AC UAS-2(0)
1 August 2018

Advisory Circular

ASSESSMENT METHODOLOGY FOR BEYOND VISUAL LINE OF SIGHT (BVLOS) OPERATIONS FOR UNMANNED AIRCRAFT

1. **GENERAL.** Pursuant to paragraph 88B of the Air Navigation Order, the Director-General of Civil Aviation (DGCA) may, from time to time, issue advisory circulars (ACs) on any aspect of safety in civil aviation. This AC contains information about standards, practices and procedures acceptable to CAAS. The revision number of the AC is indicated in parenthesis in the suffix of the AC number.

2. **PURPOSE.** This AC provides an overview of CAAS' assessment methodology for Beyond Visual Line of Sight (BVLOS) operations for Unmanned Aircraft (UA) in Singapore. BVLOS operations may be approved as part of the grant of an Operator Permit and Activity Permit.

3. **APPLICABILITY.** This AC applies to a person intending to conduct BVLOS operations using UA.

4. **CANCELLATION.** This AC is the first on the subject.

5. **EFFECTIVE DATE.** This AC is effective from 1 August 2018.

6. **REFERENCES.** The following materials were referred to for the development of this AC:
   - Air Navigation Act (ANA)
   - Air Navigation Order (ANO)
   - Advisory Circular (AC) UAS-1
   - International Civil Aviation Organisation (ICAO) Document 10019
   - American Society for Testing Materials (ASTM) Standards

- Standardisation Agreement (STANAG) 4702/ 4703/ 4671

- Joint Authorities for Rulemaking on Unmanned Systems (JARUS) Recommendations for Certification Specification for Light Unmanned Aeroplane Systems (CS-LUAS)

7. INTRODUCTION.

7.1 The ability to employ UA beyond visual line of sight will greatly enhance the utility and flexibility in UA operations. However, in BVLOS, the operator may not be able to ascertain the relative position of the UA to persons, vehicle, aircraft or property. This limitation brings about additional risks, in particular, the operator's ability to take collision avoidance action during UA operations.

7.2 To enable beneficial use of UA, CAAS has formulated a set of requirements in BVLOS operations. These requirements use risk-based approach to calibrate the range of BVLOS operations while mitigating the risks involved.

8. DEFINITIONS.

Unless the context otherwise requires, the following terms have the meanings indicated as below:

(a) **Beyond Visual Line of Sight (BVLOS)** means operation of a UA where the UA Pilot is either unable to maintain direct, unaided visual contact of the UA so as to monitor its flight path in relation to other aircraft, persons, vessels, vehicles and structures for the purpose of avoiding collision; or if the UA is more than 400m away from the line of sight of the UA Pilot, whichever is nearer.

(b) **Detect and Avoid (DAA)** means the capability to see, sense or detect conflicting traffic or other hazards, and take appropriate action.

(c) **Failure Condition in a UAS** means a condition having an effect on the UAS, 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. The severities of the failure conditions are as follows.

Catastrophic. Failure would prevent continued safe flight and landing resulting in:

(1) One or more fatalities or serious injury to persons or major property damage external to the UAS; or

(2) Uncontrolled loss of aircraft.

Hazardous. Failure would reduce the capability of the UAS or the ability of the UAS crew to cope with adverse operating conditions to the extent it would result in at least one of the following:

(1) Physical distress to persons, including injuries, or property damage external to the UAS; or

(2) A large reduction in safety margins or functional capabilities; or

(3) Higher workload such that the UAS crew cannot be relied upon to perform their tasks accurately or completely.

Major. Failure would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be:

(1) Potential of physical discomfort to persons or minor property damage external to UAS.

(2) A significant reduction in safety margin or functional capabilities.

(3) A significant increase in crew workload or in conditions impairing crew efficiency.

Minor. Failure would not significantly reduce the aircraft safety. Failure would also involve crew actions but it should be well within their capabilities. It may include slight reduction in safety margin or functional capabilities and a slight increase in crew workload (e.g. Routine flight plan change).

No Effect. Failure would have no effect on safety. (E.g. Failure conditions that only affect the operational capability of the aircraft.)

(d) **Flight Control System** includes sensors, actuators, computers and all other elements of the UAS necessary to control the altitude, speed and trajectory of the UA.

(e) **Flight Critical System** means a system, the failure of which could have a catastrophic effect on the UAS and/or affects the UAS ability to sustain flight.

Note: Examples of flight critical system will include the flight control system, propulsion system and flight termination system.

(f) **Involved Person** means a person, as identified by the Operator, who can reasonably be expected to follow directions and safety precautions given by the Operator or UA Pilot(s), in order to avoid unplanned interactions with the UA.

In principle, in order to be considered an ‘involved person’, one should:

(1) Broadly understand the risks involved in that UAS operation; and

(2) Be able to understand and carry out safeguards during that UAS operation, as introduced by the site manager, Operator and UA Pilot, to ensure safety is maintained during operations.

Uninvolved Person means anyone who is not an Involved Person.

Note: Spectators or other persons gathered for sporting activities or other mass public events (e.g. National Day Parade or the F1 race) that do not occur for the purpose of the UAS operation are generally considered to be ‘uninvolved persons’.

An example: When filming with a UAS at a large-scale music festival or public event such as the Chingay or National Day Parade, it is not sufficient for the audience or anyone present to be informed of the UAS filming through any of the following means: (1) A public address system, (2) A statement on the ticket (3) In advance by email or text message. These types of communication channels do not satisfy the points above. In order to be considered an involved person, the person should be made aware of the possible risk(s) involved and is able to carry out safeguards in place, to ensure safety during UA operations.

(g) **Operator*** has the same meaning as in the Air Navigation Act.

Note: An operator could refer to an organization or an individual. Guidance on the roles and responsibilities of the Operator is as listed in Appendix 2.

(h) **Non-Segregated Environment** means an environment where manned and unmanned aircraft share the same airspace.

(i) **Unmanned Aircraft (UA)** has the same meaning as in the Air Navigation Act.

(j) **Unmanned Aircraft System (UAS)** has the same meaning as in the Air Navigation Act.

9. ASSESSMENT METHODOLOGY FOR BVLOS OPERATIONS.

9.1 In assessing an application to conduct BVLOS operations, CAAS uses a set of requirements that commensurate with the associated risks of the proposed BVLOS operations. The assessment methodology describes the intended scope of operations and categorise these operations into Low, Medium or High risk. The stringency of the requirements commensurate with the risk categories. Figure 1 below provides an overview of the assessment methodology.

