‘Drone Collision’ Task Force

Final Report
(04/10/16)

An agency of the European Union

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1 Executive Summary

The European Aviation Safety Agency Task Force has assessed the risks resulting from collisions between drones of varying masses and different categories of manned aircraft, considering their design characteristics and operational requirements.

Chaired by EASA, the Task Force consisted of six representatives from the European aircraft industry and several EASA specialists. Additional contributions were provided by invited experts. Two formal Task Force meetings took place between May and July 2016. To support the assessment, relevant occurrences have been reviewed, as well as existing studies on the subject of impacts between drones and manned aircraft.

Early in its evaluation, the Task Force identified the need to narrow down the scope of the assessment and it decided to focus on the drones available on the mass market that correspond to the proposed EASA 'Open Category' (i.e. less than 25 kg), limiting the assessment to four classes of drones that represent the vast majority of the drones in this category flying today: 'Large' (3.5 kg), 'Medium' (1.5 kg), 'Small' (0.5 kg) and the smallest or 'Harmless' (0.25 kg). A simplified model of the drone threat has been established, considering certain parameters that are assumed to contribute to the potential severity of an impact, which led to the batteries and the motors of drones being identified as key critical components.

Within the confines of this remit and for each product type, the vulnerability of selected aircraft components has been assessed against the four classes of drone defined.

As expected, large aeroplanes and large rotorcraft are by the nature of their scale and design requirements generally more resilient to collisions with drones and the severity level is limited for the smallest drone categories ('Small' and 'Harmless'). For smaller aeroplanes and light rotorcraft, more components are vulnerable and the severity level is higher.

The landing gear and the related doors and landing lights are expected to be components with the lowest vulnerability.

More specifically, for the case of a collision with a 'Medium' drone, only an impact above 10 000 ft at cruise speed is believed to lead to 'High' severity effects. At lower altitudes, the severity level of a collision with a drone of this category is expected to be 'Low' due to the lower kinetic energy at impact.

The use of altitude protection, as defined in the drone threat specification (DTS), which might be implemented in certain drone designs, is perceived to be a means to mitigate the consequences for large aircraft airframe components of a collision with a 'Medium' sized drone. Little or no benefit is expected from the use of altitude protection for rotating components (i.e. engines, propellers, and rotors) and the airframe components of rotorcraft or general aviation aircraft.

A collision with the smallest drone category is expected to be harmless (according to the definition of 'Harmless' adopted by the Task Force), at least for large aeroplane product types. Further research is needed to determine the consequences for other aircraft product types.

Engineering judgment has been used extensively, and the limitations of both the scope and the methodology of the assessment should be taken into account when interpreting the conclusions that have been reached.

As a result of its work, the Task Force has delivered a set of three recommendations, listed below:

— **Recommendation 1**: The Task Force recommends that an analytical model of the drone threat should be developed that takes into account a more detailed analysis of the construction of drones and an assessment of the dynamic behaviour of drones and their components, (in particular their motors and batteries,) during an impact. To gain confidence in the model, the method should be validated against laboratory tests, in particular to validate the behaviour of specific drone components such as the batteries or the motors during an impact and to confirm the prediction of the overall frangibility of the drone. This validated analytical model could be used for further impact analysis (see Recommendation 3).

— **Recommendation 2**: The Task Force recommends that a specific risk assessment should be conducted to assess the behaviour of lithium batteries on impact with structures and rotating parts, and their possible ingestion by jet engines. The assessment should, if possible, be supported by testing, and should address the risks of explosion, fire and air contamination.

— **Recommendation 3**: The Task Force recommends that further research should be conducted to establish hazard severity thresholds for collisions between drones and manned aircraft. Impact analyses should be performed to determine the effects of a drone threat (as established per Recommendation 1) impacting aircraft critical components, possibly capitalising on existing computing and software capabilities and other particular risk assessments such as those for bird, tyre and engine debris impacts. To gain confidence in the model, the method should be validated against tests on representative aircraft components such as airframe parts, windshields and rotating elements (i.e. rotors, propellers and fan blades).

As a possible way forward, the Task Force believes that a coordinated and collaborative research programme should be established to further assess the consequences of a drone collision on an airborne manned aircraft. The results should be shared to inform the responsible parties and to facilitate the development of future safety measures that may be necessary to ensure the safe operation of drones.

The outcome of the research could be used to help to:

— Confirm and justify drone sub categories and their operational limitations so as to minimise the risk of collisions;

— Influence the design of drones to minimise the risk if an impact occurs;

— Categorise new drone designs that utilise new drone technologies; and

— Prevent unnecessary regulatory actions from affecting the drone and aircraft industries.

2 Introduction

Drone technologies pose a regulatory challenge because today’s aviation safety rules are not adapted to drone operations. Given the broad variety of drone types being used under very differing operating conditions, the regulatory framework must move from an aircraft-centric approach towards an operation-centric approach. Drones are a type of aircraft. If drones are operated alongside 'manned aircraft', all the existing aviation rules and procedures must be followed, which means there is a need to develop ‘detect & avoid’ or ‘command and control’ technologies for drones to ensure that drones can comply with those rule and procedures.

There are, however, smaller drones that are already flying. Recent reports have raised the awareness of politicians, authorities and the public to the risk of a collision between a small unmanned aircraft and a manned aircraft. Even if for some of the events, the actual risk is lower than perceived, this risk cannot be underestimated.

Up to now for the 'Open Category' of drones as defined by the EASA Technical Opinion [ref.: 1.], EASA has been working on reducing the likelihood of the occurrence of a collision through a combination of measures, including the operation of drones in VLOS (visual line of sight), below 150 m altitude, no closer than 50 m to people, not over crowds, drones being equipped with functions of identification and geo-limitation, drones being registered and the pilot having acquired a pre-defined knowledge level. The 'Open Category' will be defined by a set of limitations. Operations that fall outside these limitations will be in the specific category or the certified category for which the authorities will approve or certify (respectively) the proposed risk mitigation measures or the product and its operations.

The 'Open Category', includes drones up to 25 kg and it is further divided into subcategories, including a 'Harmless' subcategory. For each subcategory, a specific set of product safety standards will be defined.

In particular, the 'Harmless' subcategory would have following basic requirements:

- The drones would only be subject to market regulations (and local restrictions);
- The requirements for the operator should be limited (to avoid careless or reckless operations); and
- The manufacturer of a 'Harmless' drone would need to supply clear operating instructions with do's and don'ts on leaflets provided in the box.

As a starting point, a 250 g maximum take-off mass (MTOM) limit is proposed to be used for the 'Harmless' category.

EASA will continue to proceed with this combination of measures, and as the development of EU rules will take some time, it will discuss with Member States the possibility of accelerating the introduction of certain measures (e.g. geo-limitation).

It is necessary to understand what could happen in the case of a collision in order to confirm or to revise the operational measures taken. The phenomenon is quite complex, as there are several parameters that must be taken into account, such as the mass of the drone, the relative speeds between the aircraft and the drone, the location of the impact on the aircraft, and the behaviour of the aircraft structure during the impact, considering the various components of the drone, etc.

As a first step, EASA decided to conduct a high-level assessment of the potential consequences of a collision between an unmanned aircraft and a manned aircraft.

This assessment has been conducted by this Task Force chaired by EASA. In order to obtain a manageable and efficient working group, the number of participants in the Task Force was deliberately kept small. The Task Force included EASA and industry representatives from the European aircraft industry who were proposed by ASD and GAMA. The membership of the Task Force is detailed in Appendix III.

3 Occurrences

When looking at existing data regarding occurrences involving remotely piloted aircraft systems (RPASs), the time period was set from 2010 to May 2016. The dataset used was derived from EASA's own occurrence database, ECR data and data collected from National Aviation Authorities (NAAs) and industry. However, it should be noted that the quality of the data available for this analysis is not to the highest standards and the coding of occurrences in the European Central Repository (ECR) could be improved. Many of those reports contain sightings of drones, and most of them are considered to be real drone sightings, but due to the speed of the aircraft and the sudden appearance of these objects, as well as human limitations, it is recognised that in some cases, the perceived drone could be in fact some other object like a bird or a plastic bag.

