UAM Coordination and Assessment Team (UCAT)
NASA UAM for ENRI Technical Interchange Meeting

Background

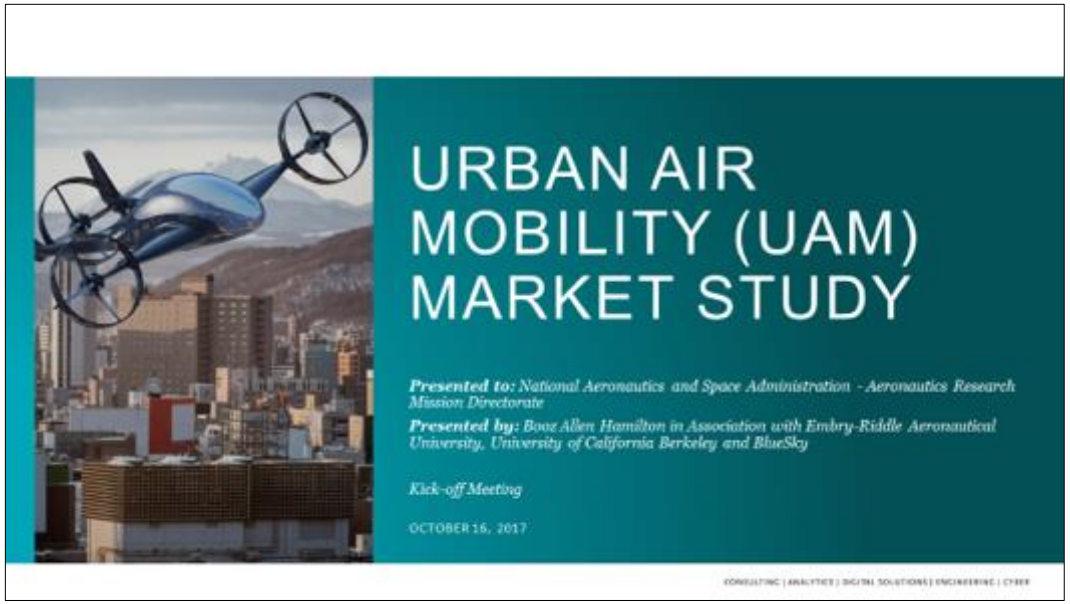
- Urban Air Mobility (UAM) is an emerging aviation market focused on the transport of passengers and cargo around metropolitan areas
  - Use of aviation similar to how ground vehicles (i.e., cars, trucks) are used today
  - Includes manned and unmanned aircraft
  - Potential to reduce ground traffic and/or provide a more rapid, alternative mode of transportation

- NASA ARMD set up the UAM Coordination and Assessment Team (UCAT) in early 2018 to explore UAM space and make recommendations for future NASA investments in UAM

- This presentation will
  - Describe some of the exploratory work and “products” of the UCAT, which lay the groundwork for NASA’s UAM investments
  - Describe the UAM Grand Challenge

Urban Air Mobility Market Studies

- ARMD funded two UAM market studies that included
  - Several air taxi/metro models, air ambulance, and last-mile package delivery
  - Considerations for different urban areas, legal and regulatory barriers, & social acceptance issues
- UAM market studies generally found that UAM has economically viable use cases if many challenges are overcome
- Large variability in specific predictions across studies based on differences in assumptions
- Overview of Results:
  - Some assumptions show by ~2028 a highly-automated "air metro" could be profitable and by ~2030 result in ~750M annual passenger trips in 15 metro areas or ~137k pax trips/day/area
  - More conservative assumptions indicate a $2.5B passenger transport market with ~8.2k pax trips/day/area
  - Air ambulance model may not be profitable, but have high impact on public good
  - By ~2030 "last mile package delivery" could be profitable and result in ~500M deliveries annually



UAM Passenger Carrying Market Comparisons

Comparisons of Passengers and Numbers of Vehicles per City

Crown Air Metro	2028	2030
# pax trips/day/city	**23,744**	**136,986**
# vehicles/city	**273**	**1,533**
# flights/day/city	5,936	34,247
# pax/flight (avg)	4	4

Aggressive on assumptions (i.e. autonomy) and implementation (i.e. vertiport infrastructure)

BAH (baseline)	Near-mid
# pax trips/day/city	**8,200**
# vehicles/city	**410**
# flights/day/city	5,500
# pax/flight (avg)	1.49

Fairly conservative assumptions in all except manufacturing volumes, and no predictions for dates

Uber Air Taxi	2025-2030
# pax trips/day/city	**60,000**
# vehicles/city	**400**
# flights/day/city	15,000
# pax/flight (avg)	4

Aggressive timeline and assumptions more in-line with Crown market study

Cost Comparisons Over Time ($/pax-mile)

Cost ($/pax-mile)	Launch	"Near-Mid-Term"	"Far-Mid-Term"	"Long Term"
BAH Baseline	N/A	6.25	~2.50	N/A
BAH Low End	N/A	~3.75	~1.50	N/A
Crown	N/A	2.00	1.20	N/A
Uber	5.73	N/A	1.84	0.44

