SCIENTIFIC ASSESSMENT FOR URBAN AIR MOBILITY (UAM)

MARCH 1, 2023

Disclaimer

The following Scientific Assessment for Urban Air Mobility (UAM) represents a consensus view from the 27-member organizations of the International Forum for Aviation Research (IFAR). It does not, however, represent the views of any one specific IFAR member, their participating research organization, or their researchers. The Scientific Assessment for UAM is meant to serve as a reference document to the international community, and IFAR members are not meant to accept the document as a formal input to their organizations.

Abstract

Better connecting the international research community and the International Civil Aviation Organization (ICAO) enables effective assessments of novel aviation innovations. The International Forum for Aviation Research (IFAR) created a working group on Urban Air Mobility (UAM) to explore the broad array of aspects relevant to the ICAO mandate. The assessment began with a study of the current industry landscape, including an overview of existing market studies, proposed aircraft designs and concepts, and potential paths of industry evolution. The Industry Assessment is summarized into key takeaways highlighting the need for international assessments on economic and societal factors associated with UAM, common understanding of the extent to which the nascent industry can leverage current infrastructure and regulatory structures, and harmonization of industrywide terminology. The subsequent Scientific Assessment, developed through cooperative efforts between international domain experts, captures 17 focus areas relevant to UAM. All focus areas present opportunities for further research. Key takeaways include: the need for further study of the impact of autonomous systems on the industry; infrastructure requirements (including vertiports and weather sensing) to support the industry; and data requirements (including domains such as cybersecurity, emissions, and safety) to ensure safe, scalable operations. Finally, a brief overview of the current standards landscape as relevant to the Scientific Assessment is presented, which displays the benefits of applying digital systems engineering techniques to map current research efforts to ongoing standards activities.

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3. Introduction

International Forum for Aviation Research (IFAR) International Civil Aviation Organization (ICAO) Partnership Formulation and Need for Urban Air Mobility Scientific Assessment

In 2020 the International Forum for Aviation Research (IFAR) and International Civil Aviation Organization (ICAO) agreed to explore how to foster interaction between the two organizations. There was mutual interest in establishing a collaboration between IFAR and ICAO to better connect the scientific community and ICAO, especially as new and disruptive technologies promote rapid changes in aviation. The Declaration of Interest, which was signed during the 11th IFAR Summit, established the grounds for exploring ways to accelerate and improve the effective assessment of new aviation technologies and innovations. Based on this declaration, IFAR created a group on Urban Air Mobility (UAM), with ICAO participating as an observer; the group is currently developing this Scientific Assessment for UAM and are looking into various aspects that are of relevance to the ICAO mandate. Increasing global harmonization while still maintaining flexibility for local adaptation, will enable the safe scaling of the Advanced Air Mobility (AAM) industry worldwide, while a lack of harmonization will result in a longer worldwide timeline to fully scaled AAM operations.

Working Relationship with the International Civil Aviation Organization (ICAO)

The Scientific Assessment for UAM focuses on sharing harmonized, consensus-driven products with ICAO that provide scientific insight into the state of AAM as well as use cases such as UAM. The IFAR international working group participants work across scientific areas to provide perspectives of international researchers on industry considerations such as the state-of-the-art and future needs. The IFAR will continue to refine its message on the focus areas for the Scientific Assessment for UAM by continuing to gather inputs from its members and refining consolidated outputs and key takeaways beyond what is presented in this current document. Outputs from focus area teams, including the key takeaways, gaps, and open research areas, were presented to the ICAO Secretariat. Although the ICAO is collaborating with the IFAR on the development of this document, formal ICAO outputs are not expected as a result. Additionally, the IFAR routinely participates in workshops to brief preliminary results, share initial ICAO reactions, and mature messages within the focus areas. These workshops enable the IFAR to further Research and Development (R&D) initiatives and prepare for discussions with ICAO leadership and working groups. It should also be mentioned that further collaboration on this subject between the IFAR and the ICAO is enabled and guided by the Memorandum of Understanding signed between the two organizations on 5 April 2022.

Air Mobility Concepts Considered

This document details considerations relevant to multiple air mobility concepts:

Urban Air Mobility[1] is a new, safe, secure, and more sustainable air transportation system for passengers and cargo in urban environments, enabled by new technologies and integrated into multimodal transportation systems.

Innovative Air Mobility (IAM)[2] is a concept intended to accommodate operations with novel aircraft designs that are conceived to offer new air mobility of people and cargo, in particular within congested (urban) areas, based on integrated air and ground-based infrastructure.

Advanced Air Mobility[3] is a broader air mobility concept of a safe, accessible, automated, and affordable air transportation system for passengers and cargo capable of serving previously hard-to-reach urban and rural locations.

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[1] "Urban Air Mobility," EASA: https://www.easa.europa.eu/en/what-is-uam.

[2] "A Drone Strategy 2.0 for a Smart and Sustainable Unmanned Aircraft Eco-System in Europe," European Commission: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0652.

[3] "Advanced Air Mobility: What is AAM? Student Guide," NASA: https://www.nasa.gov/sites/default/files/atoms/files/what-is-aam-student-guide_0.pdf.

Technical focus areas specify the scope and relevance of the findings presented, and further iterations of the findings will expand the scope beyond UAM specific details.

Expectations for Consensus

Section 5 captures a summary of the outputs from the teams covering each focus area of the Scientific Assessment. Although these outputs represent the consensus of each team, it is noted that each IFAR member nation did not participate in each team, and there is no expectation that ICAO will endorse this document or accept it as a formal input.

The IFAR consists of researchers from 27 countries, and its experts bring varying domain knowledge. Contributions were solicited from researchers with expertise in topics relevant to UAM, leading to the formation of 17 teams. Each team addressed a specific topic, with participating members of each team identified in Table 4. Additionally, the outputs from each team are at different levels of maturity, and these outputs are expected to evolve as needed. For example, some of the focus area teams have interacted with their relevant ICAO Secretariat counterparts, incorporated their feedback, and provided the updated outputs in this document, while other teams have not. Table 4 also shows the status of each team interaction with the ICAO Secretariat.

Further Scientific Assessments

The ICAO and the IFAR will consider future steps and potential arrangements to establish the grounds for exploring innovation trends, their application to aviation, and how they can help to advance our respective areas of work. Deepening the collaboration between the ICAO and the IFAR enables the taking on of complex challenges to improve lives, maintains public confidence in the aviation system, and supports international sustainability efforts.

4. Industry Assessment

This section presents current projections for the UAM market, an overview of different aircraft configurations, and potential evolutionary paths from initial operations. The key takeaways from the industry assessment are shown below, and the succeeding subsections provide more details on assessment findings.

Overview of Key Takeaways

1. The UAM industry currently has clear leaders with diverse international affiliations, use cases, and aircraft configurations. **There is no clear way to authoritatively identify the first location, use case, or organization** that will achieve a particular capability, but current expectations can be put on a timeline (such as the expectation of piloted operations occurring before autonomous operations).
2. **Piloted UAM operations leveraging much of existing regulatory structures will occur first**, but solutions to remotely-piloted configurations and general automation technologies must be worked in parallel for such operations to scale.
3. **For UAM operations to scale, common technologies necessary for step changes to both piloted and remotely-piloted operations require more emphasis across technology development and regulatory structures**. The relationship and potential to leverage the small uncrewed aircraft system (sUAS) development and operation to benefit UAM is not entirely clear.
4. Certification programs are in work across many nations, and some regulatory environments will be friendlier than others. **National assessments of economic, certification, societal, and other issues are fairly common, but there is little public information concerning international perspectives and implications.**
5. **There is a lack of understanding and commonality around expected use of Uncrewed Aircraft Systems (UASs) Unmanned Aircraft System Traffic Management (UTM) for initial operations** – whether required for safety, efficiency, or not at all – and progress will occur faster if the international community has common expectations.

Overview of Existing Market Studies

Numerous market studies have analyzed UAM market drivers and prospects. A brief overview of representative market studies is provided below, ordered from most recent to earliest release date, but the analysis is neither comprehensive nor unanimous. The scope and key findings are summarized and presented for each study.

Advanced Air Mobility: Market study for Asia-Pacific (APAC)[4] – February 2022

Scope: Passenger-carrying use cases from 15 to 250 km (air taxi, airport shuttle, and intercity operations) in the Asia-Pacific (APAC) region.

Key Findings:

1. By 2050, the APAC region will account for 51 percent of AAM aircraft in operation (82,500) and 41 percent of AAM service revenue ($36.9B).
2. Strategic partnerships and investments have made Tokyo (planned launch 2025), Seoul (planned launch 2025), and Singapore (planned launch 2024) frontrunner cities for AAM.
3. To make AAM a reality, the AAM ecosystem (charging, airspace management, maintenance, etc.) must mature while aircraft go through the certification process.

[4] "Advanced Air Mobility: Market study for APAC," Roland Berger: https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/news/press-releases/rre-apac-aam-study-16-02-2022-v2.pdf.

Advanced Air Mobility Annual Market Outlook[5] – June 2021

Scope: Passenger-carrying use cases, including air metro, point-to-point transport, subregional transport, personal transport, and emergency services operations, focused largely on the UK, but other markets were studied as well.

Key Findings:

1. Subregional transport is expected to enter service by 2030, with the United States of America (U.S.A.). believed to be the first location for commercial operations.
2. A worldwide total market value of $510B is forecasted by 2040. The greatest revenue value is expected for operators and infrastructure providers ($137B in 2040).
3. Additional public forecasts are recommended to construct more confident forecasts for early use cases in different geographic regions.

Economic Impacts of Advanced Air Mobility[6] – November 2020

Scope: Passenger-carrying airport shuttle, air taxi, regional transport, air metro, and business aviation operations, along with medical and emergency services in the greater Vancouver, Canada area.

Key Findings:

1. Investment in AAM in the greater Vancouver region is expected to create over 2,000 permanent jobs supporting the sector over the next 20 years.
2. "Spin-off" effects on other industries are expected to include indigenous-community empowerment, trans-border trade, university research, and acceleration of the hydrogen energy sector. These impacts could further increase the number of jobs created through AAM investment.
3. Some immediate economic development is also projected, with 320-permanent generated jobs forecasted for the region during the initial two- to three-year period following investment in AAM.

Urban Air Mobility Market Study[7] – November 2018

Scope: UAM operations in the United States of America (U.S.A.), including last-mile delivery, air metro, and air taxi.

Key Findings:

1. Air taxi operations are unlikely to be profitable by 2030, but operations in some localities, or serving some niche market, may operate profitably (similar to current helicopter operations in New York City, U.S.A. or other high-density areas).
2. Numerous public concerns exist surrounding trust in autonomous technology, privacy guarantees associated with sensor technology, protection of jobs from automation, environmental impacts, and both audible and visible disruptions.
3. Engagement with local communities is critical to enabling the adoption of UAM. Although the regulatory authority is largely at the federal level, local sentiments will decide the rate of market adoption.

Urban Air Mobility Market Study[8] – October 2018

Scope: Airport shuttle, air taxi, and air ambulance operations in various urban areas across the U.S.A.

Key Findings:

1. Airport shuttle and air taxi operations are viable markets with a significant market size ($500B in the best-case scenario, lower with added constraints). The air ambulance operation is not a viable market, although the

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[5] "Advanced Air Mobility Annual Market Outlook," ADS: https://www.adsgroup.org.uk/themencode-pdf-viewer-sc/?tnc_pvfw=ZmlsZT1odHRwczovL3d3dy5hZHNncm91cC5vcmcudWsvd3AtY29udGVudC91cGxvYWRzL3NpdGVzLzIxLzIwMjEvMDYvQUFNLU1hcmtldC1PdXRsb29rLXYxLnBkZiZzZXR0aW5ncz0xMTExMTExMDExMTExMTExMTAwJmxhbmc9ZW4tVVM=#page=&zoom=&pagemode=.

[6] "Economic Impacts of Advanced Air Mobility," Canadian Advanced Air Mobility Consortium (CAAM): http://www.pnwer.org/uploads/2/3/2/9/23295822/economic_impact_assesment_-_caam_-_v1.0.pdf.

[7] "Urban Air Mobility (UAM) Market Study," Crown Consulting, Inc.: https://ntrs.nasa.gov/citations/20190002046.

[8] "Urban Air Mobility (UAM) Market Study," Booz Allen Hamilton: https://ntrs.nasa.gov/citations/20190000519.

incorporation of electric Vertical Takeoff and Landing (eVTOL) aircraft could introduce response-time savings for emergency services.

2. Autonomous cars and teleworking may significantly limit the demand for air taxi operations, while high-network efficiency and an increase in supporting infrastructure may increase demand.
3. Five-seat eVTOL price per passenger mile is projected to be greater than for a luxury ground ride sharing trip.

Overview of Aircraft and Entry into Service (EIS) Timeline

Companies around the world have proposed, designed, and developed numerous UAM aircraft configurations and designs. Designs exist at varying levels of maturity, with some undergoing the certification process while others exist only in concept form. It is undecided which company, and its associated design, will be the first to achieve commercial operation, but expectations can be put on a timeline. This section summarizes some of the different aircraft configurations that have been proposed for urban air mobility operations; details a few representative designs and their capabilities; and places their expected Entry into Service (EIS) dates on a projected timeline. This section is not a comprehensive overview of all the existing designs, but resources such as the Vertical Flight Society (VFS) eVTOL Aircraft Directory[9] and the AAM Reality Index[10] provide additional information on existing designs and companies relevant to UAM operations and were used in the development of this section. **Note: EIS dates are projected, funding is listed in $M[11], and the examples provided in each section are not all-inclusive. The certification timelines, and hence EIS dates, represent optimistic projections by designers. Generally, development time and cost of new aircraft has increased over time. Incorporation of novel battery and automation technologies proposed in eVTOL designs prevent accurate predictions on final development time and cost.**

We consider three states of development for relevant designs:

1. **Ongoing certification efforts with conforming prototypes (largely the aircraft in this section):** Upwards of 10 industry original equipment manufacturers (OEMs) are flying aircraft configurations with diverse vehicle configurations and automation architectures as part of active regulatory certification programs. These configurations may or may not necessarily be conforming certification prototypes. The OEMs and regulators are advertising potential certification and commercial operations as early as 2024, but only a handful of UAM aircraft could potentially achieve this 2024 goal.
2. **Significant development based on prototype vehicle, but no scaled conforming prototype:** Many more potential OEMs have flown scaled configurations but are not in active certification programs or do not have mature designs for commercially viable vehicles configurations. Generally, it is expected that none of these companies will achieve certification until the mid-to-late 2020s, at the earliest.
3. **Aircraft in design but no prototypes:** Many universities, venture-capital funded efforts, start-up technology companies, and some traditional aviation companies have innovative designs that could embody game-changing technologies or configurations, but they do not represent a viable part of the market before 2030 without more intensive development and significantly more investment.

Tables 1-3, below, provide an overview of a small number of existing designs applicable to UAM. Different configurations may be used in different missions (e.g., cargo vs. passenger carrying); hence, these configurations may have different operational requirements.

[9] "eVTOL Aircraft Directory," The Vertical Flight Society: https://evtol.news/aircraft.
[10] "Advanced Air Mobility Reality Index," SMG Consulting: https://aamrealityindex.com/aam-reality-index.
[11] EIS dates and funding amounts are industry-reported and current as of August 2022.

Vectored Thrust Configuration

Table 1 shows multiple Vectored Thrust aircraft, which orient their thrusters for lift and cruise based on the phase of flight.

Table 1: Vectored Thrust Aircraft Details.

Aircraft	Country	EIS	Funding ($M)	Range	Cruise Speed	Capacity
Joby Aviation **S4**	U.S.A.	2024	1,844.6	241 km	322 km/h	4 passengers
Archer **Midnight**	U.S.A.	2024	856.3	100 km	241 km/h	4 passengers
Lilium **Jet**	Germany	2025	938.0	300/250 km	300/280 km/h	5/7 passengers
Vertical Aerospace **VX4**	U.K.	2025	337.3	161 km	241 km/h	4 passengers
Supernal **S-A1**	S. Korea	--	Corp. Backed	97 km	290 km/h	4 passengers

Joby Aviation S4

Lilium Jet

Vertical Aerospace VX4

Archer Midnight

Supernal S-A1

Lift + Cruise Configuration

Table 2 shows multiple Lift + Cruise aircraft, which have separate thrusters for cruise and lift without thrust vectoring.

Table 2: Lift + Cruise Aircraft Details.

Aircraft	Country	EIS	Funding ($M)	Range	Cruise Speed	Capacity
Pipistrel **Nuuva V300**	U.S.A.	2023	Corp. Backed	300 km	165 km/h	300-kg cargo
Beta Tech. **Alia S250**	U.S.A.	2024	796.0	500 km (target)	-	2 pax + cargo
Airbus **CityAirbus NextGen**	France	2025	Corp. Backed	80 km	120 km/h	4 passengers
AutoFlight **PROSPERITY I**	China	2025	115.0	250km	200km/h	4 passengers
Ehang **VT-30**	China	2025	132.0	300km	-	2 passengers
Volocopter **VoloConnect**	Germany	2026	579.0	100 km	180 km/h	4 passengers
Eve UAM Solutions **Eve**	Brazil	2026	362.4	>96 km	>241 km/h	4 passengers
Wisk **Cora**	U.S.A.	--	775.0	100 km	180 km/h	2 passengers

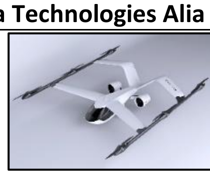
Pipistrel Nuuva V300*

Beta Technologies Alia S250

Wisk Cora*

AutoFlight PROSPERITY I

Airbus CityAirbus NextGen



Volocopter VoloConnect

Eve UAM Solutions Eve

Ehang VT-30

*Targeting autonomous initial operations.

Wingless or Multicopter

Table 3 shows multiple Multicopter aircraft, which typically use more than two thrusters - used only for lift.

Table 3: Multicopter Aircraft Details.

Aircraft	Country	EIS	Funding ($M)	Range	Cruise Speed	Capacity
Ehang **EH-216**	China	2022	132.0	35 km	100 km/h	2 passengers
Volocopter **VoloCity**	Germany	2024	579.0	35-65 km	~90 km/h	1 pax + cargo

Ehang EH-216*

Volocopter VoloCity

*Targeting autonomous initial operations.

Initial Operations and Evolutionary Path

Potential Industry Evolution Paths

Conventionally-piloted aircraft: Consensus exists that the evolutionary path of piloted UAM operations depends on the application (cargo or passenger transportation, type of aircraft, necessary technologies), with different uses needing different capabilities.

Remotely-piloted aircraft: Currently, the question of likely evolution is answered in different ways internationally. Answers range from "operations from airports to rural areas will be pursued first" to "urban operations may never be realized." Emergency and disaster applications are the first expected applications of remotely-piloted UAM operations. Piloted aircraft operations will enable testing of technologies for remotely-piloted UAM aircraft such as Detect and Avoid (DAA), Autoland, and airspace management to gather data for eventual safety credit.

