The European Organisation for Civil Aviation Equipment
L'Organisation Européenne pour l'Equipement de l'Aviation Civile

UAS / RPAS AIRWORTHINESS CERTIFICATION

"1309" System Safety Objectives and Assessment Criteria

ER-010

July 2013

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FOREWORD

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5. The purpose of this EUROCAE report is:
   - on one hand, to summarize the results of the debates and reviews which took place within the EUROCAE Working Group WG73 on selected major topics relating to Unmanned Aircraft System (UAS) / Remotely Piloted Aircraft System (RPAS) Objectives and Assessment criteria
   - on the other hand, to provide a set of subsequent recommendations to the official bodies, such as the EASA and European Commission, as identified in the European RPAS Steering Group Roadmap issued in June 2013 (Annex 1, line 13B).
6. The report aims at eventually supporting the establishment of a specific UAS Acceptable Means of Compliance AMC1309 to be included in a future set of Civil UAS Certification Specifications to be issued by EASA, as a follow up of the current EASA Policy Statement – Airworthiness Certification of Unmanned Aircraft Systems (UAS) E.Y013-01, 25th August 2009 and of the EUROCAE ER-004 Volume 3, “A Concept for UAS Certification and Airworthiness Approval – UAS Airworthiness Certification”. As such, it is principally oriented towards UAS currently under the remit of EASA (above 150 kg) albeit that some principles and recommendations could be utilized for Unmanned Aircraft below 150 kg as well.
7. Copies of this report may be obtained from

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Unmanned aircraft are considered to be aircraft and hence, in a way, similar to manned aircraft, need a Type Certificate. This Type Certificate is to cover the airworthiness of the entire Unmanned Aircraft System (UAS) / Remotely Piloted Aircraft Systems (RPAS)[1], as specified in the Type design. The UAS airworthiness requirements shall eventually be laid down in codes like the EASA Certification Specifications (CS). Of these requirements, requirement 1309 is of major importance since it sets the System Safety Objectives and Assessment criteria, which are elaborated in the associated AMC (Acceptable Means of Compliance) in conjunction with a complete set of airworthiness requirements. In particular, this AMC.1309 provides a methodology to identify and classify the failure conditions severities and to derive the required probability requirements and Design Assurance Levels (DAL).

It has been recognized by all stakeholders that the UAS Type Certification basis should adapt the airworthiness requirements and criteria used for manned aircraft, in order to take due account of the specific character of UAS applications, including the shift of the risk[2] from the crew and passengers on board to the third parties on the ground[3] or in the air.

Defining the appropriate System Safety Objectives and Assessment criteria for UAS at an early stage of the UAS rule-making process is crucial for both UAS development manufacturers and authorities since it has a direct impact on

- The overall safety level of UAS operations
- The architecture (e.g. redundancies and complexity) of the UAS
- The related amount of substantiation, development and certification effort and subsequent economic repercussions.

The current manned aircraft certification specifications, requirements and acceptable means of compliance are primarily stated in CSxx.1309 and corresponding AMC and may considerably differ depending on the applicable airworthiness code (CS 23, CS 25, CS VLA, CS 27, CS 29, CS VLR). This is typically the case for the failure probability requirements or for the single failure criteria.

While some overall principles have been proposed (see section 4.1), there are no firm and detailed criteria yet which have been agreed that would allow conducting System Safety Assessment in a similar way as performed in the case of manned aircraft Type Certification.

1.2 SCOPE AND PURPOSE

EUROCAE WG-73 has reviewed and debated the topics related to UAS Safety objectives and assessment criteria.

This document addresses UAS applications with no people onboard (see note 1).

The purpose of this EUROCAE report is, on one hand to sum up the results of these debates and reviews on selected major topics (see section 3) and on the other hand to provide a set of subsequent recommendations to the official bodies, such as the EASA and European Commission, as also identified in the ERSG Roadmap (ref.[8]).

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[1] The term unmanned aircraft will be used in this document which addresses both UAS and RPAS.
[2] In this document, the term "risk" combines both severity and probability of occurrence.
[3] The term "on the ground" is used generically throughout the document but should be understood as on any surface where a risk to a third party may occur.

The report is to support the establishment of a specific UAS AMC 1309 to be included in a future set of UAS Type Certification requirements as a follow up of the current EASA Policy Statement – Airworthiness Certification of Unmanned Aircraft Systems (UAS) E.Y013-01, 25th August 2009 (ref. [3]), and of EUROCAE ER-004 Volume 3 (ref. [4], "A Concept for UAS Certification and Airworthiness Approval – UAS Airworthiness Certification"). As such, it is principally oriented towards UAS currently under the remit of EASA (above 150 kg) albeit that some principles and recommendations could be utilized for Unmanned Aircraft below 150 kg as well.

NOTE 1: *It is assumed that standard practices and safety assessment methodology (qualitative and quantitative) to assess Unmanned Aircraft System against the proposed Safety Objectives and criteria as currently detailed in manned AMC 1309 may be largely replicated in the case of UAS and therefore are not covered by this document.*

NOTE 2: *This document addresses unmanned aircraft with no people on board. Unmanned aircraft with people on board (but no crew on board) are likely to be subject to a different set of airworthiness requirements and safety objectives.*

1.3 STRUCTURE OF THE DOCUMENT

This document is structured as follows

- Section 1 presents a general introduction, the scope and purpose and the structure of the document.
- Section 2 identifies the main references of the supporting documents[4].
- Section 3 reviews the considered approaches and provides a review of UAS "1309" topics which are under focus and have been subject to continuous debate over the past years. It includes reference to a EUROCAE WG-73 survey illustrating the outstanding consensual and non-consensual areas resulting from these debates.
- Section 4 and related appendices provide for each topic listed in Section 3 :
  - o A statement of the issue
  - o A summary overview of different related approaches as proposed by various stakeholders and debated within EUROCAE WG-73
  - o A subsequent recommendation.
- Section 5 presents the general conclusions of this report.

[4] Only officially published documents are referred here. Other draft documents such as internal EUROCAE WG-73 Work Papers have also supported this document. Some other documents, not officially released, are quoted in the appendices.

1.4 ABBREVIATIONS

Abbreviation Term	Meaning
AC	Advisory Circular
AMC	Acceptable Means of Compliance
ARP	Aerospace Recommended Practice
ATC	Air Traffic Control
AWO	All Weather Operations
AWFT	Air Worthiness Focus Team
C2	Command and Control
CA	Collision Avoidance
CAT	Commercial Air Transport
CFR	Code of Federal Regulations
CS	Certification Specification
CS – AWO	Certification Specification for All Weather Operations
DAL	Design (or Development) Assurance Level
DGA	Délégation Générale pour l'Armement
EASA	European Aviation Safety Agency
EC	European Commission
EDA	European Defence Agency
ERSG	European Commission RPAS Steering Group
EUROCAE	European Organisation for Civil Aviation Equipment
EUROCONTROL	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FINAS	Flight In Non-Segregated Airspace
FP	Flight Path
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
JAA	Joint Aviation Authorities
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
MIDCAS	Midair Collision Avoidance System (EDA project)
NATO	North Atlantic Treaty Organization
NPA	Notice of Proposed Amendment
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft System
SA	Separation Assurance
SMS	Safety Management System
STANAG	NATO Standardization Agreement

Abbreviation Term	Meaning
TCAS	Traffic Collision Avoidance System
TF	Task Force
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
USAR	UAV Systems Airworthiness Requirements
VFR	Visual Flight Rules
VLA	Very Light Aircraft
VLR	Very Light Rotorcraft
VMC	Visual Meteorological Conditions
WG-73	(EUROCAE) Working Group 73

CHAPTER 2

REFERENCES

[1] JAA-EUROCONTROL Task Force Final Report: A Concept for European Regulations for Civil Unmanned Aerial Vehicles (UAVs): 11th May 2004.

