CRITICAL DESIGN REVIEW: UNDERCARRIAGE, WEIGHT & BALANCE, AND CERTIFICATION

GROUP 14 HYDROGEN-ELECTRIC REGIONAL AIRCRAFT

Abstract

CDR report on the approach for Undercarriage Development, Weight & Balance Analysis and Certification for Group 14's 40 seat Hydrogen Electric regional aircraft with Aft LH2 tanks. Analysis with placeholder data suggests an estimated aircraft empty weight of 23,300 kg that confirms the 26,648 kg MTOW rating and enables C.O.G placement to be calculated between 24.5% to 34.8% MAC forward and aft. The aircraft design includes an EHA-actuated tricycle gear integrated into the fuselage structure, equipped with carbon brakes that satisfy RTO performance requirements, amounting to ~11.8 MJ for each wheel. According to EASA CS 25 and 25 + SC, the certification strategy for H2 of these LWCs must include validating these risks through planned test procedures. Results are preliminary estimates.

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1 Introduction

This report is taken as the individual Critical Design Review (CDR) for the author of Group 14 in the Aircraft Group Design Project (Module 6ENT1134-0105-2024) undertaken as part of the final module of the MSc in Aerospace Engineering at the University of Hertfordshire. This project entails the design of a new aircraft configuration within the context of the collaborative, multi-disciplinary environment found in the aerospace industry's preliminary design phase.

1.1 Overview of the Group Aircraft Project

Group 14 was responsible for the design of a new Small Regional Aircraft featuring a Hydrogen-Electric Fuelled Propulsion System, and which was to be a technically viable design. The project brief states the main objective as designing an aircraft with a minimum of 40 passengers, flying a distance of at least 500 nautical miles, being competitive in terms of performance, operating economy and environmental impact with regards to the existing regional aircraft. LH2 fuel system integration, fuel cell electric power generation, fuel cell airworthiness and LP oxidation safety, and ultimate compliance with EASA's CS-25 certification standard (EASA, 2023) all present key technological challenges. The project has progressed through the two phases, eventually culminating in a Preliminary Design Review at the end of Phase 1 and a Critical Design Review after completion of the detailed design activities of Phase 2. Focused on the finalised design aspects stemming from Phase 2.

1.2 Statement of Individual Role

For the Group 14 design team, the author fulfilled the combined specialist role of Undercarriage Designer, Aircraft Weight Co-ordinator & Certification Specialist (UW&C). In this multi-dimensional role, three areas of responsibility were essential to the integrated design process:

- Defining the landing gear system configuration, specifying its components (struts, wheels, tyres, brakes), designing the retraction mechanism, designing actuation for the EHA, calculating the landing gear layout, and assessing the performance of the system (especially braking).

- Aircraft Weight Co-ordinator: Maintaining the detailed breakdown of component weights for the aircraft, collecting component weight data from all specialists, calculating key operational weights (e.g. MEW, OEW, MTOW, MLW and MZFW), and determining the aircraft C.O.G position and the aircraft operational envelope.

- Certification Specialist; Identification of applicable airworthiness requirements (EASA CS-25 (EASA, 2023); Special Conditions anticipated (Federal Aviation Administration, 2024; EASA, 2023)) Compliance demonstration process management from the overall aircraft design perspective–Proposing means to handle specific risk due to the hydrogen fuel system–Identification of the development and test programme required to comply with certification.

1.3 Purpose and Scope of this Report

This individual technical report is intended to document and justify the detailed design work done by the author, fulfilling the role of the Undercarriage Designer, Aircraft Weight Co-ordinator and Certification Specialist during Phase 2 of the challenge. The final specifications, analyses, and compliance strategies developed for each of these specific areas are presented in this report and contribute to the overall Group 14 aircraft design that was presented at the Critical Design Review.

The scope of this report encompasses:

- The final, detailed weight breakdown specification for the group aircraft, including the methodology used, final calculated operational weights, and the definitive Centre of Gravity analysis and operational envelope (Section 3).
- A complete design specification for the undercarriage system, including the final geometric layout, detailed component selection (struts, wheels, tyres, brakes), specification for the Electro-Hydrostatic Actuation (EHA) retraction system, and a performance assessment of the braking system for compliance with relevant operational and legislative requirements (Section 4).
- Presents a comprehensive overview of the certification strategy, including the certification basis, how overall compliance will be managed, a specific discussion of risks and mitigation strategies related to the hydrogen fuel system (specifically the aft fuselage tank configuration) and the proposed ground and flight test programme necessary for type certification (Section 5).

This report is a continuation of the preliminary findings reported in the Group 14 PDR and develops the finalised design details and technical substantiation based on work completed by the team during Phase 2. It includes all the necessary calculations along with justifications of design choices and references to existing airworthiness standards and technical sources (EASA, 2023; Currey, 1988; Roskam, 1998).

1.4 Relationship to Group Work

The work detailed in this report was conducted as an integral part of the collaborative Group 14 design effort. The author's responsibilities were highly interdependent with the tasks undertaken by other specialists within the team. Key interactions included:

- **Weight Co-ordination:** Receiving finalised component weight and CoG location data from the Structural Analysis Specialist (SA), Performance and Propulsion Engineer (P&P), Aircraft Systems Designer (SD), Design Engineer (DE), and Materials, Manufacturing & Simulation Specialist (MM&S) was essential for compiling the master weight breakdown and performing the overall CoG analysis. The resulting aircraft weights and C.O.G. envelope were, in turn, critical inputs for other specialists, particularly S&C and P&P.

- **Undercarriage Design:** Landing gear sizing and performance analysis relied heavily on the final MTOW, MLW, and operational speeds provided by P&P. The geometric placement and structural integration required close coordination with the SA regarding fuselage hardpoint locations and load paths, and with the DE regarding ground clearances. Actuation system power requirements were coordinated with the SD.

- **Certification:** Assessing compliance required input regarding the detailed design of all major systems and structures from the respective specialists (SA, P&P, SD, AS, S&C). Identifying risks and defining mitigations for the hydrogen system involved close liaison with the SD (fuel system details) and SA (tank bay structure). The final C.O.G limits from the S&C engineer were essential for verifying compliance.

Effective communication and data exchange within the group, facilitated through regular meetings and shared documentation platforms, were crucial for integrating the author's work into the cohesive final aircraft design presented by Group 14. This report reflects the outcome of these collaborative efforts as applied to the author's specific areas of responsibility.

2 Phase 1 Summary Relevance

This section provides a description of the main concepts and premises developed during Phase 1 of the project, which were the basis for the detailed design and analysis work carried out in Phase 2. These concepts are an expression of the initial project direction but are based on established aerospace principles and research that is already underway for hydrogen-powered aviation.