Rural before urban, cargo before people, parcels before cargo: It is anticipated that this approach becomes a generalized best practice across all emerging markets, with the ability to perform robust data gathering campaigns on new configurations that can minimize risk to the market and general public.

Drones scaling up (from delivery of services to cargo, then from cargo to transport of people): Potential to scale up is foreseen for many drone capabilities. These capabilities will generally include technologies (sensors), software (DAA, m:n), concepts (UTM), and others that provide capacity, efficiency, safety, and regulatory benefits. Integration with UAS is always a consideration, from the perspectives of both synergistic technology development and issues involving mixed piloted and uncrewed operations in shared airspace. Drones scaling up also implies the development of technology that allows multiple drones to be controlled and monitored by one remote pilot. The Australian company Swoop Aero has achieved a permit to test their technology which allows a single remote pilot to operate five UAVs simultaneously from a remote operations center[12].

Automation of conventional technologies: In the near term, it is very likely that limited automation (e.g., to basic taxiing, takeoff and landing, and flight capabilities plus minimal contingency management and UTM integration) will be present. Higher level of automation including dynamic decision making will follow only in the longer run (including detect and avoid and sophisticated Artificial Intelligence (AI) technologies) because of the complexity of processes required for system interoperability.

Electrification of conventional technologies: Climate change policies are expected to force electrification over time, and the change toward electrification, including infrastructure needs, will be anticipated in the industry evolution.

Hybrid-electric distributed propulsion: For specific missions or configurations requiring longer range, hybrid-electric propulsion systems are anticipated in the industry evolution, as well as the possibility of hydrogen propulsion further in the future.

Initial Certification Timelines

Piloted Operations: The consensus in the cited documents is that the first certification of aircraft systems should happen in the 2023 to 2025 timeframe (most likely in 2024); although, this estimate is optimistic by industry leader standards. There should be a ramp-up in activities following initial operations in 2024-2025 leading to expanded passenger transport services and medical transport services in the late 2020s. Additionally, an expansion in operation areas and types of missions, including on-demand operations, is expected in the 2030s. While it is expected that the U.S.A and Europe will certify the first few prototypes in 2024 to 2025 timeframe, significant delays are possible for other countries where no equivalent certification process is in place. It is likely that European Union Aviation Safety Agency (EASA) Special Condition for small-category vertical takeoff and landing (VTOL) aircraft Special Condition for VTOL (SC-VTOL) standards will be

[12] "Local Drone Firm Wins Approval to Operate 5 Drones Per One Pilot," Australian Aviation: https://australianaviation.com.au/2022/05/local-drone-firm-wins-approval-to-operate-five-drones-per-one-pilot/.

applied for both cargo and passenger operations. Some countries have the same certification basis process with different operational hazard levels requiring more rigorous means of compliance (MOC). Barriers on the path to initial certification include pilot qualification (different between U.S.A. and Europe); energy storage; complex software and its certification; flight autonomy; electric subsystems; flight characteristics; reliability; societal acceptance; and economics (only small numbers of expensive parts or systems produced).

Remotely-piloted Operations: Remotely-piloted aircraft certification is broadly considered more challenging and expensive than piloted configurations. Lower risk use cases such as rural cargo are expected to operate with restrictions as part of the path to certification by major international regulatory agencies. The earliest certification dates for remotely-piloted aircraft are expected to occur as early as 2026 (for cargo-carrying usage) and as early as 2030 (for certifications and regulatory approvals for passenger carrying by various countries). In Addition, there are yet other countries that are not expected to have operations within the next 20 years. As discussed above, it is expected that certification for piloted simplified vehicle operations (SVO) single-pilot UAM, sUAS, commercial UAS, and other configurations or applications will likely happen before certification enabling uncrewed UAM operations. Because of the investment required for remotely-piloted eVTOL operations, industry will likely seek eventual certification for the highest return passenger-carrying missions, leveraging other applications along the way for operational experience and credit for future certification programs. The market and technology evolution will likely continue the drive to more distinctive and diverse configurations and applications, affecting predictions of certification efforts.

Technology Readiness Timelines

Piloted Operations: Although there are already ongoing pilot projects for vehicles and the first few commercial operations by industry leaders are expected around 2024 or 2025 (with other projects after that), a slow ramp-up is expected since infrastructure such as vertiports, electric supply, and Air Traffic Management (ATM) will take more time to mature. Many pilot programs to gather safety data are expected to impact commercial operations. These programs will most likely be country-specific - some being joint efforts with the respective regulators. There is no consensus about the required UTM technologies for initial piloted operations. One set of experts believes that UTM will not be required for initial piloted operations since initial operations will consist of a small number of aircraft operating on defined routes following the current regulatory structure (i.e., visual flight rules (VFR)). On the other hand, others believe that UTM is required for operation in an urban environment for increased efficiencies and functions such as flight planning, geo-fencing, and surveillance.

Remotely-piloted Operations: Many technology challenges must be overcome to certify remotely-piloted UAM aircraft. The most proximate certification-related challenges are technology and regulatory, but operational and societal considerations such as development of specialized ground stations and supporting equipment should also be considered. Future sections of the Scientific Assessment will explore details from across a broad set of challenges. Development of an overall approach to certifying these new aircraft requires a common understanding and alignment of the various international certification approaches to avoid potential inconsistencies and limit confusion. Successful UAM applications will be enabled primarily by electrification and automation, but many other certification challenges will still exist. Certification of UAM battery and fly-by-wire technologies will leverage their growing applications in conventional aircraft and UAS, as will complexities of critical automation components for contingency measures such as GPS-denied operational technologies (DAA, UTM, weather, track and locate, etc.). Societal concerns about autonomy may also play a role in certification of automation technologies. The broad array of pilot programs expected to begin in the next few years will likely focus on low-risk operations and demonstrations such as rural, sUAS, and low-complexity urban operations, gathering operational data on automation technologies, new system architectures, assessing community and societal response, and other considerations. While there are mixed opinions on the necessity of UTM-inspired concepts for early piloted operations, rural areas are likely targets for early remotely-piloted operations without UTM; however, UTM is expected to be a primary technology needed to enable remotely-piloted operations and other UAM operations on a larger scale. National efforts such as the National Aeronautics and Space Administration (NASA) National Campaign, the South Korea (K-UAM) Grand Challenge, and the United Kingdom Research and Innovation (UKRI) Future Flight Challenge along with international efforts such as the European Union (EU) Single European Sky ATM Research (SESAR)[13] are all working to test and evaluate concepts inspired by UTM as a part of the architectures under evaluation. UTM is expected to contribute or perform early functions for flight planning/approval, surveillance, monitoring, and strategic conflict management. For remotely-piloted operations in the future, UTM will likely transition to being a fully available service[14] responsible for elements of safety including tactical separation, managing traffic, weather avoidance, and other recommendations or guidance given to enhance airspace safety.

Expected Initial Operational Environments

Piloted Operations: There is a divergence in expectations surrounding the specific use cases and locations that will see initial commercial capabilities for piloted UAM operations. Potential use cases range from public good operations such as disaster response, air ambulance, or organ transport to point-to-point for business operations such as from city centers to airports, tourism, or sightseeing. Specific regions and countries are more likely to be early adopters such as the United States and members of the European Union because of the number of ongoing large-scale investments. Parts of Africa and Asia are likely early adopters because of the less rigorous, and therefore faster regulatory process. There are exceptions to expectation, however, such as the use of dedicated AAM flight paths[15] to carry passengers to the 2024 Paris Olympics.

Remotely-piloted Operations: Examples of use cases and locations where remotely-piloted commercial operations will likely emerge include air taxi or shuttle services, medical transport, fire monitoring and suppression, and remote or urban package delivery. Industry and investors will evaluate the prospects and risks of early operations and how they will transition to scalable business cases. Market studies (such as those summarized in the preceding Overview of Existing Market Studies) show that many potential use cases are profitable as they scale, but the most promising use cases, from an economic perspective, are air taxi passenger-carrying operations in urban areas. It is likely that initial UAM operations will likely become progressively more complex and prevalent. Initial operations are already taking place in extremely rural areas of countries such as New Zealand, and operations are being planned in many other countries, including the U.S.A. and Japan. Operational demonstrations of increasing maturity are expected across both commercial and governmental missions in many countries. The AAM with regional cargo operations may be a predecessor to more demanding UAM operations. Initial, less demanding services, such as remotely-piloted conventional aircraft, could be introduced anywhere, depending on the attitude of governments toward adoption of UAM. Although the landscape will continue to evolve, friendlier regulatory environments do not by themselves translate to safety or high-payoff markets without market demand and investment in infrastructure.

Evolution of Technology

Piloted Operations: Progressive automation of pilot functions is expected as the piloted UAM industry matures, and similar maturation is expected for air traffic management and control. Technologies will advance from basic assistive automation to comprehensive safety automation with the pilot as fail-safe, to "responsible" automation that can perform significant safety-critical tasks without relying on the pilot as a safety. Evolution of other technologies, such as batteries (including capacity and charging efficiency), DAA, command and control, UTM, ground collision avoidance systems, and high-reliability high-bandwidth production is expected to result in lower costs and higher levels of efficiency and safety.

Remotely-piloted Operations: Multiple simultaneous paths toward remotely-piloted UAM operations can lead to the implementation of architectures of increasing scale as international efforts progress across the various enablers of automated remotely-piloted UAM operations. Multiple international R&D agencies and industry partners have plans for technology development testing and demonstrations of key technology advances within the next three to five years. The multiple paths to automation include the following:

[13] "What is SESAR?" SESAR Joint Undertaking: https://www.sesarju.eu/.

[14] "ISO 23629-12:2022 UAS traffic management (UTM) – Part 12: Requirements for UTM service providers," ISO: https://www.iso.org/standard/78962.html.

[15] "Paris Plans Electric Flying Taxi Routes in Time for Olympics," Time: https://time.com/6124032/paris-electric-flying-taxi-olympics/.

- Pilot-assisted progression: Automation for remotely-piloted UAM operations would progress from pilot assisted to "automated" on a function-by-function basis. In this case, the main agent of operations is the service provider rather than the individual.
- Remotely-piloted progression: To implement remotely-piloted UAM operations, heavy reliance on automation / autonomy and low latency, long distance communication capabilities is expected. For safe operations (e.g., Beyond Visual Line of Sight (B-VLOS)), automation of both inner loop (e.g., roll, pitch, yaw) and outer loop (e.g., airspeed, altitude) functions are necessary. Rapid development and testing of these technologies may stimulate action of the certification process and start providing guidelines sooner.
- sUAS progression: sUAS technologies are in high demand and are generally a lower risk path to implement critical automation functions. Size, weight, and power challenges present risks to the ability of transitioning some automation technologies (sensors, contingency management, etc.) to and from sUAS.

Planned operations for 2024 are expected to have a pilot onboard; thus, the concept of operations will be similar to the current helicopter air taxi services. To realize the full potential of these vehicles, the operations must be uncrewed. The UAM aircraft specifications usually state the passenger capacity, but specifications do not include the pilot; hence, a two-passenger aircraft such as the Volocopter VoloCity carry only one passenger per flight.

The UAM will also likely leverage technological advances in other sectors (such as automotive) and synergistic convergence of multiple technologies to speed up the evolution. The remotely-piloted risk-based progression discussed above may arguably assist remotely-piloted operations to transition more rapidly into more capable scaled operational models than a piloted path. According to the EASA Artificial Intelligence Roadmap, autonomous Commercial Air Transport (CAT) operations for large aircraft are predicted to happen in 2035[16].

Evolution of Operational Environments

Piloted Operations: While piloted operations are expected to begin in 2024 to 2028, the ramp up will require many flight hours and initial growth will likely follow the traditional S-curve of slow initial adoption followed by more rapid growth after reaching an early tipping point; thus, 2030 to 2040 is a more realistic expectation for UAM operations becoming commonplace. Additionally, opinions are mixed on the expectations for adoption of truly urban operations (e.g., rooftop landings becoming commonplace in dense urban areas) within the next 10 years.

Remotely-piloted Operations: Remotely-piloted UAM has significantly more barriers than piloted UAM in the early years but has significant upsides to automation and scalability in the midterm. It will be challenging for remotely-piloted operations to happen in urban areas at scale prior to ~2030 with the current industry and government investment profiles.

[16] "EASA Artificial Intelligence Roadmap 1.0 published," EASA: https://www.easa.europa.eu/en/newsroom-and-events/news/easa-artificial-intelligence-roadmap-10-published.

5. Scientific Assessment

The IFAR began the Scientific Assessment for UAM by establishing focus areas capturing technology, operational, and societal acceptance. The IFAR identified and engaged technical experts from research agencies around the world, but every agency was not expected to provide members for each focus area, however, technical experts were expected to contribute to content development and discussions on template inputs. Leads for each focus area were identified and the teams of experts then began developing content for their focus areas. The teams captured information such as an overview of their focus area, a state-of-the-art assessment, a gap analysis, and any open research areas that still exist. Additionally, teams collected relevant research publications to their focus areas and summarized their findings as key takeaways. The supporting agencies of each team are shown in Table 4, below. The teams briefed the ICAO Secretariat throughout the Scientific Assessment process and incorporated comments received before the publication of this document. Section 5 captures one-page summaries of each of the focus areas, but the more detailed findings are captured in the documents listed in the "Adapted From" section at the bottom of each one-pager.

Focus Areas and Agency Support

Table 4, below, displays the research agencies that supported each scientific assessment focus area. Focus areas 1-9 are the **Technology** focus areas, 10-14 are the **Operational** focus areas, and 15-17 are the **Societal Acceptance** focus areas.

Table 4: List of Scientific Assessment Focus Areas and Supporting Agencies.

Focus Area	Focus Area Title	Supporting Agencies (leads in **bold**)
1	Vehicle Overview	**NRC**, KARI, NASA, BME, ILOT, VZLU, INCAS, CSIR
2	Propulsion and Energy	**NASA**, KARI, NRC, ONERA, BME, ILOT, VZLU, INCAS
3	Autonomy	**NASA**, JAXA, NRC, DLR, ONERA, NLR, BME, ILOT, VZLU
4	Airspace Integration and UTM	**JAXA**, NRC, NASA, NLR, BME, CIRA, ILOT
5	Safety Management Systems	**DLR**, NASA, VZLU, NLR, ONERA, CIRA, ILOT, CSIR, INCAS
6	Infrastructure	**NASA**, KARI, NLR, VZLU
7	Security	**NASA**, CIRA, DLR
8	Communication, Navigation and Surveillance	**NASA**, KARI, NRC, DLR, ONERA, CIRA, ILOT
9	Weather Tolerance	**NRC**, JAXA, DLR, ILOT
10	Environmental	**NRC**, KARI, NASA, ONERA, ILOT
11	Maintenance	**NASA**, DLR
12	Safety and Security	**NASA**, DLR, VZLU, NLR, ONERA, CIRA, ILOT, CSIR, INCAS
13	Intersection with Infrastructure	**NASA**, DLR, ILOT, VZLU
14	Data Protection and Security	**NASA**, CIRA
15	Autonomy	**ONERA**, NRC, NASA, DLR, ILOT
16	Environment	**NRC,** NASA, DLR, ONERA, CIRA, ILOT
17	Safety	NRC, NASA, DLR, CIRA

Overview of Output Template

The outputs from each focus area team are captured in the rest of Section 5 below. Each output is organized into the following subsections:

- **Overview of Technology / Operational / Societal Acceptance Area:** Provides a high-level overview of current technologies, standards, and policy relevant to the focus area.
- **State-of-the-Art Assessment:** Provides the more detailed findings of the technical team.
- **Gap Analysis:** Describes technology, standards, and policy gaps for UAM operationalization relevant to each focus area.
- **Open Research Areas:** Captures the technical team questions and open areas for further research.
- **Adapted From:** Provides the focus area teams with file names of full outputs if more information is desired.

Additionally, some team outputs were divided logically (e.g., Team 11, "Environmental" is divided into 11a, "Emissions" and 11b, "Noise") to provide a clearer message.

Scientific Assessment Gaps

The Scientific Assessment - broad and diverse in scope - is expected to include gaps in research. Gaps may exist within the focus areas researched by the technical teams, but there may also be gaps in the form of topics not captured within the scope focus areas of the Scientific Assessment.

Summary of Key Takeaways

The Scientific Assessment outputs are presented directly in Section 5. In Table 5, below, a summary of the key takeaways from each focus area is presented.

Table 5: Summary of Key Takeaways by Focus Area.

Focus Area	Summary of Key Takeaways
1. Vehicle Overview	There exists a variety of possible configurations with no leading vehicle configurations emerging. This variety of configurations increases the number of technological challenges. Also, a survey by EASA revealed that two main factors dominate for their social acceptance: 1) flight safety and 2) noise. Finite resources in availability of pilots and cost of vehicles can slow the time required for UAM implementation. There is also a need for new means-of-compliance for type certification. The effect of feasible noise mitigation strategies on the performance reductions for low-noise vehicles can only be developed once those new standards will become available.
2. Propulsion and Energy	Vertical takeoff and landing (VTOL) capability is necessary for operations in urban areas with confined space and congested populations, and it is desired to have operations that do not contribute to emissions. The VTOL aircraft have high-energy requirements to sustain hover, and aircraft with low-emission propulsion systems such as electric, hybrid-electric, or hydrogen are challenged by the energy density available at the current time. Current aircraft are limited in payload, range, and endurance performance. Major limitations to increased performance of electric aircraft are the energy and power density of the electric propulsion systems, particularly during hovering when a high-energy discharge rate is required. Many VTOLs are electric at the current time, with some configurations exploring hybrid-electric systems to extend range. There are proponents of hydrogen as a possible energy source with great promise, but that area is developing on a longer timeframe. Ancillary propulsion system considerations such as high-voltage system safety, battery monitoring and replacement, fire hazard containment, and thermal management must all be addressed during certification.

