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Vulnerability of manned aircraft to drone strikes

An Agency of the European Union

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Stakeholder involvement report and international collaboration (D9.1)

QinetiQ is the prime lead in this 'Horizon 2020' research framework which is sponsored by the European Commission and contracted through EASA.

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Executive Summary

This short report satisfies deliverable D9.1 under Task 9 of QinetiQ's 'Vulnerability of manned aircraft to drone collisions' programme for EASA.

At the outset of the programme, a Stakeholder Group was formed. This included representatives from drone manufacturers, aircraft OEMs/Tiered suppliers, standards organisations and expert bodies.

The purpose of the group was to aid access to relevant information and advice, and to provide an opportunity for stakeholder organisations to influence the programme, review methods and provide comments on the outcomes. Participation in the Stakeholder Group was on a voluntary basis, and the project team would like to thank all contributors for giving their time, expertise and support throughout this programme.

Section 2 of the report describes key interactions with the Stakeholders, including six-monthly group briefings on progress, results and plans, and 14 individual briefings. These provided an opportunity to provide input to the programme, and to ask questions and comment on results and methods. Contributions from the Stakeholder Group were encouraged throughout the programme.

Key inputs and contributions are detailed within Section 2, including support to the selection of example drones and example aircraft during the early stages of the programme, and the provision of test articles to aid testing activities. Later major contributions included support to the development of Impact Effect Assessment (IEA) and Hazard Effect Classification (HEC) criteria. These metrics describe the level of damage to the impacted region of the aircraft (IEA) and the associated aircraft-level hazard (HEC). The criteria were developed with input from industry professionals, aviation safety engineers and senior air accident investigators, to allow results from tests and simulations to be categorised and processed into vulnerability data.

Section 3 provides a brief summary of interactions and contributions from the international research community, and the mutual benefits that were gained through co-operation on this topic.

Finally, Section 4 provides a list of conferences and events that have been attended (either virtually or physically) during the course of this programme, to increase awareness of European activities to address this important aspect of aviation safety management.

Contents

Abbreviations

Acronym	Description
ASSURE	Alliance for System Safety of UAS through Research Excellence
ANSP	Air Navigation Service Provider
DAA	Detect and Avoid
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Authority
HEC	Hazard Effect Classification
IEA	Impact Effect Assessment
NIAR	National Institute of Aviation Research (US)
OEM	Original Equipment Manufacturer
UK	United Kingdom
US	United States (of America)

1. Introduction

1.1 Background and scope of the programme

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 crewed aviation.

Whilst conventional crewed aircraft impact threats, such as bird strike, have benefitted from decades of research, the rapid emergence and evolution of consumer drone technologies has required a more-agile response from regulators and the research community.

EASA has been active in monitoring and addressing the risks and threats associated with mid-air drone collisions. Indeed regulatory efforts have been directed to address and minimise the likelihood of a collision occurring, and creating the conditions to safely achieve gradual integration of drone operations in airspace traditionally allocated to crewed aircraft.

In 2016, EASA assembled a ‘Drone Collision’ Task Force [1] to consider potential mid-air collision threats between crewed aircraft and small, consumer-grade drones. The consumer-market drone category was selected on the basis of several considerations, including: the size and anticipated growth of this market segment; the possibility to operate such drones within the Open category with no need of specific authorisation from the Authority (“buy and fly”) and; the absence of a requirement for coordination with the Air Navigation Service Provider (ANSP) or specific Detect And Avoid (DAA) systems. Focus on the consumer market, means that the drones of interest typically occupy the lower mass classes within the Open category.

The Drone Collision Task Force in 2016 identified further research requirements with input from a broad group of industry stakeholders. Recommendations from the Task Force report [1] 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 crewed 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, as defined within EASA’s Tender Specification [4] and project description:

- *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. The work within the programme has been documented over the last 3½ year in reports to EASA, some of which have been published on their website [6].