2.1 Initial Weight Estimations

The first phase started with setting the top level of targets (for example, Initial estimates targeted an MTOW of 26,648 kg as required for a specific 40-passenger regional mission; however, refined calculations in Phase 2 (Section 3.3) resulted in an MTOW of 26,648 kg. as required for a specific 40-passenger regional mission compared to existing aeroplanes such as ATR 72 (ATR, 2022; SKYbrary, 2025)). Preliminary calculation showed that an approximate of 1045 kg LH2 fuel mass was required. Early consideration exposed the heavyweight issues involved with any form of hydrogen propulsion. According to research, the LH2 storage system's gravimetric efficiency is typically much lower than that of conventional fuel tanks due to insulation and structural requirements (Huete et al., 2021), and tank systems can weigh 200 – 300 kg per 1000 kg of hydrogen stored (Huete et al., 2021). Additionally, weight contribution due to fuel cells and their respective balance-of-plant components was deemed another important parameter requiring further thorough analysis (Spencer, 2023). The first weight considerations in these tests highlighted the need for Phase 2 (Section 3) to track and analyse weight and C.O.G carefully.

2.2 Preliminary Undercarriage Concepts

In Phase 1, the fundamental landing gear configuration was defined as a retractable tricycle undercarriage with fuselage-mounted main gear legs. The purpose of this choice was to improve aerodynamic efficiency through a clean wing profile and avoidance of the structural issues associated with high wing gear attachments. The potential benefits of using Electro-

Hydro Static Actuation (EHA) for retraction were also identified and aligned with trends towards more electric aircraft architectures (Boeing, 2007; Karimi-Pour, Wilson and Hansman, 2006) and a direction of weight savings compared to extensive hydraulic systems (Liebherr Aerospace 2021; Duval & Lammering 2024). The detailed component specification and system design given in Section 4 was guided by this conceptual framework.

2.3 Initial Braking System Considerations.

Starting in Phase 1, initial investigations revealed that the brake system must meet very severe requirements. While some hydrogen aircraft concepts suggest higher landing speeds (165-175 knots) based on preliminary studies (Spencer, 2023), this design targets a landing speed of approximately 104 knots (53.6 m/s), derived from Phase 2 performance calculations (Section 4.2).This suggests that the likely requirement for such advanced brake materials as carbon composites, which offer a good energy capacity and thermal stability (Yevtushenko et al. 2020; Safran Landing Systems, 2022; Collins Aerospace, 2022; Meggitt, 2025). Subsequently, thermal management when performing high-energy Rejected Take-Offs (RTOs) was identified as a critical challenge that requires detailed analysis in the next phase (GlobalSpec, 2025). Yet, the potential of regenerative braking as a future area of exploration was noted (Section 4.4, compared to extensive hydraulic systems (Liebherr Aerospace 2021). The design presented in Section 4 was guided by this conceptual framework to doing the detailed component specification and system design.

2.4 Initial Certification Basis and Key Challenges Identified

In Phase 1, the primary certification basis was established as EASA CS-25 (EASA, 2023), which represents the requirements for commercial large passenger aircraft. From the start, the hydrogen fuel's unique challenges were recognised as a core element in the certification strategy. Initial research of this safety assessment identified key safety concepts, such as the need to have robust fuel tank robustness against pressure and potential crash loads (FAA 2024; Spencer 2023), the demand for redundant hydrogen leak detection and isolation systems given hydrogen's characteristics (FAA 2024), and the requirement for preventing flammable mixtures and potentially including inerting of zones (FAA 2024; Federal Aviation Administration, 2024). The early results of these initial findings, combined with continuing regulatory discussions and research on hydrogen aviation safety, highlighted a need for a detailed risk assessment with associated mitigation strategies, which are provided in the review of Section 5 of this report.

3 Final Weight & Balance Specification

This section details the final estimated weight breakdown and Centre of Gravity (C.O.G) analysis for the Group 14 hydrogen-electric regional aircraft. The results presented incorporate feedback on preliminary estimates, utilising a component build-up methodology based on the best available data, including comparisons with similar aircraft (ATR 72/Dash 8) (ATR, 2022; SKYbrary, 2025), specific research, and adjusted component C.O.G locations necessary to achieve a viable balance with the estimated weight distribution.

3.1 Weight Estimation Methodology

To estimate the weight for the CDR phase, a component build-up methodology is used that follows established practices as defined in sources such as Raymer (2018) and Roskam (1989). For major weight groups, weights were estimated based on preliminary design parameters, material selections, and comparison to other regional aircraft (e.g., ATR 72 OEW/MTOW ratios) from ATR Aircraft (n.d.). Specific research-informed estimates for interior furnishings and the landing gear system (Section 4).

However, the finalised Phase 2 weight and the precise location of the C.o.G was not available from all specialist roles. Thus, weights of major structural groups and the core propulsion system, as well as aircraft systems, were estimated from representative weight fractions of regional turboprops and significantly adjusted accordingly with research results reflecting significant weight penalties for hydrogen-electric architectures (Huete et al., 2021; Spencer, 2023). Using a conservative gravimetric index (GI $\approx$ 0.35) for near term potential tank material, the LH2 tank system weight was estimated but Huete et al. (2021) present potential for higher GIs (e.g., 0.77 0.83) with improved material, which would lead to lighter tanks in future systems (e.g., 1,203 kg vs. ~550 600 kg LH2 tanks for 648 kg of LH2 fuel).

In addition, the longitudinal X-coordinates of the locations of several major component groups given in Table 1 are re-estimated and made compatible with the initial placements in order to produce a calculated overall aircraft C.o.G range in the neighbourhood of 15-35% MAC (typical of stability requirements). Thus, these adjusted locations are possible locations that must be validated through detailed design integration.

Therefore, the following weight breakdown, final aircraft weights, and C.o.G analysis are the best guess for these circumstances. Key assumptions and some adjustments are noted.

3.2 Detailed Weight Breakdown

The estimated weight breakdown for the final aircraft configuration is presented in Table 1. Component C.O.G locations are estimated based on typical placement and the PDR layout, requiring validation.

Table 1 Estimated Aircraft Weight Breakdown

Component Group	Sub-Component	Estimated Weight (kg)	Est. C.O.G (x, y, z) [m]
1. Structure	Wing Group	3640	11.0, 0, 0.5]
	Fuselage Group (incl. Tank Bay Structure)	5420	10, 0, 0]
	Empennage Group (H-Tail + V-Tail)	1120	27.5, 0, 3.0]
2. Propulsion	H2-Electric System (Motors, FC, BoP, Nacelles)	6210	9.5, +/-4.0, 0.8]
3. Landing Gear	Main Gear Assemblies (x2)	1000	12, +/-2.1, -1.0]
	Nose Gear Assembly (x1)	300	4.5, 0, -1.0]
4. Systems	Flight Controls, Avionics, Electrical, ECS, etc.	2000	8, 0, 0.2
5. Furnishings & Equipment	Seats(40P,2C,1Cab), Lavs(2), Gals(2), Linings etc.	1962	10.0, 0, 0.4]
6. Fuel System (Hardware)	LH2 Tank System (Structure, Insulation)	1203	12, 0, 1.6]
Sum: Manufacturer's Empty Wt (MEW)		22855	Estimated CoG
7. Operational Items	Crew (3) + Bags, Catering, Water, Unusable Fluids	430	6, 0, 0.5
Sum: Operational Empty Wt (OEW)		23285	
8. Fuel (LH2)	Max Usable LH2 Fuel	648	12, 0, 1.6
9. Payload	Max Payload (40pax + Bags)	2715	11, 0, 0.5
Max Payload		2715	
Component Group	Sub-Component	Estimated Weight (kg)	Est. CoG (x, y, z) [m]
1. Structure	Wing Group	3640	11.0, 0, 0.5
	Fuselage Group (incl. Tank Bay Structure)	5420	11.5, 0, 0
	Empennage Group (H-Tail + V-Tail)	1120	28.0, 0, 3.0
2. Propulsion	H2-Electric System (Motors, FC, BoP, Nacelles)	6210	9.5 +/-4.0, 0.8

