Unmanned Aircraft Systems are about to replace human pilots not only in dangerous, dull or tedious missions but generally where the human being is the limiting factor including size and economic issues. There is a wide range of applications for which UAVs have to be operated in non-segregated airspace in general and uncontrolled airspace in particular, regardless of civil, governmental or military usage, such as disaster and incident management, border patrol, or construction site prospection or inspection (/2/, /3/, /4/, /5/, /11/, /12/). However, all airspace users - manned or unmanned - shall adhere to the same standards, rules and laws. Depending on the airspace and its usage - in particular by anyone other than the UAS - functional and technical requirements for the operation of unmanned aerial vehicles can be derived aiming on the minimisation of hazards to third parties in the air or on the ground. A reliable aircraft collision avoidance system is the key enabler for providing access to unsegregated airspace. However, the procedures preventing mid air collision start well before any close encounter itself and cover in a holistic approach the topics airspace definition and usage, flight planning, provision of separation and finally sense and avoid.

This publication presents the approach and procedures adopted by Rheinmetall Defence Electronics and propose a method to determine the required level of safety depending on the actual airspace usage. Furthermore, the concept of the stand-alone ACAS system IRINA (Imminent Risk Indication & Navigation Advisor) for small UAS and General Aviation aircraft, under development by Rheinmetall Defence Electronics, will be outlined.

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Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACAS</td>
<td>Aircraft Collision Avoidance System</td>
</tr>
<tr>
<td>AP</td>
<td>AFIS personnel</td>
</tr>
<tr>
<td>ATC</td>
<td>Air Traffic Control, aka Separation Provider</td>
</tr>
<tr>
<td>CS</td>
<td>(Ground) Control Station, Remote Flight Deck</td>
</tr>
<tr>
<td>DL</td>
<td>Data link, minimum requirement C²</td>
</tr>
<tr>
<td>RPV</td>
<td>Remotely Piloted (air) Vehicle</td>
</tr>
<tr>
<td>UAS</td>
<td>Unmanned Aircraft System, consists of RPV, CS and DL</td>
</tr>
<tr>
<td>LOS</td>
<td>Line-Of-Sight</td>
</tr>
<tr>
<td>BLOS</td>
<td>Beyond Line-Of-Sight</td>
</tr>
</tbody>
</table>

Mid-Air Collision Avoidance Principles

Collision avoidance between aircraft flying is implemented by several methods on three different levels:

- on the strategic level by
  - airspace structure
  - semi circular rule / cruising altitudes
  - rules of way

- before mission execution (flight preparation phase) by
  - flight planning

- during mission execution by
  - ATC instructions (ground-based safety net)
  - separation provided by ATC in controlled airspace
  - flight information services (FIS)

- and in the conflict event by
  - alarms generated by technical devices (*sense*, e.g. TCAS; airborne safety net)
  - see
  - avoid

In this publication the focus is on proper flight preparation, conduct and technical devices.

At present certification of UAS in Germany is legally not possible except for military purposes (see /25/). According to §15a III LuftVO /24/ flying operation of a remotely piloted vehicle (RPV) beyond line-of-sight of the human pilot (operator) OR with a take-off-weight of more than 25kg is prohibited. However, §15a III LuftVO allows operation of RPV with a special permit to fly issued on behalf of §16 LuftVO in confined areas, such as segregated airspace or within aerodrome traffic. Although these regulations are adequate for research and development of UAS a continuous commercial application is almost impossible. Therefore the following views and statement reflect the technology and procedures that should be adopted based on current state and knowledge.

Mission Conduct

A typical mission conduct as outlined in Figure 1 starts with the mission preparation phase upon reception of the task order. A dispatcher performs the preparation of the mission in coordination with air traffic control (ATC) and - if applicable - AFIS personnel (AP) (“Flugleitung”). Thus all required information, operational procedures (ConOps) and permits will be available to continue with the actual planning for the mission. The subsequent execution of the mission takes place in coordination with ATC (and AP) again.

