AIRCRAFT AIRWORTHINESS CERTIFICATION STANDARDS FOR CIVIL UAVs.

D.R.Haddon, C.J.Whittaker - Civil Aviation Authority, UK

Abstract

The CAA has recognised the need to develop civil standards for Unmanned Aerial Vehicles (UAVs). Accordingly the CAA Directorate of Airspace Policy has published the document "CAP 722 - Unmanned Air Vehicle Operation in UK Airspace - Guidance", (which can be accessed via the CAA website - www.caa.co.uk/docs/33/CAP722.pdf). The document itemises the top-level military and civil regulations which impact upon the operation of UAVs in the UK. One of the items listed within the document is "Civil Certification" of UAVs. This particular aspect is the responsibility of the Design and Production Standards Division, (D&PSD), of the CAA Safety Regulation Group. The purpose of this Paper is to present and explain the current position of D&PSD regarding the appropriate design standards to be applied for the civil certification of the airworthiness of UAVs.

This Paper presents the CAA position that UAVs should be granted permission to fly by qualifying for Certificates of Airworthiness, by demonstration of compliance with defined airworthiness standards comparable to, and derived from, those applied to manned aircraft. The Paper also presents a method for determining, to a first approximation, the level of airworthiness standards which should be applied to any particular design of UAV by reference to the existing codes of airworthiness requirements for manned aircraft.

Authors

D.R Haddon B.Tech(Hons).
Surveyor,
Policy Section,
Aircraft Projects Department,
UK Civil Aviation Authority
Safety Regulation Group.

C.J. Whittaker BSc(Hons), CEng, MRAeS.
Policy Manager,
Policy Section,
Aircraft Projects Department,
UK Civil Aviation Authority
Safety Regulation Group.

1. Introduction

There appears to be a consensus view within the aerospace industry that the time is rapidly approaching when Unmanned Aerial Vehicles (UAVs) will be commonplace and will share airspace with manned aircraft. This vision of integration is already beginning to materialise around the world with the operation of military UAVs outside of restricted areas and into shared airspace. A number of civilian and paramilitary applications are emerging, with many civil operating concepts under development.

In order to be ready to accept applications to certificate civil UAVs, (in respect of design and construction), the UK CAA has undertaken a study of potential routes to airworthiness certification with the objective of providing the industry with further guidance on the airworthiness standards that the CAA will apply to UAVs.

2. Consideration of the regulatory framework for UK civil certification

As stated in the DAP guidance document referenced above, the CAA's starting point for the consideration of the regulation of UAVs is that they should pose no greater risk to persons or property in the air or on the ground than that presented by equivalent manned aircraft. The globally adopted approach to the civil certification of manned aircraft is to apply defined codes of airworthiness requirements to the design of any aircraft. Recognition of compliance with those requirements is given by the granting of a Type Certificate for the approved design and Certificates of Airworthiness to individual aircraft. The codes of requirements used, (such as JAR25), sometimes supplemented by Special Conditions, address all aspects of the design which may affect the airworthiness of the aircraft. e.g. Structural integrity, systems performance and reliability, aircraft performance, aircraft stability and control, etc. It is a common philosophy of these codes of requirements that, as far as is practicable, they avoid any presumption of the purposes for which the aircraft will be used in service.

The CAA is aware that for some military operations an alternative approach of setting an overall safety target for the aircraft within the context of a defined role and operating environment has been used. The possibility of using such an approach for civil certification of UAVs in place of conventional civil certification procedures is discussed in this Paper.

The "Safety Target" method is a top-down approach which focuses on safety critical issues which could affect achievement of the safety target, and allows potential hazards to be addressed by a combination of design and operational requirements. For example, uncertainties over the airworthiness of a UAV may be addressed by restricting operations to defined areas from which 3rd parties are excluded. Claimed advantages of the Safety Target approach are that it facilitates concentration on the key risks and is not constrained by the need to compile and comply with a comprehensive code of requirements covering all aspects of the design.

Such a strategy of identifying and tackling key risks is not a new concept in the certification of civil aircraft. Indeed, paragraph "1309" in most JAA and FAA aircraft airworthiness codes requires an assessment of all aircraft systems essential to safe flight, and justification that the frequency of occurrence of particular failures will be commensurate with the severity of their effects. i.e. The probability of a failure or combination of failures which could cause a significant hazard must be acceptably low. Compliance with "1309" is often justified using Functional Hazard Assessments, System Safety Analyses etc. However, the current codes of civil airworthiness requirements do not permit certification on the basis of such safety assessments alone. The majority of the requirements within the codes specify minimum standards for most features of the design which must be satisfied whatever the probability of occurrence of the particular critical condition. For example, a generic civil requirement is that it must be possible to maintain control of the aircraft with all power units inoperative, irrespective of the probability of failure of all power units.

In the context of a "global" assessment of a complete UAV System, (including consideration of all contributory factors, such as operational role, sphere of operations, and aircraft airworthiness), it is likely that some form of safety target will have to be established. However, the specific issue discussed in this Paper is whether the "airworthiness" contribution to the overall safety case will be to a fixed standard defined by a code of requirements, or will be variable dependent upon the operational restrictions imposed in parallel.