3. Autonomy	Autonomous systems (AS) and increasingly autonomous operations are key enablers of safe, scalable Urban and Advanced Air Mobility (UAM and AAM). The AS for aviation is a nascent research and development area with significant promise but limited operational experience or theoretical underpinnings. Current AS exhibit many of the strengths and limitations as previous automated systems (e.g., the "Ironies of Automation"). In addition to technical challenges, the use of the AS to modify the roles, responsibilities, and qualifications of pilots (and other 3rd party people) requires coordinated modifications to aviation regulations: cross-cutting operations, airman, and aircraft policy domains. As significant regulatory modifications should be supported by experience and data, maturation of AS technologies and regulations is likely to be informed by early applications where operational risks, potential benefits, and regulatory gaps are manageable (e.g., by unmanned aircraft avoiding populated areas and single-pilot operations).
4. Airspace Integration and UTM	The UAM vehicles will need to be safely and efficiently integrated into existing airspace with traditional aviation, small unmanned aircraft systems (sUAS), and other potential new entrants. The implications of integrating UAM vehicles touch upon many areas of airspace, including airspace design and procedures; evolving functional allocation between traditional air navigation service providers (ANSPs) and new entities; technologies to enable digital information sharing; surveillance and navigation capabilities; as well as policy, flight rules, and regulations. Concept of Operations (ConOps) have been under development around the world from both industry as well as ANSP organizations; these ConOps require harmonization for international operations while also allowing for regional adaptation. The ConOps work shares several key attributes such as: 1) enabling intent sharing to support deconfliction at all levels, 2) evolving ANSP roles to support scalability, and 3) establishing separation minima for interactions between UAM as well as UAM and other traffic.
5. Safety Management Systems	The ICAO Annex 19 can be considered a viable basis as a framework for a Safety Management System (SMS) of UAM operations; although, as of now, UAM operators and UTM service providers are not considered under ICAO Annex 19. The low levels of maturity regarding the new technologies, which constitute the majority of the current UAM ecosystem, result in insufficient technological and operational data as a possible basis for new or amended UAM-specific regulations; therefore, it is currently unpredictable, whether additional amendments to the current framework might be required to fully encompass the UAM ecosystem into a SMS; however, new UAM-specific regulations and processes, such as predictive safety analysis and occurrence reporting for unmanned aviation, are deemed necessary, especially with regards to enabling a scalable development of the UAM ecosystem. Furthermore, the safety risks associated with autonomous or highly automated UAM aircraft are not well understood. Unknown aspects need to be clarified and addressed in safety management. In addition, the relationship between safety and cybersecurity has to be taken into account.
6. Infrastructure	Vertiports and their associated infrastructure will be key elements enabling future UAM, AAM, and IAM operating environments. The development of that infrastructure, however, and the understanding of how they will need to be integrated within the community, aircraft, airspace, and automated services is still in its early stages. Despite its nascence, gaps have been identified that (by addressing through research and development) will help guide the community to the enabling foundations for progress and advancement. Examples of these gaps are the full consideration of the requirements for the design, location, and sizing of vertiports as

	well as the charging infrastructure needed. How that charging infrastructure impacts the larger grid performance of a municipality is also a gap in current understanding as well as the potential of alternative fuel sources and opportunities to leverage emerging transportation fuel infrastructure. Issues and impacts to urban environments for planners to incorporate in their processes will need to be identified. Challenges to position, navigation, and timing as well as communication, navigation, surveillance, and information performance are also identified gaps in understanding that will need to be addressed. In doing so, the path toward scalable, resilient, and robust operations will become clearer.
7. Security	The current approach of incorporating IT security capabilities to aviation systems is insufficient for UAM operations; therefore, new cybersecurity technologies or modifications to current IT security technologies must be developed to guarantee secure UAM operations. Artificial intelligence and machine learning will play a crucial role in modern aviation cybersecurity. Operational concepts must be developed with cybersecurity in mind from the beginning, and aviation cybersecurity standards efforts must develop and harmonize to enable security in the proposed operational concepts.
8. Communications, Navigation, and Surveillance	Lack of consensus over UAM Communication, Navigation, and Surveillance (CNS) functional requirements is a significant roadblock to progress in this area. Once UAM CNS functional and performance requirements are agreed upon and standards are developed, technology assessment and development activities may be initiated. The low-altitude interference-rich environment of urban airspace poses unique challenges that may require novel solutions unique to this industry. Cybersecurity becomes a critical concern once remotely-piloted operations are permitted.
9. Weather Tolerance	Adverse weather is expected to challenge AAM flight stability. Sensing or characterizing weather at a higher resolution within micro-environments of urban settings (due to the sensitivity of AAM to smaller-scale weather patterns and on-board sensors) to enable nowcasting of weather effects, and range estimation will be needed for decision making by the system or the operator. Standardized technologies, vertiports, and operational capabilities along with development towards universal definitions, AAM assessment methods, and weather effects will support safe operations.
10a. Environmental: Emissions	The UAM industry can be a leader in the transition of aviation towards net-zero greenhouse gas (GHG) emissions. Several industry front runners are using fully-electric aircraft designs with zero "tailpipe" emissions, however, the lifecycle emissions (e.g., from battery production, charging from electrical grid, etc.) must be considered when considering the overall environmental impact. Other designs using combustion engines exist which would still produce "tailpipe" emissions but could utilize Sustainable Aviation Fuels (SAF) or hydrogen with potentially lower net-GHG emissions. Currently, there are no emission regulations that apply to this class of aircraft (<12,500 lb) and it is unclear how the aviation industry would account for lifecycle emissions or whether it is responsible for this bookkeeping. If lifecycle emissions are regulated, then a standardized methodology for lifecycle analysis will be needed.
10b. Environmental: Noise	For UAM systems to be sustainable, sound levels should be kept near or below the usual ambient sound levels of the region and have similar noise characteristics. The UAM aircraft have new configurations therefore, only some traditional evaluation and noise reduction methods are applicable. There are numerous gaps ranging from characterizing the noise source mechanism, to propagation, and human response.

	Additionally, different considerations between urban and rural environments exist for certification requirements along with standardized methods to characterize noise.
11. Maintenance	Numerous maintenance considerations exist surrounding initial and scaled UAM operations. It is critical that the reputation of the aviation industry as being the safest mode of transportation continues - even with the increasing density of operations. Multiple relevant maintenance knowledge gaps exist ranging from novel inspection cycles to long-term maintenance of hydrogen or electric-powered systems. Standards for maintenance surrounding UAM are lacking, yet standards in some narrow areas such as additive manufacturing are maturing.
12. Safety and Security	Operational considerations regarding UAM safety vary across European, Asian, and North American domains making assessments and determining homogeneous needs complex. Although many countries have standards and regulations for UAS and helicopter operations, respectively, they do not adequately cover envisioned UAM operations. To create international harmonization, UAM safety standards and regulations must address key state-specific elements for UAM operations such as air traffic management (ATM); personnel licensing and training; airworthiness and certification; aerodrome/vertiport infrastructure; and accident/incident investigation procedures. In addition, it is important to consider emergency response procedures; environmental/weather conditions; autonomous system limitation policies; training; and cultural differences; all while considering the safety impacts to current operations that may overfly or interact with UAM flights.
13. Intersection with Infrastructure	To support the ability to safely scale UAM operations where needed, technology and/or new infrastructure is likely a necessity. As the associated technologies and infrastructure changes are identified and considered, though, a greater understanding of the proposed changes and their impacts will be necessary prior to implementation. Initial design guidance for vertiports were referenced from earlier publications related to heliports. Newer guidance from the Federal Aviation Administration (FAA) and American Society for Testing and Materials (ASTM) has been published with a dedicated focus on vertiports; however, there are broader issues to consider when examining the intersection of vertiports and infrastructure with respect to societal and environmental impacts, equity, safety and security, first responder needs, and Communications, Navigation, Surveillance, and Information (CNSI) impacts and considerations as well.
14. Data Protection and Security	Data security is a relatively mature focus of Information Technology (IT) security built on sets of protection technologies and analysis of data sensitivities. System security engineering practices are used to match protection needs (PN) against the data sensitivity requirements, whether legal regulatory, contractual, or other, and develop security requirements for the system that contains or controls the data. Operational technologies (OT), as opposed to IT, are generally defined as those digital technologies that have an effect in the physical world. Data security in this OT domain is not well defined and in many cases is fundamentally nonexistent.
15. Autonomy	Assess the motivations and needs and assess the intended benefits, impacts, and alternatives of (autonomous) UAM and initiate open, public discussions. Study the equity and sustainability of UAM, including comprehensive environmental assessments.
16a. Environment: Emissions	Urban airports draw significant public scrutiny from the public over environmental concerns, and community acceptance over emissions caused by UAM operations is critical to enabling scaled operations. Insight into societal acceptance surrounding various fuel types and their subsequent emissions is key to determining viability for UAM operations. Additionally, a holistic approach to urban transport is needed to

	optimize the emissions and noise produced by the multimodal system and to determine the role of UAM in the future integrated system. Policies need to be developed on evidence-based science, and public education may be needed as well.
16b. Environment: Noise	If the UAM sector is to grow at the rates predicted by market studies (see ”Overview of Existing Market Studies”), the perceived value of UAM will need to outweigh existing societal concerns. UAM vehicles have very different noise sources from traditional transport aircraft or helicopters, and little is known about the response to the new noise profiles. Studies are needed that will assess the impact of noise with topics that include child learning, community impact, sleep disturbance, and cardiovascular health effects. Additionally, tools that take a holistic view of the urban landscape such as a Sustainable Urban Mobility Plan (SUMP) are needed to enable sustainable urban mobility.
17. Safety	Safety experts in UAM should look to implement programs that both improve the actual safety of their customers and their feeling of safety. Acceptance is dependent on the perception of safety and other aspects related to the benefits the innovation can bring. Keeping people safe and ensuring that people feel safe are two different challenges. People expect the service providers they interact with to pose little risk to their physical, mental, or financial health; therefore, news of incidents, which are a common occurrence for the aviation community, might make the public feel unsafe nonetheless.

Overview of Technology Area

Configurations differ from legacy traditional rotorcraft with less maturity in some key areas, especially in the number of passengers; number and arrangement of rotors; motors; engines and/or propellers; blade hinges; trim control; vibration; gear boxes; and noise. The introduction of multiple, constantly changing forcing frequencies creates a paradigm shift with many differences from conventional/traditional rotorcraft. Distributed Electric Propulsion (DEP) may generate lower noise levels but can still be quantified as annoying to bystanders. The actual collision avoidance systems (Detect and Avoid (DAA)) cannot be used in dense aircraft environments due to technology limitations. The DAA will be challenged by the emergence of large numbers of UAM vehicles in the urban environment, flying at low altitudes to many different landing sites. The DAA system, for obstacles in the flight path and birds, may require more attention than previously thought.

State-of-the-Art Assessment

There are many different vehicles being developed (from conceptual design to flight test) without an emerging leading vehicle configuration - unlike the legacy rotorcraft market that has remained fairly consistent in vehicle configuration. Because initial commercial operations are not yet underway, several years are necessary to reach scaled, routine commercial operation (considering certification timelines, mass production, infrastructure, etc.). Flight tests, development, and demonstration of various vehicle prototypes are underway. There are finite resources in four main factors: 1) availability of qualified pilots; 2) cost of vehicles; 3) availability of specialized airport infrastructure (vertiport); and 4) air traffic control capacity. Pilot augmentation technology would help to reduce pilot formation time and provide sufficient qualified pilots.

Gap Analysis

There is a lack of quantification of the level of annoyance induced by the frequent passage of vehicles on the urban population. Common standards with documented methodology for noise and safety regulations are needed for UAM designs. The effect of feasible noise mitigation strategies on the performance reductions for low-noise vehicles can only be developed once those standards become available. Additionally, there will be a requirement need for improved aeromechanic predictive tools in early design stage for UAM vehicles. Standardised performance evaluation methodology for flight segments, and performance standards in urban environment for UAM vehicles, must be defined. New design requirements for vertiports, including acceptable flight paths when approaching and departing from different take-off and landing sites with sense and avoid capacity, are also required. The same level of safety as the existing air transport systems (according to their category) should be achieved; however, this means high cost, making this level of safety less acceptable from an economical viewpoint. As different opinions exist within the industry, a consensus should be obtained.

Open Research Areas

1. Is production of vehicles at low cost satisfying the severe flight safety regulations (possibly due to the small numbers produced)?
2. What is the time period required for the implementation of the various technologies needed for the different vehicle configurations?
3. What are the noise standards and possible vehicle restrictions needed for both vehicle configuration and social acceptance?
4. Can the infrasound generated by electric propulsion be minimized effectively?
5. How is the adaptability of different configurations as it relates to the various usage scenarios?

Adapted from: None.

Overview of Technology Area

To successfully operate in an urban environment and confined areas, many believe that UAM aircraft must be capable of vertical takeoff and landing (VTOL) to operate, and the aircraft should not contribute to the emissions problem that is currently present in most cities. These requirements present unique technical challenges which have resulted in designs for UAM aircraft that are VTOL and use electric or hybrid-based propulsion systems. Vertical takeoff and landing add to energy requirements, and aircraft using a large number of propellers are less efficient in hover than traditional rotorcraft resulting in payload, range, and endurance performance limitations. The major barrier to increased aircraft performance is the poor specific energy of batteries compared to liquid hydrocarbon fuels, coupled with the need for a high-energy discharge rate for hover. Many VTOL UAM aircraft are electric at the current time, with some configurations exploring hybrid-electric systems to extend range. There are proponents of hydrogen as a possible energy source with great promise, but that area is developing on a longer timeframe. There are also proponents of using SAF to reduce emissions. Any type of novel refueling/recharge system will require significant investments in technology and infrastructure. Ancillary propulsion system considerations such as high-voltage system safety, battery monitoring and replacement, fire hazard containment, and thermal management must all be addressed during certification.

State-of-the-Art Assessment

Electric propulsion systems are operational and in demonstration flight tests in many different types of VTOL aircraft. Many advances are needed in power density, reliability, packaging, monitoring, servicing, and ground infrastructure to advance to scaled commercial operations for electric propulsion vehicles. Electric motors, no matter the power source, give off low-grade thermal heating even in the best of design conditions. Cooling systems for the motors and shedding the excess thermal energy that is generated without adding significant weight is a serious design challenge for the vehicles. Hybrid-electric systems can extend the range of UAM aircraft and hybrid-electric systems are under evaluation particularly for aircraft that are targeting longer range markets, such as intracity transportation. Hydrogen fuel-cell propulsion systems are proposed as an alternative to increase range but have not been demonstrated in VTOL systems. For hydrogen systems, a major limitation is physical space on the aircraft for the fuel cells and storage tanks. The hydrogen/fuel-cell technology lags battery technology but may be more revolutionary, and the development of hydrogen alternatives is on a longer timeframe than battery-based systems. Neither electric nor hydrogen advanced propulsion concepts are currently being used in commercial operations.

Gap Analysis

Battery technology development is needed to increase the specific energy, power density, and the charge/discharge rate. Battery improvements are also needed in smart energy storage/management, rapid recharge capability, as well as weight, safety, reliability, cost, and other factors. Enabling technologies at the system level are needed to package the batteries for optimum efficiency and safety. Improvement in high-voltage hybrid-electric generators is for efficiency, although performance is needed as well. Broad updates in infrastructure and economy are needed to enable hydrogen benefits. Also, the net emissions of pure electric aircraft compared to hydrogen fuel cells needs further analysis. Certification requirements for UAM VTOL aircraft are still evolving. Some requirements indicate that components of the propulsion system may require the highest levels of reliability to meet expected safety requirements. Existing UAM aircraft concepts may have difficulty meeting a high reliability requirement. Standardization of power system connections and charging infrastructure is needed for scaled operations.

Open Research Areas

1. New motor designs that have higher reliability than current designs.
2. Advanced thermal management systems that are lightweight and work in hover and low-speed flight conditions.
3. Investigation of the mechanical fatigue of motor components (e.g., motor windings due to high-cycle thermal loads).
4. Electric components, power distribution, power quality, high-voltage systems, motor design, and integrated thermal management systems.
5. Battery life cycle, charging/discharging, safety after impact, and monitoring systems for prognostic maintenance.
6. Further research for advancement of hydrogen fuel cells, including hydrogen safe handling and storage.

Adapted from: "DRAFT V2 IFAR Scientific Assessment of UAM_prop.docx" and "Key Take Aways Propulsion and Energy Ver 2.pptx."

Overview of Technology Area

Automated systems (AS) are typically sophisticated automated systems with prescribed authority to achieve goal-directed behaviors rather than more basic reactive feedback control and scripted information-processing tasks of traditional automated systems. Applications of AS span all flight tasks including mission management, strategic flightpath planning, tactical operations, trajectory execution, and systems management in nominal and off-nominal situations. A key objective in applying AS to UAM is enabling changes to roles, authority, and responsibility, particularly final authority and responsibility between pilots and AS to enable new operations and expand markets. An eventual goal is enabling safe autonomous aircraft operation with a small ground staff supervising large numbers of aircraft. Such capability would be particularly impactful for UAM given small payloads compared to transport aircraft. In addition to on-board technologies, updates to the airspace system are an important component of enabling and accelerating the deployment of increasingly autonomous aircraft. These updates include technologies such as vehicle-to-vehicle data sharing as well as flight rules leveraging these capabilities.

State-of-the-Art Assessment

Currently, regulations vest final responsibility for safety and operation of the aircraft in the "Pilot in Command." To comply, a Pilot in Command (PIC) must be able to operate the aircraft without automated systems to the maximum extent possible. This philosophy significantly elevates minimum pilot qualifications while often reducing targeted automation capabilities, particularly in off-nominal contingencies. In contrast, the UAM community expects to develop AS that perform designated functions with better performance and safety than pilots in all situations that are not shown to be extremely improbable, with AS ultimately having responsibility for these functions and making them irrelevant to pilot workload and qualifications. While the community expects to achieve near full autonomy within ~15 years, companies are pursuing a variety of strategies to achieve this objective, including going "direct to autonomy" and more incremental strategies that change the balance of pilot and automation authority and responsibility over several generations. At present limited analysis or data has been published documenting the viability and progress of these strategies.

Gap Analysis

The regulatory requirements for AS relative to candidate functions, performance, and design assurance requirements are currently uncertain as many tasks are implicit responsibilities of human pilots and not directly contained in regulation (e.g., Detect and Avoid as one example). Means of verifying compliance with assurance requirements for nondeterministic algorithms are currently a gap. Emerging AS perform specialized tasks and the underlying technologies do not fully replace the general intelligence essential to aviation safety. As such, human-automation teaming and associated challenges will remain important for the foreseeable future, particularly, for concepts envisioning remote aircraft supervisors. The current regulatory structure governing aircraft, airmen, and flight operations is predicated on current human-centric operations and demonstrated success. Significant revisions to this structure are required to take full advantage of AS. As rapidly evolving AS expand the scope of potential human-automation teaming concepts, development and application of appropriately integrated, flexible, and effective regulations will become increasingly challenging and important. Finally, as actual operations are required to fully validate the capabilities and limits of evolving AS, developers and regulators need to cooperatively develop strategies allowing operations and learning in applications with risk tolerances consistent with the underlying concept maturity. In addition, standards for documenting and applying data from these early operations to other use cases, nominally with higher assurance and safety requirements, are needed.

Open Research Areas

1. Software verification methods for artificial intelligence and machine learning based systems.
2. Novel architectures and assurance methods for complex AS and operations including automation of abnormal operations (e.g., run-time assurance, overarching properties).
3. Safe distribution and allocation of decision making between aircraft, control station, and airspace infrastructure.
4. Pilot/crew qualification and certification with differing levels of AS.
5. Balancing diversity of AS design, competition, standardization, and burdens on regulators.
6. Airspace system development accelerating AS
7. Harmonization of standards and regulations to increase safety and scalability.

