NLR Air Transport Safety Institute
Research & Consultancy

Executive summary

Framework for Unmanned Aircraft Systems Safety Risk Management

Problem area
Although Unmanned Aircraft Systems (UAS) have now for some time been used in segregated airspace where separation from other air traffic can be assured, potential users have interests to deploy UAS in non segregated airspace. Recent technological and operational improvements give reason to believe that UAS safety and performance capabilities are maturing. But the skies can only really open up to UAS when there is an agreed upon UAS safety policy with commonly accepted UAS Safety Risk Management (SRM) processes enabling to show that the risks related to UAS operations in all the different airspace classes can be adequately controlled so that the current and existing safety level does not decrease.

Description of work
This study proposes a UAS SRM framework, which supports regulators and applicants through provision of guidelines for SRM steps to be conducted, including 1) system description, 2) hazard identification, 3) risk analysis, 4) risk assessment, and 5) risk treatment. Unmanned Aircraft System developments in four areas (platforms, control stations, communication and data-links, and operations) are discussed. Differences between manned and unmanned aircraft and the specific areas that could have specific safety implications are identified and analysed. A survey of UAS activities provides an initial view on the risks and hazards to be considered, the needs and role of potential SRM users, the scope of the aviation system to be considered, the risks to be regulated, selection of suitable risk metrics, and the setting of an acceptable level of safety. The focus is on the provision of guidelines for steps 2 to 4 of a UAS SRM process, covering both risk of a mid air collision with another (manned) aircraft and risk of collision with the ground. A framework for building the Safety Case for UAS operations in non segregated airspace is proposed. Key recommendations for the application and validation of the proposed UAS SRM processes are identified and provided.

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Results and conclusions

A survey of UAS activities has provided an initial view on the risks and hazards to be considered, the needs and role of potential SRM users, the scope of the aviation system to be considered, the risks to be regulated, selection of suitable risk metrics, and the setting of an acceptable level of safety. It is motivated that the main safety risks to be addressed to ensure that UAS can be introduced in non segregated airspace without degrading safety are *risks to other airspace users* and *third party risk* (to people/property on the ground). It is necessary to show that these risks do not increase as compared to the current aviation system with manned aircraft only.

The proposed SRM process follows five sequential steps:

1. Describe the system to be introduced or changed;
2. Identify the associated hazards and causal factors;
3. Analyze risks (characterise the risk elements in terms of both hazard severity and likelihood of occurrence);
4. Assess risks (and provide results for decision making);
5. Treat/control the risks (i.e. mitigate, monitor and track).

The proposed SRM process for *risks to other airspace users* is based on comparison of the collision risk for a baseline of commercial air traffic versus a traffic mix that includes UAS, using ICAO's unified framework for collision risk modelling. The proposed SRM process for *third party risk* is based on a method that combines an accident probability model with an accident location model and an accident consequence model, through answering the following three key safety risk questions:

1. What is the chance that a UAS accident occurs?
2. What is the likelihood of a UAS accident occurring on a given location, given that a UAS accident occurred?
3. What is the consequence of a UAS accident, given that a UAS accident occurred at a given location?

This paper provides guidelines for the establishment of a UAS risk criteria framework, but the actual implementation of such a framework should preferably be done jointly by a regulatory working group that includes the European Aviation Safety Agency (EASA), Federal Aviation Administration (FAA) and/or the Joint Authorities for Rulemaking on Unmanned Systems (JARUS).

Applicability

It is recommended to apply and validate the proposed SRM process with an operational concept brought forward by UAS standardization working group EUROCAE WG73 or RTCA-SC203.

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FRAMEWORK FOR UNMANNED AIRCRAFT SYSTEMS SAFETY RISK MANAGEMENT

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CONTENT

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Framework for Unmanned Aircraft Systems Safety Risk Management

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ABSTRACT

Although Unmanned Aircraft Systems (UAS) have now for some time been used in segregated airspace where separation from other air traffic can be assured, potential users have interests to deploy UAS in non segregated airspace. Recent technological and operational improvements give reason to believe that UAS safety and performance capabilities are maturing. But the skies can only really open up to UAS when there is an agreed upon UAS safety policy with commonly accepted UAS Safety Risk Management (SRM) processes enabling to show that the risks related to UAS operations in all the different airspace classes can be adequately controlled.

The overall objective is to develop a UAS SRM framework, supporting regulators and applicants through provision of detailed guidelines for each SRM step to be conducted, including 1) system description, 2) hazard identification, 3) risk analysis, 4) risk assessment, 5) risk treatment. The purpose is that all potential risks of the newly proposed UAS operations are controlled so that the existing safety level does not decrease (i.e. provides the baseline from which safety requirements for new proposed UAS operations are derived).

A survey of UAS activities provides an initial view on the risks and hazards to be considered, the needs and role of potential SRM users, the scope of the aviation system to be considered, the risks to be regulated, selection of suitable risk metrics, and the setting of an acceptable level of safety. It is motivated that the main safety risks that need to be addressed to ensure that UAS can be introduced in non segregated airspace without degrading safety are *risks to other airspace users* and *third party risk* (to objects on the ground). It will be necessary to show that these risks do not increase as compared to the current aviation system with manned aircraft only.

This paper focuses on the provision of guidelines for steps 2 to 4 of a UAS SRM process, covering both types of risks. The process for *third party risk* is based on a method that combines an accident probability model with an accident location model and an accident consequence model. This method enables evaluation of both *individual risk* and *societal risk*, and provides insight into probability and consequences of collision of a UAS with the ground. A method that addresses potential conflict scenarios (e.g. level busts, aircraft levelling of at the wrong flight level, flight track deviations due to operational errors) is proposed as basis for analysis of the risk of UAS to other airspace users. It is explained how the results may be used to build a Safety Case for UAS operations in non segregated airspace. Recommendations for application and validation of the proposed SRM process are also provided.

INTRODUCTION

As UAS are further developed, their introduction into the civil aviation market is considered seriously. Operation of UAS is most beneficial when they are not restricted to a designated, limited piece of (segregated) airspace. Though UAS have now for some time been used in segregated airspace where separation from other air traffic can be assured, many see requirements to deploy UAS also in Non-Segregated Airspace.

If UAS are to operate in non-segregated airspace, they must be integrated safely and adhere to the same operational practices as conventional manned aircraft. In addition to the need for reliable communications links between the UAS, its ground control station and the ground-based air traffic control, the lack of a human onboard to monitor the aircraft environment is a serious concern for the aviation community. As a result, the aviation community is investigating various concepts, systems and technologies to compensate for the loss of the onboard pilot. In addition to challenges for the design of the UAS itself, there are new challenges as well as new opportunities for the design of the Air Traffic Management (ATM) in the future, including the context of the Single European Sky ATM Research (SESAR), Next Generation Air Transportation System (NextGen) and beyond.

