

Concept of Operations for a hydrogen-electric powered modified Dash 8-300 Regional Aircraft: Performance, Operational, and Regulatory Impacts

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Abstract

This paper presents a Concept of Operations (CONOPS) that characterizes the operational use, capabilities, and system attributes of a De Havilland Dash 8-300 regional aircraft equipped with a Hydrogen Aircraft Powertrain and Storage System (HAPSS), from the perspective of its users and stakeholders.

The HAPSS modification replaces the conventional turboprop propulsion system with a low-temperature fuel cell electric configuration, with the objective of significantly reducing aviation emissions while maintaining compatibility with existing airspace operations and airport infrastructure.

This paper focuses on identifying “what” aspects of operations are expected to be impacted and outlines the outcomes required to enable the introduction of a HAPSS-modified Dash 8-300 into commercial service. It does not constitute a technical manual or design blueprint, nor does it prescribe “how” these outcomes will be achieved. The “how” will need to be validated through detailed performance data, a clearer understanding of market adoption, and robust lifecycle emissions assessments.

The CONOPS addresses aircraft performance and classification, certification and regulatory considerations, air traffic and airport integration, and the associated implications for operations, training, and crew competency. The analysis is grounded in current certification standards and operational regulations, providing a realistic assessment of the technical, operational, and regulatory changes required for entry into service.

Overall, the HAPSS modification of the Dash 8-300 is presented as a credible and practical pathway toward near-zero-emission regional aviation. By translating a regulation-aligned analysis into clearly defined and actionable areas, this CONOPS supports informed decision-making by key stakeholders. While hydrogen propulsion introduces new technical and operational challenges, these are assessed to be bounded and manageable. The study concludes that the project is ready to progress from the baselined architecture to the concept development phase.

Keywords: hydrogen; fuel cells; regional aircraft; concept of operations; certification

1 Introduction

1.1 Objective

The decarbonisation of aviation represents a significant challenge, particularly for regional air transport, where operational, infrastructural, and economic constraints limit the effectiveness of conventional mitigation measures. Hydrogen-electric propulsion based on fuel cell technology offers a promising pathway toward near-zero-emission flight. However, its introduction into commercial service requires careful consideration of operational compatibility, regulatory compliance, and system integration.

The feasibility of integrating a Hydrogen Aircraft Powertrain and Storage System (HAPSS) into the De Havilland Dash 8-300 was previously demonstrated in an ICAS 2024 publication [1]. Building on this technical foundation, the present paper shifts the focus toward operational realisation,

addressing the requirements for a safe, efficient, and acceptable entry into service within the existing aviation system.

This paper presents a CONOPS for a Dash 8-300 aircraft equipped with a Hydrogen Propulsion System (HPS), replacing the conventional turboprop propulsion system with a low-temperature hydrogen fuel cell electric configuration and a liquid hydrogen storage and distribution system integrated within the fuselage. The CONOPS is based on, and aligned with, the framework developed by the Alliance for Zero Emissions Aviation (AZEA) [2], while being tailored to the specific characteristics of a hydrogen-powered regional turboprop and the applicable European regulatory context. AZEA is a voluntary initiative comprising over 180 public and private stakeholders, united in preparing the entry into commercial service of hydrogen-powered and electric aircraft.

The CONOPS examines the implications of the HAPSS modification across the full operational ecosystem of the Dash 8-300, including aircraft performance and classification, certification and regulatory considerations, air traffic management and airport integration, and the impacts on operational procedures, ground handling, training, and crew competency. Rather than presenting a purely conceptual or aspirational framework, the analysis is grounded in current certification standards, operational requirements, and applicable technical criteria.

In doing so, this paper provides a realistic and actionable assessment of the technical, operational, and regulatory changes required to enable the entry into commercial service of a HAPSS-modified Dash 8-300.

1.2 Scope

The HAPSS configuration features a liquid hydrogen storage system situated in the fuselage between the passenger cabin and the cargo hold. Additionally, fuel cell stacks, electric propulsion units, and the associated thermal and electrical subsystems are housed within the nacelles.

The existing propellers will be retained, while the current propeller control systems will need to be adapted for the hydrogen propulsion system. The retrofit approach leverages the existing certified airframe to accelerate market entry and regulatory approval, targeting commercial deployment by the beginning of the 2030's.

Key operational characteristics of the HAPSS modified Dash 8-300 include [1]:

- A target range of 750 km including reserves for:
    - Distance to alternate destination of 100 NM;
    - Loiter time of 45 minutes;
    - Contingency fuel of 5% of trip fuel;
- Cruise altitude of FL160
- Comparable climb performance to the conventional Dash 8-300
- Maximum payload capability of 3,089 kg, corresponding to a maximum passenger capacity of 28 occupants, assuming a standard mass of 110.3 kg per passenger including baggage.
- Maximum useable fuel weight of 340 kg of hydrogen, including reserves for about 40%
- Comparable noise and performance profiles to the conventional Dash 8-300

The modified aircraft is designed to operate within current air traffic management systems and airport environments with minimal disruption. However, specific adaptations are required in ground handling, safety procedures, and flight / maintenance crew training due to the unique properties of hydrogen fuel and high-voltage systems.

The report also evaluates the regulatory implications under EASA Part 21 and Air Operations regulations, identifying areas where new definitions, special conditions, and guidance materials may be necessary. Certification will involve both a Supplemental Type Certificate (STC) for the aircraft including a STC for the propellor and a Type Certificate (TC) for the HPS certified as an engine.

This CONOPS serves as a foundational document for stakeholders, including regulatory authorities, airport operators, and airline partners—to understand the operational, technical, and regulatory impacts of introducing hydrogen-powered regional aircraft into commercial service.

1.3 HAPSS Context

The Ministry of Infrastructure and Water Management oversees the Netherlands' National Growth Fund programme Luchtvaart in Transitie (Aviation in Transition) [3], which aims to safeguard the future earning capacity of the Dutch aviation sector by funding sustainability-driven innovation and accelerating the transition toward climate-neutral aviation by 2050. As part of this program, a large project called HAPSS started in October 2022, with the ultimate objective of bringing a Hydrogen-electric Propulsion System to the market targeting the beginning of the 2030s, initially through retrofitting existing regional aircraft.

The HAPSS project is led by Conscious Aerospace [4] and comprises a cross-sector consortium integrating expertise from aerospace, automotive, and cryogenic domains, supported by leading academic and research organisations.

2 Aircraft Specification, Performance & Classification

2.1 Introduction

This chapter describes the HAPSS-modified Dash 8-300 aircraft and provides the technical and operational characteristics that define the reference aircraft configuration used throughout this document. These characteristics have been reviewed from the perspective of the applicable certification and operational regulations [5] and the associated Certification Specifications [6].

The chapter also provides the information necessary for the aircraft classification within the AZEA [2] and EUROCONTROL [5] frameworks and establishes the operational assumptions used in the subsequent certification, safety, and environmental assessments.

The topics addressed include the modified aircraft architecture, operational use and flight range, weight characteristics, maintenance considerations, noise, fuel venting, non-CO_2 emissions, operational safety, performance characteristics, and aircraft classification. Together, these characteristics form the basis for the certification, safety, operational, and environmental evaluations presented in the following sections.

2.2 HAPSS modified Dash 8-300 Architecture

The HAPSS configuration features a liquid hydrogen storage system situated in the fuselage between the passenger cabin and the cargo hold. Cabin space is reduced from 50 passengers to 28 passengers. Cockpit arrangements will not change. The mechanical power controls become wired, but for the pilot the user interface is still the same as power control knobs are prescribed by the regulations. The powerplant panel will be adapted for fuel and HPS control & indication.

Each PW123 engine is replaced by an HPS in an adapted nacelle. The HPS consists of a fuel cell system, an electric power distribution system to provide power to aircraft systems and electro motor, a starter battery, electro motor including a reduction gearbox to match efficiently the existing propeller rotational speeds, a thermal management system and an HPS control unit. This control unit manages the whole chain of energy conversions from hydrogen to electric power to mechanical power to aerodynamic thrust.

In addition, the hydrogen fuel system includes dedicated vent lines to manage pressure build-up, particularly from liquid hydrogen boil-off. These lines are segregated from the propulsion flow path and function autonomously to prevent overpressure and hazardous hydrogen accumulation.

This configuration enables a distributed and redundant power architecture, in which power generation and distribution are decoupled from individual propulsion units. As a result, the system behaviour transitions from a conventional one-engine-inoperative (OEI) paradigm to a one-propeller-inoperative (OPI) scenario, supported by distributed power availability across the propulsion system. This enhances operational resilience and fault tolerance by allowing power to be redistributed in case of individual component failures.

Removal of the PW123 engines eliminates the original bleed air supply; therefore, the cabin air conditioning compressor is relocated to the aft fuselage cone, originally reserved for optional APU installation in the Dash 8-300.

The existing propellers are retained, as they are appropriately matched to the airframe and propulsion system in terms of power absorption, torque characteristics, rotational speed (RPM), and vibration characteristics.

