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JARUS CS-HAPS,

Airworthiness recommendations for HAPS

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CONTENTS

Introduction

The intent of CS-HAPS / Applicability

The High Altitude Platform Systems (HAPS) community is global and diverse, but there are substantial commonalities. This provides an opportunity to develop consistent regulatory guidelines to enable HAPS to be approved for operation by any CAA. HAPS are unoccupied craft covered by Air Law, this CS-HAPS, largely inspired by CS-UAS, is an attempt to highlight how HAPS are somewhat different than traditional aircraft and UAS and present guidance material to appropriately address those differences.

This CS is intended to cover all HAPS aircraft types involved in Higher Airspace Operations (HAO) as described in the definitions proposed in this document. Airworthiness recommendations for unoccupied HAPS/HAO and guidance material will be presented which takes into consideration inputs from individual NAAs' experiences in HAPS/HAO operations, the HAPS Alliance (a HAPS industry trade association), EASA activities including the HAO-TF, the FAA ETM CONOPS development, and the ECHO2 exploratory research project which is planning flight tests to validate the CONOPS developed on air traffic management for HAPS/HAO.. While supersonic, hypersonic and space vehicles may do Higher Airspace Operations (HAO), they are not "Platform Systems" that are existing for very long durations in the high-altitude airspace.

This CS-HAPS intends to cover only what is not applicable or insufficiently addressed for HAPS/HAO in the existing regulations and will include relevant parts of regulations not explicitly covering airworthiness in a temporary manner until there is a regulatory framework available into which they can be moved.

The differences from traditional aviation operations and other UAS and the resulting challenges highlighted in this Annex must be addressed to enable safe and secure large-scale worldwide operations of HAPS. It is key that the regulators are aware of the challenges faced by the HAPS community and how they can help in removing regulatory roadblocks to enable the large-scale operation of HAPS. Finding solutions to the challenges will require significant engagement between the industry and regulators. This CS-HAPS seeks to facilitate that discussion.

Background:

Existing aviation requirements and guidelines were developed for various aircraft, e.g. crewed aircraft, various UAS categories including certified and other RPAS, thus they are based on assumptions about the performance and missions of crewed aircraft, and UAS including RPAS. Some of those assumptions are possibly not valid for HAPS which are different from crewed aircraft, or other UAS including RPAS, in the following ways:

1. HAPS can be operated with one craft or in HAPS fleets, and the overall safety risk of a HAPS fleet is a function of how many HAPS are operated.
2. Long-endurance HAPS operations can be 24/7/365 exposing 3rd parties to a different risk profile than more traditional aircraft and UAS flying shorter missions.
3. HAPS do not typically fly from point A on ground to point B on ground. HAPS launch to higher altitude and operate for long periods in higher altitude, potentially changing locations over time. They land for maintenance or for change of mission (e.g. change of payload).
4. The ground risk created by HAPS in nominal operation is not strictly linked to the position overflown at the moment, but is linked to the potential future position that can be tens of kilometers away.
5. HAPS missions typically require operation for months, as opposed to hours, in the stratospheric environment exposed to extreme cold, cosmic and ultraviolet radiations.
6. The turbulence levels are expected to be low in the stratosphere when compared to the atmosphere layers where other aircraft, UAS or RPAS operate.

7. HAPSs typically operate from a private airfield away from other air traffic with infrequent take-off and landing sequences.
8. HAPSs are designed to fly with a relatively slow airspeed, to be lightweight, and less manoeuvrable when compared to crewed aircraft or other UAS including RPAs, in order to minimize energy consumption..
9. HAPS are still a new emerging technology with most of the projects still in development, and new designs can emerge in near future. It is highly difficult and impractical to certify HAPS through demonstration flights - simulations and modelling will be one of the main tools for demonstration of performance on aircraft level, whereas traditional testing is envisioned for most of the subsystems.

International recognition of the Type Certificate will be a key enabler of HAPS operations at scale. Developing a flexible, internationally harmonized process that is consistent with ICAO rules would go a long way in paving the way for a HAPS Type Certification that is internationally recognized. Besides the international recognition of the Type Certificate, which should provide a level of safety acceptable to States, HAPS operations should also be secure, and their intended purposes, like remote sensing and telecommunication, will also have to be accepted by the overflown sovereign states prior to operations.

While performance-based, less prescriptive regulatory requirements allow more flexibility, showing compliance to some of the performance-based requirements poses unique challenges for HAPS due to its unique design, mission, and operating environment. The stratosphere is a relatively new operating environment and our knowledge of it is rapidly expanding. While acknowledging the existing guidelines created for crewed aircraft at lower altitudes, the HAPS community must be able to embrace new learnings and datasets as soon as they are available and will need to choose data sources that are relevant to their application. Industry consensus and dissemination of these datasets combined with extensive testing at all phases of development will be vital to enabling safe and effective HAPS design and operation.

Certification of HAPS involved in HAO in relation to the SORA process

It is the intent that this set of recommendations will support the type certification of HAPS involved in HAO. However, this set of recommendations or part of it may support an operational authorisation for HAPS involved in HAO eligible for authorisation according to the SORA methodology. However, the air risk model defined in the SORA context is currently not suitable for HAPS operation.

RELATED MATERIAL

- Chicago Convention, in particular Article 1 (Sovereignty), Article 8 (Pilotless aircraft), Article 12 (Rules of the Air), Article 29, Article 30, Article 31 (Certificates of airworthiness), etc.
- ICAO regulatory framework, e.g.: Annex 2 (Rules of the Air), Annex 8 (Airworthiness), etc.
- FAA:
    - FAA rules for unmanned free balloons (UFB) (Part 101)
    - ETM & CTMS ConOps (includes NASA, Google, focus on ATM)
- Basic Regulation REG (EU) 2018/1139 and EASA regulatory framework, e.g.:
    - EASA rules for balloons, including for UFB (Unmanned Free Balloons)
    - Reg. EU 2019/947 (UAS), e.g. Article 5 specific operations.
    - SERA (Single European Rules of the Air), e.g. Appendix 2, Etc.
- EASA preparatory activities w.r.t. HAO:
    - EASA HAO Roadmap
    - https://www.easa.europa.eu/en/newsroom-and-events/news/roadmap-higher-airspace-operations-hao-proposed-easa
- SC-RPAS.1309-03

- Existing Certification Specifications for aircraft e.g. 14 CFR Part 23, CS-31 etc.
- SESAR JU ECHO exploratory research project (note: initial ATM-focussed ConOps for Higher Airspace Operations, published on 27 June 2023) https://www.sesarju.eu/sites/default/files/documents/reports/D4.3_ConOps_1.0_public.pdf
- HAPS Alliance White Papers (more than one)
    - P1
    - P2
    - P3
    - P4
- AIA papers on CTMS and Risk, April 2022
- Air Services Australia (Dr. Steve Barry, see slides presented to TF-1 on 22/3/2023): probabilistic model approach to estimate air risks (ground risks not considered) caused by high altitude balloons, on the aviation traffic below (link to ATM separation and airspace safety issues)
- ICAO RPAS Panel (RPASP) (note: the ICAO RPAS Panel initial perimeter [CONOPS, March 2017] excludes fully autonomous operations, excludes the carriage of persons, excludes Multiple Simultaneous Operations as well as high altitude operations > FL600 or FL660)
- ICAO Separation and Airspace Safety Panel (SASP)

DEFINITIONS

Control and Monitoring Unit (CMU) is considered as a unit where a higher level of human intervention to individual crafts is possible (Human in the Loop). It is assumed, the CMU is used during the climb and descent through the controlled airspace. It is expected that only a smaller number of crafts can be managed by a single CMU as communication between the crew in the CMU and the ATC may be required.

Mission Control Centre (MCC) is considered as a unit where human intervention is done by setting goals for the system (Human on the Loop). A high degree of automation is expected which includes appropriate handling of off-nominal situation. It is expected that a large number of crafts can be managed by a single MCC.

High Altitude Platform System (HAPS) is a highly-automated aircraft system, without people on board, designed for persistent high-altitude operations, carried out mostly in the stratosphere. They can be lighter-than-air (**LTA**, buoyant aircraft, balloons, motorized airships) or heavier-than-air (**HTA**, fixed-wing motorized aircraft).

HAPS fleet is a fleet of several HAPS flying simultaneously and pursuing the same goal assigned by one operator.

Higher Airspace Operation (HAO) is aircraft operation conducted within the upper layers of the atmosphere, excluding orbital flights.

Note: this proposed JARUS definition of HAO is somewhat different from those proposed by ECHO or EASA (HAO), but the intent is similar.

HAPS Operation is an operation of HAPS, possibly in a fleet, in HAO while executing a strategic plan for meeting a goal assigned by the operator.

Collaborative Operating Environment (COE) – the environment where separation is maintained by Operators using collaborative traffic management practices.[1]

Air Traffic Control Environment (ATCE) - the environment where Air Traffic Services (ATS) are provided as applicable.

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[1] Collaborative Traffic Management in the Stratosphere (CTMS, Oct. 2019) and Upper Class E Traffic Management (ETM, FAA, May 2020) are examples of prospective CONOPS of COE.

Section 1, General Requirements for HAPS/HAO

SUBPART A – GENERAL

CS-HAPS.2000 Applicability

(see GM-HAPS.2000)

For HAPS as per definitions which cannot be certified with the existing certification specifications.

CS-HAPS.2005 Approved Operating Limitations

(see GM-HAPS.2005)

(a) The applicant must define the limitations of the operation within which safe flight, under normal and emergency conditions will be demonstrated

(b) In defining these limitations, environmental conditions must be considered

(c) There must be a means to prevent exceeding the operating limitations

CS-HAPS.2007 Transportation, reconfiguration and storage

Where a HAPS, or part of the HAPS, is designed to be transportable, assembled & disassembled or reconfigured for transportation, the following applies:

(a) The conditions defined for the transportation and storage must not adversely affect the airworthiness of the HAPS aircraft

(b) Incorrect assembly must be avoided by proper design

(c) Instructions for transportation, disassembling/assembling, reconfiguration and storage and the respective handling must be documented in the appropriate manual

CS-HAPS.2010 Airworthiness Design Standards (ADS)

(see GM-HAPS.2010)

(a) An applicant must comply with CS-HAPS by using an authority accepted Airworthiness Design Standard (ADS) or by other authority accepted means of compliance

(b) An applicant proposing an alternative means of compliance must provide this standard to the authority in a form and manner acceptable to the authority

CS-HAPS.2015 Conditional Initial Airworthiness

(see GM-HAPS.2015)

(a) The complete compliance demonstration for all applicable requirements may be impractical before the initial operation as a result of:

(1) the duration of the intended nominal operation and/or

(2) the operational environment which cannot be adequately simulated.

For these cases, an agreement can be reached between the applicant and the authority on a set of requirements for which the complete compliance can be demonstrated during the operation.

The successful demonstration of compliance under the agreed conditions is mandatory to maintain the validity of the Type Certificate to the issued extent.

(b) If the conditions agreed with the authority according to (a) are not met, following contingencies apply:

(1) landing, or

(2) reversal to the previous flight limits, or

(3) agree with the authority on different conditions for continued flight or flight termination.

SUBPART B – HAO OPERATION

CS-HAPS.2100 Mass and centre of gravity

(a) The applicant must determine limits for mass and centre of gravity that provide for the safe operation of the HAPS

(b) The applicant must comply with each requirement of this subpart at critical combinations of mass and centre of gravity within the HAPS range of loading conditions within the flight envelope according to CS-HAPS.2102

(c) The condition of the HAPS at the time of determining its mass and centre of gravity must be well defined and easily repeatable

CS-HAPS.2102 Approved Flight Envelope

(see GM-HAPS.2102)

(a) The applicant must determine the boundaries of the approved flight envelope within which safe flight, under normal, abnormal and emergency conditions, and emergency recovery capabilities, are demonstrated

(b) In determining the approved flight envelope, the operating limitations according to CS-HAPS.2005 must be considered

(c) There must be means to ensure the HAPS remains within the approved flight envelope

(d) The demonstrated flight envelope must contain a safety margin agreed by the competent authority

CS-HAPS.2105 Performance data

(see GM CS-HAPS.2105)

(a) Unless otherwise prescribed, the performance requirements of this Subpart must be met for ambient atmospheric conditions appropriate for the flight envelope in accordance with CS-HAPS.2102

(b) Performance data must account for losses due to atmospheric conditions, cooling needs, installation, downwash considerations, and other demands on power sources

(c) The methodology to develop the Performance data required by paragraph (a) of this section must be agreed to with the certifying authority

CS-HAPS.2110 Minimum speeds

(see GM-HAPS.2110)
(a) Where one applies, the applicant must determine the HAPS minimum safe speed or the minimum steady flight speed for each flight configuration and phases of flight

(b) If applicable, the minimum safe speed determination must account for the most adverse conditions for each flight configuration within the approved flight envelope

CS-HAPS.2115 Take-Off and minimum performance

(see GM-HAPS.2115)
(a) If applicable, the applicant must determine the HAPS minimum performance required for take-off

(b) If the most critical flight phase is other than take-off, the applicant in addition to (a) must determine the HAPS minimum performance for this flight phase

CS-HAPS.2120 Climb requirements

(see GM-HAPS.2120)
The applicant must determine and demonstrate minimum climb performance at critical combinations of mass, altitude, and ambient temperature within the operating limitations using the procedures published in the flight manual.

CS-HAPS.2125 Rate of descent performance

(see GM-HAPS.2125)
The applicant must determine and demonstrate rate of descent performance in normal operation and after a critical loss of lift at critical combinations of mass, altitude, and ambient temperature within the operating limitations using the procedures published in the flight manual.

CS-HAPS.2130 Landing

(see GM-HAPS.2130)
The applicant must determine the following, for ambient temperatures at critical combinations of mass and altitude within the operating limits:
(a) The area required to land and come to a stop, assuming approach paths applicable to the HAPS

(b) The approach and landing speeds, configurations, and procedures, which allows landing within the determined landing area consistently and without causing injury or unintended damage.

CS-HAPS.2135 Controllability and stability

(see GM-HAPS.2135)

(a) The HAPS must be controllable and manoeuvrable, within the demonstrated flight envelope:

(1) At all loading conditions for which certification is requested

(2) During all phases of flight, including ground phases

(3) With likely reversible flight control or propulsion system failure

(4) During configuration changes

(5) Considering all effects of sensors, and computational delay

(6) In all degraded operating modes of the flight control systems where they exist

(7) In ERC conditions which relay on controllability and stability (see CS-HAPS.2570)

(b) The HAPS must not exhibit any unrecoverable divergent stability characteristic in any phase of flight, including ground phases

CS-HAPS.2155 Ground Handling Characteristics

(a) Safe ground handling procedures must be developed assuming the specified minimum flight and ground crew, and covering all approved configurations, ancillary equipment, environmental conditions including wind conditions.

(b) Ancillary Ground Equipment must be able to safely counteract ground gust conditions and wind shifts. Maximum wind values must be established in accordance with CS HAPS.2180.

CS-HAPS.2160 Vibration and buffeting

(see GM-HAPS.2160)

Each part of the HAPS must be free from excessive vibration and buffeting within the approved flight envelope.

CS-HAPS.2165 Performance and flight characteristics requirements for flight in icing conditions

(a) An applicant who requests certification for flight in icing conditions must show compliance to the requirements in Subpart B in the icing conditions for which certification is requested under normal operation of the ice protection system(s)

(b) The applicant must provide a means to detect any inflight icing conditions beyond the approved icing envelope and demonstrate the ability of the HAPS to avoid flying in or safely exit those conditions

(c) For HAPS not certified for flight in icing conditions, CS-HAPS.2165(b) applies or the applicant must develop operating limitations, so that flight into icing conditions including take-off and landing, is unlikely

CS HAPS.2180 Maximum Wind Velocities

Maximum surface wind velocities for both the flight and the ground handling operations shall be determined and scheduled in the Flight Manual and the Ground Handling Manual.

SUBPART D – DESIGN AND CONSTRUCTION

CS-HAPS.2300 HAPS flight control systems (mechanical systems performing pilot functions)

(a) The flight control systems in accordance with CS-HAPS.2529 which are installed on the craft must be designed to operate easily, smoothly, and positively enough to allow proper performance of their functions

(b) Trim systems, if installed, must be designed to protect against inadvertent, incorrect, or abrupt trim operation

CS-HAPS.2305 Landing gear and ground contact systems

The landing gear or ground contact system must be designed to:

(a) provide sufficiently stable support and / or control to the craft during ground operation; and
(b) account for probable system failures and the operation environment; and
(c) sufficiently absorb the kinetic energy of the landing, taking into account the craft's spring/mass system and virtual inertia where relevant; and
(d) adverse loading conditions must not cause damage to the essential systems of the craft, which could lead to a hazardous or catastrophic event if not detected.

CS-HAPS.2310 Buoyancy for craft for take-off or landing on water

Craft intended for operations on water must provide buoyancy to support take-off or landing in water conditions according CS-HAPS.2005.

CS-HAPS.2320 Ground Crew Protection

(see GM-HAPS.2320)

The ground crew, required to safely conduct the HAPS flight, must be protected against serious injury due to hazards originating from HAPS ground handling.

CS-HAPS.2325 Fire protection

(see GM-HAPS.2325)

(a) The craft must be designed to minimise the risk of fire initiation due to:

  (1) anticipated heat or energy dissipation, system failures or overheat that are expected to generate heat sufficient to ignite a fire

  (2) ignition of flammable fluids, gases or vapours; and

  (3) fire-propagating or -initiating system characteristics

(b) The craft must be designed to minimise the risk of fire propagation by:

  (1) providing adequate fire or smoke detection and notification to the crew and extinguishing means when practical

  (2) application of self-extinguishing, flame-resistant, or fireproof materials that are adequate to the application and location; or

(3) specifying and designing designated fire zones that meet the requirements of CS-HAPS.2330

CS-HAPS.2330 Fire protection in designated fire zones

(see GM-HAPS.2330)

(a) A fire in a designated fire zone must not preclude an emergency recovery according CS-HAPS.2570

(b) Flight control systems, engine mounts, and other flight structures within or adjacent to designated fire zones must be capable of withstanding the effects of a fire in order to avoid a catastrophic effect

(c) Terminals, equipment, and electrical cables used during Emergency Procedures must be fire-resistant or safely shielded.