Leverage data to architect a comprehensive approach that defines a realistic progression to open the UAM passenger-carrying market

UAM Reference Missions

Passenger Carrying Reference Missions


e.g. AIR MEDICAL TRANSPORT


e.g. INTRA-METRO AIR SHUTTLE


e.g. UBIQUITOUS INTRA-METRO TAXI

INITIAL STATE **INTERMEDIATE STATE** **MATURE STATE**

Non-Passenger Carrying Reference Missions


e.g. PUBLIC SERVICE VEHICLES


e.g. SMALL PACKAGE DELIVERY


e.g. UAS MULTI-PACKAGE DELIVERY

Urban Air Mobility: UML-4 Passenger Carrying OV-1

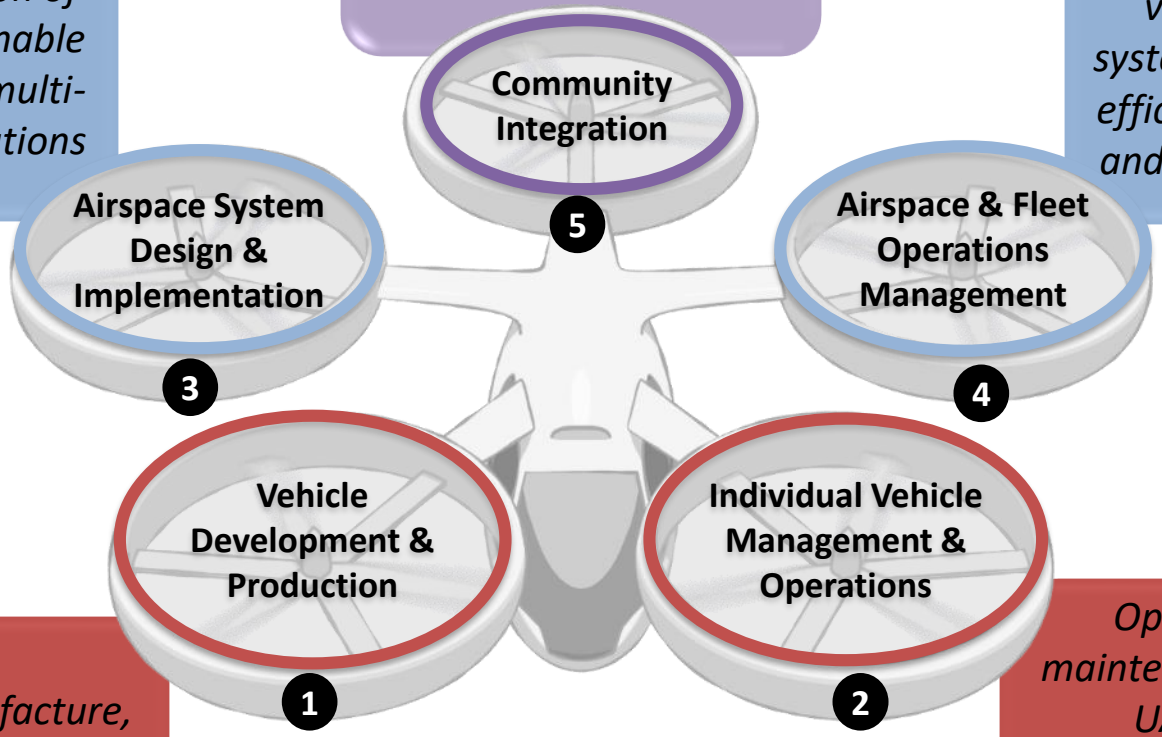
National Aeronautics and Space Administration

UAM Vision and Framework

Societal integration and acceptance of UAM operations

Design, development, and implementation of infrastructure to enable safe and efficient multi-vehicle UAM operations

Operations and management of multiple vehicles within a UAM system that enable safe and efficient sharing of airspace and other system resources



