



EXPLORE FLIGHT

WE'RE WITH YOU WHEN YOU FLY

Data and Reasoning Fabric (DRF) Phase-I & Phase-II Report

November 2020

NASA Aeronautics Research Mission Directorate (ARMD)

Transformative Aeronautics Concepts Program (TACP)

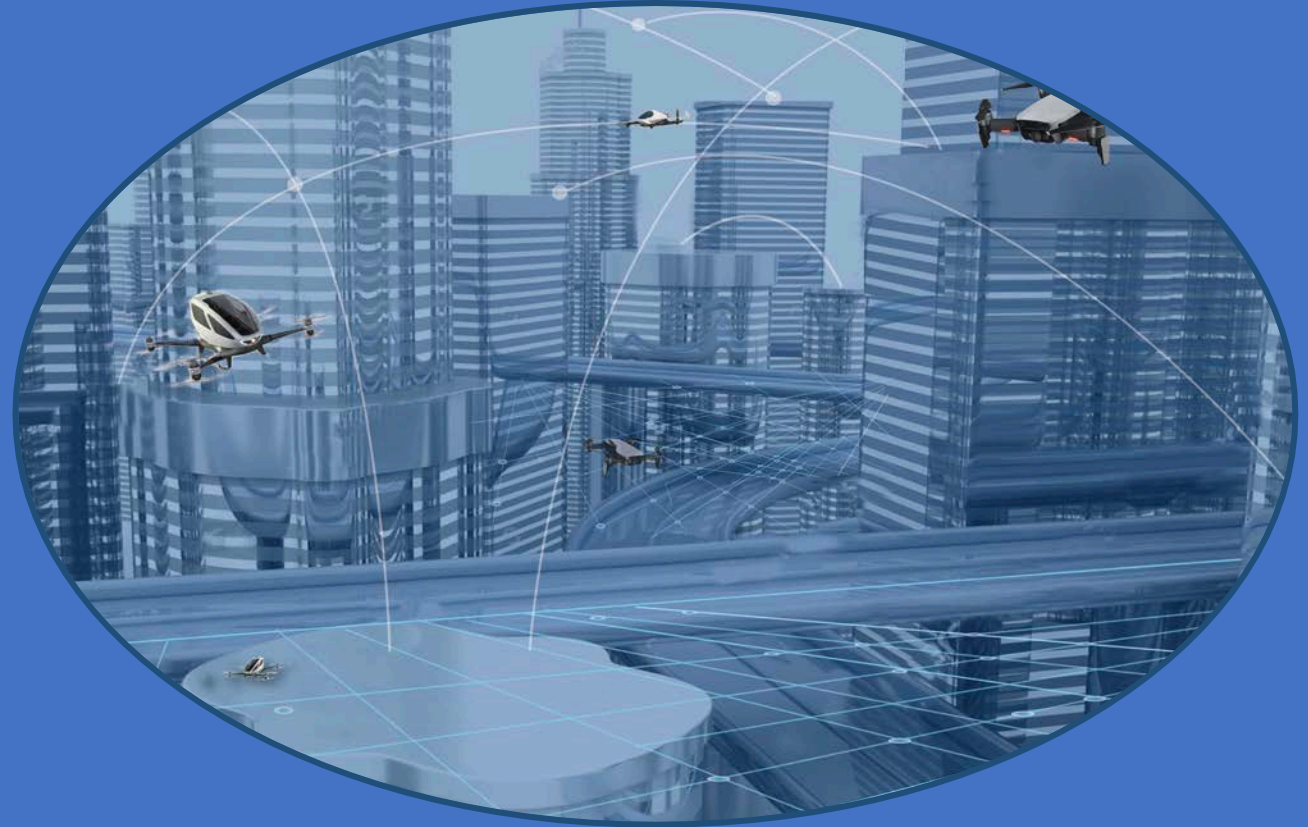
Convergent Aeronautics Solutions (CAS) Project

Data and Reasoning Fabric Team

Outline



- Executive Summary
- Motivation & Concept
- Phase I Summary
- Phase II Summary
- Desirability
- Viability
- Feasibility
- Disciplined Entrepreneurship (DE) Framework



MOBILITY CHALLENGES



- Transportation shapes society, enabling economic and social interactions
- The quality of life is impacted by ever growing commute time
- Transportation is increasingly driven by door-to-door challenges

Air Mobility can convert our 2D mobility system to a 3D mobility system, increasing mobility options for both people and goods

AIR MOBILITY DATA AND REASONING CHALLENGES



- Urban air operations require decisions based on diverse and dynamic data, including vehicle, airspace, weather, infrastructure, payload, and customer data
- Decisions need to be made where the data exist and, increasingly, data may be too large or dynamic to centralize
- The envisioned density of operations will only be achieved if decision processes continue to move from purely human decisions, to machine-intelligence based decisions with human oversight
- Machine-intelligence generally requires greater volumes of digital data of explicitly known applicability, quality, and many other “ilities.”