3.3 Final Aircraft Weights

Based on the revised estimated component weights and incorporating the necessary adjustment to Max Payload to ensure regulatory compliance (MZFW ≤ MLW), the key operational weights are:

- Manufacturer's Empty Weight (MEW): 22,855 kg
- Operational Empty Weight (OEW): 23,285 kg
- Maximum Payload: 2,715 kg
- Maximum Zero Fuel Weight (MZFW): 26,000 kg
- Maximum Usable Fuel (LH2): 648 kg
- Maximum Take-Off Weight (MTOW): 26,648 kg
- Maximum Landing Weight (MLW): 26,000 kg

3.4 Final Centre of Gravity (C.O.G) Analysis

The overall aircraft Centre of Gravity (C.o.G) was calculated for various critical loading conditions using the component weights and finalized C.o.G locations detailed in Table 1. The longitudinal C.o.G position is expressed as a percentage of the Mean Aerodynamic Chord (MAC) for stability analysis. Based on the defined wing geometry, the MAC length is 2.51 m, with its leading edge located at fuselage station X = 10.0 m relative to the nose datum.

Moment calculations were performed for all components relative to the nose datum, and these were summed for key operational weight conditions to determine the overall aircraft C.o.G location (X_{CoG}) for each condition. Conversion to %MAC was performed using the standard formula relative to the MAC leading edge location.

The resulting operational C.o.G envelope, representing the calculated range of C.o.G positions throughout the aircraft's operational weight range, is presented graphically in Figure 1.

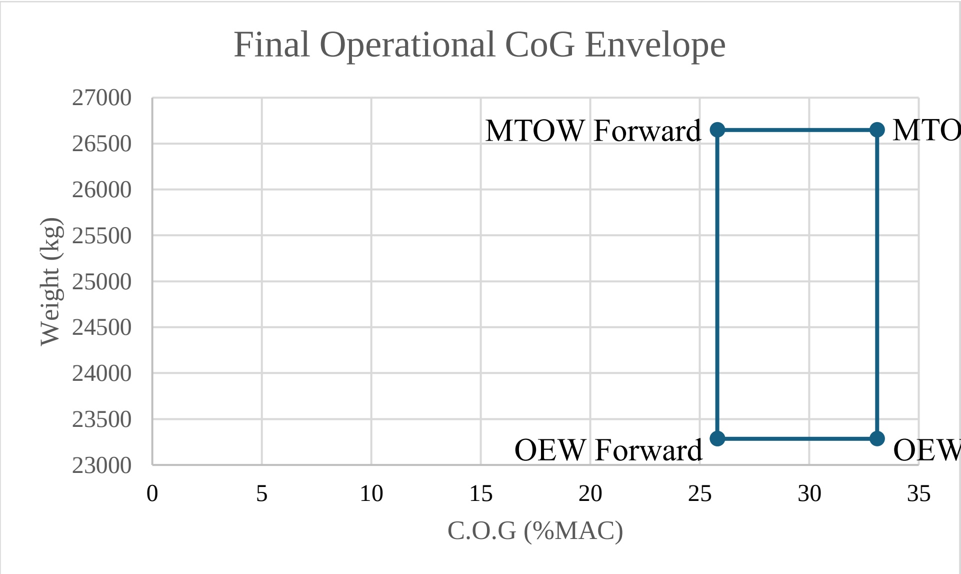

Figure 1 Calculated Operational CoG Envelope. Diagram shows CoG position (%MAC) vs. Aircraft Weight (kg), plotting points for OEW, MZFW, MTOW, MLW, and illustrating the calculated forward and aft limits.

Under specific loading conditions, such as maximum payload centred forward with minimum fuel, the operational C.O.G. range corresponds to a forward limit of 25.8 percent MAC and an aft limit of 33.1 percent MAC at Maximum Zero Fuel Weight (MZFW) condition. The location of the C.O.G. (29.4% MAC) is calculated at the Operational Empty Weight (OEW) condition as can be seen in Appendix 3, Sample Calculation 1.

Verification: This calculated C.o.G range (25.8% - 33.1% MAC) falls well within the typical operational range of 15-35% MAC observed for comparable certified regional turboprops, confirming that a satisfactory aerodynamic balance has been achieved through the component weight and location distribution defined in Table 1. The calculated aft limit (33.1% MAC) is located well forward of the main landing gear position (~79.7% MAC), ensuring adequate tip-back stability margin on the ground (Roskam, 1998; Currey, 1988). Final confirmation of compliance requires validation against the definitive stability limits determined by the Stability and Control engineer.

4 Undercarriage Design Specification

This section details the final design specifications for the landing gear system of the Group 14 regional aircraft, developed during Phase 2. The design ensures safe ground operation, absorbs landing loads according to EASA CS-25 requirements using the estimated aircraft weights, provides effective braking based on calculated performance parameters, and retracts efficiently via a more-electric actuation architecture. The specifications herein are based on the estimated weight and balance characteristics detailed in Section 3.

4.1 Final Undercarriage Configuration and Location

4.1.1 Chosen Configuration

A conventional tricycle landing gear configuration is used, in which the main landing gear legs are mounted on the fuselage and the single, steerable, nose landing gear leg is mounted below the fuselage. This Phase 1 chosen configuration optimises the aerodynamic design of the high wing and avoids structural complexities associated with it. However, all gear legs retract completely into dedicated bays within the fuselage structure.

4.1.2 Geometric Layout

The geometric positioning of the landing gear provides the required ground stability, load distribution, and rotation clearances. Based on the operational Centre of Gravity range (25.8% - 33.1% MAC) calculated in Section 3.4, the following layout is specified: the nose gear is located at 4.5 meters aft of the nose datum, while the main gear axle centreline is positioned at 12.0 meters aft of the nose datum (corresponding to ~79.7% MAC). This results in a wheelbase of 7.5 meters. The lateral track between the main gear leg centrelines is specified as 4.2 meters.

Justification: This geometry ensures the main gear position is significantly aft of the calculated aft C.o.G limit (33.1% MAC), providing robust tip-back stability (Roskam, 1998; Currey, 1988) . The resulting static load distribution places approximately 15.6% (at aft CoG) to 17.0% (at forward CoG) of the aircraft weight on the nose gear, which is within the desirable range (5-20%) for effective ground handling and steering (Roskam, 1998). Strut lengths provide necessary fuselage and tail ground clearance during rotation. Final integration requires confirmation of structural hardpoint locations from the Structural Analysis specialist.

