33RD CONGRESS
OF THE INTERNATIONAL COUNCIL
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

ICAS 2022 SWEDEN

ENHANCING UAS DESIGN PROCESS FOR SPECIFIC CATEGORY OPERATIONS USING SORA

Rupal Kalra[1,2], Pablo Flores-Peña[2], Alejandro Sanchez-Carmona[1], & Cristina Cuerno-Rejado[1]

[1]Escuela Técnica Superior de Ingeniería Aeronáutica y del Espacio, Universidad Politécnica de Madrid, Plaza del Cardenal Cisneros 3, 28040 Madrid, Spain
[2]Drone Hopper S.L., Madrid, España

Abstract

The paper presents a novel approach with the aim of enhancing the process of Unmanned Aircraft System (UAS) design for specific category operations using the Specific Operations Risk Assessment (SORA) methodology as a tool to derive requirements related to the safety objectives and consider them in the conceptual design phases. For an operation of UAS in the specific category in the European scenario, it is essential to perform a risk assessment of operation to obtain approval from the National Aviation Authorities. Through the present European regulatory framework, SORA is adopted as an acceptable means of compliance to demonstrate the operation meets the established safety objectives associated with an operation by means of supporting evidence and procedure establishment. The paper aims to optimize and enhance the UAS design process using an iterative approach of assessing an initial Concept of Operations and using SORA as a tool to evaluate and include the criteria of design safety objective as requirements in the conceptual design phases. Further, the benefits of the proposed approach are accentuated through a case study of the conceptual design of an autonomous UAS for high endurance vigilance operations in agricultural land, resulting in an optimized conceptual design exhibiting compliance with required safety objectives along with necessary evidence essential for obtaining operation approvals.

Keywords: Unmanned aerial system (UAS), Unmanned aerial vehicle (UAV), UAS conceptual design, SORA.

1. Introduction

In the past two decades, Unmanned Aerial Systems (UAS) have experienced immense development and expanding use in the aviation industry. UAS comprises the unmanned aircraft (UA) commonly referred to as drone or remotely piloted aircraft (RPA) and the ground control station (GCS) and has been employed for vast applications in the civil sector such as the delivery of goods, precision agriculture, search and rescue, real-time monitoring of road traffic, and construction and infrastructure inspection[1]–[5]. Like any other technology, there are risks associated with the operation of UAS, which is evident from the studies performed to identify the safety risks posed by the operation of UAS [6].

Even though these aircraft share their origins with manned aircraft [7], there is a major difference between the two, due to the absence of an onboard pilot in UAS and increased autonomous behavior. Consequently, there is an increased number of failure modes and accidents associated with them. Various studies revealed that they also differ in the cause of accidents and incidents associated with them. In contrast to commercial air transportation (CAT), the major causes of accidents and incidents in UAS were identified as technical issues and not human factors as was assumed for a long time [8]. This highlighted the need for regulators to focus on airworthiness requirements and promote the development of new equipment and systems for increased safety. In this view, several regulatory initiatives have emerged in the attempt to regulate the UAS operation in the non-segregated airspace by organizations like EUROCONTROL, UAV-TF, European Union Aviation Safety Agency (EASA), Federal Aviation Administration (FAA), EUROCAE, RTCA, etc. [9] In the European scenario, the activities to regulate and integrate the UAS operations into the civil airspace are governed by EASA.

The most recent and well-tailored version of regulations published by EASA that establishes the basis for all the operations associated with UAS in the European scope is the Commission Implementing Regulation (EU) 2019/947 and Commission Delegated Regulation (EU) 2019/945 further amended by Commission Implementing Regulation (EU) 2021/1166 and Commission Delegated Regulation (EU) 2020/1058 [10]. EASA adopted an operation-centric, risk-based proportional approach of classifying UAS operations into three categories decided by the extent of the risk posed by the operation. The three categories identified are 'open,' 'specific' and the 'certified' categories. The 'open' category operations are carried out based on a set of operational restrictions corresponding to the subcategory of operation (A1, A2, or A3) and technical requirements corresponding to the UAS class with the most important restriction being that the UAS must be within the visual line of sight throughout the operation. Such operations do not require authorization from the National Aviation Authority (NAA) [11]. Whereas, UAS operations not covered by the 'open' category and with a medium level of risk are required to obtain an operational authorization from the NAA of the respective member state in the European scope, where the operator needs to perform a risk assessment for the desired operation. Further, for operations with high risks obtaining type certifications from EASA is necessary. For operations in the specific category, the UAS operator is required to perform a risk assessment specific to the operation and present it to the NAA for approval. In fact, to assist the authorization process, Joint Authorities for the Rulemaking of Unmanned Systems (JARUS) introduced the Specific Operations Risk Assessment (SORA) methodology, which is included as an Acceptable Means of Compliance (AMC) to the EU regulations by EASA [11], [12].

