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Operational Risk Assessment for Airworthiness Certification of Military Unmanned Aircraft Systems using the SORA Method

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Abstract

Unmanned Aircraft Systems (UAS) are rapidly emerging not only as a key military power, such as surveillance and reconnaissance for military purposes but also as a new air transportation means in the form of Urban Air Mobility (UAM). Currently, airworthiness certification is carried out focused on the verification of technical standards for flight safety suitability of aircraft design in accordance with the Military Aircraft Flight Safety Certification Act and does not employ the model for operational risk assessment for mission areas and airspace. In this study, in order to evaluate the risk of the mission area from the perspective of the UAS operator, a risk assessment simulation has been conducted by applying the Specific Operations Risk Assessment (SORA) model to the operating environment of the Korean military UAS. Also, the validity of the SORA model has been verified through the analysis of simulation results, and a new application plan for airworthiness certification of the military unmanned aerial system has been presented.

Key Words : UAS(Unmanned Aircraft System), UAM(Urban Air Mobility), JARUS(Joint Authorities for Rulemaking on Unmanned Systems), SORA(Specific Operations Risk Assessment), Airworthiness Certification

1. Introduction

In February 2021, the Korean government announced the 3rd Basic Plan for Aviation Industry Development under the joint multi-ministerial partnership initiatives [1]. The basic plan that presents the future vision of the Korean aviation industry for the next 20 years includes the civil-military aviation industry development plan that links the recent strong interest in Urban Air Mobility (UAM) development and aircraft development technology in the civil sector to military aircraft development.

The technological advancement in the area of Artificial Intelligence (AI) and big data, which forms the core of the 4th industrial revolution, will play as a growth engine for the development of Unmanned Aircraft System (UAS) such as autonomous flying UAM, and will emerge as a key player in the national aviation industry. Seeing this situation, large enterprises and Small and Medium Enterprises (SMEs) are currently focusing their capabilities on the development of UAS. Also, the development ecosystem of UAS technology in the private sector is expected to greatly contribute to the localization of the UAS in the military.

Due to the characteristics of the UAS that has to be operated as a system composed of air vehicle, ground control system, and datalink, airworthiness certification of UAS demands a comprehensive approach covering not only safety assessment of individual system components from the technical perspectives but also risk assessment of the whole system considering operational environment including airspace and mission area.

In accordance with the Military Aircraft Flight Safety Certification Act, the Defense Acquisition Program Administration (DAPA) is responsible for

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conducting flight safety certification of military UAS, focusing on technical verification to determine compliance with airworthiness certification criteria.

More recently, Joint Authorities for Rulemaking on Unmanned Systems (JARUS), an international expert group of UAS from national rulemaking authorities, published a Specific Operations Risk Assessment to provide guidance that can be used to approve a flight operation by evaluating the ground and air risks from the comprehensive operational perspectives of UAS in January 2019 [2].

In this paper, considering the operational characteristics of the UAS, applicability of the SORA methodology to military UAS has been examined to evaluate the risk level of the military UAS operation. As a result, the new proposed scheme for military UAS using the SORA model has been proved to be effective for the purpose of military UAS certification.

2. Airworthiness Certification of Korean Military UAS

2.1. Military UAS Airworthiness Certification

In 2009, the Republic of Korea enacted the "Act on Certification of Flight Safety for Military Aircraft" (hereafter referred to as the 'Airworthiness Certification Act') to secure the safety of flight for military aircraft [3]. The Act classifies the definition of UAS within the scope of military aircraft as shown in Table 1.

Table 1 Military UAS Classification

Classification	Description
UAS or Unmanned Rotorcraft	· MTOW over 25 kg, Armed or equipped with a device for arming, transporting weapon or fuel
Airship	· Excluding fuel weight, its own weight exceeds 12 kg or its length exceeds 7 m · Armed or equipped with a device for arming

Since unmanned powered flying device up to 25kg is not subject to safety assessment, the Airworthiness Certification Act included the aircraft exceeding 25kg in maximum takeoff weight in the UAS category. In addition, any UAS equipped with a device for arming, ammunition, and oil transport for military purposes is subject to airworthiness certification regardless of the maximum takeoff weight in accordance with the Airworthiness Certification Act.

2.2. Category of Military UAS Airworthiness Certification

There are two categories of airworthiness certification as "general" and "special" in military UAS. In general airworthiness certification, both type certification and production verification steps using airworthiness certification standards and procedures are applied. When general airworthiness certification is not appropriate to apply, special airworthiness certification applies. Major differences between the two types of airworthiness certification are compared and summarized in Table 2 [4].

