Proposed Framework for developing a Comprehensive ARMD Full UAS Integration Strategy

Presented by:
Davis Hackenberg
Purpose / Scope / Outcome

• **Purpose**: Provide a framework for a strategic architecture to develop and manage a research portfolio focused on full UAS integration.

• **Scope**: Focus on what is needed to enable full integration of unmanned aircraft for civil / commercial operations within the U.S. NAS by ~2025.
  – Leverage work done under previous years UAS Full Integration Study
  – Engage Community to elicit their input
  – Provide a framework and technical approach for the analysis
  – Develop a decision support tool that can assist ARMD with determining their role

• **Desired Outcome**: A plan for a “Comprehensive ARMD Full UAS Integration Strategy”

Like manned aircraft, UAS will be able to routinely operate through all phases of flight in the NAS, based on vehicle and infrastructure performance capabilities.
Attributes of a Full UAS Integration Framework

• UAS Full Integration is a multi-dimensional challenge facing the UAS Community

• An Analytical Framework must consider all aspects, to include:
  – The **Airspace Integration Enablers** (i.e. Community Needs, Gaps & Challenges)
  – The **Operational Environment** the UAS intends to operate within (i.e. Airspace Type, UAS CONOPs, Use Cases)
  – The associated **Cost, Opportunity, Benefit and Risk** for each element within the framework
    • Gap size/complexity will drive cost/schedule and encourage partnerships
    • Cost to close the gap vs cost to implement vs potential return on investment are all important considerations
    • Each gap has unique opportunities and risks
    • Closure of gaps will have different degrees of community benefit

• Other considerations:
  – Ongoing work within the Community
  – Organizational strengths/weaknesses
  – Leadership vision
  – Political drivers
  – Social pressures

The Analytical Framework must be capable of addressing the multi-dimensional challenges associated with UAS Full Integration
UAS Full Integration Framework Study
Technical Approach

Steps for developing a Framework leading to a “Comprehensive ARMD Full UAS Integration Strategy”

1) Define & Scope Community Needs
   - 1a. Identify Full UAS Integration gaps/challenges and group into AI Enabler Categories
   - 1b. Determine appropriate Operational Environments to help scope problem
   - 1c. Define meaningful Evaluation Criteria & Weighting Values

2) Cost, Opportunity, Benefit, Risk Assessment
   - 2a. Derive relative costs needed to close the gap & implement the solution
   - 2b. Evaluate Cost, Opportunity, Benefit, Risk for each AI Enabler & Operational Environment

3) Organizational Role Determination
   - 3a. Determine NASA’s Strength and Influence specific to each AI Enabler
   - 3b. Determine the role and partnership strategies NASA should adopt
   - 3c. Develop cost estimates for those areas NASA should consider

OUTPUT
Full UAS Integration Community Needs, Operational Environments & Evaluation Criteria

OUTPUT
Relative Cost Assessment & Prioritized set of Community Needs by Operating Environment

OUTPUT
Recommendations for a Comprehensive ARMD Full UAS Integration Strategy

External Community Involvement
NASA Internal Only
STEP 1: DEFINE & SCOPE
COMMUNITY NEEDS

1) Define & Scope Community Needs
1a) Identify Full UAS Integration gaps/challenges and group into AI Enabler Categories
1b) Determine appropriate Operational Environments to help scope problem
1c) Define meaningful Evaluation Criteria & Weighting Values

2) Cost, Opportunity, Benefit, Risk Assessment
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Output
Full UAS Integration Community Needs, Operational Environments & Evaluation Criteria
Relative Cost Assessment & Prioritized set of Community Needs by Operating Environment
Recommendations for a Comprehensive ARMD Full UAS Integration Strategy
Develop AI Enablers, Operating Environments & Evaluation Criteria

Identify Gaps & Define AI Enablers

- Technology & Standards
  Technology solutions and standards implemented by UAS manufacturers and/or operators to safely access the airspace in order to achieve mission objectives.

- Policies / Procedures & NextGen
  Rules, regulations, policies and procedures necessary for efficiently managing the airspace and safely operating UAS within today’s NAS and the future NextGen airspace.

- Airspace Integration Enabler Categories
  Infrastructure & Capabilities
  Infrastructure, facilities, services, research labs and support capabilities provided to the UAS Community that help enable safe and efficient UAS operations.

- Social Components
  Guidelines and addressing UAS concerns such as legality, privacy.

Determine Appropriate Operating Environments

Define Evaluation Criteria

Use AI Enablers to scope the size and complexity of the Full UAS Integration Challenge

Use the representative set of Operating Environments to scope the analysis
Identify Community Needs/Gaps/Challenges

- Leverage previous UAS Full Integration Studies performed in 2014 & 2015
  - Assessed multiple documents from across the UAS community to identify full UAS integration gaps and challenges

- Consider new efforts & recent developments
  - NASA UTM
  - FAA Guidance (e.g. sUAS Rule)
  - Industry business cases

- Engage UAS community stakeholders
  - OGA’s (e.g. FAA, DoD, DHS, NOAA)
  - Trade Associations (e.g. AUVSI, AIAA)
  - Industry (e.g. Amazon, Google)
  - Academia (e.g. COE, UND)
  - International (e.g. ICAO, NATO)

- Utilize community needs/gaps to determine the Airspace Integration Enablers
  - Input to Decision Support Tool
  - Basis for Analytical Framework
UAS Airspace Integration Enabler Categories

**Technology & Standards**
Technology solutions and standards implemented by UAS manufacturers and/or operators to safely access the airspace in order to achieve mission objectives.

**Policies / Procedures & NextGen**
Rules, regulations, policies and procedures necessary for efficiently managing the airspace and safely operating UAS within today’s NAS and the future NextGen airspace.

**Infrastructure & Capabilities**
Infrastructure, facilities, services, research labs and support capabilities provided to the UAS Community that help enable safe and efficient UAS operations.

**Social Considerations**
Guidelines and techniques for addressing UAS-related social concerns such as safety, security, legality, privacy and noise.

Airspace Integration Enabler Categories group the previously identified gaps and challenges into similar areas that must be addressed to achieve Full UAS Integration.
Each AI Enabler Category is comprised of several AI Enablers.
Each AI Enabler is comprised of several unique gaps and challenges.
# AI Enabler Descriptions
## Technology & Standards