Adapted from: presentation by IFAR UAM WG – TECH-Area3-Aircraft Autonomy To ICAO on 20220722.

Overview of Technology Area

The Urban Air Mobility (UAM) concept is focused on, but not limited to, rules, procedures, and technologies that enable the movement of cargo and passenger aircraft in the urban environment. The FAA and NASA have defined a broader term, Advanced Air Mobility (AAM) [1], which covers regional and interregional operations as well. There are many concepts of operations in development, as given by the FAA UAM ConOps v1.0 [2], the NASA UAM Vision ConOps v1.0 [3], and U-Space ConOps created by the CORUS-XUAM Project in Europe [4], which outline various airspace integration implications and solutions. While harmonization is required at an international level for these ConOps, a key characteristic emphasized across these documents is that the growth of the UAM industry will increase traffic density and frequency in certain areas. This growth and unique set of performance characteristics will introduce operational challenges that current global ATM systems are unable to support. This technology area is focused on identifying procedures, constructs, and technologies needed to seamlessly integrate UAM operations into existing airspace environments while allowing for regional considerations.

State-of-the-Art Assessment

Novel airspace integration policies and constructs for passenger-carrying UAM vehicles, either crewed or uncrewed, do not currently exist and require significant research and assessment to develop. Globally, early UAM entrants will most likely utilize existing flight rules, procedures, and ANSP interactions to complete initial missions. Public good operations, such as disaster response, air ambulance, emergency good delivery and police operations have been in the spotlight as initial UAM use cases. While unmanned aircraft system (UAS) Traffic Management (UTM) [5] concepts have begun to be implemented across the globe, these systems are focused on enabling small, unmanned drones to access low-altitude airspace beyond visual line of sight (BVLOS) with minimal impact to the existing aviation system; however, the line between UTM and UAM operations is blurry and needs further discussion in the research community.

Gap Analysis

The UAM airspace structures, procedures, and definitions (such as enabling the use of corridors) require development and description to enable scalable operations. The UAM separation requirements are not currently standardized, and therefore will need to be researched and defined to support UAM operations. Technology, methods, and data structures for intent sharing must be defined for UAM operations. While lessons learned from UTM can be leveraged, there are significant differences for higher altitude and passenger-carrying operations that may imply different risk ratios for ANSPs. Identification of other data services, such as weather data for the urban canyon, must be outlined along with information exchange protocols. Alongside the development of intent sharing methods and other data, a comprehensive system architecture that can be applied across the globe may be required to ensure that operations can occur effectively across nations. Additionally, roles and responsibilities between different UAM ecosystem entities should be defined for varying levels of automation (including UAS and Remotely-piloted Aircraft Systems (RPAS) operations) to enable long-term UAM operations.

Open Research Areas

1. What are the information requirements, procedures, and technologies needed between UAM operators and existing ATM services to enable early and long-term operations? How do airspace systems or supporting services interoperate for diverse operations in the same geographic areas?
2. Can airspace integration methods, systems, and data structures be extrapolated from sUAS, UTM, and other relevant operations (e.g., Part 121, Part 135, disaster response practices [6])?
3. What are the navigation and surveillance performance requirements and accuracy of these capabilities needed to enable airspace integration and monitoring of UAM operations?
4. Can separation minima be defined for UAM-UAM, UAM-sUAS, and UAM-traditional traffic?
5. What new regulations and rules will be required to establish new airspace structures and procedures for UAM operations to make them scalable while preventing overburden of existing ATM services?

Adapted from: None.

Overview of Technology Area

Safety and the corresponding SMS are an integral foundation for the integration and operationalization of respective technologies as they assure their safe and secure implementation throughout the entire life cycle. Safety management systems in themselves are not an independent technology but represent a system on how to use and maintain technologies that must be laid out prior to their operation, which also includes training for the people involved to ensure a certain standard of safety and security as well as monitoring and auditing mechanisms. Safety management systems are highly advanced within the (commercial) aviation industry, often portraying a high degree of complexity, as SMS in classical aviation have continuously evolved over a period of more than 50 years to ensure pilot and passenger safety. The ICAO Annex 19 *Safety Management* contains Standards and Recommended Practices (SARPs) for Safety Management in Aviation. Appendix 2 contains the framework for a SMS. The UAM service providers may be responsible for the most safety-critical UAM operations and will need to implement SMS comparable with the SMS framework as contained in Annex 19 Appendix 2.

State-of-the-Art Assessment

With ICAO Annex 19 as a basis, a viable framework for a SMS already exists for UAM operations; however, it is currently unpredictable whether additional amendments to the current framework might be required to fully encompass the UAM ecosystem into a SMS. This is mainly due to the low levels of maturity regarding the new technologies, which constitute the majority of the UAM ecosystem, resulting in insufficient data as a possible basis for new or amended regulations. Regarding UAM, regulations safety must be considered prior to flight, managed in-flight and assessed post-flight and requires a convergence in design and operational safety techniques, which will require paradigm shifts and new standards for certification. The requirement for integrating increasingly automated and autonomous systems will require novel certification processes, techniques, and standards due to the increase in software executive capabilities. Database management tools are helpful but not sufficient. Current data analytics are not able to predictively assess safety for UAM Maturity Level (UML) 4 operations (if the UML concept is unknown, see NASA publication 20205011091). The impact of security measures (e.g., for cybersecurity) on safety is not well addressed in the information flows within the current SMS approach. Both the integrity of data and the availability of data to provide in-time results have never been fully addressed.

Gap Analysis

The UAM service providers are currently not explicitly mentioned in ICAO Annex 19 Safety Management or in ICAO Doc 9859 Safety Management Manual; therefore, which UAM service providers need to implement SMS is currently not clear and not harmonized. Additionally, the SMS of AAM/UAM service providers will rely on contractual controls and use of safety critical services provided by contractors or other organizations that are likely not all able to identify and assess operational hazards themselves. Examples include providers of Command and Control (C2)/C3 links and weather information. Adequate guidance material (best practices) to support AAM/UAM service providers in managing risks associated with safety critical services are needed. Furthermore, the safety risks associated with autonomous or highly automated UAM aircraft are not well understood. Unknown aspects must be clarified and addressed in safety management. Additionally, the highly automated systems being proposed and developed need a high level of security monitoring and analysis to assure the overall safety of the operations. The intersection of safety and cybersecurity must be addressed and will exist directly in hazard analysis, risks that can be realized by (a lack of) cybersecurity or the enhancement of cybersecurity measures, that negatively affect safety.

Open Research Areas

1. Can a SMS be effectively implemented for UAM with the current lack of data?
2. What safety data is really needed for an effective SMS implementation in the UAM domain, and can this data be extrapolated from sUAS and other relevant operations?
3. Is there an interdependency between (operational) data, safety and technology development for UAM/AAM?
4. How can the safety risks of autonomous or highly automated UAM aircraft be assessed and evaluated? How to demonstrate to the authorities that operations with such UAM vehicles will be safe?
5. Can the In-time Aviation Safety Management System (IASMS) provide in-time notification and possible mitigation of cybersecurity hazards?
6. How can IASMS and its notifications account for different levels of automation/autonomy?

Adapted from: “220202_IFAR TAA – Topic 5 – SMS – Consolidated” and “IFAR UAM WG – TECH-Area5-SMS_ShortVersion_ICAOMeeting 20220405.”

Overview of Technology Area

The development of infrastructure for vertiports is still in its infancy; however, initial low throughput operations will likely be established by modifying current infrastructure technology. It is unlikely that all infrastructure solutions employed today will be suitable to meet the future demand for UAS operations; therefore, it is assumed that the infrastructure technology solutions will need to evolve as the operations evolve. There are unique challenges associated with AAM operations and the infrastructure needed to support them. The AAM aircraft have a wide range of designs, dimensions, performance, intended use, and a variety of fuel sources. The AAM operations seek to extend beyond airport environments into nontraditional locations such as urban centers, rooftops, oil rigs, etc. Impact from a vertiport on existing operations and communities will be dependent on facility and locality; however, often the intended use to align with commercial business cases requires higher throughput operations, which will strain the security, safety, and efficiency of existing infrastructure and technology systems. Five key technology areas that need further development were identified as CNSI technologies, safety technologies, power supply and recharging technologies, security technologies, and handling technologies. Other areas for consideration of infrastructure include water and waste management, garbage collection, maintenance infrastructure, and other engineering infrastructure as examples.

State-of-the-Art Assessment

There are wide ranges of infrastructure that support aircraft operations at airports and heliports. Given the diversity of potential AAM use cases and aircraft configurations, there is no clear roadmap on the requirements necessary to support AAM operations - even at existing facilities. Current vertiport design guidance issued through an Engineering Brief from the FAA and a Vertiport Design Specification from EASA, focus primarily on the design, layout, markings, and visual aids of a vertiport facility but are less detailed in the required infrastructure to support the operations. Current facilities, primarily airports, have CNSI technologies and services that support operations; however, these technologies were designed for airport environments which may not yield sufficient performance in AAM environments (e.g., urban vertiports) or at the desired operational tempo of AAM operations. While initial low, throughput operations are targeted to leverage existing infrastructure, there is risk that a lack of planning towards infrastructure development for higher throughput operations could result in significant delays towards industries timelines.

Gap Analysis

Given the nascent state of vertiport development there are significant gaps in supporting initial and future operations. The vertiport location, sizing and the complexity of the surrounding airspace may limit the locations of vertiports, and limitations of the power grid capacity and resilience may impact eVTOL recharging and throughput at facilities. Furthermore, with vertiports located in urban environments there will be challenges with position, navigation, timing, and communication due to radio line of sight obstructions. The throughput of operations may require reliable real-time vertiport information (e.g., availability, weather, schedule, etc.). There are also gaps in ground operations such as timely and efficient cargo handling, passenger management, and cyber and physical security, which need technological solutions. The location and size of a vertiport may make fire suppression and off-nominal contingency management challenging. There are substantial gaps in the standardization of the infrastructure codes, charging systems, and communication systems, as well as regulatory gaps on design standards, CNSI standards, vertiport manager licensing, and third-party service provider approvals.

Open Research Areas

1. What are the roles and responsibilities for the Vertiport Manager?
2. What are the information requirements between the pilot/aircraft, vertiport, air traffic control, and fleet manager?
3. What parts of the ground operations and passenger handling should be digitized and automated?
4. What is the regulator oversight model and design assurance requirements for vertiport technologies?
5. What is the impact of existing ground technologies on new vertiport facilities (e.g., 5G/6G)?

Adapted from: "IFAR UAM WG 6 and 14 Infrastructure Technology and Operations.pptx."

Overview of Technology Area

To guarantee secure UAM operations, new cybersecurity technologies need to be developed or IT security technologies need to be altered for aviation, particularly ground-to-air and air-to-air communications and airframe security. Current use focus is on adding IT security capabilities to the current system without a good understanding of the impact. The IT security capabilities (such as firewalls and intrusion detection systems) often do not translate well to aviation systems, posing a significant threat to airframes and air operations. Increasing levels of insider threat requires adoption of a security culture in organizations where employees must be trained in their role in mitigating threats and adhering to cybersecurity policies and best practices. Additionally, processes and playbooks must be periodically reassessed and tested to ensure continuous improvement. Furthermore, access controls should be put in place to allow people who absolutely need clearance to certain areas to the airport or the aircraft.

State-of-the-Art Assessment

Large parts of the current air system do not enjoy the same level of protection as terrestrial internet-based systems, but modernization is occurring in some areas (of note: the Global Resilient Aviation Information Network (GRAIN) and International Aviation Trust Framework (IATF) work). Aviation cybersecurity standards are being developed in many forums, but a lack of coordination is leading to conflict and confusion. Additionally, security encryption algorithms are already facing end-of-life due to quantum decryption techniques. Artificial intelligence, and specifically machine learning, will play a crucial role in aviation cybersecurity. A weaponized AI in the hands of cyber criminals poses a high risk but also highlights the opportunity of investing heavily in AI-defense and research. Emerging machine learning models will enable greater protection against these sophisticated and complex threats. A good understanding of the vulnerability of current avionics systems to cybersecurity threats is missing. Additionally, the aviation communications environment including CNS is largely unsecured. Cybersecurity is often an afterthought in development leading to unsecure technologies and operational security gaps. Risk management practices that focus on real-world safety hazards as they are impacted by cybersecurity are also limited. Strategies like micro-segmentation will be used to divide networks into multiple micro segments and to apply separate access privileges. Micro-segmentation breaks data centers and cloud environments into segments down to the individual workload level. Organizations implement micro-segmentation to reduce attack surface, achieve regulatory compliance, and contain breaches. Work on big data and predictive analytics represent a promising domain for improving aviation security due to the evolution of aircraft sensors and processors which will provide large amounts of aviation data throughout all the aviation ecosystem including connectivity, operations, or predictive maintenance.

Gap Analysis

Operational concepts must be developed with cybersecurity at the outset. Methodologies need to be developed to translate IT cybersecurity capabilities into operational technology (OT) aviation cybersecurity operational concepts. Tests are necessary to assess the level of protection and include penetration testing (or “red teaming”) where cyber experts try to gain access to the systems, as well as vulnerability testing to look for flaws in security. Two conditions are necessary to allow the attacker to succeed: 1) the existence of a vulnerability in the aviation system, and 2) a pathway to attack that system or exploit that vulnerability. Furthermore, aviation cybersecurity standards need to be developed and harmonized.

Open Research Areas

1. Can emergent cybersecurity incidents be predicted and mitigated before having an adverse impact on the airspace system or individual aircraft?
2. Can the airspace communications systems be matured to provide the capabilities of confidentiality, integrity, and availability per the operational need?
3. Can a quantum-resistant set of encryption algorithms be developed and implemented in time to avoid operational disruption?
4. Can the current Public Key Infrastructure (PKI) IATF models be converted to quantum encryption or quantum decryption resistance?

Adapted from: None.

Overview of Technology Area

Communications: Required UAM data services which include telemetry, C2, pilot/passenger voice, and off-nominal communications must be more reliable and secure than existing aviation solutions with service volumes that extend into urban environments. Implementations may include Satellite Communication (SATCOM); Vehicle to Vehicle (V2V) technology; purpose-built Air to Ground (A2G) networks; and wireless services designed for nonaviation customers (e.g., cellular and satellite).
Navigation: On-board navigation services for remotely-piloted UAM operations must be reliable, ubiquitous, and more secure than traditional aviation navigation services due to increased cybersecurity threats, challenging operational environments, and increased reliance upon self-reported positional information.
Surveillance: New V2V communications technology and standards to support tactical deconfliction will be required. Noncooperative surveillance technologies to both validate self-reported UAM position data and identify non-UAM objects in airspace that lies below the coverage of existing aviation radar services.

State-of-the-Art Assessment

Currently in the U.S.A., there are no agreed-upon UAM CNS requirements, so it follows that there are no approved UAM CNS technologies or standards. Several candidate technologies exist at various levels of technical maturity and include the following:

- The UAS-specific C2 services (e.g., RTCA (Technical Committee for Aeronautics) DO-362, Advanced Ultra Reliable Aviation (AURA) networks.
- Commercial cellular.
- Commercial satellite.
- Multiple satellite-based positioning, navigation, and timing (PNT) sources including, but not limited to, Global Navigation Satellite System (GNSS) services.
- Multiple ground-based PNT sources and landing-assist technologies.
- The V2V communications technologies for cooperative surveillance.
- Low-power radar and radiometric tracking capabilities for noncooperative surveillance.

Most of these technologies were not designed for UAM operations, so testing is required to determine their suitability.

Gap Analysis

The UAM CNS functional and performance requirements must be developed and agreed upon followed by standards development and validation/certification procedures. These standards must be in place in order to determine if existing technologies and infrastructure are able to support UAM operations. Testing should be done in the interim in order to accelerate technology development and to inform standards bodies. Known UAM CNS technology challenges include cybersecurity, spectrum availability, scalability, reliability/criticality, coverage in urban environments, and low-altitude surveillance. A nontechnical challenge in this design space is business viability. In the U.S.A., UAM CNS services will likely be owned and operated by private industry, so profitability must be achieved while still allowing for sufficient regulatory oversight.

Open Research Areas

1. What are the functional and performance requirements for UAM CNS Services?
2. Can existing or planned consumer wireless communication services be utilized by UAM?
3. How do we split the responsibility of providing en route versus vertiport-proximity CNS services?
4. Does increased vehicle autonomy reduce the criticality of CNS or increase it?
5. How do we make UAM CNS services cybersecure?

Adapted from: "IFAR Scientific Assessment Inputs – CNS – NASA."

9. Weather Tolerance

Technology Area Overview

Overview of Technology Area

The use of AAM, expected to include flight at low altitudes and in urban areas, will subject the aircraft to **micro-weather** patterns which have higher levels of adversity along a flight path than for traditional aviation. The unique weather patterns AAM will need to survive include strong wind-speed gradients, urban-updrafts/downdrafts, building wake shear, small-scale turbulence, urban vortex shedding, and localized icing phenomenon for cold climates. These weather patterns generated in low altitude and urban environments occur at smaller timescales than for global weather, which further challenges the technology required to mitigate effects of weather hazards on AAM. Changes needed in existing weather-related aviation technologies include advancement of stationary weather sensing systems; on-board AAM weather sensors; and knowledge of the AAM limits for the range of weather characteristics and forecasting of micro-weather to predict changes in weather within a timescale that relates to the smaller size of AAM. Smaller and lightweight AAM aircraft are expected to be more sensitive to the micro-weather patterns, instigating the development of novel weather detection and mitigation technologies. These advances will primarily enable safe AAM operations but also advance weather technologies for traditional aviation.

State-of-the-Art Assessment

Initial UAM/AAM/IAM commercial operations can be safely performed when long-lasting fair and low-wind weather is predicted; however, for adverse weather, operators are relying on airport weather reports and on-board aircraft stability sensors to assess safe operating conditions. No indication of advanced micro-weather sensing/prediction have been made public although challenges associated with operations of UAS in harsh Nordic and Arctic conditions (at high mountain altitudes and for urban airflow) have been identified. Some development on the understanding of weather tolerance is underway for small AAM aircraft demonstrating the increased sensitivity of AAM to icing and complex airflow found at low altitudes. Additionally, since station keeping and course correction is expected to be challenged by urban airflow, scaled operations will require traffic management that accounts for the tolerances in flight path control of each AAM operation. Airports or helipads can be adapted for the needs of AAM by adding deicing facilities and choosing Touchdown and Lift-Off (TLOF) locations away from the wakes of structures. The key weather-related safety considerations are collision and loss of power/control due to weather effects on flight stability. Vertiport standards to mitigate adverse weather effects caused by urban structures would include strategically and closely spaced weather stations that report at shorter intervals. No standards for the certification of emerging ice protection/detection technologies exist although ASTM UAS weather standards and infrastructure for large-scale weather communication are in progress.

