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RESEARCH PROJECT EASA.2020.C04

Vulnerability of manned aircraft to drone strikes

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Collision envelope specification and justification report (D2.1)

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Executive Summary

Problem area

Recent technological developments have led to the emergence of affordable and increasingly capable remotely-piloted aircraft or 'drones' within the global marketplace. These drones present significant opportunities to consumers, businesses, research organisations and governments but – through mis-use or malfunction – they also represent a potential threat to the safety of manned aviation.

This study aims to: deepen the understanding — through experimental testing and simulation techniques — regarding the effects of a potential collision of drones in the consumer / prosumer market segment ('threat') with manned aircraft ('target'); identify drone design strategies aimed at containing the risk that drone-aircraft collision may induce on the aircraft and its occupants, and; draft design requirements and test standards for future drones to be put on the market within the EU open category (CE marking) addressing the containment of the above risk. The programme of work, undertaken by QinetiQ, is spilt into nine tasks, relating to research planning, development and validation, exploitation and mitigation, whilst remaining engaged with Stakeholders.

Description of work

The work presented here represents the output from 'Task 2' which includes definition of collision scenarios and parameters that are relevant to the aims of the programme. This includes definition of the drones involved, example aircraft to represent the Certification Specifications of interest, and prioritised impact zones on each category of aircraft. Collision speeds are also evaluated, plus the relative orientations of the drone and manned aircraft at the point of impact.

Contents

Abbreviations

Acronym	Description
ADS-B	Automatic Dependent Surveillance-Broadcast
BMVI	Federal Ministry of Transport and Digital Infrastructure
CAA	(UK) Civil Aviation Authority
DWD	Deutscher Wetterdienst
EASA	European Union Aviation Safety Agency
FAA	(USA) Federal Aviation Authority
GfL	Gesellschaft für Luftverkehrsforschung mbH
GNSS	Global Navigation Satellite System
HEC	Hazard Effect Classification
ICAO	International Civil Aviation Organization
IEA	Impact Effect Assessment
MSL	Mean Sea Level
MTOW	Maximum Take-Off Weight
NA	Not Applicable
OSN	Open Sky Network
RPAS	Remotely Piloted Air Systems
SERA	Standardised European Rules of the Air

1. Introduction

1.1 Background

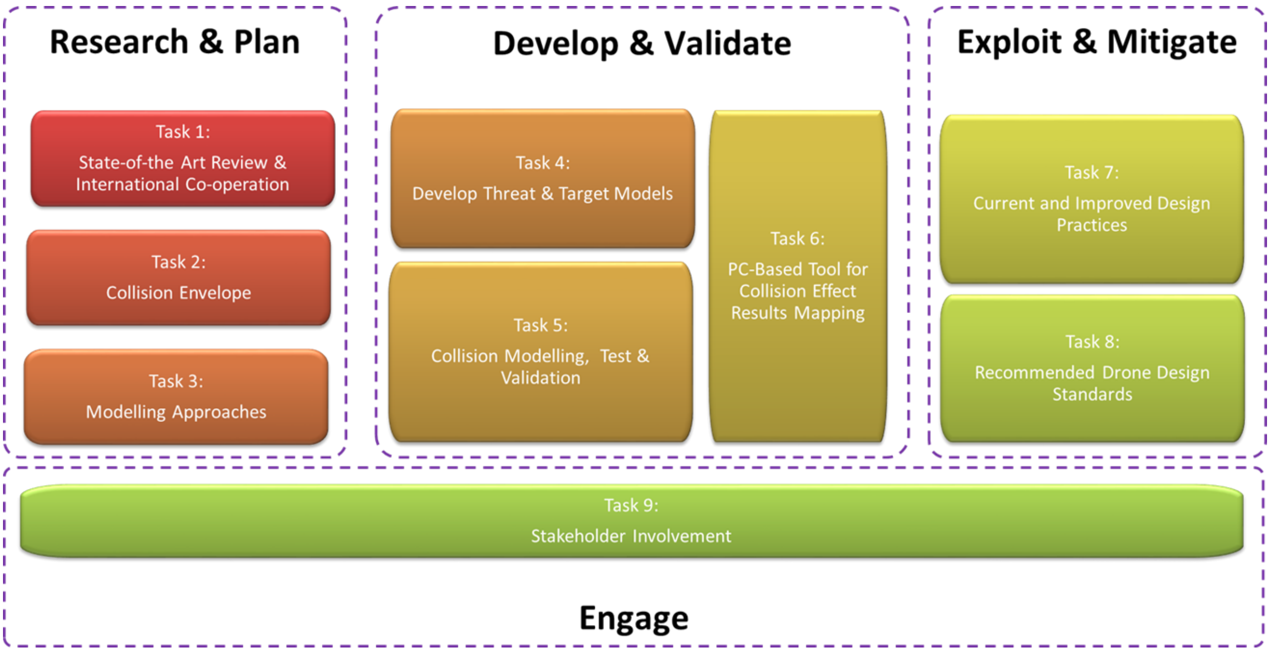
Recent technological developments have led to the emergence of affordable and increasingly capable remotely-piloted aircraft or 'drones' within the global marketplace. These drones present significant opportunities to consumers, businesses, research organisations and governments but – if used improperly – they also represent a potential threat to the safety of manned aviation.

EASA has been active in monitoring the risks and threats associated with mid-air drone collisions, including forming a Drone Collision Task Force in 2016 to identify research requirements with input from a broad group of industry stakeholders. Recommendations from the Task Force report [1] (references are summarised at the end of this document) were developed further by QinetiQ in EASA's 2017 'Research project on collision with drones' (EASA.2016.LVP.50); In this short programme, methodologies were defined and an outline programme of research was proposed to assess the severity of collisions between a broad range of drone configurations and manned aircraft types [2,3].

The current programme, 'Vulnerability of Manned Aircraft to Drone Strikes' (EASA.2020.C04) [4] is funded via the European Commission's 'Horizon 2020' research framework and has been contracted to QinetiQ. The programme is based upon the previous research and has three main objectives:

- to deepen the understanding — through experimental testing and simulation techniques — regarding the effects of a potential collision of drones in the consumer / prosumer market segment ('threat') with manned aircraft ('target');
- to identify drone design strategies aimed at containing the risk that drone-aircraft collision may induce on the aircraft and its occupants, and;
- to draft design requirements and test standards for future drones to be put on the market within the EU open category (CE marking) addressing the containment of the above risk.

The programme of work [5] is split into nine tasks, as depicted in Figure 1-1.



➡ **Figure 1-1** Programme structure

1.2 Scope of report

This report represents deliverable 'D2.1' of the Vulnerability of Manned Aircraft to Drone Strikes research programme (EASA.2020.C04). The work presented here represents the output from 'Task 2' which includes definition of collision scenarios and associated parameters that are relevant to the aims of the programme.

This includes definition of the drones selected (Section 2), example aircraft to represent the Certification Specifications of interest (Section 3), and prioritised impact zones on each type of aircraft (Section 4). Collision speeds are also evaluated (Section 5), plus the relative orientations of the drone and manned aircraft at the point of impact (Section 6).

2. Task 2.1: Drone Threat Configuration

2.1 Introduction to Task 2.1

The purpose of Task 2.1 is to select a range of drones that will be used for collision assessments, later in this programme. The aim was to identify configurations that are representative of the current (and anticipated near-future) consumer/prosumer drone market, in order to provide relevant collision severity data to support the drafting of future drone design standards (Task 8).

This has been achieved with input and support from the programme's Stakeholder Group, which includes major drone and aircraft manufacturers. Members of the Stakeholder Group are defined in Appendix A.

2.2 Drone Types

There are many examples of distinct drone configurations within the consumer/prosumer market, though only a few could be considered to be mass-market, with others having a smaller market share or being niche/specialist products.

An initial review of potential configurations was conducted as part of QinetiQ's 2016 scoping study (EASA.2016.C25) [2,3], which included recommendations for which drones should be included in a collision study. The philosophy behind the down-selection process was to focus the study on impact scenarios that were perceived to have the greatest collective probability of occurrence, the likelihood of causing damage and severity of outcome.

Figure 2-1, from QinetiQ's scoping study, illustrates some of the configuration types that represent sub-classes of drone.

Configurations within these sub-classes are wide-ranging and vary greatly in their size, mass, flight speed, range, altitude capability, structural robustness and ease of deployment. However, the study recommended the following two sub-classes as priority cases when considering drone threats:

- Quadcopters – Priority 1 (highlighted in red in Figure 2-1).
- Fixed wing (electric, propeller-driven) – Priority 2 (highlighted in orange in Figure 2-1).

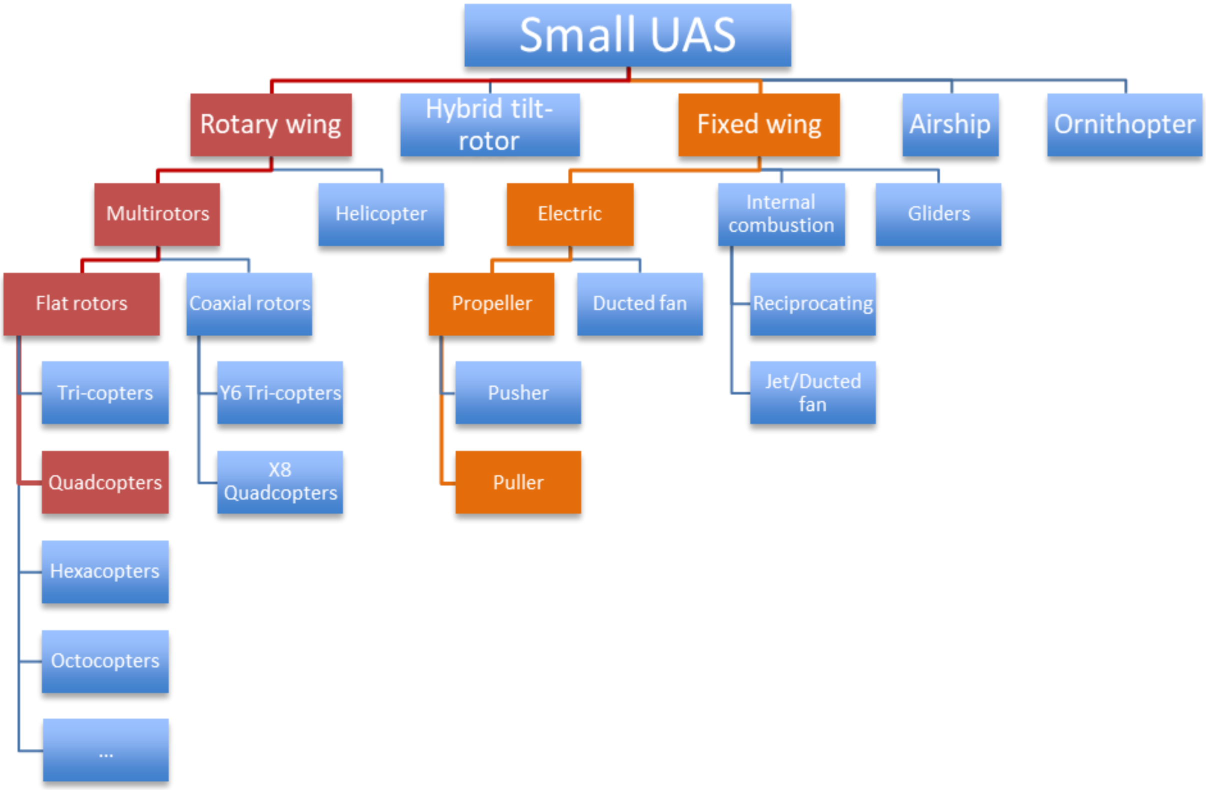


Figure 2-1 Example sub-classes of small drones

2.2.1 Quadcopters

The rapid emergence of multi-rotor drones over recent years has been greatly aided by advancements in motor, battery, flight controller, sensor and camera technologies. This class of drone can take off from and land in confined spaces and, due to increasingly sophisticated control systems, are relatively easy to control. These characteristics, coupled with their low price-point, have led to increasingly large numbers of people adopting the technology and utilising the airspace. Furthermore, because of their ease of deployment, users are no longer constrained to operating from traditional, organised flying clubs.

Quadcopters are currently the most popular class of multi-rotor and would therefore be an appropriate configuration to represent a large proportion of the emerging drone market. For a given mass class, Quadcopters are also considered to represent a more severe impact threat than drones with more rotors because:

- They require more powerful (and heavier) motors than Hexacopters/Octocopters so in the event of a collision, more energy is directed to a single impact site;
- They require smaller airframes for a given propeller diameter, thereby increasing their effective density, and;
- Impacts may occur in-line with two motors and the central fuselage, thereby resulting in multiple impacts at the same location.

It could be argued that tri-copters and coaxial configurations may present a more significant threat because they either have higher-power motors (tri-copters) or pairs of co-located motors (coaxial). However, at the time of writing, these are niche products and do not represent the majority of drones being produced or flown.

2.2.2 Fixed wing drone with electrically-driven propellers

Fixed wing model aircraft are not a new phenomenon and have been operated by hobbyists for over half a century. Traditionally, these tended to be configured either as gliders or were powered by internal combustion engines. However, some of the same technological advances that led to the emergence of practical multi-rotor aircraft have also benefitted fixed wing configurations. Consequently electrically-powered fixed wing drones are increasingly common due to their affordability, performance, flexibility and minimal requirements for set-up/maintenance.

Larger fixed wing drones require access to appropriate airstrips and so are commonly operated within organised clubs, but low-cost electrically-driven fixed wing drones that can be hand-launched are also widely available.

The airframes of fixed wing drones are typically low density, well-distributed and frangible. However, the motors (with spinners) and batteries of larger models may represent a significant threat in the event of an impact, particularly given their relatively high flight speeds compared to large multirotor drones.

Fixed wing drones are also more challenging to fly than multi-rotors and have greater range capabilities. This may present a greater risk of inexperienced pilots losing sight/control of their drone with an associated risk of unintentional deviation into manned aircraft airspace.

Although fixed wing drones may not be as prevalent as multirotor drones, the perceived potential for long-distance run-away conditions and possible levels of damage suggest that they should also be assessed through this study.

Different styles of fixed wing drones are available, though the majority of consumer/prosumer systems are either based upon conventional aircraft designs (discrete fuselage with wings and empennage) or ‘flying wing’ configurations.

2.2.3 Other drone configurations

The other drones identified in Figure 2-1 were not prioritised for the following reasons:

- Model Helicopters: Although some model helicopter systems are relatively large with powerful engines, they are not believed to be in common usage. Furthermore, because larger models are relatively complex (and expensive) machines that are harder to control, they are more likely to be piloted by trained operators. On this basis, it is considered less likely that large model helicopters would be flown inappropriately at high altitudes or at extended range from the operator.
- Hybrid tilt-rotor drones: Hybrid, vertical take-off and landing (VTOL) configurations are emerging, which provide users with the benefits of multi-rotors during take-off and landing, and the speed, range and endurance of a fixed wing configuration. However, these products are more-aligned to commercial usage such as aerial surveying and surveillance so although there are examples of VTOL toy drones, they are not a mainstream configuration.
- Reciprocating internal combustion engine drones: Whilst the engines used may pose a significant threat due to their solid construction and relatively high mass, most fixed wing drones now use electric propulsion systems. Internal combustion drones are still operated from organised clubs but this is assumed to represent a minority.
- Gas turbine drones: Although these enable drones to be flown at very high speeds, they are not in common usage.
- Gliders: Model gliders are assumed to be highly frangible with no significant high-density or damaging systems.

- Airships: Model airships are not in common usage and are unlikely to pose a significant impact threat, except by obscuration of vision or possibly blocking intakes.
- Ornithopters: Ornithopter drones are not in common usage.

2.2.4 EASA Open Category

EASA have set out requirements for drones within the Open Category, which defines different operational restrictions depending on both the drone and the operator.

Table 2-1 details each of the subcategories within the Open Category and the respective operational restrictions/operator requirements. Further information on the specific requirements of each class are published on EASA's website and are summarised in an 'Easy Access' reference guide [7].

UAS		Operation		Drone Operator/pilot		
Class	MTOM	Subcategory	Operational restrictions	Drone Operator registration	Remote pilot competence	Remote pilot minimum age
Privately built	< 250 g	A1 (can also fly in subcategory A3)	- No flying expected over uninvolved people (if it happens, should be minimised) - no flying over assemblies of people	No, unless camera / sensor on board **and** a drone is not a toy	- no training needed	No minimum age
Drones without class identific ation label	< 500 g			Yes	- read user manual - complete the training and pass the exam defined by your national competent authority	16*
Drones without class identific ation label	< 2 kg	A2 (can also fly in subcategory A3)	- no flying over uninvolved people - keep horizontal distance of 50 m from uninvolved people (this can be reduced to	Yes	- read user manual - complete the training and pass the exam defined by your national competent authority	16*
Drones without class identific ation label or privately built	< 25 kg	A3	- do not fly near people - fly outside of urban areas (150 m distance)	Yes	- read user manual - complete the training and pass the exam defined by your national competent authority	16*

➡ **Table 2-1** EASA Open Category requirements [6]

2.3 Research to support drone selection

2.3.1 Review of other mid-air drone collision studies

QinetiQ's review of worldwide drone collision studies [8] identified fourteen distinct programmes and 19 published papers/reports/theses/articles on the subject. The published report [8] includes a summary of the each of the drones selected for evaluation, and also the analysis and testing methodologies employed.

Small quadcopter multi-rotors were the focus of most studies, though a fixed wing example was also assessed within the ASSURE programme. The most commonly-referenced quadcopters within these studies were from the DJI Phantom series.

Further to this, a collaboration between China's Northwester Polytechnical University and the Civil Aviation Administration of China (CAAC) undertook a study focusing specifically focusing on the DJI range, including modern form factor drones (Mavic series) and professional drones (Inspire series) to evaluate the effect of different product masses. Other studies instead utilised parametric analysis methods, focusing on scalable generic threats to allow for comparison of the overall severity between different types of threat (i.e. bird impact or increasing drone mass).

Of the literature reviewed, the drone down-selection methodologies were not typically outlined, however several studies stated that the DJI Phantom 3 was selected due to the availability of material and validation data made by the ASSURE [9] study.

The ASSURE study was the only study to detail their down-selection process for the multi-rotor drone [10], based upon usage data. As part of their research they identified a limitation to the private ownership records, where although registration of drones above 250g is mandatory in the United States of America, the specific drone model is not required to be stated. In lieu of private ownership data, the study referenced publically available exceptions granted for commercial use of drones (Form 333) available on the FAA website, which provided a distribution of commercially flown drone models in the United States at that time. This identified the DJI Phantom 3 as the most popular, which was in-line with their understanding of the consumer market at that time and so was judged to be the most appropriate selection.

2.3.2 Market data

As discussed in Section 2.3.1, there is a dearth of accurate market data pertaining to the consumer drone market, which is primarily due to the private ownership of the major drone manufacturers and lack of specific drone information in registration methods.

The methods employed by the ASSURE team [10] to determine the relative popularity of drone used for commercial purposes was considered. However this was not considered to be the most appropriate indicator of consumer/prosumer usage and it would be difficult to recreate for Europe. Firstly, the breadth of countries regulated by EASA is much broader than those regulated by the FAA (i.e. drone registration is required directly with each home nation's civil aviation authority rather than direct to EASA). Secondly, the level of reporting, and accessibility to reports, varies from nation to nation (e.g. commercial permissions and exceptions are not publicly accessible from the Civil Aviation Authority (UK) website). Therefore, an assessment of commercial usage was not considered to be appropriate.

The availability of consumer drone registrations was also investigated. As of 31st December 2020 EASA will require private drone operators to register themselves (see

Table 2-1) with their respective nation's civil aviation authority. Some nations stipulated this in advance of this date, such as the UK's Civil Aviation Authority which required registration from the 30th November 2019. However, as with FAA registration, typical private drone operator registration does not require disclosure of the exact drone model and so do not inform private ownership figures.

To bridge this knowledge gap, several publicly available market studies were identified. Skylogic Research's 2018 survey was the most commonly referenced source, which had over 2,500 respondents and included industry sponsors such as DJI. A major finding was that DJI were the market leader with a 74% share, and that DIY/Custom drones were the joint third highest[1] with a 3% share [11]. Within the DJI range, the survey found that the most popular drone was the Phantom 4 with 29% ownership closely followed by the Mavic Pro with a 26% share [12].

Another study by Kittyhawk.io, Inc., a US-based drone software company, also supported these findings through analysis of their 2018 users' data. The study also concluded that DJI was the market leader, with 72% share of drones registered on their platform. In addition, the Mavic Pro was identified as the most popular drone model (22%); however in terms of drone family, the Phantom series was more common (30%) [13]. It is noted that Kittyhawk.io's offering is specifically marketed to DJI users, so this data may carry some inherent bias.

Both of these studies were conducted by US-based organisations, but their findings highlighted the ubiquity of products from Asian suppliers. Some variation in ownership figures might be expected within European nations, but the overall trends are considered to be applicable.

2.3.3 Design trends

Although the market studies described in Section 2.3.2 provide some insight into the composition of the consumer drone market, they are somewhat dated due to the rapidly developing field of consumer drone design. This sub-section details current design trends, with comparison to identified design trends in the period of previous mid-air collision studies.

As the identified market leaders, the evolution of DJI's flagship drone models directly correlates with the change in consumer drone design trends. As discussed in Section 2.3.1, during the time of the other mid-air collision studies, the DJI Phantom series of drone was synonymous with the consumer drone market and its form factor also became popular with other manufacturers. Since then, the consumer market has seen a shift away from the large plastic monocoque design, towards compact camera drones that can be readily carried in rucksacks or pockets. A significant consequence of this is the removal of the large energy absorbing structure around the

[1] Yuneec was second highest with 5% market share but they are now concentrating on commercial markets. Joint third was 3DRobotics, who no longer manufacture drones.

drone, in favour of more tightly-integrated assemblies that enable the drones to articulate between their flight and transportation configurations (i.e. folding the 'arms' into the body).

DJI's Mavic series exemplifies this modern compact design focus. At the time of writing, this series of drones represented mass classes from 249g consumer models (DJI Mavic Mini) to 907g prosumer models (DJI Mavic 2), with a clear shared design ethos between each model. These models cater specifically to the compact camera drone market, effectively replacing the market space previously occupied by the Phantom series.

The DJI Phantom 4 continues to represent a higher end prosumer price point and has commercial market appeal with models including a multi-spectral version, but the emergence of Mavic enterprise models will likely reduce this appeal. Given this, it is expected that DJI Phantom ownership will have decreased since the publication of the market studies identified in Section 2.3.2, and its representation in future markets is expected to reduce.

Recent developments and shifts in design direction by other major drone OEMs also support the above points. Within the consumer drone market, the number of major competitors appear to be reducing. 3D Robotics, who were identified as being a front runner behind DJI in both of the market studies (fourth highest ownership [Skylogic] and most popular non-DJI drone [Kittyhawk.io]), ceased manufacturing activities in 2016. Secondly, in a 2019 full year earnings press release, Parrot stated that they are reducing their consumer activities and increasing their focus on commercial drones and solutions [14]. Parrot's ANAFI family of drones include configurations that are applicable to the consumer/prosumer market [15]. These are also aligned with the current trend towards foldable compact systems, so concentration on this style of quadcopters would be consistent with the wider mass-market offerings.

As part of this study, a database of over 60 current or recently discontinued consumer drone products by major camera drone OEMs was generated by QinetiQ to support the above findings. This assessment highlighted the following design trends:

- The basic mass of drones is reducing as technology improves:
    - Improved efficiency.
    - Evolution of fuselage designs and material usage.
- The form factor has shifted to a compact foldable system:
    - This has also reduced the versatility of payload options, typically camera drones offer a single camera system without the option to switch (e.g. Mavic 2 Zoom and Pro models).
- The overall complexity of the airframe has increased:
    - Compact foldable systems include multiple, discrete moving parts.
    - Lightweight materials such as carbon-fibre reinforced composites, are now incorporated in consumer/prosumer models when historically these were limited to professional models (e.g. DJI Inspire).
- Quadcopters dominate the market.

2.3.4 Software safety systems

As drones have become more popular in the consumer market, major drone OEMs have made significant investments in software based safety systems (e.g. geo-fencing) to reduce the risk of misuse and allay fears of potential mid-air collisions.

Leading geo-fencing systems can provide real time analytics, included flight maps with defined geo-fenced zones prioritised by criticality, whereby 'higher level' zones required different levels of approval to fly in. Simpler geo-fencing systems are more common, typically limiting the available airspace to a conical area around the operator, thereby limiting the potential flight altitude and distance. Some of these simpler systems do not limit use in no-fly zones such as airports and instead rely on the operator's discretion.

In addition to geo-fencing, products such as the Mavic Air 2 include an Automatic Dependent Surveillance-Broadcast (ADS-B) receiver. This system alerts the drone operator with the location of aircraft in the immediate area, although at the time of this report, the system does not include aircraft altitude data and does not force the operator to take evasive action.

It is noted that these systems primarily aim to limit misuse by inexperienced pilots, but those who have intent to do harm, or do not want these 'limitations' on their drone, can illegally circumvent such methods.

Whilst the potential benefits of these safety systems are recognised, a detailed review of their current prevalence, effectiveness and fallibility is not within scope of this project. It is therefore assumed that although such systems may reduce the likelihood (risk) of a mid-air collision, they do not affect the hazard associated with a collision, which is the focus of this work.

2.3.5 Stakeholder engagement

In order to ascertain that QinetiQ's research on drone down-selection was appropriate and robust, key elements of the aforementioned findings were presented to the project's Drone Manufacturer Stakeholder Group (Appendix A) for discussion and affirmation. This Stakeholder Group includes representatives from DJI, Parrot, senseFly, Delair and Aeromapper as well as subject matter experts from the standards organisation, ASD-STAN. The key outcomes of this meeting included:

- QinetiQ's assessment of market leaders (by sales volumes) in the consumer market was agreed.
- Quadcopters were agreed as the dominant configuration for consumer drones.
- The observed trend towards compact folding designs for integrated camera drones was agreed.
- Within the DJI range, it was agreed that the Mavic series of drones have become the mainstream consumer/prosumer product line, rather than the Phantom series. It is therefore expected that Mavic drones (and comparable alternatives, such as the Parrot ANAFI) are most likely to be encountered 'in the wild'.

2.4 Drone down-selection

2.4.1 Drone styles

Within this programme, it was planned to develop and validate four unique drone threat models [5]. In addition to this, QinetiQ has previously developed and validated a DJI Inspire 2 threat model which could also be made available.

Based upon the findings of QinetiQ's research and feedback from EASA and the Stakeholder groups, the following styles of drone were selected as being of greatest relevance to this programme:

- Compact folding camera drone
    - Pocket-sized
    - Prosumer
- Professional quality camera drone
- Low cost, racing-style first-person view (FPV) quadcopter
- Fixed wing drone

Within this list, the 'compact folding camera drones' are considered to best-represent the mainstream mass-market of both consumer and prosumer products. The other styles represent important configurations which are significantly different in their construction to the compact models, but command a smaller market-share amongst consumers.

Each of these categories are discussed in the following sub-sections, including definition of specific drone products to represent them. It is intended that the down-selected drones shall be used in later tasks which will include testing and numerical modelling of collision scenarios.

The selection of example drones has been largely based upon their ubiquity within the marketplace but some consideration has been given to whether some of the drones could be readily modified and scaled to explore the effectiveness of design changes on collision severities. In general, well-integrated products are more-difficult to modify than generic configurations, though it is technically feasible to apply basic scaling rules to any drone threat model.

2.4.2 Pocket-sized compact folding camera drone - DJI Mavic Mini

This configuration represents drones in the lightest class defined in the EASA Open Category ('Class '0'), with maximum take-off mass of ≤0.25kg,

Table 2-1) This example is expected to operate within the least stringent sub-category A1 rules.