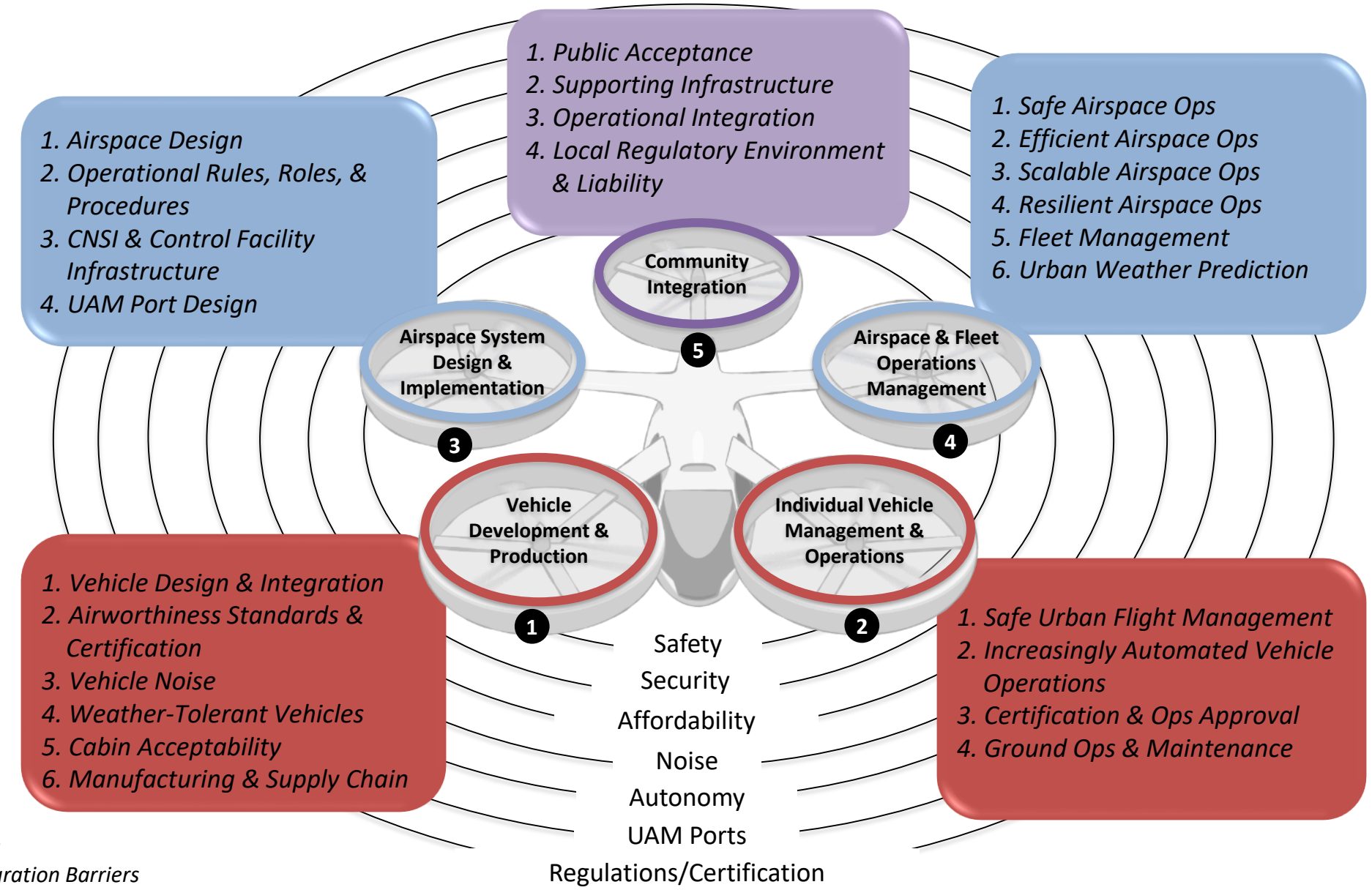
Design, manufacture, and system readiness of UAM vehicles

Operations and maintenance of a single UAM vehicle, independent of the sharing of airspace or other system resources

Urban Air Mobility (UAM) Vision
Revolutionize mobility around metropolitan areas by enabling a safe, efficient, convenient, affordable, and accessible air transportation system for passengers and cargo

Vehicle Barriers
Airspace Barriers
Community Integration Barriers
 # Pillar number

UAM Framework and Barriers



Vehicle Barriers
Airspace Barriers
Community Integration Barriers
 # Pillar number

UAM Ecosystem Needs

- **Holistic Community View.** Realizing the full vision of UAM (specifically for scaled solutions) will be complicated and reliant on a large number of technologies and capabilities maturing simultaneously. The community needs a holistic view of the full ecosystem across diverse capabilities and initiatives.

- **Coordination of Efforts.** The community is large, diverse, and fast-moving. The community would benefit from more effective end-to-end ecosystem coordination that breaks down silos and targets the priority barriers/challenges.

- **Gaps in Addressing Barriers/Challenges.** Even with all of the participants currently thinking about UAM, there are gaps that aren't being addressed. and that there are barriers/challenges that will require significant time/resources to address

- **Collaboration.** The full benefits from the UAM market won't be opened by enabling a subset of the potential markets. The community would benefit from collaboration that has broad benefits across multiple potential markets.

- **Government Engagement.** Enabling UAM requires Federal, State and Local government support. The community needs effective paths/mechanisms to engage with government across all these levels, and government entities need to engage amongst themselves.

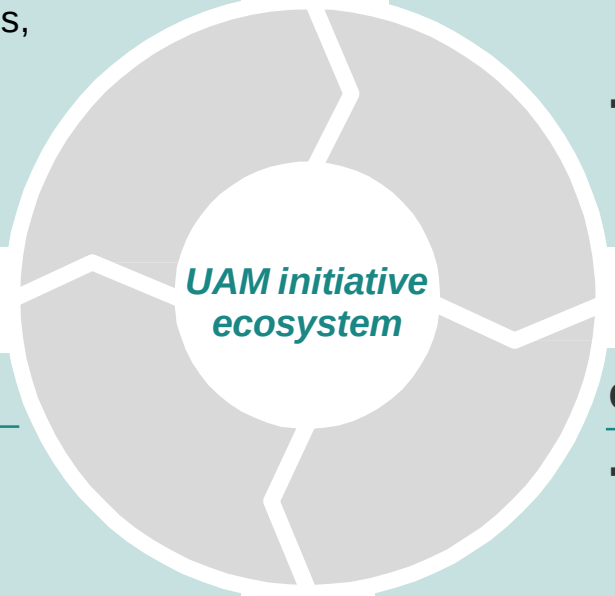
UAM Ecosystem Status

Industry and Stds Dev Organizations

- **R&D**: more than 100 vehicle prototypes in development, UAM TM ecosystem
- **Standards**: GAMA, AIA, ASTM, Elec Propulsion
- **Summits**: Uber Elevate, Farnborough UAM conference, Aviation Week UAM series,
- **Partnerships**: Uber Elevate
- **International:** US companies flying to gain experience in pilot cities; Tokyo, Singapore, Dubai, Sao Paolo