Gap Analysis

Technical and design verification requirements and standards and operational practices to achieve and benchmark all-weather resilient UAS/eVTOL operations are yet to come. At a baseline level, definitions relative to weather and AAM (weather tolerance, gust/turbulence, flight stability) need to be universal for the growth of a unified industry. A universal vocabulary and technical definitions would promote consistency in global OEM standards for weather tolerance-related technologies and flight stability criteria, which do not exist at present. Both the technological advancement in weather sensing systems at ground/vertiport stations and on-board sensors, and the development of viable business cases that provide return on investments, installation of sensors will be required to obtain weather observations and relay information at a faster rate than what currently exists for traditional aviation. Observational data has not been available to validate weather models or forecasts, which are generated through utilization of these models.

Open Research Areas

1. How do low-altitude atmospheric turbulence levels and urban airflows affect AAM stability and energy consumption?
2. Will the range in AAM configurations challenge a universal understanding of weather tolerance, or can knowledge be transferred between configurations and sizes?
3. What are effective and durable AAM-scale icephobic coatings, ice protection and deicing systems, and ice detection sensors?
4. Will extreme hot weather events require cooling systems to mitigate battery or other system failures?
5. Can weather sensing or prediction technology be adapted to the timescale and nowcasting required for AAM?
6. Can static or semi-static equivalency testing be a cost effective and reliable method to evaluate AAM for assessment of weather tolerance?

Adapted from: “220202_IFAR TAA – Topic 9 Weather–Consolidated” and “IFAR UAM WG – TECH-Area9-Weather_ShortVersion_ICAOMetting 20220615.”

Overview of Operationalization Area

The UAM industry can be a leader in the aviation transition towards net-zero GHG emissions. Several industry front runners are using fully electric aircraft designs with zero "tailpipe" emissions, however, the lifecycle emissions (e.g., from battery production, charging from an electrical grid, etc.) must be taken into account when considering the overall environmental impact. Options also exist for propulsion systems that use hydrogen (through fuel cells or direct combustion) or sustainable aviation fuels (e.g., hybrid-electric engines), which potentially increases the range of the aircraft. Although fully battery-electric aircraft will produce no CO_2 (or other) emissions, the lifecycle emissions need to be considered as the battery can represent a large portion of the overall lifecycle emissions of the operating life of the aircraft. For example, frequent replacements of the aircraft battery pack could have greater lifecycle emissions than using an engine with conventional fuel. Similarly, fuel production emissions are highly dependent on the method used by local grids to generate their electricity (for battery charging), or the method used to generate H_2 or SAF. Additionally, novel technologies under development for UAM, including those used for air quality and emissions monitoring, have the potential to positively influence other transportation sectors.

State-of-the-Art Assessment

Current emissions standards (ICAO Annex 16 Vol II) are only applicable to larger aircraft powered by turbojet/turbofan engines (>26.7 kN-thrust); therefore, the current size of UAM would not be regulated by these standards. The UAM fleet could be considered analogous to the current general aviation fleet, which represents only about 1 percent of total emissions from the aviation sector; however, depending on how the UAM sector grows, it could start to represent a larger proportion of emissions from the aviation sector. Furthermore, emissions standards currently only focus on exhaust emissions, and as mentioned in the "Overview" section, the lifecycle emissions may be a more important consideration for the UAM sector. It would need to be determined whether these emissions from energy production should be book-kept as aviation industry specific or come from other industries. Also, a standardized methodology would be needed for the lifecycle analysis so that consistent reporting occurs (similar to what ICAO had developed for SAF). Finally, the UAM propulsion technologies are predicted to eventually scale up to larger aircraft (>26.7 kN-thrust), so it is relevant to start considering these factors today.

Gap Analysis

Current studies comparing the environmental footprint of UAM to other modes of transport (such as ground electric) show that the results are highly dependent on assumptions made by the authors (e.g., there are large impacts on the assessments depending on the assumed electrical grid carbon intensity as well as passenger load). For example, some studies show UAM has nearly 2times the carbon footprint over ground electric transport while others show as low as a 6-percent difference in emissions between the two modes. As technological improvements in both UAM and ground transportation occur, continual updates to emissions studies are needed for a fair comparison. To enable the reuse or recycling of electric batteries, multiple barriers must be addressed including the high costs and lack of clear standards and regulations for the classification, storage, handling, and processing of batteries enabling predictable end-of-use conditions. Additionally, although the smaller aircraft suitable for UAM do not have emissions requirements, the emissions of large fleets of aircraft must be considered.

Open Research Areas

1. A standardized methodology for lifecycle analysis is needed, will the aviation sector track emissions due to fuel and electric production?
2. Does integrating UAM into a holistic transportation system contribute to overall lower emissions for the transportation sector? Is there an optimized way for the system to be used?

Adapted from: "Team 11-18 Environment (Emissions) Consolidated 20220303."

Overview of Operationalization Area

Currently, AAM has a wide range of noise source characteristics due to different fuselage designs, propulsion configurations, size maximum takeoff mass, and flight modes. Characterizing noise in a standardized way is challenging but will be key to ensuring sustainable operations. In urban areas, noise due to UAM operations will need assessments to account for:

- Noise that adds to current noise such as noise generated by urban transportation.
- High operational tempo near vertiports.
- Optimizing routes and operating profiles to minimize noise, and account for environmental influences such as population density, reflections, and scattering from buildings

Beyond the sources, acoustic propagation in an urban environment requires considerations such as multiple reflections, diffractions, and masking effects, which will strongly modify the noise perceived by the citizens. In rural areas, AAM should be optimized to minimize interference with the natural environment. Electric propulsion and low-noise specifications are helpful for this requirement, however further considerations should be the subject of appropriate analysis.

State-of-the-Art Assessment

Currently, the regulatory environment ranges are between insufficient and sufficient but not optimised. Action is needed to adapt existing regulations to new aircraft configurations. Current FAA interim noise certification of UAS is on a case-by-case basis using rules of particular applicability (RPA). General rules on UAS noise certification remain and continue to be developed. A multitude of noise mitigation techniques have been developed over the years that can be applied, but there are new techniques for noise reduction that are enabled by the AAM multi-rotor, alternative propulsion configurations (e.g., rotor phase-locking), while other techniques are not suitable due to the unique configurations of AAM. For decades, simulation tools have been developed to estimate the noise radiated by helicopters and propellers. Ranging from low-order models to high-fidelity methods, these tools can be applied and modified for AAM applications. Urban acoustic propagation tools have been developed for many years to evaluate the noise generated by ground vehicles (cars, motorbikes, bus, trains, etc.). As these sources are on the ground, propagation tools often use a 2.5D ray-tracing method, which is not adequate for sources moving at altitudes higher than buildings.

Gap Analysis

Sound produced from AAM aircraft will have three-dimensional profiles. As a result, new standards and measurement techniques need to be established. Current ICAO standard (for helicopters) is a single-point measurement with no correction for human perception. Additionally, further research into multidisciplinary optimization of AAM specific propulsion systems for noise and thrust is needed. Viability of current noise simulation tools for smaller rotating parts, particularly around determining effects of scaling, requires further investigation. Furthermore, it is unclear how radiation mechanisms must be modified when switching from rotors supporting blades several meters long to rotors potentially as short as a few centimeters. Assessment methods for AAM noise scattering need to be developed to adequately capture operations.

Open Research Areas

1. How can planners take advantage of ambient noise levels to mask the detectability of UAM operations?
2. How can existing urban propagation tools be applied to flying acoustic sources?

Adapted from: “Team 11-18 Environment (Noise) Consolidated with takeaway chart 20220301…”

Overview of Operationalization Area

Integrating UAM concepts into an industry renowned for being the safest mode of transportation for decades demands the continuation and improvement of that reputation. This improvement must be achieved with maintenance practices consistent with those already established that have produced desirable results. Introduction of U A M vehicles will bring technologies that pose challenges to existing maintenance practices. Namely, the use of hydrogen power systems, electric power components, and altering the application of traditional materials or air vehicle components will elicit challenges to the aviation industry. Infrastructure does not yet exist for widespread, long-term maintenance of electric or hydrogen-powered propulsion systems. Additionally, aircraft maintenance service providers are not yet equipped with the knowledge, staff, or tools to operate UAM technology on even a small scale, nor has the aviation industry developed standards for technologies unique to UAM function.

State-of-the-Art Assessment

Operational differences that may elicit maintenance adaptations are mostly related to shorter service routes and areas. The idea of on-demand or ride-sharing aircraft means an increase in the number of takeoff and landing cycles, less predictable operation and maintenance planning, more variation of engine speeds (resulting from less time spent at a cruise altitude), and vibration profiles that accompany such changes. All these factors will potentially affect the inspection cycle of components and airframes that could produce a more frequent need of repairs, component exchanges, and scheduled maintenance intervals. Demonstration of new technologies will have a noticeable impact on maintenance practices that may even affect the distribution of service centers based on the smaller scale urban operational areas. Coupled with a need for infrastructure growth to support UAM vehicle maintenance, namely with new types of powerplants, there may also be a need for specialized maintenance or servicing facilities that do not yet exist.

Gap Analysis

Generally, standards for UAM vehicles, materials, propulsion systems, and maintenance practices are lacking. The FAA does not have any regulations specific to UAM at all while the European Aviation Safety Agency does have a framework of high-level directives aimed at the establishment of UAM maintenance standards (EASA SC-VTOL-01). One exception is the existence and ongoing development of standards for additive manufacturing (three-dimensional (3D) printing), by the Society of Automotive Engineers (SAE). The SAE has published standards for fused-filament (nonmetallic) processes and fabrication as well as several metal alloys including titanium, nickel, steel, stainless steel, and aluminum. Similarly, process standards for additive manufacturing of these metals have also been published. Certified maintenance is needed for operations such as passenger transportation and development of necessary maintenance certifications for UAM lag behind pilot certifications.

Open Research Areas

1. An area often overlooked is maintenance personnel training, education, and certification. With more widespread use of additive manufacturing, new repair methods and fatigue properties (also known through study and testing to inform of servicing intervals) will be necessary.
2. Safety practices for new technologies will need to be devised and refined as use of each technology advances.
3. Infrastructure changes will be needed to ensure appropriate repair facilities for new technologies and established supply services.
4. Methods for determining vehicle health status and data-driven prognostics in real-time with trend analyses are needed.
5. Artificial Intelligence-based predictive maintenance solutions for UAM are needed.

Adapted from: None.

Overview of Operationalization Area

Safety is the most important facet of urban air mobility (UAM) operations. To sustain safety for UAM operational areas, various aspects such as certification; training; operations; system performance; UAS traffic management (UTM); infrastructure; safety management systems (SMS) (addressed in IFAR UAM WG Tech Area 5); security; and others (such as human and organizational factors or ecological aspects) must be considered. UAM vehicles and operational support systems, which are forecasted to operate under highly autonomous paradigms, will require new and modified certification techniques including the development of safety assurance arguments for machine learning/artificial intelligence utilized in their components and systems. The UAM operators and other stakeholders involved in UAM operations (e.g., vertiport operations staff) need appropriate training to reflect unique operational needs such as communication in emergencies, avoidance of (or flight in) adverse weather, contingency management, and system degradation. Additionally, operational considerations such as airspace type; environment (area size and density, time of day); transport type (cargo, air taxi, commercial/non); system tools (decision support, communication systems, SMS, sequencing, information sharing and data management); and roles (ATC, pilot, crew, airlines) must be taken into consideration. System performance considerations include initial and continuous airworthiness assessments, accident and incident investigation, manufacturing quality control, regulations, guidelines, practices, and operational procedures for safety-critical situations with human-automated system interactions.

State-of-the-Art Assessment

Currently, there is no accepted criteria for assuring the safety of UAM operations. When defining safety standards and regulations for this domain, local considerations are most relevant including the current regulatory environment, impacted aircraft resources, and other local safety considerations; however, there are many common issues when operating in similar urban environments. The FAA in the United States and EASA in Europe have safety management regulations applicable to Part 135 (helicopter) operations and UAV operations, respectively. Some of these regulations are transferable (and applicable) to UAM for many urban areas, but specific UAM safety regulations will need to be tailored for more frequent operations and/or unique urban missions. Though Part 135 regulations may be used as a starting point, UAM safety regulations will need to adjust over time as UAM operations become more mainstream and the airspace becomes more densely populated. Criteria for certification with increased autonomy and various emerging technologies in mind are needed.

Gap Analysis

Safety guidelines and regulations for helicopters, general aviation, and automobiles currently exist but they are not all transferable or relevant to UAM operations. These guidelines include performance standards like navigation, separation, communication, and external services; vertiport standards like security, passenger and cargo transfer, weather challenges and protocol; supporting systems standards like decision support, situational awareness, communication protocols, and simulation training tools; and mixed-use standards like tactical separation, contingency operations management, crashworthiness analyses, and urban traffic simulation systems. Standardizing interfaces to allow communication and navigation systems to be used across different operation types will also be important. Autonomous and highly automated aircraft can pose a different set of safety risks during operations that need to be clarified and addressed. Addressing these risks is important in demonstrating to authorities that proposed UAM operations are safe.

Open Research Areas

1. How can external factors (weather, environment, airflow, altitude, ground population, and airspace density) be modeled and corresponding safety impacts predicted?
2. How can safety assurance be tested and subsequently demonstrated to authorities? What criteria/metrics and thresholds determine safe operations? What is an adequate/acceptable level of safety?
3. How can nondeterministic AI-based systems be verified and validated from the safety perspective?
4. What resources and technology developments will be needed for ATM to handle a large volume and diversity of vehicles with different needs (minimum separation between vehicles, proximity to terrain, autonomous system reporting, etc.)?
5. What data sources and safety assessments can be conducted predictively during flights, and between flights?
6. What vehicle capabilities are needed, particularly those that may involve increased used of automation?

Adapted from: “220615_IFAR OAA - Topic 13 - Safety_summary_WAO.”

Overview of Operationalization Area

In the near term at low-operational tempo, the AAM environment will likely support operations with existing infrastructure. As operational tempo increases, however, current infrastructure solutions are unlikely to be suitable to meet the demand. To support the ability to safely scale, integration with new technology and infrastructure is likely a necessity. Examples of this are additional systems deployed to support CNSI in a city. Local and distributed weather sensors for predictive capabilities will be needed. The integration of airspace management and air traffic control systems will also be necessary; however, as the associated technologies and infrastructure changes are identified, a greater understanding of the proposed changes and their impacts will be necessary prior to implementation. Potential impacts may be on local infrastructure such as the electrical grid for facilities providing recharging services. Similarly, alternative fuels may be required, which will result in special handling and storage requirements and an understanding of the potential environmental and health impacts. Public safety and security needs also warrant consideration in not only leveraging vertiports for response efforts but also the ability to respond to incidents at the facility. Community equity considerations for vertiport placement and the needs of the community are to be considered as well as how operations integrate with intermodal transportation beyond the local facility.

State-of-the-Art Assessment

Vertiports share some similarities with heliports that enabled the initial leveraging of ICAO Annex 14 Volume 2, which defines the characteristics and limitations of a heliport or similar facility along with the provided services. Using heliports for initial inspiration provided insight into initial conceptual designs of vertiports that included elements related to the necessary markings, lighting, and the definition and dimensions of the TLOF area and Final Approach and Take-off (FATO) areas. Also, numerous organizational and operational considerations are common to both vertiports and heliports such as safety management and planned flight trajectories with respect to airspace integration. Nevertheless, as the flight characteristics and reliability of eVTOL aircraft are different to conventional helicopters, most heliport requirements should be adapted using a safety-based approach and consider the impact on local specificities. More recently, the FAA has published its Engineering Brief No. 105 on Vertiport Design, and the ASTM standards working group published its New Specification for Vertiport Design. The Civil Aviation Safety Authority (CASA) and EASA have also published vertiport design guidelines. These publications have provided further guidance on specifications for vertiport infrastructure that serves to refine the considerations and guidance; however, design is but one narrow, albeit important, aspect related to the introduction of vertiports into communities and the intersection with infrastructure. Work is underway to better understand and account for the many other elements and factors related to the establishment of vertiport facilities and accommodation of the operations that will follow.

Gap Analysis

There are open questions on what technology is required at the vertiport to support the safe movement of vehicles and what types of services can be or need to be routinely provided or available on demand. Additionally, vertiports will likely be located in a variety of traditional and nontraditional places (e.g., floating on water, rooftops) and may use different and new types of construction materials. The relationships of these materials and their ability to support high operational tempos of evolving vehicles will need to be understood. Additionally, different aircraft fuel sources will have design and operational impacts (e.g., scheduling recharging) and the environmental impact to the community will need to be considered. These issues also play a role in assessing the impact of vertiports on equity and socioeconomic issues to the local population. Understanding how the vertiports integrate to the overall transportation infrastructure of a city or broader community is also in the early stages and in need of further research.

Open Research Areas

1. How can the introduction of vertiports minimize community/environmental impact while maximizing benefit?
2. What are the CNSI and supporting service requirements associated with vertiports?
3. What are the public safety and security needs with respect to vertiports and the associated operations?
4. What are the key factors related to vertiport introduction in a community and public acceptance?
5. How do city and urban planners incorporate vertiports into their processes and considerations?
6. How can vertiports integrate to the overall transportation infrastructure of a city or broader community?
7. What are the resource requirements to support the integration of vertiports into city infrastructure?

Adapted from: "IFAR UAM WG 6 and 14 Infrastructure Technology and Operations.pptx."

Overview of Operationalization Area

Data security is a relatively mature focus of IT security and is built on sets of protection technologies and analysis of data sensitivities. System security engineering practices are used to match protection needs (PN) against the data sensitivity requirements, whether legally regulatory, contractual, or other and develop security requirements for the system that contains or controls the data. The technologies used for IT security range from network security capabilities such as firewalls and intrusion detection systems to localized data protection technologies that rely on encryption; user/component identification; and various monitoring capabilities.

Operational technologies (OT), as opposed to IT, are generally defined as those digital technologies that have an effect on the physical world. This domain includes flight management systems, engine controls, air traffic control systems, and others. Whether that is managing flight trajectories, vehicle safety, and other systems that can cause physical effects, data security in this OT domain is not well defined and in many cases is fundamentally nonexistent.

State-of-the-Art Assessment

Data security in the OT environment, and in particular UTM environments, is not well designed. Some aspects of UTM have been well addressed. Security within UTM functional architecture is based on IT security network concepts and addresses data security in the control plane of UTM. It does not, however - by design- manage data security of the overall UTM/UAM environment and is not capable of attributing behaviors to all users or systems, and as such, cannot identify the full range of possible attempts to compromise data or operations that depend on sensitive data.

Much of the current attempt at data security is focused on translating IT security concepts to the OT environment; however, this approach has not been successful. Aside from the OT interactions with the physical world, the OT environment is also not an “always connected” environment like IT and is also composed of a wide variety of operations and technologies that do not map well to IT technologies and concepts. As such, attempts to convert or translate IT concepts such as firewalls or intrusion detection systems have been generally unsuccessful. As these types of security controls and encryption are generally the methodologies used for IT security data protection, the results have been poor.