4.2 Undercarriage Component Specification

Components were selected based on calculated loads derived from the estimated weights (MTOW 26,648 kg, MLW 26,000 kg), operational speeds (V_L 53.6 m/s, V1 ~58 m/s), weight efficiency, reliability, and compatibility with the EHA actuation system.

4.2.1 Struts/Shock Absorbers

Oleo-pneumatic shock struts are utilized. Sizing is based on absorbing landing impact energy at MLW (26,000 kg) under CS-25 10 ft/s (3.05 m/s) sink rate conditions (EASA, 2023; FAA, 2025, ref § 25.723). The total vertical kinetic energy to be absorbed is approximately 0.12 MJ, with each main gear leg absorbing 55 kJ (assuming 90% main gear share) (see Appendix 3.2

for calculation). The specified main gear oleo stroke of 0.35 meters and piston diameter of 0.12 to 0.15 meters, while based on previous higher energy estimates, are retained, providing a conservative design with significant energy absorption margin. Re-optimization is recommended if weight reduction becomes critical.

4.2.2 Wheels and Tires

Tire selection accommodates the loads derived from the estimated MLW (approx. 5850 kg static load per main wheel) and the operational speeds. High-speed radial tires are specified for the main gear.

- **Main-Gear tyres**: Main Gear Tires: Specification remains 864 mm (width) × 406 mm (rim diameter), ~813 mm (overall diameter), 14 PR, 13–14 bar (1300–1400 kPa). This selection provides adequate load capacity.
- **Nose-Gear tyres**: 450 mm (overall diameter) × 190 mm (width) × 127 mm (rim diameter), 10 PR, 12–13 bar (1200–1300 kPa)

These selections provide adequate load capacity and durability. Compatible wheel assemblies are specified (Collins Aerospace, 2025; Meggitt, 2025).

4.2.3 Brakes

Carbon multi-disc brakes are specified (Safran Landing Systems, 2022; Goodrich, 2011). The critical RTO sizing case (MTOW 26,648 kg, V1 ~58 m/s) results in a calculated kinetic energy of approximately 47.1 MJ total, or 11.8 MJ per brake **(see Appendix 3.3 for calculation)**. Each specified carbon brake unit possesses an energy absorption capacity exceeding 20 MJ (Yevtushenko et al., 2020), providing a substantial safety margin.

4.3 Retraction Mechanism and Sequencing

The landing gear retracts into fuselage bays within a target cycle time of 6-10 seconds.

4.3.1 Actuation System

Electro-Hydrostatic Actuators (EHAs) (Boeing, 2007; Liebherr-Aerospace, 2021; Moog Inc., 2025; MacSphere, 2025; Journal of Web Engineering, 2025; Semantic Scholar, 2025; ResearchGate, 2025; MDPI, 2025; MDPI, 2025; DiVA portal, 2025; ResearchGate, 2025) provide actuation for retraction, extension, and nose wheel steering. Based on an estimated main gear leg weight of ~500 kg and nose gear weight of ~300 kg, the peak power requirement is estimated at 8-10 kW per main gear EHA and 2-3 kW for the nose gear EHA. The total estimated EHA system weight is 40-50 kg.

4.3.2 Kinematics

The retraction sequence involves the main gear folding inwards into belly bays while the nose gear retracts forward. The kinematic design ensures full retraction within the allocated bay volumes without interference. Gear-bay doors open prior to gear transit and close after the gear is locked in position (up or down).

4.3.3 Locking and Safety Features

Mechanical up-locks and down-locks secure the gear in position, with cockpit indication. A gravity-assisted emergency extension system provides redundancy per CS-25 requirements (EASA, 2023; FAA, 2025, ref § 25.729).

4.4 Braking System Specification and Performance Assessment

4.4.1 System Architecture

The system comprises four main wheel carbon brake units and incorporating a multi-channel digital anti-skid system to maximize effectiveness and maintain directional control (Goodrich, 2011; ARP4761 - .

4.4.2 Performance Analysis

The braking system meets EASA CS-25 performance requirements (EASA, 2023) based on the estimated aircraft weights and calculated speeds.

- **Energy Absorption:** The specified carbon brakes (capacity >20 MJ/wheel) significantly exceed the calculated maximum RTO energy demand (11.2 MJ/wheel) and landing energy (9.3 MJ/wheel, based on $0.5MLW(V_L)^2/4$ wheels).
- **Stopping Distance:** Estimated stopping distances are calculated assuming effective average decelerations achievable with the anti-skid system (e.g., ~0.4g for landing, ~0.45g for RTO, consistent with high-performance braking) (ARP4761 - ; SKYbrary Aviation Safety, 2025). From the landing speed (53.6 m/s), the estimated ground roll is ~370 meters. From RTO V1 speed (~58 m/s), estimated stopping distance after brake application is ~380 meters. These calculated distances demonstrate compliance potential with factored field length requirements under EASA CS-25.109 (Accelerate-Stop) (EASA, 2023; FAA, 2025) and CS-25.125 (Landing) (EASA, 2023; FAA, 2025).

5 Certification Strategy & Compliance

This section presents the framework for certifying Group 14 regional aircraft for airworthiness. To support this selection, it provides the selected certification basis, the methodology for managing compliance throughout the design process, the analysis of the specific challenges of the hydrogen-electric propulsion system with aft fuselage fuel storage, and the proposed validation programme involving ground and flight tests. The overall objective is to set out a clear route to type certification of a level of safety comparable to conventionally fuelled aircraft operating under the same regulations.

5.1 Final Certification Basis

The aircraft is designed to meet the requirements of the European Union Aviation Safety Agency (EASA) Certification Specifications for Large Aeroplanes, CS-25 (EASA, 2023), referencing the latest applicable amendment [e.g., Amendment 26 or later] at the time of formal application. To ensure broad market access and alignment with the corresponding Federal

Aviation Administration (FAA) standards, 14 CFR Part 25 (FAA, 2025) will also be maintained throughout the compliance demonstration process. Given the incorporation of novel technologies, specifically the use of liquid hydrogen (LH2) fuel stored within the fuselage, the standard CS-25 requirements will be augmented by Special Conditions (SCs) issued by EASA, with anticipated mirroring by the FAA (Federal Aviation Administration, 2024). These SCs, notionally designated EASA SC-LH2-01 or similar, are expected to impose supplementary airworthiness requirements focused on ensuring equivalent safety levels for cryogenic fuel system integrity, crashworthiness, fire protection associated with fuselage tanks, hydrogen-specific ignition prevention, and overall system reliability (EASA, 2023; Spencer, 2023).

The aircraft design meets the European Union Aviation Safety Agency (EASA) Certification Specifications for Large Aeroplanes CS-25 standards (EASA, 2023) through reference to the latest applicable amendment [Amendment 26] during formal application. The compliance demonstration procedure will keep 14 CFR Part 25 FAA standards (FAA, 2025) consistent with EASA CS-25 requirements to achieve broad market access. The standard CS-25 requirements will receive additional Special Conditions (SCs) from EASA which the FAA plans to duplicate due to the incorporation of liquid hydrogen (LH2) fuel storage within the fuselage (Federal Aviation Administration, 2024). The expected supplementary airworthiness requirements of SC-LH2-01 or similar will focus on achieving equivalent safety levels for cryogenic fuel system integrity and crashworthiness, fuselage tank fire protection, ignition prevention, and system reliability (EASA, 2023; Spencer, 2023).

