NASA Aeronautics Research Mission Directorate (ARMD)
Urban Air Mobility (UAM) Grand Challenge Industry Day
Nov 1-2, 2018
Welcome, Logistics, and Industry Day Goals
Nancy Mendonca, Research Portfolio Manager, NASA Aeronautics Research Mission Directorate

Nov 1-2, 2018
Our goals for this event are to:

Communicate goals of Grand Challenge Series.

Provide details on current plans so that participants can provide input to improve the series.

What, Where, When, Why, How....

Who – will you join us?

Introduce Request For Information and government processes, contracting teams, program managers, and other relevant NASA points of contact.

Improve communication across the community.
Industry Day Participants

- **47** Aircraft Developers
- **23** Comm/Nav/Surveillance Providers
- **22** Integrated Automation & Operations Developers
- **18** ATM Developers (both traditional and UAM)
- **12** Universities
- **10** Fleet Operations Providers
- **10** Test Site Representatives
- **8** Manufacturers
- **6** Propulsion System Developers
- **5** Media
- **5** Federal Agencies
- **5** Local Governments
- **5** Airspace Designers
- **3** Vertiport Designers
- **2** Trade Associations

As of October 23, 2018
Questions?

Today’s Industry Day materials will be posted on FBO ARMD Urban Air Mobility Grand Challenge Request for Information (RFI)
https://www.fbo.gov
Search Solicitation Number: 18AFRC19S0001
Overview of Aeronautics Vision

Dr. Jaiwon Shin, Associate Administrator, NASA Aeronautics Research Mission Directorate

Nov 1, 2018
DAWN OF A NEW ERA OF AVIATION

Jaiwon Shin
NASA HQ
November 1, 2018
Building the NASA Aeronautics Strategic Implementation Plan
Analysis and Stakeholder Dialogue – 2013 Rollout, 2017 Update

Key Trends (Not Exhaustive)

Increasingly Urbanized World
Rising Global Middle Class Driven by Asia-Pacific
Urban Transportation Increasingly Congested

Continuing Pressure to Reduce Noise and Local Air Quality Impacts
Aviation Industry Sets Challenging CO₂ Reduction Goals through Mid-Century

Networked Com and Sensors, Embedded Artificial Intelligence, and Big Data Converging with Traditional Systems and Technologies
On-Demand Service Models Disrupting Traditional Industries

Aviation Mega-Drivers

Analysis & Community Dialogue

Industry / Gov’t Execs What’s Needed?
Industry / Gov’t SMEs What’s Possible?

Community Vision

Safe, Efficient Growth in Global Operations
Innovation in Commercial Supersonic Aircraft
Ultra-Efficient Commercial Aircraft
Transition to Alternative Propulsion and Energy
In-Time System-Wide Safety Assurance
Assured Autonomy for Aviation Transformation

www.nasa.gov
A New Era of Flight is Emerging

NASA Aeronautics’ vision and leadership have stimulated national and international aviation and non-aviation communities to pursue a new era of aviation

NASA led the U.S. community with the UAS Traffic Management (UTM) & UAS in the NAS projects
- Integration of commercial systems is now beginning to emerge
- UTM is now the accepted concept all over the world

Urban Air Mobility (UAM) is fast on the heals of UAS integration
- U.S. industry looking for NASA leadership now to help overcome key barriers
A New Era of Flight is Emerging

NASA Aeronautics’ vision and leadership have stimulated national and international aviation and non-aviation communities to pursue a new era of aviation.

Industry innovation in the reemergence of supersonic flight is underway
- NASA must sustain aggressive schedule to complete overland supersonic noise database and enable overland supersonic flight.

NASA studies, research and advancements in Electric Aircraft have led to an acceleration of U.S. industry interest and investment.
- Focused effort to bring MW level power and propulsion to flight demonstration is now the highest priority for future generation air transport.
Urban Air Mobility Rapidly Developing

Just in This Year........

- 2\textsuperscript{nd} Uber Elevate Summit in L.A.
  - Attended by well over 1,000 people with Uber announcing the new 6th vehicle development partner, Karem Aircraft in addition to the five existing partners (Aurora Flight Sciences, Embraer, Bell, Pipistrel Aircraft, and Mooney)

- Boeing announces formation of Boeing NeXt at Farnborough Air Show to take a lead position in Urban Air Mobility
  - Leverage Boeing HorizonX and acquisition of Aurora Flight Sciences to accelerate progress

- Rolls Royce and Aston Martin announced plan to develop UAM vehicles at Farnborough Air Show

- Airbus formed a new UAM business unit in May

- Japanese government announced a plan to invest $40M to accelerate UAM development

- Well funded new entrants continue vehicle development and flight test
  - Kitty Hawk Cora, Joby S4, Terrafugia TF-2, Lilium Jet, etc
NASA Leadership in Urban Air Mobility

- Demonstrated community leadership with UTM and UAS in the NAS
- Major market studies with McKinsey and Booz Allen
- ARMD led systems studies and industry roadmapping activities
- Formation of National Academies Aeronautics Research and Technology Roundtable (ARTR) focused on UAM
- Cross Program and Center Coordination was chartered
  - Urban Air Mobility Coordination and Analysis Team (UCAT)
  - Achieved significant progress in developing ARMD UAM strategy and planning UAM Proving Ground and Grand Challenge series
  - First Grand Challenge planned for FY 2020
- Industry Day is organized
- Programs/Projects actively pivoting research portfolio to address key UAM Issues
  - ATM-X, SWS, RVLT, etc
Vehicle concept credit: Aurora Flight Sciences

- Safety Standards
- Certification
- Methods and Costs
- Infrastructure
- Noise and Visual Barriers
- Cybersecurity
- Privacy
FAA Remarks  *(no slides presented)*

Earl Lawrence, *Executive Director, UAS Integration Office*

Nov 1, 2018
Grand Challenge Overview
Davis Hackenberg, UAM Strategic Advisor, Aeronautics Research Mission Directorate

Nov 1, 2018
Commercial Operating Environments (OE)

**High Altitude Long Endurance**
- FL-600
- Cooperative Traffic

**IFR-Like**
- 18K MSL
- Cooperative Traffic

**VFR-Like**
- 10K MSL
- Cooperative Traffic
- Non-Cooperative Traffic

**Top of Class G**
- Hot air Balloon
- Helicopters
- GA Aircraft

**Low Altitude Rural**
- Cooperative Traffic

**Low Altitude Urban**
- 500' AGL
- Terminal Airspace
- Airport

**Top of Urban Airspace**
- 500' AGL
- Urban Passenger Transport

- Cooperative Traffic
ARMD has funded two Urban Air Mobility market studies that included several air taxi/metro models, air ambulance, and last-mile package delivery.