Gap Analysis

The current differences between the IT and Aviation OT security industries are numerous. Leading the list is the identification of users, processes, and system components. The ability to identify the actor in data security, and associate appropriate accesses and actions, is critical. The technologies needed to affect these capabilities may be significantly different than those used in IT. The ability to provide protection needs in an environment that is not always connected is problematic.

Open Research Areas

1. How are users, systems, software, and other processes uniquely identified and how is access provided in the UAS/UTM industrial environment? Can IT concepts be useful, or do we need new designs?
2. Can the IT concepts of capabilities such as firewall or intrusion detection be translated to the UAS/UTM environment?
3. How do we measure the effectiveness of IT technological approaches in the UAS/UTM environment?
4. What capabilities, concepts or technologies are needed to affect data security in the UAS/UTM industry.
5. How do we integrate these developments with the ICAO Trust Model and GRAIN environment?

Adapted from: None.

Overview of Societal Acceptance Area

The concept of societal acceptance needs to be carefully evaluated for UAM (including "autonomous" aircraft) as most people are unfamiliar with UAM and its significant impacts on the human (e.g., safety, noise, visual clutter, privacy, development patterns, etc.) and natural environments. For communities that choose to adopt and integrate UAM into local transportation systems, the introduction and growth of UAM should be carefully discussed, assessed, and managed to ensure equity and sustainable improvement with regards to quality of life.

Aircraft "autonomy" implies a transition from having human "experts" (a.k.a. pilots) onboard and responsible for - and directly impacted by - flight safety to new modes of operation such as "simplified on-board pilot" and "multi-aircraft remote supervision" where safety by design must be implemented in automation agents. Moreover, the assurance of air traffic safety and broader airspace management would be increasingly automated. This proposed transition needs to be carefully analyzed and managed as the process entails significant technical challenges and risks combined with potentially foundational societal changes concerning safety (real and perceived); responsibility; accountability; and liability. These issues are likely to be raised across other forms of transportation as well.

State-of-the-Art Assessment

Many public surveys that have been conducted about "UAM societal acceptance" are potentially influenced by organizational biases or domain knowledge (e.g., surveys conducted by aeronautics organizations or industries, or surveys limited to favorable categories of participants (those in higher income brackets) [2] and [3].

As far as "autonomy" and UAM is concerned, works about so-called "autonomous" cars [4] and "autonomous" weapons are likely to provide relevant early insights. A pertinent observation from these studies is that the technical word "autonomy" is ambiguous for most nonroboticists and may result in misunderstandings and/or unfounded expectations. Assessments of the potential reaction and/or acceptance of increasing "autonomy" should clearly present which functions are actually automated; reasons why the automation is expected to be beneficial; relevant limitations; and provide descriptions of human and automation authorities in potentially critical or uncertain situations.

As increasingly automated systems are introduced, accidents due to automation (e.g., self-driving cars) and those that humans could have probably mitigated are likely to cause disproportionate societal reactions, even if the overall level of safety is improved. To offset this tendency, it is likely that automated systems will need to contribute to safety levels significantly better than nonautomated systems.

Gap Analysis

Along with assessing the question of increasing "autonomy" of UAM operations, the relevance of UAM itself and of the possible societal effects (beneficial and adverse) should be assessed. For example, is UAM anticipated to fill gaps in the market (if so, which gaps) or solve issues in urban mobility (if so, which issues, and could they be solved differently)? What is the equity of UAM across a given society and territory? Is it sustainable and how is it likely to influence future development? How should related applications of "autonomous" air vehicles be considered (e.g., outside cities for food or first aid supply to remote communities, islands, disaster areas)? In a more general sense, the global question of mobility as it relates to work, facilities, and leisure should be evaluated. Moreover, there are still many uncertainties related to UAM with regards to safety, cost, time saved [1] in addition to its impacts on people, installations and environment including any rebound effects. Relative to "autonomy," the technical difficulties / benefits ratio should be carefully assessed within appropriate regulatory and oversight frameworks.

Open Research Areas

1. Identify the motivations and needs of UAM and conduct realistic simulations, experiments, and pilot deployments to assess whether they are likely to be fulfilled. Also consider in the context of automated UAM.
2. Open public discussions on UAM.
3. Conduct a comprehensive environmental assessment of UAM taking into account the vehicles and the physical and digital infrastructures.
4. Assess the equity of UAM regarding all societal components and all territories.

Adapted from: None.

Overview of Societal Acceptance Area

The aviation sector is already drawing increased public scrutiny over environmental concerns. These concerns have manifested in:

1. Public opposition to new airports or expansions due to concerns on local air quality and noise. (e.g., the London Heathrow Airport Expansion court challenge)
2. Local bans on specific fuels due to environmental/health concerns (e.g., 100LL aviation gasoline - banned at two airports in California, U.S.A.)
3. Opposition to bio-derived fuels over concerns about land-use.

The UAM sector needs to be cognizant of these societal concerns if the fleet size grows substantially. Although UAM may currently be using battery-electric propulsion systems, hydrogen and/or SAF hybrid-electric engines may also become prevalent. For example, if SAF is used as a fuel (in turbine or compression ignition engines), although potentially low in lifecycle emissions, there could be public acceptance issues in the future if it is the only sector in urban areas producing emissions. Also, if the UAM fleet is large, NO_x (smog) and odor from emissions could be an issue (smaller engines tend to have lower combustion efficiencies and therefore more odor).

State-of-the-Art Assessment

Since the 1970s, ICAO has developed emissions standards (Annex 16, Vol II) to reduce the impact of aviation on local air quality in the vicinity of airports. These standards do not apply to the class of aircraft that are being developed for the UAM sector; however, from a societal acceptance standpoint, as other urban transportation modes (buses and cars) are rapidly electrifying, any local emissions that the UAM aircraft produce may be subject to increased scrutiny. Also, UAM may have a more widespread operating footprint and be more visible to the public (e.g., many vertiports spread throughout a city vs. single local airports).

Gap Analysis

As there are many unknowns about how operations for the UAM sector will actually emerge (e.g., vertiports throughout urban areas, size of the fleet, propulsion technology, etc.), it will be difficult to predict local UAM emissions and societal acceptance of UAM.

Additionally, are public perception issues surrounding some fuels such as land-use concerns with bio-derived fuels or safety issues with hydrogen use. Public education may be needed to alleviate these concerns.

Open Research Areas

1. What will society accept in an urban environment for UAM emissions?
2. What does society accept for a “fuel” (hydrogen, SAF, batteries)?

Overview of Societal Acceptance Area

In most representative studies, community attitude towards drones is slightly more positive than negative. The opinions are based on numerous complexities such as gender and age but also on the individual's level of information and experience about drones. Opinions also differ depending on the use application, with rescue and public safety being the applications with the highest acceptance levels. Noise is one of the main obstacles for UAM deployment and acceptance challenges are expected for "nonurgent" usage (non-lifesaving). For air taxi applications: acceptance levels will decrease significantly compared to conventional aircraft noise because of possible limited usage (e.g., a transportation mode possibly limited to the wealthy). A relevant case study is needed for public reaction to nonmedical executive helicopters.

State-of-the-Art Assessment

Aircraft noise (as it concerns people on the ground, not to people in the aircraft itself) is somewhat unique as no other significant noise sources fly overpopulated areas. Tens of millions of people are affected by aircraft noise at the 55-dB day-night level in the current air transportation system. With the introduction of UAM vehicles flying in airspace away from airports where people are not accustomed to aircraft noise, there is a possibility of public concern related to safety, noise, privacy, and visual impact of UAM. Studies of noise include community impact, child children, sleep disturbances, and health effects. The UAM vehicles have very different noise sources than traditional transport aircraft or helicopters and little is known yet about the response to the new noise profiles. Many perception studies exist that have airport noise (from airplanes) because of "traditional" community complaints. Perception studies on helicopter noise are available as well but are less extensive (for reasons such as procedure specificities, lower number of operations, etc.). Studies on UAM must go beyond public perception; a low annoyance response must also be produced for operations to scale.

Gap Analysis

Urban Air Mobility operations including passenger-carrying, cargo delivery, and other nontransport opertations should support the sustainability goals of localities by following community driven guidance through a Sustainable Urban Mobility Plan (SUMP) or a similar alternative. Cities need to have tools available to design, develop, and deploy UAM operations in line with their objectives and needs. Another critical gap is the interaction with wildlife living in areas of UAM operations. Additionally, there is a need for a strategy and framework for community engagement before UAM noise concerns arise.

Open Research Areas

1. The repetitive nature of UAM may lead to a different noise perception than that of traditional airport noise (in public situations / cluttering), what is the visual impact on the auditive perception?
2. What metrics are most suitable to represent the annoyance response to UAM?

Adapted from: "Team 11-18 Environment (Noise) Consolidated with takeaway chart 20220301…"

Overview of Societal Acceptance Area

To address societal acceptance for safety of UAM, it is worth differentiating between safety and safety perception and then to assess perception for all the different impacted stakeholders. While the concept of safety is well founded and accepted within the aviation community, outside that community it is worth considering the perception of safety. Keeping people safe and ensuring that people feel safe are two different challenges. People expect the service providers they interact with to pose little risk to their physical, mental, or financial health; therefore, news of incidents, which are a common occurrence for the aviation community, might induce the public to feel unsafe, nonetheless. While the collection of historical data on UAS flights can support reliability engineering and safety assurance, the perception of safety is very vulnerable and susceptible to sudden changes. Safety experts in UAM should thus look to implement programs that both improve the actual safety of their customers and their perception of safety. Acceptance is dependent on the perception of safety and other aspects related to the benefits the innovation can bring. To identify benefits, it is necessary to assess who will be impacted. The "impacted stakeholders" in charge of accepting the UAM paradigm are those in the UAM industry (manufacturers, operators, service providers, etc.); UAM users; governments/regulators; as well as indirectly affected third parties (such as private individuals, environmental organizations, etc.).

State-of-the-Art Assessment

While there are multiple studies concerning the general acceptance of UAM applications, only few studies take into account UAM safety acceptance and perception. One such study was performed by EASA in 2021. Based on research, literature review, local market analysis, surveys and interviews, the study examined the attitudes, expectations and concerns of EU citizens with respect to UAM. When encouraged to reflect upon consequences of potential UAM operations in their city, EU citizens want to limit their own exposure to risks, in particular when related to safety, noise, security and environmental impact. While safety concerns rank first, the study shows that citizens seem to trust the current aviation safety levels and would be reassured if these levels were applied for UAM. Differences in acceptance depend on the application (e.g., medical services and deliveries, rescue operations and public safety represent the applications with the highest acceptance levels). Safety is one of the main obstacles for UAM deployment, and acceptance challenges are expected for "nonurgent" usage (not lifesaving usage).

Gap Analysis

Safety acceptance is currently reliant on the public perception of traditional aviation safety standards. Due to the lack of current operations and related data as well as the fact that the UAM ecosystem will comprise new technologies and safety acceptance – at least in the beginning – has to be gained without relying on existing standards or experience from traditional commercial operations; therefore, the respective concerns of the impacted stakeholders, with regards to roles and responsibilities of UAM agents, privacy and (cyber) security, transformation, communication, safety promotion and culture and many more topics, have to be newly assessed and taken into account when developing UAM technologies and new technical or operational regulations. Further research and comprehensive studies are required to fully understand the misgivings and possible misconceptions of the public in order to develop adequate communication strategies and other tools that encourage UAM safety acceptance.

Open Research Areas

1. What are the main concerns of impacted stakeholders with regards to UAM safety in general as well as towards certain UAM-specific technologies and procedures/operations?
2. How can we ensure coordinated actions between all authority levels, influence citizens to trust those authorities equally, and expect all levels to be involved in decision-making?
3. How can we ensure that UAM has a perceived safety level equivalent to that of current aviation operations despite its reliance on new and different technologies?
4. Can demonstrations and pilot projects encourage safety acceptance? If so, in what way?

Adapted from: None.

6. Standards Landscape

Analyzing the current standards landscape is critical for IFAR and its participating organizations to support standards development efforts across the globe and bring relevant assessments of the current standards and gaps to ICAO. This section details an ongoing digital systems engineering effort to define the current standards landscape, identify ongoing work where IFAR research is applicable, and enable optimized data sharing between research agencies and ongoing standards efforts. The current standards landscape was captured using a model-based systems engineering (MBSE)[17] tool to enable evaluation of relevant standards efforts in Standards Development Organizations (SDOs) and industry associations.

Current Progress

Metamodel

Model development started by defining the high-level relationships among IFAR, ICAO, SDOs, and industry associations. Figure 1 displays the metamodel that defines the domain of the model and the relationships it is designed to capture.

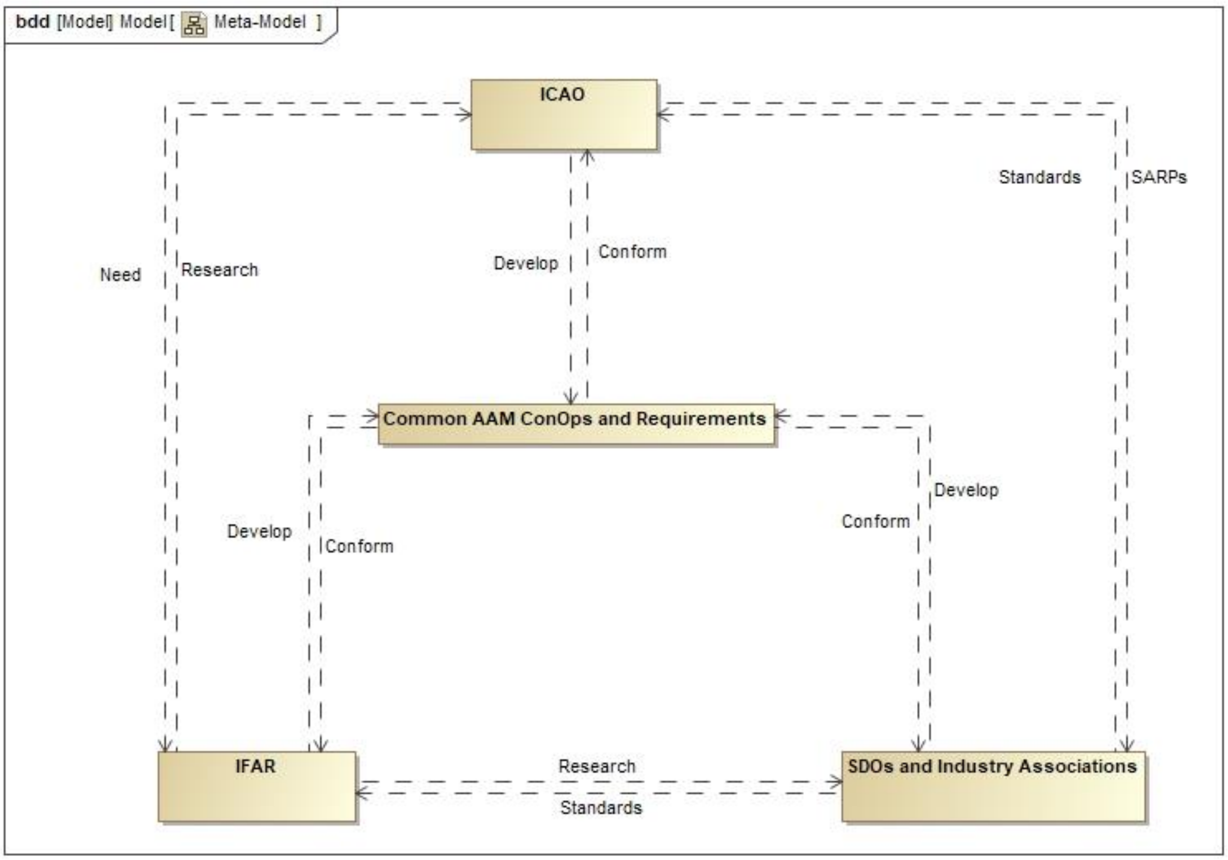


Figure 1: International Forum for Aviation Research (IFAR) Research Mapping Metamodel.

[17] "SE Transformation," INCOSE: https://www.incose.org/about-incose/transformation.

International Civil Aviation Organization (ICAO) Structure and Interfaces

Figure 2 is a block diagram representing the structure of ICAO and some of the high-level relationships between bodies. This block diagram is being matured alongside ICAO to serve as a reference and ensure research findings from IFAR are being leveraged as much as possible.

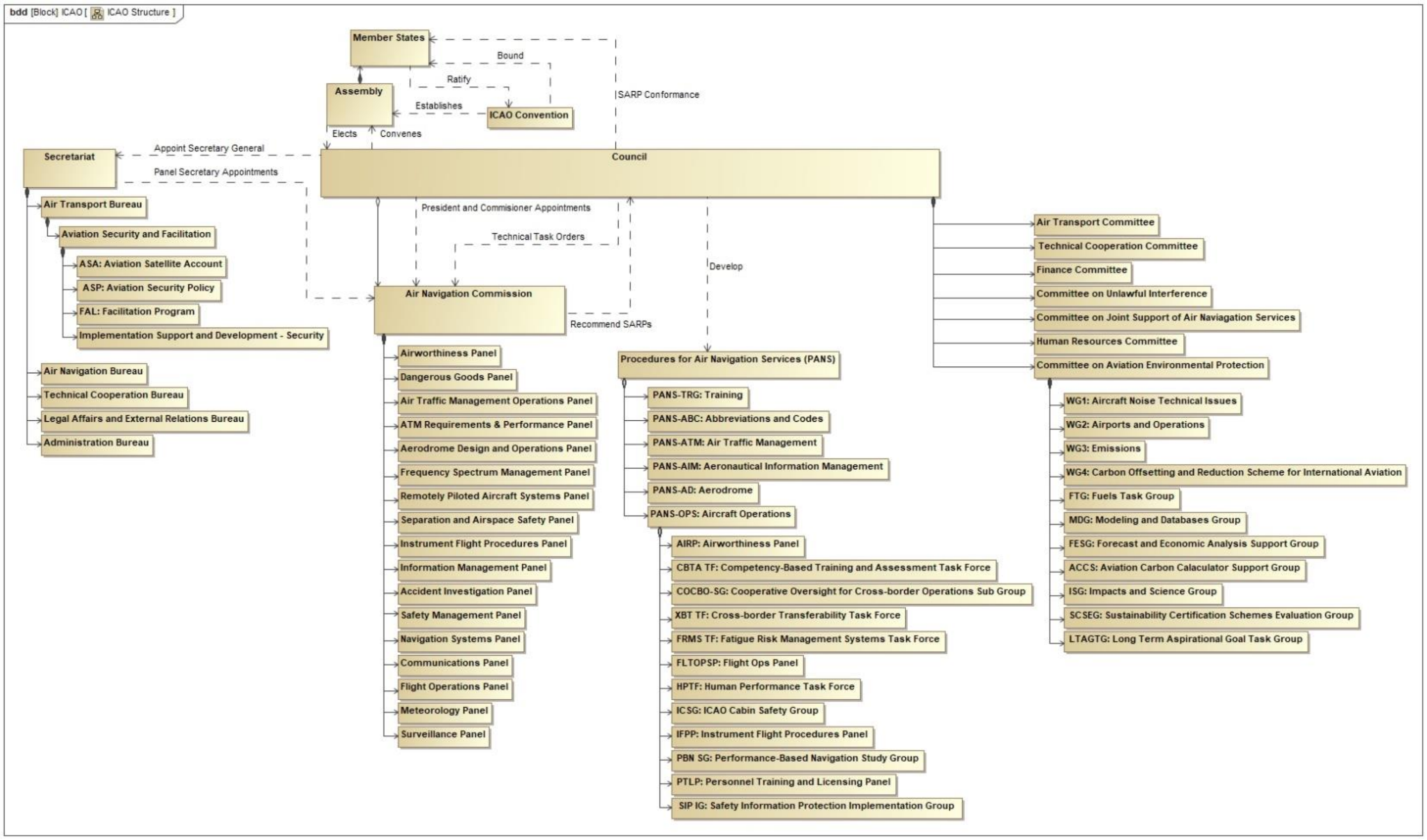


Figure 2: Draft International Civil Aviation Organization (ICAO) Structure Diagram.

