First Validation Report

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FACT

FUTURE ALL AVIATION CNS TECHNOLOGY

This First Validation Report is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 894616 under European Union's Horizon 2020 research and innovation programme.

Abstract

This document describes outcomes of the first validation activities and studies of the FACT project. In particular, all operational scenarios planned for the final project's flight demo were studied and evaluated in the Aerodrome Control simulator. Based on the results of this exercise, the definition of flight scenarios for the flight demo was updated and further refined. In addition, a series of test flights were carried to validate and refine the performance requirements on drone's and aircraft's platforms and on the experimental CNS devices to be installed on them. Furthermore, a preliminary flight evaluation of main components of the experimental CNS unit was made considering the initial hardware design. The above results are complemented with assessment of the risks that may be encountered in the flight situations using also an evaluation through experimental flights of drones. In addition, risks assessment and mitigation plans are presented for simulated flight scenarios and operational situations associated with them.

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1 Executive Summary

This document presents the results of the project FACT first validation phase which were performed by Eskisehir Technical University, Honeywell and Istanbul Technical University (ITU) with important contributions from Nokia, Sarp Air, AOPA and Eurocontrol. Validation process is an essential part of the FACT project, and outcomes of the first validation phase are used as a key input for preparation of the second validation phase consisting of the operational flight demo at Eskisehir.

As mentioned in D5.1, project's validation activities were divided into two major studies: (1) simulations to be completed using the Aerodrome Control Simulator, and (2) tests to be performed with the participation of GA aircrafts and drones. For operational safety reasons, all planned scenarios were in the first validation phase run in the Aerodrome Control Simulator. To this end, a description of 12 distinct scenarios was developed to represent various situations and risks. Impact of the additional traffic represented by drones on overall traffic management was also examined during the exercise. Results of the simulations runs were reported and discussed in detail addressing primarily situational awareness, risk mitigation and increase of workload. Obtained results are currently used in development of the detailed scenarios for the operational flight demo to be executed in the second validation phase.

The above operational validation was complemented with the series of technical evaluations focused on:

- experimental CNS device to be installed on drones and GA aircraft (performed by Honeywell), and
- performance validation of drones and their key functions to be used during the operational demo (performed by ITU).

Concerning the experimental CNS unit, Honeywell finished the preparation of the initial hardware design of the units (GA and drone's versions) and performed initial testing of the design in Labs and through testing flights in Brno. Furthermore, Honeywell took advantage of synergy with SESAR Uspace4UAM project to perform initial data collection. In particular, flight trials performed within SESAR Uspace4UAM project during autumn 2021 in Rzeszow (Poland) were used for preliminary flight evaluation of selected components for experimental CNS unit and for collection of network performance data for public LTE connection. Finally, the use of Narrow band (NB) IoT technology in cellular network were tested in Brno environment and results are also provided in this document.

Third block of validation activities performed in the first validation phase was related to evaluation of drone's platforms and their key functions essential for successful execution of the final project demo. For this purpose, ITU team focused in particular on the following drone's characteristics: (i) C2 Link Performance, (ii) Trajectory tracking performance, (iii) Geofencing/geocaging performance, and (iv) performance of the Urgent landing function. The results of all these experiments are also discussed in detail within this report.

In the scope of the first validation activities, ESTU, Honeywell and ITU performed as well risk assessment associated with addressed functions and created corresponding risk mitigation plans.

In this document, we first start by introduction and purpose of the document and deliverable structure in Section 2. Acronyms and terminology used throughout the document are also provided in this section. Next, validation activities, and outcomes are presented in detail in Section 3.

An essential part of any validation activity is the Risk Management Plan, especially in aviation sector. To this end, Section 4 is dedicated to the validation risk assessment. In this section, ESTU, Honeywell and ITU made their complementary risk assessments. In addition, stakeholders' risk assessments are provided as separate subsections in Section 4. The document concludes with a results section.

2 Introduction

2.1 Purpose and Scope of this Document

This document is the report covering first validation activities in the FACT project.

It is developed within WP5, Task T5.2. The high-level validation objectives and the work plan for the initial validation exercises are included in this delivery. In addition, scenarios, measurements and a timeline were created in detail.

In this stage, particular operational performance was simulated and tested. In parallel, technical evaluation of the selected systems and functions was performed in real and laboratory environments.

The relationships between project tasks can be summarized as in Figure 1 below.

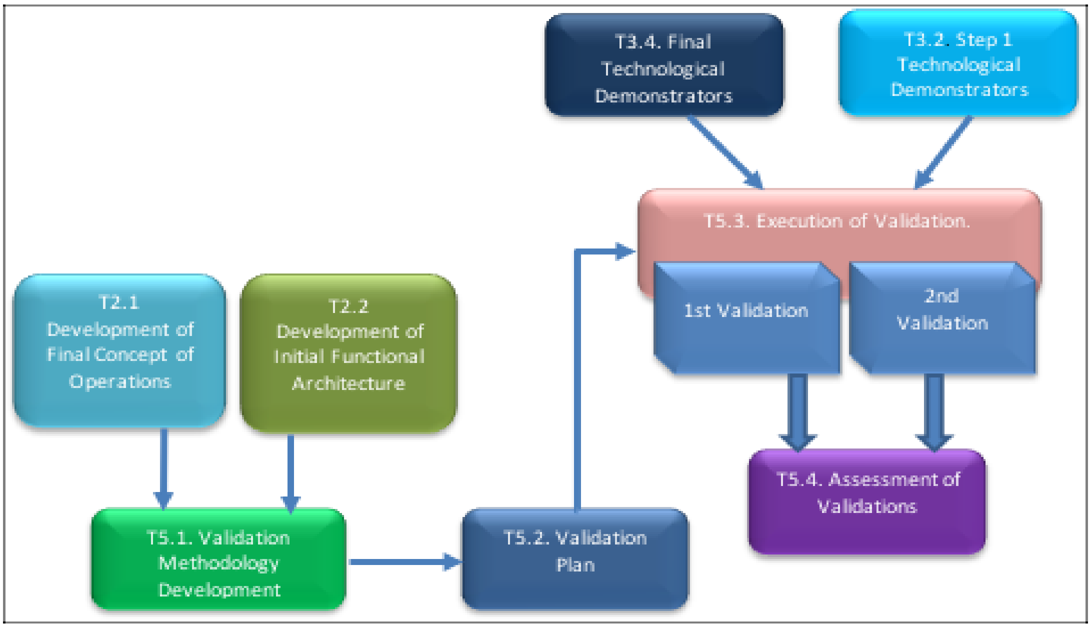

Figure 1. Relationship among T5.2 Validation Plan and other technical tasks of the project

This report relies on a number of other work undertaken as part of the project's scope. The document, in particular, uses the preliminary results of the validation methodology development activities (T5.1) to provide planning for related objectives, scenarios, validation techniques, risk management plans, and projected outcomes.

2.2 Deliverable Structure

Section 2 of this document begins with an introduction and explanation of the document's objective. This section also includes a glossary of terms and acronyms used throughout the document.

The third section describes the validation activities performed by Honeywell, ITU and ESTU.

In particular, Honeywell evaluated the design of the experimental CNS device, the robustness of the hardware and mechanical solution, the telemetry recording features from the drone, the communication over the public LTE network using the modem planned for final operational demo, and the NB-IoT network performance. ITU provided detailed information about the UAV test field and the drone and operational setup as an input for ESTU operational simulations, and shared the results of the first validation studies performed with drone's platform for final operational demo. ESTU described the features and capabilities of the validation platform, validation use cases (specific scenarios) and the overall layout of the scenarios, and results of the operational simulations.

The risk management plan is an important aspect of any validation process, especially in the aviation industry. Section 4 is devoted to risk management assessments of verification activities in this context. A comprehensive risk management including input from the partners of the project consortium, and the risk mitigation measures envisaged is presented. The document ends with a list of references and an appendix section.

2.3 Acronyms and Terminology

Acronyms and the terminology used throughout the report can be summarized as below:

Term	Definition
ABIL	AirScale Baseband Extension Sub-Module
ADS-B	Automatic Dependent Surveillance-Broadcast
AFIS	Aerodrome Flight Information Service
AIP	Aeronautical Information Publication
AMSL	Above Mean Sea Level
AOE	Eskişehir Hasan Polatkan Airport
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
AUSF	Authentication Server Function
Base-S	Baseline Scenario
CIoT	Cellular IoT
CIP	Commercially Important Person
CIS	Common Information Sharing service
CNS	Communications, Navigation and Surveillance Systems
DL	Download
DME	Distance-Measuring Equipment
ECL	Emitter-Coupled Logic
EIRP	Effective Isotropically Radiated Power
eNB	Evolved Node
ESTU	Eskisehir Technical University

FACT	Future All Aviation CNS Technology
FMC	Flight Control Computer
GA	General Aviation
GE	Gigabit Ethernet
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HW	Hardware
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
iCNS	Integrated Communications, Navigation and Surveillance
ILS	Instrument Landing System
ITU	Istanbul Technical University
ITU ARC	Istanbul Technical University Aerospace Research Center
LoRaWAN	Long Range Wide Area Network
LOS	Line-of-Sight
LPWA	Low-Power Wide Area
LTBY	Hasan Polatkan International Airport
LTE	Long Term Evolution
MCL	Maximum Coupling Loss
MME	Mobility Management Entity
MQTT	Message Queuing Telemetry Transport
NB-IoT	Narrowband Internet of Things
NF	Network functions
NG-RAN	Next Generation Radio Access Network
NLOS	Non-Line-of-Sight
NM	Nautical Mile
NNS	Non-Nominal Scenario
PGW	Packet Data Network Gateway
RAN	Radio Access Network
RC	Radio Controlled
RF	Radio Frequency
RRC	Radio Resource Control
RRH	Remote Radio Heads
RSRP	Reference Signal Received Power
RSSI	Received Signal Strength Indicator
RTK	Real-Time Kinematic
SCEF	Service Capability Exposure Function
SD	Secure Digital
SDR	Software Defined Radio
SESAR	Single European Sky ATM Research (the programme which defines the Research and Development activities and Projects within Europe)
SFC	Service Function Chaining
SGW	Serving Gateway
SNR	Signal-to-Noise Ratio
TDM	Time-Division Multiplexed

THY	Turkish Airlines
TX	Transmit
UAT	User Acceptance Testing
UAV	Unmanned Aerial Vehicles
UDM	Unified Data Management
UDR	Unified Data Repository (not shown in the figure above)
UE	User Equipment
UL	Upload/
VFR	Visual Flight Rules
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communication
USSP	U-Space Service Providers
VIP	Very Important Person
VLAN	Virtual Local Area Network
VOR	VHF Omni-directional Radio Range
WP	Work Package

3 Validation Activities

As indicated in D5.1, Table 1, validation activities are performed by multiple partners. First validation activities conducted by ESTU, Honeywell and ITU are described in detail in subsequent sections. Nokia will run their first validation activities by the end of April, 2022.

3.1 Validations by Honeywell

3.1.1 Design of Experimental CNS Device

As described in deliverables D3.1 Initial System Requirements and D2.2 Initial iCNS Functional Architecture, an experimental CNS unit will be installed on drone and on general aviation aircraft during final project validations in Eskisehir, Turkey.

The experimental CNS unit installed on drone will be responsible for following functions:

- Positioning report generation function
- Trajectory report generation function
- Communication with flight control computer of drone
- Communication over cellular network
- Receiving ADS-B data from surrounding vehicles

The experimental CNS unit installed on GA aircraft will be responsible for following functions:

- Positioning including position report generation function
- Communication over cellular network
- Receiving ADS-B data from surrounding traffic
- Traffic consolidation function

Initial hardware design of unit was prepared. The computing platform is Raspberry Pi was selected for following reasons: small size, low power consumption, affordable price and also good experience from previous projects. Next components are modem for communication with cellular network, ADS-B In receiver, real-time clock, SD card, step down voltage converter, fan and for aircraft version also GPS and power bank.

The testing of the initial HW design was done primarily through installation on testing drone used by Honeywell in Brno, but an opportunity resulting from Honeywell participation in SESAR Uspace4UAM project was also exploited for initial data collection. In particular, flight trials performed within that project during autumn 2021 in Rzeszow (Poland) were used for preliminary flight evaluation of selected components of experimental CNS unit and testing connection to public LTE network.

HW unit was mounted on drone and it was directly connected to flight control computer of drone for receiving telemetry data and for the provision of power. Main goals of flight evaluation were

- Robustness of HW and mechanical solution
- Logging of telemetry from drone
- ADS-B In reception
- Communication over public LTE network using modem Quectel RM500Q

Results for each point of evaluation are briefly described in following subsections.

3.1.1.1 Robustness of HW and Mechanical Solution

There were not observed any significant difficulties regarding the mechanical solution of the unit. There was no overheating detected and no damages of the unit resulting from the flight testing. Mechanical connection between drone flight control computer and experimental HW device was realized by ethernet cable.

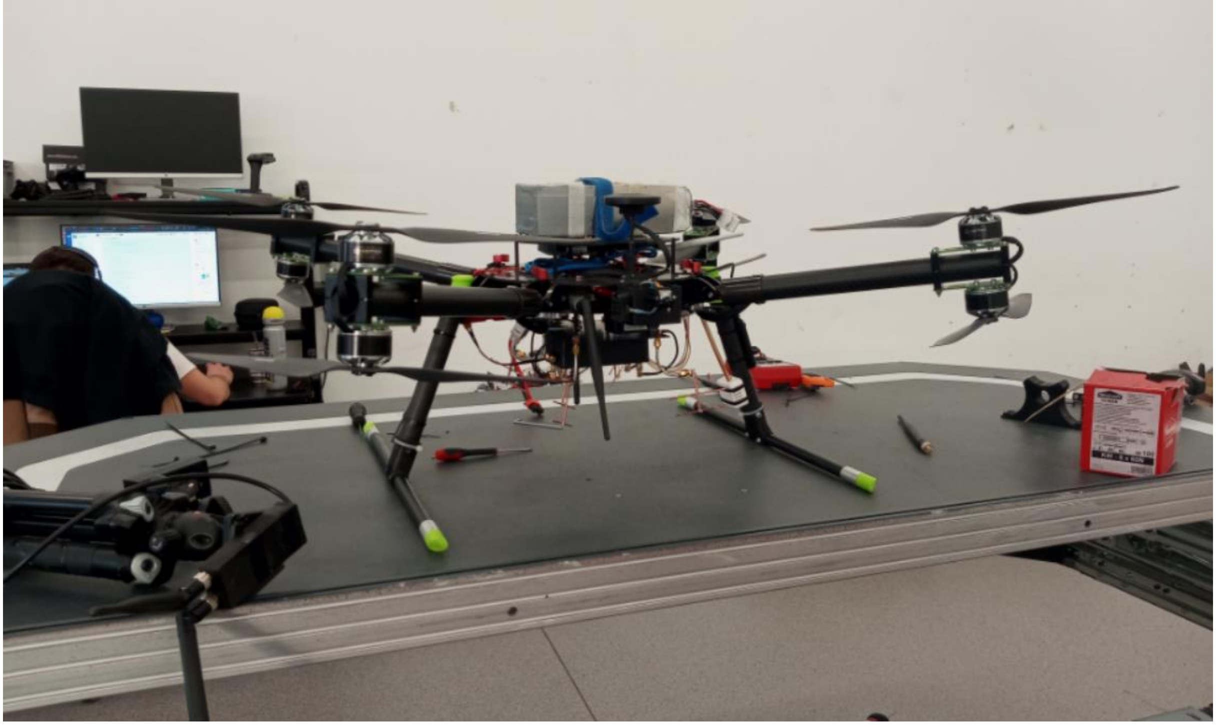

Figure 2. Experimental device mounted on drone during USpace4UAM flight trials (the black box on the drone's belly).

3.1.1.2 Logging of telemetry from drone

Within Uspace4UAM project, MQTT protocol (version 3.1) was implemented for consuming telemetry data from drone. Uspace4UAM project partner, drone operator DroneHub realized MQTT broker functionality. Experimental CNS device acted like subscriber for selected topics. Mosquito (mosquito.org, version 1.4.15) was selected as suitable MQTT client at the side of experimental CNS device.

Data format was MAVlink, the standard for drone manufacturers. List of standardized MAVlink messages is presented at http://ardupilot.org/dev/docs/mavlink-basics.html. Implemented MAVlink messages were following:

- SCALED_IMU
- GPS_RAW_INT
- HEARTBEAT
- GLOBAL_POSITION_INT
- ATTITUDE
- SYS_STATUS
- SCALED_PRESSURE
- SYSTEM TIME

Experimental CNS device stores the received drone data in json format as it is shown here:

["mqtt_client_gps_raw_int", {"mavpackettype": "GPS_RAW_INT", "time_usec": 826390000, "fix_type": 4, "lat": 500092263, "lon": 219860851, "alt": 270610, "eph": 65, "epv": 94, "vel": 110, "cog": 1703, "satellites_visible": 16, "timestamp": "2021-11-18T12:04:08.412871Z"}]

Lessons learned during testing with DroneHub will be used for setting of communication during FACT official flight trials. There is already an agreement between Honeywell and ITU about MQTT protocol and list of MAVlink messages. The communication will be directional in project FACT, drone will consume data from ground services via experimental CNS device.

3.1.1.3 ADS-B In Reception

Three ADS-B In receivers were evaluated by Honeywell through a series of testing in Czech Republic. First of them was product called ping from uAvionix company. The second one was microADSB receiver and the third one was ADS-B In receiver realized by SW defined radio using the Nooelec Nano 3 dongle.

Objectives to select the best receiver were size and weight, power consumption, quality (e.g., build quality, reception quality), capability to receive on 1090 MHz (Europe) and price and support for external antenna.

The uAvionix ping is a dual 1090 and UAT ADS-B receiver. This is the most tested sensor from this selection. The sensor was used on multiple drone flight tests (over 20 flights). The sensor performed most of the time quite well. The closer the aircraft was to the receiver the more reliable reception was received. As one would expect, the reception on drone was superior to the reception on ground.

However, we experienced a few short reception outages (for a few seconds even in short distances) – they could be caused by antenna orientation. A tracker should be able to solve short outages.

The used interface is microUSB (there is also Wi-Fi GDL90 interface, that we never used) with MAVLink communication interface, that is defined and explained in the official MAVLink web[1]. Message ADSB_VEHICLE (#246) was consumed.

Known issues:

- There is no option to connect external antenna (there are newer receivers available from uAvionix that have an external antenna).
- There is no access to some of the ADS-B performance parameters (e.g., NACp, NACv, NIC, etc.).
- One time there was a case that very close aircraft was not detected. This could be caused by an overload (too strong signal – could be an issue for some receivers) or that the aircraft was not sending messages that uAvionix pingUSB supports or that it was not sending ADS-B messages at all (it was standing still on the airport 20 meters from the receiver and reception was detected when the aircraft was approx. 40m away). This issue was not replicated in further tries, so there might be no issue with uAvionix pingUSB.

Micro ADSB-USB receiver was tested on several flight tests on GA aircraft. It has an external detachable antenna and good performance in terms of reception distance, but poor reliability. It allows to do some processing of messages on the receiver, but it is possible to get also raw messages. All message fields including performance parameters are available. Receiver has an USB interface.

Known issues:

- poor build quality (large differences between receivers)
- not possible to buy it anymore, and
- detected issue with overload (too strong signal causes receiver to not see intruders that are too close)

Software defined radio receiver can be tuned on wide range of frequencies. If it is tuned on 1090MHz (or UAT) it can be used to receive ADS-B messages. There is a need to have an ADS-B parsing on computer/platform that the SDR dongle is connected to. The usual interface is USB. There are many similar SDR dongles, they are very cheap and commonly used by ADS-B communities such as Flightradar24 or FlightAware. The disadvantage is that it cannot be tuned simultaneously to UAT and 1090MHz and have higher processing requirements on computer/platform. Testing have shown good performance and no issues with overload in case of close transmitters.

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[1] https://mavlink.io/en/messages/common.html

3.1.1.4 Communication over public LTE network using modem Quectel RM500Q

Communication parameters over LTE were logged during drone flights in Brno, Czech Republic, and also during USpace4UAM first demonstrations. The aim of the measurements was an evaluation of Quectel RM500Q following capabilities:

- capability to use datalink from RM500Q and at the same time measure quality parameters
- capability to measure SINR, RSRP, RSRQ, RSSI, CQI, CellID by list of AT commands
- capability to measure latencies, jitters, throughputs

The aim is to use collected data will serve for comparison of in-air performance of other cellular networks generations (NB-IoT, dedicated network deployed for final demonstrations).

Figure 3. Scenario 1 Flight in Rzeszow, Poland

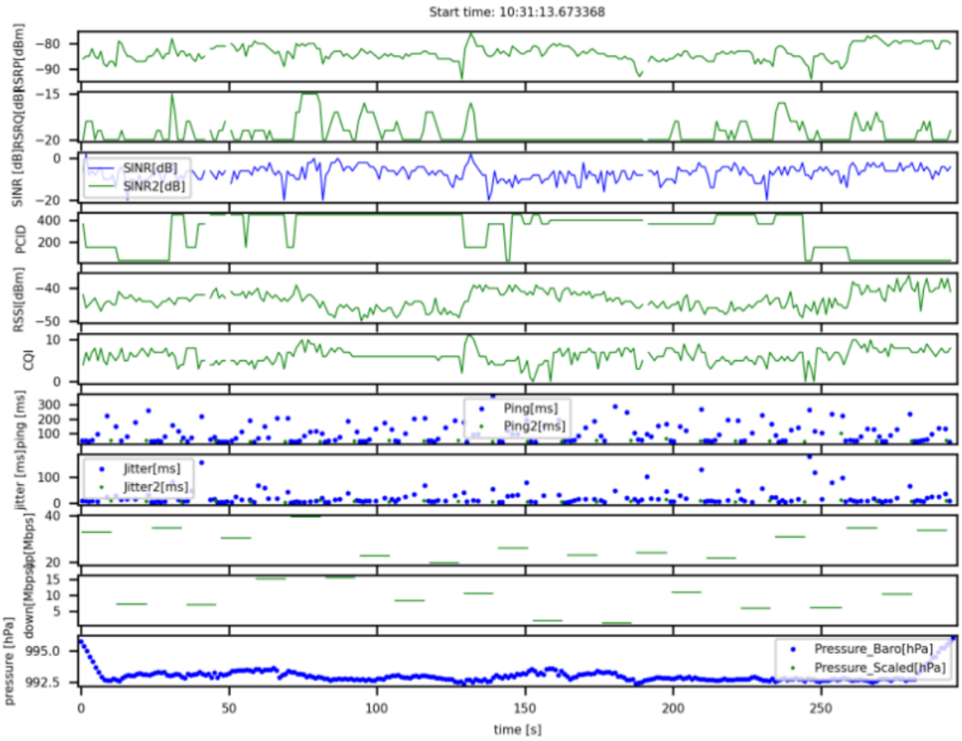


Figure 4. Example of Flight Evaluations from Flight 1.

3.1.1.5 Experimental CNS Device Design Conclusions

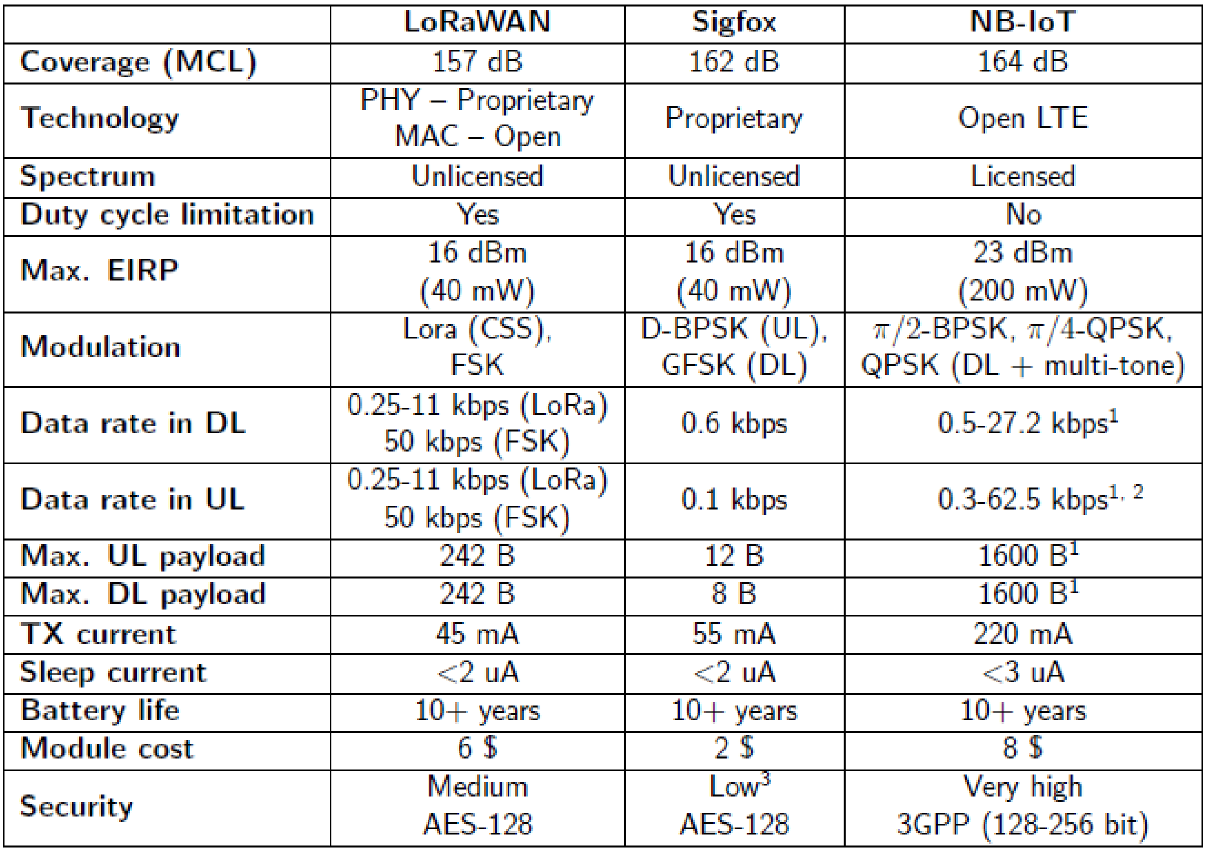
- HW and mechanical solution of the test unit passed internal tests successfully.
- Communication of test unit with drone's flight control computer via MAVlink messages was successfully tested.
- Different ADS-B receivers were tested and the most suitable one was selected.
- Candidate modem for final flight test modem was chosen and its capability to monitor network performance was successfully verified.

3.1.2 NB-IoT Network Performance

3.1.2.1 Motivation

In the course of the continuous research activities related to wireless communication technologies, as part of the fifth generation of mobile cellular systems, new communication technologies were introduced to enable long-range communication under challenging radio conditions. The two representatives which are part of the 5G networks (firstly defined in 3GPP Release 13) are: (i) Narrowband IoT and (ii) LTE Cat-M.

As both technologies operate in the licensed frequency spectrum, and as they are designed from scratch to cover different communication scenarios in comparison either with the legacy cellular systems, i.e., 2G, 3G, or 4G, they can work as the secondary (additional) communication technologies in scenarios where the conventional cellular systems do not. To see the key differences between the currently available technologies for the IoT transmissions, the Table 1 lists the representatives working in licensed and unlicensed frequency spectrum, respectively.



	LoRaWAN	Sigfox	NB-IoT
Coverage (MCL)	157 dB	162 dB	164 dB
Technology	PHY – Proprietary MAC – Open	Proprietary	Open LTE
Spectrum	Unlicensed	Unlicensed	Licensed
Duty cycle limitation	Yes	Yes	No
Max. EIRP	16 dBm (40 mW)	16 dBm (40 mW)	23 dBm (200 mW)
Modulation	Lora (CSS), FSK	D-BPSK (UL), GFSK (DL)	$\pi/2$-BPSK, $\pi/4$-QPSK, QPSK (DL + multi-tone)
Data rate in DL	0.25-11 kbps (LoRa) 50 kbps (FSK)	0.6 kbps	0.5-27.2 kbps[1]
Data rate in UL	0.25-11 kbps (LoRa) 50 kbps (FSK)	0.1 kbps	0.3-62.5 kbps[1, 2]
Max. UL payload	242 B	12 B	1600 B[1]
Max. DL payload	242 B	8 B	1600 B[1]
TX current	45 mA	55 mA	220 mA
Sleep current	<2 uA	<2 uA	<3 uA
Battery life	10+ years	10+ years	10+ years
Module cost	6 $	2 $	8 $
Security	Medium AES-128	Low[3] AES-128	Very high 3GPP (128-256 bit)

Table 1. Key parameters of LPWA technologies in the Czech Republic (07/2021).

The communication scenario implemented the most often these days is related to the remote metering, e.g., intelligent electricity meters equipped by the communication unit. Nevertheless, new communication challenges come into play as the completely new set of devices flood the market. The perfect example of a new kind of device is moving machines where we move from the ground scenario (automobiles) to the flying entities (drones). The nature of the Low-Power Wide Area (LPWA) technologies in the licensed frequency spectrum, to where the NB-IoT and LTE Cat-M belong, is to provide: (i) massive connections, (ii) enhanced coverage, (iii) reduced cost and complexity, (iv) ultra-low power consumption, and (v) flexible delay characteristics.

To answer whether the NB-IoT technology implementation in the existing 5G cellular networks has matured to the state when the technology can be used as the enabler for the service (additional) data payload transmissions for the flying devices gave rise to start this measurement campaign.

3.1.2.2 Execution Summary

The performed measurement campaign focused on the communication parameters of the recent LPWA technology in licensed frequency spectrum, i.e., Narrowband IoT (NB-IoT). To create a sufficient data set for the upcoming flight tests at the same location, see the measurements points (link), three devices were utilized:

- Tester equipped with the Narrowband IoT - uBlox Sara N211 communication module
- Tester equipped with the Narrowband IoT - Quectel BC68 communication module
- Handheld tester equipped with the Narrowband IoT - uBlox Sara N211 communication module

3.1.2.3 Narrow Band – IoT Technology Description

The narrowband (NB)-IoT represents a profound evolution and adaptation of the Long-Term Evolution (LTE) technology for the needs of the IoT applications. The technology has been developed to operate in the licensed frequency bands, in which NB-IoT might even coexist (in the case of in-band or guard band deployment) with conventional LTE. It allows for deploying the NB-IoT systems via a software upgrade of the legacy LTE base stations without the need for new hardware. Generally, NB-IoT simplifies the LTE processes by accommodating the constrained computing power and battery life of NB-IoT devices. This approach is visible in the data transfer signaling as demonstrated in Fig 6. LTE utilizes eight messages to establish a connection and transfer the data over the network, whereas NB-IoT reduces those signaling overheads to just four messages [1].

The structure of an NB-IoT network, which is depicted in Fig. 7, shares many common elements with a legacy LTE network. Even the conventional LTE eNBs often need just a software update to enable NB-IoT support. The only new element is the optional Service Capability Exposure Function (SCEF), which handles the non-IP data transfers.

Note that both the NB-IoT Control and the User Planes have been substantially optimized for enabling the Cellular IoT (CIoT). Within the Control Plane, the uplink data are transferred from the eNB to the Mobility Management Entity (MME). From there, the IP-based tra_c is transmitted to the Packet Data Network Gateway (PGW) via Serving Gateway (SGW) and the non-IP tra_c - to the SCEF. The User Plane CIoT traffic is handled similarly to the traffic in an LTE network. Note, that unlike the previously discussed LoRaWAN and Sigfox, the NB-IoT does not imply the provision of a standard server/cloud solution for user data.

NB-IoT is targeted to support end devices located in deep indoor environments that operate in remote areas, to fulfill these requirements, Release 13 contains a set of techniques to enable extended communication coverage. Based on the signal strength received from the end device and the signal strength indicated by the end device, the Evolved Node B (eNodeB) evaluates the communication link and establishes a category for the end device. This is called ECL and stands, in a nutshell, for the number of repetitions in uplink channel. There may be up to three levels, ranging from ECL 0 for normal operation to ECL 2 for the worst case. It is up to the network how EC levels are defined. In case of our work, scenario ECLs are defined as follows:

- ECL 0 - normal coverage with maximum coupling loss (MCL) up to 144 dB,
- ECL 1 - robust coverage with MCL up to 154 dB,
- ECL 2 - extreme coverage with MCL up to 164 dB.

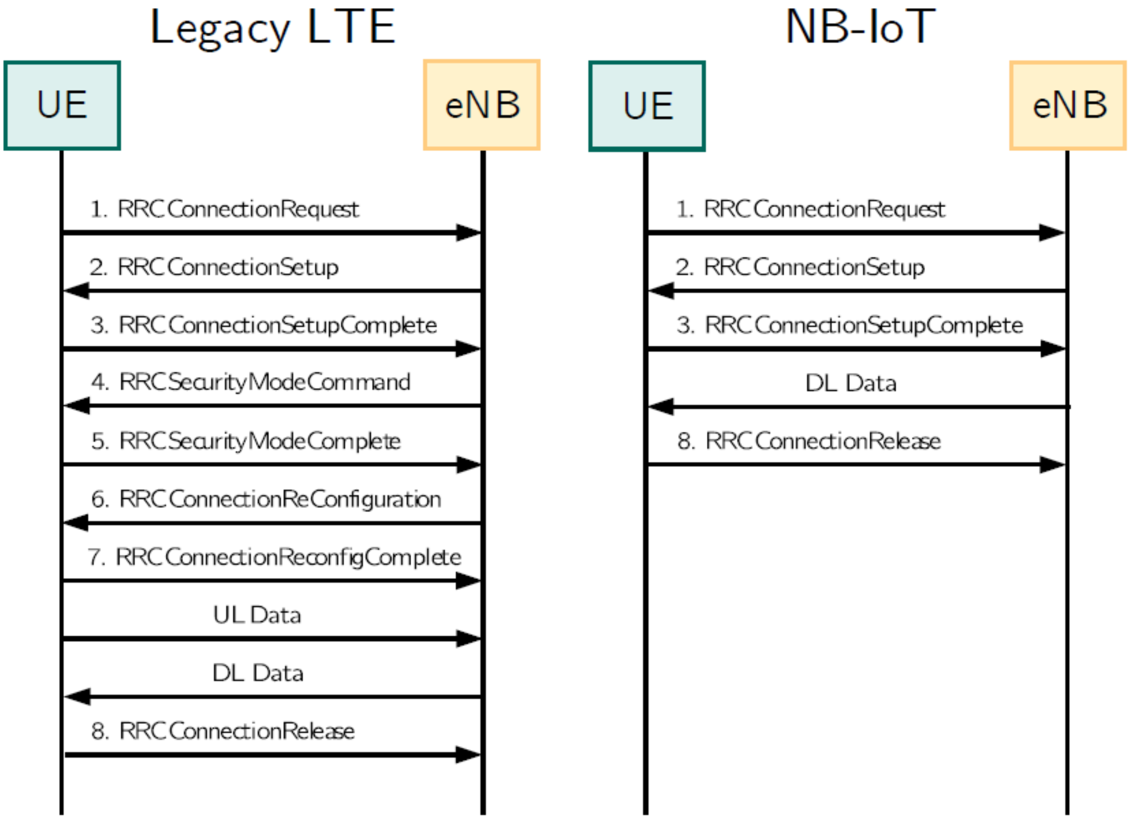


Figure 5. Comparison between signalling in legacy LTE and NB-IoT.¨

3.1.2.4 NB-IoT Ground Evaluation

The measurement campaign took place at the Medlanky airport (Brno, Czech Republic) where the 16 measurement points were selected, see Figure 6. To be able to evaluate the gathered data and further outline the usability of the NB-IoT as the secondary channel for the data transmission in case of the drone scenarios, the first measurement campaign started as a drive test, i.e., ground measurement. The reason of the drive tests was to have the “default dataset" for the further comparison of the communication parameters gathered at the different flying levels. While performing the data transmissions through the defined locations, the NB-IoT technology was capable to transmit successfully all data. Even though the interference in the licensed frequency spectrum were captured in case of the location no. 6, the technology was capable to establish the communication channel, i.e., register to the cellular network, and transmit the data towards the remote server located in the Brno University of Technology infrastructure.

