Mobility Metrics Summary Report

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Agenda

Purpose

- To deliver CCI's year end summary of mobility metrics.

Outline

- Context & Definitions
- Mission examples
- Suggested Metrics
- Local Metric Discussion
- Rationale for Metrics
- Alternate Metrics

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Context

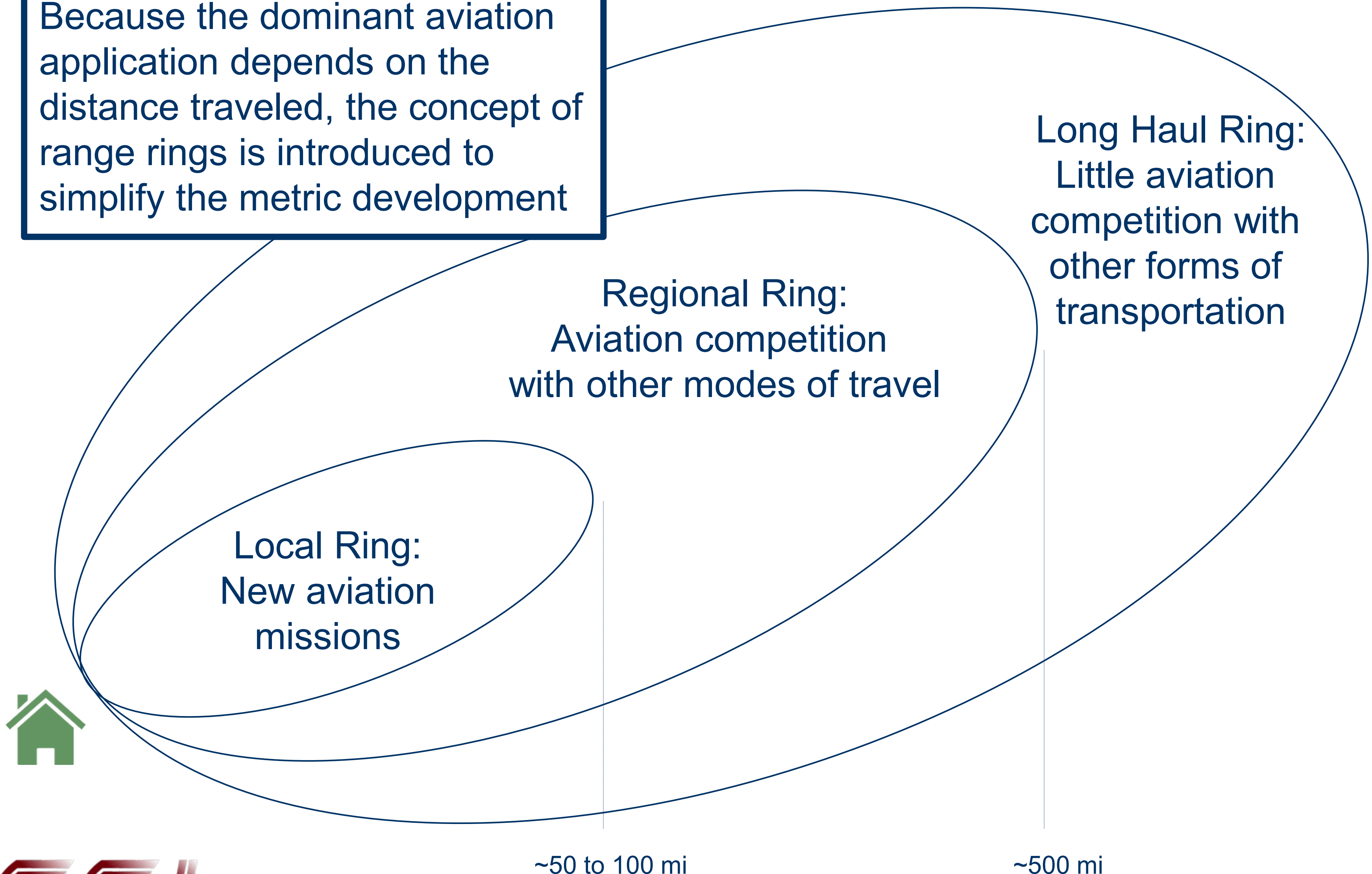
- NASA's Strategic Implementation Plan (SIP) is the guiding document for ARMD's aeronautics research
- The SIP has 5 principles that ARMD research efforts support
  - Mobility
  - Energy and Environment
  - National Security and Defense
  - Aviation Safety
  - U.S. Leadership
- Metrics for these principles are important for both the way they are portrayed to the external community and for management of ARMD's research activities
- In this context, the mobility metric is taken to be independent of the other principles, e.g., environment.
- CCI has been tasked to support the development of a metric(s) for mobility

Definition

- Mobility is the physical movement of people and mass or ability to perform a service at a distance.
  - Mobility is measured as a function of time, cost, and convenience of a mode.
  - The first two of these are directly and the last indirectly relatable to ARMD activities.
  - The relative importance of time, cost, and convenience varies greatly across regions and user categories.
- Mobility differs from access in that access contains both mobility and virtualization.
  - Mobility is the element of access that ARMD can most directly affect and the focus of this effort.

Mobility Metrics Range Rings

Because the dominant aviation application depends on the distance traveled, the concept of range rings is introduced to simplify the metric development



Mission Matrix with Representative Examples

	Local	Regional	Long Haul Subsonic	Long Haul Supersonic
People	ODM	Transporting Passengers	Transporting Passengers	Transporting Passengers
Mass	Package Delivery	Cargo/Freight Transport	Cargo/Freight Transport	Cargo/Freight Transport
Services	Precision Agriculture	Pipeline Inspection	Surveillance	Commercial Space

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Metrics Attributes

- We considered two levels of complementary and interconnected metrics
  - Mission level metrics are metrics that measure impact on missions and are useful for advocacy and community engagement (e.g. RPM).
  - Capability level metrics are metrics that measure technology advances and are useful for internal ARMD decision making and portfolio management. (e.g. sense and avoid)
- Metrics have to be readily measured or calculated and projected and it must be easily understood
  - RPM is a example because it meets all three of the requirements above.
  - It is also a good metric because it provides the integrated impact of time, cost, and convenience.
- Metrics should reflect ARMD's contribution to a given mission and/or capability
- Metrics should be continuous functions (ideally with positive slopes)

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Matrix of Suggested Mission Metrics

	Local	Regional	Long Haul Subsonic	Long Haul Supersonic
People	RPM	RPM	RPM	RPM
Mass	Number of representative UAS missions ARMD helped enable	FTK	FTK	FTK
Services	Number of representative UAS missions ARMD helped enable	Number of representative UAS missions ARMD helped enable	Not considered	Number of space access missions

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Local Metric Discussion

Carbon Neutrality Benefits Chain

Benefits chain for carbon neutrality metric

NASA performance goals (e.g., empty weight, fuel consumption)

NASA and community metric for carbon neutral aviation (tons CO_2 produced)

NASA Research → **Capabilities** → **Emissions** → **Societal/economic benefits**

Capabilities

Vehicle attributes and ATM performance

(Metric: propulsive efficiency, empty weight fraction, lift/drag ratio, battery energy storage density)

Emissions

Quantifiable based on scenario assumptions, such as demand and fleet mix

(Metric: Tons of CO_2 produced, ASM per lb. fuel)

Societal/economic benefits

NASA activities enable benefits; amount achieved is highly dependent on world conditions and emissions from other sector

(Metric: Achievement of 1.5% per year fleet fuel efficiency improvement to 2020, CO_2 emissions capped beyond 2020, 50% of 2005 level in 2050)

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Local Metric Benefit Chain

Metrics can be developed and are needed for each element in the chain

NASA Research → **Capabilities** → **Missions** → **Societal/economic benefits**

	NASA Research	Capabilities	Missions	Societal/economic benefits
Basis and Use	*Progress tracking, program/project performance assessment*	*Metrics based on NASA developed capability for use in program/project assessment*	*Metrics based on mission types or numbers for use in advocacy and portfolio management*	*Metric based on benefits for use in advocacy*

Local Metric Development

- ❖ Team brainstormed to develop metrics that applied to local region
- ❖ Several were rejected for various reasons (see slide 21)
  - ➢ Inconsistent with metric attributes (slide 7)
- ❖ Several were acceptable but not as mission metrics
  - ➢ Important metrics for elsewhere in the benefit chain
- ❖ The totality of the metrics are required to span the space from “NASA research activities” to ”Societal/economic impact”
  - ➢ These form an integrated set

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Local Metrics Related to Benefit Chain

