate for the operation can be substituted with the probability of the UAS leaving the ground buffer and entering adjacent areas. Based on the assumption that an exit from the ground risk buffer would always result in a crash in adjacent areas or, in rare and extreme cases, a collision with manned aircraft [3], and substituting in the equation 4.4:

$$TLOS_{AA} = P_{exitGB} \times N_{Fatality|AA} \quad (4.7)$$

Substituting the previous equations into equation 4.5, results in:

$$P_{exitGB} \times N_{Fatality|AA} < \lambda_{LOC} \times N_{fatality|OV} \quad (4.8)$$

Rearranging the previous equation concerning the parameter sought, the probability of the UAS exiting the ground risk buffer and entering adjacent areas per flight hour:

$$P_{exitGB} < \lambda_{LOC} \times \frac{N_{fatality|OV}}{N_{fatality|AA}} \quad (4.9)$$

The correlation between the number of fatalities in the operational volume and adjacent areas is directly affected by population density. As the population density in the operational volume rises, the expected number of fatalities within the operational volume also increases, driven by a higher number of individuals exposed to the associated risk. Consequently, in the event of a collision with an individual, it is assumed that the probability of it resulting in a fatality remains constant, i.e., $P_{fatality|impact}$ is consistent. This assumption is because the technical characteristics of the UAV inside and outside the operational volume do not change.

It is important to note that a uniform distribution of individuals throughout the defined area is assumed, all uniformly exposed to the associated risk. Given that the variable $P_{fatality|impact}$ remains constant across the considered area [61], this relationship is articulated as:

$$\frac{N_{fatality|OV}}{N_{fatality|AA}} \propto \frac{D_{pop|OV}}{D_{pop|AA}} \quad (4.10)$$

Where $D_{pop|OV}$ and $D_{pop|AA}$ represent the population density in the operational volume and adjacent areas, respectively.

Substituting this correlation into equation 4.9, obtains:

$$P_{exitGB} < \lambda_{LOC} \times \frac{D_{pop|OV}}{D_{pop|AA}} \quad (4.11)$$

For SAIL IV operations, the probability of loss of control per flight hour is less than 10^{-4} ($\lambda_{LOC} < 10^{-4}$/FH), as stated in Table 4.1.

It is assumed that the system is designed to ensure safety in operations where the population density in adjacent areas is up to three orders of magnitude higher than the operational volume, the ratio of population density between the operational volume and adjacent areas is less than 10^{-3}. This value represents a considerably high estimate, reflecting the worst possible scenario for the potential fatalities in the event of a loss of control.

Then, substituting the values in equation 4.11, results:

$$P_{exitGB} =< 10^{-4} \times < 10^{-3} =< 10^{-7}/FH \quad (4.12)$$

For SAIL IV operations, the probability of the UAS exiting the ground risk buffer and entering adjacent areas per flight hour shall be less than 10^{-7} ($P_{exitGB} < 10^{-7}$/FH).

4.3.1.3 Probability of failure of the installed FTS per flight hour

By substituting the previously found values into equation 4.2, it can be deduced that the value of the maximum acceptable probability of failure per flight hour of the installed FTS is:

$$P_{FTS(fails)} = \frac{< 10^{-7}}{< 10^{-5}} =< 10^{-2}/FH \quad (4.13)$$

In conclusion, the scope of the present MoC is intended for FTS systems installed in aircraft with the capability to operate at SAIL IV, with a population density in the adjacent area up to 1000 times greater that the operational volume, and also encompasses systems with a probability of failure below 1 per 100 flight hours.

4.3.2 Applicability of this MoC

This proposed MoC is applicable in the following contexts:

- UAS operated in an operation in the specific category classified up to SAIL IV according to SORA;
- UAS dimension: recommended for UAS whose characteristic dimension is equal to or less than 8 meters, considering the limited performance attributed to the FTS. However, the competent authority may accept higher dimensions if the kinetic energy or speed is sufficiently low, typically below 1084 KJ or 75 m/s, respectively[1]. The need to define the UAS dimension stems from MoC with Light-UAS.2511 up to SAIL II operations. However, the identified UAS characteristic dimension and the typical kinetic energy result from the UAS ConOps. Compared to SAIL II operations, these characteristics are associated with high-risk level operations;
- UAS design: there are no restrictions. For lighter-than-air, the ground risk is generally considered smaller than for heavier-than-air (assuming equal UAS dimension and scenario). However, it is important to note that the prescription for determining

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[1] These values derived from AMC1 Article 11 Rules for conducting an operational risk assessment to Commission Implementing Regulation (EU) 2019/947 [4].

the ground risk buffer, outlined in Section 4.3.8, is not applicable for lighter-than-air. The criteria to determine this buffer would need to be re-determined and agreed upon with the relevant authority [3]. The need to identify the restrictions for UAS design results from the MoC with Light-UAS.2511 for SAIL II operations.

4.3.3 Design Checklist General Requirements

A design checklist is conducted to demonstrate compliance with the required level of integrity. The outcomes allow to the applicant claim a high level of integrity. Subsequently, the applicant must substantiate that claimed integrity level through safety assessments, giving rise to the need to demonstrate compliance with the required level of assurance.

Since that the probability of the installed FTS remains constant for SAIL II and SAIL IV operations, $P_{FTS(fails)} < 10^{-2}$/FH, then the MoC with Light-UAS.2511 Containment up to SAIL II [3] can be used to give insights on the necessary design checklist.

The purpose of this section is to demonstrate compliance with point (b)(2) of the Special Conditions: when the risk associated with the adjacent areas on the ground or adjacent airspace is significantly higher than the risk associated with the operational volume including the ground risk buffer no single failure of the UAS or any external system supporting the operation must lead to its operation outside the ground risk. Compliance with the airworthiness standard referenced in this point demands substantiation through analysis and/or test data with supporting evidence [55].

The FTS should be segregated from the UAS flight control system architecture. This separation must be easily verifiable and align with Sections 4.3.3.1, 4.3.3.2, and 4.3.3.3. The activation of the FTS can be achieved manually or automatically. In instances of manual activation, the system comprises ground and air segments [3].

