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A ROADMAP FOR FLIGHT AUTOMATION IN ADVANCED AIR MOBILITY.

Creating an Automated Airspace Management and Vehicle Guidance System.

SKYROADS

EXECUTIVE SUMMARY

Skyroads AG, Munich, Germany is developing, testing and implementing an Automated Airspace Management and Vehicle Guidance System (AAVS). It is abundantly clear that a system which helps guide complex, three-dimensional traffic in congested airspace will be needed soon. Legacy ATC systems are not able to support the urban transport mode. Legislators and regulators are expecting the industry to supply solutions. Skyroads is the first company world-wide to make a comprehensive proposal. Fundamental considerations for this solution are found in our previous White Paper "Air Traffic Control for Urban Air Mobility". The operational tasks to be solved are widely acknowledged within the current deliberations by the industry and the rulemaking bodies.

In this White Paper, Skyroads addresses two crucial considerations for the further development of Advanced or Urban Air Mobility (AAM/UAM):

- How to achieve interoperable air transport automation leading to autonomy?
- How can the systems pursuing that goal add value to AAM/UAM until the required automation has been achieved and is adequately regulated?

A failure to answer these questions will jeopardize billions of investments in vehicle development.

In the chapter "Introduction", we outline the fundamental boundary conditions for the development of traffic management. We talk about the human-centric approach that guides general thinking to this day, discuss different pilotage concepts as well as certification requirements and set the scene in which development needs to take place.

In "Industry Maturity Levels" we look at those levels in order to define the market phases in which any timely development needs to supply value.

We then present in "Approaches for Simplified Vehicle Operations", an analysis for international activity with regards to the concept of Simplified Vehicle Operations, as a credible approach towards automation.

Our outside analysis concludes in "Barriers to Flight Automation", with an overview of challenges to be solved or sidestepped, in order to advance AAM/UAAM speedily.

In "Skyroads Innovation" and "Skyroads Architecture", we define the set of requirements to which an AAVS needs to be developed and briefly argue the fundamentals of our design.

In "Skyroads-enabled path to Flight Automation" and "Benefits", we show how our AAVS supports VFR and RPAS approaches simultaneously. It argues that we create the unique opportunity to speed up development. At the same time, our approach creates credibility and service record for early certification.

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ABSTRACT

Flight automation is key allowing the emerging Advanced Air Mobility industry to scale. Trained pilots and air traffic controllers are scarce. The required high safety levels demand that new avionics and traffic management systems need to be developed, and full operational integration of unmanned and manned operations of air vehicles is needed without adding additional human risk factors. At the same time, there are generally recognized gaps in current aviation rulemaking and regulations:

- A reference definition for what constitutes an urban airspace is missing.
- The current risk assessment methodology for drones does not consider air risk with other unmanned aircraft.
- Separation values between manned and unmanned air vehicles are not defined.
- Current rules of the air need to be amended or a new category needs to be added.

Easy solutions, largely based on legacy technology, are precluded by the fact that there are additional technological gaps challenging certifiable solutions:

- Data communication is currently not a safety-critical element of aviation and currently available design assurance levels are low;
- Satellite-based navigation (GNSS) does not currently provide either the accuracy, integrity or the reliability required for scaled operations.

Skyroads is developing a system that unifies air vehicles, vehicle operators and air traffic management[1] in one safe transport system, while bridging missing gaps in technology and rulemaking. In a first White Paper written in July 2020 we described our development approach. **Our new White Paper outlines two alternative paths to flight automation and identifies how a unified approach will provide added value**:

- Piloted flight, with ever increasing levels of automation, which relieves the pilot of more and more tasks, until he is “man-over-the-loop”; frequently referred to as Simplified Vehicle Operations (SVO).
- A Remote Pilot In Command (RPIC) acts as an intermediate step towards full flight automation, based on existing rules for Remotely Piloted Aircraft Systems (RPAS).

The two paths are generally assumed to remain separate until at least the turn of the decade (2030). Moreover, the transition to fully automated flight will be even further off.

Skyroads aims to prove that both paths can be significantly accelerated and the likelihood of regulatory approval can be increased by providing a unified system solution.

[1] As well as required data providers, vertiports, legacy air traffic control and other essential collaborators.

INTRODUCTION

“Advanced Air Mobility” (AAM), a superset of “Urban Air Mobility” (UAM) and “Regional Air Mobility” has the potential to become a sustainable and viable part of an intra- and inter-urban transport modal mix. Being very light on en-route infrastructure, the flexible and ad-hoc addition of routes and provision of added services becomes a fast and cost-effective possibility. Cash outlay for added transport offerings is minimal compared to roads, railroad tracks and tunnels. Chemical emissions are expected to be minimal. Advances in expected noise reduction are coming along. Visual cluttering and noise footprint management can be minimized by positive guidance systems such as the Skyroads development. In summary, AAM integrated with a Skyroads system will provide the oft-quoted digitization benefits on a scale of national economic relevance.

Automated flight is key if the business models for the emerging AAM industry are to scale to the point where the size of eVTOL fleets surpasses the size of current airline fleets. There simply will not be enough pilots to fly all these air vehicles (AVs), nor air traffic controllers to guide them safely. Additionally, both the cost and weight of pilots significantly reduce the operating margins for transport providers, rendering otherwise attractive use cases uneconomical. Moreover, significant fulfillment parameters such as safety, time-to-travel, flexibility and environmental impact can be improved by automation. This realization is a powerful driver for a shift towards flight automation, Simplified Vehicle Operations, and Remote Pilotage.

Human-centric vehicle guidance in legacy aviation

Since the beginning of powered flight in 1904, a trained pilot commands his or her aircraft with final responsibility and authority to execute actions that ensure safe passage and transport of passengers, aimed at minimizing loss of life and cargo. Historically and to this day, the pilot’s cognitive abilities and training enable him/her to provide manual command of the aircraft while coping with stress and outright danger. This has filled the performance gaps between system elements (ground control, navigation aids, aircraft performance) and system capabilities (aircraft handling qualities and equipment performance). The minimization of collateral or third-party damage and so-called ground risks are an afterthought in aviation and have only begun to make a significant impact on regulatory concepts in the past 30 years.

The entire system of aviation safety is based on the assumption that no seamless and automated interaction between system components is required, since a human makes up for the deficiencies and bears final legal responsibility.

