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INTERNATIONAL SCIENTIFIC ASSESSMENT ON URBAN AIR MOBILITY AS A CONTRIBUTION TO FUTURE AVIATION STANDARDS

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Abstract

The International Forum for Aviation Research (IFAR) is the world´s aviation research establishment network. IFAR aims to connect research organizations worldwide, to enable the information exchange and communication on aviation research activities and to develop among its members a shared understanding on challenges faced by the global aviation research community. IFAR develops views and recommendations and facilitates opportunities for networking and partnerships, while the focus of IFAR is on non-competitive aviation research and development related to global technical challenges such as Urban Air Mobility (UAM). Within its Working Group UAM, more than 80 experts worldwide are currently developing an international, scientific assessment on the topic of UAM, divided into 17 subtopics or disciplines. The goal is to jointly develop a harmonized, non-biased international scientific perspective that identifies the challenges to be addressed with priority in the field of UAM and which can serve, among others, as a basis for regulators and civil aviation authorities in the sense of global standardization.

Keywords: urban air mobility, standardization, regulation, certification, internationalization

1. Introduction to the International Forum for Aviation Research

1.1 The IFAR Network

In 2008 and in 2010 international aeronautical research organizations met and founded the *International Forum for Aviation Research (IFAR)* [1] in 2010. IFAR aims to be a cooperative forum for exchange among aviation research organizations in view of the increasing demands to aviation research on a global level and aims to support its members in the implementation of their research aims. To this end, IFAR should be a voluntary, non-binding international coordination mechanism for its members, through which individual research organizations may exchange information and facilitate their co-operation.

1.1.1 IFAR Objectives

IFAR aims to realize the activities shown in Figure 1. IFAR provides a venue to connect research organizations world-wide, to enable the information exchange on aviation research activities between its members, to facilitate opportunities for networking and creating partnerships and to coordinate views and make recommendations. IFAR should maintain a non-competitive research focus, and consider solutions to global technical challenges such as those pertaining to emissions, noise, security, safety and efficient operations, and steps to reduce the impact of aviation on climate and the environment. In detail, IFAR's five objectives frame the network's role as a forum for aviation research organizations from around the world to come together to tackle global challenges. The 5 objectives provide mutual support for each other:

- Information Exchange between the member organizations on aviation research challenges allows IFAR members to identify common areas of interest,

- Networking among and within the member organizations allows IFAR members to better understand the capabilities available around the world,
- Cooperation offers IFAR members a network for bringing together researchers and facilities to tackle challenging problems together,
- Education ensures that the next generation of aviation problem-solvers think globally and benefit from IFAR's ability to connect researchers through the Early Career Network,
- Communication enables IFAR members to showcase their work to the broader aviation research community and to enable their research to inform aviation-related policy.

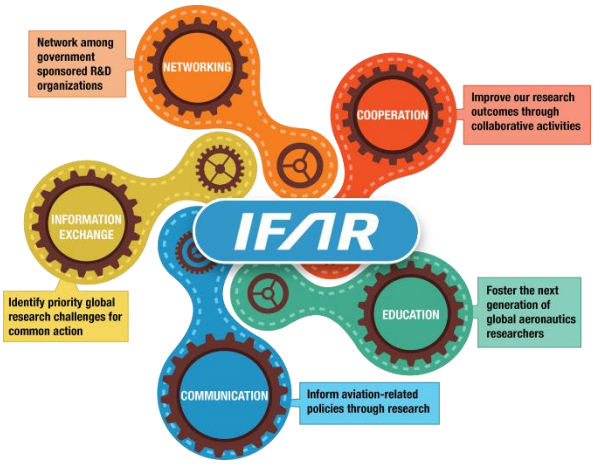

Figure 1 – Objectives of IFAR

1.1.2 IFAR Focus Areas and Activities

IFAR aims at non-competitive aviation R&D related to global technical challenges for use by its members. Concerning the technological approach IFAR initially concentrated on the following five Focus Areas which were generated as common denominator from various strategic documents by IFAR members:

- Alternative Fuel: Enable the use of alternative aviation fuels.
- Efficiency: Climate Change as a new challenge for aircraft development.
- ATM: Increase air transportation system performance to safely enable projected growth in a system operation.
- Noise:Improve management of operations at and around airports to improve efficiency and environmental impact.
- Weather: Reduce the adverse impacts of weather on air traffic management decisions and oprations.