CS-HAPS.2335 Lightning protection

(see GM-HAPS.2335)

(a) A HAPS subject to certification for operations where the exposure to lightning is likely, must be protected against catastrophic effects of lightning

(b) Operating limitations must be developed to prohibit flight, including take-off and landing, into conditions where the exposure to lightning is likely, for HAPS not certified to operate in these conditions

CS-HAPS.2340 Design and construction information

The following design and construction information must be defined:

(a) operating limitations, procedures and instructions necessary for the safe operation of the HAPS

(b) requirements for instrument markings or placards

(c) any additional information necessary for the safe operation of the HAPS

CS-HAPS.2350 Containment

(see GM-HAPS.2350)

Where the emergency procedure foresees a forced landing or a controlled crash into a designated area the following applies:

(a) The craft must be designed with sufficient self-containment features to minimize the risks resulting from possible debris, fire or explosions extending beyond the forced landing or controlled crash area

(b) The Flight Manual for the crew must contain the characteristics of the forced landing or controlled crash area

CS-HAPS.2360 Non-essential systems, equipment and installation

(see GM-HAPS.2360)

Non-essential systems and equipment, whose functioning is not required to comply with type certification requirements, airspace requirements or operational rules, must be installed and have design characteristics to ensure no hazardous or catastrophic events occur, under any foreseeable operating condition for which the HAPS is certified.

SUBPART E – POWER PLANT INSTALLATION

CS-HAPS.2400 Powerplant installation

(see GM-HAPS.2400)

(a) For the purpose of this Subpart, the craft powerplant installation must include each component that is necessary for propulsion, affects propulsion safety, or provides auxiliary power to the craft

(b) Each craft engine, propeller and auxiliary power unit (APU) must be type certified as part of the HAPS TC or hold an independent TC

(c) The applicant must construct and arrange each powerplant installation to account for:

(1) all likely operating conditions, including foreign object threats;

(2) sufficient clearance of moving parts to other craft parts and their surroundings

(3) likely hazards in operation, including hazards to ground personnel; and

(4) vibration and fatigue

(5) drive systems endurance

(d) Hazardous accumulations of fluids, vapours or gases are isolated or safely contained or discharged

(e) Installations of powerplant components that deviate from the component limitations or installation instructions must be shown to be safe

(f) For the purposes of this Subpart, 'energy' means any type of energy source for the powerplant, including, for example, fuels of any kind or electric current

CS-HAPS.2405 Power or thrust control systems

Power or thrust control systems are systems that intervene with the power selection commanded by the direct power settings by the Flight Control System or the remote crew.

(a) Power or thrust control systems must be designed so no unsafe condition will result during normal operation of the system

(b) Any single failure or likely combination of failures of a power or thrust control system must not prevent continued safe flight and landing of the craft or the emergency recovery according CS-HAPS.2570

(c) Unless the failure of an automatic power or thrust control system is 'extremely remote' or does not result in an unsafe condition, the system must:

(1) provide a means for the Flight Control System or the remote crew to override the automatic function; and

(2) prevent inadvertent deactivation of the system by other systems of the HAPS

CS-HAPS.2410 Powerplant installation hazard assessment

The applicant must assess each installation separately and in relation to other systems and installations of the HAPS to show that any hazard resulting from the likely failure of any system component or accessory will not:

(a) prevent continued safe flight and landing or, if continued safe flight and landing cannot be ensured, an emergency recovery according CS-HAPS.2570 must be initiated

(b) require immediate action by the remote crew for continued operation of any remaining powerplant system

CS-HAPS.2415 Powerplant installation ice protection

(see GM-HAPS.2415)

(a) For HAPS for which certification for flight in icing conditions is requested:

  (1) The craft design must prevent foreseeable accumulation or shedding of ice or snow that adversely affect powerplant operation

  (2) The powerplant installation design must prevent any accumulation of ice or snow that adversely affects powerplant operation in those icing conditions for which certification is requested

(b) For HAPS for which certification in icing conditions is not requested:

  (1) The craft power plant must be protected to be able to escape inadvertent icing condition; or

  (2) Operating limitations must be defined to prevent any inadvertent entry into icing conditions during the flight

CS-HAPS.2425 Powerplant operating characteristics

(a) The installed powerplant must operate without any hazardous characteristics during normal and emergency operation within the range of operation limitations for the craft and powerplant installation

(b) If required for continued safe flight and landing or emergency recovery within the approved flight envelope, the design must allow in flight:

  (1) shutdown of any powerplant or groups of powerplants

  (2) restart of any powerplant

(c) For powerplant containing rotating parts, if continued powerplant rotation after a powerplant shutdown would cause a hazardous event , means must be provided that the powerplant stops rotating

CS-HAPS.2430 Powerplant installation, energy storage and distribution systems

(see GM-HAPS.2430)

(a) Each system must:

  (1) Be designed to provide independence between multiple energy storage and supply systems so that a failure of any one component in one system will not result in the loss of energy storage or supply of another system

  (2) Be designed to prevent catastrophic events due to lightning strikes taking into account direct and indirect effects for craft where the exposure to lightning is likely.

  (3) Provide energy to the powerplant installation with adequate margins to ensure safe functioning under all permitted and likely operating conditions, and accounting for likely component failures

  (4) Provide uninterrupted supply of that energy when the system is correctly operated, accounting for likely energy fluctuations

  (5) Provide a means to safely remove or isolate the energy stored within the system

    (6) Be designed to retain the energy under all likely operating conditions
    (7) Prevent hazardous contamination of the energy supplied to each powerplant installation

(b) Each storage system must:
    (1) withstand the loads under likely operating conditions without failure, accounting for installation
    (2) be designed to prevent significant loss of stored energy under likely operating conditions
    (3) provide energy for Emergency Recovery if needed
    (4) be capable of jettisoning energy safely if this functionality is provided

(c) Each energy-storage-refilling or -recharging system must be designed to:
    (1) prevent improper refilling or recharging
    (2) prevent contamination of the stored energy during likely operating conditions; and
    (3) prevent the occurrence of hazardous events during refilling or recharging

(d) Likely errors during ground handling of the craft must not lead to a hazardous loss of stored energy

CS-HAPS.2435 Powerplant installation support systems

(see GM-HAPS.2435)

(a) Powerplant installation support systems must be designed for the operating conditions applicable to the location of installation

(b) System function and characteristics that have an effect on the powerplant installation system performance must be established

(c) Ingestion of likely foreign objects that would be hazardous to the engine must be prevented

(d) Any likely single failures of powerplant installation support systems that result in a critical loss of thrust must be mitigated

CS-HAPS.2440 Powerplant installation fire protection

The powerplant installation and its support systems must be designed to mitigate catastrophic events due to fire or overheat in operation so that an emergency recovery according CS-HAPS.2575 can be performed.

CS-HAPS.2445 Powerplant installation information

(see GM-HAPS.2445)

The following powerplant installation information must be established:

(a) operating limitations, procedures and instructions necessary for the safe operation of the craft

(b) instrument markings or placards needed for safe operation

(c) inspections or maintenance to ensure continued safe operation

(d) information related to powerplant support systems

(e) techniques and associated limitations for engine starting and stopping; and

(f) energy level information to support energy management, including consideration of a likely component failure within the system

(g) any additional information necessary for the safe operation of the craft

SUBPART F – SYSTEMS AND EQUIPMENT

CS-HAPS 2500.HAPS level system requirements

(see GM-HAPS.2500)
(a) Requirements CS-HAPS.2500, CS-HAPS.2505 and CS-HAPS.2510 are general requirements applicable to the systems and equipment of the HAPS, and should not be used to supersede any other specific CS-HAPS requirement

(b) Equipment and systems required to comply with type certification requirements, airspace requirements or operational rules, or whose improper functioning would lead to a hazard, must be designed and installed so that they perform their intended function throughout the operating and environmental limits for which the HAPS is certified

CS-HAPS 2505.General requirements on equipment installation

(see GM-HAPS.2500)
(a) Each item of installed equipment is installed according to limitations specified for that equipment.

(b) On multi-engine HAPS, engine-driven accessories essential to safe operation must be distributed among multiple engines

CS-HAPS 2510.Equipment, systems and installations

(see GM-HAPS.2500)

(a) The equipment and systems identified in CS-HAPS.2500, considered separately and in relation to other systems, must be designed and installed such that:

(1) each catastrophic failure condition is extremely improbable; and

(2) each hazardous failure condition is extremely remote; and

(3) each major failure condition is remote

(b) The systems and equipment not covered by CS-HAPS.2500 must be designed and installed so their operation does not have an adverse effect on the HAPS throughout the operating and environmental limits for which the HAPS is certified unless the adverse effect does not pose a risk to people on the ground or in the air

CS-HAPS.2512 Models

(see GM-HAPS.2512)

(a) The HAPS must contain a flight-prediction model or equivalent capability to predict flight path to comply with the requirement CS-HAPS.2560.
    (1) The input data to the flight-prediction model must be of sufficient quality and integrity and must sufficiently represent the intended operational environment.

(2) The accuracy and performance of the flight-prediction model must be sufficient to allow for the modelling of future intent according to CS-HAPS.2560.

(b) Where a digital model or a simulation is used to show compliance with the requirements in this CS-HAPS, the model and its input data must sufficiently represent:
  (1) the operational design domain in which the simulation is used,
  (2) the HAPS or its subsystem that is part of the digital model or simulation.

CS-HAPS.2515 Electrical and electronic system lightning protection

(see GM-HAPS.2515)
For a HAPS where the exposure to lightning is likely:
(a) each electrical or electronic system that performs a function, the failure of which would prevent the continued safe flight and landing or emergency recovery of the HAPS, must be designed and installed such that:

(1) the function at the HAPS level is not adversely affected during and after the time the HAPS is exposed to lightning; and

(2) the system recovers normal operation of that function in a timely manner after the HAPS is exposed to lightning unless the system’s recovery conflicts with other operational or functional requirements of the system
(b) each electrical and electronic system that performs a function, the failure of which would significantly reduce the capability of the HAPS or the ability of the crew to respond to an adverse operating condition, must be designed and installed such that the system recovers normal operation of that function in a timely manner after the HAPS is exposed to lightning

CS-HAPS.2520 High-Intensity Radiated Fields (HIRF) Protection

(see GM-HAPS.2520)
(a) Each electrical and electronic system of the HAPS that performs a function, the failure of which would prevent the continued safe flight and landing or emergency recovery of the HAPS, must be designed and installed such that:

(1) the function at the HAPS level is not adversely affected during and after the time the HAPS is exposed to the HIRF environment ; and

(2) the system recovers normal operation of that function in a timely manner after the HAPS is exposed to the HIRF environment, unless the system’s recovery conflicts with other operational or functional requirements of the system
(b) each electrical and electronic system that performs a function, the failure of which would significantly reduce the capability of the HAPS or the ability of the crew to respond to an adverse operating condition, must be designed and installed such that the system recovers normal operation of that function in a timely manner after the HAPS is exposed to the HIRF environment

CS-HAPS.2522 Cyber Security

(see GM-HAPS.2522)
(a) HAPS equipment, systems and networks, considered separately and in relation to other systems, must be protected from intentional unauthorised electronic interactions that may result in catastrophic effects on the safety of the HAPS. Protection must be ensured by showing that the security risks have been identified, assessed and mitigated as necessary.

(b) When required by paragraph (a), the applicant must make procedures and instructions for continued airworthiness (ICA) available that ensure that the security protections of the HAPS equipment, systems and networks are maintained

CS-HAPS.2523 Hazards Related to the Operational Environment

(a) Each system of the HAPS that performs a function, the failure of which would prevent the continued safe flight and landing or emergency recovery of the HAPS, must be designed and installed such that:

(1) the function at the HAPS level is not adversely affected during and after the time the HAPS is exposed to the adverse effects of the operational environment; and

(2) the system recovers normal operation of that function in a timely manner after the HAPS is exposed to an adverse Single Event or other adverse condition, unless the system's recovery conflicts with other operational or functional requirements of the system

(b) each system that performs a function, the failure of which would significantly reduce the capability of the HAPS or the ability of the crew to respond to an adverse operating condition, must be designed and installed such that the system resumes normal operation of that function in a timely manner after the HAPS is exposed to an adverse Single Event or other adverse condition under (a) (2).

CS-HAPS.2525 HAPS power supply, generation, storage, and distribution

(see GM-HAPS.2525)
The on-board generation, storage, distribution and supply of power to each system must be designed and installed to:
(a) supply the power required for operation of connected loads during all approved operating conditions;

(b) ensure no single failure or malfunction will prevent the system from supplying the essential loads required for continued safe flight and landing or emergency recovery; and
(c) have enough capacity, if the primary source fails, to supply essential loads, including non-continuous essential loads for the time needed to complete the function, required for safe flight and landing or emergency recovery

CS-HAPS.2529 HAPS Flight Control System

(see GM-HAPS.2529)

(a) The HAPS flight control system shall be designed to ensure:

(1) that the Emergency Recovery Capability and Procedures according to CS-HAPS.2570 and the Command and Control Contingency requirements according to CS-HAPS.2575 are met
(2) that the Shared intent according to CS HAPS.2560 and the Model according to CS HAPS.2512 can be met.

CS-HAPS.2530 HAPS External lights

(a) Any position lights and anti-collision lights, if required by operational rules, must have the intensities, flash rate, colours, fields of coverage, position and other characteristics to provide sufficient time for another aircraft to avoid a collision

(b) Any position lights, if required by operational rules, must include a red light on the left side of the HAPS, a green light on the right side of the HAPS spaced laterally as far as practical and a white light facing aft as far aft of the HAPS as practicable

(c) Taxi and landing lights or any other equivalent means, if required, must be designed and installed so they provide sufficient guidance for the intended operations

CS-HAPS.2540 Flight in icing conditions

(GM-HAPS.2540)
An applicant who requests certification for flight in icing conditions must show the following in the icing conditions for which certification is requested:
(a) the ice protection system provides for safe operation; and

(b) the HAPS will remain in controlled flight

CS-HAPS.2545 Pressurised systems elements

Pressurised systems must withstand appropriate proof and burst pressures.

CS-HAPS.2550 Equipment containing high energy rotating parts

(GM HAPS.2550)

Equipment containing high-energy rotating parts must be designed or installed such that, in the event they fail;
(a) they are safely contained, or

(b) they cannot damage other systems or structures,

in order to ensure continued safe flight and landing or emergency recovery in accordance with CS-HAPS.2570

CS-HAPS.2555 Installation of recorders

(GM-HAPS.2555)
If recording is required by the operational rules, the system must ensure accurate and intelligible recording, safeguarding and locating of the required data, also in conditions encountered during emergencies, crash, water immersion or fire.

CS-HAPS.2560 Sharing the intent and Conspicuity

(GM-HAPS.2560)
(a) If required by the operational rules, the following systems must be provided on HAPS:
  (1) systems ensuring the sharing of the intent,
  (2) systems ensuring conspicuity,
  (3) systems transmitting status in case the operational flight envelope is exceeded and
  (4) systems transmitting status in case of loss of command , control and communication as described in CS-HAPS.2575.
(b) The accuracy of shared intent for the intended flight operations must be sufficient for dynamic requirements enabling timely execution of deconfliction manoeuvres according to the rules of the operational environment.

(c) The systems referred to in (a) must perform to the accuracy and reliability agreed to by the relevant authorities and as required by the operational environment and rules (e.g. Cooperative Operating Practices(COPs)).

(d) The HAPS must be capable of reaching the intended position shared, within the accuracy level relevant for its operations and as required by the rules of the operational environment (e.g. COPs).

CS-HAPS.2570 Emergency Recovery Capability and Procedures (ERCP)

(GM-HAPS.2570)
The HAPS must have the capability to perform Emergency Procedures according to CS-HAPS and operational rules, to mitigate to the level accepted by the Competent Authority:

(1) Injuries to people on the ground
(2) Injuries to people in the air
(3) Damage to critical infrastructure

CS-HAPS.2575 Command, Control and Communication Contingency

(GM-HAPS.2575)
(a) Where the safe operation of the HAPS requires command, control and communication functionality, the HAPS must initiate adequate contingency procedures following a command, control or communication function loss or a degraded status which no longer ensures safe operation of the HAPS by the crew

(b) The contingency procedures must be specified in the Flight Manual for the crew for each operating situation

SUBPART G – CREW INTERFACE AND OTHER INFORMATION

The complexity of HAPS ground system configuration can vary based on their operational maturity and the scale of operations. HAPS with a single uncrewed vehicle can operate with a single control station. In this case, the control station can be included in the Type Certification and treated as a traditional RPAS. On the other hand, HAPS consisting of several fleets of uncrewed vehicles may have control stations at different locations performing various functions, such as launch and recovery, and fleet or "constellation management" of large groups of craft in High Altitude Operations. In this case, the network of control stations acts more like an airline operations center and may not have to be included in the Type Certification.

While there is recognition of the importance of these ground systems on safety, there is currently no internationally harmonized guideline for certifying such a diverse system. The FAA has the concept of associated elements for UAS which puts all the systems that reside outside the air vehicle, including the control stations, outside the Type Certification boundary. However, separating the control station, from the Type Certification process is inconsistent with ICAO Annex 8, Amendment 108 which requires that the entire UAS system, including the control station (Remote Pilot Station in ICAO language), be covered in the Type Certification for UAS.

With regard to HAPS, there is a difference in the crew interface if the HAPS operates in a controlled airspace with involvement of ATC in an Air Traffic Controlled Environment (ATCE), or if the HAPS operates in a Collaborative Operating Environment (COE) (e.g. under CTMS). Due to this fact, the subpart is divided into two separate sections – Subpart G.ATCE and Subpart G.COE with different requirements pertaining to each of the environments.

SECTION G1.ATCE – CREW INTERFACE AND OTHER INFORMATION – CRAFT SEGMENT

CS-HAPS.2602 Automated Functions and Human Intervention - Craft

The safety requirements applicable to an automated function depend on the level of automation, as well as the human control authority regarding that specific function, and should follow CS-HAPS.2500-2510

CS-HAPS.2612 Equipment and Interfaces for Data Exchange between the craft and the Control and Monitoring Unit (or Remote Pilot Station)

(see GM-HAPS.2612)

(a) Depending on the operational environment, e.g. the airspace, the HAPS must transmit:

- (1) the status of the HAPS
- (2) the performance related to the manoeuvrability
- (3) trajectory information to enable all participants in the operational environment to operate in a safe state.

(b)The transmission in (a) must have sufficient performance (e.g. range, data-rate, frequency) that the surrounding traffic can take appropriate action in a reasonable amount of time to remain in a safe state.

(c) depending on the operational environment, e.g. the airspace, the craft must be equipped to receive the messages according to (a) and (b) to take appropriate action in a reasonable amount of time to remain in a safe state

SECTION G2.ATCE – CREW INTERFACE AND OTHER INFORMATION - CONTROL AND MONITORING UNIT (OR REMOTE PILOT STATION)

CS-HAPS.2600 Control and Monitoring Unit (or Remote Pilot Station) (Performance)

(see GM-HAPS.2600)

(a) The Control and Monitoring Unit (or Remote Pilot Station) must be adequate to support the command and control of the HAPS by the remote crew for the intended operations

(b) The Control and Monitoring Unit (or Remote Pilot Station)and its installed equipment must be qualified for its expected environmental conditions required for safe operation.

