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# Experiment results on test methods for detection and avoidance (DAA) systems for unmanned aircraft systems

~~This document is the first edition of the draft technical report, the contents may be revised, including the annexes and figures.~~

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This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 16, *Unmanned aircraft systems*.

~~A list of all parts in the ISO 15964 series can be found on the ISO website.~~

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# Introduction

With rapid technological advancements, unmanned aerial systems (UAS) technology is continuing to become more autonomous in operation and accessible to consumers. Today, the use of UAS technology is not only prevalent ~~in~~for entertainment ~~purpose~~purposes but also extending into more various industrial applications such as logistics, disaster release, powerline inspection~~, etc~~. There is an increasing number of UAS operations in low altitude airspace where the safety considerations can be quite complex, especially in the context of urban areas. All types of UAS operating in such areas ~~would need to~~must be able to avoid ground obstacles like high-rise buildings, cranes, public utilities such as power grid and mobile network antennas, ~~etc.,~~ along with airspace users that share the same airspace such as low-flying helicopters, UASs and kites. Micro-weather patterns also pose a challenge ~~for~~by bringing about uncertainty, invisibility, and unpredictability.

A detection and avoidance (DAA) system is one of the key onboard systems to address these challenges. By sensing the surrounding situations, the DAA system can examine the size and distance of a particular obstacle, apply trajectory planning, and then calculate the possibility of collision. It orders the flight control system to make UAS slow down, fully stop or completely offset the obstacle in a fully autonomous manner. The function and performance of the DAA system is closely related to its safety speed, which has a direct impact on the scope of UAS. Failure detection also causes instability and unexpected braking.

A related document about the DAA system, ISO 15964, is currently under development and~~ it~~ will focus on the standardization of hardware and software of each component of DAA such as sensors, computers, and interfaces. There is an expectation that there will be further work to standardize the test and evaluation methodologies of DAA capability to ensure that operators' safety and quality meet the minimum requirements, specifically for on-board/off-board DAA ~~Systems~~systems.

To achieve a safe and secure operating environment, it is significant to develop a technical report that provides examples for test results for the safety and quality of DAA systems. This document will offer reference to latest, detailed real-world applications of ~~modeling &~~modelling and simulation, equipment tests, and flight tests.

# Experiment results on test methods for detection and avoidance (DAA) systems for unmanned aircraft systems

## 1 Scope

This document provides a report on tests that were performed to ensure the "safety and quality" requirements of detection and avoidance (DAA) systems used between UASs and other objects, including aircraft. This document describes test methods and the results of related experiments, which successfully meet the requirements of a DAA system architecture with radar and optical sensors.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/



## 4 Test subject

DAA targets break down into cooperative, non-cooperative, and other hazards as defined in ISO 21384-3:2023, Table 1 - Operations of sequence elements at VLL and Table 2 - Operations of sequence elements above VLL. The test subject covered in this document is the applications of non-cooperative DAA systems that are installed onboard the UAS for the operational procedure defined in ISO 21384-3.



## 5 Evaluation &and test method

### 5.1 General

This document is expected to serve as a useful reference for the standardization work on the test and evaluation methods of DAA capability to ensure that operators' safety and quality meet the minimum requirements.

### 5.2 Type of detection and avoidance

This document's applications of DAA systems are limited to test evaluations of avoidance of aircraft approaching in flight, including helicopters flying at high speed to the proximity of UAS in flight.

Flight tests to evaluate the avoidance action are consistent with the 6-step operational procedure defined in ISO 21384-3. The applicable relative speed varies across different applications of DAA systems, while this document is limited to the test method of manned aircraft and UAS flying at the relative speed of up to 200km200 km/h and of UAS and UAS flying at the relative speed of up to 100km100 km/h.

## 6 Test item

### 6.1 General

There are three applications for the test item: modelling and simulation, equipment test and flight test.

## 6.2 Modelling and simulation

### 6.2.1 General

The purpose of modelling is to set the parameters used in the simulation process to enable the simulation-based evaluation of collision avoidance performance. For the detail of the experiment result, see Annex A~~Annex A.~~.

### 6.2.2 Modelling

#### 6.2.2.1 General

Examples of modelling subjects are avoidance mobility performance and visibility. 6.2.2.2~~The following sections~~ and 6.2.2.3 show possible evaluations of each modelling subject.

#### 6.2.2.2 Mobility performance

The mobility performance of UAS when performing detection and avoidance is evaluated. In the evaluation, the UAS makes several manoeuvres such as lateral movements, yawing, ascending, descending, acceleration and slowing down, while the ground equipment that consists of a high-speed camera, position measuring device, and anemometer ~~measure~~measures and ~~record~~records the avoidance mobility performance.

#### 6.2.2.3 Visibility

The visibility of UAS from the perspective of manned aircraft as well as the visibility of manned aircraft via optical sensors onboard the UAS are evaluated. In the evaluation, a safety margin distance is secured between the UAS and the manned aircraft, and the UAS moves away from the manned aircraft until the visibility reaches its limit, while the ground equipment that consists of a visibility meter measures the visibility.