A design checklist document must include, at least [3] [62]:

- A high-level description of the FTS architecture, including functions, systems, and implementation;
- Details concerning the installation of the FTS on the UAS;
- An understanding of the physical and mechanism operation of the FTS;
- An assessment addressing the segregation of the air segment and ground segments, frequency considerations, and frequency diversity. Each aspect of this assessment should be supported by concrete evidence of compliance;
- Compliance evidence activities as per Section 4.3.4: perform and document safety assessment containing a description of functional and operational principles of the UAS and its architecture, perform an Functional Hazard Assessment (FHA), and perform a design and installation appraisal;

- Additional evidences as needed for substantiating compliance with the TMPRs.

4.3.3.1 Segregation of the air segment

The air segment of the FTS, encompassing the FTS elements installed onboard the UAS, must be segregated from the UAS flight control system architecture and from any other element within the UAS architecture whose failure could potentially result in a loss of control unless such failures are limited to causing a crash within the operational volume or the ground risk buffer [3].

In the event of ground activation of the FTS, the onboard receiver responsible for receiving the FTS signal must operate independently of the receiver employed for command and control functions [3].

In cases where the FTS is automatically activated, the triggering mechanism for its activation should be distinct from systems used for the UAS operation control within the operational volume. For instance, positioning information employed to initiate the FTS activation should originate from systems that are different (not necessarily implying distinct technology) compared to those used during the typical operation of the UAS [3].

The description of the UAS architecture should follow the standard ED-280, as detailed in Chapter 3 and exemplified in Appendix D of this standard.

4.3.3.2 Segregation of the ground segment (where applicable)

The unit or units employed to initiate the FTS activation must be segregated from the Command Unit (CU) responsible for UAS control during normal operations. This segregation should be designed, so that, even in the case of a loss or erroneous CU operation, the proper functioning of the FTS remains unaffected [3]. Guidance can be found in the Ed-279 standard.

4.3.3.3 Frequency and frequency diversity

When using radio frequencies to initiate a flight termination, it is imperative to ensure that the frequency band used by the FTS is distinct from the frequency band used for UAS control. If cellular technology is used for both Command and Control (C2) and FTS functions, thus is recommended to use different service providers [3].

In situations where the designated operational volume includes high-power radio frequency emitters, the frequencies used by the FTS should not overlap or be superimposed with these existing frequencies [3]. This preventive measure is essential to prevent interference and maintain the integrity of the flight termination process. ED-279 standard, Appendix E, provides some guidance on the C2 link.

4.3.4 Compliance Evidence

As stated before, it is now necessary to perform compliance demonstration activities with adequate confirmation of the compliance [62], to complement the design checklist. These activities allow the applicant to demonstrate compliance with the claimed high level of assurance.

This fact underscores the primary rationale behind the restriction of the MoC Light.2511 issued by EASA, designed to demonstrate containment compliance exclusively up to SAIL II operations.

Following Annex E of SORA 2.5 [63], integrity and assurance levels for OSOs require the applicant to provide supporting evidence that the required level of integrity is achieved. This is typically accomplished through testing, analysis, and simulation, inspection, design review, or through operational experience [63].

To adhere to the indications in Annex E of SORA 2.5, it is essential to consider the means of compliance with Light-UAS.2510 Equipment, Systems, and Installation for SAIL IV operations. Given that MoC Light-UAS.2510 is used to verify that the system does not activate when is not desired (ensuring the system does not activate erroneously), it can be understood as a guarantee that the system functions correctly, aligning with the intended purpose. Therefore, the process outlined in MoC Light-UAS.2510 can be followed to demonstrate compliance that the system operates as the applicant intends.

As illustrated in Step 4 of Section 4.2, Light-UAS.2510 also represents one of the requirements for which compliance must be demonstrated for the FTS validation. Hence, the applicant would need to undergo the Design and Installation Appraisal processes mentioned in Annex E of SORA 2.5, indicating that both requirements are related and complement each other.

Then, the realization of the processes outlined in MoC with Light-UAS.2510 (conducted to prove the system's compliance) and their respective results serve as evidence of the system's compliance. This evidence will be also used to demonstrate compliance with the Light-UAS.2511 requirement, alongside the results of the test campaign.

4.3.4.1 Compliance evidence with Light-UAS.2510

The primary goal of Light-UAS.2510 is to establish an acceptable safety level for the equipment and systems integrated into UAS. It mandates that the components outlined in Light-UAS.2500, when considered separately and in relation to other systems, must be designed and installed such that hazards are minimised in the event of a probable failure; it can be reasonably expected that a catastrophic failure condition will not result from any single failure; and if the SAIL is IV, a means for detection, alerting, and management of any failure or combination thereof, which would lead to a hazard, is available [60].

The compliance demonstration for Light-UAS.2510 is specifically focused on failure conditions that may result in a loss of control over the UAS operation. Loss of control is defined in alignment with the SORA methodology, encompassing scenarios such as [60]:

- UAS crash with the ground, infrastructure, or people;
- Unrecoverable loss of controllability;
- Controlled flight into terrain;
- Activation of the FTS, parachute, or other M2 mitigation due to an emergency;
- Erroneous activation of the FTS, parachute, or other M2 mitigation due to an emergency;
- UAS leaving the operational volume;
- Loss of payload, where a detachment poses a risk to people on the ground.

To confirm compliance with Light-UAS.2510, the applicant is required to undertake a set of compliance demonstration activities with adequate confirmation of the compliance to the competent authority [62]:

1. Perform and document a safety assessment as per ED-280 containing:
   (a) Detailed description of functional and operational principles of the UAS and its architecture;
   (b) UAS level FHA;
   (c) Failure Modes and Effects Analysis (FMEA) analysis;
2. Perform a Design and Installation Appraisal as outlined in ASTM F3309-21;
3. Provide additional evidence as necessary to support compliance with the TMPRs.

4.3.4.2 Guidance on Safety Assessment

The safety assessment under Light-UAS.2510 focuses exclusively on technical failures, excluding considerations of potential loss of control due to factors such as pilot error or errors in operational procedures. The assessment's primary scope encompasses failures of the command unit, unmanned aircraft, and any installed systems (e.g., FTS) that impact the UAS's control over attitude, speed, and flight path [60].