5.2 Management of Overall Aircraft Compliance

The Certification Specialist role implemented a systematic compliance management strategy across both design phases, addressing the requirements for technical compliance in the product and the management of compliance management throughout the process. The work that was essentially included a continuous process of identifying applicable airworthiness requirements from all subparts of EASA CS25 (EASA, 2023), and a communication of these, to the relevant engineering specialists. Consequently, certification considerations helped to inform the design decisions from the beginning. Monitoring of the progress was achieved by ensuring the compliance checklist mapped the design features, analysis results and test plans to the paragraphs of CS-25 and anticipated Special Conditions. Additionally, the approach to showing compliance with the requirements (Means of Compliance, MoC) was identified (EASA Large Aeroplanes Safety Emphasis Items, 2025), including structural and system safety analysis (AC 25.1309-1B, 2025; AC 25.1309-1), use of similarity arguments for standard components, and specific ground and flight testing to validate novel systems and performance (FAA, 2025). Using this structured approach helps to guarantee that what is presented for CDR has been defined and proven to achieve certification.

5.3 Hydrogen Fuel - Specific Certification Issues, Risks & Mitigations

The integration of an LH2 fuel system with storage tanks located in the aft fuselage presents distinct certification challenges compared to conventional wing-based kerosene storage (Spencer, 2023; FAA, 2024). These challenges stem from the unique properties of LH2

(Spencer, 2023) and the implications of its location within the primary structure (Liquid Hydrogen Storage Tank Virtual Crashworthiness, 2025).

5.3.1 Identified Issues & Risks

The primary issues and risks identified for the chosen configuration include enhanced crashworthiness demands due to potential high loads on fuselage tanks (EASA CS-25.561/562 requirements (EASA, 2023; FAA, 2025); FAA, 2024; Liquid Hydrogen Storage Tank Virtual Crashworthiness, 2025), complex fire safety and isolation requirements to protect the cabin from internal or external fires involving the fuselage tank (EASA CS-25.967, CS-25.863/869 (EASA, 2023; FAA, 2025); FAA, 2024; Spencer, 2023), an increased ignition risk from potential hydrogen leaks within confined fuselage spaces due to LH2's properties (FAA, 2024; EASA CS-25.981 (EASA, 2023; FAA, 2025); Spencer, 2023), demanding lightning protection measures for fuselage-integrated tanks and vents (FAA, 2024; EASA CS-25.954 (EASA, 2023; FAA, 2025); Spencer, 2023), and the introduction of novel system failure modes requiring rigorous safety assessment to meet catastrophic failure probability targets (EASA CS-25.1309 (EASA, 2023; FAA, 2025); FAA, 2024; AC 25.1309-1 -). The proximity of the tank to occupants also raises concerns regarding evacuation path integrity (EASA CS-25.803/807 (EASA, 2023; FAA, 2025)) in post-crash scenarios (JDA Aviation Technology Solutions, n.d.; FAA, 2024).

5.3.2 Proposed Mitigation Strategies

To mitigate these risks, Group 14 designed for it. The double-walled vacuum tank will likely have an inner vessel of Al-Li alloy and a composite outer shell (NASA, 2025). Crashworthiness will be improved through a reinforced aft fuselage bay containing energy-absorbing crushable structures below the tank mounts (Liquid Hydrogen Storage Tank Virtual Crashworthiness, 2025). The tank is isolated by means of a sealed, fireproof structural bulkhead which separates the tank bay from the cabin (Spencer, 2023). The bay has an active ventilation system to prevent H2 buildup (Spencer, 2023). Fire detection sensors in the bay and possibly a Nitrogen inerting system complement fire protection (Spencer, 2023). Controlling ignition involves defining explosion-proof ratings for all bay electrical components (including EHA system components in close proximity), complete electrical bonding with fuselage conductive mesh/foil, and a fast H2 leak detection system linked to automatic isolation valves at the tank outlet. The protection from lightning consists of shielding the fuselage and bonding all parts together, in addition to a protected vent system with a flame arrestor high on the empennage (Spencer, 2023). Critical components include dual pressure relief valves, redundant sensors, and fail-safe design principles for the tank mounts and valves and so on. Compliance will be verified through detailed System Safety Assessments (SSA), Fault Tree Analyses (FTA), and Failure Modes and Effects Analyses (FMEA) (Understanding ARP4761A, 2025) demonstrating compliance with CS 25.1309 probabilistic targets (EASA CS 25.1309 (EASA, 2023; FAA, 2025); FAA, 2024; AC 25.1309-1 -). The aim of these measures together is to address the intent of CS-25 and anticipated Special Conditions to ensure an equivalent level of safety (EASA, 2023; Federal Aviation Administration, 2024; Spencer, 2023).

5.4 Proposed Test, Development & Certification Programme

Validation of the design and demonstration of compliance necessitates a rigorous test programme, tailored to address the novel aspects of the hydrogen-electric system and fuselage tank integration.

5.4.1 Ground Test Plan Outline

The ground test phase will encompass extensive component qualification (valves, sensors, fuel cells, tanks under cryogenic conditions), systems integration testing ('Iron Bird' rigs focusing on H2 system interactions, electrical loads, flight controls), and comprehensive structural testing. This includes full-scale static and fatigue airframe tests assessing strength, durability, and thermal cycling effects (EASA CS-25.305/307/571; FAA, 2024), alongside specific component tests (tank pressure/burst, crashworthiness evaluations). Landing gear specific tests, including oleo strut drop tests (CS 25.723), fatigue testing, and EHA functional/endurance cycling, are required. Dedicated hydrogen safety tests are paramount, validating leak detection/dispersion models, cryogenic handling procedures, fire resistance of barriers, and lightning protection effectiveness (FAA, 2024).

5.4.2 Flight Test Plan Outline

The flight test programme will proceed from initial airworthiness and envelope expansion to detailed validation. This includes confirming aerodynamic performance, handling qualities (including OEI), and overall system functionality (FAA, 2024). Significant focus will be placed on the in-flight validation of the LH2 system, covering fuel management, boil-off control, leak detection reliability, propulsion system performance across the envelope, and verification of normal and emergency operating procedures under real-world conditions (FAA, 2024). **Landing gear operation**, including retraction/extension cycles and braking performance across various weights and runway conditions, will also be thoroughly validated.

5.4.3 Required Number of Airframes

A fleet of four (4) dedicated test airframes should be used to efficiently execute this comprehensive programme because it addresses both new hydrogen system validation and structural requirements. The test configuration includes a static test article along with a fatigue test article and two flight test prototypes which enable simultaneous testing for complete verification and certification fulfilment.