Good for planning & assessing progress
Defined by NASA plans

Good for advocacy, based on benefits
Uncertain, driven by externalities

	NASA Research	Capabilities	Missions	Societal/economic benefits
Basis and Use	*Progress tracking, program/project performance assessment*	*Metrics based on NASA developed capability for use in program/project assessment*	*Metrics based on mission types or numbers for use in advocacy*	*Metric based on benefits for use in advocacy and portfolio management*
Proposed metrics	Performance metrics specified for each TC	Number of UAS mission-required capabilities to which NASA will have contributed (based on a framework defining required capabilities)	Number of representative missions that NASA will have helped to enable (based on a framework relating missions to critical required capabilities)	Number of UAS flights that NASA will have helped to enable Value of the flights that NASA will have helped to enable Value of (UAS) industry sales that NASA will have helped to enable (e.g., up to $19 billion annually in 2020, based on FAA forecast)

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Obtaining the Mission Metric I

1. Define the operational conditions relevant to NASA research – for example:
   a. Operating environment (4 types, per ARMD UAS strategy team)
      I - IFR-like: UAS will be expected to meet certification standards and operate safely with traditional air traffic and ATM services.
      II – Tweeners: These UAS will operate at altitudes below critical NAS infrastructure and will need to routinely integrate with both cooperative and non-cooperative aircraft.
      III - Low-Altitude Unpopulated: Low-risk BVLOS rural operations without aviation services
      IV - Low-Altitude Populated: Must interface with dense controlled air traffic environments as well as operate safely amongst the traffic in uncontrolled airspace
   b. Level of automation/autonomy (3 levels): Automation assisted, Highly automated, Autonomous
2. For this example, this defines 4 x 3 = 12 combinations of operational conditions.
3. For each combination, identify one or more representative mission(s) for which NASA makes (or will make) a significant contribution. Descriptions of candidate missions may be selected from the 2014 IPO UAS mission analysis or other sources.
4. For each representative mission, identify the mission required critical capabilities which fall within NASA's charter (e.g., all-weather detect and avoid capability for safe operation in high-density mixed-traffic airspace). These should be at a level addressed by existing or prospective Technical Challenges.
5. The mission-level metric is the number of representative missions "helped to enable" by demonstrating the technology solutions to the critical capabilities, as determined in step 4.

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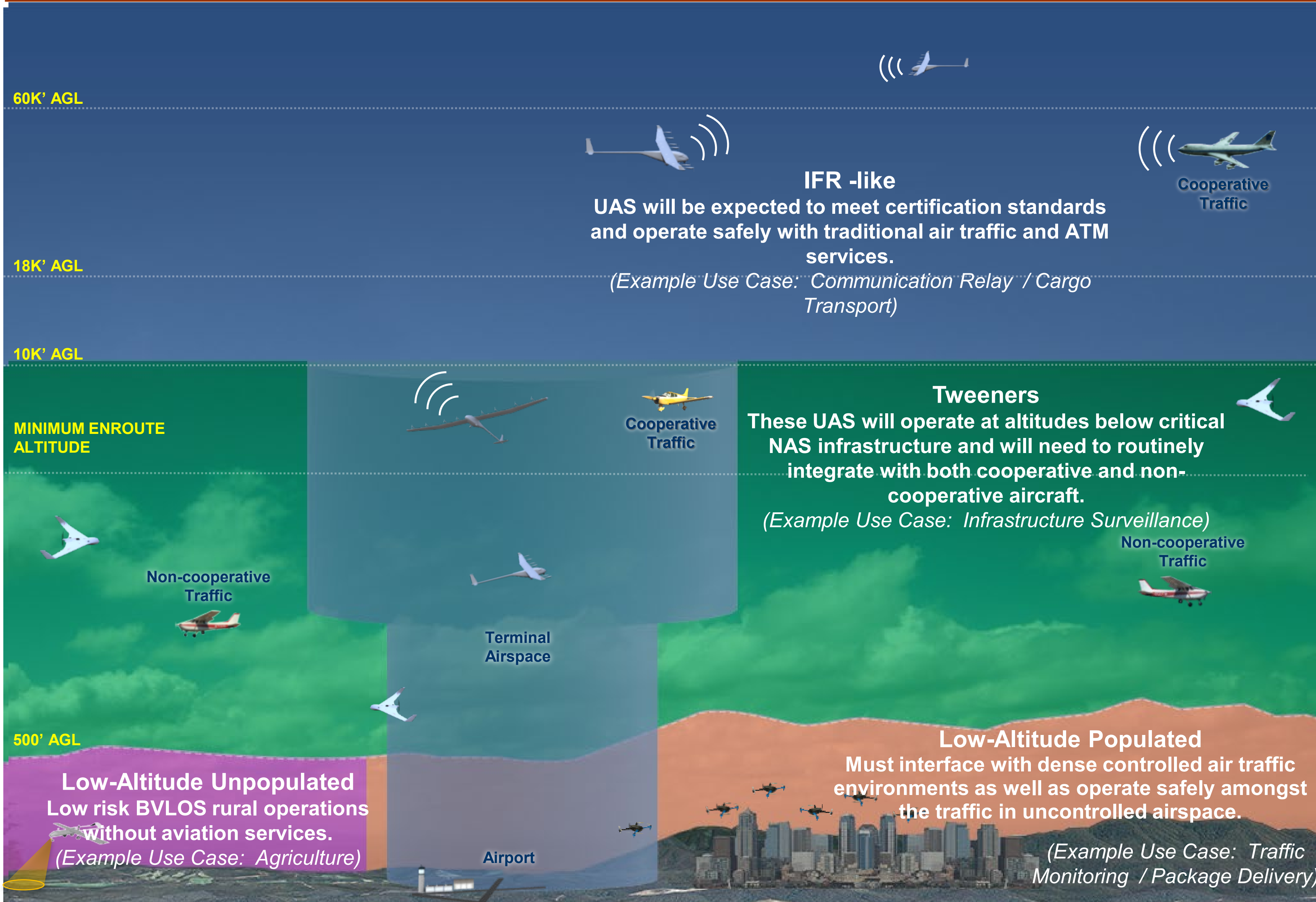
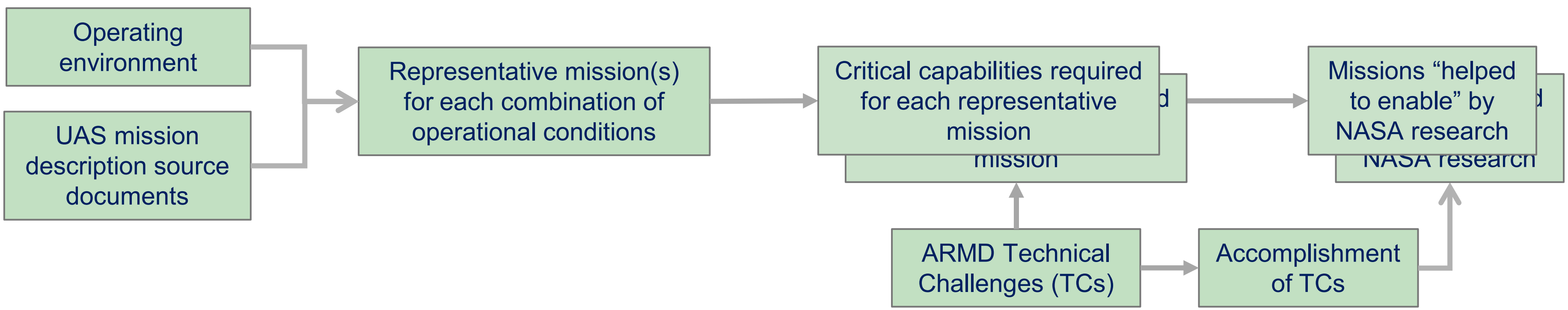
Emerging Commercial UAS Operational Environments (OE)



Obtaining the Mission Metric II

Assessment Process



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Obtaining the Mission Metric III

Strawman based on ARMD UAS strategy team presentation 12/19/2016

Operating Environment	Automation/ Autonomy	Representative Missions	Critical Capabilities*
I. Manned-like IFR	Automation assistance	Broad area surveillance	Safety assurance of UAS operations in IFR airspace
	Highly automated	Cargo transport	Integration of UAS in terminal and surface IFR operations
	Autonomous	High-altitude communications relay	Long-endurance autonomous UAS operations in IFR airspace
II. "Tweener"	Automation assistance	Horizontal infrastructure inspection	Safety assurance of UAS operations in mixed-traffic airspace
	Highly automated	Regional package delivery	Safety assurance of highly automated UAS operations in mixed-traffic airspace
	Autonomous	Passenger transport	Safe and trusted autonomous UAS vehicles and operations
III. Low-altitude populated (urban)	Automation assistance	Search and rescue	Integration and safety assurance of UAS operations in mixed-traffic airspace, including safe all-weather operation close to the ground in urban areas
	Highly automated	Traffic monitoring	Integration and safety assurance of highly-automated UAS operations in high-density mixed-traffic airspace
	Autonomous	Local package delivery	Integration and safety assurance of highly-automated UAS operations in high-density mixed-traffic airspace, including remote landing and take-off
IV. Low-altitude unpopulated (rural)	Automation assistance	Aerial photography	Safety assurance of automation-assisted UAS operations in mixed-traffic airspace
	Highly automated	Search and Rescue	Integration and safety assurance of UAS operations in mixed-traffic airspace, including safe all-weather operation close to the ground
	Autonomous	Vertical infrastructure	Autonomous precision UAS operations in close proximity to structures and obstacles