But the skies can only really open up to UAS when there is an agreed upon UAS safety policy with commonly accepted UAS SRM processes enabling to show that the risks and hazards related to UAS operations in Non Segregated Airspace can be adequately controlled. A SRM process – which contains guidelines for e.g. hazard identification, risk analysis and risk assessment – is required to be followed by applicants of new proposed UAS operations [6, 7, 8, 9, 10, 13, 14, 16, 17, 21].

The objective of this paper is to provide a framework for a UAS SRM method. The purpose of this method is twofold: a) to assist applicants (e.g. UAS operators and manufacturers, air navigation service providers and/or airport authorities) in the different steps of a UAS SRM process, and b) to support regulators with UAS risk assessment and mitigation in support of the establishment of UAS certification procedures, airworthiness standards, and operational requirements.

Before developing guidelines for UAS SRM, it is first of all necessary to understand the differences between manned and unmanned aircraft and the specific areas that could have safety implications. UAS are manufactured in a seemingly unlimited variety of sizes, speeds and operational envelopes. Even though there seems to be consensus that UAS will have to act and respond as much as possible as manned aircraft do, key differences exist and their safety implications will need to identified and evaluated during the early stage of UAS SRM.

Section 2 discusses UAS developments in the following UAS areas: platforms, control stations, communication and data-links, and operations. Section 3 provides SRM considerations, including scope of the risk assessment, users and their needs, and the different roles of stakeholders. Section 4 deals with the development of a risk criteria framework, including risks to be regulated, the suitability of risk metrics, and the setting of an acceptable safety level. Section 5 presents the proposed SRM methodology. Section 6 explained how the results of a UAS SRM process may be used to build a Safety Case for UAS operations in non-segregated airspace. Conclusions and recommendations are provided in Section 7. Finally, the references are contained in Section 8.

UNMANNED AIRCRAFT SYSTEMS

ICAO states “an unmanned aerial vehicle is a pilotless aircraft, in the sense of Article 8 of the Convention on International Civil Aviation [1], which is flown without a pilot-in-command on-board and is either remotely and fully controlled from another place (ground, another aircraft, space) or programmed and fully autonomous” [3]. Unmanned Aircraft (UA) are aircraft, and therefore existing ICAO Standards and Recommended Practices (SARPs) apply to a large extent. It is however recognized that integration of UAS at airports and in the various airspace classes necessitates the development of UAS-specific SARPs to supplement those already existing [2]. There is a broad potential scope for UAS. Missions include commercial, scientific and security applications, involving monitoring, surveillance, communications and imaging. Tasks include border and maritime patrol, search and rescue, fire detection, natural disaster monitoring, contamination measurement, road traffic surveillance, power and pipeline inspection, and earth observation. UAS are suited for use as communication relays and are already used for commercial imaging purposes such as aerial photography and video.

The following ICAO terminology is presently used [2]:

- *Unmanned Aircraft.* An aircraft which is intended to operate with no pilot on-board.
- *Unmanned Aircraft System.* An aircraft and its associated elements which is operated with no pilot on-board.

According to ICAO, the key factor for safely integrating UAS in non-segregated airspace will be their ability to act and respond as manned aircraft do [2]. This will be subject to technology – the ability of the aircraft to be controlled by the remote pilot, to act as a communications relay between remote pilot and Air Traffic Control (ATC), the performance of the communications link, as well as the timeliness of the aircraft response to ATC instructions. Performance-based SARPs may be needed for each of these aspects [2]. To support the establishment of such performance based SARPs, recent European UAS technological and operational developments have been analysed from four different points of views: platforms, control stations, communication and data-links, and operations. This provides a baseline for understanding of UAS developments and their safety implications and concerns.

UAS platforms

Developments of UAS in Europe are significantly less than those in the USA, or in Israel. European developments are, more than in the USA and Israel, aimed at small-sized UAS. Especially when considering non-military applications of UAS, the bulk of UAS developments are for small-sized vehicles. Such systems are typically used for short range missions, such as aerial photography, inspection of for instance chimneys, fire control and surveillance by police. It is expected that civil UAS will be used in the near future for two main reasons: 1) information gathering and 2) transport of goods. Not much evidence has been found for the often named third category of usage named relay station (relaying of radio signals to facilitate over-the-horizon communications or dedicated communications in build-up areas). Given the highly crowded spectrum, the aircraft separation issues and operating costs, it is doubtful whether such an application will be used civilly on a day-to-day basis. Since the requirements to allow UAS to autonomously use a runway for take-off and landing are relatively strict, it follows that the resulting equipment demands also become more expensive as compared to the smaller UAS. The result of the relatively expensive equipment is that the size of UAS is divided more-or-less into two broad categories: the small and tiny UAS and the larger UAS. Smaller UAS normally use simpler sensors and hence the lower part of the airspace, whilst larger UAS employ more sophisticated sensor suites and are targeted at flying at higher altitudes. UAS are manufactured in seemingly unlimited variety of sizes, speeds and operational envelopes. Although in the future faster UAS types are foreseen, current UAS are flying relatively slow as compared to commercial air traffic. As a result of larger speed differences between manned and unmanned aircraft there is a risk in controlled airspace that Air Traffic Controllers (ATCO) errors may becoming more frequent as a result of increased workload or errors may escalate more quickly. In uncontrolled airspace large speed differences are a confirmed hazard. ATCOs should be aware of the performance characteristics of all traffic in their sector, and thus also of any performance limitations of UAS. This is a matter of ATCO training and instruction primarily, but may lead to minimum performance requirements being imposed on UAS to facilitate normal operations in the ATM system.

UAS ground control stations

UAS Control Station (UCS) design and developments have (at least until recent) been targeted at specific UAS. Although some standardization effort has taken place like depicted in NATO STANAG 4586 [4], the majority of UCS lack commonality to allow the control of other UAS. As such, the UAS and UCS are certified for operation as a tandem system. The safety emphasis is often placed on the UAS, assuming that the UCS is not flight-critical. UAS operators fulfill different tasks, and there are often operator positions for mission planning and sensor data processing. A proper cooperation is crucial for a safe effective mission. Specific safety related issues are related to Human Machine Interface (HMI) design, UAS control versus sensor control, crew resource management, incorporation of multi-UAS control using one control station, and training issues, including assessment of the operator capabilities. How should you assemble a UAS crew? What should their expertise be? How should their tasks be allocated? In what way can multiple UAS be operated simultaneously by the fewest number of people?