[2] EASA A-NPA 16/2005 dated February 2005.

[3] EASA Policy Statement – Airworthiness Certification of Unmanned Aircraft Systems (UAS) E.Y013-01, 25th August 2009.

[4] EUROCAE ER-004 Volume 3: “A Concept for UAS Certification and Airworthiness Approval – UAS Airworthiness Certification”.

[5] STANAG 4671 (USAR) Ed 1, 3 September 2009: Unmanned Aerial Vehicles System Airworthiness Requirements.

*NOTE**:*** *This STANAG is based on the USAR, developed by the French Military Authorities, and later updated by NATO FINAS group to STANAG 4671.*

[6] ICAO Circular 328 AN/90 Unmanned Aircraft System.

[7] ICAO Annex 2 Amendment 43.

[8] Roadmap for the integration of civil Remotely-Piloted Aircraft Systems into the European Aviation System, Final Report from the European RPAS Steering Group, June 2013.

CHAPTER 3

UAS 1309 TOPICS UNDER DEBATE

EUROCAE WG-73 has extensively discussed topics related to UAS Safety Objectives and Assessment criteria. These can be listed as follows:

- Overall guiding principle
- Interrelation between Airworthiness and Operational Aspects
- Failure Severity Definition and Classification
- Quantitative Probability Requirements
- UAS Categorization.

Different approaches regarding above topics have been reviewed and debated within EUROCAE WG-73, whose members represent industry, authorities, research institutes, and airspace users.

Considering the complexity of the issue, EUROCAE WG 73 organized a survey in order to review and better identify the different interpretations and rationales relating to the following topics:

- Current EASA Guiding Principles as stated in EASA Policy (ref. [2])
- Probability Requirements
- Airworthiness versus Operations.

This survey has identified the extent to which the stakeholders have consensus on these topics, and where there is, currently, no consensus. This survey has proven to be useful in better formulating the common and parallel approaches or rationales behind those consensual and non-consensual areas; its results are summarized in Appendix 1 and are subsequently taken into account in the following sections of this report.

CHAPTER 4

CONSIDERED APPROACHES - SUBSEQUENT RECOMMENDATIONS

This section provides for each topic identified in previous section the following:

- A statement of the issue
- An overview of different approaches still outstanding as proposed by various stakeholders and debated within EUROCAE WG-73 over the past years
- A subsequent recommendation.

4.1 OVERALL GUIDING PRINCIPLE

4.1.1 Statement of the issue

The issue here is to define an overall guiding principle that may be used as the starting point to develop more detailed quantitative UAS System Objectives and Assessment criteria for designers, manufacturers and operators of these systems.

4.1.2 Considered approaches

Appendix 2 provides the detailed wording of some outstanding principles as currently formulated by different bodies. One may summarize the different formulations as follows:

(a) Broad terms with reference to manned aircraft safety or risk level (“Equivalent safety” or “Do not harm more”) such as EASA UAS Airworthiness Policy ref. [3]

(b) Broad terms with no direct reference to manned aircraft safety level (“Minimize hazards to persons, property or other aircraft”) such as ICAO Annex 2 Amendment 43 ref. [7] or recently issued ERSG Roadmap ref. [8]

(c) Broad terms with reference to a minimum level of airworthiness corresponding to EASA CS-23 or FAA FAR Part 23 requirements whilst recognizing the specific characteristics of UAS such as NATO STANAG 4671 ref. [5].

EASA UAS Airworthiness Policy ref. [3] is confined to risk on the ground while other references address risk in the air as well. See also section 4.2.

4.1.3 Recommendations

The above outstanding guiding principles bear the following difficulties:

(a) The comparison with manned aircraft bears inherent difficulties of interpretation due to the different nature of unmanned aircraft and due to the shift of the risk from the crew and passengers on board to the third parties on the ground or in the air

(b) The concept of minimizing the hazard, while being not specifically related to manned aircraft, leaves room for interpretation

(c) Reference to a specific minimum level such as CS-23 may be a possible approach but may be too specific at the level of an overall guiding principle.

It is thus proposed to state an overall guiding principle as follows

UAS shall be designed and operated in such a manner that the risk to third parties on the ground or in the air is acceptable.

Detailed interpretation of this principle is covered under section 4.4.

4.2 INTERRELATION BETWEEN AIRWORTHINESS AND OPERATIONAL ASPECTS

4.2.1 Statement of the issue

Manned aviation regulations clearly split between requirements related to design standards within the framework of Type Certification and those related to operational rules within the framework of operational certification.

Manned aircraft Type Certification essentially ensures the safety of people on board and, in general, is based upon only few assumptions[5] with regard to the operational environment. The safety of third parties in the air is ensured by:

- Operational rules which depend on the operational environment (flight rules, class of airspace), and
- Equipment as required by these operational rules (and subsequently subject to airworthiness approval).

Unmanned aircraft operations bear the following specific character:

- There is no risk to people on board and the risk of UAS operations is shifted to third parties on the ground or in the air. Existing manned airworthiness requirements do not explicitly address the risk to third parties on the ground or in the air; they assume that meeting the requirements for the safety of people on board implicitly provides an adequate level of safety to third parties. Hence this implicit assumption may lead to inappropriate safety requirements for UAS. More explicit UAS requirements with regard to risk to third parties may have to be established.
- For manned aviation, the pilot in command on board and ATC (where applicable) ensure the adherence to operational rules like safe separation and collision avoidance. Unmanned aviation may also rely on equipment to perform these tasks. UAS airworthiness approval criteria for such equipment may thus have to be subsequently adapted.

In addition, unmanned aircraft may perform operations which are beyond the (implicit and explicit) assumptions of the operational rules for manned aviation, and may have direct impact on airworthiness requirements, e.g. unmanned aircraft may:

- Orbit for prolonged period of time over densely populated areas
- Routinely take-off from and/or land at alternative sites other than aerodromes.

Considering the specific character of UAS operations and the stronger interrelation between UAS airworthiness and operational aspects, recommendations should therefore be made as to whether the conventional manned approach of splitting between requirements for Type Certification and requirements for Operational Approval may or may not be applicable in the case of UAS.

4.2.2 Considered approaches

The following approaches could be envisaged in summary

(a) Maintain the distinction between airworthiness certification and operational approval (including at requirements level), with no particular restricting assumptions concerning the kind of operations. Operational restrictions together with special conditions or “waivers” should be dealt with under Restricted Type Certification (see e.g. EASA UAS Airworthiness Certification Policy ref. [3]).

(b) Consider operational environment and operations that may have a direct impact on airworthiness and safety requirements in the Type Certification basis (as it is the case in some of the manned airworthiness requirements such as CS-VLA assuming VFR – Day light operations or CS-AWO varying safety requirements as a function of visibility conditions).

[5] There are nevertheless some examples where airworthiness requirements do make such assumptions e.g. CS-VLA assuming VFR flights only or CS-AWO Cat 2 & Cat 3 airworthiness approval assuming visibility conditions.

