# Detect & Avoid
# Design, Test & Evaluation Guideline

## Appendix I
## Key Terms and Concepts

Version 1.0

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RevAero UTM Demonstration 2023

RevAero Flight Trials 2022

RevAero; a Defence Jobs QLD delegate at Avalon Airshow 2022

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# Development and Approvals

| Developed | Approved |
|---|---|
| Mr Tom Putland<br>Senior Research, Regulation, and Product Development Engineer<br>Revolution Aerospace | Dr Terry Martin<br>CEO and Co-founder<br>Revolution Aerospace<br><br>Mr Kristian Cruickshank<br>CTO and Co-founder<br>Revolution Aerospace |

## Version History

| Version | Release Date | Description |
|---|---|---|
| 1.0 | 31 January 2024 | Initial Release |
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## Contributions

The Guideline has drawn on many different sources of DAA research, development, standardisation, and guidance material across the globe including information produced by the following organisations:

- RTCA
- ASTM
- JARUS
- FAA
- MIT
- EASA

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## Attribution

When attributing this publication (and any material sourced from it), the following wording should be used:

### References:

[1] T. Putland, A. McLaren, T. Martin, & K. Cruickshank, "*Detect & Avoid Design, Test & Evaluation Guideline-Appendix I,*" Revolution Aerospace, Brisbane, Queensland, Australia, January 2024.

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## Disclaimer

# Contents

# 1 Introduction

Selected key terms and concepts used throughout this Guideline are briefly expanded upon in this Appendix to assist readers in their understanding. These key terms and concepts are split into four categories:

- DAA Guideline Terms, and Concepts: Those terms and concepts related to Detect and Avoid and those used in this guideline that require some brief explanation.
- Airspace Rules, Terms, and Concepts: The international aviation community has, over the last century, developed terminology and concepts to harmonise language for airspace users. This section details those terms relevant to this guideline.
- Hazard and Risk Terms, and Concepts: Those terms and concepts related to safety risk management, focusing on higher-level concepts that are used to contextualise risk assessments to aviation (i.e. setting standards and acceptability criteria, or modelling risk for the purposes of understanding the effect of acceptability criteria).
- Safety Assurance and Safety Risk Management Terms and Concepts: Those terms and concepts associated with assigning an acceptable level of rigour to manage identified hazards and risks.

## 1.1 DAA Guideline Terms and Concepts

- Detect and Avoid/Sense and Avoid: A high level term describing the concept of a UAS (or other aircraft) using technology to undertake separation (of some types) and collision avoidance activities. Called both detect and avoid (DAA) and sense and avoid (SAA) dependent on jurisdiction and convention, this guideline will utilise the phrase detect and avoid or DAA.
- Operational Services and Environment Description (OSED) Assumptions: Under this Guideline, an OSED describes the concept of operations expected under nominal and off-nominal operations for a DAA-equipped UAS operating in Class G airspace. It also describes the operational context, and identifies any assumptions made when defining the scope of the Systems and Operations relevant to the Guideline. Appendix A to this Guideline is the OSED for the intended DAA systems that comply with this Guideline.
- Avoid Air Traffic (AAT) Function: The key aircraft-level function that enables a UAS to Detect and Avoid traffic. Specifically, this refers to a function, i.e. some abstract algorithm/process, enacted by systems, to undertake DAA.
- DAA System: The physical systems not inherently installed on a UAS needed to fully enable the AAT function. For example, a UAS already includes the necessary systems to navigate and control the UA's flight path, however it is likely that a DAA system does not inherently contain the sensors and logic to detect, track, and decide what avoidance manoeuvres to make. The delineation between DAA system and UAS is dependent on the characteristics of the specific UAS and DAA system being used.

