# A Detect And Avoid concept for UAS operations near Hospital Emergency Medical Services helipads in uncontrolled urban airspace (DRAFT VERSION).

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***Abstract*— This work presents a Detect And Avoid (DAA) concept which was used to enable drone healthcare logistics flight tests adjacent to a Hospital Emergency Medical Services (HEMS) helipad in Denmark. The flights tests were conducted in uncontrolled airspace above a city, where medical helicopters land on average 1-2 times a day.**

**The DAA concept utilizes ground-based ADS-B and FLARM receivers to establish situational awareness of the adjacent airspace. The DAA concept together with an associated risk assessment was included in a Specific Operations Risk Assessment (SORA) based application, which received a flight authorization from the Danish Civilian Aviation Authority (CAA).**

**During a 3 month period, a total of 354 flight tests were conducted totaling 69 hours in air. The operation was inspected by the Danish CAA who have expressed no concerns about the safety of the flight tests.**

## I. INTRODUCTION

The integration of UAS and crewed aircraft in the lower airspace is by many considered a critical prerequisite to commercial scaling of drone applications [1], [2]. This document presents a Detect And Avoid (DAA) concept for healthcare drone logistics flights between different locations at Odense University Hospital (OUH) in Denmark.

The U-space based aircraft detection is the first step of a Detect And Avoid (DAA) plan to avoid potential mid-air collisions with nearby aircraft. The DAA plan forms part of a Specific Operations Risk Assessment (SORA) based application to be submitted to the Danish Civil Aviation Authorities.

This paper is organized as follows. Section III describes the overall Concept of Operation for the aircraft detection is presented. Section II of the paper gives an overview of the state of the art with the field. In Section IV the DAA plan is described and the associated reliability, robustness, and timing requirements for aircraft detection presented in the SORA guidelines are discussed. Section V describes the technology used for aircraft detection with a focus on reliability. In Section VI the aircraft detection reliability is analyzed using historical data. Finally, section VII concludes on the presented results and discusses future work.

## II. STATE OF THE ART

TO BE INSERTED

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## III. CONCEPT OF OPERATION

During 2021 extensive drone flights will take place at OUH. The purpose is to validate the usability of healthcare logistics drones while at the same time establishing the first U-space airspace in Denmark.

The flights takes place in close vicinity of OUH's Helicopter Emergency Medical Services (HEMS) helipad (EKOH) where medical helicopters land on average 1-2 times a day.

The drone flights are conducted between relevant departments at OUH with a distance of up to a couple of kilometers. At all times will the drone be within Visual Line of Sight (VLOS) to the Pilot In Control (PIC). The flights will take place within 550 m of EKOH which is the distance to the General Practitioners clinic at J.B. Winsløwsvej 9A. The maximum drone height will be 25 m Above Ground Level (AGL).

During flight, the PIC is assisted by a pilot assistant who will support the PIC during the operation including maintaining situational awareness of the nearby airspace. This collaboration is elaborated in the SORA-based application[1] and associated Standard Operating Procedures (SOP). For the purpose of simplicity in this document the term PIC will refer to both the PIC and the pilot assistant. Furthermore, the application describes visual observation as a means to improve the situational awareness of the nearby airspace. For the purpose of simplicity, this document only deals with the U-space based aircraft detection.

### A. Detection of aircraft via ADS-B or FLARM

This Concept of Operation (ConOps) assumes that a U-space airspace is established restricting manned aircraft to only enter the U-space airspace, if the aircraft has ADS-B out or FLARM out installed and activated.

Given that the drone operation takes place near EKOH in an urban area where General Aviation (GA) is not permitted to fly below 1000 ft $\approx$ 300 m AGL, essentially only HEMS helicopters approaching the helipad are of concern. The Danish HEMS helicopters are operated by Norsk Luftambulance (NLA). Also, the German helicopters from Nieböl operated by DRF Luftrettung (DRF) occasionally visit EKOH.

Figure 1 lists the ADS-B and FLARM equipment available on HEMS helicopters that have landed at EKOH during the testing period described in section VI. The content of figure

[1] *"Ansøgning om tilladelse til flyvning, mindre end 1 km fra EKOH"*

1 has been confirmed by NLA and DRF in December 2020. It should be noted that LN-OON as the only helicopter is not equipped with ADS-B out. It does have a Mode S transponder installed. LN-OUK is not equipped with FLARM out, however an installation is being planned.

| *Tail* | *ADS-B in* | *ADS-B out* | *FLARM in* | *FLARM out* |
|---|---|---|---|---|
| LN-OOV | yes | yes | yes | yes |
| LN-OOZ | yes | yes | yes | yes |
| LN-OOW | yes | yes | yes | yes |
| LN-OUK | yes | yes | no | no |
| LN-OON | no | no | yes | yes |
| D-HDSY | yes | yes | yes | yes |
| D-HDSQ | yes | yes | yes | yes |

Fig. 1: *ADS-B and FLARM equipment on HEMS helicopters that has landed at EKOH during the testing period described in section VI.*

Figure 2 illustrates the detection of nearby manned aircraft. The ADS-B squitters and FLARM broadcasts are detected by locally placed ground receivers. The received data is transmitted from the ground receivers to a SQL database. The SQL database relays data to a DAA service and also stores data for statistical purposes. The DAA service provides the PIC situational awareness of nearby manned aircraft via a graphical and textual view of the airspace.