UAS communications and data links

A key element in the ATM system is direct communication between air traffic controllers and pilots. With the introduction of UAS, a major change is the introduction of a data-link between UAS crew and the unmanned aircraft, through which voice (and data) communications with ATC are relayed. This may be a direct data-link between control station and unmanned aircraft, but could also be relayed further via satellites or even via other unmanned aircraft. Especially latency in the voice communications (by using additional relays such as satellites) raises concerns. Although emergency procedures exist for safely handing loss of communications with (manned) aircraft, and these may be used similarly for unmanned aircraft there is a limit on the acceptable rate of voice communications loss. All inputs regarding navigation, and command and control from the UAS crew will be transferred via a data-link as well. This implies that the integrity and reliability of the data link will have a direct and crucial impact on the level of safety. Issues and factors that can degrade the quality of the data link (including e.g. latency, jamming, spoofing, hacking) will have to be considered. If the command and control data-link connection is lost, technology and sound emergency procedures will need to be in place to mitigate the safety hazards. UAS data links are important for controlling the UAS and the sensors and communicate with ATC. Unfortunately the use of data links could be limited by several factors, including e.g. 1) frequency allocation, 2) bandwidth limitations, 3) power consumption constraints, 4) solar activity, 5) satellite coverage, and 6) backup strategies.

UAS operations

As compared to manned aircraft, there is a larger variety of missions for UAS. Each mission and associated operation may bring forward safety issues (still) to be resolved. For local infrastructure inspection missions, containment of the UAS to the local area and avoidance of ground obstacles and other traffic is critical. For area surveillance missions, one has to address prevention of collisions, integration of slow flying UAS in the ATM system with faster manned air traffic, handling of failures and emergencies, aerodrome operations, data-link availability and integrity, area needed for slow climb to operational altitude, monitoring two UAS from one control station (avoiding confusion of the UAS pilot, incorrect hand-over of control between UAS, or data-link interference).

The fact that the pilot in command is not situated in a UAS undermines traditional operational concepts with three conflict layers: 1) strategic conflict management, 2) separation provision, and 3) collision avoidance. Depending on airspace class and flight rules under which the UAS and other traffic are operating, the pilot may be responsible for separation provision, where ATC does not provide it. In any case the pilot is at all times ultimately responsibility for collision avoidance, traditionally achieved by ‘see and avoid’. These tasks will need to be solved by e.g. using a visual observer on the ground (so-called visual light of sight operations) or in a chase aircraft, or, using detect and avoid systems to enable a remote pilot to fulfill his responsibilities. For any solution, it has to be demonstrated that it does not decrease safety levels.

There is consensus about the fact that established operational procedures for ATC and for UAS pilots should be applicable as much as possible and adjusted only when really needed. ‘Equivalence’ between manned aircraft and UAS implies e.g.:

- ATC and other airspace users must be able to determine courses of actions as they do for other air users in all equivalent circumstances;
- UAS should be operated in compliance to existing operation rules (minimum rule changes);
- Provision of ATC to a UAS must be transparent. ATC must not do anything different using Radio Telephony, Controller Pilot Data Link Communications or landlines than he/she would do with manned aircraft.

It is suggested to introduce additional separation for a UAS (as compared to manned aircraft) so as to cope with a delay in reaction time because of the distance between the UAS and the ground control station (especially when using satellite relay stations). For the UAS pilot, it would means that he/she could file additional UAS specific information in the flight plan. For UAS missions performed in certain areas, it is foreseen that additional co-ordination between ATC and the UAS pilot (regarding horizontal/vertical mission area limits) takes place. With respect to emergency procedures, new specific ATC emergency procedures seem to be needed for cases that require additions or modifications to current standards: voice communication failure, loss of control link, abort procedures following critical system failure.

UAS SAFETY RISK MANAGEMENT CONSIDERATIONS

It will not be possible to introduce UAS in Non Segregated Airspace, if it cannot be shown that the associated risks and hazards can be adequately regulated and controlled. ICAO states “The principal objective of the aviation regulatory framework is to achieve and maintain the highest possible and uniform level of safety. In the case of UAS, this means ensuring the safety of any other airspace user as well as the safety of persons and property on the ground.” [2].

Before developing a specific plan for UAS SRM, it is first necessary to understand UAS safety policies and guidance provided by the regulators. The FAA provides information and guidance on air traffic policies, and prescribes procedures for the planning, coordination, and services involving operation of UAS in United States’ National Aviation System (NAS) [13, 14]. This is supported by the FAA National Aviation Research Program, which applies Safety Management System (SMS) principles to UAS [5]. Guidance material for Air Traffic SRM is provided in the FAA SMS Manual [9]. Key SRM elements are ‘risk analysis’ and ‘risk assessment’. FAA Order 8080.4 [6] prescribes that ‘a case specific plan for risk analysis and risk assessment shall be predetermined in adequate detail for appropriate review and agreement by the decision making authority prior to commitment of resources. The plan shall additionally describe criteria for acceptable risk’. In Europe, EASA provides guidance for UAS airworthiness certification [15, 16] and a preliminary regulatory impact assessment [17], which recommends initiation of a rulemaking task intended to reduce the safety/environmental/economic risks identified in relation to UAS. Additionally, it is noted that for introducing and/or planning changes to the ATM system, in Europe also an ATM safety risk analysis is required by EUROCONTROL Safety Regulatory Requirement (ESARR) 4 [10].

So far, UAS are mostly used in segregated airspace under specific requirements. Therefore, with respect to SRM of UAS operations in Non-Segregated Airspace, it is a difficulty that there is only limited UAS safety data, which ‘may not be a representative sampling of UAS operations’ [27]. The accident rate of the Customs and Border Protection (CBP) was estimated at 52.7 accidents per 100,000 flight hours, which is more than seven times the general aviation accident rate and 353 times the commercial aviation accident rate [27]. As a consequence, it will be reasonable to employ default or conservative assumptions for particular hazards that cannot be quantified on the basis of historical data. It is furthermore expected that a) risks or hazards may be identified for which estimation of hazard severity or likelihood of occurrence may turn out to be difficult prior to implementation, b) the decision makers may have to deal with unknown risks or hazards. This issue is recognized by the FAA, which has initiated research to support integration of UAS in the NAS [21, 22, 23, 24, 25].

USER NEEDS

The *aviation safety regulatory authority* will have to provide the regulations for civil aviation, based on the ICAO Annexes and connected to a legal system. The regulator will have to issue a license or certificate subjects (objects, organizations or individuals) within civil aviation, and subsequently monitor the licensed or certificated subjects for continued compliance with requirements, e.g. by performing inspections or audits, proficiency checks, and review of documents. A regulator could commission its own risk assessment (or second opinion by an independent agency) to provide appropriate assurances and review risk assessments submitted by e.g. UAS operators.

For *UAS operators*, meeting the minimum safety standards set by the aviation authorities is a necessary requirement for obtaining an Air Operator Certificate (AOC). For continued airworthiness, UAS operators have the responsibility for maintenance, inspection and repair actions. This is based on maintenance procedures specified in a maintenance program. To obtain a license/certificate, a UAS operator will have to submit a risk assessment and supporting safety case, relating to flying the UAS bearing in mind built-up areas, heavily used controlled airspace and the proximity of objects on the ground.