While safety has been enhanced by creating increasingly self-sufficient subsystems and systems informing the pilot and simplifying his/her tasks, including CAT III auto-land systems and automated pinch-hitting capabilities in autopilots, flight in the 2020s and particularly its legal underpinning remains human-centric. This thinking needs to change fundamentally for Advanced Air Mobility to succeed and scale. A case can be made for AAM as a new form of aviation with a new rule set. This is mentioned with increasing frequency in regulatory deliberations. Occasionally this upcoming or wished-for rule set is referred to as "Digital Flight Rules" (DFR). We will use "DFR" in this paper to denote that future piece of regulation.

Piloted flight

As outlined above, a large part of the regulatory effort regarding flight operation to this day is based on the assumption that a (human) pilot on board the vehicle bears legal responsibility for the safe conduct of the flight and for preventing or at least avoiding danger and preventing or minimizing damage to aircraft and cargo.

Air vehicle manufacturers wishing to certify their most recent development have no other option than to use existing regulations. With regard to eVTOLs, the vehicle itself may be certifiable as a hybrid of existing airplane and rotorcraft regulations. With regard to its operations as a passenger-carrying vehicle, and in the absence of any form of "Digital Flight Rules", there is no alternative to the VFR/IFR flight rule set, which, again, assumes a pilot to be on board the vehicle.

Several eVTOL developers have introduced a new corporate function: the "Chief of Automation" (or similar). This person is charged with designing a development roadmap that shows investors and potential customers how the product can and will evolve in order to operate the air vehicle (AV) without an on-board pilot, thereby freeing up space and payload capability and lowering the operating cost of the vehicle. In this context, SVO will play a significant role, especially if the vehicle manufacturer's development is geared towards passenger transport.

The concept of SVO was originally proposed for General Aviation (GA). The main driver for the application of the SVO concept in small aircraft for GA was to raise the safety record of GA[2] and to eliminate the most common causes of fatal accidents. In order to fully apply this concept to AAM, flight rules and safety regulations need to be changed and/or amended. An initial set of regulatory requirements ([2], [3]) for smaller work drones is already available, and further concepts and requirements for passenger-carrying Air Vehicles (AV) are under development in the US [5, 8, 12], and the EU [15].

The Skyroads development will offer support on this path by providing support to pilots, providing situational awareness and flight guidance, reducing their workload and, subsequently, their qualification requirements and allowing them to operate in complex operating environments that would otherwise exceed their cognitive abilities.

Visible early use cases are likely to appear as soon as 2024-2026. These will be experimental in nature (not fully certified, but based on certifiable technology) and will be aimed at proving the utility of AAM concepts. These could be point-to-point connections in protected air corridors or leisure applications such as sightseeing or joyrides.

[2] The accident-prone segments of GA tend to be owner-flown aircraft.

Remotely piloted flight

In the past, the main drivers for remote AV control were either military requirements where the risk to a human on board was deemed too high, or low-risk leisure pursuits. No commercial passenger transport has been managed via remote control. This mode of operation is frequently referred to as Remotely Piloted Aerial Systems (RPAS).

An accepted form of heavy drone operation has been established by military applications in which multi-ton drones can be flown over long distances, with appropriate visual clues, telemetric flight instrumentation and in full radio contact with all applicable airspace authorities. Essentially, this mode of operation mimics the safety considerations that are in place for instrument flight (IFR) in a civilian environment.

We see remote pilotage as a viable path towards automated flight. Once cargo operations (no risk to occupants, but considerable ground risks) have proven that they can be safely conducted, this could progress towards passenger transport. Moreover, once it can be shown that a single operator can safely be put in charge of multiple drones simultaneously, the cost of oversight can be reduced.

The advantages of the RPAS approach are obvious: given the weight-sensitivity of eVTOLs, reducing the vehicle load opens up payload-driven revenue options at an earlier stage. On the other hand, this approach is currently limited to cargo operations. Vehicle operators whose development path can accommodate cargo-carrying vehicle-derivatives may opt for this route.

Standard traffic volumes

VFR flight is the human-centric solution to safe flight operations with essentially no central management. Probably one of the most complex traffic situations that can be imagined in the VFR context is the mass arrival of VFR-operated aircraft at the annual Experimental Aircraft Association's Fly-In in Oshkosh, Wisconsin, USA. On average there are up to 125 landings per daylight hours (16,800 landings in 11 days in 2019), which corresponds to one landing every 28 seconds. This rises to about 1 landing in 15 seconds at peak times. A significant number of pilots will not land in this environment due to its sensory and cognitive demands.

In order to make AAM landing infrastructure work at commercial levels, landing frequencies will need to exceed the numbers that can be comfortably achieved with human-centric vehicle control.

Non-cooperating traffic

Non-cooperating traffic commands wide attention in the regulatory discussion. Legacy aviation was originally designed to manage aircraft that were not systematically connected. Therefore, practically every "other aircraft" was non-cooperating in the present sense of the word. VFR flight solves this by placing human cognition at the center of its safety and avoidance strategy.

Both in order to reduce pilot workload and performance requirements or to dismiss the human element entirely from the control loop, the ability to cope with not-planned-for occurrences (such as non-participating vehicle incursions) needs to be addressed.

While strategic deconfliction understood as assigning separated airspaces to each AV could take place in busy urban environments by several means, there remains the question of how to conduct tactical deconfliction: how are not-planned-for or unknown aircraft (or other obstructions) systematically avoided? Such occurrences can be divided into AVs willing/able to cooperate and those who are intentionally malignant (rogue vehicles).

The Skyroads approach proposes solutions to the non-cooperating traffic challenge. Our solution does not primarily rely on vehicle-borne sensors emulating the pilot's perspective and cognitive abilities but is based on:

- A solution allowing the vast majority of flights to be safely conducted with strategic deconfliction only, making the requirement for tactical deconfliction a non-nominal event; and
- optional onboard sensing to support tactical deconfliction with non-cooperating vehicles (performance requirements for such a sensor are assumed to be lower as the operating mode for such non-nominal events is low demand); and
- an executable option to centralize sensing infrastructure, reducing vehicle complexity and continuous airworthiness effort.

Airspace considerations

Aviation relies on geometrically defined volumes within a country's sovereign airspace which can start at ground level, with an upper limit of 60,000ft (about 18,300m). Different airspaces have varying requirements for vehicle performance, equipment and differ with regard to primary vehicle separation responsibility (pilot or air traffic control).

Metropolitan areas in Western countries usually are not protected by any special airspaces. Limitations for overflight of these areas by general aviation, military or transport aircraft are largely defined by minimum en-route or minimum safe altitudes. A desire to protect airspaces for exclusive drone or eVTOL operations would therefore mean that present users of the airspace might either be displaced, might be required to carry additional equipment and/or might be required to conform to additional rules of the air, all of which may lead to political opposition.