Air Mobility Planning, Operations, and Performance

- Current Trajectory -

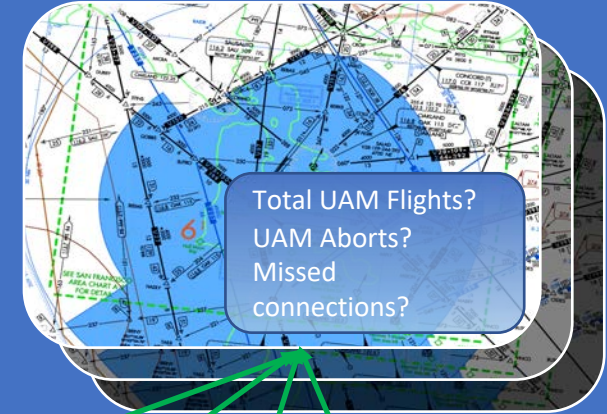
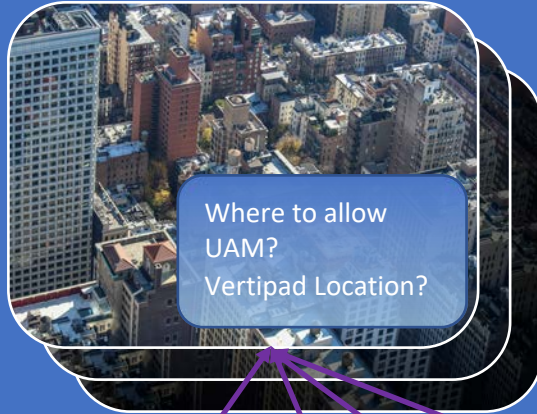


APPLICATION ENGINES

PLANNING

OPERATIONS

PERFORMANCE



CASE-BY-CASE DATA

- DISCOVERY
- AGGREGATION
- VETTING
- DATA/\$ TRANSACTIONS

City "A" Planner

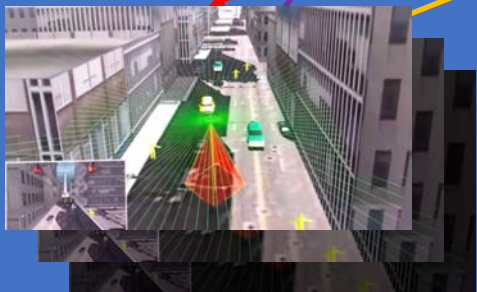
Package-As-Service Provider "A"

City "L" Planner

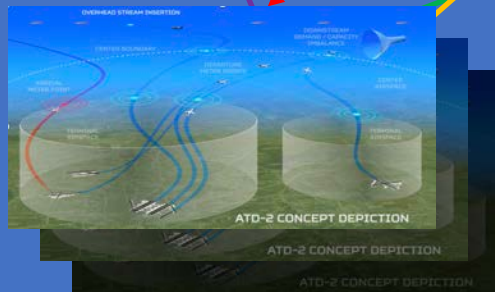
Mobility-As-Service Provider "U"