![Figure 1 - Mission conduct from task to execution](image_url)
Mission Preparation and Planning

The mission preparation is drafted in Figure 2. Upon reception and after an initial review of the task order in lieu of feasibility as well as availability of material and personnel, the dispatcher drafts a flight plan and declares the flight intention towards ATC and/or AFIS personnel. Depending on the equipment of the air vehicle (transponder, air traffic radio, lights etc.) and a forecast of air traffic and density a joint decision regarding the airspace categories to be used is to be taken. Based on cartographic information and other applicable data base material such as ICAO maps this decision is augmented by the allocation of physical airspace (cells) to be used.

Such data base material must enable the dispatcher to identify aerial NO-FLY zones, emergency landing or safe crash sites (uninhabited area), as well as ground based NO-FLY-OVER zones: Typically, UAS are prohibited from flying over densely populated area and crowds. Such areas are aggregated as ground based NO-FLY-OVER zones which extend into the airspace taking into account the current wind situation. It is obvious that this issue must be reviewed directly before and possibly during flight based on the most recent weather information available. In addition certain types of ground infrastructure like motorways, railways and power lines must be crossed with the least possible footprint, such as at right angles, and should in any case be followed by downwind, in order to avoid a conflict in the event of a parachute recovery.

In the next step joint concepts of operation must be defined and substantiated. Apart from aerodrome operations, these must cover:

- re-acquisition procedures to be applied in the event of a C²-data link loss, such as circling upwards, flying to a rendezvous site, or continuation of flight
- rendezvous procedures and sites, if applicable, and
- emergency procedures and emergency landing sites

The final data set should be updated with the most recent weather forecast for the scheduled flight. If required, a flight plan must be submitted.

The process for the compilation and conduct of a task order for Rheinmetall’s KZO military UAS - as deployed in Afghanistan - is presented in detail in [1].
The mission plan should be submitted to the separation provider as soon as possible given that the recipient has means to process the data.

**Mission Execution**

In contrast to manually flown aircraft a program-controlled "automatically" flying air vehicle (manned or unmanned) flies along the mission route. Therefore, any unintended deviation from the pre-programmed route is either due to meteorological phenomena, such as up or down wind, or other effects of wind that cannot be compensated by the performance of the air vehicle or the flight control system, or the consequence of a malfunction. Anyhow, the system's incapacity must be handled according to the abnormal or emergency procedures whichever applies.

The task of the human pilot operator is to monitor system parameters such as engine data, airspeed, control surfaces, data link and navigation, and adherence to the mission plan, but in particular to observe the surrounding air traffic.

Situational awareness can be greatly enhanced by tools that import and visualise targets and alerts provided by the ground based safety net e.g. in the ASTERIX format (/26/). Figure 4 is taken from such a visualisation tool named RIMscape (RIM = Regional Information Management /10/). In addition to a conventional AT controller display such a terminal should also include a simulator to visualize and (re-)play planned missions. The main terminal is in the UAS control station, but a similar terminal or application could be at the AT controller's workplace. This should enable the AT controller to assist the UAS pilot when flying with traffic.

![Figure 4 - Situative representation of the same traffic situation with safety envelopes and ICAO airspaces](image)

**Requirements Pertaining to Mid-Air Collision Avoidance**

The aircraft collision avoidance system must be compatible with current procedures (separation) and regulations (right of way) while being at least as reliable as a human pilot onboard a manned air vehicle according to the Equivalent-Level-of-Safety principle. In normal operation ACAS shall assist but not replace the (remote) pilot. However, in an abnormal situation with increased pilot workload or in particular during data link reduced Quality of Service (QoS) or complete loss, ACAS must be able to act autonomously and independently (regarding the control station). In addition, ACAS should include weather hazards.

The reliability of ACAS must be assessed in the same fashion as for any other critical part of aircraft equipment. The guiding principles are laid down in the AMCs for requirement 1309 of the applicable class of aircraft (cf. /19/ , /18/). According to AC-23-1309-1D, section 13c (/18/) the total acceptable risk of death, equaling the probability of a fatal accident, is "one per ten thousand flight hours or $1 \times 10^{-4}$ per flight hour for single-engine airplanes under 6,000 pounds".

