

Safety and Certification Considerations of eVTOL Aircraft

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Abstract *There are significant challenges with the design and related certification of eVTOL (Electric Vertical Take-off and Landing) aircraft. Much of this is driven by the novel aspects and diversity of technical solutions of eVTOL, for example the significantly increased levels of system complexity due to the use of distributed and integrated propulsion and advanced flight control systems. It is perceived that the regulation is lagging behind the development of novel technologies and applications which are rapidly advancing to develop eVTOL. As such, it is clear that aircraft manufacturers and regulators need to work more closely, in effect going on 'a journey' together to ensure certification is achievable. In this paper, typical eVTOL aircraft operating scenarios and design architectures are presented as the certification background. These are then considered regarding risks related to eVTOL certification together with their complex technical solutions and subsequent operation. Safety challenges and considerations are discussed for the future certification of eVTOL.*

1 Introduction

1.1 Advanced Air Mobility (AAM)

The definition of AAM, as provided by BAE Systems, is ‘...an air transport system concept that integrates new, transformational aircraft designs and flight technologies into existing and modified airspace operations¹.’ The types of AAM in development nearly all have all-electric or hybrid-electric power systems, (with some exceptions of hydrogen-powered zero emission aircraft) and are either piloted and/or remotely piloted. Currently, designs can be classified as:

- eVTOL – electric vertical take-off & landing e.g. on-demand air taxis;
- eCTOL – electric conventional take off & landing e.g. short-range trips;
- UAVs – unmanned air vehicles e.g. videography, transfer of medical supplies.

This paper will focus on eVTOLs, which typically comprise of all-electric, low noise level, distributed power propulsion and a battery power supply.

The eVTOL world has expanded recently due to the capabilities of modern electric powertrains and Distributed Electric Propulsion (DEP) technologies. Large batteries supply electrical energy to motors which power the Lift Thrust Unit (LTU)².

For an eVTOL to hover, the power required for lift is governed by equation (1):

$$P_h = \frac{W^{1.5}}{\sqrt{2\rho An}} \quad (1)$$

Where P_h is the power in hover, W is the weight of the eVTOL, ρ is the air density, A is the swept area of a rotor (a circle of radius the same as the rotor) and n is the number of propellers producing lift.³ Evidently, the power usage is heavily influenced by the overall weight of the eVTOL, making weight saving an area of significant interest for manufacturers.

Improvements in batteries and the ability to have multiple LTUs has allowed eVTOLs to become viable. Vertical flight is an energy intensive operation which requires batteries capable of delivering a significant amount of power for a period of time to encompass all flight phases. This presents an issue for manufacturers: any increase in weight requires more power and therefore more battery weight. This leads to a trade-off between the payload and the range performance an eVTOL can achieve. This means that advances in the battery power to weight ratio (specific power) will give the biggest increases in performance.

1.2 eVTOL

An ‘eVTOL aircraft is a variety of VTOL aircraft that uses electric power to take off, hover, and land vertically.⁴’ The technology is based on electric propulsion (motors, batteries, electronic controllers) and the need for new aerial vehicles for AAM that are responsive to environmental challenges, such as low-carbon transport emissions, noise levels and societal acceptance.

¹ <https://www.baesystems.com>. Accessed 24 September 2023

² The Lift Thrust Unit (LTU) is any engine that directly contributes to providing lift or thrust and includes its controller, the controlled effector (e.g., rotor, propeller, fan) and any related actuators (e.g. pitch change, tilting, vectoring).

³ From momentum theory. Reducing power requires less weight, more disc area, or more rotors.

⁴ en.wikipedia.org/wiki/EVTOL. Accessed 24 September 2023.

Aircraft are required to produce sufficient lift to maintain height and thrust to move between locations. eVTOLs typically provide lift in hover through the use of LTUs positioned vertically, similar to a helicopter. For lift in cruise, some eVTOLs continue to use these same LTUs, whereas others use a wing to fly more like a conventional aeroplane. Forward thrust is provided by either:

- Tilting the full eVTOL, similar to how small drones move;
- Dedicated propellers fitted to the front or back, in a static configuration, similar to traditional aeroplane;
- Rotating the LTU from providing lift to providing forward thrust.

The simplest eVTOLs are small, light passenger aircraft that utilise electric motors to power the propellers with on board batteries to store energy. More complex configurations have been proposed, which are outlined below.

1.2.1 Types

As eVTOLs are a novel concept, manufacturers have developed a wide array of configurations. These all pose different challenges and are tailored to serve specific market needs and operations. Before considering the challenges for certifying eVTOLs, an appreciation of the types is needed.

This paper will focus on battery powered eVTOLs. The following are examples of generic types:

- Multi-rotor (Figure 1) – examples include designs by Volocopter etc. These often use fixed-pitch LTUs with simpler rotor mechanics required for flight control.