<table>
<thead>
<tr>
<th>Airspace Integration Enablers</th>
<th>AI Enabler Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T01</strong> Certifiable Airport Surface Ops Technologies</td>
<td>Airport surface technologies, both on-board and off-board, need to be developed, validated and certified to safely and efficiently land, taxi and take-off from UAS accommodating airports.</td>
</tr>
<tr>
<td><strong>T02</strong> Certifiable DAA Technologies</td>
<td>DAA technologies for tracking and avoiding collisions with other aircraft in all classes of airspace need to be developed, validated, and certified in accordance with the established requirements and standards to enable safe operations within the NAS.</td>
</tr>
<tr>
<td><strong>T03</strong> Certifiable Hazard Avoidance Technologies</td>
<td>Hazard Avoidance technologies for avoiding collisions with obstacles and terrain need to be developed, validated, and certified in accordance with the established requirements and standards to enable safe low-altitude operations.</td>
</tr>
<tr>
<td><strong>T04</strong> Certifiable C3 Technologies</td>
<td>C3 technologies need to be developed and certified in accordance with the established requirements and standards to enable safe and secure command &amp; control, ATC communications, and BVLOS operations.</td>
</tr>
<tr>
<td><strong>T05</strong> Certifiable GCS Technologies</td>
<td>GCS technologies, interfaces and displays need to be developed, validated and certified for various types (man-in-the-loop, man-on-the-loop, autonomous) of unmanned systems.</td>
</tr>
<tr>
<td><strong>T06</strong> Certifiable Flight &amp; Health Mngmt Systems</td>
<td>Technologies need to be developed that enable the measuring of key flight status and system health parameters, assessing their current condition, predicting their future condition, and informing others within the airspace.</td>
</tr>
<tr>
<td><strong>T07</strong> Airworthiness Criteria / Standards / MOCs</td>
<td>Airworthiness C/S/M need to be developed for both large and small UAS with varying levels of autonomy. Published design criteria handbook, FAA Orders &amp; Advisory Circulars for unmanned fixed-wing, rotorcraft &amp; airships</td>
</tr>
<tr>
<td><strong>T08</strong> Certifiable Navigation Technologies</td>
<td>Navigation technologies to support the level of fidelity needed for safe UAS operations need to be developed, validated, and certified.</td>
</tr>
<tr>
<td><strong>T09</strong> Certifiable Weather Avoidance Technologies</td>
<td>Weather detection and avoidance/mitigation technologies need to be developed, validated and certified.</td>
</tr>
<tr>
<td><strong>T10</strong> Certifiable Power &amp; Propulsion Technologies</td>
<td>Power and propulsion technologies that increase safety, improve vehicle reliability, and increase endurance need to be developed, validated and certified.</td>
</tr>
<tr>
<td><strong>T11</strong> Autonomous Architectures</td>
<td>Autonomous architectures for highly complex functions need to be developed, validated and certified.</td>
</tr>
<tr>
<td><strong>T12</strong> Human Factors Guidelines</td>
<td>Human Factors guidelines and standards for UAS pilot and ATM displays (informative, suggestive, directive) need to be established.</td>
</tr>
<tr>
<td>Policies, Procedures &amp; NextGen</td>
<td>AI Enabler Description</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td><strong>P01</strong> Airspace Mngmt Policies &amp; Procedures</td>
<td>Airspace management policies and procedures for UAS operations within all classes of airspace need to be developed and adopted.</td>
</tr>
<tr>
<td><strong>P02</strong> Operating Rules / Regs / Procedures</td>
<td>Rules / Regs / Procedures for UAS operations need to be developed and adopted. FAA Orders, Advisory Circulars (AC), AIM, Pilot/Crew Quals, Training &amp; Medical requirements for UAS need to be developed and published.</td>
</tr>
<tr>
<td><strong>P03</strong> Contingency Mngmt Procedures</td>
<td>Guidelines for contingency planning and handling need to be developed and published for all levels of autonomy (man-in-the-loop, man-on-the-loop, autonomous) and classes of airspace.</td>
</tr>
<tr>
<td><strong>P04</strong> NextGen Compatibility</td>
<td>Certain UAS must be properly equipped to ensure compatibility with NextGen so as to not degrade the safety or efficiency of the NAS.</td>
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<th>Infrastructure &amp; Capabilities</th>
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<tr>
<td><strong>I01</strong> UAS Accommodating Airports &amp; Infrastructure</td>
<td>Airport infrastructure improvements are necessary to accommodate UAS operations, while still ensuring the ops tempo and safety record of airports today.</td>
</tr>
<tr>
<td><strong>I02</strong> UAS Accommodating Airspace Mngmt Infrastructure</td>
<td>The current and future Air Traffic Management (ATM) system will need to be modified to accommodate UAS operations while still maintaining the safety and efficiency of the NAS.</td>
</tr>
<tr>
<td><strong>I03</strong> Low-Altitude Airspace Mngmt Infrastructure</td>
<td>Airspace infrastructure needs maturation to manage increased capacity in densely populated airspace and at low altitudes without degrading safety and efficiency.</td>
</tr>
<tr>
<td><strong>I04</strong> Adequate Secured / Managed RF Spectrum</td>
<td>Adequate RF Spectrum for UAS command and control and payload applications still needs to be defined and secured through the FCC and WRC.</td>
</tr>
<tr>
<td><strong>I05</strong> Sufficient Test Ranges and LVC M&amp;S Facilities</td>
<td>Sufficient UAS Test Ranges and Live Virtual Constructive (LVC) Modeling &amp; Simulation facilities need to be established and available for UAS testing and evaluation.</td>
</tr>
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<tr>
<th>Social Considerations</th>
<th>AI Enabler Description</th>
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<tbody>
<tr>
<td><strong>S01</strong> Safety Criteria &amp; Methods of Compliance (MOC)</td>
<td>Safety requirements and standards need to be established for all types of UAS operations in all classes of airspace.</td>
</tr>
<tr>
<td><strong>S02</strong> Cyber &amp; Physical Security Criteria &amp; MOCs</td>
<td>Robust cybersecurity guidelines for identifying and mitigating potential cyber threats as well as criteria and techniques for ensuring the physical security of vital assets are needed to ensure overall mission assurance and public trust.</td>
</tr>
<tr>
<td><strong>S03</strong> Legal Framework for UAS Litigation</td>
<td>Legal framework needs to be established for UAS-related litigation.</td>
</tr>
<tr>
<td><strong>S04</strong> Privacy Guidelines &amp; Rules</td>
<td>Privacy guidelines and rules need to be established for large and small UAS.</td>
</tr>
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<td><strong>S05</strong> Noise Guidelines &amp; Rules</td>
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Emerging Commercial UAS
Operational Environments (OE)

I. “Manned like” IFR
UAS will be expected to meet certification standards and operate safely with traditional air traffic and ATM services.
*(Example Use Case: Communication Relay / Cargo Transport)*

II. Tweeners
These UAS are size limited and operate at altitudes above and below critical NAS infrastructure. They will need to routinely integrate with both cooperative and non-cooperative aircraft.
*(Example Use Case: Infrastructure Surveillance)*

III. Low Altitude Populated
Must interface with dense controlled air traffic environments as well as operate safely amongst the traffic in uncontrolled airspace.
*(Example Use Case: Traffic Monitoring / Package Delivery)*

IV. Low Altitude Unpopulated
Low risk BVLOS rural operations without aviation services.
*(Example Use Case: Agriculture)*

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## Operational Environment Attributes

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<th>Representative Operational Environments</th>
<th>Example Use Cases</th>
<th>Operational Environment Attributes</th>
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<tr>
<td><strong>I</strong> Manned like IFR</td>
<td>Communication Relay &amp; Cargo Transport</td>
<td>Aircraft will operate in similar fashion to current manned aircraft on the airport surface and during flight. Enabling technologies such as DAA, C3, GCS, and flight management systems will have standards validated through robust integrated simulations and flight tests.</td>
</tr>
<tr>
<td><strong>II</strong> Tweeners</td>
<td>Large Infrastructure Inspection</td>
<td>Aircraft will operate in a mixed environment with both participating and non-participating aircraft. Operations will be BVLOS and BRLOS, so onboard equipage will be required. Enabling technologies such as DAA, C3, and navigation systems will be critical, but other challenges for low swap systems and interoperability with current NAS infrastructure will be addressed through risk-based certification. Privacy, noise, and security concerns will become more challenging.</td>
</tr>
<tr>
<td><strong>III</strong> Low Altitude Populated</td>
<td>Package Delivery &amp; Traffic Monitoring</td>
<td>High numbers of aircraft will operate in both controlled and uncontrolled airspace. The operations will be interoperable with manned aircraft and the Air Traffic Management system. Performance-based operations may include reliable hazard avoidance, C3, navigation, and autonomy, teaming. Significant social considerations for noise, security, privacy, and land rights will be addressed.</td>
</tr>
<tr>
<td><strong>IV</strong> Low Altitude Unpopulated</td>
<td>Agriculture</td>
<td>Operations will be low risk, but some flights will require a minimum capability set that may include reliable hazard avoidance, C3, navigation, and autonomy. Privacy, noise, and security concerns will become more challenging.</td>
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Representative Operational Environments

Type I: “Manned like” Operations
Example Use Case: Communication Relay and Cargo Transport

Type II: Tweeners
Example Use Case: Large Infrastructure Surveillance

Type III: Low Altitude Populated
Example Use Case: Package Delivery/Traffic Monitoring

Type IV: Low Altitude Unpopulated
Example Use Case: Agricultural
## Relationship between Airspace Integration Enablers & Operational Environments

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Note: The “X” designation indicates that this AI Enabler is very important for achieving full Integration within this Operational Environment.
Cost, Opportunity, Benefit, Risk Evaluation Criteria

**Cost:** Resources required to achieve the desired outcome
- Costs needed to develop the solution necessary to close the gap
- Costs needed to implement the change needed to close the gap

**Opportunity:** Ability to accelerate schedule, reduce costs, and leverage other’s efforts
- Opportunity to accelerate implementation schedule
- Opportunity to collaborate or partner with others to reduce cost
- Opportunity to leverage existing technologies and efforts

**Benefit:** Overall contribution towards achieving Full Integration
- Relative benefit to the civil/commercial UAS market as a result of closing the gap

**Risk:** Negative effects resulting from not achieving the desired outcome
- Inability to reduce the size/complexity of the gap or implementation difficulty
- Unrealized civil/commercial UAS market
- Delay in achieving full integration
- Adversely impact the safety and efficiency of the NAS
# Opportunity & Risk Evaluation Criteria

