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

Résultats d'expériences sur les méthodes de test des systèmes de détection et d'évitement (DAA) pour les systèmes d'aéronefs télépilotés

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Foreword

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

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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 for entertainment purposes but also extending into more various industrial applications such as logistics, disaster relief, powerline inspection. 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 must be able to avoid ground obstacles like high-rise buildings, cranes, public utilities such as power grid and mobile network antennas, along with airspace users that share the same airspace such as low-flying helicopters, UASs and kites. Micro-weather patterns also pose a challenge 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 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.

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 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 and Table 2. 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 200 km/h and of UAS and UAS flying at the relative speed of up to 100 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.

6.2.2 Modelling

6.2.2.1 General

Examples of modelling subjects are avoidance mobility performance and visibility. 6.2.2.2 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 measures and 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] 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 -600 m to 600 m at 100 m interval (13 patterns)
Altitude gap	-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.

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 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 shows the hardware and software used for each operational step. Depending on the relative speed requirements of targets approaching the own ship, Annex C/D or 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 21384-3:2023, Clause 11)	DAA system (e.g. ISO 15964)	Annex C/D DAA test result (Relative speed of 100 km/h and 200 km/h for manned aircraft)	Annex E DAA test result (Relative speed of 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)
2	Recognize target	Optical sensor (camera)	Optical sensor (camera)	Optical sensor (camera)
3	Manoeuvres	Processing unit	Processing unit (autonomous management system)	Processing unit (autonomous management system)
4	Check manoeuvres result	Optical sensor (camera)	Optical sensor (camera)[a]	Optical sensor (camera)[a]
5	Return to original route	Optical sensor (camera)	Optical sensor (camera)	Optical sensor (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 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 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.

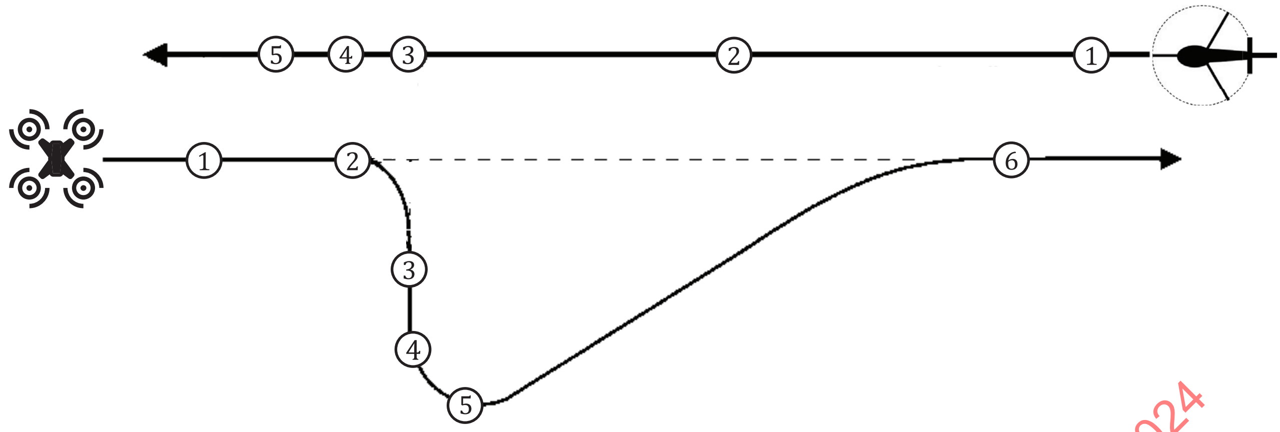

Figure 1 — Horizontal view of DAA operational steps between UAS and manned aircraft

6.4.3 Range

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

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

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

Annex A
(informative)

Modelling and simulation

A.1 Overview

This annex contains publicly available information on modelling and simulation. The release date for the reference is December 15th, 2017[3].

NEDO (New Energy and Industrial Technology Development Organization) and other collaborators carried out a visibility test of manned helicopters and UAS flying in the same airspace at the Fukushima Robot Test Field Development Site in the Futaba Industrial Park in Minamisoma City, Fukushima Prefecture, with the cooperation of the Fukushima Prefectural Government and the Minamisoma City Government. The tests were conducted sequentially from December 11th of 2017 and included the mutual visibility confirmation between the manned helicopter and UAS to clearly define the safe margin distance between them.

Collaborators:

— SUBARU CORPORATION

— enRoute Co., Ltd.

— Prodrone Co., Ltd

A.2 Details

— Multiple UASs were used along with manned helicopters to confirm the mutual visibility.

— The visibility of UAS was enhanced by use of lights and colours.