CONCERNS

- COST
- AGILITY
- SECURITY
- "MONO" ECOSYSTEMS



SMART VEHICLES



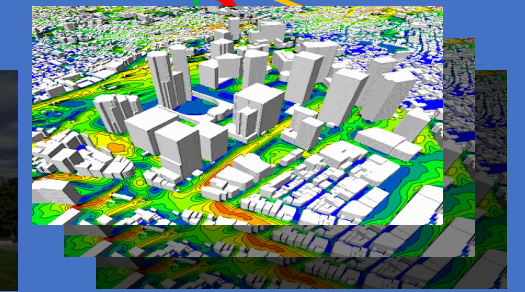
SMART AIRSPACES



SMART CITIES



REGULATORY



MICRO-WEATHER

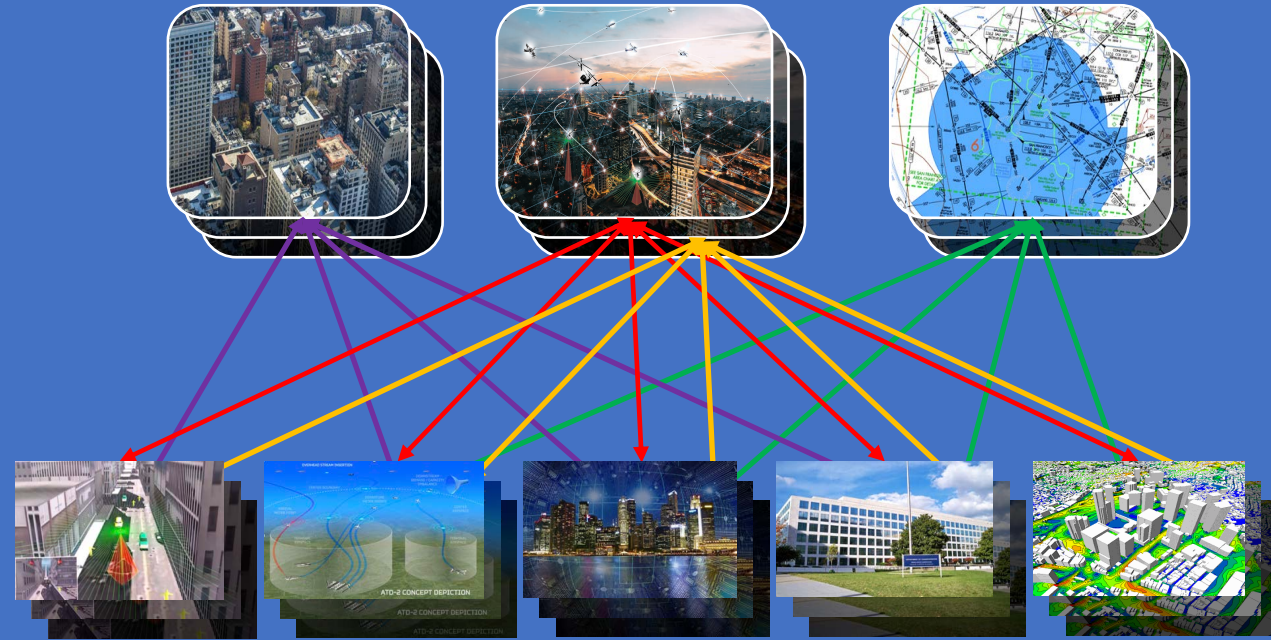


DATA Producers & Consumers

Air Mobility Data & Reasoning Current Trajectory - Concerns



- Many "stovepipe" connections:
 - Labor intensive
 - Lack agility
 - Fractured community
- Inconsistent implementation and quality
 - Security vulnerabilities
 - Varying performance
- Lack of standards
 - Inconsistent interpretation and exchange of data
 - Ongoing interoperability headaches
- Lack of common foundation
 - Difficult to define and revise systemwide policies
 - Difficult to measure systemwide performance, health
 - Difficult to support consistent, robust safety standards
 - Difficult to extend system to new missions, technologies over time



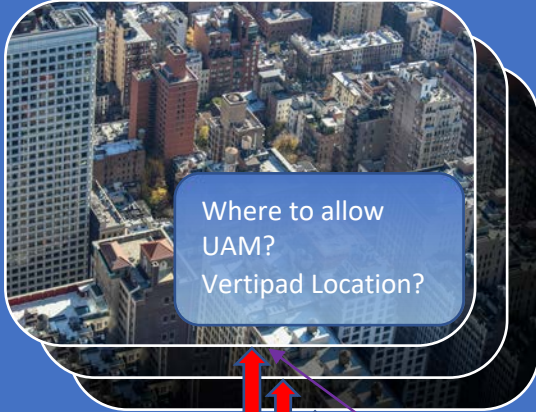
Air Mobility Planning, Operations, and Performance

- DRF Trajectory -



APPLICATION ENGINES

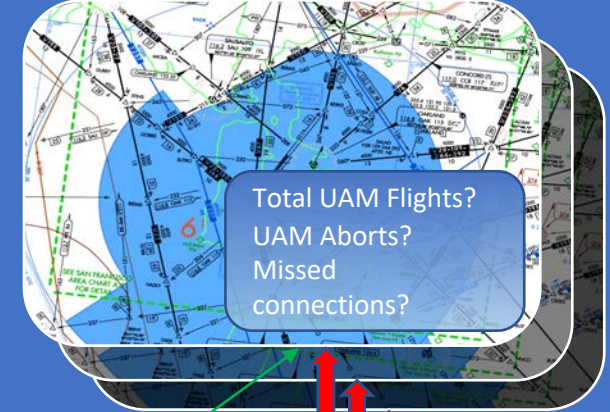
PLANNING



OPERATIONS



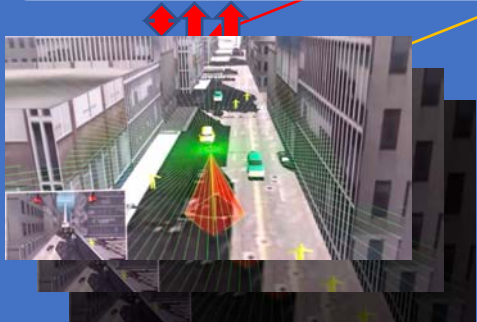
PERFORMANCE



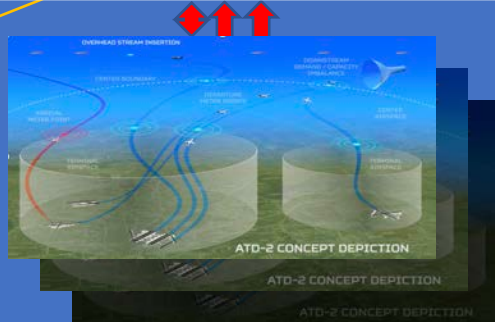
DATA & REASONING FABRIC

A set of secured software infrastructure, tools, protocols, governance and policies to implement, administer, manage and operate data sharing and reasoning services across the entire span of air mobility and other "smart" edge nodes.

- ENABLE EFFICIENT AND PERVERSIVE DATA DISCOVERY, AGGREGATION, VETTING, AND DATA/\$ TRANSACTIONS -



SMART VEHICLES



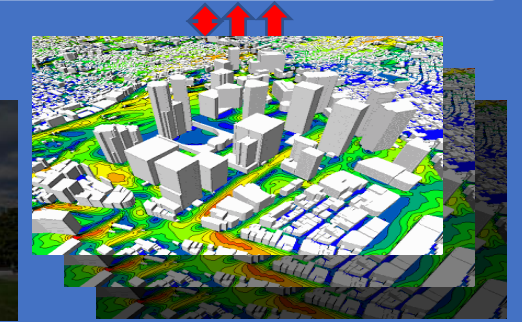
SMART AIRSPACES



SMART CITIES



REGULATORY



MICRO-WEATHER



DATA Producers & Consumers

Data & Reasoning Fabric Marketplace



DRF is envisioned to provide the foundation for a marketplace of data and reasoning to support:

- High-density air transportation, even in complex urban environments
- Transportation of people and cargo to places previously not served or underserved by aviation
- Efficient and user-friendly integration of emerging and evolving traditional air transportation capabilities

How:

- DRF will allow 1000s of small and large enterprises with different assets to exchange data and reasoning in a systemwide marketplace
- More choices and a secure transacting experience
- DRF will be inherently extensible for new data, reasoning, and other services

Allow air transportation systems to be aware of and adapt to all available data, from evolving user intent to real-time environmental, infrastructure, and ground/water transportation systems status

Data & Reasoning Fabric - Scope



A DRF Should Support:

- Dynamic discovery, assessment, and negotiated use of data and services
- Data access rights/contracts
- Standards to access data and services
- Defined service levels for data exchange
- Closed feedback loops
- Pervasive security from the data level outward
- Capture and exchange of system state and data quality (i.e. metadata)
- Definition, sharing, maintenance and execution of airspace system operating policies
- Other common core elements related to airspace safety

A DRF Should Accommodate Future Evolving:

- Flight concepts and operations
- Data standards and data/reasoning services
- Technologies used for implementation
- Community and airspace policies/rules

Providing a self-supporting marketplace for the rapid sharing of data and services
Avoid being prescriptive

Data & Reasoning Fabric - System-Level Benefits



Reduce Complexity

Reduce complexity of system-level engineering challenges for the traditional and emerging airspace system

Provide Clarity

Provide baseline requirements and architecture clarity to all stakeholders, including the private sector

Provide Incentive

Provide core elements of a framework supporting marketplace functions for data, operations and policies that provides a clarifying economic incentive to the private sector to bring the relevant innovations, products and services to market

Provide Flexibility

Build in the flexibility and extensibility of the data systems supporting the National Airspace System to give all stakeholders confidence in a path to continued innovation and increased capability in the traditional and emerging airspace system

Factors in Successfully Introducing DRF Capabilities



Involvement from the public sector

- The public sector, as regulator, plays a necessary role in defining requirements from the perspective of safety and other factors that are in the public interest.

The role of the private sector

- Clarity on requirements combined with economic incentive can cause the private sector to deliver the desired innovation and ultimately to push capabilities beyond initially envisioned goals.

Systems engineering – system of smart systems capable of safety-critical operations

- Automation and data for time-critical and safety-related operations across nominal and contingency situations.

Requirements – enabling vs. prescriptive

- The ultimate requirements are complex and cannot be fully known at the outset. Future technologies are sure to bring change.
- A foundational layer built around data can reduce complexity while encapsulating core common capabilities and providing inherent flexibility for evolving requirements, future operating policies, and future unanticipated end-applications for the airspace system



Phase I Summary (December 2019 - March 2020)

Phase I Approach



Duration: December 2019 - March 2020

Team:

NASA Civil Servants - Airspace, vehicle, pilot, architecture, and AI expertise



Radius Capital - Advanced aerial mobility technologies and economy expertise



Gartner - Market assessment expertise



Approach:

Tailored the **MIT 24-Step Disciplined Entrepreneurship** process to assess the DRF opportunity including:

- Extensive market assessment
- Interview representatives of key end-user, customer, and stakeholder communities
- Synthesized key take-away findings regarding DRF opportunity



Phase I – Stakeholder Interviews



Organization	Interviewed	Organizational Type
Garmin	Dustin Kilgore, Systems Engineer	Technology Provider - Autonomous Avionics
Lockheed Martin	Barbara Lindauer, Jonathan Hartman, Barry Ives	Vehicle Provider - Aerospace manufacturing
Dreamhammer	Josh Vinyard, Chief Engineer	Airspace Management Provider - UAV management software
SkyGrid (Boeing)	Zack Beckman; Sara; Ali (Chief Software Architect)	Airspace Management Provider - UTM/Avionics software
AirXOS (GE)	Andrea Shestopalov, UTM Production Manager	Airspace Management Provider - UTM software, GE venture
RTI (Real-Time Innovations, Inc)	Hasnat Ashiq, Regional FAE Manager	Industrial IoT Connectivity Framework (DDS)
Noblis	Mile Corrigan, Vice President and Executive Officer, Karl Wunderlich, Sterling Thomas, Scott James, Alex Murray, Matt Monaco	Autonomy at Scale, Large Scale Data Structures (SWIM), (E-IDS), and FAA Enterprise Network Services (FENS).
Google (Cloud)	Don Tirsell, Head of Strategic Partnerships	Technology/Service Provider - Cloud Stack/Infrastructure
UPS Flight Forward	Jacob Rutledge, Lead Application Developer Jim Ackerson, Procurement Manager	Air Mobility Provider - Package Delivery
Uber	Tom Prevot, Director - Airspace Systems	Air Mobility Provider - Mobility-As-Service
Town of Cary, North Carolina	Terry Yates, Smart Cities & IT Project Manager	City Government – Smart Cities Initiative
North Carolina Department of Transportation	Basil Yap, DoT Program Mgr.; Randy Breedlove (FAA); Wendy Smith; Darshin	State Government - Transportation Agency
FAA	Steve Bradford, Chief Scientist	Federal Government - Regulatory

Phase I Key Findings



#1: Does an Air Mobility Data & Reasoning Fabric address the data & reasoning challenges that must be resolved to achieve advanced air mobility?