The SORA methodology is a relatively new method introduced to support the risk assessment of UAS operations by the operator to determine if the operation could be conducted safely. Through such an assessment, the regulations aim to limit the risks posed by the specific category operations by ensuring that efficient operational procedures are observed and thus the possible risk is reduced. The SORA methodology has been under discussion and analysis for applications such as UAS-based cinematography, maritime surveillance mission, first responders and disaster management operations, UAV-assisted airframe inspection, and others as described in [13]–[17]. Through the literature present, it is evident that SORA was used as a risk assessment tool to assess the risk of operation. The focus of these studies has been to highlight the SORA methodology and suggest improvements in the existing version to propose a more complete method for assessing a broader range of UAS operations including multi-UAS operations and other associated threats.

Indeed all operators must perform a risk assessment before the operation is conducted, which can be efficiently done by utilizing SORA. The guidelines as implied by SORA are not only relevant to the operational procedures but are also related to the UAS design aspects. There may be situations where, that the UAS intended for the operation does not comply with the requirements established by SORA for the concerned operational scenario, further complicating it for the operator to make major revisions in the proposed operation which may directly affect the purpose of the operation. Moreover, it is possible the system does not have the adequate equipment or characteristics suggested by SORA to be able to operate in the desired conditions. This may result in the need to make major design revisions to the UAS, which may or may not be feasible due to operational, time, resources, cost, etc.

Furthermore, these assessments need to be supported with evidence that may not be present or may be too complex to produce at that stage.Considering these complexities of demonstrating compliance at a later stage in the operation, through this paper, a novel UAS design approach is presented that aims at including the safety requirements as established by the regulations in force, essentially into the conceptual design phases of UAS. Conventionally, the UAS design process aims to optimize the UAS designs considering requirements related to geometry, mission, performance, safety, cost, etc. [18]–[21], through the proposed approach, additional requirements as will be desirable by the user, i.e. the operator in terms that the UAS exhibits the characteristics and systems suggested by SORA.

This paper aims to introduce a novel UAS design process from the manufacturer's perspective by using specific aspects of the SORA to enhance the design process of the UAS by introducing the necessary design and analysis modifications in both the hardware and software of the UAS, as identified by SORA into the conceptual design phases itself.

The SORA as originally intended to be a risk assessment procedure to be performed by the operator

of the UAS can prove to be an important and useful tool when carefully integrated into the design process by the UAS designer or the manufacturer. By the means of the presented methodology, it is expected that the conceptual UAS design obtained will exhibit all safety requirements and objectives relevant to the UAS design. Thus, when the operator performs a SORA to evaluate and assess the safety of operation, the UAS demonstrates and fulfills all obligatory requirements.
The paper is organized into 5 sections, section 2 describes the proposed methodology for enhancing the design process of UAS using a tailored version of SORA, section 3 discusses a case study for the design of UAS for autonomous vigilance operations, section 4 presents discussions and finally, section 5 concludes the overall paper.

2. Proposed Methodology

The methodology proposed for enhancing the design process of UAS using SORA V2.0, developed by JARUS and adopted by EASA, is devoted mainly to operations in the specific category[11], [12]. The methodology aims at capturing the conceptual design and other supporting evidence such as simulations, analysis, particular system description, etc. relevant to the design aspect of UAS required at the final stages of SORA to be considered from the initial design phases.

The design of an engineering system includes three steps- conceptual design, preliminary design and verification using appropriate analysis. The system is analyzed and validated to ensure compliance with the requirements previously established, failing to which the system is re-designed and analyzed further in an iterative manner until compliance is demonstrated.

The presented approach targets to reinforce the conceptual design of UAS for ‘specific’ category operations by utilizing a tailored SORA to define and establish safety requirements and propose enhancements in conceptual design. These requirements are proposed into the design by the means of an iterative tailored SORA by considering requirements or guidelines as suggested by SORA during the different steps as feedback and incorporating the possible requirements into the system requirements and design by making the necessary changes in the preliminary conceptualized CONOPS and system architecture. The approach introduced to enhancing the UAS design process by adopting and including this feedback in the conceptual design phase of the UAS design is presented in figure 1.

The process starts by assuming a conceptual preliminary architecture of UAS on which, a slightly modified SORA is used to assess the conceptualized system. During this assessment, the requirements or restrictions as suggested by tailored SORA are used as feedback to the initially conceptualized UAS design architecture. This section further describes the process of assessment of conceptual UAS design architecture with the modified SORA describing each major step to derive the relevant inputs to establish requirements for improving the design as feedback to conceptual UAS design.