The existing propeller control system installation will require adaptation to interface with the HPS gearbox.

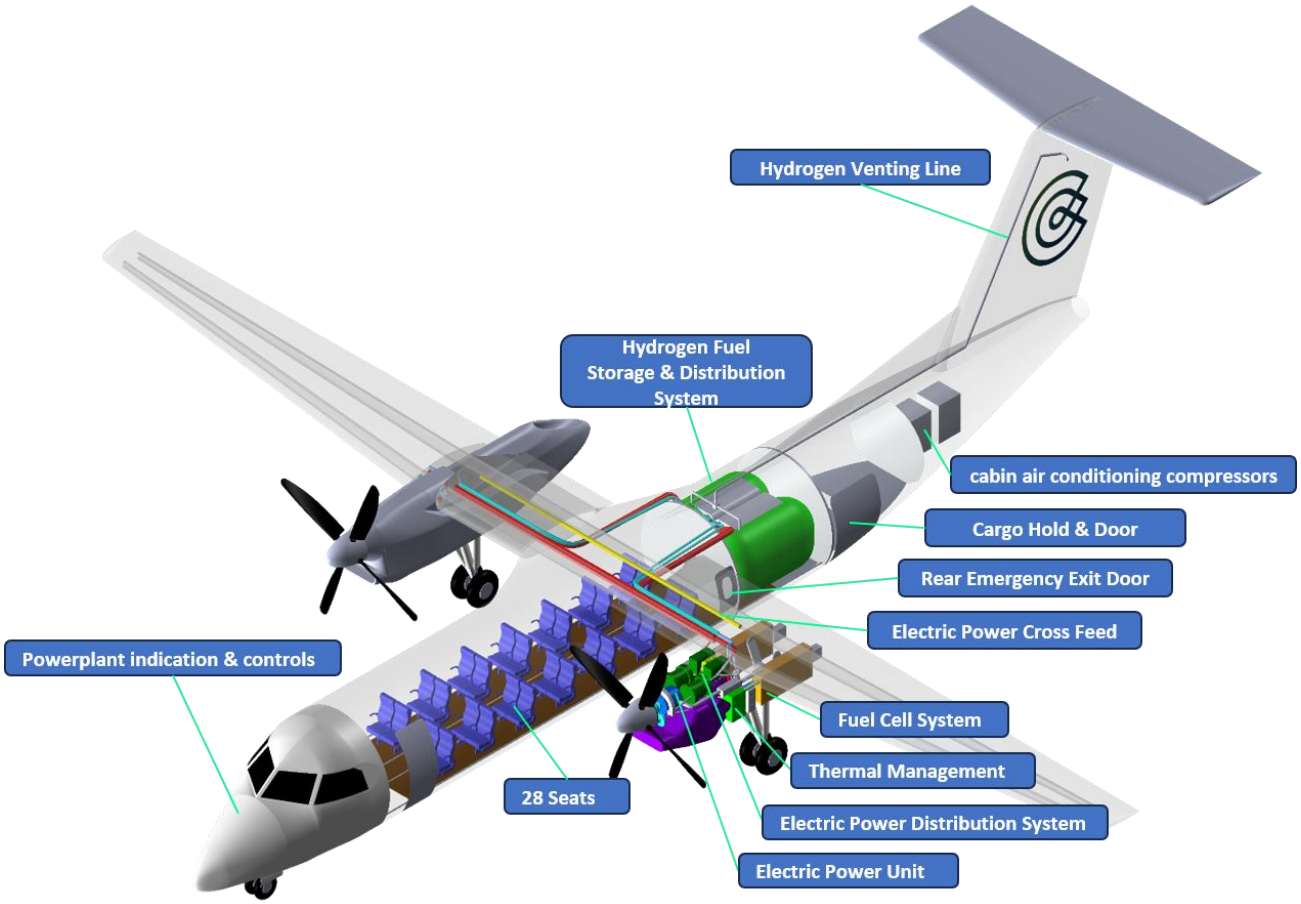


Figure 1 - The HAPSS modified Dash 8-300.

2.3 Operational Use and Flight Range

The developed aircraft has the following intended operational use:

Regional Airline Operations:

The Dash 8-300 is often utilized by regional airlines for short to medium-haul flights between smaller airports within a particular region. It can serve as a reliable and cost-effective option for connecting smaller communities. This mission will not change for the modified aircraft.

Passenger Transportation:

The modified aircraft can carry up to approximately 28 passengers, depending on the specific configuration chosen by the airline. It is suitable for transporting passengers on low intensity routes and regional airports.

Cargo and Freight:

The modified aircraft can be operated in a quick-change (QC) or combi configuration, allowing the cabin to be reconfigured for light cargo operations, including express parcels, mail, and general freight.

As part of the feasibility study [1] a survey was performed validating the target range requirement of 750 km and cruise altitudes with the existing fleet. The evaluation of the data gathered indicates that for the operators considered in this study, more than 95% of flights operated by the considered operators fall within a range of 750 km. Over 70% of global Dash 8-300 flights can manage round trips of 375 km without requiring refueling.

As evaluated in [1] the range of the HAPSS modified aircraft has potential to achieve the objective of a 750 km range with 28 passengers while flying at lower altitudes such as 10,000 and 16,000ft based on Table 1. The maximum flight level is limited to 20,000 ft due to the compressor performance of the fuel cell system, as reduced ambient pressure at altitude limits achievable compression.

Table 1 - HAPSS modified Dash 8-300 flight levels.

	Evaluated survey flight levels (ft)	HAPSS flight levels (ft)
Max flight level	25,000	20,000
1hr + flights	16,000	16,000
Flights under 30min	11,000	10,000

2.4 Weights

For the HAPSS configuration, the Maximum Take-Off Weight (MTOW) of the modified aircraft is set equal to the Maximum Landing Weight (MLW) of the baseline Dash 8-300, i.e. 19,051 kg. This is a consequence of replacing conventional wing-stored jet fuel with liquid hydrogen stored in the fuselage. In a One-Propeller-Inoperative (OPI) condition at take-off, only a few kilograms of hydrogen are consumed prior to landing, resulting in a negligible difference between take-off and landing weight, and thereby justifying MTOW equal to MLW. It should also be noted that, in emergency situations, liquid hydrogen cannot be jettisoned.

Table 2 - Weights specifications HAPSS modified Dash 8-300.

Weight Definition	Abbr.	Description	Weight (kg)	Weight (lbs)
Operating Weight Empty	OWE	Weight of the aircraft without passengers, baggage or trip fuel	15,622	34,441
Max. Fuel weight	-	Weight of liquid hydrogen as trip fuel (incl. 120 kg of reserves)	340	750
Operating Weight	OW	Weight of the aircraft without passengers, baggage but with trip fuel	15,962	35,191
Payload	Payload	Weight of maximum payload (28 pax; 113.6 kg per pax incl. baggage)	3,089	6,810
Max. Take-off Weight	MTOW	MTOW based on HAPSS modification (equals MLW of Dash 8-300)	19,051	42,000
Max. Landing Weight	MLW	Maximum weight at which 311 model can land within existing limitations	19,051	42,000

2.5 Maintenance

For the inspection aims and maintenance philosophy the following baseline has been established:

- Specific maintenance requirements due to the HAPSS modification:
  - All major components of HPS and hydrogen fuel system are defined as Line Replaceable Units (LRUs);
- Inspections of HPS and hydrogen fuel system aim to fit in with the existing maintenance scheme:
  - C-Check: every 5,000 hrs., 2 yrs. whichever comes first;
- Life limits: C-Check as main driver for life limits on Fuel Cell System
  - target Fuel Cell Stack at 10,000hrs.

2.6 Noise

The HAPSS-modified Dash 8-300 retains the installed Hamilton Sundstrand Model 14SF series propeller, driven primarily by an electric propulsion system, with the reduction gearbox and fuel cell system compressor remaining as the principal sources of mechanical noise.

As the propeller remains a dominant contributor to overall aircraft noise, the aircraft-level noise characteristics are expected to remain broadly comparable to the baseline configuration. However, the elimination of conventional gas turbine tonal components is anticipated to alter the spectral content of the noise, potentially changing the perceived acoustic signature.

It is expected that the HAPSS-modified Dash 8-300 will comply with the noise limits specified in the existing Type Certificate Data Sheet for Noise (TCDS) [7]. Nevertheless, due to the propulsion system modification, noise compliance will need to be re-demonstrated in support of an updated TCDS for noise.

2.7 Fuel Venting

Part 21 [8] provides guidance on the definition for engine environmental requirements and refers to ICAO documentation [9] stating:
'Aircraft shall be designed and constructed to prevent the intentional discharge into the atmosphere of liquid fuel from the fuel nozzle manifolds resulting from the process of engine shutdown following normal flight or ground operations.'

When hydrogen is used as fuel, venting considerations primarily relate to the storage and distribution system rather than the propulsion power generation process. In liquid hydrogen (LH_2) systems, heat ingress can lead to boil-off and associated pressure rise, requiring controlled venting to maintain system safety and integrity. Refueling and maintenance purging are conducted using closed-loop systems to minimize contamination. In accordance with [10], hydrogen venting into the fuel cell cathode exhaust is prohibited; any required venting is therefore routed via a dedicated, separate vent line.

