Concept of Operations for the Introduction of Electric, Hybrid-electric and Hydrogen-powered Zero Emission Aircraft

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1 Table of Contents

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1 Executive Summary

The Alliance for Zero Emission Aviation (AZEA) brings together a group of more than 160 stakeholders who share the objective to prepare the entry into commercial service of aircraft that use either total or partial electrical and hydrogen sources of energy for propulsion. As such, the integration of these Zero Emission Aviation (ZEA) operations into the European Air Traffic Management (ATM) system of legacy aircraft and operations needs to be optimised to accelerate the transition to zero CO_2-emissions flight and support new business models.

This Concept of Operations (CONOPS) addresses both the objective to decarbonise Commercial Air Transport (CAT) together with the challenges and opportunities that will arise from the integration of new Zero Emission (ZE) market segments into the European aviation system. It covers all components of the European ATM network, herein referred to as “the network”, in particular the airports. For the airport operations component, the CONOPS has been coordinated with AZEA WG3 and the ACAAF-TF (Airport Compatibility of Alternate Aviation Fuels Task Force) of the IIWG (International Industry Working Group).

The CONOPS does not consider unmanned operations or Urban Air Mobility (UAM). Whilst some eVTOL (Vertical Take-Off and Landing) aircraft may eventually be flown as manned / unmanned operations in U-space, eVTOL operations used for UAM solutions in U-space are out of scope of this document. However, manned eVTOL operations outside U-space airspace are in-scope.

The first version of the CONOPS is more focused on those ZE aircraft that are expected to enter into service in the short and medium term, such as electric and hybrid-electric aircraft, in the eVTOL, General Aviation (GA) and Regional Air Mobility / Regional Air Transport (RAM / RAT) market segments. Future CONOPS iterations will address additional market segments once the programmes and detailed knowledge of the performance characteristics of these novel aircraft mature.

This CONOPS considers estimated entry into service scenarios based on current knowledge and forecast assumptions, and, therefore, the CONOPS will be updated on a regular basis as and when such knowledge and assumptions evolve for each market segment.

Whilst CAT operations are likely to involve new aircraft types with a similar performance envelope to legacy aircraft, aircraft belonging to other existing or new market segments may have non-standard performance characteristics. These aircraft, which are expected to operate at intermediate and low Flight Levels (FLs) where more interactions will take place with aircraft transiting to / from upper airspace, will have to integrated into the network.

AZEA WG5 has identified nine different ZEA performance groups (see Chapter 5) with which to assess any potential integration challenges. The definition of these performance groups is based upon performance data provided by AZEA OEMs which includes cruising / maximum FLs, cruising / maximum speeds, rate of climb and final approach speeds. AZEA WG5 performance groups should be considered a work in progress and should be re-assessed once robust ZE aircraft performance assessments become available and operational concepts reach a higher level of maturity.

AZEA OEMs have also shared ten generic use cases to demonstrate how they expect the various new market segments to evolve (Appendix E). In addition, WG5 has developed four detailed use cases (see Chapter 6.2) to demonstrate how ZEA operations could evolve for four generic market segments. These use cases are:

- eVTOL operations
- LLO (Low-level operations)
- RAT (Regional Air Transport)
- CAT (Commercial Air Transport)

Some of main challenges to the integration of ZE aircraft operations into the network may be considered as follows:

- Air considerations:
  - Increased movement numbers and aircraft interactions below FL300;
  - Departure / arrival procedures;
  - ATC workload / capacity;
  - Controller tools; and,
  - Conflict detection.
- Ground considerations:
  - Aircraft weight changes;
  - Fuel storage;
  - Refuelling / battery charging;
  - On-stand procedures;
  - Engine start procedures; and
  - Rescue and Firefighting Services (RFFS).
- Other considerations:
  - Non-CO_2; and,
  - Climate change adaptation

Some of the developments foreseen in airspace design, airspace management (ASM) and Air Traffic Flow Management (ATFM) as defined in the European Route Network Improvement Plan (ERNIP) Part 2 and the EUROCONTROL High-Level Network Concept of Operation 2029 will equally apply to ZE and non-ZE aircraft. Additional requirements (e.g. related to Communication, Navigation and Surveillance (CNS) infrastructure and equipage) to accommodate ZE aircraft operations should be considered in future editions of the Network CONOPS and other documents.

It should be noted that this CONOPS is a preliminary analysis of the potential challenges and opportunities of the introduction of the different ZE aircraft in the network. It can be seen that knowledge gaps exist, in particular concerning the planned operation of electric fixed-wing and hydrogen-powered aircraft operations. These uncertainties may include the concepts of operations of each ZE aircraft segment (eVTOL, RAM/RAT and CAT operations) together with their environmental impacts (e.g. related to noise, non-CO_2 emissions etc.) and the expected market penetration / development of each ZE aircraft segment. Therefore, it is too early to make strong recommendations to address all of the challenges of integration.

As the CONOPS will be based on an iterative approach – based on current knowns and forecast assumptions – new iterations will consider any uncertainties identified in this edition, together with how the operational concepts evolve, changes in the entry into service forecasts of ZE aircraft, experiences of how the challenges of integrating new ZE aircraft into the network are met, with the appropriate chapters expanded upon in future CONOPS iterations.

2 Introduction

2.1 Concept of Operations

A CONcept of OPerationS (abbreviated CONOPS) describes the characteristics of a proposed system from the viewpoint of an individual who will use that system. It is used to communicate the quantitative and qualitative system characteristics to all stakeholders.

This document is a CONOPS for the introduction of electric, hybrid-electric and hydrogen-powered Zero Emission Aircraft (ZE aircraft – zero CO_2) into European Airspace as defined within the frame of AZEA (the Alliance for Zero Emissions Aviation). AZEA was launched by the European Commission's Directorate-General for Defence Industry and Space (DG DEFIS) and brings together a group of stakeholders who share the objective to prepare the entry into commercial service of aircraft that use either total or partial electrical and hydrogen sources of energy for propulsion. AZEA promotes the integration of these aircraft into the European Air Traffic Management (ATM) system[1] in order to ensure a safe, efficient and optimised network with a minimal performance impact upon legacy aircraft and operations.

The CONOPS provides the basis from which future ATM/ATS (Air Traffic System) operational roles, responsibilities, procedures, infrastructure and regulations required to support AZEA over the short-, medium- and long-term can be identified. One key objective of the Alliance is to comprehensively identify the challenges and opportunities posed by ZE aircraft and their integration into network operations; and propose innovative and practical solutions to address these challenges and opportunities in accordance with the European target to be climate neutral by 2050. These challenges include, *inter alia*, those related to safety, access and equity, security, capacity, predictability, flight efficiency, resilience, noise and non-CO_2.

It is a statement of "what" is envisaged. It asks and answers the question of what outcomes are required for the integration of ZE aircraft[2] - with new propulsion technologies - into the ATM system of the future. It is not a technical manual or blueprint; nor does it specify "how" things will be enabled. The "how" will have to be validated once detailed operational performance characteristics are demonstrated, precise levels of market penetration understood, and accurate assessment of life cycle emissions reduction disseminated.

This CONOPS will:

- Provide an overall picture of the expected operations of ZE aircraft using electric, hybrid-electric and hydrogen energy sources – with use cases – both

[1] The ATM system consists of a ground part and an air part, both of which are needed to ensure the safe and efficient movement of aircraft during all phases of operation. The airborne part of ATM consists of the functional capability which interacts with the ground part to attain the general objectives of ATM. The ground part of ATM comprises the functions of Air Traffic Services (ATS), Airspace Management (ASM), and Air Traffic Flow Management (ATFM).

[2] For the purpose of this document, ZE aircraft refers to any aircraft under development by AZEA Partners for electric, hybrid-electric and hydrogen-powered Zero Emission Aircraft

on the air and on the ground within the EUROCONTROL Network Manager area of responsibility, based on current information available;

- Propose a classification of new ZE aircraft relevant to aircraft performance characteristics, provided by AZEA OEMs through a questionnaire;

- Identify the challenges and opportunities for ATM and air / ground operations (e.g. in terms of safety, capacity and efficiency etc.) and the potential impacts to the network by the performance characteristics of new ZE aircraft including any impacts on the ATM performance of legacy aircraft by the safe and efficient integration of ZE aircraft into the network;

- Consider the impacts of ZE aircraft introduction and integration into the network in line with ICAO's Performance-Based approach[3]; and,

- Propose recommendations for future work from the operational, safety and policy making point of view to support the development of future CONOPS iterations.

The AZEA CONOPS is a "living document" and will serve as the vehicle for identifying those areas which will require further definition and understanding. It can be synchronised with the arrival on the market and entry into service of new aircraft i.e. it will be iterative in its development and will be updated as and when significant developments require an update e.g. the availability of more detailed performance data, changes to roll-out scenarios or when additional challenges and opportunities arise in supporting the ongoing safe and efficient integration of ZE aircraft. Together with lessons learned during deployment and implementation, this will lead to improvements in the maturity of the operational concept.

2.2 Challenges for aviation

The European Green Deal (December 2019) strives to make Europe the first climate neutral continent by reducing to zero the net emissions of greenhouse gases, while maintaining economic growth, by 2050. Whilst the global aviation sector has a role to play in 15 of the 17 United Nations Sustainable Development Goals (SDGs)[4], to meet the ambitious 2050 objective, intermediate sustainability milestones have been set for 2030: - the Fit for 55 package adopted by the European Commission (EC) in July 2021 tightens and broadens the European Union (EU) legislation to meet the ambitious 2050 objective and supports its interim goal of reducing emissions by 55% by 2030 compared to 1990 levels.

Compounded with the losses of aviation stakeholders from COVID-19 and the phasing out of the free allowances for the EU Emissions Trading Scheme (ETS), the European ATM System will need to demonstrate innovative and sustainable measures to avoid any financial burdens for aircraft operators and service providers and to comply with the stringent climate targets.

[3] As defined in ICAO Doc. 9883 (Manual on Global Performance of the Air Navigation System)

[4] https://aviationbenefits.org/un-sustainable-development-goals/sustainable-development-goals-and-aviation/

The European aviation industry together with other European players in the aviation sector has taken the strong commitment to ensure that air transport in Europe meets the 2050 climate objectives. This includes the development of zero-emission aircraft based on advanced propulsion technologies that utilise new energy sources such as electric or hydrogen.

Currently, mass SAF (Sustainable Aviation Fuel - currently SAF is only around a 0.5%[5] share of the available jet fuel) - and hydrogen deployment, remain medium to longer term solutions. However, the first electric aircraft has already been certified and with multiple start-ups and existing Original Equipment Manufacturers (OEMs) planning for the development of larger electric aircraft and for initial new or retro-fitted hydrogen-powered aircraft for entry into service, appropriate plans need to be developed to enable an easy integration of new aircraft and new propulsion types into the European network.

This CONOPS addresses the challenges to facilitate this integration.

2.3 Document objective

The CONOPS will support the work of all AZEA Working Groups (WGs), in particular the CONOPS is expected to support the work of:

- WG3 – whose objective is to perform a systematic analysis of the barriers and challenges (investments and others) as well as opportunities related to the introduction of electric / hydrogen aircraft at aerodromes and issue recommendations to address them;

- WG4 – whose objectives are to perform a regulatory gap analysis in order to identify areas requiring adaptation and issue recommendations for rule making work; to prepare and facilitate the certification of upcoming zero-emission aircraft; and, to support the definition and introduction of the required standards for rulemaking, safe operations and certification activities; and,

- WG5 - whose objective is to enable the efficient and sustainable introduction and integration of electric, hybrid-electric and hydrogen-powered aircraft into the European network and at the same time, secure the performance of the aviation system as a whole.

Focusing on the support to these WGs will allow for a holistic approach to the development of the AZEA operational concept including airport operations, air traffic operations and the operation of the ATM system as a whole. Whilst supporting the successful integration of ZE aircraft into the European ATM system, the CONOPS may also be used as a template for future innovation in the aviation industry: identifying the challenges and opportunities associated with the introduction and integration of any novel aircraft into the European aviation system, that may currently have non-standard performance characteristics and different performance envelopes. For more information about the AZEA WGs, see Appendix C.

[5] https://www.eurocontrol.int/publication/eurocontrol-data-snapshot-11-saf-airports

2.4 Intended audience

This is a high-level document and as such may be read by anyone needing to understand the general operational concept behind integrating new aircraft types such as electric, hybrid-electric and hydrogen-powered aircraft into the ATM system. This may include, but is not restricted to, some of the following aviation stakeholders:

- Industry Organisations
- Aircraft and Original Equipment Manufacturers (OEMs)
- Flight crew and aircraft operators
- Air Traffic Control Officer (ATCO) and Air Navigation Service Provider (ANSP) representatives
- Airports, vertiports and their operators
- Regulators
- Aviation authorities.
- University and academia
- Fuel producers
- ATM and airport infrastructure and logistics providers
- Financial institutions
- Leasing organisations
- Non-Governmental Organisations (NGOs)
- Standards Making Organisations (SMOs)
- International organisations
- Consultants

2.5 Introduction to AZEA

The Alliance for Zero Emission Aviation was officially launched on the 24th June 2022, by Commissioner Breton (DG DEFIS), calling on the members of the aviation community to join forces in preparing for the advent of ZE aircraft. At the 1st AZEA General Assembly, in his keynote speech, Commissioner Breton recalled the importance of aviation and the need to implement all paths supporting its decarbonisation, including: the development of electric and hydrogen aircraft supporting an energy shift of the sector, the adaptation of energy systems to deliver renewable energy sources to airports, the implication for safety and security regulation, the deployment of the required infrastructure and the need to drive the necessary investments. He encouraged AZEA to set clear objectives and Key Performance Indicators (KPIs), and to identify quick answers to address these issues, stressing the need to ensure that the entire ecosystem be ready to act together and consistently.

In order to prepare this Alliance, the Commission gathered partners' feedback through an online survey[6] carried out at the end of 2021. The survey largely endorsed the concept on which the Alliance is based, and many companies and organisations

[6] https://defence-industry-space.ec.europa.eu/path-zero-emission-flight-commission-seeks-public-opinion-2021-09-01_en

offered to play an active role in the Alliance. The report can be downloaded from the EC website[7].

The Alliance's objective is in line with the Toulouse Declaration[8] on future sustainability and decarbonisation of aviation [endorsed on 4 February 2022], which calls for sectoral roadmaps and joint efforts towards sustainability and decarbonisation of aviation worldwide.

It is estimated that hydrogen (whether used in combustion turbines or fuel cells) and battery electric propulsion will completely eliminate in-flight CO_2 emissions and significantly reduce other emissions, with an expected 50% contribution to decarbonising intra-EU flights by 2050 to be addressed by AZEA – see Figure 1.

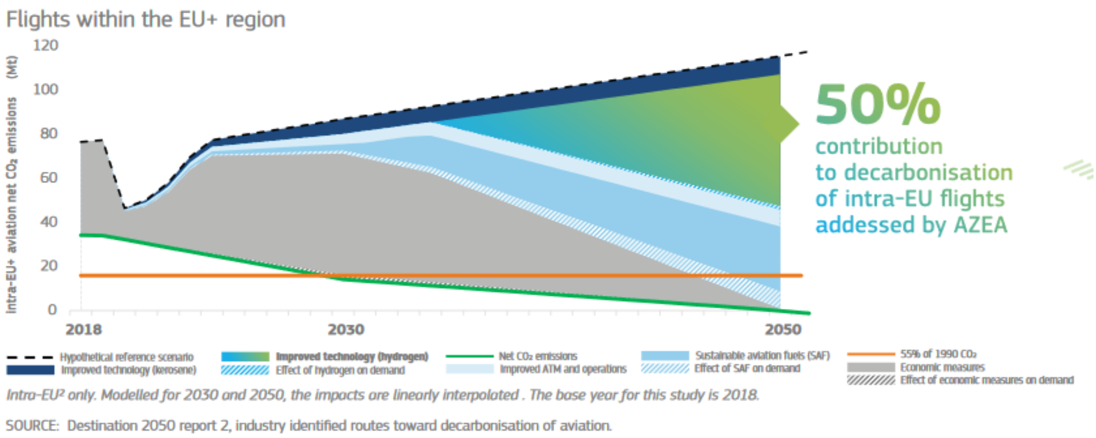

Figure 1: Estimation of % contribution to decarbonisation of intra-EU flights to be addressed by AZEA

There are many roadmaps detailing the path to net zero in 2050 such as Destination 2050[9], EAO2050[10], ATAG[11] and the ICAO LTAG[12]. Whilst the levels of ambition of each measure to contribute to the net zero target may differ, it can clearly be seen that the role of electric, hybrid-electric and hydrogen-powered aircraft (through improved technology) in reducing (or - in the case of the former – removing) kerosene emissions, form a large proportion of the expected contribution to net zero in 2050.

[7] https://defence-industry-space.ec.europa.eu/azea-summary-results-public-consultation-2021_en

[8] https://presidence-francaise.consilium.europa.eu/media/2hkh2v33/declaration-de-toulouse-pfue-ang_fr.pdf

[9] https://www.destination2050.eu/wp-content/uploads/2021/03/Destination2050_Report.pdf

[10] https://www.eurocontrol.int/publication/eurocontrol-aviation-outlook-2050

[11] https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/

[12] https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx

2.6 AZEA Members

The alliance is open to a wide range of actors – aircraft manufacturers, airlines, airports, energy companies and fuel providers, standardisation and certification agencies, passenger and environmental interest groups and regulators. Both industrial companies as well as small and medium-sized companies are part of the alliance.

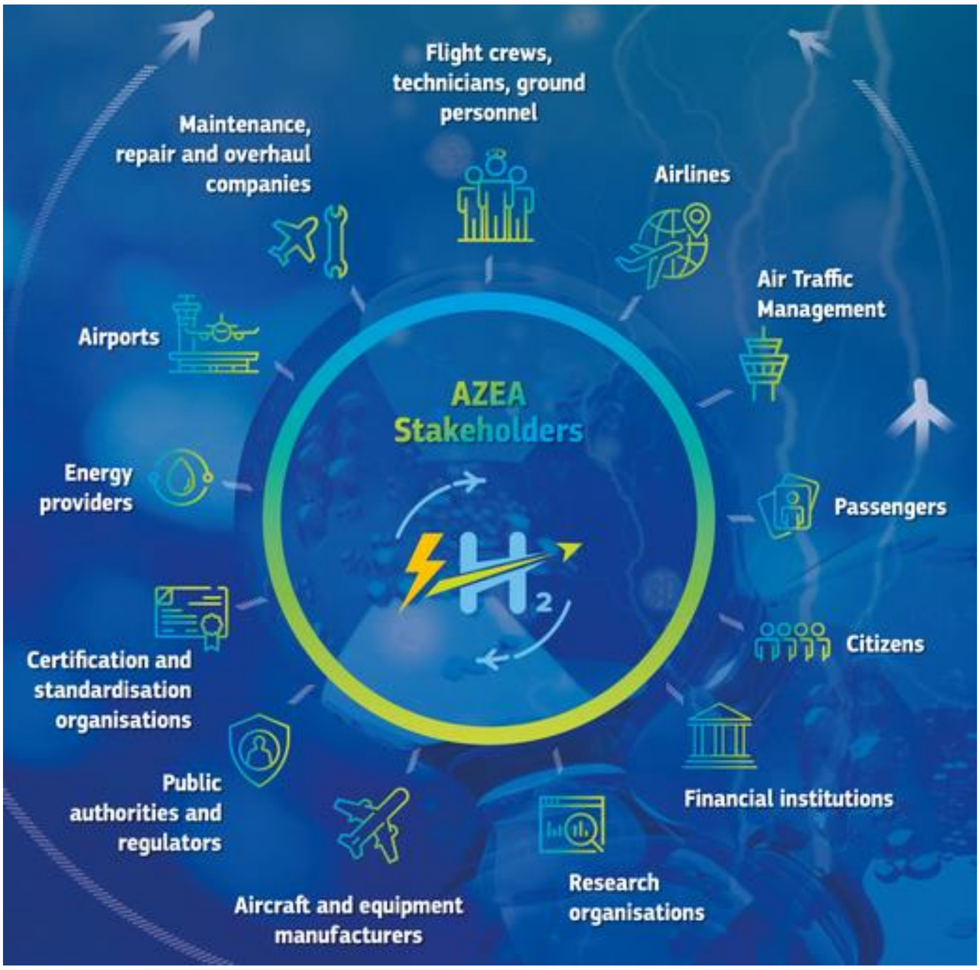

Figure 2: Actors of AZEA

As of the 22nd November 2023 there are 161 AZEA members. For a complete list of members, see appendix B.

2.7 Working Groups

AZEA is split into six working groups (WGs 1-6) that focus on such issues as infrastructure requirements, provision of new energy sources, operating requirements and regulatory issues.

The high-level objectives of each working group are detailed in Appendix C.

3 Why we need the CONOPS

3.1 Why we need the CONOPS

The operational environment in Europe has certain characteristics that make it unique and require solutions that satisfy both national and regional demands.

The management of the European ATM network has been built on strong cooperation between all stakeholders (e.g. airspace users, ANSPs, airports, regulators, the EU and its agencies, international organisations, etc.). It has been supported and codified by a coherent set of EU regulations which confer clear responsibilities on all actors involved, whilst the management of the network is an essential component of the European ATM system.

Whilst unmanned aircraft operations and higher airspace operations are entirely new paradigms in the ATM system, the integration of ZE aircraft operations into the network represents an additional profound challenge to the aviation ecosystem. Once certified, the operations of electric, hybrid-electric and hydrogen-powered aircraft are set to steadily increase in the years ahead. Therefore, it is imperative that such operations are integrated into a safe, efficient and optimised network with a minimal performance impact upon legacy aircraft and operations. The way we work today will have to evolve to fully support these new aircraft types and propulsion methods with the aim to result in a minimal impact whilst enabling full interoperability. This CONOPS will identify those evolutions that will support an optimised European airport and ATM system that enables both ZE aircraft and legacy aircraft operations.

The incorporation and integration of electric, hybrid-electric and hydrogen-powered aircraft into the European aviation system may offer distinctive challenges. ZE aircraft may introduce new performance characteristics, which will require an assessment of their impact on safety, capacity, cost-efficiency, emissions reduction and overall sustainability. Furthermore, there will be challenges for other stakeholders, such as providing ground infrastructure at airports to support these new aircraft types and propulsion methods – for example in (re)fuelling operations, maintenance and new ground operational procedures - to ensure the requisite level of safety for ZE aircraft and their operations.

This CONOPS will match the operational requirements from all operational stakeholders to the specific characteristic of the European ATM environment.

The expected market penetration of ZE aircraft can only be based on informed estimates at this time. Given the fast-paced development of these technologies, however, it is possible that adoption rates may be significant once such aircraft have been certified. While this will be a game changer for the decarbonisation of aviation in the medium-term, iterative updates to this CONOPS may be required to reflect any challenges and opportunities that arise in supporting the ongoing safe and efficient integration and operation of ZE aircraft and legacy aircraft types.

It is therefore recommended that the CONOPS be a "living document" that is continually updated to reflect the evolution of different use case operational concepts, changes in the entry into service forecasts of ZE aircraft, and to address the identified challenges of integrating new ZE aircraft into the network.

The European (and global) aviation system is supported by several different CONOPS or similar documentation. These CONOPS may cover different aspects of the aviation system but are not mutually exclusive and may overlap in certain areas. It is vital that any such overlaps are coordinated between the relevant organisations to ensure that visions, regulatory developments and technical solutions are aligned. Examples of such CONOPS include the following:

- High-level network concept of operations 2029 – https://www.eurocontrol.int/sites/default/files/2022-09/eurocontrol-high-level-network-concept-of-operations-conops-2029.pdf

This High-Level Network Concept of Operations describes the European network operations as envisaged by 2029. As such, this document is defined to enable meeting the Single European Sky (SES) Performance Targets for Reference Period (RP) 3 and 4 which addresses the period 2020-2029. The CONOPS, while delivering safer ATM operations, aims to reduce existing ATM constraints to Airspace Users, exploiting existing and emerging aircraft and ground system capabilities (both ground-ground and air-ground), and exploiting opportunities in the Single European Sky context.

- Network 4D Trajectory CONOPS 2029 - https://www.eurocontrol.int/publication/network-4d-trajectory-conops

The 4DT CONOPS aims to detail the improvements for the end-to-end 4D trajectory management described in the High-Level Network Operations Framework for 2029. This CONOPS is an essential pre-requisite for integrated Network management (iNM), in order to provide to the iNM contractor a visibility at conceptual level what is expected concerning the management of 4D trajectories. This CONOPS will be the baseline for drafting of operational/user requirements for iNM. This CONOPS might be used by all Network actors to drive their planning and investments for achieving a common goal for cooperative trajectory management at Network level.

- Trajectory Management Document - https://www.eurocontrol.int/project/4d-skyways

The Trajectory Management Document provides an overview of the target TBO concept of operations for Europe, into which the ZE aircraft will be integrated. The Trajectory Management Document provides a holistic view of SESAR TBO in a single document, providing an integrated big picture of all SESAR and non-SESAR Trajectory Management (TM) developments and outcomes, to drive current and future TM research and ICAO FF-ICE (Flight and Flow Information for a Collaborative Environment) discussions.

- U-space CONOPS – https://corus-xuam.eu/new-u-space-conops/

This CONOPS describes a set of U-space services that are provided from the ground (generally) and concern safety, security and efficient flight, how they are used and the environment in which they are used. Although there are many other closely related services that may be supplied to U-space stakeholders, for business or other reasons, which are not considered to be in the scope of this CONOPS.