NOTE 1: *The above approaches may have an impact on the way to perform Operational Safety Assessment using the ED 78 methodology. In the first case, the UAS will be assumed to be certified according to a given level (without considering operations and environment), while in the second case the UAS airworthiness safety level will be set according to its contribution to meet the overall operational safety objective.*

NOTE 2: *The second approach provides the opportunity to tailor the airworthiness requirements to meet the required level of safety for particular types or classes of operation and operational environment. This would greatly enhance the economic efficiency with which this new class of commercial aviation could be implemented.*

NOTE 3: *Refer also to Appendix 6 (and section 4.4) for examples of interrelation between operational environment and airworthiness.*

4.2.3 Recommendations

The first approach is in line with the current manned aviation practices. When considering an incremental concept of UAS integration into the airspace, it may be easier to implement and therefore it is recommended to use it on the short term.

In the longer term however, especially in the context of a future total aviation system, only the second approach may allow setting of UAS airworthiness safety requirements that properly address the risk to third parties that is directly related to the kind of operations. This would permit the safe but also economically efficient exploitation of this new sector of commercial aviation.

4.3 FAILURE SEVERITY DEFINITION AND CLASSIFICATION

4.3.1 Statement of the issue

Manned failure severity definitions and classification, such as provided in FAA AC 23.1309 or EASA AMC 25.1309, provide a scheme to classify the severity of failures according to their impact on safety, notably of the aircraft and its occupants. Since unmanned aircraft do not carry occupants (within the scope of this report), this classification may have to be reviewed and tailored to the specific character of UAS.

4.3.2 Considered approaches

Appendix 3 provides different sets of proposed failure severity definitions and classification that would parallel those given in manned AC/AMC 1309.

Basically, two different approaches may be summarised as follows:

(a) Stay as close as possible to manned aircraft general severity definitions with slight adaptation considering the absence of people on board (see Appendix 3 e.g. JARUS)

(b) Provide severity definitions specifically related to UAS inherent characteristics (see Appendix 3 e.g. STANAG 4671)

4.3.3 Recommendations

Any set of general severity definitions will in any case have to be accompanied by specific UAS failure classification examples, given the particular character of UAS applications. Hence, a third approach is recommended i.e.:

(a) On the one hand, provide a general functional failure classification considering potential end effects on third parties, UAS crew or ATC. Refer to Appendix 4, A4.4

(b) On the other hand, provide a guideline to classify various UAS failure scenarios according to failure classification scheme mentioned in (a). Refer to table of Appendix 4.

NOTE: *Probability requirements, depending on the worst possible outcome of the failure scenarios in term of actual effect on third parties, are covered in the next section.*

4.4 QUANTITATIVE PROBABILITY REQUIREMENTS

4.4.1 Statement of the issue

Although the exact wording of requirement 1309 for manned aircraft differs among the distinctive codes, in general terms it sets requirements for the design of equipment, systems, and installations based on the occurrence probability and severity of failures which could affect continued safe flight and landing. In assessing the acceptability of a design, the need to establish rational probability values for manned aircraft has been recognized (e.g. FAA AC 23.1309 or EASA AMC 25.1309) based on accident rates to establish acceptable probabilities of these failures.

Likewise, UAS AMC.1309 needs explicit quantitative probability requirements; the issue is how these can be established, while reflecting in an appropriate manner the safety of third parties on the ground (see also 4.2.1).

In addition, for unmanned aircraft, separation assurance and collision avoidance may rely more on equipment to perform these tasks. Similar to the issue of the safety of third parties on the ground, the question is how quantitative probability requirements should be established for the airworthiness approval of unmanned aircraft equipment performing these tasks in a manner consistent with the overall safety target set for mid-air collision (see also 4.2.1).

4.4.2 Considered approaches

EUROCAE WG-73 has reviewed and debated the following basic approaches:

For the risk on the ground

(a) Base the unmanned requirement purely upon manned accident rates with no mitigating factor

(b) Compare the risks by manned and unmanned aircraft, but strictly consider the end effect on third parties (e.g. by using the Bow-tie tool see Appendix 5) in order to derive UAS safety requirements

(c) Establish a specific safety target value for the acceptable probability for ground fatalities from which detailed UAS probability requirements for Class I events, as defined in Appendix 4 A4.4, shall be derived (where these events may lead to fatal injuries).

For the risk in the air

(a) Separation Assurance and Collision Avoidance (SA & CA) functions on board the UAS should meet a fixed safety target (without considering mitigation by ATC or other aircraft)

(b) Set the probability requirements for SA & CA functions on board the UAS considering mitigation by ATC for separation assurance, where applicable, and by other aircraft SA & CA (e.g. by using the Bow-tie tool, see Appendix 5).

4.4.3 Recommendations

For the risk on the ground

(a) For the risk on the ground, a specific target value for the acceptable probability for ground fatalities should be defined in line with guiding principle recommended in section 4.1.3. Detailed UAS probability requirements for Class I events, as defined in Appendix 4 A4.4 (where these events may lead to fatal injuries) shall subsequently be derived, see examples in Appendix 6.

This value should be expressed in the probability of a ground fatality per flight hour that would be considered as acceptable at societal, political and economic levels. The rationale to determine the acceptable probability value may also be based upon comparison with the risk to third parties on the ground arising from manned aviation. For instance, a target value of 10^{-6}/h (i.e. 1 fatality on the ground every million flight hours) would be consistent with historical evidence related to General Aviation Crash rate of 10^{-4}/h of which 2% caused ground fatalities[6]. It would be also consistent with the ground fatality probability target initially used to develop the DGA USAR version 3.0[7].

NOTE 1: *As illustrated above, the rationale for setting this target value could be partially based upon some comparison with manned aircraft aviation (e.g. ground fatalities statistics induced by manned aircraft crashes) but will likely be also based upon other societal, political and economic aspects.*

NOTE 2: *There may be a need to distinguish between the risk to persons who are involved and those who are not.*

For the risk in the air

(b) For the risk in the air, the second approach which takes account of all the mid-air collision factors, is recommended i.e. setting the probability requirements for SA & CA functions on board the UAS considering mitigation such as by ATC for separation assurance, where applicable, and by other aircraft SA & CA (e.g. by using the Bow-tie tool see Appendix 5).

Fail-safe criteria

(c) As previously stated in section 1.1, the single failure (or fail-safe) criteria is applied differently in different manned aircraft airworthiness codes, either by being strictly applied (i.e. regardless of failure occurrence probability) or not applied (i.e. considering failure occurrence probability).

It is recommended that, for UAS, a way combining both approaches be adopted and stated in the UAS AMC 1309 to be established. Account may be taken of the occurrence probability of failure conditions (including some single failure) and/or of experienced engineering judgment based upon the application of sound design techniques. However, as a design aim, the cases where a single failure could lead to a Class I event (where it may cause fatal injuries) should be minimized.

Design Assurance Levels

(d) The definition of Design Assurance Levels (DAL) including software levels as per methodologies of SAE ARP 4754 (or ARP 4754a wherever applicable) and EUROCAE ED-12B (or C, wherever applicable) and DAL as per EUROCAE ED-80 for Complex Electronics Hardware (or any equivalent to be accepted by the authority) should be determined in a manner consistent with the tailored severity classification and probability levels set forth in the tailored UAS AMC 1309[8] that will be established.

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[6] See for instance "Determination and Evaluation of UAV Safety Objectives" by R. Clothier and R. Walker (http://eprints.qut.edu.au/4183), referring to NTSB statistics.

[7] The DGA USAR version 3 was developed by the French Military Authorities, and later updated by NATO FINAS group to STANAG 4671; the ground fatality probability was implicitly used to develop the USAR version 3. See in particular
http://www.uavnet.org/index.php?option=com_remository&Itemid=11&func=select&id=20&orderby=1

[8] Example of such consistency between hardware probability requirements and software levels may be found in FAA AC 23.1309 1D.