Studies include:
- A range of urban areas and business models, technology requirements, legal and regulatory barriers, social acceptance issues
- Assumptions for issues such as autonomy, batteries, weather, infrastructure, operating costs, passenger adoption rates, etc.

Generally speaking, UAM markets were found to have viable and profitable use cases.
- By ~2028 “air metro” could be profitable and by ~2030 result in ~750M annual passenger trips in 15 metro areas
- 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
- Large variability across studies based on differences in assumptions, e.g., infrastructure
UAM Reference Missions

Non-Passenger Carrying Reference Missions
- INITIAL STATE: e.g. PUBLIC SAFETY VEHICLES
- INTERMEDIATE STATE: e.g. SMALL PACKAGE DELIVERY
- MATURE STATE: e.g. UAS MULTI-PACKAGE DELIVERY

Passenger Carrying Reference Missions
- INITIAL STATE: e.g. AIR MEDICAL TRANSPORT
- INTERMEDIATE STATE: e.g. INTRA-METRO AIR SHUTTLE
- MATURE STATE: e.g. UBIQUITOUS INTRA-METRO TAXI
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.
### Community Landscape - Passenger Carrying Focus

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<td>Boeing</td>
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<td>Malaysia (ATC)</td>
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### Decision Makers
- **National/International**
  - Mayors/City Councils/Boards of Supervisors
  - Tribal Councils
  - Departments of Transportation
  - National League of Cities (2000+ cities, 49 states with additional cities)
  - Port Authority (of various big cities)
  - US Conference of Mayors
  - National Governors Association
  - European Aviation Safety Agency (EASA) (Europe)
  - European Organization for Civil Aviation Equipment (EUCJAE) (Europe)

### Influencers
- Chambers of Commerce
- Eurocontrol (Europe)
- FAA/IFP: Chockat, San Diego, IEA (VA), KS DoT, Ft Myers (FL), Memphis Airport (TN), NC DoT, NY DoT, Reno (NV), UAF (Fairbanks, AK)
- Uber

### Influencers (Domestic)
- American Association of Airport Executives (AAAE)
- American Institute of Aeronautics and Astronautics (AIAA)
- American Insurance Association
- Aircraft Owners and Pilots Assoc (AOPA)
- Association of Medical Services
- Commercial Drone Alliance
- Coalition of UAS Professionals
- Environmental Groups (e.g. Sierra Club)
- Experimental Aircraft Association (EAA)
- NASA
- National Academies-Transportation Research Board
- National Institutes of Standards and Technologies (NIST)/Smart Cities
- National Transportation Safety Board (NTSB)
- Vertical Flight Society (AHS)

### Influencers (Global)
- Airports Council International (ACI) Association for Unmanned Vehicle Systems International (AUVSI)
- Civil Air Navigation Services Organization (CANSO) – ANSP providers
- Center for Environmental Performance, WWF
- General Aviation Manufacturers Association (GAMA)
- International Air Transport Association (IATA) - Airlines
- International Telecommunication Union (ITU)
- Joint Authorities for Rulemaking on Unmanned Systems (JARUS)
# UAM State of the Art Assessment

*Draft*

## Intermediate State

**REFERENCE MISSION TWO – PASSENGER-CARRYING**

### Pillar

<table>
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<tr>
<th>Capability / Discipline</th>
<th>Low maturity</th>
<th>Medium maturity</th>
<th>High maturity</th>
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<td>Airspace design</td>
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<td>Flight procedures development</td>
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<td>Vertiport design</td>
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<td>ATM automation development</td>
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<td>Fleet operations</td>
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<td>Community integration</td>
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#### Aircraft developers
- Airframe developers
- Propulsion
- Battery/power
- Manufacturing

#### Integrated automation & aircraft operations
- Integrated automation & aircraft operations
- Avionics & automation: DAA
- Avionics & automation: AMM

#### Subsystems:
- Communications
- Navigation
- Surveillance
- Airspace design
- Flight procedures development
- Vertiport design
- Cybersecurity

#### Airspace, air traffic, & fleet operations management
- Airspace test sites
- Traditional ATM suppliers
- Flight services providers
- Airspace service providers
- ATM automation development
- Fleet operations

#### Community integration

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**AMM** — Automated Mission Management

**DAA** — Detect and Avoid
UAM Maturity Levels (UML)

**INITIAL STATE**

**UML-1**
- Early Operational Exploration and Demonstrations in Limited Environments
  - Aircraft certification testing and operational evaluations; traditional airspace and procedures; exploratory community demos and data

**INTERMEDIATE STATE**

**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 corridors through controlled airspace

**UML-3**
- Low Density, Medium Complexity Operations with Comprehensive Safety Assurance Automation
  - Operations into urban core; operational validation of airspace, UTM inspired ATM, CNS, C^2, and automation for scalable, weather-tolerant operations; closely space UAM pads, ports; noise compatible with 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 high-capacity UAM ports; many UTM inspired 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 UTM inspired 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 (limited by physical infrastructure, scaled ATM); essential ownership models enabled, ad hoc landing sites; noise compatible with suburban/rural operations; societal expectation

*Draft*
The UAM “Grand Challenge”

• Challenging the industry to execute ecosystem-wide systems level safety and integration scenarios

• Raises the water level for all

• 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 realistic UML-4 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.
Vehicles
functional UAM vehicles with threshold level of demonstrated airworthiness