### 6.2.3 Simulation

In the simulation stage, the avoidance performance is evaluated with several parameters using sensor models. Examples of parameters that compose different simulation patterns are shown in Table 1.[3] ~~Table1 [1].~~ The evaluation is undertaken based on the following four items: radar detection, image recognition, avoidance, and recovery.

**Table 1 — Examples of parameters setting in simulation**

| Parameters | Values |
|---|---|
| Angle of Intersection | 360 degrees at 15 degrees interval (24 patterns) |
| Route offset | from -~~600m~~600 m to ~~600m~~600 m at ~~100m~~100 m interval (13 patterns) |
| Altitude gap | -~~60m, 0m, 60m~~60 m, 0 m, 60 m (3 patterns) |
| Detection targets | 2 aircrafts (2 patterns) |

## 6.3 Equipment test

The equipment test is undertaken for the purpose of evaluating the equipment performance of detection of manned aircraft and UAS. In the evaluation, the performance is evaluated based on whether the equipment performs appropriately to obtain information required for avoidance. In each test, the UAS performs simulated avoidance manoeuvres to enable the evaluation of the detection performance of the manned aircraft or the UAS in flight. For the detail of the experiment result, see Annex B~~Annex B.~~.

## 6.4 Flight test

### 6.4.1 General

The flight test for ensuring the performance of detection of manned aircraft and UAS is undertaken in a consistent manner with the 6-step operational procedure defined in ISO 21384-3. A DAA path is generated to perform the detection and avoidance. The path can be consistent with the steps that are defined in accordance with ISO 21384-3, although the flight test shown in Annex C~~Annex C~~ was carried out in 5 steps where the 6th step was merged with the 5th step of returning to the original route.

### 6.4.2 Hardware ~~&~~and software used for each operational step

Table 2~~Table 2~~ shows the hardware and software used for each operational step. Depending on the relative speed requirements of targets approaching the own ship, Annex C~~Annex C/D~~/D or E~~E~~ can be used as a reference for the hardware and software subsystems to realize the operational steps outlined in ISO 21384-3. The speed values are derived from conditions set for the flight tests.

**Table 2 — Hardware & software used for each operational step**

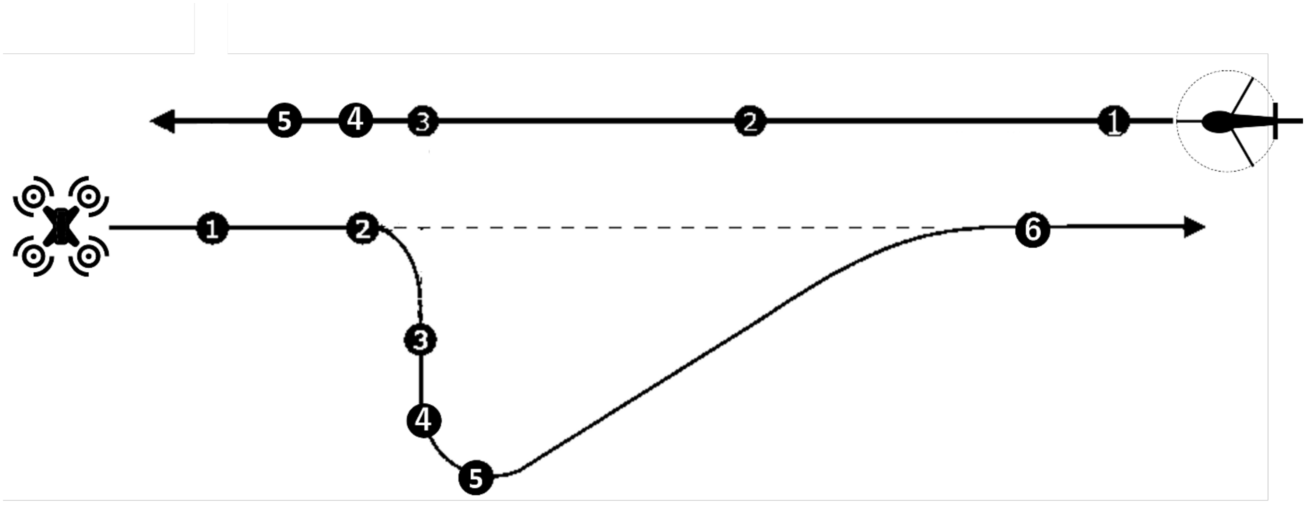
| | DAA operational procedure (ISO 21384-3~~, 11th chapter~~:2023, Clause 11) | DAA system (e.g. ISO 15964) | Annex C~~Annex C/D~~/D DAA test result (Relative speed of ~~100km~~100 km/h and ~~200km~~200 km/h for manned aircraft) | Annex E ~~Annex E~~ DAA test result (Relative speed of ~~100km~~100 km/h for UAS) |
|---|---|---|---|---|
| | Operational steps | Hardware ~~&~~and software | Hardware ~~&~~and software | Hardware ~~&~~and software |
| 1 | Detection of object | Radar | Radar | Optical sensor (~~Camera~~camera) |
| 2 | Recognize target | Optical sensor (~~Camera~~camera) | Optical sensor (~~Camera~~camera) | Optical sensor (~~Camera~~camera) |
| 3 | Manoeuvres | Processing unit | Processing unit ~~(~~[autonomous management system~~)~~] | Processing unit ~~(~~[autonomous management system~~)~~] |
| 4 | Check manoeuvres result | Optical sensor (~~Camera~~camera) | Optical sensor (~~Camera~~camera)[a] | Optical sensor (~~Camera)~~ camera)[a] |
| 5 | Return to original route | Optical sensor (~~Camera~~camera) | Optical sensor (~~Camera~~camera) | Optical sensor (~~Camera~~camera) |
| 6 | Fly on original route | Processing unit | Processing unit [b] | Processing unit[b] |