1.1.3 IFAR Core Values

IFAR focusses on four overarching core values (see Figure 2). Especially the information exchange (1) internally among its members as well as (2) externally within its bi- and multilateral international collaborations plays a central role. For IFAR the (3) empowering of early career employees with the focus on the field of aerospace engineering is key to maintain a solid research basis; in this regard the IFAR Early Career Network (ECN) composed of researchers, students, and other employees in aviation research from IFAR member agencies aims to support the growth of young researchers with high potential for national and international leadership. The fourth core value is the element of (4) external partnerships on an international scale.

Figure 2 – Core Values of IFAR

1.1.4 IFAR Membership and IFAR Organization

Membership in IFAR is open to national aviation research organizations, including universities active

in aviation research, that are (1) non-profit, (2) owned or mainly funded by public governments, and (3) charged by the country or countries in which they are located to conduct such research activities on their behalf. One organization per country is accepted for membership. Currently 26 aviation research organizations from all over the world are member of IFAR (see IFAR website, www.ifar.aero). The current members represent more than 35,000 researchers working in aviation. Not counted yet are researchers of IFAR member countries belonging to different research organizations or universities.

The IFAR network itself is organised as follows:

[1] IFAR Principals

The IFAR Principals are the heads of IFAR member organizations. Collectively they make key strategic decisions. Principals convene at least once a year at the IFAR Summit. Every two years the IFAR Chair and IFAR Vice-Chair are elected by the IFAR Summit.

[2] IFAR Summits

Annually, Principals from IFAR members convene at an IFAR Summit meeting. This event promotes the networking and information exchange of members as well as sets and endorses the IFAR goals and activities for the coming year. A Summit may establish technical and non technical expert groups for IFAR activities of high interest.

[3] IFAR Leadership Team

The IFAR Leadership Team (LT) comprises the IFAR Chair, IFAR Vice-Chair, IFAR Past Chair (rotating members with a term of two years), IFAR Founding member organisation (DLR) and IFAR Founder. The LT serves as the day-to-day decision making body of IFAR.

[4] IFAR Secretariat

IFAR activities are supported by the IFAR Secretariat.

[5] IFAR Advisory Team

The IFAR Advisory Team (AT) is comprised of working level staff from the organizations represented in the LT. The AT supports the LT and carries out the day-to-day tasks of running IFAR.

[6] IFAR Steering Committee

The IFAR Steering Committee (SC) is comprised of working level staff from all IFAR member organizations. The SC meets roughly once every 6 weeks and develops IFAR strategy and policy for consideration by the IFAR Principals and LT.

[7] IFAR Working groups and initiatives

Technical and non-technical working groups, task forces, as well as initiatives are set-up where interested members collbaorate.

1.1.5 IFAR Reach

IFAR members work across the full technology readiness level (TRL) range from 1 to 9, usually addressing TRL 1-6 in basic research with universities, and TRL 6-9 when supporting industry in proprietary development. IFAR also provides large-scale infrastructure and technology foresight (strategic R&D and technical services) and fosters consortia for large-scale technology demonstration projects (such as the EU and North American partners). In addition to that IFAR makes connections between SMEs and upper-tier suppliers and OEMs, and acts as independent consultant to society.