Table 2 Category of Military Airworthiness Certification

Airworthiness Category	Description
General Airworthiness Certification	Proving that the design meets the airworthiness certification standards for each model and is suitable for flight safety · In case of Type Certification
Special Airworthiness Certification	Cannot be conducted by applying the General Airworthiness Certification · In case of temporary operation for research, testing, export, or promotion purposes · In case of purchase, modification or upgrade airworthiness is confirmed

2.3. Procedure of Military UAS Airworthiness Certification

2.3.1. General Airworthiness Certification

The general airworthiness certification procedure toward a type certification of the military UAS is shown in Fig 1. Depending on the outcome of airworthiness examination carried out by the DAPA, if there are any items that do not meet the airworthiness certification standards, analysis of the degree of impact on flight safety through the technical risk assessment of the airworthiness certification standard needs to be performed for submission to the DAPA.

2.3.2. Special Airworthiness Certification

As shown in Table 2 of Section 2.2, the special airworthiness certification of the military UAS is applied to such cases as research, test, purchase, and performance improvement. Therefore, the airworthiness certification procedure is performed on a case-by-case basis. In the case of temporary airworthiness certification for flight approval such as research and testing, airworthiness certification is issued through review of evidence materials only with restrictions such as period of flight without applying airworthiness certification standards. Also, the applicants for airworthiness certification are expected to analyze the safety of the mission area and airspace where they plan to fly. This means that risk assessment result needs to be submitted to DAPA, and to the airworthiness certification evaluation board for their final decision if necessary.

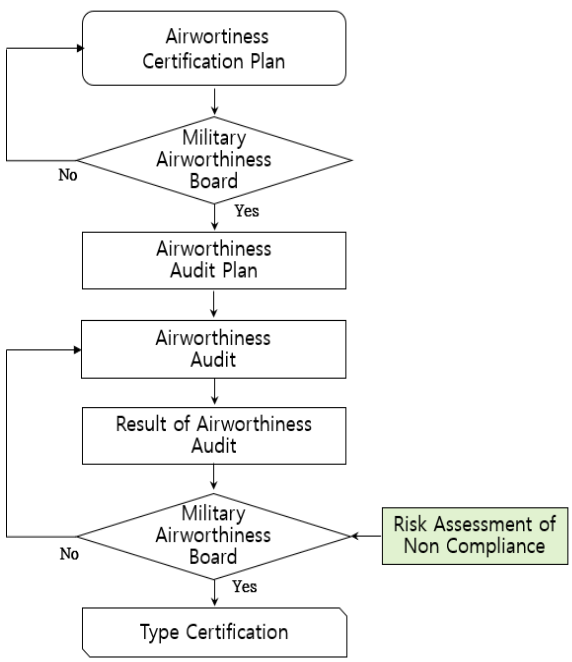

Figure 1 Type Certification Flow Chart

2.4. Risk Assessment in Airworthiness Certification

2.4.1. Target of Risk Assessment

Code of Practice for Flight Safety Certification of Military UAS (DAPA Instruction No.619) prescribes that MIL-STD-882E [5] should be used for risk assessment when non-compliance item is identified as a result of airworthiness review for UAS type certification or when the impact on airworthiness is to be evaluated following modification of UAS. Also, those who wish to apply for airworthiness certification for temporary flight for the purpose of research and test are required to submit technical evidence for airworthiness substantiation and analysis report of airspace and mission area to DAPA for their assessment.

2.4.2. Risk Assessment Method

The risk assessment of the military UAS is carried out by calculating the severity classification and the probability of a failure as shown in Table 3 and Table 4 respectively.

Table 3 Severity Level

Description (Category)	Mishap Result Criteria
Catastrophic (1)	Death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to or exceeding $10 M
Critical (2)	Permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, reversible significant environmental impact, or monetary loss equal to or exceeding $1 M but less than $10 M
Marginal (3)	injury or occupational illness resulting in one or more lost work day(s), reversible moderate environmental impact, or monetary loss equal to or exceeding $100 K but less than $1 M
Negligible (4)	injury or occupational illness not resulting in a lost work day, minimal environmental impact, or monetary loss less than $100 K

Table 4 Probability Level

Description	Level	Description
Frequent	A	Likely to occur often in the life of an item
Probable	B	Will occur several times in the life of an item
Occasional	C	Likely to occur sometime in the life of an item
Remote	D	Unlikely, but possible to occur in the life of an item
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced in the life of an item
Eliminated	F	Incapable of occurrence. This level is used when potential hazards are identified and later eliminated

The level of risk is then evaluated by substituting these values into the risk evaluation criteria and looking up the intersections of the corresponding columns and rows as shown in Table 5. The risk level is determined as one of High, Serious, Medium, and Low grades [5]. The detailed criteria for each item can be found in MIL-STD-882E Department of

Defense Standard Practice System Safety.