System Failure Conditions Probability Requirements

(e) The probability requirement due to all systems failure conditions leading to Class I events shall be derived from the probability requirement established as per above 4.4.3 (a) (see also section 4.5). Manned aircraft AMC (e.g. AMC 25.1309) or Advisory Circular (e.g. FAA AC 23.1309) assume a ratio of 10% of technical failures and 90% of operational failures (including human errors). This ratio is not necessarily applicable to an Unmanned Aircraft Systems, when considering a higher level of automation as compared to manned aircraft and a different (possibly lesser) contribution of UA pilot errors. Therefore, it is recommended to review the applicability of this ratio for UAS.

4.5 UAS CATEGORIZATION

4.5.1 Statement of the issue

The issue is whether the detailed UAS AMC.1309 failure probability requirements may apply to all types of unmanned aircraft or they may have to vary according to some UAS categorization. For instance, in the case of manned aircraft, different probability requirements are defined within FAA AC 23.1309 (as a function of weight, number or type of engine) and different probability requirements are defined between FAA AC 23.1309 and EASA AMC 25.1309. If so, can the parameters used in manned aviation be applied to unmanned aviation or should parameters more specific to UAS be defined (such as weight, size and kind of operations)?

4.5.2 Considered approaches

The UAS community has yet to determine an appropriate UAS categorization. The issue at stake here is to determine possible UAS categories that may lead to different detailed UAS safety requirements while meeting the provisions of the overall guiding principle.

(a) Basic European regulation EC 216/2008 introduces a weight threshold of 150 kg[9] under which Unmanned Aircraft are under the remit of National Aviation Authorities

(b) EASA UAS Airworthiness Certification policy (ref. [3]) introduces the concept of Kinetic Energy categories to determine the airworthiness reference code to be tailored in establishing the UAS Type Certification Basis[10]

(c) Another approach (see also the discussion under 4.2) could be to establish a UAS categorization that combines physical parameters (such as weight or crash size area) as well as operations and environment parameters.

[9] It has been widely recognized that this threshold is primarily intended to define the border of responsibilities between EASA and National Authorities and that it is not related to any significant technical meaning with regard to UAS categorization.

[10] In the military UAS context, the Weight Range applied by NATO STANAG 4671 (ref [5]) covers, as a first step, Unmanned Aircraft from 150 kg to 20,000 kg. STANAG 4671 itself was developed from DGA USAR v3 dated January 2005 which does not have upper weight limit.

4.5.3 Recommendations

In line with the third approach stated above under 4.5.2 (c), it is recommended to establish a range of UAS probability requirements for Class I events differing from each other by an order of magnitude[11] as a function of

- Operations and environment parameters such as population density and class of airspace
- The size of UA crash area, considered as the most significant parameter relating to the risk to third parties on the ground

that altogether shall allow meeting the safety target value referred to in 4.4.3.

Wherever possible, a manned reference aircraft may be used to compare size of the crash area and safety target value.

As an illustration on the way to implement this recommendation, examples are provided in Appendix 6, considering unmanned aircraft characteristics and type of operations.

[11] Such as found in FAA AC 23.1309 (Class I to Class IV) e.g. as a function of weight with quantitative probability requirements classified by an order of magnitude.

CHAPTER 5

CONCLUSIONS

This report provides a set of recommendations relative to major topics that should be elaborated in any future UAS AMC 1309.

In particular, the recommendations stated in sections 4.1.3, 4.2.3, 4.3.3, 4.4.3 and 4.5.3 of this document are proposed as an input to the ERSG regulatory roadmap ref.{8]) and envisaged future EASA UAS AMC 1309 NPA.

APPENDIX 1: EUROCAE WG-73 SURVEY

Over the past years, different approaches have been reviewed and discussed amongst EUROCAE WG-73 members representing Industry, Authorities and Research Institutes. In addition, different draft policies have been provided by various bodies. These reviews and discussions have been going on for some years already, since it proves difficult to reach a consensus among the various stakeholders. Considering this difficulty, EUROCAE WG 73 organized a survey in order to review and better define the different interpretations relating to the following topics:

- Current EASA Guiding Principles as stated in EASA Policy (ref. [2])
- Probability Requirements
- Airworthiness versus Operations

This survey has identified the extent to which the stakeholders have consensus on these topics, and where there is no consensus.

Consensual areas

The survey identified that there is consensus about the following:

(a) Whilst the difficulties in interpreting EASA Guiding principle have become apparent, the need to have a general principle aimed at calling for an acceptable level of risk introduced by Unmanned Aircraft is generally agreed.

(b) This latter principle should cover the risks both on the ground and in the air, although currently 'in the air' is beyond the current EASA policy of ref. [3]).

(c) The risk is generally defined as a combination of consequences (harm to third parties, fatalities) and probability of occurrence.

(d) There is a general agreement that, especially for UAS, airworthiness and operational aspects cannot be totally separated and that their interface has to be accounted for.

(e) The Bow-tie methodology (see Appendix 5) is viewed as one of the potential tools that allow having a holistic approach of airworthiness and operations and to model and quantify the risk mitigating factors with regard to the end effects on third parties.

Non Consensual areas & Diverging Approaches

The survey identified that there is no consensus about the way to compare between manned and unmanned aircraft risks, which leads to different and contradictory approaches:

(a) In order to derive the probability requirements, should we compare between accident rates or between actual risks of harm to third parties on the ground based upon manned aircraft statistics, or should we not compare at all?

(b) The term "equivalent category" (between manned and unmanned aircraft) is variously interpreted (as per Kinetic Energy, End effects on third parties, kind of operations or complexity) or found totally inadequate.

(c) Should the comparison be based upon the level of technology, risk apportionment including public acceptance (e.g. Commercial operations versus State Aircraft operations), should we take account of operational aspects? What about the cases where comparison is not possible at all?

APPENDIX 2: ONGOING GUIDING PRINCIPLES

The following is a list of guiding principles that have been formulated by various bodies (as available at the date of publication of this report), illustrating the different approaches that have been taken.

Item	Reference	Overall Guiding Principle (quote)
1	EASA Policy E.Y01301 (section 4.1) (August 2009)	A civil UAS must not increase the risk to people or property on the ground compared with manned aircraft of equivalent category Airworthiness standards should be set to be no less demanding than those currently applied to comparable manned aircraft nor should they penalize UAS by requiring compliance with higher standards simply because technology permits
2	ICAO Circular 328 dated 2011 (sections 2.8, 3.1)	The principal objective of the aviation regulatory framework is to achieve and maintain the highest possible and uniform level of safety. In the case of RPAS, this means ensuring the safety of any other airspace user as well as the safety of persons and property on the ground. RPAS will operate in accordance with ICAO standards that exist for manned aircraft as well as any special and specific standards that address the operational, legal and safety differences between manned and unmanned aircraft operations. Note: Above principle has been reformulated in ICAO Annex 2 Amendment 43 quoted below.
3	ICAO Annex 2 Amendment 43 (November 2012)	A remotely piloted aircraft shall be operated in such a manner as to minimize hazards to persons, property or other aircraft and in accordance with the conditions specified in Appendix 4 [of ICAO Annex 2]. Note: EASA-NPA 2012-12 ("Transposition of Amendment 43 to Annex 2 to the Chicago Convention on remotely piloted aircraft systems (RPASs) into common rules of the air") was issued on 21 August 2012.
4	EUROCAE WG-73 ER-004 (November 2010)	Recommendation is given to finalize and harmonize – between civil aviation authorities, industry and possibly military authorities – consensual and simple definitions of Catastrophic UAS failure condition and Overall Safety UAS Safety Objective, based upon an absolute acceptable quantitative risk resulting from the consequence of a UAS Catastrophic failure condition and derive quantitative criteria at UAS system level.
5	STANAG 4671 (Edition 1 promulgated in September 2009)	The intention of this document is to correspond as closely as practicable to a comparable minimum level of airworthiness for fixed-wing aircraft as embodied in documents such as 14 CFR Part 23 and EASA CS-23 (from which it is derived) whilst recognising that there are certain unique features of UAV Systems that require particular additional requirements or subparts. Note: This principle was first established for DGA USAR v3 (January 2005) and adapted by NATO/FINAS for STANAG 4671.
6	ERSG Roadmap June 2013	RPAS shall be designed, manufactured, operated and maintained in such a manner that the risk to people on the ground and other airspace users is at an acceptable level. This level shall be set through essential requirements adopted by the legislator, following substantial consensus by all involved parties during the rulemaking process. When developing the safety requirements for RPAS, the risk must be considered in relation to the different size of RPAS and the type of operation involved