To perform a safety assessment, guidance is provided in standard ED-280. According to ED-280, relevant service experience of similar systems may be used to substantiate that the probability of failure of this system is less than probable. However, such service history data are limited to the UAS fleet for which the applicant holds SORA approval, is the data owner, or possesses an agreement permitting data use if accepted by the competent authority. The applicant should be able to substantiate that a close similarity in both system design and operating conditions exists. In instances lacking service experience, all failures are presumed more like than probable (i.e., anticipated to occur one or more times during the entire operational life of each UAS), necessitating design modifications, hazard removal, or enhanced redundancy to minimise failure probabilities [60].

The ED-280 standard is a document that offers guidelines for UAS operators or manufacturers to obtain evidence of system safety and reliability, aligning with Light-UAS.2510 requirements. The methodology to perform the safety analysis at a medium level of robustness is delineated into five key steps.

One crucial step involves the description of the functional and operational principles of the UAS and its architecture. This step aims to provide a profound understanding of the UAS's physical and mechanical operations, inclusive of its architecture, functions, systems, and implementation [62].

Another vital step entails conducting an FHA at the UAS level, detailed in Section 4.3.4.3. This analysis identifies and assesses potential hazards to enhance overall safety.

Simultaneously, the applicant is required to execute a Design and Installation Appraisal according to ASTM F3309-21 §4.4. This step summarizes the outcomes of the safety assessment process [62].

4.3.4.3 Guidance on Functional Hazard Assessment

As previously mentioned, it is necessary to perform a FHA. ED-279 proposes a methodology to execute a UAS FHA, which is either the starting point to perform a detailed safety assessment or a simplified one as implicitly required by the Light-UAS.2510, Light-UAS.2511(a) and Light-UAS.2511(b)(2) requirements [64].

The primary purpose of this document is to offer support to designers undertaking the FHA process, intending to encompass a broad range of configurations. It provides UAS system developers with a framework to conduct the FHA process effectively [65].

This document offers a framework and common considerations tailored to UAS, adaptable for specific certification programs. It endeavors to present a generic high-level ”Basic FHA” for UAS, acknowledging the distinctions between UAS/RPAS design/operation and conventional manned aircraft, detailed in Appendix C. Furthermore, to illustrate this approach's practical application, specific examples for fixed-wing and rotorcraft UAS configurations are provided [66].

As the FHA serves as the initial phase in the safety assessment process, it assumes a central role in providing compliance evidence for certification and operational authorisation in front of competent authority [66].

This generic document introduces an FHA baseline that concentrates on failure severity classifications. Qualitative safety objectives and Functional Development Assurance levels are tied to specific configurations in emerging airworthiness requirements. For this purpose, the Failure Condition Classification definitions from JARUS document AMC RPAS.1309 at Issue 2 are included, as the applicable definitions for UAS/RPAS are not currently regulated [66].

Failure Conditions are classified according to the severity of their effects as follows [67]:

1. **No safety effect:** Failure conditions that would not affect safety. For example, failure conditions that would not affect the operational capability of the RPAS or increase the remote crew workload;
2. **Minor:** Failure conditions that would not significantly reduce RPAS safety and that involve remote crew actions that are well within their capabilities. Minor failure conditions may include a slight reduction in safety margins or functional capabilities, a slight increase in remote crew workload, such as flight plan changes;
3. **Major:** Failure conditions that would reduce the capability of the RPAS or the ability of the remote crew to cope with adverse operating conditions to the extent that there would be a significant reduction in safety margins, functional capabilities, or separation assurance. In addition, the failure condition has a significant increase in remote crew workload or impairs remote crew efficiency;
4. **Hazardous:** Failure conditions that would reduce the capability of the RPAS or the ability of the remote crew to cope with adverse operating conditions to the extent that there would be the following:
    (a) Loss of the RPA where it can be reasonably expected that one or more fatalities will not occur, or;
    (b) A large reduction in safety margins or functional capabilities or separation assurance, or;
    (c) Excessive workload such that the remote crew cannot be relied upon to perform their tasks accurately or completely.
5. **Catastrophic:** Failure conditions that are expected to result in one or more fatalities.

Notably, the failure conditions leading to a loss of control of the operation are singled out for further assessment. Those not resulting in such a loss do not require further assessment. The applicant, following the defined failure condition severities, uses a mapping to link them to qualitative safety objectives [62], as shown in Table 4.2.

Table 4.2: Qualitative safety objectives based on failure conditions [62].

Failure Condition Classification	Failure Condition Description	Qualitative Safety Objective
Minor	No loss of control of operation	None
Major	No loss of control of operation	None
Hazardous	Loss of control of operation	Less than probable
Catastrophic	Loss of control of operation	Less than probable

The applicant should also identify elements within the FMEA-like analysis, specifically Software (SW)/ Airborne Electronic Hardware (AEH), whose development errors may directly[2] lead to a loss of control. In such cases, development must adhere to standards like EASA AMC 20-115D or ASTM F3201-16, ED-80, or an industry standard deemed equivalent by the applicant. If an item/equipment/system can prevent a loss of control due to an error in SW/AEH development, the Development Assurance requirements do not apply, negating the need for the DAL alleviation process outlined in ARP4754A [62].

To demonstrate the absence of SW/AEH errors leading to a loss of control, the applicant may use the FMEA-like analysis in conjunction with ED-280 and a Design and Installation Appraisal [62]. This multifaceted approach ensures a robust and thorough evaluation of UAS safety.

4.3.4.4 Guidance on Design and Installation Appraisal

According to MoC with Light-UAS.2510 and ED-280, a crucial component of the safety assessment process involves the performing of a Design and Installation Appraisal to consolidate and summarize the assessment outcomes. These appraisals serve as qualitative appraisals of the integrity and safety of the system design and its installation. Guidance for conducting a Design and Installation Appraisal is well-defined in standard ASTM F3309-21 §4.4 [60].

According to the ASTM F3309-21 standard, a design appraisal involves a qualitative assessment of the integrity and safety inherent in the system design. Achieving an effective appraisal necessitates the application of experienced judgment. The features of the design that contribute to integrity and safety must be elucidated in a clear and comprehensible manner, with systems architecture or block diagrams serving as valuable aids to enhance understanding. Additionally, tools such as an extended Functional Hazard Assessment table, illustrating failure effects alongside the failure mitigations, can be instrumental in the appraisal process. Integrity and safety considerations like the use of component qualification, independence, separation, and redundancy should be thoroughly assessed as appropriate [60].

