

# ED-300

## GUIDANCE ON CONDUCTING AN AIRCRAFT FUNCTIONAL HAZARD ASSESSMENT (AFHA) AND PRELIMINARY AIRCRAFT SAFETY ASSESSMENT (PASA) FOR A VTOL USING A GENERIC EXAMPLE

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## CHAPTER 1

### INTRODUCTION

#### 1.1 PURPOSE

The purpose of this document is to provide Vertical Take Off and Landing (VTOL)-specific complimentary guidance to ED-135/ARP4761A (ref.1), and other guidance related to safety analysis. The goal is to help the applicant to understand how to start the VTOL-AFHA (Aircraft Functional Hazard Assessment) through to the point where the VTOL-PASA (Preliminary Aircraft Safety Assessment) is complete and safety objectives are defined for the applicable VTOL aircraft and systems. This is accomplished by presenting a partial example of a VTOL AFHA and VTOL PASA for a highly integrated system that accomplishes safety-critical functions.

Although the ED-79/ARP4754 (ref.8) Development process applies, this document and example therein focuses mainly upon the Safety Assessment process.

#### 1.2 NOTES REGARDING SOURCES

At the time of writing this document, ED-135/ARP4761A (ref.1) has not been published or formally recognised by EASA. For the AFHA and PASA process, the latest draft of ED-135/ARP4761A (ref.1) has been used as the main point of reference. There is also limited reference to ED-279 (ref.4); however, this document has also not yet been recognised by EASA. Therefore, it is considered as the best approach that is possible today.

As well as including the PASA part of the analysis, it is planned to verify the next version of this document (ED-300A) against the published ED-135 (including correction of referenced section numbers if needed).

#### 1.3 NOTES FOR APPLYING TO A REAL-WORLD DEVELOPMENT PROGRAM

The approach that is applied here is an example of one way to utilise the principles defined in ED-135/ARP4761A (ref.1). A different approach could be adopted, provided that acceptance is received from the certification authority.

The analysis presented in this document is not intended to be complete and it should not be simply copied and pasted without analysis for a real-world application/certification program.

It is strongly recommended that the reader familiarise themselves with the applicable guidance and methods in the latest versions of the above documents before reading and applying the guidance of this document.

#### 1.4 SCOPE

##### 1.4.1 Assessment

The assessment is as generic as possible in order to remain valid and useful for as much of the industry as possible. However, a balance has to be struck because a certain level of detail is required to conduct a sensible analysis. This has meant that certain details of the VTOL aircraft architecture and its operations will be specified in order to allow the analysis to be produced.

##### 1.4.2 Generic VTOL Type

Based on information from the Vertical Flight Society, the generic types of VTOL aircraft can be broken down into the following three types:

- Vectored Thrust (tilt-wing or propeller, same propulsion system for hover and cruise)
- Lift & Cruise (wing but two different propulsion systems for hover and cruise)
- Multicopter

For this first issue of the guidance, a generic example of a vectored-thrust type VTOL aircraft with an Electric / Hybrid Propulsion Systems (EHPS) has been considered. It is

expected that at a later date this document can be expanded to highlight key differences when considering the other two types.

#### 1.4.3 Certification Baseline

The certification baseline defines some key inputs for the VTOL safety analysis. This document is based on the following:

- VTOL will be certified to SC-VTOL-01 Issue 1 (ref.2) (i.e., no remote piloting capability, so including onboard flight crew)
- VTOL aircraft category is “Category Enhanced”
  - Aircraft is intended for operation over congested areas or for Commercial Air Transport operations of passengers.
  - This drives the most stringent requirements. Future versions of this document could highlight the differences for Category Basic.

This means that EASA’s MOC SC-VTOL (ref.3) is also applicable and particular attention is paid to MOC VTOL.2510. A full list of extracted requirements from SC-VTOL and its MOCs that have been deemed key for the complete VTOL Safety Assessment can be found in Appendix A. It should be remembered that MOC VTOL.2510 (ref.3) is the methodology for all safety assessments regardless of whether they are for direct compliance or for the determination of system configuration/conditions to be used for compliance to other requirements in SC-VTOL (ref.2).

The following requirements are also considered for establishing this document:

- SC E-19 EHPS - EHPS.80 (ref.7) about the consideration of the intended aircraft application for the evaluation of the EHPS failure conditions, the assumed aircraft-level devices and procedures, the consequential secondary failures and dormant failures, and multiple failures in the safety analysis to assess all failure conditions that can reasonably be expected to occur.
- SC E-19 EHPS - EHPS 350(e) (ref.7) requiring the EHPS control system in particular not to have any single failures or foreseeable failures that result in hazardous EHPS effect of catastrophic aircraft effect.

More-detailed specific inputs resulting from the above have been defined where required.

#### 1.4.4 Considerations For Future Versions

The next version of this document will include the second part of the scope, i.e., the PASA, as well as checking for correctness with the references that are still draft (e.g., ED-135/ARP4761A (ref.1)).

The following list summarises the key areas identified during the creation of this version of the document that are recommended for future analysis and inclusion in updated versions:

- Same approach extended to other generic types of VTOL, particularly focusing on any key differences.
- Specify differences considering VTOL aircraft Category Basic. These will be limited to different failure severity classification.
- The hover phase which might constitute a significant part of the flight due to operational constraints.
- Further consideration of different VTOL dynamic configurations (e.g., the orientation of rotors, the active rotors).
- Extend analysis to cover other main A/C functions
- Further work on examples of detailed considerations of the Failure Conditions (FC) effects in the AFHA (e.g., crew awareness, operational & environmental conditions).

## 1.5

**DEFINITIONS**

The definitions listed below (as well as the sources quoted where applicable) are taken from MOC VTOL.2510(4) and (7)(b) (ref.3):

**Certified Minimum Performance (CMP):** The set of performance data obtained by considering the effect of single failures and combinations of failures that are not extremely improbable on the nominal performance parameters. The CMP is part of the type data and is associated with limitations on the continued safe flight and landing for Category Enhanced and on the controlled emergency landing for Category Basic, to be established in accordance with VTOL.2510 and VTOL.2620. (Source: MOC VTOL.2000(10)).

**Complexity:** An attribute of functions, systems or items which makes their operation, failure modes or failure effects difficult to comprehend without the aid of analytical methods. (Source: ED-79/ARP4754).

**Continued Safe Flight and Landing:** an aircraft is capable of continued controlled flight and landing at a vertiport, possibly using emergency procedures, without requiring exceptional piloting skill or strength. (Source: VTOL.2000(b)(3)).