- Step 01- CONOPS description and initial SAIL determination

As in the original SORA that is performed when an operation falling in the specific category of operation is to be carried out, a detailed concept of operations (CONOPS) is drafted describing in detail the operational scenario, requirements, the UAS technical specifications, and operational organization. With this enhanced design process, a brief CONOPS description describing roughly the operational scenario and the proposed UAS architecture is prepared, which is evaluated for an initial value of SAIL. This SAIL value determines the risk posed by the operation and the requirements to be demonstrated to ensure the safety of the system. With the aim of maintaining the lowest possible SAIL, this initial CONOPS is continuously iterated with requirements as feedback, as obtained from SORA. Towards the final steps, it is aimed to obtain a system architecture description that would be the guidelines to finalize the actual UAS design for manufacturing considering the feedback and integrating all requirements as identified through this approach.

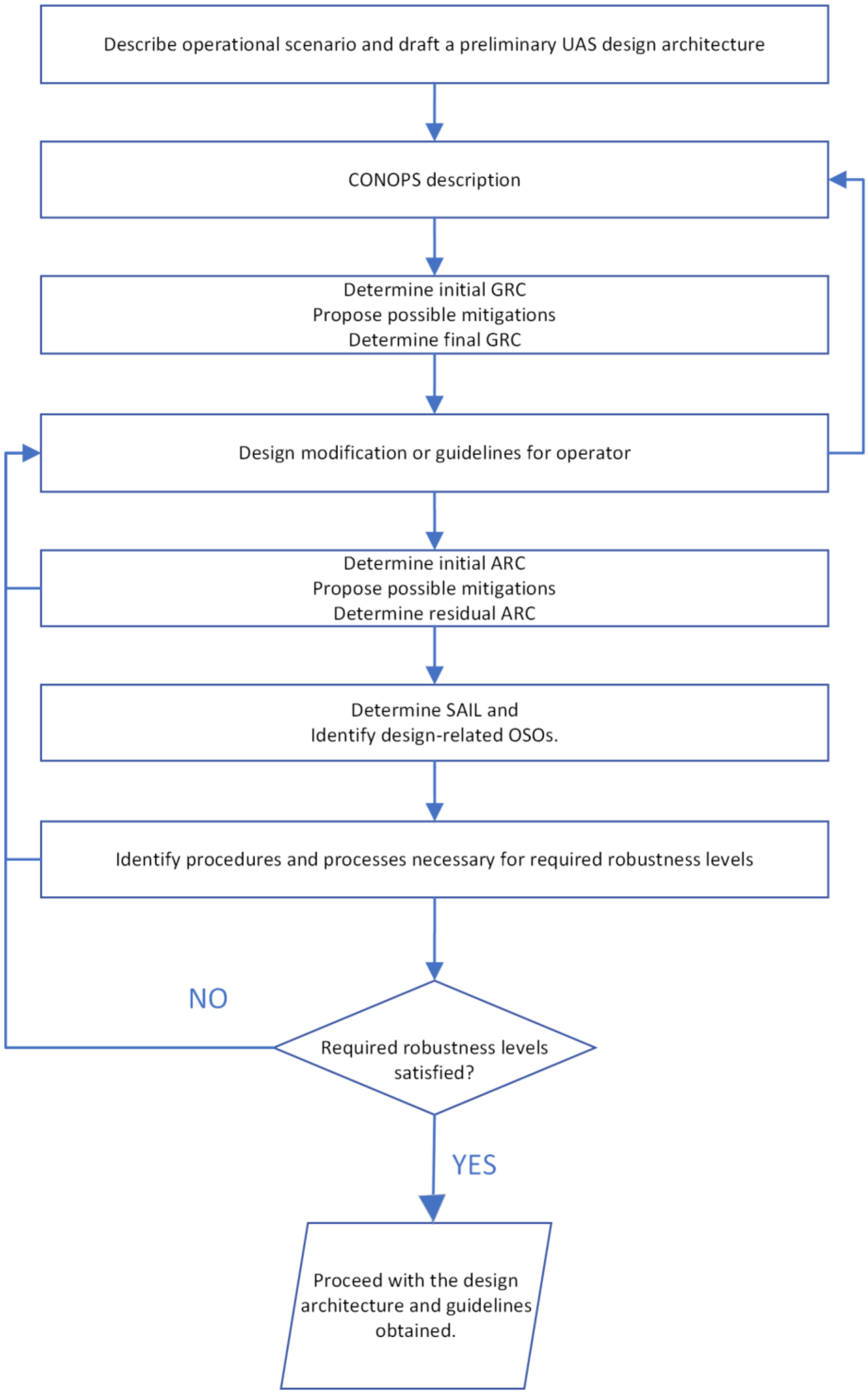

Figure 1 Proposed enhanced UAS design methodology

- Step 02- Determination of Ground risk class (GRC) and possible mitigations

Based on the initial description of the system and operational scenario, a first estimation of the GRC is made, using Table 1. Through the estimation, it is possible to determine if the intended operation is falling in a slightly higher initial GRC, attempts can be made to revise the dimensions of the initially conceptualized UAS. This will ensure that the UAS has the minimum possible intrinsic GRC associated with the intended operation.