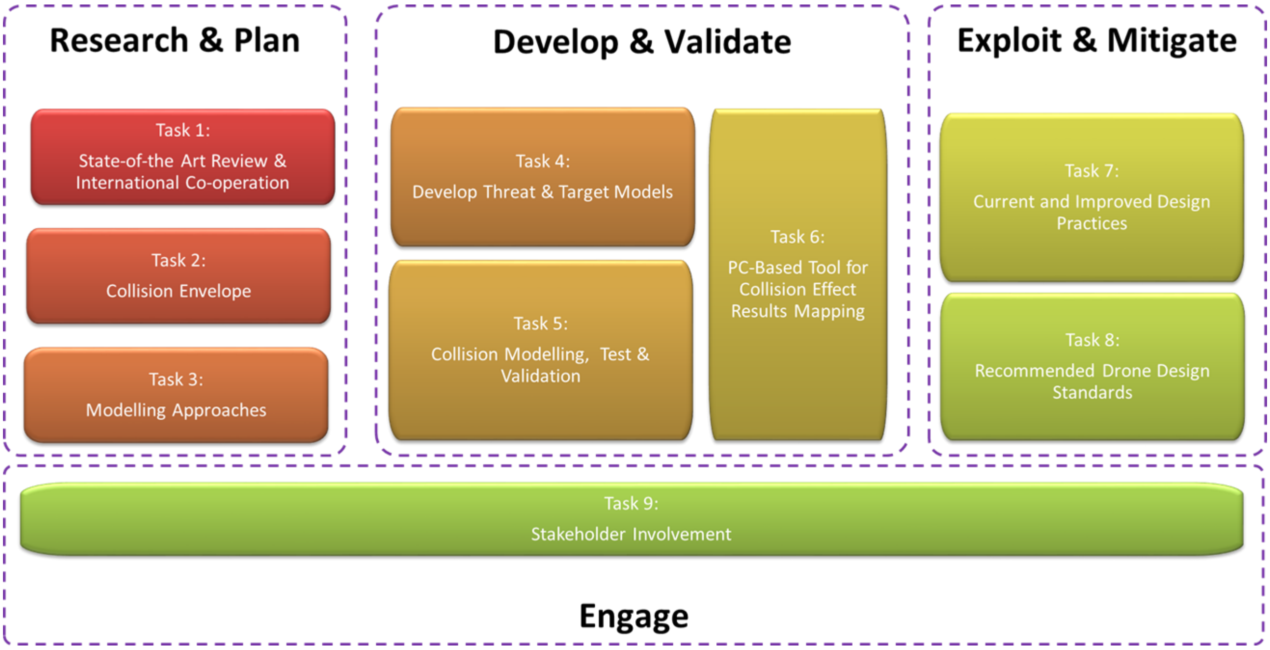

Figure 1-1: Programme structure

1.2 Scope of report

This brief report acknowledges the contributions of the project's Stakeholder Group, which included representatives from drone manufacturers, aircraft OEMs/Tiered suppliers, standards organisations and expert bodies.

Section 2 provides an overview of key interactions with the Stakeholder Group, and the contributions that they made to the form of expert advice, review and hardware for experimental testing.

Section 3 proceeds to describe interactions with the international research community, and the mutual benefits that were gained through co-operation on this topic.

Finally, Section 4 includes a list of conferences and events that were attended during the course of this programme, to increase awareness of European activities to address this important aspect of aviation safety management.

2. Stakeholder involvement

2.1 Stakeholder Group

At the outset of the programme, a Stakeholder Group was formed. This included representatives from drone manufacturers, aircraft OEMs/Tiered suppliers, standards organisations and expert bodies. A list of the Stakeholder Group members is provided in Appendix A.

The purpose of the group was to aid access to relevant information and advice, and to provide an opportunity for stakeholder organisations to influence the programme, review methods and provide comments on the outcomes. Participation in the Stakeholder Group was on a voluntary basis, and the project team would like to thank all contributors for giving their time, expertise and support throughout this programme.

2.2 Briefings

To maintain awareness and engagement with the programme, briefings were held approximately every six months. These briefings, which were typically between 1½ and 2 hours each, provided an overview of plans, assumptions, methods, validation, testing, simulation activities and results as the project progressed. In addition to group briefings, other sessions were held to introduce new colleagues within the Stakeholder community to the project, or to repeat presentations that were missed by interested parties. In total, approximately 14 individual briefings were conducted over the course of the three year programme. All presentations included opportunities for questions, and feedback and comments were actively encouraged.