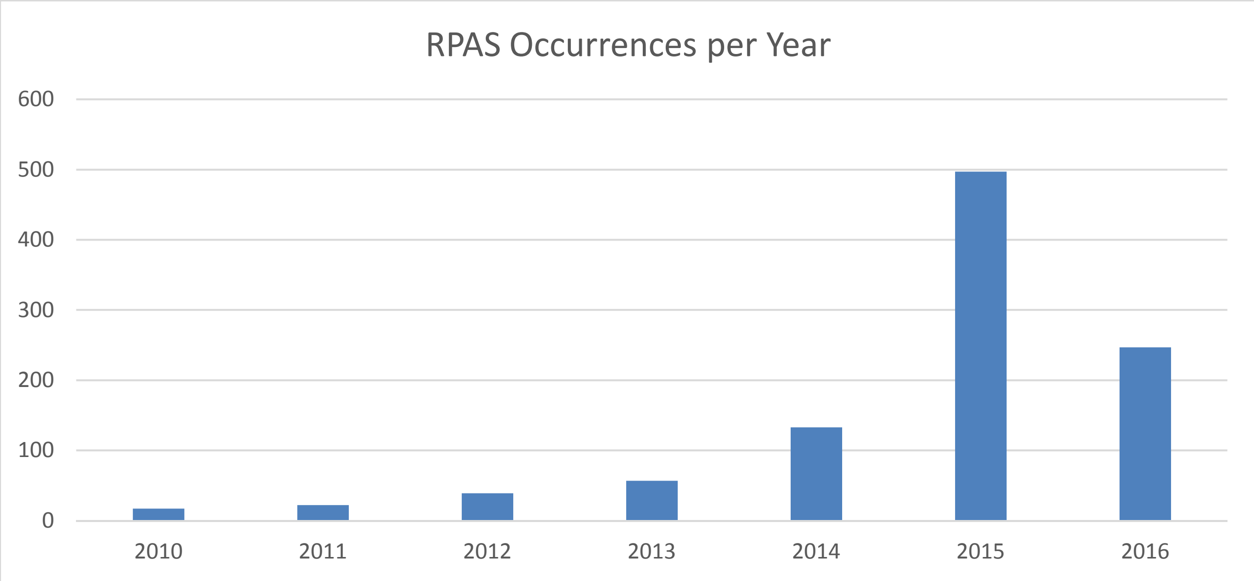

Figure 1 RPAS occurrences per year – 2010 to 31 May 2016.

3.1 Airborne Conflict

From the analysis of the event types, airborne conflict (defined as a potential collision between a drone and an aircraft in the air) is the most common type of occurrence, and closely associated with that was a number of occurrences classified as 'interference with aircraft'. Within the period 2010-2016, three collisions between non-commercial aircraft and drones were reported and investigated by EASA Member States. One collision was investigated in the United States. That last collision was also caught on video[1].

The three known collisions that occurred in Europe involved damage to the value of GBP 1 400 on a Pioneer 300 aircraft in the UK, scrapes on the wing of a French Robin DR400, and no damage when a Grumman AA-1 was struck on its undercarriage.

As this report is focused on collisions, it is well worth noting that in 1997, there was a mid-air collision between a Grob G109B touring motor glider and a radio controlled model aircraft at an altitude of 200 m or less above ground level (AGL). The model impacted the leading edge of the wing halfway along the wing. The damage was so extensive that the outer half of the right wing broke in the upward direction and separated completely just a few seconds after the collision, leading to an immediate loss of control of the aircraft. Both persons on board the touring motor glider were fatally injured.

[1] Mid air collision between aircraft and an aircraft model: https://www.youtube.com/watch?v=hoZD9pczEVs

Date	Airspace type	Altitude in ft	A/C type	Aircraft Registration	Drone type	Aircraft Damage	Comments
30/08/2015	Unknown	2500	Grumman AA-1	N3LY	Unknown	None	RPAS struck undercarriage
30/04/2015	Controlled airspace	700	Robin DR 400-180	F-GSBM	SAS Wildthing	Scraping on wing	Type of airspace unknown - final approach - exact altitude not available
05/04/2015	G	630	Pioneer 300	G-OPFA	Valenta Ray X, S037996	Scuffing and scraping (GBP 1 400)	Uncontrolled airspace
14/08/2010	Controlled airspace	50	Shpakow SA 750	N28KT	AJ Slick model airplane	Lower left wing crushed aft to the main spar	Video
03/08/1997			Grob G 109B		Dingo	Destroyed	2 fatalities

Table 1 List of known mid-air collisions with UAS.

Note: The fatal accident in Table1 is outside the scope of the rest of the data, as the general scope is from 2010 to May 2016.

3.2 Reported distance between aircraft and drone

When considering aircraft altitude in relation to the detected distance from a drone (Figure 2), there was not a great deal of data available in the ECR, so this part of the analysis includes all sources of occurrences, including data received from a number of operators in the Commercial Air Transport Aeroplanes Collaborative Analysis Group. It can be seen that most occurrences happen in situations below an altitude of 6 000 ft in which the distance from the drone is 600 ft or less. However, occurrences above 6 000 ft of altitude should not be disregarded, as aircraft groundspeeds increase with altitude, which could make an impact with a drone or even a weather balloon a very serious event.

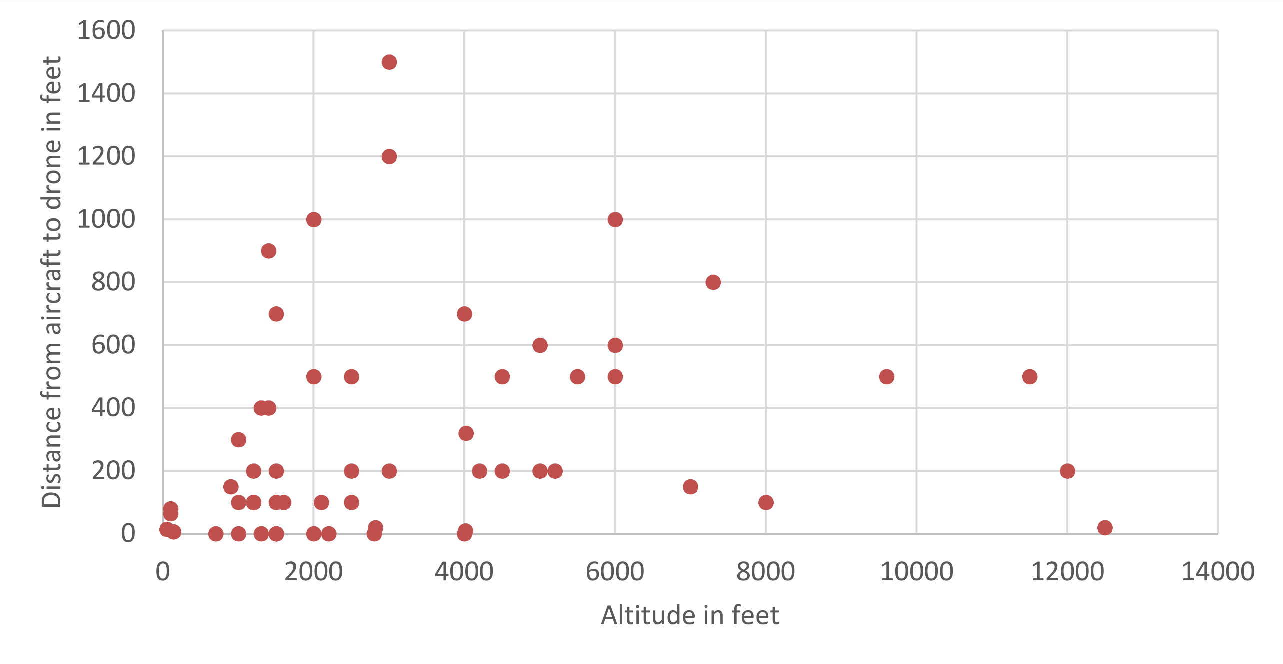

Figure 2 Distribution of RPAS Occurrences - Actual Aircraft Altitude vs Distance to Drone.

4 Analyse the existing studies

While there is a significant amount of data from studies and research available related to bird strikes on aircraft, there are currently few conclusive studies available that are relevant to the vulnerability of manned aircraft to drone collisions.

The most relevant publications that have been found to be useful for the work of the Task Force and that support the assumptions and the approach taken are listed in Appendix II.

In particular, the CASA/Monash University study (ref.: 4) analyses the potential damage to manned aircraft from a mid-air collision with a small unmanned aircraft (i.e. a UAV), and the scenarios of the ingestion of UAV components by engines and impacts into fuselages and cockpit windscreens are considered. The study provides estimates of the velocities above which penetration of the aircraft structure can be expected. It is, however, recognised that the method used in this particular study leads to very conservative results.

The Task Force also identified the following ongoing research activities for which the results are not yet published:

4.1.1 ASSURE initiative

The Alliance for System Safety of UAS through Research Excellence (ref.: 18) is a partnership of research institutions and industry/government organisations in the USA. Currently, one of the main ASSURE research projects is the 'A-3 UAS Airborne Collision Severity Evaluation' (within the 'Airworthiness' domain). This research proposes to evaluate the severity of a collision between a 'Small' UAS (i.e. with a weight less than 55 lbs) and commercial and business jet airframes and propulsion systems. This research will utilise simulation techniques validated by tests on aircraft hardware. Some results are expected in October 2016.