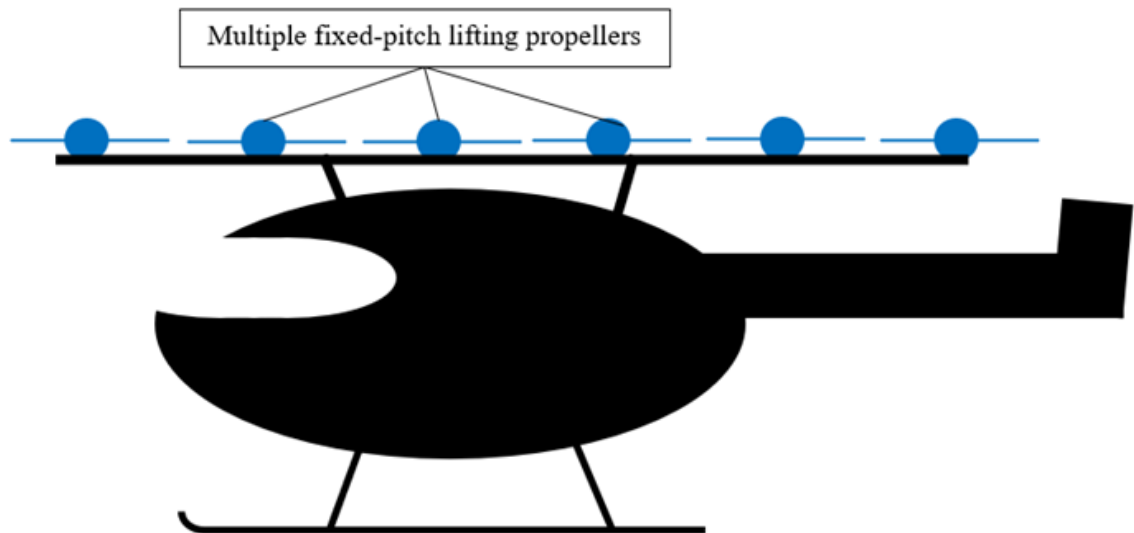


Figure 1: A multi-rotor type eVTOL

The low speed and optimisation for hover of these configurations means they suit operations at short ranges. Volocopter claim that their VoloCity is an air taxi, designed to transport passengers between hubs. This eVTOL type is best suited to operations involving long periods in hover and low-speed flight, such as small hops within a city. This is an Urban Air Mobility (UAM) operating model. The European Union Aviation Safety Agency (EASA) has also suggested the use of eVTOLs

for emergency service applications⁵, with Volocopter working with ADAC Luftrettung for air rescue operational testing⁶.

- Vectored thrust (Figure 2) – examples include designs by Lilium, Vertical Aerospace, etc. These typically include wings, LTUs, and ducts which affect the direction of thrust. The LTUs rotate for vertical take-off and landing and are horizontal in cruise (conventional forward flight). These tilting components are required to reliably and safely complete the transition from lift to the cruise phase of flight.

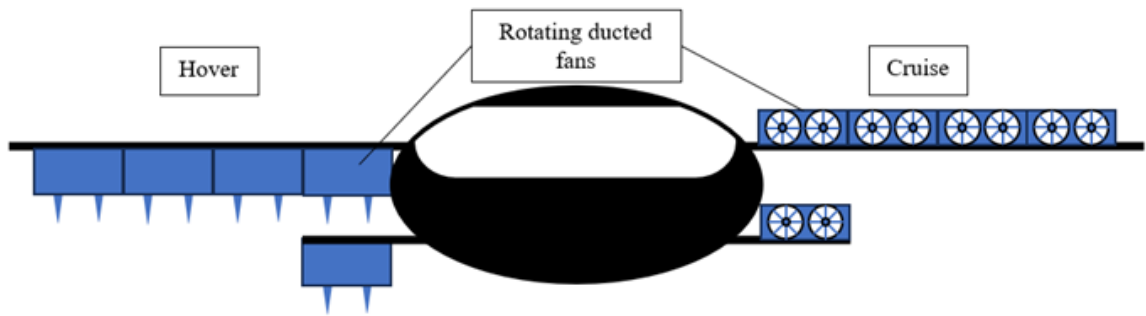


Figure 2: A vectored thrust type eVTOL

The ability to transition from lift provided by LTUs to lift provided by a wing with the LTUs providing thrust allows these vehicles to achieve a greater range than multi-rotors. The LTUs will not be perfectly optimised for hover or cruise. This means there is a compromise, so these designs may be less efficient in hover. They are therefore suitable for medium-distance flights operating between cities. 'Regional air mobility,' flying routes up to 200km between cities, has been proposed for many vectored thrust configurations, such as Lilium⁷.