Early briefings included discussion of which mainstream, mass-market consumer/prosumer drone products should be assessed within the programme. In addition to agreeing appropriate styles and example products, offers of support were received from within the Stakeholder group, to provide example drones for characterisation and testing purposes. Delair provided example UX11 airframes and DJI provided a large batch of drones, all of which were mechanically sound (for testing purposes) but had been found to be defective during manufacture or had been replaced under warranty. This assistance enabled a greater level of mechanical testing to be undertaken whilst also reducing electronic waste, since the alternative would have been to purchase flightworthy specimens for a more-limited programme of destructive testing.

The selection of representative example crewed aircraft was also agreed in early meetings. This included identification of potential impact locations on each category of aircraft and prioritisation of regions for assessment by simulation or test. As part of this process, it was acknowledged and accepted during Stakeholder Group meetings that the focus of the study should be traditional metallic airframes rather than composite configurations. Whilst it would have been desirable to assess both classes of materials, it was recognised that the scope of the programme was already ambitiously broad. Furthermore, inclusion of emerging composite designs would have introduced a large number of additional variables and availability of data would have been limited.

Additional discussions were held with a manufacturer of high performance, lightweight composite aircraft within the Stakeholder Group. Through these discussions, and building upon QinetiQ's experience of analysing composite structure, it was agreed that the damage and failure modes of composite leading edge structures would be significantly different from equivalent metallic designs. Of particular note is the increased stiffness of composite leading edges, use of bonded joints and hybrid monolithic/sandwich panel skins, and complex anisotropic material behaviours that don't include the post-yield plasticity response that prevails in collisions against metallic structures.

Stakeholder assistance was also provided when attempting to source appropriate aircraft hardware for testing, and data on materials and aircraft structures. In particular, expert guidance was provided on example windshield constructions, as well as industry contacts to discuss material grades and data. Similar information was provided for other example aircraft components such as rotorcraft pitch control linkages. This ensured that appropriate information was being used, and reduced the need for detailed surveys of difficult-to-acquire hardware.

Mid-programme briefings included results and outcomes from impact testing and model validation activities. These included review of the work undertaken to develop the drone threat models, and also to calibrate and validate models of target materials such as aerospace aluminium alloys, acrylic, polycarbonate and glass, as well as various laminated windshield constructions. The approach taken and results presented were received positively by attendees of the briefing, though it was noted that all of the testing work was completed at ambient temperature rather than at likely extremes of each aircraft's operating envelope. However, it was agreed that it is not standard practice to undertake impact testing e.g. bird strike, at elevated or reduced temperature, and doing so would greatly increase the complexity of the experimental arrangements. It was therefore agreed that the approach taken was appropriate.

Members of the Stakeholder Group were directly involved with the definition of IEA and HEC levels, descriptions and mappings. Specialists within aircraft OEMs and air accident investigators were consulted to refine the four-level IEA descriptors for each type of target structure e.g. leading edges/windshields/rotor linkages/etc. These descriptors enabled damage observed during collision testing and simulation to be unambiguously classified based upon its severity. Mappings between the IEA levels and the HEC (High or Low hazard) were also agreed, based upon the experience and judgement of the group. This was an essential part of the assessment process as it allowed comparison of results from across all impact locations on each aircraft. The outcome of this exercise was presented at wider Stakeholder Group briefings, alongside example results.

As well as presenting a summary of the individual testing and simulation results, the QinetiQ technical team distilled the large dataset of collision simulations into a more user-friendly format. These processed results were presented as tables showing the predicted likelihood that a mid-air collision will result in a hazardous (High HEC) event, accounting for the category of aircraft, type of drone and phase of flight. The tables of results were shared with the Stakeholder Group for comment.

The development of validated engine ingestion simulations was not within the scope of the QinetiQ's programme, but work has been undertaken to utilise available data within the literature. This included reference to relevant work undertaken by the Nanyang Technological University in Singapore, as well as published studies undertaken by the ASSURE programme in the US. Expert review of the Singapore data was provided by an Engine manufacturer within the Stakeholder Group, which greatly aided the interpretation of results for the purpose of this study.