The compact folding form-factor is aligned with current industry trends, but a recent literature review of published drone collision research [8] did not reveal any work involving drone products of this mass class and style. Inclusion of a product of this type will therefore provide unique data for the lightest class of camera drones.

Although most drones of this mass class have traditionally been low performance toys, recent developments in drone technologies (discussed in Section 2.3.3) have enabled the development of highly capable, lightweight camera drones into the consumer market. This sub-class represents the entry point to the mainstream camera drone market and so is likely to include a significant proportion of inexperienced drone users.

The model selected to represent this sub-class is the DJI Mavic Mini (Figure 2-2), which was released in 2019 and weighs 0.249kg. It incorporates design features that are common across the DJI Mavic series, including foldable arms and a multi-part construction, which are reflective of the design trends identified in Section 2.3.3.

Figure 2-2 DJI Mavic Mini

2.4.3 Prosumer folding camera drone - DJI Mavic 2

This category includes some of the most popular mass-market consumer camera drones. The technical specifications and price point of drones in this category cater to more experienced operators and enthusiasts, or those who want a modern, feature-rich product.

Most of these drones are expected to occupy the ‘Class 1’, ‘C1’ (0.25-0.9kg) or ‘Class 2’, ‘C2’ (<4kg) in the EASA Open Category (

Table 2-1), depending upon their mass, performance and qualifying features [7].

Previous drone collision studies have used an example from the DJI Phantom series to represent mass-market consumer/prosumer camera drones. However its market share has begun to diminish in favour of newer models which cater to emerging design trends, such as lighter and more compact designs (Section 2.3.2). It was concluded that focus on these newer designs would be of greater value to the study.

The model selected to represent this sub-class is the DJI Mavic 2 (Figure 2-3). This drone was released in 2018 and its basic mass is reported to be 0.9kg, representing the upper end of the A1 subcategory. It represents the flagship model of the Mavic series of drones and so the common design philosophies, such as folding arms and complex construction, are present.

➨ **Figure 2-3** DJI Mavic 2 (Pro variant pictured, without propellers)

No verified ownership data is available for this model, as its release post-dates both of the identified market studies (Section 2.3.2). However ownership figures of the DJI Phantom and DJI Mavic are expected to be indicative of future DJI Mavic 2 ownership due to previously discussed market trends. The Mavic 2 also represents DJI's flagship product and so, taking into account DJI's significant market share, ownership figures are expected to be high.

2.4.4 Professional camera drone - DJI Inspire 2

Professional-use filming drones typically range from approximately 3.5kg to over 15kg, occupying either 'C2' (0.9-4.0kg) or 'Class 3', 'C3' (4.0kg-25kg) within the EASA Open Category (

Table 2-1). However, the lower-end of this mass class is considered to be more-appropriate to the semi-professional/prosumer market, rather than the heavier-weight multi-rotors designed for large payloads such as high-grade professional cameras.

Although this class of products are typically piloted by professionally qualified operators, this is not a mandated requirement if they are not being used commercially.

The model selected to represent this sub-class is the DJI Inspire 2 (Figure 2-4). The DJI Inspire 2 was released in 2016 and has a basic mass of 3.44kg and a maximum take-off weight of 4.25kg, representing subcategory A2 (0.9kg-4.0kg) or A3 (4.0kg-25.0kg), depending on payload configuration.

Figure 2-4 DJI Inspire 2

The DJI Inspire 2 represents DJI's drone model catering to the semi-professional and professional film making market.

The selection of the Inspire 2 is supported by the two identified market studies discussed in Section 2.3.2, whereby the DJI Inspire 2 was found to represent 7% of DJI drone sales in 2018 in one study [12] and DJI Inspire models represented a combined 5.5% of Kittyhawk.io users [13], beaten only by DJI Phantom and Mavic models.

As stated in Section 2.4.1, QinetiQ have previously developed a validated model of the DJI Inspire 2 and a Zenmuse X5S camera (combined mass 3.89kg).

2.4.5 'Racing style' FPV - Eachine Wizard X220

This configuration is based upon inexpensive, entry-level FPV racer-style configurations. Most products of this style weigh less than 0.9kg and utilise a lightweight but robust carbon fibre frame construction to carry flight loads and provide protection to the electronic components in the event of crashes.

Although the mass of these drones suggests that the will occupy wither 'C0' or 'C1' classes and fly in accordance with protected A1 sub-category rules, the final classification will depend upon their performance capabilities, features and documentation. For example, 'C0' and 'C1' classes have a maximum speed of 19 m/s) which may be lower than the capabilities of these products. Furthermore, many low-cost systems do not provide the level of automation or situational awareness that will be required of products in this category.

It should be noted that although "Racing Style" is used as a descriptor, this configuration is not specific to racing drones, which are typically flown in obstacle-rich settings i.e. close to the ground, and at organised events. Instead this refers to a general class of small, rugged drones designed with minimal electronic aids and with an emphasis on manoeuvrability and speed.

Whilst the design intention of these products is not to operate at great heights, their high performance characteristics and lack of safeguards e.g. geo-fencing, as well as their low price-point means that it cannot be discounted. Evidence of this can be found on video sharing platforms such as Youtube, where drones of this style have been recorded achieving altitudes of over 10,000m.

The market share for DIY/Racing drones (3% [Skylogic study, Section 2.3.2]) is smaller than that for mass-market consumer camera drones and products/components are available from a range of manufacturers.

The model selected to represent this sub-class is the Eachine Wizard 220 (Figure 2-5). This was also proposed as the exemplar during QinetiQ's scoping study (EASA.2016.C25) [2,3] and it continues to be an appropriate selection, representing a large array of similar products from different manufacturers.

The simple construction and exchangeable components means that the configuration is readily modifiable and scalable, which is beneficial when investigating the effect of configuration, mass and design features in later tasks.

Industry rumours suggest that a more-mainstream FPV configuration may be entering the marketplace in the near future. These developments shall be kept under review and – if applicable – comparisons can be made with this typical, low-cost configuration.

Figure 2-5 Eachine Wizard 220

2.4.6 Fixed wing

Electric fixed wing drones are available in many sizes, designs and masses, ranging from less than 50 grams to over 4 kg (specialist systems can be considerably heavier than this). Fixed wing configurations can therefore occupy any of the sub-categories in the EASA Open Category (

Table 2-1).

For the purpose of this activity, a fixed wing drone is characterised by its ability to generate lift necessary for flight via aerodynamic surfaces, rather than directly from rotor thrust. Hybrid configurations, in which thrust can be generated/vectored to allow vertical take-off and landing (VTOL) before transitioning to lift-based flight, have been discussed as part of this exercise and were included in the down-selection.

The two most common styles within this category are 'conventional' configurations (including traditional model aircraft and more-modern designs) with distinct wings, empennage and fuselage features, or blended wing-for body 'flying wings'. In most instances, the flying wing styles use single rear-mounted ('pusher') propellers and the conventional styles use nose- or wing-mounted ('puller') propellers, though there are exceptions to this.

The size of the consumer/prosumer fixed wing market is judged to be relatively small compared with that for mainstream multi-rotors. Therefore it is planned that only one fixed wing configuration should be assessed within the first stages of the project. Variations on the selected drone may be investigated within Task 7, including scaling it to different masses and use of different airframe designs.

There has been debate within the project team as to what constitutes a consumer, prosumer and commercial product within the fixed wing market. To aid this, the drone manufacturers Stakeholder Group was requested to fill-in a short survey aimed at identifying the fixed wing configuration(s) that best-represent the consumer/prosumer and commercial/enterprise markets. The output from this survey showed general agreement between respondents that the low-end products were aimed at the consumer market, and that the high-end drones were aimed at commercial/enterprise users. There was inconsistency of opinion in what might be attractive to the prosumer market, though the products that best-matched the description were flying wing configurations.

Based upon background research and comments from the Stakeholder Group, it is observed that the consumer market for recreational flight does not overlap with the needs of professional users to the same extent as for multi-rotor drones. The consumer market is not well defined and is arguably biased towards hobbyists rather than casual consumers, as most products have a relatively steep learning curve and lack many of the automation features and flying aids that have become synonymous with other mass market consumer drone products. Some products e.g. the Parrot Disco, have attempted to address this but have since been discontinued and so the fixed wing market remains relatively niche. Notwithstanding these caveats, the consumer market includes a spectrum of products from very lightweight toys to large and highly-capable drones/model aircraft with (or without) small cameras and autopilot systems. Commercial-grade fixed wing systems include better-integrated systems and software that enable drones to reliably perform functions such as wide-area mapping/surveillance/search over extended periods. Whilst the commercials systems clearly represent more-advanced products, the additional benefits to private users are less obvious for non-fee-paying work whilst the cost of ownership is much greater.

The traditional model aircraft design was not favoured by the customer and stakeholder community as an example of modern fixed wing drones.

A flying wing configuration has been down-selected for its applicability to a broad cross-section of markets. The low-cost consumer products range from crude, lightweight (100 - 300 grams) foam models [16] as well as larger, heavier systems [17, 18] that offer greater performance and the ability to incorporate small 'action cameras' as well as FPV systems. Commercial products such as the 1.5 kg Delair 'UX11' and 1.4 kg senseFly 'eBee X' share similar form actors and also make use of lightweight and tough expanded foam materials and carbon-fibre composite tubes.

Delair has kindly offered to provide examples of their UX11 mapping drones for use in this study (Figure 2-6). As noted above, the construction of the UX11 airframe is comparable to other professional drones and some consumer products, so it is considered to be representative of a wider class of fixed wing products. It is planned that some details of the UX11 computer model shall be kept relatively generic to aid read-across with other products and aid the creation of scaled derivatives, if required, in Task 7.

Figure 2-6 Delair UX11 professional mapping drone *(Image © Delair, included with permission)*

3. Task 2.2: Target Aircraft Specification

3.1 Aircraft categories

The aims of the programme are to evaluate the effect of collisions between consumer/prosumer drones (defined in Section 2) and aircraft within the following Certification Specifications (including equivalent Federal Aviation Authority and other similar international certification categories):

- CS-23 Normal, Utility, Aerobatic and Commuter Aeroplanes [21]
- CS-25 Large Aeroplanes [22]
- CS-27 Small Rotorcraft [23]
- CS-29 Large Rotorcraft [24]

These categories encompass the vast majority of in-service aircraft and include a broad spectrum of configurations, designs and masses.

Not all manned aircraft categories, such as Gliders (CS-22), Balloons (CS-31) and Very Light aircraft (CS-LSA, CS-VLA and CS-VLR), are included within the scope of this programme. Whilst these categories of aircraft may also be susceptible to drone collisions, the current programme is focussed on categories addressed by EASA's Task Force on drone collisions with aircraft and for which practical changes to drone design practices may mitigate the severity of collision threats. This is a recognised omission that could be addressed in a future programmes, though it is also possible that some results can be read-across to other classes of aircraft. The scope of the programme shall be kept under review and opportunities to enhance the applicability of the results shall be considered based upon their individual merits and progress on core activities.

For the four selected aircraft categories it would not be feasible, within this programme, to directly assess the vulnerability of all associated aircraft types that operate within European airspace. Instead, it will be necessary to consider a combination of exemplar aircraft and generalised design features that represent a cross-section of commonly-used aircraft designs within each category. For example, the study may assess collisions between drones and a generalised empennage leading edge structures rather than try to recreate the designs of all aircraft that are included within the above categories.

This Section identifies exemplar aircraft which are later used in Section 4 to prioritise local impact areas (e.g. wing leading edges or rotors, for drone collision assessments). However, it should be noted that this programme is not necessarily limited to the assessment of these particular aircraft, nor do any special arrangements currently exist with their respective Design Authorities to provide detailed information on their construction.

3.2 Exemplar aircraft selection

The selection of exemplar aircraft to represent each of the Certification Specifications is based upon a review of typical aircraft configurations within each category, and usage statistics. In some cases other factors, such as their maximum take-off weight with respect to other models within the same category, were also considered.

The aircraft usage statistics have been calculated using historical ADS-B transponder data to identify flight activities of different aircraft types. The dataset for this assessment consisted of approximately 1.7 billion data points (1 year of data from 0 - 12,000ft, for a rectangular area encompassing the whole of Germany) before it was sampled to 30 random days, filtered and processed. Further details of the ADS-B data analysis, which was primarily undertaken to assess aircraft collision speeds in Task 2.4, are included in Section 5.

The 12,000 ft (FL120) ceiling was applied to keep the number of data points within practical limits and to concentrate efforts on altitudes at which drones are more likely to be encountered. This captures 97% of the events recorded in the Aviation Safety Network's in-flight drone sightings/collisions database [27].

The proposed aircraft have been reviewed by the programme Stakeholder Group, which includes representatives from aircraft manufacturers (covering all relevant categories), engine manufacturers, drone manufacturers and standards organisations. No objections have been raised about the proposed selection, recognising that it is not an exhaustive list of aircraft styles.

3.2.1 CS-23 Normal, Utility, Aerobatic and Commuter Aeroplanes

The CS-23 category includes a broad range of aircraft configurations and performance characteristics. For the purpose of down-selecting local impact areas, it was decided to consider two different aircraft at opposite ends of the CS-23 spectrum: A lightweight, piston-engine, single propeller-driven configuration and a small jet aircraft.

3.2.1.1 Lightweight single-propeller CS-23

Figure 3-1 shows the relative proportion of time spent flying at altitudes less than 12,000 ft (where drones are most-likely to be encountered) by different piston-engine, single-propeller CS-23 aircraft. Within this sub-category, the Cessna 172 (ICAO code, 'C172') had the greatest number of entries in the filtered ADS-B database (20.4% of total), with a further 4.1% being recorded for the slightly-larger Cessna 182 variant (ICAO code, 'C182').

The Cessna 172, which is a lightweight, non-aerobatic aircraft with braced wings was selected to be the example aircraft for this sub-category. It is popular with private owners and so typically operates from small airfields and private airstrips.

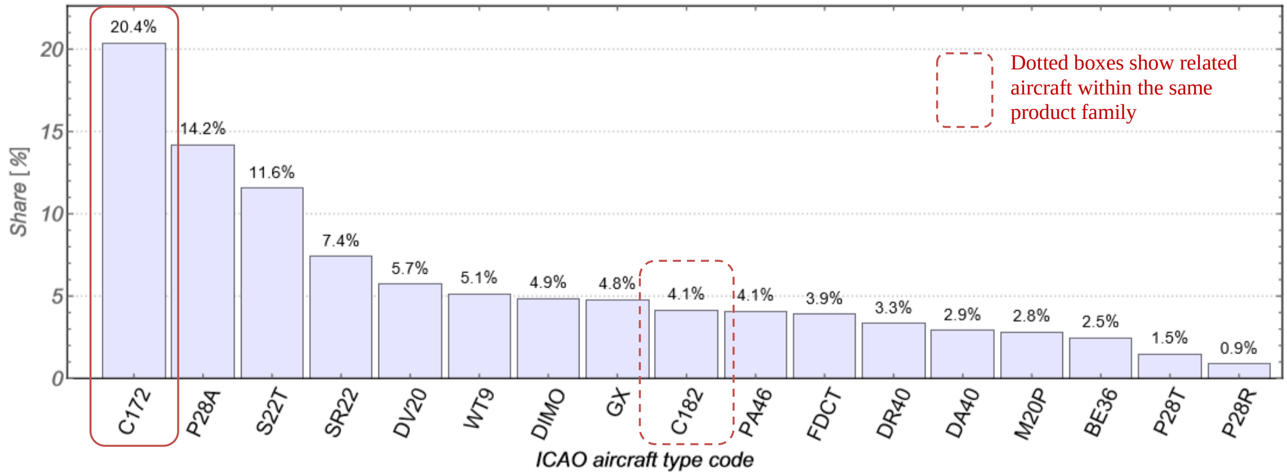


Figure 3-1 ADS-B entries below FL120 for CS-23 piston-engine single propeller aircraft

The accuracy of this survey can't be guaranteed because – at the time of writing – the use of ADS-B transponders was not mandated for this category of aircraft. However, the findings are in-line with expectations as the Cessna is reportedly the most-produced aircraft of all time [28] with over 44,000 delivered.

3.2.1.2 CS-23 lightweight jet aircraft

Figure 3-2 shows the relative proportion of time spent below FL120 by different CS-23 jet aircraft. The most commonly-recorded aircraft of this class was the Learjet 35 (ICAO code, 'LJ35') with 28.5% of the ADS-B entries. Although this would have made a reasonable exemplar, it was noted that it is close to the 8,618kg limit of the

CS-23 category and may therefore be more-representative of a small CS-25 aircraft (albeit without the CS-25 requirements). Instead, another Cessna, the 510 Citation Mustang (ICAO code, 'C510'), was selected to represent small CS-23 jets when reviewing critical impact locations. Whilst the Citation Mustang only accounts for 6.2% of the dataset, the wider family of aircraft within the Citation product line accounts for 53.9% of all entries.

Note that the slightly larger Cessna 525 would have been the obvious choice for the CS-23 jet example, but the usage data was not available when the 510 was provisionally selected. The 510 was identified as an appropriate example through discussions with members of QinetiQ's aviation teams and images of this aircraft was used in early discussions and identification of local impact zones. The superficial differences in the overall configuration of these two aircraft were considered to be sufficiently minor (for the purpose of this exercise) to warrant changing to the 525.

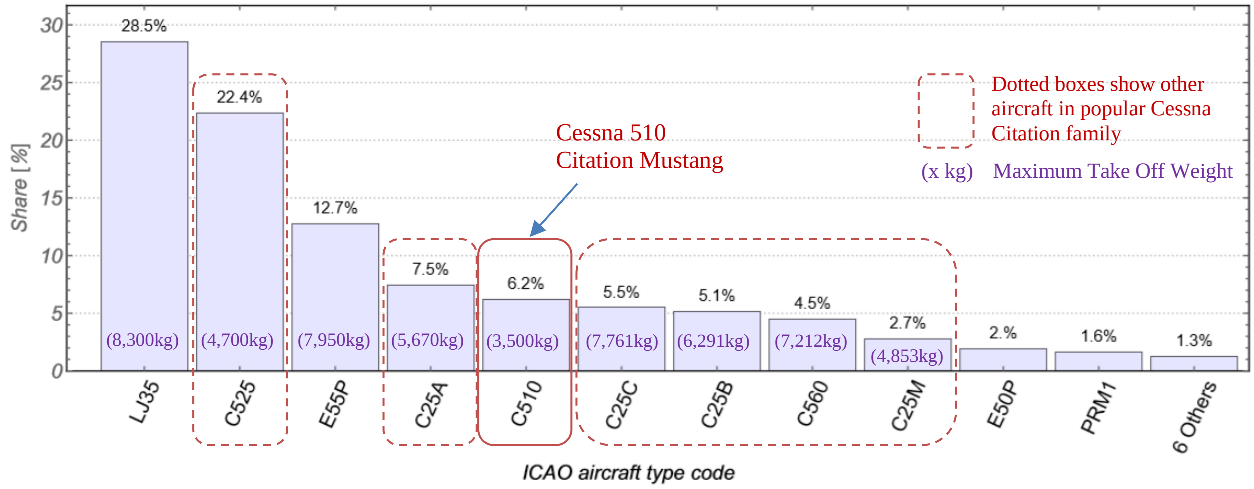
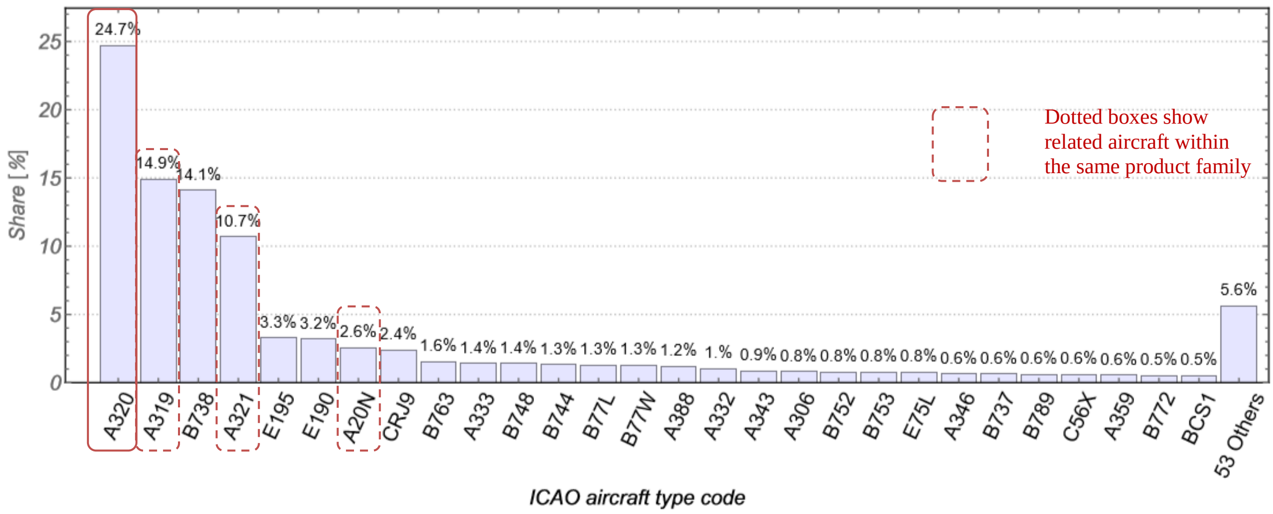


Figure 3-2 ADS-B entries below FL120 for CS-23 jet aircraft

3.2.2 CS-25 Large Aeroplanes

Figure 3-3 shows the relative proportion of time spent below FL120 by different CS-25 jet airliners. The Airbus A320 was identified as being the most common CS-25 jet aircraft, accounting for nearly 25% of all ADS-B entries. This increased to over 50% when derivative products within the same family are included. On this basis the A320 was selected as an exemplar for CS-25 jet airliners.

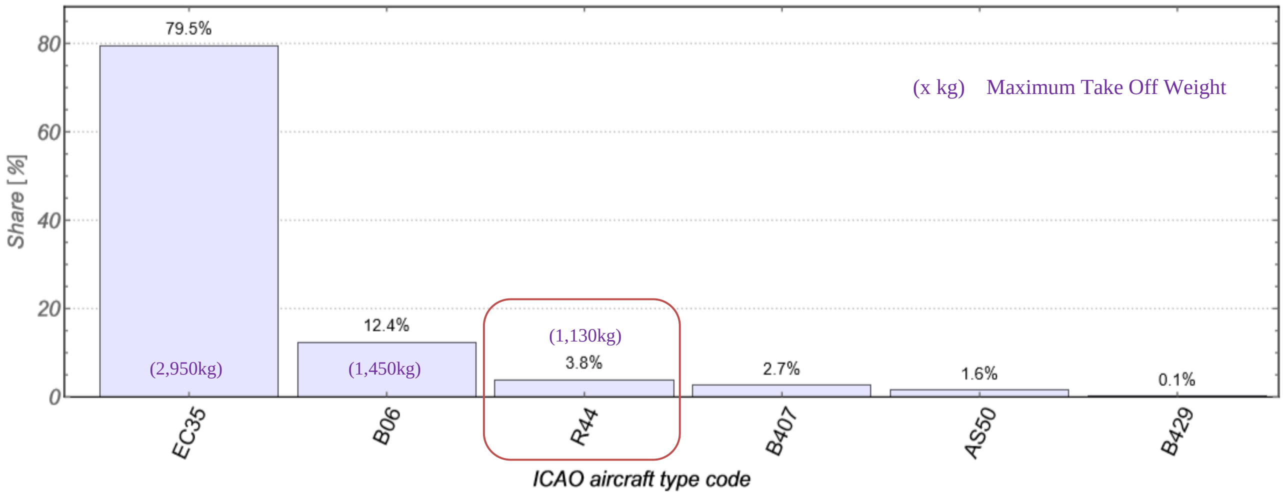


➨ **Figure 3-3** ADS-B entries below FL120 for CS-25 jet airliners

3.2.3 CS-27 Small Rotorcraft

Figure 3-4 shows the relative proportion of time spent below FL120 by different CS-27 Small Rotorcraft. The most commonly-recorded aircraft of this class was the Airbus H-135 (ICAO code, 'EC35') with 79.5% of the flight movements. However, this is a twin-engine aircraft at the top-end of the CS-27 mass range and – in these respects – is reminiscent of CS-29 platforms such as the H-145. Furthermore, it is suspected that the ADS-B data may be biased towards the larger rotorcraft used for corporate and VIP travel rather than lower-cost models that are popular with private owners. It was therefore decided to use one of the smaller CS-27 aircraft as an exemplar for this category.

Both the Bell 206 JetRanger (ICAO code, 'B06') and Robinson R44 ('R44') were considered as they have been produced in very high numbers (over 7,000 [29] for the 206 and over 5,000 for the R44 [30]). However, the R44 was identified early-on in the local impact area prioritisation process (Task 2.3) as it is the lighter of the two (1,130 kg vs. 1450 kg MTOW, 658 kg vs 1057 kg empty) and is still in production. The R44 was therefore selected as the CS-27 exemplar aircraft.



➨ **Figure 3-4** ADS-B entries below FL120 for CS-27 Small Rotorcraft

3.2.4 CS-29 Large Rotorcraft

Figure 3-5 shows the relative proportion of time spent below FL120 by different CS-29 Large Rotorcraft. The most commonly-recorded aircraft of this category was the Airbus H-145 (ICAO code, 'EC45') with 85.6% of the ADS-B entries. Although the apparent dominance of this aircraft may – in part – be due to the variable uptake of aircraft operators using ADS-B transponders, it is deemed to be a suitable exemplar for smaller CS-29 rotorcraft.

In addition to performing a passenger transport role, the H-145 is also used by police forces, air ambulance and search and rescue services. It may be postured that fulfilment of these roles, operating at low altitudes away from airfields may credibly increase the risk of encountering drones.

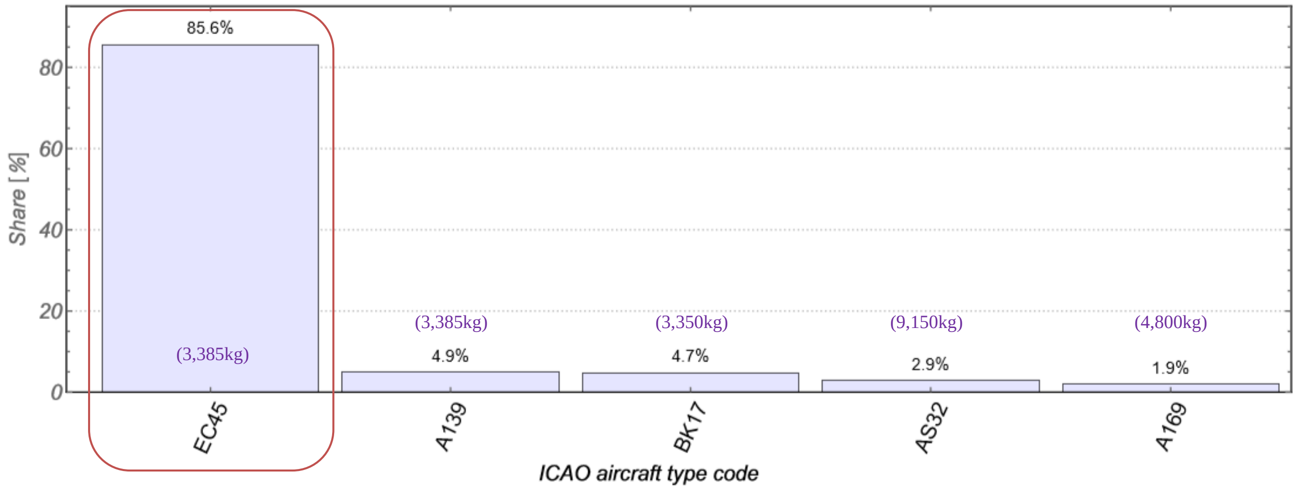


Figure 3-5 ADS-B entries below FL120 for CS-29 Large Rotorcraft

3.3 Future manned aircraft

Although the focus of this research project is on currently-certified, mainstream aircraft, future trends towards aircraft for 'Urban Air Mobility' are also being considered. In particular, some of the same technologies that have enabled the rapid advancements of drone products are appearing in manned electric aircraft, including multi-rotors such as the Volocopter VoloCity [31] and hybrid VTOL systems such as the Lilium Jet [32].