- Higher Airspace Operations (HAO) CONOPS – https://higherairspace.eu/concept-of-operations-download/

As higher airspace (airspace approximately 60,000 ft) is no longer exclusive to space rockets and military planes, it may host an expanding range of vehicles, including long-endurance balloons, high altitude platform stations (HAPS), supersonic and hypersonic aircraft. With missions varying from connectivity and surveillance to passenger transport and satellite services, these vehicles with vastly different operating characteristics present a new airspace management challenge. The HAO CONOPS defines future operational roles, responsibilities, procedures and infrastructure required to support higher airspace demand over the short, medium and long term.

- The Network Manager is currently developing a draft CONOPS containing the conceptual elements of future flow management processes and ATM system components and clarifying the role and responsibilities of the Network Manager and Operational Stakeholders.

- The European Sustainable Taxi Task Force will be delivering a CONOPS by the start of 2024.

- The ACAAF-TF (Airport Compatibility of Alternate Aviation Fuels Task Force) of the IIWG (International Industry Working Group) is developing a CONOPS on the entry into service of Electric and Hydrogen Powered Aircraft at Airports, with a view to support regulatory activities at ICAO Aerodrome Design & Operations Panel.

3.2 Scope

The CONOPS for Zero Emission aviation covers all types of electric, hybrid-electric and hydrogen-powered aircraft as planned for development by AZEA Partners. It should be noted that the CONOPS addresses both the objective to decarbonise Commercial Air Transport (CAT) together with the challenges and opportunities that will arise from the integration of new market segments into the European aviation system. This operational concept is aligned as closely as possible with the performance-based approach as advocated by the International Civil Aviation Organisation (ICAO).

The scope of ZE aircraft Operations concerned by this CONOPS includes all phases of flight from gate to gate including operations on stand, on the apron, taxiways, runways and all phases of airborne flight.

4 ZE aircraft performance

4.1 Challenges and key assumptions

4.1.1 Challenges presented by ZE aircraft operations

The safe and efficient integration of electric, hybrid-electric and hydrogen aircraft into the European aviation system could be one of the major challenges in aviation in the coming years, if their performance is markedly different to current legacy aircraft.

Whilst existing commercial aircraft manufacturers are targeting full interoperability with legacy aircraft operations at entry into service of their new aircraft, ZE aircraft pertaining to new market segments may provide new challenges in terms of flight-performance. For example, they may operate at flight levels that are not currently used to the extent that is expected for ZE aircraft operations, or with rates of climb / descent that are not consistent with current operations. This may reduce the predictability of aircraft behaviour with a corresponding degradation in the operational performance of the network, without a successful integration of these new aircraft. Therefore, in addition to the challenge of decarbonising commercial air transport operations, an additional challenge is to develop new solutions that are required to ensure a safe and effective integration of these aircraft into the new operational environment and to evaluate the associated impacts on safety, capacity and operational efficiency.

An innovative new performance-driven ATM is in development. A key driver of this system will be SESAR[13] solutions providing new or enhanced operational procedures or technologies that aim to contribute to the modernisation of the European and global ATM systems. These solutions address all parts of the ATM value chain, integrating operations on the ground and in the air, as well as the underlying system architecture and technological enablers, which are validated in real day-to-day operations. It is already estimated that by 2040, an increasing number and variety of air vehicles will be taking to Europe's skies[14]. The SESAR vision aims to deliver a resilient and fully scalable ATM system capable of handling growing air traffic made up of a diverse range of manned and unmanned air vehicles in all classes of airspace, in a safe, secure and sustainable manner.

It is expected that entry into service and penetration rates of ZE aircraft will begin in the mid-2020s before ramping up in the following decades. WG1 estimates that AZEA partners plan entry into service in the late 2020s of electric, hybrid-electric and hydrogen fuel cell powered aircraft, both evolutionary and revolutionary aircraft. Whilst these aircraft will initially be smaller in size than the new aircraft planned for the later years, it is critical that the European ATM system be ready for these new challenges and enable the early introduction and integration of the first ZE aircraft of new market segments in a seamless fashion.

[13] The Single European Sky ATM Research programme

[14] European ATM Master Plan, 2020

4.2 Key assumptions for a performance-based approach

At ICAO's 13th Air Navigation Conference in 2018, it was agreed that in order to improve system performance, the *Global Air Navigation Plan* (ICAO Doc 9750, GANP) would encourage the adoption of a globally harmonised performance management process for the modernisation of the air navigation system and the implementation of operational improvements. The meeting strongly recommended that the ATM system follows the six-step performance management process described in the Manual on *Global Performance of the Air Navigation System* (ICAO Doc 9883), based on the eleven Key Performance Areas (KPAs) that align with the global performance expectations outlined in the *Global Air Traffic Management Operational Concept* (ICAO Doc 9854, GATMOC).

The European ATM network supports and will continue to support all network operational stakeholders by helping them to reach their business needs. This is performed by ensuring an appropriate balance between the optimisation of airspace and airport capacity, flight efficiency and the overall operational costs of network operations, whilst improving network operations scalability and sustainability. To succeed, effective operational performance management of the network in partnership with stakeholders is required.

Performance objectives, including quantified targets, are aligned with the performance ambitions and they are established through the SES Performance Scheme[15] (current Reference Periods RP3 2020-2024) and the Network Strategy Plan (2020-2029).

As indicated in the Network Strategy Plan 2020-2029[16], optimising network design and network operations will both significantly contribute to meeting the capacity and environmental Key Performance Indicators (KPIs) as defined in the Performance Scheme Implementing Rule, and will also contribute to Safety and Cost-efficiency.

This CONOPS adopts the performance-based approach of which the single most important principle is that safety is paramount. Safety will never be compromised or traded off with other performance areas.

A performance-based approach requires a coordinated effort for all stakeholders in the aviation community, who should be encouraged to follow a common approach toward the development and implementation of the performance-based air navigation system.

4.2.1 Safety

It is assumed that ZE aircraft will comply with the established rules of the air. Operations will be conducted in accordance with the safety regulations provided by authorities. In order to ensure safety, the operational behaviour of ZE aircraft will need to be fully understood and validated.

Additionally, the following measures shall enhance the safe integration of ZE aircraft:

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[15] https://transport.ec.europa.eu/transport-modes/air/single-european-sky/ses-performance-and-charging_en

[16] https://www.eurocontrol.int/sites/default/files/2020-10/network-strategy-plan-2020-2029.pdf

Training / Familiarisation: Information concerning the performance characteristics of ZE aircraft should be included in both basic flight crew and ATCO training. This will help ensure that both sets of operational actors are aware of potential changes in the performance envelope of new aircraft in the air traffic environment. This will help them understand the changed air traffic environment, enabling a more resilient overall system.

Standard Operating Procedures (SOPs): SOPs for standard and non-standard situations shall cover all conceivable scenarios, including particularities of new propulsion techniques and sources of sustainable energy / fuel, like battery-driven electric or hydrogen technology.

Collision avoidance: Whilst Airborne Collision Avoidance System (ACAS) II traffic and resolution advisories are based on closure rates, there may be a need to validate whether the intentions of ZE aircraft can be fully captured in the existing system[17] and future development of ACAS X variants.

Human Machine Interface (HMI): Where possible and feasible, the highest standards of human machine interfaces should be adopted, including situational awareness and decision-making tools, integrating human-AI (Artificial Intelligence) pairing etc.

Crew Resource Management (CRM): The latest CRM concepts should also be adopted to address the implementation of new technologies, new propulsion systems, new possibilities by AI-decision making tools, and new market segments. CRM must include all persons involved: Flight Crew, Air Traffic Control (ATC), including future automated services, maintenance, company services en-route, and ground personnel.

Risk assessment: An assessment of the potential new risks coming along with potential malfunctions of electric or hydrogen-powered aircraft should be made with respective procedures to be implemented. The interaction with existing traffic should be taken into account with an emphasis on airspace usage.

4.2.2 Environment

Just like any new addition to the aviation system, a thorough assessment of the potential environmental impacts of any new vehicle or operational type is necessary before it goes into operation. This assessment helps determine the extent to which these operations can be considered sustainable. In order for ZE aircraft to be integrated into existing operations, it is recommended to undertake an Environmental Impact Assessment (EIA) to ensure that, through the integration of ZE aircraft, the environmental performance of the aviation system will be improved.

This assessment should be undertaken on two fronts:

1. **ZE aircraft environmental performance:** There is a need to assess the environmental performance of new ZE aircraft and operations to be able to understand the type and magnitude of any environmental impacts of these

[17] TCAS II is restricted to categories of aircraft capable of achieving specified performance criteria (e.g. minimum rate of climb of 2,500 feet per minute), which excludes the likes of General Aviation (GA) and Unmanned Aircraft Systems (UAS) – Skybrary.

aircraft in order that they can be mitigated as early as possible in the developmental cycle; and,

2. **Environmental impacts on legacy aircraft operations:** It is also important to undertake an assessment of the potential impact of the integration of any ZE aircraft or operation in order to understand whether, and to what extent, there will be an operational impact upon legacy aircraft operations. In this way, should any impacts be found, appropriate solutions can be identified to ensure that ATM is optimised from an environmental perspective. For example, in case emergency procedures of ZE aircraft differ significantly from those of legacy aircraft (e.g. in terms of flight path), those differences can be taken into account when defining horizontal, vertical and time separation minima.

In addition to the above points, any potential interdependencies between safety and environmental impacts need to be identified at the earliest stage possible so that they can be addressed. This requires a coordinated and integrated approach, not only to address the sustainability of the system but to ensure the safety of these operations, the safety of general and operational air traffic and the safety of the general public.

4.2.3 Access and equity

Access to the network must be on a fair and equitable basis. Fair and equitable access will rely on a regulatory framework to include safety, security and environmental considerations.

Regardless of the performance characteristics of ZE aircraft or the market segment that OEMs wish to serve, airspace, airport services and ATM provision should be open and available to all. As today, at the same time as there being a principle of equitable access, some flights may have priority, particularly aircraft in an emergency and life-saving or other emergency-response flights. Instances where non-equitable treatment are forced by circumstance should be dealt with fairly.

4.2.4 Capacity

Whilst the volume of IFR flights in upper airspace may evolve in the coming years in line with predicted forecasts, it may be assumed that CAT ZE aircraft operations will replace older aircraft types based on a normal (or enhanced) life cycle process. However, with the new business models of ZE aircraft, together with performance limitations and the interdependency between electric motor efficiency and flight altitude, an increase in both VFR and IFR flights in lower airspace may be expected, which will be supported by new / improved operational procedures. However, the current airspace structure does have limitations and boundaries to ensure safe operations. The introduction of the new models of ZE aircraft and associated new procedures should be accompanied by appropriate analyses to ensure that any activities that result in more ATCO workload (and therefore a negative impact upon sector or airspace capacity) are addressed. Such assessments can provide information on 1) when the increase in ATCO workload could become a capacity and / or safety issue, and 2) the options for potential solutions. A key element of the impact of an increase in flights or an increased interaction between flights on ATC workload may be increased radiotelephony (R/T) communications, more instructions to aircraft, increased use of controller tools or more coordination with neighbouring sectors / centres. Enhanced procedures and the move towards a performance-based CNS system should provide the enablers to make the European ATM system more flexible and resilient to the introduction of such novel aircraft and related performance.

4.2.5 Predictability

For a safe and expeditious flow of traffic without endangering the robustness of the European aviation network, it is essential that ATCOs are confident of the predictable actions of all traffic and traffic flows and are flexible to be able to adapt to a changing environment. If new ZE aircraft exhibit behaviour that is non-compliant with expectations, this can have an impact on safety, ATCO workload and airspace capacity. Therefore, the behaviour of any new ZE aircraft must, as far as applicable, be consistent in-flight and at all times, understood by ATCOs.

If performance characteristics are expected to result in aircraft behaviour that differs from legacy aircraft operations, this information needs to be disseminated to ATC practitioners and other airspace users so that appropriate training can be developed. Automation and increased data sharing can also support this process leading to enhanced predictability.

For airspace users, predictability primarily refers to the likelihood of achieving the Reference Business Trajectory (RBT) i.e. being predictable for the commercial objectives of the airline. Flight crews should be confident of receiving a predictable ATC service under normal flight conditions.

4.2.6 Efficiency

The European Network Manager (NM) has been measuring flight efficiency for many years, moving from proxy performance indicators (i.e. those measuring distance or time such as KEA or KEP) to include indicators based on fuel burn (e.g. the Excess Fuel Burn (XFB) indicator). With cross-border Free Route Airspace (FRA) expected to be fully implemented across Europe in the coming years, the amount of further performance improvements linked to the provision of more direct routings may diminish. However, for certain city pairs, because of their geographical location or constraints such as noise restrictions, the flight inefficiency may remain an issue.

For ZE aircraft, further optimising the horizontal trajectory may represent an opportunity as flights on some city pairs may currently experience longer flight or significant detours which result in substantial additions to the distance flown which in effect, can compromise the effective nominal range of the aircraft type. With zero emission aircraft, it may be possible to increase the number of feasible routes for electric aircraft by operating on routes previously not available for conventional aircraft but the extent that this will be possible will also depend on usable diversion locations and Continued Safe Flight and Landing (CSFL) sites due to regulatory requirements.

For the optimisation of Vertical Flight Efficiency, there are still many opportunities to optimise aircraft trajectories either through optimising climb and descent profiles (CCO and CDO), supporting descent from optimal top of descent points, removing level caps and constraints, and supporting the optimisation of planned vertical trajectories in FRA through FF-ICE.

4.2.7 Resilience

Within the ATM performance domain, resilience has traditionally been considered with regards to capacity. Capacity is affected when disturbances generate delays. The traditional view of resilience is the ability of the system to eliminate these delays.

The pandemic has proven that the traditional view of resilience and its link to capacity may have evolved as ATM has been impacted in new ways e.g. by events such as a major reduction in traffic demand, a high volatility of traffic flows and a high uncertainty of traffic recovery.

For ZE aircraft operations, should they require additional constraints to function efficiently, there may be a risk of reduced resilience to such disruptive events and it may be appropriate to build additional resilience into the operations. This could be in the form of a resilient organisation (e.g. to adjust to a changing framework whilst maintaining services), resilient operations (e.g. establishing business continuity regardless of disruptions) or resilient staff (e.g. staff adapt quickly to unforeseen situations and maintain competences to resume business as soon required).

4.2.8 Interdependencies

Operational changes are often made on the basis of a wide range of strategic, economic and operational reasons, which are interdependent. Such interdependencies can be positive (synergies) or negative (trade-offs).

In a performance framework, it is often not possible to prioritise the optimisation of a single performance area without influencing the performance of another performance area.

Issues of capacity, efficiency, safety and environmental impacts are often intertwined such that the true impact of an operational change may not be understood unless all relevant stakeholders are able to participate in a collaborative exercise. Whilst safety is never compromised, other considerations might have differing priorities depending on the operational issue and any proposed solutions.

Typically, a compromise or balance is required to ensure that a negative impact in one area does not outweigh the value of a positive impact in another area. However, positive and negative impacts may also be found between different aspects of the same impact area.

4.3 Other Environmental impacts

4.3.1 Noise

Whilst ZE aircraft may provide a potential solution to reduce (hybrid aircraft) or remove aviation CO_2 emissions, there is also a need to address aviation noise. Historically, there has always been an interdependency between noise and emissions as to reduce one e.g. noise, you may have to increase the other e.g. to move the traffic away from a particular area by extending the route (resulting in more emissions).

For new business models of ZE aircraft, whilst airframe noise may be similar to that of conventional aircraft, it is possible that engine (and / or propeller / fan) noise may be reduced as the noise-generating mechanisms of the electric or hybrid-electric / hydrogen powered aircraft may be different. In the case of electric aircraft, even if the overall noise level is reduced, there could be a concern relating to the spectral content of the noise. If the spectral content is different, it may be an unfamiliar noise to communities and therefore more easily 'heard' as some specific tonal ranges are generally more annoying than broadband noise. ZE aircraft propulsion technologies could also produce increased sound energy in the higher frequency range due to shorter sound propagation distances and less effective atmospheric attenuation. Therefore, there could be challenges related to community involvement, social acceptance and perceived annoyance.

For commercial ZE aircraft that replace legacy aircraft, although the noise footprint may be reduced, there is a risk that the overall cumulative noise exposure might increase with additional numbers of rotations. Likewise, introducing a large number of light aircraft operations over communities where there was previously minimal intrusion - regardless of the individual noise footprint reduction of an individual aircraft - might have a significant noise impact that could be less accepted by the communities.

Sound metrics used to monitor community noise around airports are chosen for how noise is perceived by (average) humans. If the ZE aircraft exhibit a noise profile that produces low measurements with these metrics, it should be possible to assume that the nuisance is less, as opposed to the need to identify any complimentary noise metrics.

Should ZE operations produce less noise, there may be an opportunity to develop procedures that can take full benefit of this noise reduction (e.g. through a more direct route over a population centre previously constrained for noise reasons), of course depending upon any other constraints.

It should be noted that new ZE aircraft may exhibit characteristics such as distributed propulsion, automated controls, and capabilities for vertical take-off, hovering and landing. If so, the flight profiles and reference conditions included in ICAO Annex 16 procedures that have been specifically developed for certification of conventional aircraft categories, may not be appropriate with new procedures to be defined.

4.3.2 Non-CO_2

Air traffic contributes to anthropogenic global warming by about 5% due to CO_2 and non-CO_2 aviation emissions. The latter primarily include nitrogen oxides (NOx) and their impact on Ozone (O_3) and Methane (CH_4), soot particles, oxidised sulphur species, and water vapour (H_2O). The largest aviation non-CO_2 impact that can be calculated with 'best estimates' are contrails and the resulting contrail-induced cloudiness (CiC). While aviation's non-CO_2 effects generally result in positive radiative forcing (warming), they can also lead to negative (cooling) forcing effects. Quantifying these impacts is difficult due to the considerable uncertainties surrounding their magnitude. What is known however, is that the main non-CO_2 contributions arise from contrail cirrus, CO_2 and NOx. Contrails usually form above around FL260, where temperatures are usually less than -40°C. The effects of contrails are more frequent in mid-latitude regions with heavy traffic and vary according to weather conditions and the time of day. Their warming effect is most pronounced at night in areas of ice supersaturation, resulting in persistent contrails. Compared with CO_2 and other emissions, this effect has a high net energy input into the atmosphere but is short-lived.

The integration of ZE aircraft operations is expected to significantly reduce life cycle CO_2 emissions from aviation. However, non-CO_2 emissions may still be significant, depending on the propulsion type. Of particular relevance to ZE aircraft operations are contrails, water vapour and nitrogen oxides.

The aviation industry is taking action to reduce adverse impacts by:

- developing more stringent aircraft engine emissions standards;
- introducing new technologies to reduce non-CO_2 emissions; and
- introducing operational concepts, like climate-optimised trajectories.

In addition, the aviation industry is supporting the scientific advancement in the field of understanding of non-CO_2 impacts, notably in very low soot environments such as those encountered by using SAF and hydrogen-powered aircraft. This support can be demonstrated in flight tests campaigns such as ECLIF[18] (Emissions and the Climate Impact of alternative Fuels), VOLCAN[19] or Blue Condor[20].

Climate-optimised trajectories are already being discussed to lower the non-CO_2 climate impact of operations of aircraft with kerosene engine concepts. The aim is to mitigate non-CO_2 based climate impacts in those airspaces in which persistent contrails are likely to occur. The potential effect of any resulting changes to mission length or duration will need to be weighted against any additional fuel flow and related CO_2 emissions. This depends on individual aircraft performance, which may lead to appropriately adjusted degrees of freedom of ZE aircraft climate impact mitigation trajectories, linked to the capability to manage water exhaust emissions.

It is essential to assess and communicate information on the potential non-CO_2 emissions that may be expected from ZE aircraft. It should be noted however, that in the short to medium term, the majority of ZE aircraft that are expected to enter into service (e.g. eVTOL, LLO and RAM operations) will likely cruise below FL250. As these cruising levels are below the altitudes normally associated with the development of contrails and contrail cirrus, it is likely that there will be minimal non-CO_2 (contrail and contrail cirrus) impacts from these initial ZEA operations.

Currently, there is uncertainty over whether other ZE aircraft design and propulsion methods – for example for CAT ZE aircraft - will differ significantly from those of legacy aircraft with respect to the formation of contrails. There is first a need to understand the physics behind contrails formation, which may be quite different from fossil kerosine (e.g. homogeneous or even spontaneous nucleation have to be assessed). Also, the Ice Super Saturated Regions (ISSR) where contrails persist, may differ for hydrogen-powered aircraft, due to the different nature of the droplets, which may lead to different climate-optimised trajectories. It should be noted also that hydrogen fuel cells only emit water vapour, while hydrogen-powered gas turbines produce both water and reduced amounts of NOx. It remains to be seen whether

[18] https://www.dlr.de/en/media/publications/magazines/all-digital-magazines/dlr-magazine-173/a-small-taste-of-the-future

[19] https://www.airbus.com/en/newsroom/press-releases/2021-06-french-aeronautical-players-to-fly-100-percent-alternative-fuel

[20] https://www.airbus.com/en/newsroom/stories/2022-07-how-blue-condor-will-accelerate-airbus-first-hydrogen-powered-test-flights

operational mitigation concepts of kerosine-powered aircraft are directly transferable to those powered by hydrogen.

Comprehensive analyses are necessary to accurately determine the impact of non-CO_2 emissions and the formation of contrails. The outcome of any related non-CO_2 flight test campaigns together with the latest scientific understanding will be detailed in future iterations of the CONOPS.

4.4 Adaptation of operational performance indicators

With the gradual move from proxy performance metrics towards more environmentally relevant indicators such as those based on fuel burn or CO_2, the pathway to performance-based network operations will demand the definition of new operational and environmental performance indicators or the adaption of existing performance indicators to more accurately assess the impact of performance changes. Whilst the development of new environmental performance indicators is currently out of scope of WG5, there is a need to understand the extent to which ZEA operations will contribute to decarbonisation. Therefore, appropriate time should be taken to work with other stakeholders to identify potential new performance indicators that would be able to measure the impacts of the different performance areas by the introduction and integration of ZE aircraft into the network. A discussion on modelling ZE aircraft performance and the potential development of new performance indicators will be incorporated in future CONOPS iterations.

5 ZE aircraft classification

Key message: *WG5 defined a performance questionnaire for new ZE aircraft that received 24 responses from AZEA OEMs. The requested information included cruising levels and speeds, range, turn-around time and take-off distance etc.*

Following the information provided by AZEA OEMs, WG5 has developed a ZE aircraft performance classification scheme based on four main characteristics: cruising level, cruising speed, rate of climb and final approach speed. The groups are divided into VTOL (groups 1-3) and fixed-wing performance groups (groups 4-9).

The WG5 performance groups should be considered a work in progress and should be re-assessed once robust ZE aircraft performance assessments become available and operational concepts reach a higher level of maturity.

5.1 WG1

AZEA WG1 has developed a preliminary proposal for a ZE aircraft classification scheme based primarily on mission range, expected passenger numbers and power plant type. However this does not address expected performance and is still a work in progress.

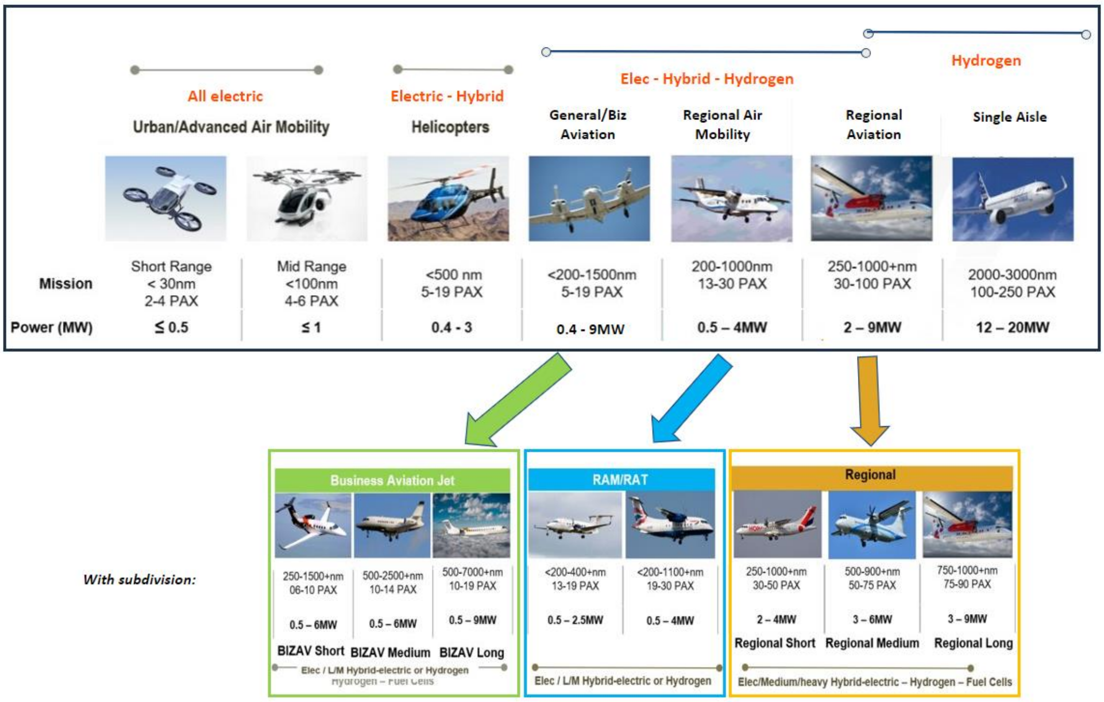

Figure 3: WG1 proposal for a ZE aircraft classification scheme

5.2 WG5

The ZE aircraft classification scheme developed by WG1 does not consider the different scope of aircraft performance expected to be addressed by the CONOPS therefore it was decided that WG5 would propose a classification scheme solely based on aircraft performance. To support this proposal, a questionnaire on aircraft performance was developed by WG5 and distributed to all OEM members of AZEA.