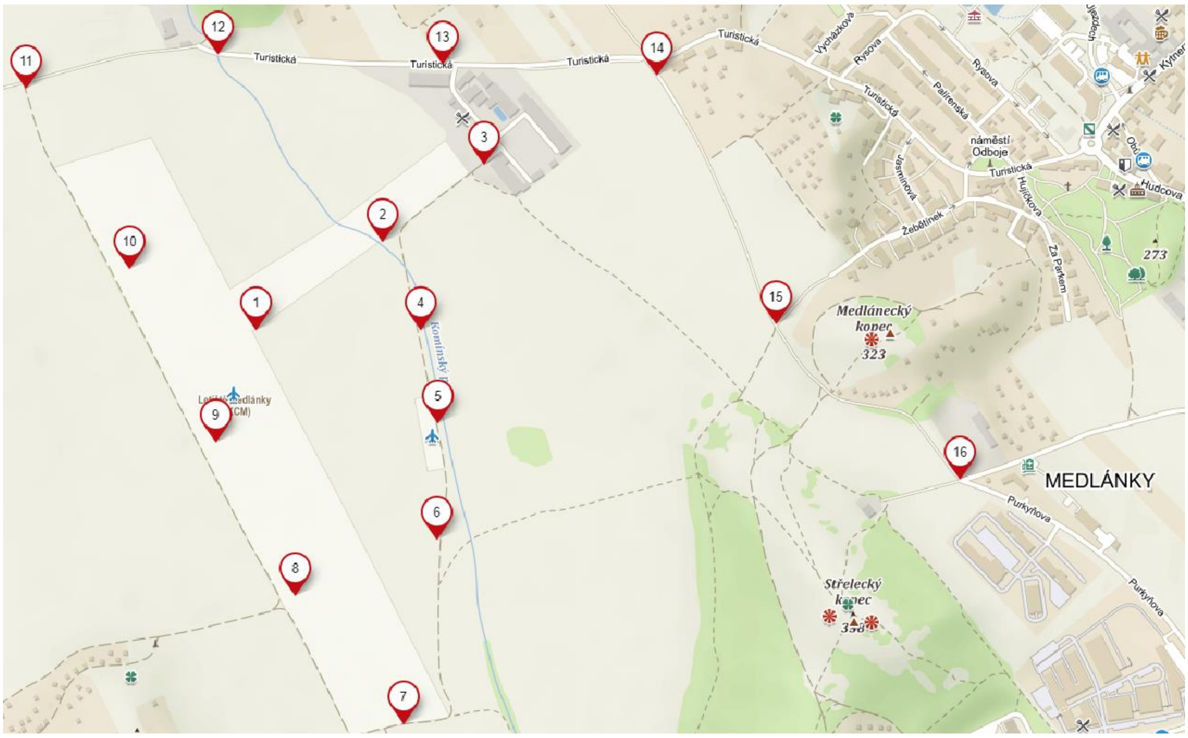


Figure 6. Map of the car drive test measurement locations near to the Medlanky airport.

During the measurement, all NB-IoT devices remained mostly connected for data transmissions via single eNodeB (observed identifier in form pf Physical Cell ID) at each measured point as depicted in Table 2. There were occasions where cell reselection occurred. Although reselections occurred only in few cases, such events could lead to delay in data transmissions due to the reselection procedure time.

Point	GPS coordinates	Physical Cell ID	
		Quectel BC68	uBlox SARA-N211
1	49°14’18.4”N 16°33’19.3”E	131	131,23[1]
2	49°14’23.2”N 16°33’28.6”E	455	455
3	49°14’26.6”N 16°33’36.3”E	443	443
4	49°14’19.4”N 16°33’30.3”E	455	455
5	49°14’12.7”N 16°33’32.7”E	455	455
6	49°14’07.0”N 16°33’32.2”E	455	455
7	49°13’58.6”N 16°33’30.3”E	455	455
8	49°14’04.0”N 16°33’22.2”E	131	131
9	49°14’08.9”N 16°33’18.5”E	131	131
10	49°14’17.8”N 16°33’11.7”E	131	131
11	49°14’30.5”N 16°33’01.1”E	264,131[2]	131
12	49°14’32.5”N 16°33’14.1”E	455	455
13	49°14’31.7”N 16°33’34.3”E	455	131
14	49°14’29.0”N 16°33’50.9”E	443	443,131[3]
15	49°14’17.2”N 16°33’59.0”E	429	429
16	49°14’10.5”N 16°34’12.0”E	464	464,231[4]

Table 2. GPS coordinates and Cell IDs of eNodeBs to which devices were connected for all 16 measured points.

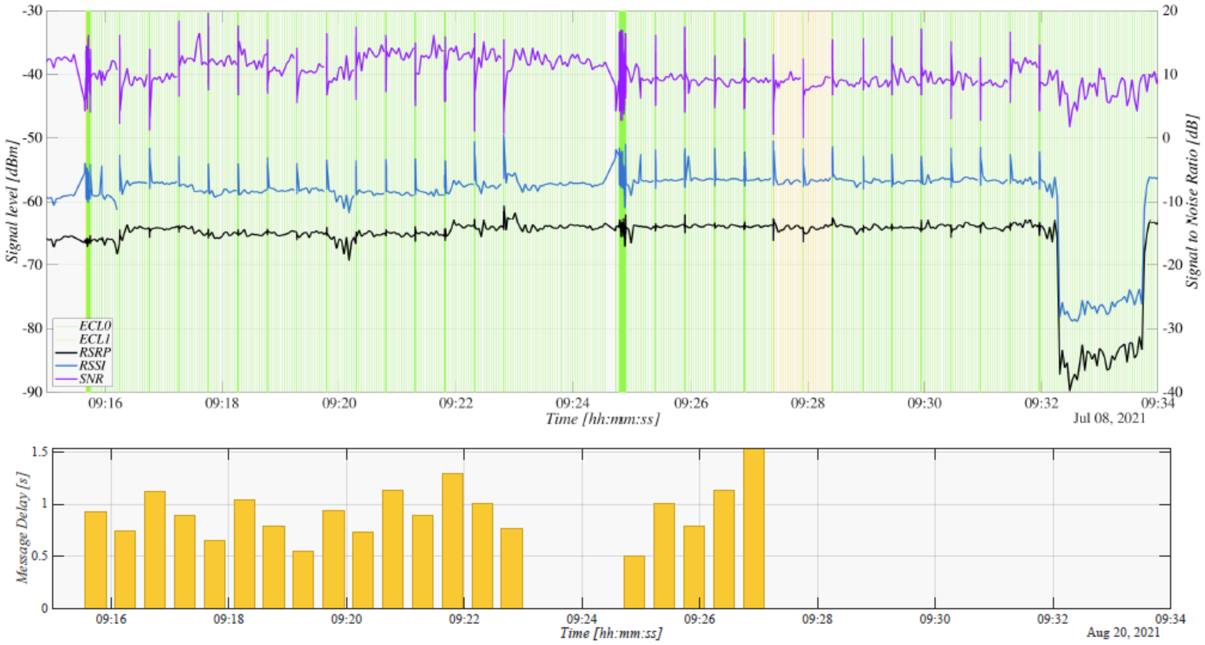
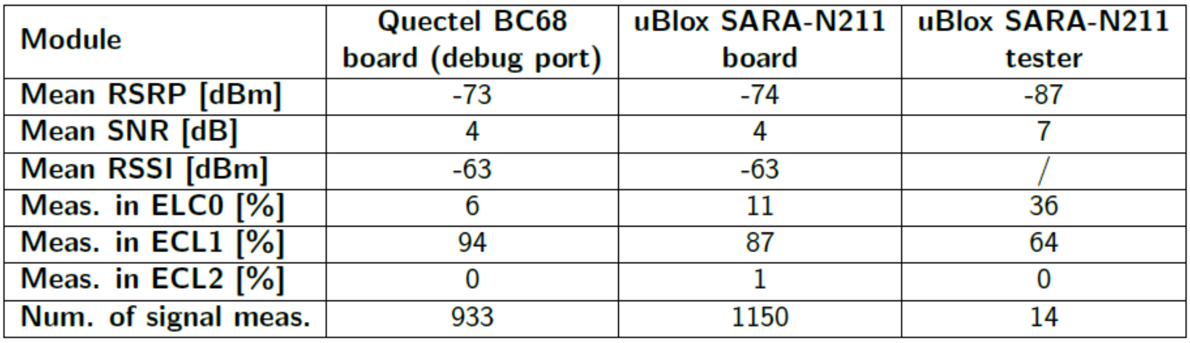


Figure 7. Example of results for Point 1 measurement results in terms of signal conditions (RSRP, RSSI, SNR, ECL) and end-to-end transmission delay obtained by debug port of module Quectel BC68.

Figure 8. Drive tests of NB-IoT.

As stated above, during the whole measurements, most of the time all NB-IoT devices remained connected to the single eNodeB. During the measurement, several fluctuations occurred, leading to reselection procedures with as could be seen from Physical Cell ID variance in Table 3. Summarized results of communication parameters are depicted in Table 4 and Table 5. During most of the measurement time, all devices indicated perfect radio conditions with RSRP around -65 dBm for boards and -85 dBm for a tester. The difference in RSRP in the case of a tester is due to the use of Surface Mount Device (SMD) antenna where the boards utilized high gain external antennas. Together with high (positive) SNR values, the captured radio conditions confirm almost ideal conditions for wireless data transmissions (most of the time) and highly possible line-of-sight (LOS) with eNodeB or with only slight obstacles (non-line-of-sight (NLOS)) between the devices and eNodeB. However, even the radio conditions were in an ideal range, signal fluctuations occurred during the measurement, leading to prolonged device duties impacting transmission and signalling delay. These fluctuations with occasional low SNR led to a transfer of SARA board to ECL2 in 2% of the time and to ECL1 in 15% of the time, which significantly increases both power consumption and transmission delay, thus service provisioning.



Module	Quectel BC68 board (debug port)	uBlox SARA-N211 board	uBlox SARA-N211 tester
Mean RSRP [dBm]	-73	-74	-87
Mean SNR [dB]	4	4	7
Mean RSSI [dBm]	-63	-63	/
Meas. in ELC0 [%]	6	11	36
Meas. in ECL1 [%]	94	87	64
Meas. in ECL2 [%]	0	1	0
Num. of signal meas.	933	1150	14

Table 3. Physical Cell ID variance

Point	1	2	3	4	5	6	7	8
RSRP	-65	-68	-70	-72	-66	-70	-71	-64
SNR	10	9	8	9	13	9	13	3
RSSI	-57	-60	-62	-64	-58	-61	-63	-54
ECL0	95	81	67	94	100	98	100	2
ECL1	5	19	33	6	0	2	0	98
ECL2	0	0	0	0	0	0	0	0
Signals meas.	2900	1457	1782	1150	1311	1134	1262	1196
Point	9	10	11	12	13	14	15	16
RSRP	-67	-65	-77	-75	-78	-68	-75	-73
SNR	11	12	4	6	8	4	3	4
RSSI	-59	-57	-66	-66	-69	-58	-64	-63
ECL0	94	100	4	53	0	0	7	6
ECL1	6	0	94	47	89	100	91	94
ECL2	0	0	2	0	11	0	2	0
Signals meas.	1190	1309	1129	1489	988	1036	1013	933

Table 4. Measured communication parameters in terms of signal conditions for NB-IoT device Quectel BC68

Point	1	2	3	4	5	6	7	8
RSRP	-85	-90	-82	-85	-88	-89	-90	-79
SNR	5	6	11	5	8	3	3	6
RSSI	/	/	/	/	/	/	/	/
ECL0	80	73	83	10	57	6	0	29
ECL1	20	18	17	90	43	94	94	71
ECL2	0	9	0	0	0	0	6	0
Signals meas.	20	11	18	21	14	17	20	14
Point	9	10	11	12	13	14	15	16
RSRP	-82	-80	-82	-94	-91	-82	-89	-87
SNR	12	11	7	3	2	1	4	7
RSSI	/	/	/	/	/	/	/	/
ECL0	100	94	95	0	0	0	0	36
ECL1	0	6	1	100	100	100	100	64
ECL2	0	0	4	0	0	0	0	0
Signals meas.	15	17	17	13	16	12	17	14
RSRP, SNR, RSSI – Values are mean values per point. ECL - Amount of occurrence expressed as a percentage in relation to other ELCs.								

Table 5. Measured communication parameters in terms of signal conditions for NB-IoT device SARA N-211

3.1.2.5 NB-IoT In-air Evaluation

As for the verification of the communication parameters of the technology in question, i.e., NB-IoT in flight levels of 60 m, 90m and 120m above ground level, the Medlanky airport in Brno, Czech Republic was used. The map of the measurement points can be seen in the figure below. Measurement points were selected to be comparable with previous car drive test. However, the selected area for the flight test was limited in accordance with the permit by Medlanky airport ATC.

Figure 9. Flight measurement locations near to the Medlanky airport.

The measurement thus aimed to evaluate the gathered data and further outline the usability of the NB-IoT as the secondary channel for the data transmission in case of the drone scenarios. The first measurement campaign was done as a drive test, i.e., ground measurement, see the section above. This section deals with scenario, where drone flies in different flight altitudes, which should simulates/be actually closer expected use-case.

Conducted measurement campaign considered already mentioned device already utilized during drive test measurement, more precisely tester fitted with module uBlox SARA N-211. Only single battery-operated device was selected due to the limited space and mounting capabilities of drone. On the contrary with drive test, tester was fitted with external antenna placed in the way to decrease signal blockage by that the body of the drone.

The measurement procedure was similar to the car drive test in terms of methodology. The device was set to transmit UDP messages of 222 B payload in 30 s intervals to remote BUT server for evaluation of end-to-end delay and message success rate. During the whole procedure, signal condition parameters were gathered and stored on an SD card in 100 ms intervals. Format and the type of gathered data are identical with car drive test only with additional pre-processing of data to achieve compression and faster the data storage.

Before the drone take-up, module SARA-N211 was rebooted, followed the initial setup of communication parameters and registration to the mobile network. After this procedure, the device began message transmissions and data gathering, which was done during the whole flight until the landing. After the device registration to the mobile network, the drone started to fly to defined positions and altitudes of 60 m, 90 m, and 120 m. Moreover, at a first point, even altitude of 160m was measured as the limit test for the communication technology.

Described procedure was identical for all 8 measured points. At each point and altitude, the drone remained stationary for approximately 2.5 minutes (about five message transmissions). It is important to note that each message transmission is initiated from RRC idle state. This means that before data transmission itself, the device is first required to transfer to state RRC connected by RRC connection procedure. This event could be more than half of the observed data transmission delay. Provided results thus indicated worst-case scenarios, including RRC state changes. It is also important to note that module SARA-N211 indicated undesired behaviour in terms of message transmissions during the measurement. Meaning that even if the indication of transmission was successful, the server occasionally did not obtain the message. As this behaviour was observable even on the ground, solely higher altitudes could not be the case of a lower success rate of data transmission, as is visible from the following sections.

Following sections contains description of conveyed measurement campaign.

NB-IoT Data Transmissions - General Description

Despite the good radio conditions ranging in upper bound of ECL0 (above -80 dBm of RSRP), the NB-IoT tester indicated multiple cell reselections at each measured point as depicted in Table 40 indicating several cells per measured point and as is visible from results in the following sections.

Point	GPS Coordinates	Cell ID
1	49°14'18.4"N 16°33'19.3"E	80131, 79952, 80259, 60009
2	49°14'06.3"N 16°33'27.8"E	80259, 79952
3	49°14'12.3"N 16°33'23.1"E	80310, 79952
4	49°13'59.7"N 16°33'32.4"E	80131, 80259, 80361, 79952
5	49°14'07.0"N 16°33'32.2"E	79952, 80131, 75676
6	49°14'12.7"N 16°33'32.7"E	80131, 75676
7	49°14'19.4"N 16°33'30.3"E	75676, 60009, 79184, 80131, 80156, 79952
8	49°14'23.2"N 16°33'28.6"E	80259, 79952, 80131

Table 6. GPS coordinates and Cell IDs of eNodeBs to which tester was connected during the flight test

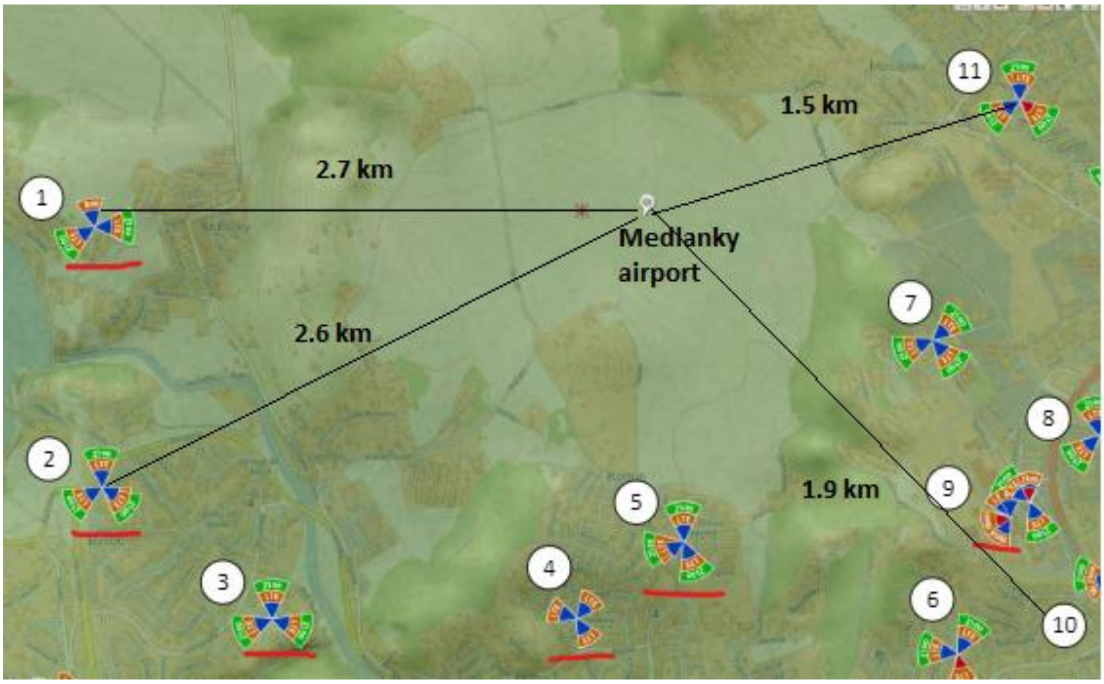
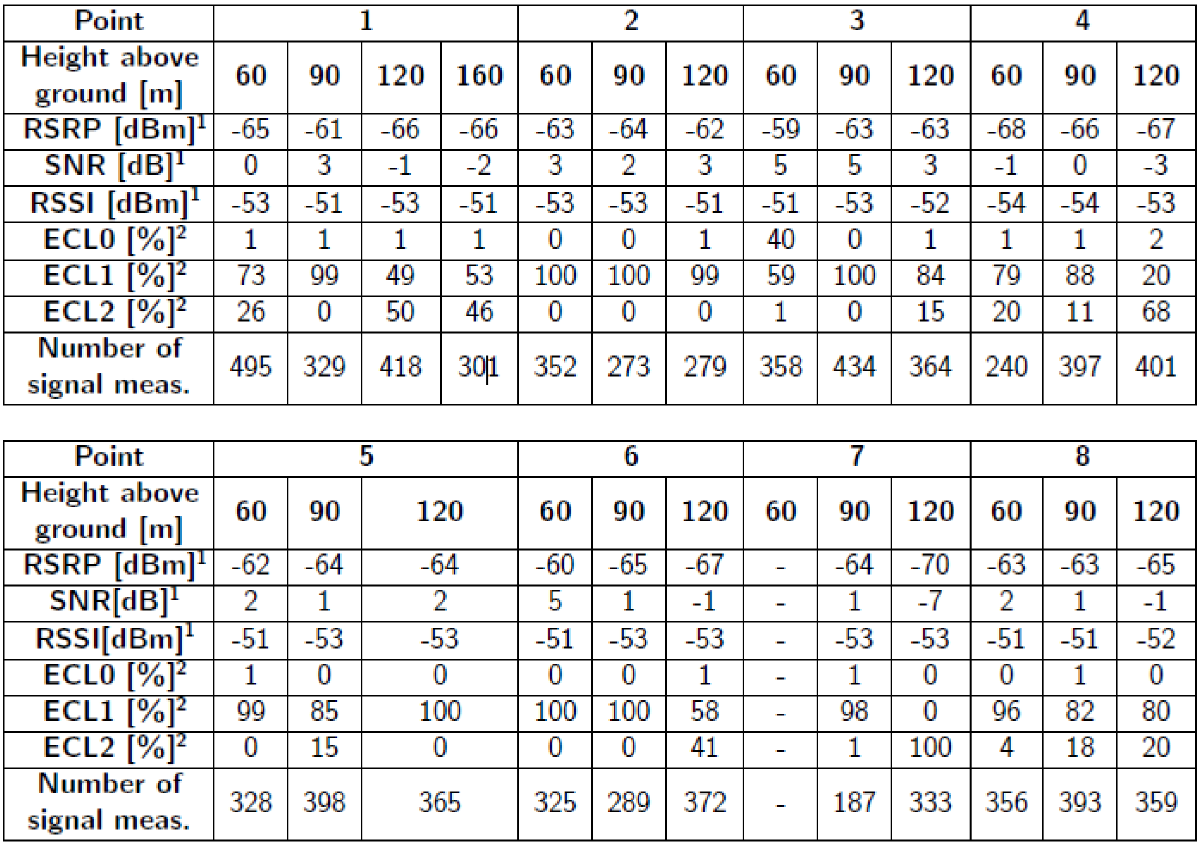


Figure 10. NodeBs to which tester was connected during the flight test and its distances to airport

Overall, the results confirmed our expectations that most of the possible communication problems during the flight could be related to severe interferences. We observed severe decreases in SNR, which lead to the use of more robust communication schemes of ECL1 and ECL2. Mentioned interferences in parallel with good radio conditions indicate that altitudes under 120m in sub-urban areas could be influenced by overlapping side lobes of surrounding base stations, which the operator does not optimize. Lack of optimization in this regard is expected since RAN optimization is focused on ground areas and not "in the air" areas where the use-cases requiring such optimizations are currently on their rise and will emerge in the near future. Nevertheless, currently conducted measurement have proven the NB-IoT capable of utilisation in side-link use-cases even with the nowadays mobile network setting. However, current implementations must consider that interferences and reselections may severely increase data transmission delay and occasionally limit continuous service provisioning.

With the above mentioned and after a closer look at all measured points and altitudes, it is worth noting that for altitudes above 100 m, service provisioning performed worse due to notably more signal outages, more time spent in ECL2, and overall less stable and less predictable radio conditions. From our observations, the ideal altitude for NB-IoT with the current network setting would be below 100 m depending on the use-case.

The tester used for measurements was the same device as in the case of drive test, thus features the same set of communication parameters listed in previous section.



Point	1				2			3			4		
Height above ground [m]	60	90	120	160	60	90	120	60	90	120	60	90	120
RSRP [dBm][1]	-65	-61	-66	-66	-63	-64	-62	-59	-63	-63	-68	-66	-67
SNR [dB][1]	0	3	-1	-2	3	2	3	5	5	3	-1	0	-3
RSSI [dBm][1]	-53	-51	-53	-51	-53	-53	-51	-51	-53	-52	-54	-54	-53
ECL0 [%][2]	1	1	1	1	0	0	1	40	0	1	1	1	2
ECL1 [%][2]	73	99	49	53	100	100	99	59	100	84	79	88	20
ECL2 [%][2]	26	0	50	46	0	0	0	1	0	15	20	11	68
Number of signal meas.	495	329	418	301	352	273	279	358	434	364	240	397	401

Point	5			6			7			8		
Height above ground [m]	60	90	120	60	90	120	60	90	120	60	90	120
RSRP [dBm][1]	-62	-64	-64	-60	-65	-67	-	-64	-70	-63	-63	-65
SNR[dB][1]	2	1	2	5	1	-1	-	1	-7	2	1	-1
RSSI[dBm][1]	-51	-53	-53	-51	-53	-53	-	-53	-53	-51	-51	-52
ECL0 [%][2]	1	0	0	0	0	1	-	1	0	0	1	0
ECL1 [%][2]	99	85	100	100	100	58	-	98	0	96	82	80
ECL2 [%][2]	0	15	0	0	0	41	-	1	100	4	18	20
Number of signal meas.	328	398	365	325	289	372	-	187	333	356	393	359

Table 7. Measured communication parameters in terms of signal conditions for NB-IoT tester during flight test.

RSRP, SNR, RSSI – Values are mean values per altitude and point.

ECL - Amount of occurrence expressed as a percentage in relation to other ELCs.

Table 7 provides results in terms of essential attributes as RSRP indicating signal strength of LTE reference signals, thus marking possible communication limits in terms of received signal strength. Then SNR, which low level significantly influences possible message retransmissions and data repetitions. RSRP, together with SNR, are critical factors for

ECL selection is described in the Section 1.2.3. ECL is divided into three levels with each providing different communication robustness to provide the capability to communicate even in harsh radio conditions with a trade-off of possible transmission delay. In summary, a device indicating ECL2 means that communication will be possible, but the delay will increase. Rows in table indication ECLs indicate a number of measurement samples in % where devices indicated the corresponding level.

3.1.2.6 NB-IoT Measurements Conclusions

Comparison of NB-Iot and LTe network performance in air is based on results from measurement performed during MoNiFly project in Netherlands [3].

	RSRP		**RSSI**		**SINR**	
Altitude / Network type	LTE	NB - IoT	LTE	NB- IoT	LTE	NB - IoT
60 m	- 81 dBm	-63 dBm	- 52 dBm	- 52 dBm	1 dB	2.1 dB
90 m	- 88 dBm	-67 dBm	- 52 dBm	- 53 dBm	-4 dB	1.7 dB
120 m	- 90 dBm	- 66 dBm	- 53 dBm	- 53 dBm	-6 dB	-0.6 dB

Table 8: Comparison of in air measurements in LTE and NB-IoT networks

Narrow Band – Internet of Things network in air measurement confirms theoretical assumption about better performance in comparison with LTE network. Reference Signal Received Power (RSRP) parameter was better by approx. 20 dBm in all three altitudes (60, 90, 120 m). Received Signal Strength Indicator (RSSI) was very similar to LTE in all measured altitudes. Signal to Noise Ratio (SINR) was better in NB-IoT also in all altitudes, significantly more at the higher ones. Thus, results of measurement confirm overall better NB – IoT signal parameters in air.

Generally, disadvantages of NB-IoT limiting its usage are limited bandwidth and low data rate. Suitability of NB-IoT for low altitudes operation can be especially for regular position reporting.

3.2 Validations by ITU

The experiments planned by ITU in the first validation phase of FACT project are listed below.

- C2 Link Performance of the drone
- Trajectory tracking performance of the drone
- Geofencing/geocaging performance of the drone
- Urgent landing performance of the drone

The planned validation period was between October 1st and December 31st of 2021. ITU team has a proprietary testing field on the west side of Istanbul, Turkey, which is called ITUARC Orencik UAV Test Field. This area was reserved for the 1st validation activity and as planned, the tests were conducted within the reserved area and time frame.

3.2.1 ITUARC Orencik UAV Test Field

The test field, with an area of approximately 7000 m^2 and a triangle-like shape, was designed for flight tests of drones and narrow-wing fixed-wing UAVs. The field includes a building with a 60 m^2 workshop, 40 m^2 office, 40 m^2 open-sky UAV integration part with paved floor and a 20 m^2 flight observation platform. The building facility is shown in Figure 10.

Figure 10. Ground and aerial photos of ITUARC Orencik UAV Test Field

The field has key points whose latitude and longitude are measured by Real-Time Kinematic GPS (RTK GPS) surveys. By means of these key points, UAVs can be landed to the well-defined points autonomously. Also, the field boundary is defined as a closed polygon whose vertices are again measured using RTK GPS equipment. The standard drone experiments are executed in the airspace surrounded by the geocage with the upper altitude limit. The autopilot features and settings are used for this geocage definition.

3.2.2 ITU ARC Drone and Operation Setup

Unmanned air traffic around ESTU aerodrome will be realized by two drones which are owned by Aerospace Research Centre (ARC) of Istanbul Technical University (ITU). These drones are middle size quadcopters with app. 10 kg take-off weight, and powered by two 6-cell 22 Ah LiPo batteries which provides approximately 30 minutes flight time. The 1st validation activities used this experiment drone whose photo is shown in Figure 11.

Figure 11. ITU ARC experiment drone prepared for FACT demonstrations

The ground control software is developed by ITU ARC and is being edited according to the system architecture and validation requirements of the FACT project. The main screen of the ground control software is shown below. A built-in 3D geospatial visualization engine is supported with a 2D map. User interface design will assist the operator while conducting the validation tests. A VoIP interface is planned to be integrated in the user interface shown in Figure 12.

1	opman_deneme	3
-	ucus1	3
-	ucus2	3

GUIDED
ALT: 25 m
BAT: %-1
D2H: 179 m
ASP: 4 m/s
GSP: 4 m/s

Figure 12. ITU ARC ground control station interface

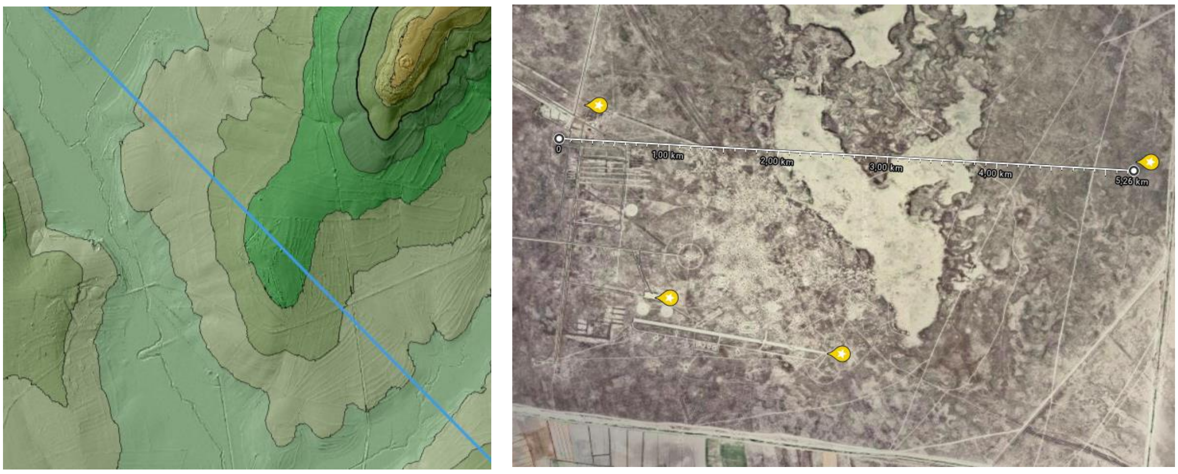
Both drones will be connected to the ground station using high-power industrial scientific medical (ISM) band C2 radios with time-division multiplexed (TDM) star network topology. Their tested range is 5 km. C2 link ensures the drone status vector (position, velocity, attitude etc.) at 1 Hz.

The flight control software of the drones is capable of tracking polynomial trajectories defining position, velocity and acceleration references. The ground control software will be capable of pre-flight trajectory planning, according to the waypoints and geofence/geocage constraints provided by the operator. The anticipated maximum trajectory tracking error is 5 meters. The geocage may consist of an altitude limit, a circle centred on the drone's home location, or a polygon defined by the operator. When the drone hits the geocage it can perform one of the three reactions, return to home, land, or hold position, according to its safety configuration.

3.2.3 Validation Activities Performed by ITU

3.2.3.1 Test #1: C2 Link Performance Test

The C2 link radio preferred for FACT validation activities is RFDesign’s RFD868x model, which has 1 W transmit power and 40 km promoted range. ITU conducted one range test in Istanbul for the 1st validation activities. As shown in Figure 13a, in the validation tests in Istanbul, a distance of 4.1 km was recorded with a connection quality of more than 90%, which means that less than 10% of the C2 messages are lost during the flight.



(a) (b)

Figure 13. (a) 4.1 km range tested in Istanbul in 2021, (b) 5.1 km range tested in Konya in 2018.

A similar test was conducted in 2018 in an open field away from the city centre of Konya, Turkey by ITU ARC Flight Test Team. Konya, located in the Central Anatolian region, is the city with the widest plains in Turkey. Hence, it was possible to conduct a deeper range test. As shown in Figure 13b, the recorded range with more than %90 connection quality was 5.1 km.

As a result, in the FACT 2nd validation tests, with the C2 link, ITUARC will be able to perform seamless LOS drone-ground station communication within a 5 km radius in the flat geography of Eskisehir.

3.2.3.2 Test #2: Trajectory Tracking Performance Test

For this test a 6-waypoint circle like trajectory has been prepared. The flight test is conducted in Orencik field. The pilot took off manually. He flew the UAV towards the 6th waypoint, then switched to autonomous mode. The drone flew the waypoints from 1 to 6 respectively, maintaining the position and altitude on the last waypoint, and went to hold mode. The autonomous mission, which was completed at this stage, was cancelled via the RC control. The pilot manually flew the drone to back to home position from the 6th waypoint and landed as shown in Figure 14.

Figure 14. From waypoint 1 to 6, the drone flew in autonomous mode. Take-off and landing phases were piloted flight.

Figure 14 shows the waypoints and the home position (0). The greatest cross-track error is recorded while the drone is at the closest point to the waypoint, due to the guidance method of the autopilot. Autopilot is configured to perform less than 2-meter cross-track error. In this representative test flight, while passing through a waypoint, the largest cross-track error is recorded as 2.4 meters. Between the waypoints, the cross-tracking error occurred below 1.5 meters.

3.2.3.3 Test #3: Geofencing/Geocaging Performance Test

Geofencing is the prevention of a UAV from entering a restricted zone which is defined by a specific area and a specific altitude. Geocaging, on the other hand, is keeping the UAV within this designated area, not allowing it to exit. Polygons are often used to define these regions. In our test case, a tetragon geocage is prepare as shown in Figure 15.

Figure 15. Geocage defined for the tests

The upper edge of this tetragon is the pushed boundary in the tests. The drone always starts its flight from the interior of the geocage region. There are five options for the geofence/geocage violation reaction given by

- Return to launch (RTL) point otherwise land,
- Brake otherwise land,
- Always land,
- Smart RTL otherwise land,
- Smart RTL otherwise RTL otherwise land.

RTL mode returns the drone to the take-off position through a straight flight path starting from the point where drone switches to RTL. Brake mode stops the drone at the current latitude, longitude and altitude. In order to be able to make RTL or brake, drone has to have a reliable GNSS measurements. In some cases, like being in the building valleys, or having a thick cloud and heavy rain, GNSS signal strength decreases. Then, drone switches immediately to land mode from RTL or brake mode in order not to drift horizontally. Options a and b are created by using these modes conditionally. Option c forces the drone to land autonomously when a geocage/geofence violation is detected by the autopilot. Smart RTL is an enhanced feature which returns the drone to the take-off point through the travelled route back. Option d first tries to make a smart RTL reaction, then it lands the drone is GNSS measurements become unreliable or any new geofence definition appears on the return route. The last option tries to make RTL when smart RTL fails due to any new geofence definition.

In the FACT demonstrations, (a) RTL otherwise land, and (b) brake otherwise land options are going to be used. In the 1st validation activities both reaction options are tested. A photo from the geocage/geofence tests are given in Figure 16. Conducted test flights are explained below.

Figure 16. A photo from geofencing/geocaging tests

Flight #1: RTL otherwise land option is selected before flight. The drone was taken-off by pilot. Then, a waypoint which is out of the geocage region is assigned by the operator. However, the drone did not react to it, did not start to fly towards the given waypoint, and stay in the air. In the continuation, control is transferred to the drone pilot. The pilot started flying the drone out of the geocage area. The drone started to move till it reaches to the edge of the geocage tetragon. Then, it started to return to take-off point immediately and autonomously. While it was returning, the pilot had the permission to give correcting commands to the drone. Then, the drone landed autonomously.