3. **Airworthiness by safety target or code of requirements?**

In assessing the possibility of using a Safety Target approach for the airworthiness of UAVs the CAA has noted that the use of the method by the military is greatly facilitated by the fact that the military UAV operators are all under the direct control of the Government, which has ultimate responsibility for safety, and is also the sole "customer". This direct control of operations is a significant advantage when accepting a safety case which relies upon the restriction of operations to compensate for uncertainties over airworthiness. In the civil environment the CAA is not the ultimate beneficiary of UAV operations and does not have an equivalent governing control over the operators. It is to be expected that in the future there will be occasions when civil UAVs from different operators will be undertaking the same missions simultaneously for competing commercial organisations; the civil regulatory system must be capable of dealing with such scenarios.

Under a Safety Target philosophy constructed on the basis of an assessment of 3rd party risks, the acceptability of the UAV would have a dependency on the frequency and duration of missions. Under such a system, limitations on the frequency and duration of missions may be part of the justification of acceptable airworthiness. The use of such a philosophy could place the CAA in the position of giving permission for one commercial operator to fly his UAVs in preference to a competitor on the basis of an assessment of the relative airworthiness of the competing fleets. The complexity of that task would be compounded by the prospect of the various operators using markedly different philosophies to compile their safety cases. Such a system would be very difficult to administer in the transparently equitable manner required of the CAA.

In contrast, certification of the airworthiness of the aircraft on the basis of defined codes of requirements provides for common standards which are not dependent upon mission frequency and length, and so avoids a direct and contrary dependency between airworthiness and utilisation for commercial gain. Also, the application of defined airworthiness standards to UAVs would build upon past experience and existing knowledge which has delivered for manned aircraft a level of safety for 3rd parties which is acceptable to the general public.

Another aspect of the military system which facilitates the Safety Target approach is that a UAV is usually developed under contract to a specific customer who has tightly defined the intended use of the aircraft. In contrast, civil aircraft developments are normally initiated by the aircraft companies in response to their perception of marketing opportunities. The viability of a civil aircraft project commonly depends upon it being readily adaptable to the diverse specifications of many potential customers.

The certification task involved in switching existing civil aircraft between diverse roles is greatly eased by the basic aircraft design having previously complied with recognised comprehensive codes of airworthiness requirements which were not inter-linked with a specific kind of operation. When an aircraft is modified in service to meet a new role it must be demonstrated that the modified aircraft continues to comply with the certification requirements. In doing so it is usual to confine the new justification of airworthiness to the modification and its effects on the aircraft. It is not normally necessary to re-assess the whole aircraft as reliance can be placed upon the prior certification of the basic aircraft to a defined airworthiness standard. Such an approach reduces greatly the resources that have to be applied to the approval of modifications by both the applicant and the regulator, and so provides a significant cost saving to the applicant. With the safety case approach a complete reassessment of the aircraft and its operating environment may be required for every change of role.

Another matter to consider for civil UAVs is the effect the chosen regulatory system may have on the process of exporting a UAV from one State and importing it into another. By the 1970's most States with civil aircraft manufacturing industries had compiled their own comprehensive codes of airworthiness requirements for civil aircraft. The marked differences between the requirements of the different States became a significant impediment to the transfer of aircraft between the civil registers of the different countries. It was generally necessary to modify the design of aircraft built for export in order to comply with the unique requirements of each customer's National Airworthiness Authority. Over the last 25 years great effort has been expended through the JAA on the harmonization of requirements to eliminate national differences and thereby facilitate the import and export of aircraft between States. If UAVs are certificated to codes of requirements derived from the existing civil aircraft requirements their manufacturers may benefit from the widespread understanding and acceptance of those standards brought about by the harmonization process. Conversely, if we adopt the safety case approach we may be faced with the task of international harmonization of safety case regulations.

It is noteworthy that the conventional approach of applying a code of airworthiness requirements gives the aircraft designer the advantage of knowledge from the outset of the minimum acceptable standards applicable to all aspects of the design. This approach is well understood by the civil aerospace industry and is compatible with their existing infrastructure.

A further aspect which must be considered for UAV certification is where these aircraft will fit into the current legal framework for civil aviation. Adoption of a Safety Target philosophy for UAVs which does not include a code of requirements to impose a minimum airworthiness standard would raise a number of issues.

For a civil aircraft to fly in UK airspace Article 8 of the Air Navigation Order 2000 (ANO) essentially requires that the aircraft has a valid Certificate of Airworthiness. Article 9 of the ANO states, amongst other things, that the CAA will issue a Certificate of Airworthiness when:

"...it is satisfied that the aircraft is fit to fly having regard to:

(a) the design, construction, workmanship and materials of the aircraft......"

It is also pertinent that Section 20 of the Civil Aviation Act 1982 requires the CAA to act on behalf of the Crown to discharge any obligation arising from the Chicago Convention; (the ICAO Convention on International Civil Aviation). The Convention obliges each contracting State to collaborate in the development and application of uniform standards. Annex 8 to the Convention defines the essential standards for Certificates of Airworthiness.