- Uncrewed Aircraft System (UAS): A UAS consists of the uncrewed aircraft (UA), and all supporting systems necessary for the operation. The combination of both is the UAS. Specifically for this guideline, the UAS is specifically the inherent, extant systems of the UAS that can undertake parts of the AAT function, due to these systems being necessary to safely operate the UAS without DAA functionality (i.e. flight path control, navigation systems, power systems). This does not include the additional systems necessary to completely undertake the AAT function.
- DAA Equipped UA: A UAS with a DAA system installed.
- Ownship: Refers specifically to the UA undertaking the AAT function during an encounter.
- Intruder(s): The "other" aircraft involved in an encounter that is/are not the Ownship.
- False Alert: An avoidance alert and/or guidance issued by the AAT function that does not correlate to an actual intruder. Can result in unnecessary manoeuvres.
- Time of closest approach: A time parameter that describes the time until the closest point of approach, given the current positions and dynamics of two aircraft under consideration. A negative time of closest approach indicates that the closest point of approach was in the past (i.e. the aircraft are diverging). For non-accelerating intruders, the time of closest approach is:

$$t_{cpa} = \frac{-(\vec{s}_{rel} \cdot \vec{v}_{rel})}{\|\vec{v}_{rel}\|^2}$$

## 1.2 Airspace Rules, Terms, and Concepts

- National Airspace System: A generic term that describes the extant state (the structures, rules, requirements, users) of airspace in a nation.
- Right of Way/Give Way: A prioritisation scheme used in conventional aviation to define the required interactions between two encountering aircraft, based on the concept of one of the aircraft having "right of way". This allows predictability of airspace encounters for both encountering aircraft. Section 3.2.2 of Annex 2 [1] to the Convention on International Aviation contains these right of way concepts replicated in most nations' regulatory rules.
- See and Avoid: Under the Australian legal framework, it is a requirement of all crewed aircraft to "see and avoid" other aircraft (Regulation 91.325 of the Civil Aviation Safety Regulations 1998 (Cth.)). This rule provides the basic criteria from which to apply right of way/give way rules. See and avoid is considered a final barrier to an airspace collision, within which a pilot which sees a potential threat aircraft attempts to avoid the intruder using the right of way rules (or in the case where there is no other option, the best manoeuvre possible).
- Keep Clear/Remain Clear: As an additional series of criteria for defining the right of way under Subdivision 91.D.4.4 of the Civil Aviation Safety Regulations 1998

(Cth.), airspace users giving way need to "keep clear" of the aircraft with the right of way. In the context of the DAA guideline, we use the phrase "remain well clear" as a way to define a boundary of where the UA has kept clear of an intruder. This allows the quantitative delineation between the processes of separation provision and collision avoidance. In conventional aviation this is not defined mathematically, instead this is left for pilots to interpret qualitatively.

- Mid Air Collision (MAC): An event where two (or more) aircraft collide during flight. In order for a MAC to occur, a Loss of Well Clear needs to occur, then a Near Mid Air Collision, and then finally, a MAC.
- Near Mid Air Collision (NMAC): An event where two aircraft get relatively close to one another that may lead to a MAC. Generally considered a high-risk situation where many risk controls have failed. More detail specific to this guideline is provided in Section 2.5.3 of Appendix E.
- Loss of Well Clear (LoWC): An event which defines the boundary between the qualitative "well clear" and "not well clear". This is quantitively defined for use by DAA systems in 2.5.3 of Appendix E to this Guideline.
- Separation Provision: Under 2.7.13 of ICAO doc 9854 [2], separation provision is "the tactical process of keeping aircraft away from hazards by at least the appropriate separation minima". For the purposes of this Guideline, the "appropriate separation minima" is the Well Clear Boundary. Tactical Mitigations used to actively avoid a well clear will be considered part of "Separation Provision" process. Note that there are many other forms of separation provision in addition to the DAA system remaining well clear (i.e. ANSP separation services), although the definition of separation minima may change for each of these services.
- Collision Avoidance: Under 2.7.31 of ICAO doc 9854 [2], collision avoidance is "not a part of separation provision" and "must activate when the separation mode has been compromised". In the context of this Guideline, the tactical mitigations used to prevent an NMAC, given that a loss of well clear has (or will, despite mitigations) happen are considered "Collision Avoidance" processes.
- Tactical Mitigations (JARUS – Air Risk): Under the JARUS Air Risk Model, tactical mitigations are those mitigations that are applied after take-off and require a feedback loop to monitor the effectiveness of the mitigation. For the purposes of this guideline, Tactical Mitigations include both Separation Provision and Collision Avoidance.
- Cooperative Traffic: A term describing traffic that are providing some sort of planned and standardised data such that other aircraft can reliably receive information (usually track information) to use as part of the Avoid Air Traffic function.
- Coordinating Traffic: A term describing traffic that, in coordination with the Ownship, provide enough separation and collision avoidance capability to meet an acceptable level of safety. This should be contrasted with non-coordinating

traffic, where the responsibility of providing separation and collision avoidance is the responsibility of both parties solely.

