UAM Coordination and Assessment Team (UCAT)
NASA UAM Update for ARTR
Overview

• UAM Market Studies
• Community-wide Perspectives
• NASA Grand Challenge
• Partnership strategy
• NASA UAM Priorities
Commercial Operating Environments (OE)

- **FL-600**
  - HIGH ALTITUDE
  - LONG ENDURANCE
  - Cooperative Traffic

- **18K’ MSL**
  - IFR-LIKE
  - Cooperative Traffic

- **10K’ MSL**
  - VFR-LIKE
  - Cooperative Traffic
  - Non-Cooperative Traffic

- **TOP OF CLASS G**
  - HOT AIR BALLOON
  - HELICOPTERS
  - GA AIRCRAFT

- **TOP OF URBAN AIRSPACE**
  - URBAN PASSENGER TRANSPORT
  - Terminal Airspace
  - Airport

- **LOW ALTITUDE**
  - URBAN
  - RURAL

- **VLOS**
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

<table>
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<th></th>
<th>2028</th>
<th>2030</th>
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<tr>
<td>Crown Air Metro</td>
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<tr>
<td># pax trips/day/city</td>
<td>23,744</td>
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<td># vehicles/city</td>
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<td># flights/day/city</td>
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<td># pax/flight (avg)</td>
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<tr>
<td>BAH (baseline)</td>
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<tr>
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<td># pax/flight (avg)</td>
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<td>Uber Air Taxi</td>
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<td># pax trips/day/city</td>
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<td># vehicles/city</td>
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<tr>
<td># pax/flight (avg)</td>
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**Aggressive on assumptions (i.e. autonomy) and implementation (i.e. vertiport infrastructure)**

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

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

#### Cost Comparisons Over Time ($/pax-mile)

<table>
<thead>
<tr>
<th>Cost ($/pax-mile)</th>
<th>Launch</th>
<th>“Near-Mid-Term”</th>
<th>“Far-Mid-Term”</th>
<th>“Long Term”</th>
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<tr>
<td>BAH Baseline</td>
<td>N/A</td>
<td>6.25</td>
<td>~2.50</td>
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<tr>
<td>BAH Low End</td>
<td>N/A</td>
<td>~3.75</td>
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<td>2.00</td>
<td>1.20</td>
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<td>Uber</td>
<td>5.73</td>
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<td>1.84</td>
<td>0.44</td>
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</table>

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

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

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

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

**Industry and Stds Dev Organizations**
- Technology Development
- R&D
- Standards
- Summits
- Partnerships
- International

**Federal agencies**
- NASA Efforts
- FAA UAM Roundtable
- FAA/OGA initiatives
- DoD

**State and local**
- Initiatives
- Smart Cities
- Partnerships
- Academic research

**Community**
- Public perception:
- Think tanks and research institutions
- Concern groups
**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.

- **R&D 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.

- **Focused 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.
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
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
UAM Maturity Levels (UML)

**UAM Framework and Barriers**

**Vehicles**
- UML-1: Late-Stage Certification Testing and Operational Demonstrations in Limited Environments
- UML-2: Low Density and Complexity Commercial Operations with Assistive Automation
- UML-3: Low Density, Medium Complexity Operations with Comprehensive Safety Assurance Automation
- UML-4: Medium Density and Complexity Operations with Collaborative and Responsible Automated Systems
- UML-5: High Density and Complexity Operations with Highly-Integrated Automated Networks
- UML-6: Ubiquitous UAM Operations with System-Wide Automated Optimization

**Airspace**

**Community**
Representative industry UAM timeline and milestones

1 Based on a range of publicly available industry projections; not a consensus view; aggressive
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.
<table>
<thead>
<tr>
<th>UAM Grand Challenge Series</th>
<th>UAM Partnership Strategy</th>
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<tbody>
<tr>
<td>The UAM GC Series is designed to facilitate technology development, testing, and partnership for critical UAM components</td>
<td>The UAM Partnership Strategy is designed to bring the entire UAM ecosystem together in partnership across key challenges and barriers</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>NASA ARMD Portfolio Execution</th>
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</thead>
<tbody>
<tr>
<td>NASA supports industry via a robust portfolio focused on key challenges validated GC and UAM Partnership Strategy</td>
</tr>
</tbody>
</table>
• 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.