This venting function is implemented as part of the hydrogen fuel system, as it enforces safety-critical pressure and containment limits independent of the primary fuel system. The vent system operates as a last-line safeguard to prevent overpressure and hazardous accumulation of hydrogen and is therefore designed to actuate autonomously when predefined thresholds are reached, irrespective of commanded system operation.

2.8 Engine Emissions (Non-CO_2)

Non-CO_2 emissions associated with the HAPSS-modified Dash 8-300 are primarily linked to the electrochemical conversion process within the fuel cell system rather than fuel storage or pressure management. The dominant emission is water vapor, produced as a natural outcome of the hydrogen–oxygen reaction within the fuel cell stack and expelled via the main exhaust.

Due to inherent fuel cell efficiency limits, not all supplied hydrogen can be fully reacted with oxygen. While the system incorporates hydrogen recirculation to maximize utilization, a small residual fraction of unreacted hydrogen may remain and require controlled discharge. This discharge is treated as an engine emission, distinct from fuel venting associated with storage system pressure control.

At present, no ICAO or EASA certification standards define compliance criteria for non-CO_2 climate impacts associated with hydrogen fuel-cell propulsion systems. For the HAPSS-modified Dash 8-300, non-CO_2 emissions are primarily limited to water vapor generated by the fuel-cell conversion process. While such effects, including potential contrail formation, are recognized by regulators, they are currently addressed through research and policy initiatives rather than Part-21 environmental certification requirements. Consequently, non-CO_2 emission effects do not constitute formal certification drivers for the HAPSS modification, although they are identified as areas for continued monitoring in line with evolving regulatory guidance.

2.9 Operational Safety

To ensure safety, the operational behavior of the HAPSS Dash 8-300 aircraft will need to be outlined and validated.

The HAPSS Dash 8-300 aircraft will comply with the established CS-25 Certification Specifications (CSs), developed Special Conditions (SCs) and rules of the air. Operations will be conducted in

accordance with the safety regulations developed by and provided by authorities. In section 4, operational aspects related to network integration are discussed in more detail.

Additionally, in terms of operational safety the following items need to be developed and incorporated in the safety strategy:

- Training / Familiarization;
- Standard Operating Procedures (SOPs);
- Human Machine Interface (HMI);
- Crew Resource Management (CRM);
- Risk assessment with an emphasis on airspace usage.

2.10 Performance Characteristics

To establish the aircraft classification, as proposed by AZEA [2], the HAPSS-modified Dash 8-300 is characterised by the following performance parameters:

Cruising speed, Rate of Climb and Final approach speed are the same as the Dash 8-300 [11]. These performance characteristics the HAPSS modified aircraft minimize the step for service entry.

Table 3 - HAPSS modified Dash 8-300 performance characteristics.

	HAPSS modified Dash 8-300	Dash 8-300
Range (incl. reserves)	750 km	1711 km
Cruising level	FL160 and in between FL100 - 180	FL250
Service ceiling	FL 200	FL250
Cruising speed (True Air Speed; TAS)	250 kts	250 kts
Rate of climb (ROC) (Indicated Air Speed; IAS)	Climb (to FL 170): 210 kts (IAS) ROC 1200 ft/min Climb (to FL 200): 210 kts (IAS) ROC: 700 ft/min	Climb (to FL 150): 210 kts (IAS) ROC 1200 ft/min Climb (to FL 240): 210 kts (IAS) ROC: 1000 ft/min
Final approach speed	Approach: 210 kts (IAS) Landing: 110 kts (IAS)	Approach: 210 kts (IAS) Landing: 110 kts (IAS)

2.11 Aircraft Classification

Based on the defined operational use and aircraft performance characteristics, the HAPSS-modified Dash 8-300 falls within existing aircraft categories already described by AZEA and EUROCONTROL. For classification purposes, the conventional De Havilland Canada DHC-8-300, ICAO aircraft type designator DH8C, is used as the reference aircraft. Accordingly, the HAPSS-modified Dash 8-300 is classified as:

- AZEA Group 7 (Commuter);
- EUROCONTROL L2T (Light Turboprop).

The use of the DH8C as reference aircraft reflects its established operational and performance characteristics and ensures consistency with the classification methodology defined by AZEA in [2].

3 Regulatory implications

3.1 Introduction

This section explores the regulatory and certification implications of the HAPSS modification of the Dash 8-300 within the framework of EASA Part 21 and applicable Air Operations regulations. The assessment identifies areas where new regulatory interpretations, Special Conditions, and supporting Guidance Material may be required to enable certification of a hydrogen-powered regional aircraft.

EASA certification policy places strong emphasis on applicant readiness, organisational maturity, and alignment between product maturity and the timing of formal applications. Experience with innovative and new-entrant programmes has shown that premature start of certification activities can result in inefficiencies or non-robust compliance demonstrations. To address this, EASA provides voluntary technical advice services, supported by guidance on applicant readiness as defined in the EASA Certification Memorandum [12].

Conscious Aerospace is using these technical advice services to structure its certification strategy, with the CONOPS serving as the initial reference point for regulatory engagement. The proposed certification approach comprises a CS-25 Supplemental Type Certificate (STC) for the modified aircraft, a CS-P STC based on an adapted propeller controls installation, and a Type Certificate (TC) for the HPS, certified as an engine and building on Special Condition SC-E19, extended for hydrogen-specific aspects.

The impact of the HAPSS modification on CS-25 is twofold: firstly the certification basis originates from the1980s [13], while CS-25 has evolved significantly to current safety standards and secondly the integration of a hydrogen propulsion system, liquid hydrogen storage and distribution system, and associated hydrogen hazards will necessitate additional special conditions.

An Innovation Partnership Contract (IPC) with EASA provides the framework to proactively manage these challenges and to support collaborative development of appropriate regulatory solutions, thereby de-risking the certification pathway for the HAPSS-modified aircraft.

3.2 Initial Airworthiness and Environmental Protection

This section outlines the key provisions of EASA Part 21 – Initial Airworthiness and Environmental Protection [8] that are relevant by the introduction of HAPSS. The implementation of HAPSS is expected to require EASA rulemaking activities to amend the relevant provisions of Part 21 as indicated in the text below.

Cover Regulation

The cover regulation defines “complex motor-powered aircraft” an airplane equipped with more than one turboprop engine (Article 1, 2 (ha) (i)) with the turboprop definition from ICAO meaning:

- Turbo-Prop engine: a simple turbojet core with the addition of a propeller output reduction gearbox and a propeller shaft.

This definition needs to be altered or refined for the HAPSS application as it impacts Annexes and subparts of the regulations.

Annex I – Section A

Subpart B - Type-Certificates and Restricted Type Certificates

- 21.A.11 Scope
  Scope includes a TC for the HPS certified as an engine.

Subpart D - Changes to Type-Certificates and Restricted Type-Certificates

- 21.A.90A Scope
  Scope includes the HAPSS modification to change Aircraft TC and Propellor TC.

- 21.A.91 Classification of changes to a type-certificate
  Linked to 21.B.85 (a) (2) Intentional Fuel Venting;
  The intended product modifications should be classified in accordance with established change classification principles, with support from EASA pre-application services under the HAPSS IPC contract.

Subpart G – Production Organization Approval

- 21.A.145 Resources
  Although no modification to the text is required it is expected that knowledge and expertise need to be developed for HPS systems including the H2 fuel system and related high

voltage systems.

- 21.A.151 Terms of approval
  The scope of work for a production organization needs to be expanded to include Hydrogen Propulsion Systems.

Subpart J – Design Organization Approval

- 21.A.245 Resources
  Although no modification to the text is required it is expected that knowledge and expertise need to be developed for HPS systems including the H2 fuel system and high voltage systems. This capability includes the independent check function of the Design Organization.

Annex I – Section B

Subpart B - Type-Certificates and Restricted Type-Certificates

- 21.B.85 (a) (2) Intentional Fuel Venting
  As discussed in 2.7 regulations require aircraft designs to avoid intentional fuel discharge. For hydrogen aircraft, this mainly affects the fuel storage and distribution system: liquid hydrogen boil-off requires controlled venting for safety, refuelling and purging use closed systems, and any necessary venting must be routed through dedicated lines—not through the fuel cell exhaust.

3.3 HAPSS Change classification

To establish a provisional certification basis supporting the development activities of the HAPSS project during the pre-certification phase, an initial change classification is performed in accordance with EASA Part 21.

The modification is classified as a Major Change under 21.A.91 and a Significant Major Change under 21.A.101, but not as a substantial change as explained in 3.4 Rationale for classification. Certification is envisaged via the Supplemental Type Certificate (STC) route for the aircraft, with a separate type-certification basis for the HPS as an engine-equivalent product.