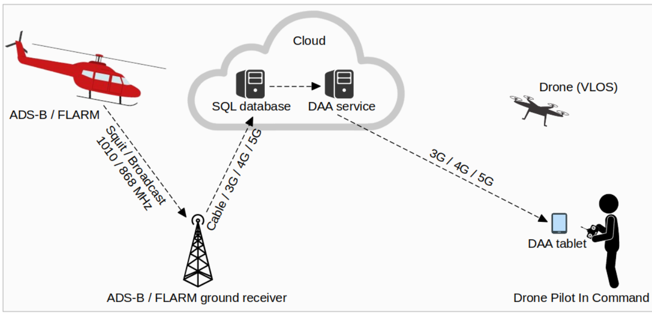


Fig. 2: *DAA architecture for detection of nearby manned aircrafts*

Based on this updated situational awareness the PIC decides appropriate actions if an aircraft approaches. Given that the vast majority of approaching aircraft will be HEMS helicopters landing at EKOH, the only appropriate action will be to immediately land the drone safely.

### B. Well Clear volume

The minimum acceptable distance between a drone and a manned aircraft is in this ConOps named the Well Clear (WC) distance. Given that the drone has to yield to all manned aircraft, the PIC has to Remain Well Clear (RWC) i.e. safely land the drone before the WC distance is breached. A contingency or emergency procedure is activated if the WC distance is breached.

The ASTM standard F3442[2] recommends lateral and vertical WC boundaries of 2000 ft ≈ 610 m and 250 ft ≈ 77 m respectively which are used in the following definition of a WC volume. The WC boundary is illustrated in figure 3.

In principle the WC volume follows the drone during flight, however, for simplicity of the operation the WC volume center will be fixed at the EKOH helipad which is close to the center of OUH. The lateral boundary is then extended by the maximum distance from the drone to the EKOH helipad defined in section III. The upward vertical boundary is extended by the maximum height of the drone AGL defined in section III:

$$WC_{lateral} = 610m + 550m = 1160m \quad (1)$$
$$WC_{vertical} = 77m + 25m = 102m\,(AGL) \quad (2)$$

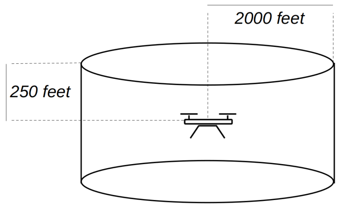


Fig. 3: *Illustration of Well Clear boundaries as suggested by the ASTM F3442F/3442M-20 standard [3]. The lateral boundary is 2000 ft ≈ 610 m. The vertical boundary is 250 ft ≈ 77 m.*

### C. Detection volume

When an aircraft approaches the drone operation, the decision whether to continue the current flight or initiate a drone landing must be based on the maximum time duration from detection of the approaching aircraft to the drone that has safely landed.

In this CopOps the decision to land the drone is made by the PIC (vice autonomously), therefore to simplify the decision-making process a detection volume is defined. The size of the detection volume ensures that if a manned aircraft breaches the detection volume, and a safe drone landing is initiated by the PIC, it will be completed before the manned aircraft breaches the WC volume.

In this ConOps the WC volume is cylindrically shaped with its center static at the EKOH helipad as described in section III-B. To keep a simple representation of the detection volume this is similarly cylindrical shaped with the same static center.

Determining the minimum size of the detection volume requires an analysis of latencies and update rates introduced in the DAA plan. This is conducted in section IV which concludes that the estimated maximum time from aircraft detection to the drone has safely landed is 28 seconds. Following this the analysis of historical recorded ADS-B data in section VI was then used to quantify the required minimum size. The proposed size based on the historical analysis is listed below:

[2]Standard Specification for Detect and Avoid System Performance Requirements https://www.astm.org/Standards/F3442.htm

$$Det_{lateral} = 3000m \quad (3)$$
$$Det_{vertical} = 300m\,(AGL) \quad (4)$$

Figure 4 depicts the WC volume and detection volume centered at EKOH and the proposed sizes listed above.


Fig. 4: *Illustration of the Detection and Well Clear volumes. The illustration is accurate to scale. The vertical lines are caused by the cylinders being represented by a polygon in this illustration. Map content is Copyright by Google.*

### D. Restricted airspace

As described in section III-A the ConOps assumes that a U-space airspace is established restricting manned aircraft to only enter the U-space airspace, if the aircraft has ADS-B out or FLARM out installed and activated.

From the principal perspective of the aircraft detection proposed in this document, the U-space airspace must be at least equal to the size of the WC volume defined in section III-B. Any nearby manned aircraft without ADS-B and FLARM are not allowed to enter the U-space airspace (WC volume), and the drone will thus remain well clear of those even if they are not detected inside the Detection volume.