— Manned helicopters and UAS were flown together to confirm their visibility against backgrounds of the sky and ground.

— In addition, the Japan Meteorological Association provided comprehensive meteorological information for UAS, including wind observations using Doppler LIDAR at the heliports of manned helicopters and UAS, and provided the observation data and weather forecasts near the test area to the operators of UAS as part of the UAS meteorological information provision function.

Annex B
(informative)

Equipment test

B.1 Overview

This annex contains publicly available information on equipment test. The release date for the reference is December 14th, 2018[4][5].

NEDO (New Energy and Industrial Technology Development Organization) and other collaborators carried out an equipment test of DAA system installed in a medium-sized UAS at the Fukushima Robot Test Field in the Futaba Industrial Park, Minamisoma City, Fukushima Prefecture, from December 10th to 14th of 2018, with the cooperation of Fukushima Prefecture and Minamisoma City.

Collaborators:

— SUBARU CORPORATION

— Japan Radio Co., Ltd.

— Nippon Avionics Co., Ltd.

— Mitsubishi Electric Corporation

— ACSL Ltd.

Table B.1 shows medium-sized and small-sized UASs used in the experiment. During the test, a simulated detection and avoidance was performed where the medium-sized UAS followed a pre-designed path to avoid a manned helicopter hovering in the air. The UAS was equipped with various sensors and a Michibiki-compatible receiver. The test confirmed that the DAA system equipped in the medium-sized UAS operates appropriately allowing the UAS to detect the target object (manned helicopter in this case) during flight.

In addition, since small-sized UAS cannot be equipped with as many sensors as medium-sized UAS, it is not possible to conduct the same detection and avoidance tests. Therefore, a simulated flight test using ultra-compact sensors and a Michibiki-compatible receiver was conducted.

Table B.1 — Medium-sized and small-sized UASs used in the experiment

UAS	Manufacturer	Size	Weight	Names used in this document
Fazer G2	Yamaha Motor Co., Ltd.	Length: 3,7 m	110 kg	Medium-sized UAS
ACSL PF1	ACSL Ltd.	Height: 50 cm	7 kg	Small-sized UAS

B.2 Details

B.2.1 General

These three tests were conducted:

— Testing and evaluation of DAA system operation and performance

— High-precision positioning evaluation using a Michibiki-system compatible receiver

— Performance evaluation of detection avoidance system in simulated flight tests

B.2.2 Testing and evaluation of DAA system operation and performance

B.2.2.1 Purpose

- To perform in-flight operational checks and performance evaluations of various sensors that constitute the detection avoidance system.
- To confirm that each sensor functions correctly and can detect objects of various sizes.

B.2.2.2 Test condition

- Hover the medium-sized UAS equipped with various sensors in mid-air.
- Approach it with a manned helicopter or a small UAS at various distances, directions, and speeds.

B.2.2.3 Result

- All detection and avoidance sensors functioned as designed for objects of various sizes at different distances, directions, and speeds.
- As a result, there is a prospect of automatically determining performing detection and avoidance with approaching manned helicopters or other UAS using the detection and avoidance system consisting of these sensors in the future.

B.2.3 High-precision positioning evaluation using a Michibiki-system compatible receiver

B.2.3.1 Purpose

To confirm the accuracy of positioning with a precision of approximately 10 cm in the 3D space when a Michibiki-compatible receiver is mounted on a drone, which was previously only able to identify its location with an accuracy of several meters.

B.2.3.2 Test condition

Drones equipped with QZSS compatible receivers were flown to evaluate their positioning accuracy during flight.

B.2.3.3 Result

- The positioning accuracy of a medium-sized UAS during flight was confirmed to be approximately 10 cm in 3D space.
- Similarly, the positioning accuracy of a small-sized UAS during flight was confirmed to be approximately 10 cm in 3D space.
- With this high-precision positioning technology, accurate detection and avoidance routes can be set for autonomous flying drones, and they can be expected to return precisely to their original flight paths after taking evasive action.

B.2.4 Performance evaluation of detection avoidance system in simulated flight tests

B.2.4.1 Purpose

To evaluate whether the detection avoidance system functions as designed when medium-sized and small-sized UASs fly along a detection and avoidance path around a manned helicopter.

B.2.4.2 Test condition: Medium-sized UAS

- Hover the manned helicopter in mid-air.

— Establish a minimum safe horizontal distance margin from the manned helicopter (150 m), and set the flight path for the medium-sized UAS to perform detection and avoidance.

— Fly the medium-sized UAS equipped with the detection avoidance system along the flight path autonomously at a speed of approximately 40 km/h. Check the operation of various sensors, Michibiki system compatible receiver, and detection avoidance system during the flight.