- Lift & Cruise (Figure 3) – examples include designs by Airbus, WISK, Embraer X etc. These designs often take the properties of fixed wing (longer range) and rotor aircraft (ability to VTOL). Additional mass for different flight modes (as the wing is not used in hover), and some aero-dynamic resistance from the LTUs could reduce the effectiveness and efficiency of these designs.

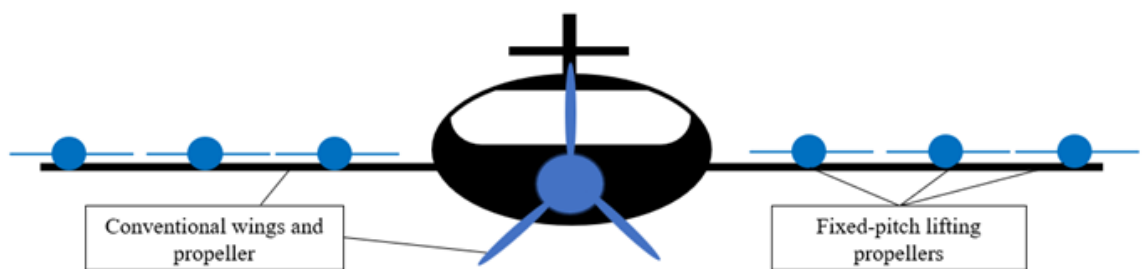


Figure 3: A lift and cruise type eVTOL

⁵ [Emergency Medical Services by Vertical Take-off and Landing aircraft | EASA \(europa.eu\)](https://www.easa.europa.eu/en/emergency-medical-services-by-vertical-take-off-and-landing-aircraft), Accessed 06 October 2023.

⁶ [ADAC Luftrettung to use electric air taxis in winter 2024/25 | AirMed&Rescue \(airmedandrescue.com\)](https://www.airmedandrescue.com/news/adac-luftrettung-to-use-electric-air-taxis-in-winter-2024-25), Accessed 09 October 2023.

⁷ [Lilium Air Mobility - Lilium](https://www.lilium.com/en/air-mobility), Accessed 09 October 2023

These designs are a compromise between multirotors and vectored thrust, using both fixed vertical propellers for lift and traditional propellers for thrust. They combine the simplicity of multirotors with the ability to turn off the LTU by using a wing and/or pusher prop. Lifting rotors are limited and draggy for forward flight,⁸ meaning lift & cruise are potentially faster than a multirotor as the LTU can be turned off. They are also better in hover than a vectored thrust eVTOL, due to the LTU being optimised for hover rather than a compromise. They are also simpler than vectored thrust designs due to having fewer moving parts. However, the vertical LTUs are still an issue in cruise, creating unwanted drag. These designs are suited for both intra- and inter-city flights, though less aerodynamically efficient than a vectored thrust design. The manufacturers believe that simplicity will help with certification. Lift and cruise configurations remain a compromise, however, as the LTUs are still limited in forward flight.

- Hybrid designs (Figure 4) – example include Archer, Vertical Aerospace, Wisk, etc. These designs include some fixed and some tilting LTUs dependent upon when required for which flight phase.

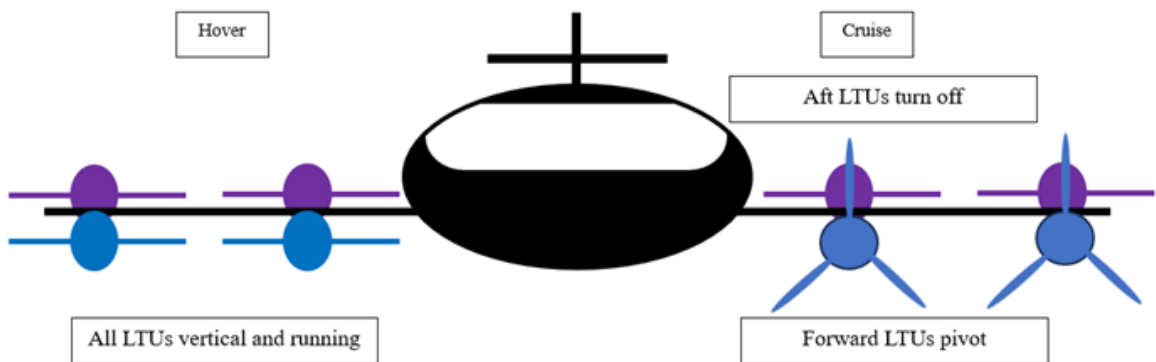


Figure 4: A hybrid type eVTOL

Hybrids remove some of the disadvantages of lift and cruise by having some of the LTUs pivot to provide forward thrust. These will target use between cities and as air taxis, with greater ranges than multirotors. However, since the LTUs that rotate need to be designed for both lift and thrust, they will be less optimised than lift and cruise configurations, which have static propellers designed purely for either lift or cruise. Nevertheless, hybrid configurations will likely have a greater range since some of the LTUs will pivot, reducing the drag they produce in cruise by contributing to thrust.