This perspective does, however, not include a buffer for inaccuracies of position and height estimation. Further, it assumes that all nearby manned aircraft operate in compliance with regulations and the restrictions of the U-space airspace.

A mitigating factor to potential manned aircraft not in compliance with regulations or the restrictions of the U-space airspace is the visual observation mentioned in section III. To simplify this visual observation it is proposed that the U-space airspace is defined as larger than the WC volume to enable the observer to easily determine if an aircraft outside but near the WC volume is not in compliance with the U-space airspace restrictions:

- Height: As stated in section III-A the drone operation takes place near EKOH in an urban area where GA is not permitted to fly below 1000 ft $\approx$ 300 m AGL. The probability of having any aircraft without ADS-B or FLARM below 300 m AGL is therefore low and it is proposed that the height of the U-space airspace is set to 300 m AGL similar to the height of the Detection volume.
- Radius: It is proposed to set the lateral radius of the U-space airspace to 3000 m similar to the radius of the Detection volume. This will simplify the visual observation while at the same time minimize the effect of the U-space airspace restrictions imposed on manned aviation flying below 300 m AGL West of Odense city.

## IV. DETECT AND AVOID PLAN

The airspace around Odense HEMS is in the SORA defined as ARC-c. The SORA application uses tactical mitigation in the form of a DAA plan. The associated Tactical Mitigation Performance Requirements (TMPR) for ARC-c airspace must be at Medium level. Figure 5 illustrates the DAA plan which is detailed below:

1) **Detect:** Nearby aircraft are detected based on ADS-B squitter and/or FLARM broadcasts. Via a DAA service, the Pilot In Command (PIC)'s establishes an airspace situational awareness using a DAA tablet.
2) **Decide:** Based on the updated situational awareness the PIC decides an appropriate action to either continue the mission or safely land the drone. According to the SORA, the drone must yield to any manned aircraft in the U-space airspace meaning that the drone will have to land if an aircraft approaches. The decision is supported by Standard Operating Procedures (SOP) described in the SORA.
3) **Command:** The PIC commands the drone accordingly. The SORA-based application states that the drone is within VLOS distance to the PIC. The PIC carries a Ground Control Station (GCS) tablet which allows the PIC to update the programmed flight route and other parameters. The PIC also carries a handheld RC transmitter (TX) for direct control of the drone which is used to suspend the programmed flight and land the drone manually if needed.
4) **Execute:** The drone executes the command received via either the TX or the GCS.
5) **Feedback loop:** This loop is continuously updated based on feedback from the drone and updated situational awareness from the DAA tablet.

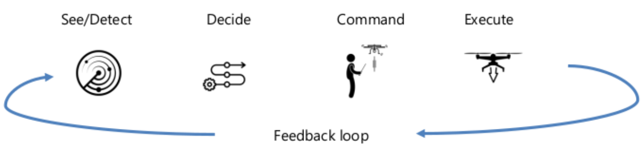


Fig. 5: *Detect And Avoid (DAA) plan for the drone operation.*

### A. Tactical Mitigation Performance Requirements (TMPR)

*1) Detection reliability and robustness:* According to the SORA TMPR requirements listed in figure 6 approximately 90% of all aircraft in the detection volume must be detected.

The SORA D.5.4. TMPR robustness (integrity and assurance) assignment states that: *The allowable loss of function* *and performance of the Tactical Mitigation System (TMS) is < 1 per 1000 Flight Hours ($10^{-3}$ Loss/FH). The rate is commensurate with a probable failure condition. These failure conditions are anticipated to occur one or more times during the entire operational life of each aircraft.*

| Medium (ARC-c) | Medium (ARC-c) | Medium (ARC-c) | Medium (ARC-c) |
|---|---|---|---|
| The expectation is for the applicant's DAA Plan to enable the operator to detect approximately 90 % of all aircraft in the detection volume[2]. To accomplish this, the applicant will have to rely on one or a combination of the following systems or services:<br>• Ground based DAA /RADAR<br>• FLARM [3/6]<br>• Pilot Aware [3/6]<br>• ADS-B In/ UAT In Receiver[6]<br>• ATC Separation Services[7]<br>• UTM/U-space Surveillance Service[4]<br>• UTM/U-space Early Conflict Detection and Resolution Service[4]<br>• Active communication with ATC and other airspace users[5].<br>The operator provides an assessment of the effectiveness of the detection tools/methods chosen. | All requirements of ARC-b and in addition:<br>1. The operator provides an assessment of the human/machine interface factors that may affect the remote pilot's ability to make a timely and appropriate decision.<br>2. The UAS operator provides an assessment of the effectiveness of the tools and methods utilised for the timely detection and avoidance of traffic.<br>In this context timely is defined as enabling the remote pilot to decide within 5 seconds after the indication of incoming traffic is provided.<br>The UAS operator provides an assessment of the failure rate or availability of any tool or service the UAS operator intends to use. | The latency of the whole command (C2) link, i.e. the time between the moment that the remote pilot gives the command and the airplane executes the command should not exceed 3 seconds. | The information is provided to the remote pilot with a latency and update rate that support the decision criteria. The applicant provides an assessment of the aggravated closure rates considering traffic that could reasonably be expected to operate in the area, traffic information update rate and latency, C2 Link latency, aircraft manoeuvrability and performance and sets the detection thresholds accordingly.<br>The following are suggested minimum criteria:<br>• Intruder and ownship vector data update rates: ≤ 3 seconds. |
| Detect | Decide | Command | Feedback loop |

