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Performing a Comprehensive Unmanned Aircraft System Full Integration Analysis for NASA ARMD

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Table of Contents

Table of Figures

Table of Tables

Executive Summary

For many years, the concept of routinely flying unmanned aircraft systems (UAS) within the national airspace system (NAS) has been a long-term goal with numerous known and unknown technology and policy obstacles. Just within the last few years, the efforts and advancements from government, industry, and academia-sponsored research and development have greatly shortened the distance to the goal. The National Aeronautics and Space Administration (NASA) Aeronautics Research Mission Directorate (ARMD) has recognized that it is uniquely positioned to play a lead role in addressing the remaining UAS airspace integration (AI) challenges. To fully understand the magnitude and scope of these challenges, NASA ARMD initiated a study in 2015 to identify what would be needed to enable full integration of UAS for civil/commercial operations within the NAS by 2025. The desired outcome was a comprehensive analysis framework that ARMD could use to develop a research portfolio focused on retiring the remaining gaps and challenges standing in the way of full UAS integration.

The technical approach used for developing this framework contained three key steps as depicted in Exhibit 1 below. The first two steps relied heavily upon community engagement and involved multiple discussions and interviews with various government agencies, federally funded research and development corporations (FFRDC), industry, and academia. The third step was reserved for NASA-internal participants only since NASA has the best understanding of its internal strengths and weaknesses and could best recommend the appropriate path forward for itself.

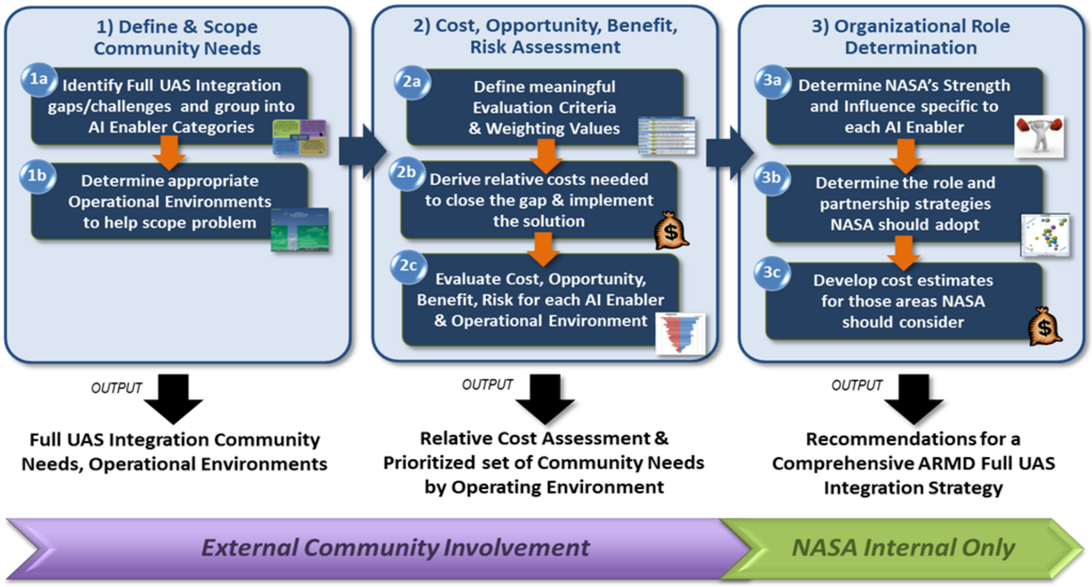

Exhibit 1: UAS Full Integration Technical Approach

The first step within the technical approach results in a comprehensive set of airspace integration (AI) enablers and operational environments (OE).   The AI enablers, shown in Exhibit 2, are a summation of over 300 community needs (i.e., gaps) that were grouped into twenty-six unique AI enablers for the purpose of conducting analysis. These enablers were evaluated across four unique OEs, shown below in Exhibit 3, that represent the multitude of environments commercial UAS are envisioned to operate within over the coming years. These OEs are critical to the analysis because the solutions developed to address the gaps/challenges contained within each AI enabler will not work in all OEs, nor will they be feasible for all groups of UAS to implement due to their unique size, weight, power, and performance characteristics.

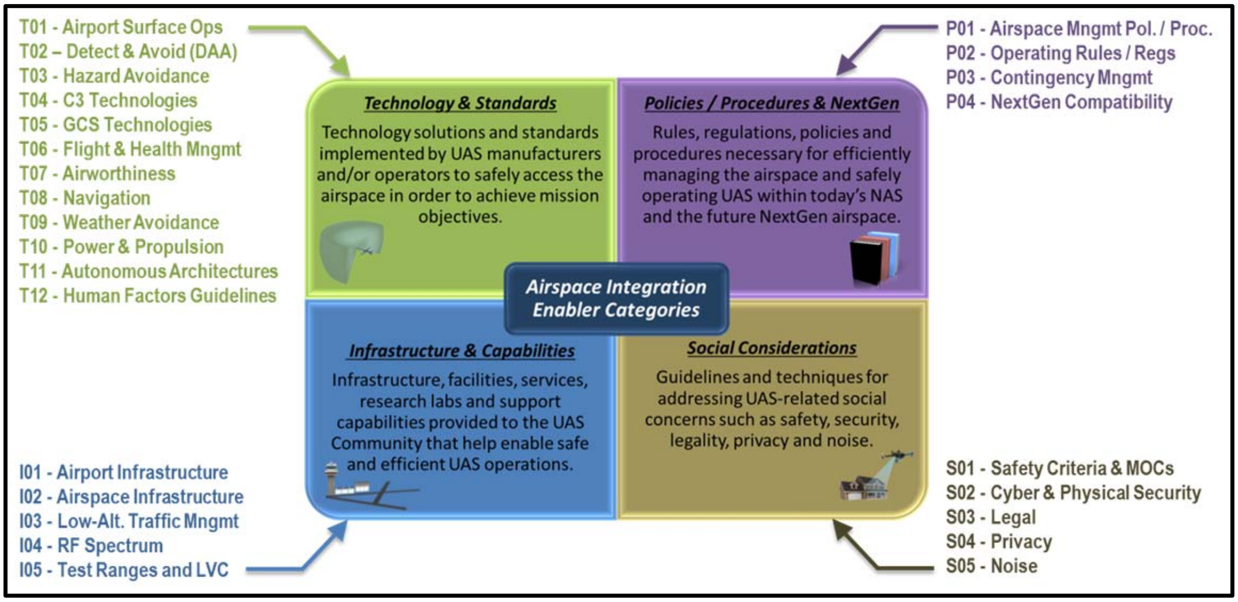

Exhibit 2: UAS Full Integration AI Enablers Allocated Across Four Distinct Categories

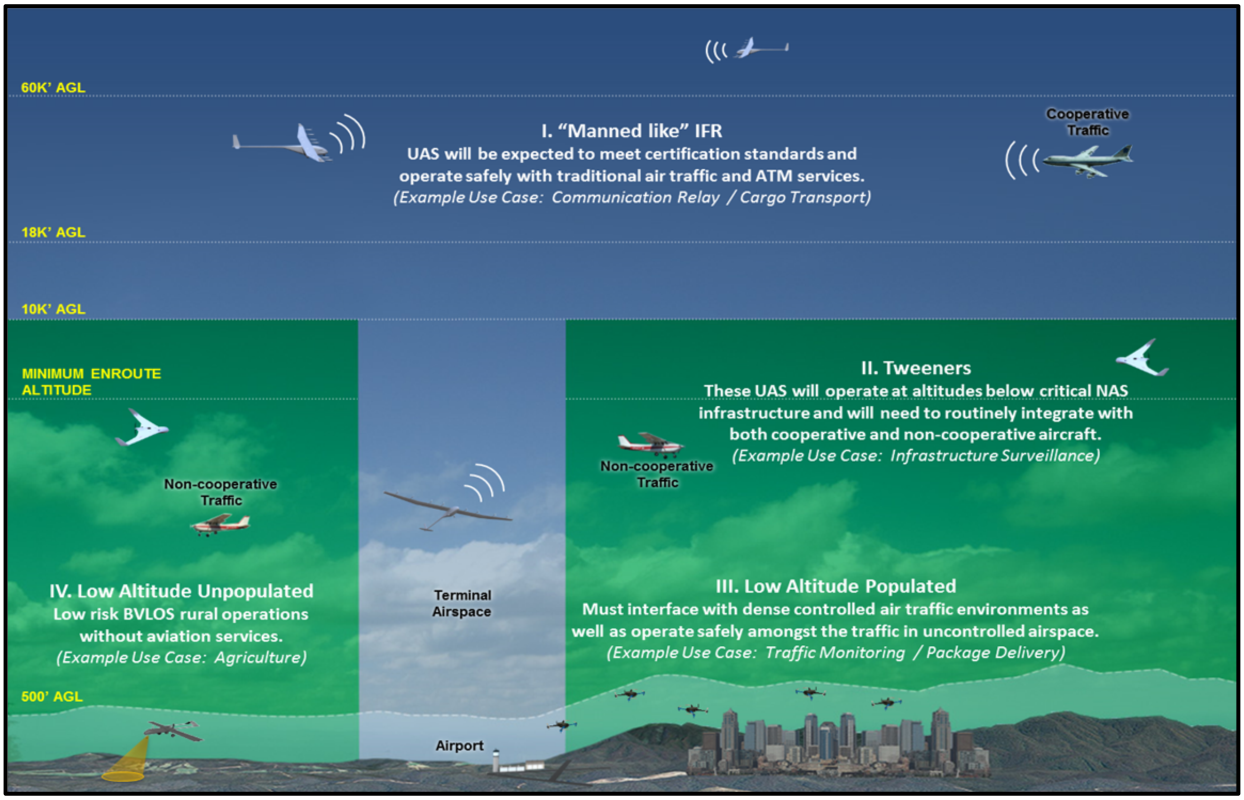

Exhibit 3: Operational Environment and Example Use Cases

Step 2 of the UAS Full Integration Technical Approach contains three sub-tasks to 1) Define Meaningful Evaluation Criteria and Weighting Values for Prioritizing the AI Enablers; 2) Derive the Relative Costs

Needed to address the AI Enabler; and 3) Perform a Cost, Opportunity, Benefit Risk Assessment for each AI enabler. Once the evaluation criteria statements and weighting values were agreed to, the research team held numerous meetings to assess each AI enabler as it related to the costs, opportunities, benefits, and risks associated with an individual OE. This was repeated four times until all operating environments were assessed. The resulting scores were used to generate cost, opportunities, benefit and risk assessment (COBRA) "tornado" plots as shown in Exhibit 4. The tornado plot was chosen because it is a great way to graphically represent the prioritized COBRA scores. Each bar shows the benefit-adjusted risk score (in red) next to the benefit-adjusted opportunity score (in blue). The AI enablers that have the greatest absolute benefit-adjusted opportunity/risk score (longest red + blue bar) are the ones that are the most important for the operating environment that they represent. The cost assessment is also displayed to the left of each bar whereby dollar signs ($) represent the relative cost for development and implementation of the solution.

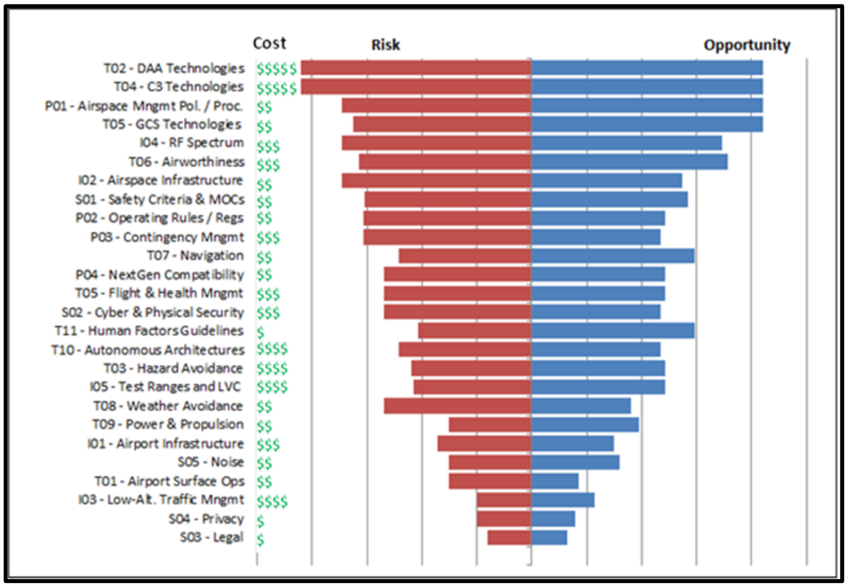

Exhibit 4: Example COBRA Tornado Plot

Step 3 of the UAS Full Integration Technical Approach contains three sub-tasks to 1) Determine NASA's strengths and weaknesses related to each AI enabler; 2) Determine the role and partnership strategies NASA should adopt; and 3) Derive cost estimates for the highest priority efforts. This part of the analyses used a modified SWOT (strengths and weaknesses, opportunities and threats) analysis technique. In a standard SWOT analysis technique, the strengths and weaknesses of an organization (their internal attributes) are plotted along the y axis and the opportunities and threats (external attributes) are plotted along the x-axis. As depicted in Exhibit 5, this modified SWOT analysis considers

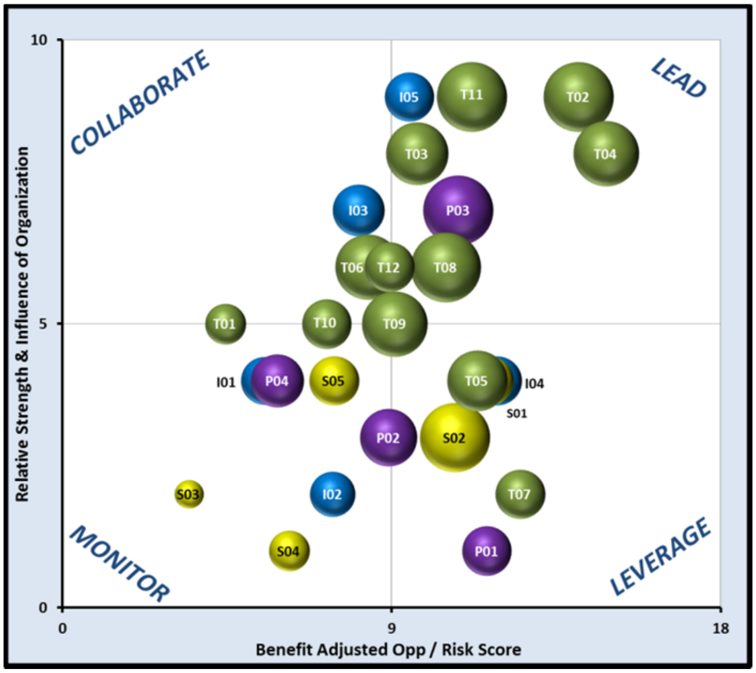

Exhibit 5: Example Organizational Role Chart

the relative strengths and influence of the organization (NASA’s **internal** abilities), and plots them against the COBRA results (the **external** integration environment). The role that NASA should take with respect to each AI for a given OE can be determined based on what quadrant the AI enabler bubble is plotted within.