For *UAS manufacturers*, a distinction has to be made between UAS larger than 150 kg and UAS smaller than 150 kg. EASA has issued a Policy regarding airworthiness certification of the larger UAS [16]. JARUS is drafting specifications regarding safety requirements for the smaller UAS. These requirements are based on the principle that an inverse relation should exist between the probability of malfunctions and the degree of the hazards. These safety requirements for UAS may be different than for manned aircraft (as specified in Paragraph 1309 of FAR CS 23/25 [11] and EASA CS 23/25 [12]) due to the lack of people aboard UAS. Meeting minimum safety requirements applicable to aircraft systems is usually necessary to obtain a type certificate and a certificate of airworthiness approval.

An *Air Navigation Service Provider* (ANSP) is responsible for ensuring that air traffic proceeds safely and efficiently while minimizing the burden to the environment. An ATM safety risk assessment will be needed before ATC service can be provided to UAS operating in Non Segregated Airspace. In the USA, guidance is provided by FAA-ATO [9]. In Europe, an ATM safety risk assessment is required by the ESARR 4 [10].

The influence of *aerodromes* on aviation safety is via the airside facilities that it provides. Airport safety standards and regulations will need to be followed before UAS are allowed to take off and/or land. An aerodrome safety management system will have rules for aircraft that are to be followed in case of e.g. refueling and driving on the apron or manoeuvring area. It is possible that airport authorities define specific safety procedures for UAS operations. Specific requirements with respect to airport risk assessment have not yet been identified.

SRM SCOPE AND OBJECTIVES

SRM is 'a formal process within the SMS composed of describing the system, identifying hazards, assessing the risk, analyzing the risk, and controlling the risk' [18]. Risk Management is defined by ICAO as 'the identification, analysis and elimination (and/or mitigation to an acceptable or tolerable level) of those hazards, as well as the subsequent risks, that threaten the viability of an organization' [7]. The objective is to ensure that risks associated with hazards to flight operations are systematically and formally identified, assessed, and managed within acceptable safety levels.

Any UAS Safety Risk Management process will have to use methods to identify and address those safety hazards that originate due to the introduction of the proposed UAS operation or in which some element of the UAS is a contributing factor. Therefore, the UAS SRM process includes various requirements and their interactions:

1. Safe and airworthy UAS (certified and maintained);
2. Safe operations provided by the UAS operator;
3. Safe departure and landings spots;
4. Safe airmanship by a pilot, with a proper airmen licence;
5. Safe provision of Air Traffic Control services.

The products of a UAS SRM process may, besides safety argumentation in support of the introduction of new proposed UAS operations, include safety evidence such as e.g. UAS safety data, risk models, results from hazard brainstorm sessions, risk assessment simulation results and safety assurance reports. These products would document and support decision-making on the proposed changes that impact safety and implement safety enhancements for UAS operation.

A UAS safety risk assessment may have to deal with the entire UAS lifecycle, including a) specification b) manufacturing c) implementation d) transition to operational service e) operational service and f) decommissioning. A primary consideration for determining the scope and level of detail is what information is required to know enough about the change, the associated hazards, and each hazard's associated risk to choose which controls to implement and whether to accept the risk of the change. A description of the system and/or proposed change should be complete (at appropriate detail level) and correct (accurate, without ambiguity or error) [9].

UAS RISK CRITERIA FRAMEWORK

Safety Risk Management is required to maintain or even improve the current level of safety. Risk criteria based policies for control of major risks have therefore been in use for many years. Many of these policies are based on some sort of quantification of the risk level that could be allowed to continue. This concept of a level of risk has a number of implications. Because safety risk of future operations cannot be measured directly, an alternative approach for evaluating safety is necessary to be able to demonstrate that a certain target will be met. Two widely spread safety risk management approaches are in use so as to control and regulate safety risks:

- Target Level of Safety (TLS) approach;
- As-Low-As-Reasonably-Practicable (ALARP) approach.

The TLS approach is based on the specification of an acceptable value of risk which can be used as a yardstick against which the risks associated with a system or procedures can be evaluated. The ALARP approach is based on a banded assessment of decision structure, which contains a tolerable region bounded by maximally negligible and minimally unacceptable levels of risk. Within the tolerable region the risk must be proven to be ALARP in order to be acceptable.

Up to now, the most commonly used risk criteria framework for aviation safety risk includes a) a single risk metric defined in terms of the probability per unit of exposure, and b) a risk requirement for this risk metric, which is based on the TLS approach. The associated basic methodology for determining whether the system is acceptably safe uses an evaluation of the system risk against a TLS, which is often expressed in terms of a maximum number of fatal accidents per flying hour.

A commonly accepted risk criteria framework for UAS does not yet exist, although proposals have been made and are being discussed. A UAS risk criteria framework contains:

1. Definitions of risks to be regulated;
2. Definitions of appropriate metrics;
3. Risk criteria for judging the acceptability of the risks.

UAS RISKS TO BE REGULATED

The FAA aims to ensure that UAS 'do no harm' to other operators in the NAS and, to the maximum extent possible, the public on the ground' [26]. FAA supports the introduction of UAS in Non-segregated Airspace 'provided that the risks of flying the unmanned aircraft in the civil airspace can be appropriately mitigated' [27]. According to EASA, risks to be regulated are 'collision with people on the ground' and 'collision with other aircraft in flight' [17]. This is in line with EUROCONTROL's approach, which suggests accounting for 1) risks to other airspace users 2) third party risk 3) potential new risks specifically related to unmanned aircraft [28]. So what are the 'risks' to be considered and regulated? Clearly the concern is that UAS operations might not only interfere with commercial and general aviation aircraft operations, but will possibly also pose a safety problem for other aircraft and objects on the ground. Various international working groups, including the regulatory authorities EASA and FAA, the Joint Authorities for Rulemaking on Unmanned Systems (JARUS), the European Organization for Civil Aviation Equipment (EUROCAE) and the Radio Technical Commission for Aeronautics (RTCA) are addressing this topic in their work program. It is expected that detailed guidelines regarding the risks to be regulated will be made available in the near future.

RISK METRICS FOR UAS

It is commonly accepted that risk is not a single quantity, has many different aspects, and may be quantified in many different ways. Different classes of metrics are distinguished:

- Risk metrics based on 'probability of an adverse event (or occurrence of undesirable events) per unit of exposure', without considering the possible consequences.
- *Economic risk metric*. The sum of expected economic losses due to fatalities and loss of equipment, where the sum is taken per time period of exposure. For loss due to one fatality two types of values are usually used: Value Of Life (VOL) and/or Value Willing to Pay (VWP).
- *Individual risk metric*. The risk experienced by a single individual in a given time period, at a given location. It reflects severity of the hazard and amount of time the individual is in proximity to the risk. It takes no account of numbers of people affected by an event.
- *Societal risk metric*. The risk experienced by a group of people exposed to the hazard, often expressed as a relationship between frequency of, and the number of people affected by, an event. There are two societal risk metrics: an FN-curve and an expected disutility.