The questionnaire garnered 24 responses from AZEA OEMs. Based on the responses, four main characteristics were used to define the WG5 classification scheme: Cruising level, cruising speed, rate of climb and final approach speed.

The proposed WG5 aircraft classification scheme is detailed in Figure 4. For more information on the questionnaire, the ranges of responses, a breakdown of the WG5 classification parameters and additional conclusions, see Appendix D.

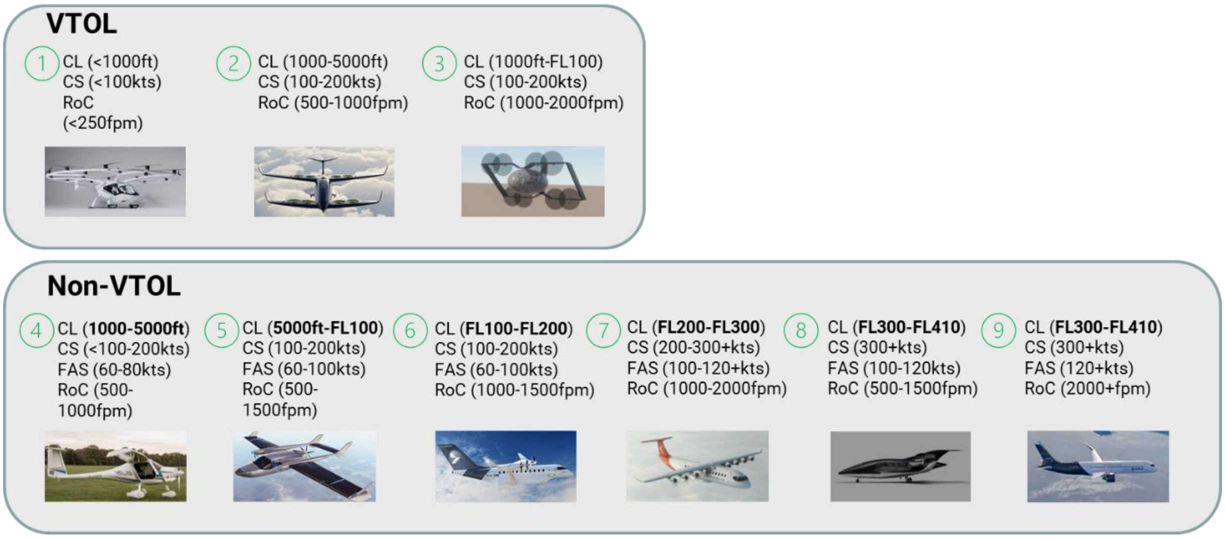

Figure 4: Initial WG5 proposal for an ZE aircraft classification scheme

The responses received resulted in aircraft being placed into the following performance groups:

Performance Group	OEM	Aircraft
1	Volocopter	VoloCity
1	Hylight	Hylighter
1	Kelluu	Beta
2	Ascendance FT	Atea
3	Lilium	Lilium Jet
3	Fleasy	X8ED
4	Pipistrel	Velis electro
4	Blue Spirit	Dragonfly
5	Cranfield Aerospace	H_2 Islander
5	Atol Aviation	E-seaplane
5	Volt Aero	Cassio 480
5	Aura Aero	Integral E
5	Væridion	Microliner
6	Heart	ES30
6	Pipistrel	Miniliner
7	Aura Aero	ERA
7	Leonardo	Hybrid-electric RA
7	Maeve	Maeve 01
7	Airbus	ZEROe 100
8	Beyond Aero	BYA-1
9	Airbus	ZEROe 200

N/A	Magpie	N/A
N/A	ZeroAvia	ZA600 engine
N/A	ZeroAvia	ZA2000 engine

Table 1: Survey responses assigned to AZEA performance groups

5.2.1 Conclusions

It may be expected that some of the performance characteristics will only be fully understood following appropriate testing and mature aircraft performance assessments. It is also possible that for some newer aircraft concepts, they may simply be based upon estimates of potential flight performance characteristics or conceptual thinking. Therefore, it is important that the performance groups are considered a work in progress and should be re-assessed regularly especially when more robust detail of the performance characteristics of new ZE aircraft types becomes available and operational concepts reach a higher level of maturity.

In addition, it should be noted that some ZE aircraft performance categories are based upon a single aircraft type whose expected performance characteristics are quite different to other ZE aircraft, hence the different category, but whose precise performance characteristics may not currently be fully understood.

In order to fully understand the impact of performance differences of ZE aircraft, it is also relevant to understand the expected market penetration of each proposed group. For example, if 80% of expected ZE aircraft are expected to be in Group X whose performance is not expected to be too different from current aircraft, the impact of integration will not be so high. Therefore, it is essential that inputs from WG1 are taken into account when assessing performance impacts.

6 Use cases and penetration rates

Key message: *Entry into service scenarios are based on current knowledge and forecast assumptions therefore the CONOPS will be updated on a regular basis as and when concepts mature for each market segment.*

AZEA OEMs have shared 10 generic use cases for the 9 AZEA performance groups (see Appendix E). In addition, WG5 has developed 4 more detailed use cases to demonstrate how ZEA operations could evolve for 4 generic business models. These use cases are:

- *eVTOL operations*
- *LLO (Low-level operations)*
- *RAT (Regional Air Transport)*
- *CAT (Commercial Air Transport)*

This chapter describes some generic operating scenarios together with examples of typical types of aircraft that are currently being developed by AZEA members.

As with new entrants such as Unmanned Aircraft (UA), the following basic principles should be expected for new ZE aircraft types:

- Operations by ZE aircraft shall be conducted in the same way as all other airspace users;
- ZEA operations will take place in the same airspace as other aircraft classifications and in accordance with the Standardised European Rules of the Air (SERA);
- ZE aircraft shall comply with the existing and future regulations and procedures laid out for current airspace users;
- Neither the integration of ZE aircraft nor the increase in legacy aircraft operations shall compromise aviation safety levels; and,
- The impact of the operations of ZE aircraft will have to be managed and will have to respect the operational performance of other airspace users.

Bearing in mind these basic principles, as the number of ZEA operations increases, it may be expected that the future ATC/ATM systems develop airspace structures, routings and procedures that favour or prioritise operations by ZE aircraft which may provide strong incentives for other airspace users to move towards ZEA operations.

6.1 Roll-out scenarios

As the CONOPS is iterative in nature, the roll-out scenarios are based on current knowledge and forecast assumptions and as the first ZE aircraft will enter into service in the current decade – with others in future decades – the CONOPS will be updated on a regular basis, as and when concepts mature for each market segment.

The first version of the CONOPS is therefore more focused on those ZE aircraft that are expected to enter into service in the short and medium term, such as electric and hybrid-electric aircraft, in the eVTOL, General Aviation (GA) and Regional Air Mobility / Regional Air Transport (RAM / RAT) market segments. Future CONOPS iterations will address additional market segments once the programs and detailed knowledge of the performance characteristics of these novel aircraft mature.

WG1 (WP1.1) has established a roll-out scenario with quantified objectives for a market uptake of electric, hybrid-electric and hydrogen-powered aircraft by 2050. This scenario of the market penetration is based on multiple internationally recognised sources together with inputs shared by AZEA WG1 aircraft OEMs.

WG1 took the current number of aircraft in the global fleet for their proposed aircraft groups / sub-groups (VTOL, helicopters, business jet, general aviation, RAT / RAM, regional turboprop, regional jet and single aisle[21]) and assessed the forecast number of deliveries between 2033-2050, together with the estimated percentage share of which will be ZE aircraft.

European market penetration rates were based on expected new aircraft deliveries, forecasts for new Advanced Air Mobility (AAM) vehicles, a new technology regional turboprop forecast and regional electric / hybrid-electric aircraft forecasts. One of the inputs to the WG1 study is shown in Table 2.

New type of aircraft	Size	Technology	Range	Aircraft segment
Electric aircraft (2 versions)	9 19	Revolutionary	Very short Short	Turboprop
Turboprop with regional jet specificities / capabilities	70	Evolutionary	Short & Medium	Turboprop
Turboprop with regional jet specificities / capabilities	90	Evolutionary	Short & Medium	Turboprop
Hybrid electric	30-40	Revolutionary	Very short & Short	Turboprop
Conventional aircraft (re-engined and upgraded)	170	Evolutionary	Medium & Long	Single aisle
Wide body aircraft (re-engined and upgraded)	300	Evolutionary	Long	Wide body
Regional jet (re-engined and new aircraft design)	145	Evolutionary	Medium	Regional jet
Electric regional aircraft	100	Revolutionary	Short	Regional jet
Hybrid electric (H2 fuel cells)	70	Revolutionary	Short	Turboprop
Hybrid electric H2	200	Revolutionary	Medium	Single aisle
Blended wing body H2 aircraft	140	Revolutionary	Medium	Single aisle
New version of the A220	150	Evolutionary	Medium & Long	Regional jet

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Table 2: One source of penetration rate data used by WG1 (source: EUROCONTROL STATFOR)

Several points to be highlighted from the WG1 roll-out scenario development include:

- WG1 estimate that the cumulative battery-electric and hydrogen aircraft deliveries until 2050 will be in the range of around 25,000 (baseline scenario) and 50,000 (ambitious scenario).
- WG1 considered the introduction of new aircraft types as opposed to substitution.
- EUROCONTROL inputs to WG1 were limited to regional aircraft based on the assumptions used in the EAO (European Aviation Outlook).
- The roll-out scenario is an aspirational goal.

[21] The WG1 categorisation is currently a work in progress and may be updated prior to the next CONOPS iteration

- According to WG1, estimations of eVTOLs in Europe by 2050 are in the range of 20,000 with over 28 million eVTOLs flight operations per year.
- It is not expected that eVTOLs will replace all helicopter operations and by 2050 both are expected to be in operation because the current and future battery density (weight-to-power-ratio) is not sufficient or expected to be sufficient to operate all viable missions, therefore, by 2050 the bigger / heavier helicopters will be too big to be battery powered.
- For General Aviation (GA) aircraft[22], battery technology will limit operational range e.g. for an all-electric aircraft such as the Cessna Caravan:
  - 30NM by 2030
  - 70NM by 2035
  - 300+NM by 2050[23]
- For the same aircraft, a hybrid-electric solution could have a range of around 150NM by 2030 and 450+NM by 2037.
- WG1 estimate that there will be around 2500 ZEA GA aircraft Including business aviation) delivered in Europe by 2050 in the baseline scenario.
- The ambitious scenario estimates up to 14000 ZEA GA aircraft to be delivered with up to 4 million cumulative flights per year.
- GA aircraft, as with RAM/RAT aircraft, will concern three major types of development:
  - Conversions of existing aircraft;
  - New innovative aircraft; and,
  - Legacy OEMs with new aircraft.
- WG1 estimate that there will be between 1000-4000 ZEA RAM aircraft in Europe in 2050, of which two thirds of new deliveries will be electric aircraft.
- WG1 estimates that over 400 hydrogen-fuelled regional turboprop aircraft will be delivered by 2050, the same decade in which hydrogen-powered regional turboprops will start to overtake the delivery of conventionally powered regional turboprops.

It should be noted however that for now, WG1 has not addressed the streamlining of OEMs and has thus 'simply' added-on declarations of market shares among various aircraft manufacturers. A degree of rationalisation can be expected in the future.

In addition, whilst previous ‘Challenges of Growth’ studies by EUROCONTROL have considered both the shift in traffic patterns due to saturation of hub airports / growth of new market segments such as low cost long-haul, and the movement of traffic towards secondary airports such as business aviation (noting importance of ground access times to final destination) and low cost carriers (noting the importance of ground access), this was not a consideration in the ZEA forecast. As the forecasting of entry into service dates evolve, the roll out scenarios will be updated in future CONOPS iterations.

Figure 5 summarises the expected % zero emission aircraft share of deliveries by 2050 of the market segments considered by WG1.

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[22] WG1 only considers GA aircraft with turbine engines i.e. piston-engined GA aircraft are not included

[23] These numbers do not take into account reserves or end of life performance, which certification requires (WG1)

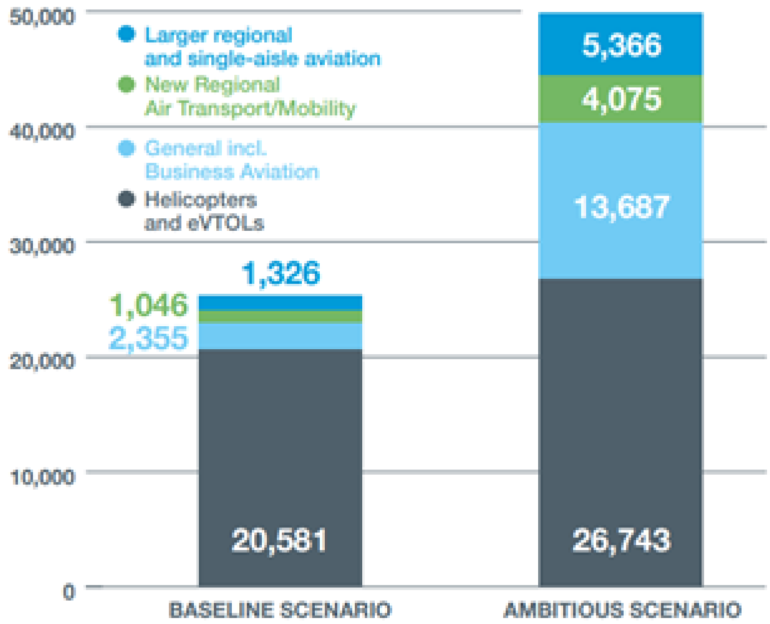

Figure 5: Cumulative battery-electric and hydrogen aircraft deliveries until 2050 for the market segments considered by WG1

6.2 Generic operational environment and use cases for AZEA performance groups

In this section, four sets of generic use cases for operational business models have been provided by AZEA OEMs:

- eVTOL operations;
- Low-level operations;
- RAT operations; and,
- CAT operations.

These use cases detail how ZEA members foresee operations evolving in the coming years, and demonstrate some of the challenges and opportunities that may need to be addressed to enable the integration of ZE aircraft into the European aviation network.

The ATM community will need to determine how these challenges can be mitigated with solutions that can be deployed both locally and network-wide. As each of the operational business models evolve (and potentially new business models arise), information on the operational solutions that may need to be deployed will have to be detailed in future iterations.

In addition to these four business model use cases, AZEA partners have provided use cases for each performance group identified by WG5. For Group 5, which contains the most examples of new aircraft under development, 2 use cases are detailed. These additional use cases can be found in Appendix E and are summarised in Table 3.

Performance Group	OEM	Aircraft
1	Volocopter	VoloCity
2	Ascendance FT	Atea
3	Lilium	Lilium Jet
4	Blue Spirit	Dragonfly
5	Volt Aero	Cassio 480
5	Væridion	Microliner
6	Pipistrel	Miniliner
7	Maeve	Maeve 01
8	Beyond Aero	BYA-1
9	Airbus	ZEROe 200

Table 3: WG5 performance group uses cases in Appendix E

6.2.1 eVTOL operations use case

One of the themes that comes across when looking at ZE aircraft use cases is the expected increase in eVTOL operations. eVTOL operations are expected to make a huge impact as a new market segment in the network out to 2050. They may be expected to operate at existing airports or new vertiports and city centre locations with a myriad of use cases. One use case is described below.

Based on the current projections of WG1, eVTOLs are expected to start to enter into service by 2025. Whilst eVTOL operations as part of UAM are not within the scope of this CONOPS, it can be expected that eVTOL operations will operate as manned operations across the network, with large numbers expected to be in operation by the mid-2030s according to current market forecasts. As eVTOLs enter into operation, new iterations of the ZEA CONOPS will address any uncertainties that arise in this edition, as the operational concepts evolve and any new challenges to their operation and integration are identified.

<u>Ascendance Flight Technologies</u>

We foresee that eVTOLs will be one of the first steps on the way to decarbonising AAM as this is where the market demand will grow the most. eVTOLs are expected to start to enter into service around 2025 – due to the detailed regulatory updates that took place in 2023 - beginning with small 4-5 seater electric eVTOLs. These will operate at existing airfields and helipads where not much additional infrastructure is required. The market segment will evolve through larger 6-10 seat hybrid-electric commuter eVTOLs in the early 2030s, eventually evolving into a more AAM service that could be based on hybrid regional aircraft with varying hybridisation ratios (i.e. not a full hybrid or not fully electric).

eVTOLs may be foreseen on the following services:

- *Intra-city flights;*
- *To open up new city pairs in locations where no RWYs are available;*
- *To open up new city pairs which are currently not connected;*
- *Medical flights; or*
- *To provide the last link on a 'hub to home' concept etc.*

At entry into service, eVTOLs will likely fly along specific routes such as existing helicopter corridors and in the early years will probably substitute light helicopter operations in fields such as ecotourism, passenger transportation and medical transport etc. In future years, it is likely that eVTOLs could completely replace light helicopter operations but would not be suitable for replacing medium / heavy helicopter operations where the objective is mass transportation e.g. from mainland to oil platforms. In addition, the majority of eVTOLs are unsuitable for hovering due both to the short rotor blade and the large impact that hovering has on battery usage.

In a U-turn in thinking even from five years ago, Ascendance see it as unlikely that eVTOLs will be used for remotely piloted operations. Even though, eVTOL aircraft will be subject to the same level of certification / safety standards as any other aircraft, this is because they will be more difficult to certify, passengers are not comfortable with the idea of no pilot and pilots may not consider an eVTOL pilot role as a good career choice if operations are likely to cease within a few years. eVTOL operations are initially likely to be flown under VFR with a fast transition to IFR as the market demands. eVTOL operations will likely only be allowed to operate above populated areas with the same diversion and emergency procedures applied to aircraft together with a similar amount of reserve fuel. eVTOLs operations will evolve to 6-10 seater aircraft based on more hybrid and hydrogen-powered solutions as limitations due to battery technologies will still remain in the short to medium term.

The gradual move from initial eVTOL operations towards RAM will support 'decentralised aviation' in a 'hub to home' concept. Whereas the existing transport grid will continue between major cities e.g. plane and train, RAM will provide further connectivity options between smaller cities in the regions. By 2040, it is likely that eVTOL aircraft will be integrated into network connections – with partnerships between operators and codeshare callsigns – as the final leg of a journey from a hub to the home e.g. London – Brussels – Liege.

Challenges to eVTOL operations include those related to airports. Airports may need new parking positions and gates dedicated to eVTOLs, big upgrades in electric supplies together with charging stations, cooling systems (for battery cooling) and large parking areas if large increases in movement numbers are expected. If charging of eVTOL aircraft takes place on-stand, the capacity of the terminal will likely be reduced so airports will prefer for charging to take place off-stand, whilst blocking stands when charging could result in increased parking fees for operators. If the eVTOLs are considered in the 'hub to home' concept then they have to be integrated into the main terminal area as passengers will not wish to have lengthy connections outside of the airport (secure area) and then have to pass through security again. For hybrid operations, the options are better – it will be possible to land at the gate, refuel, top up the battery for 15 minutes and then take-off again.

Another challenge relates to the Rescue and Fire Fighting Services (RFFS), emergency response and contingency planning: Establishing effective emergency response plans and contingency procedures is essential for handling potential incidents or accidents involving eVTOLs especially in the development of safety and fire-fighting procedures for batteries and new fuel types. Developing protocols for emergency landings, medical evacuations, and managing unexpected situations in urban environments will be critical for ensuring the safety of passengers, crew, and the general public.

An additional challenge is public acceptance and trust and addressing any new potential concerns related to safety, privacy, noise pollution, and visual impact.

It is anticipated that eVTOL operations at airports will need large spaces for eVTOL parking overnight (near hangars and away from the gates) but as more and more vertiports come online, the modus operandi will change with parking taking place at vertiports outside of cities with the eVTOL aircraft flying from the vertiport base of operations to the larger airports early in the morning to operate the daily schedule.

Avionics will need to evolve to consider new parameters related to electric propulsion whilst for operations in an urban environment, solutions may be required for more precise GPS positioning or relative positioning between eVTOLs. To ensure interoperability between eVTOL new market entrants, airport and vertiport operators need to work with OEMs and SMOs to ensure that applicable solutions are found across the board e.g. to ensure that there are limited options for charging station plugs at airports.

6.2.2 Low-level operations use case

One of the themes that comes across when looking at ZE aircraft use cases is the expected increase in operations at secondary airports, both in terms of eVTOL and RAM operations. With the large majority of ZE aircraft operations for new market segments expected to take place below FL300, a use case for low-level operations at a secondary airport has been proposed.

Based on the current projections of WG1, eVTOLs are expected to enter into service by 2025 with large numbers expected to be in operation by the mid-2030s according to current market forecasts. Electric aircraft have already been certified with operations expected to become more commonplace in the second part of the decade, especially in low level GA operations at secondary airports. Hybrid-electric aircraft will enter into operation around 2030, with operations gradually evolving from short distance (~100-300km), <19 pax RAM to longer distance (~300-1500km), >19 pax RAT, as technological advances extend the duration of operations to longer city pairs.

As these aircraft enter into operation, new iterations of the ZEA CONOPS will address any uncertainties that arise in this edition, as the operational concepts evolve and any new challenges to their operation and integration are identified.

<u>Mönchengladbach Airport</u>

In the coming years, at secondary airfields, such as those with a large proportion of GA operations, we can expect the traffic mix to develop and typical operations to reflect some of the following sectors which all include expected ZE aircraft:

- *Commuter (AAM);*
- *Business Aviation;*
- *Flight Training;*
- *General Aviation;*
- *Healthcare aviation;*
- *Flights in relation to MRO (Maintenance, Repair and Overhaul);*
- *City to city operations by airtaxi;*
- *Suburban-to-city operations by airtaxi; and,*

- *Airport-shuttle operations by airtaxi (feeder flights from vertiports or airports into airports and vice versa).*

In this use case, there is a general aviation (secondary) airport with permanent ATC control zone (CTZ) and precision approach systems (ILS and/or RNAV). The main drivers for expanded operations are a lack of slot limitations for such airports combined with an ICAO standardised environment (CNS equipment and an ATC service) which facilitate an acceleration of the integration of electric, hybrid-electric and hydrogen-based aircraft into the network.

Within all of these sectors, operations are expected to connect to larger hubs (e.g. with business aviation), regional airports (e.g. for MRO flights), other GA airports (e.g. through commuter flights, AAM and flight training) and both urban and suburban vertiports for the airtaxi sector.

The following examples show how different ZEA operations can be expected to be integrated into the different sectors.

Business Aviation

Business Aviation is performed based upon legacy aircraft. We can expect legacy aircraft to be gradually replaced by ZE aircraft in Group 8 (hybrid-electric and hydrogen fuelled business / regional aircraft).

MRO flights

Flights operated by aircraft up to turboprop size or midsize jets may be subject to MRO or cabin / systems retrofit activities. With a maturing hydrogen market, legacy aircraft must be retrofitted which will be a business opportunity for secondary airports.

Commuter

Commuting flights between several secondary airports will become more frequent as safe access to suitably equipped secondary airports improves and slot restrictions constrain hubs. Electric or hybrid-electric commuter aircraft are viable to operate from secondary airports such as ZEA group 6 and group 7 operations.

Flight Training

Flight training operations with electric aircraft are likely to be a major source of ZEA operations at GA / secondary airports with ZE aircraft in group 4. Improvements in battery capacity and endurance may make this a viable option for Air Traffic Operations (ATO) with a maturing market.

Airtaxi operation

Airtaxi operations at secondary airports, including both eVTOL aircraft (performance group 1, group 2 and group 3) and fixed wing non-VTOL aircraft (performance group 4 and group 5), serve as an 'innovation incubator' for the ZE aviation ecosystem.

Forecasts for the introduction of eVTOL aircraft into the aviation system indicate a large increase in such aircraft out to 2050. With a lack of current vertiport infrastructure, GA airfields are likely to provide a suitable alternative with transport access and the provision of ATC services.

Operations with ZE eVTOL and ZE fixed-wing aircraft should consider interdependencies with other environmental impacts. For example, with energy management and noise abatement being paramount prerequisites for a successful integration of ZE aircraft operations, these aircraft may fly more direct flight paths than legacy aircraft operations and thus fly trajectories not currently flown by legacy aircraft resulting in 'new' noise for local communities, especially if there are additional rotations due to the small capacity of such aircraft. Potential solutions include:

- *An approach and departure via the given runway system, supported by ILS / RNAV procedures but with a shortened base leg and final approach segment. This could be used at airports with no capacity restrictions – such as Monchengladbach Airport – which support the idea of optimised "door-to-door" customer journeys and cut down travel times by short turnarounds and quick intermodal changeover times, enabling the integration of airside VTOL and fixed-wing operations; or,*

- *An approach and departure perpendicular to the runway system to allow for non-interference with legacy traffic and avoid potential capacity reductions. This could be used at airports where slot restrictions do not support VTOL operations. A dedicated "Vertiport" area with two designated VTOL final approach and take-off areas (FATO) and several stands, connected by respective taxiways should be assigned at a suitable location inside or outside of the airport boundaries.*

However, any such solution will be influenced by the layout of local population centres around the secondary airport.