* Critical capabilities should correspond to objectives of Technical Challenges

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FAA IPO UAS Mission Analysis

UAS Missions	Reference Sources							
	FAA	RTCA	NASA1	NASA2	JPDO1	JPDO2	DoD	DOC
Military (DoD) - Only								
DoD Training / Demonstration			1				2	
Non-Military Public - Only								
Border Patrol / Surveillance & Tracking	1	1		2	1			
Maritime Surveillance (Search & Tracking)		1	1	1				
Hurricane Research		1	1	1				
Marine Mammals Surveying								1
Fire Detection				1				
Aerial Fire Retardant Application				1				
First Responder Situation Surveillance				2	3			
Law Enforcement - Suspect Tracking		1	1	2		1		
Crowd Control				3				
Military (DoD) & Non-Military Public								
Disaster Assessment*				1		1	1	
Forest Fire Situational Awareness*				1			1	

UAS Missions	Reference Sources							
	FAA	RTCA	NASA1	NASA2	JPDO1	JPDO2	DoD	DOC
Non-Military Public & Civil (Commercial & Non-Commercial)								
Search & Rescue*	1			4	1			
Volcanic Ash Assessment*				1				
Coal Plant Emissions Monitoring*	1	1		1	1			
Site Security Surveillance*				3				
Civil (Commercial & Non-Commercial) - Only								
Agricultural / Environmental Monitoring (High-Alt.)	1	1		2				
Precision Agriculture - Crop Scouting						1		
Precision Agriculture - Aerial Application				2		1		
Mining Exploration		1	1	1				
Critical Infrastructure Inspection				1		1		
Cargo Delivery (Domestic)	1	1	1	1	1	1		
Cargo Delivery (International / Trans-Oceanic)	1			1				
Media & Traffic Reporting	1	1		1				
Real Estate Photography				2		1		
Aerial Advertising						1		

26 mission categories

77 missions

Examples of UAS Enablers

Airspace Integration Enablers			"Manned Like" IFR (I)	Tweener (II)	Low-Alt / Populated (III)	Low-Alt / Unpopulated (IV)
Technology & Standards	T01	Certifiable Airport Surface Ops Technologies	X	-	-	-
	T02	Certifiable DAA Technologies	X	X	X	-
	T03	Certifiable Hazard Avoidance Technologies	-	X	X	-
	T04	Certifiable C3 Technologies	X	X	X	X
	T05	Certifiable GCS Technologies	X	X	X	-
	T06	Certifiable Flight & Health Mngmt Systems	X	X	X	-
	T07	Airworthiness Criteria / Standards / MOCs	X	X	X	X
	T08	Certifiable Navigation Technologies	-	X	X	X
	T09	Certifiable Weather Avoidance Technologies	-	X	X	X
	T10	Certifiable Power & Propulsion Technologies	-	-	-	-
	T11	Autonomous Architectures	X	X	X	-
	T12	Human Factors Guidelines	X	X	X	-
Policies, Procedures & NextGen	P01	Airspace Mngmt Policies & Procedures	X	X	X	-
	P02	Operating Rules / Regs / Procedures	X	X	X	-
	P03	Contingency Mngmt Procedures	X	X	X	X
	P04	NextGen Compatibility	X	X	-	-
Infrastructure & Capabilities	I01	UAS Accommodating Airports & Infrastructure	X	-	-	-
	I02	UAS Accommodating Airspace Mngmt Infrastructure	X	X	-	-
	I03	Low-Altitude Airspace Mngmt Infrastructure	-	-	X	X
	I04	Adequate Secured / Managed RF Spectrum	-	X	X	X
	I05	Sufficient Test Ranges and LVC M&S Facilites	-	X	X	-
Social Considerations	S01	Safety Criteria & Methods of Compliance (MOC)	X	X	X	X
	S02	Cyber & Physical Security Criteria & MOCs	X	X	X	X
	S03	Legal Framework for UAS Litigation	-	-	X	X
	S04	Privacy Guidelines & Rules	-	X	X	X
	S05	Noise Guidelines & Rules	-	-	X	X

Source: ARMD Briefing: Proposed Framework for Developing a Comprehensive ARMD Full UAS Integration Strategy, 2016

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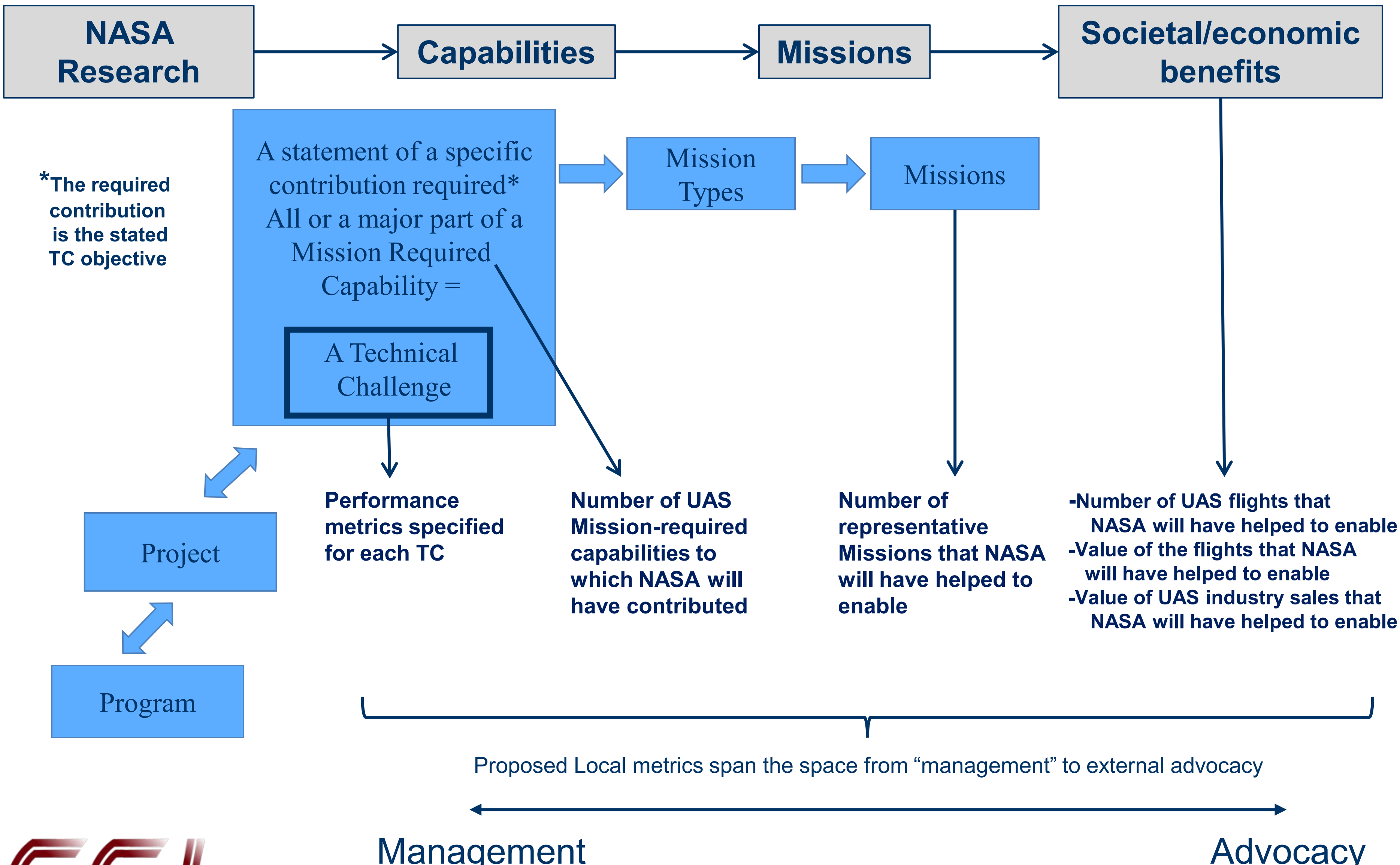
Linking TCs to required Capabilities (Local)



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Other Metrics Local We Considered

- Number of operational UAS
  - Can be projected based on UAS sales forecasts and service life, but only with high uncertainty
- Number of missions flown
  - Can be projected based on operational inventory and missions per day per UAS, but only with high uncertainty
- Number of types of missions helped to be enabled
  - This is an alternative to the chosen metric
- Number of capabilities enabled by NASA research
  - Not well suited for advocacy: not easily understood by people outside the UAS/aviation community
  - Must consider required combinations of capabilities to determine contribution to enabling specific missions
- Airspace Integration Enablers identified by the ARMD UAS team
  - These enablers provide a good framework to determine capabilities that might be needed and are a good measure of the extent to which capabilities are supported, but they are fairly general and do not reflect specific mission capabilities
  - Many of these enablers are outside the scope of NASA's contribution (e.g., regulations)