Refinement of the Data & Reasoning Fabric concept and targeted work in specific areas would create a better understanding of how, from a data & reasoning perspective, the advanced air mobility vision can be accomplished.

#2: Does NASA Aeronautics need to do anything, and if so what, to enable an Air Mobility Data & Reasoning Fabric in time to prevent data & reasoning factors from inhibiting progress towards advanced air mobility?

Hardening 1:N (people to vehicle) use cases, refining stakeholder roles, enabling open data, software, communication, and reasoning architectures is both required to achieve advanced air mobility (from a data & reasoning perspective) and appropriate to NASA ARMD's role and demonstrated competencies.

#3: Given the complexity of this opportunity assessment, are there benefits to following a disciplined entrepreneurship process to assess this opportunity?

Yes, grounds opportunity assessment in proven industrial processes, but requires tailoring, especially replacing profit focus with national impact priority.



Phase II (June – October 2020)

Phase II Objectives

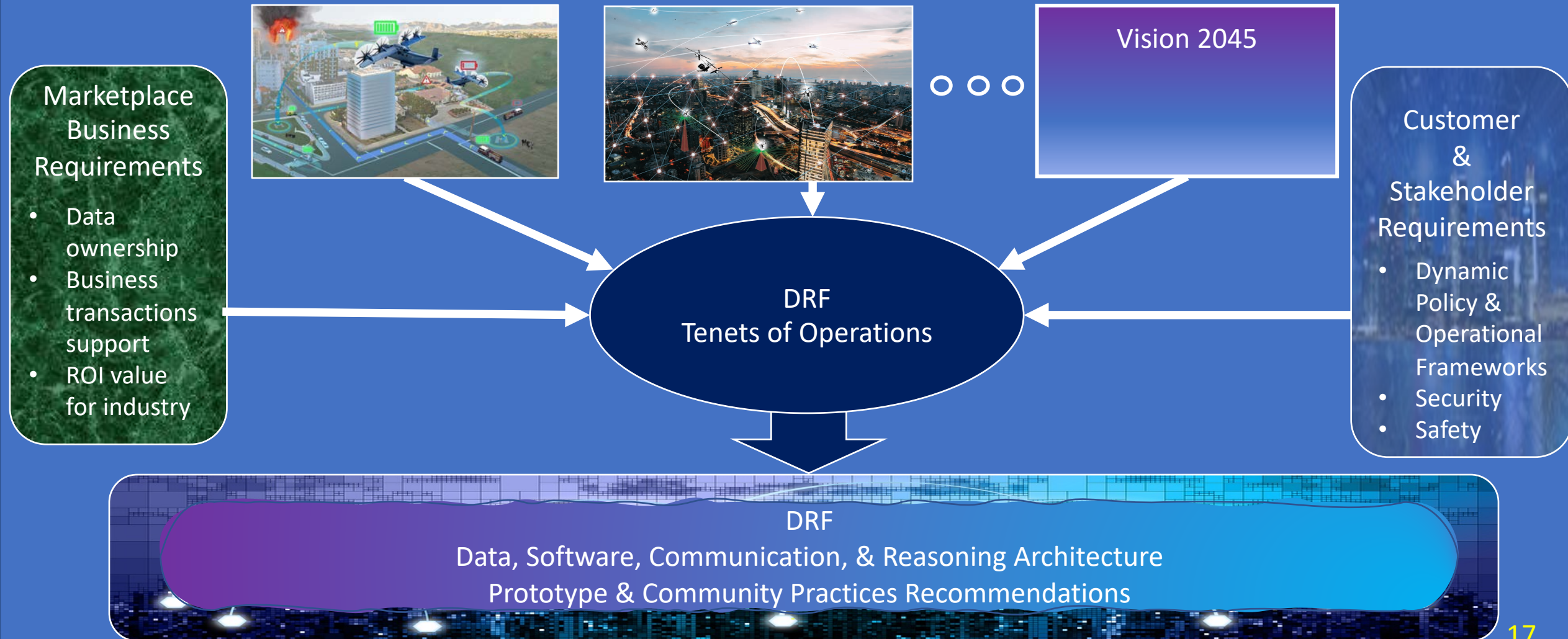


- Establish:
 - o Scope of the DRF
 - o Required DRF operational attributes (Tenets of Operations)
- Identify technologies and best practices to deploy on DRF:
 - o Down-select to initial technology stack from current & emerging foundational IT technologies
 - o Industry/marketplace best practices that can be adopted or leveraged by DRF
- Recommend:
 - o Initial DRF Architecture
 - o Prototyping activities and community best practices required to mature the DRF technical approach
 - o Strategy for testing DRF assumptions through end user engagement with DRF prototype

Phase II - Approach



Emerging Advanced Air Mobility Use Cases



Phase II - Tenets of Operations - (WHY-WHAT-HOW)



WHY

DRF is foundational leverage for the systems that support complex and ubiquitous (AAM) operations.

DRF will be for AAM what HTTP, HTML, and XML were for the Web.

WHAT

DRF is a source of data and reasoning services for all AAM stakeholders. With a foundational layer such as DRF, these capabilities can be implemented with more consistent quality, more robust real-world performance, better interoperability, better security, and greater future extensibility.