Support for the development of Standards/Guidelines was provided by drone manufacturers and Standards organisations within the Stakeholder Group. Feedback has been provided which has shaped the content and wording of the Guidelines. In one instance, comments were raised that could not be fully addressed, so a footnote was added to represent a Stakeholder viewpoint, whilst presenting the guideline as an output of the study. This example related to the guideline recommending the use of pouch-style batteries rather than steel-walled cylindrical cells. Here, it was noted by the Stakeholder that cylindrical cells may have safety benefits under low-velocity impact conditions, whereas observations from the programme suggest that they can increase collision severity and increase the risk of secondary fire events if impacted at greater speeds.

3. International collaboration

In addition to the formal project Stakeholder Group, strong links have been made with the international research community. Although formal links were not established between other related research programmes, a high level of co-ordination and collaboration was achieved through the willingness and enthusiasm of international stakeholders and researchers.

Of particular note was the project team's collaboration with the technical leadership of the ASSURE's drone collision programme, at the National Institute of Aviation Research (NIAR) in Wichita, US. Whilst it was not possible within the construct of the programme to openly share non-publically-available datasets, the programme benefitted greatly from published work, supporting data and access to the small cadre of other leading experts in this field. Tangible benefits included access to additional model validation data (to supplement the bespoke test activities undertaken within the programme), co-ordination of crewed aircraft examples, provision of relevant structural data for specific aircraft features and cross-checking of example results and conclusions.

In the final six months of the programme, a meeting was held in Wichita to compare and peer-review example simulation results produced by the two. Whilst the drones used in this programme differ from those developed by the ASSURE programme, many of the target aircraft were similar. It was therefore possible to compare results across the range of different drone types and masses. As an outcome of this exercise, it was concluded that the independently-generated results from the two programmes correlate very well and that the datasets are compatible. This provides an additional level of mutual-validation, and ensures that comparable conclusions and advice can be drawn from the two, highly complementary studies.

As part of the same visit, a briefing on the programme's aims, scope and progress was given to the wider ASSURE consortium, technical and commercial leadership, and FAA customers as part of their three-day Project Management Review.

Excellent relations were also made with leaders of the simulation-based engine ingestion study at Nanyang Technological University in Singapore. This work, which was undertaken for the Singapore Civil Aviation Authority, has been used alongside other data from the literature to assess engine ingestion hazards.

Finally, other significant international collaborations activities included discussions with the technical leadership of collision testing activities at the Canadian National Research Council. Output from these programmes provided additional validation evidence for QinetiQ's simulation work.

4. Publicity

Engagement with the Stakeholder Group and international research organisations was effective in raising the profile of this European Commission funded programme amongst the research community. In addition to these actions, presentations were also given at the following international conferences and events:

- Air Mobility with Unmanned Systems and Engineering conference (March 2021)
- FAA Round Table meeting (May 2021)
- 14th International Air Traffic Management conference (September 2021)
- UK Simulation Innovation Forum (November 2021)
- ASSURE programme review, Wichita (March 2023)
- Aerospace Structural Impact Dynamics International Conference, Wichita (June 2023)

The final programme presentation was publically advertised and was held at EASA's headquarters in Cologne in October 2023.

There continues to be worldwide interest in this topic of research, and further opportunities are likely to be available to publicise the work undertaken by QinetiQ on behalf of EASA and the European Commission.

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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 Dec 2019
6. Project web page on EASA website, https://www.easa.europa.eu/research-projects/vulnerability-manned-aircraft-drone-strikes

Appendix A Stakeholder Group Participants

Members of the project's Stakeholder Group are listed below:

A.1 Drone manufacturers

Aeromapper

DJI

Delair

Parrot

Sensefly

A.2 Crewed aircraft manufacturers and suppliers

Airbus Helicopters

Blackshape Aircraft

Leonardo Helicopters

Lilium

Mecaplex

Safran Group

Volocopter

A.3 Standards and aviation safety

ASD-STAN

UK Air Accidents Investigation Branch

European Union Aviation Safety Agency

Konrad-Adenauer-Ufer 3
50668 Cologne
Germany

Project website [Vulnerability of Manned Aircraft to Drone Strikes | EASA (europa.eu)]

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