B.2.4.3 Test condition: Small-sized UAS

— Hover the manned helicopter in mid-air.

— Establish a minimum safe vertical distance from the manned helicopter (30 m), and set the flight path for the small UAS that can perform detection and avoidance with little impact from downwash and without falling.

— Fly the small UAS equipped with a miniaturized light wave sensor and Michibiki-compatible receiver autonomously along the flight path at a speed of approximately 40 km/h. Check the operation of the miniaturized light wave sensor and Michibiki-compatible receiver during flight.

B.2.4.4 Result

— Based on the results confirmed in B.2.1, the equipment such as detection and avoidance sensors operated correctly, and medium-sized and small-sized UASs detected the manned helicopter appropriately during flight.

— Based on the results confirmed in B.2.2, the detection and avoidance path were flown based on the data from the Michibiki-system compatible receiver.

B.3 Onboard equipment

Table B.2 and B.3 show the onboard equipment of medium-sized and small-sized UASs used in the experiment, respectively.

Table B.2 — Medium-sized UAS onboard equipment

Equipment	Manufacturer	Size	Weight	Function
ADS-B (automatic dependent surveillance – broadcast)	SUBARU CORPORATION	Length: 7,5 cm Width: 2,2 cm	5 g	Position acquisition of the manned aircraft
Michibiki-compatible receiver AQLOC-VCXII	Mitsubishi Electric Corporation	Length: 13,9 cm Width: 9,4 cm Height: 3,9 cm	650 g	3D position measurement
Optical sensor	Nippon Avionics Co., Ltd.	Height: 20 cm	5 kg	Target detection and recognition via image
Radio wave sensor	Japan Radio Co., Ltd.	Height: 27 cm	5 kg	Omnidirectional detection of far-distance targets such as manned helicopters
Autonomous control system	SUBARU CORPORATION	Length: 12,2 cm Width: 9,3 cm	500 g	Autonomous decision-making on the detection and avoidance

Table B.3 — Small-sized UAS onboard equipment

Equipment	Manufacturer	Size	Weight	Function
Ultra-compact optical wave sensor and processing unit	ACSL Ltd.	Height: 4 cm	120 g	Detection of targets in the front such as manned helicopters
Michibiki-compatible receiver AQLOC-VCXII	Mitsubishi Electric Corporation	Length: 13,9 cm Width: 9,4 cm Height: 3,9 cm	650 g	3D position measurement

Annex C
(informative)

Flight test between UAS and manned aircraft, relative speed of 100 km/h

C.1 Overview

This annex contains publicly available information on flight test between UAS and manned aircraft, relative speed of 100 km/h. The release date for the reference is July 25th, 2019[6].

NEDO (New Energy and Industrial Technology Development Organization) and other collaborators carried out the world's first autonomous detection and avoidance test for medium-sized UAS flying at a relative speed of 100 km/h. The tests were conducted sequentially from July 24th to 25th of 2019 in a wide flight airspace located in Minamisoma City, Fukushima Prefecture. with the cooperation of the Fukushima Innovation Coast Framework Promotion Organization, to test the detection and detection and avoidance between the UAS flying at a speed of 40 km/h and the manned helicopter flying at a speed of 60 km/h.

Collaborators:

— SUBARU CORPORATION

— Japan Radio Co., Ltd.

— Nippon Avionics Co., Ltd.

— Mitsubishi Electric Corporation

— ACSL Ltd.

C.2 Details

C.2.1 Purpose

To confirm the performance of the detection and avoidance system installed on the UA when a manned helicopter approaches.

C.2.1.1 Test condition

— The medium-sized unmanned aircraft and manned helicopter are brought into proximity with a relative speed of 100 km/h (unmanned aircraft: approximately 40 km/h, manned helicopter: approximately 60 km/h).

— Based on the detection and identification data from various sensors installed on the medium-sized unmanned aircraft, a detection and avoidance path is generated. It is confirmed that the unmanned aircraft flies along this avoidance path to successfully perform detection and avoidance.

— Once the avoidance of the manned helicopter is completed, it is confirmed that the unmanned aircraft returns to its original flight path.

C.2.2 Result

— Confirmed that the detection and avoidance sensors appropriately detected and identified the manned helicopter.

— Based on the detected and identified data, automatic detection and avoidance was performed, and a detection and avoidance path was generated, which was confirmed.

— Confirmed that the unmanned aircraft flew along the generated detection and avoidance path and autonomously perform detection and avoidance.

— After the detection and avoidance, it was confirmed that the unmanned aircraft successfully returned to the pre-set flight path.