CS-HAPS.2603 Automated Functions and Human Intervention applicable to the Control and Monitoring Unit (or Remote Pilot Station)

(a) The safety requirements applicable to the Control and Monitoring Unit (or Remote Pilot Station) depend on:
  - (i) the level of automation and the human intervention authority integrated in the craft regarding those specific functions,
  - (ii) the level of automation and the human intervention authority integrated in the Control and

Monitoring Unit (or Remote Pilot Station) regarding those specific functions,

and should consider CS-UAS.2500 - CS-UAS.2510 accordingly

(b) This evaluation according CS-HAPS.2603 (a) must be performed for:
  (i) all levels of automation of this function for each combination of craft and Control and Monitoring Unit (or Remote Pilot Station)
  (ii) all levels of crew authority to control this function for each combination of craft and the Control and Monitoring Unit (or Remote Pilot Station)

CS-HAPS.2605 Control and Monitoring Unit (or Remote Pilot Station) Human Factors

(see GM-HAPS.2605)
(a) The Control and Monitoring Unit (or Remote Pilot Station) arrangement and its equipment must allow the remote crew to perform their duties without excessive concentration, skill, alertness, or fatigue

(b) All flight, navigation, surveillance, and powerplant controls and displays must be designed so that a qualified remote crew can monitor and perform defined tasks associated with the intended functions of systems and equipment. The system and equipment design must minimise remote crew errors, which could result in additional hazards

(c) Physical security requirements must be considered

CS-HAPS.2615 Controls and Displays required for safe Operation

(see GM-HAPS.2615)
(a) Installed systems must provide the information necessary during each phase of flight to the remote crew who monitor and, where applicable, control the parameters for the safe operation. This information must:

  (1) present the parameters in a manner that the remote crew can monitor the parameters and trends, as needed to operate the HAPS; and

  (2) include limitations, unless the limitation cannot be exceeded in all intended operations

(b) Indication systems that integrate the display of parameters required to safely operate the HAPS, or required by the operational rules, must:

  (1) not be inhibited by other parameters not essential for the remote crew to safely operate the HAPS in any normal mode of operation; and

  (2) in combination with other systems, be designed and installed so information essential for continued safe operation or emergency recovery will be available to the remote crew in a timely manner after any single failure or probable combination of failures

CS-HAPS.2620 HAPS Flight Manual

(see GM-HAPS.2620)
The applicant must provide a HAPS flight manual that must be delivered with each HAPS and contains the following information:

(a) operating limitations and procedures

(b) performance information

(c) loading information

(d) limitations for transportation, reconfiguration and storage

(e) instrument marking and placard information; and

(f) any other information necessary for the safe operation of the HAPS

CS-HAPS.2625 Instructions for Continued Airworthiness (ICA)

(see GM-HAPS.2625)
(a) The applicant must prepare Instructions for Continued Airworthiness that are appropriate for the intended operations of the HAPS

(b) If Instructions for Continued Airworthiness are not supplied with an appliance or product which is part of the HAPS, the continued airworthiness information of these appliances or products must be included in the Instructions for Continued Airworthiness of the HAPS

(c) The Instructions for Continued Airworthiness must contain a Section titled 'Airworthiness limitations' that is segregated and clearly distinguishable from the rest of the document. This Section must set forth each mandatory replacement time, structural inspection interval, and related structural inspection procedure required for type certification. This Section must contain a legible statement in a prominent location that reads: 'The Airworthiness limitations Section is approved and variations must also be approved'

(d) The applicant must develop and implement procedures to prevent structural failures due to foreseeable causes of strength degradation on the HAPS, which could result in loss of control over the HAPS or extended periods of operation with reduced safety margins. The Instructions for Continued Airworthiness must include procedures to address protection of structure

SECTION G1.COE – CREW INTERFACE AND OTHER INFORMATION - CRAFT SEGMENT

CS-HAPS.2602 Automated Functions and Human Intervention - Craft

(see GM-HAPS.2602)

(a) The safety requirements applicable to automated functions and related equipment depend on:
    (i) the level of automation regarding those specific functions
    (ii) the human intervention authority for those specific functions
(b) Where the HAO consists of different types of HAPS with different levels of automation of functions, the evaluation according to CS-HAPS.2602 (a) must be performed for:
    (i) all levels of automation of this function for each type of HAPS
    (ii) all levels of crew authority to control this function for each type of HAPS.

CS-HAPS.2612 Equipment and Interfaces for Data Exchange between the craft and the Mission Control Center

(see GM-HAPS.2612)

(a) The individual HAPS or HAPS fleet involved in the HAO must be able to transmit:

(1) the status of the HAPS

(2) the performance related to the manoeuvrability

(3) trajectory information to enable all participants in the operational environment to operate safely

(4) any other information required by the relevant airspace authorities

(b) The data exchanged in (a) must have sufficient performance (e.g. range, data-rate, frequency) to support the fulfilment of requirements established by relevant authorities for airspace participants within and outside of the fleet operation

(c) Depending on the operational environment (e.g. the airspace and/or type of fleet operation), the individual HAPS or HAPS fleet involved in the HAO must be equipped to receive the data exchanged according to (a) and (b) to take appropriate action in a reasonable amount of time to ensure safe operations

SECTION G2.COE – CREW INTERFACE AND OTHER INFORMATION – MISSION CONTROL CENTER

The mission control center, including the remote crew interfaces and/or interfaces to other essential remote segment systems and equipment ensuring the safe operation of all participants in the operational system may or may not receive airworthiness certification.

Nevertheless, the basic requirements in this Subpart G2.COE should be taken into account to enable the crew to fulfil their task. It was the idea to have these objectives sufficiently generalised to allow a potential integration in different regulatory concepts.

CS HAPS.2600 Mission Control Center (Performance)

(GM-HAPS.2600)

(a) The Mission Control Center (MCC) must be adequate to support the control and/or monitoring of the HAPS involved in HAO for the intended operations

(b) The Mission Control Center and its installed equipment must be qualified against the its expected environmental conditions required for safe operation

CS-HAPS.2603 Automated Functions and Human Intervention applicable to the Mission Control Center

(a) The safety requirements applicable to the MCC depend on:
    (i) the level of automation and the human intervention authority integrated in the craft regarding those specific functions,
    (ii) the level of automation and the human intervention authority integrated in the MCC regarding those specific functions,

and should consider CS-HAPS.2500 - CS-HAPS.2510 accordingly

(b) This evaluation according CS-HAPS.2603 (a) must be performed for:
    (i) all levels of automation of this function for each combination of craft and MCC
    (ii) all levels of crew authority to control this function for each combination of craft and MCC

CS HAPS.2605 Mission Control Center (Human Factors)

(see GM-HAPS.2605)

(a) The MCC arrangement and its equipment must allow the remote crew to maintain sufficient situation awareness without excessive concentration, skill, alertness, or fatigue, such that they are able to intervene when required.

(b) All controls and displays required for safe operation of the HAPS involved in the HAO must be designed so that a qualified remote crew can monitor and perform defined tasks associated with the intended functions of systems and equipment. The systems and equipment design must minimize remote crew errors, which could result in additional hazards

(c) Physical security requirements of the crew must be ensured

CS HAPS.2615 Controls and Displays required for safe operation

(see GM-HAPS.2615)

(a) Installed systems must provide the information necessary during each phase of flight to the remote crew who monitor and, where applicable, control the parameters for the safe operation. This information must:

    (1) Present the parameters in a manner that the remote crew can monitor the parameters and trends as needed and, where applicable, control the HAPS involved in the HAO; and

    (2) include limitations, unless the limitation cannot be exceeded in all intended operations

(b) Indication systems that integrate the display of parameters required to safely operate the HAPS involved in HAO, or required by the operational rules, must:

    (1) Not be inhibited by other parameters not essential for the remote crew to safely operate the HAPS involved in HAO in any normal mode of operation; and

    (2) In combination with other systems, be designed and installed so information essential for safe operation or emergency recovery will be available to the remote crew in a timely manner after any single failure or probable combination of failures

CS HAPS.2620 HAPS Flight Manual

(see GM-HAPS.2620)

The applicant must provide a HAPS flight manual to be delivered with each HAPS intended to participate in HAO which contains the information necessary for the safe operation in HAO.

CS HAPS.2625 Instructions for Continued Airworthiness (ICA)

(see GM-HAPS.2625)

The applicant must prepare Instructions for Continued Airworthiness dedicated for HAPS intended to participate in HAO.

SUBPART H – ANCILLARY SYSTEMS

CS-HAPS.2710 Systems for Launch and Recovery not permanently installed on the HAPS

(see GM-HAPS.2710)

(a) If a Launch System is required for normal operation

(1) The HAPS must achieve sufficient energy and controllability at the end of the launch phase to ensure safe and controllable continuation of the flight under the most adverse combination of the approved environmental and operating conditions

(2) It must be shown that the acceleration sustained by the HAPS during the launch phase is within the loads for normal operation

(3) A launch safety area must be defined as a predetermined geometrical area on the ground in which the HAPS remains after a failure or malfunction in the launch phase, calculated under any combination of approved environmental and operating conditions

(4) The size and shape of the launch safety area shall be stated in the HAPS Flight Manual

(b) If a Recovery System is required for the operation of the HAPS

(1) The Recovery System must safely reduce sufficient energy to ensure a controlled termination of the flight

(2) It must be shown that the deceleration sustained by the HAPS during the recovery phase is within the loads for normal operation, except where the HAPS is not designed for multiple recovery

(3) A recovery safety area must be defined as a predetermined geometrical area in which the HAPS remains after a failure or malfunction in the recovery phase, calculated under any combination of approved environmental and operating conditions

(4) The size and shape of the recovery safety area shall be stated in the HAPS Flight Manual

(c) In the event of a launch (or recovery) as part of a hybrid system, e.g. a balloon carrying a fixed-wing HAPS into the HAO environment and releasing it,

(1) Each part of the hybrid system must be individually certified under the appropriate rule

(2) Any interactions between the craft must be evaluated

GM to Section 1, General Requirements for HAPS

Introduction

Operational concepts for managing large numbers of HAPS are driving requirements that might normally reside in airspace integration into the traditionally separate airworthiness process. For instance, HAPS air vehicles may be required by existing operating rules to carry onboard Detect and Avoid (DAA) systems to ensure separation while operating in airspace not covered by current Air Navigation Service Providers (ANSP). Current commercially available DAA systems are not qualified to operate in the upper airspace and the weight and power requirements for a DAA system that can provide the detection range needed for a slow-moving HAPS will have a significant effect on the performance and hence on the platform viability. To address the challenges related to HAPS operations, Industry and select ANSPs have started discussing cooperative traffic management systems.

The concept of cooperative traffic management enables Operators to maintain safe distance between craft by sharing their future intent and resolving conflicts identified. The data exchange and conflict resolution processes are intended to be governed by Cooperative Operating Practices (COPs) which are agreed to amongst the HAPS Industry Operators and approved by the Regulator.[2] .

Some key terms describing this environment are “highly connected” and “information rich” and these have some direct bearing on airworthiness requirements unique to HAPS operation in Collaborative Operating Environments (COEs). HAPS Operators will need to agree with COPs that require all Operators to share intent, along with some level of statistical uncertainty, and then be able to conform to the shared intent with a high level of certainty. For example, the ASTM USS Interoperability standard covering small UAS in low altitude COEs like UTM, defines this as “95% of the time”. In order to achieve this, an Operator will need to know the performance capabilities of their craft (such as in CS-HAPS.2105 Performance data) as well as have excellent weather modelling capabilities so as to apply the predicted atmospheric effect on the craft that will need to be taken into consideration when an Operator forms their future intent.

As an example, for a balloon Operator, what wind model should be used to predict their craft’s future flight path? Use of a proprietary weather model is common among HAPS Operators since they are very aware of the weather’s impact on their flight path and take great care to develop the best model (which is most often proprietary) of the winds aloft. This example highlights another potential COP, one in which the best estimates of future state should be shared and that each Operator should therefore use their best model coupled with in-depth understanding of their crafts’ performance (CS-HAPS.2105). This realization could lead to another COP – Operators must trust other Operators predictions of future intent. There may also need to be some verification of the Operators’ weather model data integrity – also a concern of the JARUS WG-AW and addressed in CS-UAS Annex B dealing with certification of autonomy.

Naturally, both the data integrity and performance validation will not be perfect. This will result in safety “buffers” being added to the flight path shared intent. This might then require a monitoring program be put in to assess each Operators’ performance over time and potentially shrink the safety buffers leading to another COP that such Safety Buffers can shrink (or expand) over time based on operational performance achieved.

These evolving COPs for operations in COEs place incentives on reliability as well as accurate performance and weather modelling. Better reliability and more precise future shared intent will both serve to increase HAPS densities while maintaining a constant acceptable risk budget. Additionally, having a risk budget established at the discretion of the Regulator and parsed out to Operators would serve to allow HAPS to serve areas in which the Regulator saw a clear benefit to the people they serve, e.g. “connecting the

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[2] In a recent ICAO Drone Enable webinar, Steve Bradford (Chief Scientist for Architecture and NextGen Development, at the Office of NextGen – Federal Aviation Administration) remarked that these COPs for conflict management in Cooperative Operating Environments (COEs) are “like replacing the VFR Rules of the Road for highly connected Operators and aircraft in a rich information environment”.

unconnected", and thus they might be willing to accept a slightly higher risk due to access the perceived benefit that HAPS provide.

GM-HAPS.1 GENERAL

- This Guidance Material (GM) should be used as a guidance to develop one or more Airworthiness Design Standards (ADS) to comply with CS-HAPS
- An Airworthiness Design Standard (ADS) contains a mandatory set of detailed requirements and may contain Acceptable Means of Compliance (AMC) to explain how to comply with the detailed requirements
- Where the means of compliance is not part of the detailed requirement a means of compliance must be developed by the applicant
- Each applicant can either:
    - develop a new ADS to comply with CS-HAPS
    - use an accepted ADS which already complies with CS-HAPS or other accepted Means of Compliance

GM-HAPS.2000 Applicability

This Certification Specification covers as a common part for HAPS the Subparts A, B, D, E, F, G and H. Subpart C is divided into three sections – the applicant is to apply on that section if Subpart C that is relevant to him based on his type of HAPS (fixed-wing, airship, balloon).

HAPS may include systems and elements not physically installed on the aircraft.

GM-HAPS.2005 Approved Operating Limitations

The operating limitations contain:

- Approved Flight Envelope according CS-HAPS.2102
- Environmental conditions such as:
    - Temperature, Humidity (icing)
    - Wind
    - Required amount of energy where the energy is taken out of the environment
    - Electromagnetic environment (incl. lightning)
    - Cosmic radiation environment
    - UV radiation environment
- Operating limitations related to:
    - the type and function of the approved ERCP
    - Airspace entered (COE versus ATCE)
    - Applicable flight rules
    - obstacle clearance height with regard to launch and landing
    - others
- Operating limitations related to the risk budget for a specific operational area that may be defined as part of the Cooperative Operating Practices:

The prevention of exceeding the operating limitations can be done by technical means, manually following approved procedures or a combination of technical means and manually executed procedures.

Exceeding any one of the limitations above means exceeding the approved operating limitations and is considered an emergency, which requires immediate action.

The ADS must contain approved procedures to demonstrate that the HAPS is capable to safely operate within the approved operating limitations.

GM-HAPS.2010 Airworthiness Design Standards (ADS)

(a) In order to receive an approval for an ADS the applicant is expected to establish and substantiate how each requirement of CS-HAPS is met

(b) An alternative ADS developed by the applicant must:

  (1) Contain a set of detailed requirements intended to meet the objective requirement for a specific HAPS design

  (2) Clearly identify how compliance with each requirement of CS-HAPS is achieved through either a specific instruction of the ADS or an operating limitation or combination thereof

  (3) Contain a set of related AMC to explain how to comply with the detailed requirement, where the means/methods of compliance is not obvious, and

(c) An applicant can propose a new ADS by using a reduced or modified set of detailed requirements and/or related AMC, from an accepted ADS. The eliminated or modified detailed requirements must be evaluated by a hazard and risk assessment and operating limitations and conditions must be applied to compensate for the eliminated or modified detailed requirements to ensure the appropriate level of safety

GM-HAPS.2015 Conditional Initial Airworthiness

(a) Given the basic assumptions that:

- HAPS missions typically require operating for months, as opposed to hours for crewed aircraft,
- HAPS operate primarily in the stratospheric environment and are exposed to extreme cold (e.g. -70°C), low air density, cosmic and ultraviolet radiation, ozone and other environmental factors not typically seen at lower altitudes,

the complete compliance demonstration for all applicable requirements may be impractical before the initial operation as these conditions are highly difficult to simulate on ground and are not present in troposphere.

Equipment and systems (such as an electric engine) which should operate continuously for 6 months would require continuous testing of several years. In addition to that, structures and gas envelopes (foils, films, ...) cannot be sufficiently tested in laboratory conditions due to the size of the structures and envelopes to be representative of the designed loads and of the degradation due to above mentioned environmental conditions.

Data from Initial traditional testing (e.g. laboratory/ground/flight testing) is an input into the model and compliance is shown to a selected set of requirements through the model (see CS-HAPS.2512 on the model). The initial operation and surrogate “iron-bird” testing afterwards generates real data that are fed into the initial model which is then improved with this data (updated model). This data acquisition, model improvement and subsequent testing is a repetitive, iterative process.

Failure mode analysis needs to be performed in order to identify the possible points of failure and their effect on the craft as well as possible ways how they can be detected remotely. In a second step, any identified possible failure mode needs to be detected in advance where possible and/or practical. Where direct detection or measurement is not possible, corresponding indications ("finger prints" correlation) must be identified instead and agreed with the authority. These corresponding indications must be acquired during the operation. Where adequate failure prediction is not possible, the craft must be designed with sufficient redundancies or mitigating factors for parts of the craft that could experience the possible failure modes so that any failure does not lead to incidents, increased risk to third parties or excessive crew overload.

The agreement between the applicant and the authority according to (a) may contain conditions e.g. on:

(1) The conditions and limitations under which the intended operation can be performed

(2) The means and method for the complete compliance demonstration

(3) The respective pass/fail criteria

(4) The condition for the next step of alleviation from the agreed conditions and limitations where a stepwise compliance demonstration is agreed

(5) The timeframe in which the compliance must be demonstrated

(6) The time interval for repetitive compliance demonstration activities

(a)(2) The simulation means both models for simulation (see CS-HAPS 2512) as well as simulation by means of laboratory testing.