(For further details please refer to 3.4.2.2 Additional notes for defining continued safe flight & landing).

**Controlled emergency landing:** A controlled emergency landing should be performed under control, in particular it should be possible to steer the aircraft towards a touchdown area with the remaining lift/thrust units. While the objective is similar to a controlled glide or autorotation, some damage to the aircraft to absorb the impact forces can be accepted. The procedures for a controlled emergency landing should be designed so as to not injure occupants if landing is achieved on a flat solid surface. (Source: MOC VTOL.2000(3)).

**Critical Failure for Performance (CFP):** A failure or combination of failures that results in the maximum degradation for a given flight phase and performance parameter. The set of critical failures for performance is used to establish the Certified Minimum Performance and as part of the safety assessment process of VTOL.2510. (Source: MOC VTOL.2000(10)).

**Derived requirements:** Additional requirements resulting from design or implementation decisions during the development process which are not directly traceable to higher-level requirements and/or specify behaviour beyond that specified by the higher level requirements (Source: adapted from ED-79/ARP4754 and ED-12C/DO-178C).

**Development Assurance:** All of those planned and systematic actions used to substantiate, at an adequate level of confidence, that errors in requirements, design and implementation have been identified and corrected such that the system satisfies the applicable certification basis. (Source: ED-79/ARP4754).

**Development Assurance Level (DAL):** the level of rigor of development assurance tasks necessary to demonstrate compliance with paragraphs VTOL.2500 and VTOL.2510 (Source: adapted from ED-79/ARP4754). The DALs are determined by the system safety assessment process.

Two types of development assurance levels are identified in this document:

- **FDAL:** Development Assurance Levels for aircraft functions and systems
- **IDAL:** Development Assurance Levels for software and electronic hardware items

**Error:** An omission or incorrect action by a flight crew member or maintenance personnel, or a mistake in requirements, design, or implementation.

**NOTE:** *Errors may cause failures, but are not considered to be failures (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24).*

**Event:** An occurrence which has its origin distinct from the aircraft, such as atmospheric conditions (e.g., gusts, temperature variations, icing and lightning strikes), runway conditions, conditions of communication, navigation, and surveillance services, bird-strike, payload fire. The term is not intended to cover sabotage. (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24)

**Extremely Improbable:** so unlikely that they are not anticipated to occur during the entire operational life of all aircraft of one type.

**Extremely Remote:** not anticipated to occur to each aircraft during its total life but which may occur a few times when considering the total operational life of all aircraft of the type.

**Failure:** An occurrence that affects the operation of a component, part, or element such that it can no longer function as intended (this includes both loss of function and malfunction). (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24)

**Failure Condition:** A condition having an effect on the aircraft, its occupants and/or third parties, either direct or consequential, which is caused or contributed to by one or more failures or errors, considering flight phase and relevant adverse operational or environmental conditions, or external events. (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24)

**Latent failure:** A failure is latent until it is made known to the flight crew or maintenance personnel. (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24)

**Malfunction:** Failure of a system, subsystem, unit, or part to operate in the normal or usual manner. The occurrence of a condition whereby the operation is outside specified limits. (Source: AC 23.1309-1E)

**Probable:** anticipated to occur one or more times during the entire operational life of each aircraft.

**Remote:** unlikely to occur to each aircraft during its total life, but which may occur several times when considering the total operational life of a number of aircraft of the type.

**Significant latent failure:** A significant latent failure is one, which would in combination with one or more specific failures, or events result in a Hazardous or Catastrophic Failure Condition. (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24).

**VTOL:** Any vertical take-off and landing aircraft configuration with lift/thrust units used to generate powered lift and control. In this document, the term "VTOL" is used as a noun in the sense of a VTOL aircraft

## 1.6

### ABBREVIATIONS

|        |                                       |
|--------|---------------------------------------|
| A/C    | Aircraft                              |
| AC     | Advisory Circular                     |
| AFHA   | Aircraft Functional Hazard Assessment |
| AFM    | Aircraft Flight Manual                |
| AG     | Aircraft Generic (assumptions)        |
| AMC    | Acceptable Means of Compliance        |
| ARP    | Aerospace Recommended Practice        |
| ATC    | Air Traffic Control                   |
| CAT    | Catastrophic                          |
| CEA    | Cascading Effects Analysis            |
| CMA    | Common Mode Analysis                  |
| CoFFE  | Combined Functional Failure Effects   |
| CONOPS | Concept of Operations                 |
| CRI    | Certification Review Item             |
| CS     | Certification Specification           |
| CSFL   | Continued Safety Flight and Landing   |

|              |                                                  |
|--------------|--------------------------------------------------|
| CTO          | Continued Take-Off                               |
| DAL (F or I) | Development Assurance Level (Functional or Item) |
| EASA         | European Union Aviation Safety Agency            |
| ED           | EUROCAE Document                                 |
| EHPS         | Electric / Hybrid Propulsion System              |
| FC           | Failure Conditions                               |
| FCS          | Flight Control System                            |
| FH           | Flight Hours                                     |
| FHA          | Functional Hazard Assessment                     |
| FTA          | Fault Tree Analysis                              |
| HAZ          | Hazardous                                        |
| ICAO         | International Civil Aviation Organization        |
| LTi          | Less than Intended                               |
| LTS          | Lift / Thrust System                             |
| MF&MSA       | Multifunction and Multisystem Analysis           |
| MOC          | Means of Compliance                              |
| MTBF         | Mean Time Between Failure                        |
| MTI          | More than Intended                               |
| N/A          | Not Applicable                                   |
| NSE          | No Safety Effect                                 |
| OEM          | Original Equipment Manufacturer                  |
| PASA         | Preliminary Aircraft Safety Assessment           |
| PRA          | Particular Risk Analysis                         |
| RPM          | Revolutions per Minutes                          |
| RTO          | Rejected Take Off                                |
| SC           | Special Condition                                |
| TDP          | Take-Off Decision Point                          |
| WG           | Working Group                                    |
| VTOL         | Vertical Take-Off and Landing (Aircraft)         |
| VToss        | Vertical Take-Off Safety Speed                   |
| ZSA          | Zonal Safety Analysis                            |