Federal agencies

- **NASA Efforts**: Grand Challenge, X-57, UTM, UAS in the NAS, RVLT, Autonomy & Acoustics Workshops, ARTR
- **FAA UAM Roundtable**: industry roundtable, paths to certification (e.g. 21.17b) and operations (e.g part 135),
- **FAA/OGA initiatives**: DAC, UAST, UAS ExComm, IPP, UPP, DOT Autonomy Guidance and TRB



State and local

- **Initiatives:** State and local interest in initiatives like IPP, UPP, Test Sites, UAM demos
- **Smart Cities**: several local authorities are implementing city-wide initiatives
- **Partnerships**: DFW and Uber, LA Olympics
- **Academic research**: progressive leaders are funding studies to accelerate UAM

Community

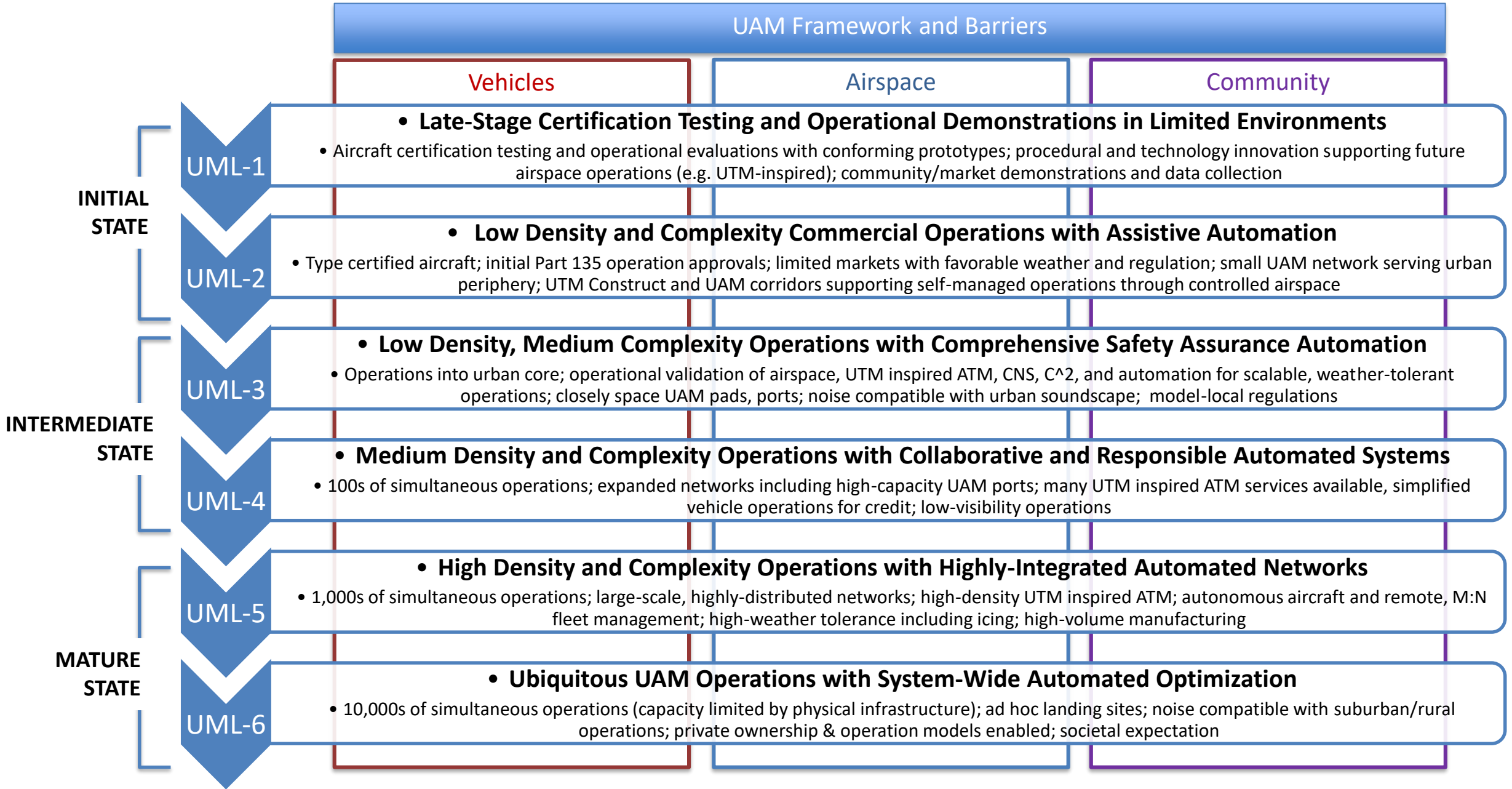
- **Public perception**: OEMs and others are working to study consumer perception of UAM (*e.g.*, Airbus)
- **Think tanks and research institutions**: Aspen Institute Future of Work
- **Concern groups**: neighborhood noise, environmental, and automation interest groups are beginning to voice interest at UAM forums

What's NASA already doing?

