

Drone Safety Risk: An assessment

CAP 1627

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1. Executive summary

- 1.1 The Civil Aviation Authority (CAA) supports the safe development of drones in the UK. Drones can bring economic and workplace safety benefits, but to achieve those we need everyone flying a drone to do so safely.
- 1.2 The use of small unmanned aircraft, more commonly known as drones, is rising in the UK, for both leisure and commercial purposes. With that increase in usage comes more questions about the unintentional risks of drones colliding with, or disrupting, manned aircraft.
- 1.3 At the time of writing there have been seven confirmed cases of direct in flight contact between drones and civil or military manned aircraft worldwide¹. There have been no known collisions between small drones and manned aircraft in the UK. However, the number of occasions where pilots have reported suspected drones in proximity to their aircraft in the UK is increasing; there were 59 such occasions between April 2016 and March 2017. Two of these involved large passenger aircraft near Heathrow, leading to concerns being voiced in Parliament, in the media and by a range of aviation bodies about the possible impact of a collision between a passenger aircraft and a drone. A further incident in July 2017, where an object believed to be a drone was seen near Gatwick, led to the runway being closed briefly and flights being diverted.
- 1.4 The CAA has undertaken an assessment of available information about the likelihood of an unintentional drone collision and the severity of any possible impact between an aircraft and a smaller unmanned vehicle (defined as under 2kg in this report). The findings are:
- The drones most likely to end up in proximity to manned aircraft are smaller drones, typically of 2kg or less, flown by operators who either do not know the aviation safety regulations or have chosen to ignore them.
 - It is considered unlikely that a small drone would cause significant damage to a modern turbo-fan jet engine; even if it did, a multi-engine aircraft would still be likely to be able to land safely.

¹ Aviation Safety Network drone database, 14th Dec. 2017 - 7 confirmed and 6 suspected collision events worldwide. (<https://aviation-safety.net/database/issue/drones.php>)

- The likelihood of a small drone being in *proximity* of a passenger aircraft when it is travelling fast enough to potentially damage a windscreen is currently observed to be about 2 per million flights, where proximity means within visual line of sight of the aircraft.
- The likelihood of a small drone actually hitting a passenger aircraft windscreen at sufficient speed to rupture it is very much smaller than the probability of it being in the proximity of an aircraft.
- The windscreens of small helicopters and light aircraft are more susceptible to rupture if struck by a small drone, even when flying below normal cruising speed.
- Helicopters face more particular risks because of the additional susceptibility of helicopter rotors to damage from a collision with a drone, and their operating patterns which typically involve lower-level flying and take-off and landing from a range of sites.

1.5 The standards of design and production of large passenger aircraft may provide some reassurance about the risk to life associated with a small drone collision. However, they raise concerns about the risks to other manned aviation. The CAA has produced a bowtie safety assessment model examining potential mitigations to these risks. At present, all such mitigations – which range from drone operator education to pilot action to enforcement to technical limitations on drones – remain essential to ensure the separation of small drones and all manned aircraft. Achieving this separation with high levels of confidence and consistency is the only way of securing high levels of aviation safety. It is critically important that those who operate drones **always** do so within the regulations and guidelines set by the CAA or Government Departments.

1.6 The risk of collision is a complex issue that depends on the interaction of many factors. For example, an increase in drone ownership may not automatically increase the probability of a collision if those drones are flown rarely or if they are flown in accordance within the safety rules and therefore away from aircraft. Comprehensive data about the frequency and nature of drone use is very limited, and therefore a reliable predictive model that would enable an assessment of changes to key risk factors is not possible at the current time. The assessment contained in this report is based on observed numbers of reported drone proximity events.

1.7 The prime responsibility for establishing research programmes into collision consequences rests with the aircraft certification authorities; in the UK, as in the rest of Europe, this is the European Aviation Safety Agency (EASA). In the US, the Federal Aviation Administration (FAA) has commissioned an extensive programme of

research which is already under way and published² some initial results on 28th November 2017 on the modelling completed to date, which suggests:

- Small drones can introduce severe damage to some aircraft structures, with greater damage at higher speeds (and therefore typically higher altitudes);
- Non-severe structural damage can create significant economic burden to aircraft operators; and
- Drone collisions cause greater structural damage than bird strikes for equivalent impact energy levels.

1.8 The conclusions of the FAA's work, which are based on extensive modelling, are broadly consistent with the findings in this assessment. The FAA is planning further work over the next two years. The CAA will continue to monitor the outcomes of such programmes as new evidence becomes available.