4.1.2 ASUR Initiative

Autonomous Systems Underpinning Research (ref.: 17) is a joint project between Dstl, QinetiQ, Thales, Selex ES, Roke, MBDA and BAE Systems. This initiative looks at how to reduce the contact pressure during impacts with given RPAS components through analysis and testing.

4.1.3 RPAS Collision Study, Joint Venture UK Military Aviation Authority (MAA), Department of Transport (DfT), British Airline Pilots Association (BALPA)

The Joint Venture lead presented the research initiative being conducted by the UK MAA, the UK Department of Transport and BALPA. The aim of the research project is to better understand the risks that drones pose to manned aircraft by studying the hazard severity of drones impacting the most safety-critical areas of rotary wing and fixed wing aircraft, and using the data produced to influence the safe operation of drones. Through testing and analysis, this research will provide a better understanding of the maximum drone mass that would result in minimal to no risk to manned aircraft, and it will also assess the severity of impacts of drones of masses of up to 4 kg against safety critical areas on selected civil and military aircraft. The project will include actual testing on representative windshields and modelling of tail rotor blades.

5 Consultation

To achieve their objectives, the Task Force considered it of the utmost importance to gather the views of the most relevant stakeholders who are not directly represented in the Task Force. A consultation with stakeholders was therefore conducted using a detailed questionnaire. The questionnaire was sent to 135 different organisations (including 74 to the manned aircraft industry) requesting the recipients to provide either a detailed impact assessment and/or feedback on the approach to drone impacts. The list of the stakeholders consulted is included in Appendix IV. Overall, around 30 % of the organisations consulted responded, which EASA recognises is symptomatic of the short timescales set for this initial activity. **Nonetheless, some very detailed and comprehensive responses have been provided and the EASA 'Drone Collision' Task Force would like to again express its gratitude to all the organisations who spent time on answering the questionnaire**.

The responses have been assessed and used when appropriate to produce the conclusions and recommendations made by the Task Force.

6 Assessment methodology

The approach taken was to assess the current situation in terms of the threat from drones and the existing means of mitigation, with the objectives of determining whether any conclusions could already be drawn on the proposed categories of drones, and if not, of providing meaningful recommendations for any further research needed to address the issue.

The manned aircraft considered included large aeroplanes, general aviation aircraft and rotorcraft. To estimate the hazard associated with a drone collision with a manned aircraft, a three-step approach was proposed:

- Step 1: Specification of a simplified generic drone threat model: the drone threat specification (DTS);
- Step 2: Evaluation of the effects of the impact of a drone threat on selected aircraft components: the impact effect assessment (IEA); and
- Step 3: The classification of the resulting hazard effect at the aircraft level on the occupants and on the operation of the aircraft: the hazard effect classification (HEC).

6.1 Drone Threat Specification (DTS)

In order to quickly assess the drone threat, a simplified model of the threat was needed. To do this, the threat was considered as a function of the following essential parameters:

— The frangibility of the drone, which addresses the potential tendency of the drone to break up into fragments through deformation rather than by deforming elastically;

— The effective kinetic energy of the drone in the impact, which is a characteristic of the energy of an item of mass in motion, namely the drone, and the relative velocity of the drone in relation to the impacted aircraft;

— The potential independent penetration capability of certain components of the drone, based on their shapes, materials, densities and kinetic energies.

A simplified generic DTS was proposed, based on the assumption that a drone can be conservatively modelled by a combination of the following:

(a) The complete drone considered as a frangible, low-density body. The associated threat is labelled 'Threat: low-density' (Tl).

(b) Less-frangible, ductile, medium density elements. The associated threat is labelled 'Threat: medium-density' (Tm).

(c) Some small stiff and sharp high density elements. These elements will have a higher penetration capability. The associated threat is labelled 'Threat: high-density' (Th).

In the context of this activity, items (b) and (c) above are designated as 'key critical components' (KCCs).

Based on the above assumptions, a simplified DTS has been established by conducting the following activities:

(a) Selection of drones that are representative of the broad range available on the mass market that are in the 'Open Category'. Recent studies indicate that the vast majority of the drones sold within this segment have a weight of less than 5 kg. Three popular products were selected to be representative of 'Large' (3.5 kg), 'Medium' (1.5 kg), and 'Small' (0.5 kg) drone threats.

(b) Studying the characteristics of each of the selected drones to establish their lists of components, their component characteristics (i.e. dimensions, weight, and materials) and the performance of the drones (in terms of altitude and speed). The data used have been confirmed by the drone manufacturers.

(c) Selection of key critical components (KCC):

    (1) Medium-density elements (Tm): for all three models of drone assessed, the battery is conservatively selected as it has the highest weight of the medium-density elements. Taking into account the overall dimensions of the battery including the casing, the density ranges from 500 to 1 000 kg/m^3, but a more detailed analysis of the design of the batteries available shows an average density of about 2 000 kg/m^3 for the cell elements.

    (2) Some small sharp, high-density elements (Th): out of the three models of drone assessed, the motor is the element with the highest density, with a typical density of 4 000 Kg/m^3.

(d) Assuming that the density of each component would be maintained in smaller drones, the parameters were scaled down in order to cover the 'Harmless' category of 250 g drones. The Task Force will not assess and will not indicate conclusions for drones weighing less than 250 g.

(e) Specifying the generic drone threat specifications for Harmless, Small, Medium and Large drones with their associated operating envelopes (in terms of altitude and speed). For each group, the three types of threat (Tl, Tm, Th) are specified in Appendix V.

6.2 Impact effect assessment (IEA) and hazard effect classification (HEC)

A simplified process for conducting IEAs and HECs is detailed in Appendix VI, where the following aspects have been considered:

6.2.1 Most critical aircraft components/zones of impact

The potentially critical aircraft components or zones of impact have been defined by assuming only frontal impacts by single drones, except in the case of rotorcraft tail rotors where side impacts were considered in conjunction with the transverse speed of the drone threat. Secondary impacts (such as by a drone bouncing off an aircraft or by debris from a drone having impacted a propeller or a rotor and then impacting a different location) were not considered.

Engineering judgment, the existing guidance material and data on bird strikes were used to select the following potential critical zones of impact for the assessment:

- Nose/radome/large antennas;
- Fuselage area below windshields;
- Canopy (the fuselage area above windshields);
- Chin Window (the fuselage area below the radome on rotorcraft);
- Wings (the leading edges, including slats, trailing edges (the flaps));
- Winglets;
- Fairings (e.g. from wing to fuselage);
- Horizontal and vertical stabilisers (leading edges);
- Engines (excluding reciprocating engines);
- Engine pylons, nacelles, air intake cowlings;
- Main and tail rotors including blades, hubs, masts and controls;
- Propellers including blades and spinners;
- Windshields; and
- Landing gear, landing gear doors and lights (which are critical for rotorcraft).

The following elements were not retained for assessment due to their low vulnerability:

- Fuselage (except the nose & cockpit areas) and windows (side impact was only considered for tail rotors);
- Reciprocating engines;
- Transmissions (main and tail rotors, except if vulnerable when a vertical stabiliser is addressed);
- APU and ECS air intakes;

- Ailerons, rudders, elevators and spoilers (usually not considered for bird strike requirements (ref.: 2); and
- Hoists.

The following elements were not retained for the assessment due to their low criticality:

- External probes, small antennas, wipers.

6.2.2 Estimation of effects at aircraft component level

The estimation of the effects of impacts on the selected components was based on comparisons with information already available or accessible. This included:

- The reference to the external threats assessed in certification (e.g. birds, ice, hail, or other foreign object damage (FOD));
- The use of other certification and industry design standards;
- Aircraft industry design practices and tools;
- Existing research conclusions; and
- Available in-service collision data.

EASA did not have any relevant or useful in-service collision data to contribute.

The characterisation of the effects on the components impacted was performed in accordance with the IEA matrix (Low, Medium, High effects) in Appendix VIII.

The vulnerability of each aircraft component was assessed against the DTS, but once any threat for a given drone category was determined to be in the 'High' effect classification of the IEA Matrix, no further threats from that drone category needed to be considered.

Within the DTS operational envelope, the most conservative aircraft conditions were selected. Those conditions are given by the highest possible aircraft speed, and the highest engine thrust or regime in revolutions per minute (RPM) for the rotors and the propellers. In the DTS, two different altitudes are considered:

- the maximum attainable flight altitude (Zd-max) above sea level; and
- the maximum altitude limit 'hard coded' in software (Zd-lim).