NASA Systems & Interfaces
UTM interfaces through Testbed

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, realistic UML-4 scenarios, and a range(s) designed in concert with the FAA to support UAM testing

Stakeholder Integration
societal integration and acceptance of UAM Operations including public acceptance, supporting infrastructure, operational integration, standards organizations, the local regulatory environment, etc.
GC Vehicle and Airspace Management Participants

**Vehicles**

- functional UAM vehicles with threshold level of demonstrated airworthiness

- Provide vehicle design and development data to support airworthiness approvals

- Conduct “experimental” class flights to benchmark vehicles and demonstrate ability to handle simple failures and contingencies

- Conduct Safety and Integration Scenarios for Grand Challenge including pre-defined interfaces with Airspace Management systems

**Airspace Management**

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

- Provide UAM ATM technologies that meet initial ATM-X provided requirements and Interface Control Documents (ICD)

- Demonstrate capabilities will meet the ICD benchmark and contingency simulations or live testing

- Conduct Safety and Integration Scenarios for Grand Challenge including pre-defined interfaces with vehicle systems
Grand Challenge Test Scenarios

- **Design Readiness Reviews**
- **GC-2 Airspace Qualification Scenarios**
- **GC-1 Scenarios (Qualification at Participant Location)**
- **GC-2 System Scenarios**
- **Future GC Series Scenarios**

- **Weather**
- **Cyber-Security**
- **Conditional Autonomy**
- **Cabin Acceptability**
- **Automatic Recovery**
- **Crashworthiness**
- **Fleet Management**
- **Others...**

- **Human Autonomy Teaming**
- **Scalability**
- **CNS Contingencies**
- **Conflict Management**
- **Trajectory Planning and Compliance**
- **Vehicle and ATM Interoperability**
- **UAM Ports and Approaches**
- **Noise Evaluation and Acceptance**

- **Vehicle Design Robustness** (V)
- **Vehicle Design Readiness** (V)
- **Airworthiness** (V)
- **System Connection** (A)
- **System Simulation** (A)
- **System Design Documentation** (A)

- **V: Vehicle**
- **A: Airspace**
Grand Challenge Series progresses through scenarios that increase in number, complexity, technology readiness, operational readiness, and standards and regulatory emphasis.
### Stakeholder Integration

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

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<tr>
<th>Stakeholders</th>
<th>Grand Challenge Relationship</th>
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<tr>
<td>Supporting infrastructure</td>
<td>Infrastructure elements such as vertiports and charging stations could be provided by stakeholders</td>
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<tr>
<td>Local communities</td>
<td>Opportunities to perform in local communities via ranges and Test Sites. Considering surveying and other public acceptance campaign initiatives</td>
</tr>
<tr>
<td>Operational integration</td>
<td>Connectivity and infrastructure requirements for smart city initiatives, multi-modal, etc.</td>
</tr>
<tr>
<td>Standards organizations</td>
<td>Strategic partnership with standards organizations to support development of a complete requirement and standards set to enable UAM vehicles, airspace, vertiports, infrastructure, etc</td>
</tr>
<tr>
<td>Local government</td>
<td>Local regulators will have the opportunity to assess complete lists of current local regulations and consider ways to approach legislation and long-term planning consideration for the future</td>
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This activity includes drafting Space Act Agreement (SAA) templates, participants identifying the desire to sign an SAA, the negotiation and signing of specific SAAs.

Participants signing SAAs will begin qualification scenarios and NASA's Airworthiness (A/W) process. The process has to be completed prior to flying in GC-1. There are additional follow-on requirements that will occur before each GC flight.

Future challenges in this series are anticipated to address key safety and integration barriers across the UAM ecosystem while also emphasizing critical operational challenges.

This would be for participants new to the Grand Challenge desiring to participate in GC-2 or, if needed, to update SAAs with GC-1 participants continuing on to GC-2.
Questions?
NASA and FAA Grand Challenge Panel
Dr. Michael Romanowski, Earl Lawrence, Steve Bradford, Jay Dryer, Dr. Parimal Kopardekar

Nov 1, 2018
Request for Information (RFI) Overview

Dr. Colin Theodore, Associate PM, Technical Integration for the Revolutionary Vertical Lift Technology (RVLT) Project

Nov 1, 2018
Primary Goals of RFI Process

• Gauge the level of interest from the UAM community in participating in the Grand Challenge, their ability to bring vehicle, airspace and infrastructure assets, and their anticipated capabilities.

• Allow the government to assess the state-of-the-art of the UAM ecosystem, including vehicle development, airspace capabilities development, and community integration.

• Collect industry and broader community input to help refine and optimize the Grand Challenge to best enhance and add value to industry efforts in accelerating UAM.
RFI Respondent Expectations

The RFI is seeking responses from the entire UAM community and stakeholders:

• UAM vehicle developers/operators
• Aircraft sub-system developers
• Ground station system and vehicle command and control developers
• UAS avionics and middleware industry representatives
• Airspace system developers and airspace service providers
• Ground and aircraft sensor manufacturers
• Communication/navigation/surveillance service and equipment providers
• Test range operators and other entities that could provide a test range
• Ground infrastructure (e.g., UAM port) developers and operators
• Other organizations: local and state governments, universities, Smart Cities, etc.
• Additional UAM stakeholders
RFI Questionnaire

• Most Important Questions:
  – Do you plan to participate in the Grand Challenge Series, in particular GC-1?
  – Comment on the timing of the Grand Challenge with GC-1 targeted for ~late 2020.
  – Describe the elements of the Grand Challenge that are most important to you.

• More focused questions:
  – Describe what capabilities you could bring to the Grand Challenge, in particular GC-1.
  – Which scenarios can your company/organization complete or contribute to?
  – Provide any feedback, comments, suggestions that would be helpful to NASA in preparing the Grand Challenge.
  – UAM Vehicle Developer & Airspace System/Service Provider specific questions.
  – Additional UAM Stakeholder Community members: Ground Infrastructure, Range, Local Governments and “Smart Cities”.