- **Lead:** NASA has *high* strength/influence and the AI enabler has a *high* benefit-adjusted opportunity/risk score. As a result, NASA should consider adopting a *leadership* role towards any efforts taken to address the gaps/challenges associated with this AI enabler.
- **Collaborate:** NASA has *high* strength/influence; however, the AI enabler has a *low* benefit-adjusted opportunity/risk score. Therefore, NASA should consider *collaborating* with industry or other organizations to address the gaps/challenges associated with this AI enabler.
- **Leverage:** NASA has *low* strength/influence; however, the AI enabler has a *high* benefit-adjusted opportunity/risk score. NASA should therefore support other organizations that are better positioned/equipped to lead the effort and/or leverage their work.
- **Monitor:** NASA has *low* strength/influence and the AI enabler has a *low* benefit-adjusted opportunity/risk score. As a result, NASA should *monitor* the efforts of industry /other organizations that are actively addressing the gaps/challenges.

After generating Lead/Collaborate/Leverage/Monitor (LCLM) plots for all four operating environments, the study team then needed a way to compare the relative importance of each AI enabler across all operating environments. To make this comparison, the team generated a prioritized “heat map” table as shown in Exhibit 6.

AI Enablers		Operational Environment				Sum	Overall Rank
		Man-Like IFR	Tweener	Low-Alt / Popul.	Low-Alt / Unpop.		
		I	II	III	IV		
T02	Certifiable DAA Technologies	151	151	138	68	508	1
T04	Certifiable C3 Technologies	124	134	123	94	475	2
T11	Autonomous Architectures	86	106	138	93	423	3
I05	Sufficient Test Ranges and LVC M&S Facilites	69	83	104	86	342	4
T03	Certifiable Hazard Avoidance Technologies	26	74	134	76	310	5
P03	Contingency Mngmt Procedures	84	76	84	59	303	6
I03	Low-Altitude Airspace Mngmt Infrastructure	11	39	151	91	291	7
T08	Certifiable Navigation Technologies	54	65	69	64	252	8
S01	Safety Criteria & Methods of Compliance (MOC)	59	59	59	57	233	9
T12	Human Factors Guidelines	60	60	60	33	215	10
S05	Noise Guidelines & Rules	30	37	88	57	212	11
T06	Certifiable Flight & Health Mngmt Systems	62	62	48	29	200	12
I04	Adequate Secured / Managed RF Spectrum	40	55	48	48	190	13
T09	Certifiable Weather Avoidance Technologies	42	45	57	45	189	14
T05	Certifiable GCS Technologies	51	60	39	32	181	15
S02	Cyber & Physical Security Criteria & MOCs	45	45	50	42	181	16
T10	Certifiable Power & Propulsion Technologies	40	35	33	38	145	17
P02	Operating Rules / Regs / Procedures	33	33	36	5	107	18
P04	NextGen Compatibility	45	41	9	6	102	19
T07	Airworthiness Criteria / Standards / MOCs	27	27	25	22	100	20
T01	Certifiable Airport Surface Ops Technologies	60	24	6	6	95	21
I01	UAS Accommodating Airports & Infrastructure	38	19	6	4	66	22
I02	UAS Accomm. Airspace Mngmt Infrastructure	21	25	11	2	59	23
P01	Airspace Mngmt Policies & Procedures	13	15	11	7	46	24
S03	Legal Framework for UAS Litigation	5	9	17	9	40	25
S04	Privacy Guidelines & Rules	3	4	12	8	28	26

Exhibit 6: Airspace Integration Enabler Heat Map

The derived scores for each AI enabler were the product of the x-axis score and the y-axis score (i.e., the AI enabler's benefit-adjusted opportunity/risk score times the NASA strength/influence score). To better distinguish the high heat-map values from the lower heat-map values, color shading was used. In this case, the higher values were shown as a darker shade of red, whereas the lower values used a lighter shade of red. Exhibit 6 also has a "Sum" column, which is the summation of all four heat-map scores and an "Overall Rank" column which was used to prioritize the numbers shown in the "Sum" column. In this case the rows were ranked from 1 to 26, with "Certifiable DAA Technologies" (T02) scoring the highest and "Privacy Guidelines & Rules" (S04) scoring the lowest.

Using a prioritized heat-map table, like the one shown above, makes it easy to see which AI enablers NASA should seriously consider working. By helping to resolve the gaps and challenges related to the AI enablers listed at the top of this table, NASA has the ability to greatly reduce the most important barriers preventing UAS full integration today. Since these barriers span all four operating environments, resources invested against the items at the top of this table will have the largest positive impact on the UAS community.

In summary, this paper documents the assumptions, technical approach, and research findings that resulted from a multi-year study to establish the strategy for integrating UAS into the NAS. In addition, this paper describes the steps taken to provide a methodology that identifies and prioritizes the many gaps and challenges currently preventing UAS integration; defines several unique operating environments developed to separate the gaps/challenges into manageable pieces; and assess NASA's unique strengths and weaknesses as they relate to each gap/challenge in order to determine the role NASA should adopt going forward.

In order to validate the technical approach, the study team used representative data to generate several plots and charts. ***It should be emphasized that these findings do not provide an official NASA position and are only provided for the purposes of showing how the process could be used to establish a framework for developing a Full UAS Integration Strategy***.

1. Introduction

There is an increasing need to fly UAS in the NAS to perform missions of vital importance to national security and defense, emergency management, science, and to enable commercial applications. Although some UAS are able to perform missions within the NAS on a very limited basis, they are far from being able to operate routinely as their manned counterparts do today. These limitations stem largely from there being several unresolved regulatory and technical barriers as well as multiple social concerns still needing to be addressed.

To fully understand the magnitude and scope of these unresolved barriers and social concerns, NASA ARMD initiated a study to identify what would be needed to enable full integration of UAS for civil/commercial operations within the NAS by 2025. The desired outcome from conducting this study was a comprehensive analysis framework that ARMD could use to develop a research portfolio focused on retiring the remaining gaps and challenges standing in the way of full UAS integration.

This paper documents the assumptions, technical approach, and research findings that resulted from a multi-year study to establish the strategy for integrating UAS into the NAS. In addition, this paper describes the steps taken to provide a methodology that identifies and prioritizes the many gaps and challenges currently preventing UAS integration; defines several unique operating environments developed to separate the gaps/challenges into manageable pieces; and assesses NASA's unique strengths and weaknesses as they relate to each gap/challenge in order to determine the role NASA should adopt going forward.

1.1 Background

Over the past several years, several government, industry, and academic organizations have participated in efforts focused on addressing the multitude of gaps and challenges preventing UAS from integrating into the airspace. Some of these efforts focused solely on identifying the underlying issues, while others attempted to recommend potential solutions to include the development of concepts of operation, guidelines, standards or even technologies to address one of more of these challenges.

One government organization that has been very involved in working UAS airspace integration challenges is NASA ARMD. According to the *ARMD Strategic Implementation Plan,* their mission is to serve the future needs of aviation by conducting research into, and developing solutions for, the problems associated with flight[1]. This plan also defines six strategic thrusts, of which one is centered on the safe integration of unmanned and autonomous systems into the NAS (i.e., Strategic Thrust 6: Assured Autonomy for Aviation Transformation). To address this thrust, research will be required in multiple areas, including some research areas with a specific UAS focus such as communications, human-machine interface, sense-and-avoid, air traffic management, safety, airworthiness, and security. It is the intent of NASA ARMD to partner with other government agencies and industry to conduct research, develop new technologies, perform meaningful demonstrations and tests, and enable verification and validation activities to help establish standards and ensure trust.

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[1] NASA Aeronautics Strategic Implementation Plan, page 9, 2015.

1.2 Scope

The scope of this effort was very broad in nature, to include all unmanned aircraft types (e.g., fixed wing, rotorcraft, and airships) and sizes (e.g., large to small) as well as multiple operating environments (e.g., rural, urban, mixed), altitudes (0 ft – 100K ft), and use cases (e.g., package delivery, agricultural, surveillance, long-duration loiter). To help bound the problem, the research team only assessed civil and commercial use cases that are being considered for the NAS between now and 2025. For the purposes of this study, "Full Integration" was defined as "*the ability for all UAS to routinely operate through all phases of flight within the NAS, based on vehicle and infrastructure performance capabilities*."

1.3 Analytical Framework

UAS full integration is a multi-dimensional challenge facing the UAS community. Before one can begin to develop comprehensive solutions, each of the dimensions of this challenge must be well understood to include their individual magnitudes, complexities, and interdependencies. When considering how to quantitatively evaluate such a complex problem, it is often helpful to first define a conceptual analytical framework that can then be used to form the basis of all future research and analysis. For this study, the analytical framework shown in Figure 1 was used to help define the three most significant dimensions related to this challenge; namely:

1) **Airspace Integration Enablers** – The gaps and challenges preventing UAS from routinely operating within the NAS
2) **Operational Environments** – The different environments UAS are envisioned to operate within; typically defined by a concept of operation, use case, or airspace type
3) **Costs, Opportunities, Benefits, and Risks** – The associated ***costs*** required to close the gap, as well as implement the solution; the ***opportunities*** that will be enabled once the gap is closed; the importance/magnitude of the ***benefit*** achieved once the gap is closed; and the associated ***risks*** to achieving full integration if the gap is not closed in a timely manner.

This three-dimensional framework established the basis for all analysis that was conducted under this study. The following sections define the technical approach used to set up the analysis and the representative findings generated by using this approach and framework.

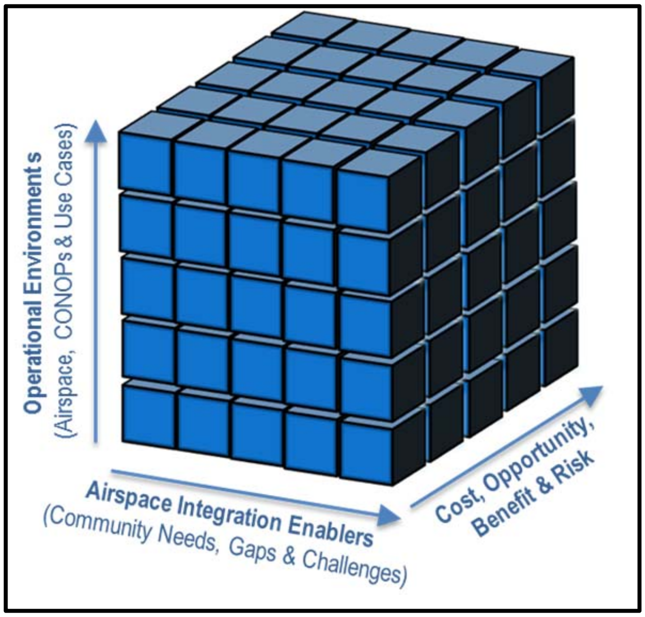


Figure 1: UAS Full Integration Analytical Framework

2. Technical Approach Overview

The technical approach used for developing a framework leading to a comprehensive ARMD full UAS integration strategy is shown in Figure 2. This figure depicts three key steps defined as:

1) Define and Scope Community Needs

2) Cost, Opportunity, Benefit, Risk Assessment
3) Organizational Role Determination.

Each of these steps and their related sub-elements will be described in more detail within the following sections. The first two steps relied heavily upon community engagement and involved multiple engagements with organizations such as the Federal Aviation Administration (FAA), Joint Planning and Development Organization (JPDO), Department of Defense (DoD), Department of Homeland Security (DHS), federally funded research and development corporations (FFRDC), industry, and academia. The third step was reserved for NASA-internal participants only since NASA has the best understanding of its internal strengths and weaknesses and could best recommend the appropriate path forward for itself.

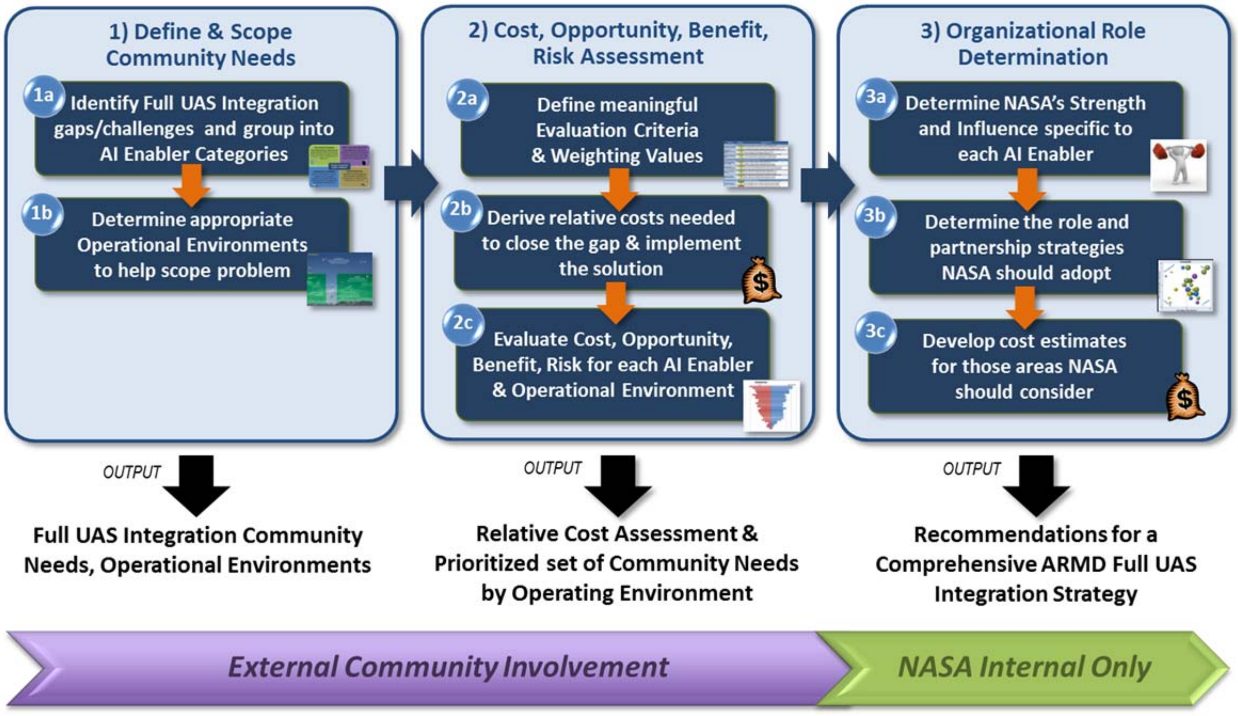


Figure 2: UAS Full Integration Technical Approach

2.1 Step 1: Define & Scope Community Needs

The first step within the technical approach results in a comprehensive set of community needs (i.e., gaps) and a set of operational environments (OE) that can be used to divide the challenge into logical pieces. Sub-task (1a) focuses on identifying all of the gaps associated with fully integrating UAS of all types and sizes into the NAS. These gaps should include items such as policies, procedures, on-board and off-board technologies, infrastructure, and even social concerns. Similar gaps can also be grouped together into AI enabler categories to help simplify the analysis. Sub-task (1b) focuses on defining the different OEs that UAS are envisioned to operate within. This is an essential step because any given solution to close a gap may not work the same across all OEs and therefore may not have the same cost, opportunity, benefit, and risk attributes.

2.2 Step 2: Cost, Opportunity, Benefit, Risk Assessment

The second step within the technical approach results in a relative cost assessment and a prioritized set of AI Enablers by operating environment. Sub-task (2a) defines meaningful evaluation criteria and weighting values that can be used to evaluate each gap against. Once these criteria and values are defined, sub-task (2b) is performed to derive a set of relative costs (very low, low, moderate, high, very high) needed to both close the AI enabler gap and implement the solution across each operational environment. Sub-task (2c) is then done to evaluate the individual cost, opportunity, benefit and risk for each AI enabler as it pertains to each operational environment. A computer-generated cost, opportunity, benefit, risk assessment (COBRA) plot is generated to help prioritize and visualize the results.