Flight #2: The drone settings were changed. Brake otherwise land option was selected. The drone was taken-off by the pilot for the second time. The pilot started to fly the drone out of the geocage area. When the drone arrives to the edge of geocage tetragon, it braked. As it has GNSS measurements, it held both its horizontal position and altitude. In the brake mode, the drone does not react to the pilot stick commands. The only way for the pilot to take control is to change the flight mode of the drone with the RC controller. If it is done, then pilot can move the drone again, but not towards the out of geocage region.

Flight #3: In the third flight, the drone was taken-off by the pilot again. In the geocage (dedicated) region, the operator asserted a land command to the drone. The drone immediately started to land while still accepting stick commands from the pilot which enables to make corrections for the landing point.

3.2.3.4 Test #4: Urgent Landing Performance

As detailed in the third flight of Test #3, the drone accepts the pilot stick inputs while landing autonomously. Using pilot sticks, pitch-roll-yaw angles can be adjusted and as a result, the drone's horizontal speed can be altered. In this way, pilot has the control on the landing point of the drone. Also, the pilot can change the thrust value using the stick and is able to slow down or speed up the landing action. This is successfully tested on the ITU ARC test field. The ways to put a drone into landing mode are listed below.

- Manually switching from
    - the RC controller by the pilot decision,
    - the operation computer by the GCS operator decision.

    - Autonomous switching triggered by any geofence/geocage violation with proper reaction settings,
    - the translation of the USSP message received from the CNS device by onboard flight management computer (FMC).

3.2.3.5 Extra Test #1: Kill Switch Test

For FACT project demonstrations, RC control switch settings have been made to provide the safest flight. The RC controller has three two-position switches and one three-position switch which are given below.

- Switch A (two-position)
    - Up position: Trigger a return to take-off position mode change
    - Down position: Do not change the mode

- Switch B (two-position)
    - Up position: Kill motors
    - Down position: Enable motor motion
- Switch C (three-position)
    - Up position: Change the drone mode to loiter (keeps 3D position when the sticks released)
    - Centre position: Change the drone mode to altitude hold (keeps the altitude but releases any horizontal drift when the sticks are released)
    - Down position: Change the drone mode to guided (keeps 3D position when the sticks are released and also accepts the waypoint commands)
- D (two-position)
    - Up position: Trigger a land mode change
    - Down position: Do not change the mode

While the pilot is controlling the translation between manual and autonomous flight modes using C switch, he/she can initiate autonomous landing and return-to-launch actions using A and D switches a and d. These capabilities add to FACT's base level of safety. On the other hand, switch B makes it possible to ensure operational safety at the expense of losing the drone. As shown in Figure 17, the kill switch tests were conducted on ground. In any flight mode of drone autopilot, kill switch has the priority, always stops all motors and crashes the drone if it is in the mid-air.

Figure 17. Kill switch test.

3.3 Validations Activities Performed by ESTU

Within the scope of this work, it was aimed to develop scenarios specific to flight operations in the arrival, departure and aerodrome phases for general aviation aircraft and unmanned aerial vehicles and to confirm them for the next validation study in Eskisehir training airspace.

12 scenarios were created for the Anadolu (Eskisehir) Airspace given in D5.1 using Best Software (Figure 18). Then, flight plans were created for each scenario.

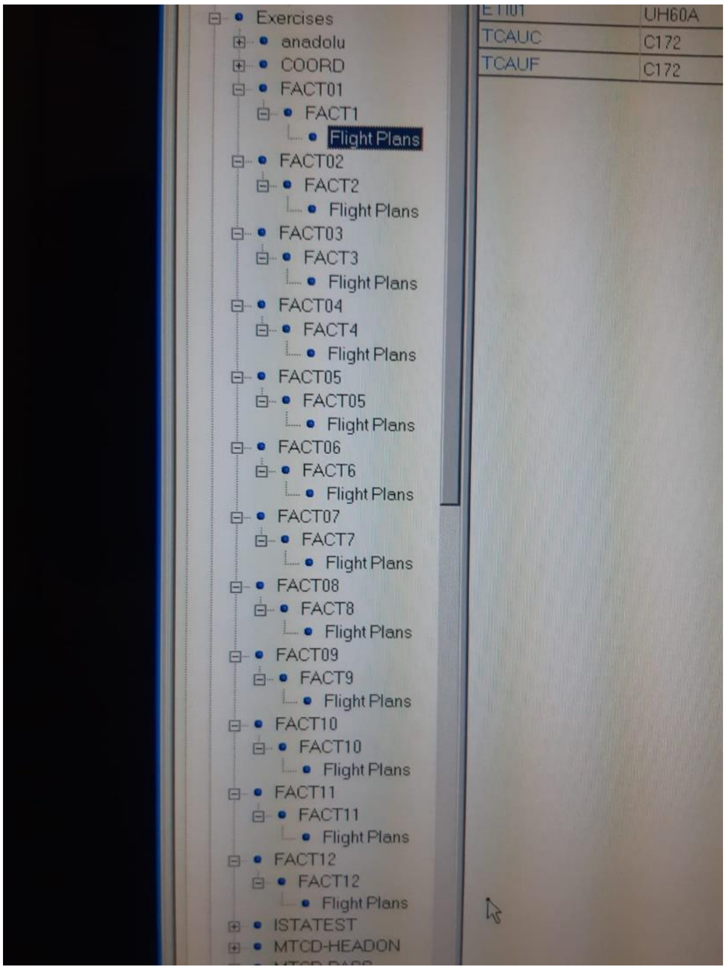


Figure 18. Screenshot of the scenario generator for FACT taken from BEST software.

3.3.1 Drone Situational Awareness Display for ATCOs

During the first validation process, ESTU initiated to develop an HMI display for the ATCOs that can observe the Drone flights in their airspace. For the initial design development, Cesium JS open-source web-based design tool was used. The airspace was used as ESTU campus for the drone flights as planned in the validation scenarios. In this context, 3D low airspace areas were created considering the safety of other general aviation flights. ATCOs will have the opportunity to monitor drone flights in 3D format that creates better situational awareness for both ATCO and GA operators concerning the drone flights. In the screenshot below, preliminary design achievements can be seen.

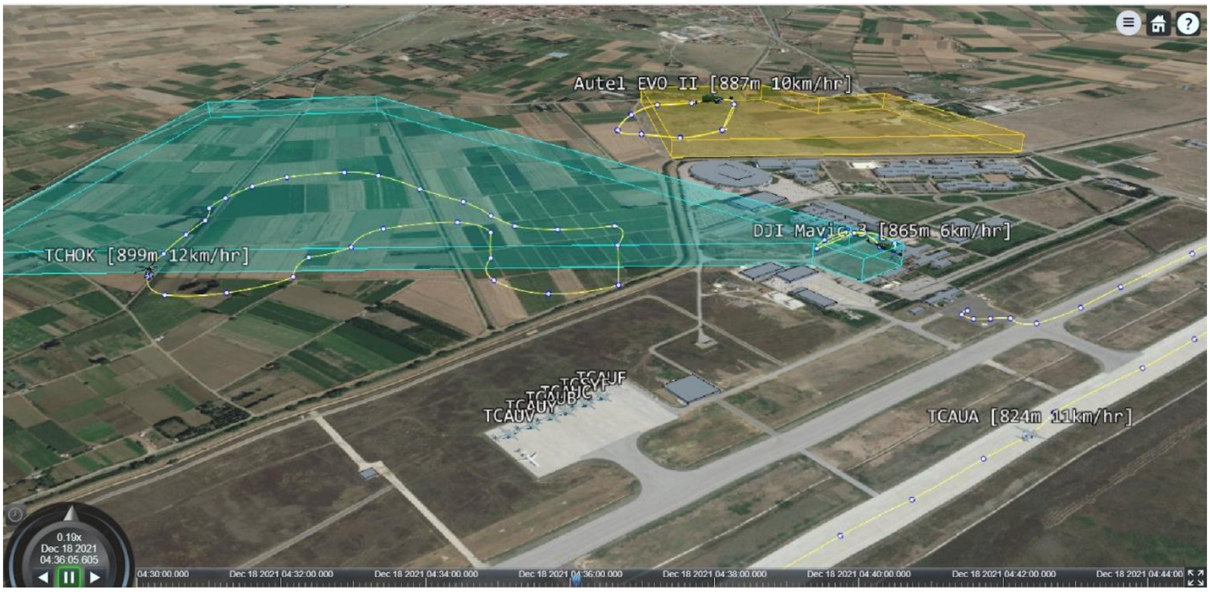


Figure 19. Situational awareness software

3D visualization design was also shared with the project members and operators to have their first validation concerning the HMI display. The feedback especially from the controllers were positive on situational awareness which is showing the development is on the right way. Design and development efforts will continue through the second validation by improving flight patterns for drones and connecting real traffic data which will create real flight operations for the ATCOs.

3.3.2 Validation Platform

The faculty has 3D and 360 degrees' aerodrome simulator systems (6 different simulation environments including the busiest Turkish airports). The system provides creating very effective airport and air traffic scenarios as well as testing even emergency and hazardous situations in the air and on the ground.

ESTU aerodrome simulation general features can be listed as:

- Realistic aerodrome image with 360 and 3D view,
- Realistic aircraft and operational performances,
- All weather conditions,
- Emergency conditions,
- 6 different airport layouts including validation airport and airspace for the FACT,
- Airport layout design tool FAB,
- Operational positions and 1 supervisor with 2 pseudo pilot positions,

- Pseudo pilot positions can be extended with radar pilot positions,

Figure 20. 3D Aerodrome control simulator

The aerodrome simulation will play an important role to create and mature FACT validation scenarios during the project studies. With the support of advanced features of the simulator and experts' collaboration, FACT validation scenarios will be developed and tested virtually to manage project objectives better considering safety and efficiency issues. System is capable of operating unmanned aerial systems with general and commercial air traffics together.

3.3.3 Training Airspace Used in Scenarios

The training airspace used by aircrafts departing from/arriving to Eskisehir Technical University airport is provided in Figure 21 below. In Figure 22 Traffic Pattern Map of Eskisehir Technical University Training Airspace is given. Lastly, in Figure 23 the dedicated flight zones for drone operations are displayed.

When developing flight scenarios for unmanned aerial vehicles, mobile control vehicles/stations, flight range and antenna location, and flight safety circumstances were all considered. For this, UAVs are planned to fly within the area indicated in yellow and blue in Figure 23.

The scenarios were prepared by considering that while the C172 aircraft completed the aerodrome tours by landing and taking off from the airport, the helicopter was flying in the aerodrome tour and planned flight zones and at point A shown in Figure 22.

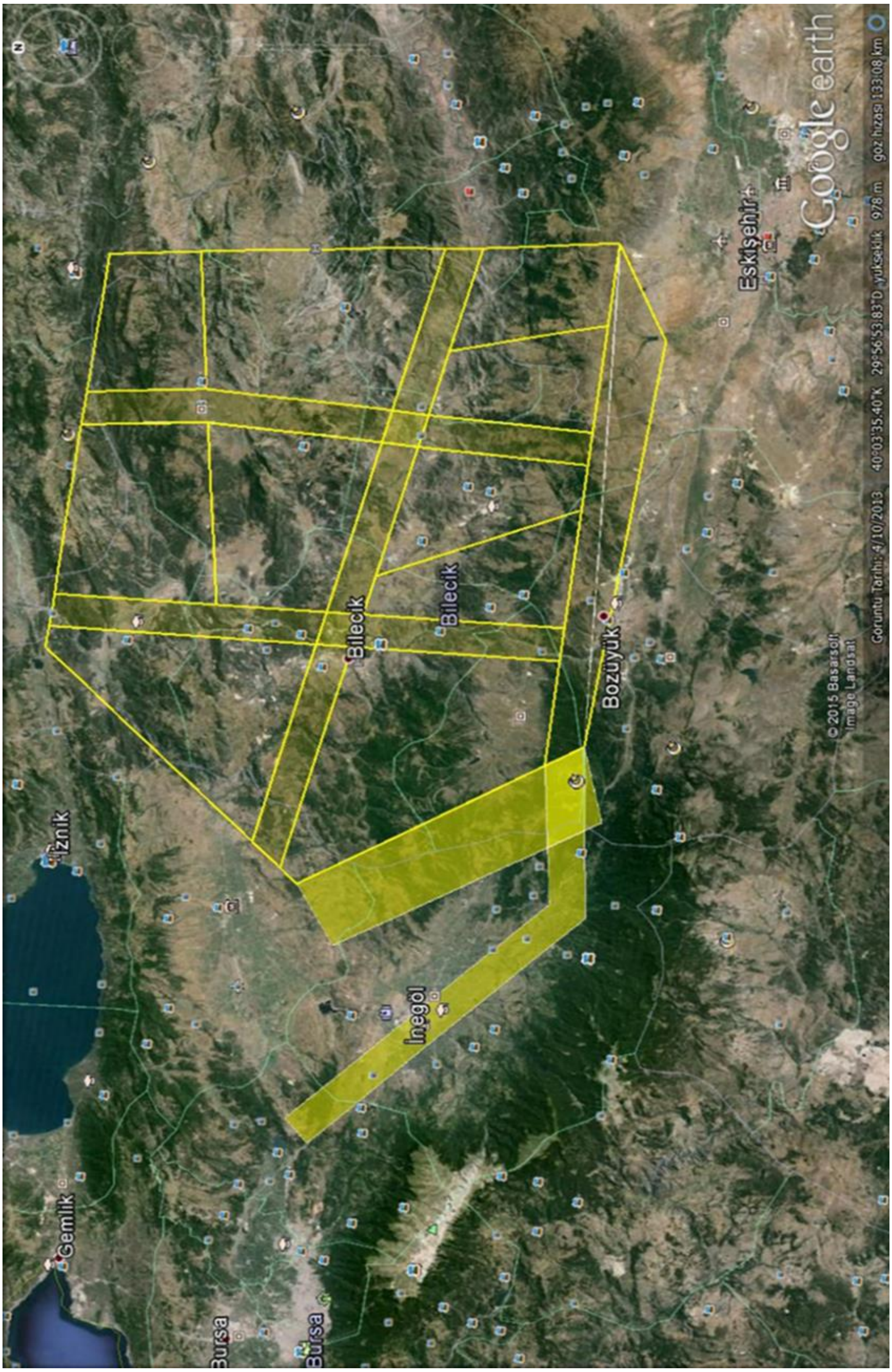


Figure 21. Eskisehir Technical University Training Airspace

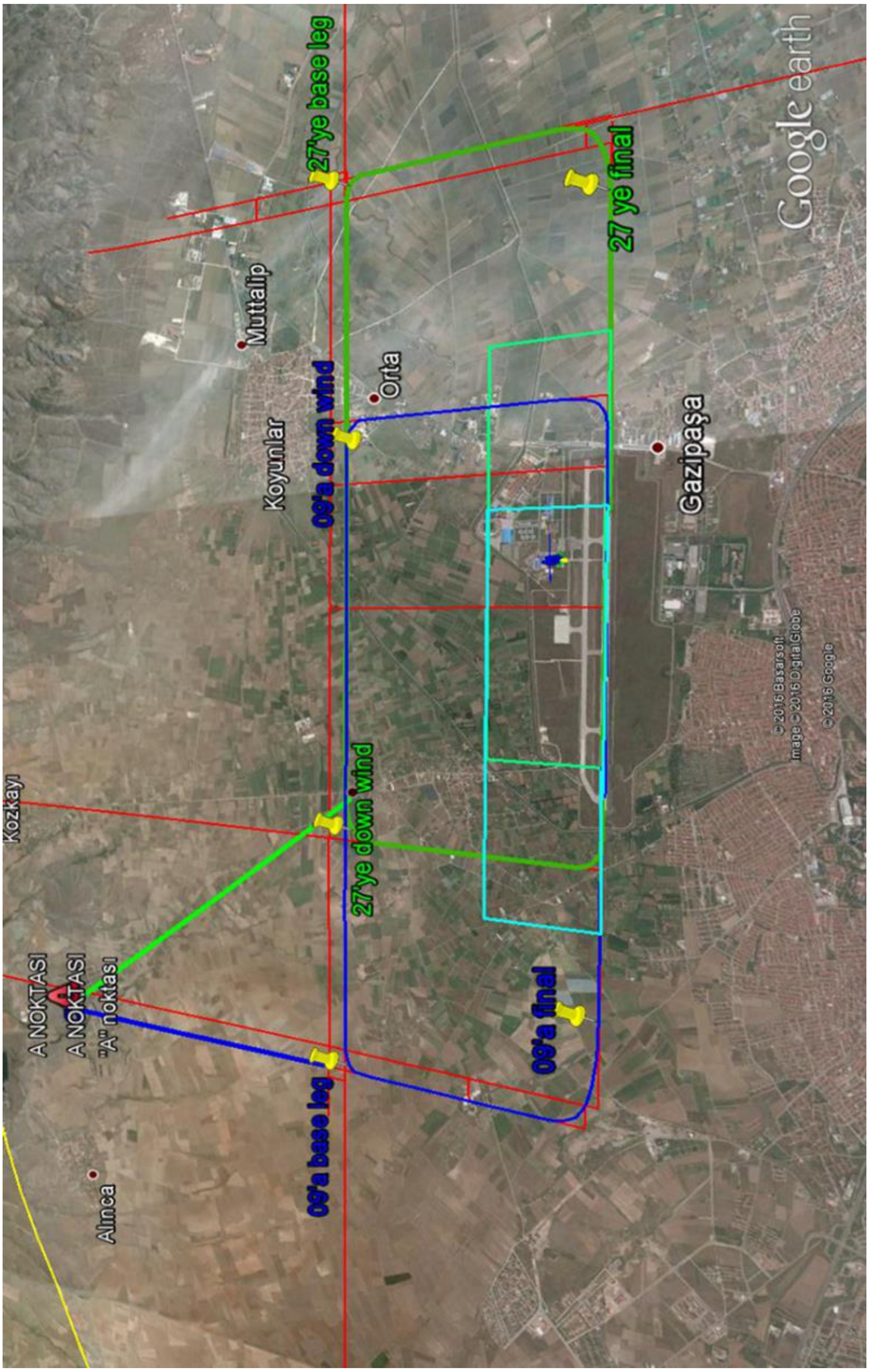


Figure 22. Traffic Pattern Map of Eskisehir Technical University Training Airspace

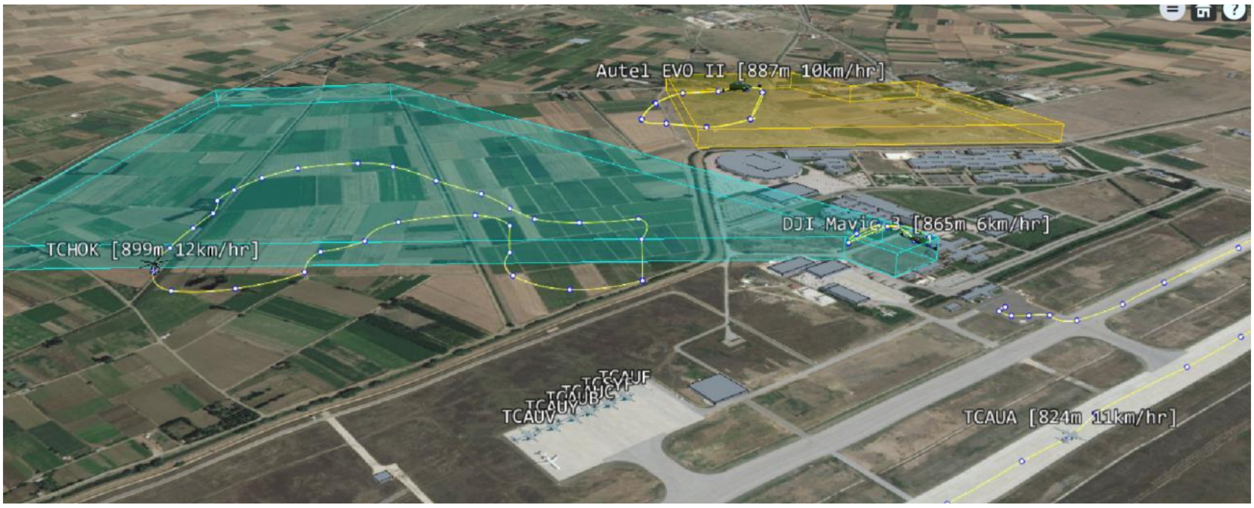
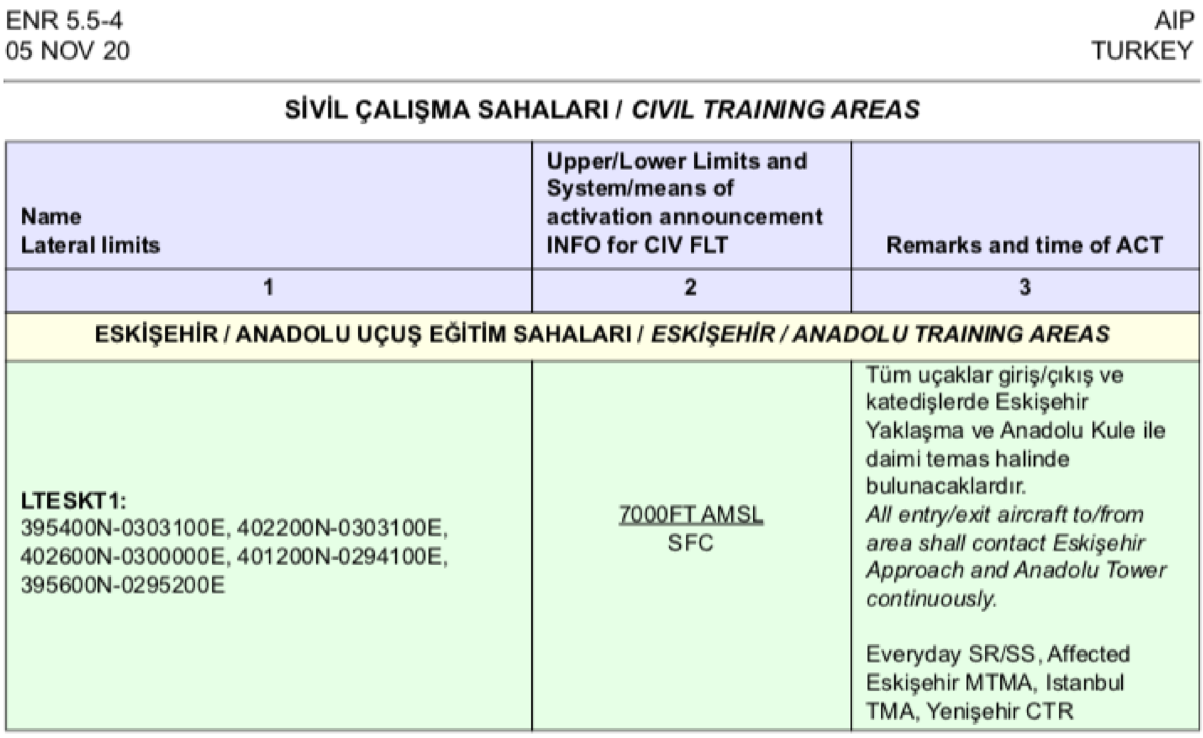


Figure 23. Flight Zones Defined for Drones



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SİVİL ÇALIŞMA SAHALARI / *CIVIL TRAINING AREAS*

Name Lateral limits	Upper/Lower Limits and System/means of activation announcement INFO for CIV FLT	Remarks and time of ACT
1	2	3
ESKİŞEHİR / ANADOLU UÇUŞ EĞİTİM SAHALARI / *ESKİŞEHİR / ANADOLU TRAINING AREAS*		
LTESKT1: 395400N-0303100E, 402200N-0303100E, 402600N-0300000E, 401200N-0294100E, 395600N-0295200E	7000FT AMSL SFC	Tüm uçaklar giriş/çıkış ve katedişlerde Eskişehir Yaklaşma ve Anadolu Kule ile daimi temas halinde bulunacaklardır. *All entry/exit aircraft to/from area shall contact Eskişehir Approach and Anadolu Tower continuously.* Everyday SR/SS, Affected Eskişehir MTMA, Istanbul TMA, Yenişehir CTR

Table 8. The technical characteristics of the civil flight training area.

Table 8 above shows the technical characteristics of the civil flight training area.

3.3.4 Eskisehir Training Airspace Features

Eskisehir Hasan Polatkan Airport, located in Eskisehir Technical University Iki Eylul Campus, mostly serves flight training activities.

Hasan Polatkan Airport, formerly known as Anadolu University Airport, was opened to traffic in March 1989. The primary purpose of the airport is to meet the training activities of the pilotage department of the Faculty of Aeronautics and Astronautics of ESTU. In addition, it contributes to national and international passenger transportation by aiming to meet the demand that may arise in Eskisehir and surrounding cities. In this context, in addition to the flight training activities of the Faculty of Aviation and Space Sciences Pilotage Department, VIP (Very Important Person), CIP (Commercially Important Person), air taxi and ambulance flights, training flights for Turkish Airline (THY) students, flights related to maintenance activities for aircraft weighing less than 5700 kg, flights for calibration of navigation equipment and emergency landing, scheduled domestic passenger transport flights, non-scheduled international passenger transport flights are carried out.

Hasan Polatkan Airport's IATA identification code is AOE and ICAO identification code is LTBY. The aerodrome is 2580 ft above sea level, the runway pavement is asphalt. The airport has a single runway with a length of 3000 m and a width of 45 m in the 09-27 direction. Hasan Polatkan Airport has three aprons and two hangars; east, west and maintenance. The east apron is also the terminal apron. It has an area of 8000 m^2 with dimensions of 100x87m and is asphalt. In addition to the terminal apron, a 7200 m^2 concrete maintenance apron with 72x100 m dimensions also serves general aviation activities. General aviation apron is used as a parking apron for training aircraft and other general aviation aircraft. A total of 18 general parking positions are available for aircraft under 5700 kg. Apart from these two aprons, there is also a west apron in front of the airport fire station. The runway is connected to the aprons by 18 m wide A taxiways, 24 m wide B, C, D, E, G, H, J taxiways, 15 m wide F and 30 m wide L taxiways. The sketch of Hasan Polatkan Airport is given in Figure 23. The airport has a 4,000 m^2 passenger terminal building used for domestic and international passenger traffic. There is an air traffic control tower within the terminal building and aerodrome control service is provided.

In the current situation of Hasan Polatkan Airport, VOR/DME device was installed in 1999, additional taxiways were built in 2002, runway and taxiway lightings, approach lights and PAPIs (Precision approach path indicator) were installed.

The tower frequency was changed to 123.750 MHz and the ramp frequency to 121.9 MHz in 2005. The airspace allocated for the realization of flight activities is a semicircle with a radius of 1.5 Nm to the north of the runway centre line, with coordinates 294835N – 030311E as the centre. The vertical limits of the airspace are 3500 ft AMSL/SFC. The call name of the air traffic service unit is Anadolu Kule and the transfer level is 7000 ft. Approach service is provided by Eskisehir Military Approach Radar. Due to the intense military flights of Eskisehir Military Airport, tours cannot be made from the south of the aerodrome.

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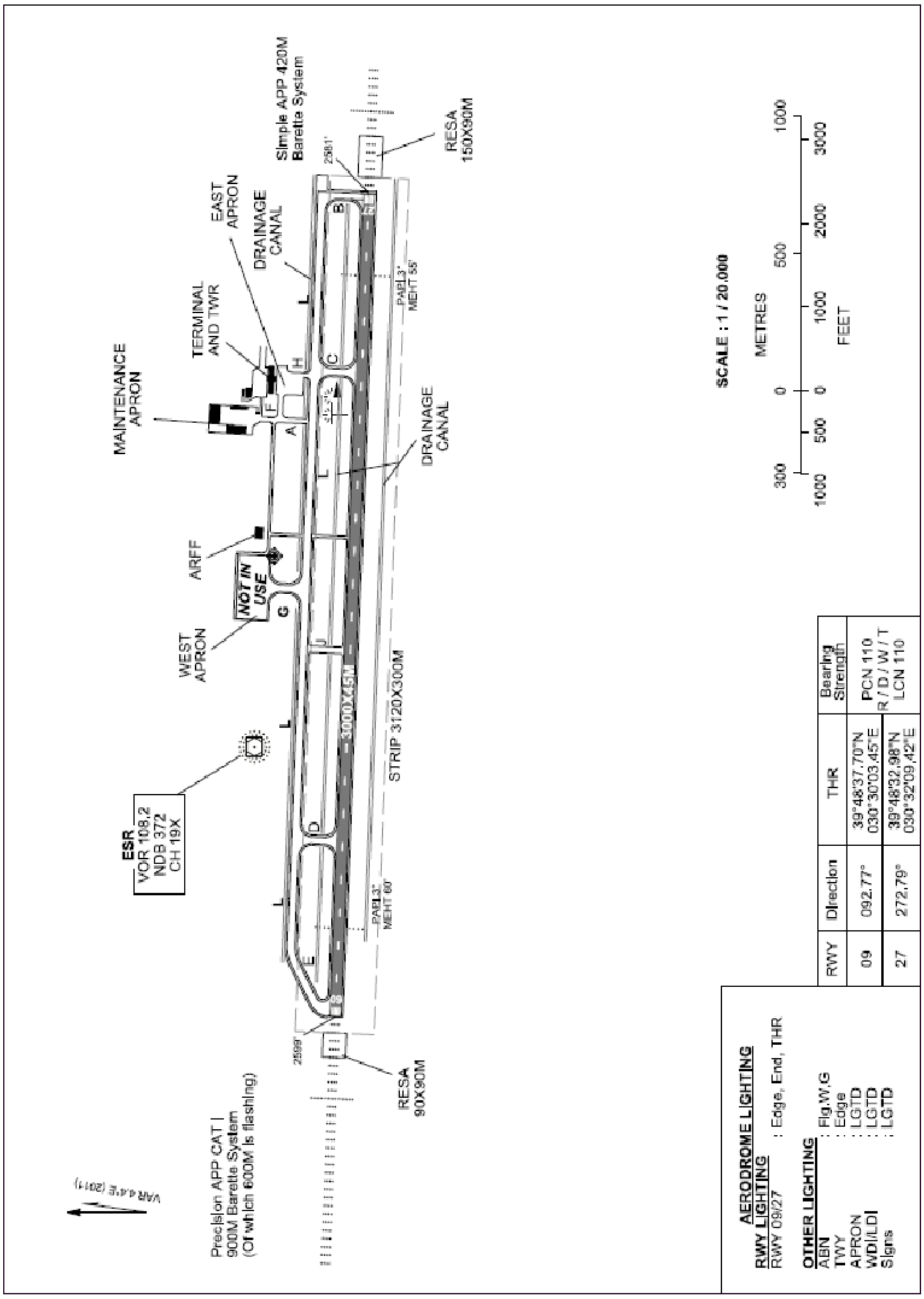
AERODROME CHART ICAO
39°48'45"N
030°31'14"E
ELEV: 2599 FT
TWR : 123.750
GND : 121.900
ESKİŞEHİR/ ANADOLU ÜNİVERSİTESİ



CHANGE: RESA DIMENSIONS

AERODROME LIGHTING

RWY LIGHTING
RWY 09/27 : Edge, End, THR

OTHER LIGHTING
ABN : Flg.W,G
TWY : Edge
APRON : LGTD
WDI/LDI : LGTD
Signs : LGTD

RWY	Direction	THR	Bearing Strength
09	092.77°	39°48'37.70"N 030°30'03.45"E	PCN 110 R / D / W / T LCN 110
27	272.79°	39°48'32.98"N 030°32'09.42"E	

DHMİ - ANKARA

AIRAC AMDT 03/14

Figure 24. Eskisehir Hasan Polatkan Airport map

The simulation study was created with the following stages;

- Preparation Phase
- Making necessary arrangements for the airspace and aircraft on the Simulation Platform
- Preparation of Scenarios
- Implementation Phase (Simulation Phase)
- Evaluation Phase (Analysis and Reporting Preparation Phase
- Making necessary arrangements for the airspace and aircraft on the Simulation Platform
- Preparation of Scenarios
- Implementation Phase (Simulation Phase)
- Evaluation Phase (Analysis and Reporting)

The preparation phase is making the necessary arrangements for the airspace and aircraft, preparing and creating the relevant scenarios. The next stage includes the realization of the flight scenarios and the finalization of the scenarios. The last stage of the simulator work is analysis, reporting and evaluation.

Risks associated with UAVs are defined as follows:

- Loss of communication link
- Loss of control link
- Loss of USSP (Communication with Controller) link
- Engine or battery failure

3.3.5 Validation Assumptions and Limitations

In scenario development, the main objective is to verify that there is a robust and clear communication and data sharing among GA pilots, drone operators and ATCOs to ensure safe and efficient operations so as to increase situational awareness of all operators in shared airspace.

In its broadest sense, scenarios fall into two categories based on whether aircrafts operate in controlled airspace or in uncontrolled airspace. Under each of these categories, there are trajectory-based scenarios and non-trajectory-based scenarios. Both classifications start with a baseline scenario in which there is no conflict among aircrafts including drones. Additional scenarios involve increased complexities such as airspace violations as a result of unexpected situations stemming from the need and/or unknown behaviours of airspace users. A schematic representation of the scenarios is provided in the following Figure 24 and Figure 31and explained in detail below.

In studies on air traffic control, the simulation method is used to examine many independent variables and uncertainties in flight operations simultaneously. Established by Micronav at ESTU Faculty of Aeronautics and Astronautics, Department of Air Traffic Control, Best 3D Arena simulator is a highly reliable real-time simulation environment where mixed traffic can be reproduced and evaluated. The assumptions and limitations of this simulation platform are an inevitable element of this study, as in any research activity.

The following assumptions were considered in this study:

- The selection, implementation and analysis of the use cases and scenarios are limited by the FACT objectives and platform capabilities of the ATM system.
- In the scenarios developed, meteorological conditions have been defined assuming that there is no significant wind, no precipitation and the view is clear.
- As the flight time, 10.00 Zulu has been selected for general aviation and unmanned aerial vehicle flights in all scenarios.
- In VFR flight under VMC conditions, pilots perform their flight and navigation according to visual references outside the aircraft. However, these visual references are used for safe separation from other aircraft. Communication between the controller and other pilots is very important to ensure flight safety in all VFR operations. In this study, it was assumed that the communication was problem-free.
- In uncontrolled airspaces, it is always the PIC's (Pilot in Command) responsibility to ensure that the aircraft is separated from other traffic. In this case, all pilots in the relevant area report their positions status and at important waypoints and provide coordination among themselves. In simulator studies, it is assumed that controllers provide this.
- Air traffic controllers change the following three parameters of aircraft so that aircraft can perform safe and efficient flight operations in controlled airspaces:
  - Aircraft speed
  - The heading or direction of the aircraft
  - Aircraft altitude/flight level
- Safe flight operations are performed during all simulations by effective use of vertical separation measures between:
  - Drones/ Fixed wing,
  - Drones/ rotorcraft
  - Rotorcraft/ fixed wing
- All communication channels (e.g. iCNS, VHF, USSP, ATC) are assumed to be available and in perfect condition (accessible) at all times.

Generally, changing one of the above parameters suffices to ensure flight safety. As a result, in the simulator studies, the most appropriate one of these three parameters were chosen by considering the situations and priorities of the aircraft with respect to each other while performing the avoidance manoeuvres.

3.3.6 Validation Use Cases and Scenarios

The numbers of fixed wing, drone, and helicopter employed in the scenarios, as well as their flying altitudes, are provided. In addition, Table 9 contains conflict and risk probability.

Scenario	Duration	FixedWing		Rotorcraft		Drone		Conflict	Risk
		Number	Altitude	Number	Altitude	Number	Altitude		
1	20 min.	2	3500 ft	1	3500 ft	1	300 ft	-	-
2	20 min.	2	3500 ft	1	3500 ft	1	300 ft	-	+
3	30 min.	2	3500 ft	1	3500 ft	2	300 ft	+	+
4	30 min.	2	3500 ft	1	3500 ft	2	300 ft	-	-
5	30 min.	2	3500 ft	1	3500 ft	2	300 ft	-	+
6	30 min.	2	3500 ft	1	3500 ft	2	300 ft	+	+
7	30 min.	2	3500 ft	1	3500 ft	2	300 ft	-	-
8	30 min.	2	3500 ft	1	3500 ft	2	300 ft	-	+
9	30 min.	2	3500 ft	1	3500 ft	2	300 ft	+	+
10	40 min.	2	3500 ft	1	3500 ft	2	300 ft	-	+
11	40 min.	2	3500 ft	1	3500 ft	2	300 ft	-	+
12	30 min.	2	3500 ft	1	3500 ft	2	300 ft	+	+

Table 9. Scenario details

Table 10 lists the durations associated with the traffic patterns analysed in the scenarios.