[Diagram with colors indicating Industry Provided, NASA Provided, and Ecosystem Wide Support]
NASA/FAA/Industry Relationship for Initial Grand Challenge

- NASA
  - Develop UAM proving ground
  - Integrated Operational Scenarios
  - Data standardization

- FAA
  - Guidance on scenario design and solution sets
  - Inform and Validate regulatory environment

- GC
  - Decision Making
  - Cert & Ops Regulatory Development

- Industry
  - Airworthy vehicles
  - Scalable airspace systems/services

Note: Future Grand Challenges also include a more focused Community perspective
Grand Challenge Tenets (draft)

• The GC series will not be a Science Fair

• Don’t over-complicate in an attempt to be perfect
  – Corollary: Make GC meaningful for the participants

• NASA is the facilitator and the UAM community is the customer
  – NASA must listen to our customers
  – NASA must ask the question to the community “What will be the most helpful to you?”
  – NASA must synthesize a community response from disparate and conflicting answers to the question above.

• At the end of the GC series we would like for the participants to say, “I got a lot out of being involved in the GC series”
## 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
Proposed Initial GC Scenarios*

- **0-V** Qualification Testing
- **0-A** Qualification Testing

**GC Qualification Activities**
1. Trajectory Planning & Compliance
2. Vehicle & AMOS Interoperability
3. UAM Ports and Approaches
4. Noise Acceptance and Evaluation
5. CNS Contingencies
6. Conflict Management
7. Vehicle Contingency Management

**Proposed Initial GC Integrated System Scenarios**

*Scenario prioritization for Initial GC ongoing with FAA and Industry*
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

- Outcome: Community learning through flight and simulation of critical UAM scenarios in a relevant environment

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: ~2022

- Outcome: Integrated Demonstrations of vehicle and operational scenarios critical to UAM commercialization

**Initial Grand Challenge: *Learning through real integrated flights***

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

GC Series: TBD

- Outcome: Validated requirement sets for scaled operations

**Series Culmination**

*Demonstrate scaled operational capabilities in urban environments*
**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

Ecosystem-wide and GC Series
- UAM Wide engagement

Initial Grand Challenge
- GC Defined*

Grand Challenge Build-up
- Integrated Flights
- Airspace Simulation

UAM Wide Partnerships**
- NASA R&D Partnerships

“Set of Requirements” for UAM

*Continue to work future GC definition through collaborative partnership workshops

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

- **Autonomy**
- **Noise**
- **Vehicle Noise**
- **Electrified Propulsion**
- **Design Tools**
- **Airspace Design**
  - Operational Rules, Roles, & Procedures
- **Public Acceptance**
  - Safe, Efficient, Resilient & Scalable Airspace Ops
- **Community Integration**
- **Airspace System Design & Implementation**
- **Airspace & Fleet Operations Management**
- **Vehicle Development & Production**
- **Individual Vehicle Management & Operations**

- **Community Integration Barriers**
- **Airspace Barriers**
- **Vehicle Barriers**
- **Pillar number**
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.
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<tr>
<th>Acronym</th>
<th>Description</th>
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<td>AAM</td>
<td>Advanced Air Mobility</td>
</tr>
<tr>
<td>AC</td>
<td>Aircraft</td>
</tr>
<tr>
<td>AIA</td>
<td>Aerospace Industries Association</td>
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<td>ARMD</td>
<td>Aeronautics Research Mission Directorate</td>
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<td>ARTR</td>
<td>Aeronautics Research and Technology Roundtable</td>
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<tr>
<td>ASTM</td>
<td>ASTM International, formerly known as American Society for Testing and Materials</td>
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<td>ATC</td>
<td>Air Traffic Control</td>
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<td>ATM</td>
<td>Air Traffic Management</td>
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<td>CONOPS</td>
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BACK-UP
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
UAM Framework and Barriers