1.9 In conclusion, CAA's review of existing risk evidence indicates that drones do pose a potential safety risk to other airspace users, though commercial aircraft are designed and manufactured to high standards. Light aircraft and helicopters are designed and built to different requirements and therefore the consequences of a small drone colliding with these forms of aircraft may be different from larger commercial aircraft. Further research is required by aircraft certification authorities and aircraft manufacturers to better understand the damage implications of a collision, and as data about usage becomes available, the probability of collision.

1.10 In any event, the best way to reduce safety risk is to prevent any two aircraft coming into proximity in the first place. The conclusions of this review therefore support the CAA's current drone priorities, which are to:

- Continue with the high-profile education and communications campaign to inform drone operators about how to fly responsibly;
- Define and publish geo-fenced areas to set electronic no fly zones;
- Strengthen the education and accountability of operators through mandatory training and registration of drone operators; and
- Link drone registration to the electronic conspicuity of drone flights and all other flights to help operators maintain safe separation from other airspace users and aid authorities in taking enforcement action against irresponsible drone operators.

² <http://www.assureuas.org/projects/deliverables/sUASAirborneCollisionReport.php>

2. The risk picture

- 2.1 For both recreational and commercial purposes, the use of small unmanned aircraft, commonly referred to as drones, has increased significantly over recent years. With lower costs and a wider range of available products, drones are now more affordable and attractive to a wider range of people. However, as their use increases, so does the unintentional risk of drones disrupting or even colliding with other air traffic.
- 2.2 At the time of writing this report, there have been seven confirmed collisions between drones and other civil and military aircraft across the world³; none of which occurred in the UK. However, there have been a number of reported instances of a drone being in the proximity of a commercial aircraft in UK airspace. These have led to growing public questions about the potential risk of collision and the damage that could result.
- 2.3 The Civil Aviation Authority (CAA) has considered available information about the safety risks linked to drones, i.e. the likelihood of a collision, or of a loss of control of the aircraft occurring as a result of proximity to a drone, and the possible impacts of such an incident. The focus, in the latter case, has been on the potential for harm to those on board an aircraft or those on the ground.
- 2.4 The CAA has not looked at the disruption that could be caused to air traffic by the presence of a drone in the flight path, nor at the potential economic costs to aircraft owners (and drone owners) of any damage to their aircraft.

How risk has been assessed

- 2.5 Risk is assessed as a combination of the likelihood of an event occurring and the severity of the outcome if it did occur. On this basis, an event that is deemed relatively likely to occur and would result in a fairly severe outcome may be considered a higher risk than either an extremely severe event that is very unlikely to occur or a minor event that may occur more often.⁴

³ Aviation Safety Network drone database, 14th Dec. 2017. (<https://aviation-safety.net/database/issue/drones.php>)

⁴ The combination is often expressed in a risk matrix, with likelihood on one axis and severity on the other. See e.g. CAP795 Safety Management Systems (SMS) guidance for organisations https://publicapps.caa.co.uk/docs/33/CAP795_SMS_guidance_to_organisations.pdf p 14-16

- 2.6 In the case of this report, the “event” being considered is injury or death to those on board the aircraft, or to third parties on the ground, either as a result of a mid-air collision (MAC) between a drone and another aircraft or as a result of loss of control of the aircraft resulting from an abrupt manoeuvre whilst trying to avoid the drone.
- 2.7 In these terms, the most severe incident would be a collision between a drone and a large passenger aircraft that resulted in the loss of the aircraft. This is because of the greater number of passengers involved and the greater risk of third parties on the ground being injured by wreckage.
- 2.8 However, there are other possible outcomes of a collision or near miss which would result in fewer injuries or none at all; most obviously, despite a collision, it is likely that the aircraft would land safely.
- 2.9 The likelihood of a safe landing following a collision would depend on, among other things, what part of the aircraft was hit, how large the drone was and at what speed the collision occurred. It could also potentially be influenced by the type of aircraft. A large passenger aircraft with several engines would not necessarily be incapacitated by a drone colliding with one of its engines. By contrast, the consequences could be more severe for a single engine aircraft.
- 2.10 Similarly, if a drone struck the windscreen of an aircraft, this could result in the flight crew being unable to see clearly, suffer injury from debris, or potentially for the drone to penetrate the screen, which could in turn cause a loss of control.
- 2.11 The report does not only consider the risk of a collision. Even if a collision were avoided, the outcome could still be very serious if the aircraft pilot, in seeking to avoid the drone, lost control of the aircraft.
- 2.12 The picture is further complicated by the fact that a near identical collision (same size drone, same type of aircraft, same point of impact) could result in very different outcomes, depending on other factors. For example, if such a collision resulted in damage to flight controls, one factor affecting the outcome could be weather conditions: on a day when there was little wind and visibility was good, a successful landing of the aircraft would be more likely. In this context, it is also worth noting that drones are less likely to be flown in poor weather conditions.
- 2.13 Figure 1 summarises some of the potential events that could follow a collision between a drone and an aircraft. However, this report focuses on the ‘immediate’ risk associated with the collision, i.e. the likelihood of the event and the severity of the damage caused, rather than trying to determine the specific risk of each of the many potential consequences that could result from a collision.