Phase	Elapsed times in traffic pattern
Request Engine start up +start up	30 + 600 second
Request taxi	30 second
Taxi from parking position to holding point	120 seond
Take of	30 second
Joining to crosswind	20 second
Crosswind	90 second
Joining downwind	20 second
Downwind	150 second
Joining baseleg	20 second
Baseleg	90 second
Landing	90 second
Total	1290 second=21.5 min

Table 10. Traffic pattern duration for Cessna 172

3.3.6.1 Scenarios for uncontrolled airspace Use Case

The scenarios for the uncontrolled airspace can be seen in Figure 25 below which represents details of the scenario distribution for the trajectory bases.

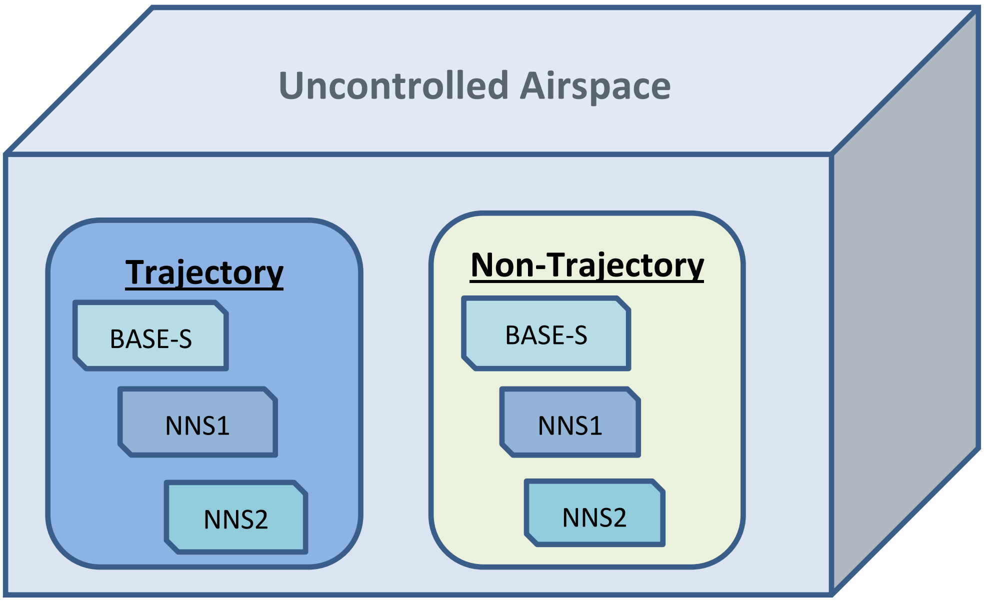


Figure 25. Uncontrolled airspace scenarios

3.3.6.1.1 Non-trajectory-based scenarios

Baseline scenario (Base-S) – no trajectory: Reference (baseline) scenario: In the baseline scenario, drones and GA flights are separated in the airspace prior to the beginning of flights. Each and every aircraft including drones fly within their predetermined allocated airspace and they are all visible in SA applications. In the baseline scenario, all flights are to be performed as expected and there will be no conflicts and/or risks posed by overlapping airspaces. All stakeholders are aware of surrounding traffic. The overall objective of the baseline scenario is to assess whether all entities can reliably and continually (without significant delay) provide information on their status to the other stakeholders on essential SA.

Non-Nominal Scenario 1 (NNS1): In this second scenario, the setting is the same as in the baseline scenario however, one of the fixed wings and/or rotorcraft has/have to enter drones' airspace due to unexpected circumstances. When this happens, GA informs ATC, ATC send info to USSP, USSP issues a geofence zone (vertical separation), drone's operator(s) receive info and change flight path to avoid geofence. If the drone operator does not comply within a predefined time period, drone is forced to land safely by appropriate procedures. Based on the ATC's instructions, drone's ground control station (with the drone's operator approval/confirmation) will send "land" command as a drone's C2 message. Consequently, the pre-defined automatic landing operation immediately start with the highest priority.

Non-Nominal Scenario 2 (NNS2): In this scenario the airspace violation is caused by the drone (drones) leaving the allocated airspace, e.g., due to technical difficulties. To avoid conflicts and possible threats to flight safety, USSP issues an alert to GA (for the operational demo purposes we assume a direct communication of the U space service with GA, however the communication can be also mediated by ATC). GA will react based on received information (pilot's decision). In addition, USSP issues a warning to the drone operator as well to make the drone operator to go back to its own geofence.

3.3.6.1.1.1 First Validation Scenario 1

In the first scenario, 1 drone, 1 helicopter and 2 Cessna 172S are used. In this scenario, C172s and helicopters flew within Eskisehir Training Airspace after performing engine start, push back, taxi and take-off movements. The drone, which was defined in the scenario with the call name Drone01, was included in the scenario in the area where it was decided that the drones could make their safe flights during the meetings with the stakeholders and that it would be the most suitable area for the equipment on the ground. Drone01 flies at an altitude of 300 ft. C172 aircrafts are included in the scenario with the call names TCAUA and TCAUC and fly at an altitude of 3500 ft. The helicopter, defined by the TCHGK call name, flies at an altitude of 3500 ft, like the other aircrafts. The airspace used in this scenario is uncontrolled airspace. Aircrafts do not have predetermined trajectories. Aircrafts are separated from each other in such a way that they do not cause traffic. All pilots have situational awareness of all aircrafts in their flight area. The scenario was run for 10 minutes, and no risky situation emerged among the aircrafts and the drone.

First Validation Scenario-1 is shown in Figure 26. In Figure 27, radar and simulation screenshots for First Validation Scenario-1 are provided. Drone, helicopter and two Cessna flight plans for Scenario-1 are shown in Appendix A.1. Radar and simulation screenshots for Scenario-1 are given in Appendix A.13.

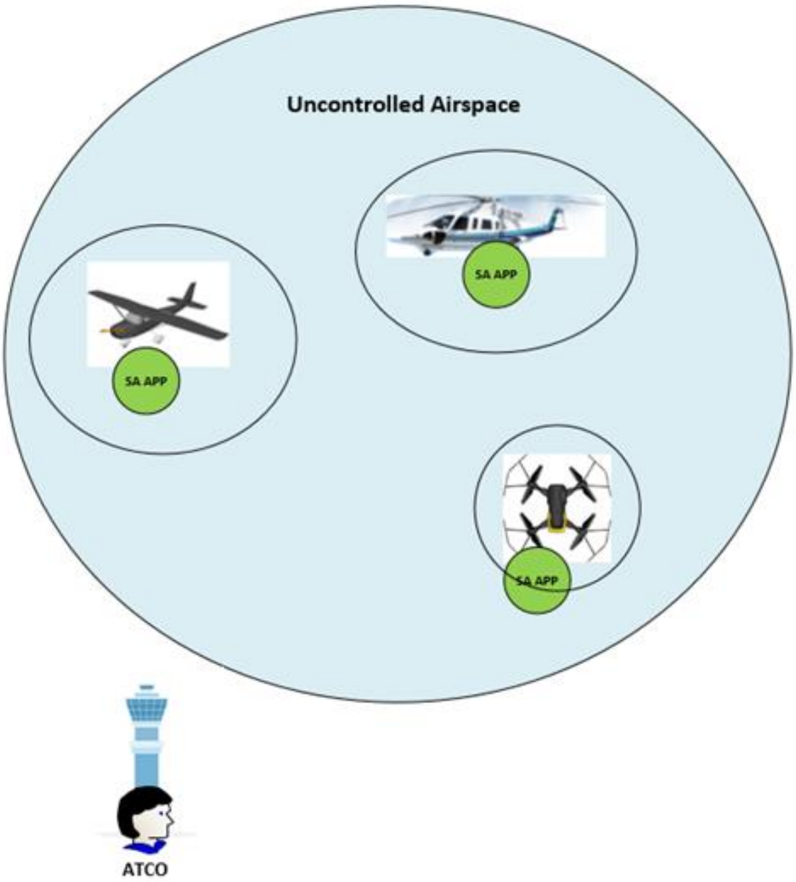


Figure 26. First Validation Scenario 1

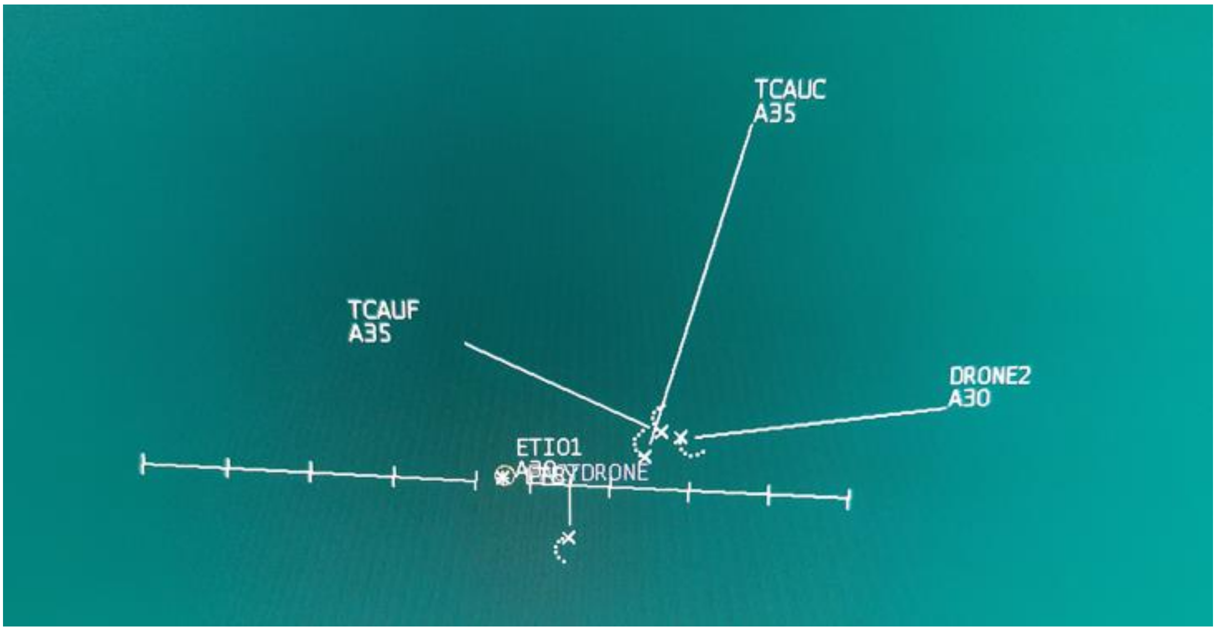


Figure 27. Radar and simulation screenshots for First Validation Scenario-1

3.3.6.1.1.2 First Validation Scenario 2

In the First Validation Scenario 2, 2 Cessna172s, 1 helicopter and 1 unmanned aerial vehicle were used as in the first scenario. In this C172s and helicopters flew within Eskisehir Training Airspace after performing engine start, push back, taxi and take-off movements. The drone, which was defined in the scenario with the call name Drone01, was included in the scenario in the area where it was decided that the drones could make their safe flights during the meetings with the stakeholders and that it would be the most suitable for the equipment on the ground. Drone21 flies at an altitude of 300 ft. C172 aircrafts are included in the scenario with the call names TCAUB and TCAUX and fly at an altitude of 3500 ft. The helicopter, defined by the call name ETI2, flies at an altitude of 3500 ft, similar to the other aircrafts. The airspace used in this scenario is uncontrolled airspace. Aircrafts do not have predetermined trajectories. In this scenario, C172s entered the flight range of the drone. Since a unsafe hazardous situation occurred for the two aircraft, the pilot of the aircraft informs ATCO. Then ATCO informs the USSP. (Here, it is measured as 10 seconds for the pilot to inform ATCO and ATCO to the USSP about the traffic situation.) After the USSP receives this information, vertical separation is made and the drone operator is instructed to make an avoidance manoeuvre by USSP. The drone is forced to land by USSP. The drone took 40 seconds to land by making an avoidance manoeuvre from 300 ft. This scenario took 10 minutes from start to finish.

First Validation Scenario-2 is shown in Figure 28. In Figure 29, radar and simulation screenshots for First Validation Scenario-2 are provided. Drone, helicopter and two Cessna flight plans for First Validation Scenario-2 are shown in Appendix A.2. Radar and simulation screenshots for First Validation Scenario-2 are given in Appendix A.14.

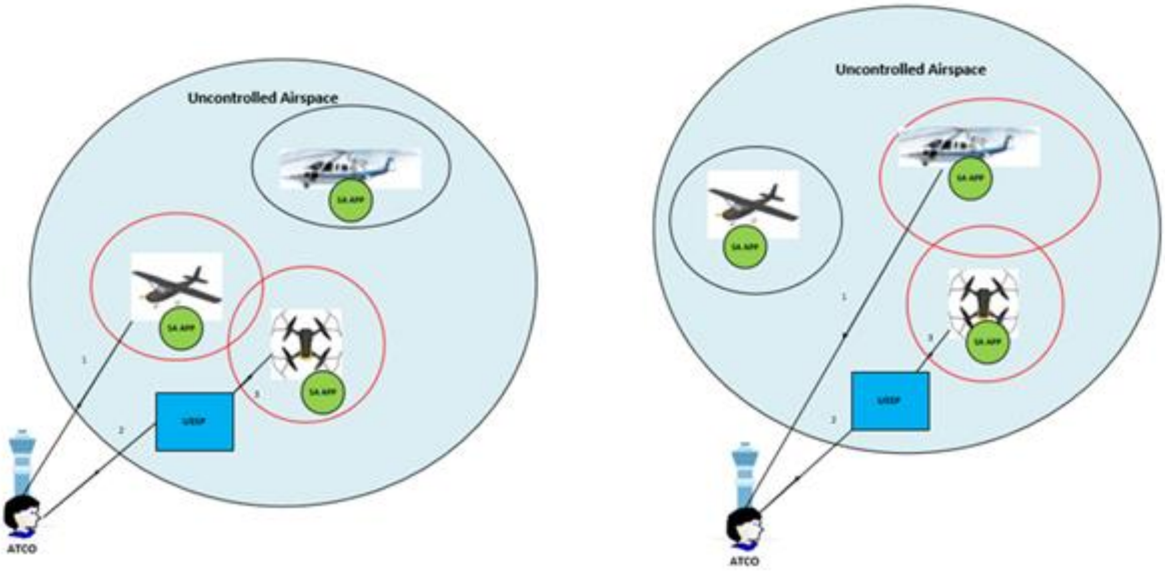


Figure 28. First Validation Scenario 2

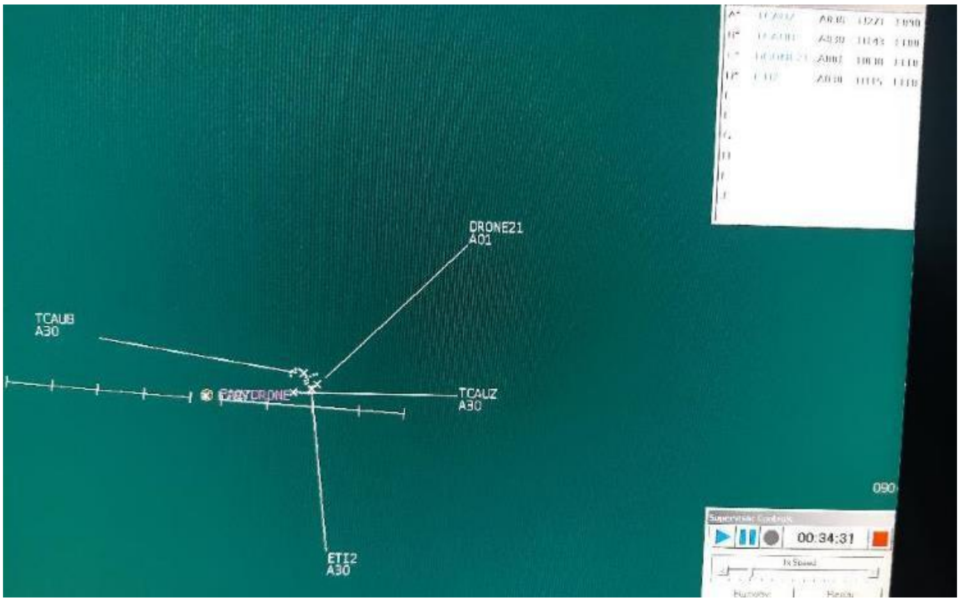


Figure 29. Radar screenshots for scenario-2

3.3.6.1.1.3 First Validation Scenario 3

2 Cessna172s, 1 helicopter and 2 unmanned aerial vehicles are used in this scenario. In this scenario, the C172s and the helicopter flew within the Eskisehir Training airspace after performing the engine start, push back, taxi and take-off movements. Drones defined in the scenario with the call names of Drone31 and Drone32, were included in the scenario in the area where it was decided during the meetings with the stakeholders that the drones could make their safe flights and would be the most suitable for the equipment on the ground. Drone31 and Drone32 fly at an altitude of 300 ft. C172 aircraft, on the other hand, are included in the scenario with the call names TCAUT and TCEUA and fly at an altitude of 3500 ft. The helicopter, defined by the ETI3 call name, flies at an altitude of 3500 ft, like other aircraft. The airspace used in this scenario is uncontrolled airspace. Aircraft do not have predetermined trajectories. In the scenario, the Drone31 enters the flight path of other aircraft. USSP sends alerts to aircraft and helicopter. Aircraft receive the warning and make an evasive manoeuvre. The USSP warns the drone to return to geofence. When the drone enters the flight path of C172, C172 is removed from the circuit and diverted to point A. After the C172 is removed from the circuit, it takes 50 seconds to establish a safe separation from the drone. Here, levelling the drone is another option. The drone makes the evasive manoeuvre from 3000 ft to 2500 ft 40 seconds.

First Validation Scenario-3 is shown in Figure 30. Drone, helicopter and two Cessna flight plans for Scenario-3 are shown in Appendix A.3. Radar and simulation screenshots for First Validation Scenario-3 are given in Appendix A.15.

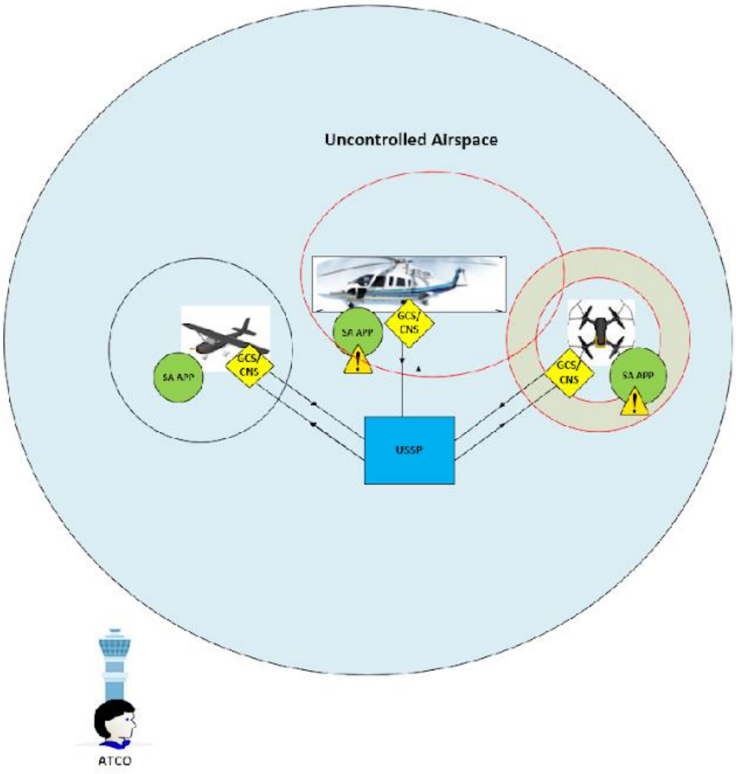


Figure 30. First Validation Scenario 3

3.3.6.1.2 Trajectory based scenarios

Base scenario (Base-S): Drones and GA flights strategically de-conflicted by trajectories mainly by vertical separation. Drones are not allowed to fly above a predetermined altitude and GA is not allowed to fly below the altitude set for the drone. This altitude level determined prior to the flights and applies to both drones and GA. Approved trajectories of surrounding traffic available for visualization in SA applications, flights are performed as planned, and all stakeholders are aware of their surrounding traffic. The overall objective of this scenario is the assessment of just feedback on essential SA among users.

Non-Nominal Scenario 1 (NNS1): NNS1 builds upon Base-S and there is a drone which starts to deviate from its approved trajectory. Once the deviating drone is detected, conformance monitoring issues an alert to all users and ATCOs. USSP will first issue a geofence zone until the new trajectory is agreed with the drone’s operator, other drones update their trajectories accordingly. Finally, GA manoeuvre only based on SA info.

Non-Nominal Scenario 2 (NNS2): NNS2 is very similar to NNS1, however conflict resolution is provided by issuing new flight updates/clearances to those users affected by the deviating drone.

3.3.6.1.2.1 First Validation Scenario 4

In the First Validation Scenario 4, the airspace used is uncontrolled airspace. All aircrafts have predetermined trajectories. Drone41, Drone42, ETI4, EUAUT and EUAUV aircraft fly in vertical separation from each other in the airspace. Flight routes are created such that the drones fly below

400 ft, and the general aviation planes fly above 400 ft. Situational awareness of all stakeholders is provided by the developed interface application and they all know each other's trajectories.

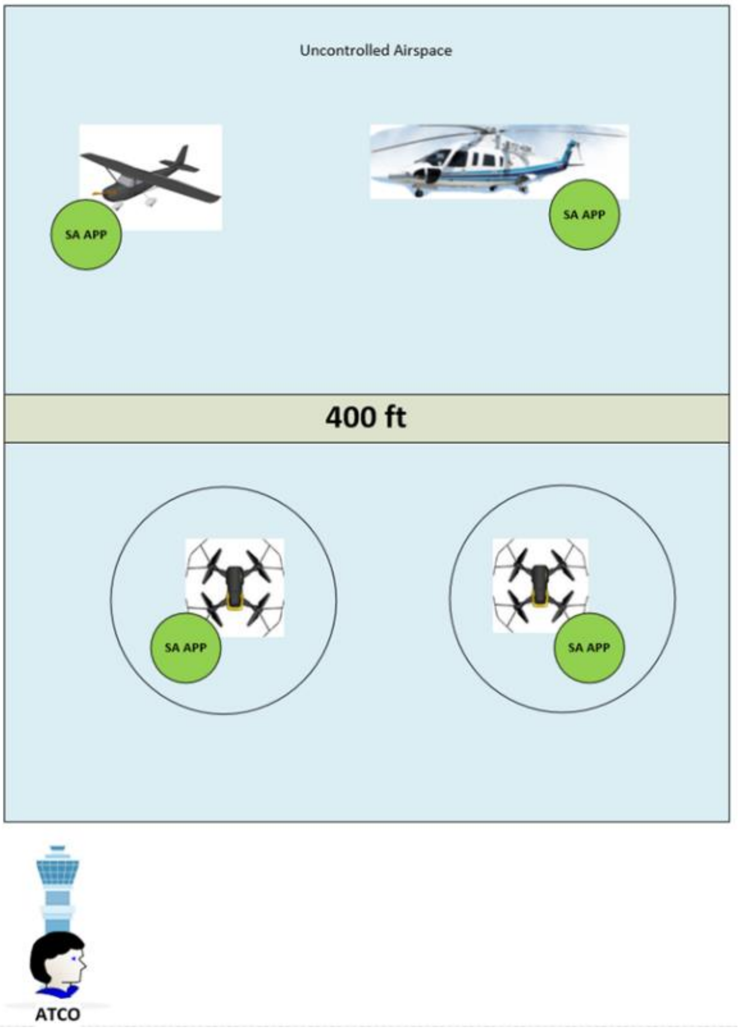


Figure 31. First Validation Scenario 4

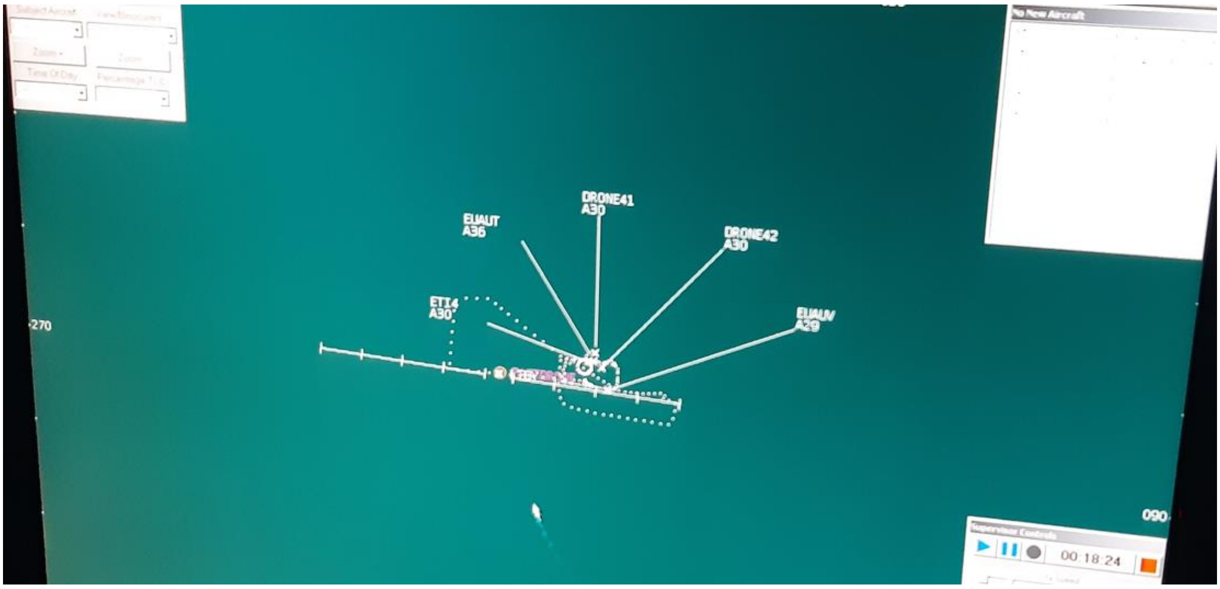


Figure 32. Radar screenshots for First Validation Scenario-4

First Validation Scenario-4 is shown in Figure 31. In Figure 32, radar and simulation screenshots for First Validation Scenario-1 are provided. Drone, helicopter and two Cessna flight plans for First Validation Scenario-4 are shown in Appendix A.4. Radar and simulation screenshots for First Validation Scenario-4 are given in Appendix A.16.

3.3.6.1.2.2 First Validation Scenario 5

In the fifth scenario, drones and general aviation aircraft are flying trajectory-based in an uncontrolled airspace. Drone51 starts deviating from its trajectory 4 minutes after the scenario starts. The USSP alerts all users and ATCOs regarding the new trajectory of Drone 51. Drone52 (the other drone) updates its trajectory according to the warning from USSP. Drone 51 is forced to make an evasive manoeuvre. From the designated flight area for the drones, it is directed towards the west of the aerodrome and waiting is made in the areas in the training airspace. It took 30 seconds for Drone51 to perform this avoidance manoeuvre. (It is assumed that information is transmitted to all users in 1 second from the USSP) Safe separation took 50 seconds for Drone51 and other general aviation aircraft. After the 50th second, all aircraft continue their safe flights.

First Validation Scenario-5 is shown in Figure 33. Drone, helicopter and two Cessna flight plans for First Validation Scenario-5 are shown in Appendix A.5. Radar and simulation screenshots for First Validation Scenario-5 are given in Appendix A.17.

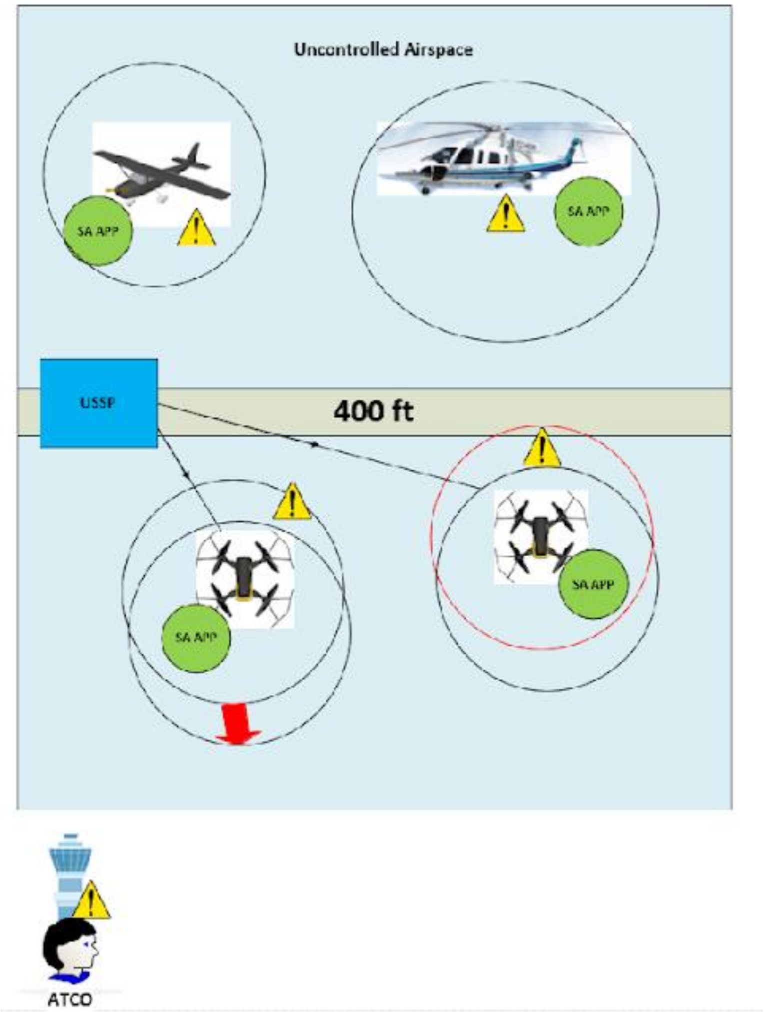


Figure 33. First Validation Scenario 5

3.3.6.1.2.3 First Validation Scenario 6

As in the other five scenarios, all aircraft are flying in an uncontrolled airspace. Similar to Scenarios 4 and 5, each aircraft has a certain trajectory. In this scenario, flight safety is ensured among aircraft by making the drone to do an avoiding action. The safe separation between the EYBUS aircraft and the Drone61 is provided by lowering Drone 61's flight level, and it took 45 seconds. Likewise, ETBYO aircraft was taken to point A and safe separation was ensured. This evasive manoeuvre was also achieved +45 seconds after the EYBUS aircraft.

First Validation Scenario-6 is shown in Figure 34. Drones, helicopter and two Cessna flight plans for First Validation Scenario-6 are shown in Appendix A.6. Radar and simulation screenshots for First Validation Scenario-5 are given in Appendix A.18.

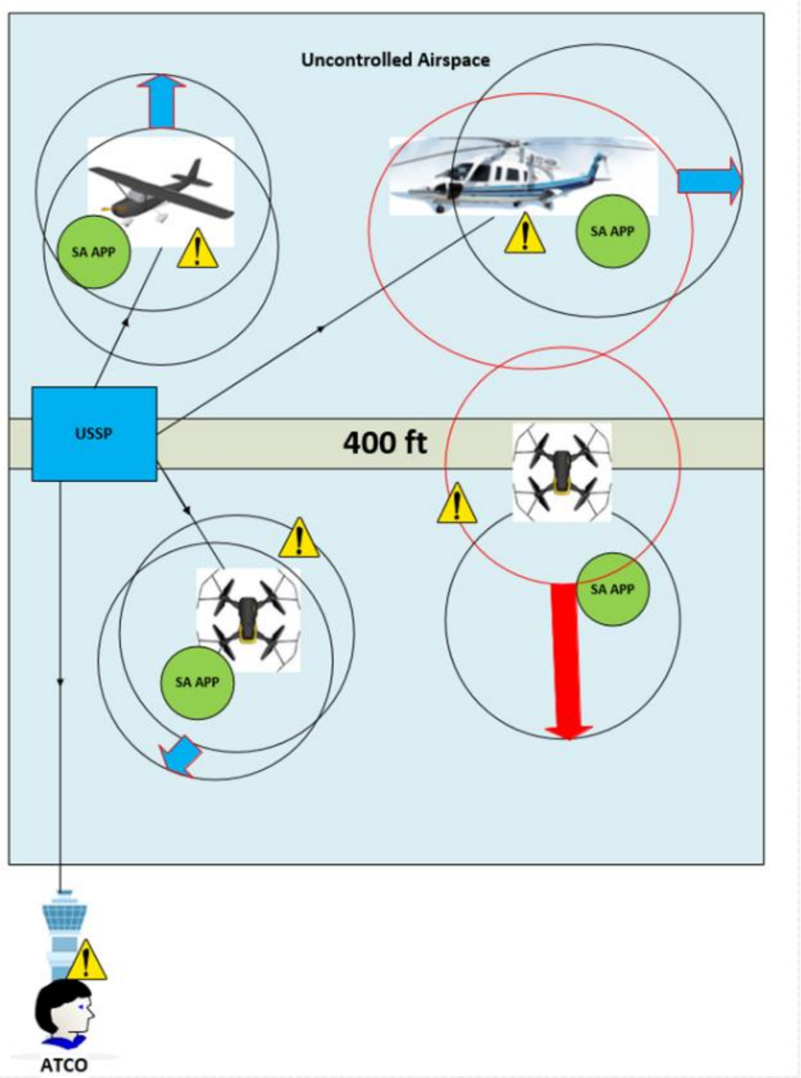


Figure 34. First Validation Scenario 6

3.3.6.2 Scenarios for controlled airspace Use Case

The main difference between scenarios for uncontrolled airspace and scenarios for controlled airspace is that in controlled airspace ATCOs play an active role in conflict resolution. As with usual GA traffic, all drone traffics (in principle) have to comply with the instructions that comes from ATCOs. The scenarios for the controlled airspace can be seen in the Figure 35 below which represents details of the scenario distribution for the trajectory bases.

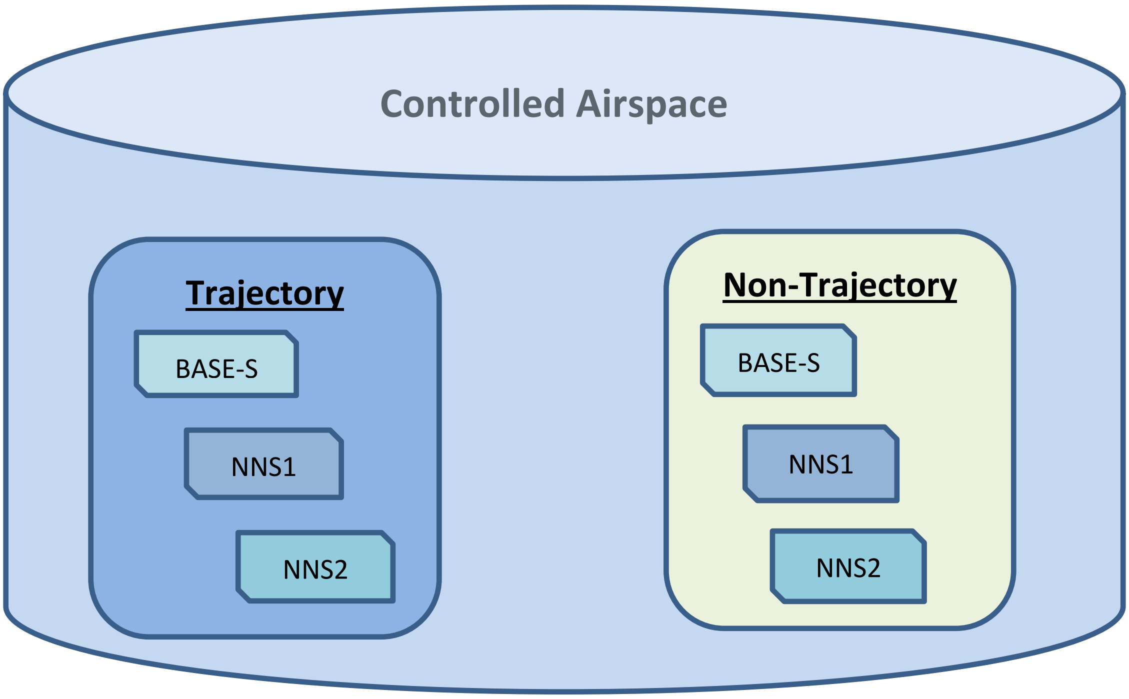


Figure 35. Controlled airspace scenarios

3.3.6.2.1 Non-trajectory-based scenarios

Baseline scenario (Base-S): In the baseline scenario, drones and GA flights are separated in the airspace prior to the beginning of flights. Each and every aircraft including drones fly within their predetermined allocated airspace and they are all visible in SA applications. In the baseline scenario, all flights are to be performed as expected and there will be no conflicts and/or risks posed by overlapping airspaces. All users are aware of surrounding traffic and the traffic is monitored by ATCOs. The overall objective of the baseline scenario is to assess whether all entities can reliably and continually (without significant delay) provide information on their status to the stakeholders on essential SA. In addition, additional workload imposed by the drones on ATCOs can also be assessed through these scenarios.