Additionally, the model captures the role for some of the panels in the ICAO, such as the ones under the Air Navigation Commission (ANC). Figure 3 provides an example showing the Aerodrome Design and Operations Panel. More panels, documentation, and relationships are continually added to the model as their relevance is determined.

#	Name	Documentation
10	Aerodrome Design and Operations Panel	Develop and maintain SARPs, procedures and guidance materials for: a) Global reporting format for runway surface condition reporting for aircraft operations on contaminated runways b) installation of arresting system to address operational issues and criteria for design specification and acceptance by State c) airport collaborative decision making (A-CDM) and industry best practices d) procedures on airport operational management activities e) airport emergency response including rescue and fire fighting f) advanced surface movement guidance and control systems (A-SMGCS) g) final approach and take-off area characteristics for heliports h) obstacle limitation surfaces SARPs and related guidance material on aeronautical studies https://www.icao.int/about-icao/AirNavigationCommission/Pages/anc-technical-panels.aspx

Figure 3: Aerodrome Design and Operations Panel Documentation Example.

The Aviation System Block Upgrades (ASBUs) described in the ICAO Global Air Navigation Plan (GANP) are also captured. These model elements are not in use currently but are intended for use in later versions (see "Plans for Further Development"). Figure 4 provides an example showing the Aircraft Collision Avoidance System (ACAS) ASBUs.

#	Name
22	Aircraft Collision Avoidance System (ACAS)
23	ACAS-B1/1: ACAS Improvements
24	ACAS-B2/2: New collision avoidance capability as part of an overall detect and avoid system for RPAS
25	ACAS-B2/1: New collision avoidance system

Figure 4: Aircraft Collision Avoidance System (ACAS) Aviation System Block Upgrades (ASBUs) Example.

The International Forum for Aviation Research (IFAR) Structure and Interfaces

The decomposition of the Scientific Assessment for UAM and its five major areas is modeled as shown in Figure 5. Although the table of contents of the document is sufficient to capture the components of the document, the relationships between topic areas are critical. Defining these relationships will enable the researchers maturing the assessment to ensure that all findings from other relevant Focus Areas are incorporated into their work.

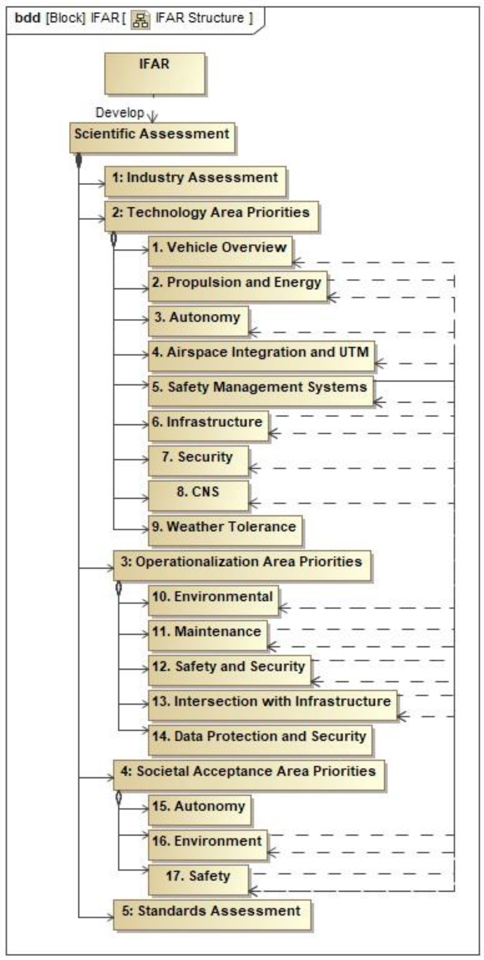


Figure 5: International Forum for Aviation Research (IFAR) Structure Block Diagram.

The right side of the diagram shows a complex map of relationships between each of the Focus Areas. Anticipating an increasingly complex mapping between Focus Areas as the Scientific Assessment is matured, the dependency matrix, shown in Figure 6, was created to more intuitively display the relationships among areas of the Scientific Assessment.

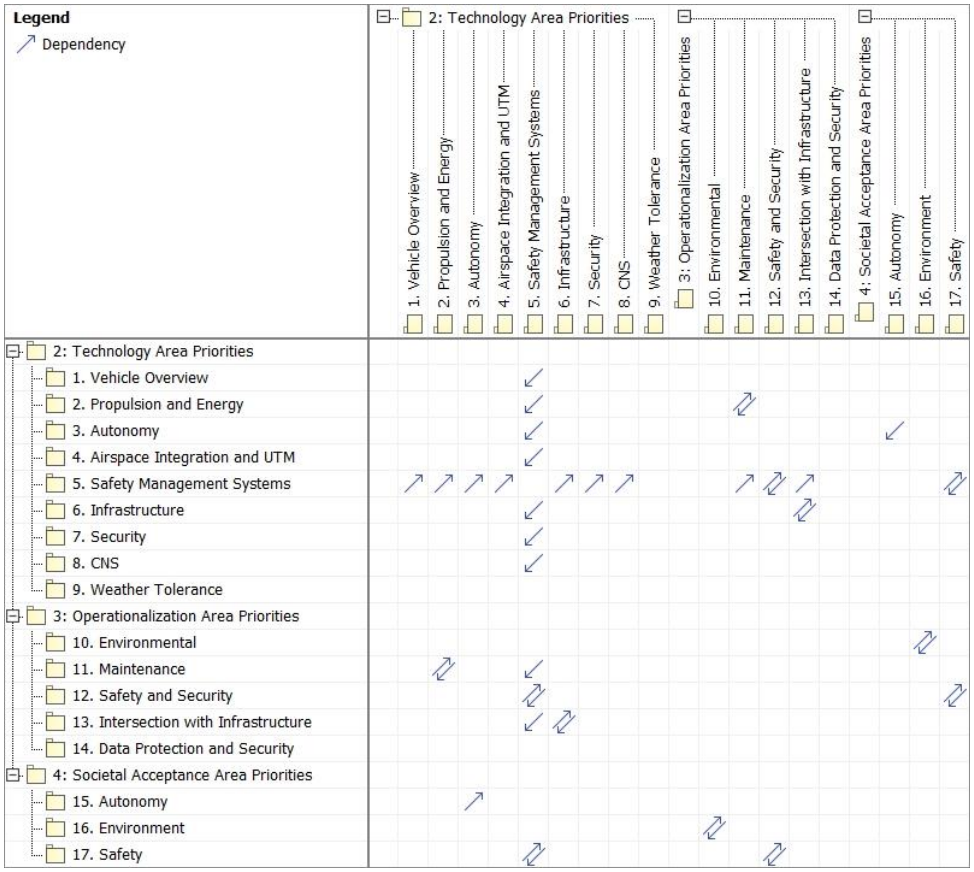


Figure 6: International Forum for Aviation Research (IFAR) Scientific Assessment for Urban Air Mobility (UAM) Focus Areas Dependency Matrix.

Additionally, a combined view of all of the relationships from a Scientific Assessment Focus Area was developed using a relationship map. Seventeen relationship maps in the model cover the Focus Areas, and these maps will mature simultaneously as the defined relationships mature. Figure 7, below, represents a draft relationship mapping from the view of one focus area:

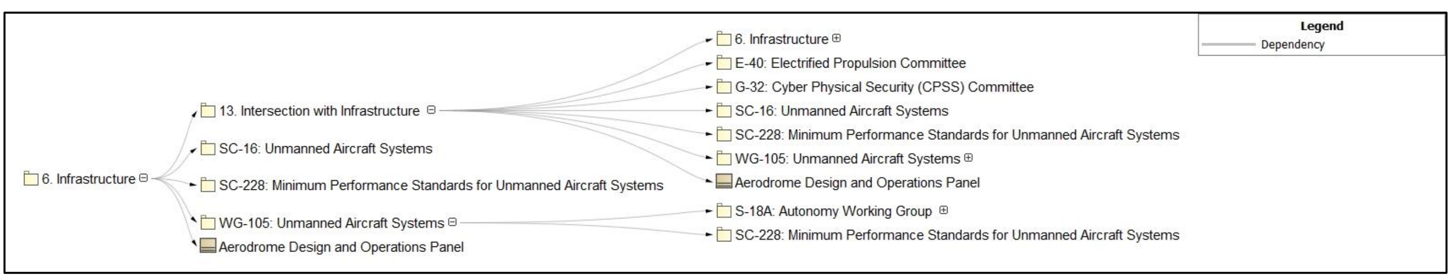


Figure 7: Infrastructure Focus Area Relationship Map Example.

Standards Development Organizations (SDOs) and Industry Association Database and Interfaces

The model captures information on standards efforts external to ICAO in SDOs and industry associations. Table 6, below, lists the SDOs and industry associations captured in this model. The SDOs and industry associations are represented at various levels of detail, but additional content is being added continually.

Table 6: Standard Development Organizations (SDOs) and Industry Associations Captured in Model-based Systems Engineering (MBSE).

SDO / Industry Association Currently Captured	Link to Homepage
Airports Council International (ACI)	https://aci.aero/
Aerospace Industries Association (AIA)	https://www.aia-aerospace.org/
ASTM International	https://www.astm.org/
European Organization for Civil Aviation Equipment (EUROCAE)	https://www.eurocae.net/
General Aviation Manufacturers Association (GAMA)	https://gama.aero/
Global UTM Association (GUTMA)	https://gutma.org/
International Organization for Standardization (ISO)	https://www.iso.org/home.html
Joint Authorities for Rulemaking on Unmanned Systems (JARUS)	http://jarus-rpas.org/
RTCA	https://www.rtca.org/
SAE International	https://www.sae.org/
Vertical Flight Society (VFS)	https://vtol.org/

The model currently captures 162 committees and subcommittees and more are added regularly as they are deemed relevant. Although not all of the committees captured are directly relevant to UAM, committees covering relevant areas that may be leveraged for UAM are captured (e.g., committees focused on AI in a broad sense rather than specific to aircraft automation). Figure 8 shows an example of how these committees are described using RTCA SC-228 as an example.

#	Name	Documentation	Related Committees
1	SAE		
27	RTCA		
28	SC-228: Minimum Performance Standards for Unmanned Aircraft System	SC-228 has successfully completed Phase One and Two and is now focused on Phase Three activities. For the AAM use case, this includes tailored detect and avoid performance standards and both satellite and cellular command and control communications standards. https://www.rtca.org/sc-228/	
29	WG-1: Detect and Avoid	Phase Three activities are focused on developing DAA capabilities that address more specialized UAS operations that require more tailored performance or constrained guidance. Two Phase Three DAA focus areas are: AAM use case. These aircraft are capable of different maneuvers and make approaches to different environments than addressed by the Phase 2 activity. Part 135 cargo operations. Phase 3 OSED development will further develop the concept and capture any changes needed.	SC-147: Traffic Alert & Collision Avoidance Sy
30	WG-2: C2	Phase Three activities are focused on creating a standard for use of cellular commercial networks for C2 Links used for type certificated UAS as part of a new standalone MOPS in collaboration with EUROCAE WG-105.	WG-105: Unmanned Aircraft Systems
31	WG-3: Lost Link	Create a joint standard with EUROCAE WG-105 for use of Cellular commercial networks for C2 Links used for type certificated UAS. Create standard for use of the UHF spectrum band used for C2 Links used in type certificated UAS Lost Link Standards.	WG-105: Unmanned Aircraft Systems
32	WG-4: Navigation	Phase Three WG4 activities are focused on creating guidance materials to enable GNSS-based UAS operations to meet navigation requirements for all phases of flight without the use of legacy ground-based navigation aids, including precision approach capability with auto-takeoff and autoland features.	

Figure 8: RTCA SC-228 Model Example.

In addition to capturing documentation on the committees, any known relationships to other committees are also captured. Table 7, below, identifies committees that are relevant to the research produced by the teams in the Focus Areas of this Scientific Assessment.

Table 7: Relevant Standard Development Organizations (SDOs) and Industry Associations to Scientific Assessment Focus Areas.

Focus Area	Focus Area Title	Relevant Committees
1	Vehicle Overview	ASTM F39, ASTM F44, SAE AE-7, SAE E-40, SAE G-35, ISO TC20 SC16, EUROCAE WG105
2	Propulsion and Energy	ASTM F-39, ASTM F-44, SAE AE-7, SAE AE-10, SAE E-40, ISO TC20 SC16, IEEE
3	Autonomy	ASTM F39, SAE AE-7, SAE AE-10, SAE E-40, SAE G-35, ISO TC20 SC16, EUROCAE WG105
4	Airspace Integration and UTM	ASTM F38, ASTM AC377, RTCA SC-147, RTCA SC-228, SAE G-34, SAE G-35, ISO/IEC JTC1 SC42, ISO ETC SC41, EUROCAE WG105, ISO TC20 SC16
5	Safety Management Systems	ASTM F38, RTCA SC-147, RTCA SC-228, SAE G-34, ISO TC20 SC16, ISO TC20 SC17, EUROCAE WG105
6	Infrastructure	ASTM F38, ASTM F44, RTCA SC-228, SAE G-28, SAE G-35, SAE S-18, ISO TC20 SC16, EUROCAE WG105
7	Security	ASTM F38, RTCA SC-228, ISO TC20 SC16, EUROCAE WG105
8	CNS	RTCA SC-228, SAE G-32, ISO TC20 SC16, EUROCAE WG105, EUROCAE WG72
9	Weather Tolerance	RTCA SC-228, ISO TC20 SC16, EUROCAE WG105
10	Environmental	RTCA SC-228, SAE AC-9C, ISO TC20 SC16, EUROCAE WG105
11	Maintenance	ASTM F39, SAE A-21, ISO TC20 SC16
12	Safety and Security	ASTM F39, ISO TC20 SC16
13	Intersection with Infrastructure	RTCA SC-228, SAE E-40, SAE G-32, SAE G-35, ISO TC20 SC16, ISO TC20, SC17, EUROCAE WG105, EUROCAE WG112
14	Data Protection and Security	ASTM F38, RTCA SC-228, SAE E-40, SAE G-32, ISO TC20 SC16, EUROCAE WG105
15	Autonomy	RTCA SC-228, SAE G-32, ISO TC20 SC16, EUROCAE WG105
16	Environment	ASTM F44, SAE A-21, ISO TC20 SC16, EUROCAE WG105
17	Safety	ASTM F44, SAE G-34, ISO/IEC JTC1 SC42, EUROCAE WG 105

Plans for Further Development

Similar to the Scientific Assessment, the standards model will receive periodic updates to maintain relevancy and address feedback. Both technical and editorial comments are requested to make further iterations of the model more robust. In addition to adding additional content, increasing the level of detail, and incorporating provided feedback, the model is designed to enable the creation of a common roadmap linking research and standards efforts. A high-level metamodel for the standards roadmap is portrayed in Figure 9, below.

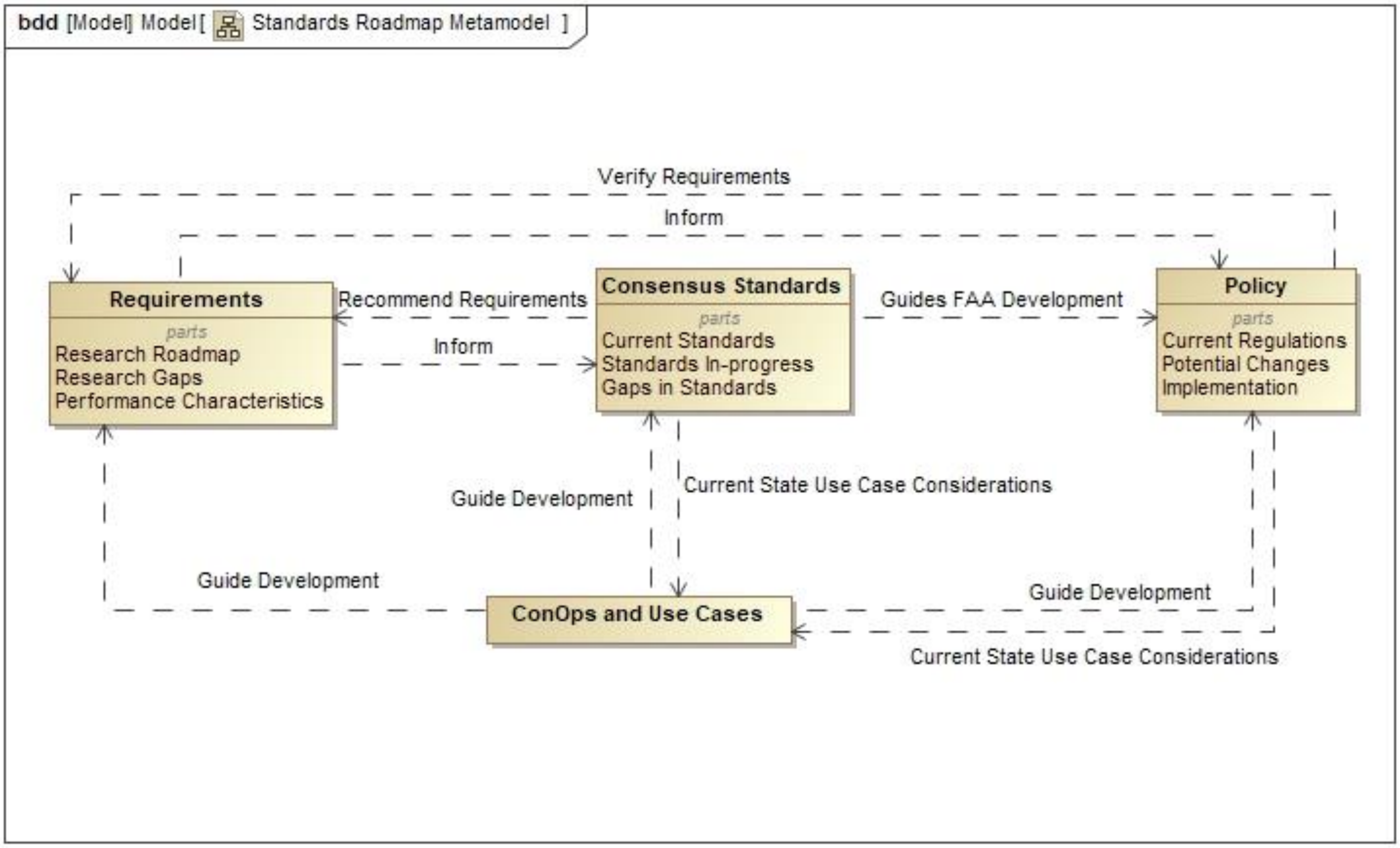


Figure 9: Standards Roadmap Metamodel.

