National Aeronautics and Space Administration

Intermediate State UAM Vision Concept of Operations (ConOps) Overview

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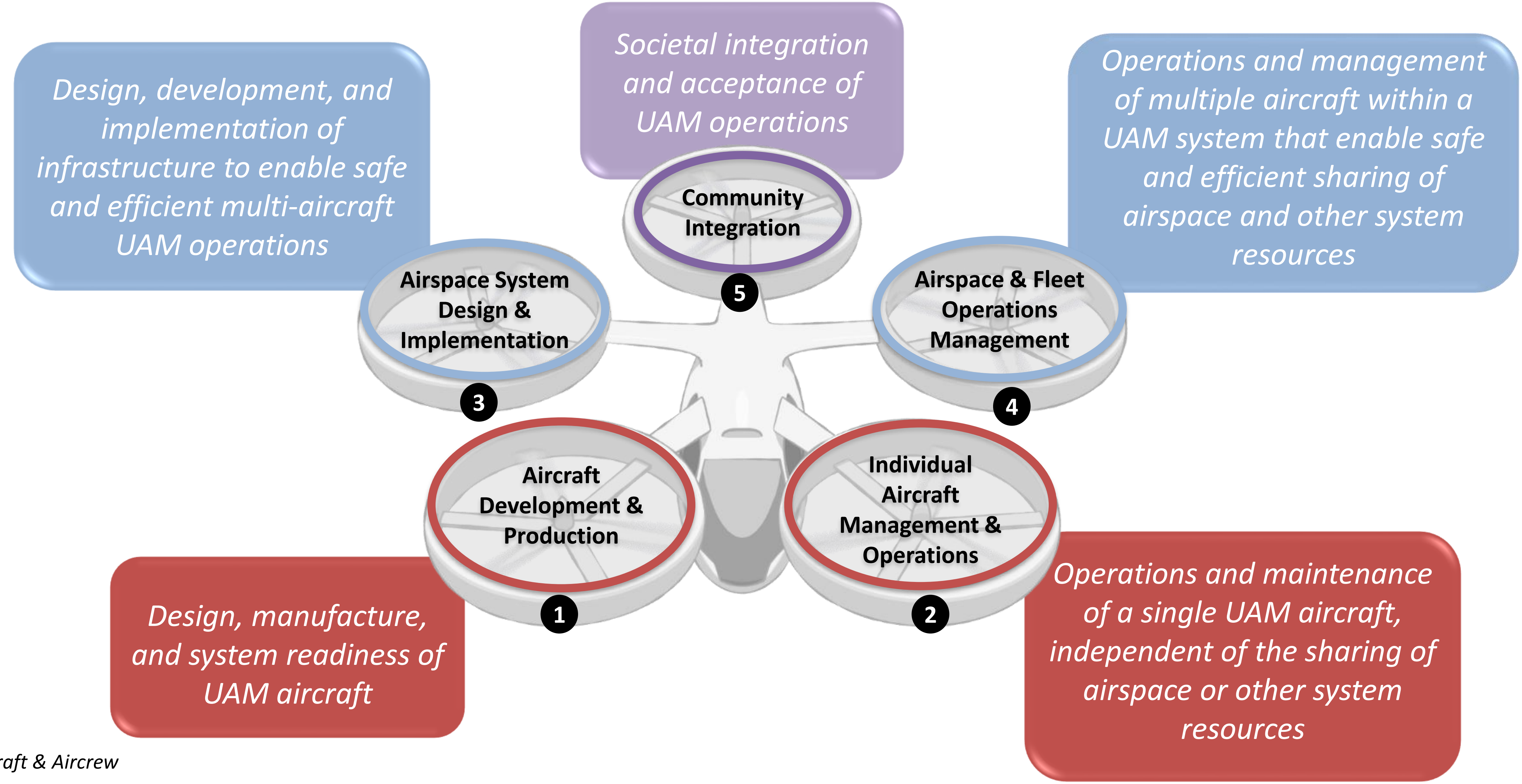
NASA

Download the full Vision ConOps at https://ntrs.nasa.gov/citations/20205011091

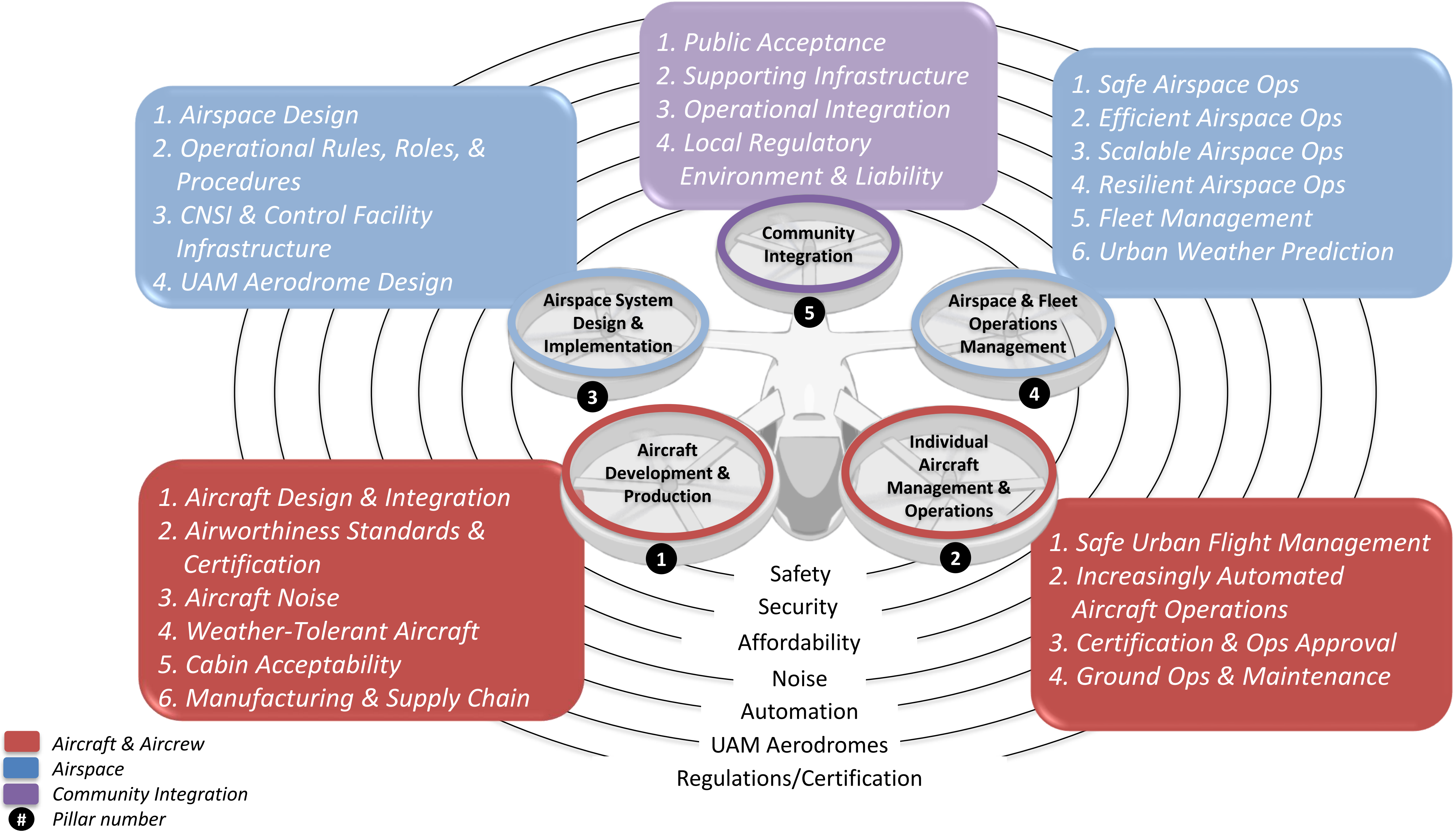
Feb 9, 2021

Background: UAM Organizational Framework



Aircraft & Aircrew
Airspace
Community Integration
\# *Pillar number*

Background: UAM Organizational Framework and Barriers



Background: UAM Maturity Levels (UMLs)

UAM Organizational Framework and Barriers

- Aircraft Development & Production
- Individual Aircraft Management & Ops
- Airspace System Design & Implementation
- Airspace & Fleet Ops Management
- Community Integration

INITIAL STATE

UML-1

- **Late-Stage Certification Testing and Operational Demonstrations in Limited Environments**
  - Aircraft certification testing and operational evaluations with conforming prototypes; procedural and technology innovation supporting future airspace operations (e.g., UTM-inspired); community/market demonstrations and data collection

UML-2

- **Low Density and Complexity Commercial Operations with Assistive Automation**
  - Type-certified aircraft; initial Part 135 operation approvals; limited markets with favorable weather and regulation; small UAM network serving urban periphery; UAM routes supporting self-managed operations through controlled airspace

INTERMEDIATE STATE

UML-3

- **Low Density, Medium Complexity Operations with Comprehensive Safety Assurance Automation**
  - Operations include urban core; operational validation of advanced airspace operations & management, including 3rd party provided ATM services, CNSI, C^2, & automation for scalable, weather-tolerant operations; few high-capacity aerodromes; noise compatible w/ urban soundscape; model local regulations

UML-4

- **Medium Density and Complexity Operations with Collaborative and Responsible Automated Systems**
  - 100s of simultaneous operations; expanded networks including closely-spaced high throughput UAM aerodromes; many federated ATM services available, simplified vehicle operations for credit; low-visibility operations

MATURE STATE

UML-5

- **High Density and Complexity Operations with Highly-Integrated Automated Networks**
  - 1,000s of simultaneous operations; large-scale, highly-distributed networks; high-density, federated ATM; autonomous aircraft and remote, M:N fleet management; high-weather tolerance including icing; high-volume manufacturing

UML-6

- **Ubiquitous UAM Operations with System-Wide Automated Optimization**
  - 10,000s of simultaneous operations (capacity limited by physical infrastructure); ad hoc landing sites; noise compatible with suburban/rural operations; private ownership & operation models enabled; societal expectation

Scope

- “Vision ConOps”
  - Generalized vision of the future with UAM
  - Broad, covering all 5 pillars of the organizational framework
  - Only implies a high-level operational construct
    - Does not dictate specific engineering details
    - Some specifics provided as *examples*
- Focused on intermediate state operations
  - UAM Maturity Level (UML) 4
  - 100s of aircraft aloft simultaneously over one metro area
  - “Medium complexity” operations, including ops. in IMC to/from closely spaced UAM aerodromes
  - Collaborative and responsible automated systems
- ConOps is generally agnostic to aircraft type and business models

Key Assumptions and Actors

Assumptions:

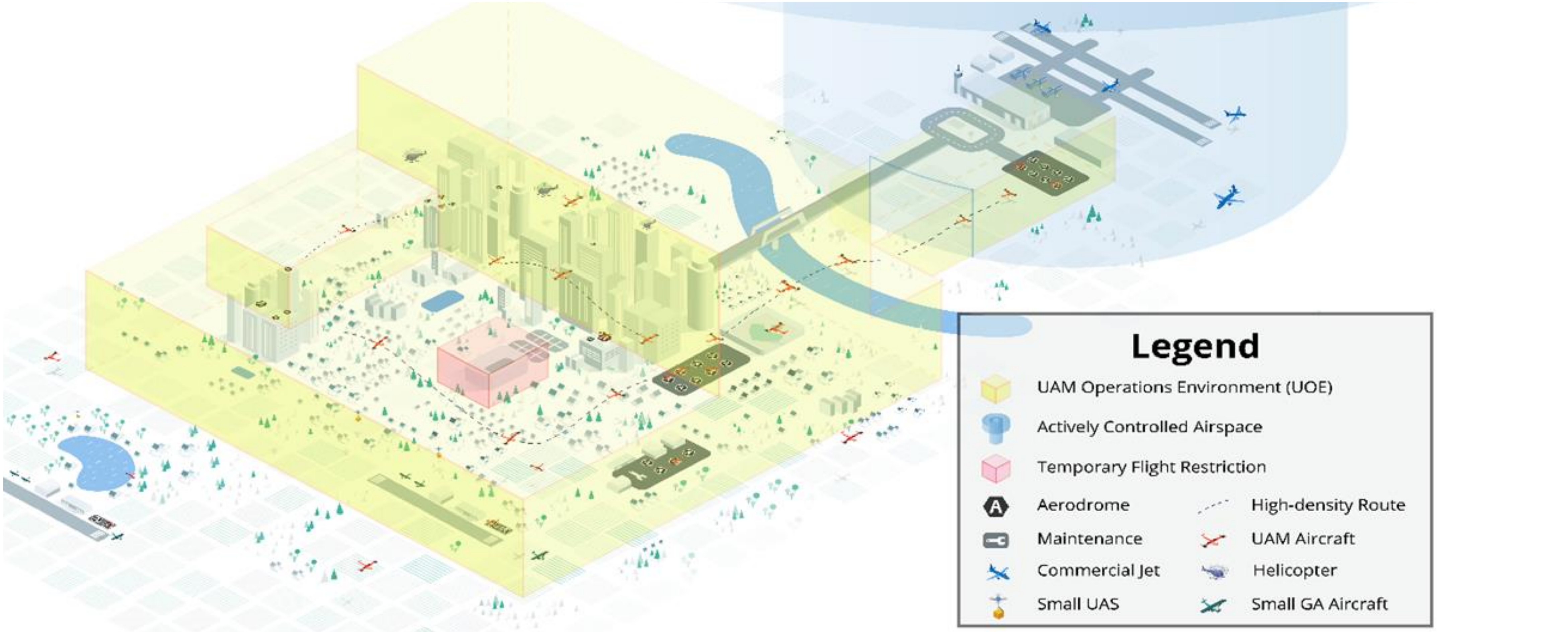
- Operations occurring in the U.S. national airspace system
- Nominal operations begin and end from designated takeoff and landing areas called "UAM aerodromes"
- Passenger-carrying focus (though concepts are generally applicable to cargo transport or aerial work missions)
- UAM is a part of an intermodal transportation system
- New or modified flight rules‡ (existing limits with VFR and IFR are incongruous with UML-4)
- Many potential types of aircraft could perform UAM missions
- Aircraft equipped with detect-and-avoid systems

Actors:

- Fleet Operator:
  - Entity responsible for operational control of UAM aircraft and fleet operations.
  - Fleet operators may have responsibility for only a single aircraft or many.
  - Examples include an individual who owns and operates his/her own single aircraft and organizations operating a fleet of multiple aircraft for commercial use
- Provider of Services to UAM (PSU):
  - Analogous to a UTM Service Supplier (USS), a PSU provides services to UAM aircraft that support operations, including being a primary means of enabling communication among actors in the UAM system.
  - A fleet operator may also be a PSU.
- Supplemental Data Service Providers (SDSPs):
  - Service providers other than PSUs that provide services that support operational decisions
  - Services can be safety-critical or optional and qualification may be required
- Aircraft Crew:
  - Human or humans who are partially responsible for the safe flight of an aircraft, sharing this responsibility with some automated system(s).
  - Aircraft crew members are not traditional pilots, but perform some of the same functions that pilots perform today, sharing the remainder with automation or other aircraft crew members
- UAM Aerodrome Operator:
  - Entity responsible for ensuring the safety of individual takeoff and landing areas and ground services (embarkation, disembarkation, maintenance, etc.) provided at a UAM aerodrome