## Proposed Criteria and Weighting Values

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<tr>
<th>Categories</th>
<th>Weighting</th>
<th>Criteria Definitions</th>
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<tbody>
<tr>
<td><strong>Opportunity: Ability to accelerate schedule, reduce costs, and leverage other’s efforts</strong></td>
<td>35%</td>
<td>How much time can be saved based on clarity/efficiency of the implementation path?</td>
</tr>
<tr>
<td>Opportunity to Accelerate the Implementation Schedule</td>
<td>High</td>
<td>A well-defined implementation path allows for the opportunity to accelerate tasks &amp; maximize schedule efficiency</td>
</tr>
<tr>
<td></td>
<td>Med</td>
<td>An implementation path is only partially or generally defined, reducing the ability to accelerate the schedule</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>An implementation path is not defined, minimizing any opportunity to accelerate the schedule</td>
</tr>
<tr>
<td></td>
<td>35%</td>
<td>How great is the opportunity to collaborate with other organizations to leverage resources and efforts?</td>
</tr>
<tr>
<td>Opportunity to Collaborate / Partner with Others</td>
<td>High</td>
<td>There are several potential partners available and interested in collaborating</td>
</tr>
<tr>
<td></td>
<td>Med</td>
<td>There are a moderate number of potential partners available to collaborate with</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Very few, if any, partners are known or available to collaborate with</td>
</tr>
<tr>
<td></td>
<td>30%</td>
<td>How can we “move up the starting line” by leveraging work already being done in other fields?</td>
</tr>
<tr>
<td>Opportunity to Leverage Existing Technologies &amp; Efforts</td>
<td>High</td>
<td>There are significant opportunities to leverage existing and/or emerging technologies</td>
</tr>
<tr>
<td></td>
<td>Med</td>
<td>There are moderate opportunities to leverage existing and/or emerging technologies</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>There are minimal opportunities to leverage existing and/or emerging technologies</td>
</tr>
<tr>
<td><strong>Risk: Negative effects resulting from not achieving the desired outcome</strong></td>
<td>35%</td>
<td>How great is the size/complexity of the gap, to include the difficulty of implementation?</td>
</tr>
<tr>
<td>Inability to reduce the Size &amp; Complexity needed to close the Gap</td>
<td>High</td>
<td>The Gap size, complexity, and difficulty of implementation is significant</td>
</tr>
<tr>
<td></td>
<td>Med</td>
<td>The Gap size, complexity, and difficulty of implementation of the Gap is moderate</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>The Gap size, complexity, and difficulty of implementation of the Gap is minimal</td>
</tr>
<tr>
<td>Unrealized Civil / Commercial UAS Market</td>
<td>30%</td>
<td>How will failure to address this gap impact the Civil/Commercial economic outlook?</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Failure to close the Gap will significantly impact the ability to realize a Civil/Commercial UAS Market</td>
</tr>
<tr>
<td></td>
<td>Med</td>
<td>Failure to close the Gap will moderately impact the ability to realize a Civil/Commercial UAS Market</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Failure to close the Gap will minimally impact the ability to realize a Civil/Commercial UAS Market</td>
</tr>
<tr>
<td>Delay in Achieving Full Integration</td>
<td>20%</td>
<td>How will failure to address this gap impact the critical path for full integration?</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Failure to close this Gap will significantly delay the date full integration can be achieved</td>
</tr>
<tr>
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<td>Failure to close this Gap will moderately delay the date full integration can be achieved</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Failure to close this Gap will minimally delay the date full integration can be achieved</td>
</tr>
<tr>
<td>Adversely Impact the Safety and Efficiency of the NAS</td>
<td>15%</td>
<td>How will failure to address this gap impact the efficiency of the NAS, without degrading safety?</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Failure to close this Gap will significantly decrease the overall safety and efficiency of the NAS</td>
</tr>
<tr>
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<td>Med</td>
<td>Failure to close this Gap will moderately decrease the overall safety and efficiency of the NAS</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Failure to close this Gap will have little impact on the overall safety and efficiency of the NAS</td>
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## Benefit & Cost Evaluation Criteria

### Proposed Criteria and Weighting Values

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<td><strong>Cost:</strong> Resources required to achieve the desired outcome</td>
<td>50%</td>
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</tr>
<tr>
<td>Gap Solution Development Cost</td>
<td></td>
<td><strong>Required resources to develop the solution(s) to close the Gap leading to Full Integration</strong></td>
</tr>
<tr>
<td>Very High</td>
<td></td>
<td><em>Very significant</em> resources required to solve the remaining Gap (&gt; $1B)</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td><em>Significant</em> resources required to solve the remaining Gap ($100M-$1B)</td>
</tr>
<tr>
<td>Med</td>
<td></td>
<td><em>Moderate</em> resources required to solve the remaining Gap ($10M-$100M)</td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td><em>Minimal</em> resources required to solve the remaining Gap ($1M-$10M)</td>
</tr>
<tr>
<td>Very Low</td>
<td></td>
<td><em>Very minimal</em> resources required to solve the remaining Gap (&lt;$1M)</td>
</tr>
<tr>
<td>Gap Solution Implementation Cost</td>
<td></td>
<td><strong>Required resources to implement the solution(s) to close the Gap leading to Full Integration</strong></td>
</tr>
<tr>
<td>Very High</td>
<td></td>
<td><em>Very significant</em> resources required to implement the solution (&gt; $1B)</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td><em>Significant</em> resources required to implement the solution ($100M-$1B)</td>
</tr>
<tr>
<td>Med</td>
<td></td>
<td><em>Moderate</em> resources required to implement the solution ($10M-$100M)</td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td><em>Minimal</em> resources required to implement the solution ($1M-$10M)</td>
</tr>
<tr>
<td>Very Low</td>
<td></td>
<td><em>Very minimal</em> resources required to implement the solution (&lt;$1M)</td>
</tr>
<tr>
<td><strong>Benefit:</strong> Overall contribution towards achieving Full Integration</td>
<td></td>
<td><strong>Criteria Definitions</strong></td>
</tr>
<tr>
<td>Relative contribution towards achieving Full Integration</td>
<td>Very High</td>
<td>Making progress against this Gap will <em>very significantly</em> contribute towards achieving full integration</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Making progress against this Gap will <em>significantly</em> contribute towards achieving full integration</td>
</tr>
<tr>
<td></td>
<td>Med</td>
<td>Making progress against this Gap will <em>moderately</em> contribute towards achieving full integration</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Making progress against this Gap will <em>minimally</em> contribute towards achieving full integration</td>
</tr>
<tr>
<td></td>
<td>Very Low</td>
<td>Making progress against this Gap will <em>very minimally</em> contribute towards achieving full integration</td>
</tr>
</tbody>
</table>

### COBRA Score

\[
\text{COBRA Score} = [(O1 \times Ow1) + (O2 \times Ow2) + (O3 \times Ow3)] \times B + [(R1 \times Rw1) + (R2 \times Rw2) + (R3 \times Rw3) + (R4 \times Rw4)] \times B
\]

where: \( O = \text{Opportunity score}, Ow = \text{Opportunity weight}, R = \text{Risk score}, Rw = \text{Risk weight}, B = \text{Benefit score} \)

### Total Cost Score

\[
\text{Total Cost Score} = (Cd \times Cdw) + (Ci \times Ciw)
\]

where: \( Cd = \text{Relative cost to develop solution}, Ci = \text{Relative cost to implement solution}, Cdw = \text{Devpmt. cost weight}, Ciw = \text{Imp. cost weight} \)
1) Define & Scope Community Needs

1a. Identify Full UAS Integration gaps/challenges and group into AI Enabler Categories

1b. Determine appropriate Operational Environments to help scope problem

1c. Define meaningful Evaluation Criteria & Weighting Values

2) Cost, Opportunity, Benefit, Risk Assessment

2a. Derive relative costs needed to close the gap & implement the solution

2b. Evaluate Cost, Opportunity, Benefit, Risk for each AI Enabler & Operational Environment

3) Organizational Role Determination

3a. Determine NASA’s Strength and Influence specific to each AI Enabler

3b. Determine the role and partnership strategies NASA should adopt

3c. Develop cost estimates for those areas NASA should consider

OUTPUT

Full UAS Integration Community Needs, Operational Environments & Evaluation Criteria

OUTPUT

Relative Cost Assessment & Prioritized set of Community Needs by Operating Environment

OUTPUT

Recommendations for a Comprehensive ARMD Full UAS Integration Strategy

STEP 2: COST, OPPORTUNITY, BENEFIT, RISK ASSESSMENT
Decision Support Tool Attributes