What types of metrics have commonly been used to regulate and control aviation safety risk? Aircraft system failure probabilities in terms of 'probability per flight hour' are used as part of the airworthiness certification process to e.g. show that any failure condition which would prevent continued safe flight and landing is extremely improbable. For aerospace system health management, commonly used metrics are Probability of Loss of Control and Probability of Loss of Vehicle. Two metrics for the collision risk between aircraft are e.g. 1) collision probability per movement (e.g. approach, take off), and 2) collision probability per year (or expected average time interval between two risk events). The collision risk of an aircraft with the ground is usually assessed for movements in the airport environment (i.e. take off or landing). Metrics used to manage third party risk to persons on the ground are usually based on individual risk metrics. Such metrics are presently used in the Netherlands and in the United Kingdom to control new housing development and purchasing of existing houses. E.g. in the UK, individual risks higher than 10^{-4} per annum are intolerable for the public and those below 10^{-6} per annum are regarded as broadly acceptable. In the Netherlands, in addition to criteria based on individual risk, criteria also exist for use of F-N curves (a way of presenting group/societal risk) although these have not been applied in practice to Dutch airports.

Which risk metrics are suitable for addressing risks related to UAS operations? At least risk metrics have to address a) risk of collision with other aircraft, b) risk of collision risk with the ground (and/or the associated risk to persons/property on the ground). Commonly accepted UAS risk metrics do not yet exist, although proposals have been made and are being discussed. The following section provides insight in the different possibilities for addressing these relevant risks types.

UAS RISK CRITERIA

A commonly accepted risk criteria framework for UAS does not yet exist. JAA/EUROCONTROL UAV Task Force [29], NATO [30, 31], and EASA [15, 16, 17] provide more insight.

The *Joint JAA/EUROCONTROL UAV Task Force* was the first international effort by aviation authorities to establish an acceptable risk criteria framework for UAS operations in Europe. This Task Force defined 5 levels of hazard severity:

- *Severity I* ("Catastrophic"): UAV is unable to continue controlled flight and reach any predefined landing site (uncontrolled flight followed by an uncontrolled crash, with potentially fatalities or severe damage on ground.
- *Severity II*: Failure conditions leading to the controlled loss of the UAV over an unpopulated emergency site, using Emergency Recovery procedures where required.
- *Severity III*: Failure conditions leading to significant reduction in safety margins (e.g. total communication loss with autonomous flight, landing on predefined emergency site that is unpopulated and fulfills certain requirements).
- *Severity IV*: Failure conditions leading to slight reduction in safety margins (e.g. loss of redundancy).
- *Severity V*: Failure conditions leading to no Safety Effect.

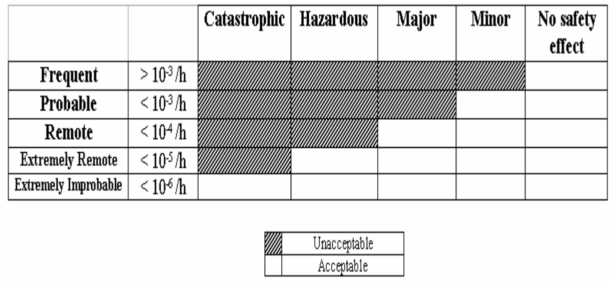
No explicit maximum allowable frequencies at which the events at the distinct hazard levels may occur are provided. However, it is stated that the quantitative safety objective for the UAV 'Severity conditions' should be set, per UAV category, based upon a rationale similar to AMC 25.1309 and FAA AC23.1309. The hazard definitions proposed by the Task Force only apply to people and property on the ground; no such levels are provided for the risk to people in the air.

NATO STANAG 4671 [30] addresses risk criteria for the risks to people on the surface. NATO recognizes that because a UAV carries no passenger or crew, the consequences of an event in terms of casualties cannot be considered with respect to the occupants of the aircraft, but only with respect to people or property on the ground or on board other (manned) aircraft. Compliance should be demonstrated by the approach defined by SAE [32], taking into account the following severity reference system as defined in AMC.1309 of STANAG 4761:

- *Catastrophic*: Failure conditions that result in a worst credible outcome of at least uncontrolled flight (including flight outside pre-planned or contingency flight profiles/ areas) and/or uncontrolled crash, which can potentially result in a fatality. Or 'Failure conditions which could potentially result in fatality to UAV crew or ground staff'.
- *Hazardous*: Failure conditions that either by themselves or in conjunction with increased crew workload, result in a worst credible outcome of a controlled-trajectory termination or forced landing potentially leading to the loss of the UAV where it can be reasonably expected that a fatality will not occur. Or "Failure conditions which could potentially result in serious injury to UAV crew or ground staff".

- *Major*: Failure conditions that either by themselves or in conjunction with increased crew workload, result in a worst credible outcome of an emergency landing of the UAV on a predefined site where it can be reasonably expected that a serious injury will not occur.
  Or "Failure conditions which could potentially result in injury to UAV crew or ground staff".
- *Minor*: Failure conditions that do not significantly reduce UAV System safety and involve UAV crew actions that are well within their capabilities. These conditions may include a slight reduction in safety margins or functional capabilities, and a slight increase in UAV crew workload.
- *No safety effect*: Failure conditions that have no effect on safety.

NATO use a probability level reference system with 5 classes: *Extremely Improbable*, *Extremely Remote*, *Remote*, *Probable*, and *Frequent* (based on occurrence levels per flight hour). The risk reference system in STANAG 4671 is based on an inverse relationship between the average probability per flight hour and severity of the effects of the failure condition (Figure 1).



		Catastrophic	Hazardous	Major	Minor	No safety effect
Frequent	$> 10^{-3}$ /h	▨	▨	▨	▨	
Probable	$< 10^{-3}$ /h	▨	▨	▨		
Remote	$< 10^{-4}$ /h	▨	▨			
Extremely Remote	$< 10^{-5}$ /h	▨				
Extremely Improbable	$< 10^{-6}$ /h					

▨	Unacceptable
	Acceptable

Figure 1 STANAG 4761 risk reference system

This matrix applies to each individual failure condition of each UAV subsystem forming the UAV System. Under specific conditions STANAG 4671 accepts as alternative that the combination of all Catastrophic failure conditions has an occurrence of 10^{-5} per flight hour or less [30].

For UAV risks to people in the air, NATO derives the most stringent requirement facing unmanned aviation from the need for operations with commercial air transport. The probability of a mid-air collision must be equivalent to, or better than, these standards or 5×10^{-9} per aircraft flight hour [31].