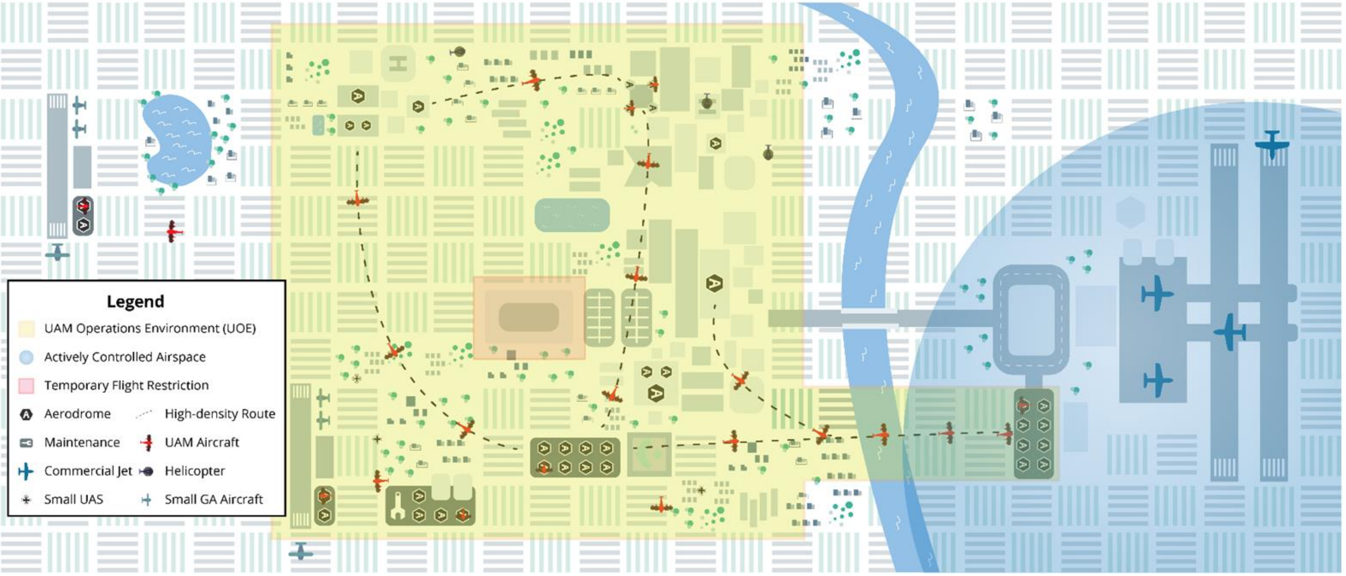
‡For example, digital flight rules: https://ntrs.nasa.gov/citations/20205008308

Airspace System Design: The UAM Operations Environment (UOE)



- Area of airspace encompassing the highest volume of UAM air traffic
- New or modified flight rules and procedures in UOE to enable higher-density operations without burdening existing air traffic control

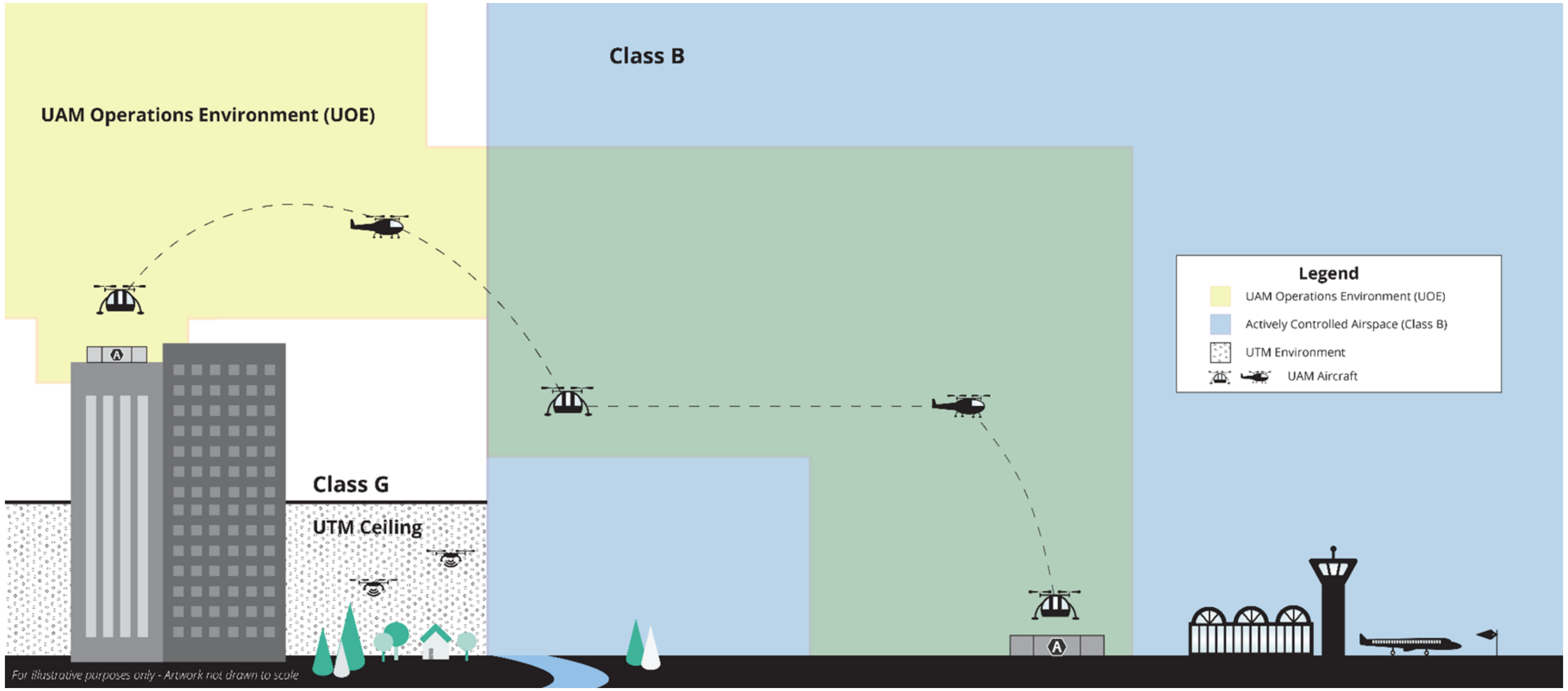
Airspace System Design: The UAM Operations Environment (UOE)



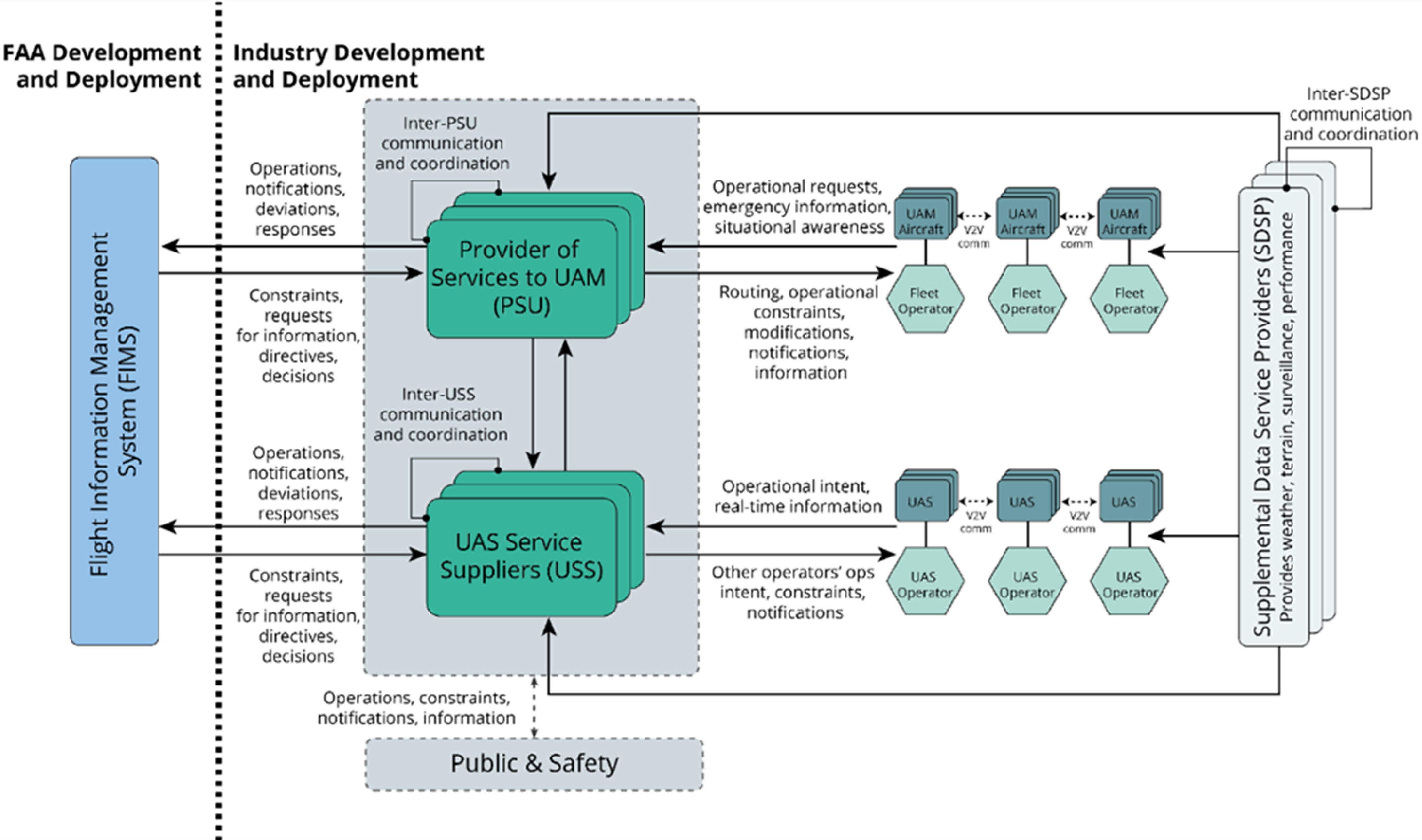
*For illustrative purposes only. Artwork not drawn to scale

- UOE can exist in all airspace classes (except Class A)
- Maximal UOE extent fixed, but available UOE extent "flexible"
  - E.g., a portion of the UOE may become unavailable due to a flow pattern change at a nearby major airport

- UTM Environment is generally separate, though some potential for overlapping areas
- UOE not limited to only UAM aircraft, *but* aircraft must be able to safely participate in the management and separation of traffic in UOE
  - Must file operations plan
  - Other potential options: connection with PSU, minimum equipage and/or performance requirements



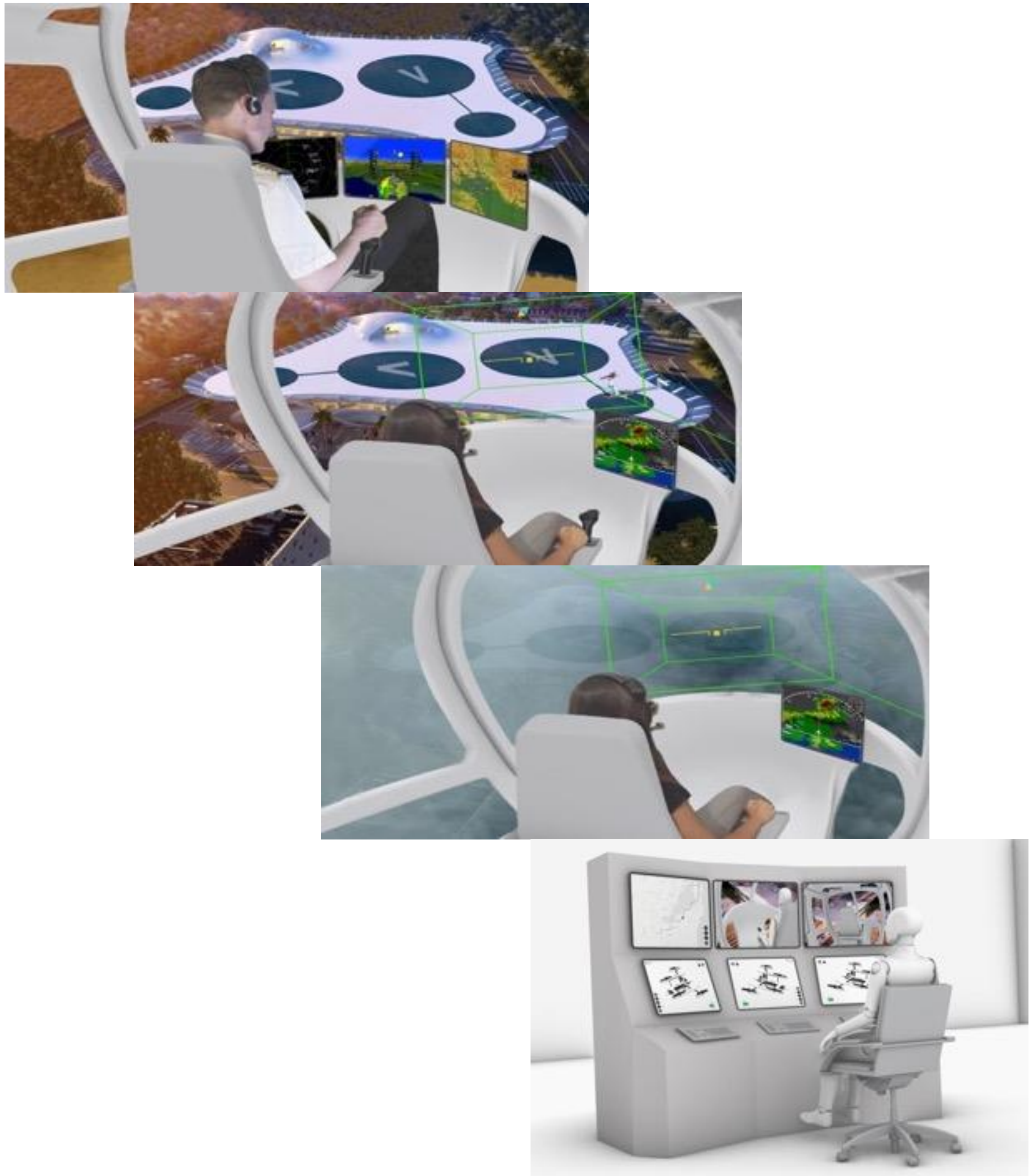
Airspace & Fleet Operations Management: Communications Architecture



Individual Aircraft Operations: “Piloting”

- Each aircraft has an individual human as pilot in command (PIC)
  - PIC may be onboard or remote (RPIC)
  - One human may be PIC for more than one aircraft
  - PIC may change during a flight

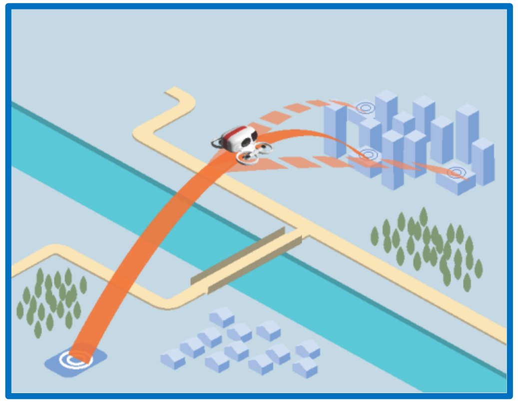
- ConOps assumes aircraft with various forms of “piloting” will be operating simultaneously
  - Enabled/supported by increased levels of automation as compared to today
  - Traditional expert human pilots not excluded, but aircraft crew roles emphasized
  - 3 example aircraft crew archetypes provided:
    - Onboard PIC with no additional crew
    - Single-aircraft RPIC with no additional crew
    - Multi-aircraft RPIC with onboard SIC



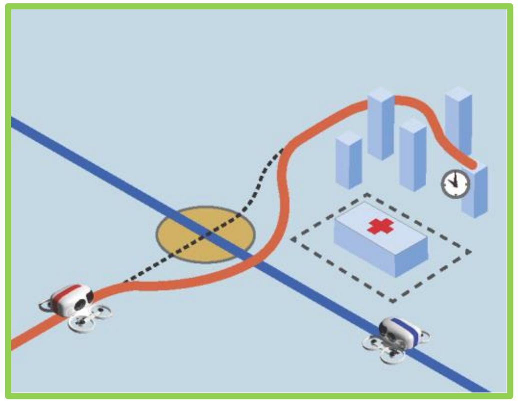
Functional Categorization of In-Flight Aircraft Operations

1) Mission Management: Planning and revising the overall mission, such as setting or changing a destination UAM aerodrome.