Non-Nominal Scenario 1 (NNS1): In this second scenario, the setting is the same as in the baseline scenario however, one of the fixed wings and/or rotorcraft has/have to enter drones' airspace due to unexpected circumstances. When this happens, the ATCO immediately informs the drone operator concerning the newly established geofence and asks the drone operator to comply. If the drone operator does not comply within a predefined time period, drone is forced to land safely by appropriate procedures. Based on the ATC's instructions, drone's ground control station (with the drone's operator approval/confirmation) will send "land" command as a drone's C2 message. Consequently, the pre-defined automatic landing operation immediately start with the highest priority.

Non-Nominal Scenario 2 (NNS2): In this scenario the airspace violation is caused by the drone (drones) leaving its allocated airspace. To avoid conflicts and possible threats to flight safety, USSP issues an alert to ATCOs, drones and GA. GA will react based on received instructions from ATCOs. In addition, both ATCOs and USSP issues a warning to the drone operator as well to make the drone operator to go back to its own geofence.

3.3.6.2.1.1 First Validation Scenario 7

Seventh scenario is a non-trajectory baseline scenario that takes place in controlled airspace. There are 2 drones, 2 C172s and 1 helicopter in this scenario. At the beginning of the scenario, drones and general aviation aircraft are all separated from each other. All aircraft fly in the airspace regions assigned to them. The drones fly in a pre-determined area, after the C172s take off. The helicopter flies in the flight training area. All of the aircraft can be seen on the developed interface, thus providing situational awareness. Monitoring the traffic is the responsibility of ATCO. The scenario was run for 15 minutes. For 15 minutes, ATCOs managed all traffic without delay. ATCOs have stated that their workload has increased due to drones. Following the drones that are not on the frequency and not being able to communicate with them on the frequency, following them with a separate interface increases the workload.

First Validation Scenario-7 is shown in Figure 36. Drone, helicopter and two Cessna flight plans for First Validation Scenario-7 are shown in Appendix A.7.

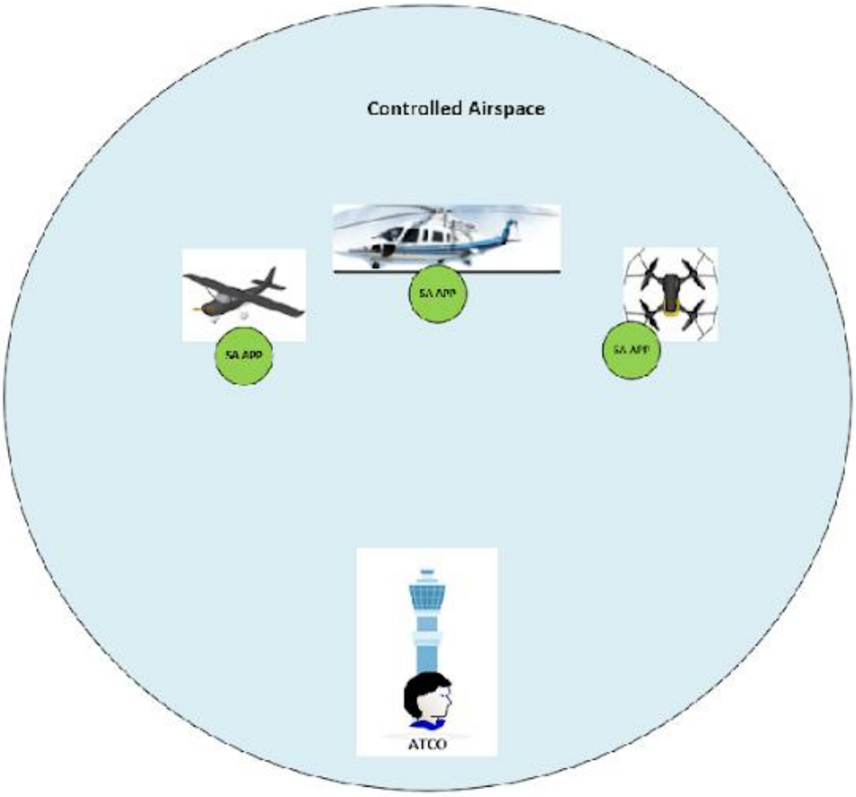


Figure 36. First Validation Scenario 7

3.3.6.2.1.2 First Validation Scenario 8

This scenario is similar to the Scenario 7. Non-trajectory is the basic scenario that takes place in controlled airspace. There are 2 drones, 2 C172 and 1 helicopter in the scenario. At the beginning of the scenario, drones and general aviation aircraft are separated from each other. All aircraft fly in their assigned zones. The drones fly in the pre-determined area, after the C172s take off. The helicopter flies in the training area. All of the aircraft can be seen on the developed interface, thus providing situational awareness. Monitoring of traffic is the responsibility of ATCO. The script was run for 20 minutes. In the 13th minute of the scenario, C172 entered the airspace of Drone 81. ATCO informed the drone operator and requested compliance with the new geofence. It took 36 seconds for the Drone 81 to land safely.

First Validation Scenario-8 is shown in Figure 37. Drones, helicopter and two Cessna flight plans for First Validation Scenario-8 are shown in Appendix A.8.

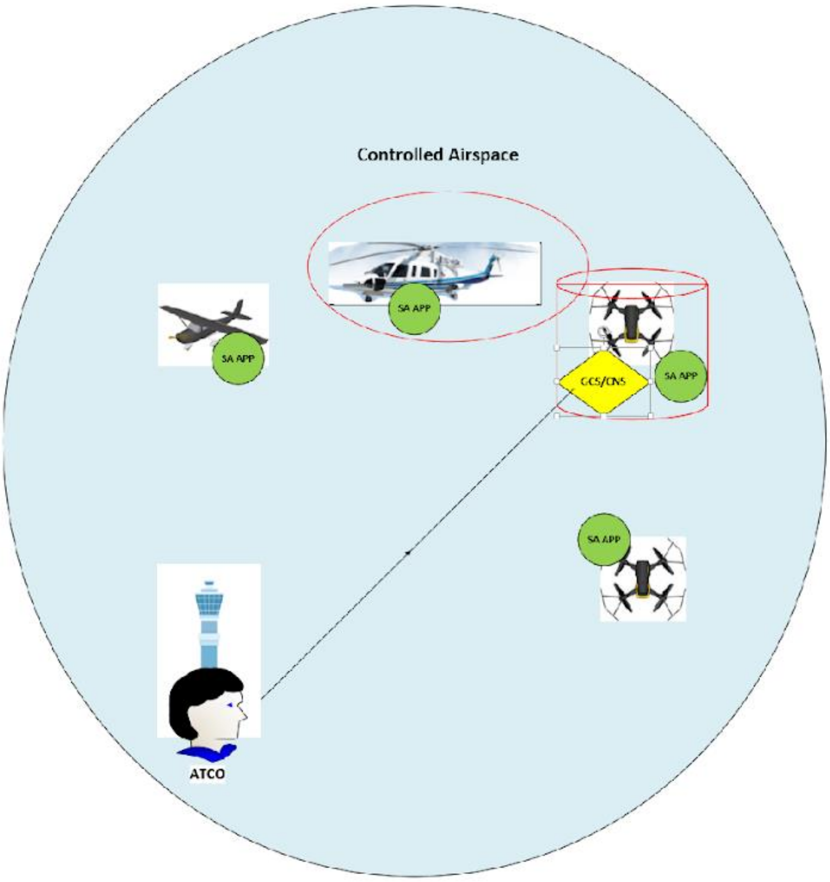


Figure 37. First Validation Scenario 8

3.3.6.2.1.3 First Validation Scenario 9

This is the non-trajectory baseline scenario that takes place in the controlled airspace. There are 2 drones, 2 C172s and 1 helicopter in the scenario. As in the other scenarios, the general aviation aircraft started the aerodrome tour after the engine start, taxi and take-off phases. While the C172 aircraft is on the airfield, the Drone91 enters the aircraft's airspace. In this case, USSP ATCO flies drone91 and other general aviation aircraft. Here, it is accepted that it takes 1 second for the USSP to send a warning message. ATCO response to message from USSP; After seeing and reading the message, it took 5 seconds to monitor the traffic with radar screens and eyes. As a result, he made the necessary decision and gave the necessary avoidance instruction within 5 seconds to the general aviation aircraft in 4 seconds. It took 5 seconds to listen to the instruction from ATCO and readback from the frequency to ATCO. Afterwards, the C172 pilot performed the safe separation maneuver within 30 seconds.

First Validation Scenario-9 is shown in Figure 38. In Figure 39, radar and simulation screenshots for First Validation Scenario-1 are provided. Drones, helicopter and two Cessna flight plans for First Validation Scenario-9 are shown in Appendix A.9. Radar and simulation screenshots for Scenario-9 are given in Appendix A.19.

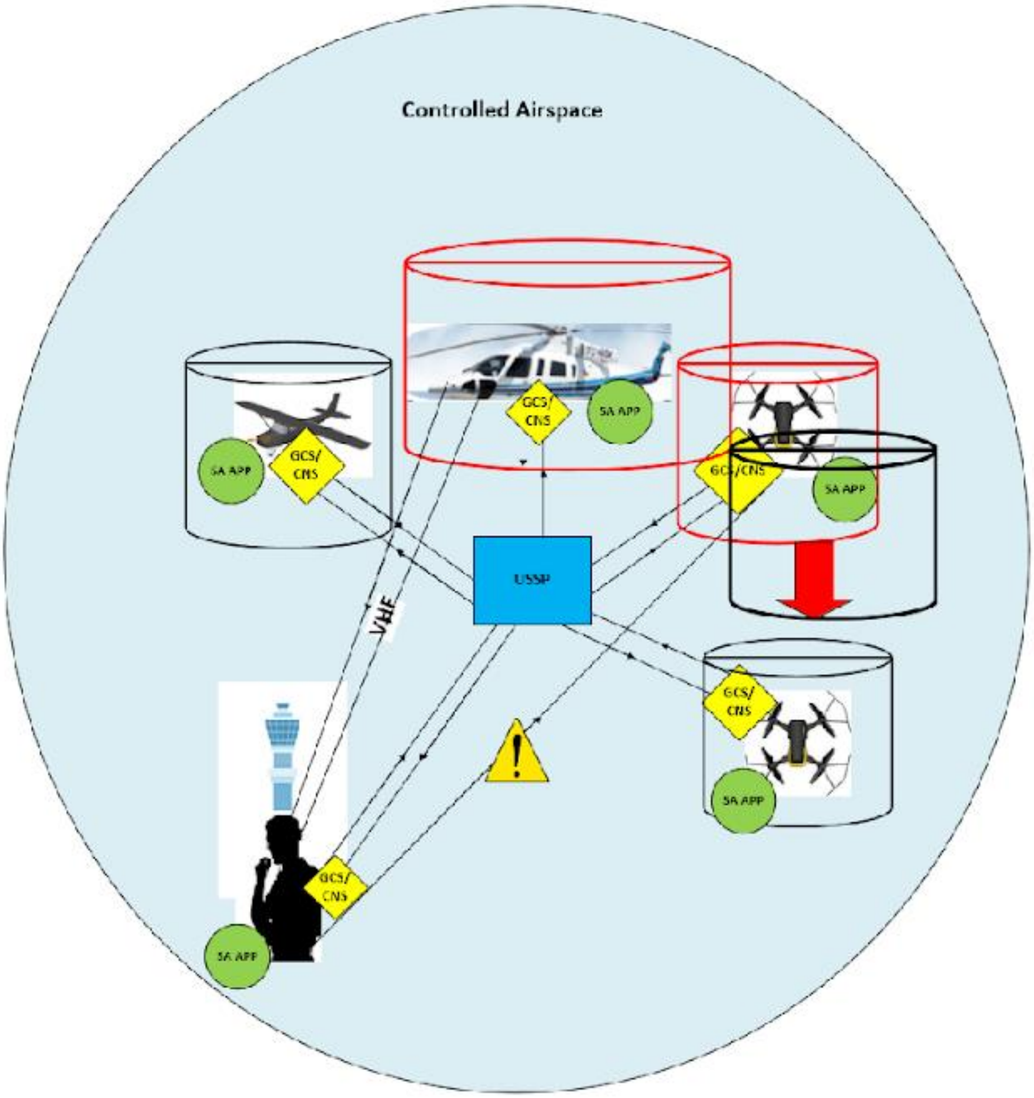


Figure 38. First Validation Scenario 9

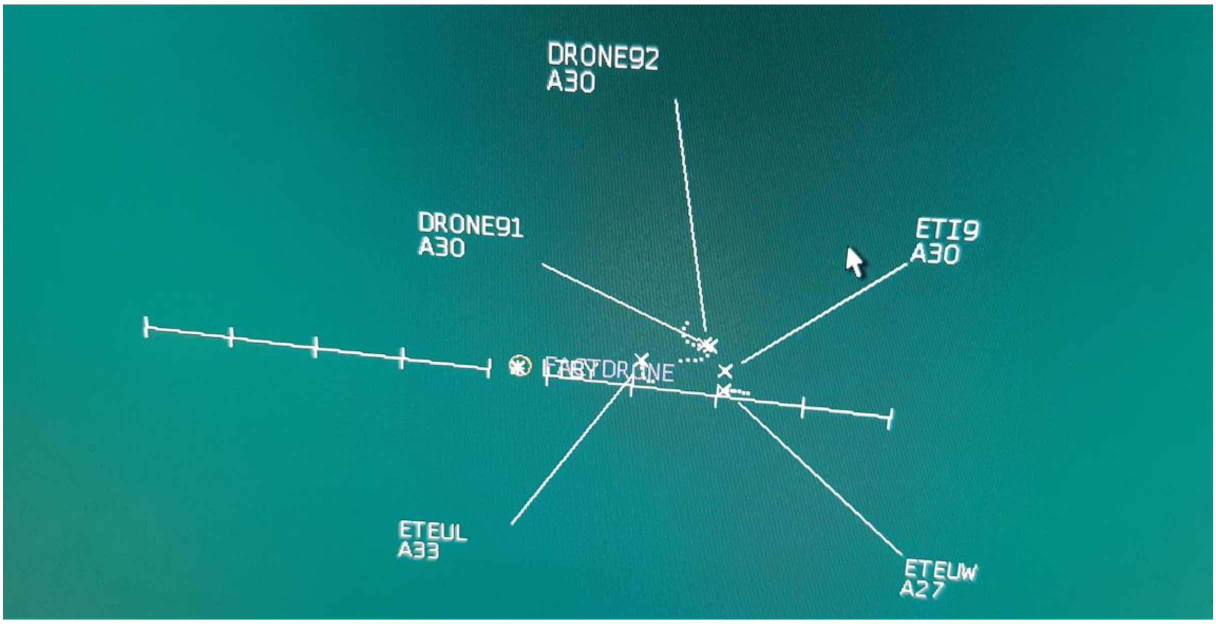


Figure 39. Radar screenshots for scenario-9

3.3.6.2.2 Trajectory based scenarios

Base scenario (Base-S): Drones and GA flights strategically de-conflicted by trajectories mainly by vertical separation as instructed by ATCOs. Drones are not allowed to fly above a predetermined altitude and GA is not allowed to fly below the altitude set for the drone. This altitude level determined prior to the flights and applies to both drones and GA. ATCOs may forbid drones from flying especially when a GA is approaching for landing and/or departing. Approved trajectories of surrounding traffic available for visualization in SA applications, flights are performed as planned, and all stakeholders are aware of their surrounding traffic. The overall objective of this scenario is the assessment of just feedback on essential SA among users.

Non-Nominal Scenario 1 (NNS1): NNS1 builds upon Base-S and there is a drone which starts to deviate from its approved trajectory. Once the deviating drone is detected, conformance monitoring issues an alert to ATCOs and ATCOs issue deconflicting measures to all those affected. ATCOs along with USSP will first issue a geofence zone until the new trajectory is agreed with the drone's operator, other drones update their trajectories accordingly. Finally, GA manoeuvre only based on ATCOs' instructions

Non-Nominal Scenario 2 (NNS2): NNS2 is very similar to NNS1, however conflict resolution is provided by ATCOs issuing new flight updates to those users affected from the deviating drone.

3.3.6.2.2.1 First Validation Scenario 10

In the scenario developed with 2 drones, 1 helicopter and 2 C172s in the controlled airspace, the traffics were provided by vertical separation by ATCOs. The scenario was run for 20 minutes. All aircraft fly in their own trajectories after engine start, taxi and take-off. Drones continue to fly below 400 ft. and other aircraft continue to fly above 400 ft. 400 ft altitude level is determined before the start of the flights. In addition to the general aviation aircraft, which are tracked with ground radar by ATCOs, the location of drones and all aircraft are also followed by the developed interface. While general aviation aircraft are taking off and landing, drones flying below 400 ft are kept in their flight zones.

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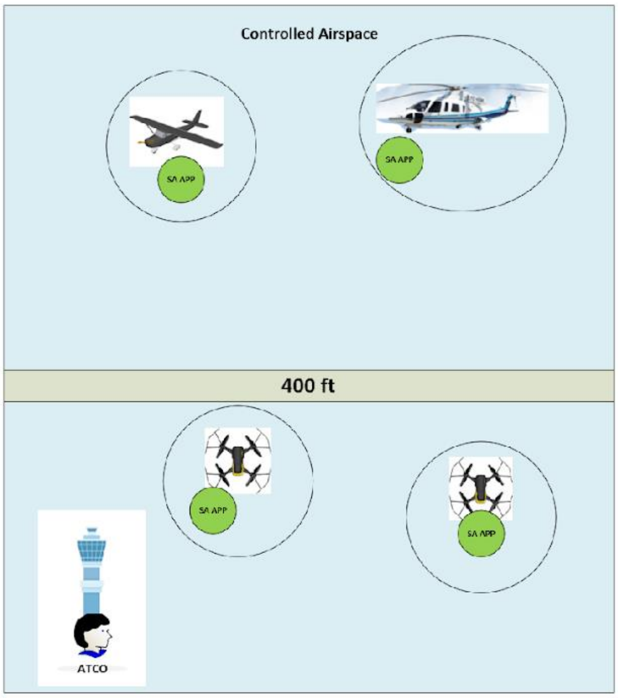
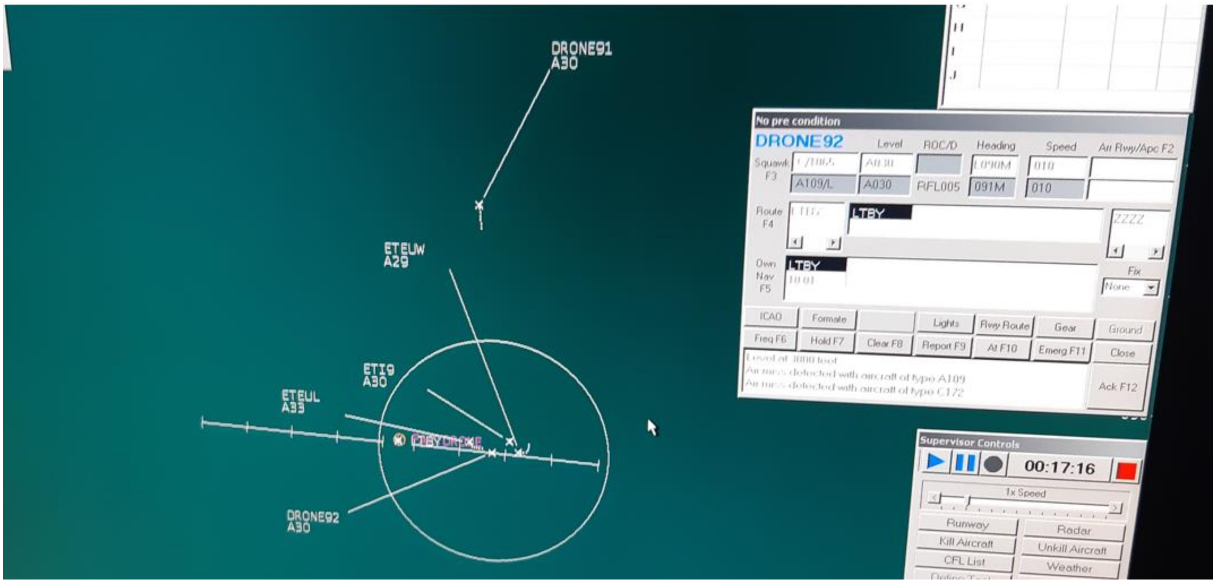


Figure 40. First Validation Scenario 10



A109/L A030 RFL005 091M 010

LTBY

Level at 3000 feet
Air miss detected with aircraft of type A109
Air miss detected with aircraft of type C172

Figure 41. Radar screenshots for scenario-10

First Validation Scenario-10 is shown in Figure 40. In Figure 41, radar and simulation screenshots for First Validation Scenario-1 are provided. Drones, helicopter and two Cessna flight plans for First Validation Scenario-10 are shown in Appendix A.10. Radar and simulation screenshots for First Validation Scenario-10 are given in Appendix A.20.

3.3.6.2.2.2 First Validation Scenario 11

This scenario was prepared in parallel with the tenth scenario. In the scenario developed with 2 drones, 1 helicopter and 2 C172s in the controlled airspace, the traffics were provided by ATCOs with vertical separation. The scenario was run for 30 minutes. All aircraft fly in their own trajectories after engine start, taxi and take-off. Drones continue to fly below 400 ft. and other aircraft continue to fly above 400 ft. 400 ft altitude level is determined before the start of the flights. In the 10th minute of the scenario, the drone that violated the take-off line of the C172 aircraft that started to take off, is noticed by ATCO. ATCO gave the traffic information of the C172 taking off to the drone. ATCO immediately directed the drone north of the runway towards the work areas, clearing the runway line. It took 5 seconds for ATCO to notice the drone and give the relevant traffic information. Afterwards, the instruction given to the drone to clear the runway line and the readback of the instruction took 10 seconds. Afterwards, it took 35 seconds for him to do the avoidance manoeuvre.

First Validation Scenario-11 is shown in Figure 42. Drones, helicopter and two Cessna flight plans for Scenario-11 are shown in Appendix A.11.

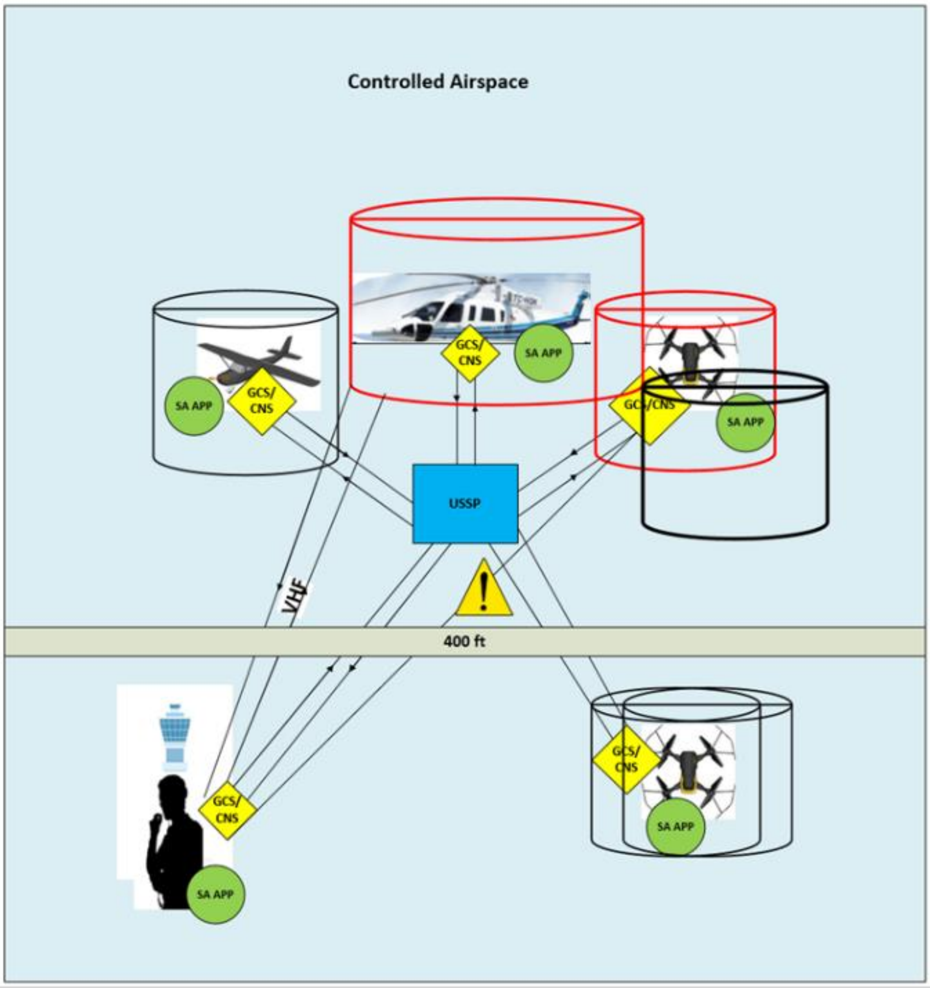


Figure 42. First Validation Scenario 11

3.3.6.2.2.3 First Validation Scenario 12

In this scenario, the C172 aircraft is evaluated when it has come to the runway and has not exceeded v1 speed. In this case, C172 was first told that its take-off was cancelled. It took 20 seconds for ATCO to cancel the take-off and get the readback. It did not pose a problem for flight safety as the C172 did not exceed V1. While C172 is landing and the drone breaches the landing line, the C172 landing is aborted while C172 is in the final approach phase. At this stage, the drone cannot be maneuvered safely and quickly. In another case, while the landing C172 was on the main leg, the drone was made an evasive manoeuvre. In this case, this movement took 30 seconds. In another case, while the C172 aircraft was in the final, if the drone was on the landing line, C172 was given an evasive manoeuvre and C172 was directed to the north of the aerodrome to the working areas. This evasive manoeuvre of C172 also took 20 seconds.

First Validation Scenario-12 is shown in Figure 43. Drones, helicopter and two Cessna flight plans for First Validation Scenario-11 are shown in Appendix A.11.

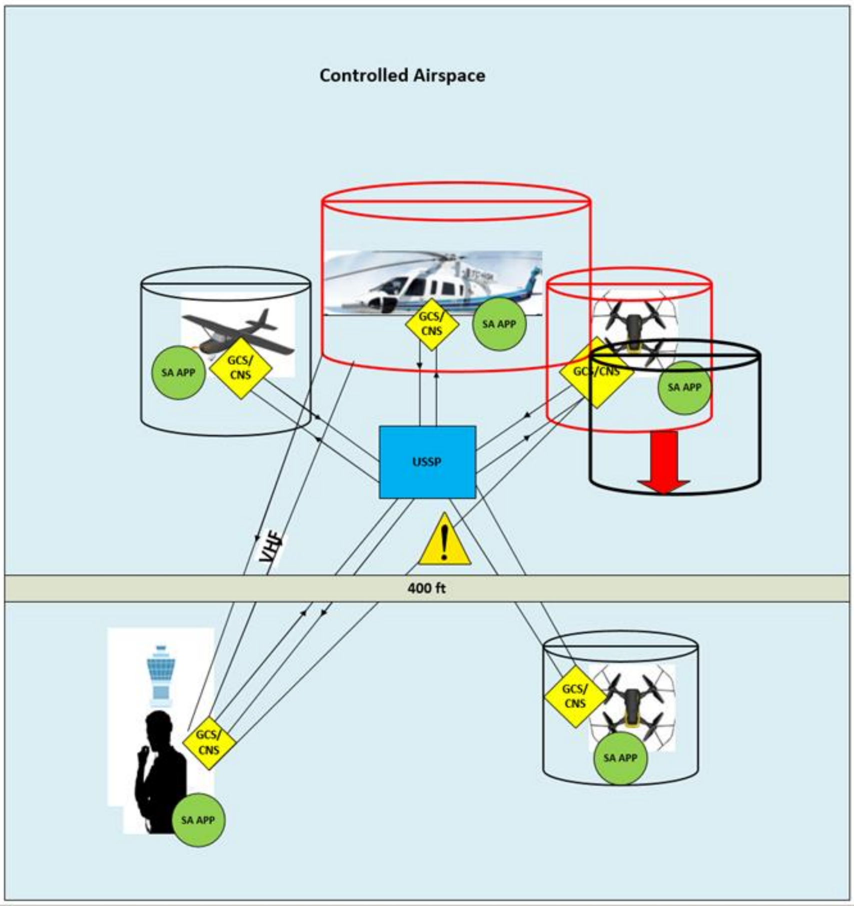


Figure 43. First Validation Scenario 12

4 Validation Risk Assessment

In this section, each partner made their own risk assessment. Sub-sections include stakeholders' own risk assessments.

4.1 First Validation Risk Assessment and Mitigation Plans by Honeywell

The applications enabled by experimental CNS device are used within the operational demo only as supporting applications enhancing situation awareness and therefore safety of the flight and traffic (separation) management are not directly relying on them. In this context, the technical risks listed below are always operationally mitigated by:

- Procedural means included in the operational scenario definition based on strategic deconfliction process.
- When a non-conformance is included in the scenario, it is always complemented with additional safety buffer in other dimensions. For instance, when a horizontal deviation from planned trajectory is anticipated, the flights are always sufficiently segregated vertically to mitigate any potential safety risk.
- All flights are performed under Visual Meteorological Conditions and Visual Line of Sight (for drones) to enable visual check/monitoring of the situation by pilots/operators.

Technical risks are related to the traffic surveillance issues (when some position reports are not received by ground tracking service, or when traffic information service information is not received by airspace users) or when an alerting information is not provided in time to pilot. Beyond the operational mitigations described above, there are some technical mitigations in place as well, such as:

- In case of missing position reports, ground tracking service is performing coasting (extrapolation) of the vehicle position based on past positions if the interval from the last report do not exceed a pre-defined threshold (if the threshold is exceeded a warning is issued and traffic position is not provided).
- There will be an operational demo observer who will monitor in real time on-going scenario and will alert the affected users or stop the scenario when needed.
- When needed it is always possible to alert and instruct pilots via voice links (VHF for GA pilots, or VoIP for remote pilots).

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4.2 First Validation Risk Assessment and Mitigation Plans by ITU

For the first validation process, ITU has defined 3 potential risks, which are

- Loss of C2 link,
- Hardware or software failure of the drone components,
- Unsuitable autonomous landing site.

The default reaction of the drone's autopilot is self-triggering the RTL mode autonomously when a C2 connection loss is detected. In common configuration a C2 link connects the drone's flight control computer (FCC) to the GCS computer. However, in our configuration for FACT project, the C2 link connects flight management computer (FMC) to GCS. FCC controls the flight and has the flight modes. Since FMC and FCC are connected by cable, FCC cannot detect C2 link loss by itself. Therefore, our FMC has been modified to notify the FCC of the link loss situation. As a result, the C2 link loss between FMC-GCS and the malfunction of FMC triggers the safely return to take-off point action on FCC.

Any hardware or software malfunction of on-board devices except the FCC can be managed by pilot-controlled modes of FCC. Within the range of visual contact between the pilot and drone, RC control is active. Beyond the visual contact range, the fail safety modes (brake, RTL, land) are utilized in the FACT demonstrations.

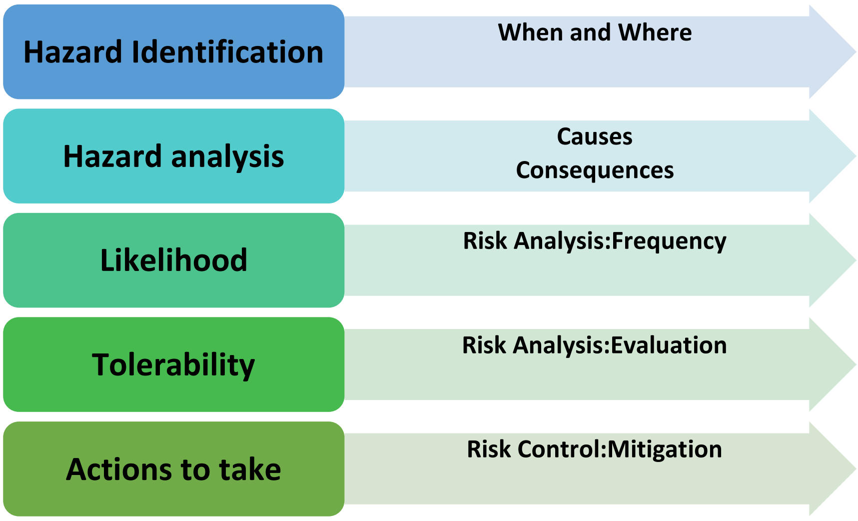
In any landing phase, either manual or autonomous, drone pilot has the permission of correcting drone flight path using RC controller. Hence, the landing point can be adjusted by the pilot.

4.3 First Validation Risk Assessment and Mitigation Plans by ESTU

Successful risk management in aviation should generally aim at risk reduction, including all systems. In operations, some risks are produced or may arise by all functional systems. These risks can be listed as follows:

- Natural hazards (earthquakes, volcanic phenomena, etc.).
- Environmental hazards (cyclones, snow or sand storms, etc.).
- Technological hazards (related to the aircraft design, maintenance, operation, etc.).
- Organizational hazards (related to the company itself, to its operating manner).
- Statutory hazards (if the organization encounters difficulty complying with the statutory requirements and with their evolution, etc.).
- Human hazards (related to training, competence, job culture, etc.).
- Physiological hazards (epidemic diseases, etc.).

These risks need to be mitigated as appropriate. This includes proactively identifying hazards and preventing accidents and incidents through safety risk management (SRM). The risk management process begins with identifying the hazard as given in Table 11, and the process ends with taking action to control and prevent the risk.