DRF includes and supports a trusted marketplace. DRF succeeds if it supports a vibrant business ecosystem with foundational support for the economically viable participation of all relevant industry sectors, as well as the minimal appropriate participation by government to assure the equitable, safe, and secure operation of the national airspace and supporting infrastructure. To the extent possible, academia should be allowed far reaching access to DRF to support their research in the effective operation of the national airspace.

HOW

DRF is flexible and application/mission-agnostic, build on the shoulders of current airspace capabilities. DRF must have a generalized framework, be inherently extensible, and enable appropriate adoption and plug-in interoperability across open standards and technologies. DRF must be backward-compatible with existing airspace systems and infrastructure, as well as extensible to other modes of transportation.

Phase II - Tenets of Operations



DRF DATA TYPES: DRF shall support definition of formats for common data elements and full lifecycle support for their extensibility. DRF shall support extensible definition of metadata to enable evaluation of data and inform its viable uses.

DRF DATA FLOW AND ACCESS RIGHTS: DRF shall implement a framework to support discovery of data sources, evaluation thereof, and transactions to acquire data flows protected via appropriate access rights.

DRF REASONING: DRF shall enable resilient 1:N increasingly automated operations via a marketplace of decision-making services that provide logical sequences and predictions in a robust and timely fashion.



DRF IN-TIME PROCESSING PERFORMANCE: DRF shall facilitate the discovery and allocation of resources for data, communications and computing as required for in-time data processing.

DRF POLICY FRAMEWORK: DRF shall support definition of policies and procedures encompassing relevant operating rules for the airspace system. DRF shall support the propagation of policies and procedures across the DRF ecosystem with consistent interpretation and appropriate execution by all nodes. DRF shall support mechanisms to establish feedback loops on policy compliance and deviations, with appropriate system-wide responses for both nominal and contingency circumstances.

Phase II - Tenets of Operations



DRF DATA TRUST AND CONFIDENCE: DRF shall provide all stakeholders the ability to express, transmit, and consume information regarding the quality of data. Data quality attributes (metadata) shall be extensible in definition and can include support of safe, secure, efficient, and reliable operations within the airspace system.

DRF SAFETY: DRF shall enable safety-critical operations through framework functionality required for systemwide coordination across data trust and confidence, communications performance, and responsive policy definition/implementation, as well as other areas that support airspace system safety goals.

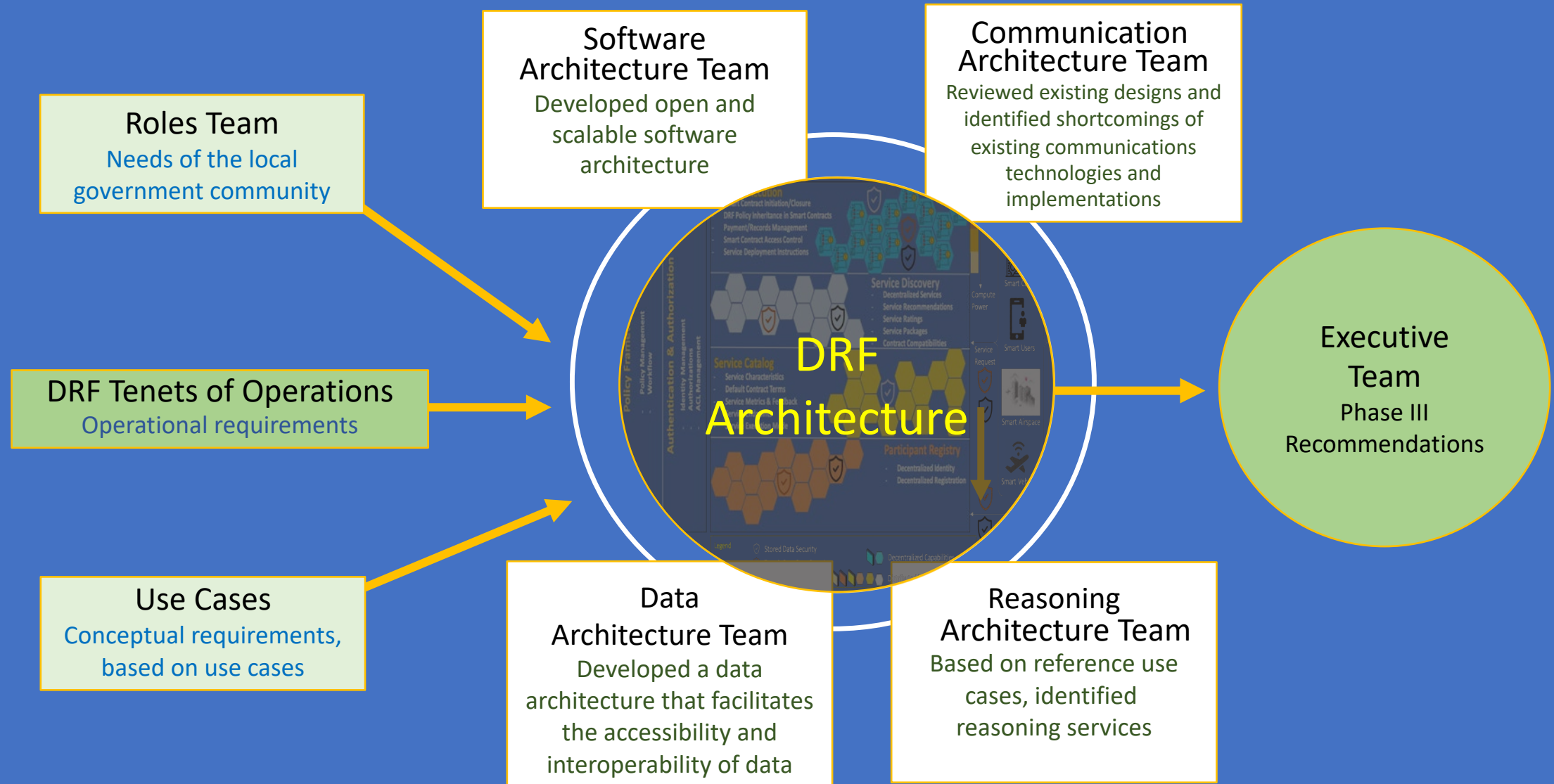
DRF COMMUNICATIONS: DRF shall support a robust, resilient, timely and dynamic communications environment that supports communications service discovery and variable performance requirements all while meeting the DRF community access requirements.