## 1.7

## REFERENCES

| Document                                                                                                                                                    | Version                                               | Date          |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|---------------|
| 1. ED-135/ARP4761A<br>Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment (see note in section 1.2) | Draft                                                 | Latest        |
| 2. SC-VTOL-01<br>SPECIAL CONDITION Vertical Take-Off and Landing (VTOL) Aircraft                                                                            | Issue 1                                               | 2 July 2019   |
| 3. MOC SC-VTOL<br>Means of Compliance with the Special Condition VTOL                                                                                       | Issue 2                                               | 12 May 2021   |
| 4. ED-279<br>Generic Functional Hazard Assessment (FHA) for UAS/RPAS                                                                                        | -                                                     | October 2020  |
| 5. ED-278A<br>Concept of Operations for VTOL Aircraft<br>Volume 1: General Considerations                                                                   | -                                                     | February 2022 |
| 6. ICAO Glossary of Terms<br><a href="http://www.intlaviationstandards.org">http://www.intlaviationstandards.org</a>                                        | -                                                     | Latest        |
| 7. SC E-19<br>CRI Consultation Paper Special Condition: Electric / Hybrid Propulsion System                                                                 | 1                                                     | 7 April 2021  |
| 8. ED-79/ARP4754A<br>Guidelines for Development of Civil Aircraft and Systems                                                                               | Rev. A<br>ED-79B is expected to be published in 2023. | 2010-12       |

## CHAPTER 2

### DOCUMENT GUIDE

#### 2.1 AFHA PROCESS AND DOCUMENT OVERVIEW

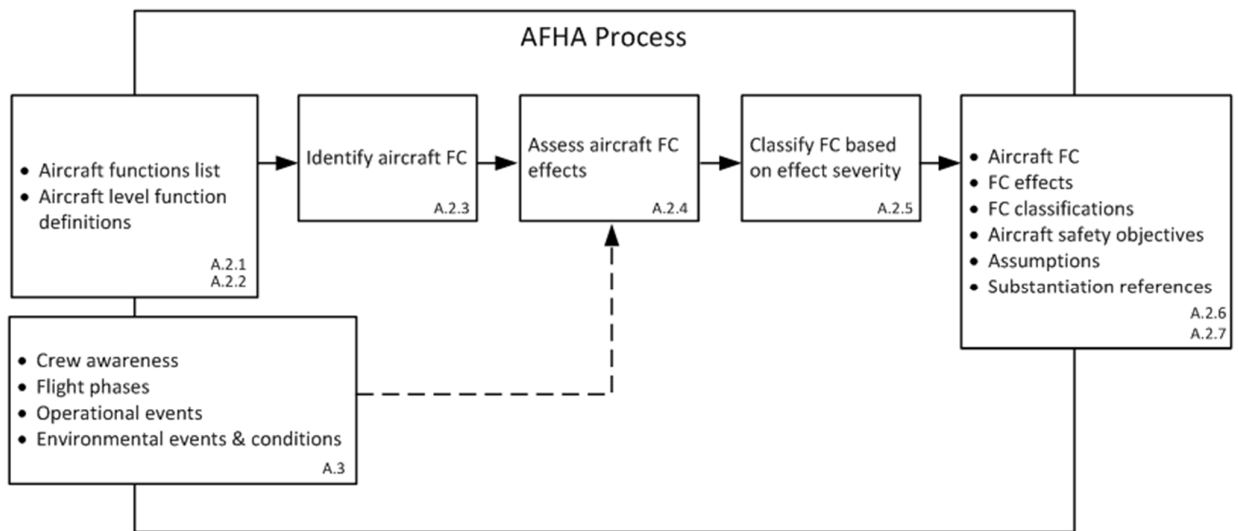
##### 2.1.1 Introduction

This section summarises the process followed for the partial AFHA, together with a quick reference guide to the contents of the AFHA chapter.

##### 2.1.2 Overview of the AFHA Process

The AFHA process is summarised in the following figure, taken from the latest draft version of ED-135/ARP4761A (ref.1), appendix A, Figure A-1. The corresponding sections in the ED-135/ARP4761A (ref.1), appendix A are noted in brackets.

**FIGURE 1: OVERVIEW OF AFHA PROCESS (ED-135/ARP4761A, REF.1)**



The main steps of the AFHA process are:

- Gather AFHA inputs,
- Review and confirm the aircraft level functions are complete,
- Determine the Failure Conditions associated with the aircraft functions,
- Determine the effects of each Failure Condition considering flight phases, operational and environmental conditions and events and crew awareness,
- Assess and classify the severity of each Failure Condition's effects,
- Capture and confirm AFHA assumptions.

##### 2.1.3 AFHA Quick Reference Guide

Each of the following tables provides information about each individual step within the process according to ED-135/ARP4761A (ref.1), Appendix A draft together with how it has been applied in this document.

### 2.1.3.1 Gather Inputs

| ED-135/ARP4761A (A.2.1, A.2.2)                                                                                                                   | Application in this document (3.1)                                                                                                                                                                                                                                                                                                                                                           |
|--------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Gather, review and check for completeness the aircraft level functions and sub-functions, plus any other operational & environmental conditions. | <p>Since no real aircraft exists, aircraft level functions have had to be defined. Only a sample portion of VTOL aircraft functions have been defined in order to provide guidance by way of examples.</p> <p>Aircraft flight phases have been defined, as have other generic assumptions about the aircraft that were needed to conduct the analysis (since there is no real aircraft).</p> |

### 2.1.3.2 Identify, Assess And Classify Aircraft Failure Conditions

| ED-135/ARP4761A (A.2.3, A.2.4, A2.5)                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Application in this document (3.2, 3.3, 3.4)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Identify FCs by considering how functions can fail, including where there is crew awareness or not (if applicable). A FC Identification matrix can be used to help consider all types of FCs (e.g., loss, partial loss and malfunction). Consider combined FCs if functions are related.</p> <p>Examine each FC to determine effects on aircraft, crew and occupants for each flight phase.</p> <p>Classify each FC based on the potential severity of the effects determined.</p> | <p>Functional failures have been identified for the limited set of VTOL aircraft functions defined for this generic example.</p> <p>A more-detailed breakdown of functional failure modes has been defined in order to minimise the chance of missing a functional failure scenario. The applicability of these to each function has then been identified. This is the same approach as ED-279.</p> <p>Each functional failure has been examined from the limited set identified. Only a relevant sub-set of flight phases have been considered since it is a generic example for guidance only.</p> <p>Effects on VTOL aircraft, crew &amp; occupants have been determined. Supporting assumptions and notes have been captured.</p> <p>A certification baseline has been assumed in order to provide other definitions and requirements, such as severities and their safety objectives.</p> <p>Finally, a consolidated set of Aircraft FCs have been defined, grouping together the functional failures with the same effects over different phases.</p> <p>The table format is different to the example in ED-135/ARP4761A however the contents are essentially the same.</p> <p>Combined failures have not been considered since only a limited set of aircraft functions have been analysed.</p> |

