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INTERNATIONAL SCIENTIFIC ASSESSMENT ON URBAN AIR MOBILITY

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Global Network of Public Aeronautical R&D Institutions

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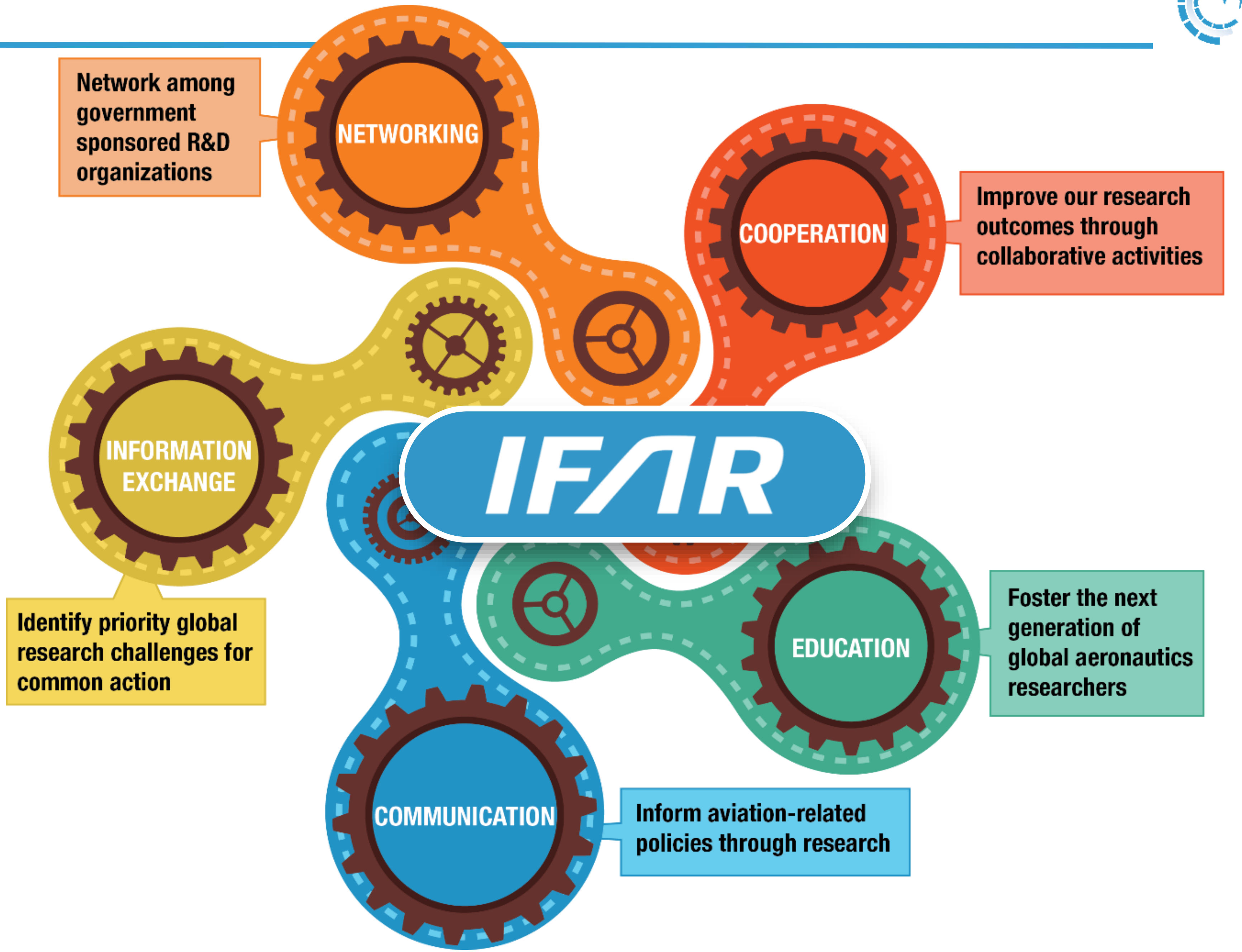
26
countries
representing 6 continents