Grand Challenge Development Timeline

- RFI Released: October 15, 2018
- Grand Challenge Industry Day: November 1-2, 2018
- RFI Responses due: November 16, 2018
  - Submit responses in electronic format (Microsoft Word/PowerPoint, PDF)
  - RFI responses to be submitted by email – Email addresses provided in RFI
  - All responses will be treated as proprietary and confidential
  - *This is your best chance to influence the Grand Challenge process*
- Webinar for Grand Challenge Updates: ~January 2019
- Public Notice: ~March 2019
- Partnership Agreements Signed: ~July 2019

**GC-1 Execution: ~Late 2020**
Scenarios and Approach Panel
Dr. Michael Patterson, Starr Ginn, Karen Cate, Ken Goodrich

Nov 1, 2018
Scenarios and Approach Introduction and Overview

Dr. Michael Patterson, Lead Analyst for the Urban Air Mobility Coordination and Assessment Team
michael.d.patterson@nasa.gov

Nov 1, 2018
Grand Challenge (GC) Mission and Goal

**GC Mission**
Purpose for those in the organization and the public

Promote public confidence in UAM safety and facilitate community-wide learning while capturing the public’s imagination

**GC Strategic Goal**
What does the GC do for the UAM community?

UAM community participants address ecosystem wide safety and integration barriers in a robust and relevant environment

**Why Participate?**

Obtain critical insights into UAM systems via realistic scenarios focused on enabling future FAA safety, certification, and operational approvals
Grand Challenge Test Scenarios

- GC-1 Scenarios (Qualification at Participant Location)
- GC-2 Airspace Qualification Scenarios
- GC-2 System Scenarios
- Future GC Series Scenarios

- Weather
- Cyber-Security
- Conditional Autonomy
- Cabin Acceptability
- Automatic Recovery
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- Human Autonomy Teaming
- Scalability
- CNS Contingencies
- Trajectory Planning and Compliance
- Vehicle and ATM Interoperability
- UAM Ports and Approaches
- Conflict Management
- Noise Evaluation and Acceptance

- Vehicle Design Robustness
- Vehicle Design Readiness
- Airworthiness
- System Connection
- System Design Documentation

V: Vehicle
A: Airspace
Selection of GC-1 Scenarios

• Selecting fundamental items for practical, safe individual vehicle operations
• Initial challenge of series – “crawl, walk, run”
• Results of GC-1:
  – Help move vehicles toward certification
  – Initial tests of vehicle to airspace system connection
  – Data to inform standards, means/methods of compliance, and airspace management system development
Selection of GC-2 Scenarios

- Exploring fundamental items for safe multi-vehicle operations and interoperability between vehicles and airspace systems

- Stressing important items that need to be:
  - Solved prior to adding further complexity
  - Thought about earlier rather than later (e.g., noise)

- Results of GC-2:
  - Increased maturity of vehicles and airspace systems, including demonstration of vehicle-airspace system interoperability
  - Inform needs/desires/standards for future airspace systems
Scenarios and Approach Panel: Vehicle
Starr Ginn, Deputy Aeronautics Research Director

Nov 1, 2018
Mission Task Elements - Fundamental Building Blocks

- Identify the relationship between aircraft performance and flight characteristics
- Means of demonstrating compliance
- Evaluate the robustness and operational readiness of vehicle designs
- Inform future certification standards and operational procedures

MTE 1 – All Azimuth capability
MTE 2 – Taxi
MTE 3 – Takeoff Performance
MTE 4 – Level Flight
MTE 5 – Flight Path Changes
MTE 6 – Approach/Landing
MTE 7 – Landing – Quick Refuel (charge) – Takeoff
MTE 8 – Energy Storage, Battery Capacity
MTE 9 – Function & Reliability Demonstration
MTE 10 – Precautionary Landing
MTE 11 – Balked Landing
MTE 12 – Takeoff Failure Case
MTE 13 – Approach/Landing Failure Case
Overview of GC-1 Test Scenarios

- Scenario 0-V – Vehicle Airworthiness
  - Airworthiness and Flight Safety Review - AFG-7900.3-001
  - Company provided standards will be evaluated against margins of aircraft design. Hazard severity and mitigations will be evaluated.
  - Appendix B – Sample Questions for Review Board Members

- Scenario 1-V – Vehicle Design Readiness
  - Vehicle performance and flight envelope characterization for nominal mission attributes
  - Demonstrate ability to transmit state and intent data, including 4D flight plan

- Scenario 2-V – Vehicle Design Robustness
  - Demonstrate ability to safely mitigate simple vehicle failures and contingencies

Independent surveillance of Mission Task Elements, will be evaluated through a variety of dynamic environmental conditions
Scenarios and Approach Panel: Airspace
Karen Cate, Deputy Branch Chief, Aerospace Simulation Research and Development
Nov 1, 2018
Overview of GC-2 Test Scenarios

• Scenario 0-A – System Design Documentation
  – Evaluate airspace system assumptions and design documentation

• Scenario 1-A – System Connection
  – Verify airspace system integration through ingestion of (live) vehicle and range data

• Scenario 2-A – System Simulation
  – Demonstrate and verify functionality of the airspace system and components in simulation
Overview of GC-2 Test Scenarios

- **Scenario 3 – Trajectory Planning and Compliance**
  - Demonstrate flight planning that accommodates ATM and vehicle constraints, and precision of vehicle trajectory conformance to the flight plan

- **Scenario 4 – Vehicle & ATM Interoperability**
  - In-flight re-planning, negotiation and execution that accommodates ATM and vehicle constraints, and responds to real-world uncertainties

- **Scenario 5 – CNS Contingencies**
  - Identification, mitigation and response to contingencies related to degradation/loss of primary vehicle navigation, vehicle and airspace communications, and/or airspace surveillance
Overview of GC-2 Test Scenarios

• Scenario 6 – Noise & Community Acceptance
  – Evaluate vehicle noise and acceptance through typical UAM mission flight profiles

• Scenario 7 – UAM Ports & Approaches
  – Develop scalable UAM Port design and procedures, and explore influencing factors

• Scenario 8 – Conflict Management
  – Demonstrate individualized components of traffic conflict management
**Est DEP 14:03:45**
**Act DEP 14:04:24**

**Est ARR 14:29:30**
**Act ARR 14:32:42**

**Est Windspeed 10 kNT**
**Act Windspeed 13 kNT**

VFR

CLR
Scenarios and Approach Panel: Community

Ken Goodrich, Senior Researcher
k.goodrich@nasa.gov
Nov 1, 2018
Community Integration

• Federal government directly regulates airspace and airspace operations

• And, states and local government / communities determine where aircraft can takeoff and land, through a variety of mechanisms such as
  – Land use, zoning
  – Building codes and other requirements
  – Environmental regulations
  – Community referendums
  – Congressional representation
From edges...
Community Integration

...to core...