A new 'Special Condition' category, SC-VTOL [33] has been defined for this category of vehicle, using the same limits on mass (3,175 kg) and passenger seats (9) as the CS-27 specification. Manufacturers and other stakeholders have been working with EASA to agree Means of Compliance proposed for the Special Condition, and determine the threats that they need to account for and design against e.g. Bird Strike, Hail Strike and Foreign Object Damage.

Drone collisions represent a credible threat within the urban and rural environments in which these aircraft may operate, so representatives of this sector are supporting the project as members of the Stakeholder group.

3.4 Task 2.2 summary

Table 3-1 summarises the aircraft have been selected as exemplars to represent the primary Certification Specifications of interest as well as examples from the SC-VTOL category which will be kept under review. These examples have been used as a starting point in Task 2.3 to review impact regions.

Certification Specification	Description	Example aircraft
CS-23	Single propeller Utility	Cessna 172 Skyhawk
CS-23	Lightweight business jet	Cessna 510 Citation Mustang
CS-25	Large Aeroplanes	Airbus A320
CS-27	Small Rotorcraft	Robinson R44
CS-29	Large Rotorcraft	Airbus H-145
SC-VTOL	Small-category VTOL aircraft	VoloCity/Lilium

Table 3-1 Summary of exemplar aircraft

4. Task 2.3: Local Target Specification

4.1 Introduction to Task 2.3

The purpose of Task 2.3 is to identify and prioritise potential impact regions on aircraft representing the primary Certification Specifications described in Section 3 (CS-23, CS-25, CS-27 and CS-29).

This has been achieved with input from subject matter experts in fixed wing and rotorcraft operations, aviation safety professionals and the Stakeholder Group.

4.2 Review of aircraft impact zones

An initial activity was undertaken to identify credible impact regions applicable to aircraft within each of the primary Certification Specifications. Inputs to this process included the list of down-selected regions that was generated by the 2016 EASA Drone Collision Task Force [1] and material published by other drone collision studies which have been summarised by QinetiQ as part of a wider literature review [8].

In addition to these inputs a review of possible impact locations was also undertaken, using the five exemplar aircraft identified in Section 3 to aid discussions. This exercise included fixed wing and rotorcraft specialists at QinetiQ's Boscombe Down aircraft test and evaluation facility, as well as Senior aircraft safety engineers. Although these discussions referenced the exemplar aircraft, other, more general aircraft configurations within the relevant category were also considered.

It was necessary to use general descriptions when defining prospective impact zones so that the total number remained manageable and the zones were not too-specific to a particular aircraft design. The final list of aircraft impact zones is shown in Table 4-1, though it should be noted that not all are applicable to each aircraft type, e.g. not all fixed wing aircraft have wing struts.

Category	Impact Location
Fuselage	Radome
	Nose
	Canopy (above windshields)
	Windshield
	Chin window (rotorcraft)
	Side windows
	Fuselage sides/rear
Aerodynamic surfaces	Wing leading edge
	Wing braces
	Wing slats
	Wing flaps
	Winglet leading edge
	Wing root fairings
	Vertical stabiliser leading edges
	Horizontal stabiliser leading edges
	Rudder/Ailerons, spoilers or elevators
Fixed wing propulsion	Engines (excluding reciprocating engines)
	Engine (reciprocating)
	Propellers
	Engine pylons
	Engine nacelle leading edges
Rotorcraft propulsion	Main rotor
	Tail rotor
	Main rotor hub & actuation
	Tail rotor hub & actuation
	Main rotor hub fairing/Mast
	Engine air intake
Gear	Wheels
	Landing gear strut/fairing
	Undercarriage housing/Fairing
	Gear bay doors
Systems	Lights
	Pitot tubes
	External antennas
	Auxiliary Power Unit & Environmental Control System intakes

Table 4-1 Aircraft Impact Zones

4.3 Evaluation of prioritisation criteria

A spreadsheet-based tool was created to aid the evaluation and review of the aircraft impact zones for the five different aircraft configurations identified in Section 3.

The criteria for this assessment was based upon the following factors:

1. The relative probability of a feature being impacted;

2. The perceived vulnerability of the feature to impact damage, and;
3. The criticality of the feature to the safety of the aircraft and its occupants.

Each of these three factors are discussed below.

4.3.1 Relative probability of impact

Historical evidence suggests that the current risk of drone collisions is low[2], though most recorded incidents have occurred within the last 5 years. However, the focus of this work is to evaluate the likely consequences of a collision and not the probability of it occurring. Therefore, for the purpose of this analysis it is assumed that a collision has occurred and that one of the defined zones has been impacted. The relative probability of impact is a measure of how likely the impact occurred to each individual zone. For example, a small feature such as an antenna would have a much lower probability of being impacted than the much larger leading edges of a wing.

A High, Medium or Low probability classification was assigned to each impact zone based upon a combination of judgement-based assessments and numerical analyses.

The use of a simple High/Medium/Low classification was deliberate as more-descriptive terms such as 'Unlikely', 'Possible' and 'Probable' may be inappropriately interpreted as having a strict probabilistic basis. Instead, classifications against each of the three factors were evaluated and used as a guide when assigning overall priorities.

4.3.1.1 Initial assessments

An initial assessment of each impact zone was undertaken to identify areas which are either not applicable to the aircraft configuration being evaluated, or were judged to have a low probability of impact.

For fixed wing aircraft, all side impacts were regarded as being not applicable since their high forward velocity during flight would render a side impact highly unlikely (significantly less probably than a frontal impact). If a side collision did occur then the resultant velocity would represent a glancing blow, with the horizontal impact velocity being limited to the speed of the drone.

For rotorcraft, side impacts were considered to be applicable but low probability since they are only likely to occur during hover or low-speed manoeuvres. In these circumstances the drone would need to actively fly into the side of it. Whilst this is considered to be a low probability event, it is still credible and a Low classification does not preclude any feature from being prioritised if it also has a sufficiently high criticality and vulnerability score.

Other features that were assigned low probability were small systems such as lights/pitot static assemblies and control surfaces (excluding high-lift devices).

4.3.1.2 Numerical assessments

The remaining impact zones were assessed by calculating their individual projected frontal areas as a proportion of the frontal area of the airframe (excluding swept area of propellers and rotors). This was achieved by constructing silhouettes of the exemplar aircraft as shown in Figure 4-1 and Figure 4-2.

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[2] Until recent events related to the COVID-19 pandemic, the number of airliner departures annually has been on an increasing trend with a rate approaching 40 million per year [35, 36] and nearly 69 million flight movements were recorded in 2019 by ADS-B transponders alone [37]. In contrast, only 24 drone collisions (confirmed and suspected) were identified in QinetiQ's review of incidents [8] over the last 23 years, and 23 of these occurred in the last 11 years. However, it should also be noted that there have been orders of magnitude more in-flight sightings and near-misses within this period.

No account was made for the influence of airflow and the effect that it may have on the trajectory of the drone. This may be of relevance to rotorcraft where down-draft from the rotors act perpendicular to the direction of travel and occurs over a wide area, ahead of the airframe. This is thought to be less significant when the rotorcraft is operating at high speed, since there would be little time between entering the down-wash and reaching the fuselage. Furthermore, it can not be guaranteed that drones entering the swept area of the rotor would not pass through without being impacted by the blades.

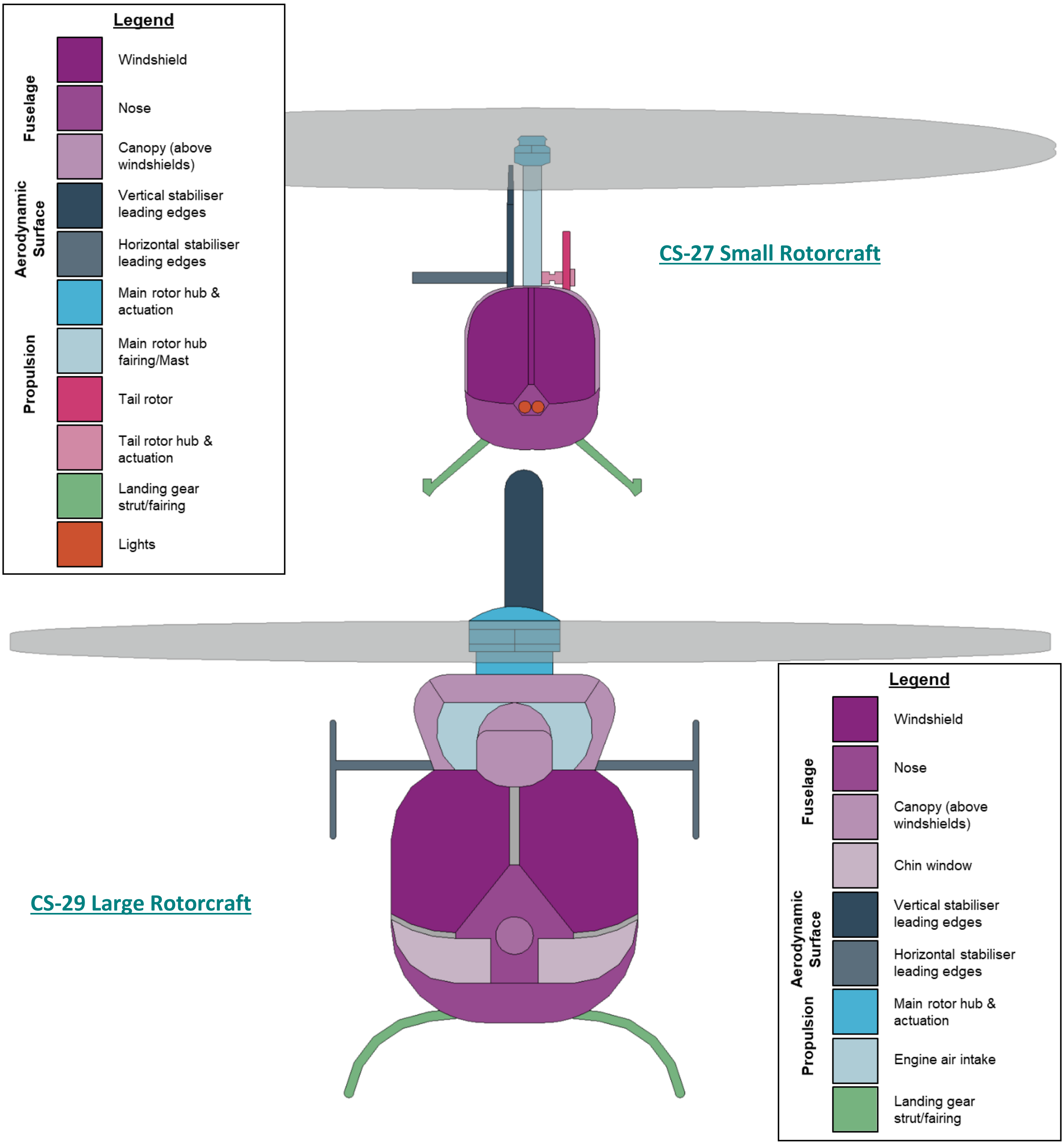


Figure 4-1 Rotorcraft silhouettes for frontal area calculation (not to same scale)

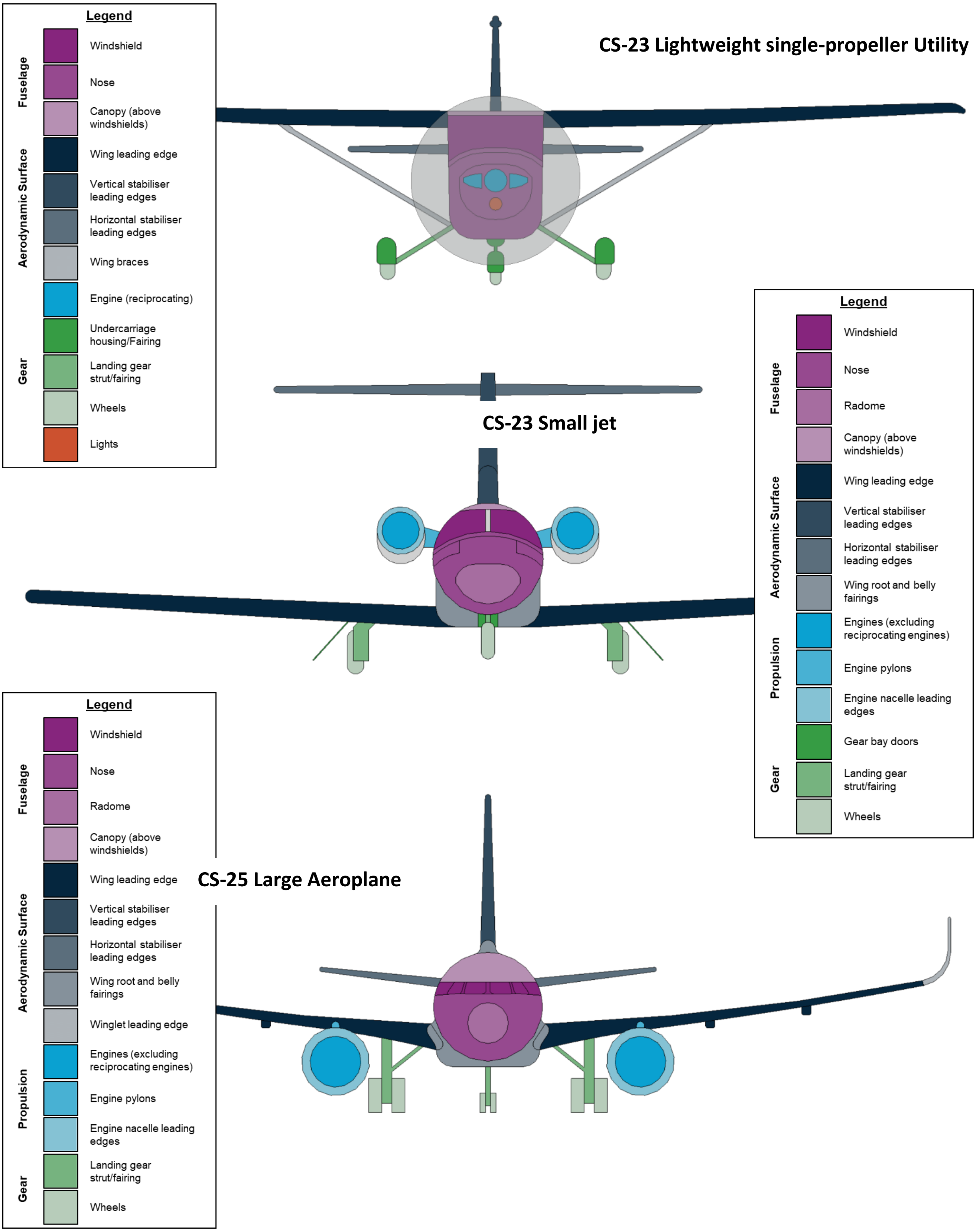


Figure 4-2 Fixed wing silhouettes for frontal area calculation (not to same scale)

Each silhouette was partitioned to represent the applicable impact zones and the relative areas calculated. Impact zones with an area less than 5% of the projected airframe were classified as being 'Low' probability and zones with an area greater than 20% were classified as 'High' probability.

Propellers were assigned 'High' probability ratings based upon their large swept area, though it is feasible that small drones could pass through propeller without being struck. Main rotors were also given a 'High' rating as they have a much greater projected swept area during forward flight[3]. Tail rotors were given a 'Low' rating as they are much less exposed during forward flight. However it is considered to be feasible that a tail rotor could be impacted, particularly during hover, manoeuvres or low speed flight.

4.3.2 Vulnerability

The Vulnerability classification provides a measure of how robust the impact zone is perceived to be and whether it is considered likely to fail if impacted. For example, a forward-facing radome structure might be considered to be more vulnerable to impact damage than a tyre.

The relative vulnerabilities of each impact zone were assessed qualitatively, using engineering judgement and knowledge of aircraft structures and other bird strike and drone strike programmes. This judgement-based approach was necessary because a mature understanding of the damage caused by drones is one of the key knowledge gaps that this programme is aiming to fill. For this reason, these preliminary assessments should be considered to represent perceived vulnerability and not statements of fact.

Commensurate with the fidelity of this assessment method, a simple High/Medium/Low grading was used, as defined in Table 4-2. When assigning these classifications, it was assumed that the drone would be a quadcopter of up to 4kg mass (as per the recommendations of Task 2.1).

Title	Classification	
Vulnerability *(Preliminary Impact Effect Assessment)*	**Low**	Unlikely to be damaged by an impact - Possibly minor dents/scratches
	Medium	Damage/Deformation is likely (default classification if unknown)
	High	High likelihood of penetration/major deformation/part detachment

Table 4-2 Vulnerability classification

The vulnerability of each impact zone (for each category of aircraft) was initially assessed in a collaborative workshop. This workshop was held at QinetiQ's Boscombe Down site and involved members of QinetiQ's drone collision team, subject matter experts in fixed wing and rotorcraft operation and a Senior aviation safety engineer. It was originally intended to include members of the programme Stakeholder Group but this was not possible due to COVID-19-related travel restrictions. Instead the workshop was held in adherence to national guidelines and QinetiQ procedures, and the assessment results were compiled into the spreadsheet tool and disseminated for review and comment. The outcome of the reviews is discussed in Section 4.4 and a copy of the input sheets from the tool are included in Appendix B, Sections B.1 to B.5.

[3] Although the passing frequency of large diameter main rotor blades is relatively low, its plane of rotation does not pitch for from the horizontal during straight and level flight, which reduces the likelihood a drone passing between the main rotor blades. Down-wash may influence the trajectory of the drone, though detailed analysis of this is outside the scope of this activity and is unlikely to affect the assigned 'High' probability rating.

4.3.3 Criticality

The Criticality classification describes the effect that damage to/failure of each impact zone would have on the safety of the aircraft and its occupants. For example, failure of a winglet might adversely affect the performance and handling qualities of the aircraft, but high velocity penetration of a windshield could have immediate and severe consequences for the aircrew.

A four-level classification was applied to the Criticality metric, as shown in Table 4-3. The 'HEC' code next to the four criticality levels refers to the Hazard Effect Classification, which is a measure proposed by the EASA Drone Collision Task Force [1] to describe the effect that localised damage on a feature would have on safety at an aircraft level. For the purpose of this prioritisation activity, the mapping to EASA's HEC levels is approximate. For reference, the full definition of the HEC levels is provided in Appendix B, Section B.6.

Title	Classification	
Criticality (Preliminary Hazard Effect Classification)	**Low** (HEC-4/5)	Anticipated damage would not significantly compromise the safe operation of the aircraft.
	Medium (HEC-3)	Anticipated damage would reduce the capability of the aircraft and/or present increased threat to the safety of aircraft and crew.
	High (HEC-2)	Anticipated damage would present a serious threat to the safety of the aircraft and crew.
	Extreme (HEC-1)	Anticipated damage would present an immediate and grave threat to the safety of the aircraft and crew.

Table 4-3 Criticality classification

The Criticality of each impact zone was discussed at length during the workshop and in subsequent reviews. Discussions considered whether the damaged impact site would present a significant threat to safety and also whether secondary damage might be caused as a result of the impact or fragments that penetrate the structure.

The criticality classifications were written-up into the spreadsheet tool and were circulated within the Stakeholder Groups and EASA for comment. A copy of the input sheets from the tool are included in Appendix B, Sections B.1 to B.5.

4.4 Prioritisation of impact zones

The impact zones on each aircraft category were prioritised based upon a combined assessment of the probability, vulnerability and criticality determinations. This was a manual process that took into account the individual classifications against the three criteria as well as the accompanying discussions and feedback from the Stakeholder group. The outcome of this activity is shown in Figure 4-3.

A High/Medium/Low/NA classification has been assigned to describe the level of priority.

It is intended that areas identified as High priority should be investigated further in this programme and plans developed (in Task 3) to evaluate their response to drone impacts. In many cases this will include a combination of physical test and/or explicit finite element modelling, but it may also be possible to exploit data from other programmes or use alterative assessment methods.

Medium priority impact zones will be re-evaluated once sufficient progress has been made against the High priority zones. It would be of benefit to investigate these zones in the programme but they are not considered to be critical.

Low priority impact zones are unlikely to be assessed within the programme unless opportunities occur to do so using only minimal project resources.

Impact location		Priority classification: CS-25 Large Aeroplane	CS-23 Jet	CS-23 Single Prop	CS-27 Small Rotorcraft	CS-29 Large Rotorcraft
Fuselage	Radome	Medium	Medium	Medium	Medium	Medium
	Nose	High	Medium	High	High	Medium
	Canopy (above windshields)	High	N/A	N/A	Medium	Medium
	Windshield	High	High	High	High	High
	Chin window (rotorcraft)	N/A	N/A	N/A	High	High
	Side windows	N/A	N/A	N/A	Low	Low
	Fuselage sides/rear	N/A	N/A	N/A	Low	Low
Aerodynamic surfaces	Wing leading edge	Medium	High	High	N/A	N/A
	Wing braces	N/A	N/A	High	N/A	N/A
	Wing slats	Medium	N/A	N/A	N/A	N/A
	Wing flaps	Medium	Medium	Medium	N/A	N/A
	Winglet leading edge	Medium	N/A	N/A	N/A	N/A
	Wing root fairings	Low	Low	Low	N/A	N/A
	Vertical stabiliser leading edges	High	High	High	Medium	Medium
	Horizontal stabiliser leading edges	High	High	High	Medium	Medium
	Rudder/Ailerons, spoilers or elevators	Medium	Medium	Medium	N/A	N/A
Fixed wing propulsion	Engines (excluding reciprocating engines)	High	High	N/A	N/A	N/A
	Engine (reciprocating)	N/A	N/A	Medium	N/A	N/A
	Propellers	Medium	N/A	High	N/A	N/A
	Engine pylons	Low	Low	N/A	N/A	N/A
	Engine nacelle leading edges	Medium	Medium	N/A	N/A	N/A
Rotorcraft propulsion	Main rotor	N/A	N/A	N/A	High	High
	Tail rotor	N/A	N/A	N/A	High	High
	Main rotor hub & actuation	N/A	N/A	N/A	High	High
	Tail rotor hub & actuation	N/A	N/A	N/A	High	High
	Main rotor hub fairing/Mast	N/A	N/A	N/A	Medium	Low
	Engine air intake	N/A	N/A	N/A	Low	Low
Gear	Wheels	Low	Medium	Medium	N/A	N/A
	Landing gear struts/brace	Medium	Medium	Medium	Medium	Low
	Undercarriage housing/Fairing	N/A	N/A	Medium	N/A	Low
	Gear bay doors	Medium	Low	Low	Low	N/A
Systems	Lights	Low	Low	Low	Low	Low
	Pitot tubes	Low	Low	Low	Low	Low
	External antennas	Low	Low	Low	Low	Low
	Aux. Power Unit & Env. Control System intakes	Low	N/A	N/A	N/A	N/A

Priority classification			
	Priority ranking based upon the assessment of ***probability*** *of a region being struck,* ***criticality*** *of the area to safe flight, and perceived* ***vulnerability*** *to damage.*	Low	Low priority - Qualitative assessment suggests that risk to safety is relatively low
		Medium	Medium priority - Judged to be a credible risk to safety and beneficial to assess but not a priority
		High	High priority - Project should investigate how to assess threat
		N/A	Not relevant to the aircraft configuration

➨ **Figure 4-3** Prioritised impact zones

A short summary of the principal reasons behind the 'High' ratings is provided below.

4.4.1 Noses

A high priority rating was assigned for aircraft types where the nose panels (excluding the Radome) are typically not highly swept and where critical systems may be damaged if the skins are penetrated. This does not apply to all aircraft within a given category and further investigation may provide justification to reduce the priority for some classes where other mitigations exist.

4.4.2 Canopy structures

Where canopy panels above the windshields are exposed, penetration of the skins could result in damage to critical systems and de-pressurisation (where applicable). This was judged to be most applicable to airliners, where the fuselage extends upwards above the windshield.

4.4.3 Windshields

As well as being in exposed to impact threats, windshields provide an essential barrier against projectiles. Although highly-robust windshields are employed for larger aircraft these can still be overmatched, particularly when the impactor is harder than the birds that they are designed to resist. Light aircraft (fixed wing and rotorcraft) commonly have thin windshields, with many not even being certified for bird strikes.

The consequences of a windshield being penetrated may be severe for the flight crew and the safety of the aircraft. Windshields have therefore been assigned a high priority rating.

4.4.4 Chin windows (rotorcraft)

Penetration of an exposed and (potentially) frangible rotorcraft chin window would likely result in the remaining projectile impacting with the flight controls and/or the feet/legs of the pilot. This was considered to present an immediate threat to the safety of the aircraft.

4.4.5 Wing leading edges

Wing leading edges represent a significant proportion of the exposed frontal area of most civil fixed wing aircraft. Damage to a leading edge may affect performance and handling but penetration could result in damage to main wing spar, which is critical to the structural integrity of the wing. The CS-23 category of aircraft have been prioritised because they will have lighter-weight front spars and are less likely to be protected by leading edge slats.

4.4.6 Wing braces

For some light aircraft, wing braces provide a critical load path from the wings, reacting shear loads and reducing peak bending moments at the wing root. Failure of a wing strut would therefore compromise the structural integrity of the wing.

4.4.7 Vertical and Horizontal stabiliser leading edges

The leading edges of the empennage structure include forward-facing surfaces, manufactured from lightweight materials. Similar to wings, penetration of the leading edges could damage the internal spars and compromise structural integrity. Damage or loss of empennage structure could reduce aircraft stability and control authority.

4.4.8 Aero engines

Although loss of thrust from a single engine on a multi-engine aircraft would not be sufficient to make engines a high priority, the risk of blade-off/fan burst and subsequent containment failure does.

It is not currently known whether ingestion of a drone could initiate sufficient damage to defeat the containment system, but if it did then the high-energy fragments could present a significant secondary threat to the aircraft and its occupants.

It should be noted that simulations undertaken by programmes such as ASSURE [34] suggest that ingestion of a 1.2kg DJI phantom quadcopter or a 4lb (1.81kg) fixed wing Precision Hawk Lancaster Hawkeye Mark III drone into the fan of an idealised engine would damage the fan but not result in containment failure. However, this work is currently being revisited with an improved engine model to verify the conclusion. Full-scale tests are also planned by ASSURE, which will provide greater confidence in the outcome of an engine ingestion event.

4.4.9 Propellers

For single-engine aircraft, failure or damage to the propeller could result in severe vibration and/or loss of thrust. With no redundancy in the propulsion system, this would represent a significant and time-critical threat to safety.

4.4.10 Tail rotors

Whilst tail rotors are – at least – partially sheltered from impacts during forward flight, it is still possible that they could be struck whilst moving or hovering. The lightweight construction of tail rotors and high tip speeds make them vulnerable to damage, and they are critical to maintaining controlled flight, especially when hovering.

4.4.11 Main rotor

Main rotors are more-robust than tail rotors but they are significantly more exposed during all phases of flight. Damage to a rotor blade could result in loss of lift and/or severe vibration.

4.4.12 Main and Tail rotor hub linkages

Although the probability of impacting them is relatively small (based upon their projected areas) rotor hubs and pitch control arms are critical systems that are necessary to maintain control over the aircraft.

4.5 Future aircraft

Future breeds of vertical take-off and land (VTOL) aircraft such as the Volocopter Volocity [31] and the Lilium Jet [32] are expected to share some of the same vulnerabilities as conventional aircraft, but others may be significantly different. For example, the windshield structure of the Volocopter is similar with that of a CS-27 rotorcraft but its multi-rotor configuration is not comparable to a conventional rotorcraft.