<table>
<tr><th rowspan="2">Risk category</th><th rowspan="2">Intended scope of BVLOS Operations</th><th colspan="4">Requirement (Requirement Code)</th></tr>
<tr><th>Basic</th><th>Level 1</th><th>Level 2</th><th>Level 3</th></tr>
<tr><td>LOW</td><td>• No overflying uninvolved persons
• Operate away from people and in an area where it is reasonably expected that no uninvolved person will be present</td><td rowspan="3">• General (BG)
• Operational (BO)
• Software (BW)
• Others (BT)</td><td rowspan="3">• Failure Management (LF)
• Navigation (LN)
• Communication (LC)
• Detect and Avoid (LD)</td><td></td><td></td></tr>
<tr><td>MEDIUM</td><td>• Flying in close proximity to uninvolved persons.
• Flying over uninvolved persons, with flight duration not exceeding 30% of the overall flight.</td><td rowspan="2">• General (MG)
• Structural (MS)
• Software (MW)
• Navigation (MN)
• Communication (MC)
• Detect and Avoid (MD)
• Propulsion (MP)</td><td></td></tr>
<tr><td>HIGH</td><td>• Flying over uninvolved persons
• High risk and complex operations</td><td>• General (HG)
• Software (HW)
• Navigation (HN)
• Detect and Avoid (HD)</td></tr>
</table>

Figure 1: Overview of Assessment Methodology for BVLOS Operations

<u>Risk category</u>

9.2 In identifying risk category of an intended BVLOS operations, the Operator should assess the severity and probability of two main risks in that operation:

(a) Air risk, in the form of collision risk, air proximity, accidents/incidents with manned and unmanned aircraft; and

(b) Ground risk, in the form of accidents/incidents involving persons and property on the ground.

9.3 In general, the Operator has to take into consideration the following:

(a) **Containment of UA.** As the main determinant of risk is dependent on the area of operation, the applicant has to ensure that the UA is confined within the specified area of operation at all times. This can be achieved either through technology or operational limitations such as flying in an enclosed area or using netting to ensure a shielded operation. Technology or system measures can be hardware-based such as a tethered system, or it can be software-based such as geo-fencing coupled with a robust navigation system and failsafe logic.

(b) **Flying over persons.** The risk to persons is associated with the duration and the population size that are exposed to the danger of drones flying within the vicinity or over them. While the higher risk categories (medium and high) permit overflying persons, the applicant should minimize flight time of the UA over persons.

Operational Scope and Risk Category

9.4 The typical BVLOS operational scope under each risk category is as follows:

(a) **Risk category – Low.**

In this category, aviation and public safety risks are considered low or negligible. Under this category, the operation of UA is in an area where it is assessed and reasonably expected that no uninvolved person will be present.

This category also serves to enable the Operator to acquire experience, build confidence, and build capabilities progressively in a safe manner through conduct of testing and trials before attempting to conduct operations in the medium and high risk categories.

(b) **Risk category – Medium.**

This category refers to an operation where the UA is flown in proximity to uninvolved persons; or where the UA is expected to fly over uninvolved persons, such overflying should be minimised and only when necessary.

As a general reference, the total duration that an UA is flying over uninvolved persons should be less than 30% of the overall flight duration.

(c) **Risk category – High.**

This category refers to an UA operation where aviation and public safety risks are significantly higher. This covers operations where the UA is flown over or in close proximity to uninvolved persons most of the time, operations of greater complexity as well as operations in a non-segregated environment.

Specific to operations in a non-segregated environment, in addition to fulfilling requirements stated in **Appendix 1**, the Operator should address additional requirements in the areas of CNS (Communication, Navigation and Surveillance) and to abide by ‘Rules of the Air’ to ensure safe and seamless integration with manned aircraft and other airspace users.

Requirements for each Risk Category

9.5 The requirements used to assess an operation commensurate with the level of assessed risks of the BVLOS operations. The higher the risk, the more stringent the requirements will be. This is reflected horizontally across in Figure 1.

9.6 The requirements are devised around the following UA systems that are considered critical for safe BVLOS operations:

(a) Failure Management Systems

(b) Navigation/Flight Control Systems

(c) Communication Systems

(d) Detect and Avoid Systems

These systems, coupled with a set of operational processes, are expected to provide higher level of assurance to mitigate the risks.

9.7 Based on the identified critical systems listed in para 9.6, the requirements are broadly classified into:

(a) Basic requirements that are considered fundamental to all BVLOS operations. They address the basic hardware and software reliability of the UAS to ensure minimum airworthiness standards are met, as well as the operational processes that should be in place to mitigate the risks.

(b) Additional requirements that are tiered into Level 1, 2 and 3 and the applicability of the specific level will commensurate with the level of risks of BVLOS operations.

9.8 In summary, an Operator proposing BVLOS operations in:

(a) The Low risk category will have to satisfy basic and Level 1 requirement;

(b) The Medium risk category will have to satisfy basic, Level 1 and 2 requirement; and

(c) The High risk category will have to satisfy basic, Level 1, 2 and 3 requirement.

9.9 Each requirement as shown in Figure 1 has been assigned a requirement code. The first letter of the code corresponds to the operational risk category (Low – L, Medium – M, High – H). The exception is the basic requirement, which is tagged with a letter B, to denote basic. The second letter of the code denotes its subcategory. For example, “General (BG)” refers to requirements that are basic and generic in nature, while “Failure Management (LF)” refer to requirements that address failure management under the Low risk category.

9.10 **Appendix 1** spells out the associated requirements to be met based on the requirement code. Should a higher level requirement conflict with a lower level requirement, the higher level requirement takes precedence over the lower level requirement, and should be highlighted by the applicant accordingly.

10. APPLICATION FOR BVLOS OPERATIONS IN SINGAPORE.

10.1 An operator who conducts BVLOS operations will be required to hold a UA Operator Permit (OP) and Class 1 Activity Permit (AP1) granted by CAAS. Applicants may wish to refer to AC UAS-1 and the CAAS website for guidance on the process to apply for OP and AP1 permits.

10.2 An Operator can only conduct an operation that is within the scope in the OP. A variation to the OP will be required should an operator wish to vary the scope that is granted in the OP.

10.3 A summary of the process to apply for, or variation to, an OP and/or AP1 to conduct BVLOS operations is illustrated in Figure 2 below.