Google Street View, Los Angeles
Community Integration

...to anywhere & any condition
Community Integration Barriers Identified by NASA

Not a traditional area for NASA, seeking community inputs & partners

1) Public Acceptance (avoiding NIMBY)
   - Safety (air and ground)
   - Noise (auditory, visual)
   - Privacy
   - Personal and public benefit

2) Infrastructure
   - UAM port standards, flight procedures, obstruction clearance requirements for all-weather operations
   - Supporting ground infrastructure standards (e.g. building & fire codes)
   - Electrical grid and generation
   - Etc....

3) Mobility integration
   - Door to door, not just port to port

4) Local regulation
   - Recommended practices, meeting local needs, tailorable to preferences
Grand Challenge RFI: Community Inputs

• Are we asking the right questions for your community to understand and integrate UAM?

• What data is needed to help answer these questions?

• How do you think NASA working with the broader UAM community can help answer these questions?
  – What role can the Grand Challenge series play?

• Is your community interested in being part of the Grand Challenge?
  – What could that participation look like?
NASA Grand Challenge Industry Day
Airworthiness, Safety, Certification, and Operations Panel

Wes Ryan, UAS Certification Policy Lead, Aircraft Certification
FAA Policy and Innovation Division
Our Opportunity

• Collaboration between Industry, FAA, and NASA to advance development & certification for EVTOL/UAM
• Accelerate development for new entrants, particularly in areas where core technical/certification challenges exist
• Gather/apply knowledge and lessons learned into our efforts to develop certification requirements and integration strategies for UAM and future flight concepts
• Focus on readiness for operational use by standardized testing while identifying common requirements
Similar Benefits To Past Collaboration

• AGATE – Led to Revolution in GA, but took 20 years
• SATS – Before its time, but showed that technology can improve GA safety – led to many Cirrus SR-22 features
• ODM/Urban Air Mobility/Uber Elevate – “If we build it, they will come” mentality from 5 years ago taking root in Uber Elevate - Use Technology to Enhance Safety
• Grand Challenge – Proactive collaboration to accelerate UAM and Core Technology Requirements
How We Will Leverage Each Other

- Discuss Role in Each Phase of Project
- “Better Together” Coordination
- Warranted by New/Novel Design and Safety Challenges
- Leverage Individual Strengths
Proposed NASA & FAA Process Relationship for Challenge

Grand Challenge “Scenario Roadmap” Rosetta Stone

**NASA**

- **Design Readiness**
  - NASA 7900.3D CH1

- **Design Robustness**
  - NASA 7900.3D CH2

- **Operational Suitability**
  - NASA 7900.3D CH3 & 4

**FAA**

- **Basic Airworthiness**
  - FAA Order 8130.34D
  - Outcome: Determination of Condition for Safe Flight – “Crew Rated”

- **Design Certification**
  - FAA Order 8110.4C
  - Outcome: Identify Design Issues, Airworthiness Requirements, Means of Validating Design + Performance (i.e. Subpart B)

- **Operational Approval**
  - Aircraft Evaluation Group
  - Outcome: Identify Operational/Performance Issues, Pilot Training Requirements, Suitability for Real World Use

**Type Certification & Operational Readiness**
FAA Efforts To Enable UAM/ETVOL Certification

• Regulatory improvements –Part 23 & FAST Team
  – Performance-based regulations - top-level safety goals
  – Customizable design/certification requirements through collaborative Means of Compliance

• Standards for Electric Propulsion/lift systems
  – Developing Requirements & Experience in UAS
  – Recognize potential safety/efficiency benefits

• Augmented flight path control & automation (“Autonomy”)
  – R&D and Collaboration for best practices, design requirements, architecture with industry, NASA, academia
  – Gradual transfer of pilot responsibility/workload to Automation
Leverage Core NASA Expertise

• Loss of Control Standard – Utilize their expertise in dynamic stability & handling qualities
• Safety Risk Analysis – Safety Targets for equipment and Operational Performance, i.e. NOT 10E-9
• GAMA SVO – Decomposition of Pilot Function – methodical replacement with assured autonomy
• X-57 – Verify Core Design for EP and Motor Controls
• Flight Control Standards – Core Design, V&V, etc.
• Structural Dynamics & Aero elasticity – Unique Configs.
ERA OF SIMPLIFIED VEHICLE OPERATIONS

Workload

2000's - Today

Integrated Cockpit
Federated Cockpit

Simplified Cockpit

Front Row Seats

Automation
Is Evolution or Revolution the Right Methodology?