### 2.1.3.3 AFHA Assumptions

| ED-135/ARP4761A (A.2.6)                                                                                                                                                                                                                                                                              | Application in this document (3.5)                                                                                                                                                                                                                                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Assumptions that have been made, due to missing information necessary for performing the AFHA, should be captured and formally communicated to the relevant parties.</p> <p>The correctness / validity of each assumption should be confirmed and tracked throughout the development program.</p> | <p>Generic input assumptions supporting the AFHA generally have been captured.</p> <p>The specific assumptions captured during the AFHA have been consolidated, given a unique reference and cross-referenced to the applicable functional failure(s) in the main AFHA table.</p> <p>Since it is a generic example, the assumptions have not been formally validated.</p> |

### 2.1.3.4 AFHA Outputs

| ED-135/ARP4761A (A.2.7)                                                                                                  | Application in this document (3.5)                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Document results of analysis: aircraft functions, detailed AFHA worksheet, assumptions, substantiation references</p> | <p>Within the limited scope of this generic partial example, the outputs have been documented. The formats may differ from the suggestions in ED-135/ARP4761A (ref 1) however, the contents are aligned.</p> <p>No substantiation references are available since it is a generic example.</p> |

### 2.1.3.5 Detailed Considerations For FC Effects

| ED-135/ARP4761A (A.3)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Application in this document (3.3)                                                                                                                                                                                                                                                                                                                                            |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>As part of the AFHA process, the influence of events and parameters on the FCs should be considered. These could intensify or mitigate effects and reduce or improve crew ability.</p> <p>For instance:</p> <ul style="list-style-type: none"> <li>Δ Create separate FCs with &amp; without crew awareness if the effects could be different.</li> <li>Δ Identify and apply consistently the normal flight and ground phases. Consider special phases, if applicable.</li> <li>Δ Consider operational events (e.g., RTO, diversions). If applicable, create new combined FCs when added to an existing FC.</li> <li>Δ Consider worst-case environmental conditions (within the approved aircraft operating envelope) and abnormal environmental events (e.g., icing conditions, cross-winds, iced runway). If applicable, create new combined FCs when added to an existing FC.</li> </ul> | <p>Most detailed considerations are use-case specific so these factors have only been considered to the degree necessary to support the partial set of examples analysed (e.g., the definition of the normal phases).</p> <p>Further detailed considerations in terms of this generic example have been captured as potential scope for future versions of this document.</p> |

### 2.1.3.6 AFHA Substantiation

| ED-135/ARP4761A (A.4)                                                                                                                                               | Application in this document                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Substantiation of the completeness and correctness of the AFHA requires documentation of the rationale and assumptions for all failure effects and classifications. | <p>Since it is a generic example, substantiation of the analysis is not the main focus and is therefore limited. During the production of this document, peer reviews are carried out at several levels (core team, WG and OC) to validate the approach and under-pinning assumptions with engineering judgement.</p> <p>In particular, the correctness of the failure effects (and as a consequence, also the FC classifications) must be conducted for a real-world example. The key assumptions and crew actions have been captured to aid the use of this example in a real-world application.</p> |

## 2.2 PASA PROCESS AND DOCUMENT OVERVIEW

**NOTE:** This section shows the intended plan for the next issue of this document with regards to the partial generic VTOL PASA example.

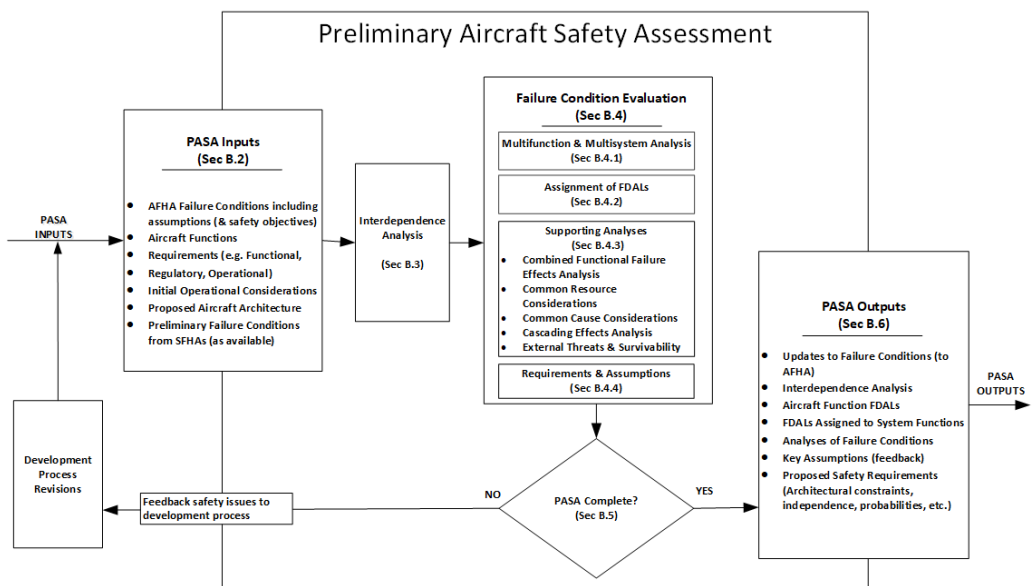
### 2.2.1 Introduction

This section summarises the process to be followed for the partial PASA, together with a quick reference guide to the expected contents of the PASA chapter in the next version of the document.

### 2.2.2 Overview of the PASA Process

The PASA process is summarised in the following figure, taken from the latest draft version of ED-135/ARP4761A (ref.1), Appendix B, FIGURE B-1. The corresponding sections in the ED-135/ARP4761A (ref.1), Appendix B are noted in brackets:

**FIGURE 2: OVERVIEW OF PASA PROCESS (ED-135/ARP4761A, REF.1)**



The main steps of the PASA process are:

- Gather input data
- Perform interdependent analysis

- Evaluate Failure Conditions (FCs) and derive safety requirements
- Document results, including requirements and assumptions.

### 2.2.3 PASA Quick Reference Guide

Each of the following tables provides information about each individual step within the process according to ED-135/ARP4761A (ref.1), Appendix B draft together with how it is planned to apply it in the next version of this document.