Some eVTOL manufacturers have stated the desire to be fully autonomous with pilotless vehicles. WISK aviation is intending to be pilotless from day-one, with VoloCopter stating a desire to begin with piloted flights with a view to eventually produce pilotless eVTOLs.

⁸ Due to dissymmetry of lift and retreating blade stall.

2 Certification Process

To certify an aircraft, regulatory organisations such as EASA (European Union Aviation Safety Agency), the FAA (Federal Aviation Administration), and National agencies such as the CAA (Civil Aviation Authority) work with manufacturers to establish a set of standards that ensure the safety and airworthiness of an aircraft during design, manufacture, and modification as well as in service and through operations. The manufacturers then must conduct comprehensive analyses and testing programmes to demonstrate that their aircraft complies with these standards. Examples of such EASA standards include (with FAA equivalents):

- CS 23 – Normal, Utility, Aerobatic and Commuter aeroplanes
- CS 25 – Large Aeroplanes
- CS 27 – Small Rotorcraft⁹
- CS 29 – Large Rotorcraft

There are 4 main steps to achieve Type Certification of an aircraft, always considered in discussion and agreement with the Regulator. These are:

- Technical Familiarisation and Certification Basis
- Establishment of the Certification Programme
- Compliance Demonstration
- Technical Closure and Issue of Approval

The first two phases begin prior to a completed design or a physical aircraft. Various analyses, including computational fluid dynamics, is used extensively to optimise the key performance characteristics of an aircraft, depending on the specific requirements of the project. Presenting the concept and the results of the analysis to the Regulator, the two parties can come to an agreement about the exact nature of the certification process. This will be unique to each aircraft.

Once the certification programme has been agreed, the next stages are Compliance Demonstration, Technical Closure, and Issue of Approval. This is where the manufacturer needs to demonstrate that an aircraft meets the requirements of its type approval.

2.1 Challenges

eVTOLs are a new type of aircraft with technologies and concepts that have not been certified before. Consequently, regulators are collaborating with manufacturers to ensure that certification is achievable. As stated by the CAA 'introducing these new aircraft and their operations involves significant work.¹⁰' This requires regulatory approval of new powerplants, LTUs etc with high levels of integration, which require potentially new ways to integrate within national and international aviation frameworks.

With AAM a novel industry, manufacturers are constantly developing their concepts to achieve the best performing designs. This has led to a huge variety of concepts, which makes defining a set of standards that are suitable for all designs a real challenge.

EASA for example, reviewed more than 150 VTOL project configurations with limited common characteristics, except for a VTOL capability and distributed propulsion. Despite having design

⁹ Helicopters and autogyros.

¹⁰ <https://www.caa.co.uk>. Accessed 22 September 2023.

characteristics of aeroplanes, rotorcraft, or both, in most cases EASA was not able to classify these new vehicles as being either a conventional aeroplane or a rotorcraft.

Applying the certification specifications for aeroplanes or for rotorcraft, depending on whether they are an aeroplane or a rotorcraft, and only adding some modifications would not ensure equal treatment. The conventional regulations as listed earlier in this paper, for example CS-23 and CS-27 have significant differences, especially in terms of system Safety Objectives and operational aspects. The opinion of EASA was that it would not be fair to treat applicants differently based on the regulatory starting point (CS-23 or CS-27) as it would probably favour some configurations, thus preventing potentially innovative concepts to compete on the market. Instead, EASA produced objective based certification requirements, which provide the necessary flexibility to certify innovative state-of-the-art designs and technology, to establish a common set of conditions for the certification of these new concepts.

With an absence of applicable regulations for eVTOL aircraft, this has led to the production of high-level objective requirements (EASA SC-VTOL-01, July 2019) that do not consider whether the eVTOL concept is a rotorcraft or a fixed wing aircraft. This prevents the introduction of any bias into the regulatory process for such technologies, without penalising a design by imposing requirements that may prevent some concepts achieving certification.

SC-VTOL and its associated Means of Compliance (EASA MOC-2 SC-VTOL, June 2022) will require harmonisation with international regulators to enhance safety and to increase efficiency for Industry and Regulators. In addition to SC-VTOL and to aid the transition from conventional propulsion systems/engines to several electric and/or hybrid propulsion system (EHPS) architectures, EASA introduced SC E19. This is a Special Condition focusing on new and emerging technologies introduced by an EHPS. This is not considered mature enough at this stage to have associated means of compliance, as they would need to encompass all possibilities for several EHPS architectures, therefore it is likely that this will need to be discussed with Regulators on an applicant-by-applicant basis.