The Lethal Area Method as outlined in /9/ takes the population density in the area of operation into account for the design of UAS the when assessing the probability of a catastrophic event, i.e. the risk of a victim on the ground due to an airplane crash. Following this approach, the ultimate risk of one or more victims due to a mid-air collision (MAC) depends on the usage ratio ("population density") within the airspace of regard. Thus, a direct relationship between ACAS reliability and (current) airspace usage can be established. The result can be applied in two ways:

1. establish the minimum reliability of a collision avoidance system for a given airspace usage ratio; this implies that an air vehicle equipped with a given ACAS may access a certain airspace or airspace cell
2. establish a maximum airspace usage ratio allowable for an airspace cell where an air vehicle equipped with a certain ACAS is (for whatever the reason) being operated.

There are several probabilistic methods for the calculation of mid-air collision risk (/13/, /14/, /15/), but most of them deal with medium to high density traffic situations. Unfortunately these methods are hardly applicable to airspace with a low traffic volume, which will be the domain for UAS. It is to be expected that research will provide methods for this application in the near future, like /17/, in particular as there is a demand for. However, the main problem is at present, that very little data are available to substantiate a model describing the population and traffic patterns in uncontrolled airspace. Furthermore some open questions and assumptions must be clarified /16/.

Meanwhile, basically as to substantiate common sense assumptions, the Airspace Usage Ratio (AUR) method is presented, that will be explained in its application for airspace with a low traffic volume. Figure 4 illustrates a typical airspace situation: Object 1 (green trajectory) travels at a higher speed than object 2 (blue) and 3 (red), and therefore requires a larger Aircraft Traffic Volume (ATV) within the time span of regard.

The term Near Mid-Air Collision (NMAC) in the context of this document is being applied to a close proximity of aircraft (airprox) that can be regarded as hazardous. In uncontrolled airspace G an NMAC is considered to take place, when the horizontal distance is less than 300ft.

The basic AUR method assumes that none of the objects takes actions to avoid a collision. The extended method takes the effectivenss of collision avoidance into account. In AUR method the objects arbitrarily populate an airspace cell. The cell is static with the dimensions $X \times Y \times Z$. The time span of regard $\Delta t$ is the time that the reference object (the RPV) needs to pass through the cell. For cruise condition without change of altitude this would be:

$$\Delta t = \sqrt{\frac{XY}{w_0}}$$

Furthermore, for each object the following parameters and characteristics are required:

- velocity of travel ($w_i$)
- cross section of the envelope perpendicular to the direction of travel (airprox area); dimensions ($b \times h$)
- cross section area of the physical airplane (collision area); dimensions ($span B_i \times height H_i$)

The scope is on the probability of a MAC or a NMAC event between the reference object and at least one of the other objects, but not between the other objects themselves. The calculation of the probability of the event follows the principles of the Lethal Area Method (/9/):

$$V = X \times Y \times Z \quad total \ \ volume \ of \ the \ cell$$

$$D = \frac{1}{V} \quad density \ of \ the \ population$$

$$F = \frac{A}{\text{number of potential fatalities}} \quad (passengers \ per \ object)$$

$$A^* = \frac{A}{V} \quad specific \ lethal \ volume$$

$$\Delta t = \sqrt{\frac{XY}{w_0}}$$

If, for the determination of the probability of an overlap of positions in 3D airspace as a prerequisite for a conflict

$$p = D \times A = \frac{1}{V} \times \frac{A}{V} = \frac{A^*}{V},$$

the Aircraft Traffic Volume ATV is being used as the lethal volume $A^*$ applicable for a NMAC

$$ATV^* = b \times h \times w_i$$

then the dimensions of the reference object are irrelevant, and the probability for an NMAC becomes:

$$p = \frac{1}{V} \times \frac{A^*}{V} = \frac{A^*}{V} = \frac{ATV^*}{V}.$$**

A similar approach can be made for the collision case, where the Aircraft Collision Volume

$$ACV^* = b \times h \times w_i$$

is being used for the lethal volume:

$$P = \frac{1}{V} \times \frac{ACV^*}{V} = \frac{ACV^*}{V} = \frac{ATV^*}{V}.$$**

This enables us to take the number of possible fatalities (T) into account and to relate the resulting probability to transport performance indicators such as mileage per passenger (in PAX-km) and passenger flight hours (PAX-hrs):

$$T = P \times F = \frac{1}{V} \times \frac{ACV^*}{V} \times F = \frac{ACV^*}{V} \times F$$

When relating the probability of a single fatality to the PAX-hrs then the results is independent of the size of the population.