Independent multi-rotor systems have some redundancy and fault-tolerance so that the aircraft can continue to fly and land normally in the event of one or more motors or rotors failing. In this respect multi-rotors may be more tolerant of impact threats, provided that any resulting debris or vibration loads to do not initiated a cascading failure from one propulsion system to the next, or other forms of critical structural failure. These are issues that designers are addressing with certification authorities to ensure safe and fault-tolerant operation.

Other critical failure locations for electric or hybrid-electric propulsion systems may include the battery systems, flight control systems and power electronics. The position of these within the aircraft, protection afforded to them and levels of redundancy may also require specific attention when evaluating impact threats, including drone strikes.

For these emerging types of aircraft, opportunities shall be sought to identify read-across and generate data that will be applicable to future passenger-carrying aircraft operating in urban environments.

5. Task 2.4: Collision Speeds

5.1 Introduction to Task 2.4

The purpose of this task was to determine the individual speeds at which the different drones and manned aircraft are likely to be travelling in the event of a collision.

Other studies have assumed values based upon the maximum performance characteristics of the drones and conservative estimates of aircraft speeds during different phases of flight. However, this may result in over-estimates of collision speeds due to compounded conservatism and this may undermine the relevance of the results.

In this task, a large data set of historical air traffic data has been acquired by GfL, Dresden (Section 5.2) to enable statistical analysis of aircraft behaviours (Section 5.3). The result of this analysis are presented in Section 5.4, including graphs showing the ground speed of different aircraft categories as a function of altitude. This analysis is also extended in Section 5.4 to account for weather conditions in which drones are unlikely to be operating and days in which winds are negligible. Section 5.5 proceeds to enrich this data with a large database of in-flight suspected drone sightings, which are used to generate a probabilistic distribution of altitudes at which drone collisions are likely to occur. This section proceeds to describe how the drone and manned aircraft data was used together in a Monte Carlo analysis to calculate a probabilistic of aircraft speeds in collision conditions. The output from this analysis is presented in a table, including different percentile values. Finally, drone speeds are discussed in Section5.6.

It is intended that the speeds calculated by this analysis shall be used when post-processing results of collision simulations, which will include assessments at higher speeds. This will provide the ability to select a speed that is appropriate to the purpose of the query and also give some understanding of the statistical basis of the condition. It does not preclude using more-conservative assumptions or values traditionally used for certification of 'Particular Risks' such as bird strike when interpreting results. However when impact tests are undertaken it will be necessary to select a nominal test velocity which may be determined through this assessment, worst-case conditions or certification speeds. The selection of test speeds shall be made on a case-by-case basis.

5.2 Flight survey data acquisition and pre-processing

5.2.1 ADS-B traffic data

ADS-B Data was obtained from the database of Open Sky Network (OSN) [38], a non-profit association specialized in the collection, processing and storage of air traffic data from private (individuals, industrial supporters) or public (universities, governmental bodies) as well as their own receivers.

The data acquisition was limited to the altitudes up to 12,000 ft. (FL120), geographical boundaries and the year 2019.

The FL120 altitude limit was selected to represent an upper-limit of likely drone encounters. Although drone flights exceeding 10,000m have been recorded [39], the vast majority of recorded incidents have been at much lower altitudes. Analysis of the data within the Aviation Safety Network's drone sighting database [27] shows that over 97% of suspected or confirmed mid-flight drone sightings occur at altitudes less than 12,000ft. Further discussion and processing of this database is included in Section 5 (Task 2.4).

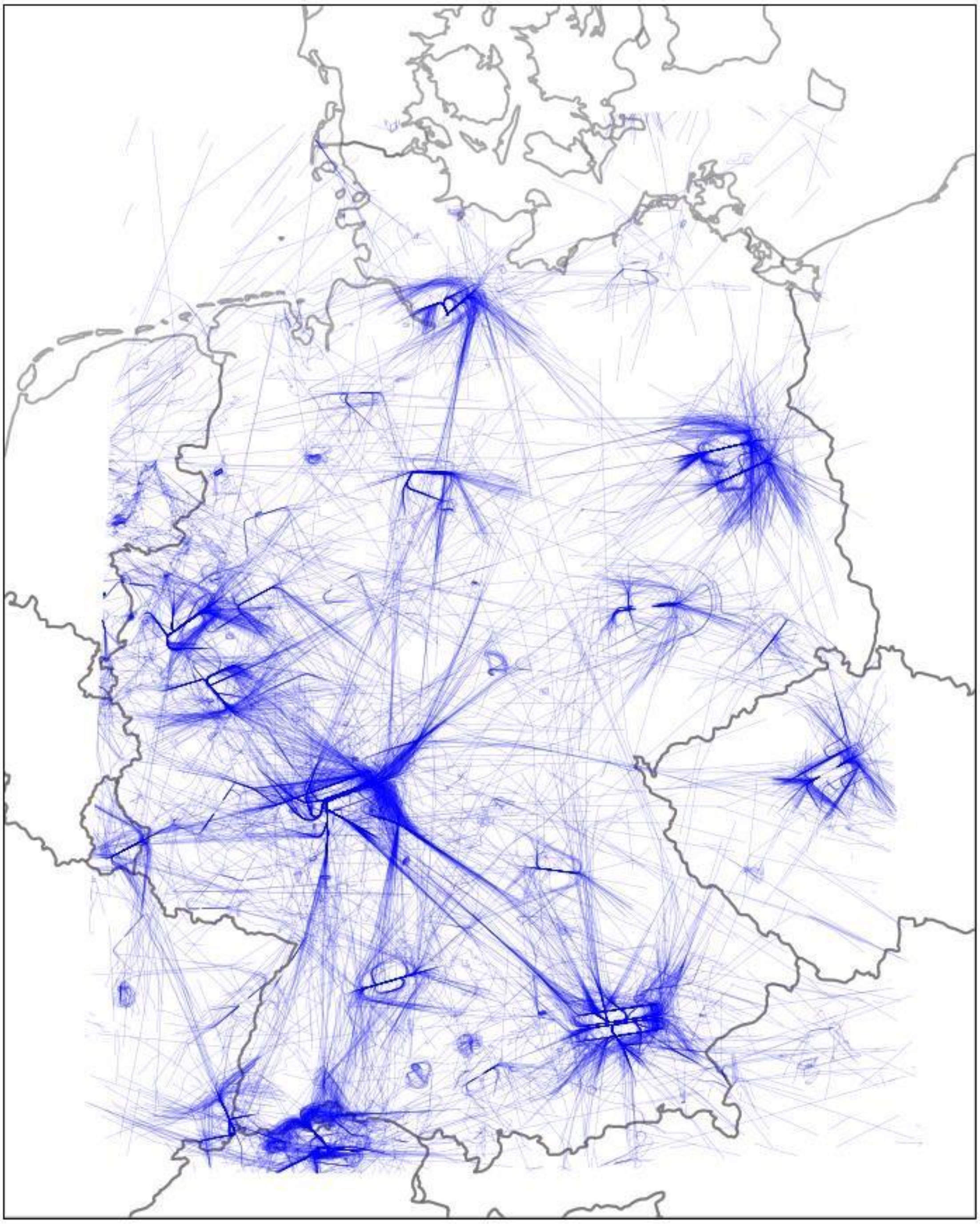
The geographical boundary for this assessment was selected to be a rectangular region that encompasses German airspace (bounding corners: WGS84 55.07°N/15.04°E and 47.27°N/5.87°E). This includes a combination of major European airports as well as rural and urban areas, and is considered to be a representative sample of flight movements within Europe. Another advantage of this region was that a rich set of data was available, including topological maps and meteorological information.

The following Table 5-1 shows an excerpt of an ADS-B data sample:

timestamp	altitude	callsign	geoaltitude	groundspeed	icao24	latitude	longitude	squawk	track	vertical_rate
2019-05-31 00:00:01	2392.68	PGT5CD	2567.94	138.346226	4b906d	52.338135	10.417480	1000.0	292.750976	-4.87680
2019-05-31 00:00:01	1127.76	BCS192	NaN	114.248272	407494	50.741287	7.460709	4153.0	231.581945	-7.47776
2019-05-31 00:00:01	274.32	PGT4Y	381.00	64.089069	4b8490	50.820053	7.216681	1172.0	317.602562	-3.90144
2019-05-31 00:00:01	975.36	TUI6773	1104.90	90.076192	3c618b	49.477441	11.291199	2142.0	278.870556	-4.87680
2019-05-31 00:00:01	518.16	HUMMEL3	655.32	46.814404	3df743	51.441061	7.937012	4426.0	292.619865	0.00000
2019-05-31 00:00:02	1112.52	BCS192	NaN	114.248272	407494	50.739395	7.456896	4153.0	231.581945	-7.15264
2019-05-31 00:00:02	312.42	SWR57R	NaN	NaN	4b1803	47.454129	8.558719	2000.0	NaN	NaN
2019-05-31 00:00:02	967.74	TUI6773	1089.66	90.076192	3c618b	49.477860	11.287264	2142.0	278.870556	-4.87680
2019-05-31 00:00:02	274.32	PGT4Y	381.00	64.060157	4b8490	50.821243	7.214974	3204.0	316.952509	-3.90144
2019-05-31 00:00:02	518.16	HUMMEL3	647.70	46.618960	3df743	51.441061	7.937012	4426.0	292.036227	-0.32512
2019-05-31 00:00:02	2385.06	PGT5CD	2560.32	137.871952	4b906d	52.339565	10.412057	1000.0	292.833654	-4.55168
2019-05-31 00:00:03	312.42	SWR57R	NaN	NaN	4b1803	47.454129	8.558719	2000.0	NaN	NaN
2019-05-31 00:00:03	266.70	PGT4Y	373.38	64.060157	4b8490	50.821564	7.214454	3204.0	316.952509	-3.90144

➨ **Table 5-1** Excerpt of ADS-B data sample from the OSN

The following Figure 5-1 depicts all trajectories of ADS-B data for one exemplary day (31-05-2019) over the target area and below FL120.



➡ **Figure 5-1** Visualisation of ADS-B data for an exemplary day – 31 May 2019

Since the ADS-B data do not contain information on the aircraft model itself, the ICAO 24-bit (Mode S) identifier of the on-board transponder was used to assign the corresponding airframe (including manufacturer, model, typecode and ICAO-type); the link between these values was made using the Open Sky Network's aircraft database. The ICAO-type was also used to filter the data into basic groups (Land Plane (L), Helicopter (H)) and count and type of engines (Jet (J), Piston (P), Turboprop/Turboshaft (T)).

The sourced data contained approximately 1.7 billion data points[4], distributed between the different basic aircraft categories as shown in Table 5-2.

Aircraft category	No. of data points
Jet aircraft	~ 1.4 Billion (~ 82%)
Piston aircraft	~ 200 Million (~ 12%)
Turboprop aircraft	~ 50 Million (~ 3%)
Helicopters	~ 50 Million (~ 3%)

Table 5-2 Approximate database sizes per aircraft category

When sourcing this data it was determined that the amount of data available on the OSN servers was more than sufficient. Actual sample size was not limited by data availability, but rather by computing time, as each data point furthermore needed to be correlated with the terrain, dawn/dusk times and wind data from nearby weather stations in order to achieve the objectives of this activity.

5.2.2 Digital Terrain Model

ADS-B data collected contained the geometric altitude above Mean Sea Level (MSL) as reported from GNSS. To derive the height above ground level – which is a more-useful measurement when considering drone collisions – information about the topography (elevation) was required. This information was obtained for Germany from official sources – the *Federal Agency for Cartography and Geodesy* – in the so-called DGM200 format [40].

As an example, Figure 5-2 shows an excerpt of the DGM200 for the greater Dresden area.

The DGM200 describes the shape of the earth's surface in a regular grid with a resolution of 200 m. According to [40], the following accuracies/resolutions apply for the DGM200:

- Resolution:
  - Horizontal[5]: 200 m
  - Vertical: 0.01 m
- Accuracy:
  - Horizontal: +/- 5 m
  - Vertical: +/- 3 – 10 m

The data are given in tabular form in ASCII Format, using the UTM32 coordinate system. DGM data generally do not include vegetation or buildings.

[4] Recording frequency of ADS-B data can be irregular, ranging from mostly one data point per second up to tens of seconds in rare events.

[5] Higher horizontal resolutions are available but would greatly extend the calculation times, as each data point has to be correlated with the given topography information. The DGM200 already consists of 9.2 million data points.

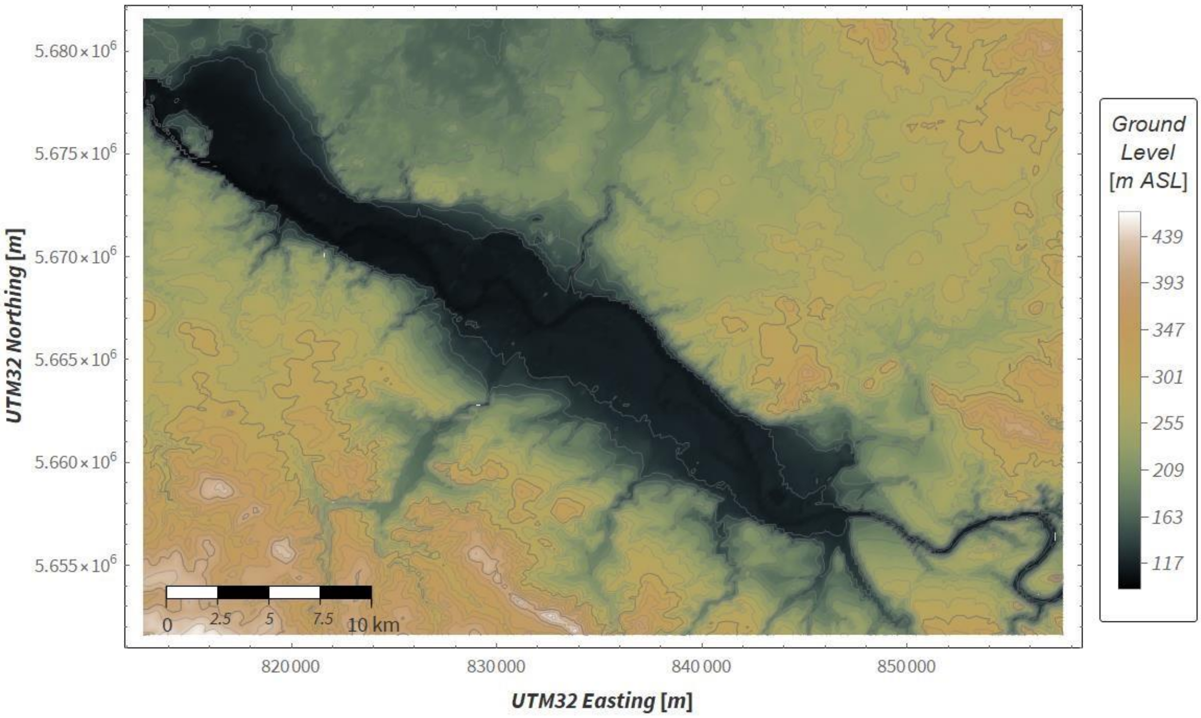


Figure 5-2 Exemplary visualisation of digital terrain data –greater Dresden area

5.2.3 Weather Data

The baseline assessment of flight speeds did not discriminate between different weather conditions, but later analyses explored the effect of weather and daylight conditions.

Weather data was provided by *Deutscher Wetterdienst* (DWD), a public institution with partial legal capacity under the *Federal Ministry of Transport and Digital Infrastructure* (BMVI). This source contains information on wind speed, wind direction, static air pressure and temperature for every meteorological station in Germany.

The data's resolution varies from intervals of ten minutes for temperature, wind direction and wind speed up to one hour for static air pressure. The weather data from meteorological stations cover the whole region of interest but contain no additional information on conditions above ground level.

For this study, historical wind data of all weather stations in Germany were downloaded from the open access file server of DWD [41, 42], and a database was generated containing all wind observations in 2019 in 10 minute intervals.

The wind at the specific ADS-B data points could then be interpolated as a weighted arithmetic mean of the three closest stations based on the square of the distance to them (to account for the increasing inaccuracy of wind speed correlation with the distance).

5.2.4 Day and Night

To distinguish between day and night operations the following definition of night, as found in the Standardised European Rules of the Air (SERA), has been used:

> *" 'night' means the hours [...] when the centre of the sun's disc is 6 [or more] degrees below the horizon [(civil dusk/dawn)]"* [43]

To simplify the problem, a grid-based model, similar to the digital terrain model, was generated, containing information on the civil dusk/dawn at individual geographical positions for every single day in the year 2019. A grid resolution of 0.1 degrees was deemed to be sufficient, leading to negligible deviations between actual and estimated dusk/dawn (always less than 1 minute).

5.2.5 Maximum Take-Off Weight

To enable classification of the aircraft by their Certification Specifications, the maximum take-off weight (MTOW) of the different aircraft types was required. After an analysis of the downloaded data a spreadsheet containing the aircraft types was created and rare aircraft (very few data points) were removed. For the remaining models the MTOW was primarily extracted from the EUROCONTROL Aircraft Performance Database [44] (~70 % of aircraft). For missing records, the MTOW was taken from the EUROCONTROL SKYbrary repository [45] (~20 %) or from official manufacturer or supplier handbooks or spec sheets (~10 %).

5.3 Statistical Analysis of Speed Distribution for Specific Aircraft Categories

5.3.1 Aircraft Classification

The intent of this flight survey activity was to produce probabilistic distributions of ground speed *vs.* height above ground, for different categories of aircraft. It was therefore necessary to define these categories using metrics that could be evaluated for a very large number of data points, via the available data[6].

Table 5-3 shows the eight different sub-categories that were defined for separate processing. Here, the CS-25 category is split into two and CS-23 is split into four, to differentiate between common propulsion systems and configurations.

Aircraft sub-category	Description	Certification Specification
AC1	Large Jet Aircraft with MTOW > 8618 kg	CS-25
AC2	Large Turboprops with MTOM > 8618 kg	
AC3	Small Jet Aircraft with MTOM ≤ 8618 kg	CS-23
AC4	Small Turboprops with MTOM ≤ 8618 kg	
AC5	Piston aircraft with 2 engines	
AC6	Piston aircraft with 1 engine	
AC7	Large Helicopters with MTOM > 3175 kg	CS-29
AC8	Small Helicopters with MTOM ≤ 3175 kg	CS-27

➨ **Table 5-3** Aircraft Classification Scheme

5.3.2 Data Preparation and Selection Process

To reduce the amount of data for the statistical analyses (from approximately 1.7 billion points) and therefore the computation time, a representative random sample was taken from the database. A total of 30 days were

[6] Whilst it is noted that other factors may contribute to the Certification Specification of an aircraft, the mass values were considered to be appropriate for assessing the majority of cases and general velocity trends.

randomly selected from which all data points were taken. Figure 5-3 shows the 30 days from 2019 that were randomly selected.

Within this sample, the number of data points per aircraft sub-category was limited to 100,000 in a given day. For days where the available data exceeded this, the 100,000 points were randomly-selected.

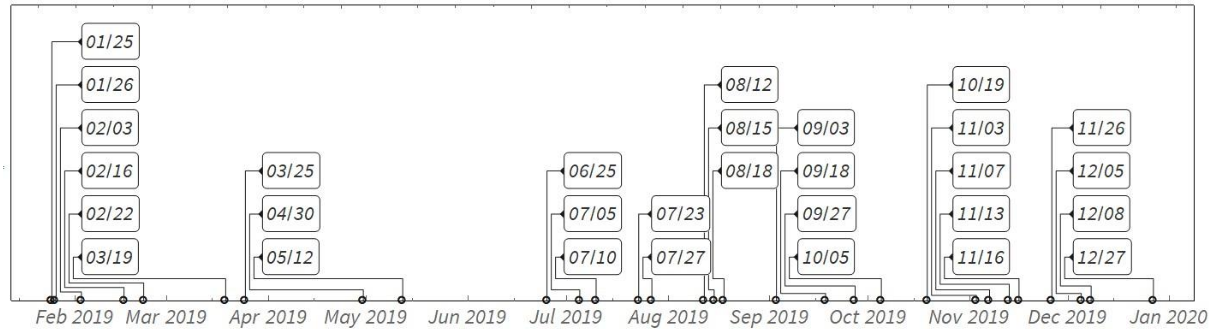


Figure 5-3 Random 30 days of traffic data selected from the database

After this selection process, the GNSS altitudes (above sea level) given in ADS-B data were converted into a height above ground for each selected data point using the digital terrain model. The aircraft type for each data point was then looked-up from the OSN airframe database using the reported ICAO 24-bit identifier of the on-board transponder.

Some removal of outlier points was performed afterwards, comprising of the following steps:

- Removal of obviously erroneous data:
  - Ground speed greater than 500 m/s
  - Geometric altitude greater than 20,000 ft
  - Very low ground speeds, different for each aircraft sub-category (from 10 kt for jets, down to less than 0.1 kt for helicopters)
- Removal of low height data points (less than 50 ft) to exclude runway/taxiway operations
- Removal of data points not included in terrain model (outside Germany)
- Removal of data points where aircraft could not be identified

To enable graphs of ground speed vs altitude be plotted, the remaining data was sorted into 'bins' corresponding to altitude bands from zero to 12,000 ft. For heights below 5000 ft, a 500 ft increment was used and for heights above 5000 ft up to 12000 ft, a 1000 ft increment used.

This filtered, cleaned and binned data was then processed to calculate mean speeds, standard deviations and specific quantiles for each aircraft classification (AC1-AC8) at each altitude. The following ground speed quantiles were processed:

- $Q_{0.01}$ (1% percentile)
- $Q_{0.05}$ (5% percentile)
- $Q_{0.25}$ (25% percentile)
- $Q_{0.5}$ (50% percentile)
- $Q_{0.75}$ (75% percentile)
- $Q_{0.95}$ (95% percentile)
- $Q_{0.99}$ (99% percentile).

5.4 Flight survey results

5.4.1 Baseline results

The baseline results presented here used all of the filtered, cleaned and binned data defined in the previous section, to evaluate ground speeds vs. height above ground for each of the 8 sub-categories of aircraft. An example of the output is shown graphically in Figure 5-4 and in tabular form in Table 5-4 but the full set of outputs are included in Appendix C.1.

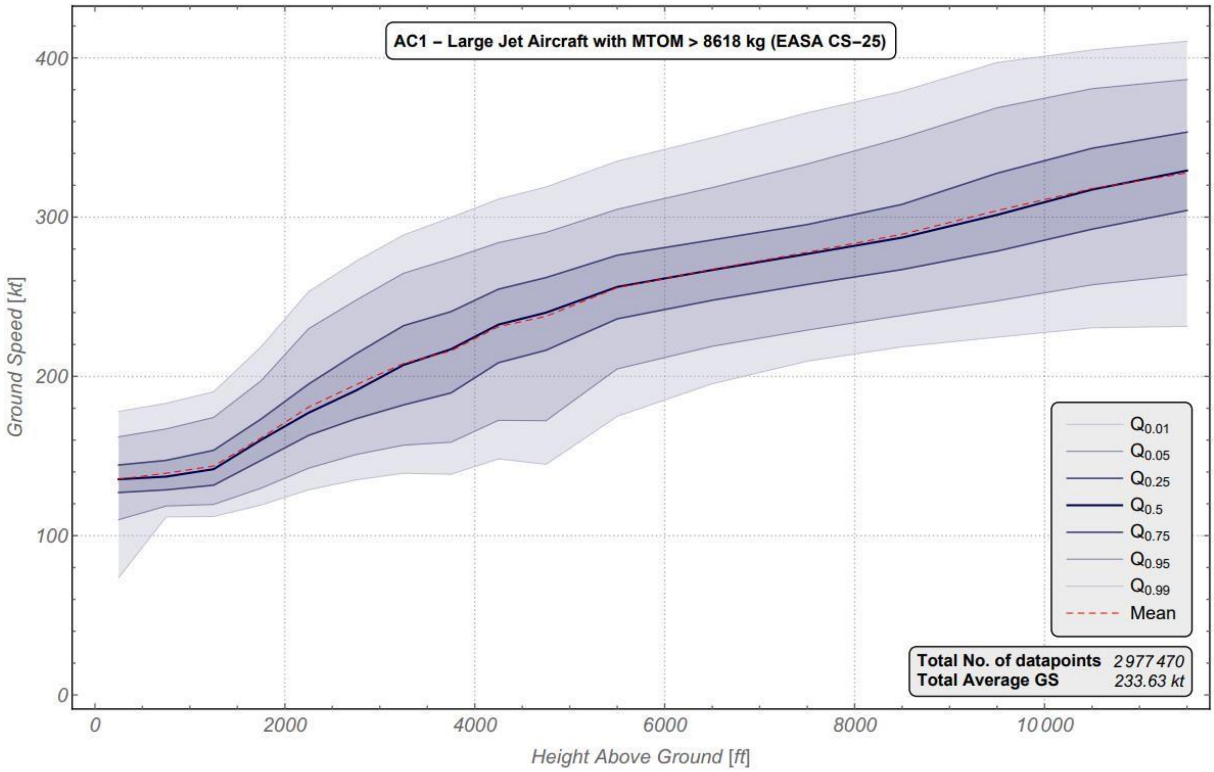


Figure 5-4 Ground speed distribution as a function of height above ground – AC1

Altitude Band	N	Mean	St.Dev.	$Q_{0.01}$	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$	$Q_{0.99}$
50 ... 500 ft	172959	135.49	17.9	73.6	110.	127.1	135.42	144.37	162.08	178.
500 ... 1000 ft	126267	139.18	15.75	111.76	118.6	128.76	137.06	147.26	167.	183.1
1000 ... 1500 ft	130420	143.71	17.6	112.02	119.62	131.67	141.74	153.58	174.23	190.32
1500 ... 2000 ft	137413	161.36	21.26	119.27	129.81	147.3	160.13	173.23	197.23	218.56
2000 ... 2500 ft	161032	180.67	26.57	128.76	142.34	162.93	177.13	195.17	229.94	253.2
2500 ... 3000 ft	200140	194.78	30.12	135.	150.96	173.4	191.16	214.22	247.82	272.24
3000 ... 3500 ft	184949	208.1	33.99	139.18	156.82	182.08	207.18	231.84	264.76	288.77
3500 ... 4000 ft	212341	216.	36.06	138.54	158.67	189.61	217.08	240.68	273.91	299.79
4000 ... 4500 ft	136460	231.26	34.62	148.19	172.41	208.6	232.54	254.77	283.98	311.28
4500 ... 5000 ft	147019	237.72	35.96	144.78	172.17	216.41	240.02	262.03	290.4	318.93
5000 ... 6000 ft	213318	255.68	31.43	174.91	204.71	236.12	256.18	276.06	304.9	335.09
6000 ... 7000 ft	203349	267.2	30.87	195.35	218.89	247.78	266.81	285.67	318.51	349.87
7000 ... 8000 ft	202055	277.92	31.47	209.54	229.05	257.75	276.86	295.32	333.31	365.43
8000 ... 9000 ft	211932	289.23	33.4	218.56	238.3	267.09	287.14	307.99	349.8	379.01
9000 ... 10000 ft	245495	304.05	36.91	224.61	247.39	278.63	301.4	327.55	368.63	397.04
10000 ... 11000 ft	206155	317.92	37.77	230.49	257.51	292.44	317.28	343.21	380.64	404.98
11000 ... 12000 ft	86166	327.73	38.07	231.39	263.9	304.18	329.19	353.36	386.4	410.41

Ground Speed in kt

➨ **Table 5-4** Ground speed vs height above ground quartiles and statistics – AC1

The statistical analysis of flight speeds showed expected behaviours for all sub-categories of aircraft, with velocity generally increasing with altitude and the higher-performance aircraft attaining greater speeds. Minor outlier points/discrepancies are noted as follows:

- A small step in velocity is observed between 4,000ft and 4,500ft on some configurations. This is most-noticeable for the AC2 (large turboprop) and AC6 (single piston engine) but is also seen for AC4 (small turboprop).
- Spikes in the two uppermost quantiles ($Q_{0.99}$ and $Q_{0.95}$):
    - Between 1,000ft and 1,500ft for AC3 (small jets), and;
    - Between 8,000ft and 10,000ft for AC7 (large helicopters)

With the exception of these minor issues, the results were judged to be robust, with a particularly good dataset for the AC1 airliners. Robustness was tested by using a different set of randomly-selected dates and the differences were negligible, with average ground speeds mostly varying by less than 1 kt.