A difficulty faced in regulating the eVTOL industry is that there is no uniformity in what operations the proposed aircraft will be performing. Urban Air Mobility (UAM) operating models for eVTOLs have suggested using the aircraft as a means of creating air taxis for inner-city environments, whereas Joby has recently delivered an eVTOL to the US Air Force for testing, demonstrating a military interest in eVTOLs¹¹.

Such diverse operations require a diversity of regulations, as the eVTOLs will each be operating in different airspace and under different classifications. EASA has considered this, introducing two categories under SC.VTOL. UAM eVTOLs will need to meet the enhanced classification certification as they fly over congested areas, whereas (non-commercial) VTOLs operating outside of city airspace may only require basic certification.

Following the definition of the general requirements of performance and operation, the certification basis dedicated to specific eVTOL architecture and concept of operations should be determined and agreed. The following section of this paper provides an overview of the safety assessment process, which is an important part of certification as the safety artefacts produced are a Means of Compliance (albeit not the only ones), which will determine whether the risks are acceptable and whether mitigations or redesign is required.

¹¹ [First Joby eVTOL Delivered to the US Air Force \(helis.com\)](https://www.helis.com). Accessed 09 October 2023.

3 Safety Assessment Process

As discussed earlier, eVTOLs are different from conventional aircraft in terms of the use of distributed electric or hybrid propulsion units and advanced flight control systems. Requirements for eVTOLs incorporate objectives and principles of a 'fail-safe' design concept, which considers the effects of failures and combination of failures.

The Safety Assessment Process aims to demonstrate that:

- Systems and components are designed and installed in a way that probabilities of failure conditions are commensurate with their classification; and
- No catastrophic failure condition results from a single failure.

It must be demonstrated that specific criteria have been met/achieved:

- Quantitative and Qualitative.
- Many forms of compliance activities to demonstrate adequate level of assurance, e.g., Analyses, Testing, Safety Assessment, etc dependent upon level of criticality.
- Application of a Safety Assessment Process.

Guidance on how to perform a System Assessment Process is contained within Aerospace Recommended Practice (ARP) 4761A¹², which is closely aligned with ARP 4754A¹³ for guidelines on the development process for civil aircraft/systems. The depth and scope of the analyses are dependent upon system criticality and/or complexity.

The Safety Assessment Process contained with ARP 4761A:

- Is an iterative process from Aircraft level decomposed to Systems and Equipment.
- Includes preliminary assessment steps to ensure that the proposed system architecture(s) can reasonably be expected to meet the safety objectives.
- Is used when identifying the aircraft and system functions and classifying the hazards associated with the Failure Conditions. The applicant will have to substantiate the effects of failure conditions with consideration to operational conditions and events.

The following section provides a summary of the ARPs used for the development and safety assessment of aircraft systems.

3.1 Summary of ARP 4761A and ARP 4754A Safety Assessment Process

SAE International's ARP 4761A provides guidelines for conducting the safety assessment process on civil aircraft, systems, and equipment. ARP 4754A provides guidelines for developing civil aircraft and systems. This section will summarise the process that these two documents contain for safety assessments.

The Safety Assessment Process assesses both the functions of the aircraft and the systems which deliver the aircraft functions. The process begins with a top-down functional assessment of the aircraft to identify requirements, decomposing down into functional and safety assessments of each system and again to an item-level requirements identification during the preliminary design phase. These activities identify the required Development Assurance Levels (DALs), both at a

¹² SAE Aerospace, Aerospace Recommended Practice ARP 4761 Rev. A, (Not yet issued)

¹³ SAE Aerospace, Aerospace Recommended Practice ARP 4754 Rev. A, Issued Nov 1996, Revised Dec 2010

functional and item level. Hardware and software for each system is then designed to these DALs. Following hardware and software design the items, systems, and finally the aircraft are verified against the safety objectives identified during the design. Figure 5 shows the development process for aircraft systems design, from ARP 4761A.

The safety assessment begins in concept development, with a top-down analysis of the aircraft functions to identify failure conditions. This is done through an Aircraft Functional Hazard Assessment (AFHA), which is updated throughout the lifecycle as new functions are identified. The outputs of the AFHA are aircraft failure conditions and severity classifications associated with them, as well as setting safety objectives for each function.