There are considerations to segregate "work drones" from "passenger drones" by airspace, or to create air corridors for passenger drones (similar to current helicopter routes).

Skyroads believes that segregated airspace can be a solution in an interim period when traffic volumes are still low. These considerations aim for a geometrical separation of types of operation, safety requirements and regulatory operating burden/cost. However, competition for airspace and its efficient use will eventually call for integration. To enable early uses of the technology aimed at eventually providing full-blown AAM, interim steps will need to be taken. One current approach is to create "aseptic" airspaces in which only one type of aerial operation is allowed, and legal and/or policing approaches are used to maintain the sanitary condition of that airspace. This approach is taken for BVLOS flight test areas within existing controlled airspace, set aside for drone flight tests.

Aseptic airspace can also allow for initial use cases to furnish proof of commercial viability and suitability of AVs, traffic management and landing infrastructure technology within that protected space. In a controlled environment, methods to safeguard against non-cooperating and rogue traffic can be tested and established with minimum risk. Skyroads uses this type of environment to test its development and is actively soliciting partnerships to expand the application of its solution.

Traffic flow management

An overall optimized plan is required to make transit of aircraft through an airspace as efficient as possible and thereby maximize the possible throughput (affecting transport scalability). This plan needs to take into account the local restrictions (no-fly zones and curfews) as well as the locally desired routing structures and physical requirements (corridors, vertiports, en-route altitudes, UAM-assigned and legacy airspaces, etc.).

Equipment

Substantial parts of an aircraft's critical equipment are certified independently from the aircraft. This is significant, since apart from physical characteristics such as speed, range, payload and energy consumption, this equipment defines the aircraft's operational capabilities (e.g., performance-based navigation) and the uses an aircraft can be put to. The regulator has satisfied himself that a vehicle with this equipment on board will have specific operational capabilities, if the equipment was installed properly (assured by original certification or approved installations).

While AV certification is an important step for an OEM (Original Equipment Manufacturer), certification by itself does not necessarily indicate a vehicle's suitability for a given operational scenario. Further certification is required for all operational aspects, including the transport organization itself, crew qualification and currency, maintenance and continued airworthiness and landing infrastructure. As a general rule, all of the above-mentioned prerequisites for a given operational scenario need to be met, proven and maintained in order to operate a vehicle.

In this paper we will argue how an integrated system as currently being developed by Skyroads[3] will open a path towards SVO and RPAS under the current regulations in the US and in the EU. Skyroads believes that in order to manage a significant number of vehicles in dense and complex airspaces, a unified method of commanding these vehicles will be required.

[3] An early prototype of this system was tested with several drones in September 2021; an evolved prototype will be validated in a large-scale demonstrator in the Munich, Bavaria region in 2022.

INDUSTRY MATURITY LEVEL

Maturity levels of vehicle manufacturers

With few notable exceptions (e.g., Wisk, Wingcopter), First Mover eVTOL manufacturers are building (and certifying) their present-generation vehicles for an on-board Pilot In Command (PIC). This allows them to start operations at the earliest time possible[4]. Followers (see table below) can dedicate more time and effort to building more advanced automation features into their vehicles, opening a path towards remotely piloted eVTOLs, and ultimately full flight automation.

OEM Stage	Maturity Level	Flight Rules	Required support by UTM/Flight Management/Guidance **during transition to full automation**
First Movers	Active testing of pre-production vehicles (100+ flight hours)	VFR/IFR RPAS	• Complex VFR/IFR • (High density) terminal operations • SVO
Followers	Advanced design, prototyping and early flight test	RPAS SVO	• Flight Guidance for flight test and demo • Contingency Management / Flight Termination • UTM for remote piloting and simplified operations
Conceptuals	Paper concepts, scaled models flying	Upcoming Fully Automated Flight Rules or DFR	• Relying on upcoming UTM for entire operations

Table 1: Maturity levels of present air vehicle developers (Skyroads analysis)

Skyroads uses the definitions in above table in order to address the requirements of similarly mature cohorts of developers/OEMs.

[4] Largely along existing VFR/IFR or RPAS operations models.

Market development phases

Summarizing countless published product and development roadmaps, Skyroads assumes that the market will develop in three distinct phases, which are largely defined by today's assumed readiness levels of various system component manufacturers and the most advanced embodiments of UAM-related technology.

Market Stage	Test Phase	Market Phase	Growth Phase
Time	2022 - 2023	2024 - 2026	2026 onward
Characteristics of most advanced AAM embodiments	Prototype vehicles and infrastructure are tested and demonstrated as proof of concept (POC); first certifications of vehicles (not necessarily allowing commercial ops)	First trial operations of vehicles and infrastructure to demonstrate operational suitability for commercially oriented use cases	2026: Early services, not necessarily fully certified 2028: Simple public services 2030: Increasingly demanding public services

Table 2: Market development stages (Skyroads analysis)

The timeframes quoted here reflect fairly aggressive statements made by AV developers. Skyroads assumes that between 24 and 36 months can be added without upsetting fundamental considerations.

In the mid-term (say as of 2028) and assuming that a significant number of developers will remain in the race, all possible development stages will be present at the same time, since contenders will have varying development start-dates and speeds.

APPROACHES FOR SIMPLIFIED VEHICLE OPERATIONS

The main goal of Simplified Vehicle Operations (SVO) is to reduce pilot training requirements and thus to train a sufficient number of pilots for AAM. There are several proposals for achieving automated, and eventually fully autonomous, flight through SVO. Different stakeholders, such as AV manufacturers, industry interest groups, regulators, or research organizations are working on SVO concepts. Five of these proposals are discussed in this chapter.

EASA
European Aviation Safety Agency

The European Aviation Safety Agency (EASA) is currently establishing a comprehensive set of new regulations to enable operations of UAS (Unmanned Aerial Systems) and aircraft with eVTOL capability and fulfill the potential of AAM.

In a recent Concept Paper [7], EASA defines and elaborates the assumptions and the criteria used for the amendment or creation of the EASA regulations needed to enable the operations of UAS in the 'certified' category and AAM.

The future changes to regulations would encompass:

- Initial Airworthiness
- Continuing Airworthiness
- Air Operations
- Flight Crew Licensing
- Air Traffic Management (ATM)/Air Navigation Services (ANS)
- Single European Rules of the Air
- Aerodromes and vertiports
- Security

The Concept Paper already contains a roadmap for the envisaged decisions by EASA (mainly planned for 2024-2025).