Concurrently, an installation appraisal is undertaken as a qualitative assessment of the integrity and safety of the system's physical installation. Similar to the design appraisal,

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[2] The term ”directly” implies that there are no additional mitigation means in place to avert the loss of control if a particular error results in the failure of one or more items, equipment, or systems.

this process demands experienced judgment. Installation features must be presented in accessible formats, such as installation drawings, equipment installation requirements, and any requisite analyses. The appraisal must extend its considerations to potential interference with other UAS systems and issues introduced by maintenance activities. For systems with major, hazardous, or catastrophic failure conditions, there is an imperative to assess the potential for external events or influences that could compromise the independence of the systems involved [60].

4.3.5 Test Campaign

The tests outlined in this section are already presented in the existing MoC Light-UAS.2511 up to SAIL II operations, as the maximum acceptable probability of failure of the FTS installed in the UAS identified before remains consistent for SAIL II and SAIL IV operations. As a result, this section serves as a summary overview of the tests delineated therein. Despite the similarity in the probability of FTS failure, conducting these tests is deemed essential. Therefore, The set of tests designed for SAIL II operations is also applicable to FTS in SAIL IV operations. However, it is recommended some specific adjustments to enhance the demonstration of compliance with the identified requirements.

To ensure the adequacy of FTS performance, a set of tests should be conducted. A detailed document outlining test procedures and results should be provided to the regulatory authority. This document covers bench tests, ground integration tests after installation of the FTS on the UAS, flight tests, and end-to-end activation tests, as specified in [3]. The number of activations for each test is explained in Section 4.3.5.6.

This documentation must include essential details such as the date and time of the test, the test configuration, and specifics regarding the FTS and test equipment used. In the event of a failed test (which could be FTS not activated, incorrectly activated, or erroneously activated), the document should include a root cause analysis and investigation of the failure. Additionally, any necessary adjustments to the FTS or test equipment configuration based on this investigation should be documented. It is important not to restart the test set without recording and analysing the failure event. Tests are deemed successful only when bench, ground, flight, and end-to-end tests have been executed consecutively and satisfactorily. In the event of a failure, a process is initiated, involving a root cause analysis, potential system modification, justification for such modification, and documentation recording, followed by the re-execution of tests starting from bench tests [3].

4.3.5.1 Bench tests on FTS

As previously mentioned, these tests are already part of the current MoC Light-UAS.2511 up to SAIL II operations from EASA. However, a brief description of the tests is provided.

To execute the bench tests effectively, they should be performed on the uninstalled FTS within a controlled environment. In cases where manual activation is applicable, the operator must initiate the termination function using the ground unit and observe that the FTS receiver correctly receives the termination signal. Typically, this entails verifying that the signal leading to the shutdown of the motors is activated accurately [3].

For scenarios involving automatic activation, it is essential to test the correct activation of the termination signal by simulating conditions that would trigger it during flight. In cases where FTS activation is determined on the base of the position of the UAS or an elaboration of such position, this information should be provided as input to the FTS to induce activation [3].

The applicant should perform a series of tests commensurate with the complexity of the FTS. A minimum of 100 activation tests is mandated. Successful bench tests are complete when the entire set of tests is consecutively passed.

4.3.5.2 Ground integration tests after installation of the FTS on the UAS

These tests aim to validate the proper activation of the FTS when installed in the UAS, ensuring the desired effect on the UAS is obtained. In cases where the FTS is activated from the ground during real operation, the tests should assess the maximum operational distance of the UAS from the antenna transmitting the command of flight termination. The ground FTS unit should replicate the real operational case by being connected to the antenna [3].

For scenarios involving automatic activation, the correct activation of the termination signal should be examined by inputting conditions that would trigger it during flight. The activation should be checked for a set of conditions, covering the entire activation envelope with controlled granularity [3].

In cases where the FTS involves a parachute, it is possible not to install it. It is adequate to confirm the proper termination of flight and ensure the signal causing parachute deployment is accurately received (without actually causing parachute deployment) [3].

The number of tests conducted should align with the complexity of the installed FTS, with a minimum of 100 activations required. Successful ground tests are deemed complete when the entire set of tests is passed consecutively.

4.3.5.3 Flight tests

Flight tests should be conducted in low-risk scenarios, typically involving VLOS operations over a controlled ground area. These scenarios should minimise the probability of encountering another aircraft, ensuring low risk in adjacent areas [3].

For UAS with MTOM below 900 grams, flight tests are generally deemed unnecessary, unless they serve as a substitute for ground tests. In flight tests, the primary goal is to demonstrate the proper activation of the on-board segment of the FTS. However, a non-destructive configuration may be employed, such as digitally recording the FTS signal, which would typically interrupt the power connection to engines when the FTS is actuated, without actually commanding power interruption during tests [3].

It is essential to verify that each activation from the ground, respectively each test case in which the FTS is supposed to be automatically actuated, results in a correct flight termination. The following minimum scenarios need to be tested [3]:

1. UAS flying straight and level toward or away from the antenna transmitting the termination signal, at both the minimum and maximum expected heights during operation (excluding climb and descent segments). A minimum of 100 activations should be triggered, with 50 at minimum height and 50 at maximum height. At the minimum height, 20 of these activations should test the maximum distance of operation at that height, while the other 30 should have an approximately equal distribution. At maximum height, 20 activations should test the maximum distance of operation at that height, while the other 30 should have an approximately equal distribution as above;

2. UAS flying straight and level in a direction perpendicular to the tests described above, maintaining the same heights and distribution.

In cases of automatic FTS activation, the conditions or scenarios set for activation should lead to automatic termination, following the distances and patterns outlined above [3].

4.3.5.4 End-to-end activation tests

These tests aim to evaluate the proper functioning of the FTS system integrated on a specific UAS throughout the entire life of the UAS [3].

These tests should be conducted using the same FTS-UAS combination that has been subject to the specified ground integration tests and flight tests [3].

The number of FTS activations, encompassing triggering and observation of proper operation, should align with the number of expected activations of the FTS for its entire life. It includes accounting for pre-flight checks, maintenance checks, and return-to-service checks. Detailed information regarding the maximum number of activations should be documented in the maintenance manual [3].

4.3.5.5 Additional recommendations

This section provides recommendations to enhance the proposed testing procedures outlined in MoC with Light-UAS.2511 Containment for operations up to SAIL II. Specifically, two suggestions are presented to refine the test section, encompassing a change in the test order and proposing a new test to complete the existing set of tests.