Both altitudes have been assessed, even if the maximum attainable flight altitude potentially adds significant conservatism, as it is at the extreme limits of the performance capability of the drone category assessed, where true airspeeds of aircraft are higher.

For information, the external threat certification requirements have been also provided for each category of product in Appendix VII.

For the assessment of a complete drone considered as a low-density body (threat Tl), the Task Force advised consideration of the bird strike data that provides relevant information to support the impact effect classification. The EASA Certification Memo (ref.: 2) addresses several issues associated with showing compliance with the CS-25 bird strike requirements and provides useful information with respect to the vulnerability of certain areas and the aircraft conditions to consider.

6.2.3 Hazard effect classification (HEC) at the aircraft level

Based on the results of the impact assessment at the component level, a classification of the hazard effect at the aircraft level was made. In cases of penetration of the component being considered (e.g. the windshield, airframe skin, etc.), the possible effects on critical systems, on the primary structure or on the aircraft occupants have been estimated. In cases of parts becoming detached (i.e. airframe or engine parts), the possible effects on the other aircraft components (such as the airframe, systems, or engines) as well as the effects on the aircraft handling qualities and performance (e.g. if the damage caused an asymmetric aircraft configuration) have been estimated. The resulting secondary effects such as fire and depressurisation have also been taken into account.

Assuming that a collision is detected and the necessary corrective actions are taken (such as flight crew action or maintenance for the following flight, etc.), a classification of the hazard effect at the aircraft level was made based on the effects described in the HEC matrix (levels 1 to 5) proposed in Appendix VIII.

6.3 Outcome of the consultation on the approach to the impact assessment.

Overall, the approach proposed by the Task Force was judged to be acceptable in terms of its scope and the assumptions taken. No major elements have been reported to be missing from the evaluation either in the impact assessment matrix (for the classification of the damage to each component exposed) or in the hazard effect classification (the level of severity and the hazard classification at aircraft level).

A number of stakeholders considered that some of the answers were based on indirectly related experience (i.e. hard body FOD ingestion) and engineering judgment, and that therefore the degree of conservatism is difficult to confirm.

7 Conclusions on the vulnerability of manned aircraft

This chapter presents the conclusions for the various products (large aeroplanes, rotorcraft and general aviation) of the EASA Task Force assessment. Where there was no consensus among the stakeholders' responses, the most conservative response to the questionnaire was retained.

To facilitate the understanding of the conclusions, the notion of a 'severity level' was introduced into the hazard effect classification (see the matrix in Appendix VIII). The Task Force agreed on the following classification:

— The severity level was declared to be 'HIGH' for HEC 1 or 2; and

— The severity level was declared to be 'LOW' for HECs 3 to 5.

The Task Force also agreed that in order for a collision to be declared 'Harmless', the HEC level must not be less than 4.

When considering the results presented below, EASA suggests that readers should recognise and understand the limitations of both the scope and the methodology of this assessment. Engineering judgment has been used extensively and there are uncertainties associated with the definition of the drone threat specifications, the assessment of the level of damage and the associated hazards at the aircraft level. The assumptions adopted are not the only possible set of assumptions, and the use of a different set of assumptions or a different methodology could have potentially produced different results.

7.1 Large Aeroplanes

7.1.1 Assumptions/hypotheses

When the Zd-max (the maximum attainable drone flight altitude above sea level) is greater than 10 000 ft, a calibrated airspeed (CAS) of 340 kt for the aircraft has been assumed (as the typical maximum operating speed of commercial aircraft).

When the Zd-max is below 10 000 ft and the Zd-lim (the drone software-limited altitude) is 500 m/1640 ft for the 'Large' and 'Medium' categories and 150 m/492 ft for the 'Small' and 'Harmless' categories, an average speed of 250 kt (CAS) for the aircraft has been used.

The Task Force made this simplification to make the assessment easier to conduct, although during operations, the speeds of large aeroplanes may be less than 250 kt on specific segments (typically during the initial climb or in the landing phase), whereas they may sometimes be greater than 250 kt in some areas at altitudes between 5 000 and 10 000 ft above ground level.

Speed limitations applied in areas of specific national airspace have not been applied, as these limitations are not uniform across the world.

Different speeds from the ones described above for Zd-max and Zd-lim might have also been considered by some respondents, but the assumptions they used were not indicated in the responses to the questionnaire that were received.

In the questionnaire, the battery (a medium-density element) and the motor (a high-density element) were the most critical of the three drone threats identified by the DTS. The damage from these individual components might be worse, and possibly completely different from that envisaged in this study, in particular when considering the impact of batteries or motors on brittle windshields. However, due to the lack of experience and knowledge of the effects of drone impacts, the kinetic energy at impact of the whole drone in comparison with that of a bird (4 lb or 8 lb, depending on the element considered) has been the main criterion used to assess the potential damage resulting from an impact.

7.1.2 Results of the questionnaire

Despite the limited number of replies from stakeholders for large aeroplanes (4 in total), the answers were quite diverse in terms of the damage and the resulting hazard from a collision with the 'Large' and 'Medium' drone categories. This difference is particularly noticeable for components located in the forward part of the aircraft (e.g. the nose/radome, the windshield and surfaces around the windshield) and for the horizontal and vertical tail planes.

The fact that there is a significant scatter in the responses of the stakeholders for some components when hit by 'Large' and 'Medium' drones is not surprising and it highlights the need for a better understanding of the physics involved and of the resulting effects on an aircraft (see the 'recommendations' section).

7.1.3 Conclusions for large aeroplanes

— Only the 'Large' and 'Medium' drone categories could trigger 'high' severity effects (HEC 1 or 2) for large aeroplanes, when impacting the following areas:

  - Fuselage areas above and below windshields;
  - Engines;

- Horizontal & vertical tailplanes/wing leading edges, and flaps;
- Nose/radomes/large antennas;
- Windshields; and
- Propellers.

— More specifically for the case of a collision with a 'Medium' drone, only an impact above 10 000 ft at cruise speed is believed to lead to 'High' severity effects. At lower altitudes, the severity level of a collision with this drone category is expected to be 'Low' due to the lower kinetic energy at impact.

— The 'Harmless' drone category may be considered harmless for large aeroplane product types according to the definition above.

— The altitude considered (Zd-max or Zd-lim) does not affect the severity of damage to engines/propellers, as the most conservative case is driven by the high thrust/rpm used during the take-off phase and the initial climb.

— The effect of altitude limitations for 'Large' and 'Medium' drones on the damage from an impact and the effects at the aircraft level were perceived quite differently by the stakeholders. Some respondents envisaged less critical impacts when the drone flight envelope was limited by software to Zd-lim (i.e. 500 m for the 'Large' and 'Medium' categories) in comparison with drones that could fly up to the Zd-max (i.e 5 000 m for the 'Large' and 'Medium' categories). This was due to the reduction in kinetic energy at impact, whereas other respondents did not consider such effects. In the absence of details regarding the methodologies used, it is difficult to understand whether those assessments came from different assumptions on the speeds at Zd-lim and Zd-max or from the fact that it is assumed that the difference in speed (~340 kt vs 250 kt) has a limited effect on the consequences of the collision for some of the components.

— The difference in the damage and event severity between Zd-max and Zd-min is most noticeable for the 'Medium' drone category. This is due to the significant differences in the kinetic energy at impact between aircraft speeds of 340 kt (above 10 000 ft) and 250 kt (below 10 000 ft). Above 10 000ft, the kinetic energy at impact is greater than that of the 4 lb bird specified in the certification specifications, while it becomes much smaller than that of the 4 lb bird at 250 kt at altitudes of less than 10 000 ft. As many areas of the forward part of an aircraft are designed to prevent penetration by a 4 lb bird, a drone impacting with a kinetic energy greater than that of a 4 lb bird could increase the risk of penetration and of a significant hazard if pilots or non-segregated critical systems were hit.

— Due these considerations, the use of altitude protection is perceived, at least by some respondents, to be a way to mitigate the consequences of a collision with a 'Medium' sized drone.

— A detailed statistical analysis of aircraft speeds in the altitude range of 0 to 10 000 ft could be useful in gaining a better understanding of the potential benefits of limitations on drone altitudes.

— For 'Large' drones, the effect of altitude limitation is considered to be less likely to provide benefits in terms of limiting penetration damage, as the kinetic energy of a 'Large' drone at 250 kt CAS is already higher than that of a 4 lb bird (at sea level and the design cruise speed, Vc, as specified in the certification specifications). Nonetheless, due to the lower cabin pressurisation loading at lower altitudes, the aircraft-level effects of drones impacting the pressurised areas may be reduced due to the use of drone altitude limitation.