Table 5 Risk Assessment Matrix

Severity / Probability	Catastrophic	Critical	Marginal	Negligible
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Serious	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

2.4.3. Limitation of Risk Assessment

The risk assessment of MIL-STD-882E is a procedure to determine the severity of erroneous basic design and the faulty installed component on the operation of UAS during the system development process for military UAS. However, since this specification is focused on the technical evaluation such as hardware and software related to the design features of the UAS, it does not specify the evaluation criteria for the environment in which the military UAS is operated. This includes the population density of the mission area and the possibility of air collision in the flight airspace. In particular, given the high population density on the small land area and complex flight airspace, system safety and risk assessment for the operating environment are considered to be very important factors for the test flight of UAS. Nevertheless, MIL-STD-882E has no specific measures therefore the evaluation of operational risk in the flight area is not properly addressed.

3. SORA, New paradigm of Risk Assessment

3.1. Background and Concept of SORA

The European Commission enacted the Commission Implementing Regulation 2019/947 for the operation of the UAS in May 2019. The operation of UAS is classified as Open, Specific, and Certified based on the risk posed by the proposed operation. The open category of operation has a low level of risk therefore it is possible to fly in compliance with the prescribed flight rule. The Specific category means that risk assessment is required to evaluate the operational risk so that appropriate mitigation measures could be introduced to reduce the risk to an acceptable level. The Certified category of operation is where the risk of the operation is too high to be mitigated without certification of the UAS. Design features of the UAS and operating conditions must be met for the characteristics of each operational area [6].

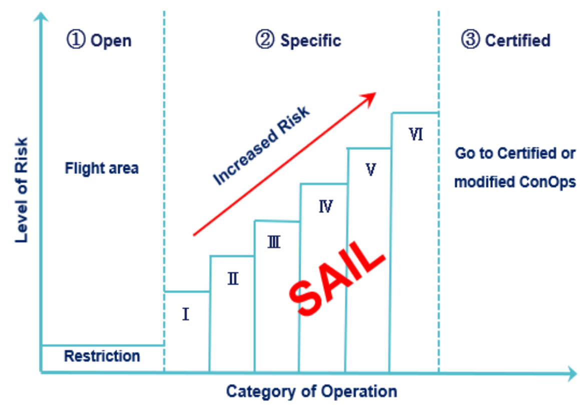

Figure 2 Concept of SORA

Recognizing the necessity of a new standard risk assessment method for the area to fly in addition to the existing technical safety verification that is used in developing UAS, JARUS proposed a new SORA methodology that can be applied to a specific category of operation among three UAS categories. It is a new risk assessment model established in January 2019 with the aim of providing a guideline for risk assessment within UAS perspectives to evaluate the risk of the ground and airspace.

As shown in Figure 2, the operation of UAS is categorized into Open, Specific, and Certified based on the level of risk. In the Open category, there is no regulatory involvement provided that the operator complies with prescribed rules such as VLOS and a maximum height of 120m because the risk level of the operation is low enough to be acceptable. In the case of the Certified category which represents the highest level of risk, UAS operation needs to be regulated in the same way as the traditional manned aviation including type certification of the air vehicle.

In the Specific category of operation, risk assessment is required to evaluate the level of risk in order to determine the Specific Assurance Integrity Level (SAIL) which represents the level of risk that is proportional to the type of operation within the Specific category. Since higher SAIL approaching the certified area means a higher level of risk, the applicant for flight approval must take mitigation measures such as separate certification or modification of the operational concept [7].

3.2. Example of SORA Model Application

The European Aviation Safety Agency (EASA) adopted the SORA model as an Acceptable Means of Compliance (AMC) for operational risk assessment of UAS in the new Implementing Regulation 2019/947 enacted in 2019 [8].

Many European countries, including Switzerland, have already adopted the SORA model for risk assessment of UAS [9] and many application cases for commercial UAS operations have been approved using the SORA methodology [10].