#### 2.2.3.1 PASA Inputs

##### Aircraft Functions and Failure Conditions from AFHA

| ED-135/ARP4761A (B.2.1)                                                 | Application in this document (CHAPTER 3) |
|-------------------------------------------------------------------------|------------------------------------------|
| Aircraft functions, failure conditions, safety objectives, assumptions. | Partial VTOL AFHA produced               |

##### Input Requirements

| ED-135/ARP4761A (B.2.2)                                                                                                                                                                                     | Application in this document (next issue)                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Requirements to aid understanding of aircraft and system functions, how they interact in their environment, for context if aircraft architecture description, e.g., Functional, Operational, Certification. | Limited to the functions selected for the VTOL AFHA, the necessary generic requirements have been defined to support the partial scope of the PASA. This includes a generic VTOL architecture, necessary high-level operational aspects and the certification basis of SC-VTOL-01 (ref.2). The latest information from WG-113 will be used as reference material (e.g., WG-113 List of standardisation needs for Hybrid Electric Propulsion, EUR 326-20 / WG113-15) |

##### Initial Operational Considerations

| ED-135/ARP4761A (B.2.3)                                                                                                                                   | Application in this document (next issue)                                                                                                                                                                                                                          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial information such as operational procedure recommendations, training outlines or flight limitations to reflect the intended usage of the aircraft. | Only the necessary generic considerations based on the CONOPS (Concept of operations for VTOL aircraft) ED-278A (ref.5) and ICAO definitions (ref.6) have been defined to support the partial VTOL AFHA and VTOL PASA, including: flight phases, mission duration. |

##### Proposed Aircraft Architecture

| ED-135/ARP4761A (B.2.4)                                                                                                                                                 | Application in this document (next issue)                                                                                                                                                                                                                         |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| The aircraft architecture definition should include the aircraft function allocations to systems, system interactions, common resource systems, and other dependencies. | Based on the defined generic VTOL architecture (VTOL aero configuration and system breakdown structure) and partial VTOL AFHA, the necessary allocation of VTOL functions to systems, their interactions, etc. has been defined to support the partial VTOL PASA. |

##### Failure Conditions from System FHAs

| ED-135/ARP4761A (B.2.5)                                                                             | Application in this document (next issue)                                                                                        |
|-----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| The PASA considers system failure conditions as they contribute to the aircraft failure conditions. | Not covered in this generic document, but should be covered by the VTOL applicant considering aircraft design and specificities. |

### 2.2.3.2 Interdependence Analysis

| ED-135/ARP4761A (B.3)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Application in this document (next issue)                                                                                                                                                                                                                                                          |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Steps:</p> <ul style="list-style-type: none"> <li>• Select an aircraft-level function and associated AFHA Failure Conditions to analyse</li> <li>• List all systems in the aircraft architecture (which may include resource systems)</li> <li>• Identify which systems could contribute to that aircraft-level failure condition</li> <li>• Repeat above steps for each aircraft level function and associated AFHA failure condition.</li> </ul> <p>Particular attention should be paid to those system functions which do not contribute to the aircraft level function but whose functional failures may nonetheless contribute to the aircraft level failure condition.</p> | <p>The steps have been followed and an interdependence table created for the partial scope of this document. It is expected that the table would be developed in more detail in future analysis for a real application, e.g., incorporating system functionality, sub-system information, etc.</p> |

### 2.2.3.3 Failure Condition Evaluation

#### Multifunction and Multisystem Analysis (MF&MSA)

| ED-135/ARP4761A (B.4.1)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Application in this document (next issue)                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| <p>Traditional top-down safety analysis which includes considerations such as failure probability allocations to systems and may capture additional independence principles to be assessed by the common cause methods.</p> <p>The supporting analyses in B.4.3 can help identify to fault tree branches or other relationships in this Multifunction and Multisystem Analysis, particularly where the systems contributing to the aircraft-level failure condition cross traditional functional boundaries.</p> | <p>A preliminary FTA has been conducted for a selection of the VTOL aircraft-level FC.</p> |

#### Assignment of FDALs

| ED-135/ARP4761A (B.4.2)                                                                                                                                                                                                                                                                                               | Application in this document (next issue)                                                                                                                                                                                      |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>FDALs are assigned for each top level aircraft function based on its failure condition classification(s) and for system functions related to the aircraft level failure condition(s). This process may also identify independence principles to support FDAL assignments based on architectural considerations</p> | <p>FDALs have been assigned for each VTOL aircraft-level function considered in the scope of this document and in accordance with the certification baseline assumed (SC-VTOL-01 (ref.2)) and for the category “enhanced”.</p> |

**Combined Functional Failure Effects Analysis (CoFFE)**

| <b>ED-135/ARP4761A (B.4.3.1)</b>                                                                                                                                                  | <b>Application in this document (next issue)</b>                                                                                                                                                                                                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Maps combined failures (whether loss of function or a malfunction) of system functions to assess the impact on the aircraft and helps to model branches in a Fault Tree Analysis. | Depending on outcome from preceding analysis, an example CoFFE table may be produced based on the example in the ED-135/ARP4761A (ref.1) for a VTOL aircraft-level FC defined within the limited scope of this document which has multiple systems contributing. |

**Common Resource Considerations**

| <b>ED-135/ARP4761A (B.4.3.2)</b>                                                                                                                           | <b>Application in this document (next issue)</b>                                                                                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Assesses the effect of the loss of resources or the erroneous outputs of those resources on the systems functions involved in the aircraft-level function. | An example Common Resource Analysis table has been produced based on the example in the ED-135/ARP4761A (ref.1) for a VTOL aircraft-level FC defined within the limited scope of this document which has multiple systems contributing. |

**Aircraft-level Common Mode Analysis Considerations**

| <b>ED-135/ARP4761A (B.4.3.3.1)</b>                                                                                                                                                                                                               | <b>Application in this document (next issue)</b>                                                                                                                                                                                                                                                                                                                                           |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Based on a tailored version of Table M-1 of Appendix M, evaluate the proposed aircraft architecture against the independent principles (e.g., in support of no single failure or DAL) identified in the MF&MS analysis and the FDAL assignments. | <p>CMA is expected to play a significant role in any VTOL development due to the fact that the LTS will consist of multiple, identical sub-systems / components, e.g., propulsors, rotors.</p> <p>Recommendations for key areas where special attention should be paid to CMA for VTOL have been highlighted.</p> <p>Other WG-63 or WG-112 work related to CMA to be cross-referenced.</p> |

**2.2.3.4****Supporting Analysis****Zonal Considerations**

| <b>ED-135/ARP4761A (B.4.3.3.2)</b>                                                                                                      | <b>Application in this document (next issue)</b>                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| Based on Appendix K, determine if the proposed physical installation adequately considers any independence or segregation requirements. | <p>Not addressed in this document.</p> <p>Other WG-112 work related to ZSA to be cross-referenced.</p> |