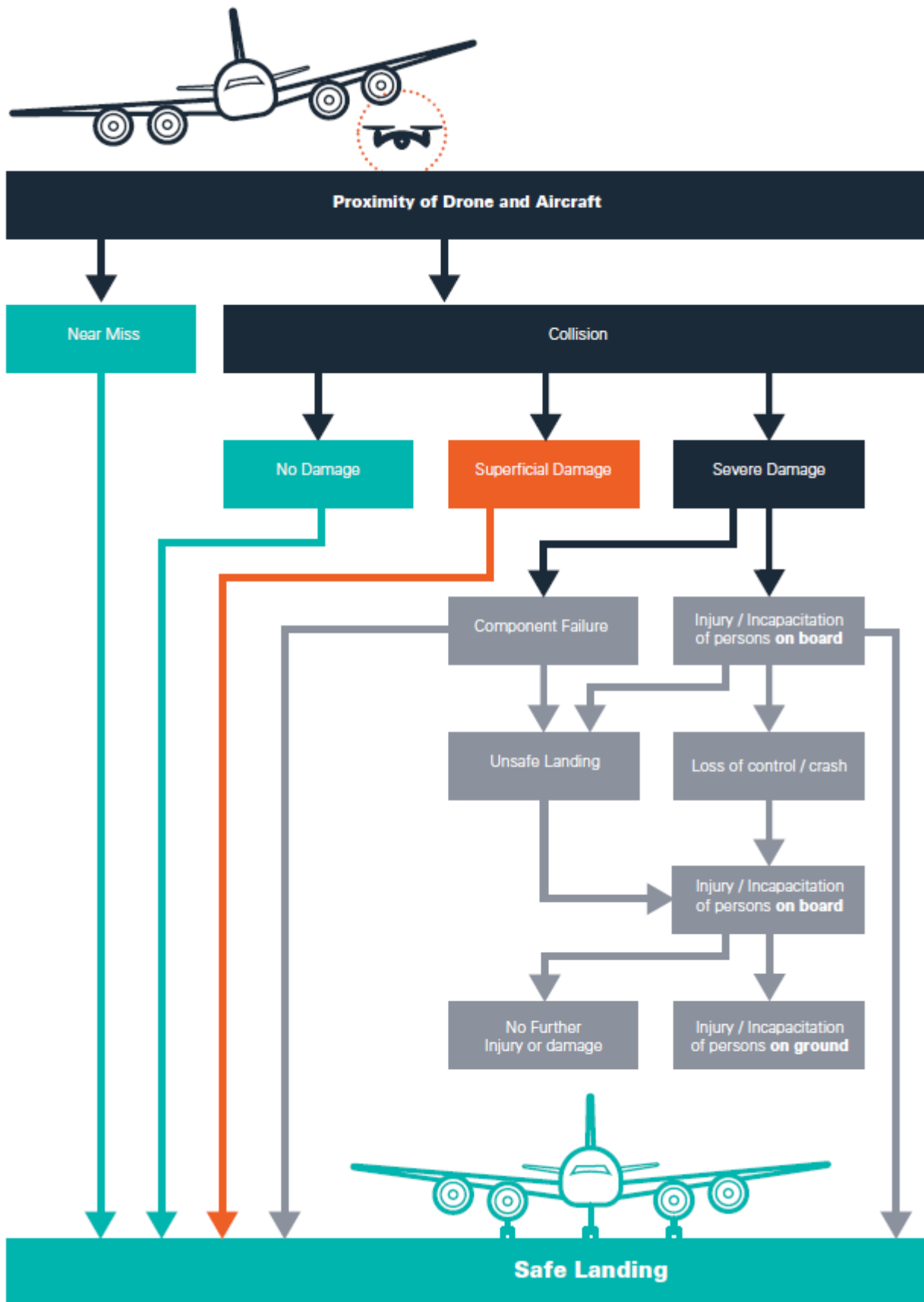


Figure 1 – Example of potential events following a collision

The CAA's approach

2.14 To assess both the likelihood and severity of a collision, the CAA has conducted a review of publicly available data and studies.