It is important to note that these suggestions are not limited to SAIL IV operations, i.e., they can also be applied to SAIL II operations covered by MoC Light-UAS.2511.

1. Order of Tests

The initial recommendation suggests that should not be mandatory to make the End-to-End tests to be performed as the last tests since they can be conducted independently.

The primary objective of these tests is to ensure that the FTS can successfully execute a specified number of activations. Importantly, the FTS does not need to be installed in the UAS and is independent of any output from preceding tests.

2. Power Cut-Off Test

Introducing a new test, named Power Cut-Off Test, addresses the need identified in all previous tests, where the FTS system (for safety reasons) only cut off a power load with low voltage and current.

The Power Cut-Off Test aims to simulate a load similar to the UAS power load, with high voltage and current. The objective is to evaluate the system's capability of withstanding and cutting off real power loads.

The test approach involves connecting the battery to the FTS system, applying a load (that can simulate the real load), and leaving the system running for 30 minutes (approx. the time of flight). After this period, send a trigger and check if the load shuts down.

This test simulates a real flight scenario and assesses the system's ability to execute a power cut-off. A minimum of 100 activation tests is mandated. Successful Power Cut-Off tests are complete when the entire set of tests is consecutively passed.

It is important to note that the Power Cut-Off Test can be performed in any order after the bench test, offering flexibility in the testing process.

4.3.5.6 Rule of three to determine the number of activations

Despite the probability of FTS failure remaining consistent for SAIL IV operations, the number of activations should exceed the count specified in the MoC with containment for SAIL II operations.

For SAIL IV operations, the assurance level should be higher than the assurance level for

SAIL II operations, given the higher risk associated with SAIL IV operations compared to operations in SAIL II.

In SAIL II operations, 30 total activations are required to achieve the confidence interval defined by the competent authority for a low level of assurance. This breakdown includes 10 activations for bench tests, 10 activations for ground integration tests after FTS installation on the UAS, and another 10 activations for flight tests.

However, for SAIL IV operations, considering the need for a higher assurance level, it proposes increasing the number of activations to 300 in total. This distribution comprises 100 activations for bench tests, 100 activations for ground integration tests after FTS installation on the UAS, and 100 activations for flight tests. This adjustment maintains the same confidence level set by the competent authority for containment in SAIL II operations but with a higher level of assurance.

The suggestion to modify the number of activations to 300 in total is derived from the statistical rule of three [68]. EASA already uses this rule in the proposed version of SORA 2.5.

In statistical terms, the rule of three asserts that if an event (under the assumption of a binomial distribution) does not occur in the first n experiments, the maximum probability of its occurrence is $3/n$ with 95% confidence [69].

In the context of this MoC, the event is FTS failure, the experiment is the number of activations, and the probability of its occurrence is the probability of FTS fails per flight hour [69].

To elucidate the rule of three, let X represent the number of events and p be the probability of observing an adverse event (where p is close to 0). The goal is to find the values of the parameter p of a binomial distribution of n observations that satisfy $Pr(X = 0) \leq 0.05$ [70].

This leads to the equation [70]:

$$(1-p)^n \leq 0.05 \quad (4.14)$$

Which is equivalent that [70]:

$$n \ln(1-p) \leq \ln 0.05 \approx -2.996 \quad (4.15)$$

Approximating $\ln(1-p)$ using the Maclaurin series, an evaluation of the Taylor expansion of the function $f(x)$ at $a = 0$, yields [70]:

$$f(x) = f(0) + \frac{f'(0)}{1!}(x) + \frac{f''(0)}{2!}(x)^2 + \frac{f'''(0)}{3!}(x)^3 + \ldots \quad (4.16)$$

Applying this to $ln(1-p)$, the approximation becomes [70]:

$$f(x) = 0 + \frac{\frac{d}{dp}\ln(1-p)(0)}{1!} + \frac{\frac{d^2}{dp^2}\ln(1-p)(0)}{2!} + \frac{\frac{d^3}{dp^3}\ln(1-p)(0)}{3!} + ... \quad (4.17)$$

Resulting in [70]:

$$f(x) = -p - \frac{1}{2}p^2 - \frac{1}{3}p^3 - ... \approx -p \quad (4.18)$$

When *p* is close to 0, then $-np \leq -2.996$ or $p \leq 3/n$, as stated [70].

Applying the rule of three to the scenario under study, where the probability of FTS failure remains the same and equal to 10^{-2}, it becomes evident that 300 total activations are necessary to comply with this principle. This entails a test campaign consisting of 100 activations for bench tests, 100 for ground integration tests after FTS installation on the UAS, and 100 for flight tests.

It is essential to note that the tests necessitate consecutive successful outcomes. If any test fails at any stage of the testing campaign (bench tests, ground integration tests after FTS installation on the UAS, and flight tests), the entire test set must recommence.

4.3.6 Flight Manual

The UAS flight manual, following the MoC with Light-UAS.2511 up to SAIL II, must encompass the following aspects either as a supplement or as integrated content [3]:

- clear delineation of limits and conditions for the FTS, including the frequency band;
- procedures ensuring the proper operation of the FTS throughout the entire lifespan of the installed system;
- implementation of a pre-flight check protocol for the FTS, conducted on the ground before the first flight of the day at a designated operational site. This check aims to mitigate latent failures, and if unsuccessful, mandates the replacement and subsequent re-check of the FTS before flight. In cases where the FTS is equipped with mechanisms to reduce impact dynamics, such as a parachute, the deployment of these mechanisms during the pre-flight check is discretionary, provided that all other components contributing to the proper functioning of the FTS undergo a thorough inspection;
- specification of the minimum extent of the ground risk buffer within the flight manual.

The flight manual should also provide information regarding the frequency bands in use and guidelines for avoiding areas that could potentially cause interference [3]. This documentation ensures that the operator has a clear and thorough reference for safe and effective UAS operations.