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Rationale for Metrics

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Matrix of Suggested Mission Metrics

	Local	Regional	Long Haul Subsonic	Long Haul Supersonic
People	RPM	RPM	RPM	RPM
Mass	Number of representative UAS missions ARMD helped enable	FTK	FTK	FTK
Services	Number of representative UAS missions ARMD helped enable	Number of representative UAS missions ARMD helped enable	Not considered	Number of space access missions

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Rationale for Local Metric Selection

- Passengers
  - RPM is a community understood measure of passenger usage
  - When significant passenger usage occurs in this region a better metric which is tied to the carrier's business models may be appropriate
- Mass
  - Metric: Number of representative UAS missions ARMD helped enable.
  - Best combination of suitability and ability to calculate of all metrics we looked at (see later chart)
- Services
  - Metric: Number of representative UAS missions ARMD helped enable.
  - Best combination of suitability and ability to calculate of all metrics we looked at

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Rationale for Regional Metric Selection

- Passengers
  - RPM is a community understood measure of passenger usage
  - An alternate metric reflecting the competition between air and ground modes in this region was derived. See below for discussion
- Mass
  - FTK is a community understood measure of air freight
  - OK for the near term but perhaps a metric closer to UAS delivery will be more appropriate. Needs to be sorted out as the users and business models are matured
- Services
  - Metric: Number of new UAS mission ARMD helped enabled.
  - Same as local region because many of the same missions are regional

Rationale for Long Haul Subsonic Metric Selection

- Passengers
  - RPM is a community understood measure of passenger usage
  - It provides the integrated effect of time, cost, convenience
  - Metrics more directly relatable to time, cost, convenience were derived for further consideration. See following slides
- Mass
  - FTK is a community understood measure of air freight
- Services
  - Not considered because of its current relative importance compared to passenger and mass metrics

Rationale for Long Haul Supersonic Metric Selection

- Passengers
  - RPM is a community understood measure of passenger usage
    - It provides the integrated effect of time, cost, and convenience
  - The dominant benefits of supersonic travel are time saved and convenience (to and from additional city pairs in a day)
  - A metric directly related to this benefit could be used, e.g., annual travel time saved
- Mass
  - FTK is a community understood measure of air freight
    - This is not expected to be significant in the near term
- Services
  - Space access missions is a representative example for now
    - This is not expected to be significant in the near term

Suggested Metric Density

Suggested Metric Density

	Local	Regional	Long Haul Subsonic	Long Haul Supersonic
People		RPM	RPM	RPM
Mass	Number of representative UAS missions ARMD helped enabled		FTK	
Services	Number of representative UAS missions ARMD helped enabled	Number of representative UAS missions ARMD helped enabled		

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Alternate Metrics

Alternate Regional Metric

- Passengers
  - Increase in aviation market share

$$= \frac{\text{Number of regional air trips}}{\text{Number of regional trips using all modes}}$$

  - Rationale for metric: Because of the ground transportation options in this region, the dominant feature is the competition between a developing air mode and the existing modes. This metric is a measure of that competition

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Alternate Long Haul Subsonic Metric

- Passengers
  - Normalized time, cost, convenience (TCC)

$$= \frac{\text{Baseline g-t-g time}}{\text{Projected g-t-g time}} \times \frac{\text{Baseline Operating Cost}}{\text{Projected Operating Cost}} \times \frac{\text{Projected CF}}{\text{Baseline CF}}$$

Overall Time, Cost, and Convenience	2015	2025	2035	2045
Metric value	1.00	1.68	2.61	4.11

- Rationale for metric: Since we postulate that mobility is a function of time, coast and convenience, a natural metric for mobility should include all three factors explicitly

  - Value of total annual cost savings

= (Traveler's Value of Time * Reduction in g-t-g time) + (Reduction in DOC per RPM * RPM)

Total Annual Cost Savings	2015	2025	2035	2045
$Billions per year	-	$ 37.6	$ 76.4	$ 132.1

- Rationale for metric: Total cost savings of any transportation mode has an important impact on the nations economy

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Alternate Long Haul Supersonic Metric

- Passengers
  - Total annual time savings
    - Rationale for metric: Major consideration for developing supersonic flight is the savings in traveler’s time. This metric directly addresses that.

Passenger time saved on 10 transcontinental city pairs				
	Passengers per Day	Flights per Day	RPM per Day	
Percent of all flights	2.6%	2.2%	5.2%	
Average gate-to-gate time for 2,393 mile trip (2013), minutes				348
Estimated Time Savings for Supersonic Flight, minutes per flight				174
Passengers' Time Savings, Billions of minutes per year				3.15

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Potential Alternate Metrics

	Local	Regional	Long Haul Subsonic	Long Haul Supersonic
People		Aviation market share	TCC	Total annual time savings
Mass	Number of representative UAS missions ARMD helped enabled		FTK	
Services	Number of representative UAS missions ARMD helped enabled	Number of representative UAS missions ARMD helped enabled		

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Summary

- Conceived the ring concept and mobility matrix to clarify the important contributors to mobility
- Populated the matrix with mission metrics
  - Some standard and some newly developed
- Showed how the metrics and ARMD TCs are related
- Proposed alternate metrics more closely aligned with ARMD activities
- Further progress should be coupled with maturity of the ARMD UAS strategy

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Thank You

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Short-range UAS Metrics Related to Benefit Chain

Good for planning & assessing progress
Defined by NASA plans

→

Good for advocacy, based on benefits
Uncertain, driven by externalities

	NASA Research →	Capabilities →	Missions →	Societal/economic benefits
Basis and Use	***Progress tracking, program/project performance assessment***	***Metrics based on NASA developed capability for use in program/project assessment***	***Metrics based on mission types or numbers for use in advocacy***	***Metric based on benefits for use in advocacy and portfolio management***
Considerations	May be based on Technical Challenge accomplishment, TRL, project goals, etc.	ARMD has identified 4 operating environments, 26 enablers, and 4 TCs. Strategic Thrust 6 roadmap provides a basis to define levels of automation/ autonomy that represent different levels of capability. NASA research is not intended to cover all capabilities required to enable all UAS missions under all conditions.	2014 FAA IPO study grouped 77 mission descriptions from other documents into 26 mission categories. IPO mission categories do not directly relate to ARMD capability construct (e.g., levels of automation/autonomy). IPO missions and mission categories are not exhaustive (e.g., did not include comm relay and small package delivery), and new missions may arise in the future. If so, the mission categories can be extended.	Metric requires numbers of flights and value of performing each mission, but estimates for these are uncertain (e.g., FAA 2016 forecast for numbers of operational sUAS in 2020 ranges from 542,500 to 7 million).
Proposed metrics	**Performance metrics specified for each TC**	**Number of UAS mission-required capabilities (slide 13) to which NASA will have contributed (based on a framework defining required capabilities)**	**Number (or percent) of representative missions (slide 15) that NASA will have helped to enable (based on a framework relating missions to required capabilities)**	**Number of UAS flights that NASA will have helped to enable** **Value of the flights that NASA will have helped to enable** **Value of (UAS) industry sales that NASA will have helped to enable (e.g., up to $19 billion annually in 2020, based on FAA forecast)**