The existing propeller will be approved under an STC, with compliance demonstrated against the applicable CS-P requirements. Compliance for the aircraft modification is expected to be shown largely against the latest applicable CS-25 requirements, supplemented by Special Conditions addressing hydrogen- and fuel-cell-based propulsion systems and relevant environmental protection aspects.

3.4 Rationale for Classification

21.A.91 – Major vs Minor Change

The modification has appreciable effects on airworthiness and environmental characteristics and therefore cannot be considered minor. Key areas of impact include:

- Mass and balance: installation of the hydrogen storage and distribution system and associated equipment leads to appreciable changes in operating weight and centre-of-gravity management. These changes are accommodated within existing limits and involve payload redistribution and cabin reconfiguration.
- Structure: new nacelles and propulsion system installations, as well as integration of an aft-fuselage tank compartment, introduce new structural loads and interfaces, while remaining within overall structural design limits.
- Systems and reliability: replacement of conventional turboprop engines and kerosene fuel systems with hydrogen fuel-cell-based propulsion, high-voltage electrical systems, hydrogen safety functions, and new fire protection features affects multiple aircraft systems and ATA chapters.
- Operational characteristics: powerplant operating procedures, abnormal and emergency conditions, one-propeller-inoperative considerations, and flight and maintenance crew

training differ materially from those of the baseline aircraft.

- Environmental characteristics: conventional engine emissions are eliminated, while new characteristics are introduced, including hydrogen venting behavior.

Based on these appreciable effects, the change is classified as Major under 21.A.91.

21.A.101 – Significant vs Substantial Change

Applying the criteria of 21.A.101(b)(1), the modification is considered Significant as it alters the powerplant configuration and invalidates several assumptions underlying the original certification basis, including those related to fuel storage location, engine behavior, and associated safety analyses.

However, the change is not substantial, as the fundamental airframe design, cockpit architecture, and many existing systems remain within the certified DHC-8-300 envelope. Compliance can be achieved through targeted modifications, updated methods of compliance, and the application of Special Conditions, rather than a substantially complete re-certification equivalent to a new Type Certificate.

3.5 Certification gap analysis method

The gap analysis on both CS25 and SC-E19 is done based on the methodology developed in CONCERTO project [14]. It consists in gathering a set of relevant data for three inputs that go through an in-depth cross-analysis, organized by certification panels as defined by EASA, to derive outputs, as shown in Figure 2. The result of this gap analysis defines regulatory gaps, critical certification areas and identifies regulatory risks. This regulatory risk should be considered as effort to close the gap.

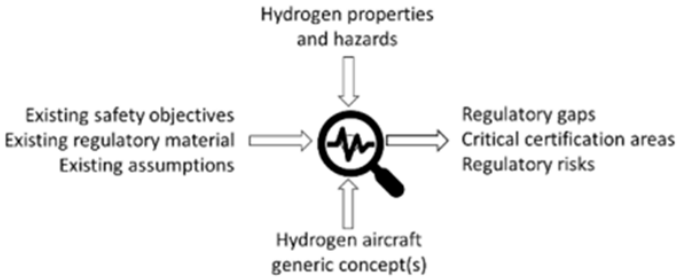


Figure 2 - Concerto risk method.

An initial evaluation identifies the underlying sources of impact associated with the HAPSS aircraft modification. These sources are mapped to the affected Certification Specifications (CS) paragraphs, followed by an assessment of the continued validity of the safety intent and assumptions, and an analysis of gaps in the existing requirements.

For the HAPSS modification, the main drivers affecting the Certification Specifications are twofold: the hydrogen-electric propulsion system (HPS) and its components, and the aircraft systems related to hydrogen fuel storage and distribution, together with their associated fire detection and protection functions.

Table 4 - Source of impact to certification specifications.

System	Source of impact
HPS	HPS functioning and installation as an engine
	Starter Battery
	Electric Power Distribution System
	Engine Electric
	Exhaust
	Fuel Cell System
	HPS Thermal System

Aircraft systems	Hydrogen fuel system
	Fire detector system
	Fire extinguisher agents
	Fire extinguisher system
	Fire extinguisher classification

In the next step the requirement's relevance to hazards associated with hydrogen as listed in [15] are assessed:

- dispersion of cryogenic H2
- Human health consequences
- inadequate dispersal/ventilation
- leaks/release
- material embrittlement
- ignition/fire/explosion
- Storage Vessel Failure

But also, in this step the implications are considered of introducing hydrogen as a fuel into aircraft design, with the objective of identifying potential gaps in the existing Acceptable Means of Compliance (AMCs).

Specifically, it assesses:

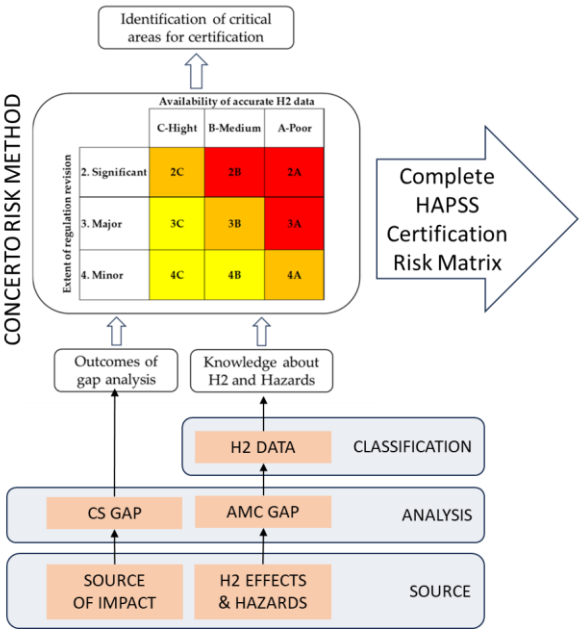
- the implications of hydrogen application for fire protection,
- the implications of hydrogen application for material properties, and
- the implications of not storing hydrogen as a fuel within the wing structure. Relevant AMCs assume implicitly that fuel is stored in wing structures, and that fuel is in direct contact with structure.

The final step is the assessment of regulatory risk, which reflects the effort required to close existing gaps. Within the CONCERTO framework, this risk is defined in two dimensions: the extent of regulatory revision required and the availability of accurate hydrogen-related data.

The resulting risk matrix classifies the extent of regulatory revision into four categories: Minor, Major, Significant, and Not Applicable. The second dimension, data availability, is categorized as High, Medium, Poor, and Not Applicable. Compared to the original CONCERTO risk matrix, additional “Not Applicable” categories have been introduced to improve clarity, completeness, and transparency of the assessment, as illustrated in the Figure 3 below.

Finally, the regulatory risk, according to CONCERTO is in the matrix is defined as:

- RED: High risk affects the timely finalization of rulemaking and standardization activities, which could delay the certification process.
- ORANGE: Medium risk could affect the timely finalization of rulemaking and standardization activities.
- YELLOW: Low risk could have a minor impact on finalization of rulemaking and standardization activities.
- GREEN: No impact on existing CS paragraphs and AMCs.



Complete HAPSS Certification Risk Matrix		H2 KNOWLEDGE Availability of accurate H2 data			
CS REVISION Extent of the regulation revision	Outcome of gap analysis	D. N/A	C. High	B. Medium	A. Poor
	1. No impact	NO 1D	N/A Selection 1C	N/A Selection 1B	N/A Selection 1A
	2. Significant	LOW 2D	MEDIUM 2C	HIGH 2B	HIGH 2A
	3. Major	LOW 3D	LOW 3C	MEDIUM 3B	HIGH 3A
	4. Minor	LOW 4D	LOW 4C	LOW 4B	MEDIUM 4A

Figure 3 - Implementation of CONCERTO gap analysis method.

3.6 Certification gap analysis

The proposed certification approach consists of a Supplemental Type Certificate (STC) based on CS-25 [6] for the aircraft, a STC for the existing propeller (as the existing controls are mounted on a new reduction gearbox) based on CS-P [16] and a Type Certificate (TC) for the Hydrogen Propulsion System, classified as an engine. The latter TC is expected to build upon Special Condition SC-E19 [17], extended to address hydrogen-specific aspects.

Results of the certification specification gap analysis, based on expert assessment, are shown in Table 5. Numerically CS25 is impacted for about 20% and SC-E19 by 10% of the existing paragraphs when the medium and high efforts are combined, as Low is only a textual update.

Table 5 - Risk analysis of CS25 and SC-E19 per subpart.