4.3.7 Maintenance Instruction

Maintenance procedures should be established to ensure the functionality of the FTS throughout the entire life of the installed system. These instructions should encompass the requisite steps to be taken post reaching the maximum expected number of activations, aligning with End-To-End activation tests. As part of maintenance, the ongoing reliability of the FTS should be systematically monitored by capturing the following key data [3]:

- Number of FHs accumulated by the UAS with FTS installed;
- In case of FTS activations failures during pre-flight checks, document the FH accumulated by the UAS at the time of the failed activation;
- In case of FTS activation failures during flight, records should be maintained covering:
  - FH accumulated by the UAS at the time of the failed activation;
  - Attempted activation distance between the CU and UAS (where applicable);
  - Specific location of the operation;
  - Presence or absence of high-power emitters in the operational volume;
- In case of FTS activations during flight, detailed records should be kept, encompassing:
  - If activation was commanded or un-commanded;
  - FH accumulated by the UAS at the time of activation;
  - Distance between the CU and UAS (where applicable);
  - Specific location of the operation;
  - Presence or absence of high-power emitters in the operational volume.

4.3.8 Prescriptions for Ground Risk Buffer Definition

The flight manual should explicitly specify the minimum extension of the ground risk buffer, ensuring that any termination event culminates in the UAS crash occurring solely within the designated ground risk buffer. To determine this extension, careful consideration must be given to the following factors [3]:

- **T** represents the human and system latencies in the activation of the FTS;

- **D1** signifies the distance covered by the UAS during time T, projected on the ground;
- **D2** indicates the distance traveled by the UAS after the termination is effectively triggered onboard, projected on the ground in alignment with its trajectory;
- **V** denotes the maximum UAS cruise speed or the maximum speed declared as part of the operational authorisation.

In the existent MoC with Light-UAS.2511, the variable T, representing human and system latencies in the activation of the FTS, is currently set at 3 seconds. However, a new suggestion came to change this value.

It is considered that a 3-second time frame for FTS activation is insufficient. Based on tests conducted at CEiiA with an FTS developed for SAIL II operations, the results indicate that the human latency in signaling to the command should be extended. Consequently, the proposed adjustment sets this value to 5 seconds. It is anticipated that the signal propagation time from the control command to the on-board system remains negligible, even under adverse weather conditions (primarily due to air condensation), in the presence of obstacles between the drone and the operator, or when the UAS operates beyond the line of sight. Even in such scenarios, the signal propagation time would still be in the order of milliseconds.

However, human reaction time should surpass 3 seconds, considering that this duration must encompass problem awareness, decision-making, and the activation of the FTS.

In conclusion, the overall time to the human and system latencies in FTS activation should be adjusted to 5 seconds.

The distance covered by the UAS during the time T, projected on the ground, is given by [3]:

$$D1 = V \times T \quad (4.19)$$

However, determining the distance traveled by the UAS after the termination is effectively triggered onboard, projected on the ground in alignment with its trajectory has different ways to calculate depending on the aircraft configuration. Three different configurations need to be counted to determine the present distance.

For rotorcraft or multirotors apply any of the following options [3]:

- Compute $D2$ as a projection of a ballistic trajectory on the ground, with a maximum drag of 0.8. The projection should be perpendicular to the operational volume along its entire perimeter. The velocity vector at termination should be horizontal, oriented perpendicularly to the operational volume, and at the maximum height of the operational volume. The modulus is calculated according to the guidance provided for V;

- Compute $D2$ as a projection on the ground of a glide trajectory with a 9-degree incidence angle (maintaining the same V in modulus and direction);
- Determine $D2$ based on tests (with V in modulus and orientation as defined above).

For fixed-wing, consider the following options [3]:

- Determine $D2$ based on tests (with V as defined above);
- Compute $D2$ as a projection on the ground of a glide trajectory with a 9-degree incidence angle (maintaining the same V as defined above).

In cases where a parachute is deployed as part of the FTS [3]:

- Estimate $D2$ as (maximum wind considered for the operation)x(height at termination)/(speed of descent with parachute). A correction should be applied to account for speed at termination, for simplicity $D2$ as calculated above should be increased by 10%;
- Determine $D2$ through tests, considering the worst environmental conditions and the maximum height of operation.

Then, the ground risk buffer is calculated based on the sum of the two different distances calculated above [3]:

$$Ground\ Risk\ Buffer = D1 + D2 \quad (4.20)$$

4.4 Conclusion

As expected, the framework has proven invaluable in elucidating the pathway to obtain a DVR. When identifying pertinent documents for the FTS, the framework allowed to identify the need to develop means of compliance aligned with Light-UAS.2511 requirement for operations up to SAIL IV.

In conclusion, the proposed MoC for demonstrating containment compliance in operations up to SAIL IV has been successfully acquired. Nonetheless, it is insightful to underscore the main distinctions between the existing MoC applied to operations up to SAIL II and the new MoC suggested for operations up to SAIL IV.

A notable disparity between the mentioned MoCs pertains to the probability of the UAS leaving the operational volume and to the probability of exiting the ground risk buffer to enter adjacent areas per flight hour. In the existing MoC for operations up to SAIL II, the probability of the UAS leaving the operational volume per flight hour stands at 10^{-3}, while the proposed MoC in this section lowers this probability to 10^{-5}. Regarding the probability of the UAS exiting the ground risk buffer and entering adjacent areas per flight hour, it is 10^{-5} in the MoC for operations up to SAIL II and 10^{-7} in the proposed MoC for operations up to SAIL IV.

Although the probability of failure of the installed FTS per flight hour remains consistent for SAIL II and SAIL IV operations, the number of activations differs due to the increase in the level of assurance.

An additional noteworthy modification in the new proposed MoC for SAIL IV operations is the introduction of a new test, termed the Power Cut-Off Test. This test is designed to augment the set of tests previously accepted by the agency in the existing MoC for operations up to SAIL II.

Another point of divergence between the two MoCs under study lies in the prescription for defining the ground risk buffer. This involves a suggested adjustment to the latency time between the human and the system in the activation of the FTS.

However, the primary distinction and contribution of the proposed MoC lies in the inclusion of the compliance demonstration activities. Consequently, a safety assessment becomes necessary to showcase the high level of assurance for SAIL IV operations. In contrast to operations up to SAIL II, where the level of assurance is low, it is now imperative for cases with higher assurance levels to demonstrate compliance with this declarative level.

This safety assessment underscores the approach required to ensure the safety and reliability of UAS, aligning with regulatory documents such as Light-UAS.2510 and associated standards like ED-280 and ASTM F3309-21. The foundational step involves conducting a thorough FHA, serving as a cornerstone for subsequent safety assessment processes. The FHA, detailed in ED-279, aligns itself with the ARP4761 philosophy, with necessary adjustments for UAS specifics. A Design and Installation Appraisal, as per ASTM F3309-21, summarising the results of the safety assessment process. This qualitative assessment of the system design and installation ensures transparency, clarity, and adherence to safety standards.