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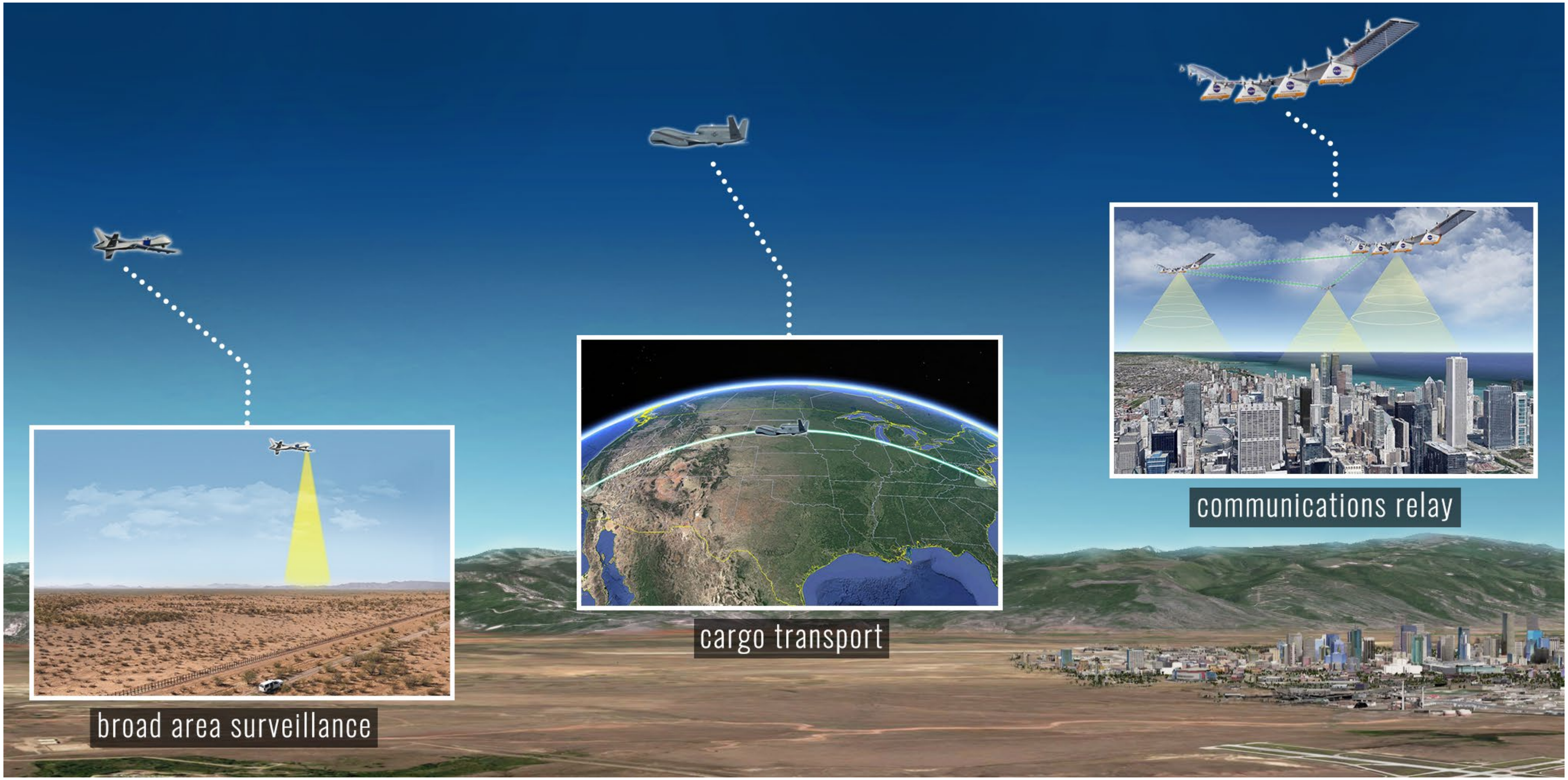
UAS Demand
"Manned-like" IFR Operations



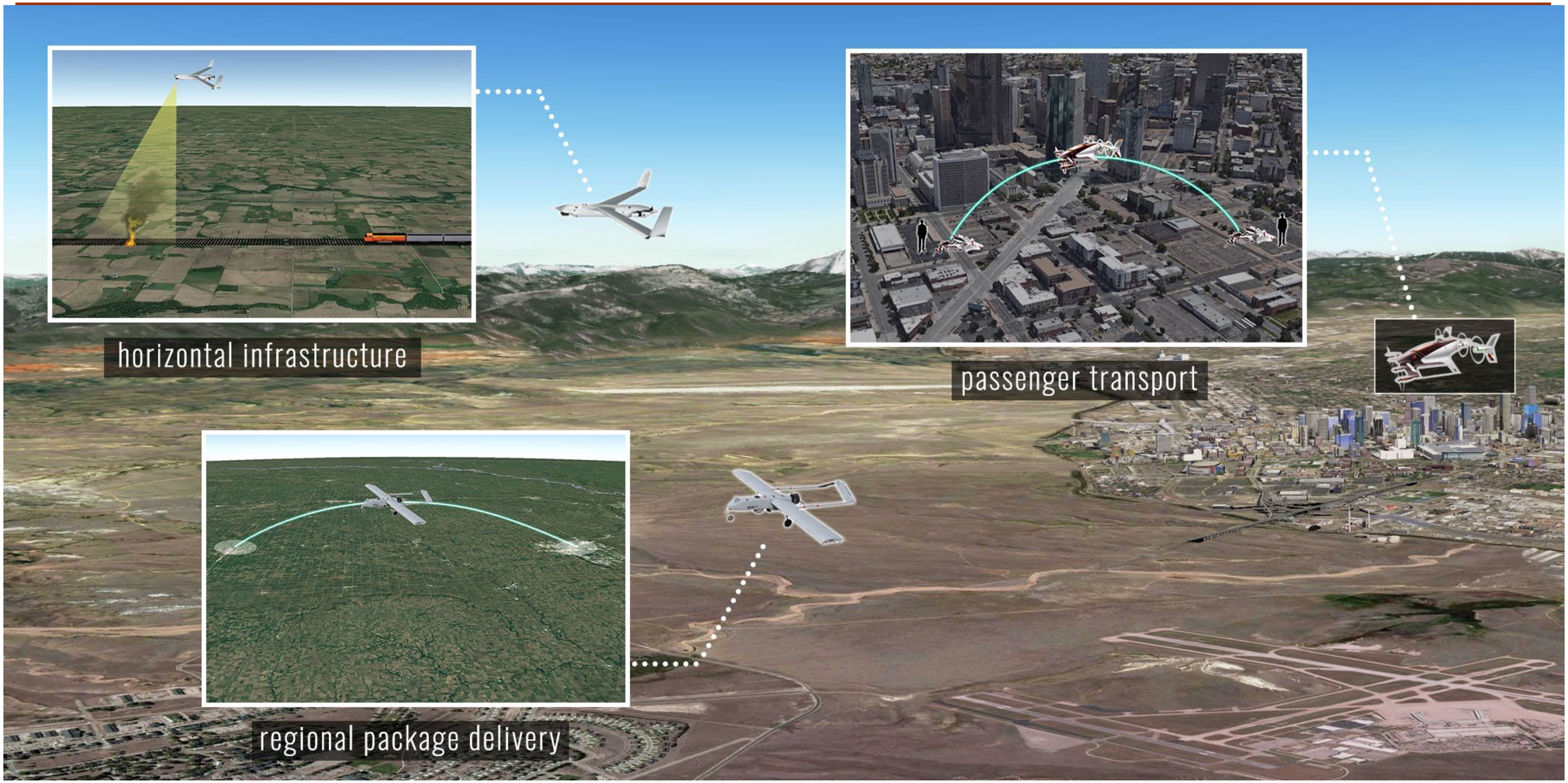
Key Challenges / Gaps

- Detect and Avoid
- C3 Technologies
- Airworthiness
- GCS Technologies
- Contingency Mngmt
- Airspace Mngmt Policies/Procedures
- Airport Infrastructure
- Airport Surface Operations
- Safety Criteria & Methods of Comp.
- NextGen Compatibility

Representative Use Cases / Example Companies

- **Communications Relay** (Facebook, Google)
- **Cargo Transport** (FedEx, DHL, Medical Supply)
- **High Alt. Broad Surveillance** (Dept of Interior, Environmental)
- Weather Monitoring (NOAA, NASA)
- Storm / Disaster Assessment (Land Mngmt, NOAA, Insurance)

UAS Demand
"Tweener" Operations



Key Challenges / Gaps

- Detect and Avoid
- C3 Technologies
- Airworthiness
- GCS Technologies
- RF Spectrum
- Airspace Mngmt Policies/Procedures
- Airspace Mngmt Infrastructure
- Autonomous Architectures
- Safety Criteria and Methods of Comp.
- Cyber Security

Representative Use Cases / Example Companies

- **Horizontal Infrastructure** (BNSF Railroad, Gas/Oil/Electricity)
- **Regional Cargo Delivery** (Amazon, Walmart)
- **Personal Transportation** (Uber, Lyft, AIRBUS)
- Humanitarian Studies (RedCross, Health Dept)
- Wildfire Monitoring (Fire Rescue, State & Local Authorities)