Intrinsic UAS ground risk class				
Max UAS characteristics dimension	1m / approx. 3 ft	3m / approx. 10 ft	8m / approx. 25 ft	>8m / approx. 25 ft
Typical kinetic energy expected	< 700 J (approx..529 ft lb)	< 34 kJ (approx..25, 000 ft lb)	< 1084 kJ (approx..800,0 00 ft lb)	>1084 kJ (approx..800,0 00 ft lb)
Operational scenarios				
VLOS/BVLOS over a controlled ground area	1	2	3	4
VLOS over sparsely populated area	2	3	4	5
BVLOS over 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			

Table 1 Determination of intrinsic GRC

Further, by adopting appropriate mitigations as suggested in [11] and incorporating them into the conceptual design, this intrinsic GRC can be lowered. This reduction is achieved by obtaining a correction factor corresponding to the level of robustness of the mitigations applied to the intrinsic GRC, as explained in Table 2.

		Robustness		
Mitigation Sequence	Mitigations for ground risk	Low/None	Medium	High
1	M1	0 (None); -1 (Low)	-2	-4
2	M2	0	-1	-2
3	M3	1	0	-1

Table 2 Mitigations for final GRC determination

The appropriate mitigations as feasible along with the necessary design considerations, analysis, and tests from given guidelines are included in the initial design as described in the CONOPS as feedback as shown in figure 1. At this step, these requirements as derived through the determination and lowering of GRC are included in the CONOPS and the conceptual design. For instance, as suggested by SORA, considerations can be made to use a parachute system to reduce the ground impact of UAS in case of failure or a tethered aircraft or other system designs to fulfill the objective, since it is easier to make such design considerations in the initial design phases. Moreover, at a later stage when SORA is to be presented to the relevant authorities, several supporting evidence that maybe include design analysis, simulations, other considerations, etc. may also be required. These requirements can be effectively included in the preliminary phases of the design process, allowing the manufacturer to fit the design to the desired operations when the platform is sold to the customers.

- Step 03- Determination of air risk class (ARC)

Although the determination of ARC is dependent on the particular airspace where the operation is intended to be performed, a preliminary estimation can be obtained by approximately considering possible airspace characteristics corresponding to the operation. This initial ARC determined can be further reduced utilizing the following 3 mitigations as suggested by SORA-[11] -

a) Strategic mitigations by the application of operations restrictions- this primarily depends on the operational scenario and the airspace.

b) Strategic mitigations by the application of common structures and rules- includes systems or equipment for conspicuity requirements, cooperative identification system, etc. to ensure interoperability with other airspace users.

c) Tactical mitigations- these are to eliminate or reduce the residual air risk of encounter or collision.

Based on the ARC as determined or a reduced ARC as anticipated given the nature of the operation, the tactical mitigations further help reduce the residual risk of collision. In fact, to achieve the airspace safety objective, tactical mitigation performance requirements (TMPR) are established considering the ARC and the extent of risk involved. For visual line of sight (VLOS) operations, these are mainly achieved by the use of human visions to detect aircraft, remain well clear and avoid collisions, which is secured by the means of a well-drafted de-confliction scheme whereas, for beyond visual line of sight (BVLOS) operations, it is necessary to use some external assistance via machine or equipment to achieve the purpose of ‘Detect and Avoid’ (DAA), which may include the use of many different systems, various sensors, architectures, etc., that may or may not involve a human in the loop.

- Step 04- TMPR assessment

Depending on the final ARC is the residual air risk and consequently, the level of robustness associated with each TMPR to be achieved to guarantee that the risk is dealt with. For relatively higher risk levels, in ARC-b, c, or d, several systems or services may need to be incorporated as required by the approving competent authorities. Amongst systems and services as suggested in [11], is the use of web-based applications, ADSB, FLARM, RADAR, dynamic geofencing, etc., and other systems to ensure awareness about the surrounding airspace status.

In addition, there are guidelines to be considered when designing the communication system to communicate information regarding the observations made when observing the airspace during operations. For instance, guidelines over the latency of the C2 link, and other flight performance characteristics as determined to be necessary to perform the emergency maneuvers in case a situation occurs- airspeed, rate of climb or descend, turn rate, etc., the minimum criteria for the update rate and latency involved.

Therefore, it is essential to consider the appropriate inputs from TMPRs, define system performance parameters as necessary and other essential equipment, and include them in the conceptual design as described in the maintained CONOPS. At this stage, the conceptual design and CONOPs are enhanced through requirements derived through previous steps.