Mission Management



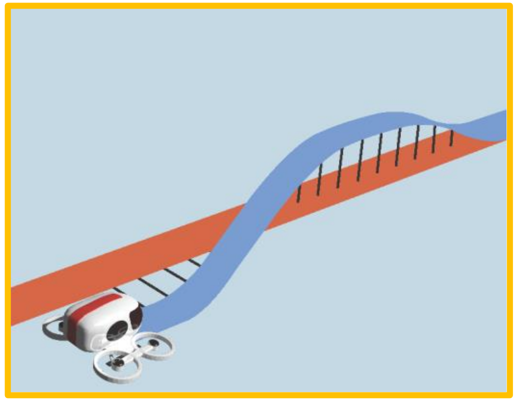
Flight Path Management



2) Flightpath Management: Setting and revising the aircraft's flightpath to achieve the mission in an effective way.

4) Aircraft Control: Controlling the physical motions and actions of the aircraft such that the aircraft remains in a safe state

Aircraft Control



Tactical Operations

3) Tactical Operations: Making modifications to the aircraft's projected flightpath or state to ensure the safety of the aircraft in the short-term, typically in response to an unanticipated hazard, which generally ignores the overall mission objective until a safe state is restored.

Original Source: Wing et al., AIAA-2020-2915, https://ntrs.nasa.gov/citations/20205000771

Exemplar Aircraft Crew Archetypes

- Three piloting "archetypes" provided as examples with responsibility delineations given for passenger/cabin management and four categories of flight management functionality

P – Primary
S – Secondary
T – Tertiary
F – Full
A – Advisory
N – None

		Archetype 1: Single Onboard PIC		Archetype 2: Single-Aircraft RPIC with No Additional Crew		Archetype 3: Multi-Aircraft RPIC with Onboard SIC		
		Automation	PIC	Automation	RPIC	Automation	RPIC	SIC
Mission Management	• Verification of operations plan from fleet operator	**P**	S	**P**	S	**P**	S	T
	• Maintenance of "standard" contingency plans	**P**	S	**P**	S	**P**	S	N
	• Oversight of overall mission continuation	S	**P**	S	**P**	S	**P**	T
Flight Path Management	• Monitoring of active operations plan • Optimization of active operations plan	**P**	S	**P**	S	**P**	S	T
Tactical Operations	• Detection of tactical hazards	**P**	S	**F**	N	**F**	N	N
	• Maneuver management for mitigation of tactical hazards	S	**P**	**P**	S	**P**	T	S
Aircraft Control	• Aircraft stability and trajectory control • Subsystem management	**F**	N	**F**	N	**F**	N	N
Passenger/ Cabin Management		A	**F**	**P**	S	A	N	**F**

Aircraft Development and Production

- Although airspace and operational constructs must accommodate a wide variety of aircraft, it is envisioned there will be new aircraft tailored to UAM missions, including:
  - Lower operating costs & noise signatures than today
  - (Distributed) electric propulsion systems
  - Electric and hybrid-electric vertical takeoff and landing aircraft
  - Specific considerations for safe, passenger-friendly design in low-altitude, urban operations
  - Some aircraft designed for unique characteristics of specific markets in which they operate (e.g., Denver’s altitude, Phoenix’s temperature)
- Certification standards and means of compliance for novel aspects of aircraft in place and harmonized internationally
- Advanced manufacturing and supply chain management techniques enable higher production volumes than seen in aviation today

Community Integration

- Public Acceptance
  - To reach UML-4, UAM must be shown to provide benefits to those who utilize it (e.g., time savings) as well as the broader public (e.g., job creation) while maintaining high levels of actual and perceived safety
  - Environmental and community concerns are addressed through multiple means, such as effective community engagement, system designs, and operational mitigations
- Supporting Infrastructure
  - Envision a spectrum of ownership models for UAM aerodromes from public to private
  - UAM aerodromes include purpose-built infrastructure as well as modified/repurposed infrastructure
  - Electrical grid expanded to support all-electric aircraft
- Operational integration
  - UAM integrated into the transportation systems of metro areas (e.g., by co-locating UAM aerodromes with other transportation infrastructure) enabling seamless intermodal transportation for passengers
  - Impacts from disruptions in one mode can be lessened by shifting of trips to other modes
- Local Regulatory Environment & Liability
  - Local regulations/ordinances can play a large role in UAM operations due to the proximity of operations to where people live and work (e.g., noise and zoning ordinances)
  - Efforts envisioned to be made to help harmonize regulations/ordinances nationwide to avoid a patchwork of disparate rules

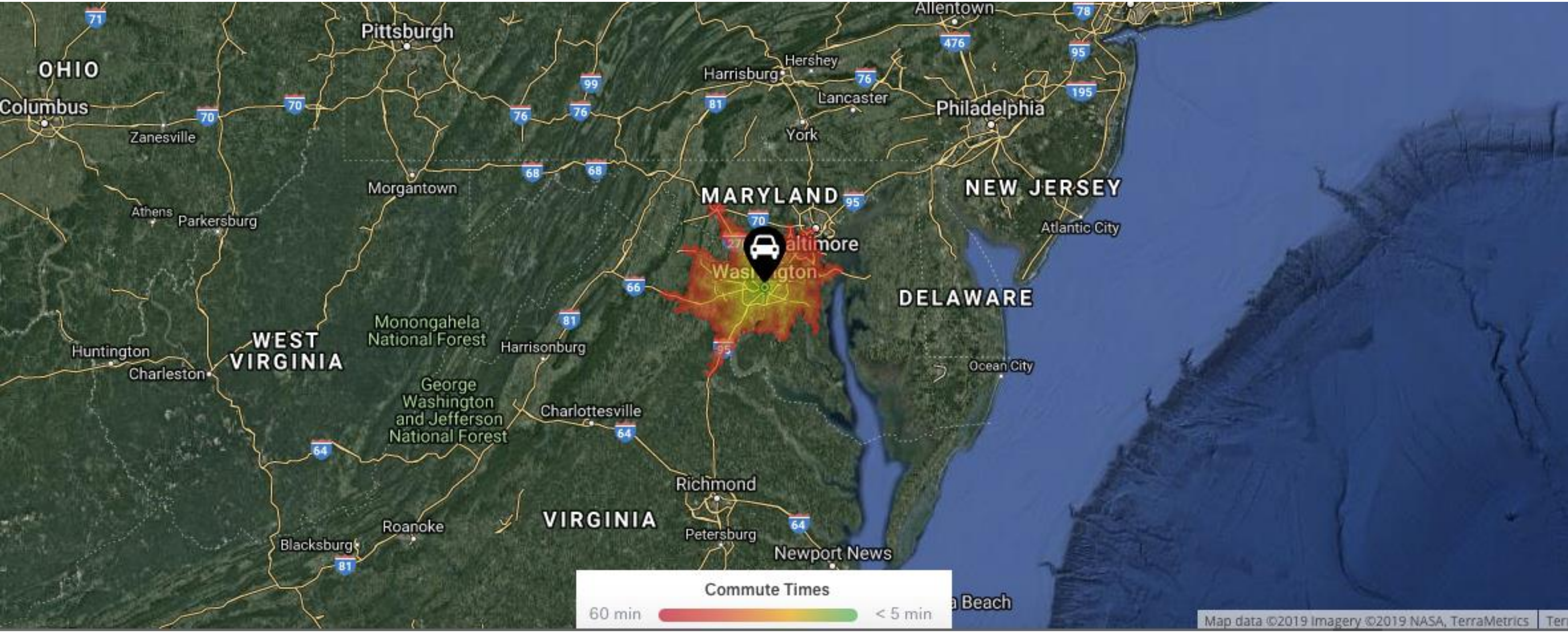
National Aeronautics and Space Administration

Questions / Discussion

Download the full Vision ConOps at https://ntrs.nasa.gov/citations/20205011091

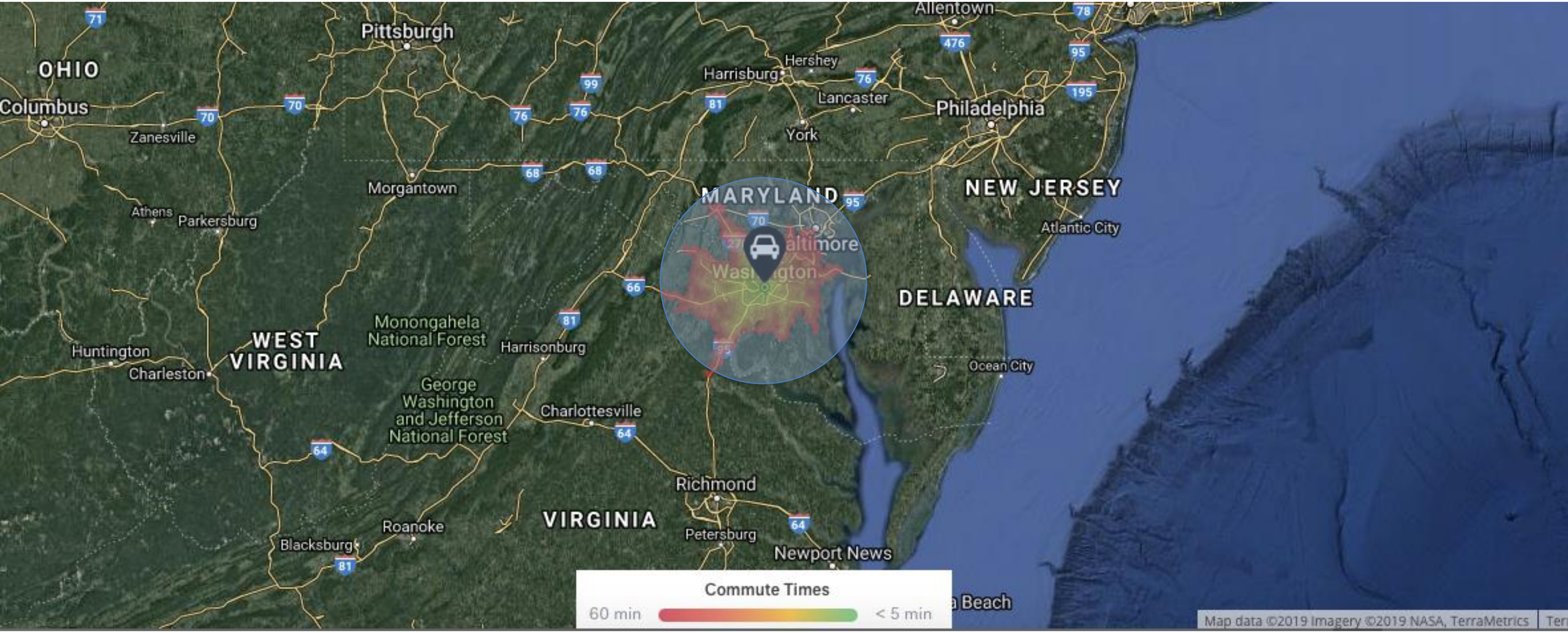
Download an AIAA SciTech 2021 Paper discussing the ConOps at https://ntrs.nasa.gov/citations/20205010104 or https://arc.aiaa.org/doi/10.2514/6.2021-1626

Urban Air Mobility Example: Aerial Reach from DC



24 hr weighted average
60 minute driving commute

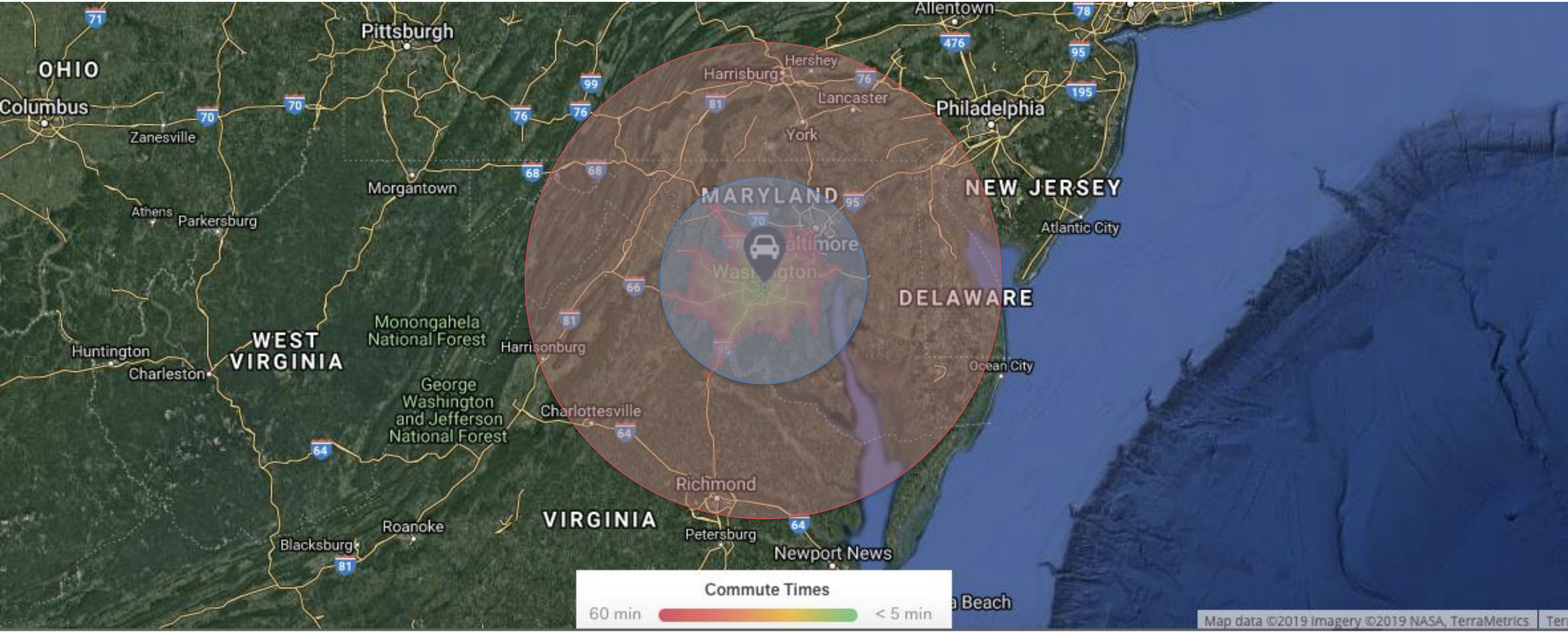
Urban Air Mobility Example: Aerial Reach from DC