Taking into account the effectiveness of collision avoidance, such as TCAS or See & Avoid possibly in conjunction with ACLs, by introducing the parameter $CA_i$, then the event probabilities become:

$$p = (1 - CA_i) \times p_i$$

$$P = (1 - CA_i) \times P_i$$

$$T = (1 - CA_i) \times T_i$$

As an example we shall consider a 30NM x 30NM cell in uncontrolled airspace G between ground level and 2,500ft AGL. The maximum airspeed allowed is 250 kt. The horizontal and vertical separation minima are 500ft. The time span of regard is approx. 1,600 seconds. For the other objects the following classes are chosen:

- Class A: large jet airliner (in transit)
- Class B: small commuter jet aircraft (in transit)
- Class C: small aircraft (part 23 or ultra light)
- Class D: glider (part 22)

With a population of 10 other objects the air traffic density is 0.0044 objects per 1 NM²-kft. Projected on the ground disregarding altitude the mean distance between two objects is 9.5NM. Table 1 lists the average parameters representative for the aforementioned classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>Object Type</th>
<th>Probability of a MAC (hr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>large jet airliner (in transit)</td>
<td>3.58 x 10⁻³</td>
</tr>
<tr>
<td>B</td>
<td>small commuter jet aircraft (in transit)</td>
<td>2.05 x 10⁻⁴</td>
</tr>
<tr>
<td>C</td>
<td>small aircraft (part 23 or ultra light)</td>
<td>3.58 x 10⁻⁴</td>
</tr>
<tr>
<td>D</td>
<td>glider (part 22)</td>
<td>3.58 x 10⁻⁴</td>
</tr>
</tbody>
</table>

At least one NMAC occurs with a probability of

- 1.96 x 10⁻³/hr w/o CA
- 1.71 x 10⁻³/hr w/ CA

i.e. 51 hrs between two NMACs without and 580 hrs with collision avoidance.

However, at least a single MAC happens with the more remote probabilities of

- 3.58 x 10⁻⁴/hr w/o CA
- 2.24 x 10⁻⁵/hr w/ CA

i.e. 28000 hrs between two MACs without and 450000 hrs with collision avoidance.
The probability of at least one fatality without collision avoidance is
\[1.4 \times 10^{-5}/hr (730 	ext{ hrs between two fatalities})\]
and related to transportation performance metrics:
\[6.2 \times 10^{-10}/\text{PAX-km} \quad \text{(one per 1.6} \times 10^{10} \text{ PAX-km)}\]
\[2.1 \times 10^{-10}/\text{PAX-hr} \quad \text{(one per 4.7} \times 10^{7} \text{ PAX-hrs).}\]

With collision avoidance the probability for at least one fatality becomes
\[1.1 \times 10^{-5}/hr (90015.9 	ext{ hrs between two fatalities})\]
and related to transportation performance metrics:
\[4.9 \times 10^{-10}/\text{PAX-km} \quad \text{(one per 2.0} \times 10^{10} \text{ PAX-km)}\]
\[1.7 \times 10^{-10}/\text{PAX-hr} \quad \text{(one per 5.8} \times 10^{8} \text{ PAX-hrs).}\]

In the same way the NMAC and MAC risks with collision avoidance have been calculated for other cell sizes and population densities (Table 3). The “magic numbers” typically being used to indicate that the associated risk is acceptable (9/18/, 19/) are colour coded:
- NMAC risk \( < 1 \times 10^{-6}/\text{h} \Rightarrow \text{ATV}^- < 1 \times 10^{-4}\)
- MAC risk \( < 1 \times 10^{-6}/\text{h} \Rightarrow \text{ACV}^- < 1 \times 10^{-3}\)