APPENDIX 3: ONGOING SEVERITY DEFINITIONS

Referenced documents in this appendix:

EASA CS-25 AMC 1309	
FAA AC-23.1309 1D (or E)	System Safety Analysis and Assessment for Part 23 Airplanes, FAA, 2011
EASA A-NPA 16/2005	See ref. [2]
NATO STANAG 4671	See ref. [5]
JARUS	Draft JARUS working paper

Severity		Definition	
Catastrophic	**Manned**	**FAA AC-23.1309 1D**	Failure Conditions that are expected to result in multiple fatalities of the occupants, or incapacitation or fatal injury to a flight crewmember normally with the loss of the airplane.
		EASA CS-25 AMC 1309	Failure Conditions, which would result in multiple fatalities, usually with the loss of the aeroplane.
	Unmanned	**EASA A-NPA 16/2005 (“Severity I”)**	The worst UAV hazard event designated hereafter as “Catastrophic” or Severity I Event may be defined as the UAVs inability to continue controlled flight and reach any predefined landing site, i.e. an UAV uncontrolled flight followed by an uncontrolled crash, potentially leading to fatalities or severe damage on the ground.
		NATO STANAG 4671 AMC 1309	Failure conditions that result in a worst credible outcome of at least uncontrolled flight (including flight outside of pre-planned or contingency flight profiles/areas) and/or uncontrolled crash *(which can potentially result in a fatality).*
		JARUS (draft June 2013 as circulated for National Authorities comments)	Failure conditions which could result in one or more fatalities.

Severity		Definition	
Hazardous	Manned	**FAA AC-23.1309 1D**	Failure Conditions that would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be the following: (i) A large reduction in safety margins or functional capabilities; (ii) Physical distress or higher workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely; or (iii) Serious or fatal injury to an occupant other than the flight crew.
		EASA CS-25 AMC 1309	Failure Conditions, which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating, conditions to the extent that there would be: (i) A large reduction in safety margins or functional capabilities; (ii) Physical distress or excessive workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely; or (iii) Serious or fatal injury to a relatively small number of the occupants other than the flight crew.
	Unmanned	**EASA A-NPA 16/2005 ("Severity II")**	Failure conditions leading to the controlled loss of the UAV over an unpopulated emergency site, using Emergency Recovery procedures where required.
		NATO STANAG 4671 AMC 1309	Failure conditions that either by themselves or in conjunction with increased crew workload, are expected to result in a controlled-trajectory termination or forced landing potentially leading to the loss of the UAV where it can be reasonably expected that a fatality will not occur.
		JARUS (draft June 2013 as circulated for National Authorities comments)	Failure conditions that would reduce the capability of the UA or the ability of the remote crew to cope with adverse operating conditions to the extent that there would be the following: a) A controlled-trajectory termination of flight potentially leading to the loss of the UA where it can be reasonably expected that a fatality will not occur or b) A large reduction in safety margins or functional capabilities or c) Loss of Detect and Avoid (UA unable to maintain safe separation)

Severity		Definition	
Major	Manned	**FAA AC-23.1309 1D**	Failure Conditions that would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be a significant reduction in safety margins or functional capabilities; a significant increase in crew workload or in conditions impairing crew efficiency; or a discomfort to the flight crew or physical distress to passengers or cabin crew, possibly including injuries.
		EASA CS-25 AMC 1309	Failure Conditions which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew workload or in conditions impairing crew efficiency, or discomfort to the flight crew, or physical distress to passengers or cabin crew, possibly including injuries.
	Unmanned	**EASA A-NPA 16/2005 ("Severity III")**	Failure conditions leading to significant reduction in safety margins (e.g., total loss of communication with autonomous flight and landing on a predefined emergency site).
		NATO STANAG 4671 AMC 1309	Failure conditions that either by themselves or in conjunction with increased crew workload, are expected to result in an emergency landing of the UAV on a predefined site where it can be reasonably expected that a serious injury will not occur.
		JARUS (draft June 2013 as circulated for National Authorities comments)	Failure conditions that would reduce the capability of the UA or the ability of the remote crew to cope with adverse operating conditions to the extent that there would be a significant reduction in safety margins, functional capabilities or separation assurance. In addition, the failure condition has a significant increase in remote crew workload or in conditions impairing remote crew efficiency.

Severity		Definition	
Minor	Manned	**FAA AC-23.1309 1D**	Failure Conditions that would not significantly reduce airplane safety and involve crew actions that are well within their capabilities. Minor Failure Conditions may include a slight reduction in safety margins or functional capabilities, a slight increase in crew workload (such as routine flight plan changes), or some physical discomfort to passengers or cabin crew.
		EASA CS-25 AMC 1309	Failure Conditions which would not significantly reduce aeroplane safety, and which involve crew actions that are well within their capabilities. Minor Failure Conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight increase in crew workload, such as routine flight plan changes, or some physical discomfort to passengers or cabin crew.
	Unmanned	**EASA A-NPA 16/2005 ("Severity IV")**	Failure conditions leading to slight reduction in safety margins (e.g. loss of redundancy).
		NATO STANAG 4671 AMC 1309	Failure conditions that do not significantly reduce UAV System safety and involve UAV crew actions that are well within their capabilities. These conditions may include a slight reduction in safety margins or functional capabilities, and a slight increase in UAV crew workload.
		JARUS (draft June 2013 as circulated for National Authorities comments)	Failure conditions that would not significantly reduce UA safety and involve remote crew actions that are within their capabilities. Minor failure conditions may include a slight reduction in safety margins or functional capabilities, a slight increase in remote crew workload, such as routine flight plan changes.

Severity		Definition	
No Safety Effect	Manned	**FAA AC-23.1309 1D**	Failure conditions that would have no affect on safety (that is, failure conditions that would not affect the operational capability of the airplane or increase crew workload).
		EASA CS-25 AMC 1309	Failure Conditions that would have no effect on safety; for example, Failure Conditions that would not affect the operational capability of the aeroplane or increase crew workload.
	Unmanned	**EASA A-NPA 16/2005 (Severity V")**	Failure conditions leading to no Safety Effect.
		NATO STANAG 4671 AMC 1309	Failure conditions that have no effect on safety.
		JARUS (draft June 2013 as circulated for National Authorities comments)	Failure conditions that would have no effect on safety for example, failure conditions that would not affect the operational capability of the UA or increase remote crew workload.