24 hr weighted average
60 minute driving commute

Any time of day
~30 minute total commute
(~40 mi radius)

Urban Air Mobility Example: Aerial Reach from DC



24 hr weighted average
60 minute driving commute

Any time of day
~30 minute total commute
(~40 mi radius)

Any time of day
~60 minute total commute
(~100 mi radius)

Functional Categorization of In-Flight Aircraft Operations

Monitor pilot, passengers, aircraft, powerplant, energy storage, systems, comms, automation, weather, destination, alternates, ATM events, …

Respond to changes that may affect mission feasibility, renegotiating arrival slot, selecting best alternate, executing diversion, …

Learn from unexpected impacts to mission and make operational changes to avoid repeats or mission setbacks, …

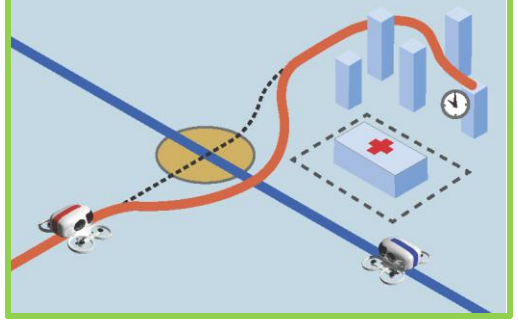
Anticipate conditions throughout remainder of mission, develop contingency plans, risk mitigation plans, …

Mission Management

Monitor / revise the mission as needed

Flight Path Management

Achieve the mission in the most effective way



Monitor traffic, weather, hazards, airspace restrictions, flightpath constraints, savings opportunities, mission parameter changes, ...

Respond by modifying flight path, altitude, or speed to resolve conflicts, apply rules, coordinate route changes, meet constraints, optimize flightpaths, …

Learn from unexpected encounters by adjusting strategies, adding buffers, sharing information, …

Anticipate future events by modeling uncertainties, pre-clearing maneuvers, avoiding risky airspace, preserving trajectory flexibility, …

Monitor guidance and control systems, conformance to stable flight, navigation performance, flight envelope excursions, …

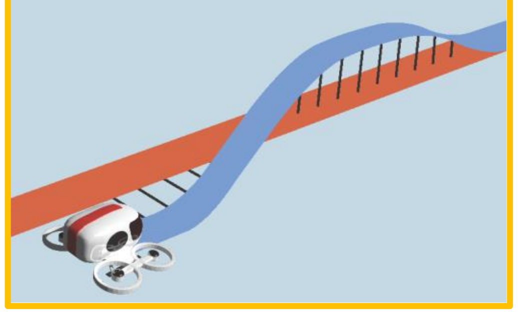
Respond to flight deviations with appropriate controls for condition of aircraft, recover from disturbances, …

Learn from flight behavior deviations; invoke or generate adaptive control laws, modify performance data, …

Anticipate aircraft performance deviations early, preemptively mitigate non-participant casualty risk, …

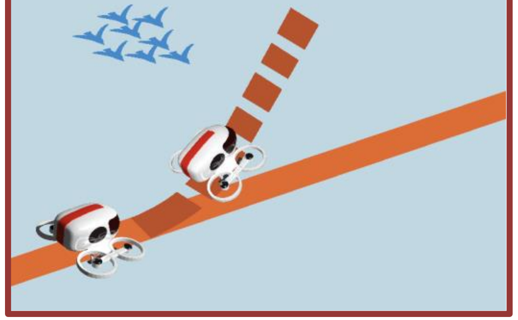
Aircraft Control

Accurately fly the mission and safely land the aircraft



Tactical Operations

Ignore the mission until safety is restored



Monitor state and hazard data sources, onboard reactive systems, sudden threats, penetration, proximity, landing site suitability, …

Respond by executing escapes, prioritizing constraints, coordinating maneuvers, regaining separation, recovering to plan

Learn from traffic behavior relative to rules, change tactics as needed based on behavior, …

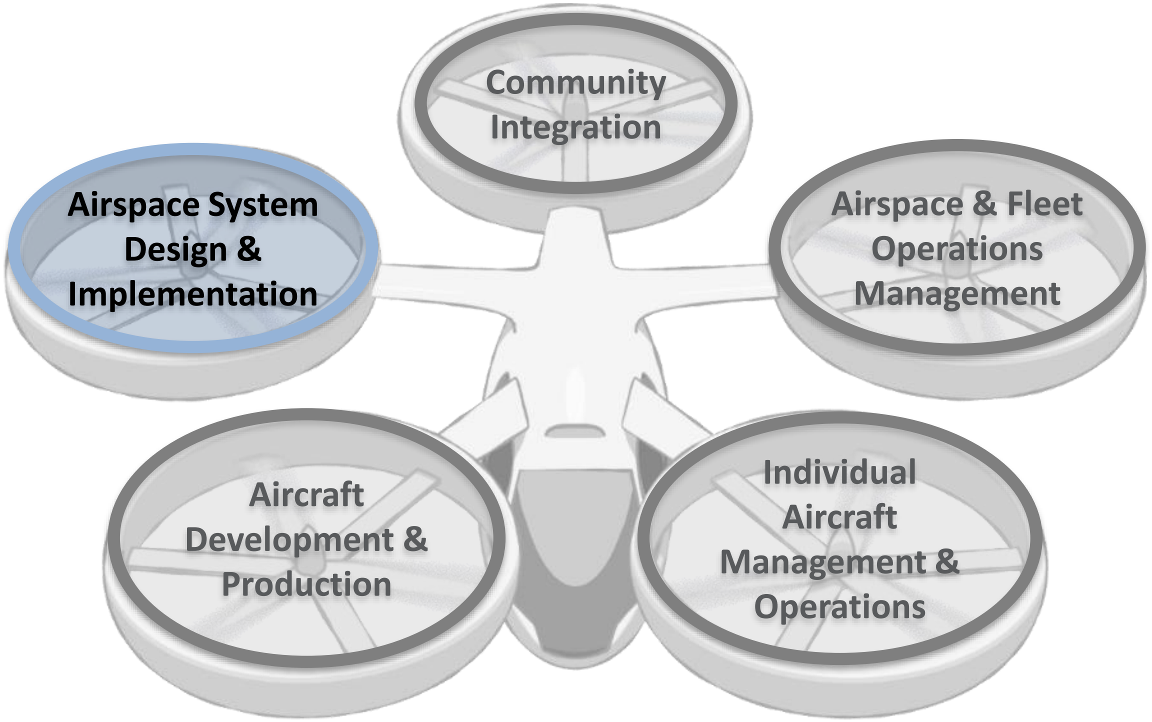
Anticipate traffic blunders, apply maneuver rules to enhance own predictability, …

Applying the Principles of Resilience Engineering: Monitor, Respond, Learn, and Anticipate

Source: Wing et al., AIAA-2020-2915, https://ntrs.nasa.gov/citations/20205000771

Airspace System Design & Implementation

Scope and Focus



Design, regulate, and manage the airspace and supporting ground facilities to enable safe, efficient, and reliable UAM flights in and around metropolitan areas.

Barriers

- Airspace Design
- Operational Rules, Roles, & Procedures
- CNSI & Control Facility Infrastructure
- Aerodrome Design

Airspace System Design & Implementation

Barrier: Airspace Design

Develop a practical, feasible, flexible, scalable, implementable, and equitable airspace design and implementation for UAM operations that includes the simultaneous operation of diverse missions and aircraft types (e.g., piloted, autonomous, VTOL, STOL, sUAS) and the placement of aerodromes to that takes into account community concerns such as noise and privacy , and consideration for cumulative fleet emissions (e.g., noise, CO2) over local communities.

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- UAM aircraft in the UOE **operate in metropolitan areas extending out to the urban periphery.**
- Each UOE area is **tailored to the unique characteristics** of the metropolitan area in which it exists and can be **dynamically adjusted** based on FAA criteria.
- The UOE is not a class of airspace itself but **exists within other classes of airspace** (B, C, D, E, and G). Fleet **operators** need to **meet the applicable** airspace requirements and **UOE requirements** to operate where UOE exists.
- UOE is **managed by Providers of Service to UAM (PSU)** through a federated architecture and ATC is aware of UAM operations where there is a possible safety impact on manned traffic.
- To enable high volumes of operations, **UOE is designed to include dynamic, demand-based, high-density routes** for aircraft meeting the performance requirements of the route.
- Redundant emergency landing locations exist for off-nominal events.

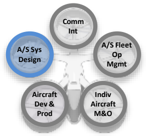
Areas with Remaining Unknowns

Scalability

UOE Requirements

Extensions into Actively-controlled Airspace

Emergency Landing Site Locations



Airspace System Design & Implementation

Barrier: Operational Rules, Roles, and Procedures

Develop operating rules, roles, procedures and airspace management Concepts of Operation that enable safe and efficient operations and are compatible with urban environments, scalable operations, interoperability, and operations in moderately poor weather operations.

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- **Provider of Services to UAM (PSU)** – Flight operations are managed and coordinated by PSUs, which are industry or public sector entities that supply flight safety services under FAA's regulatory and operational authority to supplement and integrate with manned ATC.
  - PSUs deliver flight planning, communications, and aide in separation along with onboard aircraft sensors. PSUs also ensure there is a common understanding and "picture" amongst PSUs to enable cooperative traffic management.
- **PSU Network** – The amalgamation of PSUs connected to each other and exchanging information. Each PSU is required to share certain information with the other PSUs to provide a complete operating picture and situational awareness.
- **Supplementary Data Service Providers (SDSP)** – SDSPs provide support services to enable UAM operations and may or may not be safety critical.
- **Fleet Operators** – The fleet operator of the aircraft who hires the aircraft crew (if the aircraft fleet operator is not also the aircraft crew) and in some instances performs dispatch duties. A fleet may consist of one aircraft.
- **Aircraft Crew** – Aircrafts have a crew consisting or one or more humans who share responsibility for the safety of the flight along with automated systems. This aircraft crew may be on the aircraft or controlling it remotely.
- **Aerodrome Operators** – Aerodrome operators are entities responsible for ensuring the safety of individual takeoff and landing areas, as well as any ground services (embarkation, disembarkation, maintenance, etc.) provided at an aerodrome.

Areas with Remaining Unknowns

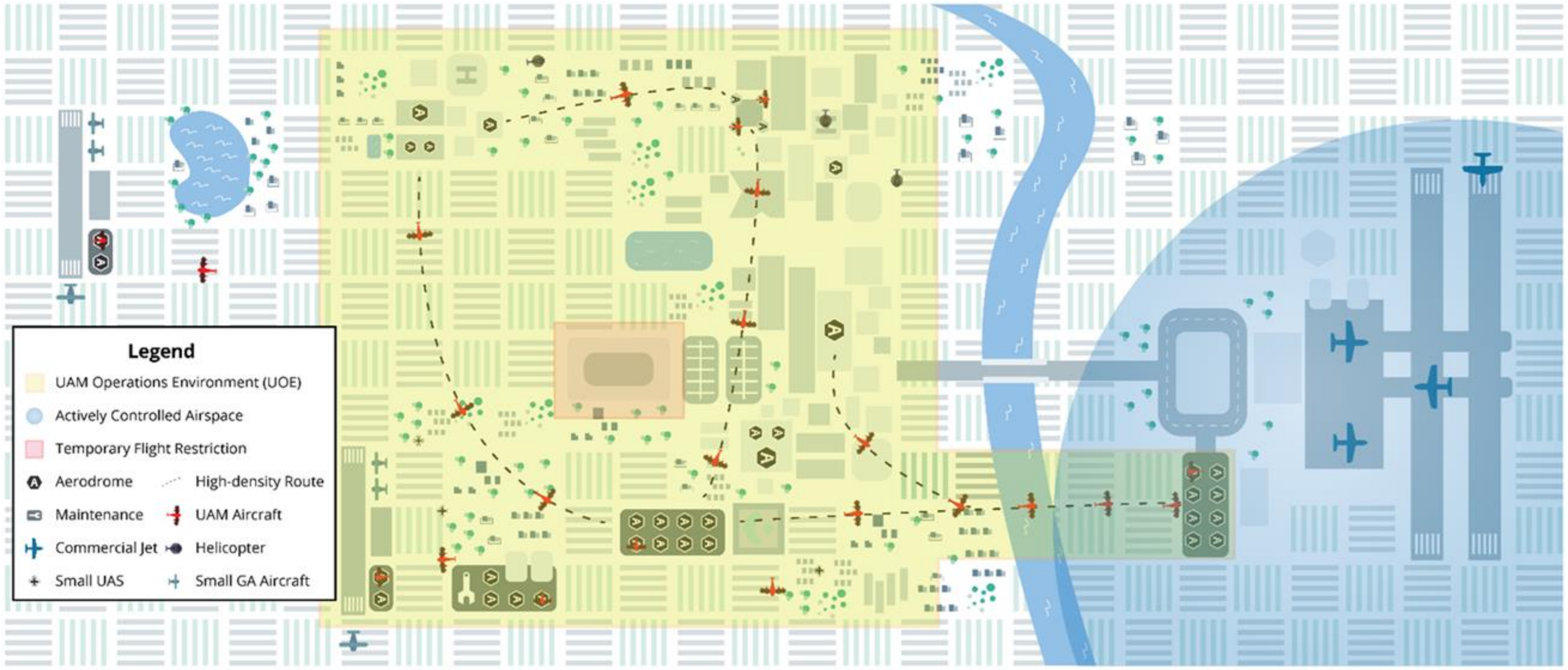
Negotiation Between PSUs	Single-PSU Regions	Impact of Dynamic Airspace Management on ATC Workload	Role of Aircraft Crew	Information-sharing Mechanism