1.2 IFAR Research Collaboration

As mentioned IFAR seeks to connect research organizations world-wide. On the one hand, this concerns the internal networking of its members in the sense of joint research projects by enabling the information exchange on aviation research activities. On the other hand, IFAR aims at external research collaborations and acitivities; here IFAR's approach is to manage the acceleration of innovation by:

- Providing a scientific basis for regulators for informed rulemaking to maintain or improve safety while allowing industry to continue to innovate, de-risk/or prove technologies towards certified products,
- Convening key players in industry, academia, and government, and
- Providing strategic, long-term vision for evolving technological trends.

A good example of an IFAR research collaboration with industry was the *Breakthrough Laminar Aircraft Demonstrator in Europe (BLADE)* [2] collaborative project with Airbus within the framework of the European Union‘s CleanSky programme. The project aimed to explore natural laminar flow (NLF) technologies for smart wings. For this BLADE employed an Airbus A340-300 aircraft refitted with wing tips aiming at the assessment of the applicability of NLF on a representative scale. Multiple IFAR partners have been involved in BLADE with the motivation of convening industry partners as well as maturing promising technologies while maintaining scientific rigour and impartiality.

1.2.1 Collaboration with International Organizations

In addition to the network-internal cooperation as well as the cooperation with industry partners, IFAR is strengthening its partnerships with international organizations in recent years. One example is the collaboration with the International Council of the Aeronautical Sciences (ICAS) [3] launched in 2016 with a clear focus on the academic and reasearch expertise. Another motivation is IFAR’s approach to managing the acceleration of innovation by providing a scientific basis for regulators for informed rulemaking and the certification of future industry products. For this reason, IFAR initiated the collaboration with the International Civil Aviation Organization (ICAO) [4] in late 2020, and two years later both organizations scaled-up their cooperation and information sharing to promote innovation through a new agreement concluded in Montréal in 2022. Focusing on the promotion of the innovative and sustainable development of international civil aviation globally, the bilateral agreement calls for ICAO and IFAR to cooperate toward their respective safety, security, and sustainability goals, and collaborate on the scientific assessment of new avenues for innovation.

1.3 IFAR Technical Working Group Urban Air Mobility

1.3.1 Technical Working Group Organization

An IFAR Summit sets the IFAR goals and activities for the coming year which will then be implemented by IFAR‘s Working Groups, Task Forces, and Initiatives. The purpose of an IFAR Technical Working Group (WG) is to catalog member activities, facilitate technical partnership opportunities among members, and represent IFAR consensus to external organizations. Participation in a WG and its Committee is open to all IFAR Members. IFAR Members who have decided to participate may decide to do so within three months after an annual IFAR Summit and will be accepted as Members. At any other times, in order to join a WG and actively participate in its Committee IFAR Members will require prior approval by the Coordinator who is steering the Committee as well as all Committee members.

1.3.2 Working Group Urban Air Mobility

The WG focusses on the interdisciplinary topic of Urban Air Mobility research. This includes information exchange about national programs, assessments of research gaps, and opportunities for collaboration internal and external to IFAR. The WG excludes industry representatives and is not being used to advance the interests of a specific company. The WG UAM output include different kind of products such as:

- A catalog of member research objectives and projects,
- Consensus documents requested by external organizations,
- Recommendations to the IFAR Leadership Team and Principals if complementary synergies and suitability are seen within the area of UAM for a mutually beneficial partnerships (e.g. recommendation for a partnership between IFAR and external organizations),
- Executive summaries and reports of internal activities that may be made available to the public.

One example of a typical WG product is the *2019 IFAR White Paper on Urban Air Mobility* [5] that

has been developed after the IFAR Summit in 2018. The core content of this product was produced by all IFAR members on the basis of the outcome of a brainstorming session called *IFAR Café*. In the following months of post-processing the content has been consolidated and finally approved by 19 IFAR members for distribution. After distribution the WG UAM received White Paper feedback from the European Commission (RTD.D3) with further recommendations.