EASA considers two possible approaches to certify the airworthiness of UAV [15]:

- *Conventional* approach, based on a defined airworthiness code to the design of aircraft. This approach is common in civil manned aviation, and it is a common philosophy of this approach that it avoids any presumption of the purposes for which the aircraft will be used in service.
- *Safety Target* approach, based on setting an overall safety objective for the aircraft within the context of a defined mission and operating environment.

EASA initially concludes that the existing civil regulatory system has delivered continually improving safety levels whilst being flexible enough to cope with the relentless evolution and development in aircraft design, and that any proposal to depart from the established system in favor of a Safety Target approach will be hard to justify today. Hence the conventional approach for airworthiness certification is used.

With regard to UAV risks to people on the surface, initially the severity levels and safety objectives used by EASA are equal to those established by the JAA/EUROCONTROL UAV Task Force [29]. With no persons onboard the aircraft, the airworthiness objective is primarily targeted at the protection of people and property on the ground. The UAS safety risk assessment shall show that the UAS complies with safety objectives e.g. the probability level associated with the risk of an uncontrolled crash is less than an agreed figure and the severity of various potential failure conditions is compatible with their agreed probability of occurrence. EASA [16] does not define these severities and probability levels because the work was still ongoing to reclassify the severity of failure conditions for UAS. Such definitions and probability values should be included in an update to the policy. As an interim position, EASA refers to the quantitative values applicable to requirement 1309 contained in the applicable airworthiness code used as the reference in defining the type-certification basis of the individual UAS, with as minimum the minimum values contained in AC 23.1309 for Class 1 aeroplanes [16]. EASA [16] addresses the intrinsic safety of the UAS, i.e. the certification of its airworthiness; it does not (yet) address the protection of other airspace users because this is dependent on ATC/ATM separation procedures and defined "detect and avoid" criteria, commensurate to the airspace class and type of operations (i.e. within or beyond visual line of sight). With the extension of EASA's remit to also cover ATM/ANS, EASA will have to deal with the protection of airspace users as well.

Risk categorization

- Most severe are events which may cause a fatalities on the ground or in the air, for example because of loss of control; it is yet unclear whether there should be different risk levels for different amounts of fatalities, or not.
- Next lower level of severity would be events that are unlikely to be fatal but may cause injuries.
- Next lower levels of severity could involve 'stress', 'increased workload', or 'nuisance', and 'no effect'; all referenced sources seem to agree that these are of too low importance to further elaborate these now.

Risk criteria

The views on acceptability of risks are less consistent than for risk categorization. According to one line of reasoning, most UAS are equivalent to CS-23 aircraft because of their weight and number of people that could be at risk, and shall meet risk criteria applicable to CS-23 aircraft. According to another line of reasoning, UAS are too complex for comparison with CS-23 aircraft, are equivalent with CS-25 aircraft, and shall therefore meet the risk criteria applicable to CS-25 aircraft.

UAS SAFETY RISK MANAGEMENT METHODOLOGY

It has been motivated that the main safety risks that need to be addressed before UAS can be introduced in Non Segregated Airspace without degrading safety are the risk of collision with objects on the ground and the risk of collision with other aircraft. Typically, SRM consists of five steps [9]:

1. Describe the system to be introduced or changed;
2. Identify the associated hazards and causal factors;
3. Analyze risks (characterise the risk elements in terms of both hazard severity and likelihood of occurrence);
4. Assess risks (and provide results for decision making);
5. Treat/control the risks (i.e. mitigate, monitor and track).

RISK OF A UAS GROUND COLLISION

Scope and objective

The objective is to obtain insight into the various UAS hazards and causal factors and their contribution to third party risk. Therefore, the assessment will have to focus on accident scenarios that may result in a collision with the ground. The effect of UAS hazards, causal factors and characteristics that contribute to third party risk will have to be investigated:

- Mass and size;
- Velocities (groundspeed, stalling speed, operating speed);
- Data link and control system failures;
- Automatic recovery systems and procedures;
- Avionics system failures;
- Adverse weather (e.g. wind-shear, clear air turbulence).

Identification of hazards and causal factors

Aviation accidents tend to result from a combination of many different causal factors (human errors, technical failures, environmental and management influences) in certain accident categories, whose causes and consequences differ according to the phase of flight in which they occur. The CATS project approached this complexity by developing 37 separate causal models for each accident category in commercial air transport [20]. These in turn are represented as Event Sequence Diagrams (ESDs) and Fault Trees (FTs). The FTs provide a logical structure showing how causal factors could combine to cause an event of the ESD. The ESD shows how combinations of these events may cause an accident. Only hazards that may result in a ground collision are considered. A review of the original 37 CATS scenarios has yielded fifteen relevant ESDs applicable to UAS operations. Five UAS specific ESDs can be added to cover UAS specific hazards that are not expected to occur in manned aviation. The result is provided in Table 1 [35]. Note that the expected consequences of a UAS mid air collision (ESD 43) are that aircraft parts will collide with the ground. Similarly, ESD 44 represents a part falling down due to e.g. maintenance and/or design failure, maneuvering outside the flight envelope, severe turbulence conditions or cargo fall.

Table 1 UAS hazards that might result in a ground collision

#	**Name of the Event Sequence Diagrams**
5	Operation of UAS by remote pilot inappropriate
6	UAS takes off with contaminated wing
7	Weight and balance outside limits (takeoff)
8	UAS encounters performance decreasing windshear
11	Fire on board UAS
12	Remote pilot spatially disorientated
13	Flight control system failure
14	Remote pilot(s) incapacitation
15	Anti-ice system not operating
16	Flight instrument failure
17	UAS encounters adverse weather
18	Single engine failure
19	Unstable approach
21	Weight and balance outside limits (approach/landing)
37	Wake vortex encounter
40	UAS positional information system failure
41	UAS data link failure
42	Unnatural conditions in UAS Ground Control Station
43	UAS mid air collision
44	A part of the UAS falls down

Risk analysis

Usually *Individual Risk* and the *Societal Risk* are analyzed. A typical method consists of 3 sub-models, which answer three questions regarding the risk of UAS to objects on the ground:

1. What is the chance that a UAS accident occurs?
2. What is the likelihood of a UAS accident occurring on a given location, given that a UAS accident occurred?
3. What is the consequence of a UAS accident, given that a UAS accident occurred at a given location?