Finally, the outlined points covered by the Light-UAS.2511 requirement are met, with a thorough demonstration of compliance for operations up to SAIL IV.

Chapter 5

Conclusions and Future Work

Chapter 5 serves as the conclusion of this dissertation and is divided into three sections: Dissertation Synthesis, Final Considerations, and Future Work. In the initial section, a thorough overview of the chapters provides a spotlight on key findings and insights acquired through the study. The second section serves to consolidate the principal outcomes of the study. Here, a concise summary details how each objective was successfully met, accompanied by a discussion of the implications arising from the obtained results. The last section outlines potential avenues for future research.

5.1 Dissertation Synthesis

The dissertation is divided into the following five chapters: Introduction, Literature Review, Methodology, Proposal of Means of Compliance for Flight Termination System, and Conclusions and Future Work.

Chapter 1 introduces the proposed work, elucidating the motivations and significance behind the project's development. The objectives of the dissertation are stated in detail, together with a description of the methodology taken to accomplish them.

The motivation for this research stems from the increasing prevalence of UAVs in daily life, extending beyond military applications to sectors such as entertainment, agriculture, logistics, surveillance, and emergency services. While the widespread use of UAVs brings operational efficiency, cost reduction, access to remote areas, and enhanced safety, it also raises concerns related to privacy, regulation, and security. Then, it needs careful consideration for the ethical and responsible use of these technologies.

Given the newness of this study area, addressing safety issues associated with UAVs and their systems becomes imperative. Collaborative efforts among regulatory entities, industries, and operators are essential for the development and implementation of standards and regulations that effectively address safety concerns linked to drone usage. Public awareness regarding the safe use of drones and the promotion of technologies enhancing safety are critical steps in mitigating risks associated with the use of UAVs.

The primary objectives outlined are:

1. Development of a general methodology applicable to any UAV system for obtaining a DVR;

2. Proposal of Means of Compliance for FTS up to SAIL IV operations.

Both objectives were successfully achieved. It is important to note that the means of compliance achieved were specifically tailored for the Light-UAS.2511 Containment requirement.

Chapter 2 is organised into five major sections: Advanced Air Mobility, UAS Regulations, Regulation (EU) 2019/947, UAS Operations in the Specific Category, and Design Verification Report.

In the first section, a study on the development and significance of AAM in contemporary daily life is conducted, emphasizing the growing demand for drone use. Following this, an examination of current regulations on a global, European, and national level within the UAS domain is undertaken, with particular attention given to Regulation (EU) 2019/947. This regulation, effective from July 1, 2019, was established to harmonise and simplify the rules related to UAS in every EU Member State, bringing significant changes in how drones are regulated across the European Union.

Considering that UAS operations can be categorised into three operation categories, the present study only focuses on the specific category of operations, due to the SAIL and the risk associated with the operation. The SORA methodology is then explored as the means to assess the risk associated with a given operation.

Subsequently, the identification of documents issued by EASA becomes crucial for DVR issuance, aiding the development of proposed means of compliance for the FTS system.

Chapter 3 aimed to develop a framework that presents the path to obtaining a DVR issued by EASA. This framework was developed based on documents previously released by the competent authority and is applicable to SAIL IV operations, aligning with the risk level presented by the FTS under study.

The framework comprises eight steps, which are: UAS Design ConOps and Operational Limitations, Propose SORA to NAA or Conduct SORA, Verify the applicability conditions, Identify the requirements from SC Light-UAS Medium Risk for which compliance must be demonstrated, Identify the relevant MoCs published by EASA or existing technical specifications or industry standards, Propose a Design Verification Programme, Conduct the verification activities, and EASA issues a DVR. Each of these steps plays a crucial function in the design verification process.

Finally, one of the dissertation's goals was achieved in this chapter, specifically, the development of a general methodology applicable to any UAV system for obtaining a DVR.

Chapter 4 is dedicated to the development of the MoC with Light-UAS.2511 requirement for SAIL IV operations. The need to establish a MoC for this requirement arises from the framework step that entails identifying relevant MoCs published by EASA or existing technical specifications or industry standards. Given the absence of a MoC tailored to the

Light-UAS.2511 requirement specifically for SAIL IV operations (currently available only for operations up to SAIL II), it becomes crucial to propose means of compliance to the competent authority.

This MoC is organised into several sections, including Scope and General Approach, Applicability, Design Checklist General Requirements, Compliance Evidence (guidance on Safety Assessment, FHA, and Design and Installation Appraisal), Test Campaign, Flight Manual, Maintenance Instructions, and Prescriptions for Ground Risk Buffer Definition.

The primary objective of this MoC is to provide a method for demonstrating compliance with the Light-UAS.2511 requirement of the Special Conditions for Light-UAS Medium Risk. It offers UAS leveraging FTS the opportunity to substantiate, through a design checklist, a set of tests, and compliance demonstration activities, the FTS performances for SAIL IV.

This chapter successfully achieves the second goal of the dissertation, which involves the development of proposing means of compliance for SAIL IV operations with the Light-UAS.2511 requirement.

Lastly, Chapter 5 offers a synthesis of the research findings, allowing finish the dissertation. This section not only summarizes the key insights and contributions made throughout the study but also delves into potential future work within the chosen theme.

5.2 Final Considerations

In conclusion, this dissertation has extensively explored the AAM theme and provides a detailed analysis of the existing regulations in this study area. The analysis undertaken in the preceding chapters has shed light on the evolving landscape of AAM and the complex regulatory challenges associated with drone integration into airspace.

The current and prospective development of UAS has significant positive impacts, especially in industrial growth, showcasing the potential to foster economic expansion and job creation. UAS demonstrates the capability to execute operations in emergency scenarios where human intervention proves impossible or challenging, contributing to life-saving efforts in humanitarian aid, search and rescue missions at sea, responses to nuclear accidents, natural disasters, and more.

However, as with other technologies, the adoption of UAS technology introduces risks that demand vigilant consideration from stakeholders, regulatory bodies, institutions, and citizens. The imperative to prevent, minimise, and address potential negative impacts becomes even more pronounced in the absence of adequate legislation and instances of illegal, dangerous, or irresponsible drone usage. Hence, the importance of legislative frameworks and the unification of airspace regulations across Member States, ensuring consistent governance to minimise risks and eliminate potential hazards.