35 000 researchers

Objectives


Network among government sponsored R&D organizations
NETWORKING
COOPERATION
Improve our research outcomes through collaborative activities
INFORMATION EXCHANGE
IFAR
Identify priority global research challenges for common action
EDUCATION
Foster the next generation of global aeronautics researchers
COMMUNICATION
Inform aviation-related policies through research

COLLABORATIONS WITHIN IFAR

Alternative Aviation Fuels

Alternative fuel effects on Contrails and Cruise Emissions Flight Test

May 2014 – ACCESS II Campaign
@ Armstrong Flight Research Center

NASA Falcon Aircraft in Flight Behind DC-8 Aircraft

NASA JAXA Japan Aerospace Exploration Agency NRC·CNRC Canada DLR

Funded by IFAR members and used by industry towards clean aviation solutions

Collaborations within Partners

BLADE

Collaborative project with Airbus on drag reduction with laminar wings

- **Convening** industry partners
- Maturing promising technologies while maintaining **scientific rigour and impartiality**
- Involvement by multiple IFAR partners in Europe

Photo courtesy of DLR

IFAR-ICAO Collaboration

“Support innovation in aviation”

- **Declaration of Intent (DoI)** signed in November 2020 at the Ottawa Summit
- **IFAR-ICAO Expert Group (EG)** created with members from IFAR and ICAO to oversee the collaboration
- **IFAR UAM Working Group (WG)** supporting EG by providing input to the key deliverable – the **UAM Scientific Assessment**
- **IFAR-ICAO Memorandum of Understanding** signed in Montréal in April 2022.

Scientific Assessment on Urban Air Mobility

- 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.
- **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 sum of all data after final consolidation with the base framework in the form of a living document.

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Industry Assessment

Part 1: Industry Assessment

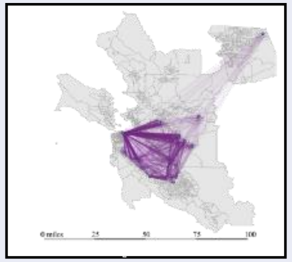
#	Key Take-Aways	Description
1	Use Cases: Time and Place	There is no clear way to unanimously identify **the first location / use case / organization**, but current expectations can be put on a timeline.
2	Existing Regulatory Structure Application to Piloted Ops	**Piloted UAM operations** leveraging as much of existing regulatory structures will happen first.
3	Cross Application Automation Dependencies	Technologies that are required for changes to piloted and remotely piloted operations require **more emphasis on technology and regulatory structure development** for UAM to scale.
4	International Assessment Studies	National assessments on economics, certification, societal, etc. are common, but there is **little public information** around international perspectives.
5	Harmonization on UTM / xTM	There is a lack of understanding and commonality around **expected use of UTM for initial operations**.

COMMON TECHNOLOGIES TO ENABLE SCALABLE UAM

Pilots, Ground Control Stations, and Fleet Management

Related IFAR Research Groups:

Airspace Management



Related IFAR Research Groups:

Airspace Management and UTM (4)

System Wide Safety

Related IFAR Research Groups:

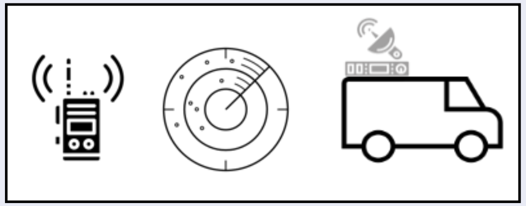
Security (7), Safety and Security (13), Data Protection and Security (15), Safety (19)

Aircraft Technologies, Electrification, and Automation

Related IFAR Research Groups:

Vehicle Overview (1), Propulsion and Energy (2), Autonomy (3), Maintenance (12), Autonomy (17)

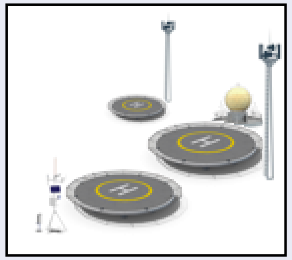
Communication, Navigation, Surveillance, Information



Related IFAR Research Groups:

CNS (8)

Vertiport Management



Related IFAR Research Groups:

Infrastructure (6), Intersection with Infrastructure (14)

PART 2: TECHNOLOGY, OPS, SOCIAL ACCEPTANCE

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14 Contributing members

80+ Experts

17 Teams

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

Part 2: Technology Watch Cards

- **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.