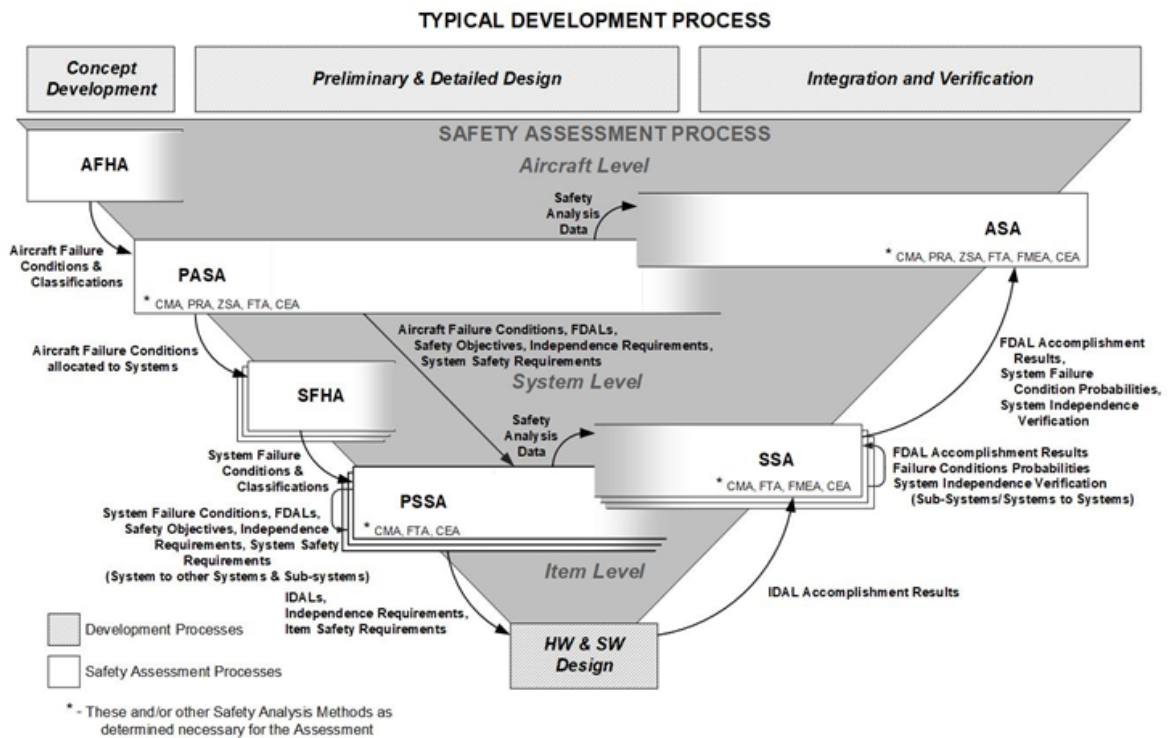


Figure 5: Aircraft System Development Process, from ARP 4761A

The Preliminary Aircraft Safety Assessment (PASA) is started during preliminary design and assesses whether the proposed aircraft architecture can meet the safety objectives set by the AFHA. The PASA considers common cause failures and allocates aircraft failure conditions to individual systems. During this stage, the PASA also identifies the independence requirements needed for individual systems. For eVTOLs there will be a considerable number of interdependent systems, as all systems depend on the electrical system for power. Failure of an electrical bus could be a common cause failure for multiple aircraft functions. The PASA will identify the need to separate eVTOL functions between multiple electrical systems, to prevent any single point failures. Functional Development Assurance Levels (FDALs) are assigned at this stage in the aircraft design. Table 1 shows the FDAL assignment based on the severity of failure conditions.

Table 1: FDAL assignment based on severity of failure conditions

Top-Level Failure Condition Severity Classification	Likelihood (Enhanced Category SC.VTOL)	Top-Level FDAL Assignment
Catastrophic	$\leq 10^{-9}$	FDAL A
Hazardous / Severe Major	$\leq 10^{-7}$	FDAL B
Major	$\leq 10^{-5}$	FDAL C
Minor	$\leq 10^{-3}$	FDAL D
No Safety Effect	-	FDAL E

FDAL assignment depends on both the failure condition severity classification and the degree of independence in the Functional Failure Set (FFS). For Functional DALs, the degree of functional independence must be identified at this stage in the design. Functional independence is achieved by having two distinct functions achieve the same outcome, reducing the likelihood of a common requirement error. Examples of functional independence relating directly to eVTOLs may include:

- Separating the provision of lift between LTUs and a wing
- Two means of directional control in the air: vectored thrust and control surfaces

During the preliminary design phase of systems, a Systems Functional Hazard Assessment (SFHA) classifies the failure conditions of system-level functions, including any aircraft-level functions which may be affected by the system. The SFHA identifies the severity of failure conditions for each system function and is used to set safety objectives for the system’s design. These system failure classifications influence the Preliminary System Safety Assessment (PSSA).

Item Development Assurance Levels (IDAL) assignment takes place at the item development phase of the design. Electronic hardware and software assurance levels come under IDALs. Item independence, the degree to which items are different to minimise the likelihood of a common mode failure, need to be identified for IDAL assignment. One example of item independence is using different operating systems on computers.