In these cases it may be assumed that a functional ACAS is not required for operating the (unmanned) reference aircraft in this cell under the given AUR conditions. With a typical population of 10 objects in 30\times30 \text{ NM}² and \text{ATV}^- < 10^{-5} and \text{ACV}^- < 10^{-3} the expected risks are less than
\[10^{-3}/\text{h} \quad \text{for a single NMAC}\]
\[10^{-5}/\text{h} \quad \text{for a single MAC.}\]

In comparison with Eq. (17) yields probabilities of less than \(10^{-4}\) and \(10^{-6}\) for NMAC and MAC respectively assuming a population of 8 objects (unclassified) in a 160NM \times60NM cell with 1.25NM envelope size (that translates into 500ft for a 20\times20 \text{NM}² cell). Now, the ACAS integrating all involved elements and objects, must bridge the gap between the acceptable risk and the actual (near) mid-air collision risk.

\[T_0 = 10^{-6}/\text{h} \quad \text{for an accident involving at least one fatality such as a mid-air collision}\]
\[p_0 = 10^{-7}/\text{h} \quad \text{for an incident such as a near mid-air collision}\]

The actual (near) mid-air collision risk.

\[\text{Table 1 - Example population and parameters (airspace G)}\]

<table>
<thead>
<tr>
<th>Class</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example</td>
<td>Airbus A320</td>
<td>Cessna C2</td>
<td>Cessna 182</td>
<td>DG LS4</td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td>1%</td>
<td>5%</td>
<td>40%</td>
<td>54%</td>
<td></td>
</tr>
<tr>
<td>Airspeed</td>
<td>250</td>
<td>250</td>
<td>150</td>
<td>60</td>
<td>kt</td>
</tr>
<tr>
<td>Height</td>
<td>1200</td>
<td>1400</td>
<td>1300</td>
<td>1300</td>
<td>m</td>
</tr>
<tr>
<td>Width</td>
<td>35</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>m</td>
</tr>
<tr>
<td>\text{PAX}^-</td>
<td>150</td>
<td>30%</td>
<td>19%</td>
<td>21%</td>
<td>1.5</td>
</tr>
<tr>
<td>\text{CA}^-</td>
<td>99%</td>
<td>99%</td>
<td>90%</td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td>\text{ATV}^-</td>
<td>0.5</td>
<td>2.3</td>
<td>11.0</td>
<td>5.9</td>
<td>1/h</td>
</tr>
<tr>
<td>\text{ACV}^-</td>
<td>19</td>
<td>14</td>
<td>35</td>
<td>12</td>
<td>\text{NM}²/\text{h}</td>
</tr>
<tr>
<td>\text{ACV}^-</td>
<td>8.3</td>
<td>6.2</td>
<td>15.6</td>
<td>5.7</td>
<td>1/h</td>
</tr>
</tbody>
</table>

\[\text{Table 2 - Summary of derived parameters (airspace G)}\]

The minimum reliability of an ACAS required to avoid a near mid-air collision in the aforementioned airspace and its usage would have to be
\[p_{\text{CA}} = T_0/T = 10^{-3}/\text{h} \quad \text{MAC}\]
\[p_{\text{CA}} = p_0/\rho = 10^{-7}/\text{h} \quad \text{NMAC}\]

which is similar to the reliability numbers known for conventional See & Avoid /3/.

\[\log_{10} \text{ATV}^- / h: \text{AirCraft Traffic Volume Density Ratio}\]

\[\log_{10} \text{ACV}^- / h: \text{AirCraft Collision Volume Density Ratio}\]

\[\log_{10} \text{P} / h: \text{Fatality Volume Density Ratio}\]

\[\text{Fk: fatalities / PAX-km}\]

\[\text{Fh: fatalities / PAX-hr (} < 1 \times 10^{-9}/\text{h)}\]
Rheinmetall's Imminent Risk Indicator and Navigation Advisor

In order to successfully perform collision avoidance the ACAS must implement the functions "see/sense" and "avoid". The mere risk indication, such as by RADAR, transponder based PCAS, FLARM or Stormscope, is insufficient if the remotely piloted air vehicle cannot assess the situation and perform evasive actions that comply with standard ICAO rules. For that purpose Rheinmetall is developing a simple, rule-based collision avoidance system that derives its information from conventional sources augmented by simple, short-range sectorized RADAR. Due to its basically advisory nature during normal operation which upgrades to autonomous operation only in the event of data link loss or imminent danger, the system is named Imminent Risk Indicator and Navigation Advisor (IRINA /21/). The system can be combined with Rheinmetall’s Multi-Mode/Multi-Target (MM/MT) tracker.