[a] In ISO 21384-3, the detection and avoidance are realized using optical sensors (cameras). However, ~~Step~~step 4 is omitted in experimental results mentioned in the Annexes. Nonetheless, the functionality of each sensor in the steps leading up to the avoidance manoeuvre is the same as specified in ISO 21384-3, providing evidence that it can demonstrate the avoidance of a manned aircraft flying at a relative speed of 200 km/h and a UAS flying at a relative speed of 100 km/h.

[b] The detection and avoidance test results in the Annex are presented in 5 steps, which is 1 step fewer than the 6 steps specified in ISO 21384-3. However, the operation indicated in the 6th step in the initial flight route represents a flight action and there is no technical difference between the two types of detection and avoidance manoeuvres.

Figure 1

~~Figure 1~~ shows the horizontal view of DAA operational steps between UAS and manned aircraft. Numbers 1 to 6 in the figure correspond to the 6-step operational procedure defined in ISO 21384-3 and the arrows indicate direction of travel.



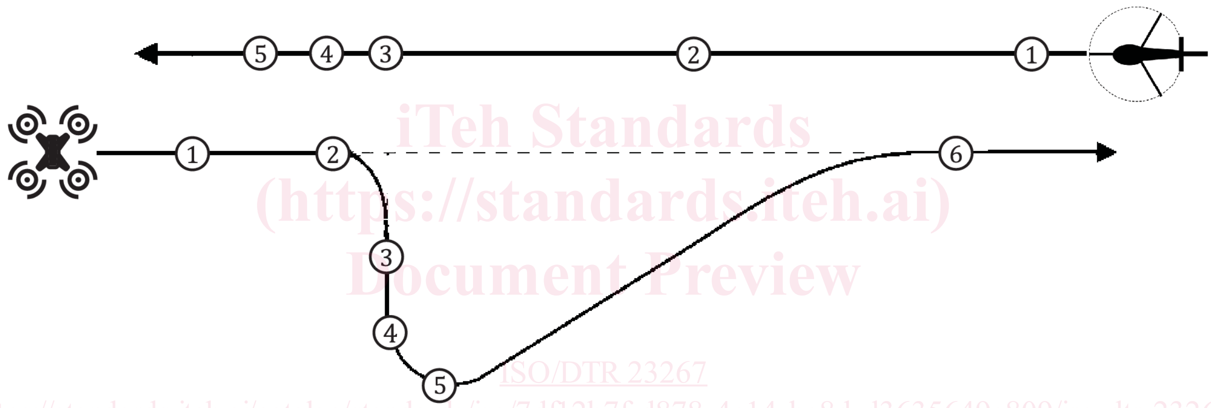




**Figure 1 — Horizontal view of DAA operational steps between UAS and manned aircraft**

### 6.4.3 Range

Table 3~~Table 3~~ shows the detection and recognition ranges for three DAA tests with relative speed of ~~200km~~200 km/h for manned aircraft and ~~100km~~100 km/h for UAS. For the detail of the experiment result, see Annex D~~Annex D~~ and E~~E.~~.

**Table 3 — The detection and recognition ranges for each DAA test**

| | DAA operational procedure (ISO 21384-3~~, 11th chapter~~:2023, Clause 11) | Annex D ~~Annex D~~ DAA test result (Relative speed of ~~200km~~200 km/h for manned aircraft) | Annex E ~~Annex E~~ DAA test result (Relative speed of ~~100km~~100 km/h for UAS) |
|---|---|---|---|
| 1 | Detection of object | ~~2km~~2 km, radar[7] ~~[5]~~ | - |
| 2 | Recognize target | ~~750m~~750 m, optical sensor[9] ~~[7]~~ | ~~250m~~250 m, optical sensor[9] ~~[7]~~ |