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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

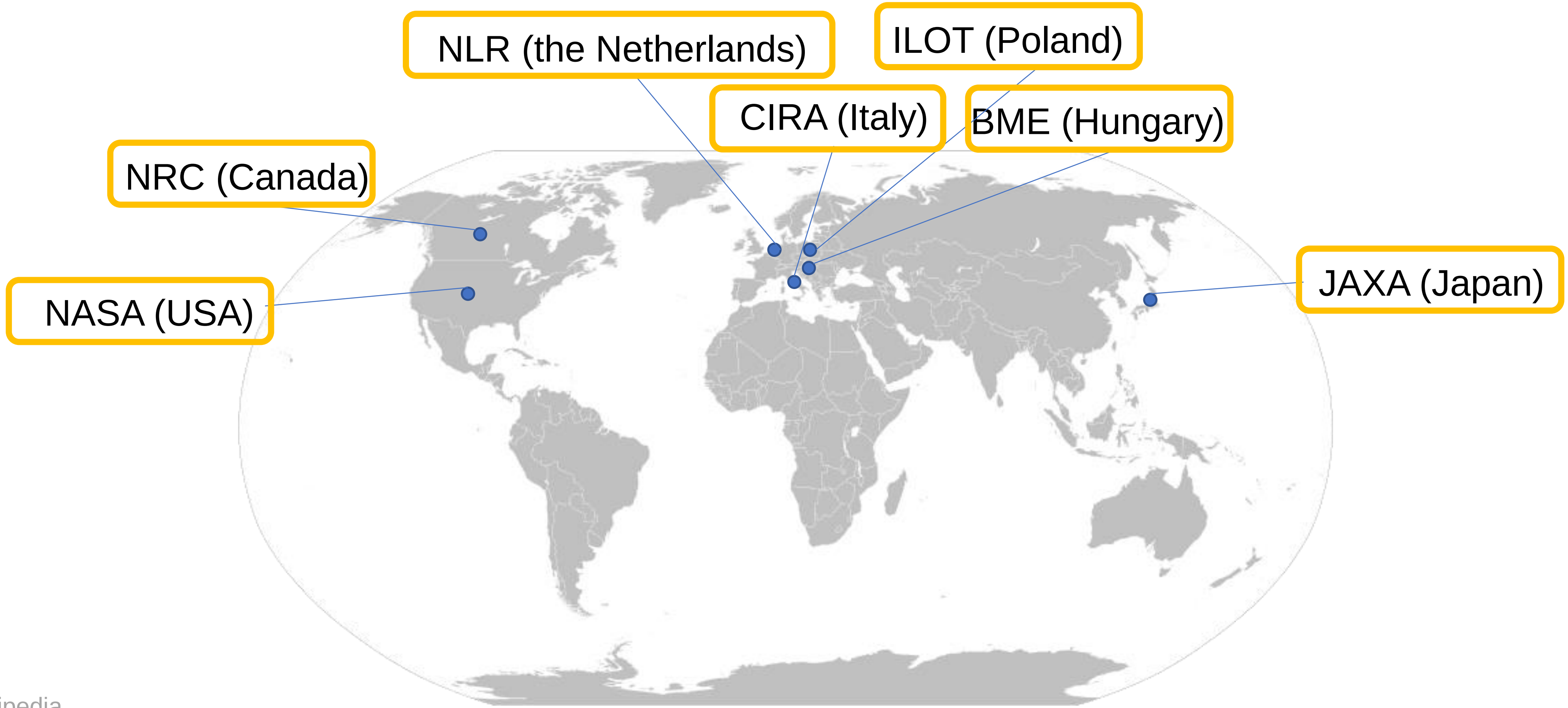
Adapted from: "DRAFT V2 IFAR Scientific Assessment of UAM_prop.docx" and "Key Take Aways Propulsion and Energy Ver 2.pptx"