2.3 Step 3: Organizational Role Determination

The third step in the technical approach results in a final set of recommendations for a comprehensive full UAS integration strategy. Sub-task (3a) determines NASA's strength and influence specific to each AI enabler. Representatives familiar with the unique capabilities that exist at each NASA Aeronautics Research Center are needed to complete this effort. Sub-task (3b) applies the previously derived values to generate a series of Lead, Collaborate, Leverage, and Monitor (LCLM) plots to help determine the role that NASA should adopt when addressing each of the AI enablers within a given operational environment. Sub-task (3c) entails the commissioning of a NASA-internal independent cost estimate for each of the high-priority items that NASA would like to Lead, Collaborate or Leverage based on the LCLM plots. Independent cost estimates should only be required for items that NASA leadership determines to be worth pursuing.

2.4 Decision Support Tool Development

To assist NASA in performing each of the steps outlined above, NASA contracted Modern Technology Solutions, Inc. (MTSI), to develop a decision support tool. This tool, depicted in Figure 3, captured all of the community needs / gaps that were found in step 1, documented the evaluation criteria and weighting values used for the analysis, provided a user-friendly interface for evaluating each AI enabler across all unique OEs, produced COBRA "tornado plots" for helping to prioritize the gaps, generated LCLM plots for helping to determine the role NASA should adopt, and produced heat-map plots used to conduct operational analysis for the purpose of finding trends in the data. Each of these plot types will be described and depicted in subsequent sections.

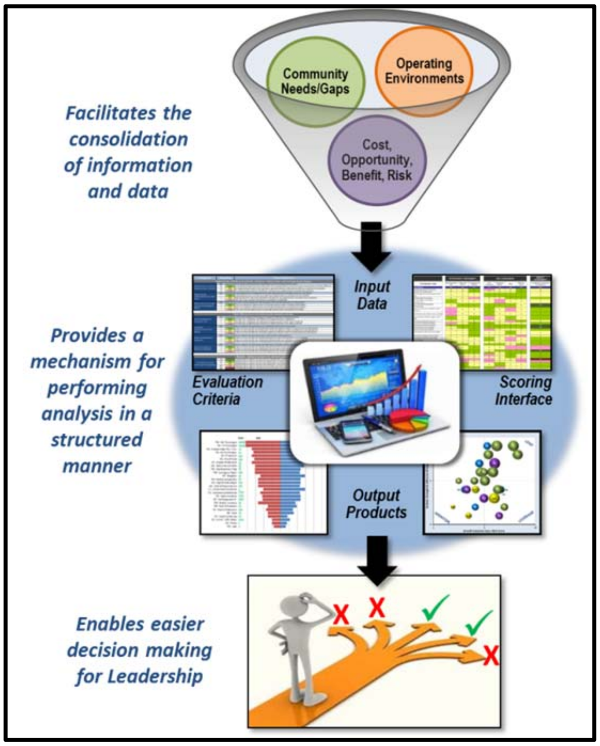


Figure 3: UAS Full Integration Decision Support Tool Depiction

3. Research Efforts and Findings

This section explains how each of the three technical approach steps was accomplished and provides the resultant findings derived by the study team. In order to validate that the process works, the study team used representative data to generate several plots and charts which will be shown below. ***It should be emphasized that these findings do not provide an official NASA position and are only provided for the purposes of showing how the process could be used to establish a framework for developing a Full UAS Integration Strategy***.

3.1 Step 1: Identify & Scope Community Needs

Step 1 of the UAS Full Integration Technical Approach contains two sub-tasks to 1) Identify the full integration gaps/challenges and 2) Define an appropriate number of unique OEs to help scope the problem and divide it into manageable elements for focusing the analysis. Both of these sub-tasks are described in more detail below.

3.1.1 Full Integration Gaps/Challenges

The first sub-task within step 1of the technical approach focused on identifying all of the gaps/challenges associated with fully integrating UAS into the NAS. To identify these gaps/challenges, the research team conducted an extensive literature search, engaged multiple stakeholder groups from across the UAS community, and even interviewed many subject matter experts (SMEs) to get their inputs. This sub-task took several months to complete and resulted in over 300 gaps/challenges being identified. The stakeholder groups and SMEs included the FAA, JPDO, DoD, NASA, Association of Unmanned Vehicle Systems International (AUVSI), and industry. Appendix II provides a list of all the references used to gather many of these gaps/challenges.

As one might expect, several of the over 300 gaps/challenges identified across all of the reference sources were redundant or similar in nature. To facilitate the future analysis activity, the study team consolidated the related gaps/challenges into twenty-six AI enablers, which were then grouped into four distinct AI enabler categories as depicted in Figure 4. These AI enabler categories were:

1) Technology and Standards
2) Policies / Procedures / NextGen
3) Infrastructure and Capabilities
4) Social Considerations.

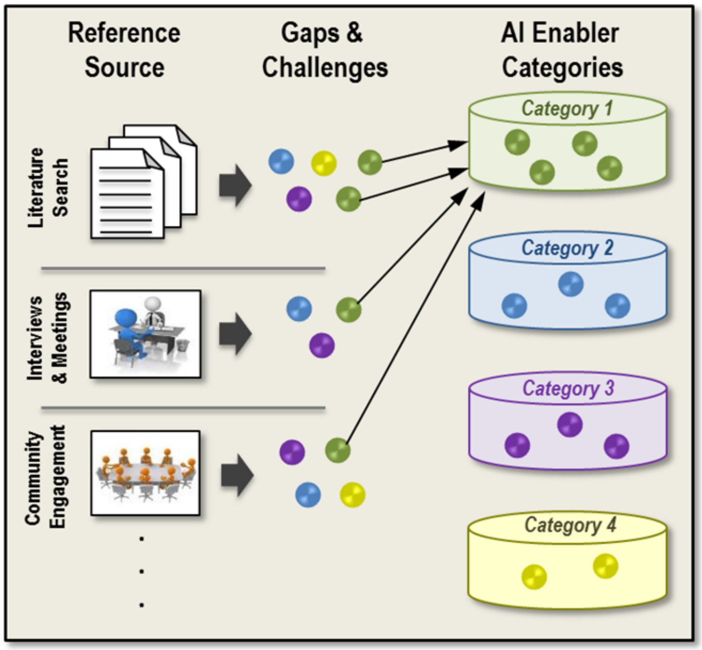


Figure 4: Consolidation of Gaps/Challenges into Similar Bins called AI Enablers

Figure 5 defines each of these four categories and shows how the 26 unique AI enablers were allocated across the four categories. Each AI enabler category is comprised of several AI enablers and each AI enabler is comprised of several unique gaps/challenges. Appendix III contains a table that defines each of the AI enablers and assigns each of them a unique identifier (e.g., T01, P03, S02). These identifiers were used in each of the plots and charts that will be shown in subsequent sections.

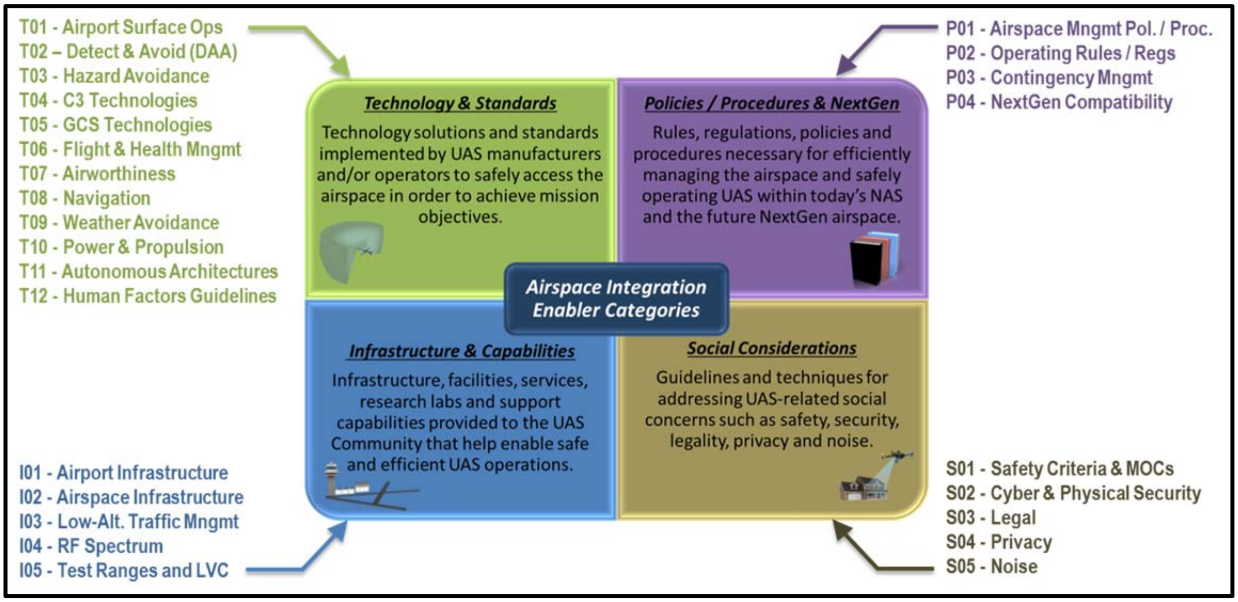


Figure 5: UAS Full Integration AI Enablers Allocated Across Four Distinct Categories

3.1.2 Unique Operational Environments

The second sub-task within step 1 set out to define several unique OEs which would enable the study team to individually evaluate each of the AI enablers across the multitude of environments commercial UAS are envisioned to operate within over the coming years. This sub-task is particularly important because many of the solutions developed to address the gaps/challenges contained within each AI enabler will not work in all OEs, nor will they be feasible for all groups of UAS to implement due to their unique size, weight, power, and performance characteristics. Figure 6 and Table 1 depict and describe the four unique OEs that the study team derived and used for this effort. These OEs are:

1) Manned-Like IFR
2) Tweeners
3) Low-Altitude - Populated
4) Low-Altitude - Unpopulated.

The potential certainly exists to consider additional OEs in the future; however, these four OEs provided a solid basis for the analysis conducted and described within this paper. Appendix IV contains a more detailed operational view (OV-1) for each of these OEs showing a representative use case for each.

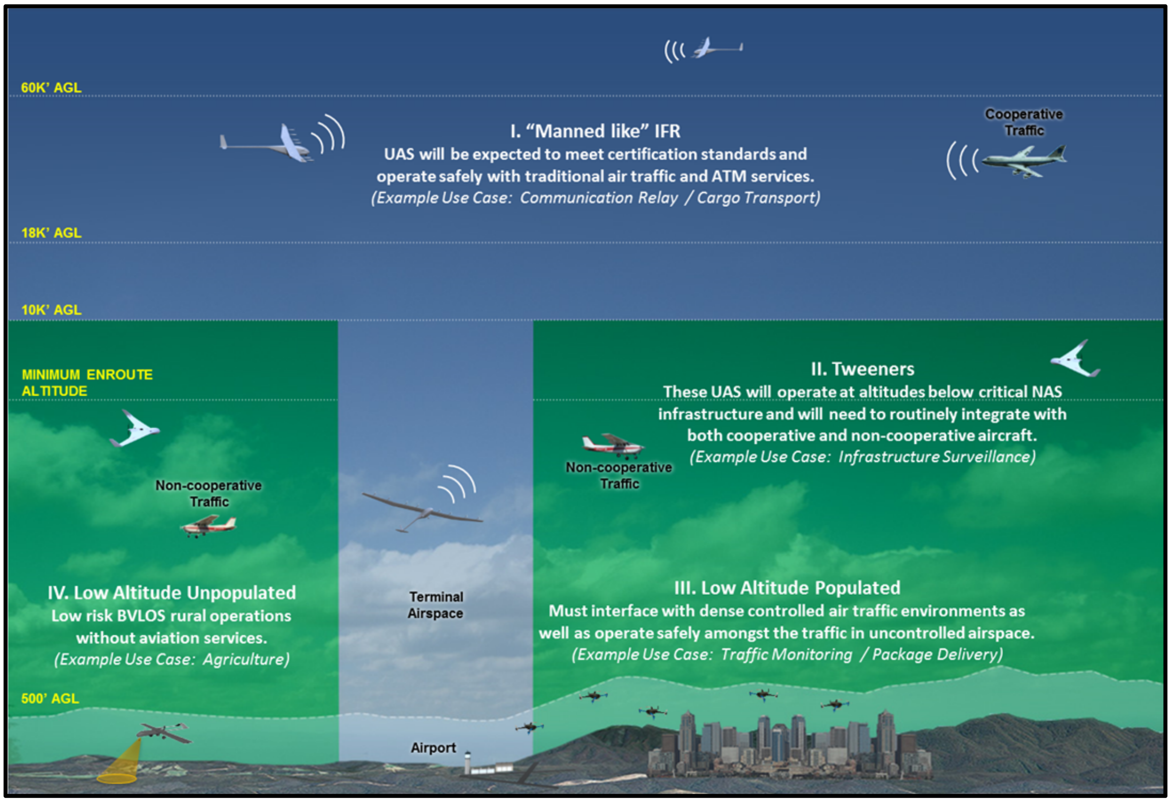


Figure 6: Emerging UAS Operational Environments

Table 1: Operational Environment Attributes and Example Use Cases

Representative Operational Environments		Example Use Cases	Operational Environment Attributes
I	"Manned like" IFR	Communication Relay & Cargo Transport	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.
II	Tweeners	Large Infrastructure Inspection	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.
III	Low Altitude Populated	Package Delivery & Traffic Monitoring	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.
IV	Low Altitude Unpopulated	Agriculture	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.

3.2 Step 2: Cost, Opportunity, Benefit, Risk Assessment

Step 2 of the UAS Full Integration Technical Approach contains three sub-tasks to 1) Define meaningful evaluation criteria and weighting values for prioritizing the AI enablers; 2) Deriving the relative costs needed to address the AI enabler; and 3) Perform a COBRA for each AI enabler. Each of these sub-tasks are described in more detail below.

3.2.1 Evaluation Criteria & Weighting Values

In order to assess and evaluate each of the AI enablers across the four OEs, a set of weighted evaluation criteria had to be established. Collectively, these evaluation factors needed to be comprehensive and meaningful so that a quantitative analysis could be performed to compare, contrast, and eventually prioritize each AI enabler so NASA could determine the most important areas to invest future resources.

The creation of these criteria was an iterative process, relying greatly on the feedback of the NASA ARMD leadership for guidance. Using existing industry best practices and guidance, such as the Project Management Institute's "Project Management Body of Knowledge (PMBOK) Guide," the research team initially developed criteria based solely around the *Benefits* and *Risks* of each AI enabler. However, after a few iterations, between the research team and NASA leadership, these two major categories evolved to also include the *Cost* and *Opportunity* criteria categories. These four evaluation criteria categories were defined as follows:

- **Opportunity**: Ability to accelerate schedule, reduce costs, and leverage other's efforts
- **Risk**: Negative effects resulting from not achieving the desired outcome
- **Benefit**: Overall contribution towards achieving Full Integration
- **Cost**: Resources required to achieve the desired outcome.

Each of these evaluation criteria categories were further broken into specific evaluation criteria statements that were used to assess each AI enabler. The *Opportunity* category had three statements and the *Risk* category had four statements. These categories are both depicted in Table 2 on the following page. Similarly, the *Benefit* category statements are shown in Table 3 and the *Cost* category statements are provided in Table 4. The specific evaluation statements for all four of these categories were developed through collaborative brainstorming sessions, assessing the broad scope of enablers and the entirety of the environment and efforts toward full U.S. airspace integration.