Fig. 6: *TMPR requirements at Medium (ARC-c): This illustration from the SORA documentation lists TMPR requirements at Medium concerning detection reliability, update rate, and latency for "Detect", "Decide", "Command" and "Feedback loop". "Execute" as well as requirements at Low have not been included as they do not elaborate on those requirements.*

*2) Latency and update rate:* **Detect:** The latency introduced from ADS-B squitters and FLARM broadcasts to presenting this information to the PIC should be a maximum of 5 seconds. The SORA document states that the PIC must look at the display at least every 5 seconds. In total, the detection delay is thus determined to be a maximum of 10 seconds.

**Decide:** Figure 6 states that the Human-Machine Interface (HMI) must enable the PIC to decide an appropriate action within a maximum of 5 seconds after the information of incoming traffic is available.

**Command:** Figure 6 states that the C2 link latency should not exceed 3 seconds. The SORA-based application describes a VLOS flight where the PIC carries a handheld RC transmitter for direct control of the drone. RC transmitter update rates are typically around 50 Hz and the latency is significantly lower than 3 seconds. However during manual flight, the Command and Execute latencies are tightly coupled, and the command latency is here kept at maximum to allow some buffer.

**Execute:** According to the SORA the drone will fly a maximum of 25 m AGL and will be on the ground after a maximum of 10 seconds.

**Feedback loop:** Figure 6 suggests that aircraft vector data is updated at a rate of a maximum of 3 seconds.

The sum of maximum latencies is used to estimate the maximum time from an aircraft that has squittered or broadcasted its position inside the detection volume to the PIC that has safely landed the drone. This is listed in figure 7.

*3) Conclusion:* The SORA-based TMPR requirements to the TMS imposes the following requirements to this operation: Approximately 90% of all aircraft in the detection volume must be detected. The DAA detection technology must support an allowable loss of function and performance of less

| DAA latency | Seconds |
|---|---|
| Detect: | 10 |
| Decide: | 5 |
| Command: | 3 |
| Execute: | 10 |
| **Total:** | **28** |

Fig. 7: *Estimation of the maximum time from an aircraft has squittered or broadcasted its position to the PIC has safely landed the drone.*

than one instance per 1000 Flight Hours ($10^{-3}$ Loss/FH). The estimated maximum total time from an aircraft that has squittered or broadcasted its position to the PIC has safely landed the drone is 28 seconds. Aircraft vector data should be updated at a rate of a maximum of 3 seconds.

## V. DAA DETECTION TECHNOLOGY

In this section the technology used for detection of nearby manned aircraft is presented, and compliance with the TMPR requirements outlined in section IV-A.3 is discussed. The section is divided into an elaboration of TMPR requirements with regards to the DAA detection technology followed by a description and assessment of the principal components of the DAA architecture illustrated in figure 2.

### A. Allowable loss of function and performance

According to the TMPR requirements listed in section IV-A.3, the allowable loss of function and performance of the TMS is $10^{-3}$ Loss/FH.

In this operation, the TMS is the DAA technology architecture illustrated in figure 2 and the principal components thereof. The sum of probabilities of loss of function and performance for each component including their respective communication links must thus meet the below requirement:

$$\begin{matrix} P_{Loss:\,Receiver} + P_{Loss:\,SQL} + \\ P_{Loss:\,DAA} + P_{Loss:\,Tablet} \end{matrix} < 10^{-3} Loss/FH \quad (5)$$

The assessment of these probabilities are discussed in the below descriptions of the components using both quantitative and qualitative arguments. To simplify the argumentation, where applicable, the theoretical assumption is used that if continuous flights were conducted, then $10^{-3}$ Loss/FH approximates an operation of 42 days with a maximum of 1 loss of function or performance.

### B. ADS-B ground receiver

The ADS-B receiver location is 900 m from EKOH. As illustrated in figure 4 the Detection volume consists of mainly urban areas. The terrain is flat with a topographical relief of only a few meters. The antenna is installed at a height of approximately 8 m AGL. While this does not provide a clear line of sight to low-altitude aircraft in the entire detection volume, the tests in section VI documents that the reception capabilities by this setup is sufficient.

The ADS-B ground receiver hardware components: a radio receiver and an embedded computer are standard commercial grade. The power supply has a redundant battery backup supporting continued operation for at least 30 minutes during a power outage. There is no available documentation of reliability parameters such as Mean Time Between Failure (MTBF), however, the hardware has proven to be very reliable[3] and has not had any downtime during the aircraft detection reliability assessment period described in section VI-B.