- A decision support tool should be developed in accordance with the UAS Full Integration Analytical Framework
  - Considers merits of all **community needs, gaps and challenges**
  - Accounts for unique **operating environments, CONOPS and Use Cases**
  - Evaluates the associated **costs, opportunities, benefits** and **risks**

- Tool helps guide the analysis by:
  - Capturing the evaluation criteria and weighting values
  - Providing an interface for scoring
  - Supporting operational analysis efforts to identify trends and research findings
  - Developing meaningful products that can be used by leadership to help make decisions

- Facilitates the consolidation of information and data
- Provides a mechanism for performing analysis in a structured manner
- Enables easier decision making for Leadership

---

**Input Data**

**Evaluation Criteria**

**Operating Environments**

**Community Needs/Gaps**

**Cost, Opportunity, Benefit, Risk**

---

**Output Products**
Use COBRA Evaluation Criteria to score each AI Enabler

Generate COBRA Tornado Plots for each Operational Environment to reveal each gap’s overall importance to Full Integration
How to Read a COBRA Tornado Plot

Notional Plot

Legend:
T = Technology & Standards
P = Policy, Procedures & NextGen
I = Infrastructure & Capabilities
S = Social Considerations

Relative costs required to develop and implement the solution

Individual Airspace Integration Enabler name with unique 3-digit designator

Red bar indicates the total Risk resulting from not successfully addressing the gap

Blue bar indicates the total Opportunity if the gap is addressed

Gaps at the top of the Tornado Plot have the highest score

Gaps at the bottom of the Tornado Plot have the lowest score
Airspace Integration Enablers

I. “Manned-like” IFR

Operational Concept: Aircraft will operate in similar fashion to current manned aircraft on the airport surface and during flight. Enabling technologies such as DAA, C3, GCS, and flight management systems will have standards validated through robust integrated simulations and flight tests.

Key Finding: Operational concepts are well understood, and many of the technologies are at high TRL levels.

Tornado Plot “Top 10”:

<table>
<thead>
<tr>
<th>Ai Enabler</th>
<th>COBRA Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>T02 - DAA Technologies: (<em>$</em>$$)</td>
<td>16.8</td>
</tr>
<tr>
<td>T04 - C3 Technologies: (**$$*)</td>
<td>15.5</td>
</tr>
<tr>
<td>T07 - Airworthiness: ($$$)</td>
<td>13.4</td>
</tr>
<tr>
<td>P01 - Airspace Mngmt Pol. / Proc.:  ($$$)</td>
<td>13.1</td>
</tr>
<tr>
<td>T05 - GCS Technologies : ($$$)</td>
<td>12.8</td>
</tr>
<tr>
<td>I01 - Airport Infrastructure: (**$$*)</td>
<td>12.6</td>
</tr>
<tr>
<td>P03 - Contingency Mngmt: ($$$)</td>
<td>12.1</td>
</tr>
<tr>
<td>T01 - Airport Surface Ops: ($$$)</td>
<td>12.0</td>
</tr>
<tr>
<td>S01 - Safety Criteria &amp; MOCs: ($$$)</td>
<td>11.8</td>
</tr>
<tr>
<td>P04 - NextGen Compatibility: ($$$)</td>
<td>11.3</td>
</tr>
</tbody>
</table>
Type I: “Manned like” Operations
Example Use Case: Communication Relay and Cargo Transport
**Operational Concept:** Aircraft will operate in a mixed environment with both participating and non-participating aircraft. Operations will be BVLOS and BRLOS, so onboard equipage will be required. Enabling technologies such as DAA, C3, and navigation systems will be critical, but other challenges for low swap systems and interoperability with current NAS infrastructure will be addressed through risk-based certification. Privacy, noise, and security concerns will become more challenging.

**Key Finding:** Operational concepts are well understood, but many of the technologies are at low TRL levels. Since flights will operate in a mixed environment that is both BVLOS and BRLOS, many technologies must be onboard. This introduces additional low SWAP constraints making Tweeners very challenging.

**Tornado Plot “Top 10”:**

<table>
<thead>
<tr>
<th>AI Enabler</th>
<th>COBRA Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>T02 - DAA Technologies: ($$$)</td>
<td>16.8</td>
</tr>
<tr>
<td>T04 - C3 Technologies: ($$$$$)</td>
<td>16.8</td>
</tr>
<tr>
<td>P01 - Airspace Mngmt Pol. / Proc.: ($$$)</td>
<td>15.3</td>
</tr>
<tr>
<td>T05 - GCS Technologies : ($$)</td>
<td>14.9</td>
</tr>
<tr>
<td>I04 - RF Spectrum: ($)</td>
<td>13.9</td>
</tr>
<tr>
<td>T07 - Airworthiness: ($)</td>
<td>13.4</td>
</tr>
<tr>
<td>I02 - Airspace Mngmt Infrastructure: ($$$)</td>
<td>12.4</td>
</tr>
<tr>
<td>S01 - Safety Criteria &amp; MOCs: ($$$)</td>
<td>11.8</td>
</tr>
<tr>
<td>T11 - Autonomous Architectures: ($$$)</td>
<td>11.8</td>
</tr>
<tr>
<td>S02 - Cyber &amp; Physical Security: ($$$)</td>
<td>11.1</td>
</tr>
</tbody>
</table>
Type II: Tweeners
Example Use Case: Large Infrastructure Surveillance
Airspace Integration Enablers
III. Low Altitude Populated

**Operational Concept:** High numbers of aircraft will operate in both controlled and uncontrolled airspace. The operations will be interoperable with manned aircraft and the Air Traffic Management system. Performance-based operations may include reliable hazard avoidance, C3, navigation, and autonomy, teaming. Significant social considerations for noise, security, privacy, and land rights will be addressed.

**Key Finding:** Operational concepts are well understood, but many of the technologies are at low TRL levels. Operations will be in a more controlled environment, but the technology challenges for managing large volumes of aircraft are still being developed. Significant gaps exist in vehicle technologies for operating at low altitudes in urban environments.

**Tornado Plot “Top 10”:**

<table>
<thead>
<tr>
<th>AI Enabler</th>
<th>COBRA Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>T03 - Hazard Avoidance</td>
<td>16.8</td>
</tr>
<tr>
<td>I03 - Low-Alt. Traffic Mgmt</td>
<td>16.8</td>
</tr>
<tr>
<td>T02 - DAA Technologies</td>
<td>15.3</td>
</tr>
<tr>
<td>T04 - C3 Technologies</td>
<td>15.3</td>
</tr>
<tr>
<td>T11 - Autonomous Architectures</td>
<td>15.3</td>
</tr>
<tr>
<td>S05 - Noise</td>
<td>14.7</td>
</tr>
<tr>
<td>S02 - Cyber &amp; Physical Security</td>
<td>12.4</td>
</tr>
<tr>
<td>T07 - Airworthiness</td>
<td>12.4</td>
</tr>
<tr>
<td>P02 - Operating Rules / Regs</td>
<td>12.1</td>
</tr>
<tr>
<td>P03 - Contingency Mgmt</td>
<td>12.0</td>
</tr>
</tbody>
</table>
Type III: Low Altitude Populated
Example Use Case: Package Delivery/Traffic Monitoring
Airspace Integration Enablers
IV. Low Altitude Unpopulated

**Operational Concept:** Operations will be low risk, but some flights will require a minimum capability set that may include reliable hazard avoidance, C3, navigation, and autonomy. Privacy, noise, and security concerns will become more challenging.

**Key Finding:** Operational concepts are well understood, but many of the technologies are at low TRL levels. Operations will be in a more controlled environment, but the technology challenges for managing large volumes of aircraft are still being developed. Significant gaps exist in vehicle technologies for operating at low altitudes in urban environments.