Each of the *Opportunity* and *Risk* statements used a relatively simple high-medium-low structure, which provided sufficient fidelity without burdening the evaluators with overly complex definitions. In addition, the various evaluation statements were weighted using a 100%-based scale, to give greater weight to the statements that the research team felt were more important, and also to generate greater variance in the final number values and thus minimize ranking "ties."

Table 2: Opportunity and Risk Evaluation Criteria

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

Unlike the *Opportunity* and *Risk* categories, the *Benefit* evaluation category, shown in Table 3 below, utilized only one statement, and as it is implemented as an overall multiplier to the final cumulative *Opportunity*/*Risk* score, its emphasis is therefore greater and thus used a "very low-low-medium-high-very high" structure.

Table 3: Benefit Evaluation Criteria

Categories	Weight	Criteria Definitions
Benefit: Overall contribution towards achieving Full Integration		
Relative contribution towards achieving Full Integration	Very High	Making progress against this gap will *very significantly* contribute towards achieving full integration
	High	Making progress against this gap will *significantly* contribute towards achieving full integration
	Medium	Making progress against this gap will *moderately* contribute towards achieving full integration
	Low	Making progress against this gap will *minimally* contribute towards achieving full integration
	Very Low	Making progress against this gap will *very minimally* contribute towards achieving full integration

Although difficult to include in the numerical calculations, the *Cost* evaluation factor is important to consider since the relative cost of developing and implementing solutions can prove to be cost prohibitive in a fiscally constrained environment. While high costs have the potential to limit who can afford to address it, they can also be used to encourage organizations to partner and pool resources, which can be a very good thing.

The decision was made by the research team to make *Cost* an additional separate score from the *Opportunity-Risk-Benefit* calculation, and display the final *Cost* value alongside the primary calculation so that it could be considered during the final assessment. The *Cost* evaluation category was split into two statements in order to separate the cost to develop an AI enabler solution, from the cost to implement said solution. It also used five levels of evaluation similar to the *Benefit* score, using a logarithmic scale to capture the relative nonspecific "rough order of magnitude" cost values for comparison's sake. For example, developing a simple communication radio might only cost hundreds of thousands (Very Low), but to implement it to every aircraft in the NAS, along with the infrastructure to support it at every airport, could cost tens of millions (Medium).

Table 4: Cost Evaluation Criteria

Categories	Weighting	Criteria Definitions
Cost: Resources required to achieve the desired outcome		
Gap Solution Development Cost	**50%**	**Required resources to *develop* the solution(s) to close the Gap leading to Full Integration**
	Very High	*Very significant* resources required to solve the remaining gap (>$1B) ($$$$$)
	High	*Significant* resources required to solve the remaining gap ($100M-$1B) ($$$$)
	Medium	*Moderate* resources required to solve the remaining gap ($10M-$100M) ($$$)
	Low	*Minimal* resources required to solve the remaining gap ($1M-$10M) ($$)
	Very Low	*Very minimal* resources required to solve the remaining gap (<$1M) ($)
Gap Solution Implementation Cost	**50%**	**Required resources to *implement* the solution(s) to close the Gap leading to Full Integration**
	Very High	*Very significant* resources required to implement the solution (>$1B) ($$$$$)
	High	*Significant* resources required to implement the solution ($100M-$1B) ($$$$)
	Medium	*Moderate* resources required to implement the solution ($10M-$100M) ($$$)
	Low	*Minimal* resources required to implement the solution ($1M-$10M) ($$)
	Very Low	*Very minimal* resources required to implement the solution (<$1M) ($)

3.2.2 Derive Relative Costs Needed to Address the Challenge

The second sub-task in step 2 was to derive the relative costs needed to both develop the solution and implement the change. As one can imagine, deriving both of these costs for each AI enabler would take a significant amount of time, resources and effort. Due to the time and fiscal constraints placed on the study team, there was insufficient time to perform an independent life cycle cost estimate on each AI enabler. Therefore, the team relied upon their general knowledge and subject matter expertise to generate an initial rough order of magnitude (ROM) assessment of the relative cost information. Depending on the fidelity of these cost numbers a more robust effort may be required to complete this sub-task.

3.2.3 COBRA Analysis & Findings

Once the evaluation criteria statements and weighting values were agreed to the research team held numerous meetings to assess each AI enabler as they relate to the cost, opportunities, benefit and risks associated with an individual operating environment. This was repeated four times until all operating environments were assessed. The resulting scores were used to generate COBRA tornado plots. The tornado plot was chosen because it is a great way to graphically represent the prioritized COBRA scores. Each bar shows the benefit-adjusted risk score (in red) next to the benefit-adjusted opportunity score (in blue). The AI enablers that have the greatest absolute benefit-adjusted opportunity/risk score (longest red + blue bar) are the ones that are the most important for the operating environment that they represent. The cost assessment is also displayed to the left of each bar in the form of dollar signs ($), one through five, that align with the values in Table 4. Figure 7 shows an example COBRA plot with the representative AI enablers already ranked and prioritized. The relative cost icons ($) are also shown on the plot as well.

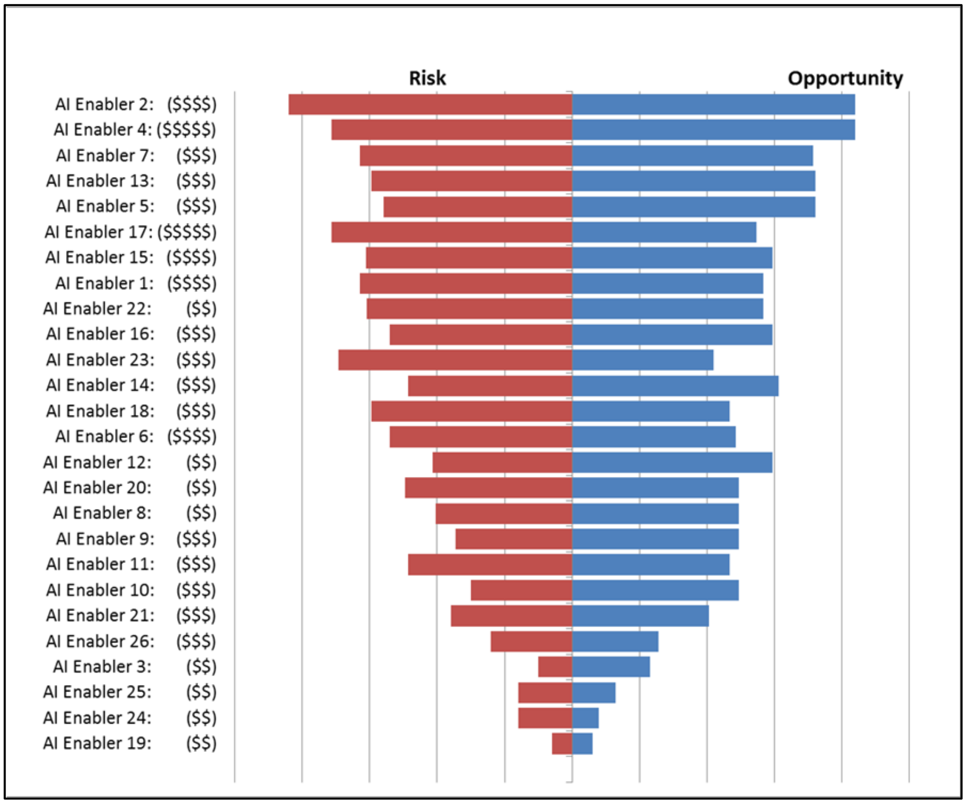


Figure 7: Example COBRA Tornado Plot

The research team's full evaluation scoring assessments are located in Appendix V, listed in 4 separate tables by operating environment. The resulting tornado plots are located in Appendix VI.

3.3 Step 3: Organizational Role Determination

Step 3 of the UAS Full Integration Technical Approach contains three sub-tasks to 1) Determine NASA's strengths and weaknesses related to each AI enabler; 2) Determine the role and partnership strategies NASA should adopt; and 3) Derive cost estimates for the highest priority efforts. Each of these sub-tasks are described in more detail below.

3.3.1 Strength / Weakness Determination

The COBRA analysis, discussed above, developed a prioritization of the AI enablers from a risk, opportunity, benefit, and cost perspective. However, in order to provide NASA with recommendations on the role they should adopt related to each of the AI enablers, an evaluation of NASA's strengths and weaknesses was needed. To facilitate this, the study team decided to tailor and modify a basic SWOT (strengths and weaknesses, opportunities and threats) analysis technique and apply it to this effort. In a standard SWOT analysis technique, the strengths and weaknesses of an organization (their internal attributes) are plotted along the y axis and the opportunities and threats (external attributes) are plotted along the x-axis. As depicted in Figure 8, this modified analysis considers the relative strengths and influence of the organization (NASA's **internal** abilities), and plots them against the COBRA results (the **external** integration environment).

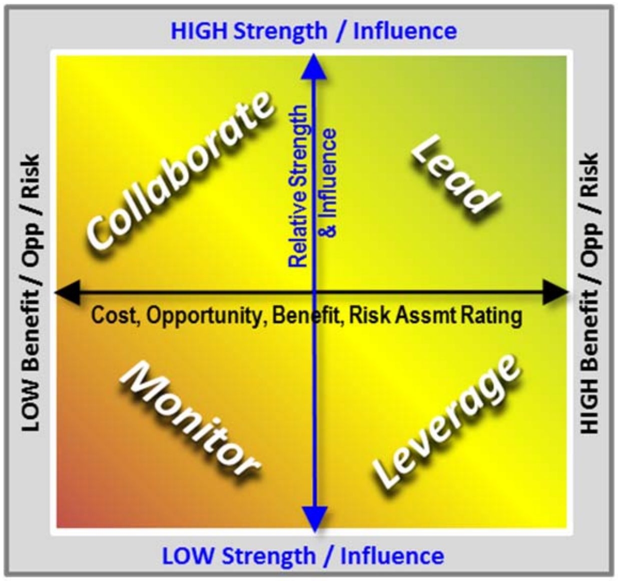


Figure 8: Lead/Collaborate/Leverage/Monitor (LCLM) Matrix

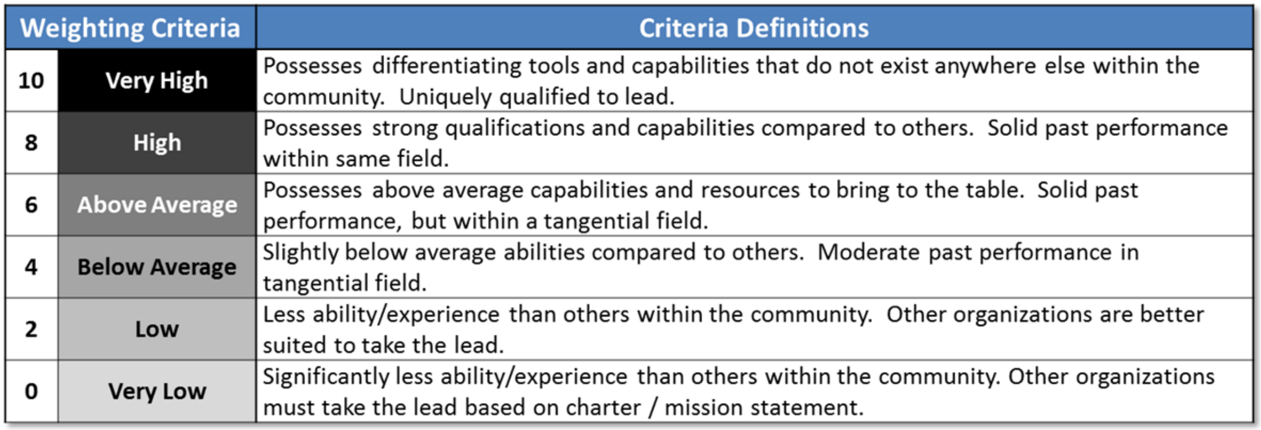
The resulting output creates four general quadrants in which the AI enablers can be grouped: lead, collaborate, leverage, and monitor. Each of these quadrants is defined in more detail below.

- **Lead:** NASA has *high* strength/influence and the AI enabler has a *high* benefit-adjusted opportunity/risk score. As a result, NASA should consider adopting a *leadership* role towards any efforts taken to address the gaps/challenges associated with this AI enabler. NASA is the obvious choice to take on a 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 the risk.

- **Collaborate:** NASA has *high* strength/influence; however, the AI enabler has a *low* benefit-adjusted opportunity/risk score. Therefore, NASA should consider *collaborating* with industry or other organizations to address the gaps/challenges associated with this AI enabler. If 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.
- **Leverage:** NASA has *low* strength/influence; however, the AI enabler has a *high* benefit-adjusted opportunity/risk score. NASA should therefore support other organizations that 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.
- **Monitor:** NASA has *low* strength/influence and the AI enabler has a *low* benefit-adjusted opportunity/risk score. As a result, NASA should *monitor* the efforts of industry /other organizations that are actively addressing the gaps/challenges. 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.

As mentioned above, the x-axis of the LCLM matrix comes directly from the previous-conducted COBRA analysis. The y-axis, however, required a new set of evaluation criteria to be applied. The development team created a relative strength and influence criteria scale, which had six levels ranging from 0 (Very Low) to 10 (Very High). The definitions for each of these levels are shown in Table 5.

Table 5: Relative Strength & Influence Criteria



Weighting Criteria		Criteria Definitions
10	Very High	Possesses differentiating tools and capabilities that do not exist anywhere else within the community. Uniquely qualified to lead.
8	High	Possesses strong qualifications and capabilities compared to others. Solid past performance within same field.
6	Above Average	Possesses above average capabilities and resources to bring to the table. Solid past performance, but within a tangential field.
4	Below Average	Slightly below average abilities compared to others. Moderate past performance in tangential field.
2	Low	Less ability/experience than others within the community. Other organizations are better suited to take the lead.
0	Very Low	Significantly less ability/experience than others within the community. Other organizations must take the lead based on charter / mission statement.

The research team again utilized team workshops to generate an initial NASA strength and influence score for all 26 AI enablers. The values used for this analysis are shown in Table 6. These strength/influence scores were applied to all four OE plots since the research team assumed NASA's abilities could consistently be applied across each of them. Based on the academic scores assigned to each AI enabler by the research team, a family of LCLM plots was generated—one for each OE. These four LCLM plots can be seen in Appendix VII.