(b) If the results from the updated, improved model and/or from testing in operation does not meet the set requirements and/or conditions for continued flight under the initially agreed conditions

SUBPART B – HAO OPERATION

GM-HAPS.2102 Approved Flight Envelope

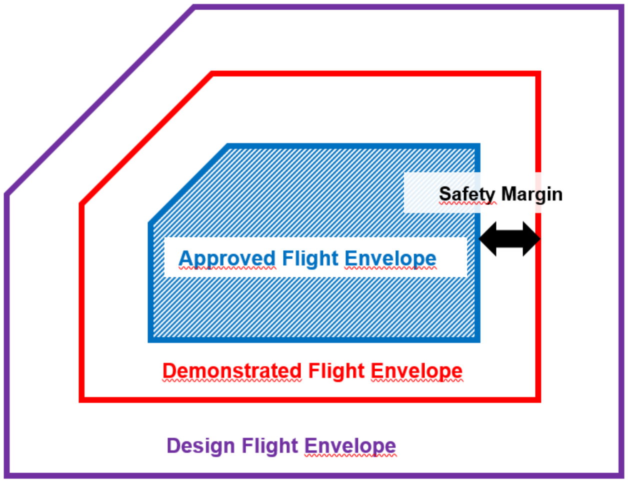
The approved flight envelope defines the limitations within which safe flight, under normal, abnormal and emergency conditions, and emergency recovery capabilities will be ensured. It is therefore expected that the applicant develops a document defining relevant parameters related to the Flight Envelope appropriate for his mission.

The Approved Flight Envelope is the Demonstrated Flight Envelope reduced by a safety margin agreed by the authority e.g. 1.1 V_{NE}

The Demonstrated Flight Envelope defines the operational limitations related to the aerodynamic- and structural limits and is demonstrated either by flight testing or other means of compliance (e.g. simulation) agreed with the competent authority.

If the Demonstrated Flight Envelope is demonstrated up to the limitation of the Design Flight Envelope, the Design Flight Envelope is the Demonstrated Flight Envelope.

The different envelopes are illustrated below:



Ensuring the HAPS remains within the flight envelope can be achieved by technical means, manually following approved procedures or by a combination of technical means and manually executed procedures.

The limitations of the approved flight envelope for abnormal and emergency conditions should take into account the required area in the air for emergency recovery.

GM-HAPS.2105 Performance data

Given the importance that HAPS operations in COEs places on the accurate sharing of future intent, accurate understanding of a craft's performance capabilities is fundamental to maintaining safe and effective airspace management. It is expected that the methodology to develop the performance data utilizes models and that models are validated as part of the certification process.
Performance models and information sources used by the applicant are expected to follow processes defined by the applicant and approved by the relevant authority.
The performance data should be included in the document defining relevant parameters related to the Flight Envelope appropriate for his mission.

GM-HAPS.2110 Minimum speed

Where relevant for the intended aircraft and mission, following guidance applies:

(a) The minimum safe speed must cover each configuration of the aircraft.

(b) Where the configuration can be changed during the flight, the minimum safe speed for the transition should be determined

(c) The minimum safe speed should be determined for each flight phase such as launch/take-off, climb, cruise, descent, approach, and landing

(d) The means to prevent exceeding the flight envelope should contain sufficient safety margin with regard to the minimum safe speed

(e) For multi engine aircraft, the minimum speeds must be defined for the most critical failure combination of engines and propellers, if any.

GM-HAPS.2115 Take-off and minimum performance

For multi engine HAPS, the minimum performance must be evaluated and demonstrated in the most critical configuration including the most critical combination of loss of propulsion.

GM-HAPS.2120 Climb requirements

For multi engine HAPS designed for continued flight after a critical loss of propulsion, the applicant must determine climb performance accounting for the most critical combination of loss of propulsion in the most critical configuration.

Fixed wing HAPS often climb slowly, so they will likely not meet traditional requirements or expectations for climb performance. Measured climb performance may directly influence the takeoff site selection to ensure obstacle clearance.

GM-HAPS.2125 Rate of descent performance

For HAPS not designed for continued safe flight and landing after a critical of loss of propulsion, the applicant must determine the rate of descent performance accounting for the most critical combination of loss of propulsion in the most critical configuration.

This rate of descent applies to any means employed to enable a controlled descent (e.g.: glide, autorotation, parachute, remaining operating engines).

Fixed wing HAPS often descend slowly, so they will likely not meet traditional requirements or expectations for descent gradients. Measured descent performance may directly influence the landing site selection to ensure obstacle clearance.

GM-HAPS.2130 Landing

(b) The determined landing area may not be the same on every flight

GM-HAPS.2135 Controllability and stability

The applicant must determine if there are any critical control parameters, such as V_{MC} or control power margins, and if applicable, account for those parameters where appropriate to develop the respective ADS or means of compliance.

Where compliance demonstration to the performance requirements is based on data obtained by computation or modelling, the stability analysis must be supported by the results of relevant flight tests or simulation (see CS HAPS.2512).

The means to protect against exceeding the demonstrated flight envelope must contain sufficient safety margin with regard to the controllability of the HAPS.

Vortex ring state must be considered for VTOL capable HAPS.

Applicant must demonstrate for VTOL capable HAPS the controllability in vertical operation and ability to land safely within the approved flight envelope.

GM-HAPS.2160 Vibrations and buffeting

When developing the respective ADS, the high speed characteristics must be considered.

SUBPART D – DESIGN AND CONSTRUCTION

GM-HAPS.2320 Ground Crew Protection.

Ground handling hazards may include HAPS high energy sources (e.g. any source of energy like mechanical, electrical or chemical energy). Rotors, propellers and other rotating parts should be considered as well. Hazards coming from LRE energy sources should also be taken into account.

GM-HAPS.2325 Fire protection

The intent of CS-HAPS.2325(b)(3) is that all combustible equipment, fluids and material which can be exposed to a potential ignition source, or are self-igniting and the risk of ignition or propagation cannot be mitigated according CS-HAPS.2325(a) and (b)(1)&(2), is placed in a designated fire zone according CS-HAPS.2330.

GM-HAPS.2330 Fire protection in designated fire zones

(a) A designated fire zone is a zone on the craft within which it is assumed that a severe fire will occur sometime in the service life of any craft

(b) A severe fire, when used with respect to fireproof materials, is one which reaches a steady state temperature of 1100°C ± 65°C / 2'000 ± 150° F for at least 15 minutes

(c) A severe fire, when used with respect to fire resistant materials, is one which reaches a steady state temperature of 1100°C ± 65°C / 2'000 ±150° F for at least 5 minutes

Note:

Source:

Severe Fire. The following thermodynamic definitions are based on AC 20-135, "Powerplant Installation and Propulsion System Component Fire Protection Test Methods, Standards and Criteria" and on the definitions in 14 CFR 1.1 for fire resistant and fireproof materials. These definitions are provided for analytical purposes.

GM-HAPS.2335 Lightning protection

As different sets of requirements may apply to the craft and the remote pilot station, different limitations may apply to the craft and the remote pilot station with due consideration of respective Lightning Risk.

In order to determine that the exposure to lightning is unlikely, reliable weather forecast provided by a recognized Service Provider or onboard lightning detection means should be used.

GM-HAPS.2350 Containment

(a) HAPS which rely on forced landing or controlled crash into a designated area as an emergency recovery procedure should be designed as far as practical so that –

    (1) projection of parts (items of mass to be considered include, but are not limited to engines and payloads) that may constitute a potential injury to people, outside the designated area, is unlikely

    (2) the craft does not constitute a source of ignition or leak of flammable fluids in hazardous quantities, and,

(3) any explosion after the forced landing must not constitute a hazard for people outside the designated area

GM-HAPS.2360 Non-essential systems, equipment and installation

If the HAPS design allows for removable non-essential systems and equipment to be installed by the installer/operator then the following must be defined by the type certificate applicant:

(a) Installation instructions and limitations, including installation interfaces to comply with the requirements of CS-HAPS necessary to demonstrate the "no hazard" criteria

(b) Data describing eligibility and suitability for subsequent installation. Possible conditions and limitations data may include methods, procedures, sketches, drawings, photographs, etc.

(c) Instructions for Continued Airworthiness (ICA) including any data and information referred to in (a) and (b)

In defining the data in (a) and (b) above necessary to prove no hazard, the type certificate applicant should assess at a minimum the following:

(1) Mechanical and electrical interfaces with the craft

(2) Direct and indirect effects of any possible failure and malfunction, including structural failures and structural performance degradation, of the non-essential equipment, system and installation on any essential equipment, systems, installation and primary structure of the HAPS;

(3) Direct and indirect effects of lightning, including zonal assessment, where lightning protection is required as per CS-HAPS.2335

(4) Electromagnetic compatibility

(5) Effect on the flight performances, stability and controllability of the craft

(6) Aeroelasticity, including buffeting and vibration

(7) Mass and balance

(8) Effect on the ICA of the HAPS

(9) Operating limitations

(10) Any other factors affecting the airworthiness of the HAPS, the airspace rules or the operational rules

SUBPART E – POWER PLANT INSTALLATION

GM-HAPS.2400 Powerplant installation

If the installed engines or propellers and APU do not have their own TCs, the ADS should include the corresponding requirements coming from CS-E, CS-P and CS-APU or equivalent specifications (e.g. for electric propulsion).

GM-HAPS.2415 Powerplant installation ice protection

The freezing of condensation is not considered as icing conditions.

GM-HAPS.2430 Powerplant installation, energy storage and distribution systems

The intent of the requirement is to ensure the physical installation of the energy storage and distribution system is designed and installed such that it can perform its intended function.

Energy distribution systems are all elements included in the distribution of the energy to the powerplant system, independent of whether the energy is fuel, electrical power hydrogen etc. As a consequence, the power wires of an electrical powerplant system are part of the distribution system.

GM-HAPS.2435 Powerplant installation support systems

For compliance with this requirement Powerplant installation support systems:

(a) Are all systems whose direct purpose is to support the powerplant or the energy storage device in its intended function as part of the powerplant installation. This includes any air intake, exhaust or venting system

(b) That have a direct effect on the engine availability must be considered in the engine reliability

GM-HAPS.2445 Powerplant installation information

(c) Where the Conditional Initial Airworthiness as per CS-HAPS.2015 is used to show initial compliance for continued operation, the maintenance instructions and inspection intervals as per CS-HAPS.2625 may be combined with CS-HAPS.2015.

SUBPART F – SYSTEMS AND EQUIPMENT

Introduction

There are important differences between traditional aircraft operation and HAPS operation with regard to certification according to Subpart F certification. These differences have impact on the acceptable safety risk. In particular:

- no people are on-board HAPS aircraft
- mission durations are typically in term of months
- the ground risk created by HAPS is not strictly linked to the position overflown at the moment, but is linked to the potential future position that can be tens of kilometres away
- HAPS missions typically require operation in the stratospheric environment exposed to extreme cold, cosmic and ultraviolet radiations
- HAPSs have relatively slower airspeeds, lightweight structures, and limited manoeuvrability
- it is highly difficult and impractical to certify HAPS through demonstration flights - simulations and modelling will be one of the main tools for demonstration of performance on aircraft level, whereas traditional testing is envisioned for most of the subsystems.

The absence of people onboard HAPS creates a fundamentally different risk paradigm as existing CS are intended to protect the people on board the aircraft, and the risk to people on the ground is already included in the risk to people on board the aircraft.[3]

For existing FAR/CS 23 crewed aircraft, safety objectives and the safety assessment process are defined in the FAA guidance material AC 23.1309-1E. Safety objectives in AC 23.1309-1E are tied to aircraft failure

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[3] See AMC RPAS.1309 Scoping Paper Issue 1

conditions and are targeted at managing the risks associated with the effects on aircraft, flight crew, and passengers. For example, AC 23.1309 considers catastrophic failure conditions that are expected to result in multiple fatalities of the occupants, or incapacitation or fatal injury to a flight crewmember normally with the loss of the airplane.

The primary safety risks for HAPS are mid-air collision with aircraft carrying people or damage to persons and property on the ground. For an example on how to address these risks for HAPS and related safety metrics, see Appendix 1 to this CS HAPS. The risk imposed by a HAPS is a function of the operational environment and mitigations incorporated in the HAPS design and flight operations. The risk imposed by a HAPS fleet (constellation/swarm) is a function of:

1) individual HAPS that are part of the HAPS fleet,
2) the interaction between the individual HAPS in the fleet and
3) the operational environment

Similar to GM-HAPS 2102, it is expected that the applicant develops a safety plan indicating the safety targets and how these should be achieved over the mission, especially with regard to the duration of the mission and the operational environment. Where different safety targets apply to different phases of the mission, it is expected that the applicant develops a safety plan indicating the safety targets and how these should be achieved over each phase of the mission.

This safety plan will be an input into the risk budget calculation for a specific operational area that may be defined as part of the Cooperative Operating Practices. In some cases, the risk budget may provide a target level of safety for the safety analysis.

GM-HAPS.2500 Aircraft level system requirements, GM-HAPS 2505 General requirements on equipment installation, GM-HAPS 2510 Equipment, systems and installations

In developing the ADS, the JARUS AMC RPAS.1309 (or an equivalent AMC recognized by the Competent Authority) should be considered in addition to requirements in CS HAPS.

GM-HAPS.2512 Models

(a) It is expected that the HAPS uses a flight-prediction model to predict its flight path. The output of this model are probabilistic data based on which the operator of the HAPS can share the future intent (expected future position of the HAPS) as required by CS-HAPS 2560.
The level of accuracy and performance of the flight-prediction model is dependent on the rules of the operational environment to allow for safe deconfliction of the HAPS.

Meteorological information is input to the flight prediction model. It is expected that a HAPS leverage either its own or a 3rd-party meteorological model to feed data into its own flight-prediction model. The input into such meteorological model are data directly measured by various institutions and companies, and data directly measured by the sensors of HAPS, possibly also by other airborne HAPS (operated either by the same operator, or by other operators).

Improvement in provision of directly measured meteorological data in higher levels of atmosphere and improvement of meteorological models will have high impact on the achieved precision and reliability of the flight-prediction models.

(b) For more detailed information on high complex systems (incl. digital models or simulations), reference is made to Annex C of CS-UAS.

GM-HAPS.2515 Electrical and electronic system lightning protection

Designing HAPS air vehicles to survive the lightning environment adds significant weight, resulting in a significant reduction in performance. This reduction in performance would likely make the platform unviable. Existing requirements assume that the aircraft will encounter lightning during operation. However, most HAPS CONOPs specify that the air vehicle will avoid lightning encounters during take-off and landing. Lightning encounters during operations in the stratosphere are rare and that risk due to lightning can generally be strategically mitigated via HAPS mission planning.

Where operation in the lightning environment is not expected or planned, the processes and systems must be in place to ensure that the HAPS does not encounter lightning.

The lightning environment shall be appropriate for the approved operation and agreed by the authority.

The concept of continued safe flight and landing or emergency recovery of the HAPS should include that the HAPS remains within the approved flight envelope, the intended flight path and within all spatial limitations when the HAPS is exposed to lightning strikes.

GM-HAPS.2520 High-Intensity Radiated Fields (HIRF) Protection

The HIRF environment of the HAPS shall be appropriate for the approved operation and agreed by the authority.

The concept of continued safe flight and landing or emergency recovery of the HAPS should include that the HAPS remains within the approved flight envelope, the intended flight path and within all spatial limitations when the HAPS is exposed to HIRF.

Where operation in the HIRF environment is not expected or planned, the processes and systems must be in place to ensure that the HAPS does not encounter HIRF.

Any radiating payload should be treated according to CS HAPS.2500-2510 and this requirement.

GM-HAPS.2522 Cyber Security

The HAPS operational requirements may include cyber security requirements as needed. The "EASA AMC 20-42: Airworthiness information security risk assessment" can be used as possible guideline to develop the ADS.

Applicants should refer to the JARUS SORA Annex E (Cyber) for the design related OSOs at the "High" levels of robustness. Although HAPS will be in the Certified Category, the Cyber Annex has a lot of value toward meeting this requirement.

GM-HAPS.2523 Hazards Related to the Operational Environment

HAPS should be designed so their performance and safety are not degraded beyond acceptable limits by exposure to the High Altitude environment to include Single Event Effects due to cosmic radiation, solar radiation, degradation of materials, temperature, etc.

Typical tropospheric weather phenomena related to higher humidity in the atmosphere like snow, icing, rain etc. are affecting HAPS only in the ascent and descent through troposphere and can be avoided by operational limitations. In higher altitudes, typically in the stratosphere, a HAPS is mainly affected by environmental conditions such as:

- Temperature, Humidity (icing)
- Wind

- Turbulence and pressure changes
- Required amount of energy where the energy is taken out of the environment
- Electromagnetic environment (incl. lightning)
- Cosmic radiation environment
- UV radiation environment

Some of the environmental conditions in which HAPSs operate are far different from those seen by typical aircraft. Existing guidelines such as RTCA DO-160 are used to specify test conditions for environmentally qualifying components used in traditional aircraft, however, the environmental categories specified in these guidelines do not adequately cover the different environmental conditions experienced by HAPS. As an example, the temperature, shock, and vibration profiles specified in RTCA DO-160 do not represent the wide temperature range and low vibrations experienced by HAPS operating in the stratosphere. In addition to this, ozone and ultraviolet radiation levels are not addressed in RTCA DO-160.

GM-HAPS.2525 HAPS power supply, generation, storage, and distribution

With respect to the RPS, the intent of the objective requirement is not to approve any power generation system supplying the RPS. The intent is to verify the performance of the RPS power source.

GM-HAPS.2529 HAPS Flight Control System

The HAPS flight control system comprises sensors, actuators, computers and all those elements of the HAPS, necessary to control the attitude, speed, trajectory and 3-dimensional position of the HAPS and to ensure the HAPS remains within the approved flight envelope, the intended flight path and within all spatial limitations in all flight phases.

If the approved flight envelope, the intended flight path or the spatial limitations can no longer be ensured, a means to transmit this information to the surrounding aviation system should be available.

HAPS Flight Control System refers to Pilot functions performed by electronic equipment according to predefined rules

1. The spatial limitations may be ensured by geo-fencing or any other technical means to prevent the aircraft from violating the spatial limitations.
2. All flight phases contain all self-movements of the HAPS including take-off and landing. An evaluation of the take-off and landing system is therefore required.
3. For HAPS with trim capability, the Flight Control System (FCS) must trim the HAPS in such a manner that a maximum of control remains and that dynamic characteristics and safety margins are not compromised
4. In case the HAPS requires a crew for safe operation:
    a. The aircraft control system comprises the equipment for the command and control between the aircraft and the RPS
    b. The aircraft control system must provide an alert to the crew for any loss or degradation of the aircraft control system which would affect the ability to safely operate the aircraft

GM-HAPS.2540 Flight in icing conditions

Humidity that freezes at altitude should not be interpreted as icing conditions.

If an ice protection system is installed, the ADS must consider the following:

(a) Protection against an accumulation of ice beyond the structural and performance limitations

(b) Ice shedding will not create any hazard to the HAPS

(c) Effects of the icing protection system to the structure and HAPS performance must be evaluated

GM-HAPS.2550 Equipment containing high energy rotating parts

Propellers are not considered to be high energy rotating parts.