5.4.2 'Drone flying weather' scenario

The baseline analysis described above was repeated with the source data filtered to exclude conditions in which flying of small (<5kg) drones is less likely i.e. in winds greater than 10m/s (typical recommended maximum for multi-rotors) or at night. The purpose of this was to determine whether the baseline data was being significantly influenced by conditions in which the threat of high-altitude drone flights might be greatly reduced.

It should be noted that the hypothesis that drones are unlikely to be flown at high altitudes in these conditions is not based upon published evidence. However, through discussions with drone pilots it was reasoned that an operator would be less likely to attempt such flights because the risk of loss would be increased, battery usage would be increased (therefore limiting altitude) and aerial footage in the dark would not be effective. Conversely it could be argued that drone operators could lose control in windier weather, but multi-rotor drones can be readily brought down to ground so, on-balance, it was judged that this was a relevant scenario.

Filtering the dataset to exclude night time operations (see Section 5.2.4) reduced it by approximately 35%. Removal of data points where the interpolated maximum wind speed in the last 10 minutes exceeded 10 m/s removed a further 7%.

Only minor differences were observed between the results of this scenario and the baseline analysis, with the average difference being approximately 1.25 kts across all eight sub-categories. Further details of this comparison are included in Appendix C.2.

Therefore, it was decided that the baseline dataset should be used in preference to this scenario.

5.4.3 Low wind scenario

In addition to the 'drone flying weather' scenario, the baseline analysis was repeated with the source data filtered to only include flights in low wind conditions. This was intended to provide an approximation of True airspeed from the measured ground speed.

The filter was set to exclude data points for which the mean wind speed exceeded 2 m/s within the previous 10 minutes. This resulted in 75% of the dataset being excluded from the analysis.

Only minor differences were observed between the results of this scenario and the baseline analysis, with the average difference being approximately 3.4 kts across all eight sub-categories. Further details of this comparison are included in Appendix C.2.

It was decided that the baseline dataset should be used in preference to this scenario.

5.5 Statistical Analysis of Aircraft Collision Speeds

5.5.1 Analysis of drone sightings

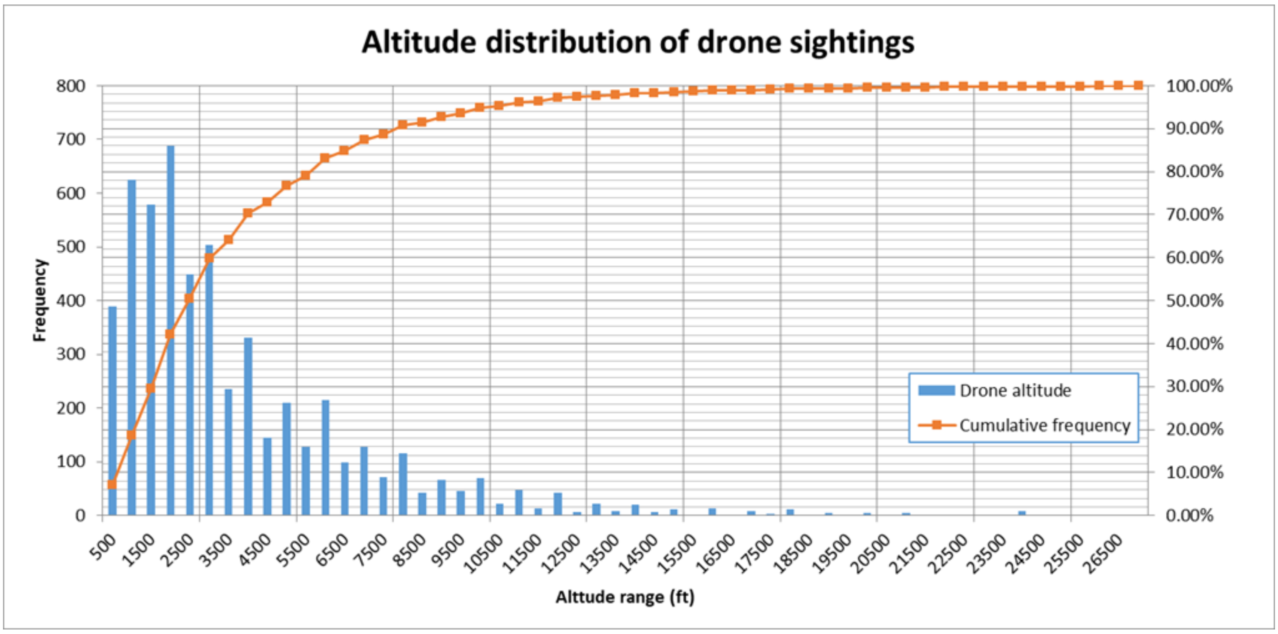
The previous sections of this chapter described how the probabilistic distribution of aircraft ground speeds was calculated as a function of altitude. This provides an evidence-based justification for the speed of different categories of aircraft during lower-altitude phases of flight, rather than relying upon generalised performance figures.

When considering mid-air collisions with drones, other major factors include the relative velocity of the drone, and the altitude at which the collision occurs (since this is used to calculate the aircraft speed). If a database of drone movements were available (similar to the ADS-B data used for manned aircraft) then a detailed analysis of potential encounters could be undertaken. However, such a database is not known to exist.

The altitude and speed capabilities of individual drones can be identified from their performance specifications, but this does not provide any indication as to how they are used in practice. The advancement of drone technologies is such that even low-cost systems have the physical potential to operate at great heights above ground and at a wide range of speeds. For example, altitudes of over 10 km have been attained by small drones [39] but this is not considered to represent typical exceedances of the 400 ft operating ceiling. Whilst using maximum altitude and speed figures might represent a conservative assumption, it is also likely to over-estimate the speeds at which collisions are most likely to occur.

Instead, an alternative approach has been used which uses the results of the flight data survey and also a large database of drone sightings (or 'near misses'), collated by the Aviation Safety Network [27]. This database currently contains over 11,000 entries documenting world-wide drone sightings from aircraft and confirmed/unconfirmed collisions. It has been compiled from a wide range of referenced sources and continues to be updated, along with supporting information on the ASN website.

Approximately half of the entries include altitude data[7], which has been processed as a frequency plot in Figure 5-5. Results from this plot show that over 97% of suspected drone encounters occurred below 12,000 ft (FL120), which was the upper limit used within the manned aircraft flight survey. Furthermore, 50.4% occurred below 2,500 ft and 76.8% below 5,000 ft.



➨ **Figure 5-5** Drone sightings by altitude (using data from [27])

It should be noted that the vast majority of entries in this database are based upon reported in-flight drone sightings and so the veracity of each entry cannot be fully-verified. It is likely that many of the sightings are subject to some error in the estimation of separation distance (between the observing aircraft and the drone), the altitude, or the classification of a flying object as a drone. However, despite these potential limitations, it represents a large and relevant dataset which is assumed to be appropriate for the purpose of defining an approximate distribution of drones by altitude.

5.5.2 Monte Carlo assessment of collision scenarios

A Monte Carlo analysis was used to combine the flight survey results with the drone sighting data. This assumed that the distribution of mid-flight drone sightings is representative of 'near misses' (or rather 'near collisions') which could equally have been collisions in less fortunate circumstances.

The results of the aircraft flight survey included mean speeds and standard deviations for each aircraft sub-category (AC1 to AC8). Assuming a normal, Gaussian distribution it is possible to represent the probabilistic distribution of speeds for each aircraft sub-category at each of the altitude bands.

The analysis was set-up so that the altitude of each of the 5,255 'near misses' were evaluated 100 times against the flight survey data. To achieve this, the 'near miss' altitude was matched with the relevant flight survey altitude band and the correct mean speed and standard deviation identified. A speed was then calculated using

[7] For the purpose of this assessment, altitude is assumed to be analogous to height above ground. Whilst these are different quantities and may result in some error where the ground level is at a significant height above sea level, this will result on over-estimates of height and will therefore be conservative once aircraft speeds have been calculated.

a random sampling of the Gaussian distribution. This process was repeated 100 times for each 'near miss' altitude and the whole process was repeated for the eight aircraft sub-categories.

The output from this Monte Carlo analysis was a matrix of approximately ½ million data points (aircraft speeds) for each of the eight aircraft sub-categories. A frequency analysis was then conducted on each matrix and speeds calculated at 50th, 75th, 95th and 99th percentile values.

A robustness check was made on the Monte Carlo process, repeating it with the same input data but a fresh sampling of the aircraft speeds. As expected, the maximum and minimum values recorded within the matrix of speeds was shown to vary, but the processed speeds (at different percentiles) remained within less than 1 kt.

5.5.3 Aircraft collision speeds

The output from this process, using the baseline flight data, is shown in Table 5-5. The calculated values represent the ground speeds at which different categories of aircraft would collide with drones, assuming that they encounter them at the same distribution of altitudes as observed over the last six years.

Percentile speed	Large Jet (CS-25)	Large turboprop (CS-25)	Small jet (CS-23)	Small turboprop (CS-23)	Twin piston (CS-23)	Single piston (CS-23)	Large helicopter (CS-29)	Small helicopter (CS-27)
	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8
50th	189	184	196	165	137	112	127	105
75th	245	225	236	195	156	139	143	127
95th	312	274	289	245	183	180	168	159
99th	354	305	330	285	202	207	191	184

Table 5-5 Probabilistic aircraft speeds in mid-air drone collisions using baseline flight survey data (speed in knots)

The same analysis has been completed using the 'drone flying weather' and 'low winds' flight survey datasets and equivalent tables produced. For the fixed wing aircraft (where the datasets remained large) the calculated speeds were typically within 3% of the baseline figures but the rotorcraft results reduced by up to 16%. It is proposed that the baseline results be used since the datasets are better populated.

The benefit of using this data is that it distils all of the available information into a single distribution of speeds from which the percentile values can be selected depending upon the level of conservatism required. Alternative approaches in which worst-case conditions are assumed or conservative assumptions are compounded are more-likely to lead to over-estimates which are harder to justify on a 'balance of probability' basis.

This data is intended to be used for general categories of aircraft. If using this data for specific aircraft models, checks should be made that the proposed speeds are appropriate to the performance limits of the aircraft.

5.6 Drone speeds

Collisions scenarios will depend upon the velocity (speed and direction) of the manned aircraft and the drone.

The performance capabilities of major drone products are defined within their product specification[8] but in most cases these represent limiting, rather than typical values.

The approach used to survey the speeds of manned aircraft could not be repeated for drones because source data for (legal or illegal) drone flights was not available. Also, drones can accelerate rapidly and are not bound by the same limits as manned aircraft on their approach and departure phases of flight. Therefore, the speeds of fixed wing and multi-rotor drones are not linked to altitude in the same way as manned aircraft i.e. the speed of a drone (within its performance envelope) is more about how the operator flies it than what it is capable of.

The flight dynamics of multi-rotor and fixed wing drones are very different and so their likely operating speeds are discussed separately.

QinetiQ's drone pilots have been consulted to discuss likely behaviours, with the intent of justifying a credible (rather than absolute worst-case) flight speed for use in collision assessments.

5.6.1 Fixed wing drone speeds

Fixed wing drones will operate within a velocity range between their stall speed and maximum flight speed (equivalent to the V_{NE} for manned aircraft).

In low-level scenarios (e.g. less than 500 ft), where the drone is doing circuits within line of sight, the actual speed may vary considerably between these two limits, depending upon the skill and aggressiveness of the operator. The greatest speeds are achieved with combinations of thrust and manoeuvres so upper-bound speeds are highly transient and not sustained. It is proposed that a maximum low-level velocity of 45 kts is used for this study, based upon the quoted performance of fixed wing drones such as the Parrot Disco (50 mph/ 43.4 kts) and Yuneec Firebird (51 mph/ 44.3 kts). The senseFly eBee has a greater quoted maximum speed (68 mph/ 59.0 kts) but senseFly clarified that this is an extreme upper bound and would not occur in normal operation, where flight speeds of 23 kts are typical.

If intending to fly at higher altitudes or transiting between distant points, then high speed flight would be inefficient and would rapidly deplete the batteries. In these cases, operators are more likely to fly at the drone's cruise speed. It is proposed that a cruise speed of 40 kts should be used, which is compatible with assumptions made in EASA's counter-unmanned air system activities.

The above speeds are intended to provide guidance for generic fixed wing drone configurations. When evaluating collisions with specific drones, it may be justifiable to use their quoted performance figures or the maximum permissible speeds for the relevant class e.g. 19 m/s for C0 and C1.

For some drone configurations, it is possible that lower flight speeds could result in greater damage to a manned aircraft. With 'pusher prop' designs, the motor and spinner face backwards and are usually mounted on the rear of the drone, whereas the nose of the drone may be solid/hollow foam either with or without a small FPV camera installed[9]. In these cases high-speed frontal impacts, (where the collision speed is the sum of the manned aircraft and drone speeds) may not be as severe as a rearward impact into the hard motor (where

[8] This is not always the case for more-generic designs, such as the 'Racing Style' quadcopters and fixed wing aircraft, where performance also depends upon other variables such as the types of batteries used. Also, these low-cost products are made to greatly reduced production budgets and formal performance testing is not undertaken/reported.

[9] Batteries would normally be mounted centrally, to maintain an appropriate centre of gravity with respect to the longitudinal aerodynamic centre of lift.

the collision velocity is equal to the manned aircraft speed minus the drone's speed). For the latter, net collisions speeds are worse when the drone is going slowly. This trend does not apply for 'puller prop' configurations, as the motor and spinner are on the front of the drone.

5.6.2 Multi-rotor drone speeds

Multi-rotor flight does not require maintenance of forward speed and so can be flown very differently.

In low level scenarios, speeds will depend upon the type of drone and the skill so of the operator. These may credibly range from hovering manoeuvres to full-speed runs under manual control ('stabilised' modes for most drone types, but Racing-Style configurations may also have 'Acro' mode for greater speed and manoeuvrability). A realistic height limit for fast, aggressive manual flying is assumed to be 500 ft. Speeds for the proposed multi-rotors are shown in Table 5-6, though more-generic values that are aligned to the drone classes outlined in

Table 2-1 could be adopted.

In mid-level scenarios (between 500 ft and 1,000 ft), it is more efficient to fly at reduced speeds to either maximise endurance or range. Within this height band it is proposed that cruise speeds (non-Sport mode) should be assumed (max range speed if available).

For high-level flight (greater than 1,000 ft), it is assumed that altitude is the objective of the flight. In this scenario it is proposed that the drone would have minimal ground speed in order to avoid drifting away from the operator. Therefore assume that the ground speed is zero.

	DJI Mavic Mini	DJI Mavic 2	Low cost, Racing style	DJI Inspire 2
Maximum speed (Sport mode on)	13 m/s	20 m/s	~27 m/s[10]	26.1 m/s
	25.3 kts	38.9 kts	52.5 kts	50.8 kts
Cruise speed (Sport mode off)	8 m/s	13.9 m/s	~15 m/s[11]	8 m/s[12]
	15.6 kts	27 kts	29 kts	15.6 kts

[10] No OEM performance data was available for the generic racing style configuration e.g. Eachine Wizard X220, but 60 mph or 27 m/s seemed reasonable based upon reported user testing (68 mph was recorded by one experienced user).

[11] A nominal 15 m/s is proposed for a 'cruise speed'.

[12] The cruise speed of the Inspire 2 is not quoted in the manufacturer's specifications but 8 m/s was reported by users.

Table 5-6 Multi-rotor flight speeds

6. Task 2.5: Collision Orientation and Vectors

6.1 Introduction to Task 2.5

Comprehensive definition of a collision between two bodies in free space e.g. a drone and an aircraft, involves many variables, though these may be of differing levels of importance to the outcome of the event. For example, primary variables include the location that the drone strikes the aircraft and their relative speeds. Secondary variables describe the relative angles of yaw, pitch and roll of the vehicles, and tertiary variables include sideslip and rise/sink rates as well as rotational velocities at the time of impact.

For the primary variables, impact locations have been proposed in Task 2.3 and collisions speeds were discussed in Task 2.4. In this section, the secondary and tertiary set-up variables are discussed and values are either proposed, or actions are taken to define them as part of the collision modelling activities.

The approach outlined in this section of the report has been informed by the methods used in other studies (outlined in the state-of-the-art review [8]) and QinetiQ's own experience in undertaking mid-air drone collision studies.

The orientation axes considered in this section are highlighted in Figure 6-1 using a DJI Inspire 2 for reference.

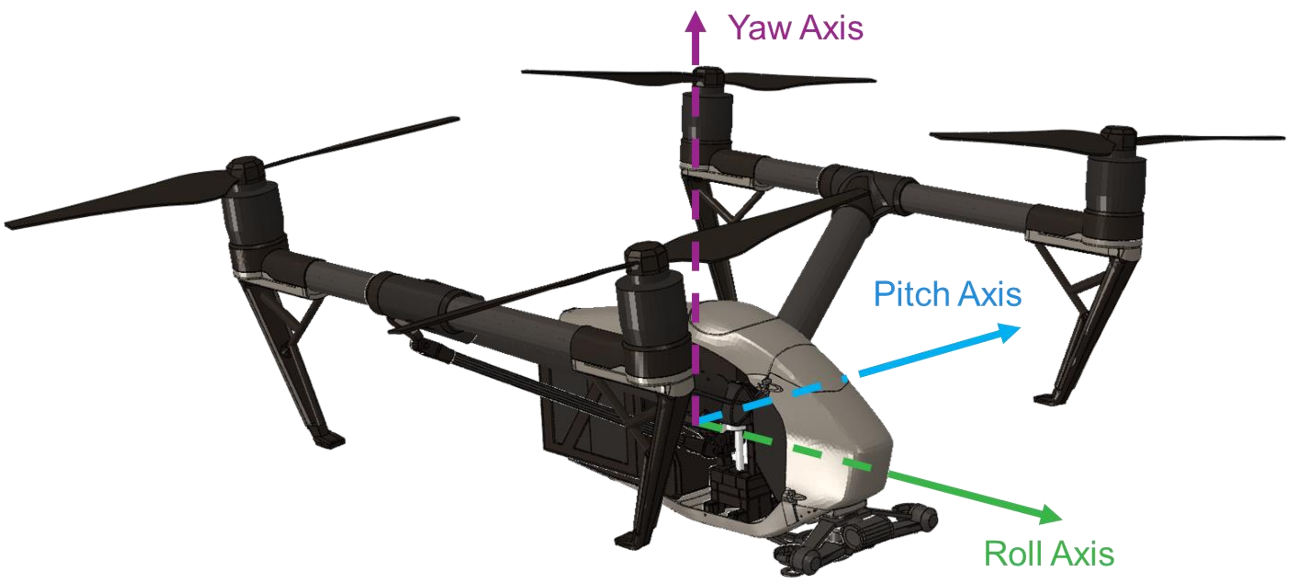


Figure 6-1 Orientation axes nomenclature, example: DJI Inspire 2

6.2 Yaw axis

The yaw angle for conventional fixed wing configurations (CS-23, CS-25 and fixed wing drones), is defined as the angular difference between the aircraft's flight path (velocity vector) and the aircraft's heading in the yaw axis (as illustrated in Figure 6-2). Typically the difference in heading and velocity vector only occurs for a short time period (e.g. the period between rudder input and change in heading) or is caused by environmental effects such as off axis wind loading (which are assumed to act equally on the manned and unmanned aircraft).

For manned rotorcraft (CS-27 and CS-29) and multi-rotor drones, their ability to fly in all directions increases the yaw angles that they can achieve (also illustrated in Figure 6-2). However, for manned rotorcraft in cruise conditions (where impact speeds are greatest), yaw inputs would not normally be commanded and the aircraft is trimmed by the vertical stabiliser.

Discounting the effect of wind (which is assumed to act on both the drone and aircraft), it is proposed that fixed wing drones and all manned aircraft (fixed wing and rotorcraft) in cruise will be flying with zero yaw angle. It is also assumed that their headings are aligned (greatest collision speed) so that they are either on the same course or mutually opposing courses, as illustrated in Figure 6-3.

The nominal condition shown in Figure 6-3 also shows the drone to have zero yaw angle, so that its axis is aligned with that of the manned aircraft. This represents a likely scenario if the headings are aligned, but multi-rotor drones are capable of rapid yawing manoeuvres and are less constrained in their yaw angles. Therefore, it is proposed that the relative yaw angle of multi-rotor drones should be reviewed once the threat models have been developed, to understand how their orientation affects the severity of impact.

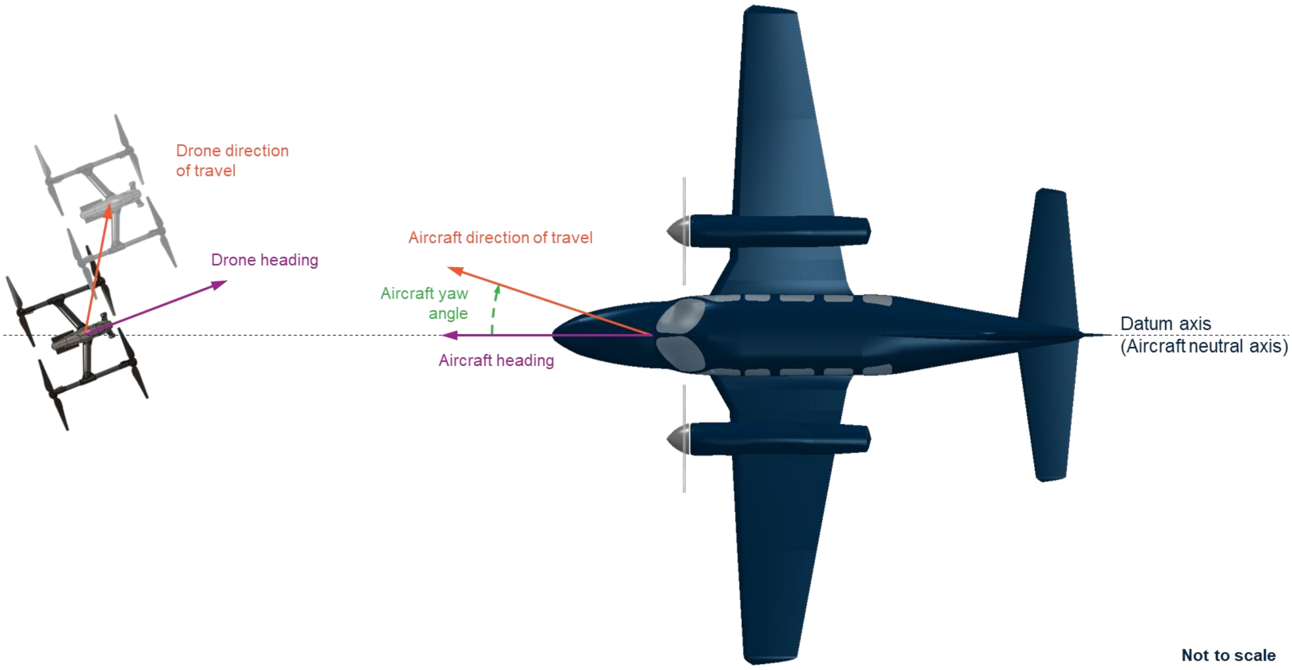
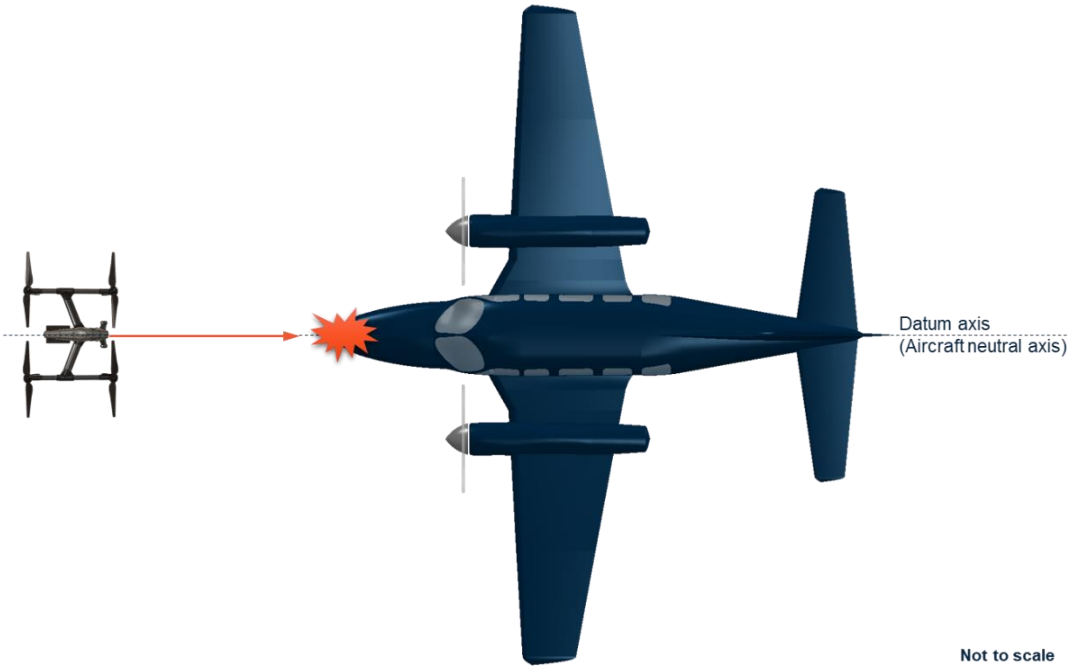


Figure 6-2 Illustration of discussed yaw conditions



➡ **Figure 6-3** Proposed nominal yaw impact condition

6.3 Pitch Axis

The pitch angle for conventional fixed wing configurations (CS-23, CS-25 and fixed wing drones) is defined as the angular difference between the aircraft's heading and a datum axis (typically the ground), as illustrated in Figure 6-4.

In practice, the pitch angle of fixed wing drones and aircraft depends upon their flight speed and current manoeuvres. It is assumed that the drone is flying straight and level at the time of impact and requires minimal pitch angle to sustain 1g conditions. However, within the altitude range in which drones collisions are most likely to be encountered (Section 5.5), most fixed wing manned aircraft types will still be climbing to or descending from their cruising altitudes. It would therefore be desirable to consider generic pitch angles that might be expected of manned aircraft in these conditions.

For manned rotorcraft (CS-27 and CS-29) and multi-rotor drones, pitch angle and flight path (velocity vector) are not directly coupled, as sink/climb manoeuvres can be controlled by thrust input (as illustrated in Figure 6-4).

With multi-rotors, it shall be assumed that the drone is flying straight and level at the time of impact, but the pitch angle will depend upon whether the operator (or autopilot) maintains demand for the same forward speed until impact or whether the drone is put into a neutral (or other) orientation as a reaction to the impending collision. The neutral pitch illustrated in Figure 6-5 is consistent with the assumptions made in other drone collisions programmes but it would be desirable to consider how alternative multi-rotor pitch angles might affect the severity of the collision.

Under steady-state cruise conditions, the fuselage of a rotorcraft is provisionally assumed to remain level, though this should be reviewed further for aircraft-specific case-studies.