UAS Demand

Low-Altitude Populated (Urban) Operations

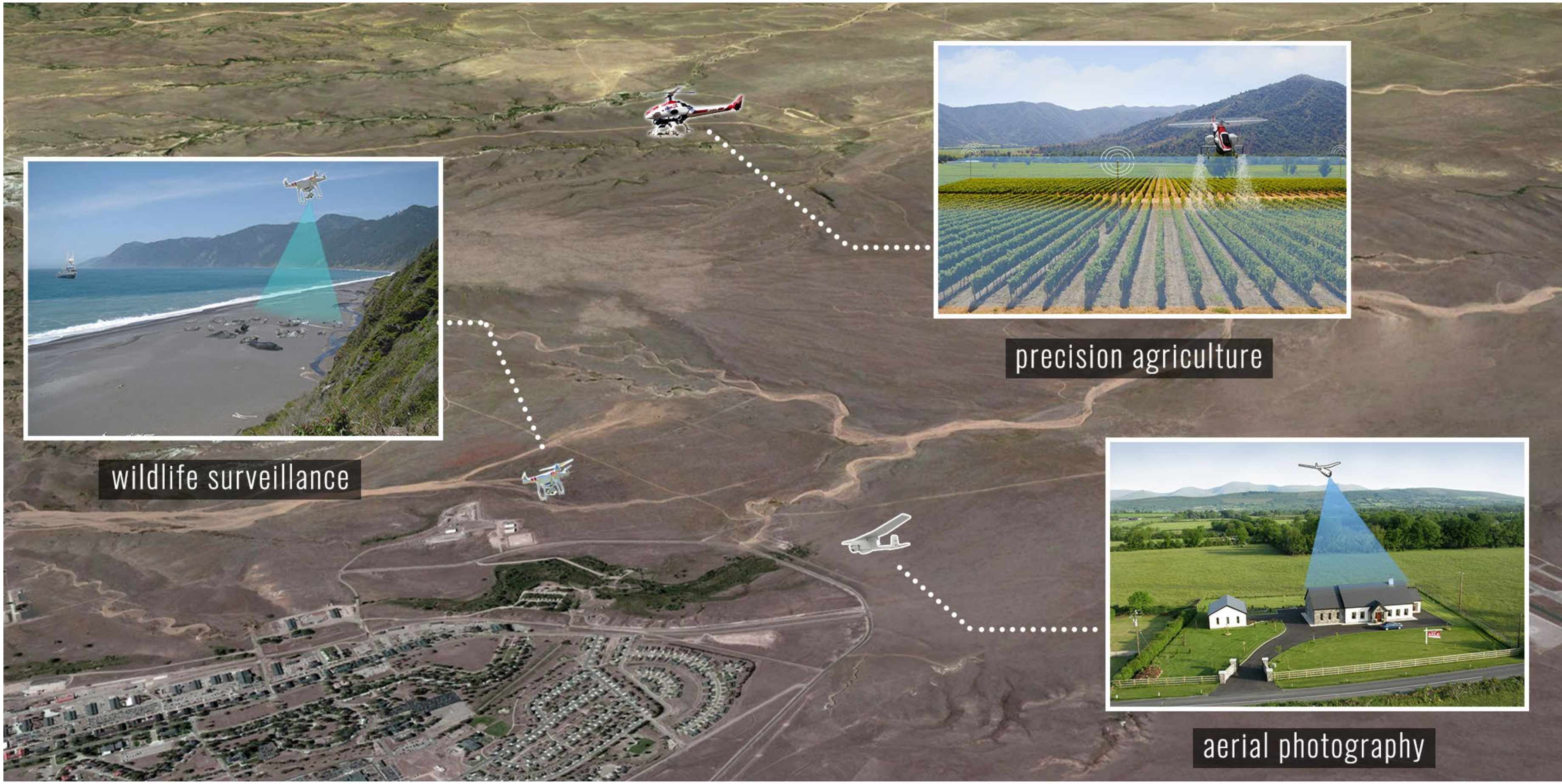
Key Challenges / Gaps

- Hazard Avoidance
- Low-alt Traffic Mngmt
- Detect and Avoid
- C3 Technologies
- Autonomous Architectures
- Noise Mitigation
- Cyber & Physical Security
- Airworthiness
- Operating Rules/Regs
- Contingency Mngmt

Representative Use Cases / Example Companies

- **Local Package Delivery** (Amazon, Walmart)
- **Traffic Monitoring** (Local News Stations, Waze)
- **Aerial Photography** (GoPro, Roofing, Real Estate companies)
- Infrastructure Surveillance & Protection (Airports, Stadiums)
- Construction Site Monitoring (Land developers, Tax & Assmt.)

UAS Demand
Low-Altitude Unpopulated (Rural) Operations



Key Challenges / Gaps

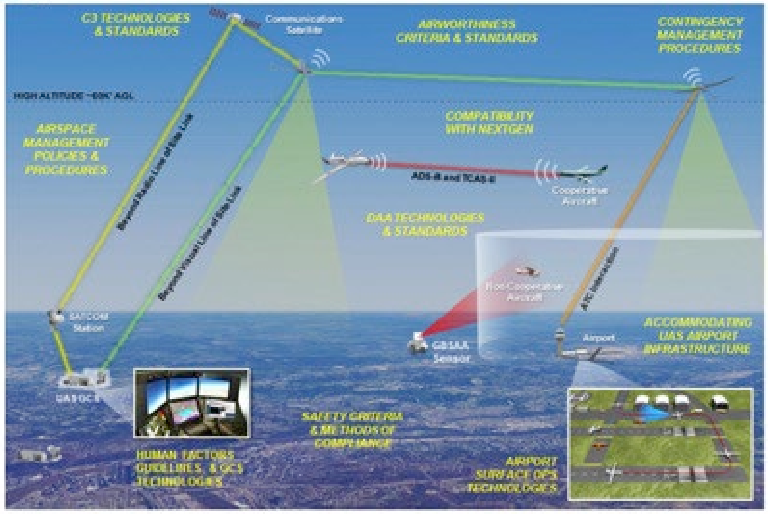
- RF Spectrum
- C3 Technologies
- Safety Criteria & MOCs
- Airworthiness
- Navigation
- Cyber & Physical Security
- Autonomous Architectures
- Low-Alt Traffic Mngmt
- Test Ranges and LVC
- Noise

Representative Use Cases / Example Companies

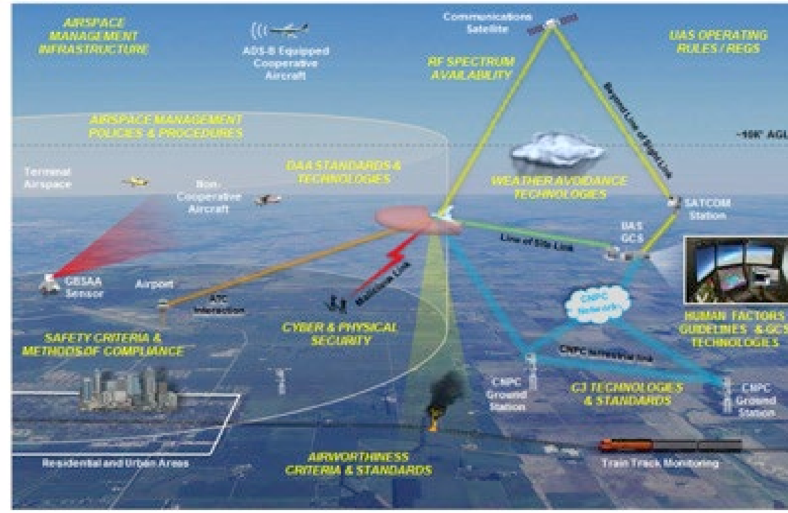
- **Precision Agriculture** (PrecisionHawk, Elbit)
- **Vertical Infrastructure** (Oil /Gas refineries, Bridge inspection)
- **Search and Rescue** (Law Enforcement, First Responder)
- Remote Surveillance (Oil / Gas, Mining, Maritime companies)
- Wildlife Tracking (National Wildlife Federation, Fish & Game)

Representative Operational Environments

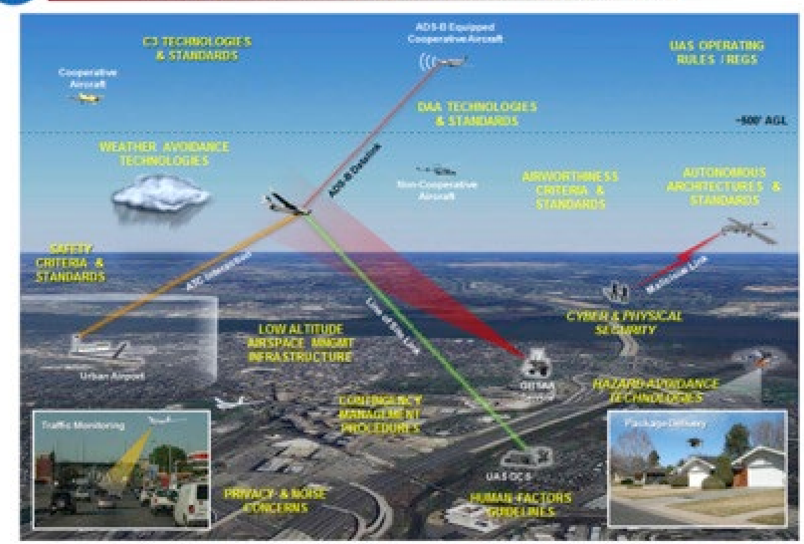
Type I: "Manned like" Operations
Example Use Case: Communication Relay and Cargo Transport



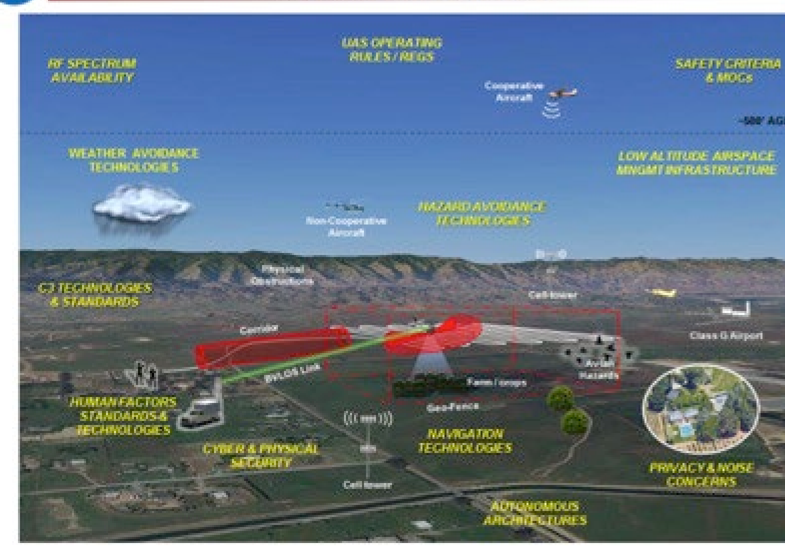
Type II: Tweeners
Example Use Case: Large Infrastructure Surveillance