Table 6: Initial Strength & Influence Scores assigned to each AI Enabler for this Analysis

Airspace Integration Enablers			Strength & Influence Rating
Technology & Standards	T01	Certifiable Airport Surface Ops Technologies	5
	T02	Certifiable DAA Technologies	9
	T03	Certifiable Hazard Avoidance Technologies	8
	T04	Certifiable C3 Technologies	8
	T05	Certifiable GCS Technologies	4
	T06	Certifiable Flight & Health Mngmt Systems	6
	T07	Airworthiness Criteria / Standards / MOCs	2
	T08	Certifiable Navigation Technologies	6
	T09	Certifiable Weather Avoidance Technologies	5
	T10	Certifiable Power & Propulsion Technologies	5
	T11	Autonomous Architectures	9
	T12	Human Factors Guidelines	6
Policies, Procedures & NextGen	P01	Airspace Mngmt Policies & Procedures	1
	P02	Operating Rules / Regs / Procedures	3
	P03	Contingency Mngmt Procedures	7
	P04	NextGen Compatibility	4
Infrastructure & Capabilities	I01	UAS Accommodating Airports & Infrastructure	3
	I02	UAS Accommodating Airspace Mngmt Infrastructure	2
	I03	Low-Altitude Airspace Mngmt Infrastructure	9
	I04	Adequate Secured / Managed RF Spectrum	4
	I05	Sufficient Test Ranges and LVC M&S Facilities	9
Social Considerations	S01	Safety Criteria & Methods of Compliance (MOC)	5
	S02	Cyber & Physical Security Criteria & MOCs	4
	S03	Legal Framework for UAS Litigation	2
	S04	Privacy Guidelines & Rules	1
	S05	Noise Guidelines & Rules	6

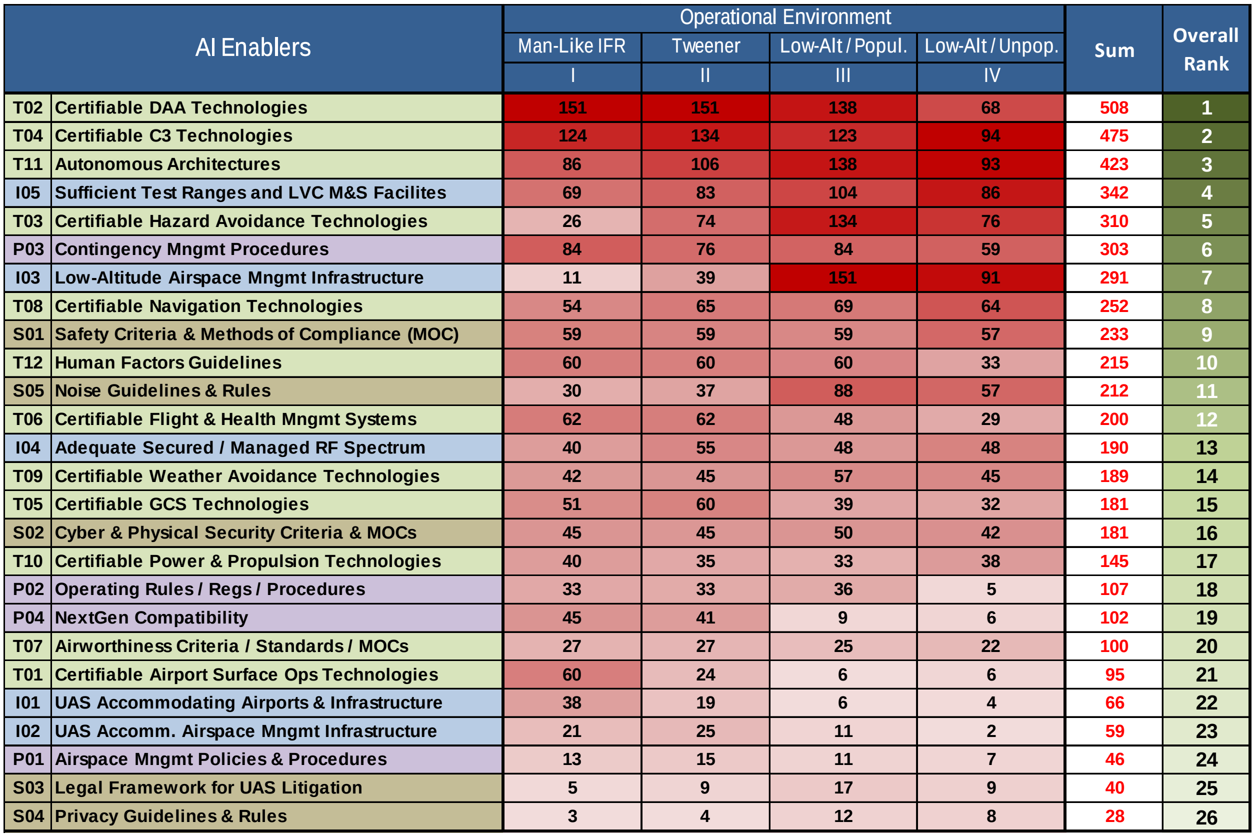
3.3.2 LCLM Findings and Recommendations

After generating LCLM plots for all four operating environments, the study team then needed a way to compare the relative importance of each AI enabler across all operating environments. To make this comparison, the team generated a prioritized heat map, as shown in Table 7 below. This table shows four scores next to each AI enabler row—one for each OE.

The derived scores for each AI enabler were the product of the x-axis score and the y-axis score (i.e., the AI enabler's benefit-adjusted opportunity/risk score times the NASA strength/influence score). For example, the heat-map score for the Certifiable C3 Technologies AI enabler (T04) for the "Man-like IFR" OE was 124. This number was calculated by multiplying the x-axis value of 15.5 times the y-axis value of 8. To better distinguish the high heat-map values from the lower heat-map values, color shading was used. In this case, the higher values were shown as a darker shade of red, whereas the lower values used a lighter shade of red.

Table 7 also has a “Sum” column, which is the summation of all four heat-map scores and an “Overall Rank” column which was used to prioritize the numbers shown in the sum column. In this case the rows were ranked from 1 to 26, with “Certifiable DAA Technologies” (T02) scoring the highest and “Privacy Guidelines & Rules” (S04) scoring the lowest.

Table 7: Airspace Integration Enablers, Final Ranking



AI Enablers		Operational Environment				Sum	Overall Rank
		Man-Like IFR	Tweener	Low-Alt / Popul.	Low-Alt / Unpop.		
		I	II	III	IV		
T02	Certifiable DAA Technologies	151	151	138	68	508	1
T04	Certifiable C3 Technologies	124	134	123	94	475	2
T11	Autonomous Architectures	86	106	138	93	423	3
I05	Sufficient Test Ranges and LVC M&S Facilites	69	83	104	86	342	4
T03	Certifiable Hazard Avoidance Technologies	26	74	134	76	310	5
P03	Contingency Mngmt Procedures	84	76	84	59	303	6
I03	Low-Altitude Airspace Mngmt Infrastructure	11	39	151	91	291	7
T08	Certifiable Navigation Technologies	54	65	69	64	252	8
S01	Safety Criteria & Methods of Compliance (MOC)	59	59	59	57	233	9
T12	Human Factors Guidelines	60	60	60	33	215	10
S05	Noise Guidelines & Rules	30	37	88	57	212	11
T06	Certifiable Flight & Health Mngmt Systems	62	62	48	29	200	12
I04	Adequate Secured / Managed RF Spectrum	40	55	48	48	190	13
T09	Certifiable Weather Avoidance Technologies	42	45	57	45	189	14
T05	Certifiable GCS Technologies	51	60	39	32	181	15
S02	Cyber & Physical Security Criteria & MOCs	45	45	50	42	181	16
T10	Certifiable Power & Propulsion Technologies	40	35	33	38	145	17
P02	Operating Rules / Regs / Procedures	33	33	36	5	107	18
P04	NextGen Compatibility	45	41	9	6	102	19
T07	Airworthiness Criteria / Standards / MOCs	27	27	25	22	100	20
T01	Certifiable Airport Surface Ops Technologies	60	24	6	6	95	21
I01	UAS Accommodating Airports & Infrastructure	38	19	6	4	66	22
I02	UAS Accomm. Airspace Mngmt Infrastructure	21	25	11	2	59	23
P01	Airspace Mngmt Policies & Procedures	13	15	11	7	46	24
S03	Legal Framework for UAS Litigation	5	9	17	9	40	25
S04	Privacy Guidelines & Rules	3	4	12	8	28	26

Using a prioritized heat-map table, like the one shown above, makes it easy to see which AI enablers NASA should seriously consider working. By helping to resolve the gaps and challenges related to the AI enablers listed at the top of this table, NASA has the ability to greatly reduce the most important barriers preventing UAS full integration today. Since these barriers span across all four operating environments, resources invested against the items at the top of this table will have the largest positive impact on the UAS community.

3.3.3 Derive Cost Estimates of High Priority Efforts

The third sub-task in step 3 is to derive cost estimates of the highest priority efforts. This sub-task was not performed by the study team and is left for NASA to complete. This activity is critical in order to properly plan and identify the necessary resources required to establish the project(s) focused on working the gaps and challenges related to the highest priority AI enablers. The intent is not for NASA to conduct an independent life cycle cost estimate for all 26 AI enablers. Rather, NASA should select the top 10, for example, and only cost out those. Hopefully, they can encourage other organizations to take the lead on addressing the gaps and challenges lower down in the heat map table since they may be better positioned/equipped to lead those efforts.

4. Conclusions

NASA ARMD recently initiated a study to identify what is needed to enable full integration of UAS for civil/commercial operations within the NAS by 2025. The desired outcome from conducting this study was a comprehensive analysis framework that ARMD could use to develop a research portfolio focused on retiring the remaining gaps and challenges standing in the way of full UAS integration.

This paper documents the assumptions, technical approach, and research findings that resulted from a multi-year study to establish the strategy for integrating UAS into the NAS. In addition, this paper describes the steps taken to provide a methodology that identifies and prioritizes the many gaps and challenges currently preventing UAS integration; defines several unique operating environments developed to separate the gaps/challenges into manageable pieces; and assesses NASA's unique strengths and weaknesses as they relate to each gap/challenge in order to determine the role NASA should adopt going forward.

The technical approach used for developing a framework leading to a comprehensive ARMD full UAS integration strategy comprised three key steps which were: 1) Define and scope community needs; 2) Conduct a cost, opportunity, benefit, risk assessment; and 3) Make an organizational role determination. These three steps were each described and explained to provide the reader with an understanding of what was performed in this study. In order to validate that the process works, the study team used representative data to generate several plots and charts shown throughout the body of this report as well as the appendices. ***It should be emphasized that these findings do not provide an official NASA position and are only provided for the purposes of showing how the process could be used to establish a framework for developing a Full UAS Integration Strategy***.

I. Acronyms and Abbreviations

AC	Advisory Circular
AI	Airspace Integration
AIM	Aviation Information Manual
ANSP	Air Navigation Service Provider
ARC	Advisory and Rulemaking Committee
ARMD	Aeronautics Research Mission Directorate
ASTM	American Society for Testing Materials
ATC	Air Traffic Control
ATM	Air Traffic Management
AUVSI	Association of Unmanned Vehicle Systems International
BRLOS	Beyond Radar Line of Sight
BVLOS	Beyond Visual Line of Sight
C/S/M	Criteria / Standards / Methods of Compliance
C3	Command Control & Communication
CANSO	Civil Air Navigation Services Organization
COBRA	Cost, Opportunity, Benefit, Risk Assessment
CONOPS	Concept of Operations
DAA	Detect and Avoid
DHS	Department Of Homeland Security
DoD	Department of Defense
EASA	European Aviation Safety Agency
ETS	Engineering and Technical Services
ExCom	Executive Committee
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FFRDC	Federally Funded Research & Development Center
GAO	Government Accountability Office
GCS	Ground Control Station
ICAST	Inter-Center Autonomy Study Team
IFR	Instrument Flight Rules
IG	Inspector General
ISRP	Integrated Systems Research Program
JPDO	Joint Planning and Development Organization
LCLM	Lead/Collaborate/Leverage/Monitor
LVC	Live Virtual Constructive
M&S	Modeling and Simulation
MOC	Methods of Compliance
MTSI	Modern Technology Solutions, Inc.
NAS	National Airspace System
NASA	National Aeronautics and Space Administration

TM	Technical Manual
NextGen	Next Generation Airspace System
NPRM	Notice of Proposed Rule Making
NRC	National Research Council
OE	Operational Environment
PM	Program Manager
PMBOK	Project Management Body of Knowledge
R&D	Research and Development
RF	Radio Frequency
ROM	Rough Order of Magnitude
RPAS	Remotely Piloted Aircraft System
SAA	Sense and Avoid
SPC	Senior Policy Committee
STI	Scientific & Technical Information
SWOT	Strengths and Weaknesses, Opportunities and Threats
UAS	Unmanned Aircraft System
USGS	United States Geological Survey
UTM	UAS Traffic Management
WRC	World Radiocommunication Conference

II. Reference Sources Used to Identify Gaps/Challenges

Table 8: Source References

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

III. AI Enabler Descriptions

Table 9: Airspace Integration Enabler Descriptions and Categories

Airspace Integration Enablers			AI Enabler Descriptions
Technology & Standards	T01	Certifiable Airport Surface Ops Technologies	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.
	T02	Certifiable DAA Technologies	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.
	T03	Certifiable Hazard Avoidance Technologies	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.
	T04	Certifiable C3 Technologies	C3 technologies need to be developed and certified in accordance with the established requirements and standards to enable safe and secure command & control, ATC communications, and BVLOS operations.
	T05	Certifiable GCS Technologies	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.
	T06	Certifiable Flight & Health Mngmt Systems	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.
	T07	Airworthiness Criteria / Standards / Methods of Compliance (CSM)	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 & Advisory Circulars for unmanned fixed-wing, rotorcraft & airships
	T08	Certifiable Navigation Technologies	Navigation technologies to support the level of fidelity needed for safe UAS operations need to be developed, validated, and certified.
	T09	Certifiable Weather Avoidance Technologies	Weather detection and avoidance/mitigation technologies need to be developed, validated and certified.
	T10	Certifiable Power & Propulsion Technologies	Power and propulsion technologies that increase safety, improve vehicle reliability, and increase endurance need to be developed, validated and certified.
	T11	Autonomous Architectures	Autonomous architectures for highly complex functions need to be developed, validated and certified.
	T12	Human Factors Guidelines	Human Factors guidelines and standards for UAS pilot and ATM displays (informative, suggestive, directive) need to be established.
Policies / Procedures NextGen	P01	Airspace Mngmt Policies & Procedures	Airspace management policies and procedures for UAS operations within all classes of airspace need to be developed and adopted.
	P02	Operating Rules / Regs / Procedures	Rules / Regs / Procedures for UAS operations need to be developed and adopted . FAA Orders, Advisory Circulars (AC), AIM, Pilot/Crew Quals, Training & Medical requirements for UAS need to be developed and published.
	P03	Contingency Mngmt Procedures	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.
	P04	NextGen Compatibility	Certain UAS must be properly equipped to ensure compatibility with NextGen so as to not degrade the safety or efficiency of the NAS.

Infrastructure & Capabilities	I01	UAS Accommodating Airports & Infrastructure	Airport infrastructure improvements are necessary to accommodate UAS operations, while still ensuring the ops tempo and safety record of airports today.
	I02	UAS Accommodating Airspace Mngmt Infrastructure	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.
	I03	Low-Altitude Airspace Mngmt Infrastructure	Airspace infrastructure needs maturation to manage increased capacity in densely populated airspace and at low altitudes without degrading safety and efficiency.
	I04	Adequate Secured / Managed RF Spectrum	Adequate RF Spectrum for UAS command and control and payload applications still needs to be defined and secured through the FCC and WRC.
	I05	Sufficient Test Ranges and LVC M&S Facilities	Sufficient UAS Test Ranges and Live Virtual Constructive (LVC) Modeling & Simulation facilities need to be established and available for UAS testing and evaluation.
Social Considerations	S01	Safety Criteria & Methods of Compliance (MOC)	Safety requirements and standards need to be established for all types of UAS operations in all classes of airspace.
	S02	Cyber & Physical Security Criteria & MOCs	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.
	S03	Legal Framework for UAS Litigation	Legal framework needs to be established for UAS-related litigation.
	S04	Privacy Guidelines & Rules	Privacy guidelines and rules need to be established for large and small UAS.
	S05	Noise Guidelines & Rules	Noise guidelines and rules need to be established for large and small UAS.