With the *2019 IFAR White Paper on Urban Air Mobility,* IFAR identified an eminent research demand regarding UAM in three topics:

- Safety standards of vehicles and operations,
- Emitted noise during operations,
- Social acceptance through customers as well as the affected population (public confidence) on the ground during operations.

IFAR WG UAM concluded that those three research pillars are crucial for an accelerated market diffusion of this new and promising field of UAM and should therefore be a focus of possible multilateral research cooperation within the IFAR community.

In this context IFAR sees its role as

- the main driver for the development of certification procedures—both for vehicles and ATM structures, and
- the leading innovator for new subsystem technologies—such as Detect and Avoid systems, safe and reliable communications links, and many more.

As of 2022, the WG UAM consists of 17 IFAR members.

2. Scientific Assessment

In times of increasing digitization, more complex systems and rising automation, the interaction of these effects also has a major impact on global technology development and thus also on the research landscape. The topic of UAM is practically a prime example of such an interaction and also represents the introduction of a new ecosystem in the field of aviation, to which research, industry as well as politics must adapt. Here, UAM means a new terrain for all stakeholders:

- For aeronautics research it means focusing on topics such as automation, sensor development, lightweight design and battery research,
- the industry must not only deal with smaller vehicles, but also consider necessary innovative infrastructures and completely new business models, and
- policymakers and especially regulators are facing ever-shorter response times to meet rising demand for new aviation standards.

Particularly with regard to the last-mentioned aviation standards, a fundamental shift in thinking is required. As mentioned, UAM is looking at a completely novel overall concept—from innovative vehicles and new infrastructures to a customized air traffic management system.

And here by establishing the collaborations with international organizations such as ICAO as the international standard-making body for international civil aviation IFAR seeks to provide a scientific global consensus from the perspective of research on the technical challenges in implementing Urban Air Mobility (UAM) and therefore to support innovation in aviation. This global consensus is to be developed by the IFAR members in the form of a Scientific Assessment of UAM (SAUAM).

2.1 Definition

With the SAUAM, IFAR pursues the strategy of providing a global perspective from a research point of view for the topic of UAM based on the broad expertise of its approximately 35,000 researchers. The core aspect and unique selling point of this product is the objective, independent presentation of the research needs in the individual subject areas. This is achieved by consolidating the inputs provided by individual IFAR members and collaboratively developing and agreeing on the final statements. The result is then detached from national interests or political-industrial goals and thus a high-value basis for the international implementation of the topic of UAM. The SAUAM itself is the sum of all data after final consolidation with the base framework in the form of a living document.

2.2 Structure

The SAUAM is looking into various aspects that are of relevance to the mandate of relevant

stakeholders such as ICAO since increasing global harmonization will enable the safe scaling of the UAM industry worldwide, while a lack of harmonization will result in a longer worldwide timeline to fully scaled UAM operations.

The document structure of SAUAM provides for the following five chapters:

I. Industry Assessment
II. Technology Area Priorities
III. Operationalization Area Priorities
IV. Societal Acceptance Area Priorities
V. Regulatory Assessment

The implementation of the SAUAM was divided into three parts for organizational reasons:

- Part 1 comprises the Industry Assessment,
- Part 2 the Technology, Operationalization, and Societal Acceptance Area Priorities, and
- Part 3 the Regulatory Assessment.

Part 2 as the core of the SAUAM is comprised of 17 collectively-identified and highly relevant sub-topics (plus two additional sections covering any 'other' sub-topic). The detailed structure of the SAUAM Part 2 is shown in Table 1. Sub-Topics 1-9 are the Technological focus area, 10-14 the Operationalization focus area, and 15-17 the Societal Acceptance focus areas.