The essential point here is that it is clearly the intent of the Air Navigation Order that, wherever practicable, permissions to fly will be given by the granting of Certificates of Airworthiness on the basis of compliance with acceptable standards in design and manufacture; and, under the Civil Aviation Act, the CAA is obliged to apply standards for such certification that are consistent with Annex 8 of the Chicago Convention. It is of course possible to amend UK legislation if such action is necessary and justifiable. However, the existing civil regulatory system has delivered continually improving safety levels whilst being flexible enough to cope with the relentless evolution and development in aircraft design over the last half-century. Any proposal to amend the UK legislation to allow the established system to be set aside in favour of a Safety Target approach will be hard to justify; especially where the new approach is not consistent with the ICAO Convention.

Following due consideration of the pertinent issues the CAA D&PSD has concluded that the appropriate system for the regulation of the airworthiness of UAVs will be to require compliance with defined codes of requirements and to grant Certificates of Airworthiness to individual UAVs when compliance with those requirements has been shown.

4. Operation without certificates of airworthiness

There is provision in the ANO for "Small Aircraft" to operate without Certificates of Airworthiness. The definition of a Small Aircraft is given in Article 129 of the ANO;

such aircraft are unmanned and the maximum weight is 20kg. A "Small Aircraft" weighing less than 7kg can be flown for aerial work purposes subject to compliance with the provisions of Article 132 and 87 of the ANO. (A "Small Aircraft" over 7kg weight requires a permission from the CAA before it may be flown for aerial work purposes). It is expected that this provision will remain in place.

Article 127 of the ANO gives the CAA powers to exempt any person or aircraft from most Articles of the ANO. A small number of UAVs above 20kg have been allowed to conduct aerial work under such exemptions which permitted flight without a valid Certificate of Airworthiness, subject to a number of conditions. However, the power to exempt from regulations does not release the CAA from its statutory duties. Before granting such exemptions the CAA must be satisfied that the risks to persons and property are acceptable and are properly controlled, and in the absence of a conventional airworthiness approval, the CAA will normally stipulate operational constraints such as limiting the operating height and range and the area to be overflown. The granting of exemptions to allow flight without Certificates of Airworthiness is a short-term measure which will be used on a small scale until the scheme of regulation for civil UAV airworthiness matures. Even when such regulation is in place there may continue to be occasions when the CAA will permit a UAV to operate for commercial purposes without a Certificate of Airworthiness, but it is expected that such permissions will be very few; every application will be subject to assessment in detail and the operation of the aircraft is likely to be severely restricted.

It is well known that the CAA also administers a system of permits to fly which allow flight in UK airspace only and are outside the provisions of the Chicago Convention. In common with Certificates of Airworthiness, permits to fly are granted on the basis of compliance with standards acceptable to the CAA. However, the CAA administers the permit system to facilitate recreational, non-commercial activities only. It is established CAA policy that permits to fly will not be valid for commercial use of the aircraft to which they refer.

5. Developing airworthiness requirements for UAVs

On the basis that most UAVs will require Certificates of Airworthiness, the next task is to explore how airworthiness requirements appropriate to UAVs will be developed and administered.

Under the relevant legislation any new code of requirements should, as far as is practicable, be consistent with ICAO Annex 8, (as most of the existing codes for manned aircraft are). In the context of establishing airworthiness requirements for UAVs it is interesting to note that the Foreword to Annex 8 states that:

> *"the objective of international airworthiness Standards is to define...... the minimum level of airworthiness.. .for the recognition...of certificates of airworthiness... thereby achieving, among other things, protection of other aircraft, third parties and property".*

Consistent with this statement the text of Annex 8 defines requirements for the assurance of the airworthiness of the aircraft, but with few specific provisions for the protection of passengers. The justification for the essential requirements for certificates of airworthiness as defined by ICAO in Annex 8 (and included in the existing airworthiness codes) is that they are necessary for the protection of third parties.

Whilst the Chicago Convention exists for the protection of 3rd parties, aircraft constructors and aviation regulators have also had to ensure, by applying additional standards, that aircraft occupants are adequately protected. Obviously, a regulatory system which protects aircraft occupants by preventing crashes will also protect 3rd parties, consistent with the objectives of the Chicago Convention. The existing airworthiness codes for manned aircraft can therefore be regarded as being derived from a set of essential requirements imposed primarily with the protection of 3rd parties in mind, plus cabin safety requirements aimed specifically at assuring adequate protection for passengers. It follows that a starting point for suitable requirements for UAVs could be reached by taking the existing requirements for manned aircraft and deleting the paragraphs which address the cabin environment and the protection of occupants. This would build upon existing knowledge and evidence that the ICAO-related requirements deliver a level of safety for manned aircraft which the public accepts.

Pursuing such a strategy gives rise immediately to two questions:

1. Can the existing airworthiness codes for manned aircraft be adapted easily to address fully automated or remotely-piloted flight, given the diversity of UAV configurations?

2. To apply the appropriate level of regulation for the different categories of manned aircraft there are a number of airworthiness codes in existence. Their applicability is commonly determined on the basis of the number of occupants to be carried as well as other parameters such as mass, and stalling speed. As the occupancy of every UAV is zero, what method will be used to choose the "root" manned aircraft code upon which the requirements for a particular class of UAV will be based?