Although first air taxi operations are expected to be conducted with manned eVTOL aircraft, in the future such operations will be performed on the same platforms but remotely piloted; therefore, it is necessary to support the transitioning phase and ensure a smooth integration of these new operational concepts into the current aviation domain. The proposed regulatory approach does not differentiate between human transport eVTOL and cargo RPAS. Considering the large spectrum of operations envisioned in the context of UAS technology and AAM, EASA has identified three types of operations for UAS in the 'certified' category:

Operations type #1: IFR operations of UAS for the carriage of cargo in airspace classes A-C (ICAO airspace classification) and taking off from and/or landing at aerodromes falling under the EASA's regulation.

Operations type #2: Operations in the U-Space airspace of UAS for the carriage of passengers (e.g., air taxis) or cargo (e.g., goods delivery services) over congested (e.g., urban) environment or non-congested (e.g., rural) environment, most likely using pre-defined routes. These include operations of unmanned eVTOL capable aircraft.

Operations type #3: Operations of manned eVTOL capable aircraft for the carriage of passengers (e.g., air taxis), in or outside of the U-space airspace.

The following assumptions are considered for these types of flight operations:

- **A human is always in command**, autonomous operations are excluded;
- the remote pilot may control one AV at a time, or control simultaneously several AVs, also of different types and from different operators; and
- the handover of command is not considered, however the handover of control of an AV between different Command Units (CU), hence between different remote pilots, is possible.

In the EASA concept, there are also considerations for the CU in the AV type design. EASA expects that future UAS design will depend highly on automated capabilities and that the remote pilot interface will focus on flight management and monitoring functions, and that together with the availability of industry standards this may **allow for standardized CU designs that may be connected to different models of AV from different manufacturers**.

The UAS type design will need to identify the CU models that may be used to operate the UAS, including UAS specific configurations, instructions for connection and handover.

Furthermore, EASA expects the CU to be a highly modular system of components (screens, communication equipment, power supply, data link...) where some of the components might have an independent equipment approval and these may get a design approval in analogy to the concept of modular avionics.

> **The ground segment of the Skyroads Air Vehicle Control System also provides, among other things, what EASA refers to as a CU.**

EHANG | 亿航

Among the many eVTOL manufacturers, EHang appears to have a very ambitious vision of a future AAM ecosystem with autonomous flight operations. In a recent Whitepaper [6], EHang describes a future air mobility infrastructure where "smart" AVs are "autonomous", thus eliminating the need for a pilot on board the AV. The paper envisions a system using cluster management techniques and a centralized Command-and-Control center on the ground. In this scenario, **a single platform would control all AAM traffic in a city**.

EHang highlights that this concept goes beyond the definition of UTM [11], which is described as merely a "traffic management" system for uncontrolled operations.

For air-ground communications, the concept relies on commercial 4G and 5G mobile communications. Commercial mobile communications networks do not meet the reliability and availability requirements for communication in manned aviation, and the paper does not describe how safe and secure communications with and control of non-EHang vehicles could be achieved. The paper describes a vision for, but no transition path towards flight autonomy.

Finally, this concept appears to aim for a closed ecosystem, effectively eliminating competition between AV manufacturers or service providers in a given city.

GAMA

The General Aviation Manufacturers Association (GAMA) has increasingly served as a forum for advancing discussions about the arrival of eVTOL aircraft in the air transportation sector, and its membership now includes several of the pioneering start-ups in the field.

GAMA predicts significant evolution in the operating model over the next five years, with much of this driven by the concept of simplified vehicle operations, i.e., fully trained pilots will not necessarily be required.

GAMA has outlined a structured approach to automating pilot tasks in GA with the ultimate aim of increasing the safety record in General Aviation (GA). In a White Paper [9] published in 2019, GAMA proposes a path towards SVO using a modular approach to pilot proficiency by breaking down the various pilot functions into skill categories. Each skill category corresponds to a function performed by a human pilot that can be automated. The authors argue that **SVO can be implemented without additional rule-making**, and that incorporating SVO into GA would allow to mitigate many common causes of fatal incidents.

The paper proposes a revised set of pilot skill categories:

- Aircraft handling
- Aircraft system emergency procedures
- Cockpit/passenger emergency procedures
- Communication
- Detect and Avoid (DAA)
- Navigation
- Planning
- Pre-flight inspections
- Risk management/decision-making
- Systems management
- Takeoffs and landings
- Taxiing
- Terminal procedures

Reversionary modes can be taken over by automated pilot functions where it enhances safety.

According to this study, the safety case for SVO is clear: "six of the top nine causes of fatal accidents can be attributed to pilot error: Loss of Control, Controlled Flight into Terrain, Fuel, Unintentional Flight into IMC, mid-air collisions, low altitude operations." These pilot-induced accidents account for 75% of all fatal accidents.

In the US, the FAA has a regulatory construct that allows to issue pilot licenses with restrictions. This would allow for a clear path for industrial development of flight automation systems and SVO without the need for changes in the current regulatory system.

> **The Skyroads Air Vehicle Control System supports SVO concepts by providing a real-time Air Situation Image in the cockpit at all times.**

International Civil Aviation Organization

ICAO [10] estimates a 10-to-20-year timeframe before a new operational environment will emerge.

The paper argues that in light of the anticipated growth in the number of manned and unmanned aircraft, traditional ATC needs a paradigm shift. In the future a combination of automation and procedures, such as preprogrammed paths through urban canyons, will guarantee terrain, obstacle and traffic “clearance”. This will affect the role of ATC - **automation is expected to perform optimization at fleet level**. Also, the roles of pilots and air traffic controllers will evolve:

- Pilots will mainly manage risks and handle constraints; and
- air traffic controllers will mainly supervise airspace and intervene only in off-nominal situations.

Challenges in the near to mid-term include:

- The need for separation standards between the different categories of AV in AAM; and
- creating a situational awareness of **all** surrounding traffic.

The paper acknowledges that a **new or revised set of flight rules may be needed, with digital situational awareness on the ground and in the air**. These new flight rules would need to be integrated in a set of requirements allowing to ensure at least current safety levels. To summarize, management by exception will be the norm for both pilot and ATC.

Regarding UTM, ICAO has proposed a common framework with core principles [11], highlighting the need for operational procedures and rules of the air (e.g., right of way). Certification of the UTM system will be required, particularly when interacting with an ATM system. Policies for means of compliance or system approval for UTM systems are still a challenge. **A safety management system, as currently required by aviation systems for manned aviation, is needed.**

> **The ICAO view is consistent with the first Skyroads Whitepaper [4].**

NASA

In a research paper published in 2020 [13], NASA has proposed a framework for SVO. Four high-level functional groups are identified:

- Mission management (e.g., flight planning, contingency planning)
- Flightpath management (e.g., conflict detection and resolution)
- Tactical operations (e.g., hazard avoidance)
- Vehicle control (e.g., envelope protection)

These groups encompass all in-flight operations and decision-making functions. The NASA paper subcategorizes and sorts them by attributes that provide resilient system performance:

- Monitor
- Learn
- Respond
- Anticipate

This subcategorization allows to identify safety-critical functions that cannot be automated under current regulations, as well as those pilot functions that actually enhance safety.