Next is an important step in this process which is the determination of the specific assurance and integrity level (SAIL) since it dictates the level of robustness to be finally demonstrated for each operational safety objective (OSOs), which is the core idea of SORA.

- Step 05- Determination of SAIL

Through the final GRC and the residual ARC obtained, the SAIL can be determined using table 3.

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

Table 3 SAIL determination

Subsequently, SAIL governs the level of robustness required to be achieved for each applicable OSO. Presently, SORA uses three robustness levels- low, medium, and high, that are to be demonstrated with adequate evidence and procedures, corresponding to each OSO. Furthermore, the level of robustness determines the extent of evidence and proof necessary to display that the required level of confidence for an operation to remain under control, has been achieved. With the present approach as adopted in the Implementing Regulation (EU) 2019/947 [11],

  - a low level of assurance can be demonstrated with the declaration of the applicant;
  - a medium level of assurance is supported by evidence exhibiting the required level of integrity which could be through testing, simulations, analysis, etc.;
  - whereas, for a high level of assurance, a competent third party ensures that an acceptable level of integrity is achieved.

- Step 06- Identification of OSOs and determination of requirements

Indeed OSOs consolidate and present an initial consideration of safety objectives required for a specific operation. Out of the 24 OSOs published in [11], the following listed in table 4, are particularly related to UAS design for which SORA further describes activities and procedures which may support compliance of the required robustness level associated with SAIL for each OSO.

Through the presented approach, once an initial SAIL is calculated, these activities and procedures can be efficiently included and established as requirements and guidelines in the conceptual design phase of UAS as illustrated in figure 1, to drive subsequent UAS development with aim of complying with these final requirements from the initial stage itself.

OSOs related to design
#02- UAS manufactured by competent and/or proven entity
#04- UAS developed to authority recognized design standards
#05- UAS is designed considering system safety and reliability
#06- C3 link performance is appropriate for the operation
#10- Safe recovery from a technical issue
#12- The UAS is designed to manage the deterioration of external systems supporting UAS operations
#18- Automatic protection of the flight envelope from human error
#19- Safe recovery from human error
#20- A human factors evaluation has been performed and the human machine interface (HMI) found appropriate for the mission
#24- UAS is designed and qualified for adverse environmental conditions

Table 4 Design related OSOs

Considering the adopted approach, for operations with a relatively low level of imposed risks, the UAS must be designed keeping the safety aspects into consideration but at the same time with the intention of keeping the level of SAIL as minimum as possible to avoid the requirements of stringent demonstrations of the robustness level for operations of considerable low level of risk.

Overall, through this procedure and from figure 1, it is observed that the conceptual CONOPS is evaluated through a tailored SORA with the UAS design in the conceptual phases. At this stage where the design has not been frozen, it is relatively feasible to propose major changes in the design and architecture of UAS, as are obtained as requirements from the different SORA steps, in contrast to the complexity of introducing such changes at a later stage when UAS has already been manufactured which, may impose unnecessary complications in obtaining authorizations for comparatively low-risk operations. To conclude the main inputs as can be derived to reinforce the UAS design were through

- Considering mitigation M1 and M2 for the reduction of intrinsic ground risk
- Establishing requirements based on TMPR
- Including requirements of design-related OSOs, with the applicable robustness defining systems and procedures necessary.

The final objective is to design and manufacture a UAS for the specified operation that will be in compliance with the necessary design requirements, complying with established safety objectives as obtained from SORA, and be adequate to perform the proposed operations without any complications at the time of performing a complete SORA as a risk assessment for obtaining the required operational authorization from the National Aviation Authority (NAA). The next section highlights the presented approach of enhancing conceptual UAS design through the design of an autonomous UAS for vigilance operation from the safety and regulatory aspect.

3. Case Study - Design of UAS for vigilance operations

In this section, a scenario of the conceptual design of UAS to perform autonomous vigilance operations for long hours in agricultural land in a rural area, without a pilot operating the UAS throughout the operation is presented. Since the current regulations governing the operations of UAS within the European scenario [11], do not permit the use of autonomous UAS in the open category of operation, the proposed operation will be in the 'specific' category or the certified category of operation further depending on the extent of risk imposed. Further, the proposed operation presents the use of an autonomous UAS in agricultural land without the need to fly over assemblies of people; it may be assumed that the operation would possibly be associated with the specific category of operation.

In regard to, implemented regulation, for operations in the specific category of operation, it is necessary to perform and present a risk assessment for an operation to obtain an operational authorization from NAA. Considering this requirement, the conceptual UAS design for this operation is enhanced by applying the novel approach presented in section 2. In addition to essential functions and performance requirements for this operation which are considered in the conventional design approach, through this enhanced methodology, essential safety objectives to be complied with are integrated into the conceptual design.