16

Airspace Integration & UTM

Team members

- Team members from 7 organizations (countries)



Map source: Wikipedia

Airspace Integration Challenges

Today

	VFR	IFR
Operation	Flight operation defined by visual references	Flight operation defined by reference to instruments
Certification	Minimum equipment dictated by airspace	Minimum equipment dictated by certification and NAVAIDS intended to be used.
Separation	Responsibility of separation maintained by the pilot	Responsibility of separation maintained procedurally or manually by ATC and the pilot

Future

- Unique operation characteristics
- Increased traffic density and tempo
- Increased level of automation

UAM Use Cases

Early or Near-Term Use Cases

2025-2035

Point to Point Transfer of Goods & Passengers

- Cargo services can pave the way for passenger transport
- Established routes (no air taxi from your home to your office, for example)
- Remote locations (transport to remote islands, suburban areas)

Public Good Operations

- Disaster response
- Medical transport
- Rescue

Long-Term Use Cases

after 2035

- On demand operations
- Increasing complexity of operations
- Higher levels of automation
- Higher volumes of traffic

Key Areas of Research for UAM Airspace Integration

Intent Sharing

Collaborative Conflict Management & Separation Minima

Airspace Design and Procedures

Communication, Navigation, & Surveillance

Airspace and Vertiport Interactions: another expert team focused on this area

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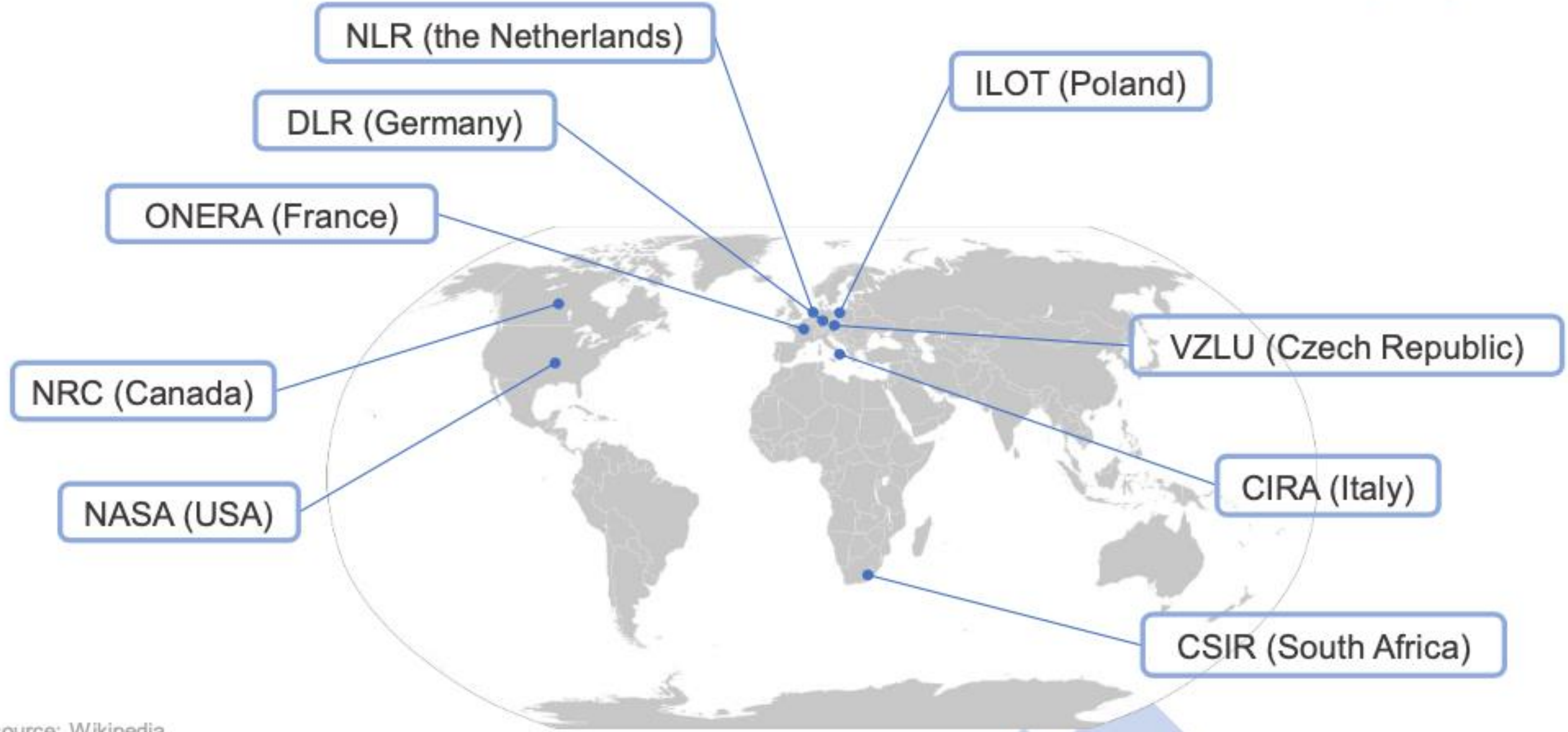
Safety Management Systems