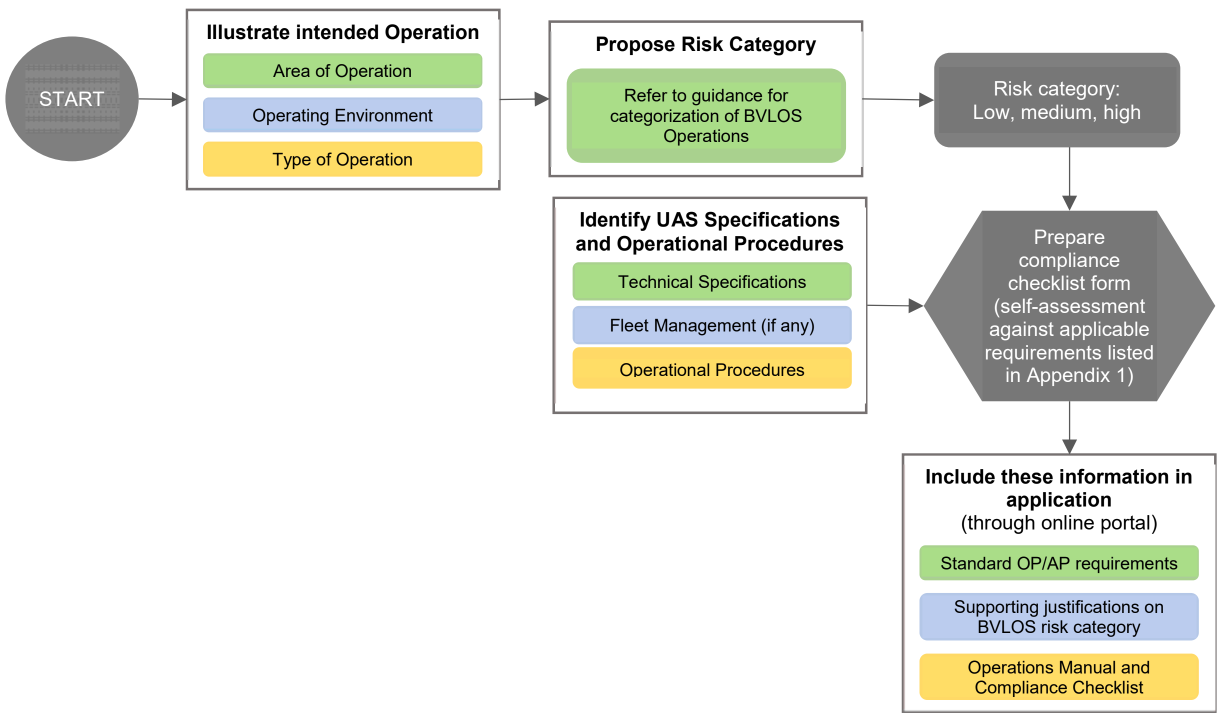

Figure 2: Application flowchart for BVLOS Operations

10.4 An applicant should include the following information in his application:

(a) Description of the intended operation:

(1) Details of the area of operation and the operating environment

(2) Type of operation and how the operation is conducted

(b) The appropriate BVLOS operational risk category, proposed by the applicant based on guidance from Paragraph 9, together with justifications to support the assessment.

The justifications should include details on how the UA could be contained within the identified area of operations, and if there are any flights over persons. When operating over any persons, information on whether there are involved or uninvolved persons, and the necessary safeguards to ensure safety of the individuals should also be provided.

(c) The design specification of the UAS identified by the applicant to minimally include:

(1) Boundaries of the operational envelope within which safe flight under normal and emergency conditions, and emergency recovery capabilities can be demonstrated;

(2) Typical design missions;

(3) Operational modes (altitude-hold, speed-hold, direct manual etc.);

(4) Launch, landing and recovery conditions;

(5) Maximum number of UA to be operated simultaneously;

(6) Operating environmental conditions; and

(7) All possible mass configurations.

(d) Completed Compliance Checklist form (CAAS-101-2-01), providing justifications to demonstrate compliance with the applicable requirements listed in **Appendix 1**. The applicant should include relevant test reports and analysis reports where applicable.

(e) Operations Manual to establish how the applicable requirements listed in **Appendix 1** are complied with.

10.5 To demonstrate compliance with the applicable requirements in **Appendix 1**, an applicant should provide substantiations supported by evidence as attestation of the UAS' airworthiness and adequacy of the risk mitigating measures. Where applicable, evidence should consist of one or more forms of the following types:

(a) Direct evidence from analysis

(b) Direct evidence from demonstration (rig testing, representative prototype ground and flight operation, operational experience)

(c) Direct quantitative safety evidence

(d) Direct qualitative safety evidence

(e) Direct evidence from hazard risk assessment

(f) Direct evidence from the design review process

(g) Direct technical description of design features and system functions

(h) Direct qualitative evidence of good design (design requirements and practices)

(i) Process evidence showing good UA life-cycle safety issue management

(j) Performing a system safety assessment which includes the following but not limited to:

(1) Functional Hazard Analysis (FHA)

(2) Failure Mode Effect and Criticality Analysis (FMECA)

(3) Fault Tree Analysis (FTA)

Any other quantitative and/or qualitative analysis provided to CAAS in order to demonstrate compliance.

10.6 The UA pilot may, in addition to fulfilling requirements for visual line of sight (VLOS) operations, be required to demonstrate additional knowledge and experience relevant to operating the UAS within its intended operations.

APPENDIX 1 REQUIREMENT FOR BVLOS OPERATIONS

This appendix provides details on the requirements to be met for each BVLOS operational risk category.

1 BASIC REQUIREMENT

1.1 General

BG1	All flight critical components in the UAS or sub-systems of the UAS affecting safety of operations, should be designed and installed such that: (i) It would perform as intended under the UAS operating and environmental conditions for which it is designed for. (ii) All other equipment/components, should they become unserviceable, should not reduce the level of safety and should not adversely affect the proper functioning of all flight critical components.
BG2	The UAS should be designed to minimise system degradation and/or failures that, at minimum, address the following: (i) Total loss of power to the avionics and propulsion system (ii) Total loss of power to the Ground Control System (GCS) (iii) Loss of the ability for UA to navigate within allowable system accuracy (iv) Loss of the ability to make autonomous decisions (v) Catastrophic or hazardous failure conditions The Operator should have to identify all possible hazards and demonstrate an acceptable level of safety to CAAS, through one or more of the following methods: (i) System redundancies (refer to **Appendix 3** for guidance) (ii) Reliability testing (iii) Operational procedures
BG3	The UA Pilot should be made aware of minor UA system failures or unsafe conditions that will result in one or more of the following: (i) Degradation to the UA's flight performance; (ii) Eventual failure of any of the UA's onboard critical flight systems; (iii) Eventual loss of capability to maintain situational awareness of airspace traffic, terrain, obstacles and/or weather; or (iv) Eventual loss of power The UA pilot must implement the relevant corrective actions as stipulated in the Flight Manual. Refer to **Appendix 3** for further guidance.
BG4	The UA Pilot should be made aware of critical UA system failures or unsafe conditions that will result in one or more of the following: (i) Severe degradation to the UA's flight performance such that the UA is unable to maintain its flight path or current location; (ii) Failure of any of the UA's onboard critical flight systems; (iii) Loss of capability to maintain situational awareness of airspace traffic, terrain, obstacles and/or weather; The UA Pilot should be able to perform emergency recovery in the event of such critical system failures as soon as practicable.