IV. Operational Environment OV-1s

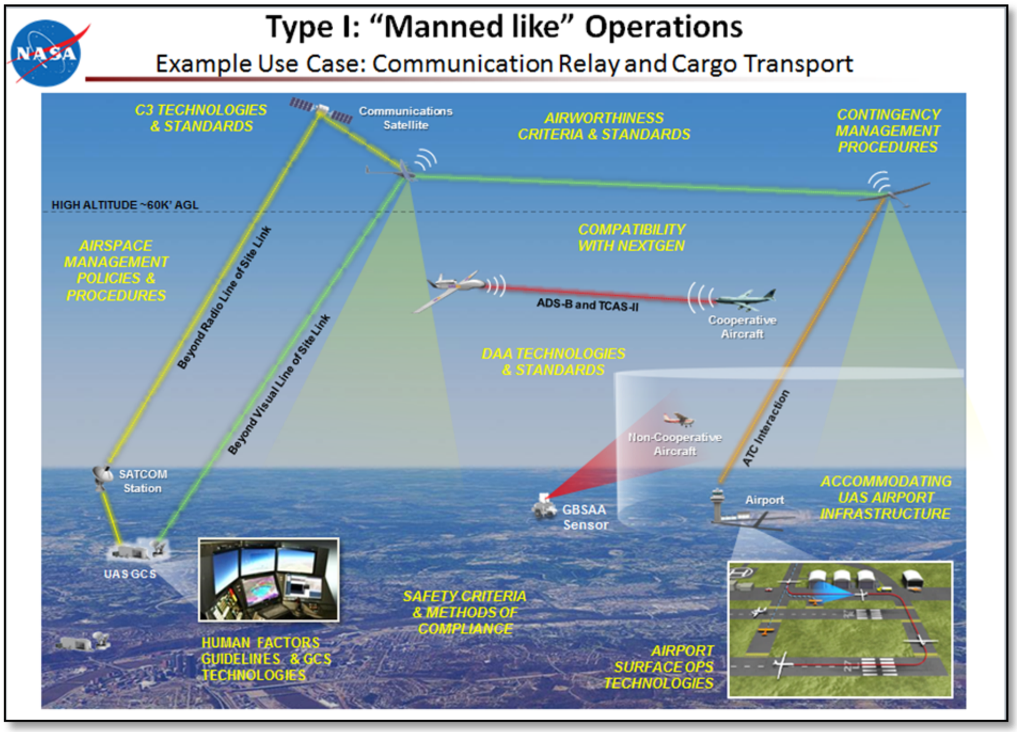


Figure 9: Operational Environment OV-1 Type 1: Manned-Like

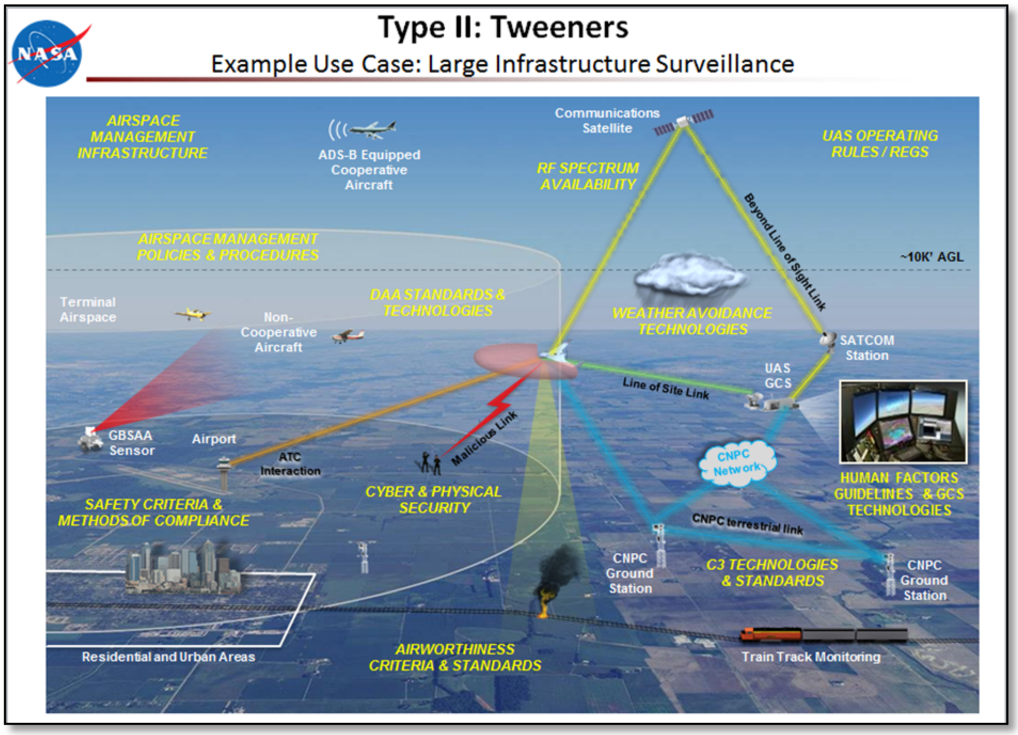


Figure 10: Operational Environment OV-1 Type 2: Tweener

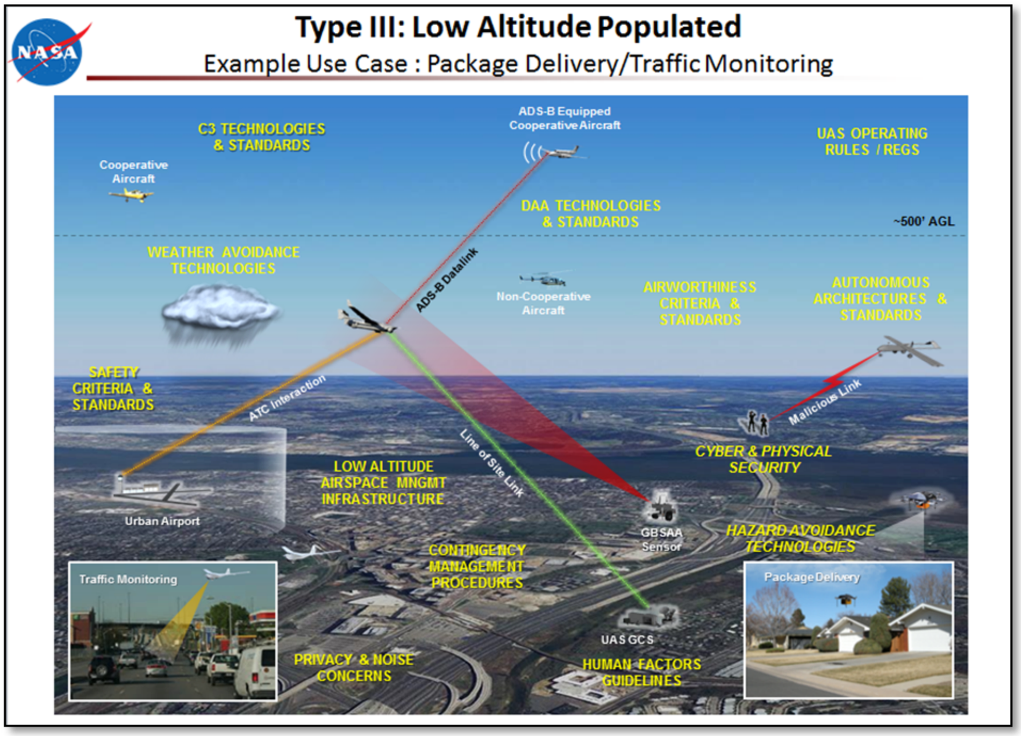


Figure 11: Operational Environment OV-1 Type 3: Low Altitude Populated

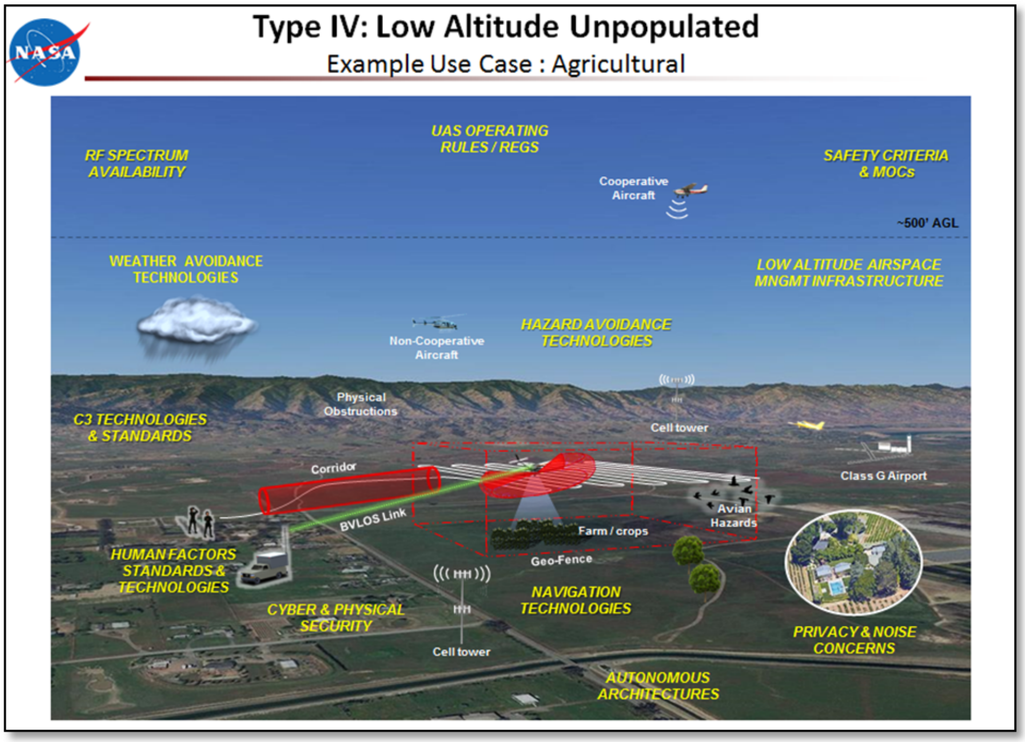


Figure 12: Operational Environment OV-1 Type 4: Low Altitude Unpopulated

V. COBRA Scoring Charts

Table 10: Manned-Like IFR Evaluation Scoring Chart

I. Manned-Like IFR		OPPORTUNITY			RISK				BENEFIT	COST	
	Full Integration Gaps	Implementation Path	Collaborate / Partner	Leverage Tech & Efforts	Size / Complexity	Unrealized Market	Delay in Achieving Full Integ.	Safety & Efficiency Impact	Contribution to Achieving Full Integration	Cost to Develop Solution to Close Gap	Cost to Implement Solution to Close Gap
AI Enabler		35%	35%	30%	35%	30%	20%	15%	100%	50%	50%
T01	T01 - Airport Surface Ops: ($$$$)	M	H	M	M	H	H	M	VH	M	H
T02	T02 - DAA Technologies: ($$$$)	H	H	H	H	H	H	H	VH	M	H
T03	T03 - Hazard Avoidance: ($$)	L	M	M	L	L	L	L	M	L	L
T04	T04 - C3 Technologies: ($$$$$)	H	H	H	H	M	H	H	VH	H	VH
T05	T05 - GCS Technologies : ($$$)	H	H	H	H	M	H	M	H	M	M
T06	T06 - Flight & Health Mngmt: ($$$$)	M	H	M	H	M	M	H	H	M	H
T07	T07 - Airworthiness: ($$$)	H	H	M	M	H	H	M	VH	L	M
T08	T08 - Navigation: ($$)	H	M	H	H	M	M	M	M	L	L
T09	T09 - Weather Avoidance: ($$$)	M	H	H	M	M	M	H	M	M	L
T10	T10 - Power & Propulsion: ($$$)	M	H	H	M	M	M	M	M	M	M
T11	T11 - Autonomous Architectures: ($$$)	M	M	H	H	M	M	M	H	M	M
T12	T12 - Human Factors Guidelines: ($$)	M	H	H	M	M	M	H	H	L	VL
P01	P01 - Airspace Mngmt Pol. / Proc.: ($$$)	H	H	H	M	H	H	H	H	M	L
P02	P02 - Operating Rules / Regs: ($$$)	H	H	M	M	M	H	H	H	M	L
P03	P03 - Contingency Mngmt: ($$$$)	M	H	H	H	M	H	H	H	M	H
P04	P04 - NextGen Compatibility: ($$$)	M	H	H	H	M	M	H	H	M	L
I01	I01 - Airport Infrastructure: ($$$$$)	M	M	H	H	M	H	H	VH	M	VH
I02	I02 - Airspace Mngmt Infrastructure: ($$$)	M	M	H	M	H	H	H	H	L	M
I03	I03 - Low-Alt. Traffic Mngmt: ($$)	L	L	L	L	L	L	L	VL	VL	L
I04	I04 - RF Spectrum: ($$)	M	H	H	M	H	H	H	M	L	VL
I05	I05 - Test Ranges and LVC : ($$$)	H	M	M	M	M	H	M	M	L	M
S01	S01 - Safety Criteria & MOCs: ($$)	M	H	M	M	H	M	H	VH	L	L
S02	S02 - Cyber & Physical Security: ($$$)	M	M	M	M	H	H	H	VH	L	M
S03	S03 - Legal: ($$)	L	L	L	L	M	M	L	L	VL	L
S04	S04 - Privacy: ($$)	L	L	M	L	M	M	L	L	L	VL
S05	S05 - Noise: ($$$)	L	M	H	M	M	M	M	L	M	L

Table 11: Tweener Evaluation Scoring Chart

II. Tweener		OPPORTUNITY			RISK				BENEFIT	COST	
	Full Integration Gaps	Implementation Path	Collaborate / Partner	Leverage Tech & Efforts	Size / Complexity	Unrealized Market	Delay in Achieving Full Integ.	Safety & Efficiency Impact	Contribution to Achieving Full Integration	Cost to Develop Solution to Close Gap	Cost to Implement Solution to Close Gap
AI Enabler		35%	35%	30%	35%	30%	20%	15%	100%	50%	50%
T01	T01 - Airport Surface Ops: ($$$)	L	M	L	M	M	M	M	M	L	M
T02	T02 - DAA Technologies: ($$$$)	H	H	H	H	H	H	H	VH	H	H
T03	T03 - Hazard Avoidance: ($$$)	H	M	M	H	M	L	M	H	M	M
T04	T04 - C3 Technologies: ($$$$$)	H	H	H	H	H	H	H	VH	H	VH
T05	T05 - GCS Technologies : ($$)	H	H	H	H	M	H	M	VH	L	L
T06	T06 - Flight & Health Mngmt: ($$$$)	M	H	M	H	M	M	H	H	M	H
T07	T07 - Airworthiness: ($$$)	H	H	M	M	H	H	M	VH	M	M
T08	T08 - Navigation: ($$)	H	M	H	H	M	M	M	H	L	L
T09	T09 - Weather Avoidance: ($$$)	M	M	M	H	M	M	H	H	M	L
T10	T10 - Power & Propulsion: ($$$)	M	M	H	M	M	M	M	M	M	M
T11	T11 - Autonomous Architectures: ($$$$)	M	M	H	H	M	M	H	VH	H	M
T12	T12 - Human Factors Guidelines: ($$)	M	H	H	M	M	M	H	H	L	L
P01	P01 - Airspace Mngmt Pol. / Proc.: ($$$)	H	H	H	M	H	H	H	VH	M	M
P02	P02 - Operating Rules / Regs: ($$$)	M	H	M	H	M	H	H	H	M	M
P03	P03 - Contingency Mngmt: ($$$$)	M	M	H	H	M	H	H	H	M	H
P04	P04 - NextGen Compatibility: ($$)	M	H	M	H	M	M	H	H	L	L
I01	I01 - Airport Infrastructure: ($$$$)	M	M	M	M	M	M	H	M	L	H
I02	I02 - Airspace Mngmt Infrastructure: ($$$)	M	M	H	M	H	H	H	VH	L	M
I03	I03 - Low-Alt. Traffic Mngmt: ($$$)	L	M	M	M	L	L	M	M	L	M
I04	I04 - RF Spectrum: ($$)	M	H	H	M	H	H	H	VH	L	L
I05	I05 - Test Ranges and LVC : ($$$)	H	M	M	M	M	H	M	H	M	M
S01	S01 - Safety Criteria & MOCs: ($$$)	M	H	M	M	H	M	H	VH	M	L
S02	S02 - Cyber & Physical Security: ($$$)	M	M	M	M	H	H	H	VH	L	M
S03	S03 - Legal: ($$)	L	M	L	M	M	M	M	M	L	L
S04	S04 - Privacy: ($$)	L	L	M	L	M	M	L	H	L	L
S05	S05 - Noise: ($$$)	L	M	H	M	M	M	M	M	M	L