In addressing the first question of whether the existing codes can be suitably adapted for UAVs it is noteworthy that the CAA and the other National Airworthiness Authorities have been very successful in adapting the various airworthiness codes for application to novel manned aircraft, often by the addition of "Special Conditions". (The combining of fixed wing and helicopter requirements for the certification of "tilt-rotor" aircraft is an example of such work). Attention is also drawn to the fact that today the majority of commercial flying hours are accumulated under autopilot control.

Except during take-off and the final stages of landing, the modern commercial aircraft is routinely being flown by computers, monitored by human pilots. The systems in the latest generation of commercial aircraft commonly have fault monitoring and diagnostic functions which can cope with many failure conditions without pilot intervention. Automatic landing including flare and ground roll has been commonplace for many years. When automation of the take-off segment of flight also becomes common it may be the norm for airliners to complete their missions without operation of the primary flying controls by a human pilot at any stage.

It is expected that automatic systems for civil aircraft will become ever more capable and demonstrate increasing reliability. As a consequence the severity of the effect of a flight crew becoming incapacitated whilst airborne will tend to diminish. Whilst the remoteness of the pilot/controller of a UAV raises major issues for aircraft operations in terms of air traffic management, compliance with the Rules of the Air etc, it can be seen that the regulatory process for airworthiness certification is already proven to be able to cope with high levels of automation. It follows that the derivation of acceptable standards of airworthiness for UAVs from the existing well-proven certification requirements for manned civil aircraft should not present any insurmountable difficulties; However, successful certification of a product will of course depend upon the ability of each applicant to develop a UAV of suitable design and to submit acceptable evidence of compliance with the applicable standards.

The second question concerns the problem of selecting which of the existing manned aircraft codes to adapt to be the basis of certification for a particular type of UAV. Addressing this issue requires a clear philosophy for the compilation of certification bases.

The development of a new code of requirements is always an iterative process requiring the application of specialist knowledge, experience and judgement together with a process of consultation and discussion. To assist in defining a starting point for such work the CAA has a method for comparing any novel aircraft, manned or unmanned, with the existing fleet and by so doing generate an outline of the appropriate standards to apply by reference to the existing codes. This method is outlined in Appendix 1 to this Paper with examples of how it could be applied to some existing UAVs. It is emphasised that this method is not to be used as the sole criterion for defining appropriate airworthiness standards; its purpose is to give a “first approximation” which can be used as a starting point for the development of a certification basis.

Briefly, the method involves the consideration of two scenarios: i) impact with the surface at a velocity appropriate to an emergency landing under control and, ii) impact at a velocity resulting from loss of control at altitude. The kinetic energy for each case is calculated and then compared with the results of similar calculations as applied to a sample of the existing manned aircraft fleet. Such comparisons give a first indication of the level of airworthiness which must be achieved by the new aircraft expressed in terms of equivalence to an existing code of airworthiness requirements, (such as JAR 23), as applied to existing aircraft.

It should be noted that the codes of airworthiness requirements for manned aircraft typically demand prior certification of the engine(s) and propellers (if fitted). It follows that similar standards will be applied to the propulsion systems of UAVs.

6. Regulation of design, production, and maintenance

In the civil regulatory environment compliance with the appropriate design requirements alone is not sufficient to ensure the validity of a certificate of airworthiness. It must also be demonstrated that each individual aircraft is in conformity with the certificated design and remains airworthy throughout its operational life. Conformity with the approved design is assured by requiring organisations that design and/or build aircraft to hold appropriate organisation approvals granted by their National Airworthiness Authorities. Additionally, replacement parts must be manufactured by approved organisations, and maintenance must be carried out by appropriately licensed engineers. Organisation approvals and personnel licences are granted on the basis of compliance with the appropriate requirements. For example, an organisation engaged in the design of complete aircraft may be approved for the purpose through compliance with JAR 21 Subpart JA. On the basis that UAVs are to be issued with certificates of airworthiness they will be subject to Part III of the ANO, “Airworthiness and Equipment of Aircraft”; i.e. their design, manufacture, and maintenance will be subject to the same requirements that are applied to these activities in respect of manned aircraft. For information, Appendix 2 to this Paper provides a listing of a selection of the current codes of requirements relevant to the design, production, certification and maintenance of aircraft qualifying for Certificates of Airworthiness.

7. Other issues pertinent to the certification of UAVs

7.1 Restrictions on international flight by pilotless aircraft.

A primary purpose of the Chicago Convention is to facilitate international flight. A Certificate of Airworthiness issued to an aircraft under the terms of the Convention is analogous to a passport issued to an individual citizen. Subject to certain restrictions imposed for reasons of national security, Air Traffic Management etc, a Certificate of Airworthiness allows an aircraft to visit or over-fly States other than the State of Registry without prior investigation of the airworthiness of the aircraft by the States being visited or overflown. However, Article 8 of the Convention, (as distinct from Annex 8), negates this privilege for “pilotless aircraft”. Whilst the Chicago Convention obliges ICAO Member States to impose Annex 8 requirements and to issue Certificates of Airworthiness to all aircraft, (no distinction being made between manned and unmanned aircraft), any civil UAV operator who has a need to send his vehicle into the airspace of another State must obtain the prior permission of the government of that State.