- Performed independent Market Studies that have demonstrated the potential of UAM
- Defining an approach with holistic systems point of view, and not simply focusing specific technologies
- Robust planning an execution of Grand Challenge Series that will address barriers/challenges and encourage community collaboration
- Ongoing projects continuing research that significantly contributes to UAM, and pivoting other projects towards a UAM focus
  - UAS Traffic Management (UTM) & UAS Integration in the NAS (UAS-NAS)
  - Flight Demonstrations and Capabilities (FDC), X-57
  - Air Traffic Management - Exploration (ATM-X)
  - System Wide Safety (SWS)
  - Transformative Tools & Technologies (TTT)
  - Revolutionary Vertical Lift Technologies (RVLT)
- New Start Projects with UAM as their top priority
  - Advanced Air Mobility (AAM)
- Leveraging government contacts to help ensure appropriate agency involvement

NASA is moving out quickly and intelligently to enable a UAM Ecosystem

UAM Maturity Levels (UML)



Preliminary UAM Community Critical Commitment

Vehicle Development and Operations Develop concepts and technologies to define requirements and standards addressing key challenges such as safety, affordability, passenger acceptability, noise, automation, etc.

Airspace Design and Operations Develop UTM inspired concepts and technologies to define requirements and standards addressing key challenges such as safety, access, scalability, efficiency, predictability, etc.

Community Integration Create robust implementation strategies that catalyze public acceptance, local regulation, infrastructure development, insurance and legal frameworks, etc.

UAM Community Critical Commitment

Deliver a validated
1) system concept and
2) corresponding set of requirements
for a safe and scalable UAM transportation system.

Achieving a "system of requirements" will require *enabling activities* such as 1) the UAM Grand Challenge Series, 2) a robust Partnership Strategy, and 3) NASA ARMD Portfolio Execution

NASA's Approach to Enabling a "Set of Requirements"

UAM Grand Challenge Series

The UAM GC Series is designed to facilitate technology development, testing, and partnership for critical UAM components

UAM Partnership Strategy

The UAM Partnership Strategy is designed to bring the entire UAM ecosystem together in partnership across key challenges and barriers

NASA ARMD Portfolio Execution

NASA supports industry via a robust portfolio focused on key challenges validated GC and UAM Partnership Strategy

The UAM “Grand Challenge” Series

- Challenging the industry to execute ecosystem-wide systems level safety and integration scenarios
- Demonstrate practical & scalable system concepts (i.e. UML-4)
- Builds knowledge base for requirements and standards
- No purse or prize money

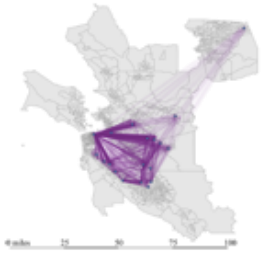
Grand Challenge (GC) Series Overview

Vehicles

functional UAM vehicles with threshold level of demonstrated airworthiness

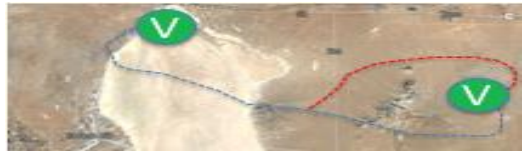
Airspace Management

airspace and air traffic management technologies and services built and simulated to a threshold level of UAM ATM requirements



Safety and Integration Scenarios

airworthiness processes and scalable scenarios designed in concert with the FAA, with range(s) and Testbeds as a UAM proving ground



Stakeholder Integration

societal integration and acceptance of UAM Operations including public acceptance, supporting infrastructure, operational integration, standards organizations, the local regulatory environment, etc.