Table 12: Low Altitude / Populated Evaluation Scoring Chart

III. Low-Altitude / Populated		OPPORTUNITY			RISK				BENEFIT	COST	
	Full Integration Gaps	Implementation Path	Collaborate / Partner	Leverage Tech & Efforts	Size / Complexity	Unrealized Market	Delay in Achieving Full Integ.	Safety & Efficiency Impact	*Contribution to Achieving Full Integration*	*Cost to Develop Solution to Close Gap*	*Cost to Implement Solution to Close Gap*
AI Enabler		35%	35%	30%	35%	30%	20%	15%	100%	50%	50%
T01	T01 - Airport Surface Ops: ($)	L	L	L	L	L	L	L	VL	VL	VL
T02	T02 - DAA Technologies: ($$$$)	M	H	H	H	H	H	H	VH	H	H
T03	T03 - Hazard Avoidance: ($$$$)	H	H	H	H	H	H	H	VH	H	M
T04	T04 - C3 Technologies: ($$$$)	M	H	H	H	H	H	H	VH	H	M
T05	T05 - GCS Technologies : ($$)	M	H	M	M	M	H	H	H	L	L
T06	T06 - Flight & Health Mngmt: ($$$$)	M	M	M	H	M	L	M	H	H	H
T07	T07 - Airworthiness: ($$$)	M	M	H	M	H	H	H	VH	M	M
T08	T08 - Navigation: ($$$)	M	H	H	H	M	H	M	H	M	L
T09	T09 - Weather Avoidance: ($$$$)	M	M	M	H	M	H	H	VH	H	M
T10	T10 - Power & Propulsion: ($$$)	M	M	H	M	M	L	M	M	L	M
T11	T11 - Autonomous Architectures: ($$$$)	M	H	H	H	H	H	H	VH	H	M
T12	T12 - Human Factors Guidelines: ($$)	M	H	H	M	M	M	H	H	L	VL
P01	P01 - Airspace Mngmt Pol. / Proc.: ($$$$)	M	H	M	M	M	H	H	VH	M	H
P02	P02 - Operating Rules / Regs: ($$$)	M	H	M	H	H	H	H	H	M	L
P03	P03 - Contingency Mngmt: ($$$$)	M	H	M	H	M	M	H	VH	H	H
P04	P04 - NextGen Compatibility: ($)	L	M	L	L	L	L	L	L	VL	VL
I01	I01 - Airport Infrastructure: ($$)	L	L	L	L	L	L	M	L	L	VL
I02	I02 - Airspace Mngmt Infrastructure: ($$$$)	L	M	M	M	M	M	M	M	M	H
I03	I03 - Low-Alt. Traffic Mngmt: ($$$$$)	H	H	H	H	H	H	H	VH	H	VH
I04	I04 - RF Spectrum: ($$$)	M	H	H	M	H	H	H	H	M	VL
I05	I05 - Test Ranges and LVC : ($$$)	H	H	M	M	H	H	M	H	M	M
S01	S01 - Safety Criteria & MOCs: ($$$)	M	H	M	M	H	M	H	VH	M	L
S02	S02 - Cyber & Physical Security: ($$$)	M	M	H	M	H	H	H	VH	L	M
S03	S03 - Legal: ($$$)	L	M	L	M	H	H	M	VH	L	M
S04	S04 - Privacy: ($$$)	M	H	M	M	H	H	M	VH	L	M
S05	S05 - Noise: ($$)	M	H	H	H	H	H	M	VH	L	L

Table 13: Low Altitude / Unpopulated Evaluation Scoring Chart

IV. Low-Altitude / Unpopulated		OPPORTUNITY			RISK				BENEFIT	COST	
	Full Integration Gaps	Implementation Path	Collaborate / Partner	Leverage Tech & Efforts	Size / Complexity	Unrealized Market	Delay in Achieving Full Integ.	Safety & Efficiency Impact	Contribution to Achieving Full Integration	Cost to Develop Solution to Close Gap	Cost to Implement Solution to Close Gap
AI Enabler		35%	35%	30%	35%	30%	20%	15%	100%	50%	50%
T01	T01 - Airport Surface Ops: ($)	L	L	L	L	L	L	L	VL	VL	VL
T02	T02 - DAA Technologies: ($$)	M	M	M	H	M	M	H	M	L	L
T03	T03 - Hazard Avoidance: ($$$$)	H	M	H	H	M	M	H	M	H	M
T04	T04 - C3 Technologies: ($$$$)	M	H	H	M	M	M	H	VH	H	M
T05	T05 - GCS Technologies : ($$)	M	H	H	M	M	M	M	M	L	L
T06	T06 - Flight & Health Mngmt: ($$$)	M	L	M	M	M	L	M	M	M	M
T07	T07 - Airworthiness: ($$$)	H	H	M	M	H	M	M	H	M	L
T08	T08 - Navigation: ($$$)	M	M	H	H	H	M	M	H	M	L
T09	T09 - Weather Avoidance: ($$$$)	M	M	M	H	M	M	H	H	H	M
T10	T10 - Power & Propulsion: ($$)	M	H	H	M	M	L	M	M	L	L
T11	T11 - Autonomous Architectures: ($$$)	M	H	H	H	H	M	H	M	M	L
T12	T12 - Human Factors Guidelines: ($$$)	M	M	H	M	M	M	M	L	M	VL
P01	P01 - Airspace Mngmt Pol. / Proc.: ($$$)	M	M	M	M	M	H	M	M	L	M
P02	P02 - Operating Rules / Regs: ($$$)	L	M	L	L	L	L	L	VL	M	L
P03	P03 - Contingency Mngmt: ($$$)	M	M	M	H	M	M	M	H	M	M
P04	P04 - NextGen Compatibility: ($$)	L	M	L	L	L	L	L	VL	VL	L
I01	I01 - Airport Infrastructure: ($$)	L	L	L	L	L	L	L	VL	L	VL
I02	I02 - Airspace Mngmt Infrastructure: ($$$)	L	L	L	L	L	L	L	VL	L	M
I03	I03 - Low-Alt. Traffic Mngmt: ($$$)	H	M	H	M	M	M	H	H	M	M
I04	I04 - RF Spectrum: ($$)	M	H	H	M	H	H	H	H	L	VL
I05	I05 - Test Ranges and LVC : ($$)	H	H	M	M	H	H	M	M	L	L
S01	S01 - Safety Criteria & MOCs: ($$)	H	H	M	M	H	M	H	H	L	L
S02	S02 - Cyber & Physical Security: ($$$)	M	M	H	M	H	H	H	H	L	M
S03	S03 - Legal: ($$)	L	M	L	L	M	M	L	H	L	L
S04	S04 - Privacy: ($$)	M	H	M	M	M	M	M	H	L	L
S05	S05 - Noise: ($$)	M	H	H	M	M	M	M	H	L	VL