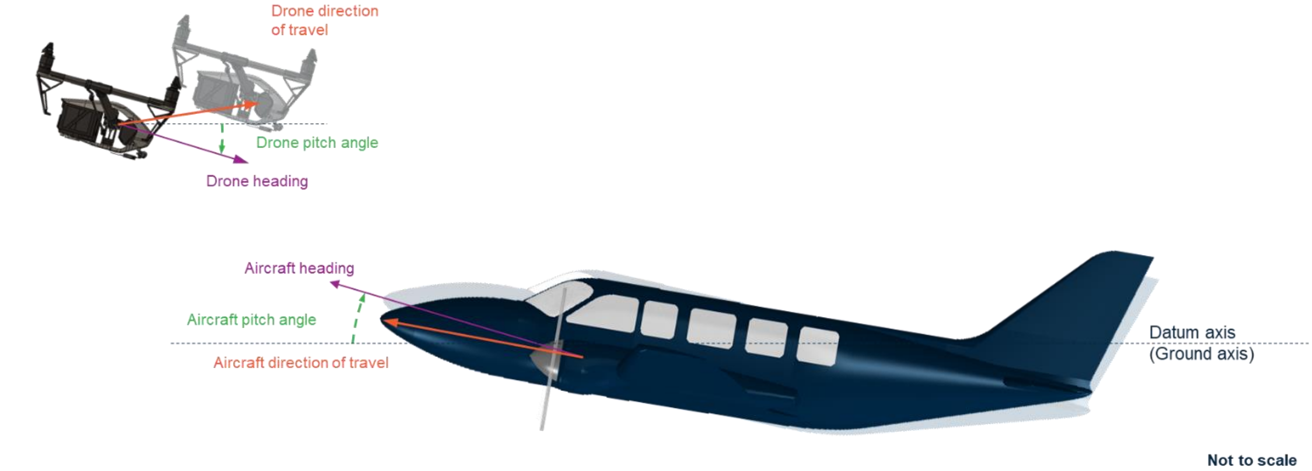


Figure 6-4 Illustration of discussed pitch conditions

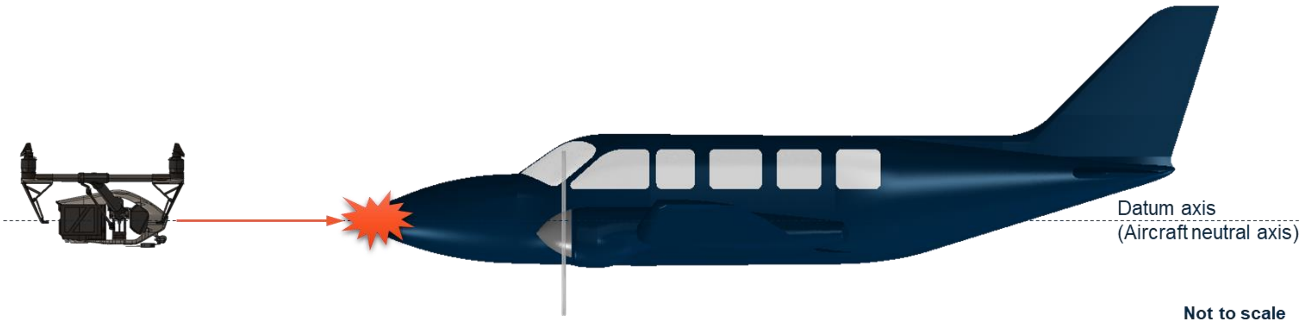


Figure 6-5 Proposed nominal pitch impact condition

6.4 Roll Axis

The roll angle (bank angle) for conventional fixed wing configurations (CS-23, CS-25 and fixed wing drones) is defined as the degree of rotation in the roll axis against a datum axis (typically the ground). Maximum intentional bank angles for airliners is approximately 30 degrees (fixed wing drone manoeuvres could greatly exceed this), though this will be a transient event during a turn and normal flight conditions will have zero roll. It shall therefore be assumed that fixed wing aircraft and drones have zero relative roll, as illustrated in Figure 6-6.

For manned rotorcraft (CS-27 and CS-29) and multi-rotor drones, the degree of rotation in the roll direction is expected to be relatively small. Therefore it is proposed to also assume zero roll angle for rotorcraft and multi-rotors.

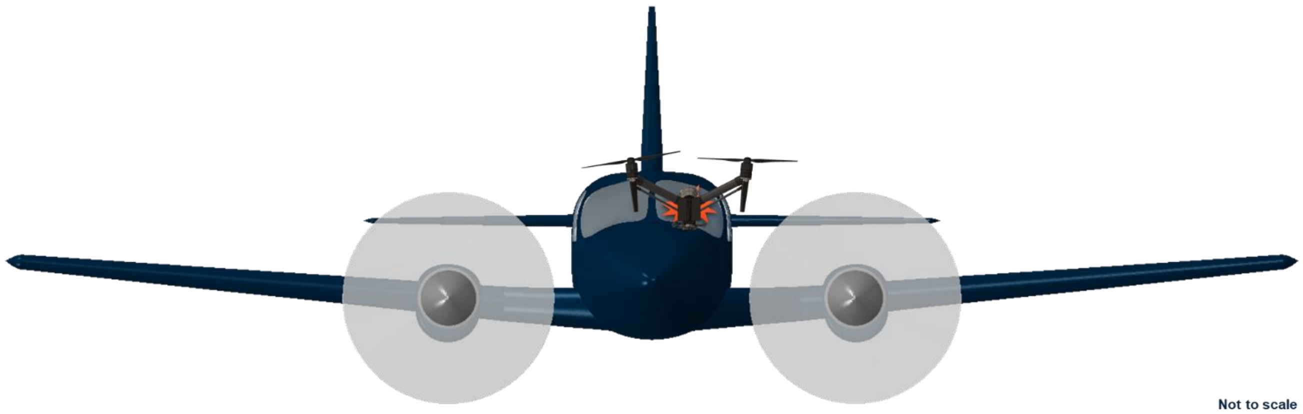


Figure 6-6 Proposed nominal roll impact condition

7. Summary

A report has been produced which fulfils the goals of Task 2 in defining collision scenarios. It includes reasoned approaches to the down-selection of specific drones and specific aircraft, and specification of local targets on each aircraft type. Probable collision speeds have been calculated and proposals have been made for the definition of collision orientations and vectors.

The down-selection of drones was achieved by research into past and current drone types, looking at market and popularity data and current design trends, along with involvement and input from market-leading drone OEMs. The selection of drones proposed are (with EASA-defined Open Category class shown in brackets): DJI Mavic Mini (Class 0), DJI Mavic II (Class 1), DJI Inspire II (Class 2), Eachine Wizard X220 (Class 1) and a E-Flite Opterra/Delair UX11 fixed wing drone. Although the EASA Open Category may include drones up to 25kg, it was determined, with agreement from Stakeholders, that most mass-market consumer/prosumer products are at the lower-end of this mass range i.e. with a maximum take-off mass of less than 5kg. The mass classes within the EASA Open Category are explained further in Section 2.2.4.

Target aircraft were selected to cover EASA Certification Specifications: CS-23 'Normal, Utility, Aerobatic and Commuter Aeroplanes', CS-25 'Large Aeroplanes', CS-27 'Small Rotorcraft', and CS-29 'Large Rotorcraft'. The selection of exemplar aircraft was based upon review of typical aircraft configurations within each type, and usage statistics.

The specification of impact locations on each aircraft has been achieved with input from subject matter experts and supporting calculations to prioritise critical areas. This assessment was based on the relative probability of a feature being impacted; the perceived vulnerability of the feature to impact damage; and the criticality of the feature to the safety of the aircraft and its occupants. The assessment awarded High/Medium/Low/NA priority classification to each considered zone of the different aircraft types, with the intention that areas identified as High priority should be investigated further (in this programme) when evaluating drone impacts.

The individual speeds at which the different drones and manned aircraft are likely to be travelling in the event of a collision has been determined by analysis. Using a large data set of historical air traffic data and a database of in-flight suspected drone sightings, it has been possible to generate a probabilistic distribution of altitudes at which drone collisions are likely to occur. Employing both databases together in a Monte Carlo analysis, it has been possible to calculate a probabilistic definition of aircraft speeds in collision conditions. Whilst analysis of collisions shall include upper-bound velocities, subsequent post-processing of the data may be informed by the calculated statistical probabilities.

Nominal collision orientations have been defined, assuming a head-on impact. This may be revisited within Task 4, where developed drone models can be used to explore the relative severity of different impact orientations.

The output of this Task 2 report is key to moving forward with Task 3, where plans to develop and validate models of drones and targets shall be established.

References

1. EASA ‘Drone Collision ‘Task Force, Final Report. 04/10/2016
2. Austen, W.J. & Lord, S.J. Research Programme on Collisions with Drones: Work Area 1 Final Report. QINETIQ/17/01933/4, 30 Nov 2017 https://www.easa.europa.eu/sites/default/files/dfu/QinetiQ%20-%20EASA.2016.LVP_.50%20UAS%20Collisions%20-%20Report%20WA1-%20Issue%204.0%20-%20For%20publication%20-%20NS.pdf
3. Austen, W.J. Research Programme on Collisions with Drones: Work Areas 2-5 Final Report. QINETIQ/17/01545/2, 31 Aug 2017 https://www.easa.europa.eu/sites/default/files/dfu/QinetiQ%20-%20EASA.2016.LVP_.50%20UAS%20Collisions%20-%20Report%20WA2-5%20-%20Issue%202.zip
4. EASA procurement documents and statement of work, “Vulnerability of manned aircraft to drone strikes”, EASA.2019.HVP.09
5. QinetiQ Response to ‘EASA 2019 HVP 09 Vulnerability of manned aircraft to drone strikes’, Issue 1, QINETIQ/1904747/1.0 17/12/2019
6. EASA website: What are the requirements under the subcategories of the ‘open’ category?, https://www.easa.europa.eu/faq/116452, last visited 13 Oct 2020.
7. EASA Easy Access Rules for Unmanned Aircraft Systems (Regulations (EU) 2019/947 and (EU) 2019/945), December 2020.
8. W.J. Austen et al, “Analysis of the state-of-the-art (D1.3), and Research Cooperation (D1.4)”, EASA.2019.HVP.09 Vulnerability of manned aircraft to drone strikes programme, QinetiQ, October 2020.
9. ASSURE Volume II – UAS Airborne Collision Severity Evaluation – Quadcopter. U.S. Department of Transportation - Federal Aviation Administration. Jul 2017
10. ASSURE Volume I – UAS Airborne Collision Severity Evaluation – Projectile and Target Definitions. U.S. Department of Transportation - Federal Aviation Administration. Dec 2016
11. Slideshare website: 2018 Drone Industry Benchmark Report by Colin Snow, published 11 Oct 2018, https://www.slideshare.net/ColinSnow/2018-drone-market-sector-report, last visited 13 Oct 2020.
12. The Drone Girl website: DJI Market Share: Here’s exactly how rapidly it has grown in just a few years by Sally French, published 18 Sep 2018, http://www.thedronegirl.com/2018/09/18/dji-market-share/, last visited 13 Oct 2020.
13. Kittyhawk.io website: Kittyhawk Insights #2 – Most popular drone models by Joshua Ziering, published: 15 Mar 2018, https://kittyhawk.io/blog/most-popular-drone-models/, last visited 13 Oct 2020.
14. GlobeNewswire website: Parrot: 2019 full-year earnings, published 19 Mar 2020, https://www.globenewswire.com/news-release/2020/03/19/2003116/0/en/Parrot-2019-full-year-earnings.html, last visited 13 Oct 2020.
15. The Verge website: Parrot exits the toy drone market by Sean O’Kane, published 19 Jul 2019, https://www.theverge.com/2019/7/19/20699905/parrot-exit-toy-drone-market-dji-consumers, last visited 13 Oct 2020.
16. Example lightweight consumer flying wing drone: https://www.gearbest.com/rc-airplanes/pp_1835948.html?wid=1433363#goodsDetail. Last visited 26 Oct 2020
17. Example mid-weight consumer flying wing drone: https://www.horizonhobby.co.uk/en_GB/product/opterra-2m-wing-bnf-basic-with-as3x/EFL11150.html, last visited 26 Oct 2020.

18. Example low-cost heavy-weight consumer flying wing drone: http://skywalkermodel.com/en/76.html, last visited 26 Oct 2020.
19. Delair UX11: https://delair.aero/delair-commercial-drones/professional-mapping-drone-delair-ux11/, last visited 26th Oct 2020.
20. senseFly eBee X: https://www.sensefly.com/drone/ebee-x-fixed-wing-drone/, last visited 26 Oct 2020.
21. European Union Aviation Safety Agency, Certification Specifications for Normal-Category Aeroplanes (CS-23) and Acceptable Means of Compliance and Guidance Material to the Certification Specifications for Normal-Category Aeroplanes, CS-23 Amendment 5 / AMC & GM to CS-23 Issue 3, 24 Jun 2020, https://www.easa.europa.eu/document-library/certification-specifications/group/cs-23-normal-utility-aerobatic-and-commuter-aeroplanes#group-table
22. European Union Safety Agency, Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes CS-25, Amendment 25, 24 Jun 2020, https://www.easa.europa.eu/document-library/certification-specifications/group/cs-25-large-aeroplanes#group-table
23. European Union Safety Agency, Certification Specifications and Acceptable Means of Compliance for Small Rotorcraft CS-27, Amendment 7, 24 Jun 2020, https://www.easa.europa.eu/document-library/certification-specifications/group/cs-27-small-rotorcraft#group-table
24. European Union Safety Agency, Certification Specifications and Acceptable Means of Compliance for Large Rotorcraft CS-29, Amendment 8, 24 Jun 2020, https://www.easa.europa.eu/document-library/certification-specifications/group/cs-29-large-rotorcraft#group-table
25. "Reported birdstrikes 2012-2016" presentation, Civil Aviation Authority.
26. J.R. Allan, "The cost of bird strikes and bird strike prevention", University of Nebraska, August 2000.
27. Aviation Safety Network website: https://aviation-safety.net/
28. Statista website, https://www.statista.com/chart/20788/aircraft-models-with-the-highest-estimated-production-figures/, last visited 12 Oct 2020
29. Global Security website, https://www.globalsecurity.org/military/systems/aircraft/b206.htm, last visited 12 Oct 2020.
30. Robinson Helicopters website, https://robinsonheli.com/robinson-helicopter-company-timeline/, last visited 12 Oct 2020.
31. Volocopter urban mobility aircraft, https://www.volocopter.com/en/, last visited 20 Oct 2020
32. Lilium electric regional aircraft website, https://lilium.com/, last visited 20 Oct 2020.
33. EASA SC-VTOL Special Condition, https://www.easa.europa.eu/document-library/product-certification-consultations/special-condition-vtol, SC-VTOL-01 Issue 1, 2 July 2019.
34. ASSURE 'Volume IV – UAS Airborne Colli-sion Severity Evaluation – Engine Ingestion', U.S. Department of Transportation - Federal Aviation Administration. August 2017.
35. Statista website, https://www.statista.com/statistics/564769/airline-industry-number-of-flights/, last visited 14 Oct 2020.
36. International Civil Aviation Organisation (ICAO) website, https://www.icao.int/annual-report-2018/Pages/the-world-of-air-transport-in-2018.aspx, last visited 14 Oct 2020.
37. Flightradar24 website, https://www.flightradar24.com/blog/flightradar24s-2019-by-the-numbers/, last visited 14 Oct 2020.
38. Schafer, Matthias ; Strohmeier, Martin ; Lenders, Vincent ; Martinovic, Ivan ; Wilhelm, Matthias. Bringing up OpenSky: A large-scale ADS-B sensor network for research. In: IPSN-14 Proceedings of the 13th International Symposium on Information Processing in Sensor Networks : IEEE, 2014 - 2014, S. 83–94
39. Specific Youtube videos of high-altitude multi-rotor drone flights not highlighted here as they are of questionable legality. However, searches for 'high altitude drone flight' reveal multiple examples.

40. German topological map. Bundesamt Für Kartographie Und Geodäsie: Digitales Geländemodell Gitterweite 200 m : DGM200 (2015). https://sg.geodatenzentrum.de/web_public/gdz/dokumentation/deu/dgm200.pdf – Überprüfungsdatum 18.08.2020
41. Dwd Climate Data Center (CDC): Historische 10-minütige Stationsmessungen der Max/Min -Mittel und Windspitzen in Deutschland. URL https://opendata.dwd.de
42. Dwd Climate Data Center (CDC): Historische 10-minütige Stationsmessungen der mittleren Windgeschwindigkeit und Windrichtung in Deutschland. URL https://opendata.dwd.de
43. European Union: Commission Implementing Regulation (EU) No 923/2012 (26. 9. 2012) (2012-09-26), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32012R0923&qid=1613129924847
44. EUROCONTROL: EUROCONTROL Aircraft Performance Database. URL https://contentzone.eurocontrol.int/aircraftperformance
45. EUROCONTROL: SKYbrary. URL https://www.skybrary.aero/

Appendix A Stakeholder Group

This programme is kindly supported by members of a joint Stakeholder Group, defined below.

A.1 Drone Stakeholder Group

Organisation	Representative
Aeromapper	Nicholas Sonnet
ASD-STAN	Christoph Mazel
Delair	Gregoire Faur
DJI	Ronald Liebsch
Parrot	Marine Ballit
senseFly	Pierre-Alain Marchand

A.2 Manned Aircraft Stakeholder Group

Organisation	Representative
Airbus Helicopters	Marc Greiller
Blackshape	Carmine Cifaldi
Leonardo Helicopters	Barbara Nassi
Leonardo Helicopters	Andrea Marinovich
Lilium	Monika Kopoczynska
Lilium	Andrew Litchfield
Safran	Laurent Jablonski
Volocopter	Michael Harms
Volocopter	Hussein Harb

Appendix B Local Target Specification

B.1 CS-23: Single propeller Utility

CS-23	(Single Propeller)		Cessna 172					
	Impact location	Relevant to config?	Exposed area (% of fuselage area)	Perceived probability of impact	Preliminary Hazard Effect Classification (Component criticality)	Preliminary Impact Effect Assessment (Vulnerabilit	Proposed priority classification	Notes
Fuselage	Radome	See note		Medium	Medium (HEC-3)	High	Medium	Not applicable for C172 but relevant to some other aircraft within lower CS-23 class e.g. some twin-prop models.
	Nose	Yes	22%	High	High (HEC-2)	Medium	High	Medium priority for glancing impacts on side of nose. May be Medium throughout (TBD)
	Canopy (above windshields)	No	1%					
	Windshield	Yes	11%	High	Extreme (HEC-1)	High	High	
	Chin window (rotorcraft)	No						
	Side windows	No						
	Fuselage sides/rear	No						
Aerodynamic surfaces	Wing leading edge	Yes	38%	High	High (HEC-2)	High	High	
	Wing braces	Yes	6%	Medium	Extreme (HEC-1)	Medium	High	Typically a tubular metal construction
	Wing slats	No						
	Wing flaps	Yes		Medium	Medium (HEC-3)	High	Medium	Only relevant when deployed (take-off and landing)
	Winglet leading edge	No						
	Wing root fairings	See note		Low	Low (HEC-4/5)	Medium	Low	Not applicable to C172 but relevant to other configurations within this sub-class.
	Vertical stabiliser leading edges	Yes	3%	Low	High (HEC-2)	High	High	
	Horizontal stabiliser leading edges	Yes	5%	Medium	High (HEC-2)	High	High	
	Rudder/Ailerons, spoilers or elevators	Yes		Low	High (HEC-2)	Medium	Medium	
Fixed wing propulsion	Engines (excluding reciprocating engines)	No						
	Engine (reciprocating)	Yes	3%	Low	High (HEC-2)	Medium	Medium	
	Propellers	Yes	75%	High	High (HEC-2)	Medium	High	
	Engine pylons	No						
	Engine nacelle leading edges	No						
Rotorcraft propulsion	Main rotor	No						
	Tail rotor	No						
	Main rotor hub & actuation	No						
	Tail rotor hub & actuation	No						
	Main rotor hub fairing/Mast	No						
	Engine air intake	No						
Gear	Wheels	Yes	2%	Low	High (HEC-2)	Low	Medium	
	Landing gear strut/fairing	Yes	2%	Low	High (HEC-2)	Medium	Medium	
	Undercarriage housing/Fairing	Yes	5%	Medium	Medium (HEC-3)	Medium	Medium	
	Gear bay doors	See note		Low	Low (HEC-4/5)	Medium	Low	Not applicable for C172 but relevant to some other aircraft within lower CS-23 class
Systems	Lights		0%	Low	Low (HEC-4/5)	Medium	Low	
	Pitot tubes			Low	Medium (HEC-3)	High	Low	
	External antennas			Low	Medium (HEC-3)	High	Low	
	Auxiliary Power Unit & Environmental Control System intakes	No						

B.2 CS-23: Small jet

CS-23 (Small Jet)		Cessna Citation 510						
	Impact location	Relevant to config?	Exposed area (% of fuselage area)	Perceived probability of impact	Preliminary Hazard Effect Classification (Component criticality)	Preliminary Impact Effect Assessment (Vulnerability)	Proposed priority classification	Notes
Fuselage	Radome	Yes	5%	Medium	Medium (HEC-3)	High	Medium	
Fuselage	Nose	Yes	12%	Medium	High (HEC-2)	Low	Medium	
Fuselage	Canopy (above windshields)	No	1%					
Fuselage	Windshield	Yes	6%	Medium	Extreme (HEC-1)	High	High	
Fuselage	Chin window (rotorcraft)	No						
Fuselage	Side windows	No						
Fuselage	Fuselage sides/rear	No						
Aerodynamic surfaces	Wing leading edge	Yes	35%	High	High (HEC-2)	High	High	
Aerodynamic surfaces	Wing braces	No						
Aerodynamic surfaces	Wing slats	No						
Aerodynamic surfaces	Wing flaps	Yes		Medium	Medium (HEC-3)	High	Medium	Only relevant when deployed (take-off and landing)
Aerodynamic surfaces	Winglet leading edge	No						
Aerodynamic surfaces	Wing root fairings	Yes	5%	Medium	Low (HEC-4/5)	Medium	Low	Includes belly fairing
Aerodynamic surfaces	Vertical stabiliser leading edges	Yes	6%	Medium	High (HEC-2)	High	High	
Aerodynamic surfaces	Horizontal stabiliser leading edges	Yes	9%	Medium	High (HEC-2)	High	High	
Aerodynamic surfaces	Rudder/Ailerons, spoilers or elevators	Yes		Low	High (HEC-2)	Medium	Medium	
Fixed wing propulsion	Engines (excluding reciprocating engines)	Yes	6%	Medium	High (HEC-2)	Medium	High	High reflects potential for uncontained failure. May only be applicable to larger drones.
Fixed wing propulsion	Engine (reciprocating)	No						
Fixed wing propulsion	Propellers	No						
Fixed wing propulsion	Engine pylons	Yes	1%	Low	Medium (HEC-3)	Low	Low	
Fixed wing propulsion	Engine nacelle leading edges	Yes	4%	Low	Medium	High	Medium	
Rotorcraft propulsion	Main rotor	No						
Rotorcraft propulsion	Tail rotor	No						
Rotorcraft propulsion	Main rotor hub & actuation	No						
Rotorcraft propulsion	Tail rotor hub & actuation	No						
Rotorcraft propulsion	Main rotor hub fairing/Mast	No						
Rotorcraft propulsion	Engine air intake	No						
Gear	Wheels	Yes	3%	Low	High (HEC-2)	Low	Medium	
Gear	Landing gear strut/fairing	Yes	3%	Low	High (HEC-2)	Medium	Medium	
Gear	Undercarriage housing/Fairing	No						
Gear	Gear bay doors	Yes	1%	Low	Medium (HEC-3)	Medium	Low	
Systems	Lights	Yes		Low	Low (HEC-4/5)	Medium	Low	
Systems	Pitot tubes	Yes		Low	Medium (HEC-3)	High	Low	
Systems	External antennas	Yes		Low	Medium (HEC-3)	High	Low	
Systems	Auxiliary Power Unit & Environmental Control System intakes	No						

B.3 CS-25: Large aeroplanes

CS-25	(Airliner)			A320/B737				
	Impact location	Relevant to config?	Exposed area (%)	Perceived probability of impact	Preliminary Hazard Effect Classification (Component criticality)	Preliminary Impact Effect Assessment (Vulnerabili	Proposed priority classification	Notes
Fuselage	Radome	Yes	4%	Low	Medium (HEC-3)	High	**Medium**	
	Nose	Yes	14%	Medium	High (HEC-2)	Medium	**High**	
	Canopy (above windshields)	Yes	6%	Medium	High (HEC-2)	Medium	**High**	
	Windshield	Yes	4%	Low	Extreme (HEC-1)	High	**High**	A greater proportion of birdstrikes are recorded than might be expected from % area
	Chin window (rotorcraft)	No						
	Side windows	No						
	Fuselage sides/rear	No						
Aerodynamic surfaces	Wing leading edge	Yes	23%	High	Medium (HEC-3)	High	**Medium**	Medium priority due to the more-robust construction of Primary Structure behind the LE and protection behind slats. May be High for outboard regions of lighter CS-25 aircraft.
	Wing braces	No						
	Wing slats	Yes		High	Medium (HEC-3)	High	**Medium**	Where present, slats may provide some protection to the LE
	Wing flaps	Yes		Medium	Medium (HEC-3)	High	**Medium**	Only relevant when deployed (take-off and landing)
	Winglet leading edge	Yes	2%	Low	Medium (HEC-3)	High	**Medium**	
	Wing root fairings	Yes	5%	Medium	Low (HEC-4/5)	Low	**Low**	Includes belly fairings
	Vertical stabiliser leading edges	Yes	4%	Medium	High (HEC-2)	High	**High**	
	Horizontal stabiliser leading edges	Yes	5%	Medium	High (HEC-2)	High	**High**	
	Rudder/Ailerons, spoilers or elevators	Yes		Low	High (HEC-2)	Medium	**Medium**	
Fixed wing propulsion	Engines (excluding reciprocating engines)	Yes	12%	Medium	High (HEC-2)	Medium	**High**	High reflects potential for uncontained failure. May only be applicable to larger drones.
	Engine (reciprocating)	No						
	Propellers	See note		High	Medium (HEC-3)	Medium	**Medium**	Applies to turboprop aircraft only
	Engine pylons	Yes	0%	Low	Medium (HEC-3)	Medium	**Low**	
	Engine nacelle leading edges	Yes	9%	Medium	Medium (HEC-3)	High	**Medium**	
Rotorcraft propulsion	Main rotor	No						
	Tail rotor	No						
	Main rotor hub & actuation	No						
	Tail rotor hub & actuation	No						
	Main rotor hub fairing/Mast	No						
	Engine air intake	No						
Gear	Wheels	Yes	6%	Medium	Medium (HEC-3)	Low	**Low**	
	Landing gear struts/brace	Yes	5%	Medium	Medium (HEC-3)	Low	**Medium**	
	Undercarriage housing/Fairing	No						
	Gear bay doors	Yes		Low	Medium (HEC-3)	High	**Medium**	Gear bay door struts may fail, resulting in doors breaking free from aircraft (likely >20kg)
Systems	Lights	Yes		Low	Low (HEC-4/5)	Medium	**Low**	
	Pitot tubes	Yes		Low	Medium (HEC-3)	High	**Low**	
	External antennas	Yes		Low	Medium (HEC-3)	High	**Low**	
	Auxiliary Power Unit & Environmental Control System intakes	Yes		Low	Low (HEC-4/5)	Low	**Low**	