7.2 Rotorcraft

The feedback obtained from the rotorcraft industry is very limited, as only 1 completed questionnaire was received out of 8 organisations who were consulted. As a result, the analysis could be limited and unbalanced due to the unavailability of comparison data, and this could therefore lead to excessively conservative or relaxed results.

The assessment carried out for rotorcraft was based on the following assumptions:

— Zd-max and Zd-Lim are not dimensioning parameters for rotorcraft, as it is assumed they can fly in the entire envelope up to the VNE (velocity never to be exceeded), provided that sufficient performance is available. Moreover, there is a considerable number of missions flown at very low altitudes and high speeds (e.g. helicopter emergency medical services (HEMS), agricultural uses, etc.).

— At any altitude, two different speed scenarios have been considered:

- Forward flight at high speed up to V_{NE}/V_H = 170 kt indicated airspeed (IAS). This value has been selected as an average value for modern high-performance medium helicopters (i.e. the upper range of CS-27 certified helicopters) and large helicopters (CS-29 certified). This value has been retained for any altitude, which is consistent with the most common modern designs. In this condition, the drone speed has been neglected.
- Hover condition with the drone flying at 20 m/s (= 39 kt). In this condition, the risk of a lateral impact into the tail boom and the tail rotor has been considered.

For the analysis of the impact effect assessment (IEA), it has been taken into account that bird strike requirements are applicable only to CS-29 certified helicopters, as indicated in appendix VII, and is limited to the following components:

— Windshields;

— Main rotors;

— Tail rotors; and

— Exposed flight control system components.

Since the analysis includes all types of helicopters, small helicopters (i.e. CS-27 and CS-VLR) are therefore the driving factor in the review, as they represent the most sensitive case in terms of the vulnerability of the above-mentioned components.

Overall, it can be concluded that for all classes of drones, the vulnerable aircraft components are the:

— Nose/radome/large antennas;

— Canopy (fuselage area above windshields);

— Fairings (including the external fuel tanks contained in the sponsons in some large helicopters);

— Main rotor including blades, hubs, masts and controls;

— Tail rotor including blades, hubs, masts and controls; and

— Windshields.

The landing gear and related doors and landing lights are expected to be the components with the lowest vulnerability, although these components were initially deemed to be critical specifically for rotorcraft.

The smallest drone category (250 g) presents a **Low** severity level, but more data are needed to better substantiate the analysis.

Further research should be conducted specifically to assess the behaviour of helicopter tail rotors in collisions with all categories of drones.

7.3 General Aviation

General Aviation (GA) aircraft are covered by CS-22, CS-LSA, CS-VLA and CS-23 and offer a huge variety of totally different aircraft concepts. Aircraft in the CS-23 commuter category only have to comply with the very low level requirement to sustain a bird strike by a small 0.91 kg (2 lb) bird, and on the windscreen only. Some more stringent requirements have been applied to individual aircraft based on a 0.91 kg bird on a case-by-case basis by means of Special Conditions. Only CS-23 aircraft have to comply with specific requirements for damage tolerance and for a minimum level of redundancy. Neither bird strike nor damage tolerance demonstrations are required for aircraft at the low end of the GA category. This is based upon the low overall flight speeds and the historic level of acceptable risk that the rules have embraced in this segment.

Recognising this, it was probably not surprising that the GA response to the questionnaire was limited and that there were large variations in the results that were submitted. The overall impression was that there was a great deal of wariness on the part of the responders to the questionnaire because they felt it might lead to future rulemaking and regulations. Some respondents therefore preferred to provide their thoughts and opinions only in the form of text responses. Those who responded with numerical data had to do this solely using their best engineering judgment, without even the possibility of relating this to bird strike testing results.

What was apparent from the limited responses was that the windscreen, and to a slightly lesser extent the empennage, were identified as areas where any strike of a 'Small', 'Medium' or 'Large' drone could have potentially severe effects. At the lowest end of the spectrum, even the so-called 'Harmless' class of drone was perceived to present a hazard with respect to the vulnerability of windscreens to collisions. Bearing in mind that the windscreens of most GA aircraft types are typically made from 3-5 mm thick single-layer polymers and that they are not required to provide protection against bird strikes, this result for collision with windscreens is considered to be realistic.

It should be borne in mind that the existing data shows that the probability of a GA aircraft sustaining a bird strike is much greater than the probability of sustaining a collision with a drone, and that this is likely to continue to be the case for the foreseeable future. A bird strike is also generally considered to be an accepted risk, especially for aircraft at the lower end of the GA category. Other considerations are that most of these aircraft operate at relatively low speeds and that their high level of manoeuvrability decreases the risk of sustaining bird strikes.

8 Recommendations and way forward

The approach proposed by the Task Force was not intended to address all the technical issues relevant to collisions with drones, rather it was intended to quickly provide an assessment of the current situation in terms of the threats and the existing means of mitigation. The Task Force assessment should therefore be considered as a first step, which could be followed by more detailed and technically-robust activities in order to accurately model the threat to aircraft posed by drones and the effects of their impacts on aircraft components. In that context, the following recommendations and a way forward are proposed below.

8.1 Outcome of the consultation

The following is a summary of the main recommendations provided by stakeholders in response to the survey:

— The DTS is representative of the current mass market of the drones flying today, but this study has not attempted to foresee what further evolutions in drone design may take place, nor has it taken into account every specific drone design that may exist;

— Extensive damage, such as that caused by collisions with hard-body objects like UAV motors, batteries or cameras, is not within the scope of the current regulatory criteria regarding the damage caused by collisions with flying objects;

— In some instances there may be items that present a different threat – e.g. fuel/liquids;

— Detailed analyses of rotating parts would be required in order to fully assess the potential distributions of impact velocities along rotor blades, propeller blades and fan blades;

— Indirect effects should be taken into account (e.g. debris/UAV parts hit by propeller blades, or a strike on the leading edge of a wing, which may result in multiple secondary strikes);

— Numerical model(s) should be developed for drones and/or their constituent parts such as motors and batteries, capitalising on existing computing and software capabilities and other existing data related to impacts with birds, and with tyre and engine debris;

— To gain confidence in the numerical model, the method needs to be validated against tests, in particular the behaviour of drones/batteries/motors during impact. Testing may enable some of the frangibility factors that influence impact energy/penetrating power etc. to be determined;

— A detailed statistical analysis of aircraft speeds in the altitude range of 0 to 10 000 ft would be helpful in supporting further activities on collisions with drones; and

— Engine OEMs (original equipment manufacturers) should be requested to collate and provide their data related to the ingestion of hard body objects and the damage that was caused as a result.

In addition and not strictly within the scope of the EASA Task Force on drone collisions, it has been recommended that EASA should:

— Conduct a complete risk assessment using the 'Bow Tie' methodology to better characterise the complete interplay between hazards, consequences, and barriers/mitigations for drone operations; and

— Consider operational and built-in drone safety features (e.g. altitude limiters, maximum battery sizes, and separation requirements) as means to reduce the threat posed by drone collisions with manned aircraft.

The Task Force also recommends that EASA should set up a working group and organise workshops with OEMs and other regulatory authorities to develop a broad-based solution to the problems posed by drone collisions with aircraft.

Overall, the manned aircraft industry community strongly resists the idea of developing certification standards for aircraft designs as a means to increase their tolerance to drone impacts or to the ingestion of drones or their components.

8.2 The drone threat

In order to quickly assess the current situation posed by the drone threat, a simplified model of the threat has been developed, based on the drones currently available on the mass market and the assumption that key critical components can be selected to conservatively represent the threat. Since very little data exists today from actual collision events and from any available studies, this assumption needs to be confirmed. The assessment made by the Task Force looked at the current situation and this does not represent what might be proposed in the future, particularly when considering the rapid evolution of technology in this domain, which will certainly allow future drones to carry greater payloads for longer flight durations and with higher performance (in terms of the speed and altitude of the drones).

Recommendation 1:
The Task Force recommends that an analytical model of the drone threat should be developed that takes into account a more detailed analysis of the construction of drones and an assessment of the dynamic behaviour of drones and their components (in particular their motors and batteries) during an impact. The research could follow a building block approach to first gain an understanding of the basic physics of any sub-component and then to progress to components, and eventually to a complete mechanical system, possibly capitalising on existing computing and software capabilities and other particular risk assessments such as those for bird, tyre and engine debris impacts. To gain confidence in the model, the method should be validated against laboratory tests, in particular to validate the behaviour of specific drone components such as the batteries or the motors during an impact and to confirm the prediction of the overall frangibility of the drone. This validated analytical model could be used for further impact analysis (see Recommendation 3).

Lithium batteries contain hazardous materials such as lithium metal and flammable solvents, which can lead to exothermic activity and runaway reactions in case of impact with aircraft components following collisions.