VI. COBRA Tornado Plots

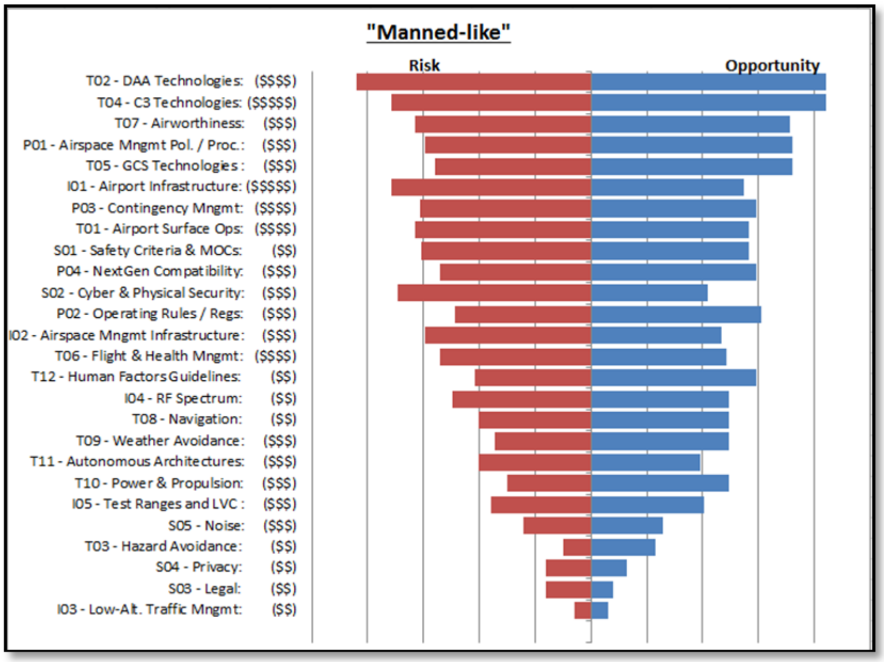


Figure 13: Manned-Like IFR COBRA Tornado Plot

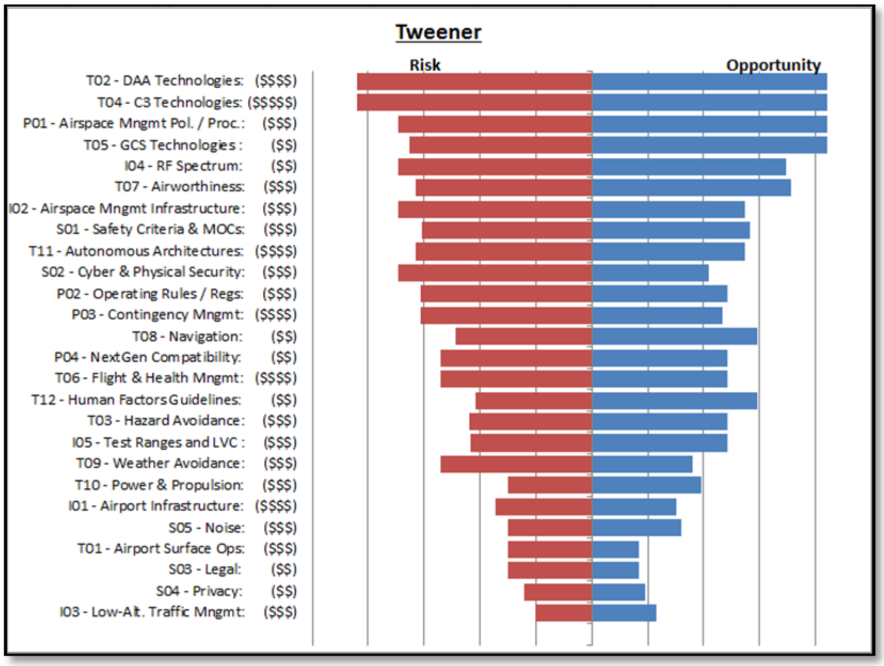


Figure 14: Tweener COBRA Tornado Plot

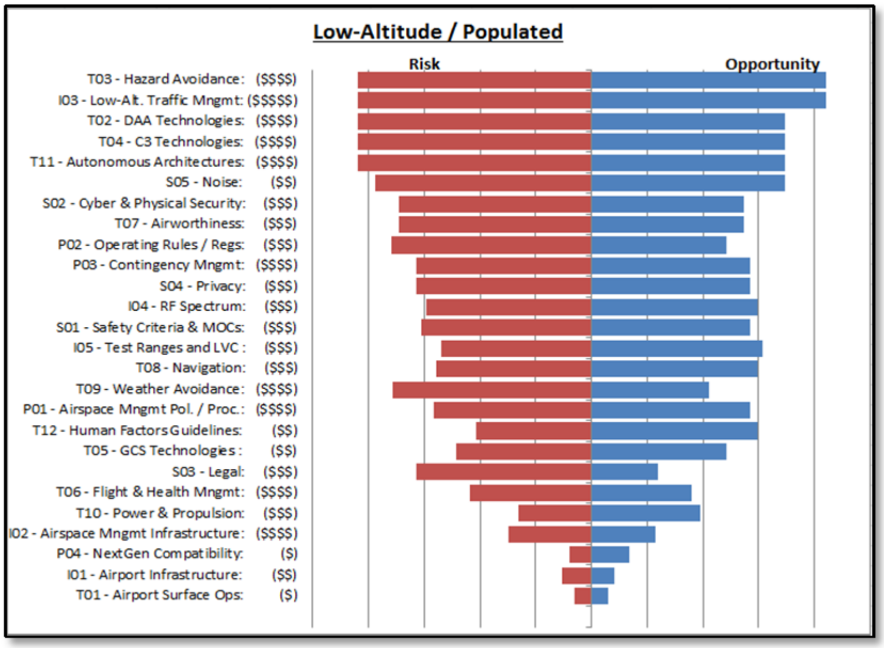


Figure 15: Low Altitude Populated COBRA Tornado Plot

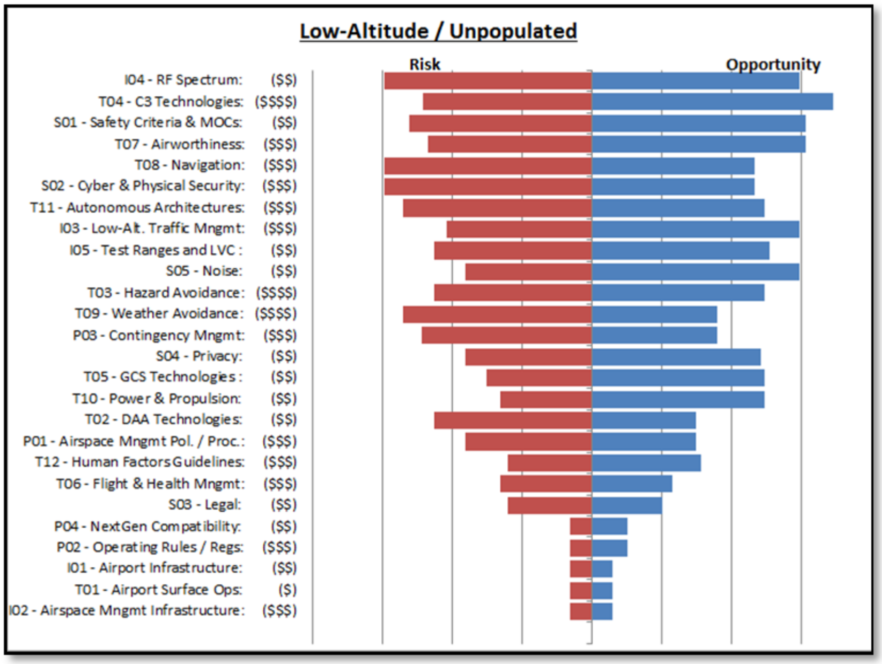
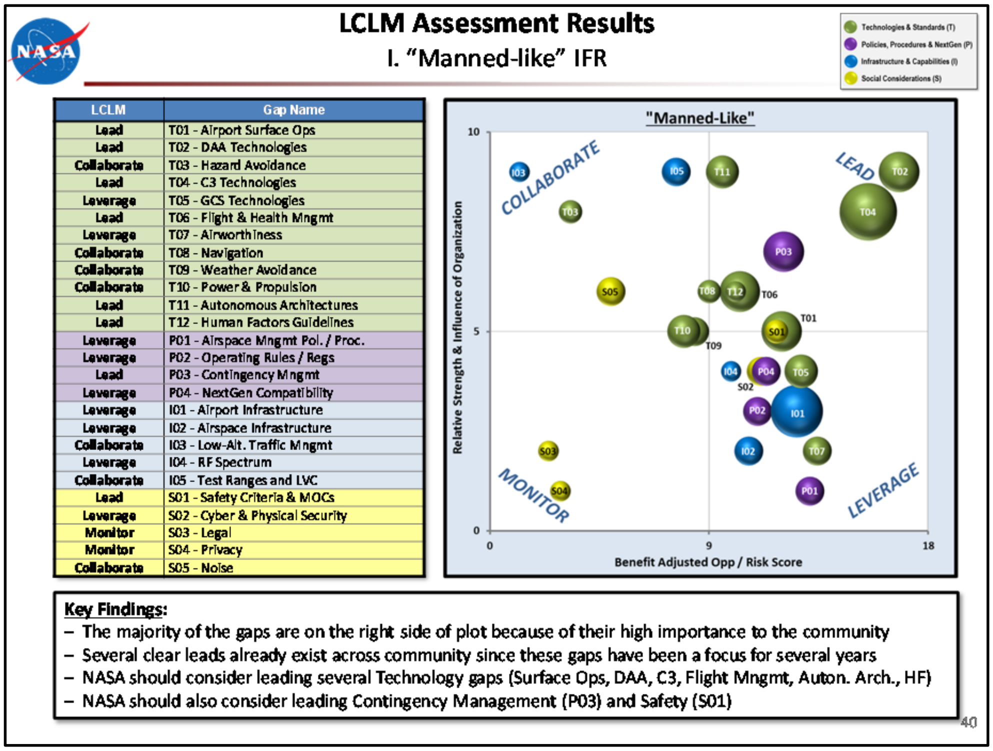


Figure 16: Low Altitude Unpopulated COBRA Tornado Plot

VII. LCLM Plots



LCLM Assessment Results

I. "Manned-like" IFR

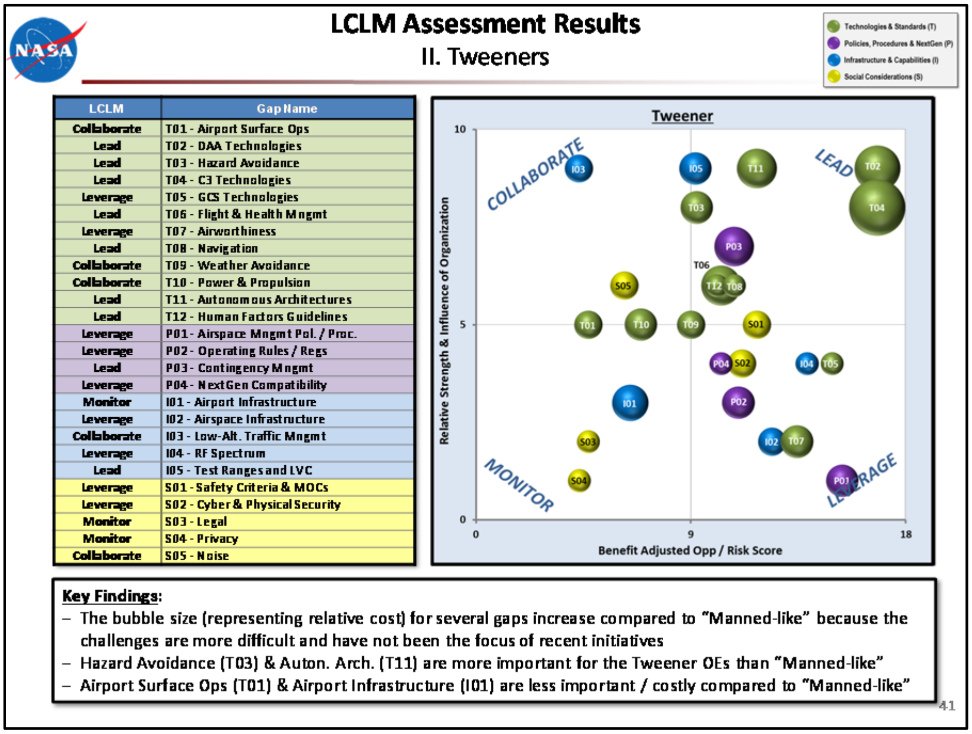
- 🟢 Technologies & Standards (T)
- 🟣 Policies, Procedures & NextGen (P)
- 🔵 Infrastructure & Capabilities (I)
- 🟡 Social Considerations (S)

LCLM	Gap Name
Lead	T01 - Airport Surface Ops
Lead	T02 - DAA Technologies
Collaborate	T03 - Hazard Avoidance
Lead	T04 - C3 Technologies
Leverage	T05 - GCS Technologies
Lead	T06 - Flight & Health Mngmt
Leverage	T07 - Airworthiness
Collaborate	T08 - Navigation
Collaborate	T09 - Weather Avoidance
Collaborate	T10 - Power & Propulsion
Lead	T11 - Autonomous Architectures
Lead	T12 - Human Factors Guidelines
Leverage	P01 - Airspace Mngmt Pol. / Proc.
Leverage	P02 - Operating Rules / Regs
Lead	P03 - Contingency Mngmt
Leverage	P04 - NextGen Compatibility
Leverage	I01 - Airport Infrastructure
Leverage	I02 - Airspace Infrastructure
Collaborate	I03 - Low-Alt. Traffic Mngmt
Leverage	I04 - RF Spectrum
Collaborate	I05 - Test Ranges and LVC
Lead	S01 - Safety Criteria & MOCs
Leverage	S02 - Cyber & Physical Security
Monitor	S03 - Legal
Monitor	S04 - Privacy
Collaborate	S05 - Noise

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)

Figure 17: Manned-Like IFR LCLM Matrix



LCLM Assessment Results

II. Tweeners

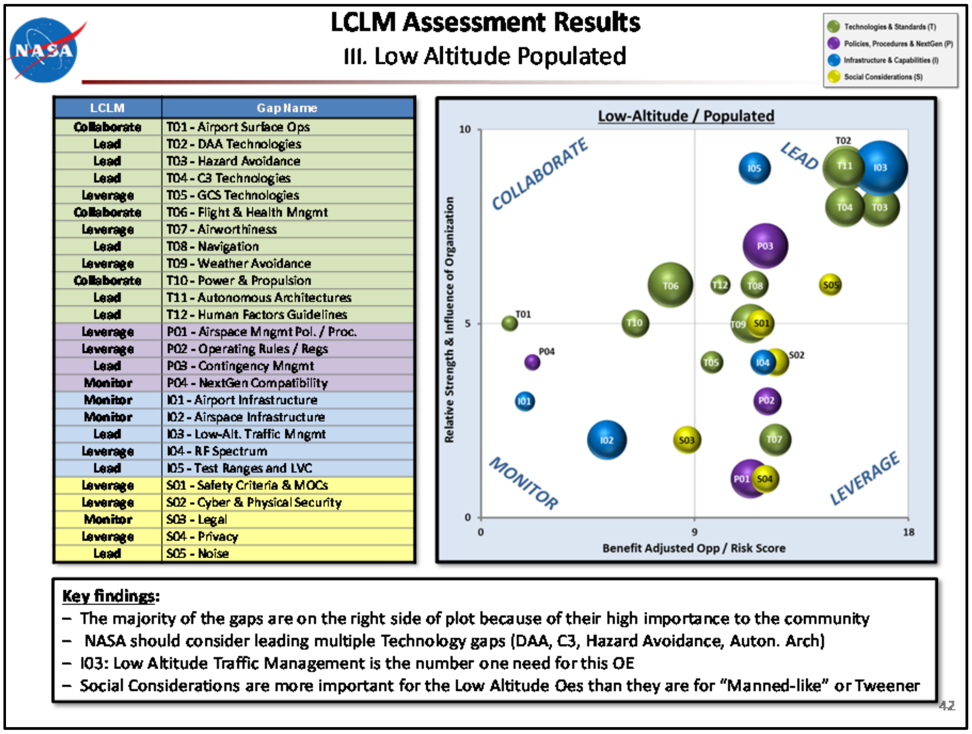
- 🟢 Technologies & Standards (T)
- 🟣 Policies, Procedures & NextGen (P)
- 🔵 Infrastructure & Capabilities (I)
- 🟡 Social Considerations (S)

LCLM	Gap Name
Collaborate	T01 - Airport Surface Ops
Lead	T02 - DAA Technologies
Lead	T03 - Hazard Avoidance
Lead	T04 - C3 Technologies
Leverage	T05 - GCS Technologies
Lead	T06 - Flight & Health Mngmt
Leverage	T07 - Airworthiness
Lead	T08 - Navigation
Collaborate	T09 - Weather Avoidance
Collaborate	T10 - Power & Propulsion
Lead	T11 - Autonomous Architectures
Lead	T12 - Human Factors Guidelines
Leverage	P01 - Airspace Mngmt Pol. / Proc.
Leverage	P02 - Operating Rules / Regs
Lead	P03 - Contingency Mngmt
Leverage	P04 - NextGen Compatibility
Monitor	I01 - Airport Infrastructure
Leverage	I02 - Airspace Infrastructure
Collaborate	I03 - Low-Alt. Traffic Mngmt
Leverage	I04 - RF Spectrum
Lead	I05 - Test Ranges and LVC
Leverage	S01 - Safety Criteria & MOCs
Leverage	S02 - Cyber & Physical Security
Monitor	S03 - Legal
Monitor	S04 - Privacy
Collaborate	S05 - Noise

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"

Figure 18: Tweener LCLM Matrix



LCLM Assessment Results

III. Low Altitude Populated

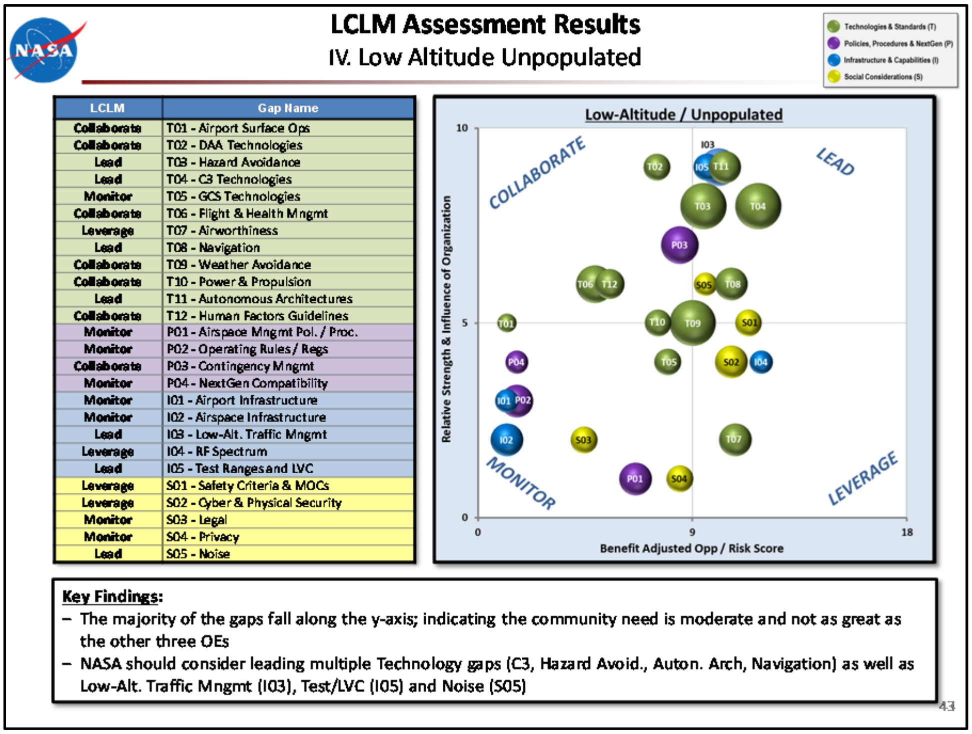
● Technologies & Standards (T)
● Policies, Procedures & NextGen (P)
● Infrastructure & Capabilities (I)
● Social Considerations (S)

LCLM	Gap Name
Collaborate	T01 - Airport Surface Ops
Lead	T02 - DAA Technologies
Lead	T03 - Hazard Avoidance
Lead	T04 - C3 Technologies
Leverage	T05 - GCS Technologies
Collaborate	T06 - Flight & Health Mngmt
Leverage	T07 - Airworthiness
Lead	T08 - Navigation
Leverage	T09 - Weather Avoidance
Collaborate	T10 - Power & Propulsion
Lead	T11 - Autonomous Architectures
Lead	T12 - Human Factors Guidelines
Leverage	P01 - Airspace Mngmt Pol. / Proc.
Leverage	P02 - Operating Rules / Regs
Lead	P03 - Contingency Mngmt
Monitor	P04 - NextGen Compatibility
Monitor	I01 - Airport Infrastructure
Monitor	I02 - Airspace Infrastructure
Lead	I03 - Low-Alt. Traffic Mngmt
Leverage	I04 - RF Spectrum
Lead	I05 - Test Ranges and LVC
Leverage	S01 - Safety Criteria & MOCs
Leverage	S02 - Cyber & Physical Security
Monitor	S03 - Legal
Leverage	S04 - Privacy
Lead	S05 - Noise

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

Figure 19: Low Altitude Populated LCLM Matrix



LCLM Assessment Results

IV. Low Altitude Unpopulated

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

LCLM	Gap Name
Collaborate	T01 - Airport Surface Ops
Collaborate	T02 - DAA Technologies
Lead	T03 - Hazard Avoidance
Lead	T04 - C3 Technologies
Monitor	T05 - GCS Technologies
Collaborate	T06 - Flight & Health Mngmt
Leverage	T07 - Airworthiness
Lead	T08 - Navigation
Collaborate	T09 - Weather Avoidance
Collaborate	T10 - Power & Propulsion
Lead	T11 - Autonomous Architectures
Collaborate	T12 - Human Factors Guidelines
Monitor	P01 - Airspace Mngmt Pol. / Proc.
Monitor	P02 - Operating Rules / Regs
Collaborate	P03 - Contingency Mngmt
Monitor	P04 - NextGen Compatibility
Monitor	I01 - Airport Infrastructure
Monitor	I02 - Airspace Infrastructure
Lead	I03 - Low-Alt. Traffic Mngmt
Leverage	I04 - RF Spectrum
Lead	I05 - Test Ranges and LVC
Leverage	S01 - Safety Criteria & MOCs
Leverage	S02 - Cyber & Physical Security
Monitor	S03 - Legal
Monitor	S04 - Privacy
Lead	S05 - Noise

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 Mngmt (I03), Test/LVC (I05) and Noise (S05)

Figure 20: Low Altitude Unpopulated LCLM Matrix