B.4 CS-27 Small rotorcraft

CS-27	(Small Rotorcraft)	Robinson R44						
Impact location		Relevant to config?	Exposed area (% of fuselage area)	Perceived probability of impact	Preliminary Hazard Effect Classification (Component criticality)	Preliminary Impact Effect Assessment (Vulnerability)	Proposed priority classification	Notes
Fuselage	Radome	See note		Medium	Medium (HEC-3)	High	Medium	Not present on R44 but applicable to other CS-27 rotorcraft
	Nose	Yes	19%	Medium	High (HEC-2)	Medium	High	Depends upon structural configuration. May be Medium priority if substantial structure
	Canopy (above windshields)	Yes	4%	Low	High (HEC-2)	Low	Medium	
	Windshield	Yes	49%	High	Extreme (HEC-1)	High	High	
	Chin window (rotorcraft)	See note		Low	Extreme (HEC-1)	High	High	Not applicable for R44 as has large single screen but relevant to other CS-27 configurations
	Side windows	Yes		Low	Medium (HEC-3)	Low	Low	
	Fuselage sides/rear	Yes		Low	Medium (HEC-3)	Low	Low	
Aerodynamic surfaces	Wing leading edge	No						
	Wing braces	No						
	Wing slats	No						
	Wing flaps	No						
	Winglet leading edge	No						
	Wing root fairings	No						
	Vertical stabiliser leading edges	Yes	3%	Low	Medium (HEC-3)	Medium	Medium	
	Horizontal stabiliser leading edges	Yes	4%	Low	Medium (HEC-3)	Medium	Medium	
	Rudder/Ailerons, spoilers or elevators	No						
Fixed wing propulsion	Engines (excluding reciprocating engines)	No						
	Engine (reciprocating)	No						
	Propellers	No						
	Engine pylons	No						
	Engine nacelle leading edges	No						
Rotorcraft propulsion	Main rotor	Yes	259%	High	Extreme (HEC-1)	High	High	
	Tail rotor	Yes	2%	Low	Extreme (HEC-1)	High	High	
	Main rotor hub & actuation	Yes	3%	Low	Extreme (HEC-1)	Medium	High	Possible mitigation: direct impact unlikely as blades provide cover in-flight
	Tail rotor hub & actuation	Yes	1%	Low	Extreme (HEC-1)	Medium	High	Possible mitigation: direct impact unlikely as blades provide cover in-flight
	Main rotor hub fairing/Mast	Yes	8%	Medium	High (HEC-2)	Medium	Medium	
	Engine air intake	Yes		Low	Medium (HEC-3)	Low	Low	
Gear	Wheels	No						
	Landing gear	Yes	5%	Medium	High (HEC-2)	Low	Medium	Skids for the R44
	Undercarriage housing/Fairing	No						
	Gear bay doors	See note		Low	Medium (HEC-3)	Low	Low	Not applicable for R44 but may be for other CS-27 configurations
Systems	Lights	Yes	1%	Low	Medium (HEC-3)	Medium	Low	
	Pitot tubes	Yes		Low	Medium (HEC-3)	High	Low	
	External antennas	Yes		Low	Medium (HEC-3)	High	Low	
	Auxiliary Power Unit & Environmental Control System intakes	No						

B.5 CS-29 Large rotorcraft

CS-29	Large helicopters	H145/AW169/AW139/Super Puma						
Impact location		Relevant to config?	Exposed area (% of fuselage area)	Perceived probability of impact	Preliminary Hazard Effect Classification (Component criticality)	Preliminary Impact Effect Assessment (Vulnerability)	Proposed priority classification	Notes
Fuselage	Radome	Yes	1%	Low	Medium (HEC-3)	High	**Medium**	Some aircraft have larger radomes and/or non-critical camera payloads.
	Nose	Yes	15%	Medium	High (HEC-2)	Medium	**Medium**	Marked as medium priority because often angled surface or reinforced.
	Canopy (above windshields)	Yes	14%	Medium	Medium (HEC-3)	Medium	**Medium**	
	Windshield	Yes	35%	High	Extreme (HEC-1)	High	**High**	
	Chin window (rotorcraft)	Yes	9%	Medium	Extreme (HEC-1)	High	**High**	
	Side windows	Yes		Low	Medium (HEC-3)	Low	Low	
	Fuselage sides/rear	Yes		Low	Medium (HEC-3)	Low	Low	
Aerodynamic surfaces	Wing leading edge	No						
	Wing braces	No						
	Wing slats	No						
	Wing flaps	No						
	Winglet leading edge	No						
	Wing root fairings	No						
	Vertical stabiliser leading edges	Yes	6%	Medium	High (HEC-2)	Medium	**Medium**	
	Horizontal stabiliser leading edges	Yes	3%	Low	Medium (HEC-3)	Medium	**Medium**	
	Rudder/Ailerons, spoilers or elevators	No						
Fixed wing propulsion	Engines (excluding reciprocating engines)	No						
	Engine (reciprocating)	No						
	Propellers	No						
	Engine pylons	No						
	Engine nacelle leading edges	No						
Rotorcraft propulsion	Main rotor	Yes		High	Extreme (HEC-1)	Medium	**High**	
	Tail rotor	Yes		Low	Extreme (HEC-1)	High	**High**	Fenestron only susceptible to side impacts, but low probability
	Main rotor hub & actuation	Yes	6%	Medium	Extreme (HEC-1)	Medium	**High**	Possible mitigation: direct impact unlikely as shielded by blades
	Tail rotor hub & actuation	Yes		Low	Extreme (HEC-1)	Medium	**High**	Less relevant for fenestron configurations e.g. later H145 models
	Main rotor hub fairing/Mast	Yes		Medium	Low (HEC-4/5)	Medium	Low	
	Engine air intake	Yes	6%	Low	Medium (HEC-3)	Medium	Low	
Gear	Wheels	Yes						
	Landing gear strut/brace	Yes	3%	Low	High (HEC-2)	Low	Low	
	Undercarriage housing/Fairing	Yes		Medium	Medium (HEC-3)	Medium	Low	
	Gear bay doors	No						
Systems	Lights	Yes		Low	Medium (HEC-3)	Medium	Low	
	Pitot tubes	Yes		Low	Medium (HEC-3)	High	Low	
	External antennas	Yes		Low	Low (HEC-4/5)	High	Low	
	Auxiliary Power Unit & Environmental Control System intake	No						

B.6 EASA Hazard Effect Classification

EASA's Hazard Effect Classification definitions are shown below.

Hazard Effect Classification at Aircraft level

Severity Level	High		Low		
Hazard Classification	**1 (most severe)**	**2**	**3**	**4**	**5 (least severe)**
Effect on A/C	Normally with hull loss	Large reduction in Functional capabilities or safety margins	Significant reduction in Functional capabilities or safety margins	Slight reduction in Functional capabilities or safety margins	No effect on operational capabilities or safety
Effect on Occupants (excluding. Flight Crew)	Multiple fatalities	Serious or fatal injury to a small number of passengers or cabin crew	Physical distress, possibly including injuries	Physical discomfort	Inconvenience
Effect on Flight Crew	Fatalities or incapacitation	Physical distress or excessive workload impairs ability to perform tasks	Physical discomfort or a significant increase in workload	Slight increase in workload	No effect on flight crew
Effect on Operations	Total loss of separation. Total loss of control, mid-air collision, flight into terrain or high speed surface movement collision.	Large reduction in separation or a total loss of air traffic control for a significant period of time	Significant reduction in separation or significant reduction in air traffic control capability.	Slight reduction in separation or slight reduction in air traffic control capability. Significant increase in air traffic controller workload.	Slight increase in air traffic controller workload.

Appendix C **Collision Speeds**

C.1 Baseline flight survey analysis

C.1.1 Aircraft sub-category 1 – Large Jets

The following Figure C-1 and Table C-1 depict the ground speed distribution as a function of height above ground for the aircraft sub-category (AC) 1:

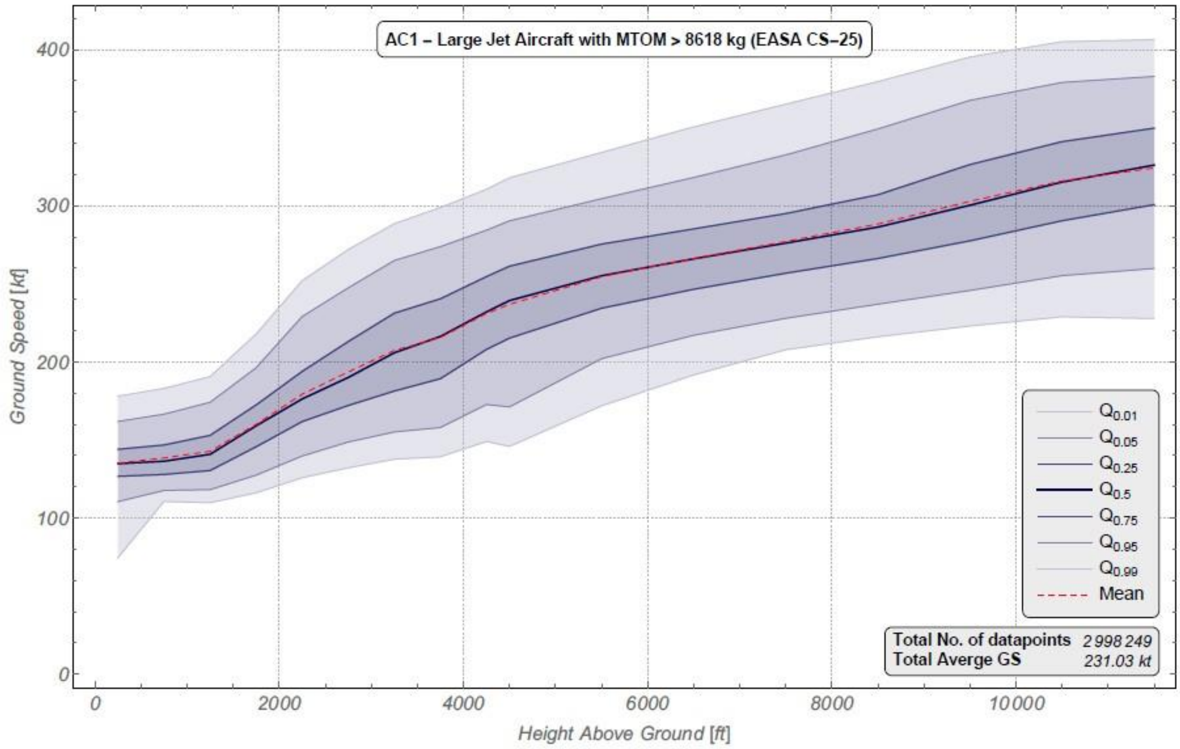


Figure C-1 Ground speed distribution as a function of height above ground – AC1

Altitude Band	N	Mean	St.Dev.	$Q_{0.01}$	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$	$Q_{0.99}$
50 ... 500 ft	186786	135.17	17.69	74.67	110.49	126.67	134.84	144.01	161.82	178.01
500 ... 1000 ft	134284	138.47	16.06	110.6	117.65	127.88	136.36	146.77	166.51	183.
1000 ... 1500 ft	137833	142.76	18.12	109.79	118.15	130.38	140.8	152.95	174.1	190.51
1500 ... 2000 ft	142176	159.99	21.88	116.11	127.44	145.6	159.06	172.41	196.24	217.83
2000 ... 2500 ft	162287	179.31	26.86	125.78	139.7	161.76	176.26	193.88	229.03	252.
2500 ... 3000 ft	197642	193.51	30.63	132.14	148.66	172.05	190.	213.01	247.37	271.89
3000 ... 3500 ft	182232	207.29	34.27	137.64	155.08	181.3	205.83	231.16	264.89	288.46
3500 ... 4000 ft	206286	215.52	35.96	139.2	157.92	189.19	216.23	240.38	273.76	298.83
4000 ... 4500 ft	137638	230.95	34.65	149.	172.66	207.93	231.95	254.57	284.3	310.46
4500 ... 5000 ft	147059	236.81	36.13	145.84	171.13	215.18	239.23	261.24	290.27	317.82
5000 ... 6000 ft	219725	254.49	32.13	171.82	202.	234.34	255.13	275.39	304.47	334.06
6000 ... 7000 ft	210079	266.26	31.36	191.61	217.01	246.46	265.97	285.12	318.04	350.46
7000 ... 8000 ft	207553	277.09	31.82	207.74	227.85	256.74	276.05	294.96	332.52	365.
8000 ... 9000 ft	217334	288.28	33.68	216.06	236.92	266.18	286.3	306.99	349.13	379.45
9000 ... 10000 ft	247213	302.8	36.93	222.93	245.7	277.48	300.28	326.34	367.46	395.21
10000 ... 11000 ft	195458	315.85	37.82	228.83	255.2	290.35	315.13	341.01	378.95	405.
11000 ... 12000 ft	66664	324.2	37.81	227.71	259.79	300.62	326.01	349.63	382.78	406.32

Ground Speed in kt

➡ **Table C-1** Tabulated ground speed distributions for selected quantiles – AC1

C.1.2 Aircraft sub-category 2 – Large Turboprops

The following Figure C-2 and Table C-2 depict the ground speed distribution as a function of height above ground for the AC 2:

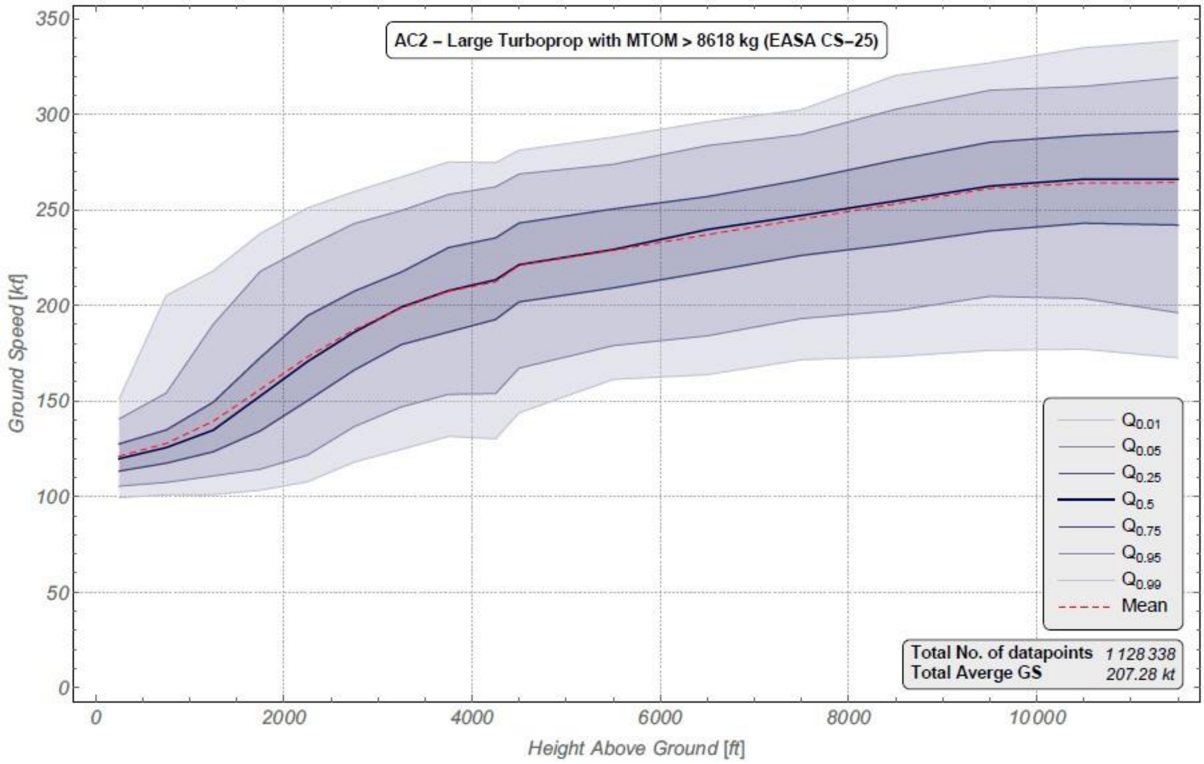


Figure C-2 Ground speed distribution as a function of height above ground – AC2

Altitude Band	N	Mean	St.Dev.	$Q_{0.01}$	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$	$Q_{0.99}$
50 ... 500 ft	69995	121.08	11.43	99.32	105.42	113.28	119.81	127.58	140.58	150.96
500 ... 1000 ft	54076	127.76	16.76	101.04	107.38	117.44	125.6	134.83	154.18	205.14
1000 ... 1500 ft	72307	139.37	23.62	101.02	110.75	123.41	134.73	149.35	190.06	218.05
1500 ... 2000 ft	52102	156.02	30.11	103.31	114.28	134.35	152.59	172.7	217.79	237.59
2000 ... 2500 ft	55057	172.98	32.95	107.67	121.63	150.05	170.56	194.54	230.82	250.89
2500 ... 3000 ft	72224	187.28	31.25	118.09	136.62	166.21	186.02	207.47	242.84	259.54
3000 ... 3500 ft	67727	198.56	30.53	124.68	146.87	179.51	199.12	217.47	249.61	267.17
3500 ... 4000 ft	64309	207.37	31.92	131.47	153.48	186.08	207.69	230.23	258.03	275.05
4000 ... 4500 ft	51090	212.32	32.37	130.25	153.8	192.61	213.34	235.31	262.	274.65
4500 ... 5000 ft	52482	220.95	30.36	143.78	167.17	201.8	221.27	243.07	268.73	281.15
5000 ... 6000 ft	90130	228.77	28.78	161.25	178.93	209.1	229.21	250.46	273.79	288.03
6000 ... 7000 ft	93070	237.01	29.14	163.77	184.07	217.56	239.68	256.91	283.59	296.06
7000 ... 8000 ft	82014	245.09	28.84	171.54	193.09	226.12	247.03	265.65	289.39	302.4
8000 ... 9000 ft	88254	253.06	32.24	173.23	197.25	232.08	254.61	275.97	302.55	320.35
9000 ... 10000 ft	92674	261.12	33.73	176.47	204.71	238.95	262.38	285.36	312.54	326.88
10000 ... 11000 ft	55133	264.02	34.02	177.1	203.58	242.99	266.02	288.92	314.59	334.77
11000 ... 12000 ft	15694	264.23	36.58	172.54	196.16	242.03	266.02	291.08	319.26	338.54

Ground Speed in kt

Table C-2 Tabulated ground speed distributions for selected quantiles – AC2

C.1.3 Aircraft sub-category 3 – Small Jets

The following Figure C-3 and Table C-3 depict the ground speed distribution as a function of height above ground for the AC 3:

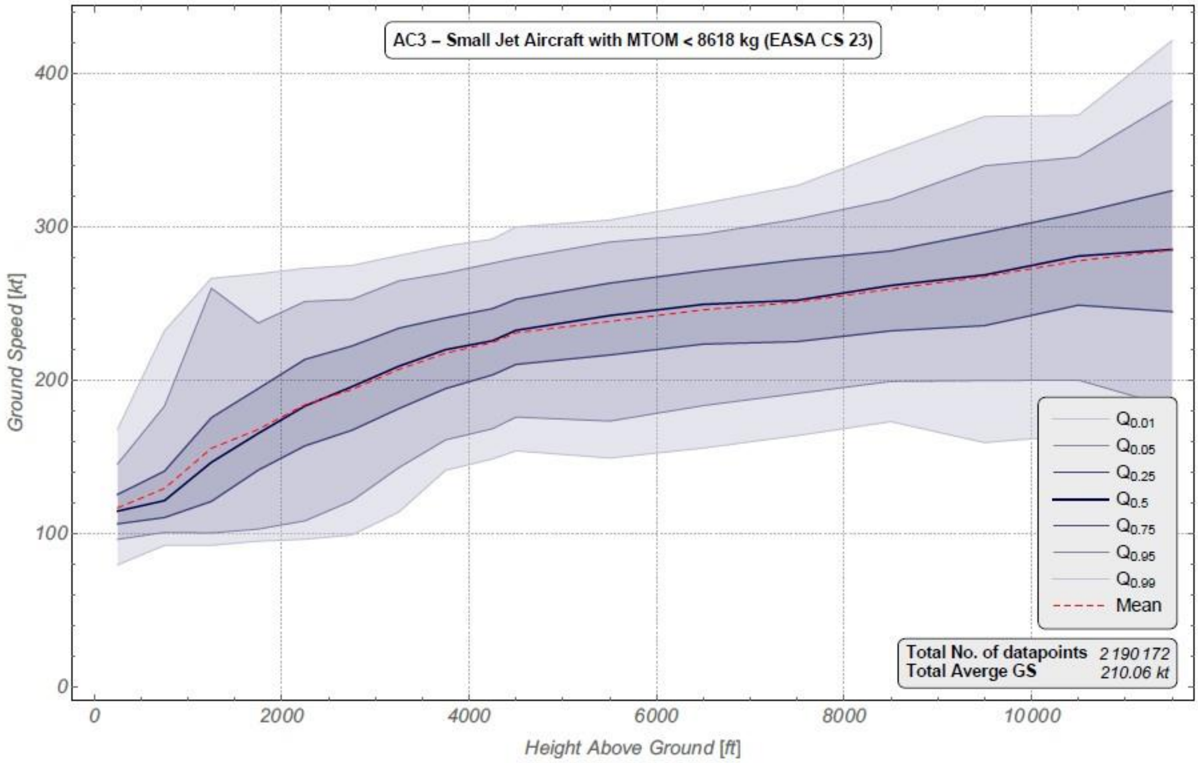


Figure C-3 Ground speed distribution as a function of height above ground – AC3

Altitude Band	N	Mean	St.Dev.	$Q_{0.01}$	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$	$Q_{0.99}$
50 ... 500 ft	117648	116.46	17.48	79.31	95.9	106.04	114.35	125.22	145.17	167.87
500 ... 1000 ft	118482	129.14	27.5	92.02	100.46	110.16	121.21	140.43	182.82	231.9
1000 ... 1500 ft	139683	155.32	45.99	92.03	100.12	120.67	146.15	175.26	259.7	266.1
1500 ... 2000 ft	163883	167.61	40.04	94.76	102.61	141.06	165.03	194.24	237.	269.08
2000 ... 2500 ft	173311	183.77	41.21	96.01	108.04	156.95	182.92	213.34	251.07	272.66
2500 ... 3000 ft	180707	193.6	39.06	98.73	121.07	167.09	195.49	222.04	252.42	274.53
3000 ... 3500 ft	154500	206.77	37.35	113.76	142.69	181.18	208.84	233.62	264.49	281.02
3500 ... 4000 ft	117149	217.34	33.37	141.01	160.8	194.26	219.66	240.42	269.55	287.24
4000 ... 4500 ft	100952	224.3	32.2	148.35	168.08	203.18	225.44	246.4	276.05	291.71
4500 ... 5000 ft	83993	230.6	31.83	153.69	175.68	210.	232.24	252.51	279.22	299.67
5000 ... 6000 ft	141010	238.04	35.25	148.95	173.05	216.18	241.87	263.03	289.86	304.11
6000 ... 7000 ft	126922	245.64	34.89	155.47	183.17	223.26	249.18	271.07	294.98	314.95
7000 ... 8000 ft	146297	250.61	36.23	163.59	191.05	224.9	251.81	278.18	304.77	326.59
8000 ... 9000 ft	147900	259.17	37.48	172.7	198.91	231.9	261.49	284.02	317.63	349.5
9000 ... 10000 ft	142368	267.23	44.01	159.03	199.46	235.32	268.37	296.08	339.56	371.73
10000 ... 11000 ft	92653	277.62	44.19	164.03	199.81	248.65	280.67	308.7	345.22	372.49
11000 ... 12000 ft	42714	284.46	60.21	131.47	182.16	244.44	285.01	323.3	381.89	421.17

Ground Speed in kt

Table C-3 Tabulated ground speed distributions for selected quantiles – AC3

C.1.4 Aircraft sub-category 4 – Small Turboprops

The following Figure C-4 and Table C-4 depict the ground speed distribution as a function of height above ground for the AC 4:

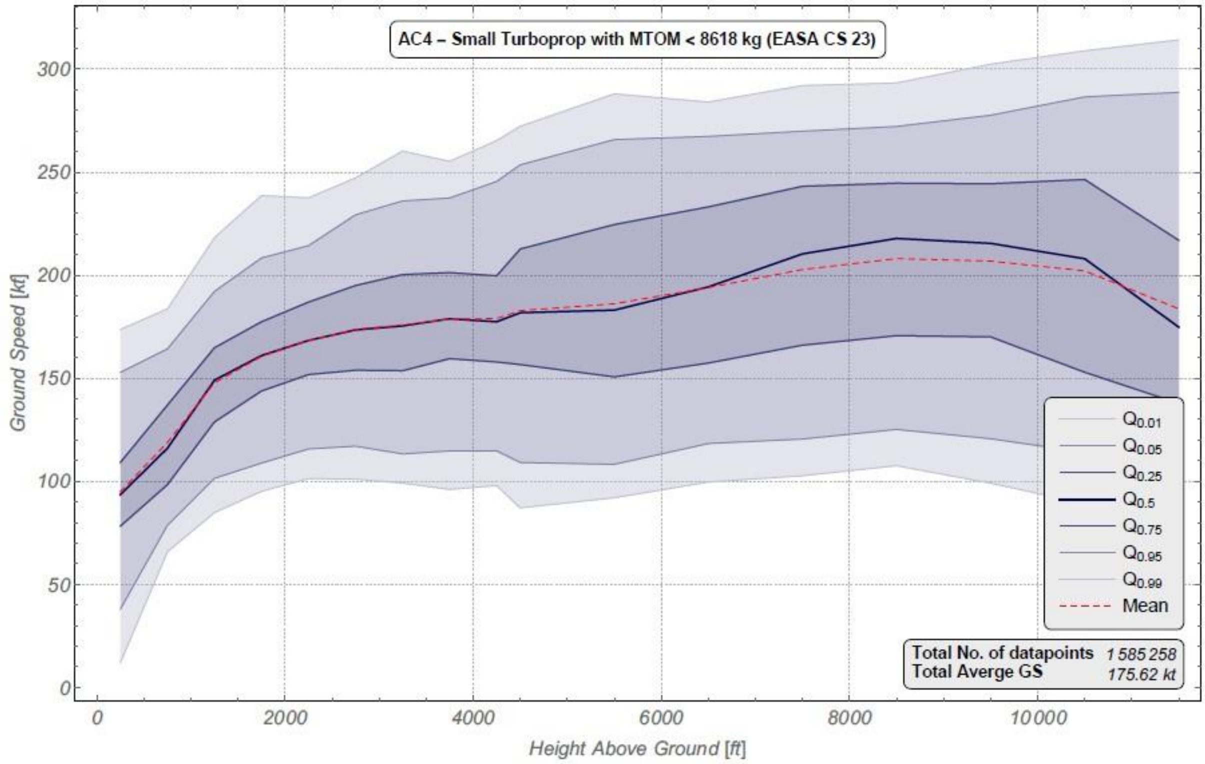


Figure C-4 Ground speed distribution as a function of height above ground – AC4

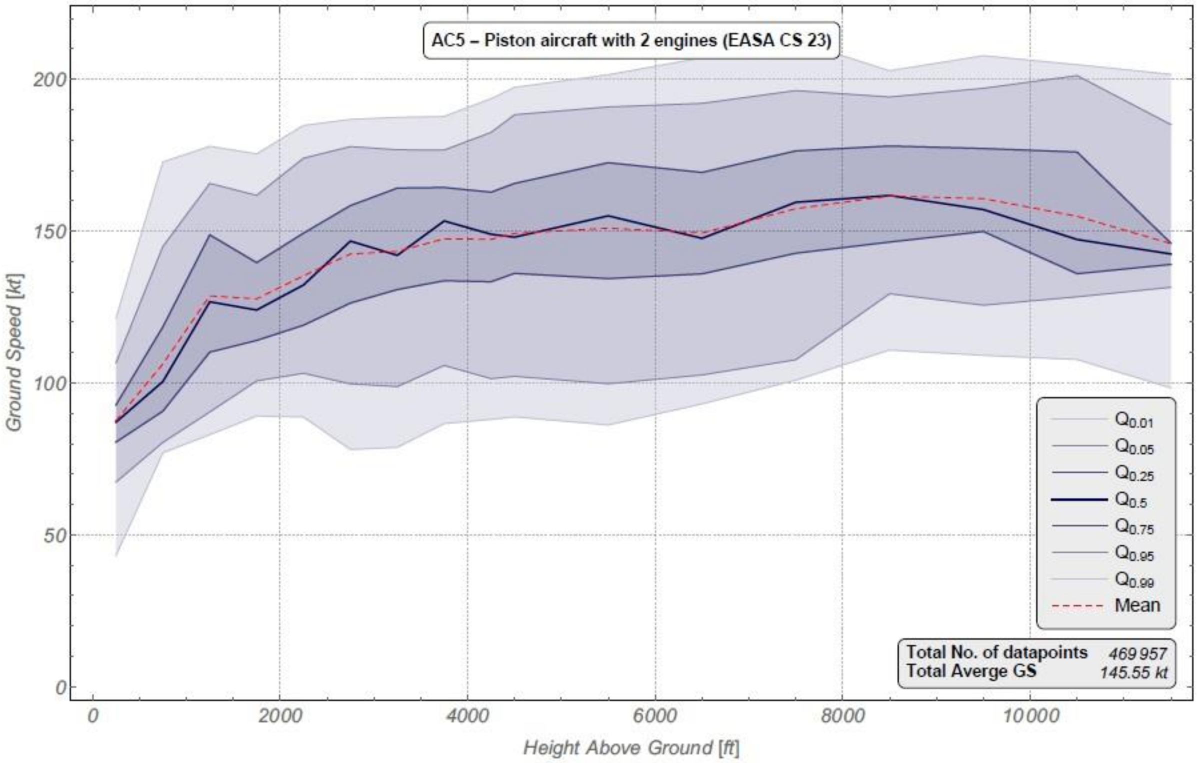
Altitude Band	N	Mean	St.Dev.	$Q_{0.01}$	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$	$Q_{0.99}$
50 ... 500 ft	82258	94.93	30.1	12.	38.01	78.24	93.56	109.18	152.9	173.69
500 ... 1000 ft	93086	118.86	27.	65.8	78.64	98.37	116.06	137.	164.28	183.64
1000 ... 1500 ft	82077	147.79	28.07	84.81	101.43	128.8	149.05	164.81	192.13	218.23
1500 ... 2000 ft	108864	160.56	28.94	95.13	108.85	143.81	161.01	177.41	208.37	238.66
2000 ... 2500 ft	131097	168.28	29.03	101.32	115.69	151.79	168.34	186.97	214.35	237.55
2500 ... 3000 ft	110905	173.8	32.57	101.02	117.04	153.88	173.46	195.	229.31	247.21
3000 ... 3500 ft	75909	175.89	35.65	99.13	113.27	153.65	175.42	200.34	236.03	260.22
3500 ... 4000 ft	97560	178.72	34.69	96.04	114.74	159.51	178.88	201.26	237.47	255.26
4000 ... 4500 ft	83444	178.99	37.07	97.94	114.76	157.89	177.42	199.72	245.49	265.32
4500 ... 5000 ft	69263	182.81	42.52	87.09	109.13	156.65	181.8	212.72	253.57	272.25
5000 ... 6000 ft	96868	186.14	48.76	92.01	108.23	150.66	183.05	224.59	265.8	288.01
6000 ... 7000 ft	104141	193.98	47.02	99.62	118.33	157.38	194.34	233.15	267.37	284.03
7000 ... 8000 ft	116154	202.75	48.71	102.69	120.5	166.05	210.34	243.15	269.88	292.04
8000 ... 9000 ft	140117	208.07	47.3	107.56	125.16	170.66	217.85	244.68	272.18	293.29
9000 ... 10000 ft	110733	206.84	50.16	99.08	120.65	170.07	215.45	244.38	277.62	302.42
10000 ... 11000 ft	62801	202.1	55.95	89.2	114.04	152.9	208.	246.46	286.53	308.88
11000 ... 12000 ft	19981	183.68	56.23	93.98	112.04	137.77	174.81	216.93	288.72	314.19