		RISK				
		No	Low	Medium	High	total
CS25	SUBPART A - GENERAL	0	1	0	0	1
	SUBPART B - FLIGHT	30	9	2	0	41
	SUBPART C - STRUCTURE	53	1	3	5	62
	SUBPART D - DESIGN AND CONSTRUCTION	84	5	1	12	102
	SUBPART E - POWERPLANT	28	8	4	40	80
	SUBPART F - EQUIPMENT	55	6	9	10	80
	SUBPART G - OPERATING LIMITATIONS AND INFORMATION	32	3	2	3	40
	SUBPART H - ELECTRICAL WIRING INTERCONNECTION SYSTEMS	15	4	1	2	22
	SUBPART J - AUXILIARY POWER UNIT INSTALLATIONS	55	0	0	0	55
		12	0	2	6	20
		364	37	24	78	503
		72%	7%	5%	16%	

		RISK				
		No	Low	Medium	High	total
SC-E19	SUBPART A - GENERAL	11	13	0	2	26
	SUBPART B - DESIGN AND CONSTRUCTION	26	26	0	9	61
	SUBPART C - SYSTEMS AND EQUIPMENT	24	22	2	4	52
	SUBPART D - SUBSTANTIATION	6	19	0	1	26
		67	80	2	16	165
		41%	48%	1%	10%	

The analysis can also be shown by EASA expert panel. As expected, the most impacted expert panels are Flight, Structures, Electric Systems, Powerplant and, Cabin Safety for CS25. Logically expert panel Propulsion is in control of SC-E19.

Table 6 - Risk analysis of CS25 and SC-E19 per EASA expert panel.

			RISK				total	Total
	Panel		No	Low	medium	high		Medium + High
CS25	Panel 0	PCM	5	1	0	2	8	2
	Panel 1	Flight	60	9	5	1	75	6
	Panel 1.b	Human Factors	2	1	1	0	4	1
	Panel 3	Structures	75	3	4	7	89	11
	Panel 4	Hydromechanical Systems	26	1	1	1	29	2
	Panel 5	Electrical Systems	36	4	1	7	48	8
	Panel 6	Avionic Systems	16	2	1	2	21	3
	Panel 7	Powerplant Installation and Fuel Systems	90	13	10	44	157	54
	Panel 8	Environmental Control Systems (ECS)	23	1	1	3	28	4
	Panel 10	Software,Airborne Eectronic Hardware (AEH), Development Assurance (DA)	0	0	0	1	1	1
	Panel 11	Cabin Safety	27	2	0	8	37	8
	Panel 12	Safety Assessment (SA)	0	0	0	1	1	1
	Panel 14	ICA	3	0	0	2	5	2
	Total		363	37	24	79	503	103
			72%	7%	5%	16%		20%

			RISK				total	Total
			No	Low	Medium	High		Medium + High
SC-E19	Panel 19	Propulsion	51	80	2	15	148	17
			34%	54%	1%	10%		11%

3.7 CS25 gap analysis

The CS25 gap analysis is a long list of detailed assessments per paragraph. The list in Table *7* gives an overview of the impacted blocks.

Table 7 - CS25 gap analysis.

SUBPART	BLOCK
Subpart A - General	-
Subpart B - Flight	General
Subpart C - Structure	General
	Supplementary conditions
	Fatigue evaluation
Subpart D - Design and Construction	Fire protection
Subpart E - Powerplant	General
	Fuel system
	Fuel system components
	Oil system
	Air intake system
	Exhaust system
	Powerplant controls and accessories
	Powerplant fire protection
Subpart F - Equipment	General
	Instruments: installation
	Safety equipment
Subpart G - Operating Limitations and Information	Operating limitations
	Markings and placards
	Aircraft flight manual
Subpart H - Electrical Wiring Interconnection Systems	EWIS

Subpart A – General

The current certification basis is limited to turbine-powered large aircraft and must be adapted to accommodate Hydrogen Propulsion System architectures. Applicability of CS-25 requires revision to explicitly address hydrogen fuel systems, fuel cells, electric motors, and electric power management systems as integrated primary propulsion elements.

Subpart B – Flight

Existing flight requirements are based on hydrocarbon fuelled engine-centric assumptions and a single critical power source, which are not representative of hydrogen-electric aircraft. Distributed and redundant power architectures introduce different performance characteristics, failure behaviours, and operational conditions. Adaptation is required to address energy management, aircraft handling qualities, environmental control, and the integration of non-wing hydrogen storage systems related to weight and balance.

Subpart C – Structure

Current structural requirements do not explicitly address hydrogen leakage, and its associated fire and explosion risks. Load, strength, and fatigue criteria are focused on conventional engine installations and overlook fuselage-mounted hydrogen tanks, electric motor torque effects, and cryogenic hazards. Dedicated guidance is required to address hydrogen embrittlement, damage tolerance, aeroelastic effects, and structural interactions with hydrogen fuel and electric propulsion systems.

Subpart D – Design and Construction

Hydrogen-specific hazards are insufficiently covered by existing safety and fire protection requirements. Scenarios such as post-crash damage to hydrogen systems, hydrogen fire behaviour, and appropriate extinguishing approaches are not clearly addressed. In addition, hydrogen compatibility of materials, electronic components, and the definition of hazardous zones require explicit revision.

Subpart E – Powerplant

Powerplant requirements are based on conventional engines, jet fuel, and wing-integrated fuel tanks, and are misaligned with hydrogen propulsion architectures. Cryogenic and gaseous hydrogen behaviour, refuelling, venting, purging, crashworthiness, and explosion risks are not adequately addressed.

In addition, control, monitoring, start-up, shutdown, and failure management concepts must be redefined for fuel-cell and electric-motor systems, including a shift from traditional one-engine-inoperative concepts to one-propeller-inoperative considerations in a distributed power architecture, supported by new terminology and dedicated guidance material.

Subpart F – Equipment

System markings and AMCs must be revised to reflect hydrogen and high-voltage electric systems as primary power sources. Terminology should move away from engine-centric concepts toward distributed electric power architectures. Flight deck design, crew procedures, system indications, and protections must be reassessed to ensure safe hydrogen operation, including specific functions such as ice protection.

Subpart G – Operating Limitations and Information

Current operating limitations and information assume conventional engines and do not adequately support hydrogen or electric power architectures. Fuel reserves, refuelling procedures, limitations, cockpit indications, and markings require adaptation. Several aircraft systems must be reassessed to ensure clear crew information, safe operation, and comprehensive documentation for hydrogen-powered aircraft.

Subpart H – Electrical Wiring Interconnection Systems

Multiple CS-25 paragraphs require revision to align with hydrogen propulsion system architectures and updated references in other subparts. Specific paragraphs will be rewritten to address hydrogen fuel systems, including liquid and gaseous hydrogen, and to realign cross-references related to fire protection, ventilation, and system safety. These changes are necessary to ensure consistency and completeness of certification requirements for hydrogen-electric aircraft.

3.8 SC-E19 impact analysis

The current scope of SC-E19 is Electric Hybrid Propulsion Systems with exclusion of hydrogen application. This special condition is a performance based special condition where several Acceptable Means of Compliance (AMC) are still in development. The assessment finds that while current CS-E and CS-APU guidance material offer a useful baseline for HPS certification, they are not sufficient without specific adaptation for hydrogen and high-voltage applications. Additional proposed special conditions are required to cover an HPS (designated SC EHPS in Table 8), as in this context the sources of impact are:

- Fuel Cell System
- Electric Power Management System
- Starter Battery
- Hydrogen as a fuel
- Hydrogen hazards and effects

Table 8 - Gap analysis SC-E19.

#Subpart	#CS No.	#CS Title
Subpart A General	EHPS.10	Scope
	EHPS.15	Terminology
	EHPS.30	Instructions for installation and operation of the EHPS
	EHPS.40	Ratings and operating limitations
Subpart B Design and Construction	EHPS.100	Fire Protection
	SC EHPS.120	Hydrogen protection
	SC EHPS.135	Electrical Bonding
	SC EHPS.140	Accessibility
	SC EHPS.150	Prevention of Corrosion and Deterioration
	SC EHPS.160	Air Intake
	SC EHPS.170	Fuel System
	SC EHPS.180	Exhaust System
	EHPS.200	Static and fatigue Loads
	EHPS.210	Strength
	EHPS.230	Vibration Survey
	EHPS.250	Rotating parts containment
	EHPS.290	Bird, hail strike and impact of foreign matter
Subpart C Systems and Equipment	EHPS.300	Fuel system
	EHPS.320	Cooling system
	EHPS.330	Equipment
	SC EHPS.342	Start-up and restart
	EHPS.350	EHPS Control System
	EHPS.360	Aircraft instruments
	SC EHPS.390	Starter battery

Subpart D Substantiation	SC EHPS.415	Propeller Functioning Tests
	EHPS.460	Operational Demonstration
	EHPS.480	EHPS Specific operation
	EHPS.490	System, equipment and component tests

Subpart A – General

The impact is a required shift from an EHPS framework excluding hydrogen application to a Hydrogen Propulsion System (HPS) framework. All requirements must consistently use HPS terminology. Existing rules remain largely applicable but need alignment to HPS-specific architecture and safety.

The HPS includes all equipment and functions required to generate, control, manage, and deliver propulsive power, including interfaces with aircraft systems. The scope encompasses installation aspects, system safety, control and monitoring, thermal management, energy storage interfacing, and power distribution, as applicable to safe and compliant operation.

Proposed Scope

This Special Condition applies to Hydrogen Propulsion Systems (HPS) intended for installation on hydrogen-fueled CS-25 airplanes. The HPS is considered a complete propulsion system, equivalent to certification with intent to a conventional engine. It covers propulsion systems using hydrogen, in liquid or gaseous form, as the energy source, including fuel cell–based architectures and associated electrical propulsion elements.