DRF RESILIENCY: DRF shall be able to support definition of adaptive systems and maintain its intended functionality when faced with off-nominal conditions, or otherwise will be able to support appropriate policy response, at both the infrastructure level and the application level, and communicate to stakeholders.

DRF SECURITY: DRF shall provide a secure environment that supports (1) mechanisms to identify the cyber risks, vulnerabilities and weaknesses of the environment, (2) secure data exchange and service interactions by maintaining secure data integrity, system resiliency and information privacy, (3) mechanisms for monitoring and detecting malicious or abnormal behavior and (4) effective countermeasures needed to take regarding a detected cybersecurity or physical event.

Phase II – Accomplishments



Phase II – Accomplishments

Roles Team - Community Engagement (Local Governments)



- After conducting ~15 stakeholder interviews in Phase I, the DRF team identified a gap in its data gathering related to local government stakeholder representatives
- Through interviews, the DRF team gathered information from a variety of local governments regarding their data needs, priorities, collaborations, and the role of NASA in AAM data exchange
- Local governments will be vital stakeholders due to their role in data usage for advanced air mobility (AAM) planning, operations and airspace performance assessments

Approach:

- For Phase II, held interviews with local government representatives (10)
 - A combination of city governments (4), state governments (4) and non-profit organizations (2) that represent multiple cities
 - Interview Technique: Structured phone Interviews with standardized questions and time for discussion



Interviews of state and local government use of data and analytics found:

- Many types of data are being collected, especially on surface traffic
- Many disparate and sometimes home-built data systems exist, with little connectivity across governments (e.g. local-to-state)
- Inter-modal connectivity, both with data and people, is of great interest, but only in early stages of implementation
- Some governments are beginning to collect and connect new modes of transportation (e.g. scooters)
- While seeing the AAM revolution on the horizon, very few (if any) have documented plans to incorporate aviation data as yet and many under-estimate the regulatory environment of aviation



Key Findings from Interviews with Local Community Stakeholders

- Safety is the highest priority
- Privacy introduces complex issues
- Use of advanced data techniques (e.g. AI/ML) is sparse but evolving
- While some standards and sharing exists, they are sporadically applied in many cases
- NASA is seen as an honest broker, for which state and local governments are looking to for AAM development

DRF needs to establish an ongoing community engagement practice and prototype assessment with local communities, as key stakeholders, data providers and users.

Phase II – Accomplishments - Communications



- Summarized communication requirements and needs of DRF core components.
Related key assumptions:
 - End-to-end communication system must support edge, cloud and physical data requirements
 - Air-to-ground / Ground-to-air communication link will be bandwidth constricted
- Identified stakeholders & listed needs / expectations
- Defined DRF required networking & wireless characteristics
- Identified metrics to assess experiment / test results
 - Transaction Time
 - Continuity
 - Availability
 - Integrity



Phase II – Accomplishments - Communications



- Summarized existing designs & identified shortcomings
 - o No current community accepted aeronautical wireless communication solution. Terrestrial solutions not necessarily applicable
 - o Technology being developed to meet terrestrial 5G performance goals is diverging from compatibility with aeronautical usage
 - o Interference from other users, not link margin, is the limiting factor for aero communications
 - o Aircraft dynamics (attitude) will impact communications performance

Wireless communications will have timing, latency, bandwidth, and availability constraints. DRF must be designed to operate securely, efficiently and safely, accounting for these constraints.



Take-Aways from DRF Phase-II



Refined the benefits DRF brings to private industry and stakeholders as a common good, justifying NASA's continued pursuit of this research

Developed tenets of operations, which helped to define initial requirements for the DRF architecture

Identified aspects of DRF that can leverage existing technology development across the relevant technology spaces

Developed recommendations for a DRF minimum viable product and stakeholder practices