Industry Provided

NASA Provided

Ecosystem Wide Support

Initial Grand Challenge Objectives

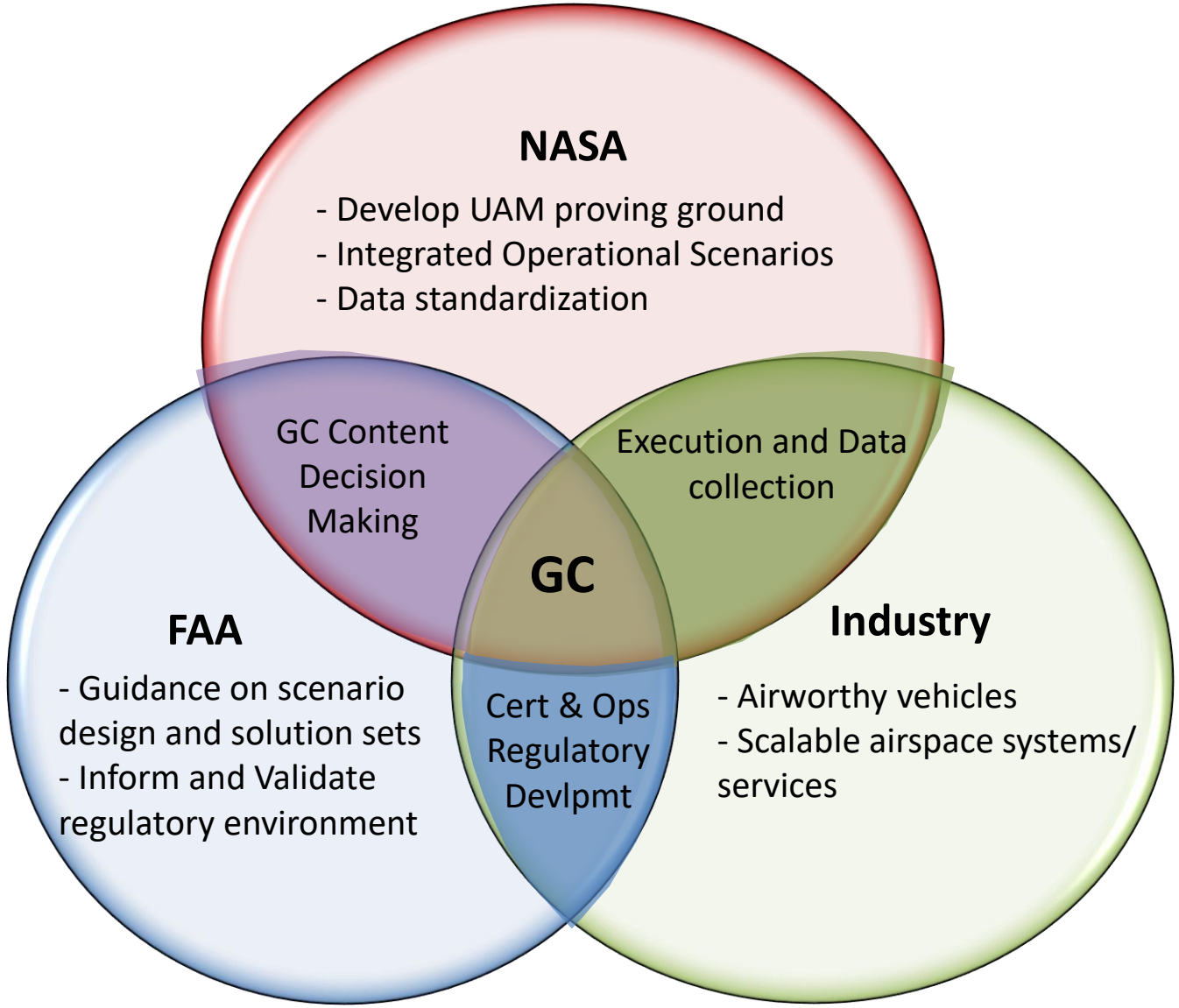
Goal

Support requirements and system development for UAM through integrated Demonstrations of vehicle and operational scenarios critical to scalable UAM commercialization

Objectives

- **Accelerate Certification and Approval.** Develop and assess an integrated approach to vehicle certification and operational approval
- **Develop Flight Procedure Guidelines.** Develop preliminary guidelines for flight procedures and related airspace design criteria
- **Evaluate the CNS Trade-Space.** Explore and evaluate communication, navigation, and surveillance requirements, options, and trade-offs
- **Demonstrate an Airspace Management Architecture.** Demonstrate and document an airspace system architecture, based on the UTM construct, capable of safely managing scalable UAM operations without burdening the current ATM system
- **Develop Autonomy Methods of Compliance.** Create and evaluate standardized flight test scenarios and candidate methods of compliance supporting certification of autonomous flight and airspace systems
- **Characterize Community Considerations.** Conduct initial characterization of passenger and community considerations through vehicle ground noise, cabin noise, and on-board ride quality measurements

NASA/FAA/Industry Relationship for Initial Grand Challenge



Note: Future Grand Challenges also include a more focused Community perspective

Initial GC Participant Value Proposition

- Opportunity to help shape future UAM Requirements, Regs & Standards – *Decrease potential for negative impacts to stakeholder designs and business cases.*
- Establish the evidence needed to convince regulators that the UAM technologies are safe & mature – *Prevent unnecessary restrictions being placed on UAM market.*
- Demonstrate vehicle systems integrated into airspace– *UTM-construct/3rd party services for scalable, responsive airspace integration*
- Help to educate federal, state and local authorities on UAM societal value & safety – *Achieve public acceptance sooner and reduce potential for push-back.*
- Leverage NASA investment in UAM test ranges and integrated simulation facilities – *Eliminates the need for industry to invest their own resources for these items.*
- Help to build credibility with potential investors and customers – *Secure the necessary capital and user base.*

By participating in the Initial UAM GC, Vehicle and Airspace Stakeholders have the opportunity to develop solutions that help solve UAM market-enabling challenges.