7.2 System components remote from the aircraft

For existing manned aircraft the flying controls, flight guidance and flight management systems are subject to regulation to ensure that system failures do not give rise to unacceptable hazards.

These systems are included in the aircraft design standard for certification and their compliance with the design requirements is essential to the validity of the certificate of airworthiness. With UAVs it is probable that at least part of the flight management or flight guidance systems will be remote from the aircraft. Applying to UAVs the same logic of assuring the validity of the certificate of airworthiness as for manned aircraft, it follows that the relevant remote equipment must be considered to be part of the aircraft for the purposes of design, manufacture and maintenance.

On that basis one of the aircraft airworthiness requirements that will be particularly relevant is JAR paragraph ".1309", (mentioned previously in paragraph 2 above). Put simply, this requires justification that all probable failures or combinations of failures of any system will not result in unacceptable consequences. For a UAV the application of ".1309" will entail an analysis of all essential systems including any external components of the system and the links between the external components and the aircraft. This analysis will involve evaluation of the potential consequences of all possible failures and, where the potential consequences are significant, a determination of the probability of the particular failures or combinations of failures. Guidance on the interpretation of paragraph ".1309" can be found in JAR AMJ25.1309 for large aeroplanes, and FAA AC23.1309-1C for Part 23 aircraft.

7.3 Flight termination systems

Many UAVs have Flight Termination Systems (FTS) installed as a means of recovering from system failures. These range from automatic flight guidance systems which navigate the aircraft to a suitable location and complete a normal landing, to devices which bring the aircraft down immediately; e.g. by deployment of a parachute. JAR paragraph ".1309" requires aircraft systems to be designed to assure "continued safe flight and landing", and so FTS's which provide for selection of a suitable location followed by a controlled landing should be acceptable. Conversely, systems which simply bring the aircraft down immediately when a failure occurs, regardless of location, are less likely to be acceptable.

It is noteworthy that parachute recovery systems have been fitted for some time to certain manned civil aircraft, notably microlights. The current CAA policy on such systems is that they may be installed on a "no hazard, no benefit" basis only. It is by compliance with the applicable certification requirements that the appropriate level of airworthiness of an aircraft is achieved. A parachute may be fitted if desired but it is not to be relied upon to prevent an accident. Accordingly, the installation of a parachute system on an aircraft does not provide a justification for accepting non-compliance with any applicable airworthiness requirement. The CAA does not require any evidence that such recovery systems perform their intended function, but is concerned that the fitment of such equipment does not introduce additional hazards to the aircraft. Applicants for the approval of aircraft embodying flight termination systems have to show that the system is protected from inadvertent operation, or that the consequences of inadvertent operation are acceptable.

8. Conclusions

Civil UAVs will be required to qualify for certificates of airworthiness by demonstrating compliance with airworthiness standards derived from those applied to manned civil aircraft. The civil certification will include any system components remote from the aircraft which support or can affect airworthiness.

The primary reasons for adopting this position are:

- Basing the applicable design standards upon existing requirements which have provided a level of safety for the existing fleet which is generally acceptable to the public gives confidence that civil UAVs will present no greater hazard to third parties than manned aircraft.

- The Type Certification of UAVs to standards based upon existing requirements will reduce the re-certification work associated with modifications and should facilitate the importation of aircraft into other States; (because the National Airworthiness Authorities of those States will be familiar with requirements of that form).

- A regulatory system which requires UAVs to comply with defined design standards in order to qualify for certificates of airworthiness is consistent with the obligations placed upon all ICAO Member States, including the UK. Such an approach is also well understood by the civil aerospace industry and is compatible with their existing infrastructure.

- The application of comprehensive airworthiness requirements avoids a dependency upon limiting the frequency and duration of operations and a potential direct conflict between safety and commercial considerations.

As a prerequisite to the granting of a Certificate of Airworthiness to a UAV, the organisation(s) which design and manufacture the aircraft will have to hold appropriate approvals under JAR 21 or equivalent requirements acceptable to the CAA.

APPENDIX 1 - A METHOD FOR SETTING DESIGN STANDARDS FOR NEW KINDS OF AIRCRAFT, INCLUDING UNMANNED AIR VEHICLES.

This Appendix 1 describes a method for obtaining a first outline of the airworthiness standards which should be applied to aircraft of novel design. The method compares the hazard presented by the new aircraft with that of existing conventional aircraft to obtain an indication of the appropriate level of requirements which should be applied. The most significant feature of the proposal is that it relies on a comparison with existing conventional aircraft design requirements which contribute to a currently accepted level of safety, and avoids controversial assumptions about future contributions to that level of safety from operational, environmental or design factors.

1 Comparison criteria

The capability of a vehicle to harm any third parties is broadly proportional to its kinetic energy on impact. For the purposes of the comparison method it is assumed that there are only two kinds of impact; either the impact arises as a result of an attempted emergency landing under control, or it results from complete loss of control. More precisely, the two impact scenarios are defined as:

1. <u>Unpremeditated Descent Scenario</u> - A failure (or a combination of failures) occurs which results in the inability to maintain a safe altitude above the surface. (e.g. loss of power, WAT limits etc).
2. <u>Loss of control scenario</u> - A failure (or a combination of failures) which results in loss of control and may lead to an impact at high velocity.