UAM Operating Environment

Operational Isometric View

UAM Operating Environment

Operational Top View



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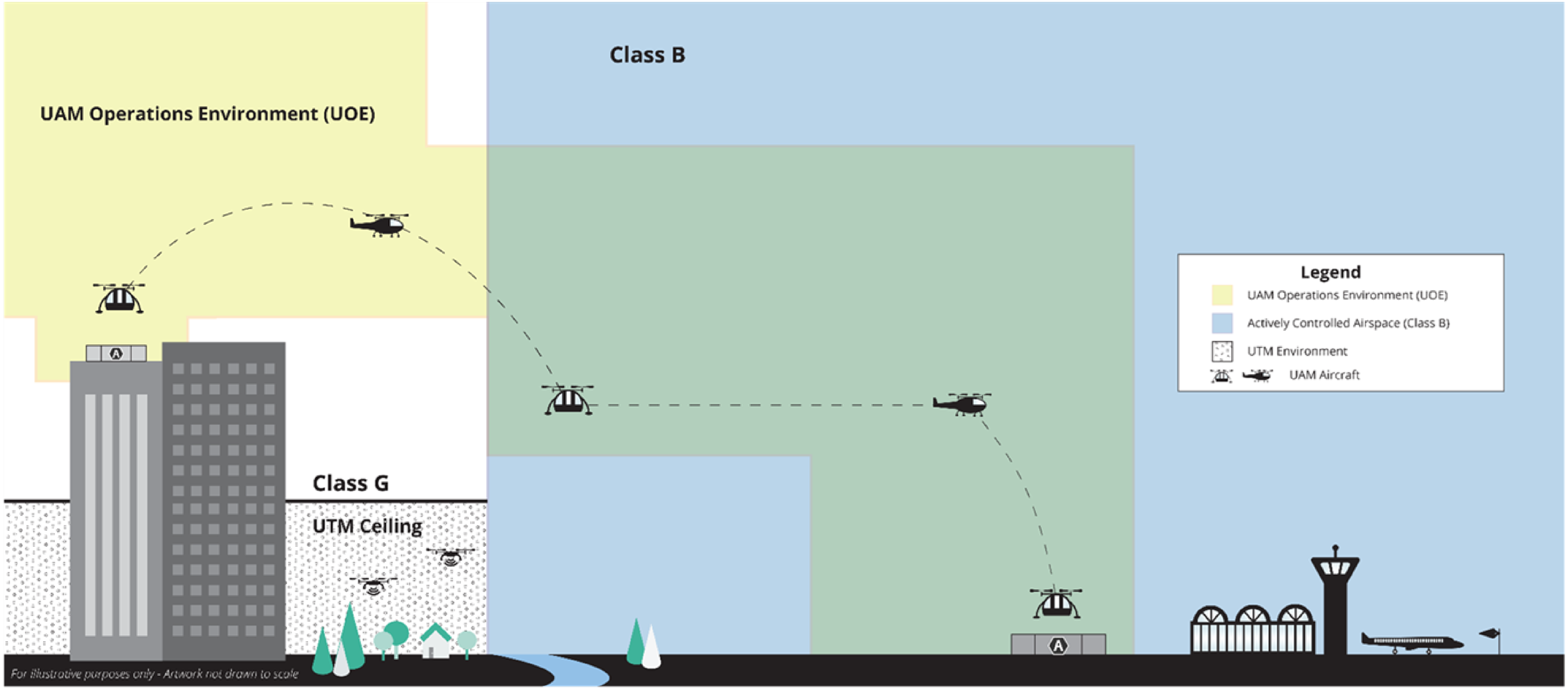
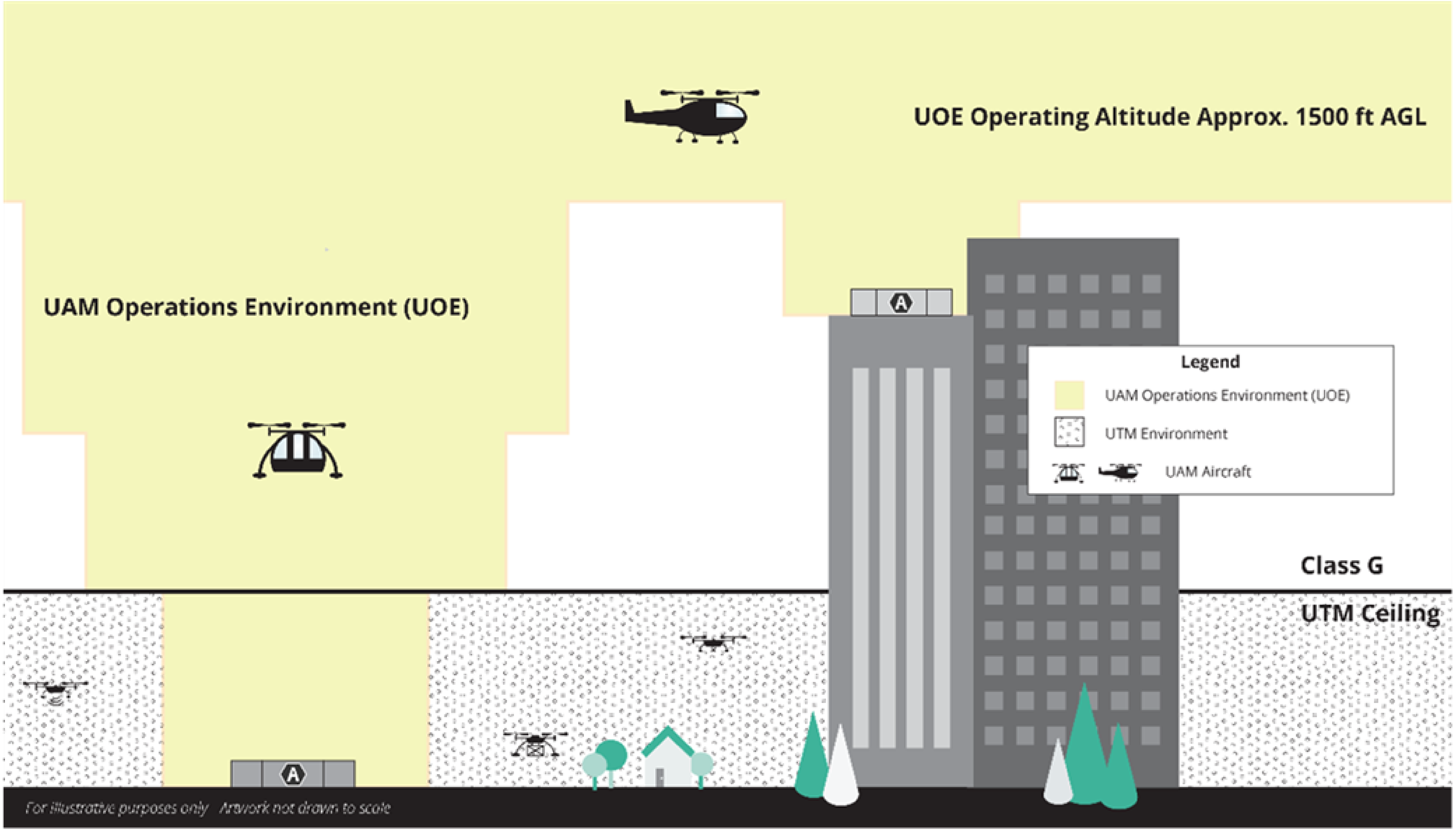
UAM Operating Environment

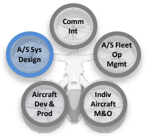
Operational Side View – Entry to Controlled Airspace



UAM Operating Environment

Operational Side View – UAM Aerodromes





Airspace System Design & Implementation

Barrier: CNSI & Control Facility Infrastructure

Develop and implement in an economically viable manner sufficient, resilient, and secure communication, navigation, surveillance, information (CNSI) and control facility infrastructure, including spectrally-efficient communication links; navigation services including but not limited to GPS; weather surveillance near the ground with high resolution; ability to account for non-cooperative aircrafts; and functionality in urban canyons.

NASA Vision ConOps

- **Communication** – Fleet operators maintain communication with PSUs and UAM aircrafts (vehicle-to-vehicle) in compliance with performance criteria and regulatory requirements to support data exchange required for safe operations. If the aircraft crew is off-board the aircraft, that person has the capability of communicating with ATC and controlling the aircraft to comply with ATC instructions.
- **Information** – Secure information exchange enables vehicle-to-vehicle and aircraft-to-infrastructure communication for data exchange, aircraft separation, and navigation.
- **Navigation** – Performance-based navigation (or future performance-based navigation-like) requirements enable dynamic precision trajectory-based operations (TBO), even in visibility-restricted conditions.
- **Surveillance** – UAM CNSI operations are supported by a range of ground, aircraft-borne, and satellite-based infrastructure. While this surveillance information will be utilized by PSUs, it is also anticipated that in some cases direct information exchange can occur between aircrafts and between ground/satellite infrastructure to enable aircraft and hazard surveillance by fleet operators and FAA.
- **Cybersecurity** – Requirements for secure communication between elements of the PSU Network, the aircraft, and aircraft subsystems ensure secure information exchange and prevent unauthorized intrusion.

Areas with Remaining Unknowns

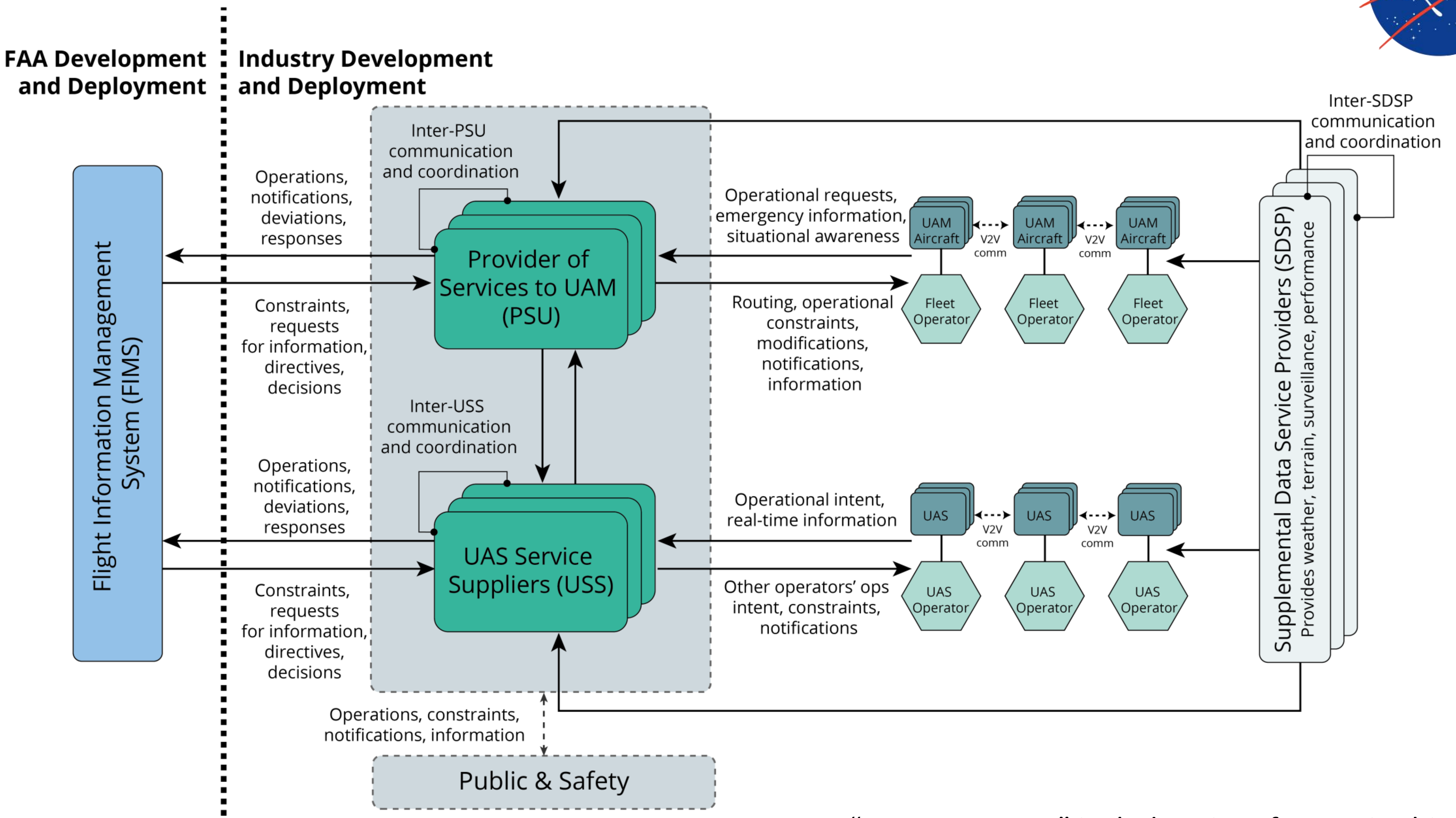
On-board Aircraft Situational Awareness

Sensors Required

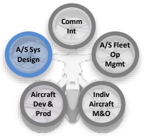
Cybersecurity Requirements

Available Spectrum

UAM Communications Networks



"UAM Operator" includes aircraft crew in this diagram



Airspace System Design & Implementation

Barrier: Aerodrome Design

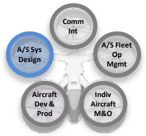
Develop an understanding of and guidelines for the optimal aerodrome design and procedures to support the anticipated number of operations, including safe handling of contingency situations, consideration of the impact on local communities, and the development of design standards.

NASA Vision ConOps

- Aerodrome **locations are strongly influenced by current and future** anticipated demand.
- **Citizens as well as businesses have significant input** on aerodrome locations as part of the public planning processes.
- Zoning **ordinances and existing infrastructure can constrain aerodrome locations**.
- Aerodromes reflect their **environmental constraints** including both the climate and the constraints of the specific site.
- When planning approach and departure paths, **fleet operators plan for trajectories that minimize the impact** on local communities.
- Aerodromes in **urban areas contain limited maintenance** and repair services **while aerodromes outside urban centers** are designed for **expanded aircraft services** such as aircraft storage, major repair and overhaul facilities, and serve as intermodal hubs.
- Aerodrome design includes **adequate physical security** features to ensure safe and secure operations.