**Particular Risk Considerations**

| <b>ED-135/ARP4761A (B.4.3.3.3)</b>                                                                                                                             | <b>Application in this document (next issue)</b>                                                       |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| Based on Appendix L and the MF&MS analysis, determine if the proposed physical installation adequately considers any independence or segregation requirements. | <p>Not addressed in this document.</p> <p>Other WG-112 work related to PRs to be cross-referenced.</p> |

**Cascading Effects Analysis**

| <b>ED-135/ARP4761A (B.4.3.4)</b>                                                                                                                                                                                                                                                                                     | <b>Application in this document (next issue)</b>                                                                                                                                                                 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Examines the direct and indirect connections between the systems and evaluates the effects resulting from the propagation of an initiating condition (e.g., a single failure or a combination of failures). The CEA is useful for understanding the behaviors of highly integrated aircraft and system architectures | Not addressed in this document.<br><br>VTOL may bring new challenges here but requires more design detail. Potential areas of interest for highlighting in a real-world analysis will be identified if possible. |

**External Threats and Survivability Considerations**

| <b>ED-135/ARP4761A (B.4.3.5)</b>      | <b>Application in this document (next issue)</b> |
|---------------------------------------|--------------------------------------------------|
| Assessed using PRA and ZSA techniques | Not addressed in this document.                  |

**2.2.3.5****PASA Safety Requirements and Assumptions****Generate Safety Requirements**

| <b>ED-135/ARP4761A (B.4.4.1)</b>                                 | <b>Application in this document (next issue)</b>                                  |
|------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Collate requirements from the analysis, together with rationale. | Requirements and rationale from this generic partial analysis have been captured. |

**PASA Assumptions**

| <b>ED-135/ARP4761A (B.4.4.2)</b>                                | <b>Application in this document (next issue)</b>                                                                                               |
|-----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| Collate assumptions from the analysis, together with rationale. | Assumptions and rationale from this generic partial analysis have been captured. Where applicable, they have also been linked to requirements. |

## CHAPTER 3

### VTOL AFHA

#### NOTES

This generic AFHA has been established with captured assumptions. Therefore, failure condition severity classifications are only examples and may vary according to specific VTOL configuration. Early coordination and acceptance of the AFHA by the certification agency is advised.

Failure condition severity classifications in this generic AFHA are justified by evaluating the functional failure effects and capturing associated assumptions since the validation is typically specific to the TC program. In a real world application, the AFHA should be properly validated to determine failure conditions and effects are correct and complete. Documentation of supporting materials (e.g., analysis/test/simulation report) should be referenced in the AFHA when relevant.

For each failure condition, it should also be determined how the aircraft will satisfy the safety objective. The choice of verification method depends on the severity classification of the failure condition, complexity of the involved systems and the availability of the in-service experience. This has not been captured in this generic AFHA; however, it should be considered in a real world AFHA.

This AFHA is not intended to be complete, rather it has been conducted to provide a limited set of inputs to enable the partial generic VTOL-PASA to be carried out. Not all functions have been considered and certain "special" failure modes have not been considered (e.g., oscillations).

#### 3.1 AFHA INPUTS

The following sub-sections capture the inputs which have been defined in order to conduct the partial generic AFHA. This includes the VTOL aircraft level functions and the flight phases. In addition, the AFHA template adopted for this analysis is also captured in this section.

##### 3.1.1 Aircraft Level Functions

Since this is a generic example, aircraft level functions have been defined as part of this analysis. ED-135/ARP4761A (ref.1) and ED-279 (ref.4) have been considered as the starting points for the function definition, selecting the top level function of "provide aerodynamic performance" which considers lift, speed and orientation. These have been adapted for this VTOL example, resulting in the functional breakdown shown in the following table. The aim of this adaptation is to show one way of defining the functions in order to be as confident as possible that the analysis captures the novel aspects of a VTOL aircraft – it is not the only way. Other VTOL functions are not included in the scope of this document.

**TABLE 3-1: VTOL AIRCRAFT LEVEL FUNCTIONS (PARTIAL)**

| Typical Function | VTOL Function        | Description                                                                                                                                                                                                                                                                                                                                                           |
|------------------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Provide lift     | Provide powered lift | Capability of the aircraft to generate vertical thrust to counter the effect of gravity, e.g., through the rotation of propellers at a certain rpm. This is the predominant method for generating lift in rotorcraft and VTOL configurations at low forward velocities where aerodynamic surfaces are not effective. <i>See additional notes following the table.</i> |

| Typical Function             | VTOL Function             | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------------------------------|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                              | Provide aerodynamic lift  | Capability of the aircraft to divert airflow over its lifting surfaces, thereby generating forces to counter the effect of gravity. This is the predominant method for generating lift in fixed-wing aircraft and VTOL configurations at higher forward velocities in order to take advantage of the aerodynamic efficiency of lifting surfaces.                                                                                                                                                  |
| Control aircraft speed       | Provide horizontal thrust | Capability of the aircraft to generate velocity generally in the horizontal plane (as opposed to providing powered lift) using a propulsion system. Propellers used to generate velocity in configurations like turboprop aircraft are not considered as contributing to powered lift. It is possible that some configurations use tiltable propellers to generate powered lift for take-off and landing, and horizontal velocity during cruise. <i>See additional notes following the table.</i> |
| Control aircraft orientation | Change roll attitude      | Capability of the aircraft to change roll attitude by generating a moment around the roll axis itself or, one or more of the other axes. In aeroplane mode, this may be achieved using a combination of propulsive and aerodynamic capabilities. In rotorcraft mode, this may be achieved using powered lift and propulsive capabilities. <i>See additional notes following the table.</i>                                                                                                        |
|                              | Change yaw attitude       | Capability of the aircraft to change yaw attitude by generating a moment around the yaw axis itself or, one or more of the other axes. In aeroplane mode, this may be achieved using a combination of propulsive and aerodynamic capabilities. In rotorcraft mode, this may be achieved using powered lift and propulsive capabilities. <i>See additional notes following the table.</i>                                                                                                          |
|                              | Change pitch attitude     | Capability of the aircraft to change in pitch attitude by generating a moment around the pitch axis itself or, one or more of the other axes. In aeroplane mode, this may be achieved using a combination of propulsive and aerodynamic capabilities. In rotorcraft mode, this may be achieved using powered lift and propulsive capabilities. <i>See additional notes following the table.</i>                                                                                                   |