**Tornado Plot “Top 10”:**

<table>
<thead>
<tr>
<th>AI Enabler</th>
<th>COBRA Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>I04 - RF Spectrum:</td>
<td>($$)</td>
</tr>
<tr>
<td>T04 - C3 Technologies:</td>
<td>($$$$)</td>
</tr>
<tr>
<td>S01 - Safety Criteria &amp; MOCs:</td>
<td>($$)</td>
</tr>
<tr>
<td>T07 - Airworthiness:</td>
<td>($$$)</td>
</tr>
<tr>
<td>T08 - Navigation:</td>
<td>($$$)</td>
</tr>
<tr>
<td>S02 - Cyber &amp; Physical Security:</td>
<td>($$$)</td>
</tr>
<tr>
<td>T11 - Autonomous Architectures:</td>
<td>($$$)</td>
</tr>
<tr>
<td>I03 - Low-Alt. Traffic Mgmt:</td>
<td>($$$)</td>
</tr>
<tr>
<td>I05 - Test Ranges and LVC:</td>
<td>($$)</td>
</tr>
<tr>
<td>S05 - Noise:</td>
<td>($)</td>
</tr>
</tbody>
</table>

Prioritized Low Altitude Unpopulated Tornado Plot
Type IV: Low Altitude Unpopulated
Example Use Case: Agricultural

- **RF Spectrum Availability**
- **C3 Technologies & Standards**
- **Human Factors Standards & Technologies**
- **Cyber & Physical Security**
- **Navigation Technologies**
- **Weather Avoidance Technologies**
- **C3 Architectures**
- **Autonomous Architectures**
- **Cooperative Aircraft**
- **Non-Cooperative Aircraft**
- **Hazard Avoidance Technologies**
- **Navigation Technologies**
- **Safety Criteria & MOCs**
- **Low Altitude Airspace Mgmt Infrastructure**
- **Wealth Avoidance Technologies**
- **Safety Criteria & MOCs**
- **Avian Hazards**
- **BVLOS Link**
- **Geo-Fence**
- **Class G Airport**
- **Privacy & Noise Concerns**
- **RF Spectrum Availability**
- **UAS Operating Rules / Regs**
- **Low Altitude Airspace Mgmt Infrastructure**
- **~500’ AGL**
- **Farm / Crops**
- **Cell Tower**
- **Physical Obstructions**
- **Autonomous Architectures**
STEP 3: ORGANIZATIONAL ROLE DETERMINATION

1) Define & Scope Community Needs
   1a. Identify Full UAS Integration gaps/challenges and group into AI Enabler Categories
   1b. Determine appropriate Operational Environments to help scope problem
   1c. Define meaningful Evaluation Criteria & Weighting Values

2) Cost, Opportunity, Benefit, Risk Assessment
   2a. Derive relative costs needed to close the gap & implement the solution
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   3a. Determine NASA’s Strength and Influence specific to each AI Enabler
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OUTPUT
Full UAS Integration Community Needs, Operational Environments & Evaluation Criteria

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Relative Cost Assessment & Prioritized set of Community Needs by Operating Environment

OUTPUT
Recommendations for a Comprehensive ARMD Full UAS Integration Strategy
SWOT analysis is an initialism for Strengths, Weaknesses, Opportunities, and Threats. It is a common technique traditionally used by organizations to help them determine whether or not they should pursue a business venture.

- The Strengths / Weaknesses axis pertains to the attributes of the organization (internal)
- The Opportunity / Threat axis pertains to the attributes of the environment (external)

A similar technique can be applied to assist organizations with determining the role they should take-on within the community.

- The Relative Strengths & Influence axis pertains to the attributes of the organization (internal)
- The Cost, Opportunity, Benefit, Risk Assmt axis pertains to the attributes of the environment (external)

Organizations can determine whether they should Lead, Collaborate, Leverage or Monitor based on which quadrant the opportunity falls.
## Organizational Role Implications

<table>
<thead>
<tr>
<th>Organizational Designation</th>
<th>Organizational Role Implications Specific for NASA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lead</strong></td>
<td>NASA is obvious choice to take on leadership role based on their unique strengths and the potential benefit that will be achieved by addressing the challenge head-on. As lead, NASA will be required to invest more than others and take on most of risk.</td>
</tr>
<tr>
<td><strong>Collaborate</strong></td>
<td>No obvious lead exists. NASA should identify strategic partners who can help address meaningful parts of the challenge so together a better solution can be achieved in a more time-efficient and cost-effective way than by going alone. Moderate risks and costs will be required.</td>
</tr>
<tr>
<td><strong>Leverage</strong></td>
<td>NASA should support other organizations who are better positioned/equipped to lead the effort and/or leverage their work. Use what they have already accomplished to advance NASA’s efforts. The other organization will be taking on a larger portion of the risks and associated costs.</td>
</tr>
<tr>
<td><strong>Monitor</strong></td>
<td>NASA should identify others in the community who are obvious leaders in the given field and observe what they are doing, without having an ability to impact the results. Learn from their research findings. No risks or resources are required.</td>
</tr>
</tbody>
</table>

### Resource Requirements

- **Collaborate**: Moderate costs, high benefit
- **Lead**: High costs, high benefit
- **Monitor**: Low costs, low benefit
- **Leverage**: Low costs, low benefit

### Strength / Benefit Trade-off

- **Collaborate**
  - High Strength, Low Benefit
  - Lead
  - High Strength, High Benefit
  - Monitor
  - Low Strength, Low Benefit
  - Leverage
  - Low Strength, High Benefit

### Partnerships

- **Collaborate**
  - No obvious lead (co-equals)
- **Lead**
  - NASA is clear lead (others support)
- **Monitor**
  - Others more skilled to lead (NASA observes)
- **Leverage**
  - Others better positioned to lead (NASA supports)
Organizational Role Determination

**LCLM Evaluation Criteria**

<table>
<thead>
<tr>
<th>Categories</th>
<th>Weighting</th>
<th>Criteria Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Very High</td>
<td>Posess differentiating tools and capabilities that do not exist anywhere else within the community. Uniquely qualified to lead.</td>
</tr>
<tr>
<td>8</td>
<td>High</td>
<td>Possess strong qualifications and capabilities compared to others. Solid past performance within same field.</td>
</tr>
<tr>
<td>6</td>
<td>Above Average</td>
<td>Possess above average capabilities and resources to bring to the table. Solid past performance, but within a tangential field.</td>
</tr>
<tr>
<td>4</td>
<td>Below Average</td>
<td>Slightly below average abilities compared to others. Moderate past performance.</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>Less ability/e organization significantly organizations</td>
</tr>
<tr>
<td>0</td>
<td>Very Low</td>
<td>The COBRA score is used for the x-axis. The desired outcome as well as the specific operational environment</td>
</tr>
</tbody>
</table>

**LCLM Scoring Tool**

<table>
<thead>
<tr>
<th>Name</th>
<th>Gap Name</th>
<th>Size / Complexity Score</th>
<th>Benefit Adj Opp / Risk Score</th>
<th>Relative Strength / Influence Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>I01</td>
<td>UAS Accommodating Airports &amp; Infrastructure</td>
<td>3</td>
<td>12.6</td>
<td>7</td>
</tr>
<tr>
<td>I02</td>
<td>UAS Accommodating Airspace Mgmt Infrastructure</td>
<td>3</td>
<td>10.6</td>
<td>7</td>
</tr>
<tr>
<td>I03</td>
<td>Low-Altitude Airspace Mgmt Infrastructure</td>
<td>3</td>
<td>1.2</td>
<td>4</td>
</tr>
<tr>
<td>I04</td>
<td>Adequate Secured / Managed RF Spectrum</td>
<td>3</td>
<td>9.9</td>
<td>9</td>
</tr>
<tr>
<td>I05</td>
<td>Sufficient Test Ranges &amp; LVC M&amp;S Facilities</td>
<td>3</td>
<td>7.7</td>
<td>1</td>
</tr>
<tr>
<td>I06</td>
<td>Airspace Mgmt Policies &amp; Procedures</td>
<td>3</td>
<td>13.1</td>
<td>3</td>
</tr>
<tr>
<td>I07</td>
<td>Operating Rules / Regs / Procedures</td>
<td>3</td>
<td>11.0</td>
<td>7</td>
</tr>
<tr>
<td>I08</td>
<td>Contingency Mgmt Procedures</td>
<td>3</td>
<td>12.1</td>
<td>4</td>
</tr>
<tr>
<td>I09</td>
<td>NextGen Compatibility</td>
<td>3</td>
<td>9.5</td>
<td>4</td>
</tr>
<tr>
<td>I10</td>
<td>Safety Criteria &amp; Methods of Compliance (MOC)</td>
<td>3</td>
<td>11.8</td>
<td>4</td>
</tr>
<tr>
<td>I11</td>
<td>Cyber &amp; Physical Security Criteria &amp; MOCs</td>
<td>3</td>
<td>12.1</td>
<td>4</td>
</tr>
<tr>
<td>I12</td>
<td>Legal Framework for UAS Litigation</td>
<td>3</td>
<td>11.8</td>
<td>4</td>
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<tr>
<td>I13</td>
<td>Privacy Guidelines &amp; Rules</td>
<td>3</td>
<td>12.1</td>
<td>4</td>
</tr>
<tr>
<td>I14</td>
<td>Noise Guidelines &amp; Rules</td>
<td>3</td>
<td>11.8</td>
<td>4</td>
</tr>
<tr>
<td>I15</td>
<td>Certifiable Airport Surface Ops Technologies</td>
<td>3</td>
<td>12.1</td>
<td>4</td>
</tr>
<tr>
<td>I16</td>
<td>Certifiable DAA Technologies</td>
<td>3</td>
<td>11.8</td>
<td>4</td>
</tr>
<tr>
<td>I17</td>
<td>Certifiable Hazard Avoidance Technologies</td>
<td>3</td>
<td>12.1</td>
<td>4</td>
</tr>
<tr>
<td>I18</td>
<td>Certifiable C3 Technologies</td>
<td>3</td>
<td>11.8</td>
<td>4</td>
</tr>
<tr>
<td>I19</td>
<td>Certifiable GES Technologies</td>
<td>3</td>
<td>12.1</td>
<td>4</td>
</tr>
<tr>
<td>I20</td>
<td>Certifiable Flight &amp; Health Mgmt Systems</td>
<td>3</td>
<td>11.8</td>
<td>4</td>
</tr>
<tr>
<td>I21</td>
<td>Airworthiness Criteria / Standards / MOCs</td>
<td>3</td>
<td>12.1</td>
<td>4</td>
</tr>
<tr>
<td>I22</td>
<td>Certifiable Navigation Avoidance Technologies</td>
<td>3</td>
<td>11.8</td>
<td>4</td>
</tr>
<tr>
<td>I23</td>
<td>Certifiable Weather Avoidance Technologies</td>
<td>3</td>
<td>12.1</td>
<td>4</td>
</tr>
<tr>
<td>I24</td>
<td>Certifiable Power &amp; Propulsion Technologies</td>
<td>3</td>
<td>11.8</td>
<td>4</td>
</tr>
<tr>
<td>I25</td>
<td>Autonomous Architectures</td>
<td>3</td>
<td>12.1</td>
<td>4</td>
</tr>
<tr>
<td>I26</td>
<td>Human Factors Guidelines</td>
<td>3</td>
<td>11.8</td>
<td>4</td>
</tr>
</tbody>
</table>