Areas with Remaining Unknowns

Aerodrome Energy Infrastructure	Aerodrome Design Standards	Repurposing Existing Buildings v. Greenfield Construction	Minimum Aerodrome Facilities

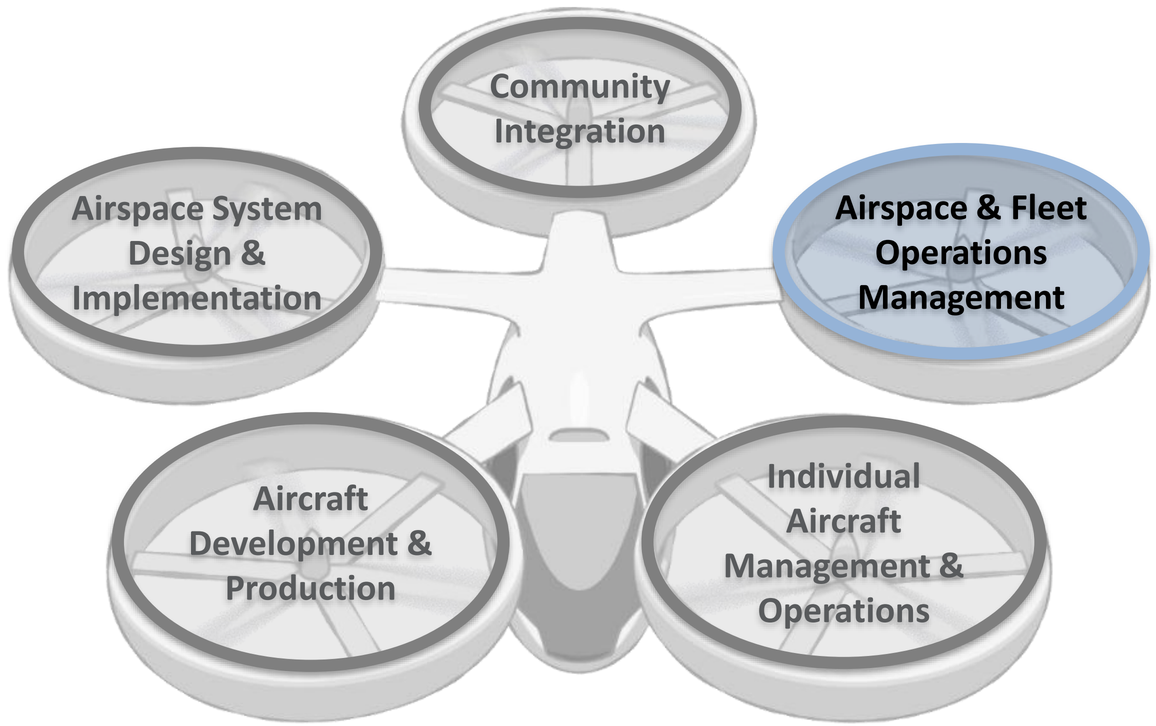


Airspace System Design & Implementation

Unknowns	Key Issues for Further Exploration
Scalability	How can the UOE be designed for scalability to enable a high throughput of operations and a variety of aircraft technologies?
Extensions into Actively-controlled Airspace	Extensions of the UOE into ATC-controlled airspace–how will they be defined and how will they function?
Single-PSU Regions	Will the U4-PSU be layered in a geographic region? Or will they be segmented to accommodate specific geographic regions?
Impact of Dynamic Airspace Management on ATC Workload	Will the FAA’s ability to dynamically alter airspace in the UOE increase ATC workload?
Role of Aircraft Crew	What is the role of the human aircraft crew (onboard or offboard)? What is the division of labor between automation and human? If no human aircraft crew is necessary, how is safe flight achieved?
On-board Aircraft Situational Awareness	What performance capabilities are required for aircraft situational awareness?
Sensors Required	Which sensors will be required equipage to operate in the UOE? Which other sensors will be potentially useful, but not necessarily required?
Available Spectrum	How will spectrum requirements for UML-4 be met?
Aerodrome Energy Infrastructure	What energy infrastructure is necessary at aerodromes to enable UML-4 operations?

Airspace & Fleet Operations Management

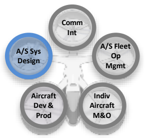
Scope and Focus



Provide airspace operations management services as well as fleet operations management services that ensure safe, efficient, scalable, and resilient UAM operations in and around metropolitan areas.

Barriers

- Safe Airspace Operations
- Efficient Airspace Operations
- Scalable Airspace Operations
- Resilient Airspace Operations
- Fleet Management
- Urban Weather Prediction



Airspace & Fleet Operations Management

Barrier: Safe Airspace Operations

Develop and implement an airspace operations management system and the corresponding regulations and procedures that enable safe, secure, sustained, resilient, close-proximity, multi-aircraft operations in constrained, urban environments and allow for interoperability of diverse missions and aircraft types, including in off-nominal situations.

NASA Vision ConOps

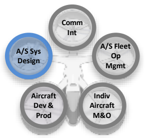
- PSUs provide **deconfliction** by exchanging data across the **PSU Network**. This dataset, with elements to be defined by industry consensus and approved by FAA, includes information such as **departure time**, **desired flight path**, **intended arrival destination**, and **alternate aerodromes**.
- PSUs provide **pre-flight strategic deconfliction**. **Tactical deconfliction** is largely provided by the aircraft, but with the support of the PSUs for **data exchange**.
- The **PSUs**, **DAA**, and **vehicle-to-vehicle** (V2V) information exchange together enable **tactical deconfliction** and **separation assurance** in nominal situations such as maintaining safe separation when following another aircraft or sequencing for landing.
- **Individual aircraft data** assessing both **internal** (aircraft speed, altitude, etc.) and **external environment** (weather, traffic, etc.) is shared via the PSU Network with PSUs and SDSPs. Data exchange across the network enables **inflight strategic deconfliction**.
- Due to the time constraints, **DAA** and potentially **aircraft crew** or **V2V** information exchange are the primary means of collision avoidance in situations where **response times need to be in seconds**, such as avoiding flocks of large birds.
- PSUs and other **safety-critical service suppliers** operating in the UOE are **qualified** by FAA based on standards developed and recommended by industry standards development organizations. Non-safety critical SDSPs may also operate on the PSU Network with **approval** of FAA.
- Entities **providing data** to or **accessing data** from the PSU Network adhere to appropriate **data authentication** and **cybersecurity** standards.
- **Streamlined processes** exist to refine and improve standardized operations and procedures to **continually enhance safety** of UAM operations.

Areas with Remaining Unknowns

Industry Safety Standards

Handling Non-cooperative Aircraft

Deconfliction



Airspace & Fleet Operations Management

Barrier: Efficient Airspace Operations

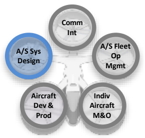
Develop and implement an airspace operations management system that provides user-preferred routing while allowing equitable, predictable, and on-demand airspace access for diverse missions and aircraft types, including legacy as well as emerging operations.

NASA Vision ConOps

- Efficient airspace operations can be considered from **three perspectives**: the **aircraft**, **UAM operations**, and the entire **urban transportation system**.
- **Aircraft efficiency** is summarized as the **time and energy** required to get from **point A to point B**.
    - Enabling aircraft efficiency relies on **collaboration between the fleet operator and PSU**, strategic and tactical **deconfliction**, **port** arrival/departure **flexibility**, and **active management** of multiple aircraft types.
- The **number of aircrafts** able to safety operate during periods of peak demand reflects **operational efficiency**. Greater **throughput** is enabled by pre-flight **strategic deconfliction**, **reducing separation** between aircrafts, and **efficient aerodrome** operations.
    - **Prioritization and sequencing criteria** will be developed by UML-4. These **FAA-approved community-based rules,** implemented by PSUs, **govern traffic flow and aircraft order**. This criteria will be **consensus-based** and **prioritize safety** with consideration of the needs of key stakeholders.
    - **Technologies** such as aircraft sensors and real-time data exchange enable **performance-based separation** with comparatively **reduced minimums**.
    - The **number of operations** is primarily driven by **aerodrome capacity**. Information exchange between aircrafts and infrastructure assists aerodrome operators with managing **capacity** at aerodromes and prevents the system from being overwhelmed.
- An efficient **urban transportation system** effectively manages demand (which may exceed capacity during peak periods). UAM operations enable an additional avenue to increase the overall urban transportation system capacity.

Areas with Remaining Unknowns

Prioritization and Sequencing Criteria	Performance-based Separation	Access and Equity	Collaboration



Airspace & Fleet Operations Management

Barrier: Scalable Airspace Operations

Develop and implement a scalable airspace operations management system to enable higher volumes of air traffic than exist today through the use of automation.

NASA Vision ConOps

- Many operations occur in dynamic **high-density routes** within the UOE, which can be modified quickly by PSUs (according to community-based rules) and are supported by air and ground infrastructure needed to support high volumes of air traffic.
- Operations along high-density routes are governed by operational procedures that enable **sequencing and spacing** of aircrafts based on the **operational characteristics** of the aircraft such as **airspeed**, **rate of climb**, **precision** along the center line, and **ability to fly in proximity** to other aircrafts.
- Criteria for prioritizing, sequencing, and spacing aircrafts will have been established by **consensus standards development organizations** and approved by FAA. These criteria can be modified by FAA as needed.
- Under the principle of **airspace equity**, any **cooperative** aircraft that meets **UOE performance-based** standards has access to these routes.
- In the UOE (particularly over cities), **air traffic management services** are predominantly provided **by PSUs**, rather than active management by ATC today.
- PSU **services may extend into ATC-controlled airspace** to enable UAM operations through ATC airspace or to landing areas.
- These **pre-approved, PSU-managed areas** and operations enable safe UAM operations **without active ATC management**.
- ATC will maintain the ability to **dynamically adjust or close** UOE areas (e.g., based on runway configuration changes or emergency situations).

Areas with Remaining Unknowns

- **Flexibility of High-density Routes**
- **Zero-airspeed Collision Avoidance**
- **Selecting and Defining High-density Routes**
- **Automation Relationship to Scalability**
- **UML Transition**
- **Location of Extensions into ATC-controlled Airspace**

Airspace & Fleet Operations Management

Barrier: Resilient Airspace Operations

Develop and implement an airspace operations management system that allows for a graceful degradation of UAM operations in reaction to un-intended disruptions to UAM services (e.g., loss of GPS, flight services, CNSI, and/or weather information; Aerodrome issues; cyber security attacks).

NASA Vision ConOps

- **Resiliency** in airspace operations is the ability of the system to **withstand a major disruption** (within parameters) and **recover in an acceptable timeframe**.
- The system has incorporated an **In-time Aviation Safety Management System (IASMS)** which features **monitor**, **assess**, and **mitigate** functions.
- The **monitor** feature is critical as a control to detect **adverse events and operations** and includes **aircraft health** monitoring information and models, **aircraft location data** to ensure the aircraft is on its approved flight path, **comparison of forecasted and actual weather** conditions, and systems to **identify and track potential non-cooperative traffic**.
- These and **many other features** are offered by the **PSUs**, **fleet and aerodrome operators,** and **SDSPs** as safety enhancement features and use them as market differentiators.
- **Redundant systems** are a means for the UAM operations to respond appropriately as it **utilizes backup systems** to **continue critical functions** while the **primary system recovers**.
- Having **more than one PSU** within an urban area, **pre-identified emergency landing areas**, and/or **backup communications** also improve system resilience.

Areas with Remaining Unknowns

Which Systems Require Redundancies

Redundant Systems Impact on Certification Time

IASMS Criteria and Certification

Airspace & Fleet Operations Management

Barrier: Fleet Management

Develop scalable, safe, secure, affordable, and efficient fleet operations management services, that ensure safe navigation and efficiently handle aircraft operations throughout the operator's UAM network while managing contingencies, meeting mission demand, and minimizing the impact of aircraft fleet emissions (e.g., noise, CO2, etc.) on the community.

NASA Vision ConOps

- Management of fleets is largely left to the **private sector to develop**; however, **traffic management is cooperative** between PSUs and fleet operators in the PSU Network, which has **implications on how fleet operators choose to manage their fleets**.
- Local regulators have input into where and when UAM aircrafts operate through **local aerodrome laws and zoning ordinances**.
- Industry leverages technology applications and new methods for **efficiently managing aircraft fleets** and **maximizing human productivity**.
- FAA authorizes **traffic management services**, industry will provide the services, and fleet operators will coordinate, execute, and manage operations in accordance with accepted standards and practices established by the FAA.

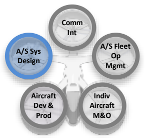
Areas with Remaining Unknowns

Aerodrome Ownership

Contingency Management

Community Impact

Cooperation with PSUs



Airspace & Fleet Operations Management

Barrier: Urban Weather

Develop a means of predicting high-resolution weather over short time frames for hyper-local conditions all the way to the ground, including understanding the impacts of wind fields in urban canyons.

NASA Vision ConOps

- Weather **in urban environments** is more **challenging** to characterize than weather **outside the urban environment**.
- Urban environment induced **micro-climates** cause sharp changes in wind speed and directions at the scales of meters.
- Urban **heat island effects** enhance **thermal activity** and cause notable changes in **density altitude** between downtown districts and airports in the suburbs or near large bodies of water.
- To achieve an **adequate degree of weather resiliency** to contribute to reliable and cost-effective operations, a combination of **airframe airworthiness improvements**, **smart siting of aerodromes,** and a **reduction in weather and wind uncertainty** caused by urban weather is required.
- The weather operations structure is a combination of **policy**, **reporting on current weather conditions**, **forecasting future weather conditions**, **information distribution**, and **decision making**.
- Arriving at this structure was the result of work by the **FAA**, **National Weather Service**, **NASA**, **DOD**, the **National Science Foundation's National Center for Atmospheric Research**, **standards development organizations**, **industry**, **trade groups**, and **universities**.

Areas with Remaining Unknowns

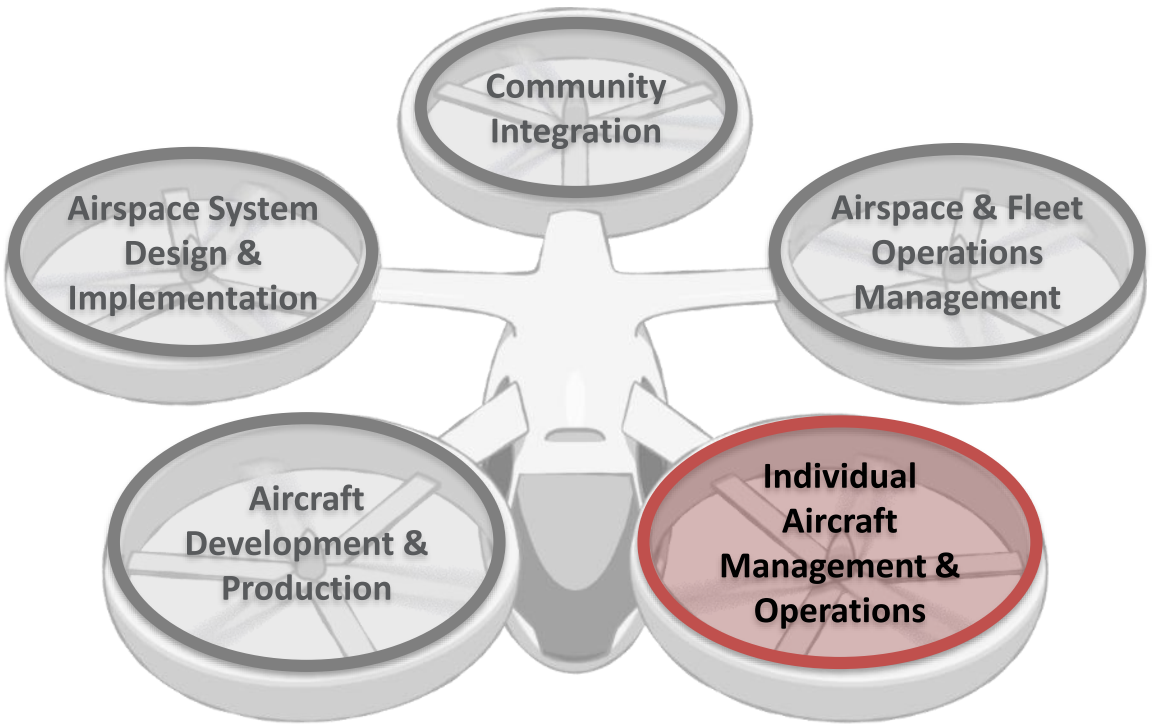
Weather Sensor Requirements	Ground Infrastructure for Weather Data Collection	Data Exchange/Quality Standards	Weather Requirements for Fleet Operators	Weather Policy

Airspace & Fleet Operations Management

Unknowns	Key Issues for Further Exploration
Handling Non-cooperative Aircraft	How will the PSU Network handle non-cooperative aircraft that enter the UOE? How will the associated situational awareness be disseminated to fleet operators in the UOE? Does ATC have a role in such situations?
Prioritization and Sequencing Criteria	How will aircrafts be prioritized within the UOE? What about for use of high-density routes or specific aerodromes? Will prioritization be first come first serve, performance-based, or operator-based?
	If a prioritization algorithm is used, is there a particular stakeholder or group of stakeholders who will be responsible for developing it?
Zero-airspeed Collision Avoidance	How will collision avoidance be managed, particularly for aircrafts that are hovering or operating at zero airspeed?
Selecting and Defining High-density Routes	How will high-density routes be defined? Will they be charted and by whom?
Redundant Systems Impact on Certification Times	How will requiring redundant systems on aircrafts impact the time it takes to obtain aircraft certification? How can this be mitigated?
Weather Sensor Requirements	Will weather sensors be required equipage on aircrafts? What additional weather infrastructure is needed to obtain adequate climate information given the unique microclimates that exist in urban areas?