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



Type IV: Low Altitude Unpopulated
Example Use Case : Agricultural



Sources of UAS Mission Descriptions

- RTCA SC-203 Operational Services and Environmental Definition (OSED) for UAS (DO-320) (June 10, 2010)
  - Includes nine mission scenarios (Law Enforcement , Marine Monitoring , Environmental Sensing, Media and Traffic Reporting, Cargo Delivery, Border Surveillance and Tracking, Hurricane Research, Mining Exploration, Agricultural/Environmental Monitoring)

- IPO UAS Mission Needs Analysis (2014)
  - 77 mission descriptions compiled from eight NASA, FAA, RTCA, DoD, JPDO, and DOC documents
  - Grouped into 26 categories
  - Includes detailed mission profiles and vehicle descriptions

UAS Missions	Reference Sources							
	FAA	RTCA	NASA1	NASA2	JPDO1	JPDO2	DoD	DOC
Military (DoD) - Only								
DoD Training / Demonstration			1				2	
Non-Military Public - Only								
Border Patrol / Surveillance & Tracking	1	1		2	1			
Maritime Surveillance (Search & Tracking)		1	1	1				
Hurricane Research		1	1	1				
Marine Mammals Surveying								1
Fire Detection				1				
Aerial Fire Retardant Application				1				
First Responder Situation Surveillance				2	3			
Law Enforcement - Suspect Tracking		1	1	2		1		
Crowd Control				3				
Military (DoD) & Non-Military Public								
Disaster Assessment*				1		1	1	
Forest Fire Situational Awareness*				1			1	

UAS Missions	Reference Sources							
	FAA	RTCA	NASA1	NASA2	JPDO1	JPDO2	DoD	DOC
Non-Military Public & Civil (Commercial & Non-Commercial)								
Search & Rescue*	1			4	1			
Volcanic Ash Assessment*				1				
Coal Plant Emissions Monitoring*	1	1		1	1			
Site Security Surveillance*				3				
Civil (Commercial & Non-Commercial) - Only								
Agricultural / Environmental Monitoring (High-Alt.)	1	1		2				
Precision Agriculture - Crop Scouting						1		
Precision Agriculture - Aerial Application				2		1		
Mining Exploration		1	1	1				
Critical Infrastructure Inspection				1		1		
Cargo Delivery (Domestic)	1	1	1	1	1	1		
Cargo Delivery (International / Trans-Oceanic)	1			1				
Media & Traffic Reporting	1	1		1				
Real Estate Photography				2		1		
Aerial Advertising						1		

- NASA LaRC R&D Roadmap of UAS Access to the Next Generation Air Transportation System (2010)
  - Scenarios for 51 missions in 25 categories (Surveillance Over Private Property, Lost Hiker Location, Real Estate Aerial Photography, Electrical Power Line Patrol, Crowd Control, Fire Situational Awareness, Pesticide Application, Coal Plant Emission Surveillance, Disaster Assessment, Aerial Fire Retardant Application, Mining Exploration, Fugitive On-foot Tracking, High Value Asset Patrol, Standoff Resolution, High Speed Fugitive Vehicle Tracking, Agricultural/Environmental Monitoring from High Altitude, Border Ground Entry Surveillance and Tracking, Cargo Delivery, Fire Detection Surveillance, High Crime Area Patrol, Marine Search and Rescue, Media and Traffic Reporting, Trans-Oceanic Cargo Delivery, Volcanic Ash Assessment, Hurricane Research)

- Missions may require updating and expansion
  - Descriptions do not include autonomous operations (might be addressed by subdividing existing missions where applicable)
  - Missions do not included package delivery (Amazon and Google concepts), communications relay (Google and others), or personal transportation (Uber and others)

UAS Technical Challenges

Technical Challenge – DAA
Detect and Avoid

Develop, mature, and provide research findings from analysis, simulations, flight tests, and validation of SC-228 Phase 2 Detect and Avoid (DAA) Minimum Operational Performance Standards (MOPS) that will enable a broader range of IFR-like UAS BVLOS operations by providing technology to safely "See and Avoid" traffic in the NAS

Technical Challenge – C2
Command and Control

Develop, mature, and provide research findings from analysis, simulations, flight tests, and validation of SC-228 Phase 2 Command and Control (C2) Minimum Operational Performance Standards (MOPS) that will enable Satellite and Terrestrial Communication System Architectures compliant with allocated spectrum requirements

Technical Challenge – ITE
Integrated Test and Evaluation

Implement UAS flight test and simulation environments that will enable development, verification, and validation of integrated DAA and C2 technologies on UAS

Technical Challenge – UTM
UAS Traffic Management

Develop comprehensive and validated airspace operations and integration requirements to safely enable large-scale persistent access to visual line of sight and autonomous beyond visual line of sight unmanned aerial systems/drones in low-altitude airspace

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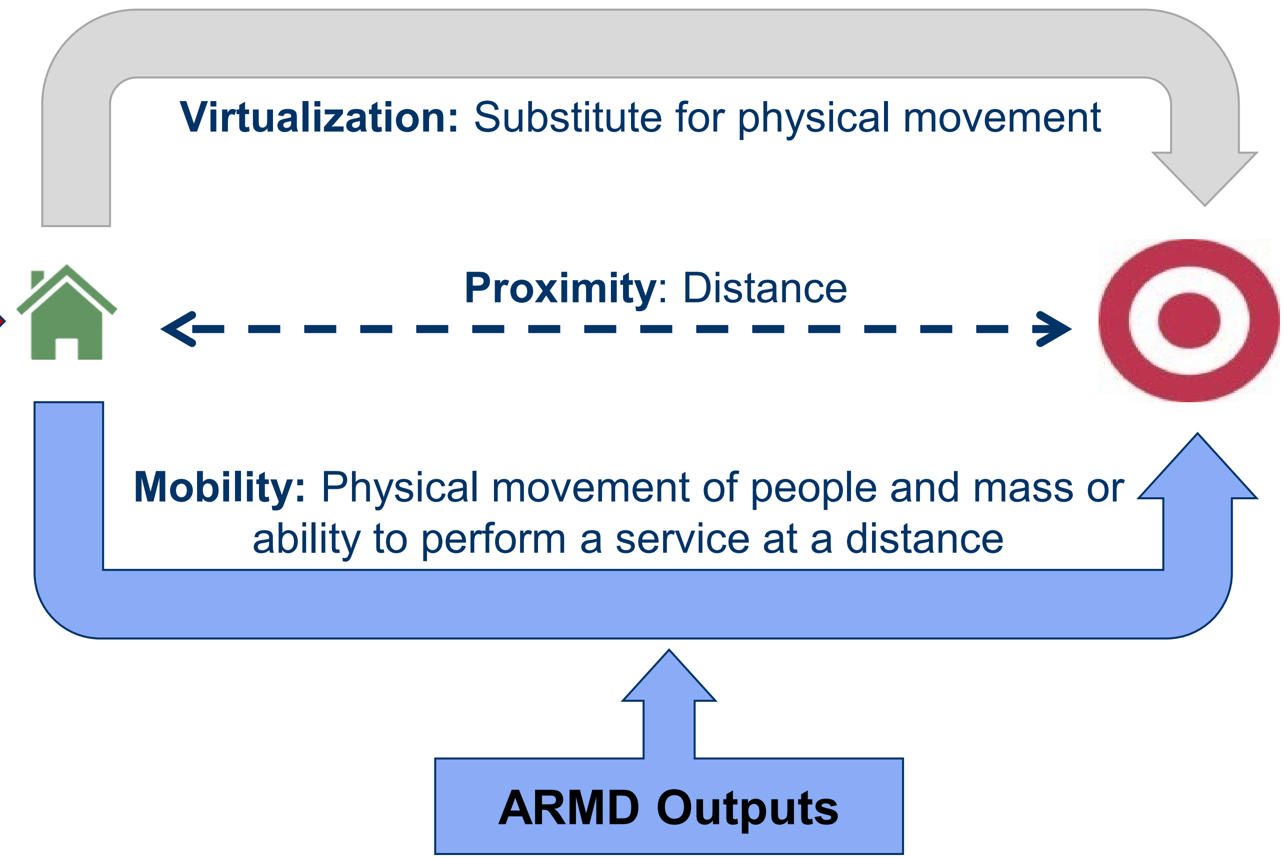
Access vs. Mobility

Access = f (Mobility, Proximity, Virtualization)