BG5	In the event of multiple failures, failure handling (either manually by the UA pilot or automatically by the UAS) should prioritise and handle all failures in order of severity.
BG6	All UAs should be entirely confined within the pre-defined area of operations at all times. This can be achieved either through technology or operational limitation such as flying in an enclosed area.
BG7	There should be adequate means to maintain situational awareness of the UA and its surroundings (both in the air and on the ground). Examples will include monitoring of flight routes and flight corridors and/or having systems on board to avoid collision with obstacles.
BG8	Prior to and during the operation, the meteorological conditions should be monitored closely in the whole area of operations. If the meteorological condition deteriorates to beyond what the UA is designed for, the UA should be recovered immediately.
BG9	The Operator is responsible for ensuring that maintenance of the UAS is performed in accordance with a set of established instructions acceptable by CAAS, and that the UAS is maintained in an airworthy condition. Maintenance includes the accomplishment of scheduled and unscheduled servicing and inspection tasks to ensure continuing airworthiness of the UAS. The Operator should have a system of assessment e.g. through reliability programme, to support the continuing airworthiness of UAS and to provide a continuous analysis of the effectiveness of the maintenance programme in use.

1.2 Operational

BO1	The Operator should establish procedures for normal operations, and means to address failure and emergency conditions in the Flight Manual.
BO2	The Operator should plan all routes (for normal operations and emergency landings) to a level consistent with safe operations. Considerations should be made based on the accuracy of the UA flight control and navigation system or the accuracy of the UAS' DAA system, whichever is less precise.
BO3	All landing areas, including emergency landing areas, should allow the recovery of the UA in an expeditious manner with adequate considerations made to safety and security (refer to **Appendix 3** for guidance). The Operator should identify landing areas for emergency recovery. If applicable, the emergency landing areas should be located within the trajectory limits of the UAS and at a safe distance from areas with human traffic.
BO4	The Operator should establish the minimum UAS crew sufficient for safe operation (refer to **Appendix 2** for guidance). Each UAS crew member should be fully aware of the following: (i) Roles and responsibilities of each UAS crew (ii) Operational procedures, including emergency and contingency procedures (iii) Details of any additional information, marking and placards
BO5	The Operator should ensure that all map data necessary for navigation, including for the purpose of situational awareness and detect and avoid, are updated in a timely manner. All map data should be accurate to a level sufficient for the safe operations of the system (to include ground fixtures and temporary erected structures if necessary).

1.3 Technical

1.3.1 Software

BW1	All software and firmware deployed on the UAS should be functional in all phases of flights. Verifications can be made through analysis or testing with special attention given to functionalities which are flight critical or in which their failure will lead to hazardous or catastrophic failure conditions.

1.3.2 Others

1.3.2.1 Display

BT1	Information of the UA(s) should be displayed on the GCS in a clear and unambiguous manner during all phases of flight, at an update rate consistent with safe operations, and not pose unnecessary workload on the UA Pilot. Information to be displayed should include, but not limited, to the following: (i) UA performance indicators and health status (for example, attitude, speed, heading, position and battery health/propulsion system data) (ii) UA mode of control (i.e. GCS ID or UA Pilot in control of UA) (iii) UA system warning and failure messages for alerting UA Pilot of any failures or any corrective actions required, or as a deterrent to prevent deviation from the intended flight envelope. Corrective actions could be carried out automatically by the UA, or manually by the UA Pilot
BT2	Where a GCS is designed to command and control multiple UA, the following functions should be designed in a manner that prevents confusion for the UA Pilot and inadvertent operation: (i) UA data displayed in the GCS (ii) UA controls for each UA (iii) All indicators and warnings
BT3	Where the UAS is designed for UA handover between multiple GCS, the in-control GCS should be clearly identified to all UAS crew.
BT4	When the system enters into ‘avoidance’ mode, triggered independently by the DAA function, this mode should be displayed on the GCS.
BT5	When the system recovers from an ‘avoidance’ mode, this mode should be displayed on the GCS.

1.3.2.2 Data Recording

BT6	The UA should be equipped with the capability to perform on-board data recording. The data to be recorded should include, but not limited, to the following: (i) UA performance indicators and health status (for example, attitude, altitude, speed, heading, position and battery health) (ii) Last command received on the UA from the GCS (iii) Any additional parameters unique to the UA design or operational characteristics
BT7	The GCS should be equipped with the capability to record: (i) Critical data transferred between the UA and GCS through the C2 link (ii) GCS Status (for example, C2 link strength and GCS battery life)

1.3.2.3 Operations in Poor Visibility or Night Operations

BT8	The UA should be installed with a strobe light system or anti-collision avoidance light system that is switched on either automatically or manually by the UA Pilot, for use in poor visibility conditions and/or during night operations. The system should be sufficiently visible to humans on the ground or to operators of manned aircraft (when operating in non-segregated environment).

2 LEVEL 1 REQUIREMENT – LOW RISK

2.1 Technical

2.1.1 Failure Management

LF1	In the event of landing failure (eg. Landing out of the planned landing zones, toppling, crash etc), actions should be taken to ensure that safety is not compromised.
LF2	The UA design should be integrated with emergency recovery capability which should consist of: (i) A flight termination system, procedure or function that allows the UA Pilot to end the flight as soon as practicable; (ii) An emergency recovery procedure that is implemented through the GCS or UA (including automatic pre-programmed course of action to reach a pre-defined landing area); or (iii) Any combination of (i) and (ii). The emergency recovery capability should be functional in all phases of flights (launch, in-flight, landing).