<u>Unpremeditated Descent Scenario:</u>

For many air vehicles the likelihood of the unpremeditated descent will be dominated by the reliability of the propulsion systems. For the calculation of kinetic energy at impact the mass is the maximum take-off mass and the velocity used is the (engine-off) approach velocity. i.e.

For aeroplanes V = 1.3 X Stalling Speed (Landing configuration, MTOW)
For Rotorcraft V = Scalar value of the auto-rotation velocity vector,
For Airships/Balloons V = The combination of the terminal velocity resulting from the static heaviness, and the probable wind velocity.

<u>Loss of Control Scenario:</u>

For the calculation of kinetic energy at impact for the loss of control case the mass is the maximum take-off mass and the velocity used is the probable terminal velocity. i.e.

For aeroplanes V = 1.4 X Vmo (the maximum operating speed)
For Rotorcraft V = Terminal velocity with rotors stationary.
For Airships/Balloons V = Terminal velocity with the envelope ruptured or

deflated to the extent that no lifting medium remains.

For each scenario the kinetic energy has been calculated for a selection of 28 different civil aircraft; (21 aeroplanes, and 7 rotorcraft). The results are shown in Figures 1 and 2. On each Figure the "applicability region" for each of the existing aeroplane and rotorcraft codes is shown. These regions have been established using practical constraints based upon the sample of the existing fleet, plus any weight and speed limitations specified in the applicability criteria of the codes of airworthiness requirements.

2 Method of comparison

To obtain the indication of the level of requirements appropriate to a novel kind of aircraft the following steps are carried out:

1. Calculate the kinetic energy of the new aircraft for each scenario.

2. Using these values and Figures 1 and 2 separately, determine the appropriate code to be applied with the intent of preventing the occurrence of each scenario. i.e:

   Figure 1 will provide an indication of the standards to be applied to any feature of the design whose failure would affect the ability to maintain safe altitude above the surface.

   Figure 2 will provide an indication of the standards to be applied to any feature of the design whose failure would affect the ability to maintain control, (particularly rate of descent). Clearly, this must include primary structure.

   If it is found that the aircraft fits within the region for more than one code then this would indicate that it may be appropriate to apply a combination of standards. (e.g. JAR-25 with reversions to JAR-23 in some areas, or JAR-23 with Special Conditions taken from JAR-25).

3. Construct a certification basis which addresses the same aspects of the design as the existing codes and to the level indicated by the kinetic energy comparison. Clearly, Special Conditions will need to be considered for any novel features of the design not addressed by the existing codes. However, the extent of such special conditions should be comparable with the general level of airworthiness identified.

Note: In addition, operational requirements may dictate the inclusion of particular design features which may in-turn necessitate the inclusion of additional certification requirements. For example, the Rules of the Air specify that an aircraft operating over a congested area must be able to maintain a safe altitude following the failure of one power unit.

3. Worked examples

3.1 Application to Global Hawk

Global Hawk is a High Altitude Long Endurance (HALE) UAV produced by Northrop Grumman in the USA with a primary role of reconnaissance/surveillance. Global Hawk is powered by a single turbofan engine. Its estimated characteristics are: a gross weight of 25,600lbs (11,600kg), a maximum operating speed (V_{MO}) of 345kts and a stall speed (V_S) of 95kts. Using these parameters gives energy levels of 0.177 (unpremeditated descent scenario) and 3.53 (Loss of control). These are illustrated in Figures 1 & 2 and indicate that JAR-25 standards are applicable throughout.

3.2 Application to Predator

The RQ-1A Predator UAV from General Atomics is a Medium Altitude Long Endurance (MALE) UAV which has seen extensive operational experience within the military. Powered by a single piston-engine, the estimated parameters for Predator are: MTOW of 1,900lbs (855kg), Vmo of 120kts and Vs in the region of 56kts. For the "unpremeditated descent" scenario, this equates to energy levels of 0.0046 (JAR-23 single-engine) and for the "loss of control" scenario 0.024 (JAR-23 single-engine). The certification basis for the Predator would therefore be JAR 23.

3.3 Application to Hunter

Hunter from IAI is a short range UAV which was/is operated by the armies of USA, Israel, Belgium and France. The Hunter comes in both standard and endurance versions and is powered by 2 Motto-Guzzi engines. The two versions of the aircraft have gross weights of 726 kg and 952 kg respectively. The values for each version and each scenario are shown in Figures 1 and 2. Although there is a small overlap with JAR-VLA in one case, it can be seen that the guideline standard is JAR-23 for both versions of the aircraft.