Whilst hub airports are expected to have the greatest level of investment in infrastructure to support ZEA operations, secondary / regional / GA airfields are likely to be the initial innovators, facing the requirement to handle electric propulsion systems for innovative air mobility (including regional and urban air mobility) and hydrogen-based propulsion systems (fuel cell and direct combustion).

These airports may find themselves in a challenging transition phase, in which both conventional and new propulsion systems – and thus redundant and evolving infrastructure and turnaround processes – are needed. Potential infrastructure changes include:

- *The storage of electricity and hydrogen – for example, space will be required for storage of electricity and there are constraints especially for airports on small islands;*
- *The provision of electricity and hydrogen to the aircraft (including peak management for electricity);*
- *Emergency management and firefighting;*
- *New ground vehicles; and,*
- *The integration of AAM into the airport environment.*

6.2.3 Regional Air Transport use case

One of the market segments that is expected to be revived by the introduction of ZE aircraft operations is regional operations either through RAM or RAT. Some manufacturers consider that with the proven historic market for regional air transport, together with the existing infrastructure and a grid of underused airports, the actual demand is not currently being fully serviced. With the introduction of electric and hybrid-electric aircraft at low technology and regulatory risk, market entry at competitive terms can be achieved enabling environmentally sustainable operations with favourable economics for the customer together with low noise levels.

The RAM sector covers operations over around 100-300km distance with a capacity of up to 19 seats.

The RAT market segment - broadly defined as 19-100 passengers, targeting routes under 1,500 km, utilising Conventional Take-Off and Landing (CTOL) airports – is currently operated by regional and narrowbody airplanes. Both these market sectors are important because they represent an incubation test bed – from short distance, <19 pax RAM to longer distance, >19 pax RAT - before technological advances enable an extension to longer city pair operations.

Based on the current projections of WG1, hybrid-electric RAM / RAT aircraft will enter into service around 2030, with operations gradually evolving in terms of size and city pair distance. By 2040, WG1 estimates that although new deliveries of ZE RAM/RAT aircraft will be less than GA aircraft and eVTOLs, a large proportion of this market segment will be based on conversions of existing aircraft.

As these aircraft enter into operation, new iterations of the ZEA CONOPS will address any uncertainties that arise in this edition, as the operational concepts evolve and any new challenges to their operation and integration are identified.

<u>Heart Aerospace</u>

Heart believes that initial use cases for the RAT segment may include:

- ***Existing routes:*** *Direct replacement of the fleet operating the airline's existing network, given the need to meet the industry wide net zero-emissions by 2050 objective by 2050 as well as the expected unit cost advantages of operating new technology versus conventionally fuelled aircraft. (drivers: lower cost, lower noise, environmentally friendly).*
- ***New routes supporting regional hub feeder:*** *This allows airlines to connect more regional destinations to existing hubs and add complementary flights within their existing network to build off-peak frequency to increase convenience and induce higher demand (drivers: lower cost, lower noise, environmentally friendly, short runway operations, reduced distance to an airport for the customer).*
- ***New routes supporting Point-to-Point ("P2P") trips:*** *This allows for new P2P markets to be opened (or re-opened in cases such as France where conventional flights are banned when a train alternative under 2.5 hours exists) and built at low risk (trip cost). Regional air networks that were previously abandoned due to low profitability may be reactivated together with new city pairs (drivers: lower cost, lower noise, environmentally friendly, regulation, short runway operations, reduced distance to an airport for the customer).*

In order to align with the mission to make air transportation greener, more accessible and affordable, Heart has undertaken a PESTLE analysis to identify key drivers, current market key challenges and how to address them. The main considerations are detailed below:

Political: *The climate challenges will be solved through innovative measures. By introducing greener ways of flying, emissions can be reduced significantly and Heart aims to launch a battery electric-hybrid low emission airplane, the ES-30, by 2028.*

Economic: *Over the last few decades, the RAM/RAT segment has been severely impacted by airline deregulation and the more challenging unit costs of smaller aircraft. Facing intensified competition, airlines consolidated, and many regional routes were abandoned. The current reality of high air fares, low frequency, and lack of direct flights for regional travellers has shifted demand from easily accessible regional airports to large, centralised hubs servicing larger cities. New hybrid-electric RAT aircraft will have cheaper energy and maintenance costs. Significantly improved trip and unit economics will enable airlines to operate regional routes profitably and grow services.*

Social: *In 1989, regional airplanes made up 45% of the total aviation fleet, compared to just 8% today. Post-COVID, a growing population has embraced the flexibility of remote work, living outside of large cities, which is contradictory to commercial air services being concentrated in larger hubs. Whilst the prime factor historically causing the decline in regional air travel is economic, there is also social pressure supporting the substitution of air travel with other forms of transportation. Using greener STOL (Short Take-Off and Landing) RAT aircraft with quiet electric operations, use can be made of almost all regional airports, which increases accessibility, enabling customers to regain the historical convenience of regional air travel by reducing their door-to-door travel time and cost.*

Technical: *The continuous improvement in renewable energy and electric technologies is driving a systematic shift to electrify transportation. Leveraging research and development investments from adjacent industries (e.g. electric vehicle automotive and trucking) associated with exponential improvements in batteries, electric propulsion and fast charge infrastructure, the aviation industry is poised to join this transition. Compared to adjacent market segments in the aviation industry e.g. UAM, where players must focus on new infrastructure of vertiports and gain the social acceptance of operating in cities, as well as medium / long-haul travel players who focus on technologies with lower maturity, higher cost and limited availability (e.g. green hydrogen), some may consider that working with achievable technologies can provide the best value proposition to compete.*

Legal (regulatory): *The airline industry is one of the most regulated industries in the world, and products must meet stringent certification standards to demonstrate the highest standards of quality and safety. The RAM/RAT segment makes use of pioneering electric propulsion to cut emissions and costs to stimulate the regional market. However, beyond the propulsion system, the aircraft are conventional so the risks can be lowered as certification can be achieved by following the same processes as conventional players.*

Environmental: *The breakdown of global aviation emissions by route length shows that around one third of global aviation emissions are from routes under 1,500 km, and around 6% from routes under 500 km. High emissions from short routes are mainly driven by emission-heavy take-offs and landings of legacy aircraft at a higher relative share of the full route, compared to longer routes. In addition, air passengers are forced to travel unnecessarily long distances to reach hub airports at environmental and social (e.g. traffic) costs. RAM/RAT may be considered prime for delivering a positive climate* *impact, with potential to mitigate a significant share of global emissions and make regional air travel a greener form of transportation.*

6.2.4 Commercial Air Transport use case

Whereas the other use cases considered in this chapter relate to new market segments that are expected to evolve with the introduction and integration of innovative ZE aircraft into the network, this final use case focuses on the decarbonisation of existing commercial air transport operations based on the evolution of kerosine-powered legacy aircraft to new ZEA operations fuelled by hydrogen.

As these aircraft enter into operation, new iterations of the ZEA CONOPS will address any uncertainties that arise in this edition, as the operational concepts evolve and any new challenges to their operation and integration are identified.

Airbus

eVTOL and RAM operations will create new opportunities and will develop new business models. They will also generate specific challenges for ATM as they will be flying in different conditions to current commercial aviation. In most of the cases, they won't replace existing commercial aviation as they won't offer the same capacity and range.

In this use case, we focus on replacing existing commercial aircraft with hydrogen-powered aircraft. These aircraft should operate similarly to current aircraft compared to eVTOL/RAM and should be easier to integrate in the existing ecosystem.

Hydrogen commercial aircraft sit in two AZEA WG5 performance groups (group 7 – hydrogen-powered turboprop, and group 9 – hydrogen-powered single aisle aircraft):

- *Group 7 and 9 have the capacity to replace existing operations from regional (like DH8D - ~90 seaters) through to the single aisle aircraft families (like A32N - ~200 seaters); and,*

- *Several OEMs are already working on concepts from group 7 and so it is more likely that aircraft from group 7 will enter the market before the aircraft from group 9.*

It is difficult to forecast how the market might evolve when they enter the market as it will also depend on the airline business model of the first customers and on the development of the infrastructure (especially the availability of hydrogen at airports). However, we can envisage different scenarios of operations in the first years:

- *Trunk routes: Aircraft from group 9 are the most likely candidates for these types of markets. However, aircraft from group 7 could also be operated on this segment in the early years, especially if aircraft from group 9 are not available in and / or, if major airports are the first ones to be equipped with hydrogen;*

- *Commuter and hub feeders: Aircraft from group 7 and 9 will offer the possibility to replace hub feeding operations, depending on the size of the market;*

- *Point-to-Point and secondary markets: The point-to-point market has grown over the last two decades, boosted by the development of low-cost carrier airlines and* *by the need to interconnect more and more secondary cities. This trend should continue and could provide significant opportunities for the group 7 (90-100 seaters), because these regional aircraft should have the right size and the right range to interconnect secondary cities, especially when the distance or the infrastructure available make other ground transports less efficient / competitive (e.g. cars, buses, train etc.).*

  - *Opening new point to point markets might also help to reduce the traffic congestion at the major hubs (slots, gates, ATM etc.) and reduce the level of intra-Europe connecting traffic. Today, many passengers have to connect as there is not enough air connectivity provided between secondary cities and this resulting connecting traffic is not efficient in terms of passenger time, energy consumption and environmental impact.*

- *Develop new regional hubs to address domestic and regional markets: Secondary airports in general, have less constraints (slot, ground space etc.) and sometimes more possibilities to develop new operations. For some of them and with the support of airlines, they might have the opportunity to develop a new hub around ZE aviation. It would support their development, their attractivity and would help to connect more people offering a full ZE journey.*

The introduction of new aircraft and new technologies should have an impact on the market, however it is still difficult to know whether the market could partially restructure or fragment the existing traffic flows, and it will be difficult to simulate and assess the gain at network level until more information is available. Firstly, because it is uncertain how the network topology might evolve, and secondly, because existing simulation tools won't necessarily have the full capabilities to simulate a disruptive network.

However, there are some simulations and some simpler analyses that can still be performed. Such simulations should demonstrate the initial impact of the introduction of these new aircraft into the traffic flow.

7 Challenges to the integration of ZE aircraft into the network

Key message: *There is a wide range of potential differences in ZE aircraft performance characteristics – such as cruising speed, cruising level, rate of climb, and final approach speed - therefore their impact upon the operation of each other and legacy aircraft operations needs to be fully understood to optimise the network integration.*

In the air, ZE aircraft operating above FL300 are assumed to have a similar performance envelope to legacy aircraft whilst the majority of new market segments are expected to operate at intermediate and low FLs where more interactions will take place with aircraft transiting to / from upper airspace.

Challenges identified include those related to departure/arrival procedures, conflict detection, ATC workload and other tactical solutions.

On the ground, challenges will have to be addressed including those related to RFFS procedures, aircraft weight, fuel storage, engine start procedures, on-stand procedures and refuelling / battery charging.

Whilst existing large-scale commercial aircraft manufacturers are targeting full interoperability with legacy aircraft operations at entry into service of their new aircraft, ZE aircraft pertaining to new market segments may provide new challenges in terms of flight-performance envelopes. Chapter 5 – the performance groups proposed by AZEA WG5 - and responses to the aircraft performance questionnaire (Appendix D) show that, compared to legacy aircraft, there is a wide range of potential differences in ZE aircraft performance characteristics – such as cruising speed, cruising level, rate of climb, and final approach speed. In this case, ATC will be responsible for providing a control service for both the ZE aircraft and the legacy aircraft type, therefore their impact upon the operation of each other needs to be fully understood to ensure network integration.

Where any differences in flight performance between ZE and legacy aircraft are related to climb performance, cruise altitude and speed, this may lead to flight trajectories that are different to what is commonly expected today. In addition, the different stage lengths served by ZE aircraft operating different market segments may lead to many different vertical profiles of flights in an individual airspace: shorter flights of between 100km and 300km have short cruise segments at lower altitudes. Trajectories with shorter mission lengths contain a higher number of vertical steps in order to be efficient, but can also result in more potential interactions with other aircraft. This may lead to shorter range ZE not having classic profiles with large cruise segments, therefore there could be a significant increase in the amount of climb and descent profiles present wholly below FL300 because of shorter mission lengths.

It should be noted that a negative impact on performance at a single location (e.g. airport, route waypoint, sector etc.) can have a further negative effect at the network level. Increased ATC workload or busier sectors may result in lower capacities, airspace constraints or flow restrictions, resulting in delays and an increase in flight inefficiency network-wide. Whilst some aircraft may in such cases be held on the ground, there may still be a knock-on effect in performance of the network in terms of emissions if aircraft are held en-route or within terminal areas, given route extensions or longer sequencing legs, or cleared to non-optimal flight levels in order to deal with any capacity constraints.

This chapter provides some examples of the potential impacts that may need to be addressed when considering the integration of ZE aircraft into the network. It is based on current operations and as the traffic evolves, the challenges may also evolve and will need to be assessed in future CONOPS iterations as new ZE aircraft models enter into service. The chapter is broken down by phase of flight.

The chapter includes comparisons with performance data of current aircraft in service[24] which may be considered to have a comparable performance to the AZEA WG5 performance groups. See Appendix E for more information.

7.1 Air

7.1.1 Departure phase

In the departure phase, three aspects of ZEA operations may introduce differences to current operations: The expected climb rates, the airspeed on the departure route, and the expected shorter routes compared to the length of the typical current Standard Instrument Departure (SID).

The rate of climb of conventional aircraft at FL100 may range from around 1100 fpm for AT72 or PA34, around 1700fpm for a DH8D, 2100fpm for a B350, 2500fpm for a C750 and 3000fpm for a A20N[25].

The responses to the questionnaire to AZEA OEMs revealed that the rate of climb expected to be performed by ZE aircraft ranges from very low (<250fpm) to very high (2000+fpm). It should be noted that in controlled airspace, the Aeronautical Information Publication (AIP) of some States (e.g. the UK) state that if at any time, a pilot is unable to climb or descend more than 500 feet per minute, the pilot is required to report this to ATC.

The slower climb rates may lead to ZE aircraft unable to reach the required exit levels at the interface with en-route airspace. In addition, many minimum climb gradients for obstacle clearances may not be achievable by ZE aircraft with lower climb rates. This

[24] Based on BADA 3.15 data

[25] BADA 3.15: A20N – A320 NEO, DH8D - Dash 8-400 series, AT72 – ATR 72, B350 – Beech Super King Air, PA34 – Piper Seneca, C750 – Cessna Citation

may result in the need for alternative (longer) non-linear routes to achieve height in space available around the departure point.

At larger airports, where RAT / CAT ZEA operations might be expected to take place, SIDs are fixed departure routes to separate departing flows into different directions. In a certain traffic situation, ATCOs may give the aircraft an instruction to shorten the SID and route direct to another waypoint. In a mixed traffic environment with slower ZE aircraft, departures could generate an immediate separation problem in the climb because of a faster conventional commercial aircraft catching up or potentially overtaking the ZE aircraft. Controller tools such as DMAN (Departure Manager), or ATFCM (Air Traffic Flow and Capacity Measures) measures – for example the application of Minimum Departure Intervals (MDI) - can take such differences into account. Tactical solutions may include speed control or vectoring the slower aircraft (potentially adding track miles) so the faster aircraft can stay on the SID and would not be slowed or held down by the slower aircraft. However, this may reduce throughput and increase workload. If there is insufficient airspace to separate the traffic then a step-climb for either the slower (preferable), or the faster aircraft would be the likely solution with subsequent impact on profile efficiency, sector exit levels, and ATCO workload. Specific SIDs, dedicated to slower flying aircraft such as ZE aircraft might help to use the airspace efficiently. Such SIDs, for turboprop aircraft, already exist at some airports to reduce the impact of their difference in performance.

For slower aircraft, at the end of the SID there could also be problems in ensuring that sequencing and separation at the interface with the en-route airspace is safe and expeditious. ZE aircraft operating from secondary or tertiary airports that are in close proximity to major airports will need to be integrated into the larger terminal airspace and so create problems between the ZE aircraft and conventional aircraft as they join the same departure routes. Examples would be the terminal airspace organisation surrounding London or Paris where aircraft from different airfields have to be safely integrated into the streams transiting to en-route airspace.

Finally, SIDs may pose a significant addition to the direct distance between city pairs, especially if they are closely located. This could potentially have an impact on the number of city pairs available to electric aircraft as even though the direct distance is short, the corresponding departure and arrival routes may be much longer and exceed the maximum range of the aircraft. One solution could be to design new departure routes - for selected city pairs – that reduce the direct distance to travel between the city pair, but this could also impact runway throughput and therefore airport capacity.

7.1.2 Cruise phase

The cruising level of conventional aircraft range from around FL210 for the PA34, FL230 for the AT72, FL250 for the DH8D, FL310 for the B350, FL370 for the A20N and FL450 for the C750.

The responses to the questionnaire to AZEA OEMs revealed that the expected cruising levels of ZE aircraft was below FL100 for five of the proposed performance groups. However, whereas ZE aircraft performance groups 8-9 are expected to operate at conventional FLs, groups 6 and 7 are those where many new aircraft are expected to operate in the intermediate level bands (FL100-300) associated with regional aircraft.

The cruising speed of conventional aircraft range from around 130kts for the PA34, 200kts for the B350, 230kts for the AT72, 300kts for the DH8D, 450kts for the A20N and 460kts for the C750.
The responses to the questionnaire to AZEA OEMs revealed that only one performance group expected a cruising speed below 100kts and two performance groups are expected to operate at conventional speeds associated with current commercial operations of legacy aircraft. Aircraft in the other six proposed performance groups are expected to operate at slower speeds of between 100-300kts.

Depending upon the number of ZE aircraft in the sector / airspace, it may be expected that there will be more planning and tactical conflicts experienced by ATC at intermediate cruising FLs which may be exacerbated by slower cruising speeds. En-route lower sectors normally deal with evolving traffic joining from a SID and transiting to higher sectors, or transiting from higher sectors and joining a STAR. If a sector originally designed for climbing / descending transitions between upper and lower airspace will have a higher number of low and slow cruising flights, it may require a rethink in terms of airspace design and sectorisation.

If operating at intermediate altitudes (FL100 – FL250), aircraft routes are likely to be more subject to local convective weather systems than at typical current cruise levels above FL300. Operations at these intermediate altitudes will need to be robust for avoiding such weather systems.

Whilst SESAR solutions[26] aimed at strategic deconfliction of aircraft during the planning phase may pre-empt some conflict situations, for those ZE aircraft that may enter into service in the near future, the assumption should be that they will operate in an unchanged ATM system with similar tactical solutions as of today.

In that case, for conflicts between slower ZE aircraft and faster conventional aircraft, one tactical solution could be to put the ZE aircraft on to a parallel or off-set track until it reaches its exit point. As the aircraft approaches the exit point the ATCO would either have to coordinate a continuation of the offset with the next sector/ACC or merge the flows back together and ensure the normal adequate separation and sequencing would be applied at handover.

One further consideration could be sequencing aircraft and separating traffic between ACCs or sectors – a transiting ZE aircraft may be clear of confliction at the sector exit point but if there is a faster aircraft following the same route at the same FL this may be a problem to the next ATCO further down the line. Whilst the next sector ATCO will know and understand that a slower ZE aircraft will be shortly entering his sector, he/she may not yet have data on the following aircraft. Controller tools such as XMAN (Extended Arrival Manager) and MTCD (Medium Term Conflict Detection), ATFCM measures such as TTO (Target Time Over) or tactical interventions such as speed control or the provision of miles in trail can solve these potential issues. However, in any case where additional monitoring, conflict detection or coordination is required by either the planning or tactical ATCO, all these examples will result in increased ATCO workload.

If ZE aircraft are operating between new city pairs or in higher numbers than in previous operations, there may need to be new agreements defined between ATC

[26] Such as those considered under PJ.18-W2-53B

sectors or centres to agree on new transfer of control conditions or Letters of Agreement (LoA).

7.1.3 Arrival phase

The final approach speeds of conventional aircraft range from around 80kts (TAS) for the PA34, 110kts for the AT72 and B350, 120kts for the DH8D and 140kts for the A20N and C750.

The responses to the questionnaire to AZEA OEMs revealed that for three of the non-VTOL performance groups, the final approach speed was under 100kts with two groups with a final approach speed between 100-120kts and one group of 120+kts. These are the ZE aircraft that are expected to enter service in the next decade or so. Therefore, appropriate solutions will need to be found to address any challenges that arise from different speed regimes.

Depending upon the number of ZE aircraft in the arrival stream and the fleet mix operating at the concerned airport, it may be expected that separation between slower ZE aircraft and faster conventional aircraft may have to be increased in order to maintain a safe separation or a strict speed control regime imposed, if no specific independent arrival routes for the new aircraft are designed. This could reduce runway throughput, increase ATCO workload, reduce airport capacity and increase arrival delay and lead to flow management measures being applied.

Should en-route speed control be applied to a concerned arrival stream, there may be challenges to integrate aircraft with different speed regimes into the same flow. Speed control would become more critical depending on the performance capabilities of both the slower ZE aircraft and the conventional aircraft. The ZE aircraft might be required to keep a maximum speed while the conventional aircraft could be required to keep a minimum speed. There could therefore be negative impacts upon other aircraft which could increase delay, reduce flight efficiency and lead to more en-route or terminal holding.

With a move towards a safe decrease in separation standards for arriving aircraft (and also for departing aircraft) through optimised wake vortex categorisation, new concepts such as individual pairwise separations may provide an opportunity to integrate slower ZE aircraft into arrival streams by ensuring minimum separation requirements based on their individual aircraft performances thereby enhancing an otherwise deteriorated runway throughput.

Depending upon the noise profile of the ZE aircraft, there could be opportunities to reduce aircraft noise at and around airports. Whilst airframe noise is not expected to change unless the new ZE aircraft employ a radical new design, it may be reasonable to assume that electric aircraft and potentially hybrid-electric and hydrogen-powered aircraft could result in lower engine noise. This could open up the possibility to design alternative more direct arrival routes over areas that were previously avoided in order to minimise noise impacts.

With the smaller non-VTOL performance groups expected to operate at secondary or tertiary airports, there could still be a requirement to introduce new arrival procedures should the vertical trajectory be radically different to existing conventional aircraft profiles.

7.1.4 VTOL take-off and landing

Electric and hybrid-electric VTOL aircraft are likely to operate initially from traditional aerodromes, evolving to also include new city locations and vertiports. The increase in vertical operations at conventional airports and – for some types – the transitioning to horizontal flight may require additional procedures in the vicinity of aerodromes to allow the changing mix of operations.

7.2 Ground

In assessing the challenges to the integration of ZEA into airport operations, various factors come into play during ground operations and throughout the Landing-Take-off (LTO) cycle. This section details some of the challenges that may have to be overcome.

Aircraft weight: One of the main challenges for ground operations at aerodromes is related to battery technology. Based on current technology, batteries are heavy and degrade over time, impacting the aircraft range characteristics and necessitating periodic replacement. In the automotive market, batteries for electric vehicles have made significant improvements in recent years, and this positive trend is expected to continue. This suggests that aerospace batteries will also improve over time, leading to more efficient electric and hybrid electric aircraft, together with the possibility to extend operating range.

One way of addressing battery limitations is to adopt a hybrid configuration. Hybrid solutions provide the flexibility to fly longer sectors, as pure battery solutions are range limited due to the weight of the batteries; enable a mitigation to degraded battery issues, allowing airlines to fly the planned routes even if batteries are degraded or if their efficiency does not evolve as expected and allows a larger margin on reserves and redundancy.

Airport pavements are usually tailored to the fleets they serve, with changes in aircraft weight or landing gear characteristics necessitating extensive airfield reconfiguration. Modifications in aircraft characteristics echo alterations in fleet composition, influencing pavement composition and thereby, airfield infrastructure. Hydrogen tanks may be quite heavy with the aircraft empty weight (landing weight) potentially exceeding the weight of the same aircraft using conventional fuel by 25%[27]. However, this may be compensated for as hydrogen is lighter than conventional kerosine so the Maximum Take-Off Weight (MTOW) may actually decrease. In addition, landing weights will be higher for electric or hybrid-electric aircraft due to the weight of the

[27] Studies have estimated that hydrogen-powered regional aircraft could be between 10-35% heavier at Operating Empty weight (OEW), with narrow body aircraft around 5-10%, depending upon the design assumptions etc. For MTOW, a similar trend for regional aircraft is predicted to be the same or slightly heavier/ lighter. For narrow body aircraft, they are likely to have a lower MTOW with mid-sized and wide-bodies a much lower MTOW (potentially around 30% lighter) because as hydrogen tanks gets larger, the lower fuel weight of hydrogen starts compensating for the heavier tank. The difference is accentuated the bigger the tank is. For example, an aircraft carrying 100 tonnes of fuel for a long-haul flight would have an equivalent hydrogen fuel mass of 33 tonnes for the same mission.

battery. Furthermore, the weight distribution of ZE aircraft and impact on the pavement may change so the effect on the new Aircraft Classification Rating – Pavement Classification Rating (ACR-PCR) system - to come into force in 2024 - will have to be assessed. For electric aircraft, their weights have been demonstrated to be significantly more than their conventionally powered counterparts. For example, the 9-seater Eviation Alice weight is 7,484kg compared to the conventionally powered counterpart the BN2B Islander at 2,990kg. This will inevitably have knock-on impacts on apron construction, and taxiway construction. For apron construction, this may adversely impact the slope gradient that can be permitted which may constrain capacity at an airport. Runway weight tolerances at smaller airports may need to be reconsidered too if the flight schedule shifts to entirely electric, because practically, the weight will be doubled and thus runway rehabilitation intervals may need to be re-examined.