Grand Challenge Series Flow

Build Up: ~Late 2020 → **Initial Grand Challenge: ~2022** → **GC Series: TBD**

Outcome: Community learning through flight and simulation of critical UAM scenarios in a relevant environment → Outcome: Integrated Demonstrations of vehicle and operational scenarios critical to UAM commercialization → Outcome: Validated requirement sets for scaled operations

Grand Challenge Build-up: *Essential activities to prepare for Initial Grand Challenge*

- Multiple critical activities that build towards Initial GC
- High Priority and focused Integrated/operational scenarios
- Incorporates trade-offs between vehicle and airspace systems
- Challenging to all; not all expected to participate

→

Initial Grand Challenge: *Learning through real integrated flights*

- Demonstrate integrated capabilities for urban operations
- Define path to commercial operations, solutions oriented

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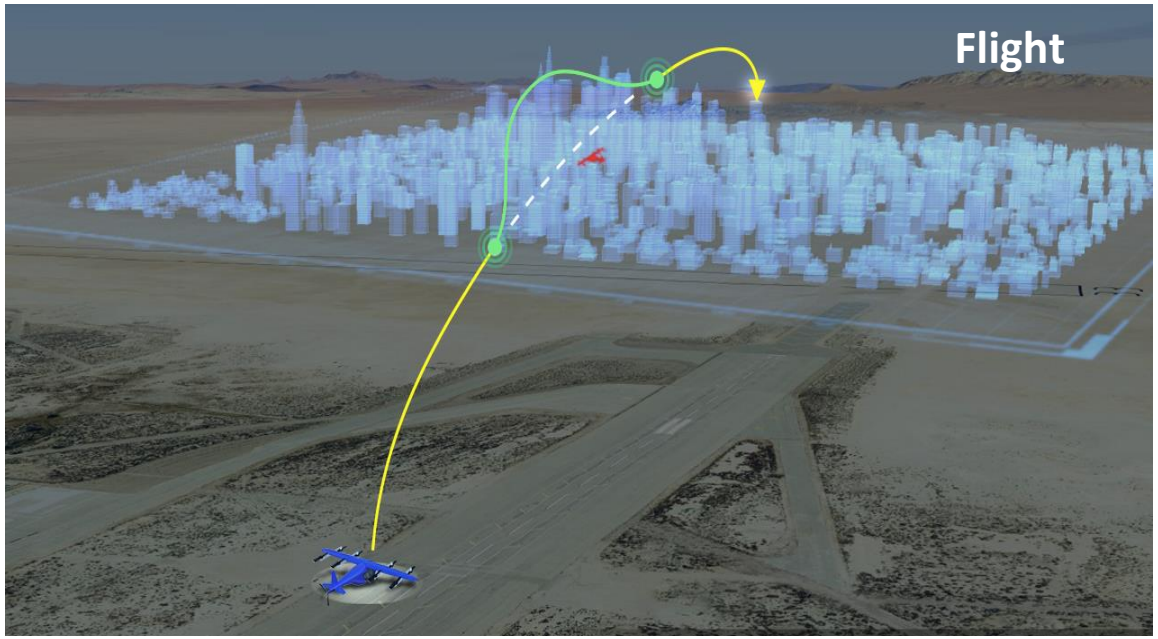
Series Culmination