Table 1 – Structure of the IFAR Scientific Assessment of UAM (part 2)

Focus Area	*No*	*Sub-Topics*
Technology	1	**Vehicle Overview** (overall A/C incl. Flight Profile, Performance)
	2	**Propulsion and Energy** (Hydrogen, Electric, other)
	3	**Autonomy** (DAA, Flight Controls, Flight Path Management, AI, etc.)
	4	**Airspace Integration and UTM**
	5	**Safety Management Systems**
	6	**Infrastructure** (Airports, Heliports, and Vertiports)
	7	**Security**
	8	**CNS** (including Spectrum, GPS-denied, etc.)
	9	**Weather Tolerance**
	10	**Other**
Operationalization	11	**Environment** (Sustainability, Emissions, Noise, Visual, etc.)
	12	**Maintenance**
	13	**Safety and Security**
	14	**Intersection with Infrastructure** (Airports, Vertiports, etc.)
	15	**Data Protection and Security**
	16	**Other**
Social Acceptance	17	**Autonomy**
	18	**Environment** (including Emissions, Noise, etc.)
	19	**Safety**

2.3 Process

In 2021, the IFAR Task Force began drafting a UAM Scientific Assessment featuring inputs from more than 80 researchers from across IFAR.

2.3.1 SAUAM Part 1

The development of SAUAM Part 1 covering the Industry Assessment was conducted in summer 2021. It captures 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 captured below and the subsequent subsections explain the findings of the assessment in more detail:

1. There are clear leaders in the UAM industry with diverse international affiliations, use cases, and configurations. **There is no clear way to unanimously identify the first location / use case / organization**, but current expectations can be put on a timeline.

2. **Piloted UAM operations leveraging as much of existing regulatory structures will happen first,** but for operations to scale, solutions to remoted piloted configurations and general automation technologies must be worked in parallel.
3. **Common technologies that are required for step changes to both piloted and remotely piloted operations require more emphasis across technology development and regulatory structures for UAM to scale.** The relationship and potential to leverage sUAS development is not entirely clear.
4. Certification programs are in work across many nations, and some regulatory environments will be more friendly than others. **National assessments on economics, certification, societal, etc. are fairly common, but there is little public information around international perspectives.**
5. **There is a lack of understanding and commonality around expected use of UTM for initial operations** (required for safety, just for efficiency, or not needed at all) and progress will happen faster if the international community has common expectations.

2.3.2 SAUAM Part 2

IFAR began the SAUAM Part 2 in fall 2021 by establishing focus areas capturing technology, operationalization, and societal acceptance considerations. IFAR technical experts were identified from research agencies around the world, but every agency was not expected to provide members for each sub-topic. However, technical experts were expected to contribute to content development and discussions on template inputs. Leads for each sub-topic were identified and the teams of experts then began developing content for their sub-topic. 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 sub-topic and summarized their findings as key takeaways. Some teams have presented their findings to ICAO while others are in process of briefing.

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2. Propulsion and Energy Technology Area Overview

Summary of Key Takeaways

Vertical take-off and landing add to energy requirements, and eVToL aircraft can have significantly less range capability than traditional rotorcraft. The major limitation to increased vehicle performance is the gravimetric energy density of batteries compared to liquid hydrocarbon fuels coupled with currently insufficient battery technology to support the high energy discharge rates required for takeoff and landing. Certifying authorities are working to adapt existing rules or adopt new ones where needed. There are many areas that need to be developed for the vehicle and the ground infrastructure to ensure operational safety and the safety of the public.

Overview of Technology Area

To successfully operate in the urban environment, many believe that UAM vehicles must be capable of vertical take-off and landing (VTOL) to operate in small area and the vehicles should not contribute to the emissions problem that is present in most cities. These requirements present unique technical challenges and result in designs for UAM vehicles that are VTOL and use electric or hybrid-based propulsion systems. A critical challenge for UAM market growth is to gain public acceptance for being as safe as - or safer than - commercial air travel or automotive transportation. Vertical take-off and landing add to energy requirements, and aircraft using a large number of propellers are less efficient in hover than traditional rotorcraft. The major limitation to increased vehicle 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. Any type of novel refueling/recharge system will require significant investments in technology and infrastructure.