As fidelity of the model increases, traceability becomes possible between more discrete elements such as the ICAO ASBUs and individual standards. The relationships currently defined between research areas, ICAO panels, and standards committees will become implied and the lower-level model elements will maintain the dependency. The roadmap will open pathways for prioritizing further work in open research areas through traceability to applicable standards and their roadmap for development. The IFAR and ICAO are in a unique position to enable international harmonization between research agencies and standards development bodies to mature a globally consistent AAM ecosystem. As shown in Figure 1, a common ConOps and set of AAM requirements are a foundational step for building global harmonization. Interoperability with traditional aviation and other forms of transportation must also be considered – thus a need exists to capture standards efforts wider than those that are AAM-specific.

7. Next Steps

As stated in Section 3, a key focus of this first Scientific Assessment is to establish a rigorous and efficient process for providing consensus research findings to the ICAO. Coordination is ongoing between the IFAR research teams and the relevant ICAO panels to refine the content presented in Section 5 and identify opportunities for further cooperation. Additionally, regular updates are expected to both this document and the associated model presented in Section 6. One-page formatting will enable easier updating over time and provide a straightforward method to identify differences between versions.

The entire document has a planned refresh following its original release. Although the original scope of the document focused on UAM, the IFAR plans to broaden the scope of the document to be AAM wide to capture regional and low-altitude operations in addition to a refresh of the current content.

8. Appendix A: Relevant Recent Research Publications and References

1. **Vehicle Overview**
   - Gorton, S., -2021, NASA's Direction for Vertical Lift, presented at Academia Day, February 2021.
   - EASA publishes first guidelines on noise level measurements for drones below 600kg.
   - EASA Study on the societal acceptance of Urban Air Mobility in Europe, May 2021.
   - Skowron M, Chmielowiec W, Glowacka K, Krupa M, Srebro A. 2019. Sense and avoid for small, unmanned aircraft systems: Research on methods and best practices, Journal of Aerospace Engineering, 2019.

2. **Propulsion and Energy**
   - Highlights of GAO-22-105020, a report to U.S. Congress.
   - Hazard Analysis Failure Modes, Effects, and Criticality Analysis for NASA.
   - Design of a Tiltwing Concept Vehicle for Urban Air Mobility.
   - NASA Reference Motor Designs for Electric Vertical Takeoff and Landing Vehicles.
   - National Fire Protection Agency Beyond Batteries.
   - EASA SC-VTOL-01, "Special Condition for small-category VTOL aircraft.
   - The Key Things To Know About eVTOL Batteries.
   - Guidance On Determination Of Accessible Energy In Battery Systems For Evtol Applications.
   - SAE International AE-10 High Voltage Committee.

3. **Autonomy**
   - Ironies of Automation, Bainbridge.
   - Automated Low-Altitude Air Delivery - Towards Autonomous Cargo Transportation with Drones.
   - Autonomy Research for Civil Aviation - The National Research Council.
   - Advanced Aerial Mobility: A National Blueprint. National Academies of Sciences, Engineering, and Medicine.

4. **Airspace Integration and UTM**
   - [1] Federal Aviation Administration. Urban Air Mobility and Advanced Air Mobility. 2022. Available: https://www.faa.gov/uas/advanced_operations/urban_air_mobility.
   - [2] FAA. UAM Concept of Operations (ConOps) version 1.0. 2022. Available: https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf.
   - [3] NASA. UAM Vision Concept of Operations (ConOps) UAM Maturity Level (UML) 4. 2020. Available: https://ntrs.nasa.gov/citations/20205011091.
   - [4] CORUS-XUAM project funded by SESAR JU. U-space Concept of Operations. Available: https://corus-xuam.eu/wp-content/uploads/2022/11/CORUS-XUAM-D4.1-delivered_3.10.pdf.
   - [5] FAA. UTM Concept of Operations ver.2. 2020. Available: https://www.faa.gov/uas/research_development/traffic_management/media/UTM_ConOps_v2.pdf.
   - [6] Andreeva-Mori A., Ohga K., Kobayashi K., Okuno Y., Homola J., Johnson M. and Kopardekar P. Management of Operations under Visual Flight Rules in UTM for Disaster Response Missions. SESAR Innovation Days, Virtual, 2021.
   - EASA ASSURED UAM Initial Concept of Operations Definition.

5. **Safety Management Systems**
   - CANSO – Standard of Excellence for Safety Management.
   - IATA – IATA Operational Safety Audit (IOSA).
   - NASA In-Time System Wide Safety Assurance (ISSA) for UAM ConOps.

- Architecture and Information Requirements to Assess and Predict Flight Safety Risks During Highly Autonomous Urban Flight Operations.
- National Academies Report on In-time Aviation Safety Management.

6. Infrastructure

- Transforming mobility with eVTOL.
- NASA AAM Vertiport Automation Trade Study.
- NASA High Density Vertiport CONOPS.
- Vertiport Automation Software Architecture and Requirements.

7. Security

None Cited.

8. Communication, Navigation, and Surveillance

- Goodrich, Theodore, "Description of the NASA Urban Air Mobility Maturity Level (UML) Scale," (NTRS, Doc. ID 20205010189).
- Levitt et al., "UAM Airspace Research Roadmap," (NTRS, Doc. ID 20210019876).

9. Weather Tolerance

- Aerospace America *Weather Alert* for AAM.
- RPAS operator guidance for the urban environment.
- SAE EDGE review of icing of AAM.
- Ice Accretion on Fixed-Wing Unmanned Aerial Vehicle - A Review Study.

10a. Environment: Emissions

- Role of flying cars in sustainable mobility.
- Urban Air Mobility (UAM) Market Study Final Report.

10b. Environment: Noise

- Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations.

11. Maintenance

None Cited.

12. Safety and Security

- Architecture and Information Requirements to Assess and Predict Flight Safety Risks During Highly Autonomous Urban Flight Operations.
- In-time System-wide Safety Assurance (ISSA) Concept of Operations and Design Considerations for Urban Air Mobility (UAM).
- NLR Safety Targets for UAM vehicles - from Third Party Risk Perspective, TR-2021-278.

13. Intersection with Infrastructure

- ICAO Annex-14-Aerodromes-Volume-II-Heliports.
- FAA ENGINEERING BRIEF #105 Vertiport Design.
- ASTM WK59317 New Specification for Vertiport Design.
- Advanced Air Mobility Vertiport Considerations: A List and Overview.

14. Data Protection and Security

None Cited.

15. Autonomy

- [1] Definition of “social acceptance.”
- [2] Commuting in the Age of the Jetsons: A Market Segmentation Analysis of Autonomous Ground Vehicles and Air Taxis in Five Large U.S. Cities.
- [3] Study on the societal acceptance of Urban Air Mobility in Europe.
- [4] Ethical Issues Regarding “Autonomous Vehicles.”
- [5] Implementing Mitigations for Improving Societal Acceptance of Urban Air Mobility.

16a. Environment: Emissions

- Study on the societal acceptance of Urban Air Mobility in Europe.
- ICAO Global Environmental Trends.

16b. Environment: Noise

- The acceptance of civil drones in Germany.
- Investigating attitudes towards drone delivery.
- Gender differences in noise concerns about civil drones.
- Drone Acceptance and Noise Concerns – Some Findings.
- Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations.
- Initial Investigation into the Psychoacoustic Properties of Small Unmanned Aerial Vehicle Noise.

17. Safety

None Cited.

9. Appendix B: Glossary of Terms

Term	Description of Term
Advanced Air Mobility (AAM)	Safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions. There are generally three broad application categories within Advanced Air Mobility: Urban Air Mobility, Regional Air Mobility, and Low Altitude Mobility. These missions may be performed with many types of aircraft (e.g., crewed or uncrewed; conventional takeoff and landing, short takeoff and landing, or vertical takeoff and landing; over or between many different locations (e.g., urban, rural, suburban); and to or from far more locations than typical commercial aviation (e.g., novel aerodromes, existing underutilized small/regional airports).
Air Metro	An Urban Air Mobility market that resembles current public transit options such as subways and buses, with predetermined routes, regular schedules, and set stops in high-traffic areas throughout each city.
Air Taxi	An Advanced Air Mobility market providing point-to-point passenger transportation and not operated on regular schedules or routes.
Autonomy	The ability of a system to achieve goals while operating independently of external control. Autonomy requires self-directedness to achieve goals and self-sufficiency to operate independently.
Collision Avoidance	The maneuver of an aircraft after becoming aware of conflicting traffic. This capability is currently achieved by one of the following means: visual observation, Airborne Collision Avoidance System alert, or traffic information provided by Air Traffic Control.
Communication-Navigation-Surveillance-and-Information (CNSI)	The elements of the air traffic management (ATM) system associated with real time acquisition and transmission of operationally relevant information on aircraft position, identification, meteorological phenomena, system status, and ATM control actions. It includes the parts of the aircraft system associated with control of own aircraft position using acquired data.
Concept of Operations (ConOps)	A description of the overall high-level concept of how the system will be used to meet stakeholder expectations, usually in a time sequenced manner. It describes the system from an operational perspective and helps facilitate an understanding of the system goals. It stimulates the development of the requirements and architecture related to the user elements of the system. It serves as the basis for subsequent definition documents and provides the foundation for the long-range operational planning activities (for nominal and contingency operations), and it provides the criteria for validation of the system.
Electric Vertical Takeoff and Landing (eVTOL)	An aircraft that uses electric power to hover, take off, and land vertically. These aircraft include a variety of configurations, such as Lift+ Cruise, Multiple Rotor, and Tilt Wing
Environmental Sustainability	The rate of renewable resource harvest, pollution creation, and non-renewable resource depletion that can be continued indefinitely.
Fully Autonomous Aircraft	An aircraft that can perform all necessary piloting functions, including determination of a new course of action in the absence of a predefined plan, while operating independently of any external control, including control from a human pilot, aircraft operator, and/or multi-aircraft supervisor.
Infrastructure	The basic physical and organizational structures and facilities (e.g., buildings, roads, power supplies) needed for the operation of a society or enterprise.
Maintenance	Any repair, adaptation, upgrade, or modification of National Airspace System equipment or facilities, including preventive maintenance.

Noise	Sound that is unwanted. Noise has both an objective, physical component, as well as a subjective component that takes account of a person's individual perception, or reaction, to a sound.
Provider of Services for Urban Air Mobility (PSU)	An entity that assists Urban Air Mobility (UAM) operators with meeting UAM operational requirements to enable safe and efficient use of UAM corridors and aerodromes. This service provider shares operational data with stakeholders and confirms flight intent.
Regional Air Mobility (RAM)	A part of Advanced Air Mobility that focuses on building on existing airport infrastructure to transport people and goods using innovative aircraft that offer a huge improvement in efficiency, affordability, and community-friendly integration over existing regional transportation options for trips of approximately 50 to 500 miles.
Safety	The state in which the risk of harm to persons or property damage is acceptable.
Safety Management System	An integrated collection of processes, procedures, policies, and programs that are used to assess, define, and manage safety risk.
Scalability	The ability of a system to maintain its performance and function, and to retain all its desired properties when its scale is increased greatly, without causing a corresponding increase in the system’s complexity.
Simplified Vehicle Operations (SVO)	The use of automation coupled with human factors best practices to reduce the quantity of trained skills and knowledge that the pilot or operator of an aircraft must acquire to operate the system at the required level of operational safety.
Standard	A manufacturing, design, maintenance, or quality standard or method, technique, or practice approved by or acceptable to a civil aviation authority. It includes, but is not limited to, standards for aircraft design and performance, required equipment, manufacturer quality assurance systems, production acceptance test procedures, operating instructions, maintenance and inspection procedures, identification and recording of major repairs and major alterations, and continued airworthiness.
Uncrewed/Unmanned Aircraft System (UAS)	An uncrewed aircraft and its associated elements related to safe operations, which may include control stations (ground, ship, or air based), control links, support equipment, payloads, flight termination systems, and launch/recovery equipment.
Urban Air Mobility (UAM)	The vision of a safe, efficient, convenient, affordable, and accessible air transportation system for passengers and cargo that revolutionizes mobility around metropolitan areas. This vision includes everything from small package delivery drones to passenger-carrying air taxis that operate above populated areas. Urban Air Mobility is a subset of the broader vision for Advanced Air Mobility.
Urban Canyon	Locations in the urban setting between buildings, such as where a street is flanked by tall buildings. Weather in urban canyons can differ from the surrounding areas outside, particularly with respect to temperature, wind patterns, and air quality.
Vertiport	An area of land, or a structure, used or intended to be used, for electric, hydrogen, and hybrid VTOL aircraft landings and takeoffs and includes associated buildings and facilities.
Weather-Tolerant Operations	Operations resistant to the effects of severe weather conditions, including visibility, winds, turbulence, precipitation, and icing.

10. Appendix C: Table of Acronyms

Acronym	Definition
AAM	Advanced Air Mobility
ABC	Abbreviations and Codes
ACAS	Aircraft Collision Avoidance System
ACCS	Aviation Carbon Calculator Support Group
ACI	Airports Council International
AD	Aerodrome
AI	Artificial Intelligence
AIA	Aerospace Industries Association
AIM	Aeronautical Information Management
AIRP	Airworthiness Panel
ANC	(ICAO) Air Navigation Commission
ANSP	Air Navigation Service Provider
APAC	Asia-Pacific
AS	Automated Systems
ASA	Aviation Satellite Account
ASBUs	Aviation System Block Upgrades
A-SMGCS	Advanced Surface Movement Guidance and Control Systems
ASP	Aviation Security Policy
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
ATF	Assurance Technical Framework
ATM	Air Traffic Management
ATM-X	Air Traffic Management – eXploration
AURA	Advanced Ultra Reliable Aviation
A2G	Air to Ground
BME	Budapest University of Technology and Economics
BVLOS	Beyond Visual Line of Sight
CAAM	Canadian Advanced Air Mobility Consortium
CASA	Civil Aviation Safety Authority
CAT	Commercial Air Transport
CBTA	Competency-based Training and Assessment
CIRA	Centro Italiano Ricerche Aerospaziali
COCBO	Cooperative Oversight for Cross-border Operations
CSIR	Council for Scientific and Industrial Research
CNS	Communication, Navigation, and Surveillance
CNSI	Communication, Navigation, Surveillance, and Information
ConOps	Concept of Operations
CTOL	Conventional Takeoff and Landing
C2	Command and Control
DAA	Detect and Avoid
DEP	Distributed Electric Propulsion
DLR	German Aerospace Centre
DO	Document Order
EASA	European Union Aviation Safety Agency
EIS	Entry Into Service

eVTOL	Electric Vertical Takeoff and Landing
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FAL	Facilitation Program
FAR	Federal Aviation Regulation
FESG	Forecast and Economic Analysis Support Group
FLTOPSP	Flight Ops Panel
FRMS	Fatigue Risk Management Systems
FTG	Fuels Task Group
GAMA	General Aviation Manufacturers Association
GANP	(ICAO) Global Air Navigation Plan
GCAS	Ground Collision Avoidance System
GCS	Ground Control Station
GHG	Greenhouse Gas Emissions
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRAIN	Global Resilient Aviation Information Network
GUTMA	Global UTM Association
IAM	Innovative Air Mobility
IASMS	Intime Aviation Safety Management System
IATF	International Aviation Trust Framework
ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronics Engineers
IFAR	International Forum for Aviation Research
IFPP	Instrument Flight Procedures Panel
IFR	Instrument Flight Rules
ILOT	Łukasiewicz Research Network – Institute of Aviation
INCAS	National Institute for Aerospace Research
ISG	Impacts and Science Group
ISO	International Organization for Standardization
IT	Information Technology
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
JAXA	Japan Aerospace Exploration Agency
KARI	Korea Aerospace Research Institute
LTAGTG	Long Term Aspirational Goal Task Group
MBSE	Model-based Systems Engineering
MDG	Modeling and Databases Group
MOC	Means of Compliance
m:n	Many to Many Control
NASA	National Aeronautics and Space Administration
NRC	National Research Council Canada
NLR	Netherlands Aerospace Center
OEM	Original Equipment Manufacturer
ONERA	ONERA The French Aerospace Lab
OPS	Aircraft Operations
OT	Operational Technology
PANS	Procedures for Air Navigation Services
PBN SG	Performance-based Navigation Study Group

PIC	Pilot in Command
PKI	Public Key Infrastructure
PN	Protection Needs
PNT	Positioning, Navigation, and Timing
PTLP	Personnel Training and Licensing Panel
PSU	Provider of Services for Urban Air Mobility
RAM	Regional Air Mobility
RPA	Rules of Particular Applicability
RPAS	Remotely-piloted Aircraft Systems
R&D	Research and Development
SAF	Sustainable Aviation Fuel
SARPs	Standards and Recommended Practices
SC SEG	Sustainability Certification Schemes Evaluation Group
SATCOM	Satellite Communication
SC-VTOL	Special Condition for VTOL
SDOs	Standards Development Organizations
SDSP	Supplemental Data Service Provider
SESAR	Single European Sky ATM Research
SG	Subgroup
SIP IG	Safety Information Protection Implementation Group
SMS	Safety Management System
sUAS	Small Uncrewed Aircraft Systems
SUMP	Sustainable Urban Mobility Plan
SVO	Simplified Vehicle Operations
TF	Task Force
TLOF	Touchdown and Lift-off
TRG	Training
TRL	Technology Readiness Level
UAS	Uncrewed Aircraft System
UAM	Urban Air Mobility
UKRI	United Kingdom Research and Innovation
UML	UAM Maturity Level
UTM	UAS Traffic Management
VFR	Visual Flight Rules
VFS	Vertical Flight Society
VTOL	Vertical Takeoff and Landing
VTT	Technical Research Center of Finland
VZLU	Czech Aerospace Research Center
V2V	Vehicle to Vehicle
WG	Working Group
XBT	Cross-Border Transferability
3D	Three-Dimensional