2.15 In terms of likelihood, the CAA has considered observed data that is available about drone ownership and usage, and about incidents where objects described as drones have been reported in close proximity to aircraft. This includes data from the Mandatory Occurrence Reporting (MOR) Scheme⁵, Airprox reports⁶, radar data, CAA data on aircraft movements and Office of National Statistics (ONS) data. We have looked at where these incidents have occurred, both in terms of the geographical location and the altitude to reach an assessment about observed level of current risk. The absence of comprehensive data about the levels of drone ownership and the frequency and nature of its use means that a reliable predictive model is not achievable at present. Moreover, the relationship between levels of drone ownership and risk to other aircraft is not likely to be straightforward. For example, while drone ownership is widely reported to be increasing, this will not automatically lead to a material change to the probability of drone collision risk. The risk of collision will depend on a range of factors including:

- How often drones are actually flown;
- How well drone operators educate themselves about the rules and regulations that are designed to keep other aircraft safe, and use technology such as recognised pre-flight information apps to give them information to enable them to fly safely;
- How well these operators adhere to the rules; and
- How well other aircraft are able to take avoiding action.

2.16 To help assess the severity of a collision, the CAA has looked at the effects of birdstrikes on aircraft – on the basis that these are potentially similar in size and weight to drones. We have also reviewed current aircraft certification standards, some of which include specific requirements for the aircraft to be able to withstand birdstrikes and other events.

⁵ The MOR scheme is a means of recording data about all incidents which endanger or which, if not corrected, would endanger an aircraft, its occupants or any other person. The purpose of occurrence reporting is to improve aviation safety by ensuring that relevant safety information relating to civil aviation is reported, collected, stored, protected, exchanged, disseminated and analysed. See www.caa.co.uk/mor

⁶ An Airprox is a situation in which, in the opinion of a pilot or air traffic services personnel, the distance between aircraft as well as their relative positions and speed have been such that the safety of the aircraft involved may have been compromised. Such incidents should be reported to the UK Airprox Board, which collects and analyses this data to support aviation safety. www.airproxboard.org.uk

- 2.17 The CAA has not conducted any primary research of its own, but it has been able to draw on the published outcomes of a recent study into the impact of drones colliding with commercial aircraft windscreens.⁷ In addition, CAA technical opinion has been used to assert a case for likely damage severity.
- 2.18 On 28th November 2017, ASSURE, the research centre of US aviation regulator the FAA, published its own preliminary modelling research into the potential severity of drone collisions⁸. Based on detailed modelling, the conclusions of this work are that:
- Small drones can introduce severe damage to aircraft structures but whether it does so depends on the location of the impact on the airframe, the velocity of the aircraft and design and construction of the drone. Non-severe structural damage can cause significant economic burden for aircraft operators;
 - Damage severity to the aircraft increases with the mass and velocity of collision;
 - Velocities above landing speeds are critical for masses above 1.2 kg;
 - Most damage is produced by the stiffer components of a drone (e.g. battery, motor); and
 - Drone collisions cause greater structural damage than bird strikes for equivalent impact energy levels (mass and impact velocity).
- 2.19 The results of the FAA's work, which are based on extensive and detailed modelling, broadly align with the findings of this assessment. The FAA has further research work planned over the coming years. The CAA will monitor the outcome of this research and other published work on collision consequences.
- 2.20 This assessment has been reviewed by members of the Safety and Accident Investigation Centre at Cranfield University and reflects their input.

Bowtie model

- 2.21 Drawing this different data and input together, the CAA has developed a bowtie safety assessment model that examines the potential outcomes of proximity between a drone and a manned aircraft and how these outcomes could be mitigated.
- 2.22 Bowtie models are regularly used by the CAA to provide an effective, visual depiction of risk. They consist of different elements that build up the risk picture. The risk picture revolves around the hazard (something in, around or part of an organisation

⁷ Department for Transport (DfT), Military Aviation Authority (MAA) and British Airline Pilots' Association (BALPA) - *Small remotely piloted aircraft systems (drones): mid-air collision study* www.gov.uk/government/publications/drones-and-manned-aircraft-collisions-test-results.

⁸ FAA ASSURE UAS Airborne Collision Hazard Severity Evaluation Final Report: www.assureuas.org/projects/deliverables/sUASAirborneCollisionReport.php