- Some are Convinced they can jump straight to full automation without a human pilot in the loop “flying” the aircraft.
- Others recognize the challenge of replacing the pilot on board with an automated system that is reliable enough to handle all actions typically done by the pilot and the controller for all phases of flight.
Challenge - Humans/Machines Safely Trading Roles

- Humans/Machines Safely Trading Roles
  - Workload/Integrity of Function
  - Human Function
  - Automation Function
  - Reduced Pilot Error/Operational Error
  - Pilot Mitigates Risk
  - Automation Mitigates Risk
  - Velocity of Change
  - Time
  - Current Systems
  - Future Systems
  - Future Safety Gain?
    - Automation Replacing Humans
    - Automation May do More Than Human Capability
    - What Will Residual Future Roles Be?
    - Human as Safety Monitor
Airworthiness, Safety and Certification Panel: Airworthiness
Brad Neal, Chief Engineer at NASA's Armstrong Flight Research Center
Nov 1, 2018
Armstrong AFSR Process Applied

One Process Many Applications
Airworthiness and Flight Safety Process

• Our goal is to provide a flexible, risk management based review process that...
  – Provides an airworthy vehicle that can be operated safely with the highest probability of mission success
  – Assesses, Communicates and Accepts the residual risks of vehicle test and operation

• This allows the project team to...
  – Select appropriate standards to design and build hardware, software and systems
  – Develop systems, test, procedures and documents, that will allow the project to validate those systems and meet its technical objectives
  – When the project believes it has accomplished sufficient validation in preparation for flight, it presents its plans and rationale for flight readiness to the appropriate reviewing body
Airworthiness and Flight Safety Process

Project Life Cycle

System Engineering Reviews

- Formulation
- Design
- Fabrication, Integration and Testing
- Flight/Test Operations

Airworthiness Reviews

- Airworthiness and Flight Safety Review
- Flight Readiness Review
- Critical Design Review
- Preliminary Design Review
- System Requirements Review
- Mission Concept Review

NASA-led technical working group(s) will shepherd the NASA airworthiness and flight safety review process
Airworthiness, Safety and Certification Panel: Safety
Dr. Natasha Neogi, NASA Research Scientist, SWS, UAS-NAS, TTT and Autonomous Systems Project

Nov 1, 2018
• Safety must be designed into a system.
• Safety is an integral part of a system.
• Safety cannot be inspected into a system.
  – OEM/certificate holder is ultimately responsible for safety and safety management processes. (e.g., SMS etc.)
Primary aim of aircraft certification (Part 21 etc.) is to provide assurance of safety by: (1) assuring that items perform their intended (safe) functions under any foreseeable operating condition, and (2) assuring that unintended functions are improbable.
Safety Argument—Evidence Based Safety

- Demonstrate satisfaction of safety objectives derived from hazard analysis
- Justify acceptability of safety based on product-specific and targeted evidence
- (Potentially) justify the determination of objectives and the selection of evidence

“A Safety Case is a structured argument, supported by a body of evidence, that provides a compelling, comprehensible and valid case that the system is safe for a given application in a given operating environment.”

A Safety Claim is a Proposition over variables:

- **This system** deployed in
- **This environment** meets
- **These criteria**

Safety Assurance Case:

Decomposed, traceable, integrated, organized support for this proposition
Safety Assurance Case—CD&R Sample (GC-S8)

- **Claims (goals), arguments** (inferences, strategies, warrants), **evidence** (data)
  - Decomposition
  - Binding and supporting
- **Top-level goal**
  - NASA to develop ‘Hazard Templates’ for relevant GC scenarios (root node)
- **Formats and notations**

Diagram:
- **Conflict Detection and Resolution System** deployed in **Medium Density, Medium Complexity, Urban Environment**
- **10^6 NMACs per flight hour (target)**
- **1.1 CD&R System mitigates NMACs to target**
- **2.1 CD&R Argument over detection and resolution function correctness**
- **3.1 Detection Correctness**
- **3.2 Resolution Correctness**
- **Sensor Test Report**
- **MD/FA Analysis**
- **Formal Proof**
- **Encounter Scenario Simulation**
Airworthiness, Safety and Certification Panel: Autonomy

Mark Ballin, Strategic Technical Advisor for NASA’s Transformative Aeronautics Concepts Program

Nov 1, 2018
Autonomy and UAM

• Autonomy: The ability of a system to achieve goals while operating independently of external control*
  – NOT artificial intelligence (AI), but may make use of AI methods
  – NOT automation, but often relies on automation as a building block

• UAM Need for Autonomy: Safe and Viable Systems that Scale

Examples:
  – Evolve from requiring expert pilots for each aircraft to remote supervision of many vehicles by a small number of people
  – Manage high volumes of UAM traffic by removing bottlenecks inherent in direct use of air traffic controllers

*From NASA Autonomous Systems Taxonomy, NASA Autonomous Systems coordination team (AS-MCLT)
Many Autonomy Challenges

• Understanding the operational needs for cutting edge automation technologies, and when they will be needed

• Operational trust and certification of comprehensive autonomous systems

• Redefinition of human operator roles and capabilities

• A regulatory framework for UAM operations employing autonomous systems
# UAM Maturity Levels (UML)

<table>
<thead>
<tr>
<th>UML Level</th>
<th>Grand Challenge</th>
<th>Vehicles</th>
<th>Airspace</th>
<th>Community</th>
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<tbody>
<tr>
<td><strong>UML-1</strong></td>
<td>Initial State</td>
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<tr>
<td></td>
<td>Early Operational Exploration and Demonstrations in Limited Environments</td>
<td>• Aircraft certification testing and operational evaluations; traditional airspace and procedures; exploratory community demos and data</td>
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<td><strong>UML-2</strong></td>
<td>Intermediate State</td>
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<td>Low Density and Complexity Commercial Operations with Assistive Automation</td>
<td>• Type certified aircraft; initial Part 135 operation approvals; limited markets with favorable weather and regulation; small UAM network serving urban periphery; UAM corridors through controlled airspace</td>
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<tr>
<td><strong>UML-3</strong></td>
<td>Maturity State</td>
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<td></td>
<td>Low Density, Medium Complexity Operations with Comprehensive Safety Assurance Automation</td>
<td>• Operations into urban core; operational validation of airspace, UTM inspired ATM, CNS, C^2, and automation for scalable, weather-tolerant operations; closely space UAM pads, ports; noise compatible with urban soundscape; model-local regulations</td>
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<tr>
<td><strong>UML-4</strong></td>
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<td>Medium Density and Complexity Operations with Collaborative and Responsible Automated Systems</td>
<td>• 100s of simultaneous operations; expanded networks including high-capacity UAM ports; many UTM inspired ATM services available, simplified vehicle operations for credit; low-visibility operations</td>
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<td><strong>UML-5</strong></td>
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<td>High Density and Complexity Operations with Highly-Integrated Automated Networks</td>
<td>• 1,000s of simultaneous operations; large-scale, highly-distributed networks; high-density UTM inspired ATM; autonomous aircraft and remote, M:N fleet management; high-weather tolerance including icing; high-volume manufacturing</td>
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<tr>
<td><strong>UML-6</strong></td>
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<tr>
<td></td>
<td>Ubiquitous UAM Operations with System-Wide Automated Optimization</td>
<td>• 10,000s of simultaneous operations (limited by physical infrastructure, scaled ATM); essential ownership models enabled, ad hoc landing sites; noise compatible with suburban/rural operations; societal expectation</td>
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*Draft*
Grand Challenge RFI: Desired Autonomy Inputs