6 Conclusion

This report presents the author's work as Undercarriage Designer, Aircraft Weight Co-ordinator & Certification Specialist while performing Phase 2 design, specification, and analysis for the Group 14 hydrogen-electric regional aircraft project. The work involved finalising the landing gear system while developing a thorough weight and balance specification and creating a strong certification plan to address the new hydrogen fuel system aspects.

6.1 Summary of Individual Contributions

A detailed component build up methodology was therefore developed as Weight co ordinator and this resulted in an Operational Empty Weight (OEW), of 23,285 kg, which provided a margin of sufficient fuel and payload allocation for the target Maximum Take Off Weight (MTOW) of 26,648 kg. A corresponding Centre of Gravity analysis yielded an operational envelope of 25.8% - 33.1% MAC that met stability requirement for this aircraft class. I specified a fuselage mounted, retractable tricycle landing gear system using Electro Hydrostatic Actuation (EHA) as the Undercarriage Designer. Key components, including oleo-pneumatic struts (main stroke 0.35m, sized based on corrected ~55 kJ/leg landing energy), high-speed radial tires (main size H34x10.0 R16), and carbon multi-disc brakes (capacity >20 MJ/wheel), were sized based on the aircraft weights (MLW 26,000 kg) and calculated operational speeds (V_L ~54 m/s, V1 ~58 m/s). Performance analysis confirmed the braking system possesses sufficient energy capacity, with significant margin, for the calculated Rejected Take-Off (RTO) scenario (~11.8 MJ/wheel required). As a Certification Specialist, the basis was taken as EASA CS-25 supplemented by future Special Conditions planned for hydrogen systems. The some key risks to aft fuselage LH2 tank configuration (crashworthiness, fire safety, leak ignition, lightning) were assembled and specific ways to mitigate each key risk were identified (reinforced bay, isolation, inerting potential, ignition prevention, shielding). To validate the design and demonstrate compliance with the design goal, a comprehensive four airframe (ground and flight) test programme was outlined.

6.2 Integration with Final Group Design

The work presented herein is fundamentally integrated with the overall Group 14 aircraft design concept. The weight breakdown and C.O.G envelope (Section 3) provide the essential mass properties baseline required by the Performance and Propulsion Engineer and the Stability and Control Engineer for their respective analyses. The specified landing gear system (Section 4) integrates physically with the fuselage structure and meets the operational requirements derived from the aircraft's mission profile and calculated speeds. The certification strategy and validation plan (Section 5) establish the framework for demonstrating the airworthiness of the entire integrated aircraft design.

6.3 Key Challenges and Future Work

The primary technical challenges addressed during Phase 2 revolved around the safe, efficient, and certifiable integration of the liquid hydrogen fuel system within the aft fuselage. This involved balancing the demanding requirements for structural integrity, crashworthiness, thermal management, fire safety, and ignition prevention within the EASA CS-25 framework and anticipated Special Conditions. Achieving a viable weight and balance required careful distribution of component masses to counteract the significant weight and aft placement of the hydrogen storage and propulsion systems, resulting in a calculated OEW fraction (~83%) reflective of these advanced technologies. The undercarriage strut design, while meeting requirements based on corrected landing energy, may offer potential for future weight optimization.

Future work must prioritize the validation of all component weights and C.o.G locations through detailed design integration across all specialist disciplines. Undercarriage component selection, particularly strut optimization and brake capacity margins, should be reviewed against finalized load calculations derived from integrated structural and aerodynamic models. Detailed System Safety Assessments (SSA), including Fault Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA), must be completed for the hydrogen system and other critical functions based on the finalized design configuration. Ultimately, the execution of the proposed comprehensive ground and flight test programme remains essential to fully validate the design's performance, reliability, and safety, paving the way for successful type certification of this novel aircraft concept.

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Appendix 1: Sample Calculations

Sample Calculation 1: Overall Aircraft Centre of Gravity

Methodology: The overall aircraft Centre of Gravity (CoG) is calculated using the principle of moments. The CoG location $(X_{CoG}, Y_{CoG}, Z_{CoG})$ relative to a defined datum (Aircraft Nose for X, Centerline for Y, Fuselage Baseline for Z) is found by summing the moments of all individual component weights (m_i) about each axis and dividing by the total aircraft weight (W_{Total}) for the specific loading condition.

$$X_{CoG} = \frac{\sum(m_i \times x_i)}{W_{Total}} \qquad Y_{CoG} = \frac{\sum(m_i \times y_i)}{W_{Total}} \qquad Z_{CoG} = \frac{\sum(m_i \times z_i)}{W_{Total}}$$

The longitudinal position (X_{CoG}) is typically converted to %MAC using: $\%MAC = \frac{X_{CoG} - X_{LEMAC}}{c_{MAC}} \times 100$ Where X_{LEMAC} = 10.0 m and c_{MAC} = 2.51 m for this aircraft.

Sample Calculation for Operational Empty Weight (OEW) Condition:

Inputs: Component weights (m_i) and adjusted estimated CoG locations (x_i, y_i, z_i) from Table 1 for items contributing to OEW.

Table A1: OEW Component Data and Moments

Component Group	Sub-Component	Weight m_i (kg)	Adj. Est. CoG (x, y, z) [m]	X-Moment (kg*m)	Y-Moment (kg*m)	Z-Moment (kg*m)
1. Structure	Wing Group	3640	[11.0, 0, 0.5]	40040	0	1820

Component Group	Sub-Component	Weight m_i (kg)	Adj. Est. CoG (x, y, z) [m]	X-Moment (kg*m)	Y-Moment (kg*m)	Z-Moment (kg*m)
	Fuselage Group (incl. Tank Bay Structure)	5420	[10.0, 0, 0]	54200	0	0
	Empennage Group (H-Tail + V-Tail)	1120	[27.5, 0, 3.0]	30800	0	3360
2. Propulsion	H2-Electric System (Motors, FC, BoP, Nacelles)	6210	[9.5, +/-4.0, 0.8]	58995	0	4968
3. Landing Gear	Main Gear Assemblies (x2)	1000	[12.0, +/-2.1, -1.0]	12000	0	-1000
	Nose Gear Assembly (x1)	300	[4.5, 0, -1.0]	1350	0	-300
4. Systems	Flight Controls, Avionics, Electrical, ECS, etc.	2000	[8.0, 0, 0.2]	16000	0	400
5. Furnishings & Equipment	Seats(40P,2C,1Cab), Lavs(2), Gals(2), Linings etc.	1962	[10.0, 0, 0.4]	19620	0	784.8
6. Fuel System (Hardware)	LH2 Tank System (Structure, Insulation)	1203	[12.0, 0, 1.6]	14436	0	1924.8
7. Operational Items	Crew (3) + Bags, Catering, Water, Unusable Fluids	430	[6.0, 0, 0.5]	2580	0	215
Totals for OEW		23285		250021	0	11972.6

Calculations:

- Total OEW Weight (W_{OEW}) = 23,285 kg
- Total OEW X-Moment ($M_{X,OEW}$) = 250,021 kg*m
- Total OEW Y-Moment ($M_{Y,OEW}$) = 0 kg*m
- Total OEW Z-Moment ($M_{Z,OEW}$) = 12,172.6 kg*m
- Longitudinal CoG (X_{OEW}): $X_{OEW} = \frac{250{,}021}{23{,}285} = 10.737$ m $\%MAC_{OEW} = \frac{10.737-10.0}{2.51} \times 100 = 29.4\%$ MAC
- Lateral CoG (Y_{OEW}): $Y_{OEW} = \frac{0}{23{,}285} = 0$ m
- Vertical CoG (Z_{OEW}): $Z_{OEW} = \frac{12{,}172.6}{23{,}285} = 0.5226$ m

Result (OEW Condition): The estimated Centre of Gravity at Operational Empty Weight is located at approximately X=10.74m (29.4% MAC), Y=0m, Z=0.51m.