#### Additional notes for the roll, yaw and pitch functions

- Failures of the functions „Change roll / pitch / yaw attitude” may arise from the loss of, or degradation in, the ability to generate moments around more than the respective axis itself. This is due to the inherent coupling between the different axes. Moments generated around either of the three axes in the body frame have an impact on the roll, pitch and yaw attitudes.
- The tilt rotor of the vectored thrust configuration may, within a certain range of roll/pitch/yaw attitudes, provide an additional degree of freedom to control the flight path vector. The degree to which this additional degree of freedom is available depends on the individual configuration and the control strategy chosen. For the purpose of this analysis, it is assumed that the effectivity of the tilt rotor is a combination of achieving additional horizontal thrust (in turn coupled with aerodynamic lift) or powered lift, depending on the current configuration (wing-borne / hover), along with a direction change represented by roll/pitch/yaw attitude changes. This allows for the vectored thrust functionality to be considered in the

fault tree analysis during the PASA without having a separate aircraft level function in the AFHA. If a specific configuration allows for change in direction of the vehicle through vectored thrust without significant changes in roll/pitch/yaw attitudes, this should be considered separately as a stand-alone function in the AFHA itself.

### 3.1.2 Flight Phases

Since this is a generic example, aircraft flight phases have been defined as part of this analysis. The following flight phases are based upon both the ICAO (ref.6) definitions and those in ED-279 (ref.4), with alterations to tailor for VTOL-specific operations. Transitions between Rotorcraft and Aeroplane are explicitly defined as sub-phases to ensure they are fully considered within the scope of this analysis.

**TABLE 3-2: VTOL AIRCRAFT FLIGHT PHASES**

| Flight Phase       | Description                                                                                                                  | Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|--------------------|------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Standing           | Prior to pushback or taxi, or after arrival, at the gate, ramp, or parking area, while the aircraft is stationary.           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Taxi               | The aircraft is moving on the aerodrome surface under its own power prior to take-off or after landing.                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Initial Take-off   | From the application of take-off power to the Take-off Decision Point (TDP).                                                 | The TDP will be chosen by the OEM, before the TDP a Rejected Take-off back to the vertiport needs to be possible.<br>After the TDP a continued Take-Off needs to be performed.<br><i>See additional notes after the table.</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Continued Take-off | From the TDP to the first prescribed power reduction, or until reaching the end of the take-off path, whichever comes first. | The TDP will be chosen by the OEM, before the TDP a Rejected Take-off back to the vertiport needs to be possible.<br>After the TDP a continued Take-Off needs to be performed.<br><br>The take-off path extends from the take-off point to a point at which the aircraft is 305 m (1000 ft) above the take-off elevation at the final take-off configuration.<br><b>NOTE:</b> <i>The altitude of 1000 ft is proposed in the development of the take-off flight path as currently used for Category A helicopters. Different take-off heights can be considered if compatible with the departure and en-route structure (ref. EASA MOC SC-VTOL.2115 sect.2, (ref.3)).</i><br><i>See additional notes after the table.</i> |

| Flight Phase                                                                  | Description                                                                                                                                                                                                                                            | Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Transition - Rotorcraft to Aeroplane<br><br>(sub-phase of Continued Take-off) | From operating as a rotorcraft (flight using the lift system, the propulsion system, aerodynamic lift and the control surfaces together) to operating as an aeroplane (flight using the propulsion system, aerodynamic lift and the control surfaces). | Refer to latest EASA MOC for VTOL.2115 and VTOL.2120 for more details.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| En-Route                                                                      | From completion of Continued Take-off, through cruise and controlled descent to the beginning of the landing path.                                                                                                                                     | En-Route includes the following climb (to a cruise altitude), changes in cruise altitude, descent and holding                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Approach                                                                      | From the beginning of the landing path to the landing decision point (LDP).                                                                                                                                                                            | <p>The landing path begins when the aircraft is 305 m (1000 ft) above the take-off elevation at the final take-off configuration.</p> <p><b>NOTE:</b> <i>The altitude of 1000 ft is proposed in the development of the take-off flight path as currently used for Category A helicopters. Different take-off heights can be considered if compatible with the departure and en-route structure (ref. EASA MOC SC-VTOL.2130, Fig.1 (ref.3)).</i></p> <p>In the event of a Balked Landing, Missed Approach / Go-Around, the VTOL needs to return to the Continued Take-off phase</p> |
| Transition - Aeroplane to Rotorcraft<br><br>(sub-phase of Approach)           | From operating as an aeroplane (flight using the propulsion system, aerodynamic lift and the control surfaces) to operating as a rotorcraft (flight using the lift system, the propulsion system, aerodynamic lift and the control surfaces together). | Refer to latest EASA MOC for VTOL.2130 for more details.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Landing                                                                       | From the landing decision point (LDP) through rotorcraft flare until touchdown on the vertiport.                                                                                                                                                       | In case of a critical failure for performance the touchdown will still be performed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

**NOTES:** *Note that some specific phases such as pre-flight operations, controlled emergency landing, hover, or abnormal operation (e.g., go around, rejected take-off) have not been considered in the analysis. These and others could be defined in a real-world application and the flight phase definitions should be reviewed for applicability.*

### Additional notes for Take-Off Trajectory

It is worth noting the following from MOC SC-VTOL.2115 (ref.3) regarding Take-off performance:

The applicant may choose to have a pure vertical or a backup (rearward) take-off trajectory.

Configuration changes requiring action by the crew are allowed only after the aircraft reaches VTOSS.

(g) The aircraft configuration (e.g., tilt wings/thrust units, flaps, gear) and power settings (contingency/take-off and maximum continuous power) may automatically change along the take-off path. Configuration changes requiring action by the crew are allowed only after the aircraft reaches VTOSS.

### 3.1.3

### Flight Phases and Function Applicability

The following table summarises the applicability of the functions during each phase. This knowledge of the aircraft and its operations at this early stage supports a more effective analysis.