3.3. SORA Model Procedure

SORA process determines the risk class based on the concept of operation proposed by the applicant for flight approval and demonstrates suitability for the operational safety objectives that are allocated proportionally in accordance with the robustness level. Figure 3 below shows the flowchart of the 10 systematic steps for the SORA process [11].

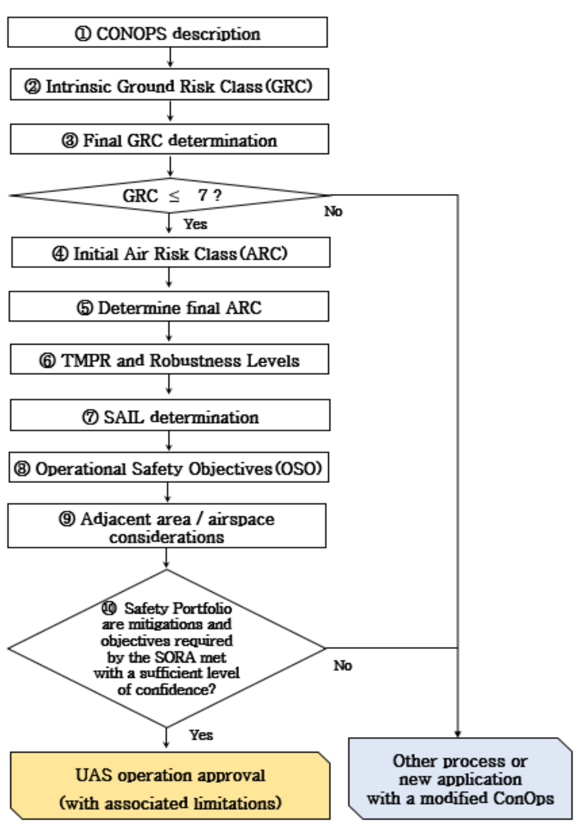

Figure 3 Flowchart of SORA

In order to evaluate the risk posed by the proposed operation and the suitability of mitigation measures to reduce such risk to an acceptable level, SORA methodology begins with the assessment of ground and air risks, which are detailed in Section 3.4. When the reliability level of the operational safety objectives required by the SORA is substantiated through the applicant's risk mitigation measures, the proposed operation is approved with any applicable limitations, if necessary.

3.4. Input Parameter of SORA Model

As shown in Figure 3, the input parameters required for the SORA process are composed of Ground Risk Class (GRC), Air Risk Class (ARC), Tactical Mitigation Performance Requirement (TMPR), Specific Assurance Integrity Level (SAIL), and Operation Safety Objectives (OSO).

3.4.1. Concept of Operation

The Concept of Operation (ConOps) is prepared by the applicant who proposes an operation of UAS in the specific category described in Section 3.1. The ConOps typically includes the flight operational range, related technology, and system information. Also, the ConOps could be updated during the course of the SORA process because the level of risk initially evaluated, depending on the additional risk or mitigation identified later, may increase or decrease.

3.4.2. Ground Risk Class (GRC)

The ground risk is associated with the kinetic energy that is transferred to a person on the ground by the UAS therefore environmental conditions need to be considered to determine the ground risk class. In order to find a ground risk class, the applicant first needs to know the maximum dimension of the unmanned aircraft and the mode of operation as shown in Table 6.

Initial GRC is determined as an intersection between the vertical axis representing the maximum dimension or kinetic energy of the UAS and the horizontal axis representing a mode of operation. Then, mitigation measures could be applied to reduce the GRC level using technical means to lower the kinetic energy expected when the air vehicle collides with the ground.

Table 6 Ground Risk Class

Max UAS Dimension	1m	3m	8m	>8m
Kinetic Energy	<0.7kJ	<34kJ	<1,084kJ	1,084kJ
VLOS/BVLOS	1	2	3	4
VLOS in sparsely populated	2	3	4	5
BVLOS in populated	3	4	5	6
VLOS in populated	4	5	6	8
BVLOS in populated	5	6	8	10
VLOS in over gathering of people	7	Go to Certified Category		
BVLOS in over gathering of people	8			

The value of GRC is proportional to the level of risk that affects people on the ground and can be determined between 1 and 10 as presented in Table 6. Fig.4 shows the relationship between the GRC values and the corresponding severity level defined by the FAA [12].