State of the Art Assessment

Electric propulsion systems are operational and in demonstration flight tests in many vehicles. Many advances are needed in the power density, reliability, packaging, monitoring, servicing, and ground infrastructure to advance to scaled commercial operations. 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 is a serious design consideration for the vehicles. Hybrid-electric systems can extend the range of the UAM vehicles. Hydrogen fuel cell propulsion systems are proposed as an alternative to increase range but have not been demonstrated. For hydrogen systems, a major limitation is physical space on the vehicle for the fuel cells and storage tanks. The TRL for hydrogen/fuel-cell technology lags battery technology but may be more revolutionary. Neither of these advanced propulsion concepts is currently being used in commercial operations.

Gap Analysis

Battery technology development is needed to increase the specific energy and the charge/discharge rate. Battery improvements are also needed in smart energy storage/management, rapid recharge capability, high-voltage hybrid-electric generators, 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. 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 vehicles 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 vehicle concepts may have a difficult time meeting this high reliability required. Standardization of power system connections and charging infrastructure is needed for scaled operations.

Open Research Areas

1. Are there 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 (ex: 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 need further research.

Recent Research Publications

- 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

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

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Figure 3 – Example of the TWC one-page format for the SAUAM Part 2 sub-topic output

For the first version of the document, the so-called 'intermediate product' a uniform one-page format, modeled on the NATO Technology Watch Cards (TWC) [6], was chosen for better coordination of the sub-topics. The output from each focus area team is captured on an individual TWC (see Figure 3) and is organized into multiple sections:

- **Summary of Key Takeaways:** States the technical team's main findings, gaps, and further research needs for each focus area.
- **Overview of Technological / Operationalization / 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 technical team's more detailed findings.
- **Gap Analysis:** Describes technology, standards, and policy gaps for UAM operationalization relevant to each focus area.
- **Open Research Areas:** Captures questions and open areas the technical teams have for further research.

- **Recent Research Publications:** Includes links to publicly available documents relevant to the technical team's research. Also captured at the bottom of the template are the source document(s) of the information presented.
- **Adapted From:** Provides the file names of the focus area team's full outputs if more information is desired.

2.3.3 SAUAM Part 3 and Revision

The final part of the SAUAM is expected to be the Regulatory Assessment, with the goal of evaluating the global landscape of relevant regulations and regulatory approaches for the implementation of UAM. As IFAR's expertise and focus is clearly on the three categories of Part 2, the final implementation of Part 3 will depend on the feedback and cooperation with the international partners such as ICAO and will decide on the need for this part.

In terms of continuous revision, IFAR will continue to refine its message on the Focus Areas for the SAUAM Part 2 by continuing to gather inputs from its members in the future and refining consolidated outputs and key takeaways beyond the status of the current document version.

3. Outlook

The intermediate product is scheduled for completion by the end of 2022. Together with the existing Part 1 – Industry Assessment, the Part 2 outputs from focus area teams will continue to go through a vetting process with the partner organization leadership where key takeaways, gaps, open research questions, and any other outputs are openly shared for discussion. The goal of the assessments and observations from IFAR researchers is to promote informed standards development within the partner organizations on emerging technologies and industries. Additionally, IFAR routinely participates in external workshops to brief preliminary results, share initial external feedback, and mature messages surrounding focus areas. These workshops enable IFAR to further R&D initiatives and prepare for discussions with partner organization leadership and working groups.

4. Concluding Remarks

The strategic task of the IFAR Scientific Assessment of UAM is focused on sharing harmonized consensus products with international stakeholders that provide scientific insight into the state of UAM. The resulting product enables IFAR members to provide their research expertise to e.g. ultimately help international authorities such as ICAO be better prepared for the coming innovation that will impact international civil aviation.

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6. Copyright Statement

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