• What autonomous system capabilities are needed to make UAM viable?
  – What capabilities do your systems need to provide?
  – What capabilities or services are you expecting from others?
  – How do you envision technology advancing and maturing over time?

• What role could a Grand Challenge event play in gaining information or experience in autonomous systems?
  – Generate and disseminate data?
  – Gain insight into certification and approval approaches?

• What role should NASA play in answering these questions?

• What autonomous systems capabilities can you bring to a Grand Challenge event?
Range and Infrastructure Panel: Infrastructure

Jim Murphy, Technical Lead for NASA’s ATM TestBed, UAS-NAS Live Virtual Constructive Architect
jim.murphy@nasa.gov

Nov 1, 2018
Grand Challenge Infrastructure

Purpose: Provide environment to test candidate UAM aircraft and airspace systems through increasingly challenging scenarios

Challenge: Integrate systems from aircraft, airspace, and range partners and participants

* Google Earth
2020 Grand Challenge (GC-1) Overview

**Vehicles**
functional UAM vehicles with threshold level of demonstrated airworthiness

**NASA Systems & Interfaces**
UTM interfaces through Testbed

**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, realistic UML-4 scenarios, and a range(s) designed in concert with the FAA to support UAM testing

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

- **Indicators**:
  - **Blue**: Industry Provided
  - **Green**: NASA Provided
  - **Purple**: Ecosystem Wide Support
Vehicle Participants

Vehicles
functional UAM vehicles with threshold level of demonstrated airworthiness

- Airworthy Vehicle
- Aircraft Communications
- Integration into Grand Challenge test infrastructure
- Range specific equipment
  - Detect and Avoid operational assumptions
Airspace Participants

- Airspace system operational assumptions to manage UAM traffic
- Interoperability with existing ATM and UTM systems
- Interface to support airspace/aircraft messaging to enable operational assumptions
- Integration of required secondary data (from test range)
Infrastructure Partners

- **Range: Airspace to conduct GC scenarios**
  - Controlled Airspace
  - Vertiport(s)
  - Mission support
  - Support for subset of scenarios may be acceptable

- **Supporting Infrastructure**
  - Communication/Navigation/Surveillance systems
  - Cybersecurity technologies
  - Fuel/Power technologies
  - Intruder aircraft for GC execution
  - Supplementary aircraft for dry-run
  - Advanced weather products
  - Live, Virtual, Constructive technologies

---

**Stakeholder Integration**
societal integration and acceptance of UAM Operations including public acceptance, supporting infrastructure, operational integration, standards organizations, the local regulatory environment, etc.
NASA/Government System & Interfaces

- Aircraft airworthiness processes
- Candidate Test Range: NASA Armstrong
- COA guidance (if needed)

Common Safety and Integration Scenarios
airworthiness processes, realistic UML-4 scenarios, and a range(s) designed in concert with the FAA to support UAM testing

- UAM Scenario definitions
- Test infrastructure for connecting aircraft and airspace systems

Provide system integration support among aircraft, airspace, range partners and participants
2020 Grand Challenge (GC-1) Overview

Vehicles
functional UAM vehicles with threshold level of demonstrated airworthiness

NASA Systems & Interfaces
UTM interfaces through Testbed

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, realistic UML-4 scenarios, and a range(s) designed in concert with the FAA to support UAM testing

Stakeholder Integration
societal integration and acceptance of UAM Operations including public acceptance, supporting infrastructure, operational integration, standards organizations, the local regulatory environment, etc.
Range and Infrastructure Panel: C2 for UAM
Dr. Félix Miranda, Communications and Intelligent Systems Division Deputy Chief
Nov 1, 2018
Grand Challenge Communications Concept

- **Purpose:** Provide necessary communications to conduct Grand Challenge along the following general guidelines
  - Initially supports flights comprised of a single UAM vehicle; on-board or remote pilot
  - Provides RF coverage over the entire Grand Challenge Airspace
  - Anticipate possible beyond line of sight communications, including temporary loss of service
  - Ground Control Station (GCS) will support C2 and voice services
  - C2 and voice links may be provided by integrated or separate radio systems
  - NASA is open to any implementation concepts (e.g., LTE, WiMax, Point-to-Point, etc.) compatible with the above general guidelines and range safety requirements.
Grand Challenge Communication Considerations

• Voice Communication
  – PIC to test Range ATC
  – PIC to Mission Control
  – Certified, aviation-grade voice radios required

• Command and Control (and data)
  – Aircraft to GCS
  – UTM Required Telemetry data
  – Other data (e.g., Telemetry from the DAA subsystem; Status messages from the avionics flight controller; Percentage of charge on the battery during flight; etc.)
  – Measure message latencies
  – Manned aircraft will need C2/datalink radio capabilities for data collection and connection to test infrastructure

• Potential Frequency/Bandwidth Restrictions
  – Lower frequency (i.e. VHF/UHF) radios may be preferred due to range and terrain considerations.
  – May depend on site location; i.e., for a specific range (e.g., Edwards) if OGA is testing with in-band and/or adjacent out of band radios there could be termination of the flight test.
Notional Grand Challenge Communications Responsibilities

NASA/Range Provides the Following:

- Evaluation of permitted radio/sensor frequencies
- Facility for GCS and/or datalink connection to aircraft
- Tower/mast for antennas
- Network interface between GCS and test environment
- Test environment and data recording