Assign a NASA-specific Strength/Influence score to each AI Enabler

Generate LCLM Plots for each Operational Environment to show what role NASA should adopt

LCLM = Lead, Collaborate, Leverage, Monitor
Organizational Role Scoring Criteria

Relative Strength & Influence Scale (y-axis)

<table>
<thead>
<tr>
<th>Weighting Criteria</th>
<th>Criteria Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td><strong>Very High</strong></td>
</tr>
<tr>
<td>8</td>
<td><strong>High</strong></td>
</tr>
<tr>
<td>6</td>
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<td><strong>Low</strong></td>
</tr>
<tr>
<td>0</td>
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</tr>
</tbody>
</table>

COBRA Score (x-axis)

The COBRA Score from the previous analysis is used for the x-axis. This takes into consideration the overall benefit to achieving the desired outcome as well as the opportunities and risks associated with each AI Enabler.
**NASA’s Strength & Influence Rating**

<table>
<thead>
<tr>
<th>Airspace Integration Enablers</th>
<th>Strength &amp; Influence Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>T01 Certifiable Airport Surface Ops Technologies</td>
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<td>T07 Airworthiness Criteria / Standards / MOCs</td>
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<td>T08 Certifiable Navigation Technologies</td>
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<td>P04 NextGen Compatibility</td>
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<td>I01 UAS Accommodating Airports &amp; Infrastructure</td>
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<tr>
<td>I02 UAS Accommodating Airspace Mngmt Infrastructure</td>
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<td>I03 Low-Altitude Airspace Mngmt Infrastructure</td>
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<td>I04 Adequate Secured / Managed RF Spectrum</td>
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<td>I05 Sufficient Test Ranges and LVC M&amp;S Facilities</td>
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<td>S04 Privacy Guidelines &amp; Rules</td>
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<tr>
<td>S05 Noise Guidelines &amp; Rules</td>
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**Strength & Influence Rating Scale:**

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<tr>
<th>Weighting Criteria</th>
<th>Description</th>
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<td>2</td>
<td>Low</td>
</tr>
<tr>
<td>0</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

The same NASA Strength & Influence ratings were used for each Operational Environment assessment.
How to Read an LCLM Bubble Plot

Legend:
- Technologies & Standards (T)
- Policies, Procedures & NextGen (P)
- Infrastructure & Capabilities (I)
- Social Considerations (S)

Quadrant title specifies the role NASA should likely adopt for all bubbles within that quadrant.

Y-axis is NASA’s Strength / Influence Score (0 – 10) relative to the AI Enabler gap.

X-axis is the COBRA Score (0 – 18) resulting from the Tornado Plots.

Bubble color designates the AI Enabler Type.

Bubble designator (eg. T07) identifies the unique AI Enabler gap.

Bubble size is the relative investment cost score for the AI Enabler gap.
# LCLM Assessment Results

I. “Manned-like” IFR

## Key Findings:
- The majority of the gaps are on the right side of plot because of their high importance to the community
- Several clear leads already exist across community since these gaps have been a focus for several years
- NASA should consider leading several Technology gaps (Surface Ops, DAA, C3, Flight Mngmt, Auton. Arch., HF)
- NASA should also consider leading Contingency Management (P03) and Safety (S01)

### LCLM Assessment Results

#### Gap Name

<table>
<thead>
<tr>
<th>LCLM</th>
<th>Gap Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>T01 - Airport Surface Ops</td>
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<tr>
<td>Lead</td>
<td>T02 - DAA Technologies</td>
</tr>
<tr>
<td>Collaborate</td>
<td>T03 - Hazard Avoidance</td>
</tr>
<tr>
<td>Lead</td>
<td>T04 - C3 Technologies</td>
</tr>
<tr>
<td>Leverage</td>
<td>T05 - GCS Technologies</td>
</tr>
<tr>
<td>Lead</td>
<td>T06 - Flight &amp; Health Mngmt</td>
</tr>
<tr>
<td>Leverage</td>
<td>T07 - Airworthiness</td>
</tr>
<tr>
<td>Collaborate</td>
<td>T08 - Navigation</td>
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<tr>
<td>Collaborate</td>
<td>T09 - Weather Avoidance</td>
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<tr>
<td>Collaborate</td>
<td>T10 - Power &amp; Propulsion</td>
</tr>
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<td>Lead</td>
<td>T11 - Autonomous Architectures</td>
</tr>
<tr>
<td>Lead</td>
<td>T12 - Human Factors Guidelines</td>
</tr>
<tr>
<td>Leverage</td>
<td>P01 - Airspace Mngmt Pol. / Proc.</td>
</tr>
<tr>
<td>Leverage</td>
<td>P02 - Operating Rules / Regs</td>
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<tr>
<td>Lead</td>
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<td>P04 - NextGen Compatibility</td>
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<tr>
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<td>I02 - Airspace Infrastructure</td>
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<tr>
<td>Collaborate</td>
<td>I03 - Low-Alt. Traffic Mngmt</td>
</tr>
<tr>
<td>Leverage</td>
<td>I04 - RF Spectrum</td>
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<tr>
<td>Collaborate</td>
<td>I05 - Test Ranges and LVC</td>
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<td>Lead</td>
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<tr>
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<tr>
<td>Monitor</td>
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<tr>
<td>Monitor</td>
<td>S04 - Privacy</td>
</tr>
<tr>
<td>Collaborate</td>
<td>S05 - Noise</td>
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![Diagram of Manned-Like]
LCLM Assessment Results
II. Tweeners

<table>
<thead>
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<td>Lead</td>
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<td>T09 - Weather Avoidance</td>
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<td>T10 - Power &amp; Propulsion</td>
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<td>T11 - Autonomous Architectures</td>
</tr>
<tr>
<td>Lead</td>
<td>T12 - Human Factors Guidelines</td>
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<td>Leverage</td>
<td>P01 - Airspace Mngmt Pol. / Proc.</td>
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<tr>
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<tr>
<td>Leverage</td>
<td>P04 - NextGen Compatibility</td>
</tr>
<tr>
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<td>I01 - Airport Infrastructure</td>
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<tr>
<td>Leverage</td>
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<td>Monitor</td>
<td>S04 - Privacy</td>
</tr>
<tr>
<td>Collaborate</td>
<td>S05 - Noise</td>
</tr>
</tbody>
</table>