Safety management: Electric aircraft may require additional safety measures during charging, posing challenges in congested areas like aircraft stands. For electric aircraft, potential issues that should be taken into consideration include issues with the electrical system or with an electric engine, or from a thermal runaway (an internal chemical self-heating chain reaction of a Li-ion battery). Aircraft long stay parking positions will likely need extra considerations. For example, there may be an initial need to park electric aircraft away from contact stands during overnight parking to avoid the safety risks of thermal runaway and subsequent fire hazards close to the terminal building, or the charging mechanism may have to stop and be disconnected overnight. Overnight charging will also require an assessment of the possibility to charge without human oversight, which may have implications for RFFS service provision.

Specific Training: All personnel involved in ground operations and parking manoeuvres may require specialised training. Such specialised training may concern both electric and hydrogen-powered aircraft and may need to be specific to each aircraft type, as well as the differential procedures compared to conventional aircraft.

RFFS Services: RFFS services must be equipped to respond effectively to any ZEA incidents linked to electric aircraft, mirroring the current standards for kerosene aircraft. Because of the high energy density of batteries and their distinguished characteristics in case of fire, RFFS services will need to be able to deal with exposure of fire fighters to electrical hazards, together with protection of passengers in terms of exposure to heat or heavy metal vapours during any in-flight fire or landing / departing incident. This may also have impacts on where RFFS stations are located due to the need to have a timely response to any emergencies linked to electric aircraft.

For hybrid concepts, RFFS teams must be aware that the aircraft has two different energy carriers with very distinctive hazards and fire properties: in an emergency situation, an initial identification and confirmation of the type of fuel and propulsion system of the aircraft will be required, to be followed by a quick assessment of the nature of the situation (e.g. thermal runaway, gaseous leak, fire, collision with damage etc.). This could have knock-on impacts as to which stands at an airport are viable for certain aircraft energy types, be they electric, hydrogen fuel cell or liquid hydrogen-powered aircraft.

In the case of Li-ion battery fire, current thinking is that foam and water are the best options for extinguishing a fire. However, to put out a 3MW electric aircraft fire could tie up aerodrome RFFS resources and equipment resulting in the inability to continue operations at the aerodrome. RFFS managers will need to review their Task and Resource Analysis (TRA) and Water Needs Analysis (WNA) in light of the potential increased risks posed by the increased use of Li-On batteries as power sources.

Whilst gaseous hydrogen may already be produced at airports such as Kansai, Toulouse e.g. to power airport buses, liquid hydrogen is expected to first be used as a commercial aviation fuel towards the end of the 2020s and will require safety analysis to identify potential risks of a secure transport.

For aircraft using hydrogen (fuel cell or jet engine), hydrogen leaks (gaseous or liquid) together with fire or explosion hazards will determine emergency procedures. In all cases, risks and emergency operations may be potentially different (e.g. hydrogen burns with an almost invisible flame, radiates less heat[28] etc.) from those for aircraft using kerosene, where the risk is a wide ground spread of kerosene, flammable, with high temperatures and a high radiation dose emitted. This needs further study.

Similar to the requirements for electric aircraft, initially there may be a need to re-evaluate the potential fire or explosion hazards for contact stands. During operations, such hazards could be related to refuelling procedures for example whether hydrogen fuel cell or liquid hydrogen-powered aircraft can be parked beside large glass structures (terminal facades) or whether there needs to be explosion precautions to be taken before ground servicing (baggage offload etc.) can be commenced.

In addition, there may need to be considerations for bowser fuelling versus hydrant fuelling. Hydrant placement under the apron and associated airport infrastructure will require analysis into the feasibility, and associated safety risks. Hydrogen bowser trucks may be restricted in their driving routes, such as driving through sub-surface tunnels. This will cause some knock-on impacts during fuelling operations and require longer travel time between depot and the aircraft that is to be serviced.

Specialised Human Resources: For hydrogen-powered aircraft, a specialised workforce will be required. Key positions, such as safety monitoring, maintenance of hydrogen systems, and refuelling services will be required, supported by a plan to develop and train staff. In addition, there may need to be specific and dedicated ground staff to manage dual fuelling of dual fuel aircraft (i.e. staff for hydrogen, electric & SAF). Logistic and staffing issues could be exacerbated if stands are not multi-fuel compatible.

Information sharing: Appropriate information sharing should take place through the AIP: Airports will need to publish the availability of each fuel type on-site together with fuel capacities in the planning and tactical phases, through appropriate updates to the AIP. With the introduction of mixed fuel types it would also be prudent to publish information on where the closest diversion airfields are located with similar fuel availabilities. Charging facilities and local charging procedures will also need to be published in the AIP for flight planning purposes. Here it would be advisable to have a standard format that can be understood and applied across all EU states.

[28] A hydrogen fire would release about 10% of its heat as thermal radiation compared to 30-40% for an equivalent fire of Jet A-1 (ACI)

Stand infrastructure: Electric aircraft will require rapid charging electric connections at aircraft stands. In addition, if the operational concept relates to changing batteries during aircraft turnarounds, this will pose additional challenges compared to regular charging. The use of both electric and hybrid-electric / hydrogen powered ZE aircraft will require major changes to airport infrastructure. Unlike ASTM D1655 certified blended SAF (biofuels or e-fuels, which are hydrocarbons similar to fossil-kerosene), hydrogen cannot be combined with existing aviation fuel, so it will require completely separate transportation and storage infrastructure facilities. This may have substantial implications on fuel supply storage and distribution systems at the airport. There is currently quite some way to go to have a demonstrator concept for such a hydrant distribution system. Due to the volume of hydrogen required, hydrant systems can be viewed more as a long-term objective to define.

Hybrid-electric and hydrogen-powered aircraft may have different servicing and maintenance requirements to those of current aircraft, some of which are as yet unknown.

Hydrogen storage: Liquid hydrogen has a number of requirements to be taken into consideration for aircraft operations (e.g. it must be stored at -253°C). Therefore, unless risk can be mitigated by design, new safety procedures will be required (e.g. to mitigate the risks of frostbite amongst ground crew, to remove the possibility of asphyxiation in enclosed spaces in case of a liquid hydrogen spill and also to mitigate the risk of fire due to the flammability of hydrogen). An example of this risk would be in an MRO hangar where hydrogen that is vented in a closed space would need to be exhausted in some way. This would likely require guidance to enable hydrogen MRO facilities at airports.

Storage facilities will be required for liquid hydrogen whilst the liquid hydrogen also needs to be supplied to aircraft, either through bowser trucks or a hydrant system, in either case using cryogenic temperatures. The use of cryogenic temperatures, coupled with the use of large storage tanks such as Horton sphere's, present a spatial planning and safety analysis requirement which will need further research. At present, large hydrogen tanks are stored in industrial areas away from sensitive infrastructure. However, there will need to be extensive analyses into the safety precautions that need to be accounted for to permit liquid hydrogen storage at an airport. This will prove difficult in brownfield airports, where moving infrastructure to accommodate new energy storage will increase costs of any business case. A further consideration related to hydrogen storage is the storage tank location e.g. whether they are located on another part of the airport away from the stands in use. In this case, bowsers could have higher travel times to and from service points. To mitigate this, tunnels could be used, however, due to safety requirements some airports do not allow fuel bowsers to travel through airside tunnels.

Some concepts such as the Universal H_2 concept – where H_2 modules are transported directly from green H_2 production sites and inserted directly into the aircraft - may generate additional infrastructure, procedures, security and certification requirements different from those generated by other aircraft concepts.

Other considerations: These include understanding how the sequencing of fuelling / charging activities will vary based on the operating model the aircraft is being used for and ground time available. In addition, the requirements for any special needs expected for first flight out, aircraft conditioning (priming or chilling) will have to be assessed.

For aircraft concepts with exchangeable pods or batteries, the refuelling procedure may be replaced by a tank-swap procedure, requiring training, new procedures and even new ground support equipment whilst related energy supply, storage and distribution infrastructure will be required. For liquid hydrogen fuels, thicker and heavier hoses will be required for refuelling.

As knowledge matures and requirements developed, this section will be expanded upon in future CONOPS iterations.

7.2.1 Stand

Airfields are usually designed to accommodate specific aircraft models which shape the dimensions of aircraft parking positions and determine overall apron capacity. Operational considerations should be given to emphasise the importance of narrowbody hydrogen-powered aircraft being able to fit within current ICAO Code C aircraft dimensions. While ZE aircraft designs may plan to align with existing aircraft dimensions, some aircraft families might experience changes in the length or width of the fuselage, especially for clean sheet hydrogen-powered aircraft, potentially resulting in updated airport design requirements. This will be a particular hurdle for brownfield airports that need to reactively adapt to new airport design requirements. Hydrogen-powered aircraft are likely to have liquid hydrogen stored in fuselage tanks, which may make them longer than comparable conventional aircraft. This can in part be compensated by wider fuselages. If the aircraft are not compatible with Code C stands, then they (with some feasibility assessment) could be located in stands designated for Code D / Code E in the interim. However, in many airports, this would limit the number of usable stands.

In addition, the size and position of future liquid hydrogen refuelling vehicles is not yet known. If these vehicles are large or need to be located at a certain distance from the aircraft / stand or have to be positioned near the aircraft's rear fuselage, they may be difficult to operate on short parking stands without sufficient space available.

Safety regulations may demand specific infrastructure and / or a specific allocation of stand positions for hydrogen-powered ZE aircraft whilst the use of hydrogen may impose constraints on airfield design, potentially affecting safety distances from hydrogen injection points. Some processes are time-dependent e.g. refuelled hydrogen-powered aircraft may have a limited dormancy period of the tanks, after which hydrogen could warm-up and start boiling off, requiring venting to avoid tank overpressure. This could limit the time between refuelling and the start of the operation. In the case of start-up delays, or indefinite delay for technical reasons, mitigation procedures must be available, for example de-fuelling, venting hydrogen to a gaseous hydrogen collection point / truck / pipeline, or the possibility of external cooling of the tanks, and deplaning of passengers in appropriate timeframes.

When refuelling on stand, an appropriate safety case will be required to both understand to what extent it can take place with passengers on board, and to define what parallel activities are allowed, if any. For example, during hydrogen refuelling operations some gaseous hydrogen is generated and needs to be extracted (vented) from the aircraft's tanks. Technologies will have to be developed that enable high transfer rates of liquid hydrogen, managing any vented gas with appropriate collection and storage processes, and at the same time enabling maximum safety for passengers and ground staff.

Whilst current information on the challenges of ground operations is limited, considerations will become more detailed in future CONOPS iterations as the knowledge and experience matures. These considerations could include the need to investigate what ground servicing can take place during charging / fuelling, whether disembarking can be undertaken remotely, how large a safety zone will be required based on aircraft configuration and risk assessment etc.

7.2.2 Engine start

The responses to the questionnaire to AZEA OEMs revealed that whilst the majority of new ZE aircraft expect to perform engine start whilst at the gate, four partners expected their conceptual aircraft to expect start during taxi and three partners expected start on the runway (either on the runway itself or at the runway holding point). Under the assumption that engine start takes place either under the own power of the electric aircraft or under the power of an electric taxi solution such as a taxibot, several considerations should be noted.

Conditioning of the aircraft for engine start (electric aircraft in particular) will use ground power to reduce draw on the battery therefore aircraft that might previously have relied on APU will need to disconnect ground power before pushback. The robustness of new infrastructure will have to be assessed to see whether there are additional risks during pushback of damaging charging infrastructure on the aircraft (e.g. charging connection points) or fuelling infrastructure on the ground (e.g. hoses and hydrants, etc.).

Electric motors will not need the same amount of time to start as for non-electric aircraft, just a change between ON or OFF status. Also, it will not be necessary to have the propulsion system working in order to power the other systems like in conventional aircraft. Therefore, the perceived time from power available to propulsion and ready for departure could be very small, enabling a faster start-up procedure.

Should engine start be preferred off-stand e.g. during taxi, it should be noted that engine warm-up / cool down time, especially those belonging to new generation aircraft engines require longer start-up and warm-up times to previous generation engines. If this is the same for new ZE aircraft then the layout of the airfield will have an important impact. If there are limited holding points or taxiways, engine start up may result in a taxi queue if the departure flow is not well organised. In addition, it may be necessary to define specific start-up areas on/near the main taxiways that need to be depicted on Ground Movement Charts (GMC). This could take the form of something similar to a de-ice pad but for engine start. Therefore, any engine startup locations should preferably be located where the aircraft can be taken out of the departure sequence if required, so as not to occupy the taxiway if something goes wrong with the engine start procedure.

Start up on the runway is not advised due to the time needed to perform engine checks, unless the departure flow at an airport or the airport layout, are such that the procedure will not have an impact upon other departing or arriving aircraft in terms of delay or flight inefficiency.

At such airports where hybrid start up locations are in place, the aviation industry will need to learn how legacy taxi traffic and operations of ZE aircraft can safely and efficiently co-exist. What matters will be the net safety / capacity impact (either positive, negative or neutral) set against the environmental benefits it can bring. A simulation study and trials could be beneficial in order to assist with assessment, balancing pros and cons.

7.2.3 Taxi and departure

Whilst it may be assumed that hybrid-electric and hydrogen powered aircraft will have similar operating characteristics to their conventional counterparts, it will have to be assessed whether take-off performance and departure procedures will be impacted by any potential differences in the performance characteristics of ZE aircraft.

The use of sustainable taxi solutions to delay engine start up may have limited capability to taxi a heavier aircraft.

Sustainable taxi solutions are considered under the EUROCONTROL Sustainable Taxi Task Force.

7.2.4 Turn-around time

The responses to the questionnaire to AZEA OEMs revealed that there is no clear pattern in the turn-around time expected for ZE aircraft. Turn-around time ranged from 0-10 minutes to 30+ minutes, however it should be noted that in no example was turn-around time expected to be higher than for current commercial aircraft operations.

Turn-around time is commercially crucial to airlines, since it affects the utilisation of highly expensive aircraft assets, the maintenance and repair of aircraft and crew rostering. Whilst different propulsion methods will require different procedures during turn-around (e.g. battery charging, battery change, exchange of hydrogen fuel pods, additional fuel tanks, refuelling of gaseous or liquid hydrogen etc.), resulting in different ground infrastructure requirements, it appears that turn-around time may not be a significant impediment to the integration of ZE aircraft, with OEMs aiming for compatibility in turnaround operations and equipment, especially for CAT operations.

For electric and hybrid-electric aircraft, there may be implications on turnaround time related to battery charging with two aircraft charging models / modes may that can be considered: quick and slow (overnight) charging. If slower charging modes are used during the day - either due to limitations of charging infrastructure and/or a decision for procedures that lengthen battery lifetime - longer turnaround times may be expected.

The refuelling operation of CAT hydrogen-powered aircraft may be similar to current refuelling operations, i.e. with a refuelling truck positioned near the aircraft at the parking stand, and a duration of the operation similar to current references for conventional aircraft. However, if hydrogen refuelling has to take place at an airport location away from the passenger / cargo loading / unloading area either for safety reasons or due to other practicalities then this could lead to significant time penalties. In addition, if the hoses used to fuel hydrogen will have a larger diameter and/or be heavily insulated, this might impede an operator from handling them by hand, so semi-robotic or semi-assisted equipment might be required. If turn-around times do change, the potential impacts upon block time and slot coordination may have to be considered.

It is also currently expected that refuelling operations for different propulsion methods will have to remain separated, at least initially, particularly until further analysis of potential safety impacts have been assessed: if there is no dedicated apron area for hydrogen-powered aircraft, this may significantly affect those operations based on short turn-around times, such as those by Low Cost Carriers (LCCs) where turn-around time is minimised as refuelling is often undertaken while passengers are embarked or disembarked. Such limitations could have impact on airport capacity planning and the carrier's business model.

7.3 Other

7.3.1 Climate change adaptation

Climate change adaptation in aviation terms is the act of adapting the aviation infrastructure and operations to the impacts of climate change. Examples of such impacts include a change in storm intensity, sea level rise, a change in wind patterns, a change in flight axes due to a change in tourism patterns, or the experience of longer / more intense periods of hotter weather. Whilst this may appear something for the future, Europe has itself experienced higher than average hot temperature spells over the last 20 years or so[29]. For ZE aircraft, one potential risk could be to consider the impact that heatwaves could have on requirements for battery cooling / battery storage etc. for electric and hybrid electric aircraft. In addition, cooling in warmer operating conditions might also be an issue for low-temperature operation of fuel cells. Another risk - specifically impacting hydrogen turbine-based engines - that is also applicable to legacy turbine engine aircraft operations, is the reduction of thrust at higher ambient temperatures. Temperature increases may require aircraft performance adaptation leading to longer take-off distances whilst the TORA (take-off run available) or TODA (take-off distance available) may remain unchanged. The European Climate Change Adaptation Working Group (EACCA) was established in 2022 to share expertise and best practices on how to avoid or reduce operational, infrastructure, business and safety risks for the European air traffic management caused by climate change impact. Publications include guidance on actions to prepare for adverse weather in summer[30] and in winter[31].

The European Network on Impact of Climate Change on Aviation (EN-ICCA) has also been launched by EASA to better understand the effects of climate change on aviation, so as to equip the industry and aviation authorities to cope better with these changes and thus ensure aviation maintains its high level of safety.

[29] The ten warmest years for Europe have all occurred since 2000, with the seven warmest years being 2014-2020 (EU Copernicus)

[30] https://www.eurocontrol.int/news/eurocontrol-and-aci-europe-release-guidance-actions-prepare-adverse-weather-summer

[31] https://www.eurocontrol.int/news/joint-guidance-prepare-adverse-weather-winter-eurocontrol-and-aci-europe-release-new-report

8 AIR TRAFFIC MANAGEMENT

Key message: *The focus of ATC service provision for ZEA operations is likely to initially focus on the entry into service of eVTOL and electric / hybrid-electric LLO operations when flown as IFR.*

Some ZEA operations, e.g. eVTOL, are expected initially to start under VFR rules in class G airspace. With VFR being unsuitable for most commercial operations, one solution could be to take a harmonised approach and implement procedure-based IFR operations in class G. It should be noted that IFR routings may not always be optimal for energy-constrained aircraft.

Some of the developments foreseen in airspace design, ASM and ATFM as defined in ERNIP Part 2 and the High-Level Network CONOPS 2029 will equally apply to ZE and non-ZE aircraft. Additional requirements to accommodate ZEA aircraft operations should be considered in future editions of the Network CONOPS and other documents.

This chapter summarises all the elements of network operations that are expected to provide challenges or opportunities to the operation of ZE aircraft in the European ATM system.

Based on the base scenario of the European Aviation Outlook (EAO)[32], the European ATM network needs to accommodate an average of around 44,000 flights per day in 2050, which is an approximate increase of 44% compared with 2019 traffic demand. In order to cope with this traffic demand, the performance of the European ATM Network needs to be substantially improved to ensure equitable access to all airspace users whilst maintaining the same level of safety with the increased amount of traffic and address resilience and upwards / downwards scalability and societal need.

It is expected that overall network performance will continue to be closely monitored and managed, including monitoring of the performance targets for the main actors in aviation.

The future network concept of operations relies on a paradigm shift from airspace-based operations to (business / mission) trajectory-based operations (TBO) in which all flights' trajectories interact from the strategic into the tactical phases.

ZE aircraft operations will be one of many new market segments expected to be fully integrated into the European Network in the coming years.

[32] https://www.eurocontrol.int/publication/eurocontrol-aviation-outlook-2050

8.1 ATM Operational concept components

8.1.1 Air Traffic Control (ATC)

Whilst the principles of the provision of an ATC service are expected to remain the same i.e. to provide a safe, orderly and expeditious flow of air traffic, there are a number of challenges that may arise with the introduction and integration of ZE aircraft operations into the network.

The focus of ATC service provision in relation to ZEA operations is likely to initially focus on the entry into service of eVTOL and electric / hybrid-electric LLO operations when flown as IFR. One of the key challenges for electric aircraft will be that a higher propulsive efficiency needs to be reached due to the weight of the batteries based on current and near future technologies. Basic flight mechanics make propellor efficiency more efficient in short haul, hence why the majority of current electric aviation concepts are using propellors.

However, this efficiency comes at the cost of speed: propellors are only efficient at lower airspeeds. By itself, this is only a commercial issue (passengers and cargo travel longer). However, when such aircraft are going to be introduced in large commercial airports, capacity will be negatively affected under current procedure designs.

Operations in present day Terminal Manoeuvring Areas (TMAs) are usually tailored to a mostly-jet fleet. Most, if not all of these flights, optimally operate in the TMA at or above 200 knots. With speeds in a narrow band, there is little risk of two consecutive aircraft on the same route overtaking each other. Hence the only critical separation parameter becomes the wake-turbulence relation between the two aircraft.

As described in chapter 7, a much slower aircraft, such as a turboprop aircraft, will risk an overtaking situation. Therefore, ATC will need to increase the departure interval to ensure separation, leading to lower airspace capacities unless other solutions such as separate departure routes designed specifically for turboprop aircraft are implemented. Even now, ATC will often vector these propellor aircraft ad-hoc to separate them from the jet traffic as soon as possible. However, such vectoring increases workload, hence reducing capacity, whilst also potentially adding on additional track miles flown.

If mixed operations are expected in high-density TMAs, procedures will need to be adapted. This could be in the form of additional routes, specifically for slower traffic. TBO may help in planning conflict-free routes and reducing ATCO workload. Other challenges associated with the integration of ZEA operations into the ATM system include those related to operations in classes of airspace designed and managed for legacy IFR traffic.

The objective of this document is to highlight the operational elements that may need to evolve to enable the integration of commercial ZE aircraft into the European aviation system, and in particular the ATM system. Given the limitations of VFR operations to Visual Meteorological Conditions (VMC), VFR is unsuitable for most commercial operations. Therefore, in the future, an IFR type certificate is likely to be considered as a pre-condition for all the ZE aircraft for which this CONOPS applies.

However, rotorcraft operations inside controlled airspace and TMAs are often limited to VFR flights in VMC, due to their different operational characteristics to fixed-wing aircraft, especially with their lower speed and vulnerability to bad weather. Rotorcraft flights under IFR are often severely constrained or even prohibited altogether. The introduction of IFR procedures specifically designed for rotorcraft enables their safe integration into controlled airspace without adversely affecting existing fixed-wing operations.

For eVTOL VFR operations, at first entry into service, it is expected that they will utilise existing helicopter or VFR routes as well as VFR waypoints or newly defined procedures based on these existing procedures, where they are available or where a high traffic density is expected. Existing procedures may have to be evaluated with new arrival and departure routes for existing airport and helicopter sites developed in order to facilitate the eVTOL integration into the airspace.

If more operations are flown under VFR then ATCO workload will likely increase in certain classes of airspace, if more traffic information is provided. At entry into service, some ZE aircraft may be equipped but not yet certified for IFR so may have to fly VFR. New landing sites (vertiports) and the use of existing sites that currently only allow for VFR operations will need to be designed to support IFR operations including adequate separation provision, lighting, and other requirements.

The provision of IFR routes in controlled airspace procedurally separates rotorcraft and fixed-wing traffic. Current IFR minima is often related to:

- An assumption that an aircraft wants to receive an ATC service;
- An incorrect assumption that in some European States it is prohibited to fly IFR in uncontrolled airspace. IFR flights in uncontrolled airspace are allowed in European airspace, but European States are struggling to implement the principles, with a few exceptions. European agencies such as the European Union Agency for the Space Programme (EUSPA) assist the European States in implementing these principles[33]; or
- If controlled, the need for, and availability of, radar and radio coverage.

EASA's NPA 2022-06 proposes the establishment of predefined routes for all VTOL operations in urban areas to avoid conflicts with other airspace users. This will include dedicated routes / areas to be used by VTOL operators, as a means to mitigate safety risks in areas with a high volume of air traffic. However, predefined routes should strictly be limited to high traffic / congested areas to not endanger the entry into service of VTOL operations at an early, low tempo stage. Operators should be awarded some route planning flexibility to plan for the most efficient route taking into account differences in aircraft performance, type of operations and operational conditions (e.g., weather, NOTAMs, emergencies, etc.).

<u>Controller tools</u>

ATC operations may be supported by safety nets such as the STCA (Short Term Conflict Alert) or by controller tools such as TCT (Tactical Controller Tools) or MTCD (Medium Term Conflict Detection). The latter tool works by detecting potential

[33] https://www.euspa.europa.eu/sites/default/files/uploads/gnss-based_instrument_flight_procedures_implementation_for_general_aviation.pdf

conflicts within a configurable look ahead time parameter (e.g. 20 minutes) based on current trajectory information. If the speed of a new ZE aircraft is significantly different to those speeds configured within the controller tool, such tools may need to be reconfigured or the system may even need to be redesigned to achieve the MTCD goal.