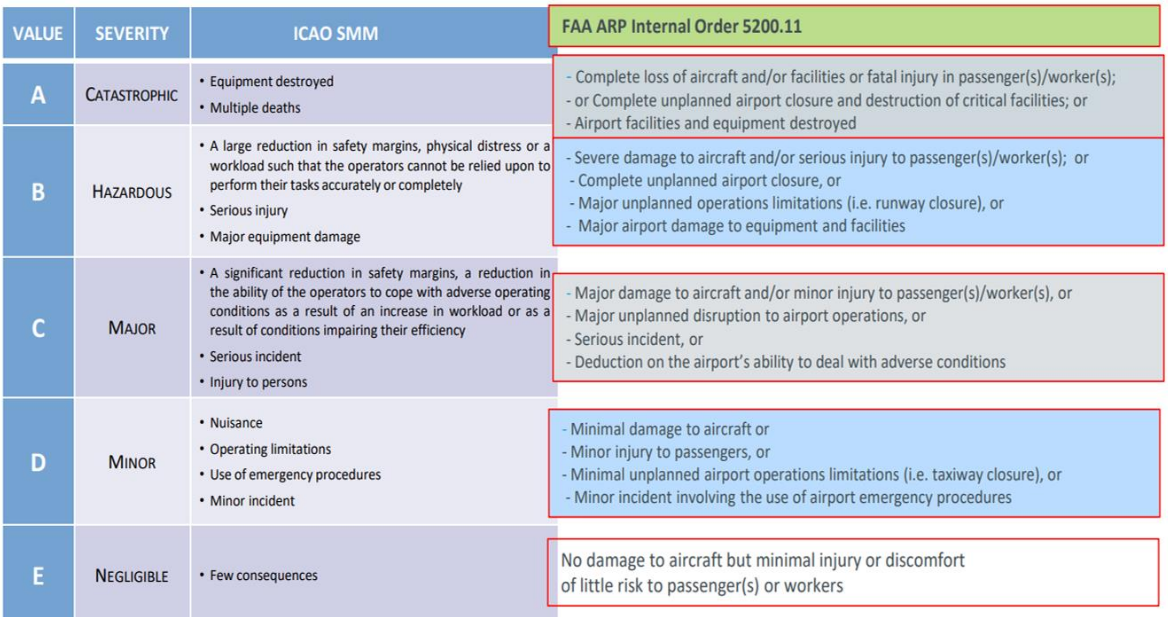
Hazard Identification	**When and Where**
Hazard analysis	**Causes** **Consequences**
Likelihood	**Risk Analysis:Frequency**
Tolerability	**Risk Analysis:Evaluation**
Actions to take	**Risk Control:Mitigation**

Table 11. Risk Management Process (ICAO 2018) [2]

The ICAO Risk matrix in Figure 46 [2] is a method of safety risk assessment based on the anticipated probability and severity of consequences or consequences arising from an existing hazard and situation. In this method, risk assessment, probability and severity are evaluated. The next step is to see where they intersect in the risk matrix. The colour of the box at which they intersect determines the required preventive action. A factor with major significance and occasional probability is in a yellow box labelled 4C. This risk assessment, which coincides with the yellow zone, may mean that a senior official approves this risk assessment and controls.

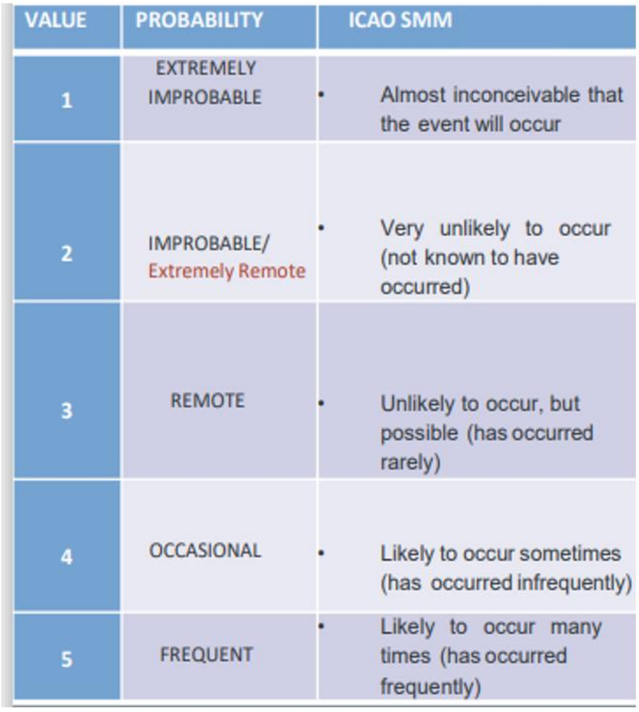
Risk is the composite of each possible consequence's predicted probability (or likelihood) and severity.

Risk Score (RS) = Probability of Occurrence (Degree) x Magnitude (Degree) of Loss



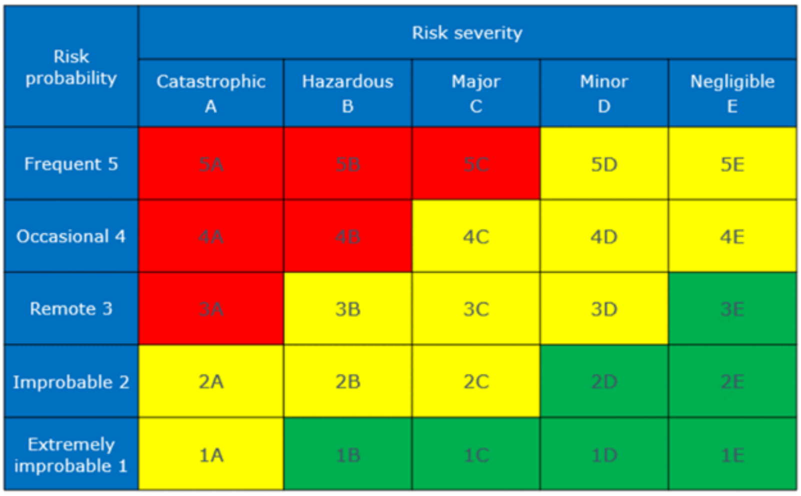
VALUE	SEVERITY	ICAO SMM	FAA ARP Internal Order 5200.11
A	Catastrophic	• Equipment destroyed • Multiple deaths	- Complete loss of aircraft and/or facilities or fatal injury in passenger(s)/worker(s); - or Complete unplanned airport closure and destruction of critical facilities; or - Airport facilities and equipment destroyed
B	Hazardous	• A large reduction in safety margins, physical distress or a workload such that the operators cannot be relied upon to perform their tasks accurately or completely • Serious injury • Major equipment damage	- Severe damage to aircraft and/or serious injury to passenger(s)/worker(s); or - Complete unplanned airport closure, or - Major unplanned operations limitations (i.e. runway closure), or - Major airport damage to equipment and facilities
C	Major	• A significant reduction in safety margins, a reduction in the ability of the operators to cope with adverse operating conditions as a result of an increase in workload or as a result of conditions impairing their efficiency • Serious incident • Injury to persons	- Major damage to aircraft and/or minor injury to passenger(s)/worker(s), or - Major unplanned disruption to airport operations, or - Serious incident, or - Deduction on the airport's ability to deal with adverse conditions
D	Minor	• Nuisance • Operating limitations • Use of emergency procedures • Minor incident	- Minimal damage to aircraft or - Minor injury to passengers, or - Minimal unplanned airport operations limitations (i.e. taxiway closure), or - Minor incident involving the use of airport emergency procedures
E	Negligible	• Few consequences	No damage to aircraft but minimal injury or discomfort of little risk to passenger(s) or workers

Figure 44. Severity Risk Matrix (ICAO, 2018) [2]



VALUE	PROBABILITY	ICAO SMM
1	EXTREMELY IMPROBABLE	• Almost inconceivable that the event will occur
2	IMPROBABLE/ Extremely Remote	• Very unlikely to occur (not known to have occurred)
3	REMOTE	• Unlikely to occur, but possible (has occurred rarely)
4	OCCASIONAL	• Likely to occur sometimes (has occurred infrequently)
5	FREQUENT	• Likely to occur many times (has occurred frequently)

Figure 45. Risk Probability (ICAO, 2018) [2]



Risk probability	Risk severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely improbable 1	1A	1B	1C	1D	1E

Figure 46. Risk Matrix (ICAO, 2018) [2]

The hazardous situations identified in the scenarios realized within the scope of the FACT project were analysed with the participation of aviation safety experts. These experts include the experienced instructor air traffic controllers and flight training instructors at Eskisehir Technical University, a helicopter pilot from Sarp Air and a GA aircraft pilot from AOPA, and the identified hazardous situations are listed below:

- The drone operators and ATCOs do not share a common language in aviation terminology. The drone operators also do not have aviation safety training. As a result, it will be dangerous if the drone operators do not understand and follow their instructions.

- ATCOs are unfamiliar with drone operations and terminology. The additional traffic will add to the workload of ATCOs, causing faster degradation in their performance and additional mental workload.

- General aviation pilots should consider the heavier-than-normal traffic created by drones, affecting their mental workload. Drone trajectories should not obstruct the general aviation flight path. However, the ambiguous behaviour of drones adds complexity to the tasks of general aviation pilots. The same is true for uncontrolled airspace as well.

- Not sharing a common language among stakeholders is a serious danger. Regardless of who is responsible for managing drone traffic, a common communication platform must be established to ensure safe operation.

- The only communication platform envisioned for drones is 5G. The absence of a backup system poses a serious danger to communication with drones. Flight safety must be ensured if there is a loss of communication with the drones due to 5G equipment failure or any other reason.

Based on the assessment above, the risks posed by these hazards are listed as follows;

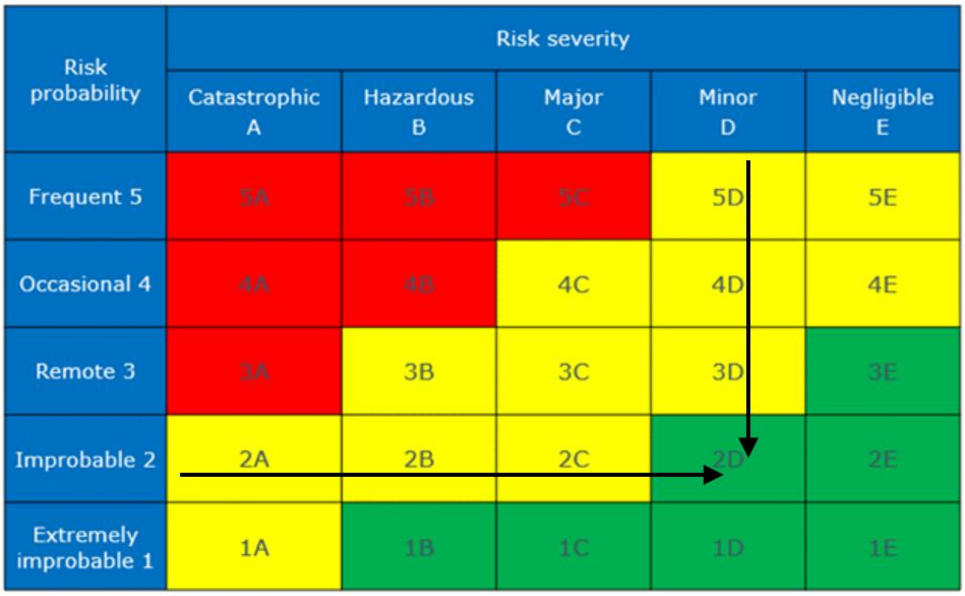
- Loss of control in flight

- Systemic malfunctions in air vehicle

- Malfunctions that may occur in the communication system
- Malfunctions that may occur in the interface implementation
- Inappropriate actions of the flight crew
- Drone hitting the ground
- Collision between air vehicle
- Unexpected meteorological events
- Improper ATCO instruction

The probabilities and severity of these risks are shown in the risk matrices, respectively.

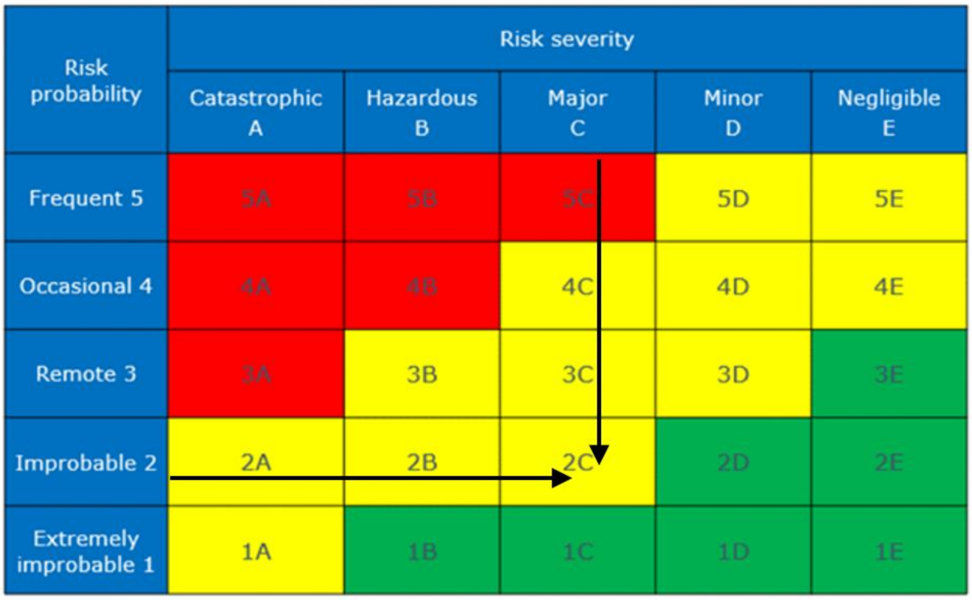
The risk assessment for loss of control in flight is shown in Table 12. The risk assessment for loss of control in flight, and risk probability and risk severity are determined as improbable (2), and minor(D), respectively.



Risk probability	Risk severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely improbable 1	1A	1B	1C	1D	1E

Table 12. The risk assessment for loss of control in flight

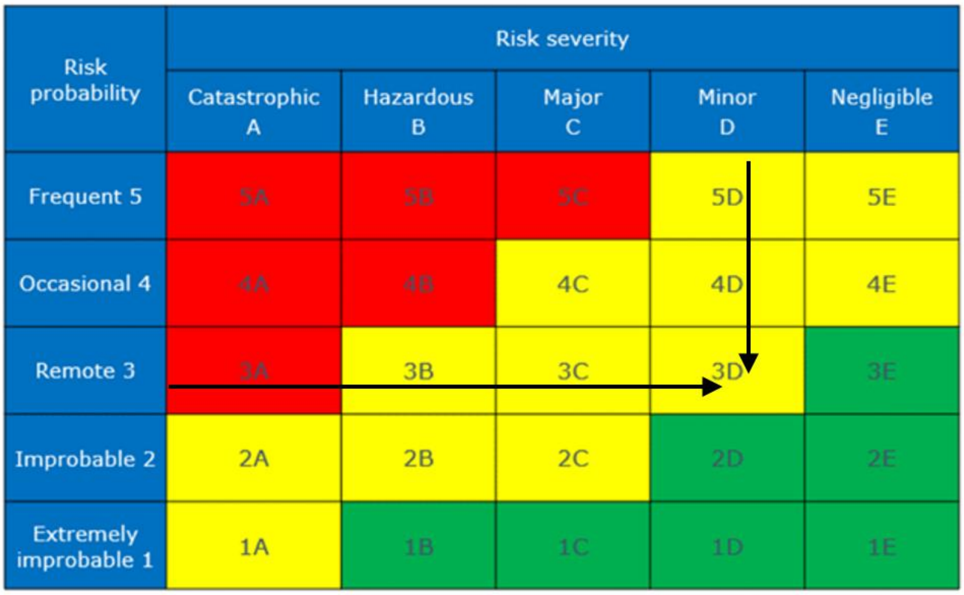
The risk assessment for systemic malfunctions in air vehicle is shown in Table 13 and the risk probability is determined as improbable (2) and the risk severity is major (C).



Risk probability	Risk severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely improbable 1	1A	1B	1C	1D	1E

Table 13. The risk assessment for systemic malfunctions in air vehicle

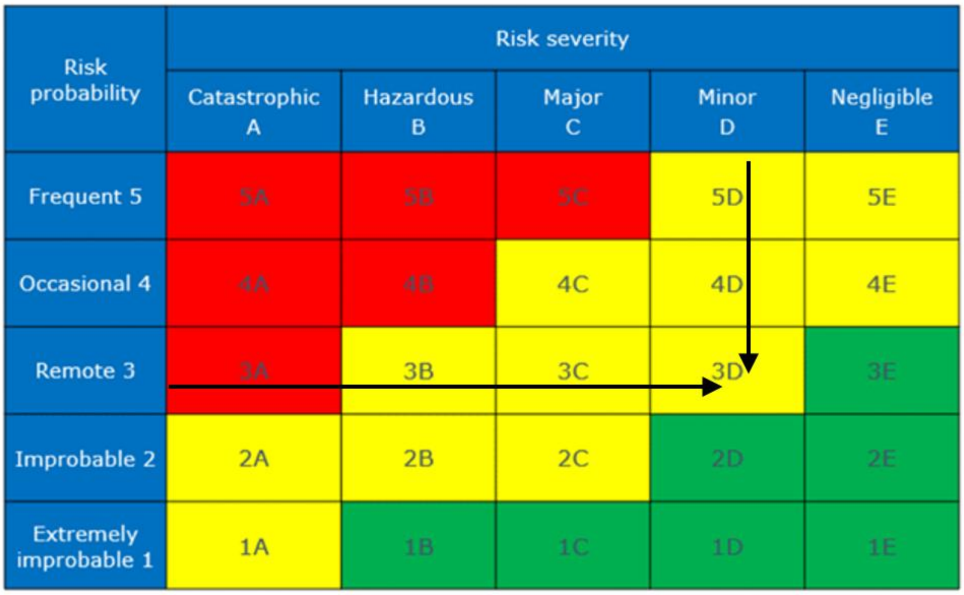
The risk assessment for malfunctions that may occur in the communication system is shown in Table 14, and risk probability and risk severity are determined as remote (3), and minor (D), respectively.



Risk probability	Risk severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely improbable 1	1A	1B	1C	1D	1E

Table 14. The risk assessment for malfunctions that may occur in the communication system

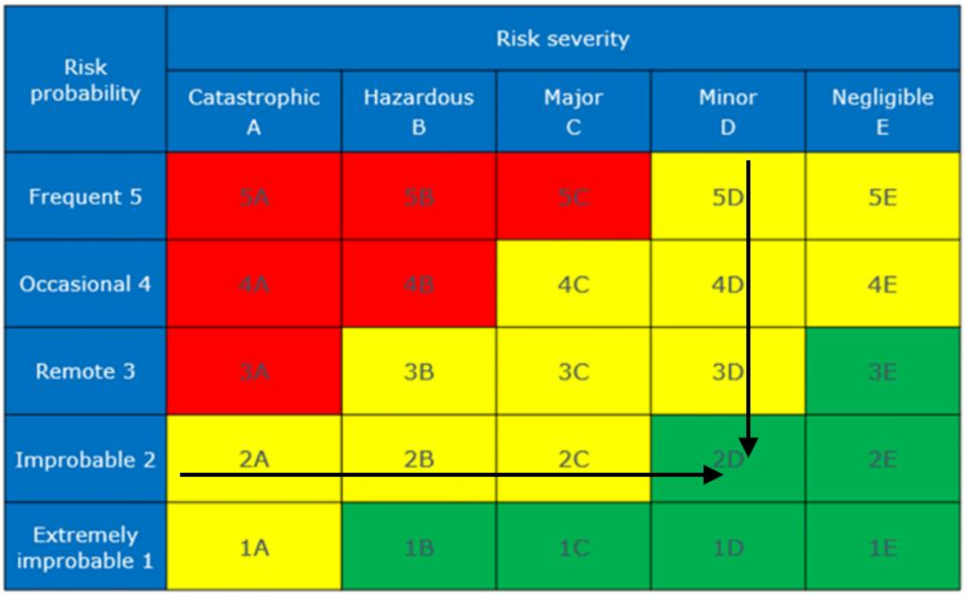
The risk assessment for malfunctions that may occur in the interface implementation is shown in Table 15 and the risk probability is determined as remote (3) and the risk severity is minor (D).



Risk probability	Risk severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely improbable 1	1A	1B	1C	1D	1E

Table 15. The risk assessment for malfunctions that may occur in the interface implementation

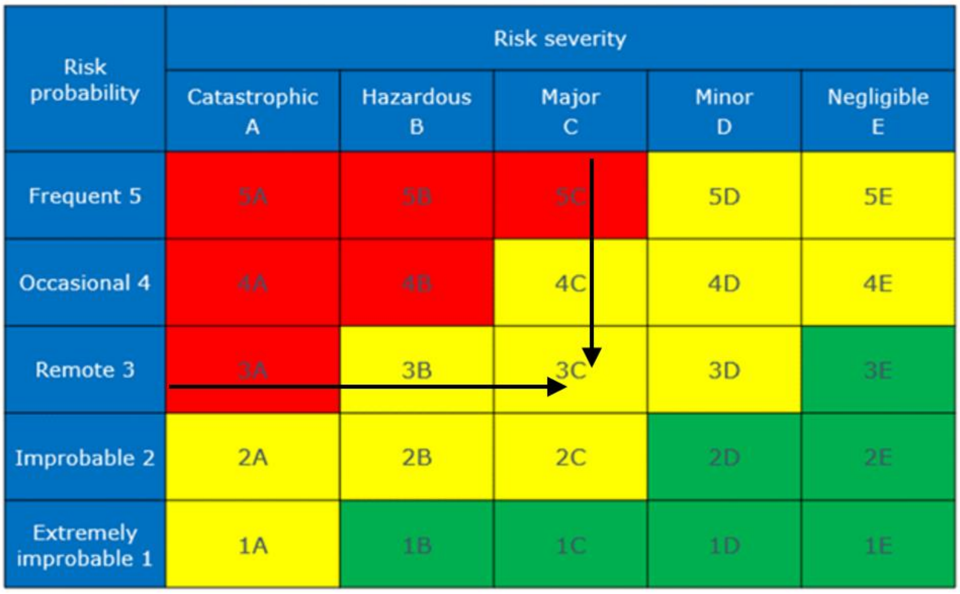
The risk assessment for inappropriate actions of the flight crew is shown in Table 16, and risk probability and risk severity are determined as improbable (2), and minor (D), respectively.



Risk probability	Risk severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely improbable 1	1A	1B	1C	1D	1E

Table 16. The risk assessment for inappropriate actions of the flight crew

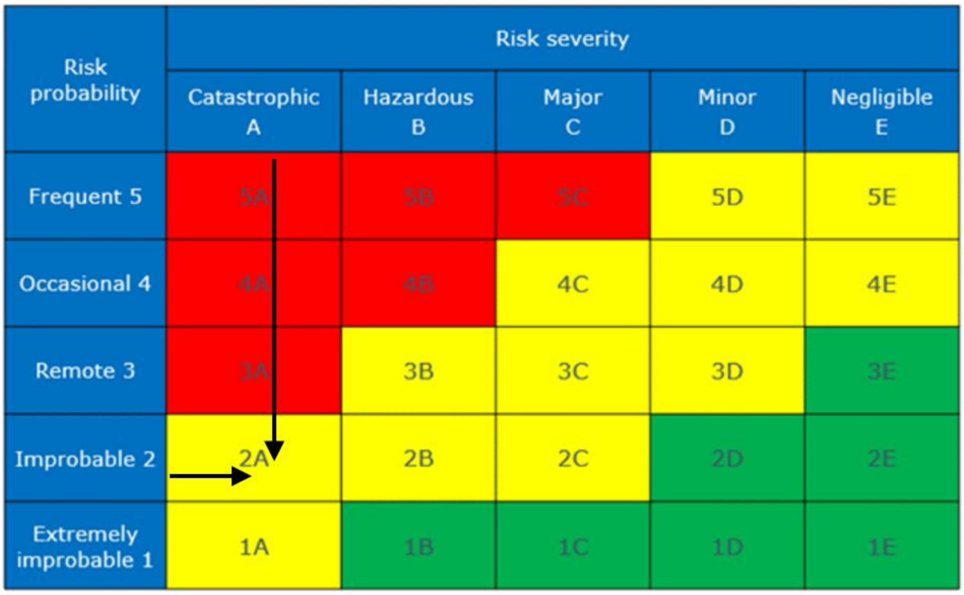
The risk assessment for drone hitting the ground is shown in Table 17 and the risk probability is determined as remote (3) and the risk severity is major (C).



Risk probability	Risk severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely improbable 1	1A	1B	1C	1D	1E

Table 17. The risk assessment for drone hitting the ground

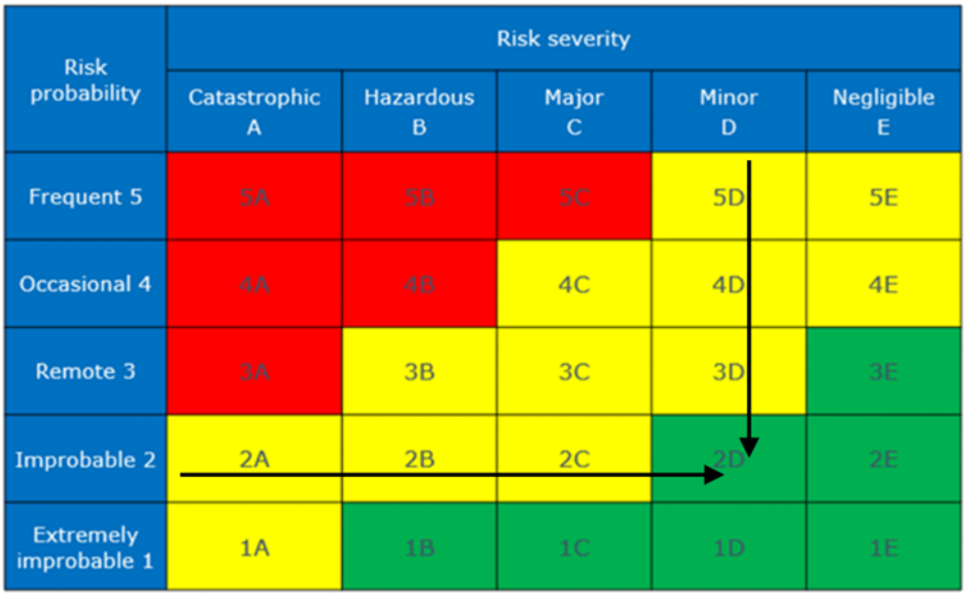
The risk assessment for collision between aircraft is shown in Table 18, and risk probability and risk severity are determined as improbable (2), and catastrophic (A), respectively.



Risk probability	Risk severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely improbable 1	1A	1B	1C	1D	1E

Table 18. The risk assessment for collision between aircraft

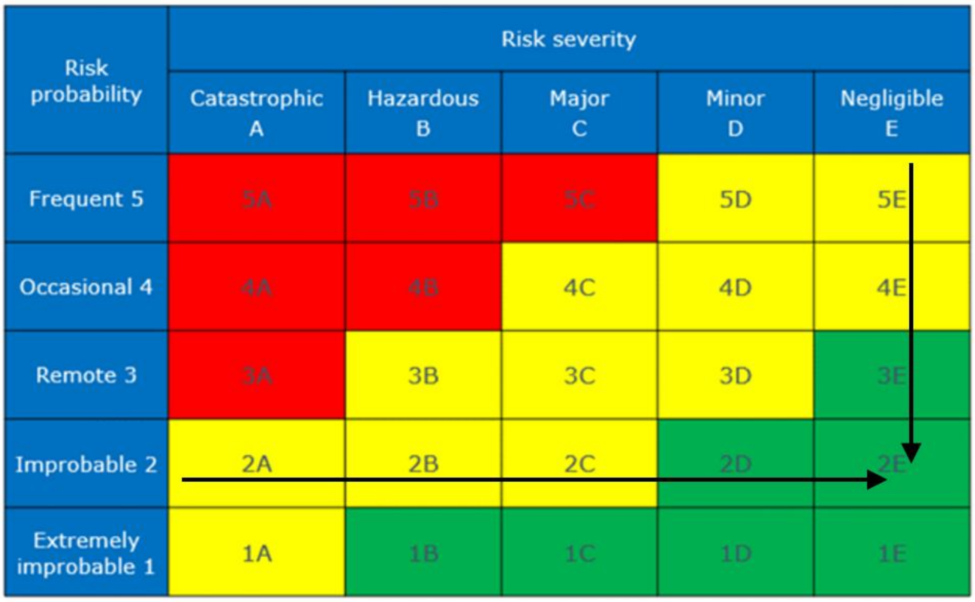
The risk assessment for unexpected meteorological events is shown in Table 19 and the risk probability is determined as improbable (2) and the risk severity is minor (D).



Risk probability	Risk severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely improbable 1	1A	1B	1C	1D	1E

Table 19. The risk assessment for unexpected meteorological events

The risk assessment for improper ATCO instruction is shown in Table 20, and risk probability and risk severity are determined as improbable (2), and negligible (E), respectively.



Risk probability	Risk severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely improbable 1	1A	1B	1C	1D	1E

Table 20. The risk assessment for improper ATCO instruction

5 Results of Operational Validation

Within the scope of the simulator studies planned for the first validation, the details given in D5.1, we worked with expert air traffic controllers who had worked in Eskisehir training airspace for many years as aerodrome controllers. In total, 12 scenarios were run in 3D real-time aerodrome control simulators. As a result of the studies carried out;

- Since ATCOs cannot provide direct data communication with drones, this situation creates a risk for flight safety in all scenarios. It has been observed that ATCOs workloads increased due to increased anxiety and stress. In addition, the workload for both parties increases since ATCOs and drone operators do not have direct data transmission. The drone operators also do not have a good grasp of the terminology and phraseology used commonly by all aviation stakeholders.
- The fact that the south side of the aerodrome cannot be used in the Eskisehir flight training airfield, where the scenarios are tested since it is military airspace and above residential areas, imposes limitations on ATCOs and all aircraft in cases of avoidance manoeuvres and collisions.
- Despite all these situations, in scenarios where there are violations and risk of collisions, all aircraft are ensured to separate safely when the ATCOs make the necessary avoidance manoeuvres.
- In addition, having a situational awareness application (interface) for all airspace users will minimize possible incidents and accidents.

Taking into account these results and results of the consortium discussions about the scenarios at the project meetings, the scenarios were adjusted, and it was decided on five basic situations and five scenarios, as shown in Figure 47 through Figure 51. These scenarios will be further elaborated to reflect observed results and used as a basis for preparation for final operational demo at Eskisehir.

Co-funded by the European Union

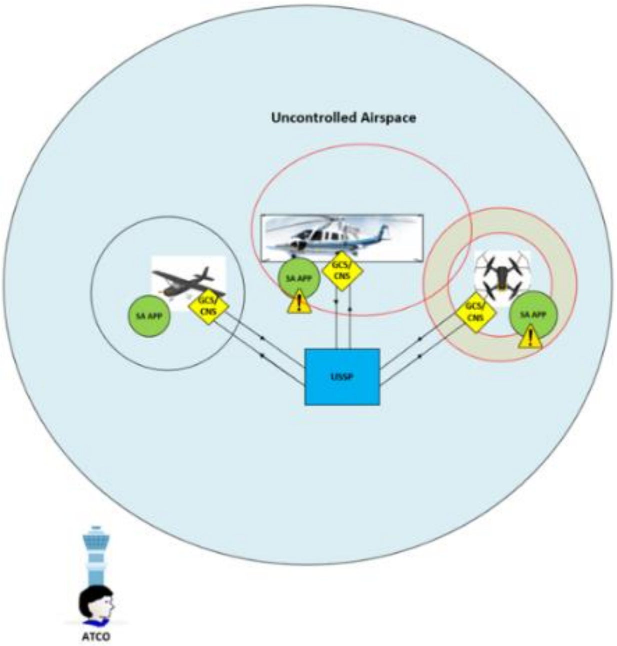


Figure 47. Scenario 1

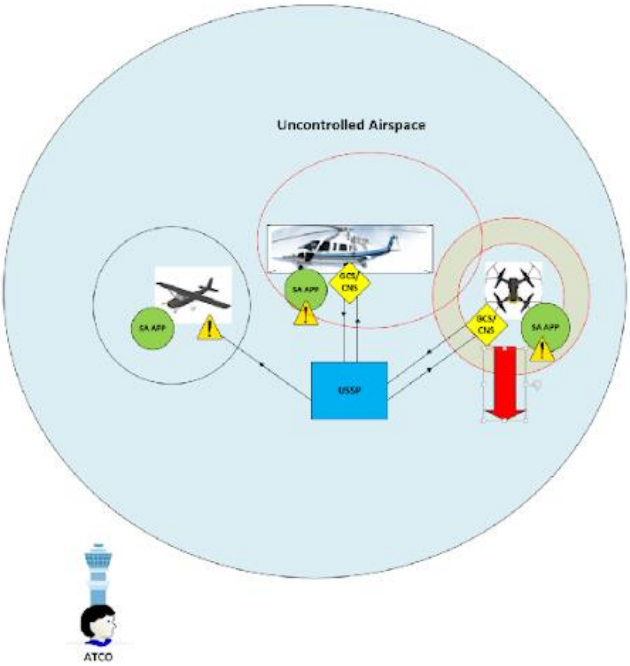


Figure 48. Scenario 2

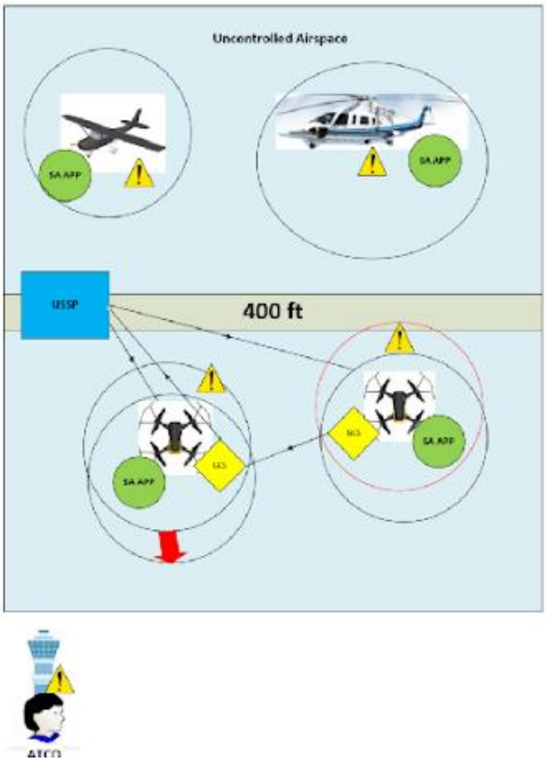


Figure 49. Scenario 3

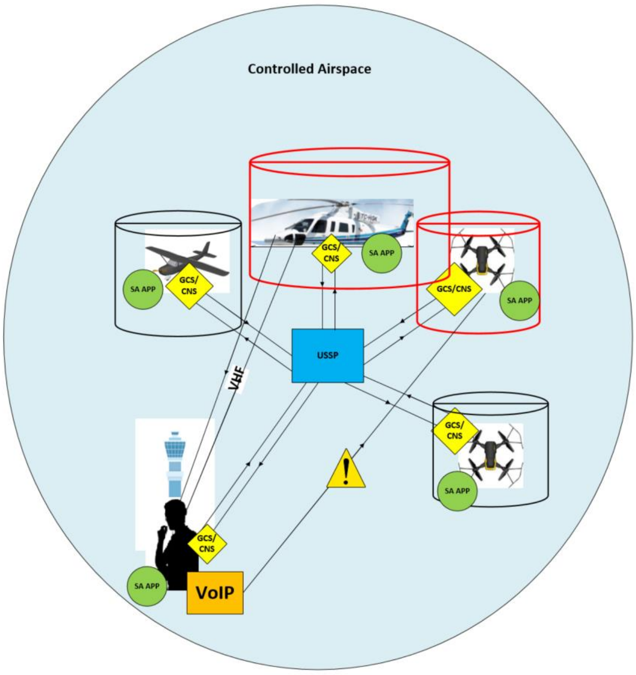


Figure 50. Scenario 4

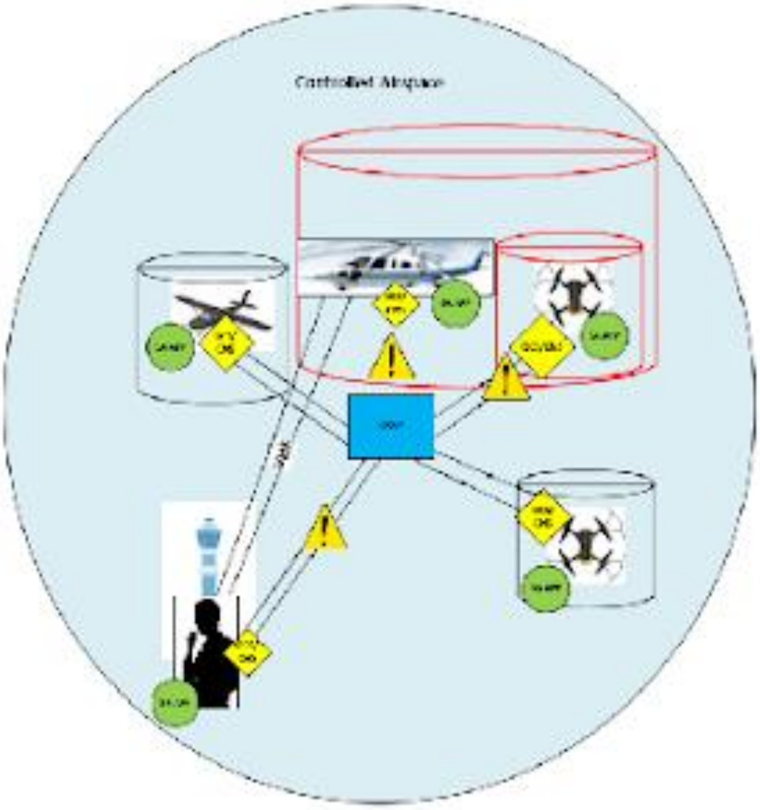


Figure 51. Scenario 5

6 References

[1] Liberg, O., Sundberg, M., Wang, E., Bergman, J., & Sachs, J. (2017). Cellular Internet of things: technologies, standards, and performance. Academic Press

[2] ICAO 2018 https://www.icao.int/MID/Documents/2018/Aerodrome%20SMS%20Workshop/M2-1-SMS_Aerodrome_Risk%20Assessment.pdf

[3] Korenčiak L., Cásek P., Tománek P. (2020). Report on Mobile Network at Twente Airport. Available at: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5cee3b2d0&appId=PPGMS

Appendix A Validation Use Cases and Scenarios

A.1 Flight plan for scenario-1

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE01	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	F003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1005	A003	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
Drone training		
ICAO Route		
Script Items		
DRONE01 LIGHTS[YYYYYYYY] DRONE ORBIT LEFT		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
TCAUF	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	F035	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1001	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1	00:02:00	
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
09 local traffic		
ICAO Route		
Script Items		
TCAUF LIGHTS [YYYYYYYY] TCAUF STRIP TIME 01 TCAUF DEPARTURE RUNWAY 09 TCAUF CISCUIT DIR LEFT		

Table 21. The flight plan for drone (left) and Cessna (right) at scenario-1[2]

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[2] Requested Flight Level is in the format required by the ESTU simulator.