Recommendation 2:
The Task Force recommends that a specific risk assessment should be conducted to assess the behaviour of lithium batteries on impact with structures and rotating parts and their possible ingestion by jet engines. The assessment should, if possible, be supported by testing and should address the risks of explosion, fire and air contamination.

8.3 Impact effect assessment (IEA) and hazard effect classification (HEC)

Simplified IEA and HEC processes have been proposed. In particular, the selection of the most critical aircraft components or zones of impact has been done assuming only frontal impacts by single drones. Side impacts have only been considered for helicopter tail rotors. Secondary impacts (such as drone bouncing, or the debris from a drone impact with a propeller or a rotor then impacting a different location) have not been considered.

In the assessment of large aeroplane products, 340 kt has been assumed for the aeroplane speed above 10 000 ft and 250 kt (CAS) below 10 000 ft. This is a simplification and in reality, the speed is likely to be lower during the initial climb or in the landing phase and it may be greater than 250 kt in the altitude range 0 to 10 000 ft on quite a regular basis, depending on the operating rules.

The estimation of the effects of impacts on the selected components has been done based on engineering judgment and the information immediately available or accessible. This approach considerably limited the extent of the coverage of the assessment, as the external threat that is examined is essentially limited to a comparison with the effects of bird strikes in the cases where they are required to be considered by the Certification Standards.

The hazard effect classification at the aircraft level has been done assuming that the collision is detected and that any necessary corrective actions are taken. This will not be always the case and the hazard effect classification should also consider undetected impacts and their consequences for the following flights.

Recommendation 3:
The Task Force recommends that further research should be conducted to establish hazard severity thresholds for collisions between drones and manned aircraft. Impact analyses should be performed to determine the effects of a drone threat (as established per Recommendation 1) impacting critical aircraft components, possibly capitalising on existing computing and software capabilities and other particular risk assessments such as those for bird, tyre and engine debris impacts. It is suggested that the research should take into consideration: — The level of criticality established in the report for each of the product types; — The manned aircraft parameters (aircraft speed, angles of incidence, etc.), including a detailed statistical analysis of typical aircraft operational speeds in the altitude range of 0 to 10 000 ft; — The critical components or zones of impact; — The impact velocity distributions along rotor blades, propeller blades and fan blades; — The possible side impacts (when relevant); and — The secondary effects (of drone bouncing or of debris from a drone that impacted a rotary part then impacting a different location). To gain confidence in the model, the method should be validated against tests on representative aircraft components such as airframe parts, windshields and rotating elements (i.e. rotors, propellers and fan blades).

8.4 Way forward

The outcome of the recommended research may be used to help to:

— Confirm and justify drone sub-categories and their operational limitations so as to minimise the risk of collisions;

— Influence the design of drones to minimise the risk if an impact occurs;

— Perform the categorization of new drone designs that utilise new drone technologies; and

— Prevent unnecessary regulatory actions from affecting the drone and aircraft industries.

Various research initiatives to assess the vulnerability of manned aircraft to drone strikes are already ongoing across the world and within the EU. If the decision is taken to launch further research projects at the EU level, prior coordination work should be conducted with OEMs, governmental and research organisations to:

— Review in detail the past and ongoing research programmes and the available data;

— Baseline the assumptions;

— Discuss and review engine OEM’s experience with respect to hard body ingestion; and

— Develop a broad-based solution and a collaborative research roadmap to minimise duplication of the recommended R&D activities.

A coordinated and collaborative research programme should be established to further assess the consequences of a drone collision on an airborne manned aircraft. The results should be shared to inform the responsible parties and facilitate the development of future safety measures that may be necessary to ensure the safe operation of drones.

The work performed by the Task Force should be seen as part of a global Safety Risk Management process associated with EASA regulatory actions. The Task Force assessed the severity level of possible drone collisions with manned aircraft, and this should be followed by further research and a full risk assessment in which the severity level should be assessed against the likelihood of the event considered.

APPENDIX I: Acronyms and Definitions

Acronyms

A/C	aircraft
AGL	above ground level
ASD	AeroSpace and Defence Industries Association of Europe
CAS	calibrated air speed
DTS	drone threat specifications
EASA	European Aviation Safety Agency
ECR	European Central Repository
FOD	foreign object damage
HEC	hazard effect classification
IEA	impact effect assessment
KCC	key critical components
MTOM	maximum take-off mass
OEM	original equipment manufacturer
RPAS	remotely piloted aircraft aystem
TF	Task Force
Th	Threat: high-density (ref.: Appendix V)
Tl	Threat; low-density (ref.: Appendix V)
Tm	Threat; medium-density (ref.: Appendix V)
UAS	unmanned aircraft system
VLOS	visual line of sight
VMO	maximum operating limit speed (ref.: EASA CS Definitions)
Zd-lim:	drone maximum altitude limited by software limitation (ref.: Appendix V)
Zd-max:	drone maximum flyable altitude capability above sea level (ref.: Appendix V)

Definitions

Drone. This term is used by the general public to refer to unmanned aircraft (see below)

'Geo-limitation'. In the context of this document, this term means the use of geographical limitations to prevent (certain) unmanned aircraft from entering defined airspace volumes or zones (for safety and/or security reasons

'Open Category' means an operation conducted with an unmanned aircraft system that:

a. has a maximum take-off mass of 25 kg or less,

b. is operated in VLOS at a safe distance from persons, properties, ground vehicles, public roads or streets, and

c. is separated from other airspace users, and complies with the limitations defined in particular areas by the competent authority of the Member State

RPAS (Remotely Piloted Aircraft System). An unmanned aircraft (see below) that is piloted from a remote pilot station.

Unmanned Aircraft System (UAS) means the unmanned aircraft and any equipment, apparatus, appurtenance, software or accessory that is necessary for its safe operation

'Visual Line of Sight (VLOS) operation’ is an operation in which the remote pilot maintains a continuous unobstructed and unaided visual contact with the UA, allowing the remote pilot to monitor the UA’s flight path in relation to other aircraft, persons, or obstacles for the purpose of maintaining separation and avoiding collisions.

APPENDIX II: References

1.	EASA	Technical Opinion. Introduction of a regulatory framework for the operation of unmanned aircraft. European Aviation Safety Agency (EASA). 18 December 2015
2.	EASA	EASA CM - S – 001 Issue: 01, Compliance with CS-25 Bird Strike Requirements
3.	FAA	Wildlife Strikes to Civil Aircraft in the United States, 1990–2014
4.	CASA/Monash University	Potential damage assessment of a mid-air collision with a small UAV
5.	MERCATUS CENTER	Do Consumer Drones Endanger the National Airspace? Evidence from Wildlife Strike Data
6.	Exponent	Exponent Project No.1408989.EX0 - Exponent, Washington, DC - December 16, 2014
7.	Aero Kinetics Aviation	The real consequences of flying toy drones in the national airspace system
8.	Aalborg University	Mass threshold for 'Harmless' drones
9.	Massachusetts Institute of Technology, Cambridge/AIAA	Safety Considerations for Operation of Different Classes of UAVs in the NAS (Roland E. Weibel and R. John Hansman, Jr.)
10.	Bell Helicopter Textron,	UAV failure rate criteria for equivalent level of safety, David W. King, Allen Bertapelle, Chad Moses, 2005
11.	University of Tennessee	Approaches for Autonomous Vehicles in Civil Airspace: Giving Sight to the Blind, Nicholas Scott Hardman, 2005
12.	Australian Research Centre for Aerospace Automation (ARCAA), Queensland University of Technology (QUT)	A casualty risk analysis for unmanned aerial system (UAS) operations over inhabited areas, 2007
13.	Konstantinos Dalamagkidis, Kimon P. Valavanis, Les A. Piegl	Evaluating the Risk of Unmanned Aircraft Ground Impacts, Konstantinos Dalamagkidis, Kimon P. Valavanis, Les A. Piegl, 16th Mediterranean Conference on Control and Automation Congress Centre, Ajaccio, France, 2008
14.	Range Commanders Council	Rcc 321-02, standard 321-02, common risk criteria for national test ranges, subtitle: inert debris
15.	Reece Alexander Clothier B.E. (AeroAv)	Decision support for the safe design and operation of unmanned aircraft systems, 2012
16.	FAA	Operation and Certification of Small Unmanned Aircraft Systems
17.	ASUR	Autonomous Systems Underpinning Research (https://www.asur-programme.co.uk/?doing_wp_cron=1469015528.4156310558319091796875)
18.	ASSURE	Alliance for System Safety of UAS through Research Excellence (http://www.assureuas.org/)

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APPENDIX III: Task Force Membership