APPENDIX 4: HIGH LEVEL UAS FAILURE CLASSIFICATION

This appendix identifies the risk scenarios for unmanned aircraft and their potential outcomes (or end events) by

- Defining the functions to be performed during any type of UAS mission,
- Identification of the effect on the behaviour of the unmanned aircraft if these functions are not performed as intended, and
- The assessment of the potential effect on people on the ground and in the air.

A4.1 DEFINITION OF THE HIGH-LEVEL FUNCTIONS

All aircraft perform the following functions from immediately after take-off:

- The following of a flight path, along an intended route, in terms of geographical position and altitude,
- The assurance of safe separation from other aircraft, and the avoidance of collisions, and
- Landing.

  A major difference between the 'flight path' and 'separation assurance' and 'collision avoidance' is that the 'flight path' is always applicable and can be planned beforehand, while 'separation assurance' and 'collision avoidance' only apply when there are other aircraft in the vicinity, and cannot be planned.

The following unmanned aircraft aspects are of particular relevance when defining a high-level functional failure categorization:

- Unmanned aircraft can be programmed to follow a flight path according to a navigation plan[12] which defines the trajectory e.g. by a series of navigation waypoints which shall be passed at a predefined altitude and time within a specific accuracy.
- There may be Emergency Recovery procedures[13], i.e. functions that could be implemented by the crew or by an automatic pre-programmed course of actions that are intended to navigate the UA to a predefined emergency site for a safe landing, or terminate the flight[14].
- Unmanned aircraft may use dedicated sites for take-off and landing instead of a conventional airport or heliport. Any site that is not the intended landing site or predefined by emergency recovery procedures (see above) is an 'unplanned' landing (or crash) site. The pilot may be able to select an unplanned landing site that is uninhabited and thus minimize the hazard risk to third parties on the ground.

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[12] The term 'navigation plan' is used to indicate that this is the routing as intended by the UAV crew; this may be the same routing as in the ATC flight plan, but since an ATC flight plan may not be mandatory for each flight, the term 'navigation plan' is used instead.
[13] This definition is consistent with the EASA policy.
[14] This may include a controlled crash.

A4.2 EFFECT ON THE BEHAVIOUR OF NOT PERFORMING THE FUNCTIONS AS INTENDED

As a result of a system failure, the UA may not be able to perform as intended one or more of the high-level functions defined in A4.1, 'Flight Path', 'Separation Assurance and Collision Avoidance', and 'Landing'. The classification level of a failure depends on the extent to which these functions cannot be performed any more. The following parameters are subsequently proposed to be analysed in classifying the UAS failure conditions:

- Flight Path:
  - Can the UA still follow its flight path according to its intended and planned flight path?
  - If not, can the UAV follow an unplanned but predictable and safe flight path (e.g. according to well defined emergency procedures)
  - If none of the above, then the UA flight path is unpredictable (which is tantamount of an uncontrolled flight)
- Separation Assurance and Collision Avoidance
  - Can the UA still be safely separated from other air traffic?
  - Can the UA still perform Collision Avoidance in case safe separation is lost?
- Landing / Crash Site:
  - Can the UA land at its intended "normal" landing site?
  - If not, can the UAV land at an intended, safe landing site (e.g. to a pre-planned uninhabited emergency landing / crash site, such that the hazard risk to third parties on the ground is minimized)?
  - If it cannot land or crash at above pre-planned site, does the UA pilot have still the means to select an unplanned but uninhabited landing or crash site (such that the hazard risk to third parties on the ground is minimized)?
  - If none of the above, then the landing / crash location is totally unpredictable (which is tantamount to an "uncontrolled crash")?

NOTE: *The term "Separation Assurance" in the context of this document is used as a generic term referring to, depending on the class of airspace, either separation provided by ATC or or self-separation by the unmanned aircraft if required by the applicable class of airspace and flight rules.*

This yields the following failure scenarios for the high-level functions from Par A4.1:

- After occurrence of the failure, the unmanned aircraft is still able to continue its flight according to its intended and planned flight path (failure scenario FP1).
- After occurrence of the failure, the unmanned aircraft is not able to continue its flight (including take-off and landing) according to the intended flight path, leading to one of the following cases:
  - The unmanned aircraft follows an unplanned but predictable and safe flight path e.g. in accordance with predefined "Emergency" Procedures (failure scenario FP2.1)
  - The unmanned aircraft does not follow its intended and planned flight path with the required accuracy (typically undetected erroneous navigation) while its attitude is still under control (failure scenario FP2.2, which could lead the UA to fly out of the assigned airspace or even to CFIT)
  - The unmanned aircraft enters an uncontrolled flight or taxiing (failure scenario FP2.3).
- After occurrence of the failure, the unmanned aircraft is still able to land on the normally planned landing site (failure scenario L1).

- After occurrence of the failure, the unmanned aircraft is not able to land on the normally planned landing site, leading to one of the following cases:
  - o The unmanned aircraft can land or crash at a pre-planned uninhabited emergency site (failure scenario L2.1),
  - o The unmanned aircraft cannot land or crash at a pre-planned uninhabited emergency site but its pilot has still the means to select an unplanned uninhabited emergency site (e.g. through an on-board camera) where to land or crash the unmanned aircraft (failure scenario L2.2),
  - o The unmanned aircraft has neither option L2.1 nor L2.2 and crashes on an uncontrolled manner at a location totally unpredictable ("uncontrolled crash") (failure scenario L2.3).

The 4 different options for the flight path and the 4 different options for the landing yield 16 combinations, of which some are not applicable because they are correlated. For example, if the flight continues as per navigation plan (option FP1) this implies that also the landing is as planned (option L1), and the options L2.1 - L2.3 are not applicable. A review of all the options yields to 9 possible combinations:

	FP1	FP2.1	FP2.2	FP2.3
L1	+	+	+	-
L2.1	-	+	+	-
L2.2	-	+	+	-
L2.3	-	-	+	+

Each of these may also have an effect on Separation Assurance (SA) and Collision Avoidance (CA):

- Separation Assurance functions properly or not,
- Collision Avoidance functions properly or not.

This yields 4 combinations for each of the options in the table above[15].

A4.3 EFFECT ON PEOPLE ON THE GROUND AND IN THE AIR

The effect on people on the ground and in the air may be:

- Physical hit or stress to third parties in the air or in the ground,
- Workload increase to the crew or ATC.

A4.4 FUNCTIONAL FAILURE CLASSIFICATION LEVELS

1. Class I: Failure condition that is expected to directly or indirectly lead to physical hit of third parties in the air or on the ground (see notes below)
2. Class II: Failure Condition that is not expected to lead to physical hit of third parties in the air or on the ground but is expected to lead to stress to third parties in the air or on the ground as a result of nearby collision or crash nearby third parties.
3. Class III: Failure Condition that is not expected to lead to physical hit of third parties in the air or on the ground nor to stress to third parties in the air or on the ground but is expected to lead to a significant increase in workload to UAS crew, to ATC.

[15] SA OK + CA OK, SA not OK + CA OK, SA OK + CA not OK, SA not OK + CA not OK

4. Class IV**:** Failure Condition that is not expected to lead to physical hit of third parties in the air or on the ground nor to stress to third parties in the air or on the ground but is expected to lead to a slight increase in workload to UAS crew or ATC
5. Class V**:** Failure Condition that is not expected to lead to physical hit of nor stress to third parties in the air or on the ground and will not increase the workload to UAS crew or ATC.

NOTES:

a. Above classification levels do not necessarily parallel the classical manned severity classification (Catastrophic, Hazardous etc…) used for manned aircraft which is oriented towards onboard crew or passengers.

b. The term "physical hit" is intentionally used to cover physical effects on third parties, rather than specifying their exact nature in terms of injuries or fatal injuries. The most severe outcome would depend on specific unmanned aircraft characteristics. Probability requirements should then be determined as per recommendation stated in section 4.4.3, considering the most severe effect on third parties.