2.1.2 Navigation Systems

LN1	The UAS should have a means to determine the UA's position, attitude, speed and heading while in flight.
LN2	The navigation system should be sufficiently accurate for the operations, and is acceptable by CAAS. If deemed necessary, the navigation accuracy has to be verified by flight test in all the UA operational modes, in terms of maximum error from an established waypoint on ground, altitude and speed. Information on the worst possible navigation accuracy should be provided by the Operator and detailed in the Flight Manual.
LN3	A flight-path deviation warning should be displayed and the appropriate procedure established when excessive deviation from the pre-programmed flight-path occurs, to ensure that the UAS crew is able to intervene at any time, to safely control the UAS back into the flight envelope as defined and accepted by CAAS.
LN4	For effective management of failures that has direct impact to UAS navigation capability, there should be sufficient indications available for the UA Pilot to observe and act on accordingly to mitigate the associated risk to an acceptable level.

2.1.3 Communication Systems

LC1	The UAS should include a command and control data link for control of the UA with the following functions: (i) Transmittal of commands from the GCS to the UA (uplink), and (ii) Transmittal of UA status data from the UA to the GCS (downlink). This status data should include, to the appropriate extent, navigational information, response to UAS crew commands, and equipment operating parameters; and (iii) Data necessary for DAA function (if applicable)
LC2	There should be a positive indication at the GCS that the intended UA has been paired and full control has been established prior to flight.
LC3	Bandwidth, latency, link availability, link continuity and link integrity of the overall communications system should be considered when determining transmission rates consistent with safe operation.
LC4	For each command and control data link, the integrity of the link should be continuously monitored at a refresh rate consistent with safe operations.
LC5	The Operator should specify the effective maximum range of each command and control data link (which should include an identified safety margin) in the Flight Manual. The effective maximum range should cover the entire intended area of operations.
LC6	The Operator should specify a command and control data link loss strategy in the Flight Manual, taking into account the emergency recovery capability. The strategy should include an automatic reacquisition process in order to try to re-establish in a short reasonable time the original command and control data link or any other available GCS.
LC7	The command and control data link should be protected against electromagnetic interference (EMI) and should have safeguards against electromagnetic vulnerability (EMV) by means of design or operational procedures that takes into consideration the operating environment.
LC8	The command and control data link should be electromagnetically compatible with the simultaneous operation of any electronic or radio units that are part of the UAS.
LC9	Where multiple radiofrequency links are used for redundancy or for a specific function such as local control for launch and landing elements, the Operator should pre-determine and specify the role of each operating frequency in the Flight Manual.
LC10	The command and control data link should be designed such that there is no single failure that could lead to a hazardous or catastrophic event.
LC11	Switchover is the operation that consists of performing the transfer of the UA command and control from one data link channel to another channel within the same GCS. The switchover of a command and control data link should not lead to an unsafe situation. The UA should be under continuous positive control at all times during switchover or it should be demonstrated that no positive control will not lead to unsafe conditions during the switchover.
LC12	Where the UAS is designed for UA handover between multiple GCS: (i) Positive control must be maintained during handover; and (ii) Handover between two GCS should not lead to unsafe conditions; and (iii) The in-control GCS should have the required functionality to accommodate emergency situations

2.1.4 Detect and Avoid (DAA) Requirements

LD1	The UAS should be able to avoid all static obstacles, including both known and unknown obstacles, minimally through the UA Pilot's intervention.
LD2	The Operator should specify procedures to effectively handle separation provisions and DAA in the Flight Manual. If the UA Pilot's intervention (to avoid all known static obstacles) is required, procedures should take into consideration transmission and decision time needed from the point of initial detection, to effectively maintain minimum separation between the obstacle and the UA.
LD3	The DAA should be functional in all phases of flights (launch, in-flight, landing). Ground-based radar systems may be utilised to provide a means of meeting DAA requirements or maintaining separation provision if the system is able to fulfil the following: (i) Meet all DAA and separation provision requirements to an equivalent level of safety acceptable by CAAS; and (ii) Personnel are suitably-trained and equipped to use the system effectively; and (iii) Provide horizontal and vertical coverage (with safety buffer) over the entire area of operation Guidance on effective detection and avoidance of obstacles are as provided in **Appendix 4**.

3 LEVEL 2 REQUIREMENT – MEDIUM RISK

3.1 General

MG1	The UAS should be designed to meet the safety objective where probability of a catastrophic failure condition does not exceed $1x10^{-6}$ per flight hour.
MG2	The UA Pilot should ensure that there is reasonable control and maneuverability of the UA under all anticipated operating conditions in a manner that will not compromise safety of flight. The UA Pilot should also ensure that the UA remain in a predictable flight condition that does not exhibit any tendencies to depart from controlled flight throughout the launch and recovery/landing phase.
MG3	The effect of cyclic loading, environmental and operational degradation and likely subsequent part failures should not reduce the integrity of the UA, in terms of its structural integrity, and flight critical functions.

3.2 Technical

3.2.1 Structural

MS1	All flight critical components and structures, whereby failure would lead to a hazardous or catastrophic failure condition, should be able to withstand all static and dynamic loads (based on the intended concept of operations), by a safety factor of at least 1.25 for static load and 1.5 for dynamic loads. Verifications can be made through analysis or testing. The identified safety factor should be added to 'limit loads', which is the maximum allowable load at which the structure would not exhibit deformations detrimental to the performance of the UA. Identification of limit loads should take into consideration the operational envelope and the life of the UA, which includes any additional load induced during launch and landing.

MS2	For all flight critical components and structures, the safety factor as identified in BS1 should be multiplied by an additional special factor in the following cases: (i) 2.0 on bearings at bolted or pinned joints subjected to rotation (ii) 4.45 on control surface hinge-bearing loads (iii) 2.2 on push-pull control system joints (iv) 1.5 for attachments in frequently assembled and disassembled structural parts (v) 1.2 for composite structures The identified safety factor should be added to limit loads, which is the load at which the structure must not exhibit deformations detrimental to the performance of the UA.
MS3	The UA should be free from any aero-servo-elastic instability and excessive vibration.
MS4	The manufacturing processes and materials used in the construction of the UA must result in known and reproducible structural properties. Any changes in material performance related to the operational environment must be accounted for.