Team Members Safety Working Group



Map source: Wikipedia

Safety Working Group Key Takeaways

Different Countries, Different Regulations

- Requirements for operations that require SMS differ between countries
- Harmonization
- New UAM-specific regulation/processes are necessary (e.g. predictive safety analysis, occurrence reporting for uncrewed aviation)

Illustrative Deep Dive: Crash Safety

- Some regulatory environments may need to be amended to handle UAM Accident Safety
- New crash conditions (e.g. structural design, heavy mass distributions (rotors, batteries), impacts loads incl. directions and impactor types, etc.) must be considered
- Aeronautical standards (GA, HE, A/C) and also automobile industry standards could apply

Safety Working Group Key Takeaways (cont.)

SMS according to Annex 19

- Currently UAM operators and UTM service providers are not considered
- Different requirements in terms of safety and SMS for different technologies / operations? (e.g. risk-based approach such as SORA)

Data deficiency for setting up SMS and safety baselines

- Technological data (new technologies and more complex systems)
- Operational data (little to no operations yet, therefore little to no data)
- Potential for ”vicious cycle” (Data vs. Safety vs. Technology Development)

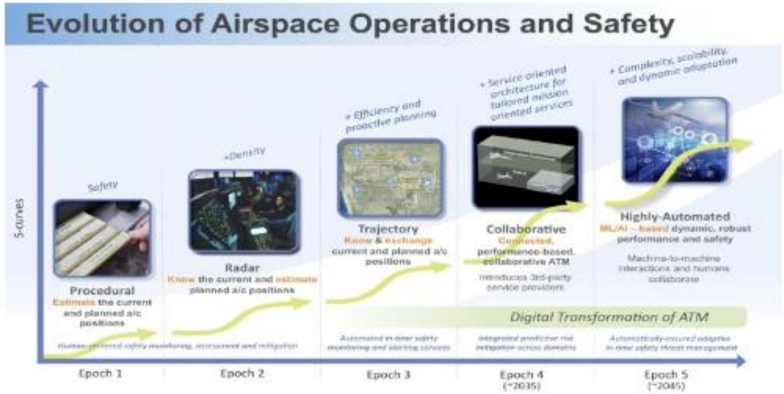
The Way Forward: Use Cases, Timeframes and Complexity

Continuing detailed analysis with regards to specific use cases

1) Passenger carrying UAM-Vehicle (piloted, RPAS)
2) Passenger carrying UAM-Vehicle (automated, autonomous)
3) Cargo carrying UAM-Vehicle (automated, autonomous)
4) Smaller sUAS (cargo, inspection, etc.)
5) Public services operations (e.g. disaster response, medical transports, rescue)

➔ Is there an „enabling use case“ in terms of safety regulations and SMS development?