The ADS-B ground receiver internet connection to the cloud-based SQL database described in section V-D has in Feb. 2021 been upgraded to facilitate a redundant fallback to a 4G modem connection.

The ADS-B ground receiver software is developed and maintained by SDU. It is in part based on open source software which has been improved and extended over the past years. During the period of recording historical data which is analyzed in section VI, the software exhibited an error that caused the detection to sometimes stop functioning after loss of the internet connection. The error has not occurred since the introduction of the redundant internet connection and software changes to fix the error.

The operational state and functionality of the ADS-B receiver is continuously monitored using an independent monitoring service. This service monitors the full functionality of the ADS-B receiver. If the latest aircraft squitter or broadcast sent to the cloud-based SQL database is more than 60 seconds old, an alert is sent via SMS to the PIC.

Based on the above description of the ADS-B ground receiver reliability and redundancy and on the results from the reliability assessment in section VI it is concluded that the detection rate using this receiver alone is > 90% and that $P_{Loss:\,Receiver} << 10^{-3} Loss/FH$.

### C. FLARM ground receiver

Aircrafts emitting FLARM are detected by two independent FLARM receivers:

- An Open Glider Network (OGN) based FLARM receiver is located at HCA Airport (EKOD) approximately 10 km from EKOH. The antenna is installed at a height of approximately 14 m AGL providing a clear line of sight in the lateral direction. This receiver provides OGN-based FLARM detections to the SQL database. This setup provides detailed data of FLARM-equipped aircraft operating around EKOH.
  The receiver has only been in operation for a short period of time though and it does not have a redundant power source or internet connection. It is therefore not considered a reliable source of FLARM detections.
- A PowerFLARM-based receiver is located 900 m from EKOH. The antenna is installed at a height of approximately 8 m AGL. This does not provide a clear line of sight to low-altitude aircraft in the entire detection volume. This is a recent installation and the FLARM detection capabilities are yet unknown. This receiver is thus not considered a reliable source of FLARM detections.

Overall the FLARM detection appears to be working well but is at this point not considered reliable due to pending reliability upgrades and the lack of statistical data to document reliability.

### D. Cloud-based SQL database

The SQL database runs on a virtual server hosted by HostEurope[4], a server hosting company with a Service Level Agreement (SLA) that guarantees a minimum 99.95% uptime based on monthly mean. The host testing company HOSTtest.de has measured 99.88% uptime. HostEurope has been used for hosting the database for more than 5 years.

The installed SQL server instance with no real-time redundancy is likely the weakest point of the SQL database, however, it has worked for years without any unscheduled downtime or other problems and did not contribute to detection loss during the reliability assessment conducted in section VI.

The operational state of the SQL database is continuously monitored using an independent monitoring service. This service performs a database request every minute which validates that the database has been updated with new data from either of the ground receivers. If this validation fails it is assumed that the database is not operational and an alert is sent via SMS to the PIC.

The measured uptime of the virtual server (99.88%) corresponds to a downtime of 10.5 hours per year which from a purely statistical perspective contradicts the requirement of 42 days continuous service stated in section V-A. It should be noted though that the vast majority of downtime is scheduled maintenance work by the hosting company which takes place during night time and is announced to customers days in advance. Based on this, the extra integrity provided by the independent monitoring service and the results from the reliability assessment in section VI it is concluded that: $P_{Loss:\,SQL} << 10^{-3} Loss/FH$.

### E. Cloud based DAA service

The Cloud based DAA service for this operation consists of a web page retrieving data from the SQL database via a Restful Web Service at a rate $\geq$ 1 Hz. The web page shows a map of the detected aircraft in the vicinity of EKOH. Below the map is a list of the aircraft including those not broadcasting their position and thus not shown on the map. The page may show additional DAA guidance on the map or above or below the list of aircraft.

The DAA service is hosted on a webserver running on the same virtual server as the SQL database. Like the SQL server instance, the webserver has no real-time redundancy but has worked for years without any unscheduled downtime. Should any downtime occur without warning, the PIC will become

[3]Measured February 22nd, 2021 the current ADS-B ground receiver computer has a registered uptime of 991 consecutive days without the need for a restart.