Further automation of ATCO conflict detection tools - with support for conflict resolution taking into account environmental constraints and safety net parameters based on the performance profiles of new ZE aircraft - should be undertaken.

In order to support more efficient arrival traffic management, the extension of AMAN horizon may be required in order to propagate the AMAN delays further en-route. Extended AMAN advisories may need to be implemented on the wider scale with full network involvement and awareness. LoAs and operational procedures may have to be adapted with the provisions of extended AMAN delay apportionment. These procedures should take into account any performance characteristics expected by the change in traffic composition as new ZE aircraft are integrated into the ATM system.

<u>ATC workload</u>

The workload of a controller must be accurately assessed to permit optimum efficiency. If it is too high for too long, the ATCO may become overstretched. If it is too low for too long, this not only constitutes an inefficient application of resources but is likely to increase the chances of an ATCO losing situational awareness and becoming distracted from their primary task which is to separate aircraft.

When electric and smaller ZE hybrid-electric aircraft are flying IFR with non-standard performance characteristics, one impact could be additional planning conflicts and an increase in ATC workload, depending on the number of aircraft in the sector / airspace. In addition to an increase in planning workload, tactical control of aircraft at lower levels may require more additional interventions and use of controller tools etc. This in turn could lead to a reduction in sector capacity and potentially the issuance of capacity restrictions. Capacity restrictions are normally determined based on traffic counts and Monitoring Values (MVs), looking tactically at the traffic mix. MVs are normally linked to strategic capacity values (traffic entry or occupancy counts) that are based on experience. If more ZEA enter with non-standard climb / descent rates and cause capacity issues, this can result in lower declared capacities.

In this chapter, several examples of impacts to ATC workload from the integration of ZE aircraft into the network have been identified. Besides additional time spent on conflict searches, these may include increased time spent on Radio Telephony (R/T), giving additional or longer clearances, increased coordination with neighbouring controllers, or between planning and tactical controllers, increased use of controller tools and more instructions related to speed or level control etc.

It should also be noted that around 15 years ago, it was foreseen that a new type of aircraft would need to be integrated into the network, namely the VLJ (Very Light Jet). This aircraft also had performance characteristics atypical to conventional aircraft. Although this industry did not develop as expected, in part due to the global economic crisis, studies and simulations concluded that the integration of such aircraft would result in:

- An increase in the amount of ground-ground communication for exit-entry coordination and the number of level change instructions;

- An increase in the number of STCA alerts in the en-route airspace; and,
- Conflict free separation involving VLJs being mainly performed at the tactical level by the executive controller resulting in additional workload.

ATCO workload has a direct link to sector capacity: the more workload, the less the sector capacity. Therefore, if the introduction and integration of ZE aircraft into the network has an impact on ATCO workload, and therefore indirectly on capacity, it could lead to many consequences such as increased delay, reduced flight efficiency, the application of flow control, a requirement for extra ATCOs, increased demand for ATC training etc.

One concept that may be considered in the future is Intermediate Stop Operations (ISO). On a typical long-haul flight for a heavy aircraft (e.g. a 10 hour A330 flight), the fuel burnt could be around 5.7 tonnes/hr with a total weight of 57 tonnes plus contingency / discretionary fuel etc. As there is a need to burn fuel to carry fuel - a rule of thumb is that 3% of the fuel load per hour is required to transport it - carrying one tonne of extra fuel for 10 hours will waste around 300kg of fuel. Therefore, if 30 tonnes less fuel is carried on 2 equivalent 5 hour flights, the equivalent savings could be in the range of 9 tonnes (minus the fuel burnt during the two lighter take-off events). Therefore, in order to reduce the effect of burning fuel for carrying fuel on long-haul flights one solution could be to undertake ISO so that intermediate refuelling can be performed to reduce the aircraft's weight on each flight segment. It should be noted that whilst overall climate impact might be reduced, considerations would have to be made for the additional take-offs and landings and their effect upon both flight crew and ATCO workload, capacity constraints at the most frequently used ISO airports, and the need for similar infrastructure to support electric, hybrid-electric and / or hydrogen -powered operations etc. The intermediate stop itself and the required time for refuelling could also both increase travel time, direct operation costs (such as additional airport landing fees, enhanced wear, reduced maintenance intervals) and enhanced costs for staff due to increased travel time. A similar concept could support an initially limited range of short-haul operations for electric aircraft.

An increase in both VFR and IFR flights below FL300 (and especially below FL100), may be foreseen for ZE aircraft and the airspace does have limitations and boundaries in terms of safe operations. Analysis should be undertaken to better understand 1) when this becomes an issue and 2) how this can be solved.

Separation standards

Energy-efficient flight by electric, hybrid-electric and hydrogen powered aircraft may result in significantly lower air speeds in the proximity of airports, both during take-off and climb as well as during approach and landing. At the same time, lighter aircraft are more prone to the aerodynamic vortices of ahead flying aircraft. Separation schemes with preceding and succeeding aircraft may have to be developed for an increased variety of aircraft.

8.1.2 Airspace Management (ASM)

Some of the developments foreseen in ASM as defined in the High-Level Network CONOPS 2029[34] will support optimising the trajectory of airspace users for initial TBO. The assessment of the AZEA CONOPS team is that the content of this section applies equally to ZE and non-ZE aircraft. Additional requirements for ASM to accommodate ZEA aircraft operations should be considered in future editions of the Network CONOPS. The vision of the Network CONOPS is to improve the prediction of traffic demand and available capacity, permitting the European ATM Network to gradually transition from demand / capacity forecast to demand / capacity planning. Some of the developments include:

- The combined operation of Flexible Airspace Management and FRA is expected to enable all airspace users, including ZE aircraft, to fly as closely as possible to their preferred trajectories without being constrained by fixed airspace structures or fixed route networks.

- Enhanced notification processes of updated airspace status in real time will allow Airspace users (Aus) to improve flights efficiency, leading to an optimised airspace utilisation.

- Short notice reserved / restricted airspace request updates are continuously shared between the ATM partners in a rolling airspace update process, facilitating immediate responses from service providers and airspace users. The real time ASM coordination can offer more direct and shorter routeings and it can be used efficiently in case of airspace release. Airspace availability is shared in real time via full rolling AUP/UUP mechanism to optimise utilisation of airspace.

In the coming years, Higher Airspace Operations (HAO) and Unmanned Aircraft vehicles (UAV) will be integrated into the European ATM Network, together with the associated Space Traffic Management (STM) and Unmanned Traffic Management (UTM). The validation and early deployment of conceptual elements for network integration of such new entrants will provide lessons learned for any further integration of new ZE aircraft on a large scale including the development of associated new ASM process and procedures.

8.1.3 Aerodrome operations

Aerodromes can be located in controlled or uncontrolled airspace. While operations in uncontrolled airspace are a common occurrence for most pilots, operating in controlled airspace is much more complex due to higher traffic density and larger aircraft. When operating from an airport surrounded by a control zone (CTR), ATC clearance must be given for all flight phases inside the CTR. At high-frequency airports where ATC capacity is often near its limits, additional aircraft movements (i.e., arrivals and departures) that can be conducted will likely be very limited. Without appropriate procedures and infrastructure, additional eVTOL traffic could further impede ATC capacity. To overcome this issue, one solution could be to create independent flight / approach paths in a dedicated new airspace close to the FATO, that enable

[34] https://www.eurocontrol.int/sites/default/files/2022-09/eurocontrol-high-level-network-concept-of-operations-conops-2029.pdf

simultaneous operations with runway traffic with the objective to reduce additional workload for ATC. With this solution, appropriate consideration would have to be made for land-use planning procedures and other potential environmental impacts.

At aerodromes where eVTOL operations occur, where possible, separate flight paths and procedures for eVTOL from / to the FATO should be created to allow for further scale-up of eVTOL operations without interfering with regular traffic. These procedures should allow for simultaneous and independent operations with runway traffic. One way to achieve this is to ensure lateral separation between the FATO and runway edge of at least 250 meters, where simultaneous operations take place. This distance is based on Certification Specifications for surface-level VFR heliports located at aerodromes (CS-HPT-DSN) and ICAO Annex 14, Vol. II. It is also defined in the EASA Prototype Technical Specifications for the Design of VFR Vertiports for Operation with Manned VTOL-Capable Aircraft Certified in the Enhanced Category (PTS-VPT-DSN). It is assumed that in many cases, eVTOL flight paths will not be routed parallel to the runway or that the pilot is in charge for separation during VFR operations, according to the exceptions allowed by ICAO and EASA regarding applicable separation minima.

Challenges and opportunities for ZEA operations at aerodromes include those related to aircraft weight, RFFS services, stand infrastructure and hydrogen storage (see chapter 7.2 for more information).

8.2 Other Network Operations components

8.2.1 Airspace Design

Airspace design in Europe is undertaken following a set of principles defined in ERNIP Part 1 - European Airspace Design Methodology Guidelines.

While many Operational Stakeholders have introduced FRA, the lack of ECAC-wide cross-border FRA and connectivity with TMAs continues to limit AUs' flexibility in optimising their trajectories according to their own business models, with associated environment and flight efficiency penalties.

The current plans for airspace design look out to 2030 and are detailed in ERNIP Part 2. The objective of the ATS Route Network (ARN) Version 2023 - 2030 as detailed in ERNIP Part 2 addresses the enhancement of European ATM capacity, flight efficiency and environmental performance through the development and implementation of FRA, an improved ATS route network and TMA systems structures supported by corresponding improvements to the airspace structure and the optimal utilisation rules.

Looking further ahead to 2035, SESAR has developed the proposal for the future architecture of the European airspace. In order to initiate the transition towards this future architecture, SESAR makes the following three recommendations[35]:

- To launch an airspace re-configuration programme supported by an operational excellence programme to achieve quick wins;

[35] Airspace Architecture Study

- To realise the de-fragmentation of European skies through virtualisation and the free flow of data among trusted users; and,

- To create a legal and financial framework that rewards early movers.

After 2035, new concepts may be required or existing concepts continually adapted to address further challenges that may arise in the future ATM system and reflect the future operational environment.

The assessment of the AZEA CONOPS team is that the current content of ERNIP Part 2 applies equally to ZE and non-ZE aircraft. In the coming years, a number of challenges will also have to be addressed to facilitate the integration of safe and efficient operations of new aircraft types (such as ZE aircraft) at and around aerodromes, which should be considered in future editions of ERNIP Part 2. Some of the improvements detailed in ERNIP that may impact ZEA operations include:

- FRA will gradually be extended vertically to TMA boundaries to ensure the connectivity with TMA fixed route structures established and managed flexibly to best suit the expected traffic demand. TMA operations will benefit from the capability to dynamically extend the scope of terminal airspace, which is further optimised by the application of advanced continuous climb and descent operations for improving descent and climb and synchronisation of arrival / departure flows. This will support optimised ZEA operations below FL245.

- The development of operational concepts such as those for HAO, UTM and ZEA should enable the effective integration of such operations into Network Operations.

- The recognition by NM that as technologies and concepts mature, this will lead to a change in traffic composition from that of today, with new actors emerging as well as a change in the typology of operations (e.g. eVTOL operations, RAM, business aviation including supersonic flights) increasing the complexity of network operations. However, the scale of impact will only really be understood when the entry into service dates, the penetration rates of each new market segment together with the new performance envelope are fully understood.

- The acknowledgement by NM of the need to plan for expected changes in airport business models such as a constant growth of operations at local, regional or secondary airports, with de-location of traffic facilitated by the connectivity provided by new aircraft type operations such as UAV and eVTOL operations. In addition, point to point operations may be replaced by high density small aircraft operations between local or secondary airports which require expansion of current TMA structures. This will support those ZEA use cases identified in Chapter 6.2.

- A further challenge will include the impact of vertiports for eVTOL operations, that are being planned or integrated into existing airport infrastructure, the operation of which may place temporary restrictions on surrounding airspace.

Whilst such evolutions may be expected to bring new business models for a number of the future network operational stakeholders, it is expected that such operational stakeholders will run modernisation programmes engaging in digital transformation, which involves not only system modernisation, but a profound transformation of the business processes through the use of today's digital technologies capabilities, leading to higher levels of effectiveness. This may include the use of big data, machine learning and artificial intelligence technologies which will augment the human capabilities to a level otherwise not possible, allowing to anticipate problems and to provide the best solutions, to timely plan and adjust in a seamless and coordinated manner with all actors.

8.2.2 Air Traffic Flow Management (ATFM)

Air traffic flow management is the regulation of air traffic in order to avoid exceeding airport or air traffic control capacity in handling traffic, and to ensure that available capacity is used efficiently.

In the coming decades, some of the developments foreseen in ATFCM as defined in the High-Level Network CONOPS 2029[36] will support optimising the trajectory of airspace users for initial TBO. The assessment of the AZEA CONOPS team is that the content of this section applies equally to ZE and non-ZE aircraft. Additional requirements for ATFM to accommodate ZEA aircraft operations should be considered in future editions of the Network CONOPS. Some of the improvements detailed in the High-Level Network CONOPS 2029 that may support ZEA operations include:

- At network level, ATFCM will be managed on the basis of end-to-end 4D business / mission trajectories, provided by AUs using the FF-ICE flight plan (eFPL). Flight plans may be updated in-flight, following optimisation and negotiation similar to pre-departure coordination processes. Therefore, new business models of ZEA operations will be managed effectively.

- Flight information (both for FPL and eFPL) exchanged during the pre-tactical and tactical phases by ATC systems and Network Manager supports the predictability of network events and their impact, and it reduces uncertainty, including for non-standard operations, thereby improving operational performance.

- Trajectory prediction including expected performance profiles will be improved by the integration of Extended Projected Profile (EPP) data at local and regional level. The EPP contains an updated FMS route prediction and it includes the predicted aircraft weight, predicted horizontal and vertical speeds and up to 128 future waypoints along the route. The network actors will receive EPP data via the ADS-C ground distribution. ANSPs will share EPP data with ATCOs, providing them with expected performance profiles - including non-standard profiles - and facilitate optimised traffic management.

- ATFCM will move to Flow Centric operations through cooperative traffic management mitigating imbalances from a network performance perspective and through Integrated Network-ATC Planning (INAP). It includes the allocation of target times for airspace volumes and airports to mitigate imbalances and to optimise arrival sequencing, including their use in support of extended arrival

[36] https://www.eurocontrol.int/sites/default/files/2022-09/eurocontrol-high-level-network-concept-of-operations-conops-2029.pdf

management procedures. Target times of arrival, together with other ATCO tools, will facilitate sequencing of ZEA operations in the case of a non-standard performance profile. Operations are based on cooperative traffic management procedures for the operational use of targeted measures, on continuous sharing of real-time traffic information and on collaborative decision-making process between all actors.

- The monitoring process of Network Capacity will take into account new performance indicators and threshold values related to complexity and workload. This requires en-route and airport capacities to be updated in real time. This will provide more flexibility to operations with non-standard performance characteristics, such as ZEA operations.

8.2.3 Operations at secondary airports

In recent decades, the market share of regional aviation has declined due to rising costs and unfavourable economics associated with traditional regional and commuter aircraft, together with a comparative growth in the commercial aviation sector. As a result, airline traffic has concentrated at larger hub airports, leading to reduced or cancelled services at regional airports, resulting in many regional airports remaining underutilised. While the entire aviation sector is under pressure to reduce emissions, the regional sector faces a greater challenge due to the availability of alternative transportation options.

Electric, hybrid-electric and hydrogen-powered aircraft operations can offer a viable solution to rejuvenating regional operations and leverage the available capacity at the regional or secondary airports, noting that the capacity of the electricity (and hydrogen) supply to cope with increasing demands may be limited in some locations (e.g. small island nations that are not connected to a grid). By offering lower operating costs, these aircraft enable airlines to restore, and expand, connectivity that may previously have been reduced or lost. And this can be achieved with significantly lower emissions compared to conventional aircraft and other modes of transport.

WG3 has identified that the airports likely to support the roll-out of ZE aircraft operations can be classified depending upon several factors such as:

- Airport size – potentially the largest airports based on forecast 2040 passenger volumes;
- Traffic structure – airports with the highest share of flights under 800NM (allowing for out-and-back flights on one tank of fuel);
- “Macro-logistics” – airports with favourable access to hydrogen supply and /or green energy; and,
- “Micro-factors” – airports with no on-site space constraints and commitment to promote hydrogen and / or electrification projects.

WG3 have therefore classified airports as the following:

- GA (General Aviation)
- Island / Domestic
- Regional (Intra-Europe)
- Major regional / International hub

This classification of airports takes into account the type of operation that could be expected based on aviation sector but does not take into account where the airport sits as part of multi-nodal network. In addition, regional airports are often difficult to define as they can be associated with serving peripheral regions in some States whilst in others, they may refer to any airport not serving country capitals. However, more often than not, they are usually peripheral to the main urban and metropolitan regions and have a relatively small size in terms of passengers.

Large metropolitan regions are often served by several airports, one being the primary airport with the largest share of metropolitan traffic, and the rest being secondary. Whilst primary airports are the largest airports in multi-airport systems and airports acting as the main or only gateway in large urban areas and cities, secondary airports may still have significant commercial traffic and have the ability to absorb the traffic spill from the primary or focus on lower yielding or specific traffic categories, particularly when mandated by government regulations. These airports likely have fewer movements and hence can afford a lower level of equipage.

One assumption made for the operations of ZE aircraft is that smaller aircraft are likely the starting point for the integration and maturation of electric and hydrogen-based propulsion systems to reduce emissions. These smaller aircraft have the benefit that they usually operate from local and more easily accessible airfields and airports with shorter runways and a cheaper cost base for operations, even though they may not benefit from economies of scale. Should flight restrictions at hub airports be in place for environmental reasons in the future, one outcome might be an increase in decentralised and regional commercial air transport operations, providing that the decentralisation does not result in additional noise impacts. In addition, ZE aircraft may be expected to be based at, and operate between, secondary airports also because of cost considerations and slot availability at major airports.

Therefore, at entry into service, a lot of these aircraft – especially in the eVTOL, LLO (and some RAM / RAT operations) market segments - may be expected to depart / arrive at so-called secondary (regional) airports. Such airports could be classed as innovation incubators as potential new operational concepts of flight will likely develop at such secondary airports until their concept has been demonstrated to work well. Airspace integration - in very low-level airspace (e.g. below radar vectoring altitude) in en-route as well as in the terminal area of airports - is needed to demonstrate these concepts and can be regarded as the “market-enabler” of advanced air mobility.

In the future, the airport business model will likely evolve, with growth expected at secondary and regional airports, with a potential shift of traffic facilitated by the connectivity provided by new aircraft type operations, 4D trajectories and equitable access to network operations. As this evolution occurs, it will be necessary to identify whether there are any additional requirements on secondary airports that are different for ZE aircraft compared to fuel-powered aircraft.

Further activities and research projects are ongoing to foster electronic conspicuity, the interoperability of systems and the development of harmonised controlled flight procedures in very low-level airspace.

8.2.4 Operations at Vertiports

Initially, many eVTOL ZE aircraft may be certified for VFR operations only and, in a first phase, will mainly be operated from existing aerodromes and heliports, based on existing rules and procedures. The feasibility of an upgrade of existing landing sites to one that can accommodate eVTOL will need to be evaluated on an individual, case-by case basis. based on the following considerations:

- Appropriate size and material of Touchdown and Lift-off Area (TLOF), Final Approach and Take-Off (FATO) and Safety Area;
- Adequate parking areas and ground facilities;
- Existing or new take-off and landing procedures;
- Airspace limitations and operating requirements;
- Charging infrastructure requirements or availability;
- Safety and environmental impact, and;
- Required regulatory and government approvals.

A number of aircraft concepts have the ability to depart vertically, followed by horizontal, wing-borne, flight. These concepts may require new procedure design paradigms as the current ones are designed for either vertical operations (helicopters), or fixed wing operations.

VTOL operations may be carried out at vertiports that are either standalone entities, co-located with existing airport infrastructure or developed in new locations such as city centres / on buildings etc. A co-located aerodrome / vertiport is an aerodrome specifically adapted in terms of infrastructure and organisation, to allow within the same site, both aviation operations and VTOL operations and will facilitate intermodality options. Many vertiports are likely to be built within or close to cities and in 2022, EASA published guidance for the design of vertiports which offers new and innovative solutions specifically for these congested urban environments.

Building vertiports in urban areas poses challenges related to infrastructure and urban planning. Vertiports are “mini-airports”. Ensuring that vertiport locations are accessible, environmentally sustainable, and compatible with the surrounding urban infrastructure is a significant challenge. Vertiports will likely use remote tower technology and include a large amount of automation.

These considerations may vary as each location may have unique characteristics and challenges requiring further analysis. One notable innovation is the concept of a funnel-shaped area above the vertiport, designated as an “obstacle free volume”. This concept is tailored to the operational capabilities of the new VTOL aircraft, which can perform landing and take-off with a significant vertical segment. Depending on the urban environment and on the performance of certain VTOL-capable aircraft, omnidirectional trajectories to vertiports will be also possible. Such approaches can more easily take account of environmental and noise restrictions and are more suitable for an urban environment than conventional heliport operations, which are constrained in the approaches that can be safely applied.

Since conventional / traditional IFR ground equipment may be too large and cumbersome to be integrated into the location of a vertiport, new solutions will need to be defined and implemented. This is the case for vertiports at commercial airports as well as vertiports in challenging locations (e.g. on rooftops with very limited space).

New rules will have to be developed to cater for these specificities. For existing landing sites, it is likely that existing IFR procedures will be utilised, where available and compatible with eVTOL aircraft (e.g. PBN procedures like LPV/ LNAV, Circling or Point in Space (PinS) helicopter operations). Such procedures may also have to be defined and implemented for new landing sites to allow for IFR operations.

8.2.5 Low level operations

If ZEA operations leads to an increase in the number of aircraft operating in low level airspace, the need for separation services may increase in areas where this is currently not available. This is even more so if IFR operations are used to operate such aircraft when weather precludes visual operations - weather avoidance rerouting requests are likely to be higher at lower levels.

Many of the proposed concepts for small electric or hybrid-electric aircraft operate at or below FL100. In present-day European airspaces (with the exclusion of TMAs), these altitudes are currently primarily used by general aviation, often operating under VFR and without a separation service by ATC.

Initial challenges to low-level operations that will have to be overcome include:

- The establishment of a reliable and scheduled transportation service building on ZEA operations, which are expected initially to start under VFR rules;

- The harmonisation of flight rules for the safe conduct of low-level operations in order to meet the limited energy resources of fully electric aircraft or the operation profile of air taxis by taking into account an optimised vertical profile and the most direct routing;

- A harmonised approach to implement procedure-based IFR operations in class G. It should be noted that IFR routings may not always be optimal for energy-constrained aircraft;

- Consideration of the lowering of initial vectoring altitudes in order to reduce the forcing of energy-constrained aircraft to sacrifice range by pushing their mass to higher than needed altitudes;

- The development of digital solutions to provide traffic situational awareness to pilots (while flying in uncontrolled airspace), in order to ensure the interoperability between different systems, including CNS / ATM systems. Examples for these solutions include FLARM, mobile-network-based transceivers (potentially relaying their position messages), ADS-B, ADS-L, satellite-based ADS-B, etc. to realise electronic conspicuity; and,

- The handling of non-cooperative, non-electronic conspicuous targets as a potential thread to cooperative, electronic conspicuous targets.

The SESAR low-level IFR routes solution[37] is a solution designed for rotorcraft to fly from FATO to FATO in IMC, and a similar solution could be designed for eVTOL and

[37] SESAR solution #113

fixed wing electric aircraft who want to fly low. The solution enables the design of IFR routes at very low level, based on the ability of suitably equipped rotorcraft to navigate very accurately using global navigation satellite systems (GNSS) using the European Satellite-Based Augmentation System (SBAS): the European Geostationary Navigation Overlay Service (EGNOS). Routes are designed to an enhanced Required Navigation Performance (RNP) standard that allows an optimised use of the airspace within medium and dense / complex TMAs. Routes are designed to either RNP 1 or RNP 0.3 depending on the altitude and degree of precision needed as a result of neighbouring procedures, airspace and/or terrain. The integration of an optimised low-level IFR route network can enhance flight safety and weather resilience of operations. Benefits for the environment may also be expected due to fewer VFR flights at very low altitude and avoidance of noise-sensitive areas thanks to narrow and / or curved low-level procedures. When these low-level IFR routes arrive at the FATO, they can be directly linked to dedicated PinS arrival and departure procedures where published, enabling Simultaneous Non-Interfering (SNI) operations that are procedurally separated from conventional fixed-wing operations. If they require an air traffic control service, they will need both radio and surveillance coverage as basic requirements. Where there is no radar coverage, the best choice for surveillance at low level would be satellite based ADS-B.

In addition to the low level IFR routes solution, SESAR has a number of other solutions that could potentially provide solutions to some of the challenges to initial ZEA operations. Some examples of these solutions can be found in **Error! Reference source not found.**:

SESAR solution reference	SESAR solution name
PJ.02-05	Independent rotorcraft operations at the airport
PJ.04-W2-28.1	Connected regional airports
Solution #113	Optimised low level IFR rules for rotorcraft aircraft
Solution #60	Enhanced STCA for TMAs
PJ.01-06	Enhanced rotorcraft operations in the TMA
PJ.10-02a1/Release 9	Improved performance in the provision of separation without use of ADS-C/EPP data
PJ.18-W2-53B	Improved performance of CD/R tools enabled by reduced trajectory prediction uncertainty

Table 4: Examples of SESAR solutions that can facilitate ZEA operations

8.2.6 CNS infrastructure

CNS infrastructures are enablers to optimised operational performance.