GM-HAPS.2555 Installation of recorders

The ADS must consider that:

(a) The recorder includes features to locate the memory medium after an accident

(b) The recorder should be powered by the most reliable power source and remains powered for as long as possible without jeopardising service to essential or emergency loads and emergency operation of the HAPS.

GM-HAPS.2560 Sharing the intent and Conspicuity

If required by the rules of the cooperative operational environment (COE), the operator must share the future intent of the HAPS, based on the output from flight-prediction model required according to CS-HAPS.2512. This is the expected future flight path of the HAPS with given probability. A safety buffer should be included as a mitigation for any inaccuracies in the prediction due to shortcomings of the HAPS performance model or the atmospheric influence prediction.

The shared future intended position is dynamic information that changes over time. The minimum update rate of future intended position is dependent on the performance of the HAPS, on the rules of operational environment and on the expected use and density of participants in the operational environment. Required update rates will be established amongst the Operators by COPs.

Within nominal operation, the declared intended position should take into account all possible errors and inaccuracies to the level required by the relevant authority, such that the HAPS final position is always within the previously declared intended area. If HAPS is repeatedly not meeting the declared intended position, it should result in increasing the overall safety buffer contained in the declared intended area. This would also influence the potential allocated risk budget over time as written in Appendix 1.[4]

There is an interdependency between CS HAPS-2560 (c) and (d).
Additional discussion on COEs can be found on ICAO website.[5]

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[4] See Appendix 1.

[5] https://www.icao.tv/featured-category/videos/utm-as-an-enabler-for-collaborative-operating-environments

GM-HAPS.2570 Emergency Recovery Capability and Procedures

The aim of the requirement is to ensure the HAPS is capable to perform Emergency Procedures either by the remote pilot or automatically by the on-board systems.

(a) The Emergency Recovery Capability and Procedures (ERCP) must:

    (1) Perform the Emergency Procedures automatically according to the requirements for certification for scenarios when the pilot has lost the ability to perform them remotely (lost link, RPS failure, vortex ring state etc.)

    (2) Achieve the safety targets in accordance with CS-HAPS.2500 through CS-HAPS.2510. This may create the need for operating limitations

    (3) Comply with operational requirements

(b) The Emergency Recovery Capability and Procedures may consist of the following:

    (1) Controlled flight termination system or function:

        i) To reduce the impact energy to an acceptable level

        ii) For a forced landing to an area with an acceptable low population density (down to zero population density)

        iii) To reduce the impact energy together with the population density of the forced landing area such that the risk of fatal injuries on ground caused by the HAPS, possible debris, fire or explosions is acceptable

        iv) To mitigate further movement of the aircraft after the landing that could cause damage or injury beyond acceptable level.

    (2) Predictable continuation of the flight supported by Emergency Procedures:

        i) For a continuation of the flight with the use of on-board systems and either internal or external DAA capability where manual control is no longer possible

        ii) On a predefined path which will be cleared from all other air traffic or which is free from air traffic, which will be followed either manually, or performed by the on-board systems

    (3) Any combination of (b)(1) and (b)(2)

    (4) Any other procedure or technical means accepted by the authority to fulfil the requirement in CS-HAPS.2570

(c) The credit that can be given for the Emergency Recovery Capability and Procedures in relation to other design requirements must be agreed by the authority

(d) Reserved

(e) Critical infrastructures should be defined in accordance with the State where operations are carried out. The ADS could provide detailed definitions

GM-HAPS.2575 Command, Control and Communication Contingency

(a) The intent of this requirement is to have procedures and/or technical functionalities on board in case of a total loss or degraded command and control function. This includes emergencies in the RPS and its environment where the crew is required to evacuate the RPS.

The basic assumptions for this rule are:

(1) The quality of the “signal in space” cannot be guaranteed. Only the equipment involved in transmitting and receiving the “signal in space” can be certified

(2) A total loss or degradation does not necessarily mean the Emergency Recovery Capability and Procedure in accordance with CS-HAPS.2570 needs to be initiated immediately

(3) The transition times before the HAPS begins the contingency procedures due to the command and control function loss must be consistent with the Emergency Recovery Capability and Procedure established in accordance with CS-HAPS.2570. The transition times which are needed to safely perform the Contingency Procedures must be specified in the Flight Manual for the crew

(b) After the total loss of the command and control function or a degradation to a point where remote active control of the HAPS in a timely manner appropriate to the airspace and operating conditions is no longer ensured.

(1) The Remote Pilot Station (RPS) must provide an alert to the crew, and

(2) The onboard system shall execute pre-defined procedures[6]. These pre-defined procedures may contain:

i) Procedures to re-establish the command and control function to the original or any other available RPS

ii) Execution of an Emergency Recovery Capability and Procedure in accordance with CS-HAPS.2570

iii) Procedures to safely continue the flight without activating the ERCP by utilizing onboard installed systems

iv) Any combination of (i) through (iii)

(c) There shall be a means to transmit to the surrounding aviation system the relevant information about the HAPS contingency procedures

SUBPART G – CREW INTERFACE AND OTHER INFORMATION

SECTION G1.ATCE – CREW INTERFACE AND OTHER INFORMATION - CRAFT SEGMENT

GM-HAPS.2612 Interface to the HAPS segments not installed in the aircraft

In the ATCE, a flight plan explaining the limitations and requirements can substitute this section.

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[6] See DO-400 Guidance Material: Standardized Lost C2 Link Procedures for Uncrewed Aircraft Systems

SECTION G2.ATCE – CREW INTERFACE AND OTHER INFORMATION - The Control and Monitoring Unit (or Remote Pilot Station)

GM-HAPS.2600 Control and Monitoring Unit (or Remote Pilot Station) (Performance)

(a) The physical parameters (e.g. size, temperature, power supply, earth bonding, maximum capacity …) deemed as essential for operation and that define the infrastructure suitable for the control station must be stated in the HAPS Flight Manual

(b) The Control and Monitoring Unit (or Remote Pilot Station) equipment operating conditions (temperature, humidity, air quality, ventilation, vibration, noise, heat emissions …) must be adequate to allow the safe execution of the flights under the established conditions in (a)

(c) In non-stationary Control and Monitoring Unit (or Remote Pilot Station) , the effect of Control and Monitoring Unit (or Remote Pilot Station) motion must be considered

(d) The Control and Monitoring Unit (or Remote Pilot Station) should provide an unimpeded and rapid escape to the crew (see GM-HAPS.2575)

GM-HAPS.2605 Control and Monitoring Unit (or Remote Pilot Station) (Human Factors)

The Control and Monitoring Unit (or Remote Pilot Station) equipment should be shown, individually and in combination with other such equipment, to be designed so that qualified remote crew members trained in its use can safely perform their tasks associated with its intended function by meeting the following requirements:

(a) controls should be designed to allow accomplishment of these tasks and information necessary to accomplish these tasks should be provided

(b) controls and information intended for crew use should:

  (1) Be presented in a clear and unambiguous form, at resolution and precision appropriate to the task

  (2) Be accessible and usable by the crew in a manner consistent with the urgency, frequency, and duration of their tasks

  (3) Be plainly marked as to its function and method of operation, except these controls whose function is obvious, and

  (4) Enable crew awareness, if awareness is required for safe operation, of the effects on the aircraft or systems resulting from crew actions

(c) Operationally-relevant behaviour of the installed equipment should be:

  (1) Predictable and unambiguous, and

  (2) Designed to enable the crew to intervene in a manner appropriate to the task

(d) The equipment should allow the crew member to perform his duties without unreasonable concentration, fatigue or workload.

(e) To the extent practicable, installed equipment should enable the crew to manage errors resulting from crew interactions with the equipment that can be reasonably expected in service, assuming the crew is acting in good faith

(f) The crew workplace conditions (temperature, humidity, air quality, ventilation, vibration, noise, heat emissions …) must be adequate to allow the safe execution of the flights

(g) The crew workplace lights, if available must:

  (1) make each indicator, data display, information, markings, placard and control easily readable and discernible

(2) be installed so that their direct rays, and rays reflected from any surface, are shielded from the crew's eyes

(h) Physical security requirements must be developed as needed within the ADS to protect the Control and Monitoring Unit (or Remote Pilot Station) and the crew (e.g. access control) from intentional unauthorized acts that may prevent continued safe flight and landing or emergency recovery.

GM-HAPS.2615 Flight, navigation, and powerplant instruments

If it is desired to hide some parameters from full-time display, an equivalent level of safety to full-time display shall be demonstrated. Criteria to be considered include the following :

(a) Continuous display of the parameter is not required for safety of flight in all normal flight phases.

(b) The parameter is automatically displayed in flight phases where it is required

(c) The hidden parameter is automatically displayed when its value indicates an abnormal condition, or when the parameter reaches an abnormal value

(d) Display of the hidden parameter can be manually selected by the remote crew without interfering with the display of other required information

(e) If the parameter fails to be displayed when required, the failure effect and compounding effects should meet the requirements of CS-HAPS.2500 up to 2510. The analysis is to clearly demonstrate that the display(s) of data is consistent with safe operation under all probable operating conditions

(f) The automatic, or requested, display of the hidden parameter should not create unacceptable clutter on the display; simultaneous "pop-ups" should be considered

(g) If the presence of the new parameter is not sufficiently self-evident, suitable alerting should accompany the automatic presentation

GM-HAPS.2620 HAPS Flight Manual[7]

The procedures to be covered by the ADS must consider:

(a) Normal procedures

(b) Abnormal procedures

(c) Emergency procedures

(d) Procedures for launch and recovery systems or equipment

(e) Performance Data

GM-HAPS.2625 Instructions for Continued Airworthiness (ICA)

CS-HAPS.2625 (a) applies for all systems (powerplant, mechanical-, electrical-, electronical-, hydraulic-, pneumatic- etc. system).

Discussion material - we are looking for ideas and comments on the following points:

reference to Part 21 – if minor, operator applies the changes; if major, regulator needs to be addressed before any changes are applied; middle ground – follow the process – this process needs to be sufficiently robust and needs to be approved by the regulator

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[7] ASTM F2908 or other reference could be used to provide guidance on the FM contents

approval process has 2 parts: 1st part – neither minor, no major -> middle ground, 2nd part – middle ground, what to do about it

example: database switchover

Update on redundant systems – doing one by one (likelihood of the system not being currently in use and not likely to be used during the update)

Where the update may have impact on C2 link, communication or manoeuvrability, inform the environment that this update will be taking place during next *x* minutes. Potentially degraded capability of the aircraft during the update.

Document all the processes and updates - configuration management must be properly done.

Middle ground may not include the cases pertaining to the performance of the aircraft?

Where in-flight maintenance is required with regard to ICA – CS.HAPS 2625 (apply similarly CS-HAPS.2015?):

(1) Inflight upgrades and patches

(2) Inspection Intervals

(3) Use of Predictive Maintenance

SECTION G1.COE – CREW INTERFACE AND OTHER INFORMATION - CRAFT SEGMENT

The requirements and Guidance in SUBPART G1.COE – CREW INTERFACE AND OTHER INFORMATION must be interpreted for operation in COE to address these specific operations.

In case of operation in COE relative to each other, it may be sufficient that only the leading aircraft transmits certain required information. The remote pilot must be made aware of abnormal or emergency situations with any of the aircraft involved in the operation in COE.

GM-HAPS.2602 Automated Functions and Human Intervention - Craft

Operation in COE may require a high level of automation in the HAPS and the required infrastructure on the ground to ensure continued safe flight for all HAPS involved in the operation in COE.
The rigor of certification depends on the criticality of the function, system or subsystem according to CS-UAS.2500 to CS-UAS.2510.
In general, a higher level of automation requires more stringent airworthiness requirements set to the automated function and potentially different requirements on the MCC.
When all emergency conditions can be handled by automated functions themselves, no technical requirements are specified for the MCC.

When the crew is “in” or “on the loop” for contingencies from abnormal and emergency conditions, competency requirements should be developed by the operator for operation in the COE.

Guidance for levels of automation, crew authority to control the flight and corresponding safety consideration can be found in the JARUS Document “JARUS Methodology for Evaluation of Automation for UAS Operations”.

Management of operation in COE requires automation to ensure sufficient management over the operation. It is assumed that:

- The different functions within a HAPS can have different levels of automation, and/or
- That HAPS participating in operation in COE, including a HAPS fleet, can have different levels of automated functions.
- The different levels of automated, interdependent functions may lead to different human intervention possibilities.

The Table below shows the Flight Control Authority at Different Levels of Automation. For the definition of the different levels of Autonomy, please refer to the JARUS Document “Methodology for Evaluation of Autonomy for UAS Operations”.

	Flight Control Authority		
Level of Automation	Normal	Abnormal	Emergency
Level 0	Human		
Level 1	Human AND Machine[1]	Human	Human
Level 2	Human AND Machine		Human
Level 3	Machine	Human AND Machine[2]	Human[3]
Level 4	Machine		Human AND Machine[4]
Level 5	Machine[5]		

	Flight Control Authority		
Level of Automation	Normal	Abnormal	Emergency
Level 0	Human		
Level 1	Human AND Machine[1]	Human	Human
Level 2	Human AND Machine		Human
Level 3	Machine	Human AND Machine[2]	Human[3]
Level 4	Machine		Human AND Machine[4]
Level 5	Machine[5]		

Note 1: This shared authority is design-dependent – the design will dictate to what degree authority is provided to the machine vs. the human and the degree may vary from function to function.

Note 2: This shared authority has the machine making the decision but allows the crew to override decisions.

Note 3: The human can always override the machine to manage the flight operations.

Note 4: Both the machine and human can manage the emergency. The machine will keep trying to recover the system, but the human has the ultimate decision to take over. Ultimate responsibility for the outcome lies with the human operator (as described above). The machine needs to declare the emergency as it has sole awareness of the system condition and authority to monitor and declare the emergency. The human has the authority (which may not be sole authority depending on the design of the system) to take any action within the bounds of the declared emergency (e.g., terminate flight, advise ATC and other airspace users of emergency procedures/manoeuvres).

Note 5: For cases where a superordinated authority (e.g., ATC) has responsibilities to ensure the safety of the airspace there may be emergencies which require them to provide direct or indirect commands to manage the emergency. The ability to do this will depend on the particular airspace design and the availability of supporting infrastructure.

As mentioned, it is assumed, that in an operational environment with multiple heterogeneous and simultaneous operations, a superordinated system supports the controlling and supervision of the operational environment to ensure the continued safe flight and landing of all participants. This superordinate system itself may have automated functions and different possibilities or levels of human intervention as well.
Safe operation depends to a large extent on the interdependent functions that make up the overall system working together as intended.

The different levels of automated interdependent functions combined with different human intervention possibilities may results in function and/or system dependencies. These dependencies must be evaluated. The JARUS Document “JARUS Methodology for Evaluation of Automation for UAS Operations” describes a path to a Capability Dependency Matrix, which can be utilized for this evaluation.

The rigor of certification depends on the criticality of the function, system or subsystem according to CS-HAPS.2500 to CS-HAPS.2510.

GM-HAPS.2612 Equipment and Interfaces for Data Exchange between the craft and Mission Control Center

(a) The information required in CS-HAPS.2612(a) should be transmitted by either:
    (1) One single HAPS involved in the operation in COE
    (2) All individual HAPS involved in HAPS fleet operation in COE as individual messages
    (3) A collective message representing all involved HAPS transmitted by:
        (i) One single HAPS involved in the operation in COE

        (ii) All individual HAPS involved in HAPS fleet operation in COE as collective message
    (4) Any combination of the above (1) to (3).

It may be sufficient for a fleet operation in COE where the individual HAPS are operating relative to each other (e.g. swarm or formation) that only one HAPS involved HAPS fleet operation in COE transmits the actual data related to the manoeuvrability and the intended trajectory information for all involved HAPS. For other types of operations, it may be required that all participating HAPS transmit this information individually. This latter condition will be most prevalent when there are a number of different operators each with their own fleet of HAPS.

(b) The transmission performance should consider the manoeuvrability of the HAPS involved in operations in the COE as well as the needs driven by the operational environment. It is assumed that the operational environment is shared with other participants with potentially significant differences in velocity/manoeuvrability. Therefore, the safety distances (e.g. Remain Well Clear, RWC) that allow for a safe operation should be time based unless distance-based separation supports safer operations.

(c) The "appropriate action in a reasonable amount of time to ensure safe operations" should be understood to be initiated:

    (1) By the participants in a COE

    (2) By the HAPS itself
    (3) A combination of (1) and (2)

SECTION G2.COE – CREW INTERFACE AND OTHER INFORMATION - MISSION CONTROL CENTER

GM-HAPS.2605 Mission Control Center (Human Factors)

(c) The intent of the physical security requirements is to provide access control and threat mitigation to the MCC. This is to ensure that the crew can fulfil their duties without physical interference from uninvolved parties.

See also GM to SUBPART G2.ATCE – CREW INTERFACE AND OTHER INFORMATION THE CONTROL AND MONITORING UNIT (OR REMOTE PILOT STATION) where relevant. Control and Monitoring Unit (or Remote Pilot Station) is to be interpreted for this section as Mission Control Center.

SUBPART H – ANCILLARY SYSTEMS

GM-HAPS.2710 Systems for Launch and Recovery not permanently installed on the aircraft

This requirement applies to systems required for the launch and recovery of the HAPS which are not permanently installed and may be used for multiple HAPS. The equipment which is part of these systems is known as Launch and Recovery Equipment (LRE). Such systems are sometimes referred to as "Associated Elements".

The Launch and Recovery Equipment, even if not permanently installed on the aircraft, is part of the HAPS and therefore the requirements CS-HAPS.2500 up to 2510 apply.

The launch phase ends when the HAPS leaves the flight safety area associated to the launch safety area required in CS-UAS.2710.

CS-HAPS.2710(b) applies as well for recovery systems required by CS-HAPS.2570.

The energy referred to in CS-HAPS.2710(a)(1) and (b)(1) includes all types of energy required for a safe launch or recovery of the HAPS.

The intent is to open two options for the launch and recovery system (LRE) with relation to the launch or recovery safety area in (a)(3) and (b)(3):

(1) For systems where only the performance of the LRE is defined, the requirements in appropriate Subpart C and Subpart D may be met by equivalent level of safety. Therefore, the structural integrity of the LRE may not be ensured and the loss of the structural integrity of the LRE must be considered in the calculation of the safety area

(2) All parts of the LRE for which strength degradation could result in fatal injuries or loss of the HAPS must comply with the applicable requirements in appropriate Subpart C and Subpart D. Therefore, the structural integrity of the LRE is ensured and the loss of the structural integrity of the LRE need not be considered in the calculation of the safety area.