Access includes availability/suitability of modes

User Choices

- Origin and destination
- Mode selection



Alternate Regional Metric

Increase in Air Mode Market Share

$$= \frac{\text{Number of regional air trips}}{\text{Number of regional trips using all modes}}$$

- Notes
  - Variants of this metric might be based on passenger miles rather than number of trips (one-way origin to destination) or on percent increase in these quantities
  - This metric may be computed for both current and projected values
  - This metric is sensitive to the selection of distance boundaries defining regional travel
- Pros
  - This recognizes the increasingly competitive nature of regional air travel choices
  - This metric reflects the results of comparisons of the values of time, cost, and convenience for each mode, as perceived by travelers
- Cons
  - This metric does not directly indicate the time or cost savings to travelers
  - Computation of this metric requires modeling of travel demand, door-to-door time, cost, and convenience for air and surface trips and the impact of these factors on travelers mode choices
  - The metric does not show the specific contribution of NASA research, unless the numerator is changed to the increase in regional air trips attributable to NASA research

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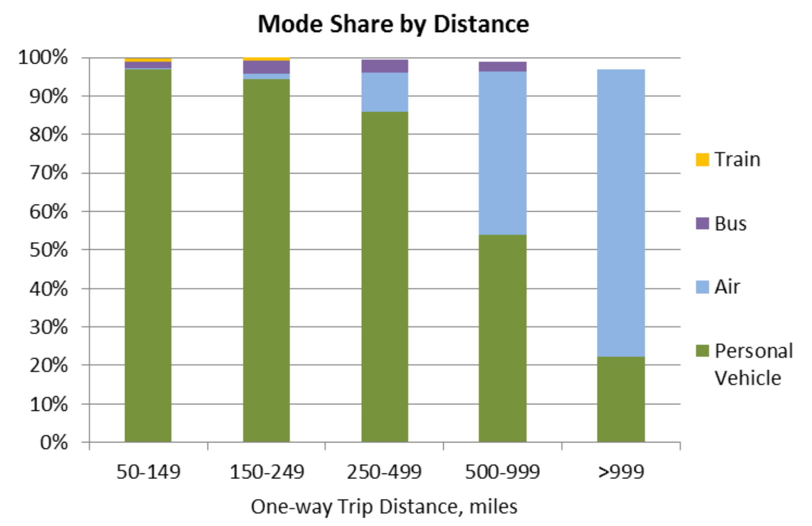
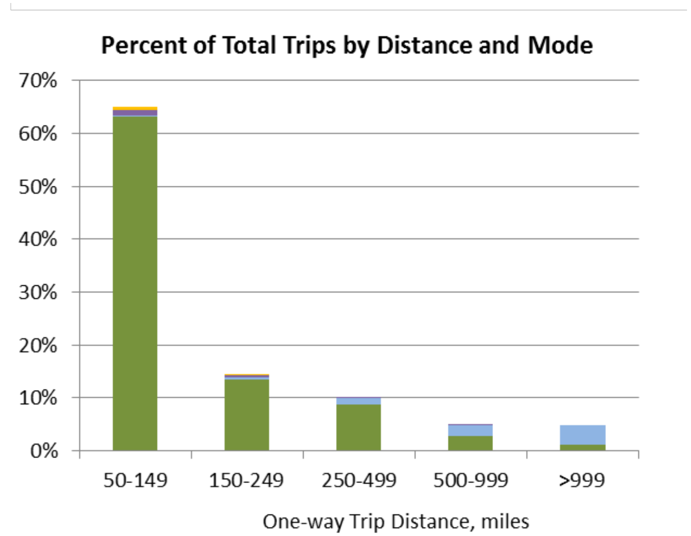
Representative Values for Regional Metric

Air Mode Market Share

Mode Share Data from 2001 National Household Travel Survey





NASA-enabled PAV could enable a rapid growth in % of air travel for trips of 150 to 500 miles

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Alternate Long Haul Subsonic Metric (LH1)

Overall Time, Cost, and Convenience

$$= \frac{\text{Baseline g-t-g time}}{\text{Projected g-t-g time}} \times \frac{\text{Baseline Operating Cost}}{\text{Projected Operating Cost}} \times \frac{\text{Projected CF}}{\text{Baseline CF}}$$

- Notes
  - Operating cost calculated per RPM
  - CF could be estimated (see previous (LH3) metric) or set to 1.0
  - Projected values based on ARMD goals
  - Formula could be additive vice multiplicative and incorporate weighting factors
- Pros
  - Includes all three factors influencing mobility
  - Baseline data available for relatively easy calculation
  - Can include supersonic aircraft or be used as a separate supersonic metric
- Cons
  - Convenience factor is difficult to evaluate, especially as a result of NASA contributions
  - Implicitly places equal importance on each component in the metric
  - Somewhat hard to explain in “elevator speech”
  - Small savings in each flight could be lost due to normalization

Representative calculations show a > 67% improvement in 2025, growing to over 300% in 2045 compared to 2015

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Representative Values for LH1

Overall Time, Cost, and Convenience

$$= \frac{\text{Baseline g-t-g time}}{\text{Projected g-t-g time}} \times \frac{\text{Baseline Op Cost}}{\text{Projected Op Cost}} \times \frac{\text{Projected CF}}{\text{Baseline CF}}$$

Overall Time, Cost, and Convenience	**2015**	**2025**	**2035**	**2045**
Baseline (2015) Gate-to-gate Time, minutes	171	171	171	171
Projected Gate-to-gate Time, minutes	171	166	161	156
Gate-to-gate Time Ratio	*1.0*	*1.0*	*1.1*	*1.1*
Baseline (2015) Operating Cost per RPM, $	$ 0.14	$ 0.14	$ 0.14	$ 0.14
Projected Operating Cost per RPM, $	$ 0.14	$ 0.11	$ 0.09	$ 0.08
Operating Cost Ratio	*1.0*	*1.3*	*1.5*	*1.8*
Baseline (2015) Average Deviation from Desired Departure Time, minutes	65	65	65	65
Projected Average Deviation from Desired Departure Time, minutes	65	51	40	31
Convenience Ratio	*1.0*	*1.3*	*1.6*	*2.1*
Overall Time, Cost, and Convenience Product	**1.0**	**1.7**	**2.6**	**4.1**

Operating cost reduction based on ARMD efficiency goals and constant (2015) fuel price
Gate-to-gate time is assumed to be reduced by 3%, 6%, and 9% for 2025, 2035, and 2045 relative to 2015
Convenience factor is based on ¼ of average time between flights on the same route, calculated from number of flights per day on stratified sample of routes

All data based on MIT Airline Data Project (http://web.mit.edu/airlinedata/www/Revenue&Related.html) unless otherwise indicated

Representative calculations show a > 67% improvement in 2025, growing to over 300% in 2045 compared to 2015

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Alternate Long Haul Subsonic Metric (LH2)

Total Annual Cost Savings

= (Traveler's Value of Time * Reduction in g-t-g time) + (Reduction in Oper. Cost per RPM * RPM)

- Notes
  - Operating Cost calculated per RPM
  - Assumes Operating Cost savings are passed on to the passengers
  - Passengers' Value of Time based on FAA recommendations
  - Could be shown as % cost savings
- Pros
  - Easy to understand
  - Baseline data available for relatively easy calculation
  - Can include supersonic aircraft or be used as a separate subsonic-only metric
  - Small savings per flight will show significant overall benefit of NASA research
- Cons
  - Travelers "value of time" is a mix of business and leisure travel and varies by flight and passenger
  - Does not include convenience contribution to mobility

Representative calculations show 13% cost savings per trip (including value of time) in 2025 compared to 2015

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Representative Values for LH2

Total Annual Cost Savings

= Reduction in (Travelers’ value of time * g-t-g time) + (Operating Cost per RPM * Miles)

Total Cost Savings	2015	2025	2035	2045
Total Passengers' Time Saved Relative to Baseline (2015), billions of minutes per year	-	4.9	12.7	24.4
Annual Passengers' Savings Due to Value of Time Relative to Baseline (2015), $ billions per year	-	$ 3.8	$ 9.8	$ 18.9
Annual Passengers' Savings Due to Reduction in Operating Cost Relative to Baseline (2015), $ billions per year	-	$ 34	$ 67	$ 113
Total Annual Passengers' Savings (including operating cost and value of time) Relative to Baseline (2015), $ billions per year	**-**	**$ 38**	**$ 76**	**$ 132**
Percent of Passengers' Savings Due to Reduction in Operating Cost	-	90%	87%	86%
Average Cost per Passenger Trip, Operating Cost Only, $ per trip	$ 161	$ 126	$ 108	$ 91
Average Cost per Passenger Trip (including value of passenger's time), $ per trip	$ 293	$ 255	$ 233	$ 211
Reduction in Average Cost per Passenger Trip (including value of passenger's time), %	**-**	**13%**	**21%**	**28%**

Passengers’ value of time is based on FAA-recommended values as adjusted using BLS employment cost index, per Airlines for America, 2016

Representative calculations show 13% cost savings per trip (including value of time) in 2025 compared to 2015

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