FFS with greater independence allow for a lower FDAL and IDAL to be assigned to each individual item as no single failure will lead to the top hazard materialising. An eVTOL with item independence will not require as high a DAL as one without. For example, if one eVTOL uses multiple computers (each with dissimilar software) to control the thrust vectoring it will not require as high a DAL as another eVTOL which uses a single computer, or multiple computers each using the same software. Hardware and software are designed to meet the IDAL targets set from the PSSA.

Some of the prototype eVTOL designs lack functional independence, such as multirotors that have a single means of providing lift with no other means of delivering this function. Similarly, multirotors depend on one system for directional control. All eVTOLs rely on electrical power for all functions, so there is a functional dependence on delivery of power for all other systems. As such, the IDAL and FDAL for the electrical systems will need to be higher than many conventional aeroplanes. Most elements of the Battery Management System (BMS), including the control systems, battery monitoring and delivery buses will need to be developed to DAL-A, but this is dependent upon the architectural design of the BMS.

Following the preliminary design of the aircraft and detailed design of hardware and software, System Safety Assessments (SSAs) and the Aircraft Safety Assessment (ASA) verify through tests that the systems are integrated correctly and meet the required DAL and failure condition probabilities. System independence is verified at this stage. The ASA is a comprehensive evaluation of the completed aircraft to show that the safety objectives are all satisfied.

A key consideration throughout the Safety Assessment Process is common cause failures. Independence between both functions and systems is required to ensure the level of safety is acceptable and to meet regulatory requirements. For example, SC.VTOL states that a catastrophic failure condition must not result from any single point of failure. Independence principles are established for aircraft-level functions at the PASA and systems-level functions at the PSSA stages of the SAP. Common Cause considerations are used to determine whether the proposed architecture can meet the independence principle that is required.

It is necessary to ensure that independence exists, or that the associated risk is acceptable. 'Particular Risk Analyses (PRAs), Zonal Safety Analyses (ZSA) and Common Mode Analyses (CMA) are methods for the evaluation of independence, or the identification of specific dependencies due to a common cause.' (ARP 4761A) These methods can aid the PASA and PSSA stages in generating independence requirements, whether physical installation requirements or functional requirements. In summary, ZSA examines physical zones of an aircraft to address physical installation & interference between systems, PRAs address hazards that are internal or external to the aircraft which could impact more than one system, for example bird strike, and CMA addresses the independence of functions, for example identical systems susceptible to common development errors.

For eVTOLs, there will be a greater degree of interdependency for both systems and aircraft functions when compared to conventional aircraft. As mentioned earlier, weight saving for eVTOLs is of critical importance even when compared to traditional aviation. There is therefore a desire for eVTOLs to have software solutions rather than traditional hardware redundancy. eVTOLs will have a greater degree of interdependency with electrical power, both for systems and functions, which the eVTOL will not have means of generating in-flight. Common cause considerations are therefore essential throughout the design of a new eVTOL to ensure that sufficient independence is in place, or that the associated risk is acceptable.

At the SSA and ASA stage, these analyses are used to verify that the independence requirements have been implemented into the design.

3.2 Challenges

Many eVTOL proposals have no functional or item independence, which reflects the levels of integration and interdependencies. Hence conventional regulations require amendment and innovative application. Mitigations, evidence, and rationale are required to demonstrate what is considered 'good enough' therefore demonstrating the need for manufacturers to work closely together with Regulators. For example, with multirotors provision of lift is from one source (LTUs) which are all driven by the electric system. eVTOL manufacturers must therefore work with the regulators to ensure that the certification requirements are both suitable for eVTOLs and supported with evidence and rationale for why the proposed architecture is sufficiently safe.

Traditional aviation benefits from decades of evolution, improvements and well-established processes used to build compliance arguments. Since eVTOL designs have little of this experience, there will likely be design errors in the early years of development. eVTOLs will need to demonstrate that each of the novel systems are sufficiently robust and safe to achieve certification.

The proposed scale of eVTOL production has interested parties who view them as a possible 'air taxi.' This is further evidenced by the interest that Uber showed in UAM from 2016 with the Uber Elevate white paper (Uber, 2016). This has produced many eVTOL manufacturers which have experience from the automotive industry. The regulators must therefore work with these companies to ensure that eVTOL certification requirements are clearly understood.

It was briefly mentioned earlier in this paper that some eVTOL manufacturers are exploring self-flying eVTOLs. The regulators will need to establish certification specifications for autonomous eVTOLs. However, many suggest that 'autonomy is a long way from reality' (October 2023 Emerging Technologies Forum in Japan).

3.3 General Safety Issues

Designers of eVTOL systems must consider the complexity of control mechanisms and demonstrate that any failures do not prevent continued safe flight and landing (CSFL). Designers must demonstrate that continued safe flight and landing is possible including emergency landings as part of the safety assessment process.