Ground Speed in kt

Table C-4 Tabulated ground speed distributions for selected quantiles – AC4

C.1.5 Aircraft sub-category 5 – Two Piston Engine Aircraft

The following Figure C-5 and Table C-5 depict the ground speed distribution as a function of height above ground for the AC 5:



➨ **Figure C-5** Ground speed distribution as a function of height above ground – AC5

Altitude Band	N	Mean	St.Dev.	$Q_{0.01}$	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$	$Q_{0.99}$
50 ... 500 ft	12982	87.59	13.36	43.19	67.36	80.52	87.09	92.76	106.61	121.38
500 ... 1000 ft	18011	106.23	21.7	77.	80.41	90.71	100.46	118.46	144.9	172.74
1000 ... 1500 ft	22244	128.67	24.07	82.98	90.44	110.14	126.72	148.76	165.7	177.92
1500 ... 2000 ft	40886	127.68	19.22	89.09	100.66	113.99	124.02	139.62	161.76	175.41
2000 ... 2500 ft	27999	135.27	22.38	88.75	103.17	119.	132.26	149.33	174.	184.78
2500 ... 3000 ft	20224	142.47	23.84	78.09	99.69	126.3	146.7	158.39	177.81	186.78
3000 ... 3500 ft	14754	143.29	23.66	78.79	98.79	130.74	142.02	164.15	176.78	187.45
3500 ... 4000 ft	22430	147.45	22.37	86.61	105.76	133.64	153.33	164.34	176.66	187.75
4000 ... 4500 ft	13636	147.27	23.69	87.97	101.4	133.3	148.95	162.81	182.48	193.58
4500 ... 5000 ft	11308	149.23	24.07	88.84	102.18	136.07	148.	165.68	188.31	197.31
5000 ... 6000 ft	25701	150.96	27.82	86.16	99.72	134.35	155.01	172.51	190.87	201.47
6000 ... 7000 ft	48220	149.34	27.	93.11	102.63	135.92	147.61	169.31	192.04	207.04
7000 ... 8000 ft	43010	157.36	25.94	100.9	107.63	142.71	159.48	176.4	196.25	212.6
8000 ... 9000 ft	56987	161.51	20.74	110.82	129.36	146.39	161.72	178.01	194.15	202.79
9000 ... 10000 ft	53244	160.7	22.23	109.07	125.59	149.86	157.09	177.18	197.	207.74
10000 ... 11000 ft	31853	154.87	24.54	107.7	128.35	135.96	147.22	176.03	201.19	204.79
11000 ... 12000 ft	6468	145.87	17.2	98.35	131.48	139.01	142.47	146.01	185.06	201.61

Ground Speed in kt

➨ **Table C-5** Tabulated ground speed distributions for selected quantiles – AC5

C.1.6 Aircraft sub-category 6 – One Piston Engine Aircraft

The following Figure C-6 and Table C-6 depict the ground speed distribution as a function of height above ground for the AC 6:

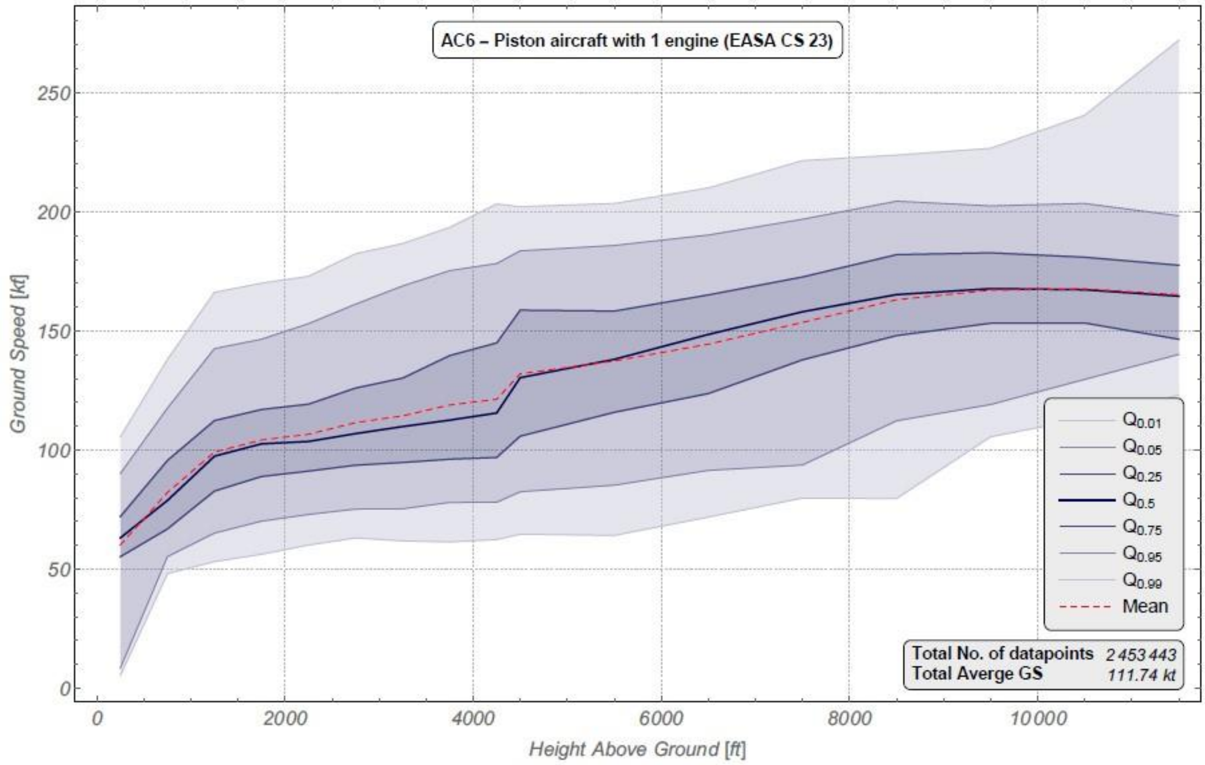


Figure C-6 Ground speed distribution as a function of height above ground – AC6

Altitude Band	N	Mean	St.Dev.	$Q_{0.01}$	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$	$Q_{0.99}$
50 ... 500 ft	125762	60.19	22.09	5.39	8.49	55.22	63.13	72.09	90.14	105.55
500 ... 1000 ft	241883	82.16	20.21	48.09	55.23	66.85	78.82	95.6	117.59	138.03
1000 ... 1500 ft	317962	99.15	23.23	53.14	65.12	82.76	97.41	112.36	142.58	166.17
1500 ... 2000 ft	358094	104.19	23.25	56.22	70.11	88.86	102.59	117.	146.49	170.04
2000 ... 2500 ft	327046	106.59	23.68	60.08	72.95	91.14	103.59	119.25	153.06	172.93
2500 ... 3000 ft	221090	111.5	26.09	63.07	75.19	93.61	106.89	126.02	161.23	182.39
3000 ... 3500 ft	142823	114.32	27.94	61.85	75.33	94.76	109.84	130.19	168.86	186.68
3500 ... 4000 ft	100622	118.9	30.65	61.4	77.99	96.13	112.54	139.64	175.28	193.44
4000 ... 4500 ft	79230	121.29	32.43	62.37	78.06	96.88	115.52	144.96	178.28	203.27
4500 ... 5000 ft	62029	131.99	32.94	64.66	82.46	105.8	130.36	158.71	183.6	202.16
5000 ... 6000 ft	108527	137.35	30.93	64.13	85.23	115.83	138.06	158.32	185.87	203.48
6000 ... 7000 ft	112403	144.44	31.33	71.85	91.44	123.69	148.52	165.11	190.25	210.01
7000 ... 8000 ft	98029	153.55	30.37	79.81	93.68	137.84	158.03	172.63	196.86	221.47
8000 ... 9000 ft	76592	163.09	28.95	79.63	112.26	148.03	165.25	182.	204.45	223.81
9000 ... 10000 ft	47427	167.05	25.13	105.55	119.08	153.22	167.73	182.78	202.47	226.63
10000 ... 11000 ft	25147	167.66	25.61	113.22	129.63	153.31	167.29	180.94	203.48	240.53
11000 ... 12000 ft	8777	165.2	26.71	123.06	140.12	146.49	164.58	177.55	198.32	272.

Ground Speed in kt

Table C-6 Tabulated ground speed distributions for selected quantiles – AC6

C.1.7 Aircraft sub-category 7 – Large Helicopters

The following Figure C-7 and Table C-7 depict the ground speed distribution as a function of height above ground for the AC 7:

➨ **Figure C-7** Ground speed distribution as a function of height above ground – AC7

Altitude Band	N	Mean	St.Dev.	$Q_{0.01}$	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$	$Q_{0.99}$
50 ... 500 ft	256435	36.86	30.84	1.	2.24	12.17	28.43	55.	102.47	123.43
500 ... 1000 ft	548456	89.99	36.26	2.	12.37	68.68	100.24	117.17	133.7	144.51
1000 ... 1500 ft	596833	102.1	36.04	2.	12.04	93.65	112.68	124.4	140.89	153.23
1500 ... 2000 ft	371966	103.97	39.01	1.41	9.22	97.01	116.3	128.69	144.63	156.19
2000 ... 2500 ft	186408	112.79	34.91	3.61	18.87	104.62	121.02	133.	153.26	162.73
2500 ... 3000 ft	84441	117.81	26.13	16.76	66.6	109.02	123.43	134.13	148.07	156.78
3000 ... 3500 ft	41603	123.2	25.13	47.85	75.07	109.88	126.09	141.38	158.83	166.01
3500 ... 4000 ft	28478	124.43	26.41	37.85	63.51	113.64	129.29	139.94	157.89	186.46
4000 ... 4500 ft	14029	127.63	31.62	16.	83.6	111.02	126.14	146.58	183.5	188.72
4500 ... 5000 ft	10829	115.83	29.27	33.6	43.08	103.25	122.07	135.66	147.41	163.92
5000 ... 6000 ft	13419	133.1	33.48	23.09	47.42	117.66	138.85	159.05	171.03	173.63
6000 ... 7000 ft	13080	126.06	22.8	58.83	97.91	111.65	118.95	145.43	159.05	168.07
7000 ... 8000 ft	11712	121.78	17.03	48.37	101.04	114.39	122.18	128.08	147.23	157.89
8000 ... 9000 ft	3654	117.01	26.19	39.46	68.59	110.69	120.21	122.19	138.62	257.03
9000 ... 10000 ft	3706	132.08	20.42	84.2	118.68	122.78	134.62	137.36	141.68	261.87

Ground Speed in kt

➨ **Table C-7** Tabulated ground speed distributions for selected quantiles – AC7

C.1.8 Aircraft sub-category 8 – Small Helicopters

The following Figure C-8 and Table C-8 depict the ground speed distribution as a function of height above ground for the AC 8:

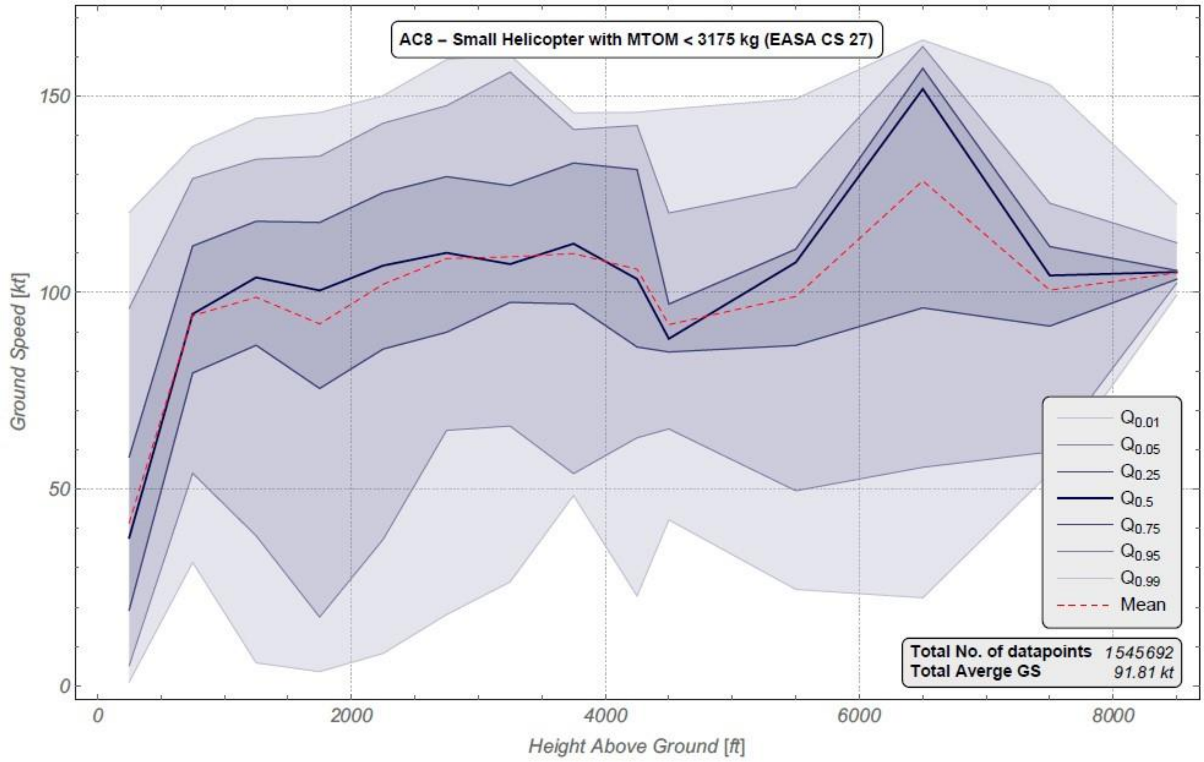


Figure C-8 Ground speed distribution as a function of height above ground – AC8

Altitude Band	N	Mean	St.Dev.	$Q_{0.01}$	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$	$Q_{0.99}$
50 ... 500 ft	132 143	41.42	27.47	1.	5.1	19.24	37.64	58.19	96.01	120.34
500 ... 1000 ft	405 109	94.11	23.27	31.38	54.04	79.51	94.53	111.83	128.95	137.12
1000 ... 1500 ft	478 648	98.77	28.24	5.83	38.12	86.58	103.82	118.09	133.87	144.26
1500 ... 2000 ft	350 099	92.01	35.09	3.61	17.46	75.58	100.5	117.8	134.62	145.73
2000 ... 2500 ft	95 865	102.08	31.48	8.25	37.22	85.62	106.83	125.4	143.03	150.03
2500 ... 3000 ft	43 511	108.64	27.36	18.11	64.94	89.89	110.07	129.45	147.49	159.21
3000 ... 3500 ft	12 141	109.03	25.9	26.4	66.03	97.49	107.2	127.14	156.04	160.35
3500 ... 4000 ft	7269	109.89	26.87	48.37	53.94	97.08	112.4	132.91	141.43	145.67
4000 ... 4500 ft	3859	105.89	27.94	22.83	63.06	86.13	103.39	131.24	142.44	145.78
4500 ... 5000 ft	5928	91.83	17.44	42.19	65.31	84.86	88.23	97.05	120.21	146.6
5000 ... 6000 ft	4802	98.99	23.78	24.52	49.58	86.53	107.65	111.	126.78	149.21
6000 ... 7000 ft	4627	128.38	38.42	22.36	55.54	96.08	151.73	156.98	162.53	164.19
7000 ... 8000 ft	1436	100.57	19.71	54.15	59.46	91.44	104.32	111.66	122.69	152.8
8000 ... 9000 ft	255	104.99	9.62	99.32	102.39	103.35	105.19	105.59	112.64	122.41

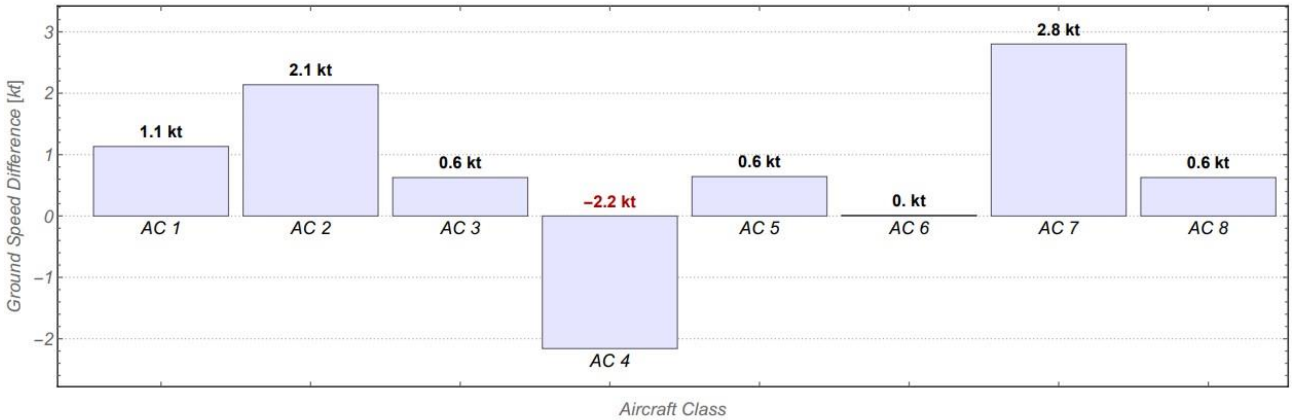
Ground Speed in kt

Table C-8 Tabulated ground speed distributions for selected quantiles – AC8

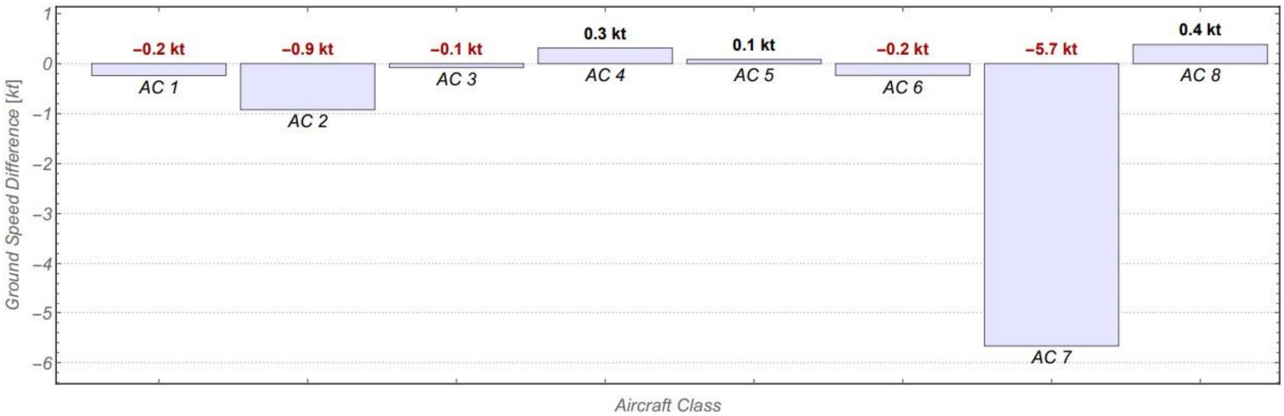
C.2 'Drone flying weather' data summary

The 'drone flying weather' scenario is described in Section 5.4.2, where it was also concluded that there were minimal differences with the baseline aircraft speed results.

The differences between the results of this scenario and the baseline analysis are shown in Figure C-9 and Figure C-10.



➨ **Figure C-9** Differences in average ground speeds (drone flying weather vs baseline scenarios)



➨ **Figure C-10** Differences in standard deviation of ground speeds (drone flying weather vs baseline scenarios)

It can be seen that the differences in average ground speeds are minor, though there is a general trend for speeds to be slightly greater when strong winds are excluded. This makes sense for lower-altitude conditions where take-off and landing are typically executed facing upwind.

An exception to this trend is a reduced speed for the AC4 (small turboprop) category, though this may be attributed to the composition of the sample, where there is a slightly greater proportion of slower aircraft. However, the differences are minor (2.2kt average), with a difference of 3-4 kt above 5,000 ft and similar results closer to the ground.

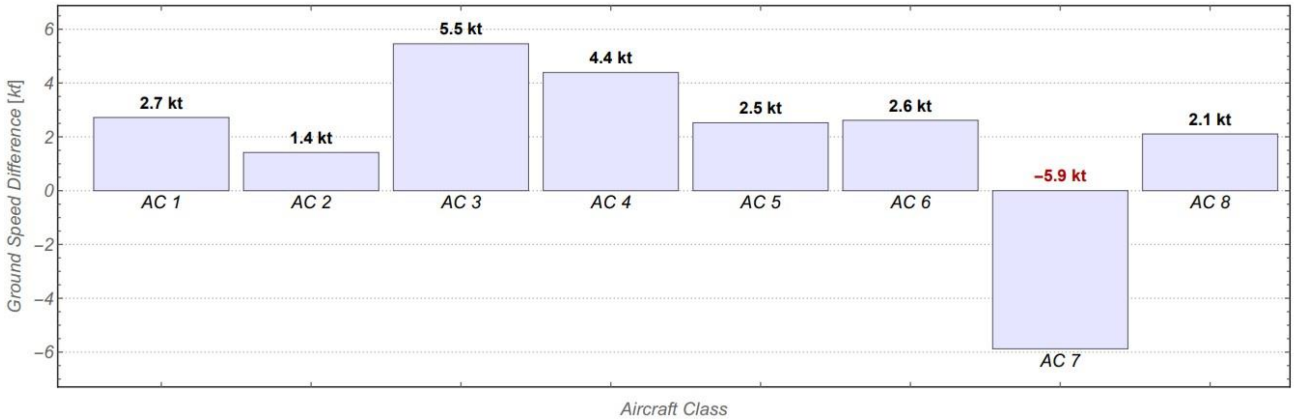
The standard deviation of the results are also very similar, with the exception of AC7 (large helicopters), where there is a reduction by 5.7 kt. This implies that the behaviour of this category is more homogenous during lower wind conditions and daylight hours.

Overall, the differences between the baseline dataset and the 'drone flying weather' dataset are minor. Therefore the baseline dataset has been used in later analysis of aircraft speeds.

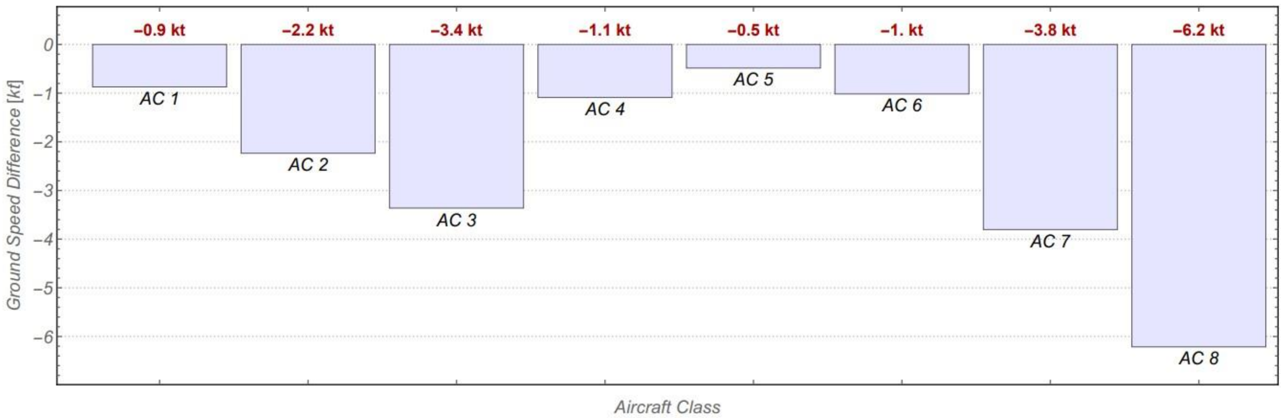
C.3 Low wind scenario

The 'low wind' scenario is described in Section 5.4.3, where it was also concluded that there were minimal differences with the baseline aircraft speed results.

The differences between the results of this scenario and the baseline analysis are shown in Figure C-11 and Figure C-12.



➨ **Figure C-11** Differences in average ground speeds (low wind vs baseline scenarios)



➨ **Figure C-12** Differences in standard deviation of ground speeds (low wind vs baseline scenarios)

The differences in average speeds for the fixed wing aircraft are as expected. In the low wind scenario, the average ground speed is greater than in the baseline scenario because low altitude operations (approach and departure) are mainly conducted against the wind.

The contrasting behaviour of large helicopters (AC7) in this sample was not known but may be due to the differences in the relative proportions of different rotorcraft within the sample.

The standard deviation of the speeds is reduced for the low wind scenario, as the very low and very high ground speeds due to high winds are absent.

Overall, the differences between the baseline dataset and the ‘low wind’ dataset are minor. Therefore the baseline dataset has been used in later analysis of aircraft speeds.

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