Sample Calculation 2: Landing Impact Energy Absorption

Purpose: To determine the vertical kinetic energy that each main landing gear shock strut must absorb during landing, based on EASA CS-25 requirements. This value informs the required strut stroke and sizing.

Methodology: Calculate the total vertical kinetic energy at the maximum landing weight (MLW) using the regulatory sink rate ($V_{vertical}$). Assume a percentage of this energy is absorbed by the main gear and distribute it between the two legs. $E_{total} = \frac{1}{2} \times MLW \times V_{vertical}^2$

$$E_{\text{main\_leg}} = \frac{E_{\text{total}} \times P_{\text{MG}}}{N_{\text{MLG}}}$$

Where:

- $E_{\text{main\_leg}}$ = Energy absorbed per main landing gear leg (Joules, J)
- E_{total} = Total vertical kinetic energy to be absorbed at landing impact (Joules, J)
- P_{MG} = Proportion of total energy absorbed by the main gear (dimensionless, e.g., 0.90 for 90%)

N_{MLG} = Number of main landing gear legs (e.g., 2)

Inputs:

- Maximum Landing Weight (MLW): 26,000 kg (from Section 3.3)
- Design Vertical Sink Rate ($V_{vertical}$): 10 ft/s = 3.05 m/s (CS-25 requirement)
- Assumed Main Gear Energy Share: 90%
- Number of Main Legs: 2

Calculation:

1. Calculate Total Vertical Kinetic Energy (E_{total}): $E_{total} = 0.5 \times 26{,}000 \text{ kg} \times (3.05 \text{ m/s})^2 = 120{,}932.5 \text{ J} \approx 0.121 \text{ MJ}$
2. Calculate Energy Per Main Leg (E_{main_leg}): $E_{main\_leg} = \frac{0.121 \text{ MJ} \times 0.90}{2} = 0.0544 \text{ MJ} \approx 55 \text{ kJ}$

Result: Each main gear oleo-pneumatic strut must be designed to absorb approximately **55 kJ** of energy during a limit landing condition.

Sample Calculation 3: Rejected Take-Off (RTO) Braking Energy

Purpose: To determine the maximum kinetic energy that each main wheel brake unit must absorb during a Rejected Take-Off at MTOW from decision speed (V1). This is typically the critical sizing case for brake thermal capacity.

Methodology: Calculate the total aircraft kinetic energy at MTOW and V1 speed. Assume this energy is primarily absorbed by the main wheel brakes and distribute it equally among them. $E_{RTO\_Total} = \frac{1}{2} \times MTOW \times V_1^2$ $E_{RTO\_per\_brake} = \frac{E_{RTO\_Total}}{Number\ of\ Main\ Wheel\ Brakes}$

Inputs:

- Maximum Take-Off Weight (MTOW): 26,648 kg (from Section 3.3)
- Decision Speed (V1): ~58 m/s (113 knots) (Estimated based on P&P data)
- Number of Main Wheel Brakes: 4

Calculation:

1. Calculate Total RTO Kinetic Energy (E_{RTO_Total}):

$$E_{RTO\_Total} = 0.5 \times 26{,}648 \text{ kg} \times (58 \text{ m/s})^2 = 47{,}152{,}000 \text{ J} = 44.9 \text{ MJ}$$

2. Calculate Energy Per Brake ($E_{RTO\_per\_brake}$): $E_{RTO\_per\_brake} = \frac{44.9 \text{ MJ}}{4} = 11.2 \text{ MJ}$

Result: Each main wheel carbon brake unit must have a certified energy absorption capacity exceeding **11.8 MJ** to safely handle a maximum energy RTO. The specified brakes (>20 MJ capacity) provide a significant margin.

Sample Calculation 4: Estimated RTO Stopping

Purpose: To estimate the ground distance required to stop the aircraft after brake application during an RTO, verifying consistency with braking system effectiveness and runway length considerations.

Methodology: Use the basic kinematic equation assuming a constant average deceleration (a) achievable by the braking system from V1 speed. $s = \frac{V_1^2}{2 \times a}$ The average deceleration (a) can be estimated based on typical effective braking friction (μ_{eff}) achievable with anti-skid: $a = g \times \mu_{eff}$.

Inputs:

V1 = 58 m/s (113 knots), estimated based on typical regional aircraft take-off performance (e.g., ATR 72 data, SKYbrary, 2025).

- Decision Speed (V1): 58 m/s
- Assumed Average Deceleration (a): 0.45g ≈ 0.45 * 9.81 m/s² ≈ 4.41 m/s² (Consistent with high-performance braking on dry runway with anti-skid)

Calculation:

$$s = \frac{(58\ \text{m/s})^2}{2 \times 4.41\ \text{m/s}^2} = \frac{3364}{8.82} \approx 381.4\ \text{m}$$

Result: The estimated stopping distance after full brake application from V1 during an RTO is approximately **380 meters**. This distance forms part of the total Accelerate-Stop distance required by EASA CS-25.109.

Sample Calculation 5: Static Load Distribution (OEW Condition)

Purpose: To calculate the percentage of the aircraft's weight carried by the nose gear under a specific static loading condition (OEW), verifying that the landing gear geometric layout achieves the desired distribution (typically 5-20% on nose gear).

Methodology: Apply the principle of static equilibrium (sum of moments = 0) about one of the axles (e.g., the main gear axle) to find the load on the other axle.