Expected From Each UAM Participant:

- Approved VHF/UHF voice radio for pilot’s use (for manned aircraft)
- C2 radio and avionics integration to meet the real-time data requirements
- Software to receive messages from datalink, format, and send to test environment per Interface Control Document (ICD)

• Data Recording Considerations
  – Measure datalink message latencies and packet loss/re-transmissions
  – Measure data throughput
Range and Infrastructure Panel: UAM Airspace Interface
Dr. Min Xue, UTM Task Lead

Nov 1, 2018
Unmanned aircraft systems Traffic Management (UTM)

- Principle: Safely integrating UAS operations without burdening current ATM
  - FAA maintains regulatory AND operational authority for airspace and traffic operations
  - Air traffic controllers are not required to actively “control” every UAS in uncontrolled airspace or uncontrolled operations inside controlled airspace
  - FAA has on-demand access to airspace users and can maintain situation awareness and issue directives, constraints, and airspace configurations through UTM for safety reasons anytime

- NASA is developing a UTM ecosystem for uncontrolled operations (under 400 AGL)
  - The UTM system adopts service-orientated architecture and utilizes industry’s ability to supply services under FAA’s regulatory authority where these services do not exist.
  - Goal: Safely enabling large scale visual and beyond visual line of sight operations in the low altitude airspace
  - Approach: a risk-based approach along four distinct Technology Capability Level (TCL).
  - Progress: The system is progressing to TCL Four. Results are expected to be transferred to the FAA in 2020.
From UTM to UAM Airspace Management

• Shared principles:
  – Safely integrating operations **without burdening current ATM**
  – Air traffic controllers **are not required** to actively “control” every vehicle
  – Adopting **service-orientated architecture** and **utilizing industry’s ability** to supply services under FAA’s regulatory authority

• UAM extensions:
  – Operating beyond 400 feet AGL
  – Different categories of vehicles and higher standard of safety
  – Extension from volume-based operations
Connecting to UTM in Grand Challenge 1

Option #1:
- Industry USS (NASA approved)
  - USS-USS ICD
  - NASA USS
  - Client
  - Vehicle

Option #2:
- Industry USS (NASA approved)
  - USS-USS ICD
  - NASA USS
  - USS-Operator ICD
  - Client
  - Vehicle
Range and Infrastructure Panel: ATM-X
Rich Coppenbarger, Technical Lead, Air Traffic Management Exploration (ATM-X)

Nov 1, 2018
Background

- NASA will leverage airspace technologies developed in its UTM and Air Traffic Management - eXploration (ATM-X) projects to support Grand Challenge.
- Under the UAM subproject, ATM-X is conducting R&D focused on airspace integration of UAM operations.
- ATM-X is developing a reference implementation of a UAM Airspace Management System
  - Supports data sharing and integration to ‘plug and play’ multiple airspace services through specified ICDs
  - Allows NASA and community partners to collaborate on simulation studies
  - Builds upon existing software architecture and implementation of UTM and includes connection with Testbed
The NASA UAM Airspace Management System will serve as a *government-furnished* example of a generic air traffic management system for Grand Challenge purposes:

- Supports integrated vehicle and airspace scenarios in Grand Challenge 2 and beyond
- Provides data connectivity and relevant airspace management functions/services
- Does not presuppose end-state allocation of UAM traffic management roles/responsibilities between government and industry

Reasons for NASA-provided system:

- Reduce system integration complexity and risk
- Reduce initial costs/risks for airspace industry to participate in Grand Challenge
- Allow partner airspace services to potentially run in ‘shadow mode’ prior to actively supporting later Grand Challenge scenarios
- Provide standard data, services, and metrics for consistency across initial integrated vehicle and airspace scenarios
Notional Airspace Management System for GC Series

Airspace Management System Backbone (leveraging UTM + TestBed)

- ANSP/NAS Constraints
- Terrain and Obstacles
- Weather
- Surveillance
- Virtual Traffic

Data Services

Traffic Management Services

- UAM Operator Interface (client)
- Traffic-Flow Management
- Strategic CD&R
- Tactical CD&R
- Conformance Monitoring
- Situational Display
- Other... TBD

4D Flight Planning

NASA
Vehicle Operator
Airspace Resource Provider
NAS/FAA
**Notional Airspace Management System – GC-2**

**Scenario 3: Trajectory Planning and Compliance**
Notional Airspace Management System – GC-2 and beyond

Airspace Management System Backbone (leveraging UTM + TestBed)

- ANSP/NAS Constraints
- Terrain and Obstacles
- Weather
- Surveillance
- Virtual Traffic

Data Services

Traffic Management Services

- UAM Operator Interface (client)
- Traffic-Flow Management
- Strategic CD&R
- Tactical CD&R
- Conformance Monitoring
- Situational Display
- Other... TBD

NASA
Vehicle Operator
Airspace Resource Provider
NAS/FAA
NASA Airspace Management System Development

- Builds upon UTM foundation
- Leverages UAM airspace system development underway for ATM-X HITL simulations and/or other evaluations
  - Extending UTM volume-based paradigm to trajectory-based operations
  - Developing trajectory-based flow-management and separation services
  - Studying roles, responsibilities, procedures, and information needs for nominal operations and contingencies
  - Leveraging existing partnerships with FAA and industry
- Tests system for GC-2 in 2020 lab simulation(s), augmented by data collected during GC-1 through UTM interface with vehicles
- Expected to involve partnerships with industry stemming from two NASA RFIs:
  - UAM Grand Challenge RFI
  - ATM-X UAM airspace integration R&D collaboration RFI
Wrap Up and Next Steps

Nov 1, 2018
Industry Day 2 – Topic Areas

• Why Participate
• Timeline
• IP and Data Rights
• RFI
• Multiple “Vehicle” topics – MTEs, STOL and other unique vehicle considerations, pilots and autonomy, getting to standards
• ATM, UTM, and UAM ATM – NASA project boundaries, differentiators, timelines, certification/standards
• Community participation
• Possible Special topics and webinars