Different use cases, different (possible) time frames



There are many interdependencies / common complexities concerning technologies and operations

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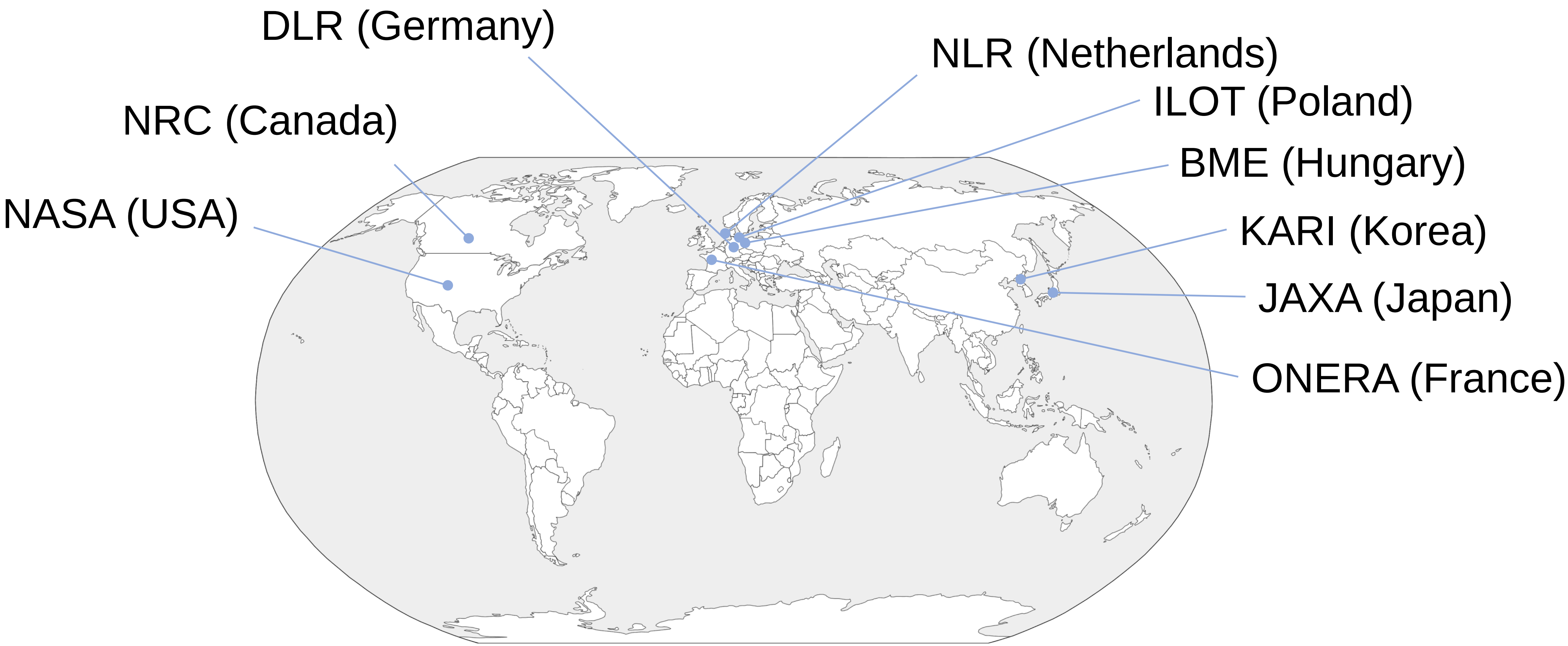
AIRCRAFT AUTONOMY