All eVTOLs must consider the risk of fire as a particular risk. Battery fire or explosion may arise due to issues with charging and protection devices, which must be assessed and mitigated in the event of these failures. Thermal battery runaway constrains safe cell temperatures and pressures that must be maintained during charging or discharging conditions (ICAS 2020 0231paper.pdf). Thermal runaway can result in fire and /or explosion, which can spread to adjacent cells. Containment structures may prevent these effects but can add significant weight, hence presenting a challenge of meeting requirements and weight reduction to enable viability of eVTOLs.

In relation to batteries another concern is the amount of energy the batteries can hold and the power delivery. The batteries on an eVTOL are sized based on the required power draw and the energy needed for the expected range. Presently, Li-Ion batteries have a limited range which will be improved as this technology evolves to increase energy and power densities. An additional battery margin is needed in case of a single battery failure or in case of diversion or delay. Aeroplanes and helicopters are required to carry contingency fuel, alternative destination fuel and final reserve fuel. The regulators will need to introduce contingency energies for eVTOLs, to ensure sufficient energy is available for abnormal occurrences.

Another relevant particular risk is bird strike. Bird strikes are significantly more likely at low altitudes, so the likelihood of multiple bird strikes is increased. The Enhanced Category of SC.VTOL requires continued safe flight and landing (CSFL) after an impact. Potential damage includes windshield penetrations, propeller failure, battery fires, and pitot and angle of attack (AOA) sensor damage. Manufacturers will need to understand the possible effects of bird strikes to ensure eVTOLs can still maintain safe flight for credible damage scenarios when considering size/mass of bird, operation altitude and maximum operating speeds.

As mentioned earlier, many eVTOL configurations lack functional independence. All eVTOLs depend on the integration and interdependencies of the flight control system and electrical related system for thrust, lift, and control. All these scenarios require analysis based on safety requirements and evidence to determine an acceptable level of safety commensurate with the eVTOL and its mode of operation.

Currently, eVTOL manufacturers have developed different configurations and there is not yet an agreement on what a certified eVTOL will look like. The eVTOL industry would benefit from sharing knowledge about errors and lessons learned rather than treating all information as proprietary. This would require a cultural shift that would enable progression of development and certification of such technologies. There have been incidents during early prototype testing of some manufacturers. For example, Vertical Aerospace's prototype had an accident during flight testing. Vertical Aerospace has been forthcoming in sharing what happened and released public statements on the chain of events leading to the accident. Transparency on these accidents is necessary from all eVTOL manufacturers to ensure that lessons are shared about the evolution of eVTOL technology, which may in turn aid a more efficient route to certification.

4 Conclusions

In this paper different types of eVTOL aircraft have been identified. An overview of the Certification process and the System Safety Assessment process have been presented, together with identification of some challenges that such technological advancements may introduce and will need to be addressed to achieve a certifiable product.

Adapting the regulatory frameworks to help with the Certification of eVTOLs by incorporating existing regulations together with objective-based requirements is underway. In parallel with this an increased level of cooperation, consistency, and negotiation between eVTOL manufacturers and regulatory authorities is necessary. eVTOLs represent a significant change from traditional aviation, with significantly increased levels of system complexity due to the use of distributed and integrated propulsion and advanced flight control systems.

The key points within this paper are, the increased integration of systems which means that there will be greater emphasis on specific aspects of the system safety assessment process of ARP 4761A in the production of the Preliminary Aircraft Safety Assessment, increased emphasis on common cause considerations, and the verified Aircraft Safety Assessment to reflect the correctness & completeness of the analysis of interdependencies, and on ARP 4754A to aid the verification and validation of the entire Safety Assessment process.

Appendix A Abbreviations

AAM	Advanced Air Mobility
AFHA	Aircraft Functional Hazard Assessment
AOA	Angle of Attack
ARP	Aerospace Recommended Practice
ASA	Aircraft Safety Assessment
BMS	Battery Management System
CAA	Civil Aviation Authority
CMA	Common Mode Analysis
CS	Certification Specification
CSFL	Continued Safe Flight and Landing
DAL	Development Assurance Level
DEP	Distributed Electric Propulsion
EASA	European Union Aviation Safety Agency
EHPS	Electric and/or Hybrid Propulsion System
eVTOL	Electric Vertical Take-off and Landing
FAA	Federal Aviation Authority
FDAL	Functional Development Assurance Level
FFS	Functional Failure Set
IDAL	Item Development Assurance Level
LTU	Lift Thrust Unit
PASA	Preliminary Aircraft Safety Assessment
PRA	Particular Risk Analysis
PSSA	Preliminary System Safety Assessment
SC	Special Condition
SFHA	System Functional Hazard Analysis
SSA	System Safety Assessment
UAM	Urban Air Mobility
UAV	Unmanned Air Vehicles
VTOL	Vertical Take-off and Landing
ZSA	Zonal Safety Analysis

Appendix B References

References

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