3.2.2 Software

MW1	General considerations in software development for UAS are as provided in **Appendix 5**. The software and firmware developed has to be verified and tested to demonstrate with a high degree of confidence that errors that could lead to hazardous or catastrophic failure conditions as determined by the safety assessment process, have been removed. In the verification of software, a requirement-based approach could be considered in the identification of test cases which includes: (i) Developing specific test cases to cover normal range test cases and abnormal range use cases for the purpose of testing the software robustness. (ii) Developing specific test cases from software requirements and error sources inherent in the software development process (iii) Generation of test procedures from the test cases. The testing should be conducted in a systematic manner, and the scope should include: (i) A review and testing of the source code to verify the implementation of low level requirements identified during the software design process. (ii) Software integration testing performed on the combination of software modules, to verify the software functional performance and the code stability. This testing method focuses on the inter-relationships between the software requirements and the implementation of the requirements within the software architecture. It should also ensure that software components interact correctly with each other and satisfy the software requirements. (iii) Software/hardware integration testing, to verify the operation of the software in the target computer environment and the implementation of the high level requirements. Such tests are conducted on complete, integrated system involving both hardware and software, and validates the integrated software system operations.

3.2.3 Navigation Systems

MN1	For navigation systems that utilize an external reference source (such as GPS) as the primary means of ensuring navigation performance, the Operator should specify the following information in the Flight Manual: (i) Navigation sensor accuracy (to include both normal and degraded modes); (ii) Areas of navigator susceptibility that can result in the degraded mode (such as clock timing errors etc.); and (iii) Any operational procedures that must be performed by the UA Pilot to compensate for the degraded navigation.
MN2	The Flight Control System should satisfy the following capabilities: (i) Contain maneuver limits to keep the UA in the flight envelope protection; (ii) Except in case of total loss of data link, the UA Pilot should have the opportunity to intervene at any time during the flight to ensure safe operations of the UA; (iii) Designed and adjusted so that, within the range of adjustment (if any) available to UA Pilot, no unsafe condition should arise; (iv) Have a comprehensive self-test available and operating during all phases of flight, including during pre-flight; and (v) Data exchanged between components of the flight control system or received from components external to the flight control system should be verified for the integrity of the information prior to use. Information received from external sources should be verified within appropriate rate of change and range boundaries for the appropriate phase of flight before using in the computations. Guidance on the Flight Control Indication System is as provided in Part 1 of **Appendix 6**.

3.2.4 Communication Systems

MC1	For all UA attitudes and orientations relative to the signal source within the design envelope, the UA antenna margin should be consistent to maintain an adequate level of communication link quality of service for safe operation.
MC2	The command and control data link should be designed to be protected against electrostatic, lightning (if applicable) and electromagnetic emission (EME) hazards.

3.2.5 Detect and Avoid Systems

MD1	The UAS should be able to avoid all static and dynamic-collaborative obstacles at a total system and/or human reaction time sufficient to prevent hazardous or catastrophic failure condition.
MD2	The Operator should demonstrate measures taken to mitigate risks caused by non-collaborative obstacles, for acceptance by CAAS.
MD3	The DAA system should be sufficiently autonomous and robust to ‘stop flight’ (limited to rotorcrafts) or avoid obstacles with minimal human intervention. Guidance on effective detection and avoidance of obstacles are as provided in **Appendix 4**.

3.2.6 Propulsion System

MP1	The propulsion system should produce, within its stated limits, the thrust or power demanded of it at all required flight conditions, taking into consideration environmental effects and conditions.
MP2	The UA should be designed to withstand asymmetrical load resulting from the failure of critical engine/motors.

4 LEVEL 3 REQUIREMENT – HIGH RISK

4.1 General

HG1	The UAS should be designed to meet the safety objective where probability of a catastrophic failure condition does not exceed 1×10^{-7} per flight hour.
HG2	The UAS should be designed in such a way that no single failure will lead to: (i) Any catastrophic and hazardous failure conditions; (ii) Total loss of power to the avionics and propulsion system; or (iii) Total loss of power to the GCS.

4.2 Technical

4.2.1 Software

HW1	The software and firmware integrated in the UAS should perform intended functions with a sufficient level of safety acceptable by CAAS. Evidence of safe software and firmware engineering at an acceptable level of assurance could be provided through compliance to internationally-recognised standards such as RTCA/DO-178C or AOP-52 for software and RTCA/DO-254 for firmware. This should have to be coupled with analysis to ensure safe use within the context of hardware design. The software Development Assurance Levels (DAL) should be based upon the contribution of software to potential failure conditions as determined by the DAL derived from the safety analysis. The DAL allocation should be as referenced from internationally-recognised standards such as that in RTCA/DO-178C or relevant STANAG requirements. The Operator should make available all standards adopted for acceptance by CAAS. Where alternative means of compliance are proposed, the Operator should provide justifications to demonstrate a level of safety equivalent to that of an internationally-recognised standard.

4.2.2 Navigation Systems

HN1	For each sensor where failure would prevent continued safe flight and landing, the following requirements apply: (i) A continued power supply monitoring is required; and (ii) The installation and power supply systems must be designed so that: (a) The failure of one sensor will not interfere with the proper supply of energy to the remaining sensors; and (b) The failure of the energy supply from one source will not interfere with the proper supply of energy from any other sources. Guidance on the design consideration and accuracy of the sensors (airspeed measuring devices, Pressure altitude system, and Direction measure device) are as provided in **Appendix 6**.

4.2.3 Detect and Avoid Systems

HD1	The UAS should be able to avoid all static and dynamic obstacles at a total system and/or human reaction time sufficient to prevent hazardous or catastrophic failure condition.
HD2	The DAA system should be sufficiently autonomous and robust to 'stop flight' (limited to rotorcrafts) or avoid obstacles with no human intervention. Guidance on effective detection and avoidance of obstacles are as provided in **Appendix 4**.

APPENDIX 2 ROLES AND RESPONSIBILITIES OF THE OPERATOR

This appendix supplements **Appendix 1** and provides guidance on the roles and responsibilities of the Operator and workload considerations for minimum UAS crew.