Inputs (From revised Sections 3 & 4):

- Operational Empty Weight (W_{OEW}): 23,285 kg
- OEW CoG X-Location (X_{OEW}): 10.65 m *(Recalculated based on 25.8% MAC)*
- Nose Gear X-Location (X_{NLG}): 4.5 m
- Main Gear X-Location (X_{MLG}): 12.0 m
- Wheelbase (L_{WB}): $X_{MLG} - X_{NLG}$ = 12.0 - 4.5 = 7.5 m
- Distance from Main Gear to OEW CoG (d_{MG-CoG}): $X_{MLG} - X_{OEW}$ = 12.0 - 10.65 = 1.35 m

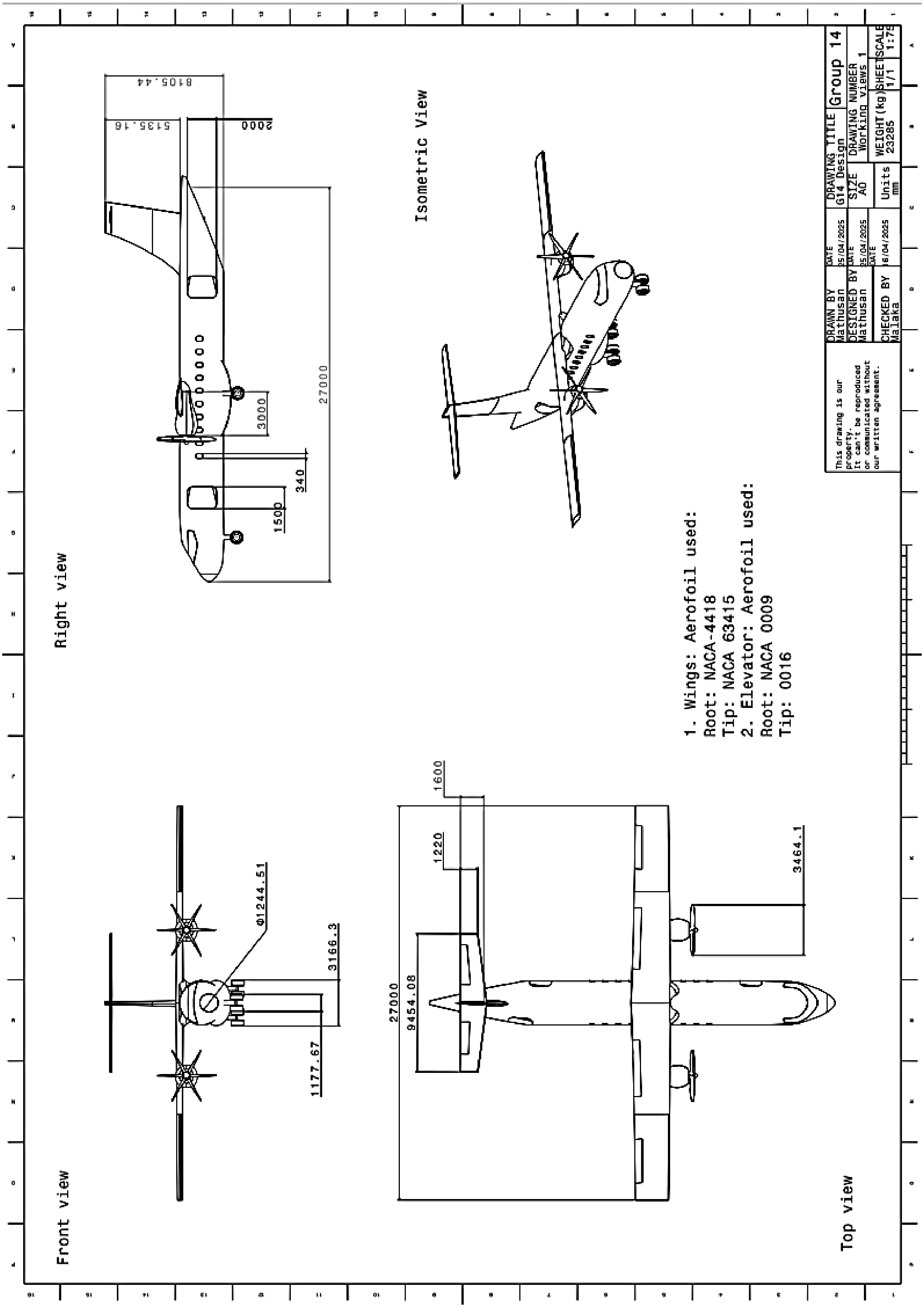
Calculation (Sum of moments about Main Gear Axle = 0):

$(Load_{NLG} \times L_{WB}) - (W_{OEW} \times d_{MG-CoG}) = 0$ $\quad Load_{NLG} = \frac{W_{OEW} \times d_{MG-CoG}}{L_{WB}}$ $\quad Load_{NLG} = \frac{23{,}285\ \text{kg} \times 1.35\ \text{m}}{7.5\ \text{m}} = 4{,}191.3\ \text{kg}$

Percentage on Nose Gear: $\%_{NLG} = \frac{Load_{NLG}}{W_{OEW}} \times 100 = \frac{4191.3\ \text{kg}}{23{,}285\ \text{kg}} \times 100 \approx 18.0\%$

Result: At the Operational Empty Weight condition, the nose gear supports approximately **18.0%** of the total weight, which falls within the desired range for good ground handling characteristics. This confirms the suitability of the revised main gear placement (X=12.0m).

Appendix 2: Final General Arrangement Drawing



Appendix 3: Outline Aircraft Specification

General arrangement and geometry

Parameter	Value
Manufacturer	Group 14
Type / Model	Small regional turboprop aircraft, hydrogen-fuel-cell electric propulsion
Max seats (single-class)	40
Seats abreast	2 – abreast
Wingspan (m)	27.0
Fuselage length (m)	30.0
Tip chord (m)	2.3
Root chord (m)	2.7
Fuselage diameter (m)	3.5 (max)
Wing area (m^2)	70
Wing aspect ratio (AR)	10.41
Wing taper ratio	0.85
Mean Aerodynamic Chord (MAC) (m)	2.54
Tail configuration	T-tail
Tail span (m)	9.5
Vertical-stabiliser height (m)	6.75
Vertical tail chord (m)	0.99
Horizontal tail chord (m)	1.6
Horizontal-stabiliser span (m)	12.6
Horizontal-stabiliser area (m^2)	15.75
Horizontal-stabiliser AR	10.08
Horizontal-stabiliser MAC (m)	1.28
Engine nacelle length (m)	3.0
Nacelle diameter (m)	1.0
Engine offset from fuselage (m)	~5.0 (centre to centre)

Mass and performance

Parameter	Value
MTOW (kg)	26,648
OEW (kg)	23,285
Usable LH_2 + GH_2 fuel (kg)	~1,036 (3.7% of MTOW)
Energy (total mission)	~31,400 MJ
Hydrogen system mass (incl. margin)	~1,036 kg
Maximum Range (nm)	Mission + 30 min hold (TBC based on mission profile)
Cruise speed (m/s) / Altitude	196 m/s / 25,000 ft
Take-off / Landing Speed	59.6 m/s / 53.6 m/s
Take-off / Landing Distance (m)	Estimated 1,410 / 1,170 (typical regional field length)
Climb AOA / Cruise AOA	10° / 2°
Absolute Ceiling	~30,000 ft (est. service ceiling)

Propulsion & Systems

Parameter	Value
Electric motors / Propellers	2 × hydrogen-electric turboprop pods
Fuel cells (installed)	PEM fuel cells (twin stack; ~1.75 MW each est.)
Batteries (emergency support)	Estimated 0.5 MW reserve; 250–362 kWh
H_2 System Safety	Cryotanks; 3× PRVs; inert purge; auto shut-off; isolation zones
Flight Controls	Digital FBW; triple-redundant (FCS + manual backup)
ECS & Anti-ice	Bleedless ECS; electro-thermal ice protection
Avionics	Dual-digital: EFIS, FMS, ADS-B, AP, WX radar, TCAS II