Key Findings:
- The bubble size (representing relative cost) for several gaps increase compared to “Manned-like” because the challenges are more difficult and have not been the focus of recent initiatives.
- Hazard Avoidance (T03) & Auton. Arch. (T11) are more important for the Tweener OEs than “Manned-like”
- Airport Surface Ops (T01) & Airport Infrastructure (I01) are less important / costly compared to “Manned-like”
### LCLM Assessment Results
#### III. Low Altitude Populated

<table>
<thead>
<tr>
<th>LCLM</th>
<th>Gap Name</th>
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</thead>
<tbody>
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<td>Collaborate</td>
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</tr>
<tr>
<td>Lead</td>
<td>S05 - Noise</td>
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</tbody>
</table>

**Key findings:**
- The majority of the gaps are on the right side of plot because of their high importance to the community
- NASA should consider leading multiple Technology gaps (DAA, C3, Hazard Avoidance, Auton. Arch)
- I03: Low Altitude Traffic Management is the number one need for this OE
- Social Considerations are more important for the Low Altitude Oes than they are for “Manned-like” or Tweener
LCLM Assessment Results
IV. Low Altitude Unpopulated

<table>
<thead>
<tr>
<th>LCLM</th>
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<td>Monitor</td>
<td>I01 - Airport Infrastructure</td>
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<td>S04 - Privacy</td>
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<tr>
<td>Lead</td>
<td>S05 - Noise</td>
</tr>
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</table>

Key Findings:
- The majority of the gaps fall along the y-axis; indicating the community need is moderate and not as great as the other three OEs
- NASA should consider leading multiple Technology gaps (C3, Hazard Avoid., Auton. Arch, Navigation) as well as Low-Alt. Traffic Mgmt (I03), Test/LVC (I05) and Noise (S05)
How do the AI Enablers Migrate across Quadrants?
Technology & Standards Example

- **AI Enabler**: *T03 – Hazard Avoidance*

- **Migration Path**:
  - Manned: Collaborate
  - Tweener: Lead
  - Low Alt. / Pop: Lead
  - Low Alt. / Unpop: Lead

- **Relative Cost**:
  - Manned: Low
  - Tweener: Medium
  - Low Alt. / Pop: High
  - Low Alt. / Unpop: Medium

- **Key Finding**:
  - Hazard Avoidance is not needed for the Manned-like OE, but becomes increasingly important for the Tweener and Low Alt. Populated OE’s.
  - NASA has significant strength & influence regarding this AI Enabler and should consider leading any efforts to address this challenge.

**Trends**:

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>Relative Cost</th>
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<td>C</td>
<td>L</td>
</tr>
<tr>
<td>M</td>
<td>L</td>
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</tbody>
</table>
How do the AI Enablers Migrate across Quadrants?
Policy, Procedures & NextGen Example

- **AI Enabler:** *P04 – NextGen Compatibility*

- **Migration Path:**
  - Manned: Leverage
  - Tweener: Leverage
  - Low Alt. / Pop: Monitor
  - Low Alt. / Unpop: Monitor

- **Relative Cost:**
  - Manned: Medium
  - Tweener: Medium
  - Low Alt. / Pop: Low
  - Low Alt. / Unpop: Low

- **Key Finding:**
  - NextGen compatibility is essential for full integration within the Manned-like and Tweener OE’s.
  - Current indications are that the planned NextGen technologies will not be available for use within the Low-Altitude OE’s.

**Trends:**

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>Relative Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>L</td>
</tr>
<tr>
<td>M</td>
<td>L</td>
</tr>
</tbody>
</table>
How do the AI Enablers Migrate across Quadrants?
Infrastructure & Capabilities Example

• **AI Enabler**: I01 – UAS Accommodating Airports & Infrastructure

• **Migration Path**:
  - Manned: Leverage
  - Tweener: Monitor
  - Low Alt. / Pop: Monitor
  - Low Alt. / Unpop: Monitor

• **Relative Cost**:
  - Manned: High
  - Tweener: Medium
  - Low Alt. / Pop: Low
  - Low Alt. / Unpop: Low

• **Key Finding**:
  - Accommodating airports and infrastructure is essential for the Manned-like OE, beneficial for the Tweener OE, but of little value to both Low Alt. OE’s.
  - NASA has relatively low to moderate strength & influence regarding this AI Enabler and should consider allowing others to take the lead.

**Trends:**

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>Relative Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
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<tr>
<td>M</td>
<td>L</td>
</tr>
</tbody>
</table>

**Diagram:**
- The diagram illustrates the migration paths and relative costs for different quadrants, showing how the AI Enabler I01 moves across different capabilities and cost levels.
How do the AI Enablers Migrate across Quadrants?
Social Considerations Example

- **AI Enabler:** *S04 – Privacy Guidelines/Rules*

- **Migration Path:**
  - Manned: *Monitor*
  - Tweener: *Monitor*
  - Low Alt. / Pop: *Leverage*
  - Low Alt. / Unpop: *Monitor*

- **Relative Cost:**
  - Manned: *Low*
  - Tweener: *Low*
  - Low Alt. / Pop: *Medium*
  - Low Alt. / Unpop: *Medium*

- **Key Finding:**
  - Privacy Guidelines are of little importance for the Manned-like OE, is moderately important for the Tweener and Low Alt. Unpopulated OE’s, but is very important for the Low-Alt. Populated OE.
  - NASA has relatively low strength & influence regarding this AI Enabler and should consider allowing others to take the lead.
**How do the AI Enablers Migrate across Quadrants?**

**Social Considerations Example**

- **AI Enabler:** *S05 – Noise Guidelines/Rules*

- **Migration Path:**
  - Manned: Collaborate
  - Tweener: Collaborate
  - Low Alt./Pop: Lead
  - Low Alt./Unpop: Lead

- **Relative Cost:**
  - Manned: Medium
  - Tweener: Medium
  - Low Alt./Pop: Low
  - Low Alt./Unpop: Low

- **Key Finding:**
  - Noise Guidelines are of little importance for the Manned-like OE, is moderately important for the Tweener and Low Alt. Unpopulated OE’s, but is very important for the Low-Alt. Populated OE.
  - NASA has above average strength and influence for this AI Enabler and should consider leading it for both Low-Altitude OEs.
  - Anticipate costs to solve and implement for Low Alt. OE will be less than Manned-like & Tweener OEs since the Low Alt. engines are less complex and many are electric motors, which already have a low noise signature.
# NASAs Potential Role in UAS Full Integration

## LCLM Roll-up

<table>
<thead>
<tr>
<th>Airspace Integration Enablers</th>
<th>Operational Environment</th>
<th>LCLM Summary</th>
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<td></td>
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<td>Tweener</td>
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<tr>
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### Total

|                                  | 38   | 22  | 27 | 17  |

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**Note:** This table outlines various aspects of UAS integration, detailing roles and responsibilities across different domains such as technology, standards, policies, and social considerations.
### NASAs Potential Role in UAS Full Integration

#### Airspace Integration Enabler “Heat Map”

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**Note: Heat Map score = COBRA score multiplied by NASA's Strength/Influence score (i.e. X-axis x Y-axis)**

**Heat Map Legend**
- High NASA Strength x COBRA Score
- Low NASA Strength x COBRA Score

**NASA should consider leading the cells having the darkest color.**

The Low Alt. Populated OE has the highest payoff given NASA's strength and influence.