In general, no difference is expected from current operations. However, for those ZE aircraft that will operate at lower FLs, the current coverage for surveillance may be insufficient. This issue is recognised in present-day – typically VFR – operations where separation is not provided, but also not available due to lack of line-of-sight to a radar.

If traffic levels remain similar to current VFR operations, no significant change is required. However, if growth in smaller aircraft operations or a growth in the need for operations in all visibility conditions is required, communication, surveillance and separation provision may need to be expanded.

To improve surveillance coverage at low level, a dependent solution is most likely to succeed in providing coverage from ground level upwards and which would not be limited by terrain features. Such solutions could include:

- ADS-B, be it via land-based receivers or satellite-based solutions. The first still requires placing antennas such that line-of-sight is provided everywhere; and,
- Interoperability of systems and respective data interfaces (e.g. interfacing airborne and ground systems with CNS/ATM and U-Space systems).

However, most of the use case operational concepts identified in chapter 6.2 are for IFR operations which are likely to climb above the Minimum Safe Altitude (MSA) for safety where they will leave the U-space domain. Nevertheless, the altitudes for some operational concepts may lead to issues in conspicuity.

As all of the ZE aircraft currently considered in this CONOPS are piloted aircraft with passengers flying higher than U-space and only crossing it for approach and departure, the interaction with U-space, USSP and U-space users has to be ensured in a safe way. Even if a long-term vision is that VTOL will also be unmanned, the reality will look different for the next years. The infrastructure should be pre-blocked by the flight plan and remain blocked at the estimated arrival time at the destination vertiport.

9 Stakeholder roles and responsibilities

9.1 Stakeholder roles and responsibilities

In order to achieve the AZEA objectives, all involved stakeholders may assume different roles during the planning and execution of flights.

9.1.1 Flight Crew

Flight crew of both legacy aircraft and ZE aircraft will interact with each other on an equitable basis as they fly their mission objectives across the network. Appropriate training should ensure that all flight crew have an understanding of any non-standard performance characteristics that ZE aircraft may have that are different to those of legacy aircraft.

9.1.2 Aerodrome operators

Aerodrome operators will provide clearance delivery, apron and ground control services in addition to support services such as fuelling (kerosine, SAF etc.), charging and maintenance services. Where possible, all support services should be fully integrated into the ground operations and infrastructure so that regardless of propulsion type, all operations are treated on an equitable basis.

9.1.3 Computerised Flight Plan Service Provider (CFSPs)

CFSPs will support aircraft operators by planning the optimum 4D flight trajectory taking into account any network constraints. Flight planning tools will be adapted to consider the performance characteristics of ZE aircraft should they differ from those of legacy aircraft.

9.1.4 Ground Handler

Ground handlers will support ground operations at aerodromes by facilitating an aircraft ground repositioning, preparation prior to, and after conclusion of a flight and will include both customer service and ramp service functions. When ramp services include fuelling and maintenance operations, ground handling companies will ensure training and awareness of new procedures related to ZE aircraft including appropriate safety management and risk assessments related to new propulsion technologies.

9.1.5 Air Navigation Service Provider (ANSP)

An ANSP will primarily provide ATC control services to enable a safe and efficient air traffic operation to both legacy aircraft and new market segments such as ZE aircraft. The ATCOs of the ANSP should enable a seamless integration of ZEA operations into the network. ANSPs can also provide advisory, alerting and flight information services.

9.1.6 Network Manager (NM)

The NM performs the network functions as described in chapter 8 across the entire continuum of airspace. Where necessary, at the request of its stakeholders, NM may adapt and add capabilities to meet the operational needs of ZEA stakeholders. NM will operate within its defined role to support ANSP's, authorities and other relevant operational stakeholders and deliver an integrated network supporting legacy and ZE aircraft operations.

9.1.7 Regulators and authorities

Regulators and competent authorities will support the entry into service of ZE aircraft and ensure that regulations enable equitable access to European airspace for all market sectors and that no market sector is punished for having an atypical performance envelope.

10 Recommendations

It is recognised that the integration of ZE aircraft into the European network, including airports, is a challenge that will be addressed iteratively as technologies mature, operational concepts evolve and forecasts for the entry into service of new market segments develop. To support the evolution, this CONOPS proposes a number of recommendations that should be taken into consideration to support the integration of ZE aircraft into the European network.

It should be noted that this CONOPS is a preliminary analysis of the potential challenges and opportunities of the introduction of the different ZE aircraft in the EU Air Transport Network. There are still a lot of uncertainties, meaning it is too early to make strong recommendations. These uncertainties may include the concepts of operations of each ZE aircraft segment (eVTOL, RAM/RAT and CAT operations) together with their environmental impacts (e.g. related to noise, non-CO_2 emissions etc.) and the expected market penetration / development of each ZE aircraft segment.

It is therefore expected that these recommendations will be further developed in future CONOPS iterations. The recommendations in this chapter are divided into those related to operations, safety and policy making.

10.1.1 Operations

It is recommended that AZEA stakeholders support the integration of ZE aircraft into the European network by:

- Implementing continuous monitoring and feedback processes relating to the operational performance of ZE aircraft operations in accordance with established (and new) KPIs, to ensure a safe and efficient integration of ZE aircraft;
- Considering the different operational performance of ZE aircraft in all phases of flight in future airspace design;
- Planning and adapting the ATM rules progressively and collaboratively to reflect a potential increasing number of ZEA operations;
- Considering that the introduction of IFR operations at lower levels and the associated increase in ATC service provision will require surveillance coverage, which can best be achieved through dependent means;
- Assessing the demand forecast for IFR flights wishing to fly lower than current IFR routes to support airspace re-categorisation, and definition of aircraft equipage and procedure requirements to enable the provision of an ATC service. This may entail considering the extension of the VDL Mode 2 mandate below FL290 and considering the equipage of new aircraft from the start of the development process;
- Promoting the development of tools that support ATC in handling a traffic mix with an increased diversity of performance envelopes;
- Supporting the seamless integration of the new vehicles from the start date of entry into service by providing relevant ATM stakeholders with required data to support ATM R&D activities;
- Developing procedures that allow for simultaneous operations of aircraft with different mission profiles to serve operations both at low level and at airports; and,

- Considering additional requirements for airspace design, ASM and ATFM to accommodate ZEA aircraft operations in future editions of ERNIP Part 2 and the Network CONOPS respectively.

10.1.2 Safety

It is recommended that AZEA stakeholders support the integration of ZE aircraft into the European network by:

- Continuously assessing in safety management systems the representation of ZE aircraft in the European network and their safety impacts upon aircraft operations;
- Monitoring the impact on ATM in terms of the volume of movements at lower altitudes and airspace capacity, in order to ensure that future operational concepts facilitate a safe and efficient access to airspace for ZE aircraft;
- Identifying the risks and safety hazards on the ground and in the air associated with new types of energy carriers and propulsion systems; and,
- Developing, verifying and certifying emergency procedures related to those safety risks.

10.1.3 Policy Making

It is recommended that AZEA stakeholders support the integration of ZE aircraft into the European network by:

- Ensuring that certification approaches embrace specific characteristics of energy carriers and propulsion systems;
- Being aligned with the current policy framework when integrating ZE aircraft into the air transportation system, and expanding that framework when and where necessary;
- Aligning policy making and R&D activities related to the different aspects of ZEA, e.g. measurement of non-CO_2 emissions, aircraft with non-standard performances etc.;
- Providing recommendations reflecting the specific needs of ZE aircraft operations for developing new, and adapting existing, airport infrastructure and landing sites;
- Identifying key performance indicators for the safe and efficient introduction and operation of ZE aircraft; and,
- Developing appropriate European standards (synchronised with ICAO) for modernising the current ATM system in order to enable ZEA operations.

APPENDIX A - Definition of terms

Term	Definition
AAM	Advanced air mobility
ACAAF-TF	Airport Compatibility of Alternate Aviation Fuels Task Force
ACAS	Airborne collision avoidance system
ACC	Area control centre
A-CDM	Airport – collaborative decision making
ACR	Aircraft classification rating
ADS-B	Automatic dependant surveillance – broadcast
ADS-C	Automatic dependant surveillance – contract
ADS-L	Automatic dependant surveillance – light
AHA	Aircraft hazard area
AI	Artificial intelligence
AIP	Aeronautical information publication
AIRAC	Aeronautical information regulation and control
AMAN	Arrival manager
ANSP	Air navigation service provider
APU	Auxiliary power unit
ARN	ATS route network
ASM	Airspace management
ASTM	American society for testing and materials
ATAG	Air transport action group
ATC	Air traffic control
ATCO	Air traffic controller
ATFCM	Air traffic flow and capacity management
ATM	Air traffic management
ATO	Air traffic operations
ATS	Air traffic services
ATS B2	Air Traffic Services Baseline 2
AU	Airspace user
AUP	Airspace use plan
AZEA	Alliance of zero emissions aviation
BOM	Bill Of Materials
CAT	Commercial air transport

Term	Definition
CCO	Continuous climb operations
CDM	Collaborative decision-making
CDO	Continuous descent operations
CD/R	Conflict detection / resolution
CFSP	Computerised flight plan service provider
CH_4	Methane
CHA	Contingency hazard area
CiC	Contrail induced cloudiness
CL	Cruising level
CNS	Communication navigation and surveillance
CO_2	Carbon dioxide
CONOPS	Concept of operations
CPDLC	Controller pilot data link communications
CRM	Crew resource management
CS	Cruising speed
CTOL	Conventional take-off and landing
CTR	Control area
CTZ	Control zone
DAA	Detect and avoid
DAC	Dynamic airspace configurations
DEVT	Ducted electric vapoured thrust
DG DEFIS	Directorate-General for defence industry and space
DMA	Dynamic mobile areas
DMAN	Departure manager
EACCA	European Climate Change Adaptation working group
EACCC	European Aviation Coordination Crisis Cell
EAO	European aviation outlook
EASA	European Aviation Safety Agency
EC	European Commission
ECAC	European Aviation Civil Conference
ECLIF	Emissions and the climate impact of alternative fuels
EDA	European Defence Agency
eFPL	FF-ICE flight plan
EGNOS	European Geostationary Navigation Overlay Service

Term	Definition
EIS	Entry into service
EMS	Emergency medical services
EN-ICCA	The European Network on Impact of Climate Change on Aviation
EPP	Extended projected profile
ERND	European Route Network Design
ERNIP	European route network implementation plan
ERP	Emergency response plan
ETS	Emissions trading scheme
EU	European Union
EUSPA	European Union Agency for the Space Programme
eVTOL	Electric vertical take-off and landing aircraft
FAS	Final approach speed
FATO	Final approach and take-off area
FCI	Future communications infrastructure
FF-ICE	Flight and flow information for a collaborative environment
FIR	Flight information region
FIS	Flight information service
FL	Flight level
FPL	Flight plan
FRA	Free route airspace
GANP	Global air navigation plan
GATMOC	Global air traffic management operational concept
GMC	Ground movement charts
GNSS	Global navigation satellite system
H_2O	Water
HAO	Higher airspace operations
HAPS	High altitude platform systems
HMI	Human machine interface
ICAO	International civil aviation organisation
IFR	Instrument flight rules
IIWG	International industry working group
IMC	Instrument meteorological conditions
iNM	Integrated network management
INAP	Integrated network ATC planning

Term	Definition
ISO	Intermediate stop operations
ISSR	Ice super saturated region
KEA	Performance indicator – horizontal en-route flight efficiency - actual
KEP	Performance indicator – horizontal en-route flight efficiency - planned
KPI	Key performance indicator
LCC	Low cost carrier
LLO	Low level operations
LNAV	Lateral navigation
LoA	Letter of agreement
LPV	Localiser performance with vertical guidance
LTAG	Long-term aspirational goal
LTO	Landing and take-off cycle
MDI	Minimum departure interval
MRO	Maintenance, repair and overhaul
MSA	Minimum safe altitude
MTCD	Medium-term conflict detection
MTOW	Maximum take-off weight
MV	Monitoring values
NGO	Non-governmental organisation
NM	Network manager
NOTAM	Notice to airmen
NOx	Nitrogen Oxides
NPA	Notice of proposed amendment
O_3	Ozone
OAG	Official airline guide
OEM	Original equipment manufacturer
OEW	Operating empty weight
P2P	Point to point
PAX	Passengers
PBN	Performance-based navigation
PCR	Pavement classification rating
PESTLE	Political, economic, social, technical. Legal. environmental
PinS	Point in Space
PPE	Personal protective equipment

Term	Definition
R/T	Radiotelephony
RAM	Regional air mobility
RAT	Regional air transport
RBT	Reference business trajectory
RFF	Rescue and firefighting
RFFS	Rescue and firefighting services
RNAV	Area navigation
RNP	Required navigation performance
RoC	Rate of climb
RWY	Runway
SAF	Sustainable aviation fuels
SBAS	Satellite-based augmentation system
SDM	SESAR deployment manager
SES	Single European sky
SESAR	Single European sky ATM research
SID	Standard instrument departure
SMO	Standards-making organisation
SNI	Simultaneous non-interfering
SOP	Standard operating procedure
STAM	Short-term ATFCM measures
STAR	Standard arrival route
STATFOR	Statistical forecast
STCA	Short-term conflict alert
STM	Space traffic management
STOL	Short take-off and landing
TBO	Trajectory-based operations
TCAS	Traffic collision and avoidance system
TCT	Tactical controller tools
TLOF	Touchdown and lift-off area
TMA	Terminal manoeuvring area
TODA	Take-off distance available
TORA	Take-off run available
TRA	Task and resource analysis
TTO	Target time over

Term	Definition
UA	Unmanned aircraft
UAM	Unmanned aircraft mobility
UAV	Unmanned aircraft vehicle
UIR	Upper flight information region
USSP	U-space service provider
UTM	Unmanned traffic management
UUP	Updated airspace use plan
VDLM2	VHF datalink Mode 2
VFR	Visual flight rules
VLJ	Very light jets
VMC	Visual meteorological conditions
WG	Working group
WNA	Water needs analysis
XFB	Excess fuel burn
XMAN	Extended arrival manager
ZE	Zero emission
ZEA	Zero emissions aircraft

APPENDIX B – AZEA Members as of 22nd November 2023

- Abelo Capital Aviation Management Limited
- ACI-Europe
- Aciturri Aeronáutica
- Aegean Experts
- AELIS Group
- AerCap Holdings
- Aernnova
- Aeromechs
- Aéroports de Paris (Groupe ADP)
- Aeroporto Guglielmo Marconi di Bologna
- Aeroports Públics de Catalunya
- Aerospace and Defence Industries (ASD)
- Aerospace Valley
- Air France-KLM
- Air Liquide
- Airbus S.A.S.
- Aircraft Design & Certification
- Aircraft Leasing Ireland
- Airlines for Europe (A4E)
- Airport Regions Council
- Airsight
- Amedeo Ltd.
- Amelia
- Ascendance Flight Technologies
- ASL Group
- Asociación Cluster de Aeronáutica y Espacio del País Vasco – HEGAN
- Association of European Research Establishments in Aeronautics (EREA)
- ASTM International
- ATR
- Aura Aero
- Aviagility
- Avions Mauboussin
- Beyond Aero
- Blue Spirit Aero
- Bundesverband der Deutschen Luft- und Raumfahrtindustrie e.V. (BDLI)
- CEN and CENELEC
- Centre of Competence for Climate, Environment and Noise Protection in Aviation (CENA)
- Centro Italiano Ricerche Aerospaziali (CIRA)
- CHESCO - Center for Hybrid Electric Systems Cottbus
- Clean Aviation Joint Undertaking
- Collins Aerospace Ireland
- Compañia Española de Sistemas Aeronáuticos
- Conscious Aerospace
- Consorcio del Aeropuerto de Teruel
- Cranfield Aerospace Solutions

- Cranfield University
- DAHER Aerospace
- Den Helder Airport
- Destinus
- Deutsches Zentrum für Luft- und Raumfahrt (DLR)
- Dublin Airport Authority (daa)
- EasyJet
- EENUEE
- EH Group Engineering
- Electric Flying Connection (EFC)
- Electron Aerospace
- Elixir Aircraft
- ELSA Industry
- Estonian Aviation Academy
- Euroairport (Basel-Mulhouse-Freiburg)
- EUROCAE
- EUROCONTROL
- European Business Aviation Association (EBAA)
- European Cockpit Association (ECA)
- European Federation for Transport and Environment (T&E)
- European Flyers
- European Regional Aerodromes Community (ERAC)
- European Regions Airline Association Ltd. (ERA)
- European Union Aviation Safety Agency (EASA)
- Federation of European Tank Storage Associations (FETSA)
- Fleasy
- Flughafen Friedrichshafen
- Flying Whales
- Fokker NextGen
- Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung
- FSR TU Darmstadt
- Fundación CTA - Centro de Tecnologías Aeronáuticas
- GE Avio
- General Aviation Manufacturers Association
- GKN Aerospace Sweden AB
- Green Aerolease
- Green Aviation Hub
- Groningen Airport Eelde
- Groupe Absolut
- H2Fly
- H3 Dynamics SARL
- Hamburg Aviation
- Hamburg University of Applied Sciences (HAW Hamburg)
- Heart Aerospace
- Hevel Eilot Hub
- Hydrogen Europe
- IATA
- IBEROJET (Evelop Airlines SA)
- IMIEU
- Impact on sustainable aviation e.V.
- IndustriAll European Trade Union
- Instituto Nacional de Tecnica Aeroespacial (INTA)

- ITP Aero
- Jeppesen
- Lazarski University
- Leibniz University Hannover, Institute for Electric Power
- Leonardo
- Lilium
- Linde
- Lufthansa Innovation Hub
- Łukasiewicz Research Network - Institute of Aviation
- Maeve Aerospace
- Magpie Aviation
- MTU
- Napier Park Global Capital
- Netherlands Airport Consultants (NACO)
- New Electric Aircraft Engines-GSI
- Nordic Aviation Group
- Nordic Initiative for Sustainable Aviation (NISA)
- Normandie AeroEspace
- New Electric Aircraft Engines-GSI
- nrg2fly
- Office national d'études et de recherches aérospatiales (ONERA)
- Panta Holdings
- Pipistrel
- Poznan Airport
- Pratt & Whitney Rzeszow
- Région Nouvelle-Aquitaine
- Région Occitanie / Pyrénées – Méditérannée
- Rhein-Neckar Flugplatz (Mannheim)
- Roland Berger
- Rolls-Royce
- Royal Netherlands Aerospace Centre (NLR)
- SAE International
- Safran
- SATA Air Açores
- Scandinavian Seaplanes
- Service technique de l'Aviation civile (STAC)
- SESAR 3 Joint Undertaking
- SiriNoR
- SKYCORP
- SONACA
- Stichting AeroDelft
- Stichting Luchtvaart in Transitie
- Supernal
- Swedavia
- Swedish Aviation Industry Group (SAIG)
- Thales
- To70
- Torino Airport - SAGAT
- TU Delft
- TUI AG
- Universal Hydrogen Europe SAS
- VÆRIDION

- VELICA
- VGA
- Vinci Concessions
- Volocopter
- VoltAero
- Výzkumný a zkušební letecký ústav (VZLÚ)
- Widerøe Zero
- Wizz Air Innovation
- Wright Electric
- Zadar Airport
- ZE-Aviation Alliance
- Zentrum für angewandte Luftfahrtforschung ZAL
- ZeroAvia

APPENDIX C – AZEA Working Groups and interrelationships.

Working Group 1

This WG will develop a roll-out scenario for electric, hybrid-electric and hydrogen-powered aircraft to implement the transition to climate-neutral flight, making use of industry market forecasts, business cases, existing studies and the Clean Aviation Technology Evaluator platform[38]. It will be based on assumptions and requirements related to the entry into service of the different aircraft sizes and propulsion technologies, taking into account the operational presence of propulsion technologies with low or zero greenhouse gas emissions, in combination with the use of Sustainable Aviation Fuels (SAF). The activities will include an evaluation of performance characteristics of such aircraft, operational aspects and safety requirements etc. It will also consider the broader ecosystem context of the operations of hydrogen and electric aircraft, including decarbonised electricity and hydrogen costs, future travel patterns together with the identification of passenger markets, airlines and networks that can serve as "early adopters" for zero-emission aviation.

The WG will identify the requirements that should characterise a future network of destinations served by hydrogen, electric and hybrid-electric aircraft. It will establish requirements for decarbonised electricity and gaseous/liquid hydrogen availability and indicate a repartition of the needs between aerodromes across Europe. These key metrics and figures of reference of the future zero emission aviation will also serve as a unique reference to communicate and perform the advocacy efforts toward net zero aviation by 2050.

Working Group 2

This WG shall ensure that the decarbonised electricity and hydrogen requirements necessary for the roll-out of electric and hydrogen aircraft are adequately integrated in the broader context of energy policies and cross-sectorial initiatives, like the Hydrogen Alliance. It shall identify and promote appropriate synergies with those initiatives. The working group will also address the competition for decarbonised electricity / hydrogen with other fuels (SAF) and sectors such as heavy industries, shipping or road transport together with establishing recommendations to develop the necessary production and distribution infrastructures and ensure the readiness of the global electricity and hydrogen supply chains in order to secure the availability of the required hydrogen and/or electricity at aerodromes in time, quantity and price at the appropriate aerodromes for the fleet of aircraft.

Working Group 3

This WG shall perform a systematic analysis of the barriers and challenges (investments and others) as well as opportunities related to the introduction of electric / hydrogen aircraft at aerodromes and issue recommendations to address them. The analysis should cover both the required infrastructure and the related investment requirements as well as all other barrier that may exist. The analysis should also help identify opportunities associated with the transition to zero-emission aircraft in order to facilitate aerodrome long-term development strategies.

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[38] https://www.clean-aviation.eu/clean-sky-2/technology-evaluator

Working Group 4

This WG has the objective to identify the developments and / or adaptations of the aviation regulatory framework (in particular safety, environmental and security requirements) required to support an effective market uptake of aircraft using electric and hydrogen power sources and the roll-out of zero emission aviation. The WG will also prepare and facilitate the certification of upcoming zero-emission aircraft, in close cooperation with the Clean Aviation Joint Undertaking, together with supporting the definition and introduction of the required standards for rulemaking, safe operations and certification activities.

Working Group 5

This WG has the objective to enable the efficient and sustainable introduction and integration of electric, hybrid-electric and hydrogen-powered aircraft into the European network and at the same time, secure the performance of the aviation system as a whole, providing an understanding of what the integration of aircraft powered by electricity or hydrogen fuel as a power source means in terms of their operational performance, airspace capacity, the provision of Air Traffic Services (ATS) and Air Traffic Flow Management (ATFM).
A secondary objective of this WG will be to assess the effectiveness of incentive mechanisms and their impacts on operational stakeholders and the network.

Working Group 6

This WG shall identify the incentives necessary to promote the adoption of aircraft using electric, hybrid-electric and hydrogen aircraft by passengers and the wide public and to stimulate the necessary investments by the different stakeholders, in particular airlines and aerodromes. This will be undertaken with a systematic analysis of the barriers and opportunities of the integration of electric and hydrogen aircraft into operators' fleets, addressing all operational aspects including ground processes and planning aspects (e.g. tankering), maintenance costs and aircraft utilisation.

Interrelationships between working groups

In order to deliver the objectives of AZEA, there needs to be a transparent sharing of material between the working groups within the applicable IPR constraints. This role will be undertaken by regular inter-working group coordination meetings.

As the overarching working group in AZEA, cross-working group inputs of relevance to WG5 will come from:

- WG1
    - Aircraft performance characteristics
    - Market forecast (traffic, aircraft entry-into-service, penetration rate, etc.) including potential changes to the network topology (e.g., new regional operations)
    - Energy requirements for electric and hydrogen propulsion as applicable to the different aircraft categories
    - Breakdown of the number of flights per market segment
- WG2:
    - Electrical energy for battery recharging and green hydrogen production and corresponding required electricity generation capacities for several low-carbon generation technology.

  - Distribution infrastructure to the aerodromes.
  - Expected Capex Investment for generation (upstream) and distribution (downstream)
- WG3:
  - Operational considerations related to stand management, turnaround, taxiing operations, ground handling, passenger management, etc.
  - Ground logistics at airport and impact of the infrastructure availability on the network
- WG4:
  - Hydrogen engine emission requirements and timeline for standardisation / certification
- WG6:
  - Operational incentives as well as those related to the running costs of electric and hydrogen aircraft.

The outputs of WG5 are planned to deliver the following content to the other AZEA WGs:

- WG6
  - Comprehensive assessment across different indicators, simulating integration of electric and hydrogen-powered aircraft into the air traffic management system. Modelling will include airspace users cost structures
  - Operational and financial incentives for airports
  - Incentives for secondary airports

Cross-working group inputs of relevance to WG3 will come from:

- WG1
  - Rollout scenario/development over time
    - Green electricity figures (charging vs. battery exchange)
    - Hydrogen figures
    - Energy availability
    - Airports to deploy technology and support airport network
- WG2:
  - Time dependent availability of green electricity and hydrogen
    - Quantity structure
    - Distribution channels
    - Aggregate state
- WG4:
  - Safety requirements.
  - Standards for handling and storing of electricity and hydrogen (standardisation / certification infrastructure for distribution, nozzle, at airport) [gap analyses].
- WG6:
  - Structural and operational incentives to overcome barriers and challenges, and to foster new business models.