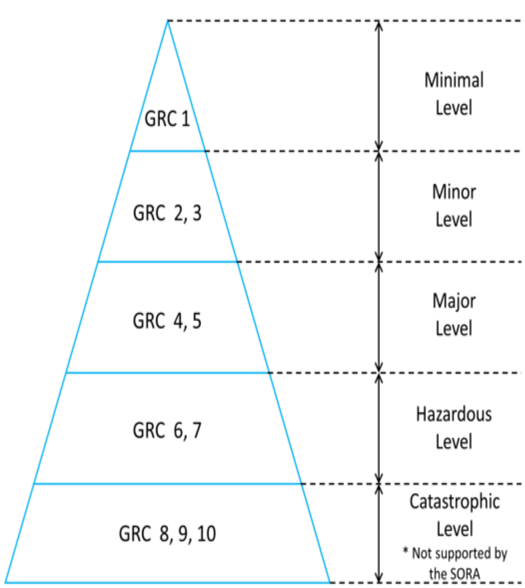

Figure 4 Severity of Ground Risk Class

3.4.3. Air Risk Class (ARC)

The initial air risk class is determined based on the airspace characteristics requested in the Concept of Operation, and strategic mitigations such as specific airspace could be applied final class as shown in Table 7.

Table 7 Air Risk Class

ARC	Description
a	Almost no probability of encountering a manned aircraft in the flight area
b	Possibility of encountering a manned aircraft in the flight area is low
c	Possibility of encountering a manned aircraft in the flight area is rich
d	Probability of encountering manned aircraft in the flight area is very high

3.4.4. Tactical Mitigation Performance Requirement (TMPR)

In order to mitigate the residual air risk determined in the previous step, tactical mitigations that are necessary to achieve the target level of safety are introduced. Tactical Mitigation Performance Requirement (TMPR) is assigned as shown in Table 8 based on the initial ARC. For BVLOS operation, such measures as TCAS (Traffic Collision Avoidance System) and ADS-B (Automatic Dependent Surveillance-Broadcast) could be used to comply with the requirement. Otherwise, see and avoid under VLOS operation is considered as acceptable tactical mitigation for air risk.

Table 8 Determination of TMPR

ARC	Determination of TMPR
a	No requirement
b	Low
c	Medium
d	High

3.4.5. Specific Assurance Integrity Level (SAIL)

SAIL indicates the level of operational risk for the specific mission area where the applicant intends to fly when operating the UAS through the ground risk determined in Section 3.4.2 and the air risk calculated in Section 3.4.3. A higher value of the SAIL means that the risk of the operation is high. Table 9 is used to determine the value of SAIL, which ranges from I to VI depending on the GRC and ARC.

Table 9 Determination of SAIL

GRC	ARC			
	a	b	c	d
≤2	I	II	IV	VI
3	II	II	IV	VI

4	III	III	IV	VI
5	IV	IV	IV	VI
6	V	V	V	VI
7	VI	VI	VI	VI
>7				

3.4.6. Operational Safety Objectives (OSO)

A total of 24 Operational Safety Objectives that have been used historically to ensure the safe operation of UAS needs to be evaluated with appropriate robustness levels based on associated SAIL values. The robustness of the operational safety objective is an important factor that determines the level of risk mitigation for the applicant to demonstrate.

Table 10 Determination of OSO

Flight Operation Scenario	SAIL					
	I	II	III	IV	V	VI
Ensure the operator is competent and/or proven	L	L	M	M	H	H
UAS manufactured by competent and/or proven entity	O	O	O	L	M	H
UAS maintained by competent and/or proven entity	O	O	L	M	H	H
UAS developed to authority recognized design standards	O	L	L	M	H	H
UAS is designed considering system safety and reliability	L	L	M	M	H	H
C3 link performance is appropriate for operation	L	M	H	H	H	H
Inspection of the UAS to ensure consistency to the ConOps	L	L	M	M	H	H
Operational procedures are defined, validated and adhered to	L	M	H	H	H	H
Remote crew trained and current and able to control the abnormal situation	L	L	M	M	H	H
Safe recovery from technical issue	L	L	M	M	H	H
Procedures are in-place to handle the deterioration of external systems supporting UAS operation	L	M	H	H	H	H
The UAS is designed to manage the deterioration of external systems supporting UAS operation	L	L	M	M	H	H
External services supporting UAS operations are adequate to the operation	L	L	M	H	H	H
Operational procedures are defined, validated and adhered to	L	M	H	H	H	H
Remote crew trained and current and able to control the abnormal situation	L	L	M	M	H	H
Multi crew coordination	L	L	M	M	H	H
Remote crew is fit to operate	L	L	M	M	H	H
Automatic protection of the flight envelope from Human Error	O	O	L	M	H	H
Safe recovery from Human Error	O	O	L	M	M	H
A Human Factors evaluation has been performed and the HMI found appropriate for the mission	O	L	L	M	M	H
Operational procedures are defined, validated	L	M	H	H	H	H
The remote crew is trained to identify critical environmental conditions and to avoid them	L	L	M	M	M	H
Environmental conditions for safe operations defined, measurable	L	L	M	M	H	H
UAS designed and qualified for adverse environmental conditions	O	O	M	H	H	H