The *accident probability model* is used to determine frequency of occurrence of a UAS accident that causes potentially third party damage or fatalities on the ground. Based on the UAS accident and accident avoidance scenarios as listed in Table 1, safety requirements (maximum allowable probabilities) for each of the hazards and causes represented in the associated FTs are derived. The *accident location model* is the likelihood of a UAS accident occurring on a given location, given that a UAS accident occurred. This model will provide a two-dimensional probability distribution function that is tailored to route network and sector traffic in the non segregated airspace to be investigated. The consequences of a UAS accident in terms of affected area and fatal injuries are expressed in the *accident consequence model*. In this model, the area affected by a UAS accident is defined as consequence area, whereas the chance of a fatal injury inside this consequence area is defined as lethality (ratio of the number of third party fatalities and number of people in the consequence area). The models are combined to calculate individual risk and societal risk.

Risk assessment

From the viewpoint of introducing UAS operations in Non Segregated Airspace, it is not desirable that a future risk situation will be worse than the current situation. A 'stand-still' principle should apply. If a) the distribution of UAS accident locations is expected to show a similar pattern as manned aircraft, and b) third party consequences are expected to be similar for UAS and comparable manned aircraft, one could aim to 'maintain existing accident rates'. By keeping the UAS accident probability comparable with the current accident probability for manned aircraft, one would under these assumptions then achieve 'stand still' third party risk.

RISK OF COLLISION OF A UAS WITH OTHER (MANNED) AIRCRAFT

Scope and objectives

The objective is to obtain insight in the relative importance of the various UAS characteristics and their relative contribution to the collision risk for operations in Non Segregated Airspace. Therefore, the assessment will have to be based on a comparison between baseline commercial air traffic only versus a traffic mix including UAS. A distinction between the different components of collision risk will have to be made; conflict scenarios that cover vertical collision risk and conflict scenarios that cover horizontal collision risk. For both, a distinction will have to be made between risk arising in the normal operation (technical risk) and risks due to operational error and non-nominal operating conditions (including pilot error). The effect of different UAS factors that may contribute to collision risk will have to be investigated:

- Performance characteristics and size;
- Detect and Avoid system performance characteristics;
- Command and control link characteristics;
- Procedures for contingencies and recovery procedures;
- Lateral or vertical separation minimum (standard).

Identification of hazards and causal factors

To adequately control collision risk in controlled IFR airspace, air traffic controllers apply *separation minima* (lateral and vertical separation standards). The methods used to achieve separation are varied and complex, depending on the phase of flight and the relative trajectories of the aircraft involved:

- Vertical separation is achieved by requiring aircraft to use a prescribed altimeter pressure setting within designated airspace, and to operate at different levels expressed in terms of altitude/flight level. Minimum vertical separation for IFR flight is 1000 ft (300 m) below FL290 and 2000 ft (600 m) above FL290, except where RVSM applies.
- Lateral separation is achieved by various means, which include a) position reports which indicate the aircraft are over different geographic locations, b) requiring aircraft to fly on specified tracks separated by a minimum angle.
- Longitudinal separation is applied so that the aircraft spacing is never less than a specified amount. For aircraft following same or diverging tracks, this may be achieved by requiring aircraft to make position reports (and comparing times) and by speed control.

Details of the separation applied depend on circumstances. In controlled IFR airspace, separation depends on route network:

1. Aircraft on two parallel tracks separated by a lateral separation minimum (standard).
2. Aircraft on multiple (near-) parallel tracks.
3. Aircraft flying in the same direction on the same flight level of the same track.
4. Aircraft on different flight levels of the same track, flying in the same or opposite directions.
5. Aircraft flying on the same flight level of intersecting tracks.
6. Aircraft flying on different flight levels of intersecting tracks.

In view of collision risk, one difference between manned aircraft and unmanned aircraft is the fact that the UAS pilot may not at all times be able to immediate control the flight. Failure modes related to the use of a ground-air data link could induce a time latency of pilot command and control actions or may even lead to complete loss of control. Other possible differences that might negatively impact operator errors and collision risk are e.g. single pilot operations and autonomous flight recovery. Issues to be considered are:

1. Introduction of many UAS leads to a different traffic mix, which increases the complexity.
2. Increased pilot errors (due to lack of proficiency, automation confusion/distraction, increased workload, single pilot operations), increased communication errors with ATC and increased ATC errors due to misinterpreted performance characteristic of UAS are expected to lead to track deviations or longitudinal errors (horizontal deviations) and vertical deviations (including level busts).

One should be aware that for small UAS operating among larger commercial aircraft implies that wake vortex encounters are likely more severe when UAS are crossing below such aircraft, and may then potentially need to be addressed as well.

Potential causes of the risk of collision between a UAS and other (manned) aircraft should be identified. This may be done in the form of “conflict scenarios”, which will serve as a basis for collision risk modeling and assessment. The conflict scenarios are to cover both nominal and non-nominal aircraft and pilot behavior. Examples of conflict scenarios are level busts, aircraft leveling off at different flight levels than being cleared for, and additional errors due to single pilot operations. It may be questioned whether UAS will increase collision risk by being slower or faster than manned aircraft and/or by having larger or more frequent flight path deviations. There are two specific issues that are to be investigated for UAS:

1. Assessment of collision risk for a traffic mix with UAS;
2. Evaluation of applicability existing separation standards.

Risk analysis

It is an option to start with high-level qualitative collision risk assessment (taking into account different conflict scenarios defined) and assess the different contributions of UAS aircraft performance, navigation performance and human factors to the different components of collision risk (lateral, vertical, longitudinal). Following such a qualitative study, a more sophisticated collision risk model may be developed and used in order to capture in more detail dynamics of the scenarios.

Collision risk assessment. The assessment may be based on a comparison between a baseline of commercial air traffic only versus a traffic mix including UAS. Collision risk models will be used for assessment of the effect of UAS on different components of collision risk (lateral, vertical, longitudinal) and the effect of different factors that may contribute to collision risk, such as speed difference, navigation performance and conflict scenarios. For characterizing the collision risk, it is suggested to use the unified framework for collision risk modeling as described in the ICAO Circular 319-AN/181 [33]. NLR provides three mathematical risk models that could possibly be used for three conflict scenarios [34]:

- Loss of control due to wake vortex encounter
- Mid-air collision due to vertical deviations
- Mid-air collision due to horizontal deviations.

Evaluation of separation standards. The applicability of the existing separation standards (lateral, longitudinal and vertical) for en-route air space and TMA for a traffic mix including UAS will have to be evaluated. A particular issue to investigate is whether or not data link failures (loss of control link, time latency issues) could imply a need for increased separation. Given a smaller size of the UAS as compared to commercial aircraft, the effect of wake vortices generated by (large) manned aircraft on the controllability of a UAS may need to be studied as well. Results could be used to decide whether separate pathways or 'tubes' will need to be introduced for UAS at high altitude en-route airways and what the possible size of such tubes would then have to be.