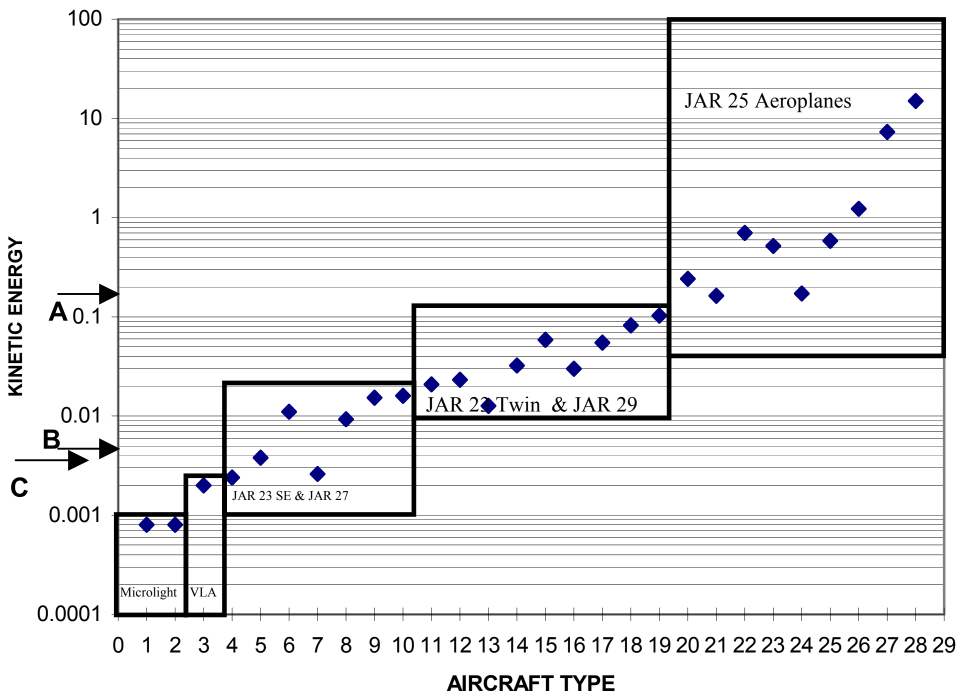
3.4 Application to StratSat

StratSat is an unmanned communications airship intended for long duration missions stationed above population centres. For this aircraft the "unpremeditated descent" analysis indicates that a standard equivalent to JAR-23 as applied to single-engine aeroplanes would be appropriate. This is convenient as the existing UK requirements for airships, BCAR Section Q, provide a standard which is equivalent to JAR-23. The "loss of control descent" analysis indicates that standards equivalent to a combination of JAR-25 and JAR-23 Commuter Category should be applied to reduce the probability of such an event. Thus the basis for civil certification of this aircraft should be BCAR Section Q supplemented as necessary by requirements from JAR-25 and JAR-23 Commuter.

4. Conclusions

A method of comparing novel aircraft with existing manned aircraft is presented together with examples of its application to specific UAV projects. It is appreciated that no simple method can give a complete answer to the definition of the certification bases, and the conventional processes using judgement and debate will still be required. However, the method presented provides a useful tool for anticipating the general level of airworthiness requirements to be set.

FIGURE 1 - UNPREMEDITATED DESCENT SCENARIO



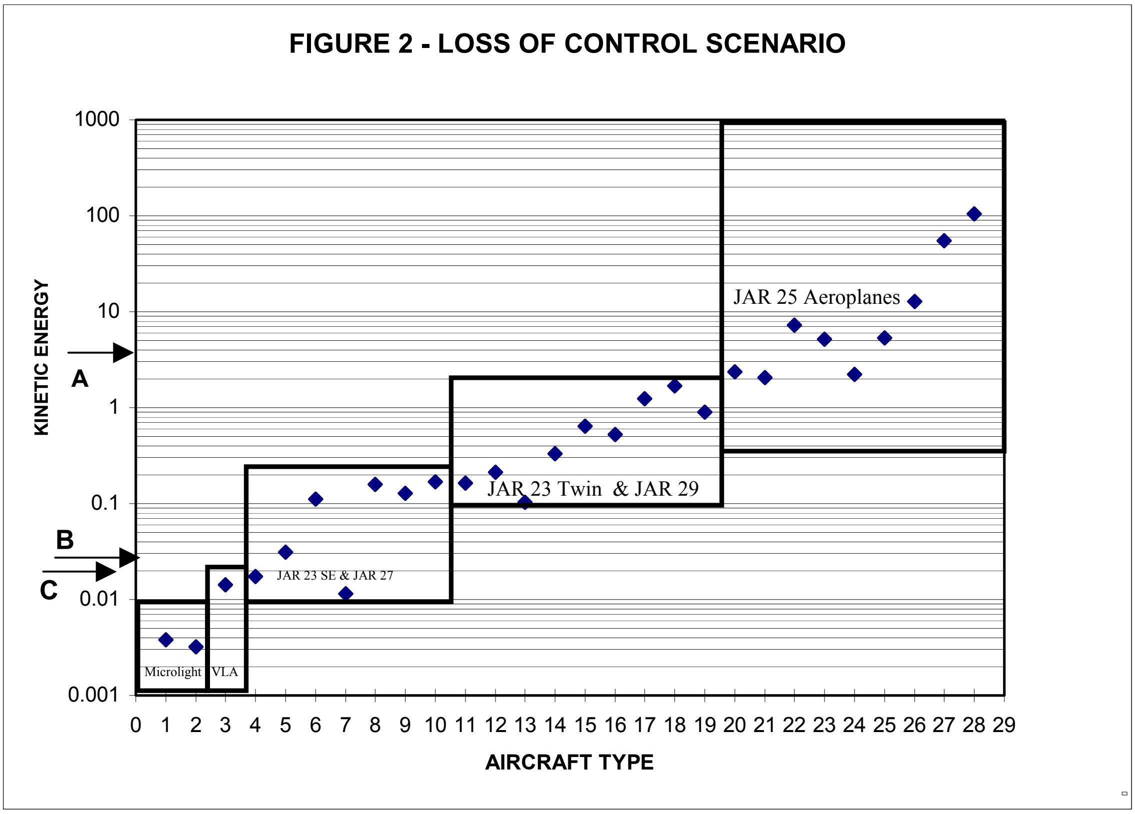
Kinetic Energy (as plotted) = (Mass (kg) X Velocity (kt)^2) / 10^9