Section 2, Requirements for HTA fixed wing HAPS

SUBPART C – STRUCTURES

CS-HAPS.2200 Structural design envelope

(see GM-HAPS.2200)

The applicant must determine the structural design envelope, which describes the range and limits of aircraft design and operating parameters for which the applicant will show compliance with the requirements of this Subpart. The applicant must account for all aircraft design and operating parameters that affect structural loads, strength, durability, and aeroelasticity, including:

(a) structural design speeds

(b) flight and ground load conditions to be expected in service

(c) mass variations and distributions over the applicable mass and centre of gravity envelope, within the operating limitations

(d) loads in response to all designed control inputs

(e) rotors/fans/propellers rpm ranges for power-on and power-off

(f) rotational speed ratios between powerplant and each connected rotating component; and

(g) redistribution of loads if deflections under load would significantly change the distribution of external or internal loads

CS-HAPS.2205 Interaction of systems and structures

(see GM-HAPS.2205)

For aircraft equipped with systems that affect structural performance, either directly or as a result of failure or malfunction, the applicant must account for the influence and failure conditions of these systems when showing compliance with the requirements of this Subpart.

CS-HAPS.2210 Structural design loads

(see GM-HAPS.2210)

The applicant must determine structural internal and external design loads at all critical combinations of parameters, at and within the boundaries of the structural design envelope.

CS-HAPS.2215 Flight load conditions

(see GM-HAPS.2215)

The applicant must determine flight load conditions, to ensure:

(a) Critical flight loads are established for symmetrical and asymmetrical loading from all combinations of speeds and load factors at and within the boundaries of the manoeuvre and gust envelope

(b) Vibration, including air resonance, and buffeting does not result in structural damage up to the maximum design speed

(c) Flight loads resulting from a likely failure of an aircraft system, component, engine, rotor or propeller are determined

CS-HAPS.2220 Ground and water load conditions

(see GM-HAPS.2220)

(a) The applicant must determine the structural design loads resulting from taxi, take-off, launch, landing, handling and transportation conditions on the applicable surfaces in normal and adverse attitudes, configurations and conditions

(b) The aircraft must have no tendency to develop dangerous ground resonance in normal conditions

(c) If the aircraft is equipped with ground resonance prevention subsystem, the aircraft must have no tendency to develop dangerous ground resonance after any likely failure

CS-HAPS.2225 Component loading conditions

(see GM-HAPS.2225)

(a) The applicant must determine the loads acting upon all relevant structural components in response to:

  (1) interaction of systems and structures

  (2) structural design loads

  (3) flight load conditions

  (4) ground and water load conditions

  (5) powerplant

  (6) drive system

(b) Pressurised compartments must be designed to withstand the differential pressure loads corresponding to the maximum relief valve setting multiplied by an appropriate safety factor (e.g. 1.33 as defined in CS-23), without considering other loads

(c) The applicant must determine the structural design loads acting on rotor assemblies, considering loads resulting from flight and ground conditions, as well as limit input torque at any rotational speed.

CS-HAPS.2230 Limit and ultimate loads

(see GM-HAPS.2230)

(a) Unless special or other factors of safety are necessary to meet the requirements of this Subpart, the applicant must determine:

  (1) the limit loads, which are equal to the structural design loads; and

  (2) the ultimate loads, which are equal to the limit loads multiplied by a 1.5 factor of safety unless otherwise provided

(b) Some strength specifications are specified in terms of ultimate loads only, when permanent detrimental deformation is acceptable

CS-HAPS.2235 Structural strength

The structure must support:

(a) limit loads without:

(1) interference with the safe operation of the aircraft; and

(2) detrimental permanent deformation

(b) ultimate loads without failure

CS-HAPS.2240 Structural durability

(see GM-HAPS.2240)

(a) The applicant must develop and implement inspections or other procedures to prevent structural failures due to foreseeable causes of strength degradation, which could result in fatal injuries, or extended periods of operation with reduced safety margins. Each of the inspections or other procedures developed under CS HAPS.2240 and/or CS HAPS.2015 must be included in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness required by CS HAPS.2625

(b) Unless it is not practical, the procedures developed for compliance with CS HAPS.2240(a) and/or CS HAPS.2015 must be capable of detecting structural damage or partial failure before the damage could result in a catastrophic structural failure

(c) For aircraft with pressurised compartments:

(1) the aircraft must be capable of continued safe flight and landing or emergency recovery following a sudden release of pressure in any pressurised compartment, as a consequence of any probable cause

(2) for aircraft with compartments subject to pressurisation cycles the procedures developed for compliance with CS HAPS.2240(a) must be capable of detecting damage to the pressurised compartment structure before the damage could result in rapid decompression or in a structural failure that would result in a catastrophic event

(d) The aircraft must be designed to minimise hazards to the aircraft due to structural damage caused by high-energy fragments from an uncontained engine or rotating-machinery failure

CS-HAPS.2245 Aeroelasticity

(a) The aircraft must be free from flutter, dangerous control reversal, and divergence:

(1) at all speeds within and sufficiently beyond the structural design envelope

(2) for any configuration and condition of operation

(3) accounting for critical degrees of freedom; and

(4) accounting for any critical failures or malfunctions

(b) The applicants' design must establish tolerances for all quantities that affect flutter

CS-HAPS.2250 Design and construction principles

(a) Each part, article, and assembly must be designed for the expected operating conditions of the aircraft

(b) Design data must adequately define the part, article, or assembly configuration, its design features, and any materials and processes used

(c) The suitability of each design detail and part having an important bearing on safety in operations must be determined

(d) The flight control system must be free from jamming, excessive friction, obstruction and or excessive deflection when the aircraft is subjected to expected limit air loads

(e) Doors, access panels and canopies must be protected against inadvertent opening in flight, unless shown to create no hazard, when opened in flight

CS-HAPS.2252 Critical Parts

(see GM-HAPS.2252)

(a) A critical part is a part of any aircraft, the failure of which could prevent continued safe flight and landing or emergency recovery of the aircraft and for which critical characteristics have been identified which must be controlled during design and production to ensure the required level of integrity.

(b) If the type design includes critical parts, a critical parts list shall be established. Procedures shall be established to define the critical design characteristics, identify processes that affect those characteristics, and identify the design change and process change controls necessary for showing compliance with the applicable quality assurance requirements recognized by the Competent Authority .

CS HAPS.2255 Protection of structure

(see GM-HAPS.2255)

(a) Each part of the aircraft, including small parts such as fasteners, must be protected against deterioration or loss of strength due to any cause likely to occur in the expected operating environment

(b) Each part of the aircraft must have adequate provisions for ventilation and drainage

(c) For each part that requires maintenance, preventive maintenance, or servicing, the applicant must incorporate a means into the aircraft design to allow such actions to be accomplished.

(d) There must be enough clearance between movable or rotating parts (such as propellers or rotor blades) and other parts of the structure to prevent the movable or rotating parts from striking any part of the structure during any operating condition including emergency recovery

CS-HAPS.2260 Materials and processes

(a) The applicant must determine the suitability and durability of materials used for parts, articles, and assemblies, the failure of which could prevent continued safe flight and landing or emergency recovery, accounting for the effects of likely environmental conditions expected in service

(b) The methods and processes of fabrication and assembly used must produce consistently sound structures. If a fabrication process requires close control to reach this objective, the applicant must define the process with an approved process specification as part of the design data

(c) Except as provided for in CS HAPS.2260(f) and (g), the applicant must select design values that ensure material strength with probabilities that account for the criticality of the structural element. Design values must account for the probability of structural failure due to material variability

(d) If material strength properties are required, a determination of those properties must be based on sufficient tests of material meeting specifications to establish design values on a statistical basis

(e) If thermal or humidity effects are significant on a critical component or structure under normal operating conditions, the applicant must determine those effects or account for them as per CS-HAPS.2015

(f) Design values, greater than the minimums specified by CS HAPS.2260(c)(d)(e), may be used, where only guaranteed minimum values are normally allowed, if a specimen of each individual item is tested before use to determine that the actual strength properties of that particular item will equal or exceed those used in the design

(g) An applicant may use other material design values if specifically approved by the Authority

CS-HAPS.2265 Special factors of safety

(a) The applicant must determine a special factor of safety for each critical design value for each part, article, or assembly for which that critical design value is uncertain, and for each part, article, or assembly that is:

  (1) likely to deteriorate in service before normal replacement; or

  (2) subject to appreciable variability because of uncertainties in manufacturing processes or inspection methods

(b) The applicant must determine a special factor of safety using quality controls and specifications that account for each:

  (1) type of application

  (2) inspection method

  (3) structural test requirement

  (4) sampling percentage; and

  (5) process and material control

(c) The applicant must multiply the highest pertinent special factor of safety in the design for each part of the structure by each limit load and ultimate load, or ultimate load only, if there is no corresponding limit load.

GM to Section 2, Requirements for HTA fixed wing HAPS

SUBPART C – STRUCTURES

GM-HAPS.2200 Structural design envelope

(a) As far as the design speed envelope is concerned, the ADS must consider the following elements:

  (1) for fixed wing configuration structural design airspeeds to be considered when determining the corresponding manoeuvring and gust loads must:

    (i) be sufficiently greater than the stalling speed of the aircraft to safeguard against loss of control in turbulent air; and

    (ii) provide sufficient margin for the establishment of practical operating limiting airspeeds

(b) For the ground loads, the ADS must also consider transportation, reconfiguration and storage (wind speed, light conditions, shock and vibration, water and moisture effect, particulate matter, electromagnetic fields, thermal conditions and wearing), where part of the approved operating envelope

(c) When defining aircraft design and operating parameters that affect structural loads, strength, durability, and aeroelasticity, credit may be taken for an installed automatic flight envelope protection system provided the requirement in CS-HAPS.2205 is met

One of the existing performance-based structural requirements is to demonstrate, through analysis and test, that HAPS structures can withstand the expected turbulence encountered during the HAPS mission. The existing prescriptive design guidelines traditionally used as a means of compliance to these requirements are based on aircraft data collected at lower altitudes, from aircraft which spend a far higher percentage of their mission at those lower altitudes. These guidelines may not be appropriate for the majority of the operating environment in which HAPS are expected to operate, and the statistical guidelines in the portions of the environment that *are* represented are likely overly conservative, given typical HAPS operational restrictions (e.g. avoiding windows of inclement weather during launch and recovery).

Existing guidance specifies turbulence amplitudes that have implicit assumptions of dynamic similarity to past—non-span-loaded, higher wing loading—designs, and that also assume a similar mission type (e.g. passenger carrying operations). Older criteria—for example, 14 CFR Part 25 Appendix G—attempt to describe the atmospheric turbulence environment as the probability of any given level of turbulence as a function of altitude. This suggested statistical description is at least an attempt to describe the whole environment, rather than imposing specific amplitudes that are based on assumptions about aircraft and missions. Again, the statistics are still potentially overly conservative at low altitude (because HAPS have more operational restrictions than traditional aircraft) and they are lacking in statistically significant data at higher stratospheric altitudes where HAPS intend to operate for months at a time. Since this statistical description was published in the 1960s, many new measurement and modeling efforts for turbulence at all levels in the atmosphere have been undertaken. Google Loon, for example, has collected over 2 million hours of environmental data at stratospheric altitudes. While many of these new modeling or measurement datasets are available, most have not been distilled down into relevant high-altitude statistical guidance suitable for the aircraft designer. Nor have many of these been recognized and vetted by regulatory agencies to the same extent that existing guidance has been.

Given an accurate description of the turbulence environment in which HAPS operate a mission design approach (such as that suggested in the former 14 CFR Part 25 Appendix G) will allow HAPS structures to be designed to a required structural exceedance rate. These designs can take advantage of HAPS primarily high-altitude operations and operational restrictions such as picking takeoff and landing times or being able to move away from storms. For instance, turbulence hazards caused by the ‘Jet Stream’ and wind shear effects are a major consideration in determination of launch and recovery timing.

An approach similar to the above environmental description of turbulence can be used for many other environmental parameters that are needed by HAPS designers. These include for example the frequency, location and severity of lightning, wind, rain, icing, ozone, UV radiation, cosmic radiation, temperature, and many other environmental characteristics.

GM-HAPS.2205 Interaction of systems and structures

In developing the ADS for this requirements the following elements must be considered:

(a) All systems that may affect structural performance must be evaluated under this requirement.

(b) In the analysis, all failures should be considered unless shown to be extremely improbable

(c) Severity and probability of failure conditions are defined according CS-HAPS.2510

(d) The adjustment of safety factors required by this CS-HAPS Subpart C must be determined as a function of the failure probability and failure rate

(e) The limit loads must be derived at least at the following conditions

    (1) System fully operative

    (2) System in the failure condition at the time of occurrence

    (3) System in the failure condition for the continuation of the flight

(f) Failure detection and indication

(g) Dispatch with known failed system

GM-HAPS.2210 Structural design loads

In developing the ADS for this requirements the following elements must be considered:

(a) Structural design loads resulting from likely externally or internally applied pressure, force or moment which may occur in flight, ground and water operations, ground- and water- handling or transportation, and while the aircraft is parked, stored or moored

(b) The magnitude and distribution of these loads must be based on established physical principles or any other rationale accepted by the authority, within the structural design envelope

GM-HAPS.2215 Flight load conditions

(a) As far as the critical flight loads are concerned, the ADS must consider the following elements in the boundaries of the manoeuvre and gust envelope:

    (1) each altitude within the operating limitations, where the effects of compressibility are taken into account when significant

    (2) each mass from the design minimum mass to the design maximum mass

    (3) any practical but conservative distribution of disposable load within the operating limitations for each configuration of altitude and mass; and

    (4) the maximum design speed is expected to be greater than the design dive speed

GM-HAPS.2220 Ground and water load conditions

(a) The loads in adverse landing conditions should be defined as the loads in normal landing conditions multiplied by a load safety factor greater than 1 which accounts for the expected variability of the landing manoeuvre

(b) As far as the ground resonance is concerned, the ADS must consider the following elements

  (1) the probable range of variations, during service, of the damping action of the ground resonance prevention means, and

  (2) any probable malfunction or failure of a single ground resonance prevention subsystem

GM-HAPS.2225 Component loading conditions

(a) As far as the component loading conditions are concerned, the ADS must consider, as a minimum, the following structural components, if they are applicable for the configuration to be certified:

  (1) rotor and rotating parts assembly

  (2) structures

  (3) rotor pylon

  (4) fuselage

  (5) landing devices

  (6) powerplant and drive system

  (7) propeller structures

GM-HAPS.2230 Limit and ultimate loads

Reserved – safety factors for HAPS are currently under discussion

GM-HAPS.2240 Structural durability

The following conditions related to CS-HAPS.2240(b) are examples which are considered impractical:

(a) Rapid or unstable propagation of the damage

(b) Insufficient accessibility to perform effective inspection

CS-HAPS.2240 (b) requires the design applicant to define methods to prevent catastrophic structural failure. This may include methods executed on ground or during flight (e.g. Health Usage Monitoring System).

GM-HAPS.2252 Critical Parts

See FAA AC 27-1B Para. AC 27.602, as far as applicable and practicable to the aircraft configuration, to provide more information to develop the ADS.

GM-HAPS.2255 Protection of structure

As far as parts related to CS-HAPS.2255(b) are concerned, the ADS must include rotor blades and other rotating parts.

(c) Processes and procedures to cut the structure and repair it afterwards can be acceptable.

Section 3, Requirements for LTA airship HAPS

SUBPART C – STRUCTURES

CS HAPS.2200 Structural Design Envelope

(see GM-HAPS.2200)

The structural design envelope must be determined, which describes the range and limits of Airship design and operational parameters for which the applicant will show compliance with the specifications of this subpart. The design envelope must account for all Airship design and operational parameters that affect structural loads, strength, durability, and aeroelasticity, including:

(a) Structural design airspeeds to be considered when determining the corresponding maneuvering and gust loads must comply with operating limitations, incl. CS HAPS.2190.

(b) Flight load conditions to be expected in service;

(c) Mass variations and distributions over the applicable mass, heaviness and centre of gravity envelope, within the operating limitations;

(d) Loads in response to all designed control inputs;

(e) Redistribution of loads if deflections under load would significantly change the distribution of external or internal loads;

(f) Effects of aerostatic and aerodynamic loads;

(g) Loads associated with ground operations and when the Airship is secured to the ground.

CS HAPS.2205 Interaction of Systems and Structures

For Airships equipped with systems that affect structural performance, either directly or as a result of failure or malfunction, the applicant must account for the influence and failure conditions of these systems when showing compliance with the requirements of this subpart.

CS HAPS.2210 Structural design loads

The applicant must:

(a) Determine structural design loads resulting from any externally or internally applied pressure, force or moment which may occur in flight and ground operations, ground handling, ditching and any transition between them including when the Airship is parked or moored;

(b) Determine the loads required by paragraph (a) of this section at all critical combinations of parameters, on and within the boundaries of the structural design envelope, and

(c) the magnitude and distribution of these loads must be based on established physical principles within the structural design envelope.

CS HAPS.2215 Flight Load Conditions

(a) Critical flight loads are established for symmetrical and asymmetrical loading from all combinations of flight parameters and load factors at and within the boundaries of the maneuver and gust envelope:

- at relevant altitudes and temperatures within the operating limitations;
- at each mass from the design minimum mass to the design maximum mass; and
- at any practical but conservative distribution of disposable load within the operating limitations for relevant altitudes and heaviness;
- at each lift from the minimum design lift to the maximum design lift (static lift, aerodynamic lift, vectored thrust);
- when determining loads, the influence of adverse environmental conditions must be accounted for.

(b) Vibration or buffeting must not result in structural damage up to V_{CD}.
(c) Flight Loads resulting from a likely failure of an Airship system, component, or propulsion system must be determined.

CS HAPS.2225 Component Loading Conditions

The applicant must determine the loads acting upon all relevant structural components, in response to:

(a) Interaction of systems and structures;
(b) Structural design loads;
(c) Flight load conditions;
(d) Ground load conditions;
(e) Propulsion system load conditions;
(f) Personnel and load conditions resulting from maintenance.

CS HAPS.2230 Limit and Ultimate Loads

(a) Unless special or other factors of safety are necessary to meet the specification of this subpart, the applicant must determine

- The limit loads, which are equal to the structural design loads; and
- The ultimate loads, which are equal to the limit loads multiplied by a 1.5 factor of safety, unless otherwise provided.

(b) Some strength specifications are specific in terms of ultimate loads only, when permanent detrimental deformation is acceptable.

CS HAPS.2235 Structural Strength

The structure must support:

(a) Limit loads without:

(1) Interference with the safe operation of the Airship; and
(2) Detrimental permanent deformation.

(b) Ultimate loads.

CS HAPS.2240 Structural Durability

(a) The applicant must develop and implement inspections or other procedures to prevent structural failures due to foreseeable causes of strength degradation, or extended periods of operation with reduced safety margins. Each of the inspections or other procedures developed under this section must be included in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness required by requirement CS HAPS.2625.