The operator should:

(i) Develop the policy and procedures adapted to its operation and size, and designate UA pilot(s) for each operation;

(ii) Ensure that before conducting an operation, the UA pilot and all other personnel directly involved in the operations are competent to perform their tasks, are familiar with the Operator's policy and procedures, and are in sound physical and mental condition that would enable the safe operation of the UAS; and

(iii) Ensure the robustness of the safety risk assessment contextual to the equipment used, competency of personnel, types of operations and the environment in which the operations would be conducted

In establishing the minimum UAS crew sufficient for safe operations, the operator should take into consideration the following when assigning workload and the roles of each UAS crew member:

(i) Flight path control
(ii) Separation and collision avoidance with ground obstacle or air traffic
(iii) Navigation
(iv) Communications
(v) Operation and monitoring of all UA systems required for continued safe flight and landing
(vi) Tasks not related to piloting (e.g. payload operation)
(vii) Command decisions
(viii) The accessibility and ease of operation of necessary controls by the appropriate UAS crew member during all normal and emergency operations when at the UAS crew member flight station
(ix) The kinds of operation as approved by the authority
(x) UAS Crew required for ground operation

APPENDIX 3 GUIDANCE ON THE DESIGN OF UAS TECHNICAL SYSTEMS

This appendix supplements **Appendix 1** and provides further guidance in the following technical areas:

(i) Examples of Redundancy Systems
(ii) Examples on minor and critical system failures
(iii) Examples of possible solutions to address safety and security considerations when operating the UA

Redundancy Systems

Examples of redundancies typically includes, but is not limited, to the following:

(i) Emergency Recovery Board, that acts as a self-powered mini-computer that is able to detect failures and to perform limited actions, for the purpose of performing emergency landing (e.g. deploying of parachute).
(ii) Dual Flight Control Computers (FCC) that performs automatic switching to the Slave FCC upon detection of failure in the Master FCC.
(iii) Dual navigation system (i.e. IMU, magnetometer, barometer) that performs automatic switching upon detection of failure. One set of navigation system could be an accurate and complete set while the backup navigation system could be of a lower accuracy, and/or a partial set that uses a combination of sensor data and software solutions enough for safe navigation to nearest landing zone.
(iv) Dual location positioning system, that uses multiple hardware (e.g. dual GPS), software solutions (e.g. dead reckoning), or a combination of both.
(v) Motor failure logic that allows other operational motors to compensate and perform controlled descend of the UA in event of single motor and/or propeller failure.
(vi) Dual band usage that UA is able to perform automatic switching based on the Received Signal Strength Indicator (RSSI) values.
(vii) Dual power supply to the GCS that allows automatic switching in the event of single power failure.

UA System Failures

Examples of minor system failures typically includes, but is not limited, to the following:

(i) Degraded sensor performance
(ii) Failure in one system with redundancy
(iii) Intermittent downlink loss
(iv) Any other recoverable failures

Examples of critical system failures typically includes, but is not limited, to the following:

(i) Flight Control Computer failure
(ii) Navigation (e.g. IMU, barometer, airspeed sensor) system failure
(iii) GPS loss
(iv) Uplink loss
(v) Any other non-recoverable failures

Measures to Ensure Safety and Security

(i) CCTV cameras on the landing zones and immediate surrounding areas
(ii) Physical barriers around the landing zones
(iii) Instruction and/or warning signs placed around the landing zones
(iv) Advisory and/or warning lights placed around the landing zones to indicate different phases of the operation
(v) Warning indicators (visual and/or audial) installed on the UA to alert nearby personnel when approaching landing zones The appropriate UAS crew member should be accessible to, and operate with reasonable ease the necessary controls, during all normal and emergency operations when at the UAS crew member flight station

APPENDIX 4 DETECT AND AVOID SYSTEM

This appendix supplements **Appendix 1** and serves to illustrate the concept of 'detect and avoid' and some key design considerations.

To ensure safe execution of UAS operations, conflict management approach will have to be adopted to limit the risk from the following identified hazards:
(i) Conflicting traffic
(ii) Terrain and obstacles
(iii) Hazardous meteorological conditions
(iv) Ground Operations
(v) Other Airborne Hazards

Broadly, the conflict management approach can be broken down into three stages namely:

(i) Strategic conflict management phase
Airspace organisation and management, demand and capacity balancing, traffic synchronization components

(ii) Separation provision phase
Tactical process of keeping aircraft away from hazards by at least the appropriate separation minima or distance

(iii) Collision avoidance phase
Must be activated when the separation minima has been compromised

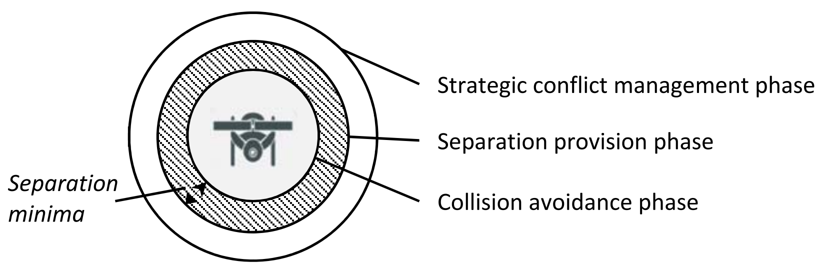

Figure 3: DAA Conflict Management Approach

With the UA operating beyond visual range, separation provision and collision avoidance functions can no longer be conducted by a UA pilot/visual observer. An alternative means of ensuring this capability will have to be addressed through either:
(i) Having in place a DAA system (technical means);
(ii) Other mitigating measures or procedures; or
(iii) A combination of (i) and (ii).

Depending on the risk category of the operation, the Operator will need to progressively mitigate the risk derived from the hazards listed above.

In assessing the capability of the DAA system, the following factors should be considered while establishing compliance with the requirements, for its intended operational risk category.
(i) To identify potential obstacles in the operating environment, and determine obstacles that can be detected and avoided. For obstacles that could not be detected, there should be mitigating measures in place to mitigate the risk of potential collision.
(ii) Taking into consideration the nature/behaviour of the obstacle(s) and the technical capability of the operating UA, the following parameters should be defined with reference made to Figure 4:
  (a) Separation provision threshold
  (b) Collision avoidance threshold
  (c) Collision volume
  (d) Maneuver Time
(iii) Information on the DAA system specifications as well as any analysis or testing done to address the reliability of the system should be evaluated.

(iv) Any assumptions made in the design of the DAA function.
(v) Using the parameters defined above and available DAA functions, the operational limits should be scoped accordingly.

Note: Depending the risk category of the operation, the means to justify the DAA capabilities of the UA system are not limited to the example as provided above. The example serves to illustrate the concept of DAA, and key considerations that have to be in place.