Team Members



Autonomy is Transforming Aviation

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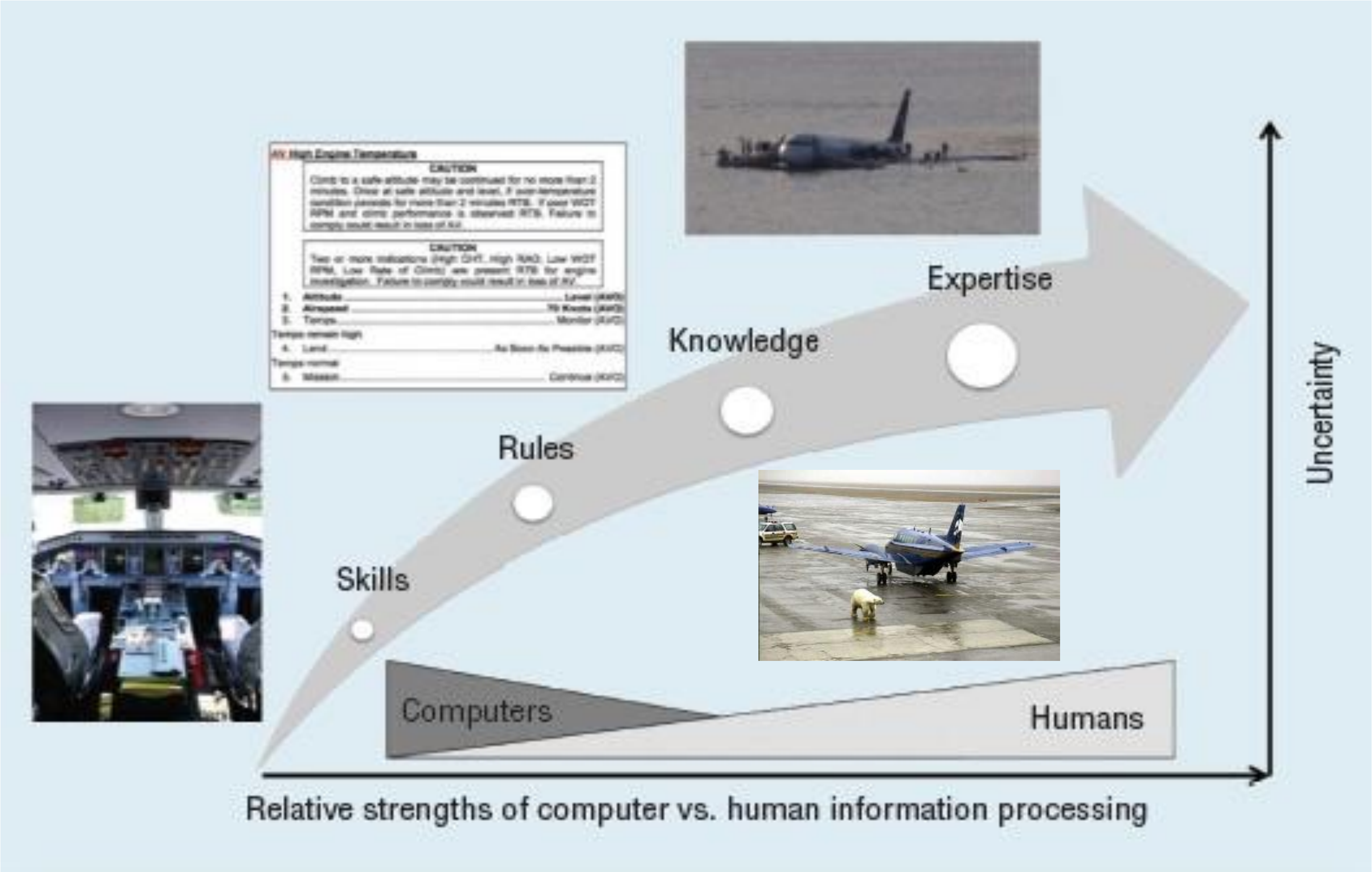
Many UAM missions/business cases depend on highly autonomous aircraft

- Industry expects routine, “m:N” remotely supervised operations in 5-15 years (Ambitious!)
- May retain some level of human oversight, but no longer safety-critical
- Many developers of passenger UAM targeting augmented piloted ops., as steppingstone

Major Gaps Between Vision and State of the Art



- Passenger carrying UAM requires specialized *and* general intelligence
  - Emerging autonomy provides mostly specialized intelligence
- Very limited experience with highly autonomous aircraft (current RPAS ≠ Autonomous)
- Major Gaps across
  - On-board automation, particularly integrated awareness and response
  - Human-autonomy teaming
  - Airspace and operations
  - Regulation & policy
    - Airworthiness
    - Airman
    - Airspace operations