The significance of this dissertation extends to actively contributing to current drone legislation, recognising its increasing relevance and everyday use.

The framework presented in Figure 3.1, illustrating the Design Verification Process, represents a noteworthy advancement for European UAS legislation. It intends to facilitate a deeper understanding of this process.

One crucial achievement of this study is the development of a proposal means of compliance with Light-UAS.2511 Containment for operations in SAIL IV. While the MoC for containment for SAIL IV operations is yet to be formally developed and published by EASA, its value is indisputable for UAS manufacturers seeking to implement FTS systems in the UAS.

Despite the initially outlined objectives in this dissertation having been achieved, it is crucial to recognise that much work remains in the broader domain of UAVs and their associated legislation. Moving forward, addressing a series of requisites becomes imperative to ensure that UAVs do not compromise the fundamental rights of citizens, encompassing privacy, data protection, safety, and security.

As looking to the future, the findings of this dissertation underscore the ongoing need for collaborative efforts among industry stakeholders and regulatory entities to further define and adapt MoCs in response to the dynamic nature of the UAS operations.

5.3 Future Work

The proposed means of compliance in this dissertation, strategically centered on achieving compliance with the Light-UAS.2511 requirement for containment, not only serves as a critical milestone but also opens the way for compelling future endeavors. A crucial next step involves the proposal of innovative MoCs finely tuned for the intricate demands of SAIL IV operation, addressing the requirements associated with the FTS, as meticulously detailed in Step 4 of Section 4.2.

Taking on the challenge of formulating means of compliance for Subpart G and Subpart H of the Special Conditions for Light-UAS Medium Risk in operations leading up to SAIL IV emerges as a high initiative. This effort carries substantial significance, presenting an opportunity to influence industry standards and contribute to the continual evolution of aerial safety.

In addition to these initiatives, a promising avenue for future work involves the adaptation of the proposed MoC Light.UAS.2511 to higher SAIL operations, with a higher level of risk.

Given the increase in the UAS industry, used for surveillance, agriculture, delivery services, etc, the need to ensure the safety and reliable operation of these systems becomes even more pronounced. In response to the expanding UAS landscape, a critical future endeavor lies in the development of means of compliance with safety requirements for all airworthiness specifications applicable to UAS operating in the specific category. This implies demonstrating compliance with all the airworthiness specifications identified in the Special Conditions for Light-UAS Medium-Risk.

Finally, some requirements already boast established means of compliance for demonstrating compliance to airworthiness specifications. Examples include Light-UAS.2510 Equipment, Systems, and Installation for SAIL IV operations, Light-UAS.2511 Containment for SAIL II operations, Light-UAS.2512 Mitigation Means linked with Design for medium robustness, MoC with the Special Condition VTOL, SAIL III MoC with OSO #05/ 10 /12 "System safety and reliability" and others.

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Appendix A

Articles Submitted

A.1 Article Submitted to Journal of Airline and Airport Management (JAIRM)

Unmanned Aircraft Systems: A Pathway to Obtain a Design Verification Report

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Abstract

Purpose: Nowadays, the use of unmanned aerial vehicles continues to expand in our daily lives, due to their versatility and practicality across various domains. However, there is a growing concern regarding the responsible use of these vehicles. Issues related to privacy, safety, job displacement, and environmental and social impacts must be carefully considered when adopting this technology. To address these concerns and mitigate associated risks, regulatory entities, stakeholders, operators, and European Union Member States must collaborate in developing regulations that unify and clarify the use of these vehicles. This article aims to contribute to the evolution of legislation for unmanned aerial vehicles, addressing topics that still raise many questions, such as design verification. The purpose is to systematically outline the steps to obtain a Design Verification Report (DVR), considering a wide array of potential scenarios, giving rise to a framework.

Design/methodology/approach: The research begins with a literature review of the legislation for UAS, with a particular focus on Regulation (EU) 2019/947 issued by EASA.

After that, attention is directed towards documentation helpful to formulate the framework, such as the Guidelines on Design Verification for UAS operated in the Specific Category, issued in 2023.

Findings: Findings suggest that the framework represents a roadmap, offering guidance through the intricate process of compliance verification and ensuring the safety and reliability of UAS operations. The design verification process can be divided into eight steps, ending in a DVR issuance by the competent authority. The primary objective of this document is to guide applicants seeking design approval from EASA.

Originality/value: The value of this research lies in illustrating the Design Verification Process, which represents a noteworthy advancement for European UAS legislation. The framework intends to facilitate a deeper understanding of the design verification process.

Keywords: Unmanned Aircraft Systems, Design Verification, Specific Category, Specific Assurance and Integrity Level, Specific Operations Risk Assessment

A.2 Article Submitted to IX RIDITA International Congress of the Iberoamerican Air Transport Research Network

Proposal of Means of Compliance for Flight Termination System - Medium Risk

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Abstract

The purpose of this research is to contribute to the evolution of legislation for unmanned aerial vehicles, by proposing Means of Compliance (MoC) for Flight Termination System up to SAIL IV operations. The research begins with a literature review of UAS legislation, with a particular focus on documentation and industry standards essential for developing the proposed MoC with Light-UAS.2511 requirement for SAIL IV operations. The development of the proposed MoC integrates insights from the existing MoC for operations up to SAIL II, already issued by EASA, but adapted to address operations with a higher level of risk. Findings suggest that MoC for SAIL II operations can be useful for demonstrating compliance with Light-UAS.2511 up to SAIL IV operations. However, the main difference lies in the necessity of conducting compliance demonstration activities, supported by evidence through safety assessments and design and installation appraisals. The number of tests needed to demonstrate the FTS performance increases, due to the increase of operation risk level to SAIL IV. Regarding the contribution of this paper, it is mainly the development of proposed means of compliance, offering a pathway for demonstrating compliance with the requirement Light-UAS.2511 for Containment up to SAIL IV operations. It allows the UAS operator to demonstrate that systems comply with industry standards, adhering to safe and sustainable practices.

Keywords: Unmanned Aircraft Systems, Specific Category, Specific Assurance and Integrity Level, Specific Operations Risk Assessment, Design Verification, Design Verification Report