Flight Plan Editor

Callsign	**AircrafType**	**SSR Fitted**
TCAUC	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	F035	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA6	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1002	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1	00:03:00	

Approach Capabilitiy

ILS

Route

LTBY

Comment

09 Local Traffic

ICAO Route

Script Items

TCAUC LIGHTS [YYYYYYYY]
TCAUC DEPARTURE RUNWAY 09
TCAUC CISCUIT DIR LEFT
TCAUC STRIP TIME 01

Flight Plan Editor

Callsign	**AircrafType**	**SSR Fitted**
TCHGK	UH60a	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A035	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA6	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1004	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1	00:02:00	

Approach Capabilitiy

ILS

Route

LTBY

Comment

09

ICAO Route

Script Items

TCHGK DEPARTURE RUNWAY 09
TCHGK STRIP TIME 01
TCHGK LIGHTS [YYYYYYYY]
TCHGK CISCUIT DIR LEFT

Table 22. The flight plan for Cessna-2 (left) and for helicopter-1 (right) at scenario-1

A.2 Flight plan for scenario-2

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE21	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	F003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
2004	A003	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
Drone training		
ICAO Route		
Script Items		
DRONE21 ORBIT LEFT DRONE21 LIGHTS[YYYYYYYY]		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
TCAUX	B200	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	F035	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA6	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
2003	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1	00:01:00	
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
09		
ICAO Route		
Script Items		
TCAUX LIGHTS [YYYYYYYY] TCAUX CISCUIT DIR LEFT TCAUX STRIP TIME 01 TCAUX DEPARTURE RUNWAY 09		

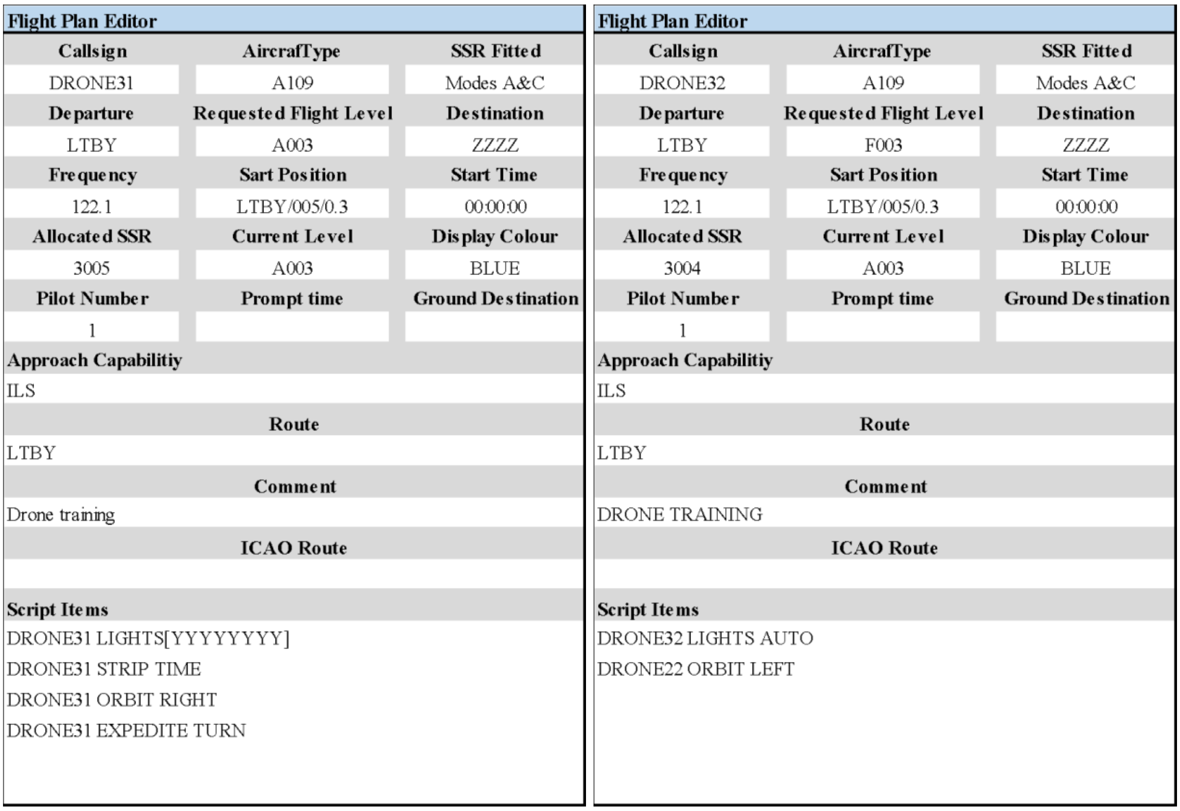
Table 23. The flight plan for drone (left) and for Cessna-1 (right) at scenario-2

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
TCAUZ	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	F035	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
2002	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1	00:02:00	
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
09 local traffic		
ICAO Route		
Script Items		
TCAUZ LIGHTS [YYYYYYYY] TCAUZ CISCUIT DIR LEFT TCAUZ STRIP TIME 01 TCAUZ DEPARTURE RUNWAY 09		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
TCHGK	UH60A	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	f035	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA9	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1004	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1	00:02:00	
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
09		
ICAO Route		
Script Items		
TCHGK DEPARTURE RUNWAY 09 TCHGK STRIP TIME 01 TCHGK LIGHTS [YYYYYYYY] TCHGK CISCUIT DIR LEFT		

Table 24. The flight plan for Cessna-2 (left) and for helicopter-1 (right) at scenario-2

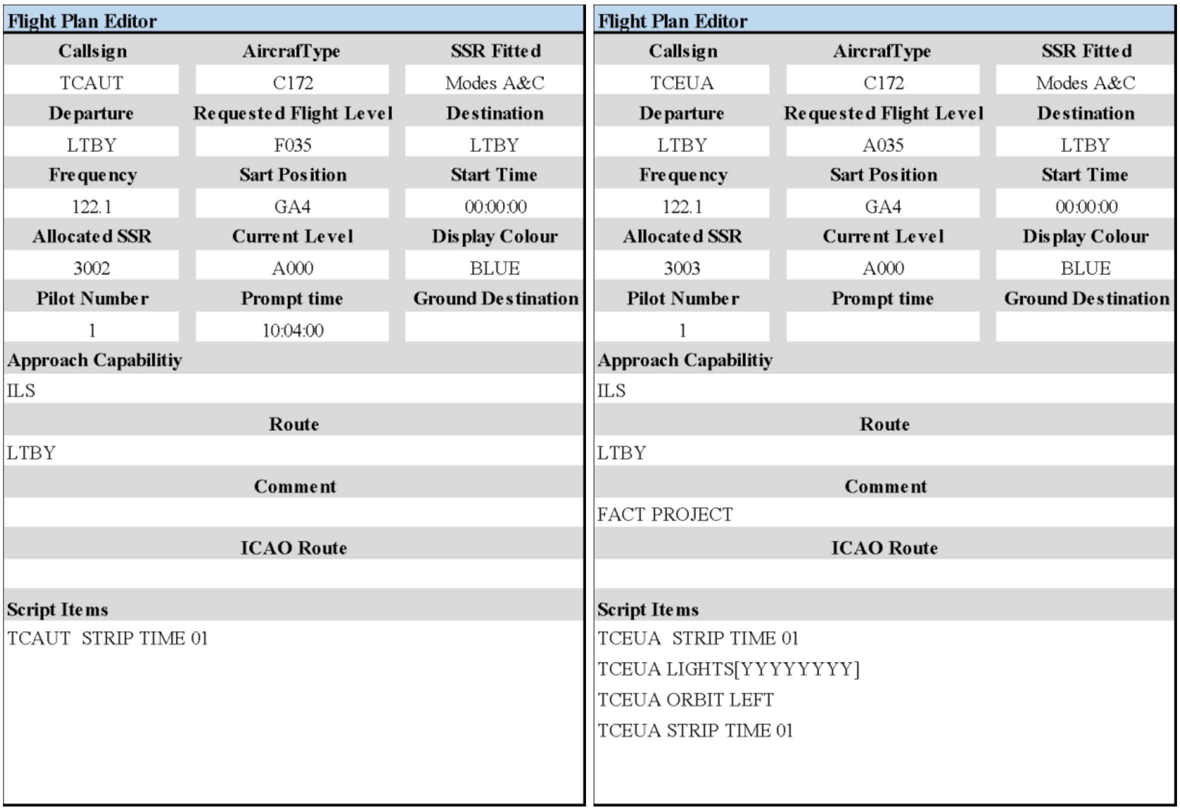
A.3 Flight plan for scenario-3



Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE31	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
3005	A003	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
Drone training		
ICAO Route		
Script Items		
DRONE31 LIGHTS[YYYYYYYY]		
DRONE31 STRIP TIME		
DRONE31 ORBIT RIGHT		
DRONE31 EXPEDITE TURN		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE32	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	F003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
3004	A003	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
DRONE TRAINING		
ICAO Route		
Script Items		
DRONE32 LIGHTS AUTO		
DRONE22 ORBIT LEFT		

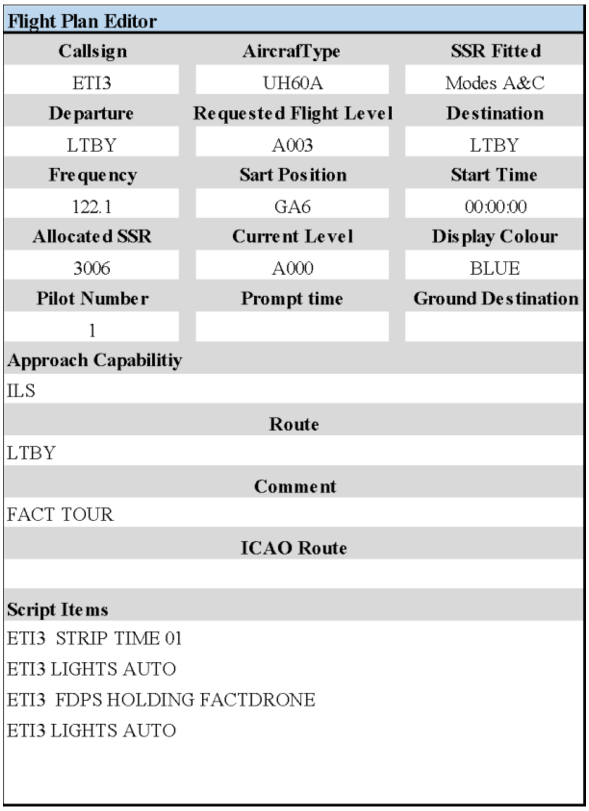
Table 25. The flight plan for drone (left) and for drone (right) at scenario-3



Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
TCAUT	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	F035	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA4	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
3002	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1	10:04:00	
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
ICAO Route		
Script Items		
TCAUT STRIP TIME 01		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
TCEUA	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A035	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA4	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
3003	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
TCEUA STRIP TIME 01 TCEUA LIGHTS[YYYYYYYY] TCEUA ORBIT LEFT TCEUA STRIP TIME 01		

Table 26. The flight plan for Cessna-1 (left) and for Cessna-2 (right) at scenario-3



Flight Plan Editor

Callsign	**AircrafType**	**SSR Fitted**
ETI3	UH60A	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA6	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
3006	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		

Approach Capabilitiy

ILS

Route

LTBY

Comment

FACT TOUR

ICAO Route

Script Items

ETI3 STRIP TIME 01
ETI3 LIGHTS AUTO
ETI3 FDPS HOLDING FACTDRONE
ETI3 LIGHTS AUTO

Table 27. The flight plan for helicopter-1 at scenario-3

A.4 Flight plan for scenario-4

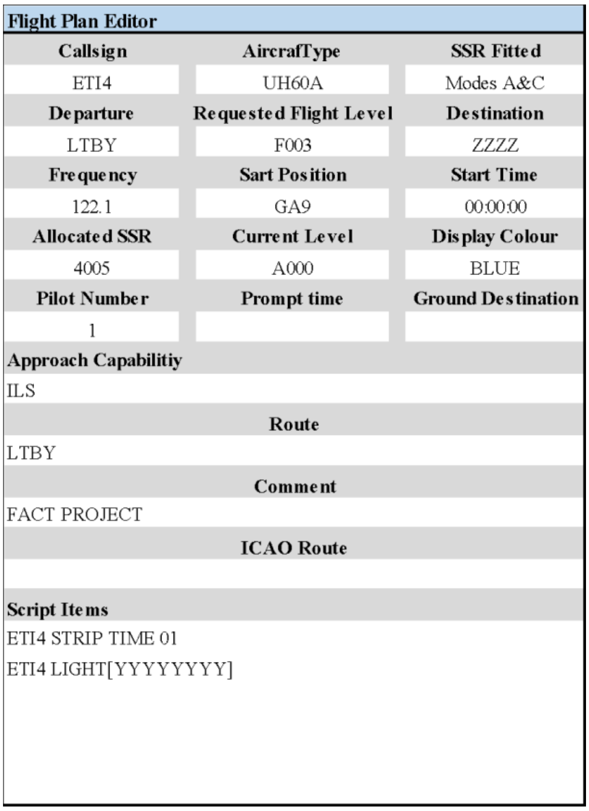
Flight Plan Editor			**Flight Plan Editor**		
Callsign	**AircrafType**	**SSR Fitted**	**Callsign**	**AircrafType**	**SSR Fitted**
DRONE41	A109	Modes A&C	DRONE41	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**	**Departure**	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ	LTBY	A003	ZZZZ
Frequency	**Sart Position**	**Start Time**	**Frequency**	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00	122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**	**Allocated SSR**	**Current Level**	**Display Colour**
4001	F003	BLUE	4001	F003	BLUE
Pilot Number	**Prompt time**	**Ground Destination**	**Pilot Number**	**Prompt time**	**Ground Destination**
1			1		
Approach Capabilitiy			**Approach Capabilitiy**		
ILS			ILS		
	Route			**Route**	
LTBY			LTBY		
	Comment			**Comment**	
FACT PROJECT			FACT PROJECT		
	ICAO Route			**ICAO Route**	
Script Items			**Script Items**		
DRONE41 STRIP TIME 00			DRONE41 STRIP TIME 00		

Table 28. The flight plan for drone-1 (left) and for drone-2 at scenario-4

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
EUAUV	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	F003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA6	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
4004	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
EUAUV STRIP TIME 01		
EUAUV LIGHTS AUTO		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
EUAUT	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA4	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
4001	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
EUAUT STRIP TIME 01		

Table 29. The flight plan for Cessna-1 (left) and for Cessna-2 (right) at scenario-4



Flight Plan Editor

Callsign	**AircrafType**	**SSR Fitted**
ETI4	UH60A	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	F003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	GA9	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
4005	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
ETI4 STRIP TIME 01 ETI4 LIGHT[YYYYYYYY]		

Table 30. The flight plan scenario-4 for helicopter-1

A.5 Flight plan for scenario-5

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE51	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A005	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
5001	F005	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
DRONE51 STRIP TIME 00		

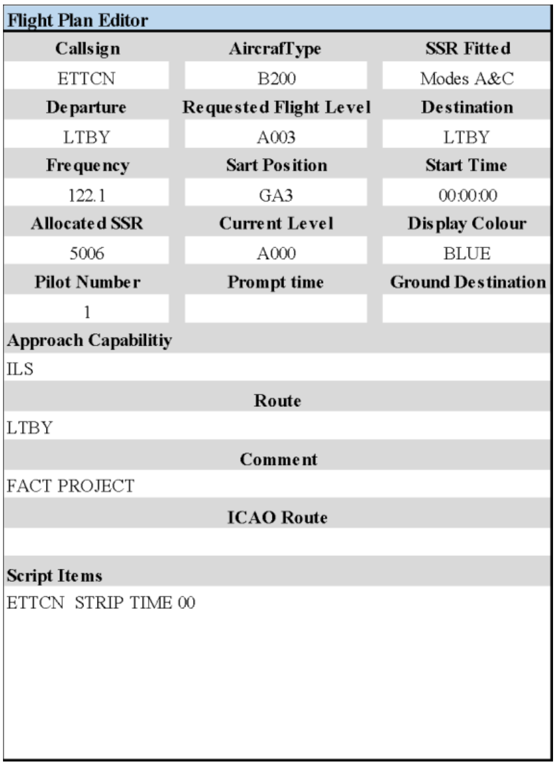
Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE51	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A005	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
5001	F005	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
DRONE51 STRIP TIME 00		

Table 31. The flight plan for drone-1 (left) and for drone-2 at scenario-5

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETACF	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA6	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
5003	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
EUAUT STRIP TIME 01		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETACL	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA5	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
5004	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
ETACL LIGHTS AUTO		

Table 32. The flight plan for Cessna-1 (left) and for Cessna-2 (right) at scenario-5



Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETTCN	B200	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
5006	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
ETTCN STRIP TIME 00		

Table 33. The flight plan for helicopter-1 at scenario-5

A.6 Flight plan for scenario-6

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE61	A10	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A005	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
6004	F005	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
Drone training		
	ICAO Route	
Script Items		

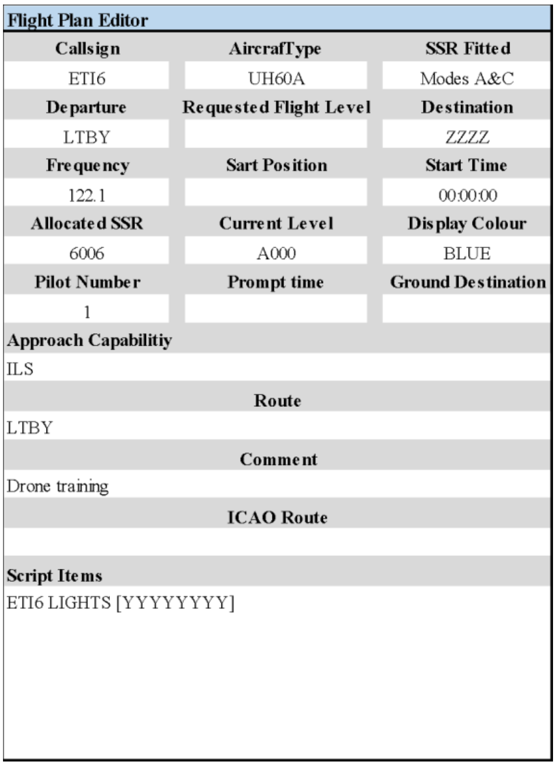
Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE62	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A005	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
6005	F006	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
	ICAO Route	
Script Items		
DRONE62 LIGHTS AUTO		

Table 34. The flight plan for drone-1 (left) and for drone-2 (right) at scenario-6

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETACF	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA6	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
5003	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
EUAUT STRIP TIME 01		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETACL	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA5	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
5004	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
ETACL LIGHTS AUTO		

Table 35. The flight plan scenario-6 for Cessna-1 (left) and for Cessna-2 (right)



Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETI6	UH60A	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY		ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1		00:00:00
Allocated SSR	**Current Level**	**Display Colour**
6006	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
Drone training		
	ICAO Route	
Script Items		
ETI6 LIGHTS [YYYYYYYY]		

Table 36. The flight plan scenario-6 for helicopter-1

A.7 Flight plan for scenario-7

Flight Plan Editor

Callsign	**AircrafType**	**SSR Fitted**
DRONE71	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
7003	F003	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		

Approach Capabilitiy

ILS

Route

LTBY

Comment

ICAO Route

Script Items

DRONE71 STRIP TIME[MIN]
DRONE71 REPORT BASE

Flight Plan Editor

Callsign	**AircrafType**	**SSR Fitted**
DRONE72	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A005	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.4	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
7004	F005	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		

Approach Capabilitiy

ILS

Route

LTBY

Comment

ICAO Route

Script Items

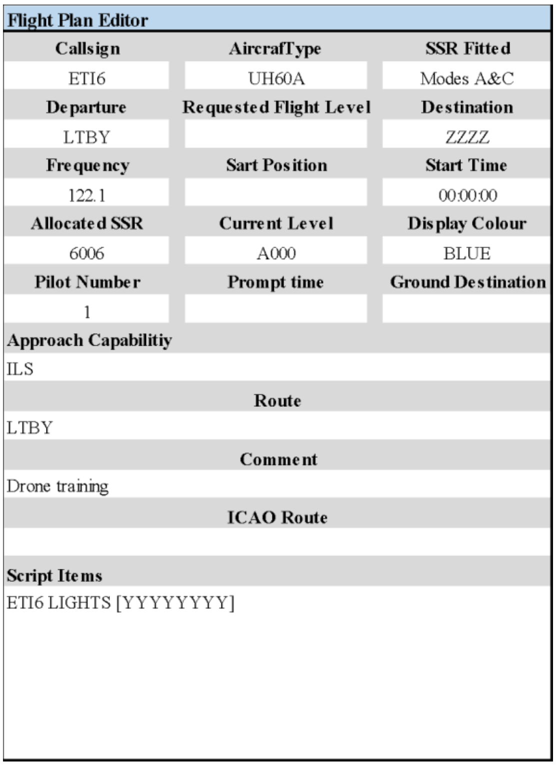
DRONE72 STRIP TIME 00

Table 37. The flight plan for drone-1 at scenario-7 (left) and for drone-2 (right) at scenario-7

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETACF	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA6	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
5003	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
EUAUT STRIP TIME 01		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETACL	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA5	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
5004	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
ETACL LIGHTS AUTO		

Table 38. The flight plan for Cessna-1 (left) for Cessna-2 (right) at scenario-7



Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETI6	UH60A	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY		ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1		00:00:00
Allocated SSR	**Current Level**	**Display Colour**
6006	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
Drone training		
ICAO Route		
Script Items		
ETI6 LIGHTS [YYYYYYYY]		

Table 39. The flight plan for helicopter-1 at scenario-7

A.8 Flight plan for scenario-8

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE81	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1071	F005	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
DRONE81 STRIP TIME 00		

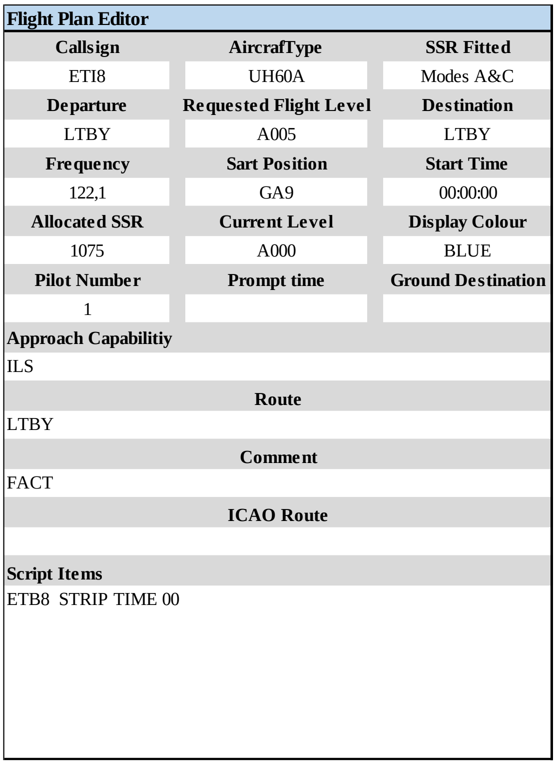
Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE82	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	GA9	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1073	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT DRONE		
ICAO Route		
Script Items		
DRONE82 STRIP TIME 00		

Table 40. The flight plan for drone-1 (left) and for drone-2 (right) at scenario-8

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
EUETC	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA4	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1072	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
ICAO Route		
Script Items		
EUETC STRIP TIME 00		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETACL	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA5	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
5004	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
ETACL LIGHTS AUTO		

Table 41. The flight plan for Cessna-1 (left) and for Cessna-2 (right) at scenario-8



Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETI8	UH60A	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A005	LTBY
Frequency	**Sart Position**	**Start Time**
122,1	GA9	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1075	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT		
ICAO Route		
Script Items		
ETB8 STRIP TIME 00		

Table 42. The flight plan for helicopter-1 at scenario-8

A.9 Flight plan for scenario-9

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE91	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1064	F003	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
DRONE91 STRIP TIME 00		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE92	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A005	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1065	F005	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
DRONE92 STRIP TIME 00		

Table 43. The flight plan for drone-1 (left) and for drone-2 (right) at scenario-9

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETEUL	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA4	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1061	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
ETEUL STRIP TIME 00		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETEUW	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA5	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1062	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
ETEUW STRIP TIME 00		

Table 44. The flight plan for Cessna-1 (left) and for Cessna-2 (right) at scenario-9

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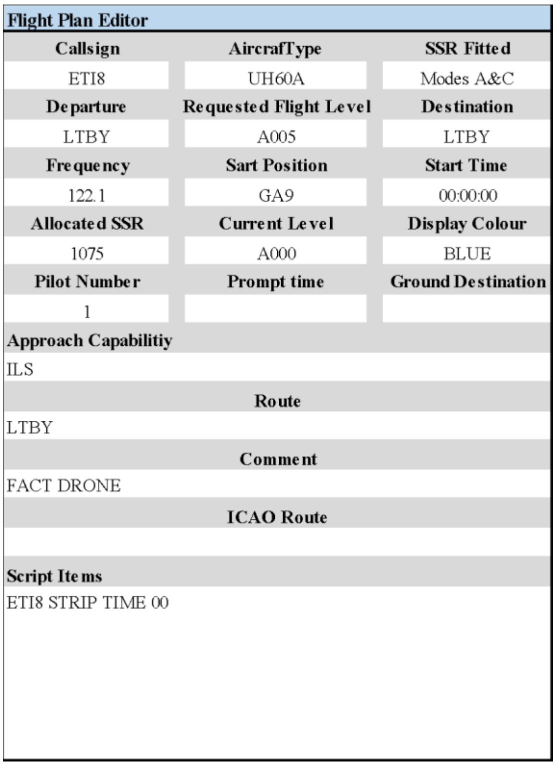


Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETI8	UH60A	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A005	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA9	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1075	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT DRONE		
	ICAO Route	
Script Items		
ETI8 STRIP TIME 00		

Table 45. The flight plan for helicopter at scenario-9

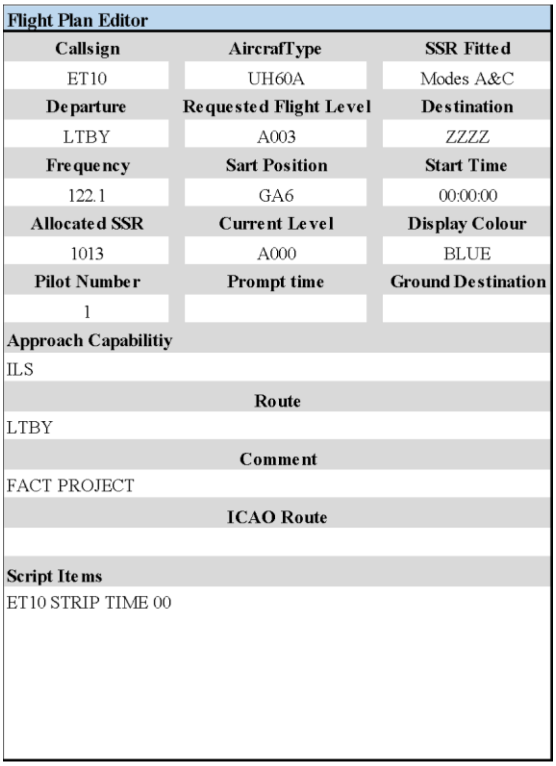
A.10 Flight plan for scenario-10

Flight Plan Editor			**Flight Plan Editor**		
Callsign	**AircrafType**	**SSR Fitted**	**Callsign**	**AircrafType**	**SSR Fitted**
DRONE91	A109	Modes A&C	DRONE91	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**	**Departure**	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ	LTBY	A003	ZZZZ
Frequency	**Sart Position**	**Start Time**	**Frequency**	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00	122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**	**Allocated SSR**	**Current Level**	**Display Colour**
1064	F003	BLUE	1064	F003	BLUE
Pilot Number	**Prompt time**	**Ground Destination**	**Pilot Number**	**Prompt time**	**Ground Destination**
1			1		
Approach Capabilitiy			**Approach Capabilitiy**		
ILS			ILS		
	Route			**Route**	
LTBY			LTBY		
	Comment			**Comment**	
FACT PROJECT			FACT PROJECT		
	ICAO Route			**ICAO Route**	
Script Items			**Script Items**		
DRONE91 STRIP TIME 00			DRONE91 STRIP TIME 00		

Table 46. The flight plan for drone-1 (left) and for drone-2 (right) at scenario-10

Flight Plan Editor			**Flight Plan Editor**		
Callsign	**AircrafType**	**SSR Fitted**	**Callsign**	**AircrafType**	**SSR Fitted**
ETEUP	C172	Modes A&C	ETEUW	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**	**Departure**	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY	LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**	**Frequency**	**Sart Position**	**Start Time**
122.1	GA5	00:00:00	122.1	GA5	00:00:00
Allocated SSR	**Current Level**	**Display Colour**	**Allocated SSR**	**Current Level**	**Display Colour**
1012	A000	BLUE	1062	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**	**Pilot Number**	**Prompt time**	**Ground Destination**
1			1		
Approach Capabilitiy			**Approach Capabilitiy**		
ILS			ILS		
	Route			**Route**	
LTBY			LTBY		
	Comment			**Comment**	
FACT PROJECT			FACT PROJECT		
	ICAO Route			**ICAO Route**	
Script Items			**Script Items**		
ETEUP STRIP TIME 00			ETEUW STRIP TIME 00		

Table 47. The flight plan for Cessna-1 (left) and for Cessna-2 (right) at scenario-10



Flight Plan Editor

Callsign	**AircrafType**	**SSR Fitted**
ET10	UH60A	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	GA6	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1013	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		

Approach Capabilitiy

ILS

Route

LTBY

Comment

FACT PROJECT

ICAO Route

Script Items

ET10 STRIP TIME 00

Table 48. The flight plan for helicopter at scenario-10

A.11 Flight plan for scenario-11

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE91	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1064	F003	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
DRONE91 STRIP TIME 00		

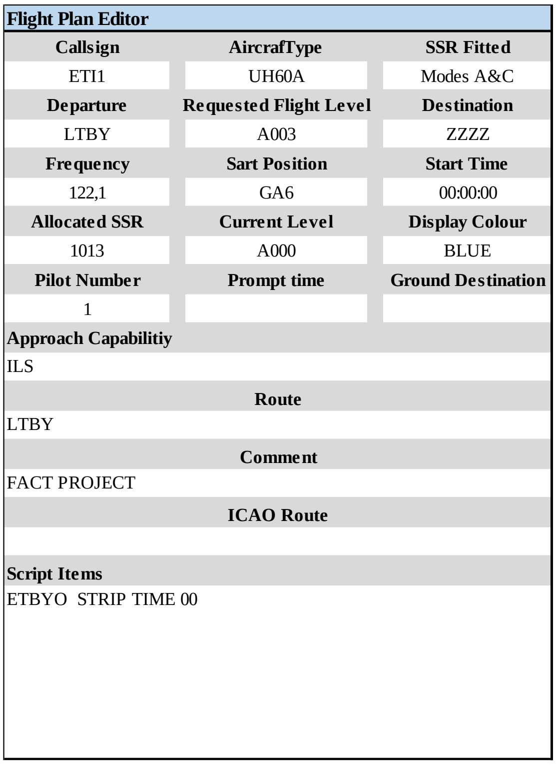
Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
DRONE92	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A005	ZZZZ
Frequency	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1065	F005	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
DRONE92 STRIP TIME 00		

Table 49. The flight plan for drone-1 (left) and for drone-2 (right) at scenario-11

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETEUW	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA5	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1062	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
ETEUW STRIP TIME 00		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETEUW	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA5	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1062	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
ETEUW STRIP TIME 00		

Table 50. The flight plan for Cessna-1 (left) and for Cessna-2 (right) at scenario-11



Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETI1	UH60A	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122,1	GA6	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1013	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
ETBYO STRIP TIME 00		

Table 51. The flight plan for helicopter at scenario-11

A.12 Flight plan for scenario-12

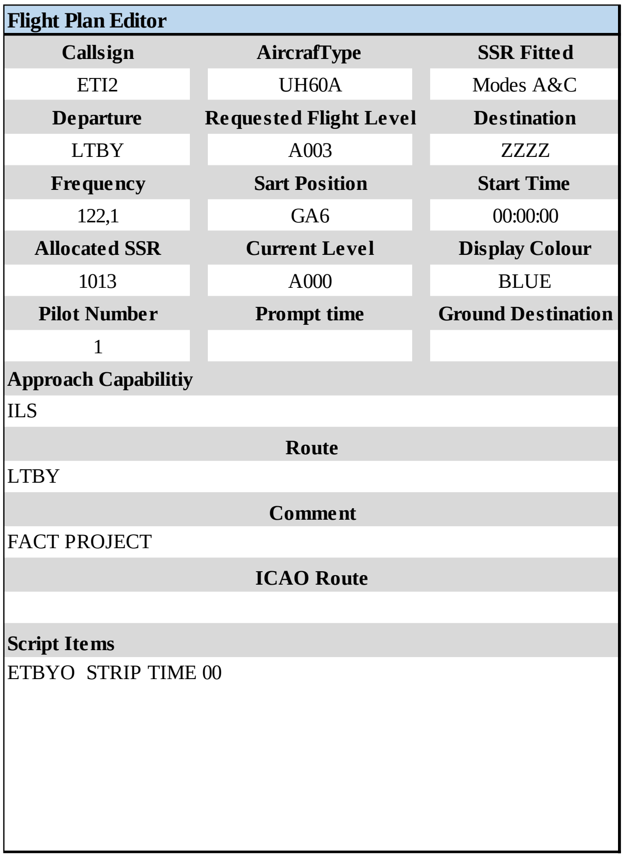
Flight Plan Editor			**Flight Plan Editor**		
Callsign	**AircrafType**	**SSR Fitted**	**Callsign**	**AircrafType**	**SSR Fitted**
DRONE91	A109	Modes A&C	DRONE92	A109	Modes A&C
Departure	**Requested Flight Level**	**Destination**	**Departure**	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ	LTBY	A005	ZZZZ
Frequency	**Sart Position**	**Start Time**	**Frequency**	**Sart Position**	**Start Time**
122.1	LTBY/005/0.3	00:00:00	122.1	LTBY/005/0.3	00:00:00
Allocated SSR	**Current Level**	**Display Colour**	**Allocated SSR**	**Current Level**	**Display Colour**
1064	F003	BLUE	1065	F005	BLUE
Pilot Number	**Prompt time**	**Ground Destination**	**Pilot Number**	**Prompt time**	**Ground Destination**
1			1		
Approach Capabilitiy			**Approach Capabilitiy**		
ILS			ILS		
Route			**Route**		
LTBY			LTBY		
Comment			**Comment**		
FACT PROJECT			FACT PROJECT		
ICAO Route			**ICAO Route**		
Script Items			**Script Items**		
DRONE91 STRIP TIME 00			DRONE92 STRIP TIME 00		