Demonstrate scaled operational capabilities in urban environments

GC Build-up



Integrated Vehicle and Airspace Build-up

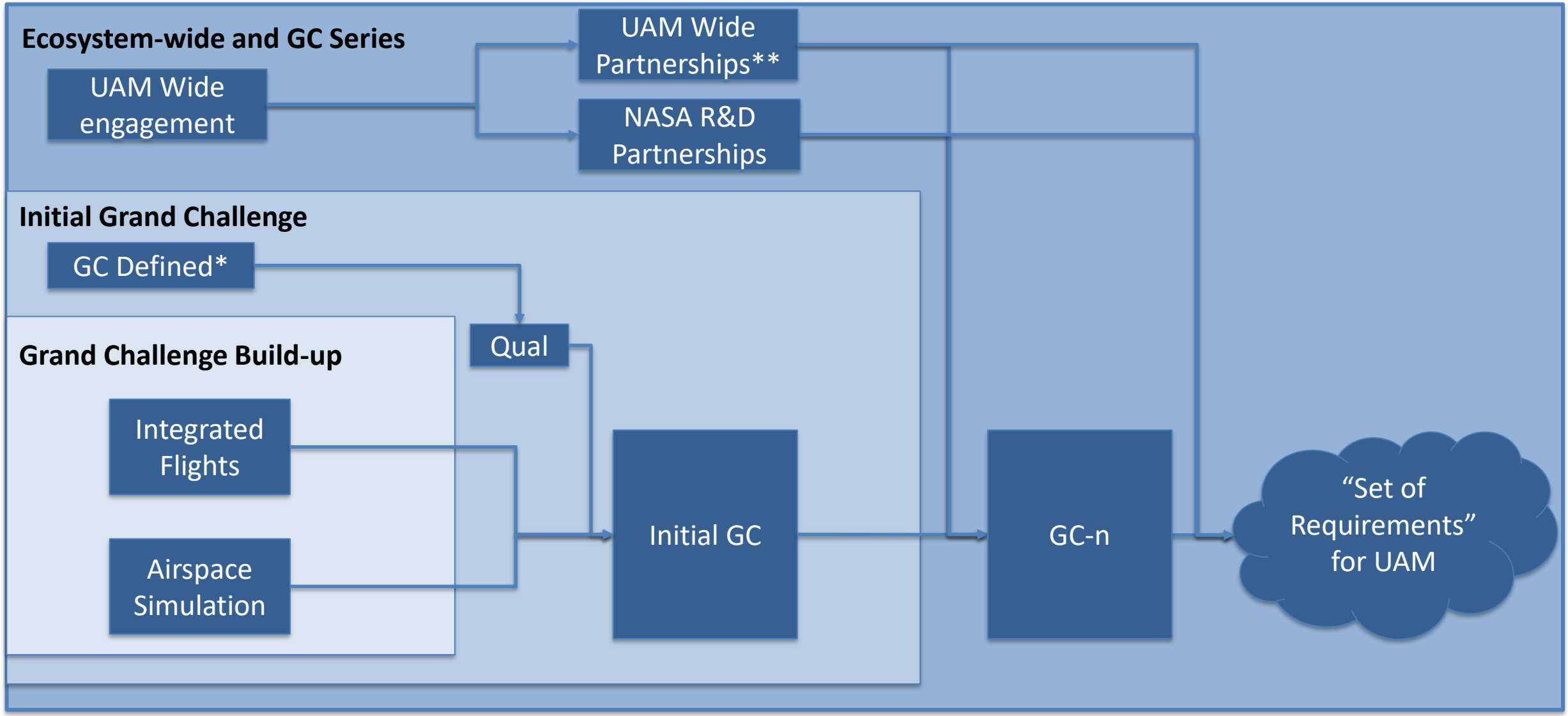
- Vehicle and airspace systems come together to fly high-priority integration scenarios
- Checkout Initial GC flight scenarios to verify mission and success criteria

Interoperability Build-up with Airspace

- Define common interfaces
- Simulations to checkout integrated services before Initial GC
- Checkout of end-to-end services that will eventually demonstrate requirements for scalable UAM ops

Activities necessary to ensure NASA builds a successful Initial Grand Challenge and provide Industry an opportunity to demonstrate airspace interoperability

NASA Proposed UAM Partnership Strategy



*Continue to work future GC definition through collaborative partnership workshops

** NASA recognizes it will not be involved in all UAM wide partnership activities

Summary

- NASA believes we understand the needs of the UAM community and we are implementing early efforts to address areas where NASA can have a high impact
- The UAM Grand Challenge is a solutions oriented pathway that requires a critical mass of industry to accelerate UAM
- NASA is robust in our Grand Challenge planning and ready to begin executing
- NASA is implementing a robust research portfolio that we will work in partnership with the industry, and focus on accelerating critical elements of UAM

Acronyms

AAM	Advanced Air Mobility
AC	Aircraft
AIA	Aerospace Industries Association
ARMD	Aeronautics Research Mission Directorate
ARTR	Aeronautics Research and Technology Roundtable
ASTM	ASTM International, formerly known as American Society for Testing and Materials
ATC	Air Traffic Control
ATM	Air Traffic Management
ATM-X	Air Traffic Management-eXploration
C^2	Command and Control
CC	Critical Commitment
Cert	Certification
CNS	Communication, Navigation and Surveillance
CNSI	Communication, Navigation, Surveillance, and Information
Comm	Communication
CONOPS	Concept of Operations
DAC	Drone Advisory Council

Acronyms

DFW	Dallas/Fort Worth International Airport
DOT	Department of Transportation
eVTOL	Electric Vertical Takeoff and Landing
ExComm	Executive Committee
FAA	Federal Aviation Administration
FDC	Flight Demonstrations and Capabilities
GAMA	General Aviation Manufacturers Association
GC	Grand Challenge
IPP	Integration Pilot Program
LA	Los Angeles
M&S	Modeling and Simulation
MOC	Means of Compliance
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
OAA	Office of Associate Administrator
OEM	Original Equipment Manufacturer
OGA	Other Government Agency

Acronyms

Ops	Operations
Pax	Passenger
PM	Project Manager
Qual	Qualification
R&D	Research and Development
RFI	Request for Information
RVLT	Revolutionary Vertical Lift Technologies
sUAS	Small Unmanned Aircraft Systems
SWS	System Wide Safety
TBD	To Be Determined
TC	Type Certificate
TRB	Transportation Research Board
UAM	Urban Air Mobility
UAM TM	Urban Air Mobility Traffic Management
UAS	Unmanned Aircraft System
UAST	Unmanned Aircraft Safety Team

Acronyms

UCAT	UAM Coordination and Assessment Team
SE	Systems Engineering
SME	Subject Matter Expert
SPMR	Strategic Portfolio Management Review
TTT	Transformative Tools & Technologies
UML	UAM Maturity Level
UPP	UTM Pilot Program
US	United States
UTM	Unmanned Aircraft System Traffic Management
V&V	Verification and Validation