The proposed approach described in the previous section was carefully applied to the given scenario for designing UAS. Through this process of design, a tailored SORA was performed on the preliminary idea of the UAS and operation, and consequently, through each step, adequate requirements to enhance the safety of this system will be integrated as feedback into the design architecture of UAS to be designed.

Step 01- CONOPS description and initial SAIL determination

Firstly, an approximate description of CONOPs was made assuming different aspects that could be modified throughout the design process. As the UAS was not fully designed, approximations for system specifications were made for estimating the required data. As a preliminary conceptual design of the UAS, a quadrotor mounted with a camera was considered, with assumptions of the characteristic dimension i.e. the maximum distance between the rotors of about 1.5 to 2m, an electric propulsion system, taking into account the flight time required, an MTOW of about 25 kg and flight time of around 3 hours. Secondly, based on the available data, a sparsely populated area of operation was hypothesized, since the operation is to be performed on agricultural land and the maximum altitude of flight is 100 m.

To highlight the advantages of the proposed approach, an estimation of the first value of SAIL for the present CONOPS was made. According to the first version of CONOPS, the intrinsic GRC was estimated as GRC ‘4’ using table 1, corresponding to column 3 and ‘BVLOS over a sparsely populated area’, as it is an autonomous operation and the pilot would not be present to control the aircraft throughout the operation. Next, the initial ARC is considered to be ARC-b, corresponding to, ‘operations in uncontrolled airspace over rural area’. Based on the initial values of GRC, as ‘4’ and ARC as ‘ARC-b’, the initial SAIL determined using table 3 was calculated to be ‘SAIL- III’, which, corresponds to ‘medium’ level risk of operations. With the aim of reducing, the initial SAIL obtained and effectively the risk associated with the operation, this initial CONOPS was iterated through the proposed approach through subsequent steps.

Step 02- Determination of GRC and possible mitigations

Considering that GRC ‘4’ is a relatively high value, which later affects the final SAIL obtained, it was appropriate to explore the possibility of introducing mitigations to reduce the risk imposed by the operation and consequently lower the GRC. In this context, it was first proposed to limit the size of the UAV to a maximum dimension of 1 m with expected kinetic energy of less than 700 J. This is the minimum initial GRC that could be associated with UAS for this operation, which is determined using table 1. With these design guidelines, the new GRC was ‘3’, which was lower than the initial GRC assumed.

Further, SORA gives possibilities of lowering this initially determined GRC and enhancing the safety of UAS by the means of applying mitigations. Considering the possible mitigation to reduce this level of initial GRC determined mentioned in [11], a medium level of robustness for mitigation M1 - Strategic mitigations for ground risk, could be achieved by designing a tethered UAS in compliance with all the requirements established. In addition to the enhanced safety of the design, the tethered UAS has increased autonomy, which was desirable for the operation. These guidelines specified the design and validation of the tether considering compatible ultimate loads, and other relevant safety considerations. Furthermore, certain analyses, simulations, and tests would be necessary to demonstrate the adequacy of the applied mitigation. All these guidelines and requirements were considered and fed as feedback to the design architecture of UAS, updating the initial CONOPS. Additionally, it is advisable for the operators to always validate and implement an ERP complying with the regulatory requirements to ensure the safety of operation and avoid an increase in the initial GRC level.

Application of these mitigations lowered the initial GRC of '3' to the new GRC of '1', introducing a correction factor of '-2', referring to table 2; final GRC determined as 3-2 i.e. 1. As a result, the current CONOPS exhibits a GRC-1 in contrast to GRC-4 of the previous CONOPS, in addition to the inclusion of enhanced safety design features.

Step 03- Determination of ARC

For the presented case, ARC is considered to be corresponding to 'operations in uncontrolled airspace over rural area', i.e., ARC-b, which is the same as was estimated initially. The ARC level initially determined can be lowered by introducing operational restrictions and procedures on part of the operator [11].

Step 04- TMPR assessment

Further, to mitigate any residual risk of mid-air collision and achieve an acceptable airspace safety objective, tactical mitigations determined by the TMPR and robustness levels are applied. Since no pilot is continuously monitoring and controlling the aircraft, it is considered BVLOS and with the present ARC-b, a low level of TMPR was needed. Considering the five functions of the TMPR, the following possible design enhancements were proposed to be incorporated into conceptual UAS design to cater to the desired TMPR level-

- Detect- use of (web-based) real-time aircraft tracking services or low-cost ADS-B or U-space Dynamic geofencing, and other such functions which at a later stage, it may be complicated to introduce systems into the system architecture.
- Command- considering the guidelines on the specifications of latency in the C2 link, i.e. 5 seconds, it was proposed to be specified in the design requirements of the communication and control system.