[4]https://hosteurope.com

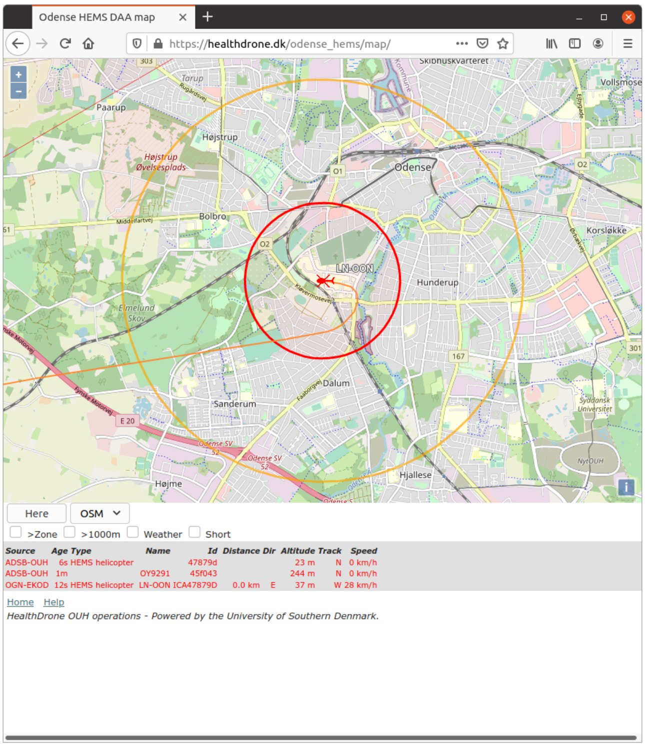


Fig. 8: *The map view is available via the cloud-based DAA service. The current view shows how the helicopter LN-OON (which as documented in figure 1 is the only HEMS helicopter not equipped with ADS-B) is listed as both a Mode S aircraft without position and is listed and shown on the map based on FLARM data. OY9291 is another aircraft in the vicinity that has only Mode S. The aircraft are all marked red because they report an altitude less than the height of the Detection Volume (300 m).*

aware just like if the DAA tablet looses connection to the internet (see section V-F). Based on this it is concluded that: $P_{Loss:\,DAA} << 10^{-3} Loss/FH$.

### F. DAA tablet

A tablet based on Android or IOS will be used to provide the PIC the situational awareness required for DAA. The tablet is considered the overall weakest component with regards to the $10^{-3}$ Loss/FH requirement. Considering a theoretical continuous operation for 42 days there is a risk that either the wireless internet connection or the tablet itself or the web browser running on the tablet experiences temporary problems. While this is not expected to happen often, the probability of loss of function or performance is likely > $10^{-3}$ Loss/FH. This will be mitigated by SOP and independent monitoring of the operational state:

Operational procedures defined in SOP's will specify requirements for using a dedicated tablet, proper charging before and during operation, restart and testing of the tablet before use, as well as a readily available backup tablet or phone running on a different cellular network. Also, the procedures will specify that the PIC continuously monitors if the web page is "frozen" indicated by error messages or lack of updated data.

The operational state of the web page running on the tablet is continuously monitored using an independent monitoring service. This service performs a request to the DAA service each minute which validates that the web page is continuously requesting updates from the DAA service. If this validation fails it is concluded that the DAA tablet is not operational and an alert is sent via SMS to the PIC. The SMS transmission time has experimentally been measured to be < 15 seconds which means that the PIC will be alerted < 75 seconds after a loss of function.

Based on the operational procedures to mitigate the risk of a DAA tablet fault and the extra integrity provided by the independent monitoring service it is concluded that: $P_{Loss:\,Tablet} << 10^{-3} Loss/FH$ under the condition that a probability of loss of function or performance where the PIC is alerted > $10^{-3}$/FH is acceptable. This is discussed further in section VII.

## VI. AIRCRAFT DETECTION RELIABILITY ASSESSMENT

In this section the reliability of the aircraft detection described in section III-A and V is assessed based on an analysis of historical recorded data from the ADS-B ground receiver. The purpose is to substantiate the arguments presented in section V concerning the reliability of the DAA architecture.

The recorded data is compared to a hand-written log of all EKOH HEMS activities. This hand-written log is maintained by the nurse at the OUH emergency room who is in direct contact with the HEMS helicopters via the SINE radio network. The following sections describe the method used and the results.

### A. Method

The recorded data is continuously saved in the SQL database. Each time an ADS-B squit is received from a ground receiver, a record is stored in the database[5]. The record contains among other information the time of reception by the ground receiver, the ADS-B ICAO ID, the geographical position, and altitude if available. The following procedure was used to process the data:

1) To exclude data of no interest a search was performed for ADS-B squitter records with altitude $\leq$ 1000 m. Since there is only data from one ADS-B ground receiver a lateral limitation was not necessary.
2) To establish a list of aircraft all found ADS-B squitter records containing a valid geographical position traversed. Each was tested if the geographical position (including altitude if available) was within the detection volume defined in section III-C using a radius of 3000 m and a height of 300 m AGL. If so the aircraft ICAO ID was added to the list of aircraft if not already listed.

[5] FLARM broadcasts are stored similarly to ADS-B data, but FLARM data is not included in the analysis as the FLARM ground receiver has only been connected to the SQL database since December 2020.