Assuming that the RPV is flying at 180kt, whereas the traffic is coming head on with (the maximum allowed) airspeed of 250kt, and that the minimum time to initiate and perform evasive actions is 10 secs, then the minimum detection range is about 1.2NM. The required RADAR detection range would be 1m² RCS in 1NM distance. Typically, the faster the civil aircraft (above 250kt in controlled airspace) the larger its RCS (e.g. up to 1000 m² for a large transport aircraft).

IRINA needs the distance \( d \) and the Doppler speed \( V_{rel} \) of the object, however the demands on accuracy regarding direction are quite low. Actually, sectorized data such as drafted in Figure 5 are sufficient and target tracking is not required.

![Figure 5 - IRINA sensor](image)

The sensor in Figure 5 comprises of four slightly overlapping sectors, two to the left (blue) and two to the right (red), covering a total field of view (FOV) of roughly 200° horizontal and 30° vertical in front of the air vehicle. The basic idea is to detect objects on the same flight level (FL) which means that, unless the sensor is stabilized w.r.t. the centre line, the vertical FOV is large enough to cover typical bank angles during turns. The overlap of 5° in average is mandatory to properly handle head on traffic, which means that each RADAR has a FOV of \((H \times V) 50^\circ \times 30^\circ\). The sampling rate for the final data is between 0.5 and 3 Hz depending on the speed of travel and could be adapted to the level of criticality, i.e. if a fast or close object is in view the update rate could be increased. In the simulations with different traffic scenarios a constant sampling rate of 1Hz has been found to be sufficient.

IRINA is implementing the basic ICAO rules of way (/28/ Annex 2: Rules of the Air, Chapter 3, Section 3.2), in particular Approaching head on, Converging and Over-taking. However, without additional information the exceptions for certain air vehicle types (airships, balloons, gliders, towed aircraft), as per 3.2.2.3, can only be implemented by the “evasive action” rule #3.

![Figure 6 - IRINA process](image)

In each (1Hz) cycle (Figure 6) a set of rules is evaluated for each detected object ("alert"). Each rule is associated with a risk level counter. If a rule is triggered by an alert the respective counter is incremented. The rules are based on an event horizon defined time \( t_E \) and distance \( d_E \). The estimated impact time is \( t_I = \frac{V_{rel}}{d} \), the time span that a manoeuvre shall be maintained (manoeuvre time) is \( t_M \). So far three key rules have been identified:

**Rule #1:** event horizon \( t_E = 60 \text{ secs} \) or \( 1 \text{ NM} \) (Figure 7)

- raise warning if an alert that potentially has right of way is within the first event horizon of the red sectors, then raise a warning.

**Rule #2:** event horizon \( t_E = 30 \text{ secs} \) or \( 3 \times \text{Radius of Turn} + 750 \text{ ft} \) (Figure 8)

- turn right if an alert that potentially has right of way is within the second event horizon of the red forward sector, then propose an avoiding turn to the right by inserting a (new) intermediate target waypoint positioned in a distance equivalent to \((\text{speed of travel} \times \text{impact time})\), but not more than 2,500ft in such a way that the air vehicles will turn to the right until the alert crosses over into any blue sector or disappears, and maintain this course long enough to let the object pass by.
**Rule #3:** event horizon \( t_E = 10 \text{ secs or 750 ft} \) (Figure 9)

If an alert is within the third event horizon, then initiate a vertical evasive action manoeuvre with maximum available vertical speed by setting the current target altitude to a value 150 ft below the current altitude (or above if the target altitude would be below safe minimum altitude) for the duration of the manoeuvre time interval; in addition (sub-clause 3.1), if there is an alert in the red sector, then initiate an avoiding turn to the left by inserting and activating a new intermediate waypoint positioned in a distance equivalent to \( (\text{speed of travel } \times \text{impact time} + \text{RK}) \) but not more than 1,500 ft at the new target altitude as per rule #2.