Individual Aircraft Management & Operations

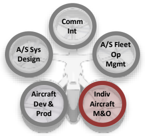
Scope and Focus



Safely operate UAM aircrafts in and around metropolitan areas while maintaining compliance with all required operational rules and procedures.

Barriers

- Safe Urban Flight Management
- Increasingly Automated Aircraft Operations
- Certification & Operations Approval
- Ground Operations & Maintenance



Individual Aircraft Management and Operations

Barrier: Safe Urban Flight Management

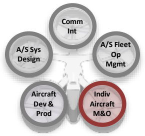
Develop capabilities for safe, efficient, and accommodating flight planning and execution in metropolitan areas, including navigation performance sufficient for medium complexity operations in urban environments, assuring controlled flight for safe contingency management (including cyber attacks), and compliance with regulations other constraints (such as noise limits).

NASA Vision ConOps

- **Sufficient actual navigational performance** to operate in metropolitan environments
- Automation ensures operations occur within a safe operating envelope
- **Advanced technology** such as detect and avoid (DAA) and digital vision enables operations in IMC
    - This includes operations around uncooperative obstacles (birds) and aircraft and unplanned obstacles (cranes, antennas, etc.)
- Robust **navigation systems allow aircraft to operate safely**, even in GPS-degraded/denied operating environments
- **Advanced aircraft technology** (CNSI, avionics etc.) and information exchange allow for **performance-based operation**

Areas with Remaining Unknowns

Navigational Performance Requirements	NOTAMs	CNSI Requirements	Off-Nominals & Contingency Operations	Specific Equipage and DAA Technology



Individual Aircraft Management and Operations

Barrier: Increasingly Autonomous Aircraft Operations

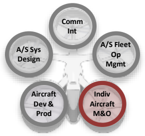
Develop highly automated capabilities and associated operational procedures to enable cost-effective scalability by increasing the ratio of aircraft operations to human operators and support staff.

NASA Vision ConOps

- **Highly automated aircrafts** capable of performing most operations with minimal human interaction
- **Increasingly automated capabilities** of aircrafts **reduce cost for aircraft crew training and fleet operations** while maintaining an **equivalent level of safety**
- **Advanced automation** compared to what is currently available **will enable the aircraft to identify the lowest risk emergency landing alternative.**

Areas with Remaining Unknowns

DAA Technology	Certification of Automated Systems	Training for Aircraft Crew	Human Interaction Roles & Responsibilities



Individual Aircraft Management and Operations

Barrier: Certification and Operations Approval

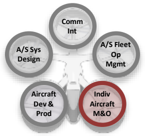
Develop a framework and corresponding methods of compliance for the holistic certification of advanced automation, humans, and operations of a UAM aircraft, as well as regulations and approval processes for commercial urban operations.

NASA Vision ConOps

- **Certification likely occurs under the existing framework** regulations (14 C.F.R. 121, 135, et al.)
- **Advanced methods to test and certify high-levels of automation** approaching artificial intelligence will likely be developed
- **Certificated maintenance processes have been developed** to ensure aircrafts are properly maintained
- **Aircraft crew and maintenance professional training** will include a curriculum that **covers areas unique to UAM**
- The **aircraft crew will have sufficient training** to meet their allocated requirement of identifying possible maintenance actions

Areas with Remaining Unknowns

- **Holistic Certification**
- **Certification of Aircraft**
- **Certification of Aircraft Crew**
- **Certification of Operator**
- **Certification of Maintenance Facilities & Personnel**
- **Certification of Parts & Supply Chain**



Individual Aircraft Management and Operations

Barrier: Ground Operations and Maintenance

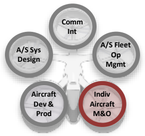
Develop guidance and requirements to ensure safe and efficient maintenance and routine aircraft handling between flights, including considerations for Aerodrome design and operations.

NASA Vision ConOps

- **Ground operations at the aerodrome will be the responsibility of the aerodrome operator** who may contract with fleet operators and ground services to provide routine aircraft maintenance at the aerodrome, and maintenance, repair, and overhaul (MRO) providers
- **Ground operations include an efficient way to recharge/refuel aircraft** in a manner that ensures **safe operation and ensures the safety of aircraft crew, ground services, and passengers**
    - May include an automated or aircraft crew safety briefing
    - Passengers are guided safely through the aerodrome environment and around safety hazards
- **MRO facilities will provide both minor and major maintenance** supplied by secure certificated supply chains
    - The types of services provided at aerodromes may be constrained by the location of the aerodrome and the level of traffic at the aerodrome

Areas with Remaining Unknowns

- **Ground Services Training**
- **Minimum Level of Maintenance Needed at Aerodromes**
- **Supply Chain Certification**
- **Non-Maintenance Services at Aerodromes**

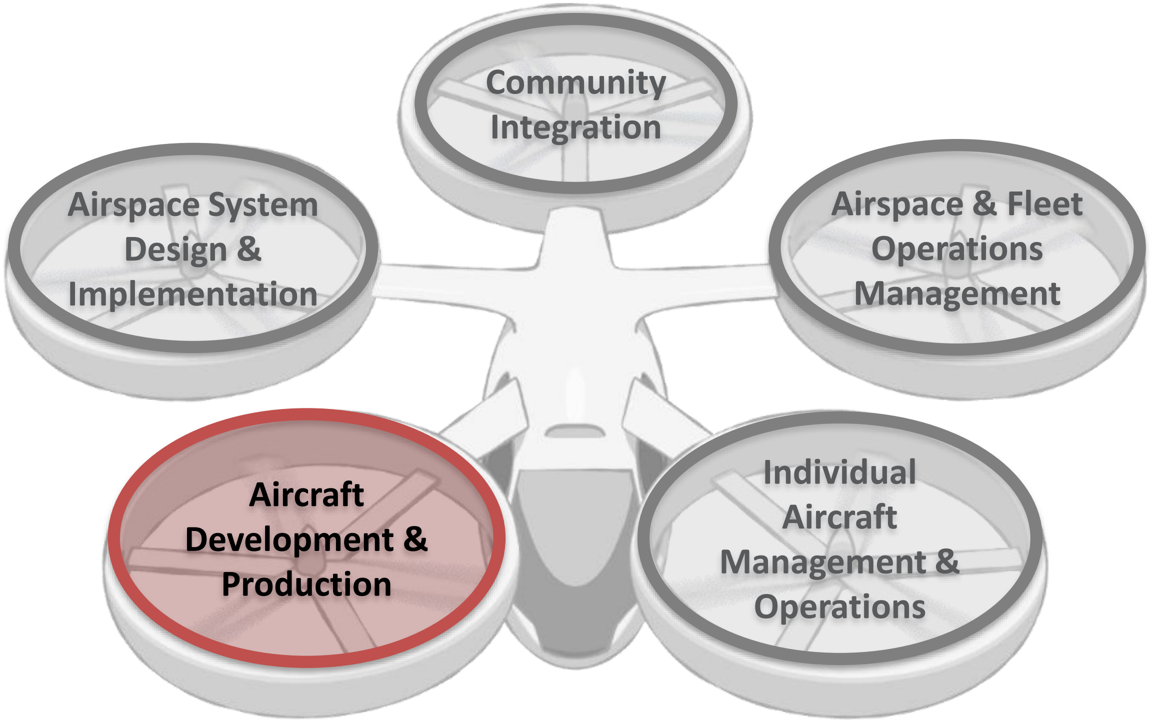


Individual Aircraft Management & Operations

Unknowns	Key Issues for Further Exploration
Off-Nominals & Contingency Operations	How will off-nominal situations be managed and what is the role of the aircraft crew? How does this differ if there is no crewmember onboard the aircraft?
DAA Technology	What are the key outstanding research questions that remain for detect and avoid? What will be the requirements for these systems in the UAM context?
Training for Aircraft Crew & Operator	What amount of flight hours and educational training requirements will there be for aircraft crews, fleet operators, and maintenance professionals? How does the training compare to that of a traditional pilot? How does it differ?
Human Interaction Roles & Responsibilities	What is the aircraft crew capability? How is automation envisioned to enable this? Does it rely on there being someone onboard the aircraft?
Holistic Certification	How will aircrafts, fleet operators, aircraft crews, and maintenance professionals/facilities be certified? Can occur using the existing framework or are new regulations needed? How will automation be certified?
Supply Chain Certification	How can the integrity of the supply chain be ensured?

Aircraft Development & Production

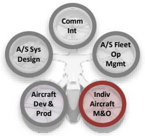
Scope and Focus



Design, certify, and produce airworthy, mission-capable, integrated aircrafts that operate safely in all weather conditions required by the mission, with adequate passenger comfort and sufficiently low levels of noise.

Barriers

- Aircraft Design & Integration
- Airworthiness Standards & Certification
- Aircraft Noise
- Weather-tolerant Aircrafts
- Cabin Acceptability
- Manufacturing & Supply Chain



Aircraft Development & Production

Barrier: Aircraft Design and Integration

Develop "mission-capable," integrated aircrafts with automated flight critical systems that are compatible with Aerodromes and meet all required attributes simultaneously to be safe; operationally and economically competitive with competing transportation modes; environmentally responsible; and secure from digital attack.

NASA Vision ConOps

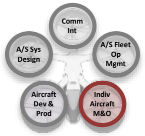
- **Electric propulsion systems and lightweight structures** enable aircraft configurations tailored to UAM missions, with **lower manufacturing and operational cost** and **lower noise signatures** (compared to aircrafts in the 2010s).
- **Fly-by-wire control systems** enable new smaller UAM aircraft configurations to take advantage of electric propulsion.
- Current aircraft **fuel reserve requirements will be modified** to account for the short distance of UAM flights.
- **High-speed computing** and **advanced automation** accelerate **development cycles** to efficiently bring promising concepts to market.
- Aircraft design eliminate **electromagnetic interference (EMI)/radio frequency interference (RFI)** between onboard systems, offboard systems, and other radio frequency-emitting devices in urban areas.

Areas with Remaining Unknowns

Resiliency to EMI/RFI

New Testing and Verification Approaches

Fuel Reserve Requirements



Aircraft Development & Production

Barrier: Airworthiness Standards & Certification

Develop a means of initially certifying and allowing for continuing certification of novel and/or rapidly evolving aircrafts in a cost- and time-effective manner, including developing certification requirements and means of compliance for aircrafts and propulsion systems as well as ensuring harmonious international regulations and standards.

NASA Vision ConOps

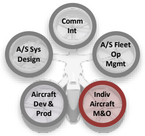
- **Enhance existing regulatory framework**, where appropriate, for the certification of UAM aircrafts.
- Some **certification requirements may be updated**. For example, rather than **freeze the configuration**, there may be ways for the process to be more adaptable so that manufacturers can **certify as they build**.
- Standards for UAM aircrafts incorporate **unique elements of UAM operations** such as **automation/artificial intelligence**, **distributed electric propulsion**, and **interoperability with the UOE.**
- Approaches for **aircraft and component certification** for UAM will keep pace with **accelerating technology development.**
- **Surveillance** standards, standards for **detect and avoid**, and **maintenance/inspection** standards will be developed.
- New testing and certification standards and are **harmonized internationally** so that flight operations are **not cost-prohibitive.**

Areas with Remaining Unknowns

Standards for New Technology

Certification

DAA Standards



Aircraft Development & Production

Barrier: Aircraft Noise

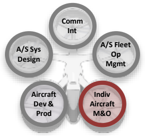
Develop aircraft designs and technologies to reduce aircraft noise during all phases of flight; including taxi, take-off/departure, approach/landing, and cruise.

NASA Vision ConOps

- Aircrafts designed to meet **noise levels that are acceptable to the communities in which they operate**.
- Noise level only slightly above the level of **ambient noise**.
- Aircraft noise reduced through **advanced design** and incorporation of **noise reduction technologies** enables quiet aircraft operations including **distributed electric propulsion** and **low-noise rotors.**
- Community noise **measured in the context of a fleet** in addition to measuring noise from a single aircraft.
- Noise standards at UML-4 are reduced compared to UMLs 1 through 3 and will continue to **evolve**.

Areas with Remaining Unknowns

Noise Standards



Aircraft Development & Production

Barrier: Weather-tolerant Aircrafts

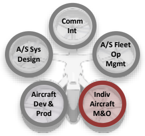
Develop aircrafts that are capable of safely flying into and maintaining control in poor, yet frequently experienced, weather conditions, including moderately high winds, low visibility, and high density altitudes.

NASA Vision ConOps

- UAM aircrafts operate safely in weather and climate conditions experienced in the **urban environment**, such as **turbulence** due to thermal heating/cooling or **wind shear** due to obstacles.
- Designed for the characteristics of the **local markets** in which they operate, such as Denver's altitude, Phoenix's temperature, and Chicago's wind.
- Aircrafts designed with performance consummate with the **weather** expected in the location in which they operate.

Areas with Remaining Unknowns

Weather Monitoring



Aircraft Development & Production

Barrier: Cabin Acceptability

Develop aircrafts that provide an acceptable level of passenger comfort and payload protection including ride quality, cabin noise, interior climate control, and vibrations.

NASA Vision ConOps

- Cabins **safe for passengers and cargo** in both **nominal and off-nominal** events.
- **Seat belts** that are effective and simple to use and **ergonomically designed spaces** reduce injuries in an accident.
- **Crashworthiness principles** and safety technologies such as **energy absorbing seats** support occupant survivability in crash landings.
- Cabin design will **minimize vibration and noise during turbulence, provide climate control,** and **assure passenger safety and comfort.**
- Cabins designed so that necessary maneuvers **do not provide significant adverse impact to passenger comfort**.
- Use of **consumer research** and testing will promote strong understanding of **metrics for passenger acceptance.**
- Factors considered in cabin design include **ambient noise**, **illumination**, **vibration**, **temperature**, and **seating configuration.**
- Safe and efficient access to the cabin provided for passengers–including **children and persons with disabilities**.
- Support for **communication between passengers** by active or passive noise cancellation, personal mobile phones for convenience.

Areas with Remaining Unknowns

Minimum Cabin Design Requirements

Metrics for Cabin Acceptability

Cabin Monitoring

Aircraft Development & Production

Barrier: Manufacturing & Supply Chain

Develop safe, certifiable, high-volume, affordable, secure and rapid manufacturing capabilities as well as a supporting supply chain ecosystem that is robust and scalable.