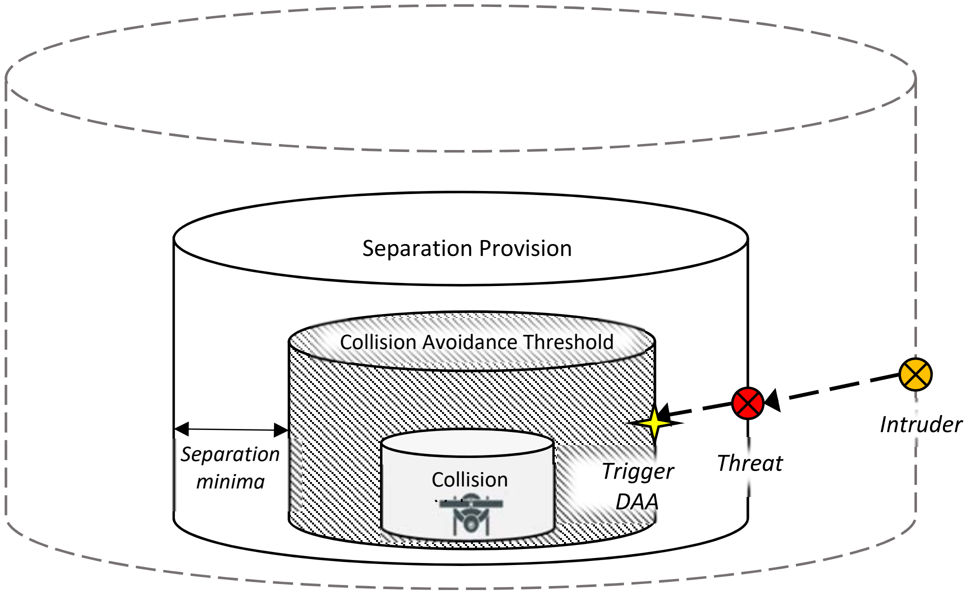

Figure 4: Pictorial Representation of DAA Function

<u>Definitions for DAA Parameters</u>

Collision Volume: A cylindrical volume of airspace centred on the UA within which avoidance of a collision can only be considered a matter of chance.

Conflict Point: The time of a predicted collision or point of closest approach that is within the collision volume.

Maneuver Time, t: The time required for the UA to execute a maneuver that ensures the point of closest approach of an obstacle remains outside the collision volume. This value can be determined either from the manufacturer of the UA or through analysis.

Detection Function:
Obstacles should be detected within a pre-defined volume of space at a pre-defined acceptable time frame prior to conflict point.

Separation Function:
The UA Pilot should be informed and provided with sufficient information to enable appropriate and timely action, if an obstacle enters within a pre-defined volume of space.

Collision Avoidance Function:
The UA Pilot should be warned if an obstacle enters the collision volume. The minimum warning time (minimally taking into consideration maneuver time, human reaction time and detection time) should be within a pre-defined time frame prior to conflict point. The avoidance manoeuver strategy should abide by the 'right of way' rules and should not lead to an unsafe situation.

APPENDIX 5 SOFTWARE LIFE CYCLE

This appendix supplements **Appendix 1** and serves to explain the software life cycle concept.

Software development should follow the typical life cycle which involves the following processes:

(i) Software planning process
The purpose of the software planning process is to identify the means of producing the software that will satisfy its intended requirements and provide the level of confidence that is expected from the software.

(ii) Software development process
This process involves producing the software product, through collation of the software requirements, designing of the software, coding of the software and integration of the software modules. In general, the software development process involves one or more levels of software requirements.

High-level requirements are produced directly through analysis of system requirements and system architecture. These high-level requirements are usually further developed during the software design process thus producing one or more successive lower levels of requirements.

(iii) Integral process
The integral processes include verification of the software developed, management of software configuration and quality assurance of the software, which ensures correctness of the software output and provides confidence level in the software developed.

APPENDIX 6 NAVIGATION SYSTEMS

This appendix supplements **Appendix 1** and provides guidance on the design consideration and accuracy of the sensors (airspeed measuring devices, Pressure altitude system, and Direction measure device) typically existing in the navigation system.

Part 1:

There must be a means in the GCS to indicate to the UAS crew the active UA control mode of the flight control system.

UAS elements to control altitude, speed and trajectory, as well as to ensure UA remains in the approved flight envelope, should perform as intended. When any UAS element is not in the position required, it must be indicated to the UAS crew by adequate means.

Where single (or multiple) failure, not shown to be extremely improbable, affects the flight control system or limits the flight envelope or maneuverability, the UAS crew must be alerted. Failures under this scope must be extremely improbable.

An aural or equally effective warning device(s) must be provided to inform the UAS crew, if an element necessary to control the altitude, speed and trajectory of the UA and to ensure the UA remains within the approved flight envelope in all flight phases, is not in a position required for the actual phase of flight.

Part 2:

For all airspeed measuring devices:

(i) The design and installation of each airspeed measuring device must provide positive drainage of moisture from the pitot static plumbing.

(ii) Each airspeed measuring device must have a heated pitot tube or an equivalent means of preventing malfunction due to icing, if applicable.

(iii) Throughout the flight envelope, the airspeed measurement sensor must be calibrated to measure true airspeed at sea-level with a standard atmosphere and within a system error not exceeding 3% of the calibrated airspeed or 9.3 km/h (5 knots).

(iv) Where dual or greater airspeed measurements are required by system redundancy and flight safety requirements, the respective pitot tubes or other airspeed measuring devices must be far enough apart to avoid damage to both tubes in a collision.

For Pressure Altitude system:

(i) Each instrument with static air case connections must be vented so that the influence of UA speed, airflow variation, and moisture or other foreign matter does not seriously affect its accuracy.

(ii) Static pressure system must be calibrated to indicate pressure altitude (with standard atmosphere) with minimum practicable instrument calibration error. Throughout the flight envelope, the pressure altitude presented to UA Pilot, should not exceed an overall error of more than 30 feet.

(iii) For pressure altitude not reliant on static pressure, its performance should be at least equivalent to the pressure based systems under all operating conditions.

(iv) Each static pressure port must be designed and located in such a manner that the UA altitude measuring system is able to operate reliability and accurately when the UA encounters icing conditions, if applicable.

For Direction measuring device:

(i) Each magnetic direction measuring device, if existing, must be installed so that:
    (a) Its accuracy is not excessively affected by the rotorcraft's vibration or magnetic fields and,
    (b) The compensated installation may not have a deviation, in level flight, greater than 10° on any heading.

(ii) A magnetic non-stabilized direction measuring device may deviate more than 10° due to the operation of electrically powered systems, if either a magnetic stabilized direction measuring device, which does not have a deviation in level flight greater than 10° on any heading, or a gyroscopic direction measuring device, is installed. For magnetic non-stabilized direction measuring device with deviations of more than 10°, the magnetic heading or track displayed in the GCS must be automatically compensated for the deviation.

(iii) For direction measuring system that is not reliant upon the earth's magnetic field, the system should meet the requirements in sub-paragraph (ii) and provides indication with inclusion of the position appropriate magnetic deviation.