Organisation	Name	Role
EASA	Mr. Eric Duvivier	Task Force Leader
EASA	Mr. Antonio Marchetto	Drone Technologies Expert Task Force Secretary
EASA	Mr. Richard Minter	Structure specialist
EASA	Mr. Alexandre Peytouraux	Large Aeroplane EASA focal point
EASA	Mr. Paul Hatton	General Aviation EASA focal point
EASA	Mr Raffaele Di Caprio and Mr. Clement Audard	Rotorcraft EASA focal point
EASA	Mr. Karl Hoier,	Engines and Propellers EASA focal point
EASA	Mr. Yngvi Rafn Yngvason	Safety Analysis
EASA	Mr. Selcuk Akdogan	Trainee
Airbus	Mr. Thierry Salmon	Large Aeroplane Industry focal point
Airbus Helicopters	Mr. Marc Greiller	Rotorcraft Industry focal point
Dowty	Mr. Gabor Zipszer	Propellers Industry focal point
SAFRAN	Mr. Charles Douguet	Engine Industry focal point
GAMA	Mr. Brian Davey and Mr. Oliver REINHARDT	General Aviation Industry focal point

APPENDIX IV: List of the organisations consulted

Aircraft Industry

AERO Vodochody Aerospace a.s.
Airbus
Airbus defence and Space
Airbus Helicopters
Aircraft Design & Certification Ltd.
Aircraft Industries a.s.
ATR
AVIA Propeller
Bell Helicopter (Textron Company)
Blackshape Aircraft
Blaník Aircraft CZ s.r.o.
Boeing
Bombardier
Cirrus Aircraft (CirrusJet)
Czech Sport Aircraft a.s.
Daher Soccata
Dassault
Diamond Aircraft Industries
Dornier Seawings GmbH (Seastar)
Dowty (GE)
Embraer
Enstrom
Evektor spol. s r.o.
EXTRA Flugzeugproduktions & Vertriebs & GmbH
Finmeccanica Helicopters
Flight Design GmbH
GE Aviation Czech
General Electric
Gomolzig Flugzeug- und Maschinenbau GmbH
Grob-Aircraft AG
Guimbal
Gulfstream
Hartzell
Honda Aircraft Company, LLC
Honeywell
HPH, spol. s r.o.
LOM Praha s.p.
Mooney
MT-Propeller
Nextant
Oma SUD SpA
One Aviation
PBS Velká Bíteš a.s.
Piaggio Aerospace
Pilatus Aircraft
Piper Aircraft, Inc.
Pipistrel
Pratt & Whitney
PZL Mielec (M28)
Quest Aircraft Company
Robinson
Rolls-Royce Corp.
Rolls-Royce Deutschland
Rolls-Royce plc
RUAG Aviation
SAAB
Safran Aircraft Engines
Sikorsky
Steinbeis Flugzeug- und Leichtbau GmbH
TAI - Turkish Aerospace Industries, Inc.
Tecnam - Costruzioni Aeronautiche Tecnam
Textron
Thrush Aircraft Inc.
UTC Aerospace Systems (Hamilton Sundstrand)
UTC Aerospace Systems (Ratier-Figeac)
Zlin Aircraft a.s.

Governmental Organisations

AESA (Spanish CAA)
ANA (Portuguese CAA)
ANAC (Brazilian CAA)
Austro Control
Belgian CAA
CAA Bulgaria
CAA Singapore
CAAS
CASA
CAA Republic of Lithuania
Colombian CAA
Croatian CAA
Czech Rep. CAA
DGAC (French CAA)
Dutch Ministry of Infrastructure and Environment
ENAC (Italian CAA)
Estonian Ministry of Economic Affairs and Communications
FAA
FOCA (Swiss CAA)
GCAA (Georgia CAA)
Greek CAA
IAA (Ireland Aviation Authority)
Icelandic Transport Authority

Joint DGCA (Directorate General of Civil Aviation)
Latvian CAA
LBA (German CAA)
Luxembourg CAA
Malaysia CAA
Malta Transport Authority
Ministry of Infrastructure, Slovenia
Ministry of National Development Civil Aviation, Maritime and Inland Navigation
Norwegian CAA
Department Transport and Civil Aviation
Polish CAA
Republic of Macedonia CAA
Romanian CAA
Swedish Transport Agency
TRAFI
Trafikstyrelsen (Danish CAA)
Transport Authority Slovak Republic
Transport Canada
'Air Accident Investigation Sector
UAE General Civil Aviation Authority
UK MOD

Associations

Aerospace Industries Association (AIA)
AeroSpace and Defence Industries Association of Europe (ASD)
European Cockpit Association (ECA)
European Regions Airline Association (ERA)
General Aviation Manufacturers Association (GAMA)

Drone Industry

3DR
DJI Europe BV
Drone Alliance Europe
GoPro
gplus europe
Parrot
Yuneec Europe GmbH

Others

British Airways (operator)
EasyJet (operator)
Virginia Tech (research)

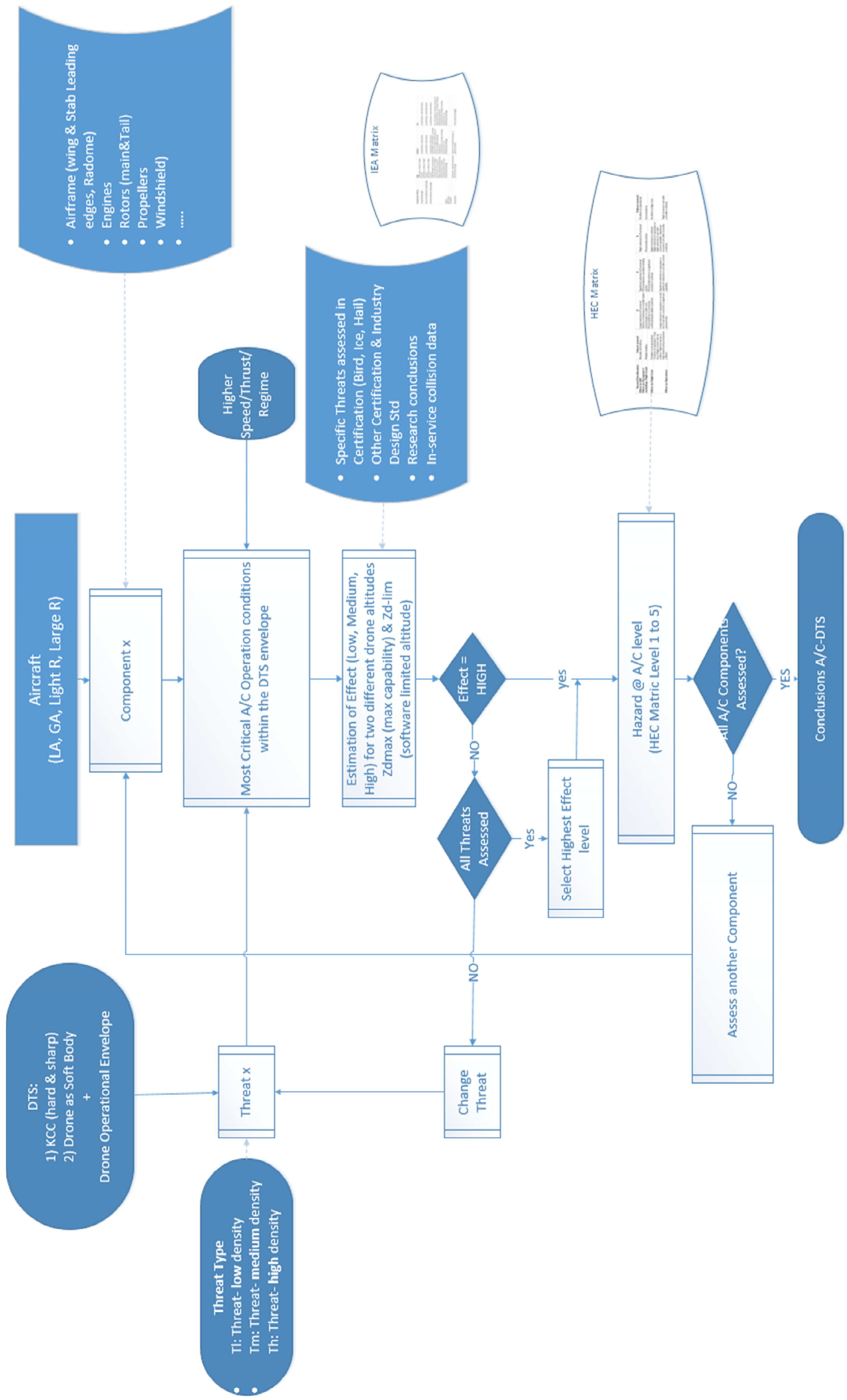
APPENDIX V: Generic Drone Threat Specifications