(b) The procedures developed for compliance with paragraph (a) of this section must be capable of detecting structural damage before the damage could result in a structural failure.

(c) The Airship must be designed to minimize hazards to the Airship due to structural damage caused by high-energy fragments from an uncontained engine or rotating machinery failure.

CS HAPS.2245 Aeroelasticity

(a) The Airship must be free from critical flutter characteristics, control reversal, and divergence:

  (1) At all airspeeds within and sufficiently beyond the structural design envelope;
  (2) For any configuration and condition of operation;
  (3) Accounting for critical degrees of freedom; and
  (4) Accounting for any critical failures or malfunctions.

(b) The design must account for tolerances for all quantities that affect critical flutter characteristics.

CS HAPS.2250 Design and Construction Principles

(a) Each part, article, and assembly must be designed for the expected operating conditions of the Airship.

(b) Design data must adequately define the part, article, or assembly configuration, its design features, and any materials and processes used.

(c) The suitability of each design detail and part having an important bearing on safety in operations must be determined.

(d) The control system must be free from jamming, excessive friction, and excessive deflection when the Airship is subjected to expected limit air loads.

(e) The Airship must be designed to ensure avoidance with a likely bird impact.

CS HAPS.2255 Protection of Structure

(a) Each part of the Airship, including small parts such as fasteners, must be protected against deterioration or loss of strength due to any cause likely to occur in the expected operational environment.

(b) For each part that requires maintenance, preventive maintenance, or servicing, the applicant must incorporate a means into the Airship design to allow such actions to be accomplished.

CS HAPS.2260 Materials and Processes

(a) Materials used for parts, articles, and assemblies, the failure of which could prevent continued safe flight and landing must be suitable and durable, accounting for the effects of significant likely environmental conditions expected in service.

(b) The methods and processes of fabrication and assembly used must produce consistently sound structures.

(c) Except as provided in paragraph (f) of this section, the applicant must select design values that ensure material strength with probabilities that account for the criticality of the structural element. Design values must account for the probability of structural failure due to material variability.

(d) If material strength properties are required, a determination of those properties must be based on sufficient tests of material meeting specifications to establish design values on a statistical basis.

(e) If environmental effects are significant on a critical component or structure under normal operating conditions, the applicant must account for those effects.

(f) Design values, greater than the minimums specified by this section, may be used, where only guaranteed minimum values are normally allowed, if a specimen of each individual item is tested before use to determine that the actual strength properties of that particular item will equal or exceed those used in the design.

CS HAPS.2265 Special Factors of Safety

(a) A special factor of safety must be determined for each critical design value for each part, article, or assembly for which that critical design value is uncertain, and for each part, article, or assembly that is:

  (1) likely to deteriorate in service before normal replacement; or
  (2) subject to appreciable variability because of uncertainties in manufacturing processes or inspection methods.

(b) The applicant must determine a special factor of safety using quality controls and specifications that account for each:

  (1) type of application;
  (2) inspection method;
  (3) structural test requirement;
  (4) process and material control.

(c) The applicant must multiply the highest pertinent special factor of safety in the design for each part of the structure by each limit and ultimate load, or ultimate load only, if there is no corresponding limit load, such as occurs with emergency condition loading.

GM to Section 3, Requirements for LTA airship HAPS

SUBPART C – STRUCTURES

GM-HAPS.2200 Structural design envelope

One of the existing performance-based structural requirements is to demonstrate, through analysis and test, that HAPS structures can withstand the expected turbulence encountered during the HAPS mission. The existing prescriptive design guidelines traditionally used as a means of compliance to these requirements are based on aircraft data collected at lower altitudes, from aircraft which spend a far higher percentage of their mission at those lower altitudes. These guidelines may not be appropriate for the majority of the operating environment in which HAPS are expected to operate, and the statistical guidelines in the portions of the environment that *are* represented are likely overly conservative, given typical HAPS operational restrictions (e.g. avoiding windows of inclement weather during launch and recovery).

Existing guidance specifies turbulence amplitudes that have implicit assumptions of dynamic similarity to past—non-span-loaded, higher wing loading—designs, and that also assume a similar mission type (e.g. passenger carrying operations). Older criteria—for example, 14 CFR Part 25 Appendix G—attempt to describe the atmospheric turbulence environment as the probability of any given level of turbulence as a function of altitude. This suggested statistical description is at least an attempt to describe the whole environment, rather than imposing specific amplitudes that are based on assumptions about aircraft and missions. Again, the statistics are still potentially overly conservative at low altitude (because HAPS have more operational restrictions than traditional aircraft) and they are lacking in statistically significant data at higher stratospheric altitudes where HAPS intend to operate for months at a time. Since this statistical description was published in the 1960s, many new measurement and modeling efforts for turbulence at all levels in the atmosphere have been undertaken. Google Loon, for example, has collected over 2 million hours of environmental data at stratospheric altitudes. While many of these new modeling or measurement datasets are available, most have not been distilled down into relevant high-altitude statistical guidance suitable for the aircraft designer. Nor have many of these been recognized and vetted by regulatory agencies to the same extent that existing guidance has been.

Given an accurate description of the turbulence environment in which HAPS operate a mission design approach (such as that suggested in the former 14 CFR Part 25 Appendix G) will allow HAPS structures to be designed to a required structural exceedance rate. These designs can take advantage of HAPS primarily high-altitude operations and operational restrictions such as picking takeoff and landing times or being able to move away from storms. For instance, turbulence hazards caused by the ‘Jet Stream’ and wind shear effects are a major consideration in determination of launch and recovery timing.

An approach similar to the above environmental description of turbulence can be used for many other environmental parameters that are needed by HAPS designers. These include for example the frequency, location and severity of lightning, wind, rain, icing, ozone, UV radiation, cosmic radiation, temperature, and many other environmental characteristics.

Section 4, Requirements for LTA balloon HAPS

SUBPART C – STRUCTURES

Refer to EASA CS.31 GB Subpart C – Structure 21, 23, 25 and 27. Basket to be interpreted as payload, gondola or similar.

GM to Section 4, Requirements for LTA balloon HAPS - RESERVED

APPENDIX 1 to CS HAPS

text below is work in progress from HAPS Alliance – subject to change

Some example risk assessment concepts are discussed. These are examples of some of the new ways of thinking that will be necessary given the unique aspect of ultra-long duration flight and fleet operations. The first example is from the HAPS Alliance, but there is also some work in ICAO SASP on extending the air risk work they had previously done in Australia to ground risk.

1.1 HAPS ALLIANCE PROPOSED "ACCEPTABLE LEVELS OF RISK FOR HAPS"

DRAFT Version 2023-06-15

Status: Seeking AWG Comments/Feedback

Aviation risk metrics do not work for HAPS

Traditionally, aviation has used safety metrics that measure the risk on a per-flight-hour, or per-mission (per-flight) basis (typically a probability of catastrophic accident). Lin et al. 2009[8] give an excellent summary of historic aviation target levels of safety and societal expectations of risk.

Per-flight-hour or per-mission safety metrics work well for passenger transport because they measure the risk with a unit of time that relates directly to the exposed individuals (the people onboard).

These metrics are however inadequate to quantify the risk for High Altitude Platform Systems (HAPS) which do not carry people on board. Per-flight-hour or per-mission metrics are "***platform-centric***", and can promote system designs that are misaligned with true safety goals. In particular, platform-centric metrics will disadvantage platforms with longer mission duration and will disadvantage larger platforms even when those create safer overall systems (see examples for details).

Because HAPS do not carry people, they create risk to 3rd parties exclusively. As they operate above commercial traffic the main source of risk comes from the possibility of an "unplanned descent" which can create the following two types of risk:

- Risk to populations on the ground, general public (3rd Parties)

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[8] Lin X, Fulton NL, *Target level of safty measures in air transportation – review, validation and recommendations*, Proceedings of the IASTED International Conference, Modelling, Simulatgion and Identificatgion, October 12-14, Beijing, China, **2009**

- Risk to manned air traffic operating below HAPS (mid-air collision during unplanned descent) (3rd Parties)

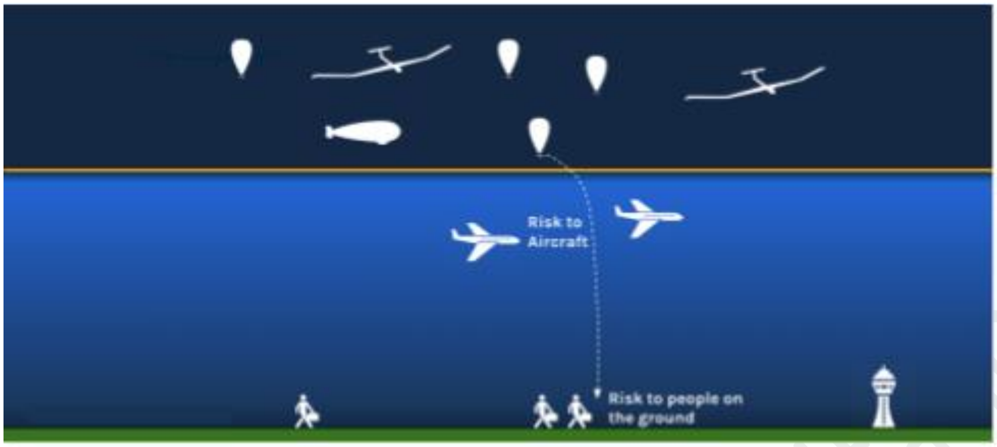

Figure 1 - HAPS operate above aircraft traffic. Unplanned descents are the main source of risk - risk to ground populations, risk of a mid-air collision with manned aircraft traffic operating below.

From a safety point of view, HAPS can be considered as ***Airborne Infrastructure*** - They are networks of “flying cell phone towers”, earth monitoring devices, or other kinds of semi-permanent infrastructure. In many cases, continuous coverage is maintained by cycling platforms during maintenance such that there is always the appropriate number of platforms in the sky (e.g. to ensure constant connectivity service). Even though the actual platforms and missions may be cycled, from the perspective of exposed populations, there is always the same number of platform(s) in the sky.

Therefore, to evaluate HAPS safety, we must use metrics and acceptable levels of risk that consider the system as a whole, and account for the platform density. We cannot use platform-centric metrics (per-mission or per-flight-hour), because the number of missions (maintenance cycles) or number of flight hours (platform density) can vary greatly with system designs (see examples in appendix).

HAPS risk is then per real hour, or more practically per year, and needs to encompass all HAPS in a region, not just those from one operator.

This paper proposes safety metrics and acceptable levels of risk for HAPS that are ***victim-centric*** (i.e. where the risk is measured from the perspective of the ground-individual exposed aircraft operating below HAPS fleet) rather than the traditional aviation metrics which would measure the risk from the perspective of the platform.

In proposing acceptable levels of risks we consider both the ***individual risk*** (the risk to each individual exposed) as well as a ***collective risk or societal risk*** (the risk to a group of people).

We use ***comparable risks*** to propose acceptable levels of risk that are in line with risk levels currently accepted by the exposed parties:

- aviation risk standards to establish an acceptable level of risk to exposed aircraft.
- infrastructure standards (such as UK HSE ALARP Framework[9] for pipelines, power

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[9] https://www.hse.gov.uk/foi/internalops/hid_circs/permissioning/spc_perm_37/#Tools-for-ALARP

plants, dams, industrial plants, etc.) to establish the risk for ground populations.

Finally, we propose a ***dynamic collective-risk management*** in which each HAPS operator computes the collective risk integral (using actual trajectories, population density data, and aircraft density data) and is responsible to maintain the collective risk under the defined acceptable level of risk.

The approach proposed in this paper is consistent with the work performed by the ICAO SASP[10] for HAPS.

Victim-centric individual risk

To appropriately evaluate the risk created by HAPS, and incentivize appropriate safety decisions, we must consider a system as a whole, rather than each platform (or aircraft) individually.

An adequate risk metric is one that measures the risk per unit of time, of an exposed individual or exposed aircraft (victim-centric) rather than a unit of time associated with the uncrewed platform (platform centric). We propose the following:

- The risk to manned aircraft flying below HAPS should be measured as the probability of mid-air collision per exposed aircraft flying hour.

- The risk to ground populations living in the HAPS service area should be measured as the probability of being fatally impacted per exposed person per year.

Note that the above metrics intrinsically embed the level of exposure (i.e. the density of HAPS).

Because the risk is measured in the potential victims' frame of reference, we can set the Acceptable Level of Risk to match other risks already accepted by the exposed party:

- For mid-air collision -
    - ICAO uses a target level of safety of 1.5×10^{-8} per aircraft flight hour for en-route separation. Because the HAPS risk is additional, the ICAO SASP has used 5×10^{-9} per Exposed (Manned) Aircraft Flight Hour[11] in its work on Unmanned Free Balloons, which is currently being generalized to HAPS.
    - We propose to keep this Acceptable Level of Risk of 5×10^{-9} mid-air collision per exposed aircraft flight hour.

- For ground populations -
    - The UK HSE ALARP[12] Framework sets the acceptable level of risk to the general public for pipelines, power plants, etc. between 10^{-4} (Limit of tolerable risk) and 10^{-6} (limit of broadly acceptable risk) per person per year. This level can be set to match other risk levels that individuals are exposed to. For example:

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[10] ICAO Separation Airspace Safety Panel

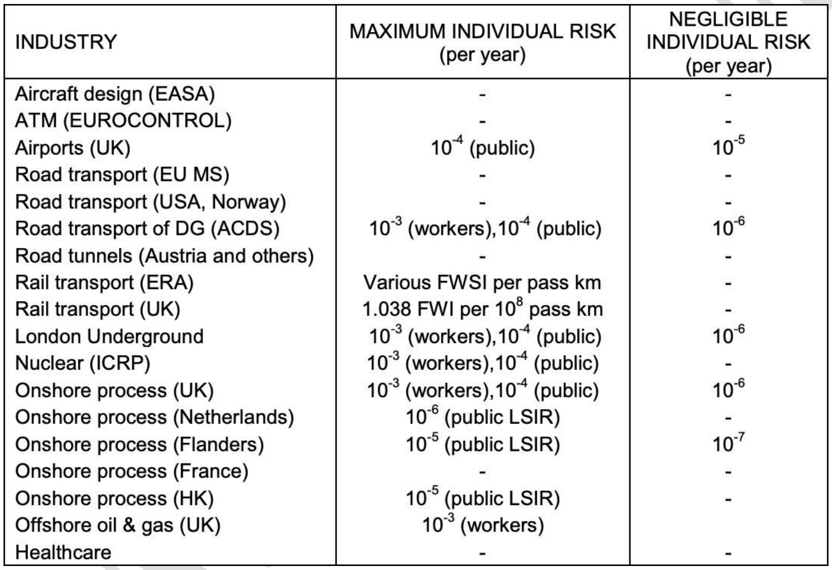
[11] The ICAO SASP Pannel uses a value of 5×10^{-9} per exposed aircraft flight hour, this risk is additional to the overall en-route separation 1.5×10^{-8} Target Safety Level.

[12] https://www.hse.gov.uk/foi/internalops/hid_circs/permissioning/spc_perm_37/

    - The likelihood that a pedestrian is struck by a car in the US 2×10^{-5} each year [NEED REF]

    - Consistent with the UK ALARP, we propose to set a tolerable range between 10^{-4} and 10^{-6} probability of fatality per person per year.

- Other risks -
  - If we were to set an acceptable level of risk to commercial space operations, we could set the acceptable level of risk such that HAPS do not create a risk far greater than the risk already accepted by astronauts (e.g. 1×10^{-4} per rocket launch)



INDUSTRY	MAXIMUM INDIVIDUAL RISK (per year)	NEGLIGIBLE INDIVIDUAL RISK (per year)
Aircraft design (EASA)	-	-
ATM (EUROCONTROL)	-	-
Airports (UK)	10^{-4} (public)	10^{-5}
Road transport (EU MS)	-	-
Road transport (USA, Norway)	-	-
Road transport of DG (ACDS)	10^{-3} (workers), 10^{-4} (public)	10^{-6}
Road tunnels (Austria and others)	-	-
Rail transport (ERA)	Various FWSI per pass km	-
Rail transport (UK)	1.038 FWI per 10^{8} pass km	-
London Underground	10^{-3} (workers), 10^{-4} (public)	10^{-6}
Nuclear (ICRP)	10^{-3} (workers), 10^{-4} (public)	-
Onshore process (UK)	10^{-3} (workers), 10^{-4} (public)	10^{-6}
Onshore process (Netherlands)	10^{-6} (public LSIR)	-
Onshore process (Flanders)	10^{-5} (public LSIR)	10^{-7}
Onshore process (France)	-	-
Onshore process (HK)	10^{-5} (public LSIR)	-
Offshore oil & gas (UK)	10^{-3} (workers)	
Healthcare	-	-

Figure 2 - Individual risk criteria in different industries - Source: European Maritime Safety Agency[13]

Individual risk sharing between operators.

The risk that one individual is exposed to is the sum of the risk from all HAPS operating above (which may be operated by different operators). This raises the question of risk sharing between operators. However, due to the complexity of operating in the stratosphere, only a handful of operators are expected to operate. As a first approximation, we, therefore, propose that the individual risk (which intrinsically embeds the number of HAPS) be specified per operator - this avoids the complexity of risk sharing and attribution between HAPS operators. This can later be revised as needed should the number of operators scale dramatically.

Current airspace operations already demonstrate concepts of sharing risk between operators, although it is usually not framed in terms of risk but as capacity. Arrivals at airports are heavily constrained by airport capacity rates set to ensure separation minima are met, and to accommodate reduced arrivals rates

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[13] https://www.emsa.europa.eu/publications/reports/download/3547/2419/23.html

during adverse weather. Complex ground-delay and airborne delay systems are used to 'fairly' distribute delay which is a cost to the industry. Similarly, many arrival and departure slots are a sold by airports to operators, recognising the associated capacity and risk constraints. Here, commercial market forces dictate access to the scarce resource. A similar system would inevitably evolve as the density of HAPS increases.

Societal (Collective) risk for HAPS

The measure of Individual Risk discussed above does not account for population density or aircraft density. This is because the Individual Risk measures the risk to each exposed individual (or aircraft). The risk to one individual is not affected by the presence of other individuals.

Additional safety criteria may be needed to assess Societal risk. Societal risk is defined as the relationship between frequency and the number of people affected by the harm in a given population from the realization of specified hazards. Societal risk limits have been defined in the transportation of Dangerous Good[14], by the UK HSE[15], and a similar Collective Risk concept has been used by the FAA ALR approach for commercial space[16]. Societal risk criteria can be defined with F-N curves which specify the acceptable frequency of an accident involving N or more fatalities. Societal risk can also be measured using Expectation Value (the expected number of fatalities per year).