Table 52. The flight plan for drone-1 (left) and for drone-2 (right) at scenario-12

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETEUW	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA5	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1062	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
ETEUW STRIP TIME 00		

Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETEUW	C172	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	LTBY
Frequency	**Sart Position**	**Start Time**
122.1	GA5	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1062	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
	Route	
LTBY		
	Comment	
FACT PROJECT		
	ICAO Route	
Script Items		
ETEUW STRIP TIME 00		

Table 53. The flight plan for Cessna-1 (left) and for Cessna-2 (right) at scenario-12



Flight Plan Editor		
Callsign	**AircrafType**	**SSR Fitted**
ETI2	UH60A	Modes A&C
Departure	**Requested Flight Level**	**Destination**
LTBY	A003	ZZZZ
Frequency	**Sart Position**	**Start Time**
122,1	GA6	00:00:00
Allocated SSR	**Current Level**	**Display Colour**
1013	A000	BLUE
Pilot Number	**Prompt time**	**Ground Destination**
1		
Approach Capabilitiy		
ILS		
Route		
LTBY		
Comment		
FACT PROJECT		
ICAO Route		
Script Items		
ETBYO STRIP TIME 00		

Table 54. The flight plan for helicopter at scenario-12

A.13 Radar and simulation screenshots for scenario-1

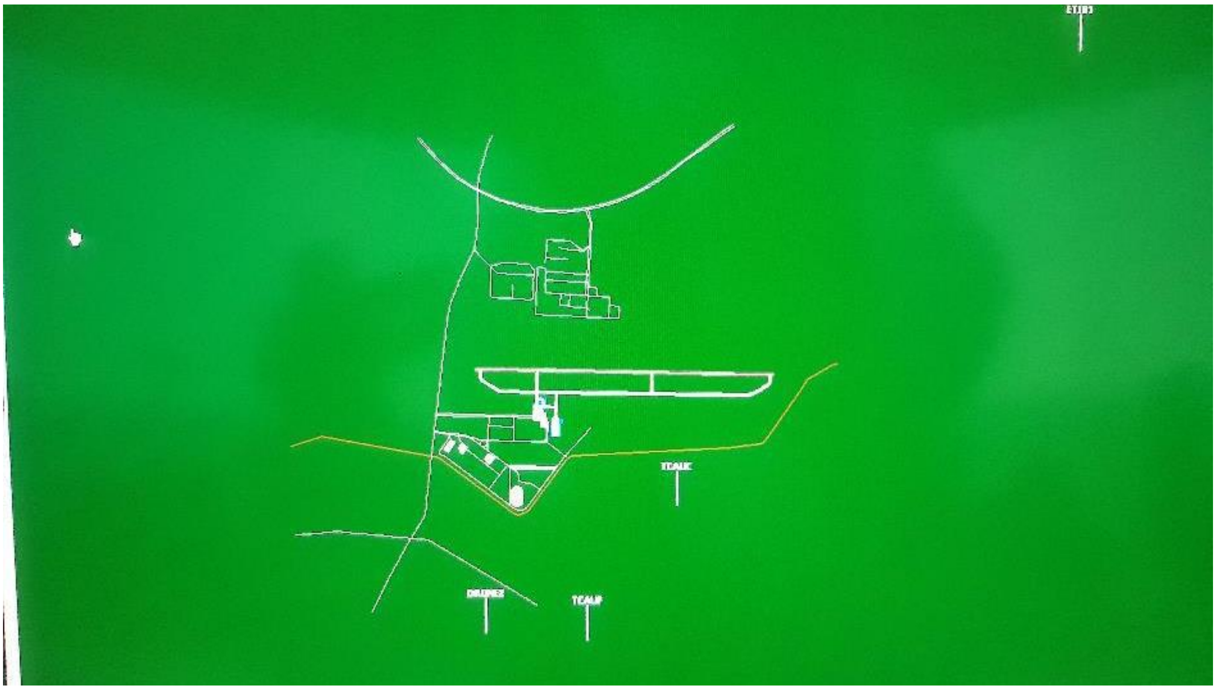


Figure 52. Radar and simulation screenshots for scenario-1

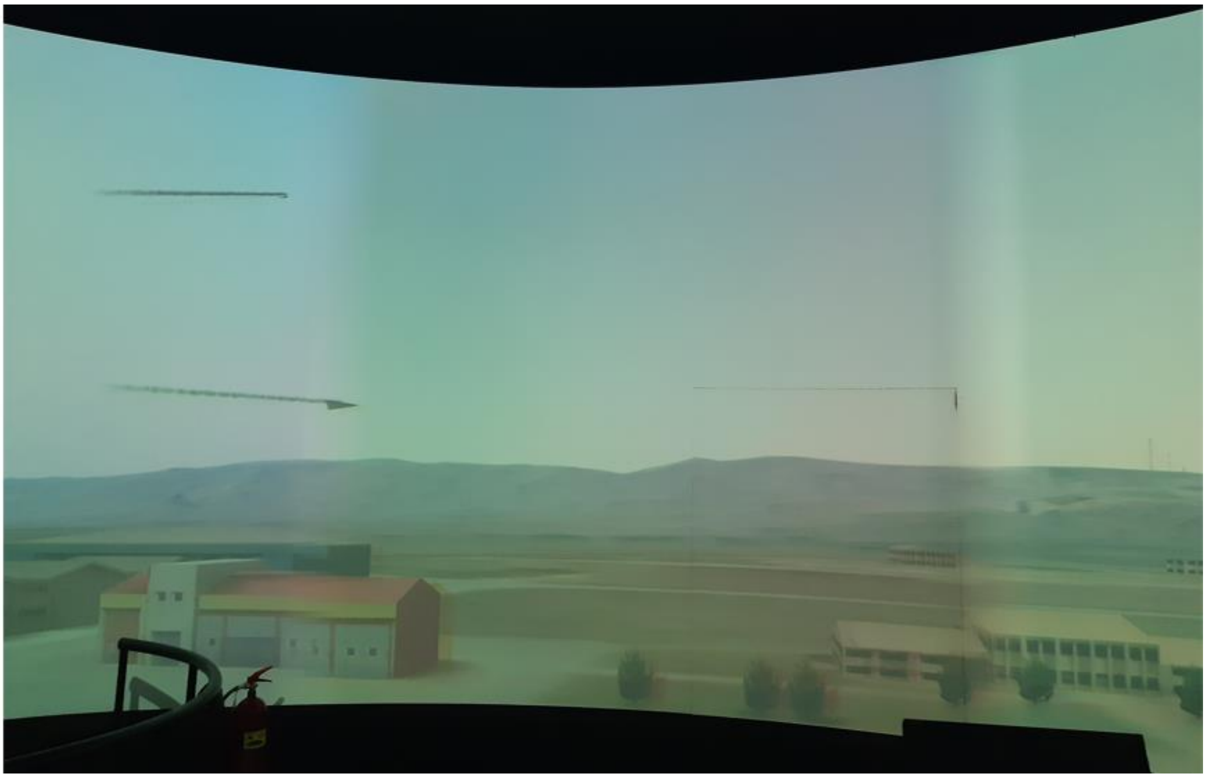


Figure 53. Simulation screenshots for scenario-1

Figure 54. Simulation screenshots for scenario-1

A.14 Radar and simulation screenshots for scenario-2

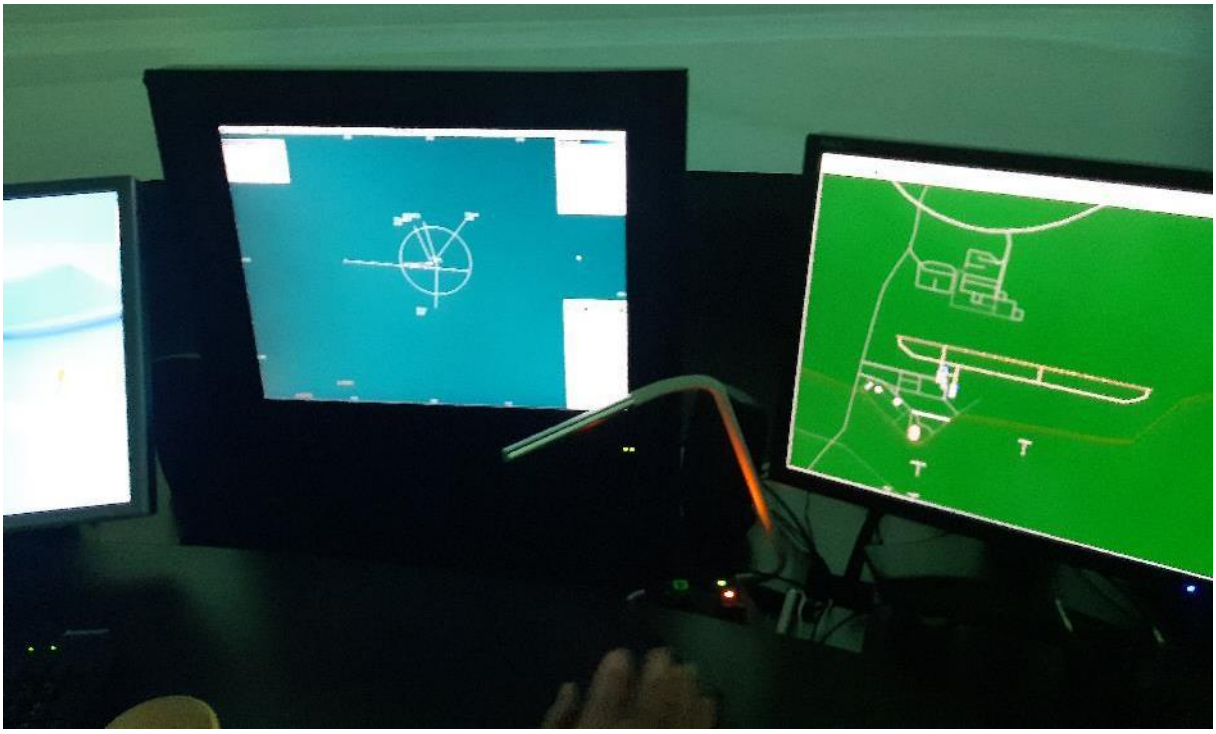


Figure 55. Radar screenshots for scenario-2

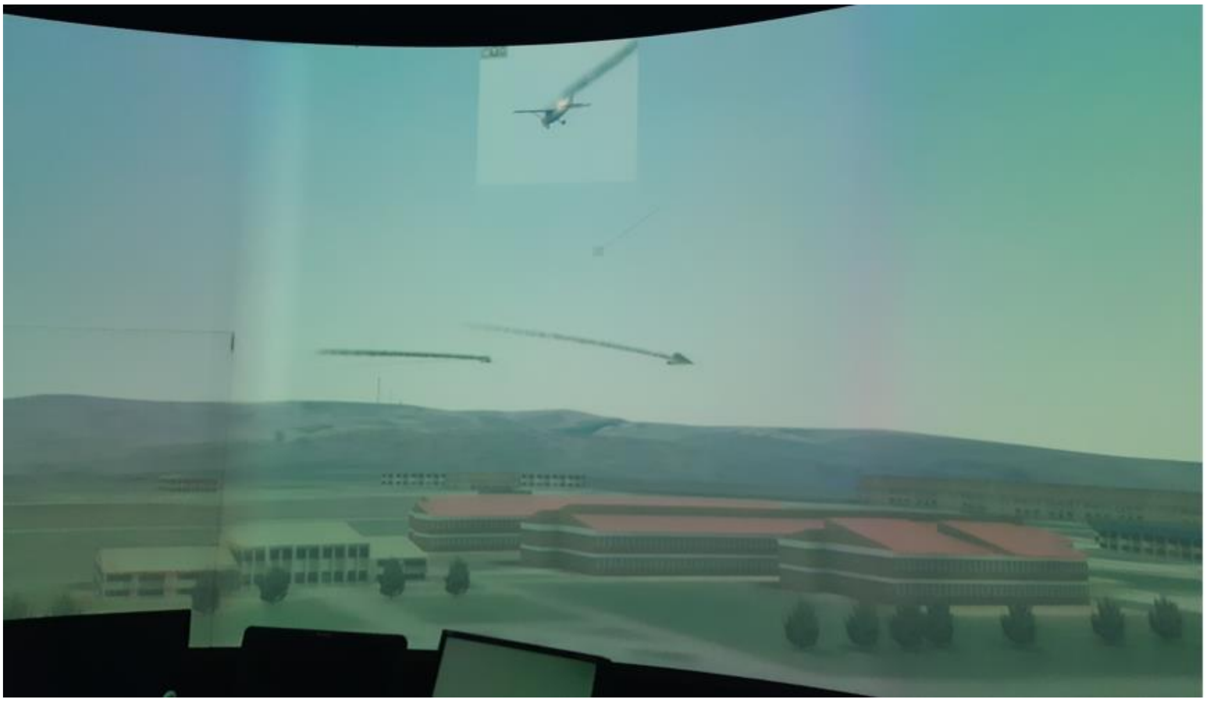


Figure 56. Simulation screenshots for scenario-2

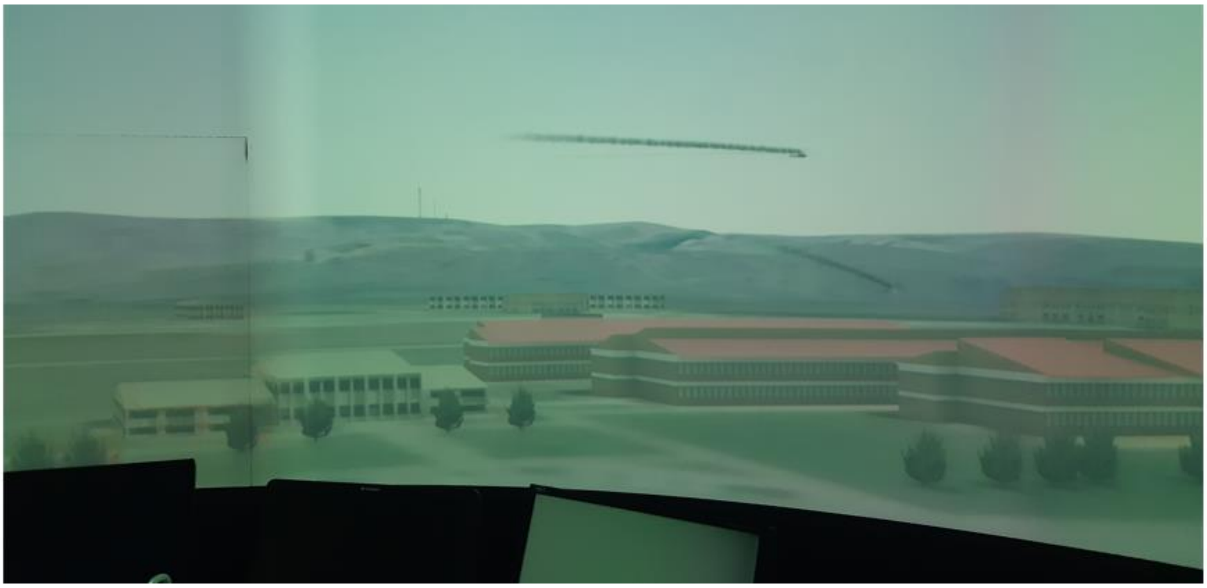


Figure 57. Simulation screenshots for scenario-2

A.15 Radar and simulation screenshots for scenario-3

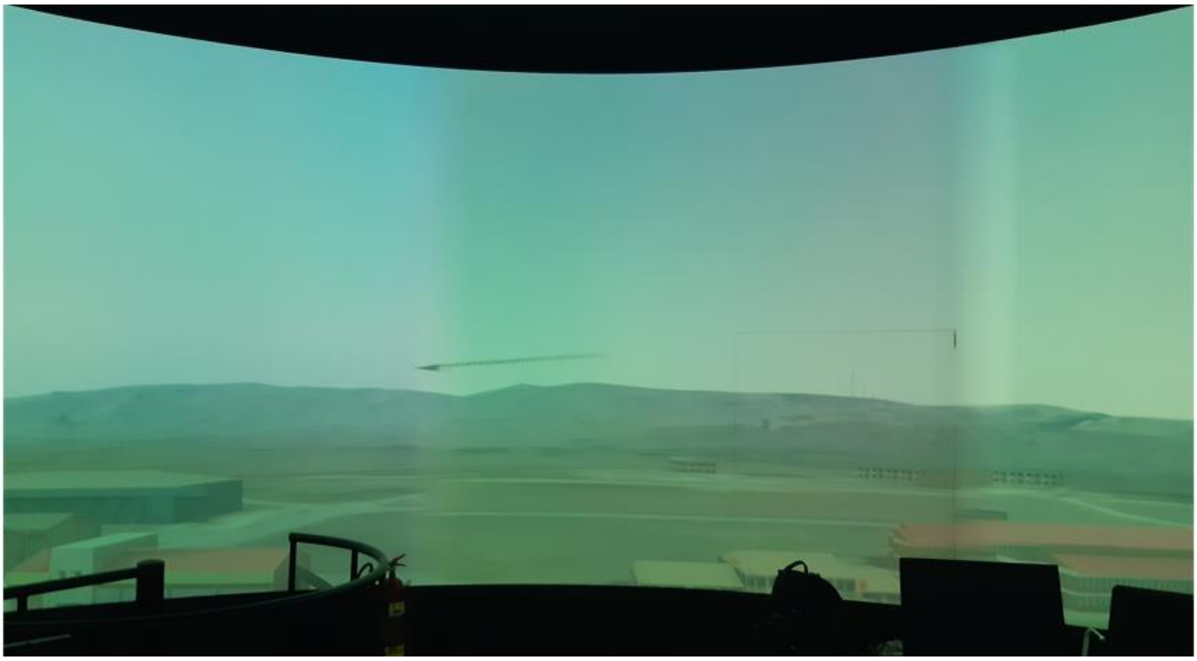


Figure 58. Simulation screenshots for scenario-3

Figure 59. Simulation screenshots for scenario-3

A.16 Radar and simulation screenshots for scenario-4

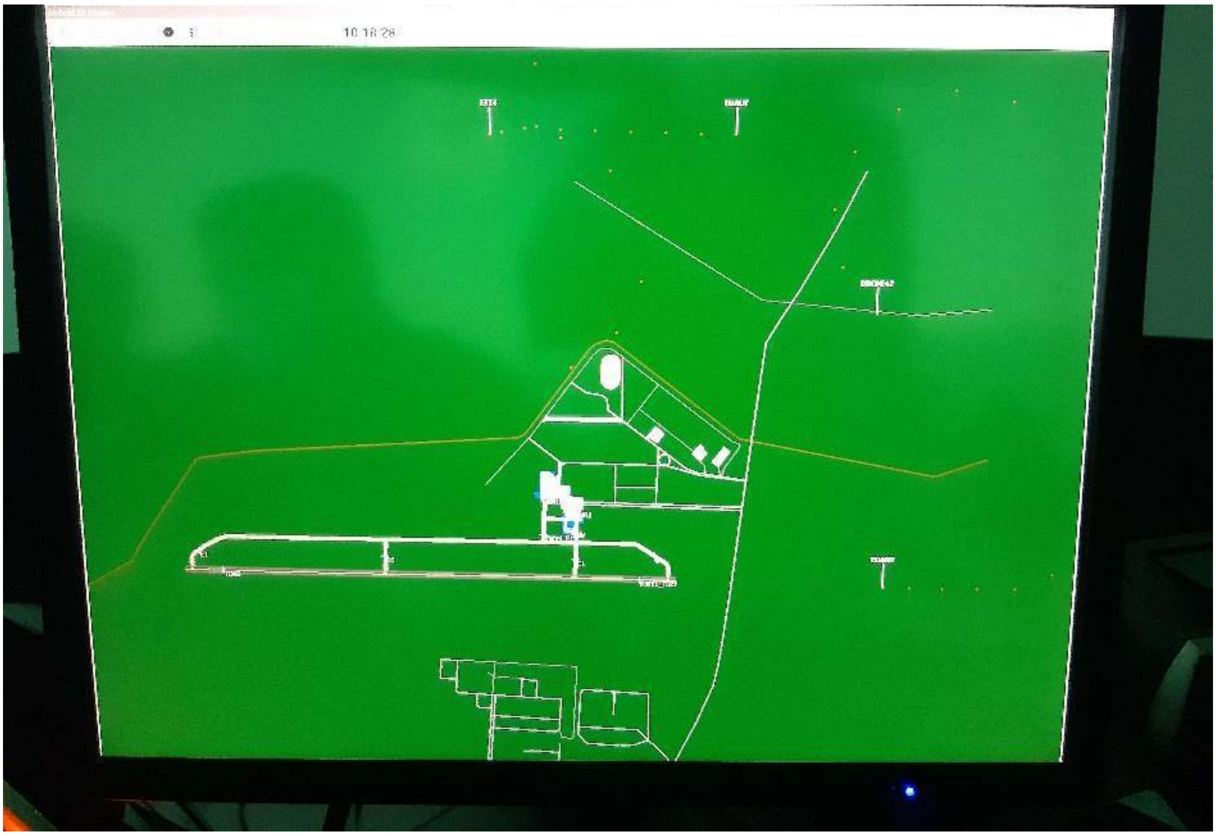


Figure 60. Radar screenshots for scenario-4

Figure 61. Simulation screenshots for scenario-4

Figure 62. Simulation screenshots for scenario-4

A.17 Radar and simulation screenshots for scenario-5

Figure 63. Simulation screenshots for scenario-5

Figure 64. Simulation screenshots for scenario-5

A.18 Radar and simulation screenshots for scenario-6

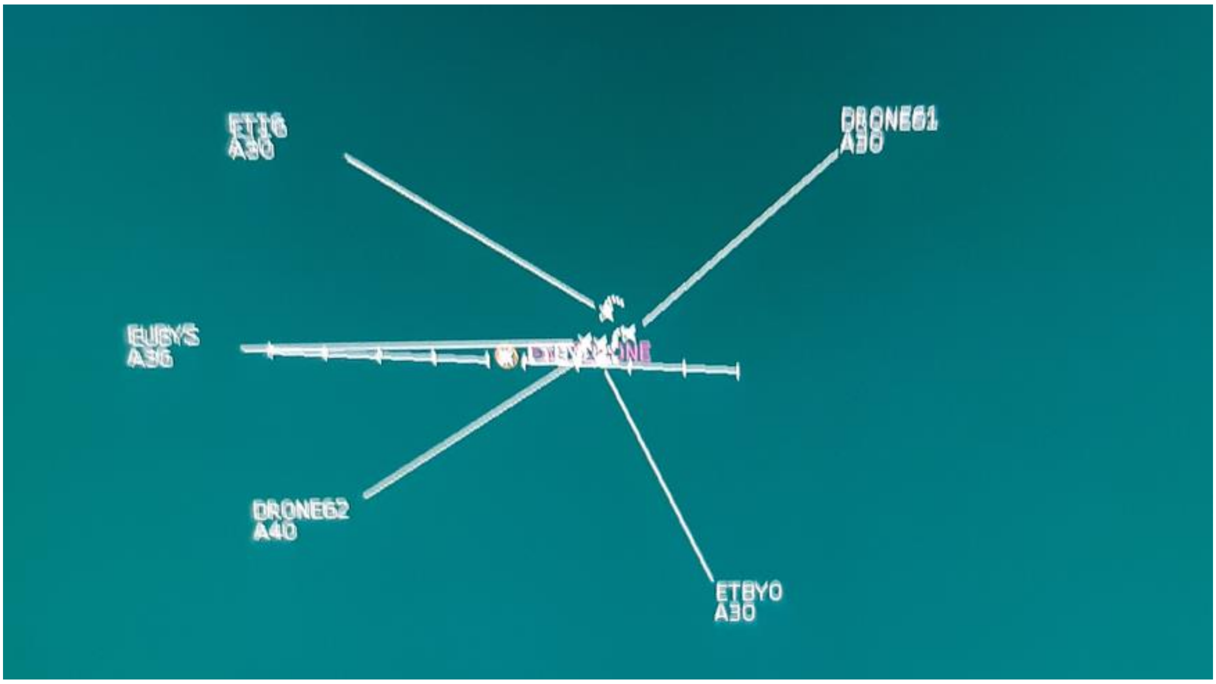


Figure 65. Radar screenshots for scenario-6

Figure 66. Radar screenshots for scenario-6

Figure 67. Simulation screenshots for scenario-6

A.19 Radar and simulation screenshots for scenario-9

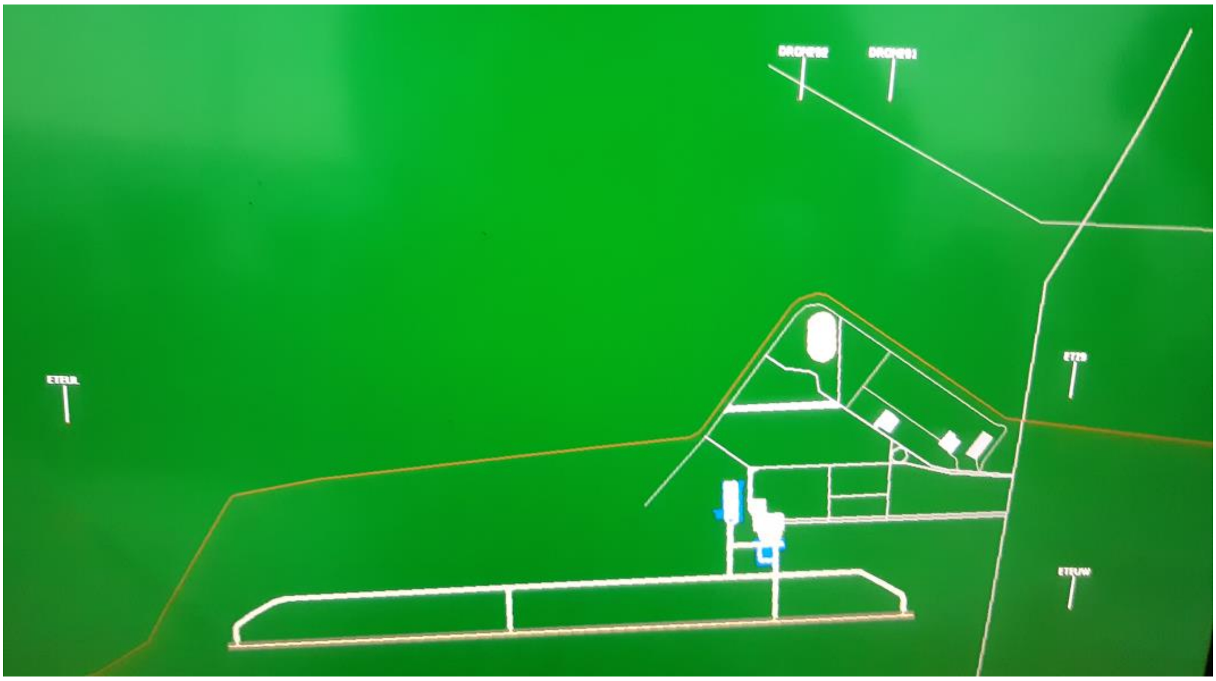


Figure 68. Radar screenshots for scenario-9

Figure 69. Simulation screenshots for scenario-9

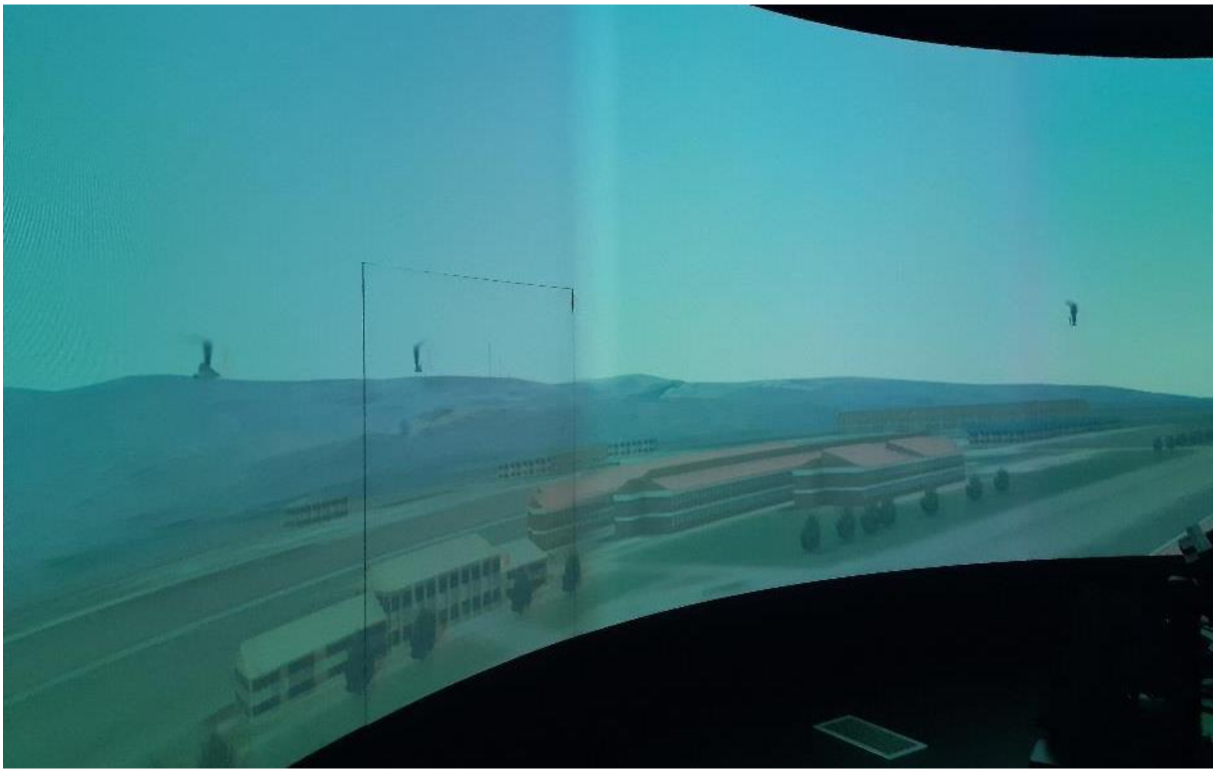


Figure 70. Simulation screenshots for scenario-9

A.20 Radar and simulation screenshots for scenario-10

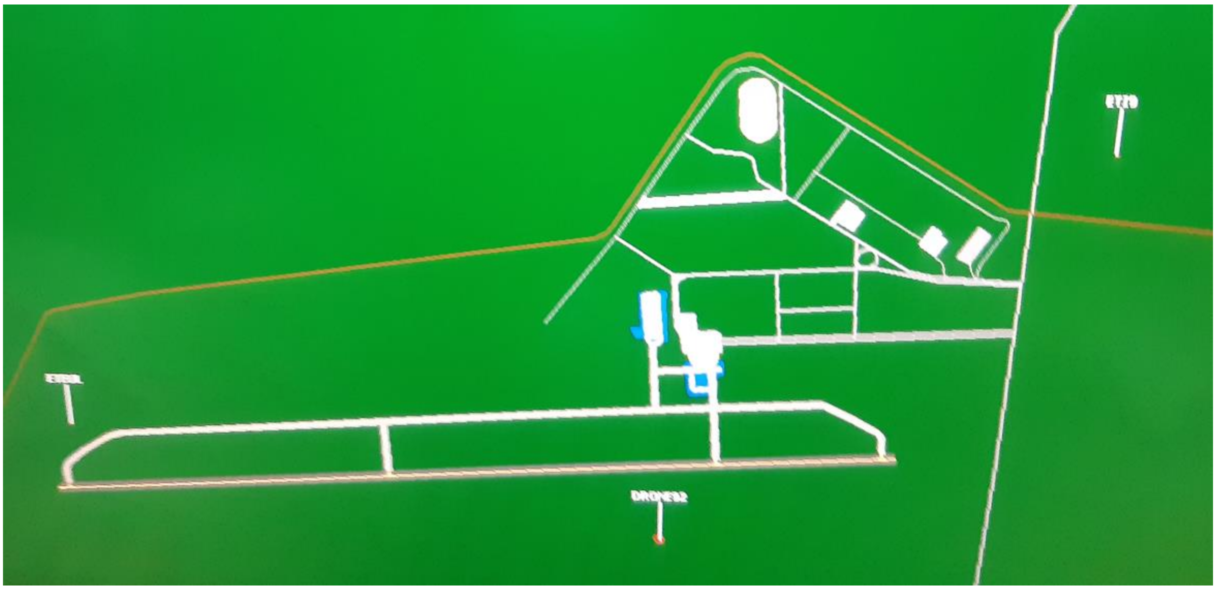


Figure 71. Radar screenshots for scenario-10

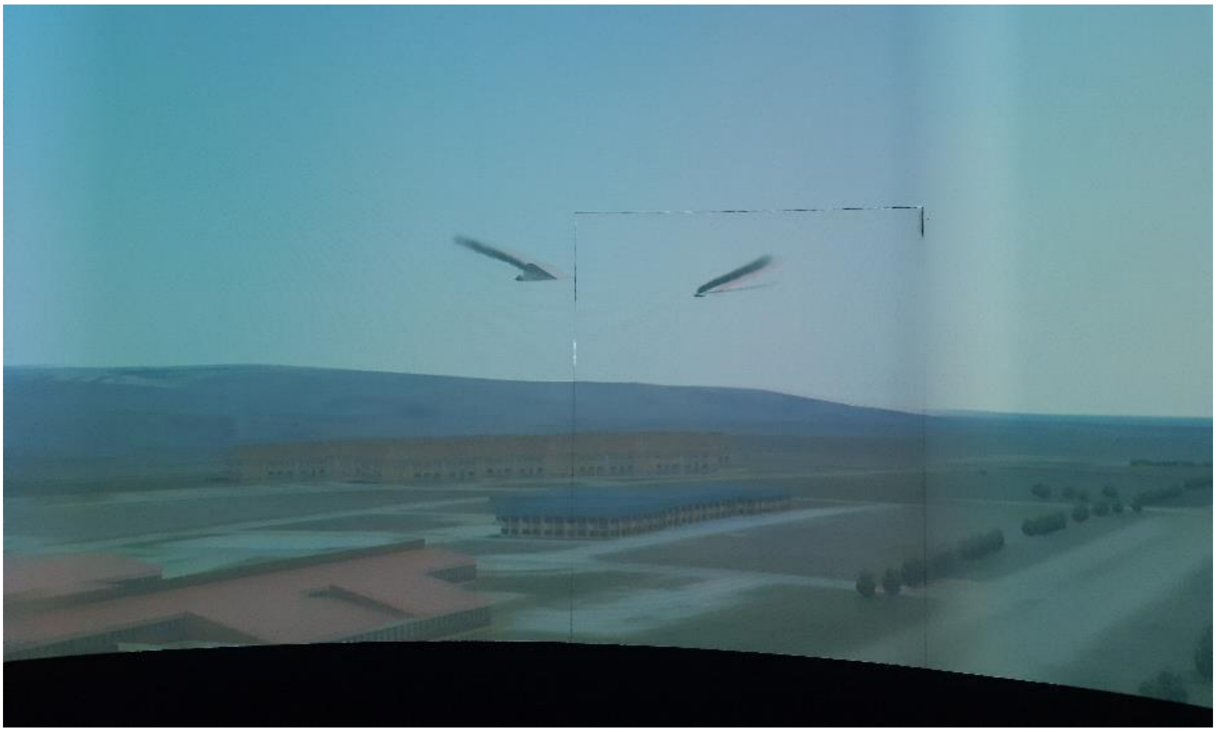


Figure 72. Simulation screenshots for scenario-10

Figure 73. Simulation screenshots for scenario-