Drone Class	Threat Type	Element	Weight (g)	Density (kg/m3)	Dimensions (mm)/Typical Shape	Quantity	Max speed (m/s)	Zd-max (m)	Zd-lim (m)
Large	Tl	Drone	3500	-	450x450x301	-	20	5000	500
	Tm	Battery	670	2000	Parallel piped	1			
	Th	Motor	106	4000	Cylinder	4			
Medium	Tl	Drone	1500	-	290x196x290	-	20	5000	500
	Tm	Battery	462	2000	Parallel piped	1			
	Th	Motor	56	4000	Cylinder	4			
Small	Tl	Drone	500	-	328x382x89	-	18	1000	150
	Tm	Battery	130	2000	Parallel piped	1			
	Th	Motor	15	4000	Cylinder	4			
Harmless	Tl	Drone	250	-	200x200x140	-	18	1000	150
	Tm	Battery	65	2000	Parallel piped	1			
	Th	Motor	7.5	4000	Cylinder	4			

Threat Type:
- Tl: Threat: **low** density
- Tm: Threat- **medium** density
- Th: Threat- **high** density

Altitude:
- Zd-max: Maximum flyable altitude capability above sea level.
- Zd-lim: Max altitude limited by hard-coded software limitation

APPENDIX VI: Impact & Hazard Effect Assessment Process



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APPENDIX VII: External threats Certification Requirement

Components	Requirement	Title	Threat Category	Threat Specification	A/C Conditions	Pass/Fail Criteria
CS23 Commuter						
Windshield	CS 23.775(h)	Windshields and Windows	Bird	Bird 0.91 kg (2 lbs)	VFE	continued safe flight and landing,
CS23 High Performance and Jets						
Windshield	By Special Condition CRI typically	Windshields and Windows	Bird	Bird 0.91 kg (2 lbs) Tested on W Screen.	VFE	continued safe flight and landing,
Airframe	By Special Condition CRI typically	Bird Strike	Bird	0.91 kg by analysis on A/F critical areas only	Worst Case	continued safe flight and landing,
CS25 Large Aeroplane						
Complete Aeroplane	CS 25.631	Bird strike damage	Bird	4 lbs	VC at sea-level or 0·85 VC at 2438 m (8000 ft.),Vc	continued safe flight and landing
Empennage	FAR 25.631	Bird strike damage	Bird	8 lbs	Vc	continued safe flight and landing
Windshield	CS25.773b4	absence of openable windows	Sever Hail	multiple 2 inch ice balls impact (ANSI/ASTM F 320-10)	approach & landing	it is shown that an area of the transparent surface will remain clear sufficient for at least one pilot to land the aeroplane safely in the event
windshield	CS 25.775	Windshields and windows	Bird	4 lbs	VC at sea-level or 0·85 VC at 2438 m (8000 ft.),	must withstand, without penetration
CS29 Large Rotorcraft						
Windshield, Main Rotor, Tail Rotor, Exposed flight control system components	29.631	Bird strike	Bird	Bird 1 kg (2.2 lbs)	Vne or Vh (whichever is lesser) and altitude up to 8000 ft.	No penetration in the windshield - Category A rotorcraft capable of continued safe flight and landing after impact - Category B rotorcraft capable of safe landing after impact
CS E: Engines						
Engine	E540, E800	Strike and Ingestion of Foreign Matter; Bird Strike and Ingestion	Large Bird Impact; Hard Body Impact	Bird Mass between 1,85 and 3,65 kg,	Engine speed 100 % T/O, Aircraft seed >200 kt	No hazardous engine effect

Components	Requirement	Title	Threat Category	Threat Specification	A/C Conditions	Pass/Fail Criteria
Engine	E790	Ingestion of Rain and Hail	large hailstones	One 25-millimetre diameter hailstone for Engines with inlet throat areas of not more than 0.0645 m2. One 25-millimetre diameter and one 50-millimetre diameter hailstone for each 0.0968 m2 of inlet throat area, or fraction thereof, for Engines with inlet throat areas of more than 0.0645 m2.	Maximum true air speed, for altitudes up to 4500 metres, associated with a representative aircraft operating in rough air, with the Engine at Maximum Continuous power/ thrust,	Must not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion, or require the Engine to be shut down.
Engine	E780	Icing Conditions	Ice shedding/ Ice Slab	The applicant should determine the ice slab dimensions by linear interpolation between the values of AMC E780 Table 3, based on the actual Engine's inlet highlight area. (from 88.5 cm3 to 1435 cm3)	The ingestion velocity and the Engine operating conditions must be determined. Those conditions shall be appropriate to the Engine installation on the aircraft.	Engine will function satisfactorily following the ingestion. No unacceptable: (1) Immediate or ultimate reduction of Engine performance, (2) Increase of Engine operating temperatures, (3) Deterioration of Engine handling characteristics, and (4) Mechanical damage.
CS P: Propellers						
Propeller	P360	Bird Impact	Bird	Birds which are specified in the aircraft specifications applicable to the intended installation of the Propeller. The mass of the bird must not exceed 1.8 kg,	most critical location and the flight conditions which will cause the highest blade loads in a typical installation	No Major or Hazardous Propeller Effect.

APPENDIX VIII: Impact Effect Assessment and Hazard Effect Classification Matrix

Impact Effect Assessment (IEA) at Component Level

Component/Effects	High	Medium	Low
Nose/Radome/Large antennas	Penetration, major deformation, part detachment	No penetration but limited deformation.	Only dents or scratches
fuselage area below windshields	Penetration, major deformation, part detachment	No penetration but limited deformation	Only dents or scratches
Canopy (fuselage area above windshields,)	Penetration, major deformation, part detachment	No penetration but limited deformation	Only dents or scratches
Chin Window (fuselage area below Radome on rotorcraft)	Penetration, major deformation, part detachment	No penetration but limited deformation	Only dents or scratches
Wings (leading edges (including slats), trailing edges (flaps))	Penetration, major deformation, part detachment	No penetration but limited deformation	Only dents or scratches
Winglets	Significant damage, part detachment.	Limited damage, no part detachment	Only dents or scratches
Fairings (e.g. wing to fuselage)	Penetration, major deformation, part detachment	No penetration but limited deformation	Only dents or scratches
Horizontal Stabiliser Leading edge	Penetration, major deformation, part detachment	No penetration but limited deformation	Only dents or scratches
Vertical Stabiliser leading edges	Penetration, major deformation, part detachment	No penetration but limited deformation	Only dents or scratches
Engine pylons, nacelles, air intake cowling	Penetration, major deformation, part detachment	No penetration but limited deformation	Only dents or scratches
Engine (gas turbine)	Significant mechanical damage or detachment of parts. Immediate or ultimate reduction of Engine performance. Significant deterioration of Engine handling characteristics. (see note (*) below)	Non-significant mechanical damage. Reduction of Engine performance, deterioration of Engine handling characteristics and possible Increase of Engine operating temperatures,	No or acceptable damage (as per AMM)
Main & Tail Rotor (blade/hub/controls)	Significant damage resulting in unsustainable rotor unbalance and instability. (Jamming, pitch link breakage or failure, etc.)	Non-significant damage resulting in rotor unbalance within sustainable limits. (Pitch link deformation, etc.)	No or limited damage with no effect on rotor integrity and performance.
Propeller (blades and spinner)	Significant damage resulting in unsustainable propeller unbalance and instability.	Non-significant damage of the blade(s) resulting in propeller unbalance within sustainable limits. No effect on rotor stability.	No effect
Windshield	Penetration or total loss of visibility	No Penetration, partial loss of visibility.	No or limited damage, Non-significant loss of external visibility
Landing gear, and landing gear doors and light	Damage preventing LG safe deployment or affecting essential functions. Total loss of lighting (rotorcraft)	Damage preventing LG safe retraction or other limited damage.	No or limited external damage not affecting operability

(*) Note: For the engine, the potential resulting effects should be provided as part of the engine effect assessment to allow proper classification at aircraft level. According to CS.E.510 (and the associated AMC), the resulting effects could be:

- Non-containment of high-energy debris or release of low-energy parts
- Concentration of toxic products (e.g. oil) in the Engine bleed,
- Thrust in the opposite direction to that commanded by the pilot, generation of thrust greater than maximum rated thrust or significant uncontrollable thrust oscillation
- Fire (Uncontrolled or Controlled), case burn-through
- Failure of the Engine mount system, leading to inadvertent Engine separation or loss of integrity of the load path of the Engine supporting system without actual Engine separation
- Release of the propeller by the Engine (if applicable),
- Complete inability to shut the Engine down.
- Vibration levels

The expected results shall be provided by the engine manufacturer in the detail section of the questionnaire.

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.