Aircraft Key:

1. Flex wing microlight,
2. 3-axis microlight,
3. Piston Single - JAR-VLA
4. Piston Single 2 seat,
5. Piston Single 4 seat,
6. Large Piston Single
7. Helicopter 2 seat
8. Mid-size Helicopter
9. Mid-size Helicopter
10. Mid-size Helicopter
11. Piston twin
12. Piston twin,
13. Piston twin
14. Piston twin
15. Light Corporate Jet
16. Large Helicopter
17. Large Helicopter
18. Large Helicopter
19. Small Twin Turboprop
20. 50 seat Turboprop
21. 50 seat Turboprop
22. 100 seat airliner
23. Corporate Jet
24. Corporate Jet
25. 50 seat airliner
26. Single-aisle Airliner
27. Wide Body Airliner
28. Wide Body Airliner

Example Key: A. Global Hawk, B. Predator & Hunter C. Hunter (Light)

FIGURE 1 - UNPREMEDITATED DESCENT SCENARIO



Kinetic Energy (as plotted) = (Mass (kg) X Velocity (kt)^2) / 10^9

Aircraft Key:

1. Flex wing microlight,
2. 3-axis microlight,
3. Piston Single - JAR-VLA
4. Piston Single 2 seat,
5. Piston Single 4 seat,
6. Large Piston Single
7. Helicopter 2 seat
8. Mid-size Helicopter
9. Mid-size Helicopter
10. Mid-size Helicopter
11. Piston twin
12. Piston twin,
13. Piston twin
14. Piston twin
15. Light Corporate Jet
16. Large Helicopter
17. Large Helicopter
18. Large Helicopter
19. Small Twin Turboprop
20. 50 seat Turboprop
21. 50 seat Turboprop
22. 100 seat airliner
23. Corporate Jet
24. Corporate Jet
25. 50 seat airliner
26. Single-aisle Airliner
27. Wide Body Airliner
28. Wide Body Airliner

Example Key: A. Global Hawk, B. Predator & Hunter C. Hunter (Light)

FIGURE 2 - LOSS OF CONTROL SCENARIO

APPENDIX 2 - LISTING OF RELEVANT CIVIL REQUIREMENTS.

JAR-VLA **Very Light Aeroplanes**

Maximum weight 750 kg; Single piston engine; Stalling speed not exceeding 45kt CAS in the landing configuration; Day-VFR only; Not more than 2 seats.

JAR 22 **Sailplanes and Powered Sailplanes**

Weight (kg) divided by span^2 (m^2) not to exceed 3; Maximum weight 850 kg; Not more than 2 occupants.

JAR 23 **Normal, Utility, Aerobatic and Commuter Category Aeroplanes**

Normal, utility and aerobatic - Maximum weight 5670 kg; If unable to meet minimum rate of climb requirements with the critical engine inoperative the stalling speed in the landing configuration must not exceed 61 kt CAS; Maximum number of occupants 9 + pilot(s).
Commuter Category - Maximum weight 8618 kg; More than one engine; Maximum number of occupants 19 + pilot(s).

JAR 25 **Large Aeroplanes**

Any multi-engine aeroplane with maximum weight in excess of 5700 kg.

JAR 27 **Small Rotorcraft**

Maximum weight 3175 kg; Maximum number of occupants 9 + pilots(s)

JAR 29 **Large Rotorcraft**

Rotorcraft not within JAR 27 applicability

BCAR Section Q **Non-Rigid Airships**

Multi-engine non-rigid airships with envelope volume not exceeding 42,450 m^3

JAR 21 **Certification Procedures**

Procedures for the certification of aircraft and related products and parts including:

JAR 21 Subparts JA and JB:
Requirements for the approval of organisations for the design of aircraft products, parts and appliances.

JAR 21 Subpart G
Requirements for the approval of organisations for the production of aircraft products, parts and appliances.

(Note: Aircraft qualifying for UK Certificates of Airworthiness, and parts for such aircraft must be designed and manufactured by organisations approved for the purpose by the CAA or a non-UK National Airworthiness Authority acceptable to the CAA).

BCAR Section A **Airworthiness Procedures where the CAA has Primary Responsibility for Type Approval of the Product**

CAA National Procedures for the certification of aircraft and related products and parts, including requirements for the approval of design and manufacturing organisations that are not within the JAR 21 system.