3) The NLA helicopter LN-OON listed in table 1 was manually added to the list of aircraft. It contains only a Mode S transponder so no positions are stored in the records.
4) For each aircraft in the aircraft list a search was made in the found ADS-B squitter records for records squittered by that aircraft. This subset was then sorted by the time of reception and traversed to identify individual flights. A period of 300 seconds without a squit triggers a new flight. Fligths with less than 15 seconds between the first and last squit were disregarded as stray receptions due to low reception quality, most likely from aircraft at too low altitudes.
5) Each flight was analysed further: If a recorded flight began outside and ended inside the detection cylinder it was marked "Arrival". Similarly, if a recorded flight began inside and ended outside the detection cylinder it was marked "Take-off". All other flights remaining outside or without any geographical positions were marked inconclusive by a "?".
6) For each flight marked "Arrival" the first squit after entering the detection volume and WC volume respectively was identified. Based on this the time inside the detection volume was calculated as $(time_{first\ squitin\ det.\ vol.} - time_{first\ squit\ in\ WC\ vol.})$. Similarly, the time before reaching the detection volume was calculated as $(time_{first\ squit\ with\ position} - time_{first\ squitin\ det.\ vol.})$.
7) All flights were sorted according to the timestamp of the first squit and the resulting flight log was formatted for comparison. The hand-written log was manually entered into a spreadsheet. A manual comparison of the two logs was conducted identifying all matching flights defined as a clear relation between the landing time and take-off time in the flight log and the corresponding entry in the spreadsheet.

### B. Results

The period of comparison is June 11th, 2020 to December 1st, 2020 decided by available comparable log material. This amounts to 179 days in total.

A total of 295 arrivals at EHOH were registered by comparing the ADS-B based flight log with the handwritten log. The average number of arrivals per day is thus 1.6.

The ADS-B ground receiver received and stored in the SQL database 290 of the 295 arrivals. The statistical detection is thus 98.3%.

Figure 9 shows a distribution of Odense HEMS arrivals with ADS-B based on the time from the first position received from the aircraft to the aircraft breaching the Well Clear volume.

Figure 12 shows the number of arrivals across the time of day. While there are flights at all times, the majority appear to be between 8 and 22 hours. As seen in figure 13 the arrivals do not exhibit any apparent pattern with regard to the days of the week.

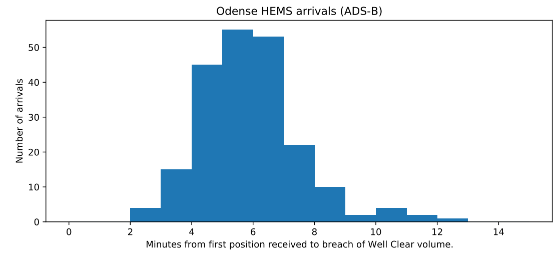


Fig. 9: *Distribution of Odense HEMS arrivals with ADS-B based on the time interval from the first position received from the aircraft to the aircraft breaching the Well Clear volume.*

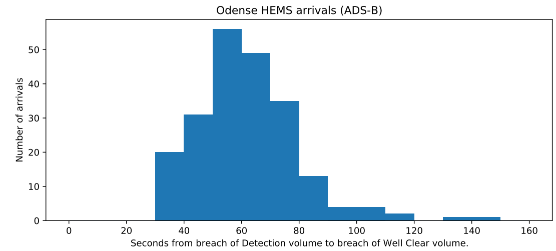


Fig. 10: *Distribution of Odense HEMS arrivals with ADS-B based on the time interval from the aircraft breaching the Detection volume to the aircraft breaching the Well Clear volume.*

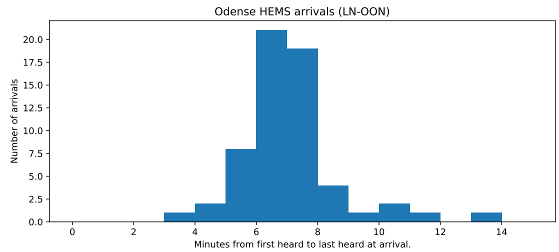


Fig. 11: .

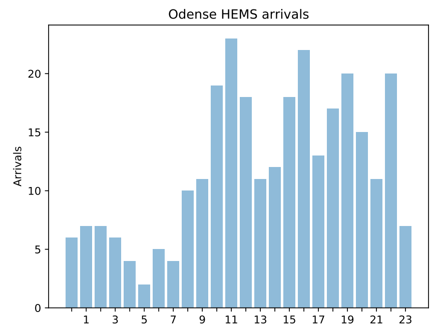


Fig. 12: *Distribution of Odense HEMS arrivals across the hours of the day.*

The list of aircraft and flights from the processed ADS-B squitter records is available for review at the link below. Clicking the individual flights presents the flight squitters on

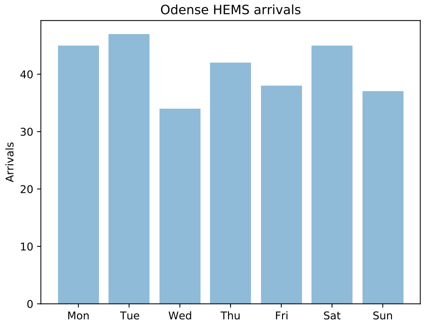


Fig. 13: *Distribution of Odense HEMS arrivals across the days of the week.*

a map (if positions were squittered) and an altitude plot (if altitude was squittered) as seen in figure 14. Zooming into the map enables clicking each ADS-B squit to view relevant information. Figure 1 lists the different HEMS helicopters that landed at EKOH during the period of the historically recorded data.