3.5. Comparison with MIL-STD-882E and SORA

Both MIL-STD-882E and SORA model are used as risk assessment procedures. Although the evaluation targets and items are different, the final result plays as a criterion in the judgment of the process for impact on the flight safety. As shown in Table 11, MIL-STD-882E mainly focuses on a technical risk aspect for the impact of unmanned aerial vehicle defects on flight safety. On the other hand, the SORA model is designed to evaluate the operational risk for ground and airspace in consideration of the operational characteristics of UAS.

Table 11 MIL-STD-882E and SORA

ITEM	MIL-STD-882E	SORA
Application	Military	Civil
Vehicle	Man & Unmanned	Unmanned
Input factor	Severity and probability of fault	Ground & Air risk
Output	Risk Level	Risk Level

4. SORA Model Risk Assessment Simulation

4.1. Simulation Method and Application

In the simulation, the ground and air risks were calculated based on the typical mission area of the Korean military UAS following the step-by-step procedure proposed in the SORA methodology. The ground risk level was determined assuming the populated area typical to the operation of the forward units, and the air risk level was applied to the mission altitude for each UAS article to be examined.

UAS I	Performance
	· MTOW : 34 kg · Dimension : 1 m · Vmax : 75.6 km/h · Operation Altitude : MSL 1,500 ft · Endurance : 2 hr
UAS II	Performance

· MTOW : 150 kg
· Dimension : 4 m
· Vmax : 198 km/h
· Operation Altitude : MSL 10,000 ft
· Endurance : 5 hr

Figure 5 UAS I and UAS II

As shown in Figure 5, the vertical take-off and landing UAS (hereinafter referred to as 'UAS I') with a maximum take-off weight (MTOW) of 34 kg and a fixed-wing UAS with a maximum take-off weight of 150 kg (hereinafter referred to as 'UAS II') were selected among military UAS currently in operation for the military service. The characteristic dimensions of the UAS have been rounded to the one decimal place to apply the ground risk calculation criteria presented in Table 6 of Section 3.4.2.

4.2. Simulation Step and Procedure

The simulation was performed following steps 1~8 as per the procedure proposed by the SORA model as shown in Figure 3. Steps 9 and 10 are the provisions prepared to suggest risk mitigation measures, so they have been excluded from the scope of this paper. For risk assessment, the input coefficients described in the previous Section 3 were determined based on the performance of UAS Ⅰ and Ⅱ as well as the military flight operation environment. Specific Assurance Integrity Level was then identified as per the result, and verification of the compliance with the operational safety goal has been conducted.

4.2.1. Simulation Input parameter

4.2.1.1. Ground Risk Class (GRC)

In order to determine the input coefficients for UASⅠ and Ⅱ, typical military UAS missions were assumed to be operated in BVLOS mode and sparsely populated environment. Table 12 shows the GRC values for UAS I and UAS II calculated using Table 6 in Section 3.4.2 with a maximum dimension of the UAS or kinetic energy at impact on the ground.

$$\mathrm{KE} = \frac{1}{2} m V^2 \ (\mathrm{J}) \quad (1)$$

Kinetic energy is calculated using Equation (1) based on the weight (m) and the flight speed (V) of the air vehicle. As for the speed, the maximum flight speed is used for fixed-wing aircraft, and the terminal speed is used for all other configurations. In the case of UAS Ⅰ, the terminal speed was not known therefore 1.3 times the maximum flight speed was applied with reference to the airworthiness certification policy statement for UAS [13].

As summarized in Table 12, there are mismatches in GRC values between maximum UAS dimension and kinetic energy for both UAS I and UAS II cases. In this case, the JARUS guideline for SORA recommends substantiation for the chosen decision. In this study, higher values of 4 for UAS I and 5 for UAS II determined from kinetic energy have been chosen because a conservative, safer approach would be more appropriate.