Risk assessment

The main task is to compare the estimated collision risk with acceptability criteria defined within a risk criteria framework. There are two basic methods for determining whether a system is acceptably safe: a) relative (comparison with a reference system) or b) absolute (evaluation of system risk against threshold(s)). The comparison methodology is usually applied if the reference system is proven to be safe (historically or theoretically) and if the assessed system is very similar to the reference in the risk-related aspects. The threshold(s) in the second method are usually referred to as a TLS. In order to ensure with a predetermined level of confidence that the estimated risk is below the TLS, it would be necessary that each calculation step in the risk assessment leads to an exact or conservative value. See the previous section for guidance.

BUILDING THE SAFETY CASE

The results from the proposed UAS SRM process are being used by NLR to produce a 'Safety Case' for introduction of UAS in non-segregated airspace. A Safety Case is defined as 'documented assurance of the achievement and maintenance of safety' [19]. It is a means of structuring and documenting a summary of Safety Assessment results, and other activities (e.g. simulations, surveys, etc.), in a way that a reader can follow the reasoning as to why a change (or on-going service) can be considered safe. A Safety Case consists of a set of *safety arguments* together with *safety evidence* to show that all arguments are valid. Figure 2 represents a project lifecycle, in which a *Safety Argument* is a statement to claim that a concept is safe. The top-level Claim states that an operational concept is *acceptably safe*, by referring to a risk criteria framework that would be either absolute, relative, and/or ALARP based.

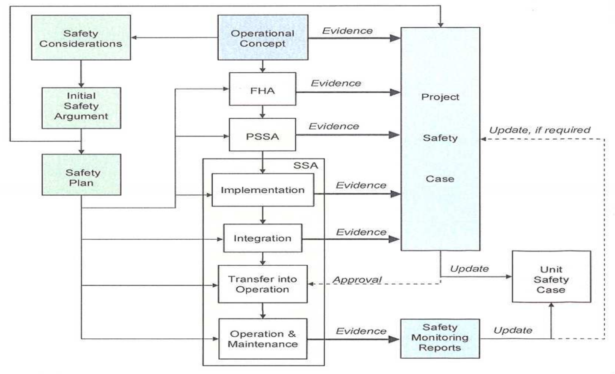


Figure 2 Safety throughout the project lifecycle [19]

An initial Safety argument for introduction of UAS operations in non segregated Airspace would start with the *Claim* that the aviation system, following the introduction of UAS, will (still) be *acceptably safe* (see Figure 3 for a proposed starting point).

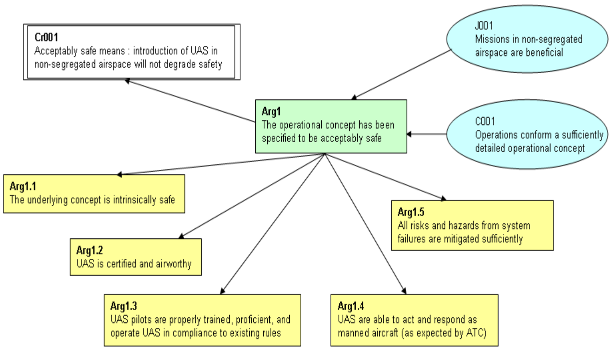


Figure 3 Initial safety argument for the introduction of UAS

The Safety Evidence to be gathered will have to be used to construct the justification that the concept is sufficiently safe to be operated in the foreseen environment. The justification of safety may be submitted to aviation regulators for approval.

SUMMARY/CONCLUSIONS

Although UAS have already been used in segregated airspace where separation from other traffic is assured, many see requirements to deploy UAS in non segregated airspace. A UAS SRM framework, supporting regulators and applicants of new proposed UAS operations through provision of guidelines for each SRM step to be conducted, has been proposed.

A survey of UAS activities has provided an initial view on the risks and hazards to be considered, the needs and role of potential SRM users, the scope of the aviation system to be considered, the risks to be regulated, selection of suitable risk metrics, and the setting of an acceptable level of safety. It has been motivated that the main safety risks to be addressed to ensure that UAS can be introduced in non segregated airspace without degrading safety are *risks to other airspace users* and *third party risk* (to objects on the ground). It will be necessary to show that these risks do not increase as compared to the current aviation system with manned aircraft only.

The proposed SRM process follows five sequential steps:

1. Describe the system to be introduced or changed;
2. Identify the associated hazards and causal factors;
3. Analyze risks (characterise the risk elements in terms of both hazard severity and likelihood of occurrence);
4. Assess risks (and provide results for decision making);
5. Treat/control the risks (i.e. mitigate, monitor and track).

The proposed SRM process for *risks to other airspace users* is based on comparison of the collision risk for a baseline of commercial air traffic versus a traffic mix that includes UAS, using the ICAO unified framework for collision risk modeling. The proposed SRM process for *third party risk* is based on a method that combines an accident probability model with an accident location model and an accident consequence model, through answering three key questions:

1. What is the chance that a UAS accident occurs?
2. What is the likelihood of a UAS accident occurring on a given location, given that a UAS accident occurred?
3. What is the consequence of a UAS accident, given that a UAS accident occurred at a given location?

It has been explained how the results of the SRM process are being used to build a Safety Case for UAS operations in non segregated airspace. It is recommended to apply and validate the proposed SRM process with an operational concept brought forward by EUROCAE WG73 and/or RTCA-SC203.

However, it should be noted that a commonly agreed risk criteria framework for UAS operations does not yet exist. Such framework, which has to be defined by regulators, is crucial for judging the acceptability of risk. This paper provides guidelines for the establishment of such framework, but the actual implementation should preferably be done jointly by a group that includes EASA, FAA and/or JARUS.

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ABBREVIATIONS

AC	Advisory Circular
AIP	Aeronautical Information Publication
ALARP	As Low As Reasonably Practicable
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATO	Air Traffic Organization
AOC	Air Operator Certificate
CATS	Causal model for Air Transport Safety
CBP	Customs and Border Protection
CS	Certification Specification
EASA	European Aviation Safety Agency
ESARR	Eurocontrol Safety Regulatory Requirement
ESD	Event Sequence Diagram
EUROCAE	Europe Organization Civil Aviation Equipment
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FL	Flight Level
FMEA	Failure Mode and Effects Analysis
FT	Fault Tree
HMI	Human Machine Interface
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
JARUS	Joint Authorities for Rulemaking on UAS
NATO	North Atlantic Treaty Organization
NAS	National Aviation System
NextGen	Next Generation Air Transportation System
R&D	Research and Development
RTCA	Radio Technical Commission for Aeronautics
RVSM	Reduced Vertical Separation Minima
SAE	Society of Automotive Engineers
SARP	Standards and Recommended Practices
SESAR	Single European Sky ATM Research
SMS	Safety Management System
SRM	Safety Risk Management
STANAG	Standardization Agreement
TLS	Target Level of Safety
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UCS	UAS Control Station
UK	United Kingdom
VOL	Value Of Life
VFR	Visual Flight Rules
VWP	Value Willing to Pay