Once these requirements were identified, the CONOPS was again updated including these requirements in the conceptual UAS design. The most updated CONOPS included a system that considers and implements TMPR, in addition to the previously introduced design features.

Step 05- Determination of SAIL

The SAIL was again calculated using table 3 in coherence with the updated CONOPS with final GRC-1 and ARC-b as SAIL II, which is lower than the SAIL estimated through the initial CONOPS, i.e., SAIL III. This indicates that evidence of processes and procedures to be observed during design and operation would be less restrictive than with SAIL III.

Step 06- Identification of OSOs and determination of requirements

Referring to [11], it was observed that for the majority of OSOs, the robustness level associated with SAIL II was either optional or low, which further indicated that compliance with defined safety objectives could be demonstrated through minimum efforts, for both the manufacturer and the operator. Concentrating mainly on the design-related OSOs as mentioned in table 4 and studying the requirements and guidelines to achieve the said robustness levels, proposed guidelines were studied through [11] in detail resulting in the requirements identified presented in table 5.

Subsequently, the requirements and guidelines derived directly from OSOs are fed as an input to the conceptual design of UAS to be adequately incorporated into the system for enhanced performance and safety compliance, further resulting in an updated CONOPS that now includes a conceptual UAS design considering requirements of OSOs.

OSO	Robustness level	Requirements derived
#02- UAS manufactured by competent and/or proven entity	O	No definite requirements since it is optional
#04- UAS developed to authority recognized design standards	O	No definite requirements since it is optional
#05- UAS is designed considering system safety and reliability	O	No definite requirements since it is optional
#06- C3 link performance is appropriate for the operation	L	Consider the performance and RF spectrum usage are adequate for the operation, mechanisms to protect against interference, continuous monitoring of C2 link signal strength, and alert system if signal strength becomes too low.
#10- Safe recovery from a technical issue	L	Applicable for operations over assemblies of people or populated areas
#12- The UAS is designed to manage the deterioration of external systems supporting UAS operations		
#18- Automatic protection of the flight envelope from human error	O	Designed with a flight envelope that describes its safe performance limits concerning minimum and maximum operating speeds and structural strength.
#19- Safe recovery from human error	O	No definite requirements since it is optional
#20- A human factors evaluation has been performed and the human machine interface (HMI) found appropriate for the mission	L	Designs consider HMI evaluation with required inspection or analysis.
#24- UAS is designed and qualified for adverse environmental conditions	O	No definite requirements since it is optional

Table 5 Determining requirements from design OSOs

Finally, a CONOPS with a conceptual design of UAS considering the safety objectives as highlighted by SORA was obtained which included inputs from different steps of SORA such as mitigations for GRC, TMPR levels, and lastly OSOs. This conceptual UAS design can be studied and analyzed for inclusion of all requirements as derived from the guidelines of SORA. Since the presented approach is iterative, more than one possible set of design requirements to enhance the safety of operation could be derived to achieve the same level of SAIL depending on the feasibility of implementing the requirements governed by other factors such as performance, cost, resources, etc. Once the conceptual UAS design is implemented, it is expected that UAS will exhibit all systems and specifications as expected by the regulations and ensure the operational safety objectives are achieved.

4. Discussion

In the previous section, the enhanced conceptual design of UAS for the operational scenario of autonomous vigilance in agricultural land was presented. Initially, through the first version of CONOPS with assumed UAS design parameters resulted in an initial SAIL III. Later, when the UAS is designed and manufactured and the operator needs to perform a risk assessment of the system using SORA and present the analysis to the national authorities to obtain authorization, there are possibilities that the system design does not include all the safety features and requirements as specified by the standards. For instance, the system may not meet the required TMPR criteria, as it may not have been considered during the design phase.

Additionally, to demonstrate that the required safety objectives for the operation have been achieved, on analyzing OSOs for SAIL III, the associated robustness levels were either low or medium with the exception of high for a few, which further indicated that demonstrating compliance with defined safety objectives could be complicated for the operator [11]. These may be sometimes complicated to achieve for relatively simple operations, such as demonstrating that system design and established procedures are drafted following particularly strict standards with detailed evidence in the form of analysis, simulations, tests, and documentation. For instance, considering OSOs 8, 11, 14, and 21 related to the operational procedures, a high robustness level is to be achieved, which requires the validation of procedures, flight tests, checklists, and simulations by a competent third party. In such a scenario, the operator may need to implement other operation-related mitigations to lower the level of SAIL that may or may not be favorable for a given scenario, failing which, operational restrictions would be introduced limiting the objective of the operation.

On the contrary, when the CONOPS was iterated as proposed by the process described in figure 1, where the requirements derived through different steps of SORA were included in the conceptual design, the final SAIL was estimated as SAIL II. This is lower than the initial SAIL, and consequently, on analyzing robustness levels of OSOs, it was observed that they were mainly optional or low with few exceptions of medium, which are relatively easier to achieve and demonstrate by the operator, although it is always recommended to ensure the safety of UAS both from design and operation aspects.