Table 12 GRC of UAS I and UAS II

UAS I		UAS II	
Max UAS Dimension	Kinetic Energy	Max UAS Dimension	Kinetic Energy
1 m	12.7 kJ	4 m	226.9 kJ
GRC 3	GRC 4	GRC 4	GRC 5

4.2.1.2. Air Risk Class (ARC)

Initial ARC (Air Risk Class) for the typical airspace expected for military UAS operation is determined from the probability of air encounters with the manned aircraft when UAS I and II fly in the mission airspace. Considering its low mission altitude of 1,500 ft for typical operation of the UAS I, the probability of encounters with the civilian manned aircraft is relatively low. On the other hand, in the case of UAS II, the possibility of encountering the manned aircraft is high because it flies at a mission altitude of 10,000 ft. With this information in mind, the criteria table for the air risk class presented in Table 7 of Section 3.4.3 has been used to find a corresponding air risk level as shown in Table 13.

Table 13 ARC of UAS I and UAS II

Item	UAS I	UAS II
Probability to detect other aircraft	Low	Medium
Detect and Avoid	No	No

Air Space Controller	Yes	Yes
ARC	b	c

4.2.1.3. Tactical Mitigation Performance Requirement (TMPR)

The Tactical Mitigation Performance Requirement is the required level for air risk mitigation determined in Section 4.2.1.2. Depending on the level of ARC, TMPR is evaluated qualitatively such as High, Medium, Low, and No Requirement. The required level of TMPR for UAS I and UAS II identified using the decision criteria provided in Table 8 of Section 3.4.4 are summarized in Table 14.

Table 14 TMPR of UAS I and UAS II

Item	UAS I	UAS II
ARC	b	c
TMPR	Low	Medium

4.2.1.4. Specific Assurance Integrity Level (SAIL)

Table 15 shows the result of SAIL determined by substituting the ground risk and air risk levels into the SAIL calculation criteria table presented in Table 9 of Section 3.4.5 for UAS I and II and identifying the corresponding intersection. SAIL is a numerical value indicating the level of risk in the ground and air environment in which the military UAS is intended to be operated, and serves as a standard for selecting Operational Safety Objective (OSO).

Table 15 SAIL of UAS I and UAS II

Input Item	UAS I	UAS II
GRC	4	5
ARC	b	c
SAIL	III	IV

4.3. Simulation Results and Analysis

4.3.1. Simulation Results

Table 16 and Table 17 show the operational safety objectives of UAS I and Ⅱ determined from Table 10 of Section 3.4.6 as the final result of the SORA model.

Table 16 Operational Safety Objectives level

Flight Operation Scenario	Level	
	UAS I	UAS II
Ensure the operator is competent and/or proven	M	M
UAS manufactured by competent and/or proven entity	O	L
UAS maintained by competent and/or proven entity	L	M
UAS developed to authority recognized design standards	L	M
UAS is designed considering system safety and reliability	M	M
C3 link performance is appropriate for operation	H	H
Inspection of the UAS to ensure consistency to the ConOps	M	M
Operational procedures are defined, validated and adhered to	H	H
Remote crew trained and current and able to control the abnormal situation	M	M
Safe recovery from technical issue	M	M

In the case of UAS I , the simulation result shows that 5 OSO items associated with datalink and operational procedures are High, 5 OSO items related to human errors are Low, and the other OSO items such as design and maintenance and operator and crew competence are Medium. As for the UAS II, manufacturing capability-related OSO items were evaluated as Low, 7 operational OSO items were evaluated as High, and the other 16 OSO items were evaluated as Medium.

Table 17 Operational Safety Objectives level(Continued)

Flight Operation Scenario	Level	
	UAS I	UAS II
Procedures are in-place to handle the deterioration of external systems supporting UAS operation	H	H
The UAS is designed to manage the deterioration of external systems supporting UAS operation	M	M
External services supporting UAS operations are adequate to the operation	M	H
Operational procedures are defined, validated and adhered to	H	H
Remote crew trained and current and able to control the abnormal situation	M	M
Multi crew coordination	M	M
Remote crew is fit to operate	M	M
Automatic protection of the flight envelope from Human Error	L	M
Safe recovery from Human Error	L	M
A Human Factors evaluation has been performed and the HMI found appropriate for the mission	L	M
Operational procedures are defined, validated	H	H
The remote crew is trained to identify critical environmental conditions and to avoid them	M	M

Environmental conditions for safe operations defined, measurable	M	M
UAS designed and qualified for adverse environmental conditions	M	H

4.3.2. Result Analysis

The analysis result of risk assessment simulation using the SORA model for military UAS can be summarized as follows.