NASA Vision ConOps

Manufacturing

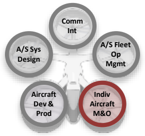
- Use of **advanced manufacturing techniques** combine practices and processes developed across the **automotive**, **aerospace**, and **other industries**.
- Manufacturing processes supported by **integrated design**, **modular configurations**, **and advanced materials**, and **new techniques** (e.g., 3D printing).
- **Supply scaled** to the number of aircrafts anticipated, flexible **aircraft configurations.**
- **Strict quality and authenticity standards verified by electronic processes** for tracking, providence, and authentication of safety-critical components (e.g., block chain, digital authentication) and to protect against **cyber and physical security threats**.

Supply Chain

- Approaches for **supply chain qualification** keep pace with levels of production for manufacturing high volumes of aircrafts.
- **Less vertical integration** and dependency on single suppliers in supply chains; **greater diversity of manufacturers** and **distributors** of parts and materials.
- **Close integration** between the OEMs, fleet operators, and manufacturers to **optimize supply chain management and control costs.**

Areas with Remaining Unknowns

Advanced Manufacturing processes | **Production Rates** | **Secure Supply Chain** | **Supply Chain Diversity**

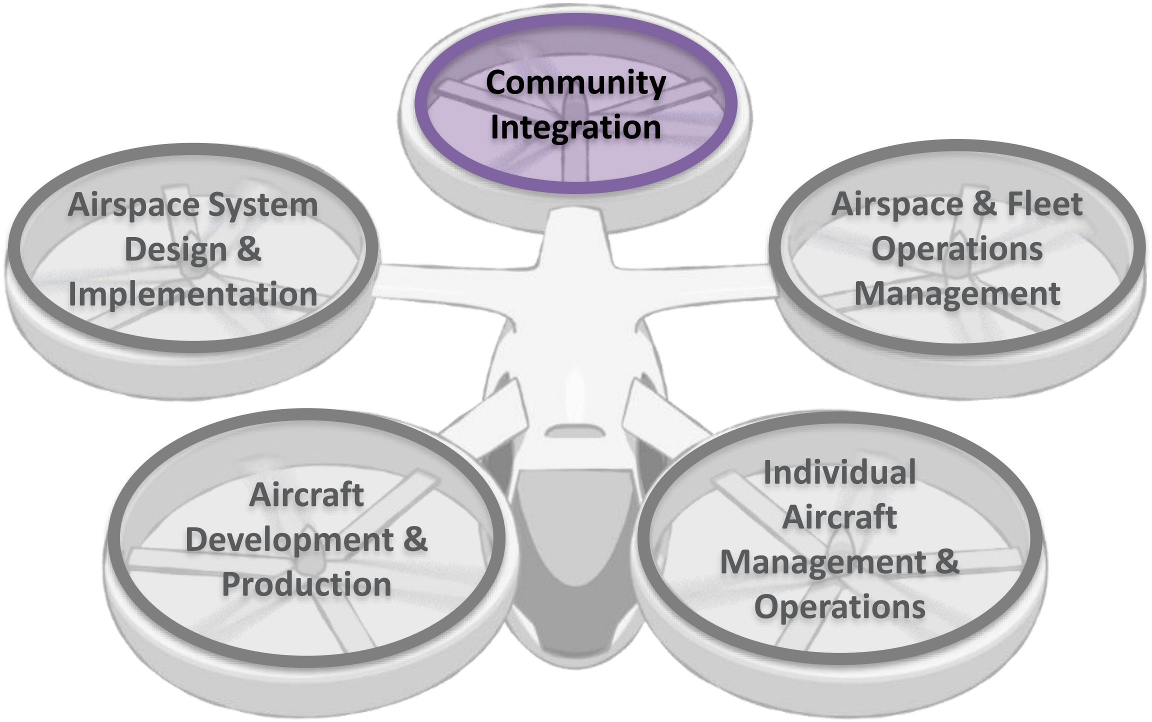


Aircraft Development & Production

Unknowns	Key Issues for Further Exploration
Resiliency to EMI/RFI	How can aircrafts be designed to be resilient from EMI/RFI, both of which are prevalent in urban environments?
New Testing & Verification Approaches	Will new testing methods be employed for UAM aircrafts or will testing occur using existing methodologies?
Fuel Reserve Requirements	How will fuel requirements be determined for different UAM aircrafts?
Certification	Will there be UAM-specific regulation for certification or will certification occur within the existing framework?
Noise Standards	How will noise standards be determined? Will these standards be stricter than they are for traditional manned aircraft? Will local communities have a role (or be consulted) in determining noise standards?
Weather Monitoring	Will aircrafts be designed to include weather sensors? Will weather sensors be mandatory? What type(s)?
Metrics for Cabin Acceptability	What metrics or factors will be used to determine cabin acceptability? Will cabin acceptability differ for passengers on UAM aircrafts than for passengers flying on traditional commercial aircraft?
Secure Supply Chain	What are the security risks associated with aircraft production? How will parts be authenticated?

Community Integration

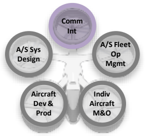
Scope and Focus



Achieve public acceptance of UAM aircraft operations in and around metropolitan areas by addressing UAM-related social concerns such as safety, security, affordability, noise, privacy, and liability.

Barriers

- Public Acceptance
- Supporting Infrastructure
- Operational Integration
- Local Regulatory Environment & Liability



Community Integration

Barrier: Public Acceptance

Achieve public acceptance of the UAM concept overcoming concerns regarding safety, demonstrating public benefit, and addressing community and environmental impacts.

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Safety

- The **foundation built at UMLs 1-3** enables **safe passenger-carrying operations at UML-4**.
- The UAM industry builds confidence by **proactively identifying hazards** and their safe resolutions.

Public Benefit

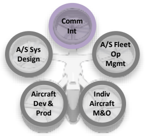
- Employment by **UAM manufacturers, fleet operators, PSUs, SDSPs** and others in the UAM ecosystem creates a equitable mix of **technical and non-technical jobs** and **spurs economic development**.
- Successful **demonstration** of UAM at earlier UMLs of operations such as **medical transport** proves the concept and enables **public acceptance**, which leads to higher **passenger usage** (which will **drive down cost** on a per ride basis) and decrease public resistance.

Community/ Environmental Impact

- UAM enables metro commuters to **travel farther and faster** than today, potentially **reducing commuter time and congestion.**
- At UML-4, aircrafts are **quieter** than **previous UMLs** due to the evolution of technology.
- Regulators will have established **aircraft and fleet noise standards** and worked with communities to address localized concerns through **flight route planning**, **temporal modifications**, and **flight procedures.**
- Mitigating privacy concerns occurs through **effective community engagement** and builds upon privacy policies being developed for unmanned aircraft systems (UAS) today.
- **Emission** levels conform with **existing standards** and development of **new standards** is iterative and compliant with regulations.

Areas with Remaining Unknowns

- **Public Familiarity with UAM**
- **Emissions Standards**
- **Economic Impact**
- **Mitigating Visual Impacts**
- **Noise Standards**
- **Demonstrating Affordability**
- **Demonstrating Safety**



Community Integration

Barrier: Supporting Infrastructure

Develop and implement the required supporting infrastructure for integrating UAM operations into metropolitan areas, including utilities, data networks, and Aerodromes.

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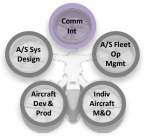
- The physical infrastructure for aerodromes, navigation, and data networks can be **publicly owned**, **privately owned**, or part of a **public-private partnership**.
- Municipalities, fleet and aerodrome operators, and utility companies **cooperatively** determine how much **infrastructure investment** is required to sustain a UAM market and decide **who bears the costs**.
- Fleet and aerodrome operators **coordinate with municipalities and utility companies** to ensure **sufficient power** is available for aircraft charging operations.
- Emergence of new and innovative **partnership models** between fleet and aerodrome operators and energy companies may offer opportunities to simultaneously **satisfy energy needs** and **incorporate alternative energy sources**.
- UML-4 includes UAM "**purpose-built**" aerodrome structures in addition to **preexisting**, **repurposed** aerodromes (e.g., a heliport retrofitted to be a aerodrome or one that serves both helicopters and UAM aircrafts).
- Aerodromes are designed and built with safety and security infrastructure in place to ensure safety and security for passengers.
- **Passenger demand** and **scalability** are critical for determining **aerodrome location & infrastructure requirements.**
- Communities can control UAM growth areas via **zoning** ordinances.

Areas with Remaining Unknowns

Financing Infrastructure Upgrades

Data Network Ownership & Responsibility

Energy Infrastructure Requirements



Community Integration

Barrier: Operational Integration

Implement multi-mode transportation integration and address operations-related community impacts, including passenger/cargo security, protection from malicious use of aircrafts and denial of service attacks, and graceful degradation of the transportation ecosystem in reaction to disruption of UAM services.

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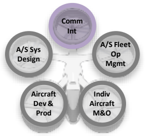
- At UML-4, operational integration creates opportunities to **integrate UAM** with other transportation modes, including autonomous cars, to allow for a **seamless transportation experience**.
- Advanced security technologies expedites **passenger and cargo screening**.
- UAM ecosystem is built to address the **vulnerabilities** of **automated systems** and includes **safety measures** to defend against and mitigate threats such as **cybersecurity** attacks.
- The **transportation ecosystem** at UML-4 includes mitigation strategies to account for service disruptions on **any particular mode**, such as **strategically placing** aerodromes in order to **prevent overloading** of any single mode of transportation in event of **service disruption and graceful degradation** of the entire transportation ecosystem in event of disruption of one or more of the various modes.

Areas with Remaining Unknowns

Multi-Modal Integration

Cybersecurity

Security Screening & Boarding



Community Integration

Barrier: Local Regulatory Environment & Liability

Enact laws and regulations for governing UAM operations, such as zoning, privacy, and noise, striving for consistency across operating locations (i.e., states, municipalities) and develop a framework for the analysis of liability associated with the development and operation of increasingly automated and autonomous systems.

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- The legal and **regulatory framework** and **case law** incorporates the roles and authorities of each: **FAA**, **DOT**, other **federal agencies** (e.g., **EPA** and **FCC**), **state** government, and **local/city/municipal** government.
- FAA maintains its role as **federal regulator**, and while **federal preemption** applies, rules that do not conflict with, or occupy the “field” of, a federal regulation/regulator may be promulgated at the **state and/or local** level.
- Because UAM aircrafts operate so close to where people live and work, much **local involvement** and **public interest** in the **rulemaking** process surrounding UAM is anticipated.
- By UML-4, **FAA and industry** have improved **forums and processes** used in 2010s to engage **state and local leaders** to a greater extent than they did in the 2010s in order to **harmonize** regulations/ordinances promulgated at the state and local level **avoiding a patchwork of rules**.
- Communities maintain their **power to control** the development of **ground infrastructure** (aerodromes, weather sensors, etc.) through **zoning ordinances** and **noise** through **noise ordinances**.
- Laws and other means to assign **liability will be based upon current common carrier liability principles** and will be **updated to address the utilization of autonomous systems**.

Areas with Remaining Unknowns

Federal and Local Government Engagement

Role of Local Governments

Harmonization of Local UAM Regulations

Community Integration

Unknowns	Key Issues for Further Exploration
Public Familiarity with UAM	How can the public be made aware of UAM's benefits in order to promote public acceptance?
Mitigating Visual Impacts	How can stakeholders respond to public concern regarding visual noise created by UAM operations and aerodromes?
Noise Standards	How can public concern regarding noise be mitigated? Will the public's threshold of acceptability for UAM-related noise be different than their threshold for noise created by commercial aviation?
Demonstrating Safety	How can UAM stakeholders demonstrate UAM safety?
Financing Infrastructure Upgrades	How can public-private partnerships be utilized in financing infrastructure and aerodromes for UAM? Is this the best solution? What alternatives are available?
	How will aerodromes be funded?
Energy Infrastructure Requirements	What tools or analyses can municipalities use/perform to determine how much energy infrastructure is needed to support a metropolitan UAM market?
Multi-Modal Integration	What needs to occur to enable operational integration of UAM with other forms of transportation?
Security Screening & Boarding	How will passengers and cargo be screened and processed at aerodromes?
Federal and Local Government Engagement	How can federal regulators better engage local government as the UAM ecosystem develops? What about the reverse?

UAM Ecosystem Key Responsibilities

Role	Responsibility
Aircraft Crew	A human or humans partially responsible for the safe flight of the aircraft who share this responsibility with some automated system(s). An aircraft crew member is not a traditional pilot, but rather performs the role of aircraft operator, multi-aircraft operator, or aircraft steward. An aircraft operator may be either onboard or off-board, a multi-aircraft operator is located off the aircraft, and an aircraft steward is located onboard. One aircraft crew member is designated the PIC (or RPIC) at a time, though the PIC or RPIC may change during flight. Typically, the aircraft crew work on behalf of the fleet operator to support UAM operations. A fleet operator can utilize a traditional pilot, a single aircraft crew member, or a combination of aircraft crew members as required for safety in light of their particular business model. For example, the use of an onboard aircraft crew may bolster public acceptance by providing human interaction throughout the UAM experience.
FAA	Regulatory and oversight authority for all civilian aircraft operations in the NAS. Collaborates with the PSU Network.
Fleet Operator	The fleet operator of the aircraft who hires the aircraft crew (if the aircraft fleet operator is not also the aircraft crew) and in some instances performs dispatch duties. A fleet may consist of one aircraft.
Flight Information Management System (FIMS)	FIMS is an interface for data exchange between FAA systems and UTM/UAM participants. FIMS enables exchange of airspace constraint data between the FAA and the PSU Network. The FAA also uses this interface as an access point for information on active UAM operations. FIMS also provides a means for approved FAA stakeholders to query and receive post-hoc/archived data on UAM operations for the purposes of compliance audits and/or incident or accident investigation. FIMS is managed by the FAA and is a part of the UAM ecosystem.

UAM Ecosystem Key Responsibilities

Role	Responsibility
Providers of Services to UAM (PSU)	**Public or private (e.g., third-party) entities that provide ATC and flight safety services under rules and regulations established by the FAA. Services provided by PSUs include routing, traffic deconfliction, operational constraints, modifications, notifications, and information. A PSU is analogous to a USS in the UTM paradigm and is contracted by the fleet operator (i.e., airspace user). .**
PSU Network	**The amalgamation of PSUs connected to each other and exchanging information. Each PSU is required to share certain information with the other PSUs to provide a complete operating picture and situational awareness.**
Supplemental Data Service Providers (SDSPs)	**Data sources external to the PSUs that supplement the decision-making and information-sharing of the PSU and fleet operator. These can include weather sources and ground risk assessments, among others. PSUs can access SDSPs via the PSU Network for essential or enhanced services (e.g., terrain and obstacle data, specialized weather data, surveillance, constraint information). SDSPs may also provide information directly to PSUs or fleet operators through non-PSU Network sources (e.g., public or private internet sites).**
UAM Aerodrome Operators	**UAM aerodrome operators are entities responsible for ensuring the safety of individual TLOA, as well as any ground services (embarkation, disembarkation, maintenance, etc.) provided at a UAM aerodrome. UAM aerodrome operators may be private or public entities.**