Using this framework would support a human-centered approach to designing SVO solutions, i.e., retain pilot involvement broadly across all functions until permanent automation functions are certified and available. This design approach helps to avoid the risk of an "out-of-the-loop" unfamiliarity.

BARRIERS TO FLIGHT AUTOMATION

The limiting factors of airspace capacity in controlled airspace today are air traffic controllers' workloads and the cognitive capabilities of pilots on the one hand, and the ability to ensure vehicle trajectories to very close tolerances on the other hand.

The current ATM system is reaching its limits, and the expected UAS traffic and flying characteristics of UAVs (with no pilot on board and a higher level of automation) are different from those of manned aircraft. EASA considers that ATM is not the only appropriate means to safely and efficiently manage the upcoming UAS traffic. Therefore, the existing EU regulations for UAS operations in the 'open' and 'specific' drone categories need to be complemented with an EU regulatory framework. The new services defined there are called "U-space services" and are intended to ensure the safe management of UAS traffic.

In view of the emerging new forms of aviation, Airbus and Boeing argue in a joint paper [1] that ATM needs to be modernized and that interoperability needs to be ensured:

- Between ATM service providers;
- Between different vehicle types;
- Between different operation types.

Since UAS Traffic Management (UTM) and ATM need to converge, the paper calls for industry action to develop scalable and flexible new systems.

Furthermore, there are different levels of automation in UAS Traffic Management (UTM, highly automated) and ATM (human-centered). The question of how to integrate all types of drones into unsegregated airspace, and the conceptual work on automation of UTM-ATM procedures and interfaces is still in a very early stage [14]. As a result, we expect that in the short to mid-term eVTOLs will fly with a fully licensed pilot on board, and under Visual Flight Rules (VFR).

Different types of barriers exist that would need to be surmounted to operationalize higher levels of flight automation in AAM.

Service regulation barriers

U-space services in the EU, and UAM services in the US are still in an R&D stage.

Systems built for managing non-passenger-carrying UTM cannot organically be "upgraded" to reach the safety level required for regulatory certification. The two main standardization bodies RTCA and EUROCAE do not expect any changes to software safety standards in the next years.

Missing flight rules

- Separation minima (time or distance based) between manned and unmanned flight; Rules for handling non-cooperative AV
- Digital flight rules, i.e., VFR-like flexibility in Instrument Meteorological Conditions (IMC)
- Collision avoidance and Right of Way
- Minimum and maximum heights for aircraft flying in VFR or IFR
- Flight Plans
- Visual meteorological conditions to fly in VFR
- Instrument and Visual Flight Rules
- Services provided by air traffic controllers
- Unlawful interference
- Interception

Missing technology

- Common altitude reference system for manned and unmanned AVs
- Certified detect-and-avoid (DAA) systems
- Positioning systems (GPS-denied)
- Data communication (vehicle-to-ground/vehicle-to-vehicle; The data link service provider is not an aviation approved organization under the future regulation on the 'certified' category of UAS/eVTOL aircraft operations. Nevertheless, the data link, having safety critical functions will need to be under safety oversight through the safety management of the UAS/eVTOL aircraft operator. To facilitate this, voluntary industry standards might be used as Acceptable Means of Compliance.

Political challenges

- Willingness or ability to set aside sufficient segregated airspaces for system trials and service introduction
- Ability of communities to formulate operational requirements
- Ability of communities to provide real estate for landing infrastructure
- Ability or willingness of national or regional governments to provide reliable operating frameworks to transport service providers in order to reduce their development and implementation risk

SKYROADS INNOVATION

Skyroads will contribute to the development of the AAM industry by proposing and demonstrating a solution that adds a safe mode of human and cargo transport to the existing modal mix of urban and regional transport, while supporting the transition from human-in/over-the-loop operations to fully automated operation.

The Skyroads system provides a commercially viable means to meet the ambitious timelines quoted by the industry. Skyroads agrees that speed is essential in order to serve public expectations and to justify the investments already made into the industry[5].

The Skyroads system serves the following uses

- Passenger transport
- Cargo transport

It supports the following operation models

- Piloted flight
- Remote piloted flight
- Fully automated flight (and eventually autonomous flight)

It fulfills the following commercial requirements

- Enable cost-effective scalability of AAM in a simple, unified system
- Support vehicle developers on their individual paths to full automation
- Reduce vehicle acquisition and maintenance cost (common infrastructure)
- Open participation models for data-service providers
- Allow cities to retain ownership of their skies' use patterns
- Ensure interoperability and equitable access for all service providers
- Supply a business platform for operators/transport providers and XaaS providers
- Empower cities and local government to remain in control of the space above them

It allows certification as a safety-critical system while

- Combining required system elements, including vehicles, vertiports, legacy ATC, and
- bridging technological gaps

The Skyroads solution is an integrated system based on deterministic planning, optimization, deconfliction and positive control, while enabling full, real-time vehicle operation flexibility.

[5] Failure to make public transport offerings within the next decade may create industry-crippling disillusionment.

SKYROADS ARCHITECTURE

The combination of Skyroads features is enabled by the system architecture and a set of design tenets. Basics are quoted here in order to support the claims made in the following chapter "Skyroads-enabled path to flight automation".

The design goal is to provide the air vehicle, or the human pilot, with a continuous stream of deconflicted, system-compatible and continuously updated navigation information **on-board the vehicle**, that allows the vehicle maximum operational flexibility. As mentioned above, the reliability of this data stream needs to be substantially higher than some of the underlying technology is designed to (most notably the communication link).

The system is comprised of a ground station (GST) and an airborne segment, the Flight Guarding Computer (FGC), connected by a data link (DL) and an external link to the participating outside actors. A data repository, the Data Hub, contains the Air Situation Image (ASI) which represents all information required to create and maintain valid navigation solutions for the entire traffic system, at all times. Appropriate sub-sets of this ASI may be stored and continuously updated at various physical locations, most notably the FGC. There may be additional edge computing capability in proximity to the data link in order to assure latency-free availability of data throughout the system. The ground segment can be aided by ground-based sensors that allow for airspace monitoring and detection of the position of participating vehicles and the intrusion of non-participating vehicles and objects.