For UAS Ⅰ, most OSO requirements except a few out of 24 items could be satisfied with Low or Medium level of robustness. The main contributing factor for this result is the low kinetic energy level of the UAS I which has only 34kg in MTOW and wing span of 1m despite being operated at 1500ft altitude in BVLOS and sparsely populated environment. It should be noted that some operational elements such as data link and the control system of the UAS still need to be substantiated with a High level of robustness.

In UASⅡ, there are 7 OSO items are High, and 16 items are Medium level. This is due to its much higher kinetic energy value caused by heavier maximum take-off weight and higher flight speed. As a result, applicants are required to take intensive risk mitigation measures such as the installation of air collision avoidance equipment or modification of the concept of flight operation.

5. SORA Model Application Scheme based on the Simulation Result

5.1. General Airworthiness Certification

In order to address the non-compliant items during the process of general airworthiness certification, it is regarded as the best way to satisfy the airworthiness certification standard through a design change. However, the Code of Practice for Flight Safety Certification of Military UAS prescribes that airworthiness certificates could be approved via temporary or permanent exemption as long as the result of risk assessment using MIL-STD-882E shows that there is no or little impact on flight safety.

Therefore, if there is any non-compliant item has been identified, the SORA model could be adopted to analyze the level of risk posed by the UAS operation in the proposed mission area and airspace so that the result could be used as additional evidence to determine the relevant impact on the flight safety.

5.2. Special Airworthiness Certification

For temporary flight approval for the purpose of research and testing of the military UAS, applicants are required to analyze the safety of the mission area and airspace where they intend to operate along with the test results and other supporting data, however, no analysis models that can be used are currently available. In the case of special airworthiness certification, simulation results performed for UAS I and UAS II showed that the SORA model is an effective modelling tool to determine the level of flight safety through its systematic risk assessment procedure. In other words, since the SORA model is effective in determining the impact of flight safety such as flight airspace, it can be applied as a method to supplement the limitations of verifying technical substantiation data that is required by the Code of Practice for Flight Safety Certification of Military UAS.

6. Conclusions

The airworthiness certification of the military UAS for the purpose of military operational capability through system development can be classified into General Airworthiness Certification which issues a type certificate through the determination of whether standard airworthiness certification standards or other airworthiness certification standards have been met, and Special Airworthiness Certification for which issuance of airworthiness certificates is provided for temporary flights in the designated area.

This study presented a risk assessment method for military UAS by applying the SORA model, a new paradigm for the risk assessment of UAS operation, in the general and special airworthiness certification process. In order to examine the feasibility of applying the SORA model to airworthiness certification of military UAS, GRC and ARC have been determined to use as an input for the simulation.

According to the simulation results, the maximum take-off weight of the UAS system for vertical take-off and landing of 34 kg presented a moderate risk thus can fly by complying with the flight recommendations. On the other hand, it was analyzed that the fixed-wing UAS with a maximum take-off weight of 150 kg was evaluated as a high-risk level so risk mitigation measures such as airworthiness certification following separate airworthiness certification procedures or installing air collision prevention equipment are necessary to reduce the risk level. Although the SORA model was originally developed for the civil aviation domain, it can be used as a qualitative risk assessment method for the mission environment such as the operation area of the military UAS.

Overall, conclusions of the simulation result of this study using the SORA model are twofold. First, in the general airworthiness certification process, the SORA model turned out to be effective in determining the impact of flight safety through an objective risk assessment on the operating environment in parallel with the technical risk assessment for those items that do not meet the airworthiness certification standards.

Second, in the special airworthiness certification process towards temporary flight approval for research and testing purposes, the outcome from the risk assessment using the SORA model can also be used as objective data in determining the impact of flight safety by evaluating the risk level in the flight area and airspace as a supplement to the limitation of technical verification.

When it comes to the limitation of the SORA model, since the SORA is mainly focused on risk assessment from the operational point of view of the UAS, it does not provide an in-depth insight into the verification of its design from the air vehicle perspective. In order to supplement this limitation, if the proposed operational risk assessment using the SORA model is performed concurrently with the technical verification of design suitability in accordance with the currently implemented Military Aircraft Flight Safety Certification Act, more objective verification of the impact of flight safety could be achieved.

Overall, the effectiveness of the SORA model was proven to be effective in the risk assessment of the military UAS. Also, it was confirmed that the SORA model can be implemented as an assessment tool to determine the impact of flight safety during the process of airworthiness certification.

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