Subpart B – Design and Construction

Across most Subpart B requirements, textual renaming EHPS to HPS, and additional or adapted Means of Compliance are needed to address hydrogen-specific hazards. These include leakage, accumulation, material embrittlement, corrosion, fire, and high-voltage effects that are not adequately covered by existing standards.

Many environmental, ingestion, and impact requirements are assessed as aircraft level responsibilities, but their interfaces with HPS cooling and fuel cell systems must still be demonstrated. Significant gaps remain in materials, safety assessment, critical parts, and electrical bonding, driving the need for bespoke analyses, test methods, and reliability data.

To close these gaps, several new Special Conditions are proposed as shown in Table 8 above.

Subpart C – Systems and Equipment

Most requirements remain applicable with no or minor impact and mainly require renaming from EHPS to HPS. Hydrogen properties and fuel-cell architecture introduce targeted changes, particularly in the fuel system, automatic shutdown logic, and start-up behavior. The ignition system is not applicable, but its safety intent is replaced by new start-up and restart requirements. Control, cooling, instrumentation, electrical power, and dispatch provisions largely rely on existing guidance with limited adaptation. Propulsion battery requirements do not apply, but a dedicated starter battery creates new requirements for safety, protection, charging, monitoring, and integration. Overall impact is concentrated on hydrogen handling, startup and shutdown functions, and electrical energy storage and supply of starter battery, while the remainder of the framework is largely preserved.

Subpart D – Substantiation

The substantiation framework of subpart D remains largely valid but requires adaptation from EHPS to HPS and explicit integration of a representative propeller and a representative powerplant configuration in system-level testing. The main impacts are in endurance, durability, and operational demonstrations, which must be expanded to address hydrogen fuel characteristics, electric power and thermal limits, and integrated system behavior. Several tests are not directly applicable to fuel-cell architectures, but their safety intent is retained through revised or new requirements. Overall, the existing test philosophy is preserved, while hydrogen effects, electric-specific failure modes, start-up and restart behavior, and propeller-coupled performance

drive the necessary changes.

3.9 HAPSS Certification Testing Roadmap

In the context of the three Type Certificates of the HAPSS modification, the following product certification test roadmap is foreseen:

HPS:

Ground Tests:

Tests to understand the system's behavior and failure cases;

Demonstration with single hydrogen driven engine;

Clearance for demonstrator flights.

TC for the HPS as an engine and propeller STC.

HAPSS Test Aircraft:

Aircraft ground and flight tests:

Installation of one HPS and one existing combustion engine.

Under jurisdiction of ILenT (Dutch Civil Aviation Authorities)

As demonstrator aircraft are national responsibility.

HAPSS Dash 8-300:

Aircraft ground and flight tests with two HPS installed:

Full certification on series conforming aircraft.

Under jurisdiction of EASA

STC HAPSS Dash 8-300.

As a clarification related to the propellor STC, the existing propellers will be retained, while the current propeller control systems will need to be adapted for the hydrogen propulsion system.

4 Network Integration

4.1 Introduction

The integration of hydrogen-powered regional aircraft into existing aviation systems requires careful consideration of both ground and air operations.

Evaluating network integration emphasizes that flight performance during departure, cruise, and arrival phases remains largely comparable to conventional turboprops, minimizing the need for significant air traffic control (ATC) adjustments.

Evaluation of ground operations presents more substantial changes. The introduction of cryogenic hydrogen fuel demands enhanced safety protocols, specialized crew training, and updated emergency procedures to mitigate risks such as fire, venting, and frostbite. While infrastructure modifications are minimal, hydrogen refueling—initially via mobile bowsers—requires defined safety zones and may affect turnaround times. Additionally, rescue and firefighting services must adapt to hydrogen-specific hazards, including invisible flames and low heat radiation.

For air operations of the HAPSS aircraft each flight phase will be addressed:

- Departure;
- Cruise;
- Arrival.

For ground operations a section outlines the integration of HAPSS Dash 8-300 into airport operations and a section discussing phases associated with ground operations:

- Engine Start
- Taxi and Departure
- Turn-Around Time

4.2 Air Operations

The AZEA framework [2] defines departure, cruise, and arrival phases to structure the assessment of impacts on air operations.

Departure Phase

The departure phase starts after take-off at 1500ft and covers climb. The performance characteristics of the HAPSS modified Dash 8-300 are specified not to impact the departure phase of the aircraft and thus remain within the normal climb performance expected (climb rate and air speed). Departure routes are expected to be shorter as the aircraft range is reduced, meaning a lower cruise level thus flying a more direct route to the destination.

As the aircraft's climb rate and airspeed are within the normal range for regional transport category aircraft, no additional ATC measures are required. The lower service ceiling could impact departures over mountainous terrain thus departure procedures at selected airfields need to be assessed prior to flight clearance.

Cruise Phase

For the cruise phase the airspace impact is mostly linked to flight level and cruise speed. The expected cruise altitude is FL160, as this provides the maximum range (750 km) within the capability of the HPS. This flight level is also normally associated with regional aircraft operations. When operating at intermediate altitudes (FL100 – FL200), aircraft routes are likely to be more subject to weather systems thus operations at these intermediate altitudes will need to be robust for avoiding such weather systems. Cruise speeds of the HAPSS aircraft are like the 'classic' Dash 8-300 thus no operational impact is foreseen also in terms of airspace design and sectorization. As an additional explanation lower cruise altitudes and speeds are beneficial for the HAPSS range however as the intended use is in the current airspace environment regular altitudes and speeds will be maintained to ease integration.

Arrival phase

The final approach speeds for the HAPSS variant are like the 'classic' Dash 8-300 of conventional aircraft range around 210 kts and landing speeds of about 110 kts. With the conventional approach speed no specific independent arrival routes for the HAPSS aircraft, speed control regimes or additional ATC measures are required.

4.3 Ground operations aspects and considerations

The following aspects and considerations are relevant for ground operations. It should be noted that detailed specification and implementation will be further developed in subsequent project phases, particularly during demonstrator development and certification activities. Although these elements are not within the direct scope of the TC holder, the aircraft design should, where possible, anticipate and accommodate these operational requirements to support future integration and certification.

Aircraft weight:

- As the HAPSS variant is based on an existing airframe, currently certified weight limits are not exceeded. Consequently, there is no expected impact on allowable airfield ramp weights.

Safety management:

- Ground operation safety risks include:
  - Fire hazards associated with:
    - Hydrogen fuel and venting
    - Hydrogen refuelling (de-fuelling considered a maintenance activity)
    - Parking with cryogenic hydrogen without human oversight
- Ground safety management considerations:
  - Embarking and disembarking procedures
  - Operations in congested areas and parking conditions
  - Long-duration parking positions

Training

- Specific training will be required for personnel involved in ground operations, including parking manoeuvres and procedures that differ from those used for conventional aircraft.

Rescue and Fire Fighting Services (RFFS)

- Safety analysis and risk identification:
  - Airfield transport of cryogenic liquid hydrogen
  - Hydrogen leaks (gaseous or liquid), including associated fire and explosion hazards
- Emergency response considerations:
  - Hydrogen flames are nearly invisible and emit significantly less thermal radiation (approximately 10%) compared to Jet A-1 fires (30–40%), requiring adapted detection and intervention procedures

Specialized human resources

- Key areas requiring specialized personnel include:
  - Safety monitoring
  - Maintenance of hydrogen systems:
    - Cryogenic hydrogen systems
    - High-voltage systems
- Refuelling services
  - A structured plan for recruitment and training of personnel will be required.

Infrastructure

- Stand infrastructure:
  - No dedicated stand infrastructure is currently foreseen for HAPSS
  - Ground Power Units (GPU) are assumed to be standard airfield-provided equipment
- Hydrogen storage and handling:
  - On-aircraft storage:
    - Liquid hydrogen storage introduces new safety considerations, including:
      - Prevention of frostbite risks for ground crew
      - Avoidance of asphyxiation in confined spaces in case of spills
      - Mitigation of fire risks due to hydrogen flammability
    - Hangar parking and MRO activities:
      - Parking of an HAPSS aircraft inside a hangar introduces additional constraints due to the enclosed environment.
      - Specific requirements will need to be defined for:
        - Detection and management of hydrogen leaks (gaseous and liquid)
        - Ventilation systems to prevent accumulation of hydrogen and associated asphyxiation or explosion risks
        - Safe venting procedures during maintenance and storage
        - Restrictions or conditions for storing aircraft with liquid hydrogen onboard inside hangars (e.g. maximum dwell time, mandatory monitoring, or defueling requirements)
      - These aspects will be further addressed during certification and demonstrator phases and will influence airport MRO facility design and procedures.
- Off-aircraft storage:
  - For early adoption phases, hydrogen supply is expected via bowser trucks and tank trailers, positioned in designated safe zones at airfields

Stand / platform operations

From an aircraft dimensional perspective, the HAPSS variant remains identical to the conventional Dash 8-300 and does not impact apron capacity. However, additional safety margins related to

hydrogen operations still need to be defined.