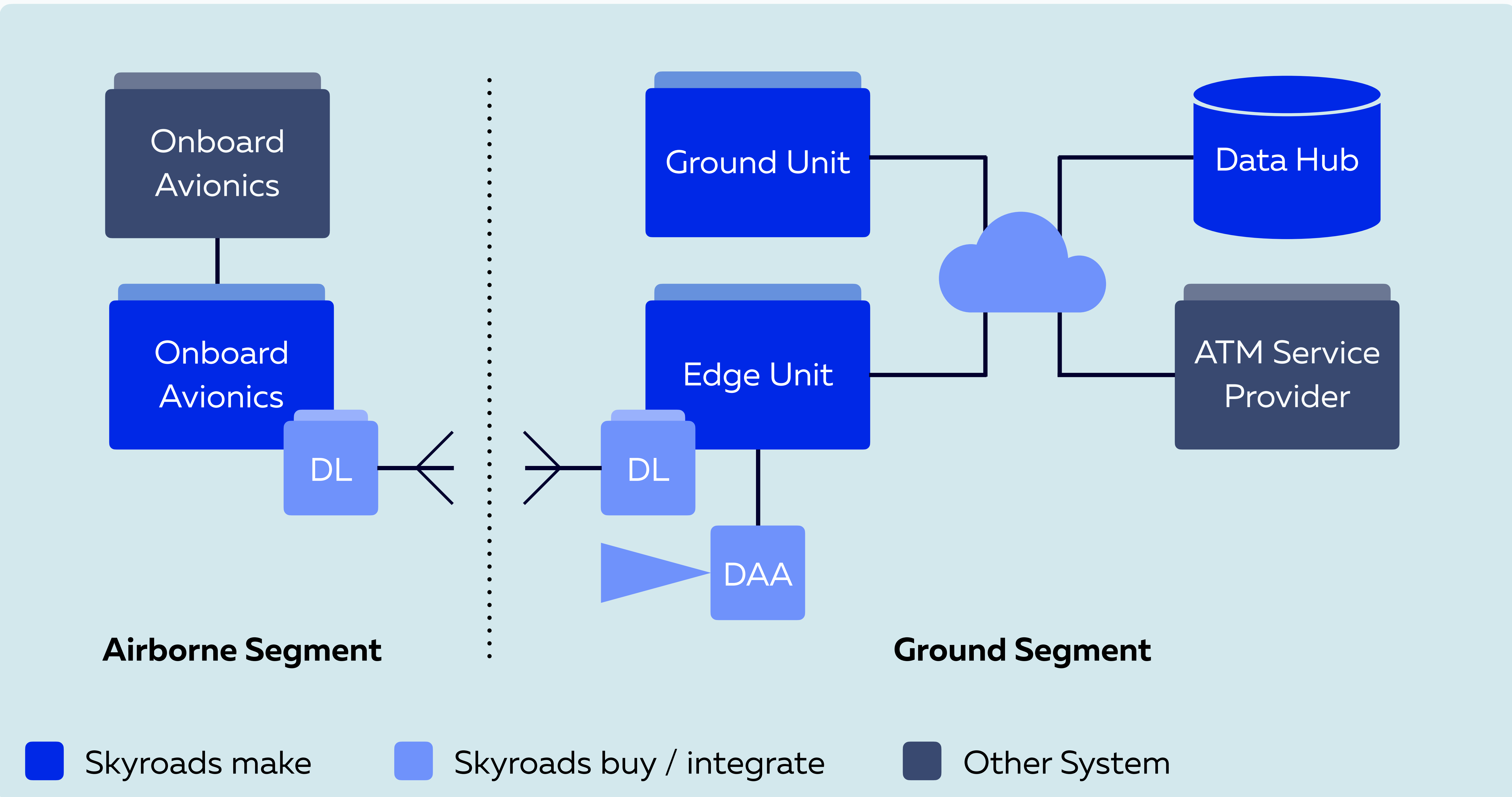

Figure 1: Skyroads system architecture overview

The FGC provides continuous navigation information to the vehicle at a very high design assurance level. It can enter reversionary modes when information reliability from the ground becomes unreliable or onboard sensors (including positioning systems) provide information in conflict with ASI information. The reversionary mode will override the ground information until the reliability of ground information or integrity of all available information has been restored.

The fundamental advantage of this solution is that all reversionary modes are identical throughout the fleet and are, therefore, fully predictable. This solution safeguards against failure propagation and runaway conditions throughout the system. The reversionary mode will include pre-determined safety-landing modes for non-nominal situations that are fully compatible with both the performance parameters of the vehicle itself and are fully coordinated with the capability of other vehicles to accommodate required plan changes as well as the ground infrastructure to accept ensuing short-term modifications of the overall traffic scheduling.

Compared to the bulk of current thinking, the Skyroads solution moves the demarcation line of nominal (strategic deconfliction) and non-nominal (tactical deconfliction) behavior very far towards the highly improbable. Standard traffic, even with highly agile plan changes (individual plan changes of AVs always lead to a fully harmonized total system solution) will always be nominal. Therefore, vehicles do not have to integrate local detect-and-avoid information via aircraft-based sensor systems into their nominal behavior. **This substantially reduces the required design assurance levels of onboard sensing and decision-making and significantly reduces continued airworthiness cost.** Moreover, it assures compatible vehicle behavior from day one. The system can prove its ability to perform during initial AAM stages and be in time for the foreseeable congestion of the mid-term future.

The chosen architecture ensures certifiability of the entire system, since it is based on a fully transparent and wholly deterministic and embedded (where required) design. Moreover, the integrated design allows for high development speed, ensuring early availability, to be compatible with presently claimed OEM planning.

This system allows for the integration of a large number of service providers to provide the data required to be present in the ASI.

It allows for interoperability, since the Skyroads avionics will have a very light footprint and be compatible with all conceivable vehicle architectures.

SKYROADS-ENABLED PATH TO FLIGHT AUTOMATION

Among eVTOL manufacturers, most early movers have chosen piloted flight for early certification, using existing (generally aviation-type) solutions and levels of automation to support pilot tasks. Some fast followers expect improved cockpit automation systems to emerge.

A few early movers are sticking to their plan of automated people movement, probably at the cost of early certification, but likely with the benefit of the increased commercial viability that comes with a higher level of flight automation. Their vehicle test strategy is frequently aligned with RPAS operations.