Vehicle Barriers
1. Vehicle Design & Integration
2. Airworthiness Standards & Certification
3. Vehicle Noise
4. Weather-Tolerant Vehicles
5. Cabin Acceptability
6. Manufacturing & Supply Chain

Airspace Barriers
1. Airspace Design
2. Operational Rules, Roles, & Procedures
3. CNSI & Control Facility Infrastructure
4. UAM Port Design

Community Integration Barriers
1. Public Acceptance
2. Supporting Infrastructure
3. Operational Integration
4. Local Regulatory Environment & Liability

Airspace System Design & Implementation
1. Safe Urban Flight Management
2. Increasingly Automated Vehicle Operations
3. Certification & Ops Approval
4. Ground Ops & Maintenance

Airspace & Fleet Operations Management
1. Safe Airspace Ops
2. Efficient Airspace Ops
3. Scalable Airspace Ops
4. Resilient Airspace Ops
5. Fleet Management
6. Urban Weather Prediction

Vehicle Development & Production
1. Safety
2. Security
3. Affordability
4. Noise
5. Autonomy
6. UAM Ports
7. Regulations/Certification

Individual Vehicle Management & Operations
1. Safe Urban Flight Management
2. Increasingly Automated Vehicle Operations
3. Certification & Ops Approval
4. Ground Ops & Maintenance

Community Integration
1. Public Acceptance
2. Supporting Infrastructure
3. Operational Integration
4. Local Regulatory Environment & Liability
NASA UAM Priorities

Airspace Design (ATM-X)
Operational Rules, Roles, & Procedures (ATM-X, AAM, TTT, SWS)

Public Acceptance (All)

Vehicle Noise (RVLT)
Electrified Propulsion (RVLT, X-57)
Design Tools (TTT)

Safe, Efficient, Resilient & Scalable Airspace Ops (ATM-X, SWS)

Safe Urban Flight Management (AAM, TTT)
Increasingly Automated Vehicle Operations (AAM, TTT, SWS)

Autonomy (TTT, AAM, SWS, ATM-X)

Noise (RVLT, ATM-X)

Safety (SWS)

Airspace System Design & Implementation

Airspace & Fleet Operations Management

Individual Vehicle Management & Operations

Vehicle Development & Production

Community Integration
### Vehicles

**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; UTM Construct and UAM corridors supporting self-managed operations 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

**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 (capacity limited by physical infrastructure); ad hoc landing sites; noise compatible with suburban/rural operations; private ownership & operation models enabled; societal expectation
### Functions to “unlock” a UML

<table>
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<tr>
<th>UML-1 Conforming prototype</th>
<th>UML-2 Initial Commercial Ops</th>
<th>UML-3 Initial Urban Operations</th>
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<td><strong>Iteration &amp; resiliency</strong></td>
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<td>Integrated AC &amp; subsys dev.</td>
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<td>Powerplant electrification</td>
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<td>Int. avionics &amp; control sys.</td>
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<td><strong>Initial UAM pilot cert.</strong></td>
<td><strong>Vehicle health mgmt</strong></td>
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<td><strong>UAM airspace design</strong></td>
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<td><strong>UAM development &amp; test</strong></td>
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<td><strong>System integration</strong></td>
<td><strong>Initial infra. deployment</strong></td>
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<tr>
<td><strong>Airspace System Design &amp; Implementation</strong></td>
<td><strong>Air. ops. &amp; disrupt. mgmt.</strong></td>
<td><strong>Airspace cybersecurity stds</strong></td>
<td><strong>Infrastructure installation</strong></td>
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<td><strong>Infrastructure installation</strong></td>
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<td><strong>Community Integration</strong></td>
<td><strong>Policy development</strong></td>
<td><strong>Initial infra. deployment</strong></td>
<td><strong>Minimally impacted</strong></td>
</tr>
</tbody>
</table>

**Significant work to reach maturity**
**Moderate work to reach maturity**
**Minimal work to reach maturity**
**Assessment incomplete**

*Iterative improvements on existing pillars in order to improve scale & resiliency*
Representative industry UAM timeline and milestones

1 Based on a range of publicly available industry projections; not a consensus view; aggressive