## 1.3 Risk Terms, and Concepts

- Target Levels of Safety (TLOS): A TLOS is a quantitative performance metric used as a quantitatively equivalent value to the qualitative statement "acceptable level of safety". A TLOS allows for the translation of qualitative metrics into quantitative metrics and subsequent engineering and technical risk management of hazards.
- Hazard Severity Classification Model: Risk exists along a continuum of probability and severity. A risk assessment relies on a series of thresholds to demarcate the severity (or consequence) of hazards. The demarcation between severity classifications for a given context is the hazard severity classification model for that specific context.
- Hazard Probability/Assurance Classification Model: Accompanying the Hazard Severity Classification Model, a hazard probability classification model defines maximum allowable probabilities for each severity level, defining the maximum permissible rate of occurrence for a hazard, given the level of severity.
- Probabilistic Collision Risk Model (PCRM): The PCRM is central to the safety case argument for DAA and the derived performance requirements. It defines the likelihood of conditional events that lead to a MAC, and their relative effects on the TLOS. This is necessary to help understand the causal chain of events that could result in a MAC.
- Risk Ratio: A Risk Ratio is a quantitative measure of the performance of a DAA system. The objective of the Risk Ratio is to set a baseline for the required effectiveness of the DAA System compared to an identical but unmitigated situation where the DAA system is not present. Specifically, within the context of DAA, a useful delineation of "System" and "Logic" risk ratios is utilised.
    - System Risk Ratio: The risk ratio that includes all possible effects on the capability of the AAT Function (i.e. system failure, development errors, adverse environment) to detect and avoid air traffic. Note that the system risk ratio also includes the effect of the function and systems working entirely as expected but does not manage to detect and avoid an intruder.
    - Logic Risk Ratio: The risk ratio specific to when the system is functioning as intended, within the intended operating environment. This can be thought of as a ratio specific to a subset of conditions considered in the system risk ratio.

## 1.4 Safety Assurance and Safety Risk Management Terms and Concepts

- Protective Functions and External Events: Within the context of system safety engineering, the AAT function can be considered a "Protective Function" (as per Section 5.2.4 of ARP4754A [3]), with an external event of "aircraft on a collision

course". This categorisation of the AAT function provides a solid foundation for which to reduce development assurance and reliability requirements compared to conventional aviation requirements. This is further discussed in detail in Appendix F to this Guideline.

- Operational Hazard Analysis (OHA): An operational hazard analysis is a hazard analysis process that allows for the identification of operational hazards for the purposes of identifying appropriate risk controls to prevent the occurrence of the identified hazards, based on the severity of each event. A detailed OHA for this guideline can be found in Appendix F.
- Functional Hazard Analysis (FHA): An engineering hazard analysis process, focused on evaluating aircraft functions and their severity, such that appropriate engineering verification and validation processes can be undertaken to ensure risk controls and mitigations are acceptable. A detailed FHA for this guideline can be found in Appendix F.
- Verification and Validation: The process of ensuring that functions and systems both meet their specified requirements (Verification), and that the specified requirements meet their intended outcome (Validation).
- Functions and Systems: From a system engineering perspective, it is important to differentiate functions and systems. Functions are abstract concepts that describe an intended or desired algorithm that affects provides some desired outcome (i.e. flight path control). Systems are the physical embodiment of these functions, providing the necessary software and hardware that allow functions to actually work in the real world. Functions can be embodied by multiple systems, and systems can be used across multiple functions.

# 2 References

[1] Annex 2 to the Convention on International Civil Aviation - Rules of the Air, 10th ed., Montreal: International Civil Aviation Organization, 2005.

[2] Global Air Traffic Management Operational Concept, 1st ed., Montreal: International Civil Aviation Organization, 2005.

[3] ARP 4754A - Guidelines for Development of Civil Aircraft Systems, SAE Aerospace, 2010.