New “Digital” Flight Rules” (DFR) as proposed by ICAO [10], are still over 10 years in the future. Nevertheless, and based on the aforementioned work done inter al. by GAMA and ICAO, **Skyroads agrees that there are** (at least) **two viable paths from piloted flight to full automation:**

- **SVO:** having a human in final command on board until automation creates assurance levels to replace him/her with fully automated functionality.
- **RPAS:** having a human in final command off-board (remote) until automation creates assurance levels to have one remote controller control multiple aircraft and eventually replace him/her with fully automated functionality.

Addressing both paths, Skyroads supports the automation of SVO functional groups as defined by NASA [13]:

- **Mission Management:** Primarily on the ground, with the ASI and FGC components for tactical execution. This will provide the required safety, and it addresses contingency scenarios, e.g., in the case of lost communication.
- **Flightpath management:** Deterministic planning on the ground, and replanning to solve any detected non-time-critical conflicts. In such a case, an updated flight path is provided to the FGC to set the AV’s course accordingly.
- **Tactical operations:** After detection of an immediate hazard by a DAA sensor resulting evasive or contingency maneuvers are executed as part of a system updates of the planned flight route; reversionary procedures, are initiated if necessary.
- **Vehicle control:** Performed by the AV’s own flight controls. The Skyroads FGC provides the on-board native avionics system with the pre-planned safe flight route in multiple formats.

Among the pilot skill categories (defined by GAMA) [9], the Skyroads system provides automation for

- **Communication:** Via air-ground data link for both voice and data communication.

- **Navigation:** pre-planned flight routes are provided to the AV via the FGC; data is provided to visually inform the pilot of his adherence to the cleared flight path.
- **Planning:** with the automatic provision of pre-planned and conflict-free routes, airspace management, and integration with vertiport operator systems.
- **Risk management/decision-making:** with the centralized and deterministic route planning, System-Wide Air Situation Image, and the provision of supplemental data such as weather, traffic, airspace etc.

Simplified vehicle operations

In the first scenario, vehicle manufacturers who built their AVs for passenger operations from the very beginning, would initially operate piloted flights in VFR, with a fully licensed pilot, and with no changes required to the existing rules of the air.

Skyroads' support for successive automation in this scenario could be realized in four steps:

01 The Skyroads FGC provides decision support to the pilot via the Air Situation Image (consistent with the air situation in the ground-based planning segment of the system).

02 The FGC interface to the AV's Flight Control Computer allows relieving pilot of navigation tasks, flights will still be in VFR, an initial focus on en-route automation could be imagined as an additional intermediate step here.

03 The on-board pilot does not need to have a full license any more (see also the corresponding GAMA proposal), he/she would act as a safety pilot, training could be provided by Skyroads.

04 The on-board safety pilot receives support from a ground-based Command Unit, first 1:1, then possibly 1:n.

Remotely piloted flight

In the second scenario, vehicle manufacturers who plan to start with cargo operations, and move on to passenger flights only in a later stage, could at first operate remotely piloted flights following the existing rules of the air for RPAS. Cargo drones will be controlled from a Command Unit on the ground. In addition, smaller cargo drones in the "specific" category can be operated applying the existing SORA and BVLOS rules.

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Skyroads’ support for successive automation in this scenario could be realized in four steps:

Today: One remote pilot for RPAS, under VFR or IFR.

01 One remote pilot per cargo drone in the “certified” category (VFR, precond. TBD).

02 One remote pilot for 1..n cargo drones in the “certified” category (VFR).

03 One remote pilot per passenger-carrying drone (VFR).

04 One remote pilot for 1..n passenger-carrying drones (VFR or IFR).

Benefits of simultaneous support

The following illustration gives an overview of the proposed two alternative paths.

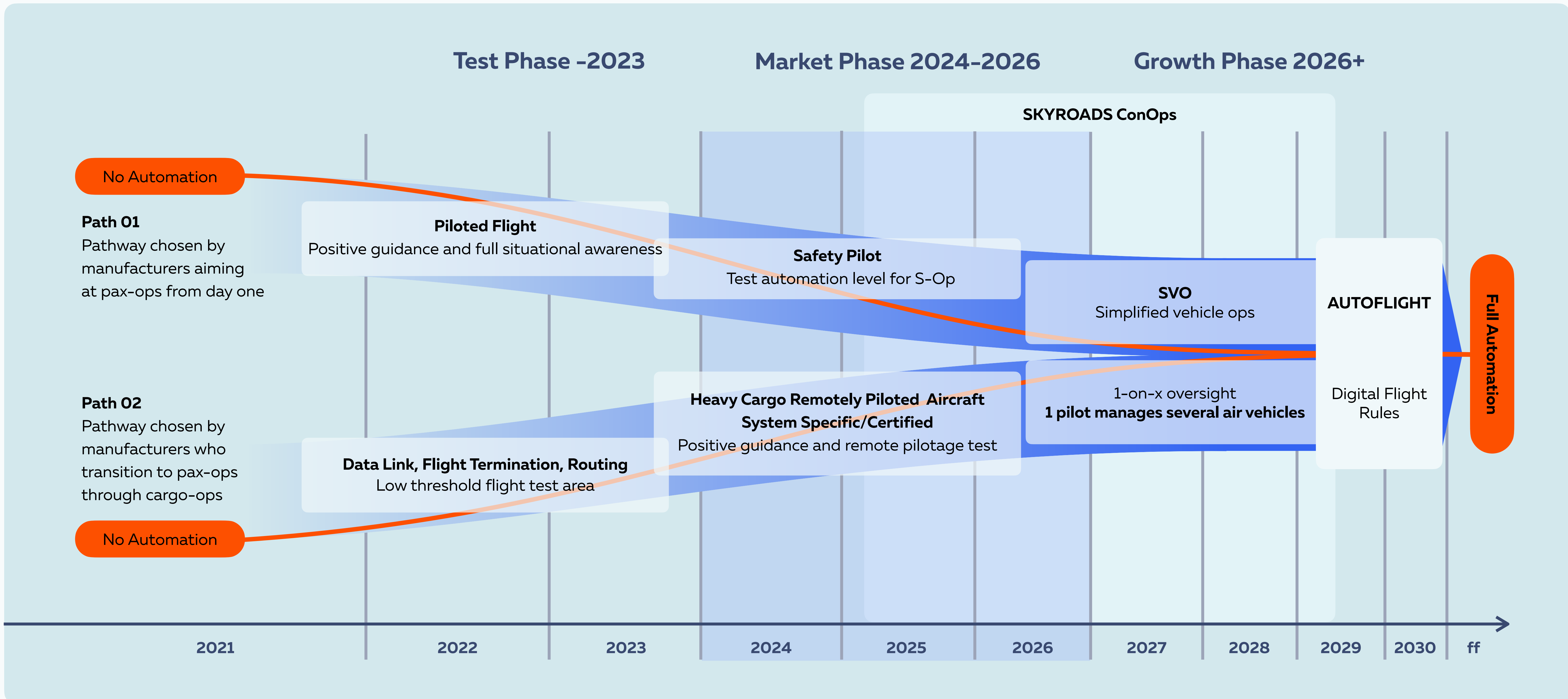

Figure 2: Alternative but simultaneous paths to automation, unified

Additional options and benefits of a combined approach:

- System adoption will be faster if one system supports all approaches.
- System allows for simplified testing and early use cases.
- Certification and regulatory approval may be accelerated if SVO can be supported by enhanced RPAS; the "simple pilot" will have a "mature" ground-based pilot/supervisor. This may speed up both SVO and pax-RPAS.