Operational considerations include:

- Limited dormancy period of hydrogen tanks; boil-off may occur due to heat ingress, requiring controlled venting to prevent overpressure
- Potential constraints on the allowable time between refuelling and departure
- Evaluation of heat influx effects on storage stability

Safety Zones

For hydrogen-fuelled aircraft operations, safety zones are established to protect passengers, personnel, equipment, and aircraft from hazards associated with hydrogen releases, ignition, cryogenic exposure (for liquid hydrogen), and overpressure events. Typically, two distinct zones are defined because the risk profile, as shown in Table *9* is different during fuel transfer (refuelling) and during connection/disconnection of the fuelling system (coupling & decoupling).

The hydrogen refuelling safety zone is the controlled area surrounding the aircraft fuelling interface, transfer hose, fuelling vehicle, and venting locations during active fuel transfer. Only personnel directly involved in the operation may enter the zone, and all ignition sources shall be excluded.

The coupling and decoupling safety zone is the restricted area established around the hydrogen fuelling interface while hoses are connected or disconnected. The zone protects personnel from hydrogen releases, cryogenic exposure, and ignition hazards associated with pressurized connections.

Table 9 - Safety zones for refuelling operations.

Aspect	Refueling Zone	Coupling & Decoupling Zone
Activity	Active fuel transfer	Hose connection/disconnection
Main hazard	Continuous transfer leak	Release from connectors and trapped hydrogen
Duration	Entire fueling operation	Short transitional period
Area covered	Aircraft, hose, fueling equipment, vents	Immediate vicinity of connector
Personnel access	Fueling personnel only	Minimum essential personnel
Critical controls	Ignition source control, monitoring, ESD	Leak checking, purge, depressurization

An integrated overview of the operational concept is provided in a single figure, combining both the safety zones during hydrogen refuelling and a representative platform arrangement. Figure *4* below illustrates:

- Both safety zones during fueling operations
- Positioning of hydrogen supply equipment (e.g. bowser trucks or tank trailers)
- Aircraft stand arrangement and ground handling interfaces

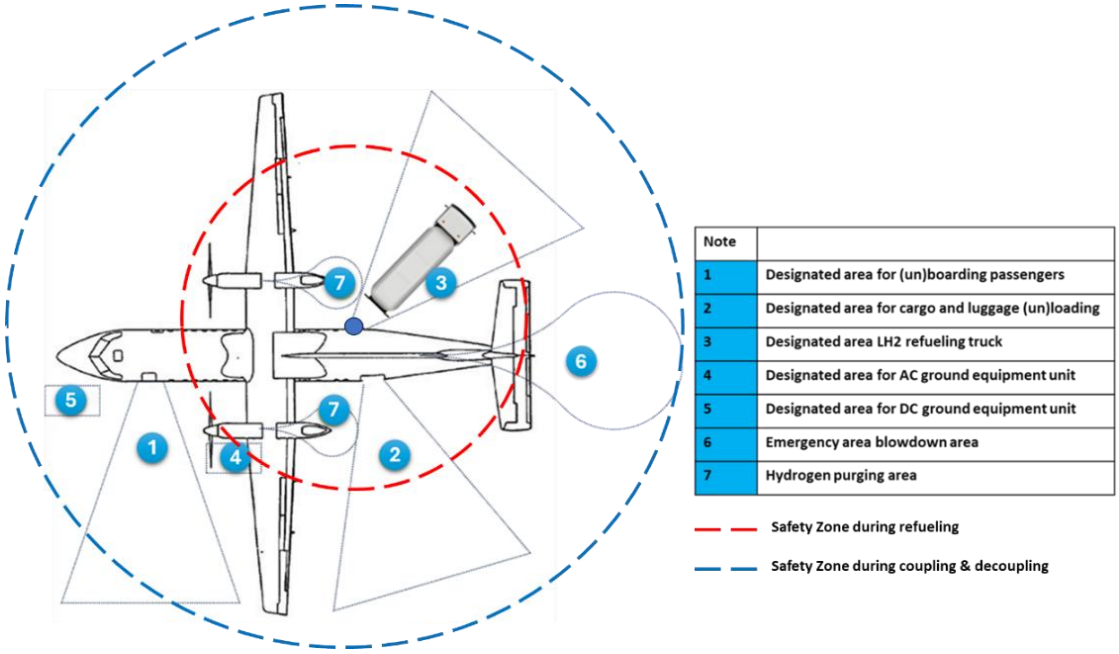


Figure 4 - Integrated overview of safety zones and platform arrangement for hydrogen ground operations.

4.4 Ground operations

Ground operations are defined as follows:

Engine start

- For the HAPSS powerplant, “engine start” differs from a conventional turboprop. It consists of conditioning and energizing the fuel cell stacks to bring the power generation section online, without immediately producing thrust.
- The system is powered up while at the gate/parking/platform, with the propulsion section remaining inactive. This reflects the architectural separation between the power generation (fuel cells) and propulsion functions.

Taxi and departure

- No significant impact is foreseen for taxi and departure procedures for the HAPSS-modified Dash 8-300.
- Departure performance, including Weight–Altitude–Temperature (WAT) considerations, is expected to remain comparable to the baseline (“classic”) Dash 8-300.

Turn-Around Time (TAT)

- An initial evaluation has established a minimum expected TAT of 36 minutes, as illustrated in Figure *5* below. Depending on the results of the stand/platform safety assessment, the order and timing of ground operations may be modified accordingly.

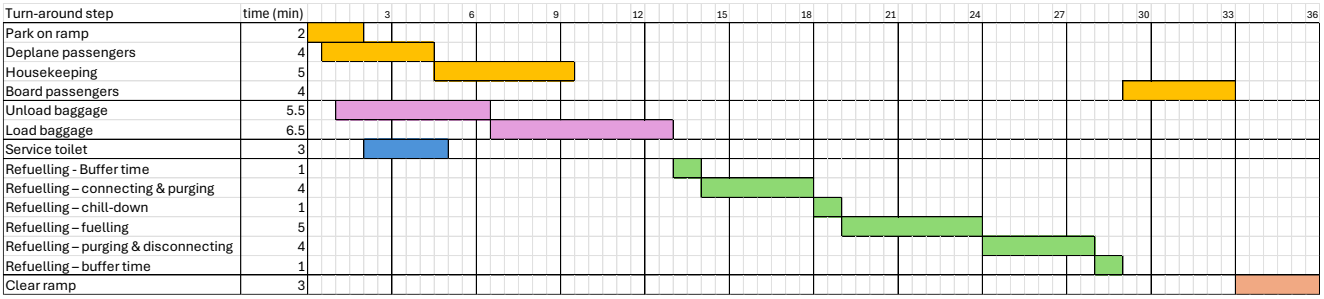


Figure 5 - HAPSS expected minimal turnaround time including refuelling.

- The refuelling procedure and associated time estimate assume a tank that remains close to its nominal operating temperature (~20 K), as a significant fuel reserve is retained during normal operations. This reserve corresponds to approximately 40% (≈120 kg) of the total liquid hydrogen (LH_2) tank capacity of 340 kg. Under these conditions, refuelling of 220 kg LH_2 can be done within 5 minutes at a mass flow rate of 0.8 kg/s.

- If the reserve fuel has been largely depleted, refuelling of a “warm” or “hot” tank requires additional conditioning steps—such as cooling and boil-off management—which increase both the complexity and duration of the refuelling process.
- TAT benchmarking: An assessment of typical turnaround times in current airline operations has been conducted to evaluate the alignment of the HAPSS concept with existing practices. Turnaround times vary depending on airline operating models and utilization strategies. For many Dash 8-300 operators, aircraft are typically deployed in relatively low-frequency operations, meaning that TAT is not a primary operational constraint. The analysis indicates that a minimum TAT of approximately one hour would not adversely affect current operations.

These findings provide a reference framework for assessing the operational compatibility of the HAPSS concept and identifying potential impacts on scheduling and airport throughput.

As illustrated in the stand/platform arrangement in Figure *4*, the refuelling truck is positioned near the aircraft, enabling an operational concept comparable to conventional refuelling. However, further detailed safety assessments may require refuelling to be conducted in a designated safety area, physically separated from the aircraft stand. Such a requirement could introduce additional operational constraints and potential penalties on turnaround time.

5 Air Traffic Management

5.1 Introduction

The main elements of ATM (Air Traffic Management) operations that are impacted by the HAPSS solution: Air Traffic Control (ATC), Air Space Management (ASM), Aerodrome Operations are discussed.

Additionally impact to other Network Operations Components as Airspace Design, Air Traffic Flow Management, Operations at Secondary Airports, Low Level Operations, Communication Navigation and Surveillance (CNS) Infrastructure are discussed.

Evaluation of impact to Air Traffic Management concludes that the aircraft’s lower cruising altitude places it within busier lower airspace, potentially impacting sector capacity and increasing weather-related complexity. Although speed profiles and route structures remain consistent with current turboprops, contingency planning must incorporate hydrogen-specific emergency scenarios. Coordination with air navigation service providers (ANSPs) is essential to ensure compliance with ICAO standards and to define safe operational procedures.