Furthermore, since the conceptual design was enhanced directly through the requirements of SORA that finally need to be demonstrated for operation by the operator to receive the operational authorization if implemented efficiently, the final system would demonstrate all necessary safety aspects as demanded by SORA. For example, in the considered scenario, as the operation is in BVLOS and UAS must include essential measures to reduce residual air risk in the form of TMPR. Through the proposed approach, as these were integrated into the conceptual design in the initial design phase, the final system would contain and demonstrate all necessary equipment and specifications defined by regulations, which may be difficult to implement later after the UAS is manufactured. The major outcomes as achieved through the presented approach as summarized in table 6.

Parameters	Initial CONOPS	Final CONOPS
GRC	4	1
ARC	ARC-b	ARC-b
TMPR	Not considered	Requirements considered in the design phase
SAIL	III	II

Table 6 Outcome of enhancing UAS design through the proposed approach.

As a result of enhancing the conceptual design of the UAS for the said operation, through the proposed process, it was observed that it was possible to achieve a lower SAIL by introducing design requirements into the conceptual design, which is quite desirable for complicated operations. Additionally, the design as obtained following this novel approach ensured that the safety objectives established by the regulations were taken into consideration from the early design phases. Further, it included defining the specifications, systems, validation, and documentation requirements in the early phases of design, hence when the UAS would be manufactured, it would have all supporting material to demonstrate its compliance with the safety objectives already available, thus reducing the burden of the operator and any complications of introducing major design changes to realize the operation.

5. Conclusions

The paper presented an enhanced approach for UAS design considering a tailored version of the SORA methodology as a tool to determine and implement major safety objective requirements in the conceptual design phases. It was observed that through this proposed novel approach the UAS design conceptualized featured the desired systems, procedures, and safety aspects as expected by risk assessment through SORA when performed by the operator.

The case study demonstrated that through the proposed approach, not only there exists a possibility to introduce design modifications and approaches to maintain a lower SAIL, but also other necessary activities like consideration of particular standards, systems, analysis, simulations, flight tests, etc. could be supplied as complete requirements to the early design phase of the system. This consequently reduces the likeliness of a high SAIL as evaluated by the operator at the time of performing a risk assessment to obtain authorization from the concerned authorities, further avoiding the complexity of demonstrating compliance of applicable OSOs to achieve the associated robustness levels.

Additionally, in case the manufacturer is the operator as well, this approach can be extended to consider all aspects- design and operational in the initial phase of UAS design to highlight and consider the simulations, procedures, checklists, tests, training, etc. that would be necessary for the particular operation considered into the initial operation requirements, essentially reducing the amount of effort and resources to develop evidence and procedures at a later stage.

It is important to note that, the aim of the approach is not only to possibly minimize the SAIL but in principle to ensure that the final UAS design exhibits all safety features and systems essential for the operation. This was evident through the inclusion of feasible mitigations and TMPR equipment and specifications as essential requirements in the conceptual design phase promising that the final system would exhibit these safety features.

This approach of predicting the requirements as would be necessary for operational authorization at a later stage and including them in the design process of the UAS from the early stages would be advantageous in several ways-

- Possibility of lowering the final SAIL, thus reducing the burden of demonstrating high robustness of OSOs.
- Eliminate the need to introduce major design modifications to the UAS at later stages when the operator performs SORA as a risk assessment before requesting operational authorization from the NAA.
- Maintain the necessary documentations, analysis, or simulations done during the design process or testing to be provided as MOCs for the various requirements introduced by the novel regulatory framework.
- save the time and effort in performing the SORA at a later stage before operation since the necessary documentation, evidence of analysis and simulations, etc. will already be available from the design process which had been carried out in accordance with the guidelines as extracted from SORA.

This paper presented an optimized design approach that considered the safety aspect of the UAS and its operations from the early design phase, using SORA as an added criteria aiding in defining the requirements to ensure that UAS meets the required safety objectives. Lastly, it is considered interesting to explore the possibility of further optimizing this enhanced UAS design process for conceptualizing UAS design, in a way to enable the same system is able to perform a wide range of operations perhaps introducing a modular approach for operations in different scenarios.

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8. Contact Author Email Address

Rupal Kalra- rupal.kalra@alumnos.upm.es

9. Funding

This Industrial Doctorate research, developed at Universidad Politécnica de Madrid and Drone Hopper S.L. , received a grant from Comunidad Autónoma de Madrid (CAM), under the program ‘Ayudas para la Realización de Doctorados Industriales en la Comunidad de Madrid’, with ID- IND2019/IND-17206