**TABLE 3-3: FLIGHT PHASES & FUNCTION APPLICABILITY**

| Flight Phase                                                                                 | Relevant Function(s)<br>(e.g., Engines/Rotors position)                                        | Relevant Function(s)<br>(e.g., VTOL Attitude Control)                                                    |
|----------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| Standing                                                                                     | Prepared for Powered lift<br>(e.g., Tilted downwards<br>(vertical position))                   | N/A                                                                                                      |
| Taxi                                                                                         | Horizontal thrust<br>(e.g., Horizontally<br>aligned)                                           | N/A                                                                                                      |
| Initial Take-off                                                                             | Powered lift<br>(e.g., Tilted downwards<br>(vertical position))                                | Powered lift, Pitch/Roll/Yaw<br>control<br>(e.g., Rotors only)                                           |
| Continued Take-off<br>(before transition)                                                    | Powered lift<br>(e.g., Tilted downwards<br>(vertical position))                                | Powered lift, Pitch/Roll/Yaw<br>control<br>(e.g., Rotors only)                                           |
| Transition -<br>Rotorcraft to<br>Aeroplane<br>( <i>sub-phase of<br/>Continued Take-off</i> ) | Powered lift and<br>Horizontal thrust<br>(e.g., Transition vertical<br>to horizontal position) | Powered and Aerodynamic lift,<br>Pitch/Roll/Yaw control<br>(e.g., Rotors and Flight control<br>surfaces) |
| Continued Take-off<br>(after transition)                                                     | Horizontal thrust<br>(e.g., Horizontally<br>aligned)                                           | Aerodynamic lift,<br>Pitch/Roll/Yaw control<br>(e.g., Flight control surfaces<br>only)                   |
| En-Route                                                                                     | Horizontal thrust<br>(e.g., Horizontally<br>aligned)                                           | Aerodynamic lift,<br>Pitch/Roll/Yaw control<br>(e.g., Flight control surfaces<br>only)                   |
| Approach (before<br>transition)                                                              | Horizontal thrust<br>(e.g., Horizontally<br>aligned)                                           | Aerodynamic lift,<br>Pitch/Roll/Yaw control<br>(e.g., Flight control surfaces<br>only)                   |
| Transition -<br>Aeroplane to<br>Rotorcraft<br>( <i>sub-phase of<br/>Approach</i> )           | Horizontal thrust and<br>Powered lift<br>(e.g., Transition vertical<br>to horizontal position) | Aerodynamic and Powered lift,<br>Pitch/Roll/Yaw control<br>(e.g., Rotors and Flight control<br>surfaces) |

| Flight Phase                | Relevant Function(s)<br>(e.g., Engines/Rotors position)      | Relevant Function(s)<br>(e.g., VTOL Attitude Control)       |
|-----------------------------|--------------------------------------------------------------|-------------------------------------------------------------|
| Approach (after transition) | Powered lift<br>(e.g., Tilted downwards (vertical position)) | Powered lift, Pitch/Roll/Yaw control<br>(e.g., Rotors only) |
| Landing                     | Powered lift<br>(e.g., Tilted downwards (vertical position)) | Powered lift, Pitch/Roll/Yaw control<br>(e.g., Rotors only) |

### 3.1.4 AFHA Template

As an input to the analysis, an AFHA template has been defined for the VTOL-AFHA and is shown in the following table, together with a key to the contents.

**TABLE 3-4: VTOL-AFHA TABLE TEMPLATE**

| ID | VTOL Function | Flight Phase | Failure Mode | Functional Failure | Functional Failure Effects |                  | Severity Class. | Notes / Assumptions | FC ref. |
|----|---------------|--------------|--------------|--------------------|----------------------------|------------------|-----------------|---------------------|---------|
|    |               |              |              |                    | VTOL Aircraft              | Crew / Occupants |                 |                     |         |
| 1  | 2             | 3            | 4            | 5                  | 6                          | 7                | 8               | 9                   | 10      |

1. This column is used to provide an identification number, for ease of reference and tracking.
2. Name of VTOL function under analysis.
3. Name of flight phase under consideration.
4. Generic functional failure mode.
5. Functional failure based on columns 2 and 4.
6. Concise summary of worst-case credible effects to the VTOL aircraft due to the functional failure in the phase specified.
7. Concise summary of worst-case credible effects to the crew or occupants due to the functional failure in the phase specified. Note that be consideration of CSFL, third parties (i.e., ground population or other airspace users) are also covered.
8. FC classification based on severity.
9. Any additional notes and/or assumptions considered pertinent to that line of analysis.
10. Cross-reference to the FC identification from a consolidation of the table.

## 3.2 IDENTIFY AIRCRAFT FAILURE CONDITIONS

In this section, the Failure Conditions are developed.

### 3.2.1 Method

The ED-135/ARP4761A suggests that a Failure Condition Identification Matrix *may* be used. In this approach, a matrix has been used, similar to that used in ED-279 (ref.4).

#### 3.2.1.1 Generic Functional Failure Modes

Similar to the approach in ED-279 (ref.4), the two basic functional failure considerations – Loss of Function and Malfunction – are broken down in a manner suitable for the aircraft type. See the table below.

**TABLE 3-5: VTOL FUNCTIONAL FAILURE MODES**

| Functional Failure Mode |            | Description                                                       |
|-------------------------|------------|-------------------------------------------------------------------|
| Basic                   | Specific   |                                                                   |
| Loss                    | Total Loss | Complete loss of the ability to perform a function, when required |

| Functional Failure Mode |                                   | Description                                                                                                                                     |
|-------------------------|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| Basic                   | Specific                          |                                                                                                                                                 |
|                         | Partial Loss                      | Partial loss of the ability to perform a function, when required. This is usually covered by total loss as a worst-case, or less than intended. |
| Malfunction             | More Than Intended                | Function does not perform as expected - more than required                                                                                      |
|                         | Less Than Intended                | Function does not perform as expected - less than required                                                                                      |
|                         | Inadvertent Activation / Spurious | Provision of function when not required (i.e., without the intentional demand from the pilot or outside its intended activation conditions)     |
|                         | Late                              | Provision of function later than required                                                                                                       |
|                         | Early                             | Provision of function earlier than required. This is typically covered by inadvertent scenarios.                                                |
|                         | Inability to Stop                 | Inability to stop function. This is typically covered by more than intended / erroneous scenarios.                                              |
|                         | Inability to Start                | Inability to start function. This is typically covered by loss scenarios.                                                                       |

Note that erroneous is considered as corrupted or wrong information / value. This is covered by the above specific functional failure modes under malfunction. For example, failure modes such as more than intended and less than intended can be considered as types of erroneous behaviour.

Note that asymmetry (along vertical axis of VTOL) has been considered in the AFHA for functions related to lift and thrust where deemed relevant and as examples (e.g., because of different potential effects and/or severity when compared to symmetrical failures).

### 3.2.1.2 Preliminary Applicability of Functional Failure Modes to Functions

In this section, preliminary determinations of the applicability of each of functional failure mode to each function is determined. This approach helps to eliminate AFHA line items that do not apply and to eliminate duplicate line items.

Notice that functional failure modes marked with an “x” are analyzed. The others are not analysed because they are the same as another stated mode(s) or are not applicable.

It is emphasised that this list may not be complete, and the user of these guidelines may identify other functional failure modes during the real-world application.