The ICAO SASP has traditionally not used F-N risk metrics, since their work has focussed on larger regular public transport operations where the loss of an aircraft is always a significant number of fatalities. However, regulators often use F-N curves when assessing risk in regions where general aviation mix with smaller operators; the probability of loss of a 2-person recreational aircraft is treated differently to the potential loss of a 40-person regional operator.

One benefit of Societal risk is that it incentivizes continuous safety improvement. It allows for a progressive approach to safety in which early R&D can benefit from low operational volumes and low-density operating areas to maintain acceptable levels of risk. As the systems mature and are proven more robust, it allows operators to gradually increase the density of population and aircraft overflown, and gradually increase operational volume (HAPS density), while monitoring that the collective risk always remains within the acceptable level.

Societal risk criteria can however be challenging to establish and do not scale with the societal value provided[17]. In particular, it can be difficult to translate societal risk from one industry to another[18], and it can be challenging to define an appropriate area over which Societal Risk should be accumulated.

We propose the following:

- To define Societal risk metrics (and acceptable level of risk) as:
    - Risk to Aircraft - The (maximum) expected number of mid-air collisions for Regular Public Transport[19] per year in a standard airspace grid.

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[14] https://railroads.dot.gov/sites/fra.dot.gov/files/2020-02/Evaluation%20of%20Risk%20Acceptance%20Criteria.pdf
[15] https://www.hse.gov.uk/foi/internalops/hid_circs/permissioning/spc_perm_37/#Tools-for-ALARP
[16] https://www.faa.gov/sites/faa.gov/files/space/additional_information/faq/SLR2_Final_Rule_450_2.pdf
[17] https://www.emsa.europa.eu/publications/reports/download/3547/2419/23.html
[18] Ibid.
[19] Regular public tranport is intended to cover commercial flights and not small-sized general aviation aircraft

  - Risk to ground populations - The (maximum) expected number of fatal accidents per year in a standard-size region

- To define standardized world grids (which equal cell area/volume) over which the societal risk is integrated over time. The acceptable level of risk is defined for each cell within the grid. This essentially prevents an excessive geographical concentration of risks and accidents.

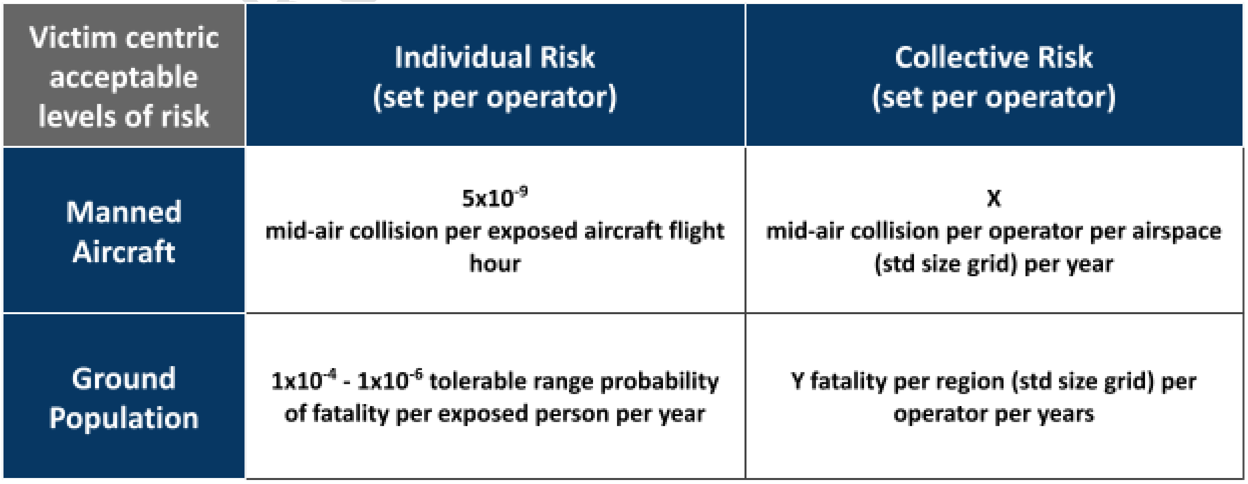
  Such a grid should be defined with a sufficiently fine mesh such that the geographical expansion of a service (which provides additional value) can scale with risk.

- The acceptable levels of societal risk should be revised on a regular basis to remain in line with societal acceptance.

Societal risk sharing between operators.

Similar to individual risk sharing, we propose that due to the limited number of HAPS operators expected the ALR criteria be set for each operator (avoiding risk sharing complexity). As the ETM/CTMS/ECHO concepts get developed further, mechanisms can be introduced to incentivize efficient airspace use, and efficient risk-budget use in high-demand regions. For example, bidding systems (even if non-monetary) could later be set to incentivize operators accessing high-demand airspaces to use the airspace more efficiently (precise intents are cheaper to bid), and to use risk budget efficiently (lower-risk operations using less risk budget are cheaper to bid on).

Summary of proposed Acceptable Levels of Risk for HAPS



Victim centric acceptable levels of risk	Individual Risk (set per operator)	Collective Risk (set per operator)
Manned Aircraft	$5x10^{-9}$ mid-air collision per exposed aircraft flight hour	X mid-air collision per operator per airspace (std size grid) per year
Ground Population	$1x10^{-4}$ - $1x10^{-6}$ tolerable range probability of fatality per exposed person per year	Y fatality per region (std size grid) per operator per years

Operator Managed Societal Risk

An important benefit of using a Societal Risk Criterion is that it can be easily computed (even in real-time) and operationally managed by operators in a way that is auditable by regulators. The following is needed:

- A standardized grid for summing the risk.
- A standardized world population/aircraft traffic data, is computed for that grid.
- **Platform-specific "risk factor" constants**. Indicator of the performance and risk of a specific design that is normalized per unit flight time and unit population density.

The risk factors for a specific platform ***could be obtained through an airworthiness/certification process*** *or empirical flight data with mathematical modeling or simulation.*

Example risk factors:

  - Air-risk factor - 1.4×10^{-13} mid-air collision per platform flight hour per aircraft density overflown (aircraft per square kilometer)
  - Ground-risk factor - 3.8×10^{-12} ground fatality per platform flight hour per population density overflown (people per square km)

- Timestamped historical fleet trajectories.

The May 2023 ICAO SASP meeting proposed a simple 0.1 x 0.1 degree grid (~6 x 6 = 36 NM^2) with an allowance in the calculation for actual area. This allows for simpler calculations than use of hexagonal-like global grid systems.

With the above information, an operator can dynamically compute the Societal risk across its entire fleet (e.g. via sum-product in an Excell sheet), and ensure that the risk budget is never exceeded in any grid cell.

Without needing operational approval for each new region, or every time the operator wishes to vary fleet density, the operator can flexibly adjust operational volumes, operational regions, and overflown population/air traffic densities to ensure that the societal risk is never exceeded in any cells of the standard grid. Regulators can be confident that the total system risk is maintained at all times, and can audit operators by requesting historical fleet trajectory data. Operators could also share the computed societal risk such that regulators keep a real-time map of the total risk map.

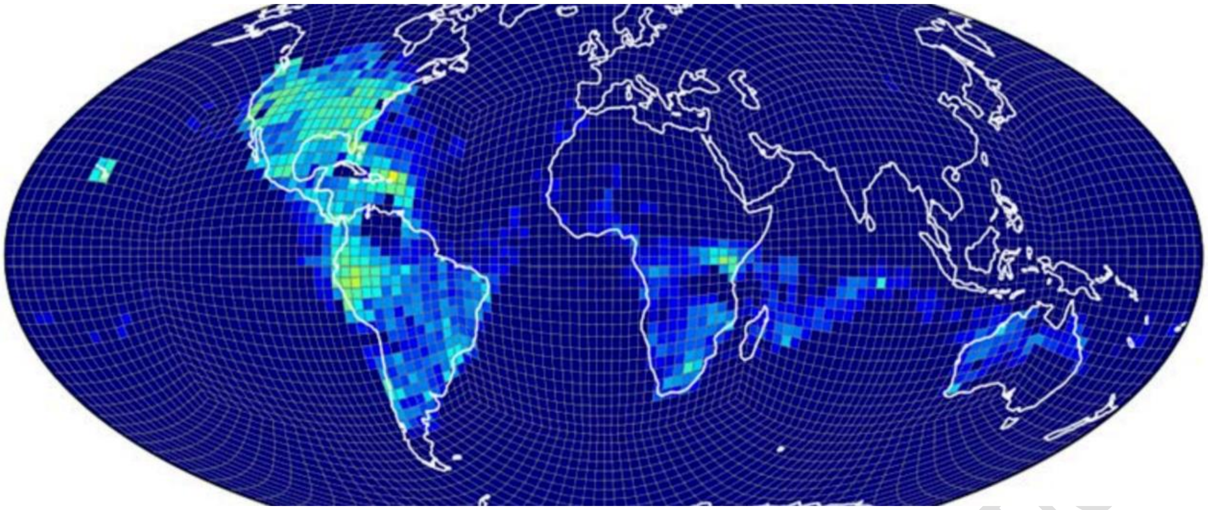


Figure 3 - *Example grid and risk map computed by Loon to estimate the societal mid-air collision risk (in real-time) for the entire fleet. The color in each cell represents the number of years between expected mid-air collisions with aircraft (minimum cell value ~ 500,000 years).*

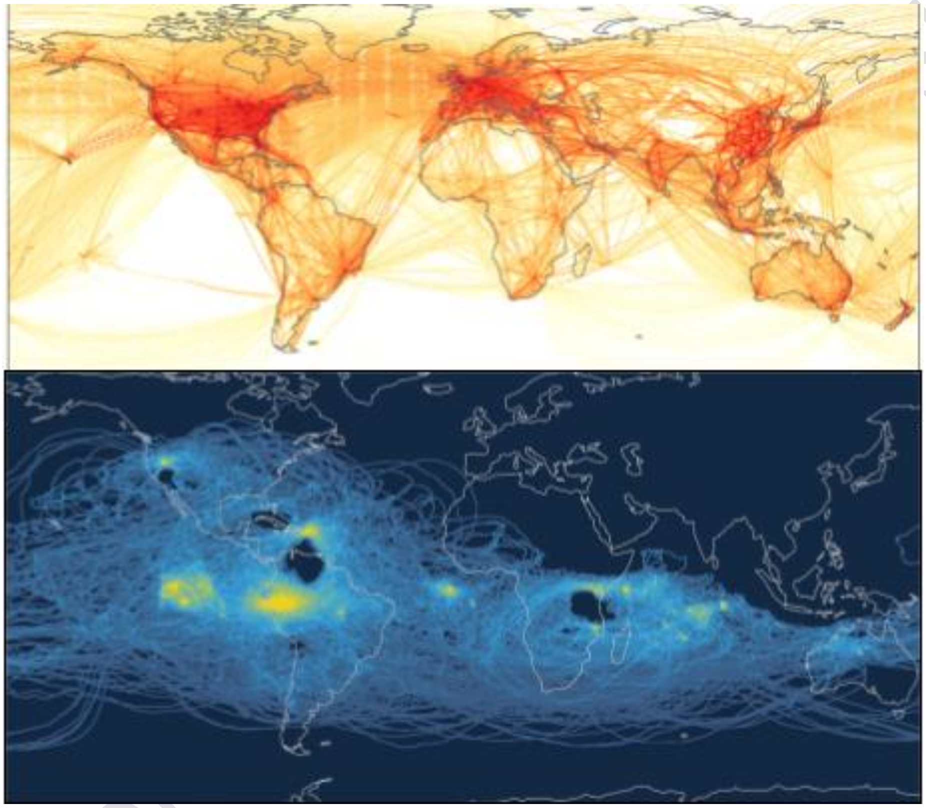


Figure 4 - *(Top) Statistical Aircraft Density Data used by Loon to compute Figure 3 - (Bottom) Historical fleet position used by Loon to compute Figure 3*

1.2 RESERVED

1.3 RESERVED

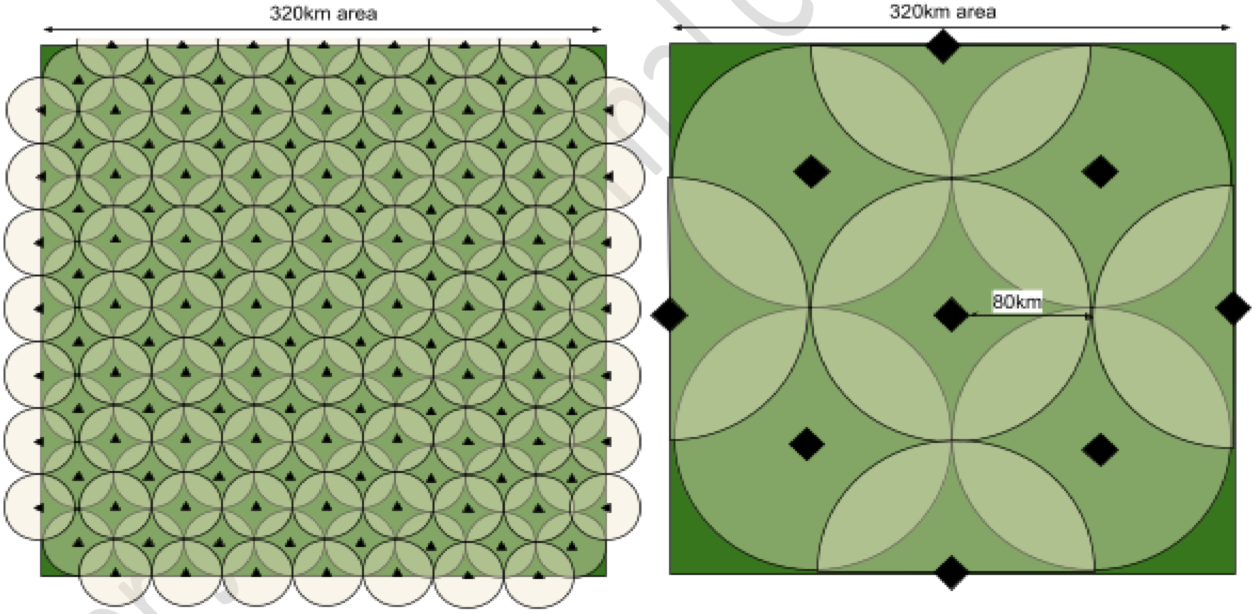
Annex - Examples of why aviation metrics don’t work

Example #1 - Per flight hour risk metric is inadequate

Imagine a HAPS designer considering the following two platform options to provide connectivity over an area of 320km by 320km.

Design A is the smaller alternative, weighing 100kg, which can provide coverage over a radius of 20km. A platform of Design A has a likelihood of an unplanned descent of 1 in 100,000 flight hours. The likelihood that an unplanned descent results in a fatality on the ground can be estimated at 1 in 1,000 for the population density of the service area.

Design B is the larger platform alternative, weighing 1,000kg and capable of carrying a multi-beam payload that provides connectivity over a radius of 80km. ***As a result of this larger coverage, Design B requires 16x fewer platforms to cover the service area than Design A***. A platform of Design B has a likelihood of an unplanned descent of 1 in 100,000 flight hours. Due to its larger size, the probability that an unplanned descent results in a fatality on the ground can be estimated at 1 in 100 for the population density of the service area.



Design A - 141 Smaller HAPS providing coverage over service area, each with connectivity radius of 20km

Design B - 9 Larger HAPS providing coverage over service area, each with connectivity radius of 80km

Figure 5: Example of two possible design choices, one leveraging smaller HAPS operated at higher density, and another using larger HAPS with bigger coverage

If we look at the risk per flight hour for the population density in the service area, we would conclude that Design A is 10x safer than Design B:

- Design A
    - 10^{-8} probability of ground fatality per HAPS flight hour (= 1/100000 * 1/1000)

    - 1 Ground Fatality every 81 years[20]
- Design B
    - 10^{-7} probability of ground fatality per flight hour (=1/100000 *1/100)
    - 1 Ground Fatality every 127 years[21]

Design B is however a safer choice when looking at the operation holistically, despite having a risk per flight hour 10x greater than Design A.

This example illustrates how a TLS defined on a per-flight-hour basis (or a Type Certification Process that focuses on a per-flight-hour basis) could miss the big picture and incentivize HAPS manufacturers to opt for designs that is less safe than a disqualified alternative.

Note: The monitoring method proposed at the May 2023 SASP meeting only considered the risk to aircraft flying underneath a HAPS. Here, the number of aircraft points (each a 5-second sample) in a month (or similar long period), is recorded in each 0.1 x 0.1 degree grid and hence the risk over time for any operation can be calculated as proportional to the number of HAPS points times the number of aircraft points. The real-time accumulation of risk allows owners to modify HAPS operations to balance total risk against mission goals. The total risk can be measured against the number of aircraft hours in the overall region ($< 10^{-8}$ collisions per flight hour), some reasonable measure of years between collisions, or some measure of collisions per flight. The SASP work recognised that what constitutes the ’region’ and hence ‘years between collisions’ is not absolute, and will need to be individually considered by the regulator.

Example #2 - Per-mission risk metric is inadequate

Imagine a HAPS designer that is considering the following two system designs for operating a single HAPS continuously:

Design A uses advanced materials that make it capable of staying aloft for an entire year. It has a probability of an unplanned descent of 1 in 1,000 missions. Each of these unplanned descent has a probability of 1 in 1,000 to generate a mid-air collision with manned traffic operating below.

Design B uses different materials such that the platform can only remain airborne for 1 month at a time. To maintain continuous connectivity service during the year, two platforms are used and cycled each month such that there is always one airborne platform while the other one is in maintenance. The probability of unplanned descent for Design B is 1 in 5,000 missions, each of these unplanned descent has a probability of 1 in 1,000 to generate a collision with manned traffic operating below.

On a per-mission basis, Design A has 5x more risk of mid-air collision than Design B. However, when looking at the system holistically, Design A is the safer choice.

- Design A

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[20] 1 / (365days * 24hours * 141 platforms * 10-8 fatality/hour) = 81 years between fatalities

[21] 1 / (365days * 24hours * 9 platforms * 10-7 fatality/hour) = 127 years between fatalities

- 1x10^{-6} mid-air collison per mission (= 1/1000 x 1/1000)

    - 1 mid-air collision expected on average every 1 million years[22]

- Design B
    - 2×10^{-7} mid-air collision per mission (= 1/5000 x 1/1000)
    - 1 mid-air collision expected on average every 416 thousand years[23]

A HAPS manufacturer may therefore elect Design B (or be constrained to do so if Target Safety Levels were specified on a per-mission basis).

We can see from this example how a TLS defined on a per-mission basis (such as proposed by EASA's draft) can be misaligned with true safety objectives for HAPS, and could incentivize HAPS manufacturers to opt for designs that optimize for that metric rather than optimizing for overall safety.

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[22] 1 / (10^{-6} collision per mission x 1 mission per year) = 1M years between collisions

[23] 1 / (10^{-7} collision per mission x 12 missions per year) = 416k years between collisions