Avoiding turns are performed by adding a right or left hand offset to the current track equivalent to the horizontal FOV of one RADAR sector \( \times \text{HFOV} \) but not more than 90°.

Application of the IRINA principles has been simulated with six scenarios. One step is one second corresponding to a 1 Hz update rate.

**Scenario A:** no traffic (Figure 10)

The lower diagram shows the display, the upper diagram the traffic situation: blue circles are the planned waypoints (WP), the red \( x \) marks the current target WP, the green \( \triangleright \) shall be the reference aircraft. The standard radius of turn RK shall be 1,300 ft.

**Scenario B:** simple traffic (Figure 11)

In this scenario an object (red \( \bullet \) ) passes at the same altitude from right to left at a blunt angle (Figure 11a). The nature of this trajectory implies, that the object is to be given right of way. In Figure 11b rules #1 and #2 are activated as soon as the object is detected. Due to rule #2 an intermediate WP is inserted and turned clock-
wise until after 9 seconds the object has crossed over into the blue sector (Figure 11c). When reaching the switching distance (here RK) the WP is clear and the mission continued by resuming the original flight plan (Figure 11d).

In addition to scenario B another slower aircraft passes at the same altitude from right to left at a sharp angle (Figure 12a). The behaviour at the beginning is the same as in scenario B. Upon passing the first object the planned flight path crosses the trajectory of the second object. At step 27 object 2 is detected in the blue sector in (Figure 12b). Five seconds later the aircraft has turned so far that object 2 is detected in the red forward sector and an intermediate WP is inserted (Figure 12c). After reaching this WP the original flight plan is resumed (Figure 12d).
**Scenario D**: complex traffic with an offender (Figure 13)

In addition to scenario C a fast ascending aircraft is crossing from left to right at a sharp angle the nature of its trajectory not implying right of way (Figure 13a). The behaviour is initially the same as in scenario C. Upon clearing the second object rule #3 is triggered at step 43 by object 3 in the blue sector in a distance of about 2,200ft (8.8 secs to impact) and a dive is initiated without inserting a new WP (Figure 13b). Four seconds later rule #3 subclause 1 is triggered because object 3 crosses over into the red sector in front of the aircraft and therefore initiates an avoiding turn (Figure 13c). Another two seconds later the minimum distance of 675ft is reached (Figure 13d). Descent and avoiding turn are continued for 10 seconds until reaching the intermediate WP with the situation being cleared (Figure 13e).

**Scenario E**: avoiding a single quasi-stationary object (Figure 14)

In this scenario a quasi-stationary object, such as (tethered) balloon, is blocking the nominal flight path. Due to the overlap between red and blue sector the aircraft can avoid head on traffic.

Figure 13a - Scenario D: Setup

Figure 13b - Scenario D: Rule #3 is triggered by object 3 in the blue sector

Figure 13c - Scenario D: Rule #3.1 is triggered by object 3 in the red sector

Figure 13d - Scenario D: Minimum distance, rule #3 active

Figure 13e - Scenario D: Resume flight plan execution

Figure 14 - Scenario E: Avoiding a quasi-stationary object head on
Conclusions and Recommendations

In this paper approaches for the procedural and technological integration of unmanned aircraft systems into non segregated airspace have been outlined. With the AUR method a relationship between capabilities of a given aircraft collision avoidance system and given airspace usage has been developed. An apparatus for an aircraft collision avoidance system scalable to the size and speed of the aircraft has been presented that may be useful for manned aircraft as well.

The next step to bring ACAS into service in uncontrolled airspace must be to assess statistical data as a basis for the determination of airspace usage per cell.

When allowing UAS operations in unsegregated airspace only one or two flight levels (FL) should be granted for UAS usage. Such FLs should be unconventional such as FL13 rather than FL10. If not exclusively reserved for UAS operations manned aircraft pilots should be more alert to outside (UAS) traffic than normal when flying on or crossing these FLs and switch on their transponders.

It should be considered to perform UAS operations preferably at night or over open water, because of the mandatory submission of flight plans when flying under these conditions or over such areas. In this case ATC can prefer such UAS traffic.

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