T02 Certifiable DAA is the most important AI Enabler across all 4 OEs
NASAs Potential Role in UAS Full Integration
Cumulative “Heat Map”

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Note: Cumulative Heat Map score = Average Heat map score for each AI Enabler Category

Key Findings:
- NASA’s strongest contributions should be in the Technology & Standards and Infrastructure & Capabilities gaps
- Technology & Standards for Manned-Like, Tweener & Low-Alt./Populated OE’s are the 3 highest scoring categories
- The Low-Alt./Populated OE should be the highest pay-off area
- The Manned-Like and Tweener OE’s are a close second and third pay-off area

High scoring gaps from the full UAS integration analysis are important for ARMD to consider research against. NASA should consider developing project goals or technical challenges around achieving DRM demonstration flights in final year of project.
### Leadership Considerations across all four Operational Environments

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### Key Findings:

- Overall Heatmap scores correlate closely to the number of times an AI Enabler was placed into the “Lead” quadrant.
- NASA should consider leading the “Top 12” prioritized AI Enablers:
  1) DAA Technologies
  2) C3 Technologies
  3) Autonomous Architectures
  4) Test Ranges & LVC M&S
  5) Hazard Avoidance
  6) Contingency Management
  7) Low Alt. Airspace Mgmt
  8) Navigation Technologies
  9) Safety Criteria & MOCs
  10) Human Factors Guidelines
  11) Noise Guidelines
  12) Certifiable Flight & Health Mgmt
Questions?
Identify Community Needs/Gaps/Challenges

- Leverage previous UAS Full Integration Studies performed in 2014 & 2015
  - Assessed 27 documents from multiple organizations identifying several hundred community needs/gaps

- Also need to consider new efforts & recent developments
  - NASA UTM
  - FAA Guidance (e.g. sUAS Rule)
  - Industry business cases

- Should engage UAS community stakeholders (as required) to ensure nothing is missing
  - OGA’s (e.g. FAA, DoD, DHS, NOAA)
  - Trade Associations (e.g. AUVSI, AIAA)
  - Industry (e.g. Amazon, Google)
  - Academia (e.g. COE, UND)
  - International (e.g. ICAO, NATO)

- Utilize community needs/gaps to determine the Airspace Integration Enablers
  - Input to Decision Support Tool
  - Basis for Analytical Framework

<table>
<thead>
<tr>
<th>UAS Community Documents Used to Derive Needs / Gaps / Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ASTM F.38 Standards Gap Analysis Briefing</td>
</tr>
<tr>
<td>2. JPDO NextGen UAS Research, Development and Demonstration Roadmap</td>
</tr>
<tr>
<td>3. GAO Report: Measuring Progress and Addressing Potential Privacy Concerns Would Facilitate Integration Into the NAS.</td>
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<tr>
<td>4. FAA Integration of UAS into the NAS Concept of Operations, Version 2.0</td>
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<tr>
<td>5. FAA Integration of Civil UAS into the NAS Roadmap</td>
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<tr>
<td>6. FAA SAA Second Workshop Final Report</td>
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<tr>
<td>7. NASA UAS-NAS Project Recommendations (Objectives + Technical Proposals)</td>
</tr>
<tr>
<td>8. GAO Report: Continued Coordination, Operational Data, and Performance Standards Needed to Guide Research and Development</td>
</tr>
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<td>9. UAS ARC Integration of Civil UAS in the NAS Implementation Plan</td>
</tr>
<tr>
<td>10. JPDO NextGen UAS R&amp;D Prioritization Briefing</td>
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<tr>
<td>11. Terms of Reference, RTCA SC-228 Minimum Performance Standards for UAS</td>
</tr>
<tr>
<td>12. European RPAS Roadmap for the integration of civil Remotely-Piloted Aircraft Systems</td>
</tr>
<tr>
<td>13. JPDO UAS Comprehensive Plan</td>
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<tr>
<td>14. DoD Report to Congress on UAS Challenges</td>
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<tr>
<td>15. Inter-Center Autonomy Study Team (ICAST) Briefing</td>
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<td>16. CANSO ANSP Considerations for RPAS Operations</td>
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<tr>
<td>17. IG Audit of FAA Oversight of UAS</td>
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<tr>
<td>18. NRC Study: Autonomy Research for Civil Aviation: Toward a New Era of Flight</td>
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<tr>
<td>19. NextGen SPC Actions: Initial FY14 Results</td>
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<tr>
<td>20. UAS ExCom Science and Research Panel Gap list</td>
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<td>21. DoD Report to Congress on UAS R&amp;D</td>
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<tr>
<td>22. GAO Report on UAS Integration</td>
</tr>
<tr>
<td>23. FAA Small UAS Notice of Public Rulemaking (NPRM)</td>
</tr>
<tr>
<td>24. GAO Report on Test Sites and International Cooperation</td>
</tr>
<tr>
<td>25. EASA RPAS CONOPS</td>
</tr>
<tr>
<td>26. USGS UAS Roadmap 2014</td>
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<tr>
<td>27. UTM CONOPS</td>
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</tbody>
</table>

Documents reviewed for previous study effort identified 350+ community needs
# UAS Full Integration

## What Being Finished Looks Like

<table>
<thead>
<tr>
<th>Focus Area Bin</th>
<th>What Being Finished Looks Like</th>
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<tbody>
<tr>
<td><strong>Airport Surface Ops</strong></td>
<td>Airport surface operational requirements and standards have been adopted and the supporting technologies, both on-board and off-board, are developed and certified for use on all airport-capable UAS and at UAS accommodating airports.</td>
</tr>
<tr>
<td><strong>Airspace Management</strong></td>
<td>Adoption of all airspace procedures for UAS Operations within all classes of airspace. Development and acceptance of systems that enable aircraft to autonomously share and assess information to make decisions that improve system performance objectives such as capacity, safety, and efficiency.</td>
</tr>
<tr>
<td><strong>Automation</strong></td>
<td>Design, development and validation of autonomous architectures &amp; technologies for multi-vehicle ops, self deterministic flight path planning, sensing, perception &amp; cognition.</td>
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<tr>
<td><strong>Certification Criteria</strong></td>
<td>Adoption of all Airworthiness Criteria, Standards and Methods of Compliance (MOCs) for large and small UAS with varying levels of autonomy.</td>
</tr>
<tr>
<td><strong>Contingency Management</strong></td>
<td>Published guidelines &amp; standards for contingency planning and handling of in-flight contingencies for all levels of autonomy in all classes of airspace. Certified technologies that enable self awareness, health monitoring &amp; correction.</td>
</tr>
<tr>
<td><strong>Detect and Avoid</strong></td>
<td>Published requirements and standards for Detect and Avoid (i.e. aircraft, obstacles, ground) within all classes of airspace. Certified technologies for safely detecting, alerting, avoiding hazards and interoperating with ATM.</td>
</tr>
<tr>
<td><strong>Human Systems Integration</strong></td>
<td>Human factor guidelines and standards defined for man-in-the-loop, man-on-the-loop and fully autonomous UAS. UAS/Pilot and UAS/ATM requirements defined. GCS technologies developed and certified for all levels of autonomy.</td>
</tr>
<tr>
<td><strong>Navigation</strong></td>
<td>Published navigation standards for UAS operations within all classes of airspace. Certified navigation technologies, to include ground navigation and flight path planning. Certified GPS anti-jamming/anti-spoofing technologies.</td>
</tr>
<tr>
<td><strong>Operating Rules/Regs (Large UAS)</strong></td>
<td>Adoption of all Requirements / Rules / Regs for Large UAS operations within all classes of airspace. Published FAA Orders, Advisory Circulars (AC), AIM, Pilot/Crew Quals, Training &amp; Medical requirements for large UAS.</td>
</tr>
<tr>
<td><strong>Operating Rules/Regs (Small UAS)</strong></td>
<td>Adoption of all Requirements / Rules / Regs for Small UAS operations within applicable classes of airspace. Published FAA Orders, ACs, AIM, Pilot/Crew Qualifications, Training &amp; Medical requirements. Published VLOS &amp; BVLOS Rules.</td>
</tr>
<tr>
<td><strong>Power &amp; Propulsion</strong></td>
<td>Adoption of Power / Propulsion requirements and standards. Development and certification of power and propulsion technologies that increase safety, improve vehicle reliability, and increase endurance.</td>
</tr>
<tr>
<td><strong>Reliable &amp; Secure C3</strong></td>
<td>Published C2-link, ATC-Comm link and link security standards for UAS operations within all classes of airspace. Certified C3 technologies. All RF Spectrum required for UAS airspace integ. secured through FCC and WRC.</td>
</tr>
<tr>
<td><strong>Safety Criteria</strong></td>
<td>Published Safety requirements and standards for all types of UAS operations in all classes or airspace. Defined acceptable level of safety. Guidelines established for allocation, substantiation, tracking and reporting of UAS safety.</td>
</tr>
<tr>
<td><strong>Social Concerns</strong></td>
<td>Proven guidelines and techniques for addressing UAS social concerns such as legal, privacy, noise, emissions, safety, and trust with adaptive / non-deterministic systems. Demonstrated international leadership in UAS adoption.</td>
</tr>
<tr>
<td><strong>Test &amp; Evaluation</strong></td>
<td>Establishment of a relevant test environment for assessing UAS technologies and procedures. Fully operational FAA UAS Test Sites. Multiple civil/commercial airports capable of accommodating all types of UAS.</td>
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<tr>
<td><strong>Weather</strong></td>
<td>Certified technologies for weather event detection and avoidance or mitigation during UAS operations, to include unique turbulence events such as wake vortices, or icing conditions.</td>
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