		High Level End effect of UAS failure				**Potential Effect to people**		**Proposed Class (see A4.4)**
		FP	**L**	**SA**	**CA**	**Ground**	**Air**	
1	**1.1**	**FP1 (per flight path)**	**L1 (Normal)**	**OK**	**OK**	None	None	V
2	**1.2**	**FP1 (per flight path)**	**L1 (Normal)**	**NOK**	**OK**	None	Stress	II
3	**1.3**	**FP1 (per flight path)**	**L1 (Normal)**	**OK**	**NOK**	None	None	IV
4	**1.4**	**FP1 (per flight path)**	**L1 (Normal)**	**NOK**	**NOK**	Physical	Physical	I
5	**2.1**	**FP2.1 (Emergency)**	**L1 (Normal) or L2.1 (Predefined)**	**OK**	**OK**	None	None	IV
6	**2.2**	**FP2.1 (Emergency)**	**L1 (Normal) or L2.1 (Predefined)**	**NOK**	**OK**	None	Stress	II
7	**2.3**	**FP2.1 (Emergency)**	**L1 (Normal) or L2.1 (Predefined)**	**OK**	**NOK**	None	None	III
8	**2.4**	**FP2.1 (Emergency)**	**L1 (Normal) or L2.1 (Predefined)**	**NOK**	**NOK**	Physical	Physical	I
9	**3.1**	**FP2.1 (Emergency)**	**L2.2 (Unplanned selected)**	**OK**	**OK**	None	None	III
10	**3.2**	**FP2.1 (Emergency)**	**L2.2 (Unplanned selected)**	**NOK**	**OK**	None	Stress	II
11	**3.3**	**FP2.1 (Emergency)**	**L2.2 (Unplanned selected)**	**OK**	**NOK**	None	None	III
12	**3.4**	**FP2.1 (Emergency)**	**L2.2 (Unplanned selected)**	**NOK**	**NOK**	Physical	Physical	I
13	**4.1**	**FP2.2 (inaccurate navigation)**	**-**	**-**	**-**	-	-	I (Worst case)
14	**7.1**	**FP2.3 (Uncontrolled flight)**	**L2.3 (Unplanned unselected)**	**-**	**-**	Physical	Physical	I

NOTE: *When classifying failure conditions according to above Class levels, account may be taken of existing design mitigation factors.*

<u>Example 1</u>: Where the unmanned aircraft is designed with dual redundant control surfaces such that in case of any failure of one of them, its ability to follow the flight path is not affected, the loss of one control surface would correspond to line 1 in the table, hence Class V.

<u>Example 2</u>: In case of total loss of Command and Control Link (C2 link loss), i.e. inability to transmit UAV flight control & navigation commands from the Ground, several cases have to be envisaged as a function of design mitigating factors

(a) If the UAS has no design compensating provisions, then the unmanned aircraft flight path eventually becomes uncontrolled and the unmanned aircraft cannot land on a normal landing site or on a pre-planned one. Thus it corresponds to the line 14 of the above table, hence Class I.

(b) If the UAS has design compensating provisions such as "Return Home" mode i.e. autonomous pre-programmed course of actions, including multiple way points enabling the unmanned aircraft to reach a predefined uninhabited emergency landing site, it may correspond to lines 5, 6, 7, or 8 (resp. Class IV, II, III or I) as a function of the effect on separation assurance and collision avoidance depending on several design and operational parameters

   – Airborne transponder able to automatically switch to pre-set emergency code to inform ATC about the link loss
   – Flight Plan coordination with ATC including pre-programmed Flight Path in case of C2 link loss
   – Capability of unmanned aircraft to land at an uninhabited site without C2 link
   – Capability of unmanned aircraft to perform separation assurance and collision avoidance functions in the absence of C2 link.

APPENDIX 5: BOW-TIE AND PROBABILITY REQUIREMENTS

For manned aircraft it is evident that people are at risk since manned aircraft have occupants on board who may be injured or killed by an accident. This is confirmed by accident statistics that also show that such accidents may yield casualties among people on the ground, but not at every accident:

- Many accidents are on the runway or in the approach or take-off area, which are cleared of people for reasons of safety;
- Accidents en route are mostly in areas of low population density, since VFR pilots should execute their flights such that they can always make a safe landing in case of an engine failure;
- Populated areas are avoided as much as possible for reason of noise abatement during departure and arrival.

Although the technical and operational requirements for manned aircraft may not explicitly address the safety of people on the ground, their safety is implicitly covered by ensuring the safety of the occupants on board.

For unmanned aircraft it is not possible to cover the safety of people on the ground by the safety of occupants since unmanned aircraft do not (yet) carry passengers. So the question then becomes: how may unmanned aircraft be a risk to people on the ground, and how can it be ensured that this risk is acceptable?

The analogy with manned aviation shows that safety consists of two levels:

- The risk to the occupants on board, which is covered by technical requirements for the designer and manufacturer, and by operational requirements for the operator, pilot and maintenance organisation;
- The risk to people on the ground, which is covered by additional operational requirements (e.g. routing).

By the additional operational requirements, the risk to people on the ground is always less that the risk to people on board. Or: by the additional operational requirements there is no one-to-one correlation between aircraft accidents and casualties on the ground.

This can be illustrated by a diagram like Figure 1[16], a so called ‘bow tie diagram’. At the centre there is some ‘hazardous event’ to the system (like an aircraft accident), which may lead to several potential outcomes (like casualties among people on the ground). Figure 1 may be understood by using an example from daily life, the ‘hazardous event’ of a pedestrian crossing a street without looking for traffic. A potential outcome could be that he is hit by a car. Yet not all pedestrians who cross the street without looking are hit by a car:

- The car driver may spot the pedestrian, anticipate that he may cross the street and reduce speed;
- The crossing may be controlled by traffic lights, so the pedestrian may safely cross the road if he has a ‘green light’;
- The crossing may be a zebra crossing, so car drivers are warned of pedestrians.

[16] From: http://www.skybrary.aero/index.php/Bow_Tie_Risk_Management_Methodology (URL April 2013).

These are examples of controls to mitigate the outcome of crossing a street without looking for cars. Reversely, it may be that a car driver ignores the traffic lights; this is an example of an 'escalation' which aggravates the outcome of the hazardous event.

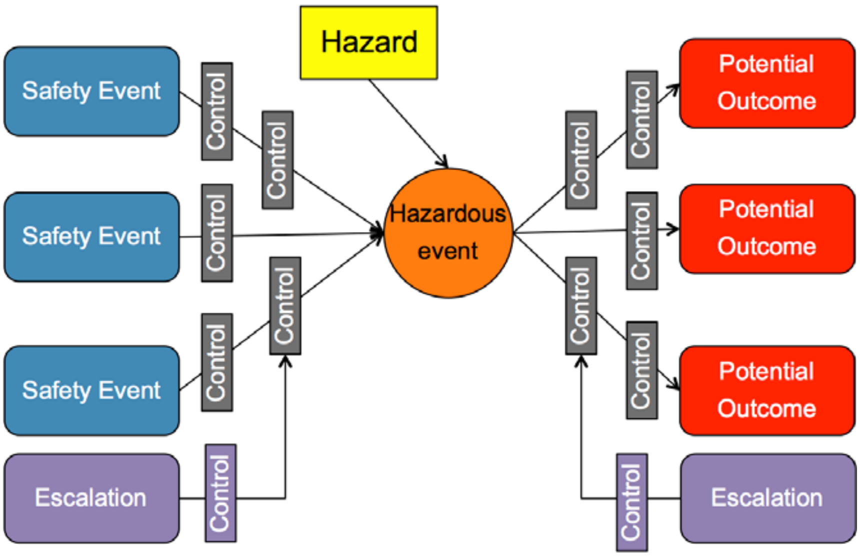

FIGURE 1: BOW-TIE METHODOLOGY[17]

In fact, the left hand side of the bow tie is the 'Fault Tree' of events that lead to the hazardous event, and the right hand side the 'Event Tree' of events that determine the outcome of the hazardous event[18]. EUROCONTROL considers the bow tie methodology 'an excellent way of visualising risk management and communicating the context of the controls (barriers and mitigations) put in place to manage risks'[19].