Collaborative concept validation

Skyroads will demonstrate incremental versions of its system prototypes together with different OEMs and drone manufacturers in low-threshold flight test areas (very large-scale demonstrators). The first such test area will be set up in Germany (Munich region), with large-scale demonstrators planned for 2022 and 2023. In a second stage, test areas can be added in different geographies, depending on market demand/customer request.

In a first step, the main purpose is to validate the data link and routing functions. The loss of communication from the ground to the AVs has been described as a main pain point by AV manufacturers. Among the main stakeholders, vehicle manufacturers are the most hardware driven. Fixed system designs are difficult and costly to change after design freezes. Therefore, vehicle manufacturers need to be addressed at a very early stage, before vehicle designs are frozen for production at scale.

Ultimately, the Skyroads avionics component (FGC) shall be interoperable across OEMs. In the absence of new or amended rules of the air, interface and procedures, the validation of prototype implementations will be consistent with the current R&D and validation efforts in the EU and the US.

Continuous evolution and integration

The integrated system architecture of the Skyroads AVCS with airborne and ground components allows for continuous evolution and the integration of new functions as market requirements evolve. Such evolutions can be performed without delay by harmonization and standardization of the datalink within the Skyroads AVCS, allowing to support special use cases as they arise.

Nonetheless, long-term standardization of interfaces will be needed to increase system adoption and acceptance. Skyroads' knowledge will also support this standardization process based on the experience gained.

BENEFITS

The Skyroads system provides flexible, optimized and inherently conflict-free flight routes, thus enabling an efficient use of airspace to accommodate the expected growth in AAM traffic.

Skyroads considers that the vast majority of system functions are nominal, therefore strategic (as in strategic deconfliction). Tactical deconfliction is already considered off-nominal. This is a Skyroads-specific statement/finding, since tactical deconfliction is currently and generally seen as being part of nominal operations (although this stems from human-in-the-loop aviation).

One example for how off-nominal/reversionary modes can be handled with the support of flight automation as envisaged by Skyroads:

- AVs are able to reach contingency landing pads from every part (segment) of the flight. Each segment has an associated contingency landing pad. In the event of a vehicle malfunction combined with of a total loss of the air-ground datalink (primary and backup link), an affected AV can navigate to the next landing pad on its own. The Skyroads Flight Guarding Computer, located on board the AV, provides up-to-date contingency trajectories, compatible with the entire system planning, to the AV's avionics system (or pilot display).

The Skyroads solution integrates an airborne and a ground segment (dedicated integrated software/hardware inside the AV and on the ground). It automates the communication between the two segments, provides safe, collision-free (deconflicted) routings as well as back-up on-board intelligence for contingency/escape maneuvers and thus allows for continuous use of airspace and capacity optimization.

As a resulting product strategy, Skyroads has determined that product value can be demonstrated at the earliest through adoption by vehicle manufacturers. We believe that OEMs will choose to remain with the Skyroads software/hardware solution, if the evolution of Skyroads system capabilities suits their requirements and those of their customers.

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ABBREVIATIONS

AAM	Advanced Air Mobility
AAVS	Automated Airspace Management and Vehicle Guidance System
ANS	Air Navigation Services
ASI	Air Situation Image
ATC	Air Traffic Control
ATM	Air Traffic Management
AV	Air Vehicle
BVLOS	Beyond the Visual Line Of Sight
CU	Command Unit
DAA	Detect And Avoid
DFR	Digital Flight Rules
DL	Data Link
EASA	European Union Aviation Safety Agency
EUROCAE	European Organisation for Civil Aviation Equipment
eVTOL	Electric Vertical Take-Off and Landing (Vehicles)
FAA	US Federal Aviation Administration
FGC	Flight Guarding Computer
GA	General Aviation
GAMA	General Aviation Manufacturers Association
GS	Ground Station
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
NASA	US National Aeronautics and Space Administration
OEM	Original Equipment Manufacturer
PIC	Pilot In Command
RPAS	Remotely Piloted Aircraft System
RPIC	Remote Pilot In Command
RTCA	Radio Technical Commission for Aeronautics
SORA	Specific Operations Risk Assessment
SVO	Simplified Vehicle Operations
UAM	Urban Air Mobility
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UTM	UAS Traffic Management
VFR	Visual Flight Rules

GLOSSARY

Advanced Air Mobility

Compared to UAM, this more inclusive term encompasses a wider range of applications enabled by electrification and automation, including the transport of people, goods or aerial work operations, in addition to large-scale air taxi operations in both rural and the more challenging and complex urban environments.

Air Vehicle

A passenger-carrying vertical take-off and landing capable Air Vehicle.

Air Vehicle Control System

The Skyroads Air Vehicle Control System is defined as the combination of an airborne segment (located in participating Air Vehicles) and a ground segment that allows to perform deterministically planned and deconflicted flights with Air Vehicles along predefined routes.

Data Link

The Data Link is used for flight critical data transmission (e.g. navigation data update, flight plan, AV status, telemetric data, voice communication) between the Skyroads airborne segment and the ground segment.

Safety Pilot

A licensed pilot on board, able to assume manual control of an automatically flown Air Vehicle.

U-Space

U-space is a set of new services relying on a high level of digitalization and automation of functions and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. It is an enabling framework designed to facilitate any kind of routine mission, in all classes of airspace and all types of environments - even the most congested – while addressing an appropriate interface with manned aviation and Air Traffic Control.

Urban Air Mobility

A system that enables the safe and efficient air traffic operations in a metropolitan area for manned aircraft and unmanned aerial systems (UAS).

Vertiport

A Vertiport is a landing and take-off location with one or more Pads. The Vertiport may support multiple Air Vehicles.

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