The outputs of WG3 are planned to deliver the following deliverables to the other AZEA WGs:

- WG2
  - Consumption of airport infrastructure.

    - Internal demand from the airport (logistics, consumption, heat etc.).
    - Similar segmentation as WG 1?
- WG4
    - Changes to airport infrastructure with an impact on EASA regulations.
- WG5
    - Operational considerations related to stand management, turnaround, taxiing operations, ground handling, passenger management, etc.
    - Ground logistics at airport and impact of the infrastructure availability on the network.
- WG6
    - Constraints / barriers per type of airport (regional, intermediate, hub).
    - Detailed scenarios of all airport operations required to support the different types of aircraft configurations (electric, fuel cell, hydrogen capsules, direct hydrogen a/c refuelling, etc.).
    - Material related to the intermodality of different transport types.

APPENDIX D - WG5 aircraft performance questionnaire

Questionnaire

The questionnaire included questions related to:

- Expected power plants;
- Mission range;
- MTOW;
- Maximum and cruising Flight Levels;
- Maximum, cruising and final approach speeds;
- Rate of climb;
- Take off distance;
- Turn-around time; and,
- Location of engine start-up.

It was noted that the latter three questions were designed to identify potential performance characteristics that could have an impact on current ground control and related procedures.

The questionnaire can be found at https://www.smartsurvey.co.uk/s/RS83KR/

ZE aircraft performance

Based on a set of performance information acquired from AZEA OEMs, a first set of clusters of performance categories for ZE aircraft has been proposed.

To develop the clusters, four primary performance characteristics were used - cruising flight level, cruising speed, rate of climb and final approach speed – together with differentiating between VTOL and non-VTOL aircraft as the former may be considered to operate at different airfields / vertiports.

Cruising level (CL)

For VTOL and non-VTOL aircraft, the cruising level clusters were broken down as follows:

- VTOL aircraft: <1000ft, 1000-5000ft and 1000ft-FL100; and,
- Non-VTOL aircraft: 1000-5000ft, 5000ft-FL100, FL100-200, FL200-300 and FL300-410.

Cruising speed (CS)

For each propulsion method / cruising level cluster, the grouping was further broken down by cruising speed:

- VTOL aircraft: <100kts and 100-200kts; and,
- Non-VTOL aircraft: 100-200kts, 200-300+kts and 300+kts.

Rate of Climb (RoC)

The following categories of rates of climb were considered in the classification proposal:

- VTOL aircraft: <250feet per minute (fpm), 500-1000fpm and 1000-2000fpm; and,
- Non-VTOL aircraft: 500-1000fpm, 500-1500fpm, 1000-1500fpm, 1000-2000fpm and 2000+fpm.

Final Approach Speed (FAS)

The final performance characteristic considered in the classification was final approach speed. The following breakdown was used:

- VTOL aircraft: this characteristic was not considered; and,
- Non-VTOL aircraft: 60-80kts, 60-100kts, 100-120kts and 120+kts.

WG5 proposal

When developing the initial proposal for an ZE aircraft classification based on performance, the underlying assumption was that the most important factor to consider for characterising ZE aircraft performance would be cruising level, then cruising speed, RoC and finally, final approach speed. This is because it was assumed that the majority of new business model ZE aircraft would likely operate at secondary airports[39] (as noted also by WG3) with less capacity constraints whilst exact final approach speed may currently be only based on approximations.

Based on these categories, a proposed performance classification tree for ZE aircraft can be broken down as follows, resulting in 9 categories. Note that this tree can be further broken down into additional branches should new aircraft proposals be identified.

- VTOL aircraft
    - Cruising speed - <100kts
        - Cruising level - <1000ft
            - RoC - <250fpm
                - Group 1
    - Cruising speed – 100-200kts
        - Cruising level – 1000-5000ft
            - RoC – 500-1000fpm
                - Group 2
        - Cruising level - 1000ft-FL100
            - RoC – 1000-2000fpm
                - Group 3
- Non-VTOL aircraft
    - Cruising speed - <100-200kts
        - Cruising level – 1000-5000ft
            - RoC – 500-1000fpm
                - FAS - 60-100kts
                    - Group 4
    - Cruising speed – 100-200kts
        - Cruising level – 5000ft-FL100
            - RoC - 500-1000fpm
                - FAS - 60-80kts
                    - Group 5
        - Cruising level – FL100-200
            - RoC - 1000-1500fpm
                - FAS - 60-100kts
                    - Group 6
    - Cruising speed – 200-300+kts
        - Cruising level – FL200-300
            - RoC - 1000-2000fpm

[39] See section 8.2.3

        - FAS – 100-120+kts
            - Group 7
- Cruising speed - 300+kts
    - Cruising level – FL300-410
        - RoC – 500-1500fpm
            - FAS – 100-120kts
                - Group 8
        - RoC – 2000+fpm
            - FAS - 120+kts
                - Group 9

It should be noted that there are other AZEA WG5 partners, who did not respond to the questionnaire, that are developing new concepts of aircraft, new engines or new concepts of operation. At present, these are not integrated into the performance characteristic tree. Any evolution of new business models and their associated performance characteristics should be refined in future iterations of the CONOPS.

Whilst only the four performance characteristics have been used to develop the classification proposal, it should be noted that there are other performance characteristics that may also be considered as more detailed information on performance characteristics emerges.

It was noted from the questionnaire feedback that any aircraft integration issues between ZE aircraft and conventional aircraft are likely to occur outside of main cruising level bands of FL310+ as only one aircraft type / group was expected to cruise in this level band with a (current) non-standard rate of climb. That said, it is likely that the majority of integration challenges for the current proposed ZE aircraft will be focused below FL300, outside of the normal band of FLs currently flown by conventional aircraft.

It is also useful to note that whereas commercial ZE (and non-ZE) aircraft cruising levels may operate in the normal level bands, for shorter haul flights, even for larger jets, they may be capped at lower levels by means of the RAD to avoid busy airspace above, potentially leading to more interaction between aircraft at lower flight levels.

For performance on the ground, the majority of performance considerations should take into account a variance in turnaround time and the location of engine start-up together with the provision of infrastructure related to new propulsion methods.

Additional conclusions

To try to understand the potential differences between the performance of current aircraft types and ZE aircraft, a high-level comparison between ZE aircraft performance characteristics were made with aircraft types currently in the EUROCONTROL BADA aircraft performance tables to see if there were common aircraft types with similar performance characteristics. The conclusions of this analysis showed that:

- For ZE aircraft cruising at the main network cruising levels (e.g. FL300-410), a similar performance may be expected to current aircraft;

- For ZE aircraft cruising at very low levels (e.g. up to FL100), a similar performance to current aircraft may be expected;

- For ZE aircraft cruising at levels below the main network cruising levels (e.g. from FL100-FL300), this is where differences in performance may be more apparent;

- However, taking this into account, and comparing to existing BADA 3.15 performance tables, there may be existing aircraft with similar performance characteristics, for non-VTOL aircraft (based on a quick and dirty analysis)[40]:

  - Group 4 – a current aircraft with a similar performance is the Cessna 172;

  - Group 5 – an aircraft with a similar performance is the PA34 although the RoC appears dissimilar;

  - Group 6 – a current aircraft with a similar performance is the C208 except the rate of climb;

  - Group 7 - a current aircraft with a similar performance is the DH8D;

  - Group 8 – Similar current aircraft include the EA50 (a very light jet) and the C510 – the climb rate appears to be very low or a jet but the aircraft is alone in this performance category so performance data may not necessarily be fully mature; and,

  - Group 9 - a current aircraft with a similar performance is the A320.

- For VTOL aircraft, because they are new to the ATM system, at first it is expected that they will operate at locations mainly at existing aerodromes (heliports, airfields and airports) based on the infrastructure availability. Eventually these locations are expected to evolve to include city locations or new vertiports.

Based on this analysis it appears that the main performance difference between ZE aircraft and current aircraft could be the rate of climb (RoC) and the final approach speeds (FAS) although more information can potentially be obtained from one to one discussions with AZEA OEMs in order to understand the maturity of some of the expected performance data for ZE aircraft.

[40] C172 - Cessna 172: a single engine piston aircraft seating 4

PA34 – Piper Seneca: a twin-engine piston aircraft seating 6

C208 – Cessna Caravan: a single engine turboprop seating 14

DH8D – Dash 8 Q400: a twin-engine turboprop seating up to 90

EA50 – Eclipse 500: a single engine business jet seating 6

A320 – Airbus A320: a twin-engine commercial jet seating up to 180

APPENDIX E - Generic use cases for AZEA performance groups

Group 1 – e.g. Volocopter VoloCity

We are developing a fully battery-electric eVTOL aircraft, part of a family that will cover the entire urban passenger and cargo market. This eVTOL with 18 distributed rotors will have two primary uses:

- Passenger carrying commercial operations from/to vertiports or integrated into airports (GA, regional or international hubs); and,
- Provision of EMS (Emergency Medical Services) from/to vertiports or integrated into airports (GA, regional or international hubs).

For commercial operations, these could be taken both in an urban environment (e.g. airport / to city centre vertiport – A-B) or outside of city locations (e.g. airport to airport / vertiport to vertiport, on a touristic sightseeing flight – A-A).

In the future, Volocopter believes that AAM will become a regular means of mobility and transportation that will diversify the options for the people to move around and between cities and regional hubs.

Group 2 – e.g. Ascendance Atea

We are developing a hybrid-electric VTOL aircraft powered with JetA1 fuel with the STERNA propulsion system.

Our concept Atea provides a regional mobility solution where the traditional transportation system is not fully efficient (or simply existing). The concept is based around regional operations to complement existing aviation and railway options, both inter-city and the connection of remote locations. Our operations are expected to be substitutions for helicopter operations, air taxi, regional cargo transportation, emergency medical services, medical transfers etc., operating from major hub to urban vertiport or urban vertiport to urban vertiport.

Examples of a typical operation could be:

- Passenger transport (4 PAX + 1 pilot) on regional flights which would substitute a helicopter operation, performing the same mission with 4x less noise and -80% CO2 emissions (e.g. passenger transportation, ecotourism, surveillance operation):
    - In areas where natural obstacles such as mountains or water bodies exist, more efficient mobility solutions are provided where ground transportation is circuitous and long-winded and travel by helicopter is not an environmental or economic viable alternative e.g. inter-island between the Balearic islands in Spain;

    - A new city to city mobility solution with a more direct, point to point transportation system, without the additional hurdles of transit to the airport, via new infrastructures (vertiports) closer to urban centres, enabling an interconnected and multimodal mobility network and a direct, point to point trip from city A to city B e.g. between already well-connected city pairs or new city pairs such as London to Paris or Riga to Daugavpils;

  - The provision of mobility solutions, as a regional alternative to helicopter flights within metropolitan areas where natural obstacles exist that lengthen the trip using ground transportation, such as in large metropolitan areas with heavy congestion and inefficient transportation systems e.g. across Paris, Berlin, Madrid etc.;

  - Mobility solution in underserved areas can be provided with an efficient, infrastructure-light transportation to link those areas e.g. a route between Toulouse and Clermont-Ferrand where no current direct plane route or high-speed rail connection is available so a stopover is required in Paris.

- Medical services (1 patient, 1 medic, 1 paramedic + medical equipment) to transfer patients from a secondary hospital to a central one on a typical distance of 100 to 200km

- Cargo transportations: liaisons between major hub (e.g. Cologne or Frankfurt) with local distribution centres around cities, typically distance 200-250km

- In the future we expect the number of regional eVTOL routes will grow to better complement the existing transportation network and reduce CO2 emissions by offering the most efficient solution on a given trip. This will be facilitated by the integration of such operations in ATM rather than segregation (corridors) enabling optimised flight routes.

<u>Group 3 – e.g. Lilium Jet</u>

The Lilium Jet, as one example for a Regional Air Mobility aircraft, is a VTOL capable aircraft featuring forward canards and main wings with a distributed propulsion system providing vectored thrust. The core technology is Ducted Electric Vectored Thrust (DEVT), which uses 30 ducted fans as the propulsion system allowing for the combination of safe and low-noise vertical take-off with efficient cruise flight performance utilizing small ducted high-tip speed propellers. The fans are embedded on the canards and main wings in a 6:9 configuration and can rotate to provide lift and thrust in different directions. The aircraft is designed to be simple, safe, low-noise and efficient. It can carry up to six passengers and one pilot with a cruise speed of over 250 km/h over a physical range of 250 km (operating range initially expected to be 175 km).

From an operational point of view, the Lilium Jet can utilize any type of infrastructure that is designed to receive aircraft. Lilium foresees operations targeting existing helipads and major hubs at the start of entry into service – modified accordingly to accommodate operations of VTOL aircraft - as there will not be many dedicated vertiports available. By 2028, operations may also be seen at secondary, regional and GA airports. As the eVTOL business scales up, it is expected that that dedicated (new built) vertiports will emerge in the vicinity and inside of cities and in rural areas.

The Lilium Jet serves the market of regional air mobility (RAM), connecting cities and regions with high-speed, low noise, sustainable transportation service. The Lilium Jet is not an air taxi and the main operations are expected to serve the sectors of business aviation, general aviation, regional commuter and airport transfer traffic.

Lilium believes these routes can generate meaningful time savings for customers, including both enterprise and general and business aviation customers, at a lower cost per seat-mile, while allowing the achievement of higher load factors per jet than intra-city services would be able to generate. Services will be launched with a few, high-demand routes and grow over time, as the services gain support and acceptance among our customers.

A network developed for RAM will enable communities to connect where conventional high-speed connections previously did not exist. As significantly less infrastructure (and costs) is needed to develop eVTOL landing sites, both for conventional airports and ground based means of transport, remote regions can be connected through small investments and become more attractive.

Longer-term, the network will expand to provide high-speed connectivity to all major urban and suburban cities within a region which may be expected to be substantially cheaper and faster to deploy than traditional high-speed rail infrastructure.

Regional Air Mobility VTOL aircraft, like the Lilium Jet, are expected to operate a variety of mission profiles over their lifetime. Initially, a typical operation will cover 80-150 km connecting airports, cities and first/last mile destinations. As battery technologies evolve, this will likely increase to around 300km.

In the future, Lilium expects eVTOL services to be commonplace in all major cities across Europe in 2050, increasing trade between cities through facilitating faster connections. Regional Air Mobility has a huge potential to develop into a regular mode of transportation, connecting regions or cities with regions in areas where the traditional ground transportation systems are limited in demand, speed and infrastructure. With the technological advancements, in particular in the area of batteries, Lilium is convinced that bigger (CTOL) aircraft with 50+ PAX seats can be developed covering ranges of more than 1000km by 2040. Lilium's initial aircraft architecture will serve as the basis to develop a whole family of sustainable aircraft in the future catering to an even larger market. As battery capacity continuously evolves, Lilium's technology could potentially fully electrify commercial aviation at distances of up to 1000 km within the next 10 years. This corresponds to an addressable market of up to ~55% of all commercial flights and 70% of all business jet flights in Europe.

WG1 considers that by 2050, aircraft similar to the performance characteristics of groups 1-3 will have a 100% share of the eVTOL market with an estimated 20,000 eVTOL aircraft already delivered in Europe by 2050.

<u>Group 4 – e.g. Blue Spirit Dragonfly</u>

The Dragonfly is a hybrid-electric hydrogen fuel cell powered aircraft with 12 propellors, each with its own pod, with 6 pods to a wing. Each pod is built with a H_2 fuel cell, an electric motor and a propeller.

The concept foreseen for the Dragonfly is as a training or leisure aircraft with customers expected to be flying schools or GA / leisure pilots. Due to the STOL behaviour of the aircraft, operations may be allowed from the vast majority of existing runways, both concrete and grass.

For the pilot training concept, the Dragonfly can seat up to 3 students plus one instructor aboard. Training will cover the complete training regime (i.e. take-off and landing practice, navigation, manoeuvrability etc.). It means the flights may be used for take-off and landing / circuit practice at the same airport as well as a 2 to 3 hours flight with navigation practice. For navigation missions, the aircraft will seat 2 students and one instructor. Halfway through the mission the first student will land and swap position with the second student who was previously an observer. This second student takes off and continue the mission to go back to the base airport.

These pilot training schools will have a captive fleet meaning they require a minimum amount of stations to operate, the larger stations being located at the base airport and the other stations at important airfields to where navigation missions are likely to take place.

In the future and as the technology develops, it is expected that a family of larger aircraft (below 19 pax to remain within the CS23 scope) may be certified. These aircraft might be used for additional market segments such as taxi aircraft (transport of passengers from secondary, regional or general aviation airport to another one) for 2 to 3 hour flights, up to a range of around 700 km.

WG1 considers that by 2050, ZE aircraft with similar performance characteristics to Group 4 aircraft will constitute an estimated 20-25% of around 2500 aircraft of a similar category expected to be delivered in Europe by 2050.

Group 5 (1)– e.g. VÆRIDION Microliner

The VÆRIDION Microliner is a full battery-electric, multi-engine, single-propeller aircraft that is non-pressurized and capable of carrying up to 2 pilots and 9 passengers. The aircraft is designed to provide fast short-haul air travel services, with the intention to connect regional airfields and decentralized regions. The aircraft is capable of flying Visual Flight Rules (VFR) and Instrumental Flight Rules (IFR), and Instrumental Meteorological Conditions (IMC) Commercial Air Transport (CAT) operations.

The Microliner is designed for Regional Air Mobility (RAM): it will operate in a decentralized network of secondary, regional, and general aviation airports (with both grass and concrete runways), as well as feeding hubs for connection flights. Generally, these operations will be operated on both a scheduled and / or charter basis. A typical mission under nominal conditions for the Microliner aircraft is therefore flying passengers and / or cargo between (regional) airport pairs up to 400km IFR distance. Typical cruise altitudes are between 5,000 to 10,000ft, as the aircraft is unpressurized. To support regular IFR operations and provide flexibility in bad weather operations, airports need to be equipped with an ILS or GPS precision approach system together with the necessary battery charging and thermal conditioning ground equipment. The multi-engine propulsion architecture, together with a maximum take-off mass of below 5,700kg, will also allow the Microliner to perform single pilot CAT operations.

In the future, because of technological advances in batteries and taking advantage of potential new legislation banning or reducing conventional domestic flights, VÆRIDION expects that the RAM market will see a significant increase until 2050. Compared to the current situation, it may be expected to see more full-electric aircraft, in the 6 to 19 passenger range, starting to operate from secondary and regional airports as operations de-centralise. One major benefit of RAM is the conventional take-off and landing, which does not require the construction of new (vertical) take-off and landing infrastructure, like vertiports. Furthermore, it avoids the need of building additional infrastructure related to other modes of transport (e.g., new highways, railroads etc.) in places where it does not yet exist. Ultimately, RAM will allow travellers to save door-to-door travel time in an energy efficient and sustainable way.

An increased number of IFR movements will lead to workload pressure on ATCOs so there will need to be appropriate automation and innovation to develop solutions to reduce this pressure.

Group 5 (2) – e.g. VoltAero Cassio 480

The Cassio 480 is a 6-seater (1 pilot, 5 PAX) general aviation aircraft, powered by a proprietary hybrid-electric powertrain. The Cassio 480 will be operated within a RAM environment which will entail operations in and between regional airports, general aviation airports, executive airports as well as potentially major hubs, especially if performing ‘hub and spoke’ type operations.

As part of a RAM network, typical operations will involve scheduled regional operations, air taxi, charter and in the future, on-demand services, upon system maturity. Furthermore, private ownership, including in the frame of business aviation, as well as fractional ownership, depending on operator availability, are possible. Finally, cargo and special operations, such as medevac, are envisioned.

In the future, as battery gravimetric specific density values gradually increase with new and improved battery cell chemistry, RAM stands to experience a re-invigoration it has not seen since the 1950’s-60’s, when dedicated regional routes were abundantly available. The economic viability of such routes gradually decreased over time, in large part due to the increasing unsustainability of fuel costs and decreasing passenger numbers. Consequently, scheduled flight operations largely gravitated towards major hub airports, with a small minority of airports responsible for handling the large majority of passenger traffic. With 63% of global flights being less than 1100km (OAG), the market for RAM is extremely large.

With airport capacities continuously being squeezed by an ever-rising volume of traffic coupled with increasing regulatory restrictions aimed at curbing climate change, the difficulties stemming from this trend will only be further exacerbated with time. The introduction of a fundamentally new type of vehicle, using new types of propulsion and energy storage (battery, hydrogen, etc.) which could integrate into a de-centralized, regional operational network in a more cost-effective, clean and harmonious manner could relieve the growing pressure on hub airports by developing the RAM network, which has the potential to take over regional operations.

Electric aircraft and their variants are the key element of this formula, and as battery energy density values increase, so will the autonomy, range and payload capacities of hybrid aircraft at first, ultimately transitioning to full electric powertrains, which would allow to expand regional networks and bring costs down.

<u>Group 6 – e.g. Pipistrel Miniliner</u>

We consider two concepts:

- A commuter concept travelling from to / from a home base with several stops of up to 200NM in between; and,
- A micro-feeder concept feeding passengers from local airfields to larger hubs.

A fuelled / charged aircraft will depart the base airfield (with appropriate charging / refuelling infrastructure) and fly between local airfields (any airfield with grass, gravel or concrete RWYs of a minimum 800m length) for a maximum of 5 hops of up to 200NM long. The aircraft will then return to base for refuelling / recharging. Operations are commuter based between local airfields that are currently under-utilised.

The aircraft will carry up to 19+1 passengers and crew.

In the future with these concepts, we will see the rejuvenation of local airfields as enhanced operations encourage and support local investment and infrastructure development. As the micro-feeder concept is utilised, the local airfields will become starting points to air travel and enable integrated air transport from local airfields to larger / major hubs.

WG1 considers that by 2050, ZE aircraft with similar performance characteristics to Groups 5-6 aircraft will constitute an estimated 23-28% of around 750 aircraft of a similar category expected to be delivered in Europe by 2050.

Group 7 – e.g. Maeve 01

Maeve 01 is based on a conventional RAM aircraft platform, fitted with a full-electric propulsion design. The concept foresees operations by regional operators in the 50pax turboprop category, with the all-electric Maeve 01 allow regional operators to offer their customers true zero-emission flight and increase operating profitability. Maeve's aircraft platform design will enable future variants to increase payload-range by means of hybridization of its propulsion system while maintaining the Bill of Materials (BOM).

With its short-take-off-and-landing (STOL) capabilities, Maeve 01 may operate from all large commercial airports as well as many smaller regional airports with a minimum take-off field length of 1150m.

Maeve 01's target market will be focussed on regional turboprop carriers and small cargo operators. Maeve envisages its beachhead customers to arise from internal commitment to sustainable air travel, local abundance of green electricity (e.g. Scandinavia) or areas impacts by governmental mandates to reduce emissions (e.g. France).

In the future, with the stepwise improvements in battery energy density and the development of its aircraft derivatives, Maeve expects grow both in routes coverage and passengers numbers and with that unlocking new markets to sustainable flight.

WG1 considers that by 2050, ZE aircraft with similar performance characteristics to Group 7 aircraft will constitute an estimated 17-22% of around 1550 aircraft of a similar category expected to be delivered in Europe by 2050.

Group 8 – e.g. Beyond Aero BYA-1

The BYA-1 aircraft is a hybrid-electric hydrogen fuel cell-powered midsize business jet.

The concept of Beyond Aero focuses on business aviation, operating at all type of airfields. With environmental focus often unfairly targeting the business aviation sector, this represents an opportunity for business aviation operators who wish to decarbonise their fleets, potentially ushering in a new era of zero-emission corporate jet travel.

A typical operation would see 4-8 pax on a city pair of up to 800NM enabling travel between the top business aviation airports such as Le Bourget, Nice, Geneva, London Farnborough, London Biggin Hill etc.

In the future, all will depend on the availability of the relevant infrastructure and where it is in place to refuel small and certified aircraft with gaseous hydrogen, evolving then to facilitate the storage and refuelling capabilities for liquid hydrogen for bigger aircraft.

WG1 considers that by 2050, ZE aircraft with similar performance characteristics to Group 8 aircraft will constitute an estimated 3-8% of around 4200 aircraft of a similar category expected to be delivered in Europe by 2050.

Group 9 – e.g. Airbus ZEROe

Airbus is working on two different concepts for commercial air transport ZE aircraft – the ZEROe 100-seater and the ZEROe 200-seater.

The Airbus ZEROe 200-seater is an evolution of todays medium-sized single aisle commercial aircraft that may be fuelled by 2 different propulsion technologies: hydrogen combustion technology and electrical motors powered by fuel cells. This propulsion could be also used in a hybrid mode, the combustion being supported by an electrical motor powered by fuel cells in that case.

ZEROe operations will be operated by commercial aviation. They should operate mainly from major hubs and from secondary airports, as with current operations, with one potential constraint at entry into service being the necessary infrastructure availability for hydrogen storage and fuelling.

The length of a typical sector will depend on the airline and region, but for the 200 seater ZEROe aircraft may be up to 2000NM bringing flights between Helsinki – Gibraltar or Glasgow – Larnaca into range.

WG1 considers that by 2050, ZE aircraft with similar performance characteristics to Group 9 aircraft will constitute an estimated 5-10% of around 8500 aircraft of a similar category expected to be delivered in Europe by 2050.

ALLIANCE FOR ZERO-EMISSION AVIATION

FOR HYDROGEN AND ELECTRIC FLIGHT