https://uaswork.org/project/healthdrone/odense_hems_sora

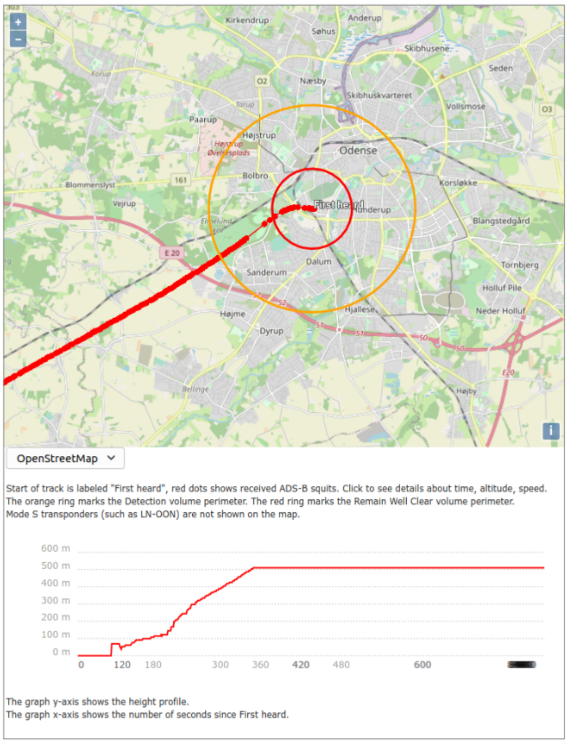


Fig. 14: *Map showing a flight based on the processed ADS-B squitter records.*

## C. Discussion

As described above 290 out of 295 arrivals were successfully retrieved and stored in the SQL database. Of the remaining 5: at least 4, and very likely all 5, were not detected due to a brief internet outage triggering the known ADS-B Ground receiver software error described in section V-B. This leads to the conclusion that while the statistical detection based on approximately 6 months of data is 98.3%, the future detection rate will likely be higher.

# VII. CONCLUSION

The concept for aircraft detection proposed in this document defines two airspace volumes shaped as cylinders around EKOH. The innermost Well Clear volume based on the ASTM standard F3442 defines the airspace where, if breached by a manned aircraft, the drone must have landed. The outermost Detection volume defines the airspace where, if breached by a manned aircraft in compliance with the U-space restrictions, the drone pilot must initiate a safe landing.

Aircraft detection is performed using a DAA architecture consisting of ADS-B and FLARM ground receivers that send detections to a SQL database. A DAA service reads the SQL database and presents a DAA view in a web browser on a tablet observed by PIC.

While the FLARM receivers provide valuable supplementary information, they are not considered a critical part of the DAA architecture and are thus not included in the TMPR compliance assessment.

The reliability of aircraft detection in the Detection volume was analysed by comparing historical ADS-B data recorded near EKOH during 6 months in 2020 to a log maintained by OUH. The analysis documents that 290 of 295 registered helicopter arrivals (98.3%) were successfully detected. 4 of the remaining 5 (1.4%) were not detected due to a known software error.

Only one HEMS helicopter (LN-OON) operates at EKOH without ADS-B. During the aircraft detection reliability assessment period, LN-OON was consistently detected via the ADS-B ground receiver using the Mode S reply.

The proposed concept for aircraft detection is compliant with all TMPR requirements on timing and latency. The historical ADS-B data documents that the aircraft detection reliability is on the order of 10 times better than the TMPR requirement of approximately 90%. TMPR specify a maximum loss of function and performance to $10^{-3}$ loss/FH. For the proposed concept of aircraft detection, this is a very challenging requirement to meet without full redundancy on all principal components, especially when a tablet with wireless communication is used to present DAA information to the PIC. Operational procedures and independent monitoring of system integrity are introduced to mitigate the risk and consequence of exceeding this requirement. These mitigations will not improve reliability per se but will ensure that a contingency is triggered and thus a safe landing is conducted. It should be noted that while the $10^{-3}$ loss/FH requirement is more challenging to comply with than the detection reliability for the proposed concept of aircraft detection, an undetected aircraft approaching EKOH likely poses a higher risk than a brief loss of detection functionality at the order of maximum 75 seconds.

The historical ADS-B data was used to define a distance from the Detection volume to the Well Clear volume which ensures adequate time for a safe landing. The Detect And Avoid plan documents that a maximum of 28 seconds are needed for detecting an aircraft and landing the drone. The historical ADS-B data documents that given the proposed size of the volumes 7% of the arrivals completed this distance in 30-40 seconds, 11% in 40-50 seconds and the remaining arrivals took longer time. It should be noted that all detected aircraft were detected at least 120 seconds before entering the Well Clear volume.

Based on the above it is concluded that the proposed concept for aircraft detection at EKOH is compliant with requirements defined in the EU regulation for drone operations in the specific category. This conclusion is based exclusively on the U-space based detection. It does thus not take into account the visual observation described in the concept of operation which adds an additional layer of safety.

## ACKNOWLEDGMENT

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