The bow tie methodology illustrates the dilemma which distinguishes unmanned aircraft from manned aircraft: while a crash of a manned aircraft (the 'hazardous event') is a direct risk to the occupants on board, and also a responsibility of the designer and manufacturer of the aircraft, they can have no responsibility on the effect of such a crash to people on the ground since this ('potential outcome') depends on operational factors (routing in relation to population) which are beyond the scope of the designer and manufacturer. While for manned aircraft the objectives for the technical safety requirements (or 'airworthiness') are set by the 'hazardous event' in the centre of the bow tie, these objectives have no meaning for (unoccupied) unmanned aircraft and have to be deduced from the safety objectives for people on the ground, set by the 'potential outcome' on the right hand side of the bow tie. Or: the safety objectives for the design and manufacture of unmanned aircraft can only be set by:

1. Setting the safety objectives for people on the ground, and by
2. Determining how the effect of a crash is mitigated by operational factors.

[17] From: http://www.skybrary.aero/index.php/bow_tie_risk_management_methodology

[18] See e.g. 'Safety Management System and Safety Culture Working Group (SMS WG) Guidance on Hazards Identification' and 'Air Traffic Organization Safety Management System Manual - Version 2.1'.

[19] See http://www.skybrary.aero/index.php/Bow_Tie_Risk_Management_Methodology (URL April 2013).

APPENDIX 6: UAS CATEGORIZATION EXAMPLES

The following examples are only aimed at illustrating the way to set UAS probability requirements that would allow meeting the safety target value referred to in section 4.4 as a function of UAS categorization parameters proposed in section 4.5 (as a function of unmanned aircraft characteristics and type of operations).

Example 1: An unmanned Cessna 172 orbiting over a stadium which is tantamount of flying above a 10 fold population density that is normally flown by a manned Cessna 172[20]. Both unmanned and manned aircraft have the same crash area. As a consequence this category of unmanned aircraft[21] can only meet the safety target value of e.g. 10^{-6}/h (see 4.4.3) if its required probability for Class I event is set at 10 times more severe than the one set for the manned Cessna 172 e.g.10^{-5}/h instead of 10^{-4}/h.

Example 2: A 200 kg unmanned aircraft with a wingspan of 3 m and a speed of 40 kts leading to a crash area of less than 10% of the crash area of a Cessna 172 flying under the same operational environment. As a consequence, this category of unmanned aircraft[22] could meet safety target value of e.g. 10^{-6}/h (see 4.4.3) if its required probability for Class I event is set at 10 times less severe than the one set for the manned Cessna 172 e.g.10^{-3}/h instead of 10^{-4}/h.

Example 3: A 10,000 kg unmanned aircraft with a wingspan of 20 m and a speed of 200kt leading to a crash area of more than 10 times but less than 100 times the crash area of a Cessna 172 while flying under the same operational environment. As a consequence, this category of unmanned aircraft[23] could meet safety target value of e.g. 10^{-6}/h (see 4.4.3) if its required probability for Class I Event is set at 100 times more severe than the one set for the manned Cessna 172 e.g.10^{-6}/h instead of 10^{-4}/h.

Example 4: An unmanned Cessna 172 flies IFR in Class E airspace among General Aviation aircraft under VMC. ATC will separate this Cessna from other IFR traffic, but since it is VMC, there may be also be VFR traffic from which ATC cannot provide separation. Hence all aircraft have to perform self-separation, and all aircraft have to provide collision avoidance. Assuming a target value of 10^{-7} collisions per hour, the target value of 10^{-7}/h could be achieved by a failure rate of 10^{-4}/h for each. As a consequence, this category of unmanned aircraft[24] could meet the safety target of e.g. 10^{-7} collisions per hour if its required probability for Class I event is set as severe as for a manned Cessna 172 in Class E airspace under VMC, e.g. 10^{-4}/h.

Example 5: A small unmanned aircraft flies IFR in Class E airspace among General Aviation aircraft under VMC. ATC will separate this unmanned aircraft from other IFR traffic, but since it is VMC, there may be also be VFR traffic from which ATC cannot provide separation. Hence all aircraft have to perform self-separation, and all aircraft have to provide collision avoidance. Unlike Example 4, if this unmanned aircraft cannot be detected by manned aircraft, hence these cannot perform self-separation (if they fly VFR) nor provide collision avoidance. As a consequence, this category of unmanned aircraft[25] can only meet the safety target of e.g. 10^{-7} collisions per hour if its required probability for Class I event is set to meet this target, e.g. 10^{-7}/h, since the manned aircraft cannot contribute to meeting this objective.

[20] Provided it follows ICAO Annex 2, Chapter 4 Visual Flight Rules
[21] Size of crash area is not more than that of a Cessna 172, prolonged flying over population densities up to 10 times the average population density.
[22] Size of crash area is less than 10% of that of a Cessna 172, flying over the average population density.
[23] Size of crash area is not more than 100 times than that of a Cessna 172, flying over the same operational environment as a Cessna 172.
[24] Unmanned aircraft that is large enough to be visually detected by other aircraft for separation, in airspace where ATC does not separate, with only General Aviation.
[25] Unmanned aircraft that is too small to be visually detected by other aircraft for collision avoidance, in airspace where ATC does not separate, with only General Aviation.

Example 6: An unmanned Cessna 172 flies IFR in Class C airspace among General Aviation aircraft under VMC. ATC will separate this unmanned aircraft from all other IFR and VFR traffic, each aircraft has to perform its own collision avoidance. In this airspace there is also Commercial Air Traffic, hence the safety target for a collision in mid-air is e.g. 10^{-9}. Assuming that the separation by ATC contributes a factor of 10^{-3}, then the collision avoidance by both aircraft has to contribute 10^{-6}. If TCAS would improve the collision avoidance by reducing the MAC rate by 10^{-2}, then the CA capability (without TCAS) should achieve 10^{-4} (for both aircraft combined, divided among the aircraft similar to the examples 4 and 5).

As a consequence, this category of unmanned aircraft[26] can only meet the safety target of e.g. 10^{-9} collisions per hour if its required probability for Class I event is set to meet this target, e.g. 10^{-2}/h.

NOTE: *Above figures (such as safety target value of 10^{-7} and 10^{-9} for the MAC rate) are provided for illustration and currently based upon MAC rate statistics (see FAA Sponsored "Sense and Avoid" Workshop Second Caucus Report dated 18 January 2013) and are similar to the values of 5.10^{-7} and 5.10^{-9} used in MIDCAS (see MIDCAS-T-0173 'Working Paper - Collision Avoidance concept and Operational aspects considered in MIDCAS').*

[26] Unmanned aircraft that is large enough to be visually detected by other aircraft for collision avoidance, in airspace where ATC separates, among General Aviation and Commercial Air Transport.

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