Autonomy – Emergence from Automation and Environment

Aircraft Functions & Components

Mission Management / Automation
Semantic Environmental Perception
Detect & Avoid
Contingency & Emergency Management
System Health Management
Trajectory & Motion Planning
Trajectory Optimization
Robust & Fault-tolerant Flight Control
State and Weather Sensing

External Systems and Services

Airspace Services (UTM / U-space)
Position Systems
Datalink Infrastructure

Human Involvement

Monitoring / Responsibility
Procedures
Human Factors
Crew Qualification

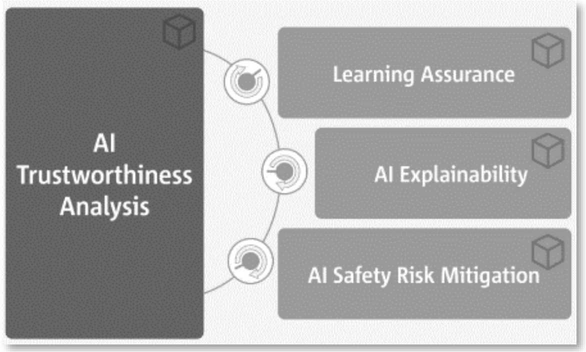
Levels of Autonomy

Cooperation with other (autonomous) Systems

Transport Infrastructure
Manned Aviation
Ground / Water Vehicles

Challenges and Preliminary Recommendations for Safe Autonomy

- Enable both: Established software verification methods (e.g. DO-178) and new methods fitting for new (deep) AI-based systems
- Master complex operating conditions and complex safety critical technical systems, (e.g. by runtime monitoring and assurance)
- Concepts for safe distribution and allocation of the of decision-making (e.g. aircraft, pilot (if present), operations center, airspace, infrastructure, etc...)
  - Datalink requirements for off-board allocations
- Pilot and crew qualification & certification for different levels of autonomy
- Balancing diversity of design, competition, standardization, & burdens on CAAs
- Guidance on leveraging operational experience, technologies and data across certification categories



EASA 2020, Artificial Intelligence Roadmap
EASA 2020, CoDANN
EASA 2021, First usable guidance for Level 1 ML applications
EASA 2021, CoDANN II

Studies on verification methods for AI-based systems

Runtime assurance for complex operation conditions / technical systems

Autonomy Summary

- Key enabler of UAM and other missions over coming decades
- High potential benefit, ***but also risks***
- Community has ***limited experience*** and widely varying expectations
- Initial experience & trust likely gained through more risk tolerant use cases such as sUAS, autonomous cargo, select manned (e.g. single-pilot)
- Full realization requires significant technical and policy review, update
- Societal acceptance (separate team evaluating)
  - Operational introduction of new tech *usually reveals emergent hazards*

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Questions to the Panelists

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Airspace Integration & UTM
Additional Slides

Key Factors (1/2)

- Integration with existing aviation
  - Required with traditional traffic, drones (UTM) and other new entrants
- Intent sharing
  - Paramount for deconfliction at all levels
    - Strategic, tactical, (collision avoidance)
    - Both pre-flight and in-flight
- ConOps
  - Developed all over world, suggesting new airspace structures, roles and responsibilities
  - Some elements need harmonization (in particular at high-level, but allowing for regional adaptations)

Key Factors (2/2)

- Navigation and surveillance
  - Availability, accuracy and reliability are key
    - Radar coverage inadequate for low altitude
    - Low level weather and radar are not readily available
    - Cellular network/GPS availability and accuracy might be inadequate
- Separation minima
  - Separation minima need to be defined for UAM-UAM, UAM-UTM and UAM-Traditional traffic
  - eVTOL(air taxi) performance capabilities will likely dictate separation minima
  - Traffic density will depend on separation minima (but not only)
- Regulations
  - UAM vehicles can operate under current day VFR rules and regulations.
  - New regulations might be required for establishing new airspace structures, procedures for UAM operations to make them scalable