5.2 Operational concepts for ATM

Air Traffic Control (ATC)

- In principle, the HAPSS-modified Dash 8-300 is expected to operate similarly to conventional turboprop aircraft. As such, no additional requirements are anticipated with respect to:
  - Controller tools
  - ATC workload
  - Air traffic separation standards

Airspace Management (ASM)

- From an airspace management perspective, the HAPSS Dash 8-300 is also expected to behave comparably to existing turboprop aircraft. Therefore, no significant impact on ASM processes or structures is foreseen.

Aerodrome operations

- Aerodrome operations are not expected to be significantly affected, as aircraft ground movement characteristics remain unchanged.
- Taxi procedures are considered equivalent to those of the baseline aircraft.
- Departure and arrival performance characteristics of the HAPSS aircraft are expected to be in line with current operations.
- The impact of hydrogen refuelling operations is addressed separately in section 4.

5.3 Other Network Operations Components

Air Traffic Flow Management (ATFM):

- As the HAPSS configured aircraft operates within the speed regimes of typical turboprop aircraft ATFM is not impacted.

Operations at regional airports:

- Within the broader network context, HAPSS operations are primarily envisaged at regional airports, as these align with the operational profile and commercial use of turboprop aircraft. As part of the overall network integration, including ATM, aerodrome infrastructure, and ground handling—both operators and airports will need to implement appropriate provisions to enable safe and efficient HAPSS operations.

Low Level Operations:

- As the HAPSS configured aircraft operates within the altitude regimes of typical turboprop aircraft low level operations are not impacted. Future developments in airspace design could provide the option to fly at lower altitudes which are more efficient for the HAPSS aircraft but currently not considered.

Communication Navigation and Surveillance (CNS) Infrastructure:

- These infrastructures are not affected by the introduction of a HAPSS configured aircraft.

Airspace Design:

- The HAPSS modified Dash 8-300 can operate within the current limitations of the airspace design.

6 Operational Integration and Training Impact

6.1 Introduction

As operators of the HAPSS Dash 8-300 are expected to represent early adopters of hydrogen-powered aviation, the primary objective is to enable its introduction with minimal disruption to existing flight planning and operational processes.

Flight operations involve multiple stakeholders across the aviation network, each with defined roles and responsibilities. This section therefore addresses the integration of HAPSS into these operational frameworks, with particular emphasis on training requirements and their implications for safe and effective operational deployment.

6.2 Flight Crew

Two distinct flight crew groups are considered flight crews operating the HAPSS Dash 8-300 and flight crews of other aircraft operating within the same airspace and network as the HAPSS modified Dash 8-300.

HAPSS Dash 8-300 Flight Crew

- Conversion training is required for flight crews operating HAPSS aircraft to become proficient with the modified aircraft, covering topics like adapted aircraft flight manual, operational flying, normal and emergency procedures, and propulsion system functionality differ from those of the conventional Dash 8-300.
  - Identified training topics include, but are not limited to:
    - Flight Performance:
    - Take-off performance;
    - Reduced operational ceiling;
    - Maximum take-off weight (MTOW) close to maximum landing weight (MLW).
  - Operations
    - Powerplant start-up procedures;
    - Powerplant failure modes;
    - Hydrogen (H_2) fueling operations;

    - Human–Machine Interface (HMI).
- Propulsion System
    - Difference training specific to the hydrogen propulsion system.

Network Flight Crews

- To ensure situational awareness among flight crews of other operators sharing the same airspace, the regulatory authority may issue an information bulletin. This bulletin should highlight differences in aircraft performance and any specific ground operations relevant to safety management.

6.3 Aerodrome Operators

Aerodrome operators will be required to provide or accommodate support services associated with HAPSS operations:

ATC Clearance Delivery

- To prevent extended delays following engine start or push-back, particular attention must be given to hydrogen fuel capacity relative to mission range. This is especially critical for HAPSS operations, which are expected to operate near maximum fuel capacity with limited reserves.
- Targeted ATC training is therefore anticipated, focusing on the key performance characteristics and operational sensitivities of the HAPSS Dash 8-300.

Apron and Ground Control

- Tower and ground controllers are responsible for authorizing ground movements of HAPSS aircraft. No fundamental changes to ground maneuvering procedures are anticipated for the HAPSS Dash 8-300.
- However, depending on defined safety management requirements (see Section 4), additional controller workload may arise. This could include the use of segregated fueling areas or temporary apron restrictions during specific operations. The impact on training requirements requires further assessment.

Fueling

- Fueling procedures for hydrogen-powered aircraft will differ significantly from those for conventional fuels. Additional training will be required in areas including:
    - Operation of hydrogen fuel trucks;
    - Coupling and decoupling of hydrogen fuel nozzles;
    - Hydrogen-specific safety management.

Line Maintenance

- Line maintenance activities will be performed by specially trained and licensed maintenance personnel. The training required is expected to include:
    - Hydrogen safety;
    - High-voltage systems;
    - Hydrogen propulsion system technical training.
- Line maintenance tasks will largely mirror those of conventional aircraft and include:
    - Visual inspections of critical components for damage, wear, leaks, or abnormalities;
    - System checks of hydraulic, pneumatic, electrical, and avionics systems;
    - Component servicing, such as replenishment of essential fluids and consumables in accordance with manufacturer guidance;
    - Scheduled maintenance, including lubrication, filter replacement, and system calibration as defined in the aircraft maintenance program.
- A HAPSS-specific maintenance program will be developed in parallel with dedicated maintenance training materials and courses.

6.4 Computerized Flight Plan Service Providers (CFSPs)

CFSPs will support operators by generating optimal four-dimensional flight trajectories while

accounting for network constraints and HAPSS aircraft performance characteristics.

Key impacts include the need for enhanced weather assessment due to reduced operational ceiling and cruise altitude, which may increase the requirement for weather avoidance. The availability and adequacy of procedures and briefing information for flight crews must therefore be evaluated.

6.5 Ground Handlers

Ground handling activities include:

- Aircraft repositioning;
- Pre- and post-flight preparation;
- Customer service and ramp operations.

Ramp services may encompass:

- Hydrogen fueling;
- Line maintenance support.

Ground handlers supporting HAPSS operations must establish appropriate safety management systems and conduct risk assessments addressing the introduction of hydrogen propulsion technologies.

6.6 Air Navigation Service Provider (ANSP)

ANSPs will require dedicated training programs and performance datasets related to HAPSS flight characteristics to support safe integration into the air traffic management network.

It must be confirmed that adequate procedures and information are available to support weather avoidance and enable Air Traffic Control Officers (ATCOs) to provide appropriate advisory, alerting, and flight information services.

6.7 Network Manager (NM)

The Network Manager must be informed of HAPSS aircraft performance characteristics to evaluate potential network-wide impacts. While many performance parameters remain aligned with the conventional Dash 8-300, the following factors may influence integration:

- Reduced service ceiling;
- Reduced cruise altitude.

These aspects will need to be considered in overall network planning and flow management.

7 Conclusion

This paper demonstrates that the integration of a Hydrogen Aircraft Powertrain and Storage System (HAPSS) into the Dash 8-300 represents a credible and practical pathway toward near-zero-emission regional aviation. The developed CONOPS shows that a hydrogen-electric modification can be implemented while maintaining a high level of compatibility with existing air traffic management systems, operational concepts, and airport environments. This is a key finding, as it indicates that the introduction of hydrogen propulsion does not require fundamental changes to the overall aviation system.

The analysis shows that, although the overall operational impact is limited, targeted adaptations are required in specific areas. These primarily relate to ground operations, safety management, and the training of flight, maintenance, and ground personnel, reflecting the introduction of hydrogen fuel and high-voltage electrical systems. Importantly, these adaptations are considered bounded and manageable within current operational and organisational frameworks.

From a regulatory perspective, the study outlines a coherent certification approach, combining a Supplemental Type Certificate (STC) for the aircraft, a Type Certificate (TC) for the Hydrogen Propulsion System as an engine, and a complementary propeller STC. The analysis further identifies areas where new definitions, Special Conditions, and supporting guidance material will be required, thereby providing clarity on the certification scope and associated regulatory effort.

Overall, this CONOPS translates a regulation-aligned assessment into clearly defined and

actionable areas for key stakeholders, including regulators, manufacturers, operators, and airport authorities. While hydrogen-electric propulsion introduces new technical and operational challenges, these are not considered fundamental barriers to entry into service. The results therefore support progression from the baselined architecture toward the next phase of concept development, enabling informed decision-making and reducing risk in the transition to hydrogen-powered regional aviation.

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11 Disclaimer

The analyses, assumptions, conclusions, and certification perspectives presented in this paper are solely those of Conscious Aerospace B.V. and the authors. They do not necessarily reflect the views of the contributing organisations or supporting institutions. Any technical contribution of project stakeholders shall not be interpreted as approval, endorsement, certification support, validation, or a statement of no technical objection by those entities.

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