Desirability

Opportunity holds demonstrated value to stakeholders

- Alignment with ARMD Mission
- Market Analysis
- Handoff / Infusion Path



Desirability - Alignment with ARMD Mission

- The NASA Aeronautics Strategic Implementation Plan provides the NASA Aeronautics Research Mission Directorate (ARMD) vision for the next 25 years and beyond.
- It encompasses investigating a broad range of technologies to meet future needs of the aviation community, the Nation, and the world for safe, efficient, flexible, and environmentally sustainable air transportation.
- ARMD organizes its research portfolio around six Strategic Thrusts, which represent ARMD's prioritization of aeronautics objectives
- DRF aligns with three of the six ARMD Strategic Thrusts
 - Strategic Thrust 1: Safe, Efficient Growth in Global Operations
 - Strategic Thrust 5: In-Time System-Wide Safety Assurance (ISSA)
 - Strategic Thrust 6: Assured Autonomy for Aviation Transformation

Desirability - Alignment with ARMD Mission

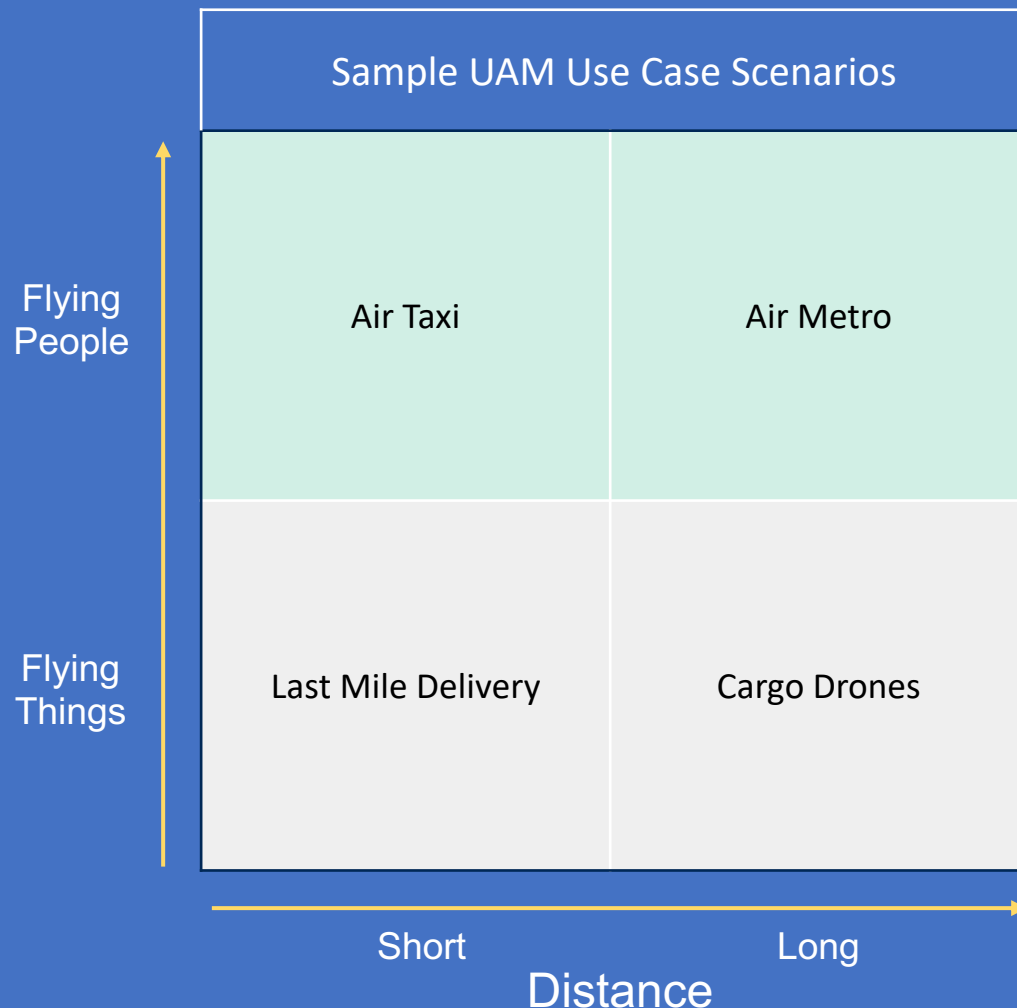


- Strategic Thrust 1: Safe, Efficient Growth in Global Operations
 - ARMD will work with the emerging UAM ecosystem, developing concepts to enable a safe, scalable system for the growth of this new transportation sector.
 - DRF will support the ARMD strategy by enabling the reasoning services, required to scale UAM operations to the UML-6 vision
- Strategic Thrust 5: In-Time System-Wide Safety Assurance (ISSA)
 - ISSA is a safety net that utilizes system-wide information to provide alerting and mitigation strategies in time to address emerging risks. Aviation safety needs to take advantage of modern information availability and intelligent systems.
 - Within UAM environments, DRF will build a marketplace that provides access to data, information and reasoning, in support of advanced air mobility operation, including aviation safety
- Strategic Thrust 6: Assured Autonomy for Aviation Transformation
 - Ever-increasing levels of automation and autonomy are transforming aviation, and this trend will continue to accelerate. ARMD will lead in the research and development of intelligent machine systems capable of operating in complex environments
 - In order to enable the vision for UML-6, reasoning services will be required to help humans guide advanced air mobility operations. The reasoning services enabled by DRF will help improve automation and autonomy for advanced air mobility operations

Desirability - Market Analysis



Participants roles and interactions within the UAM ecosystem are defined by two overarching use cases



Flying people are use cases that move humans from point to point. Use cases include but are not limited to:

- Air Taxis
- Air Metro
- Personal Vehicles

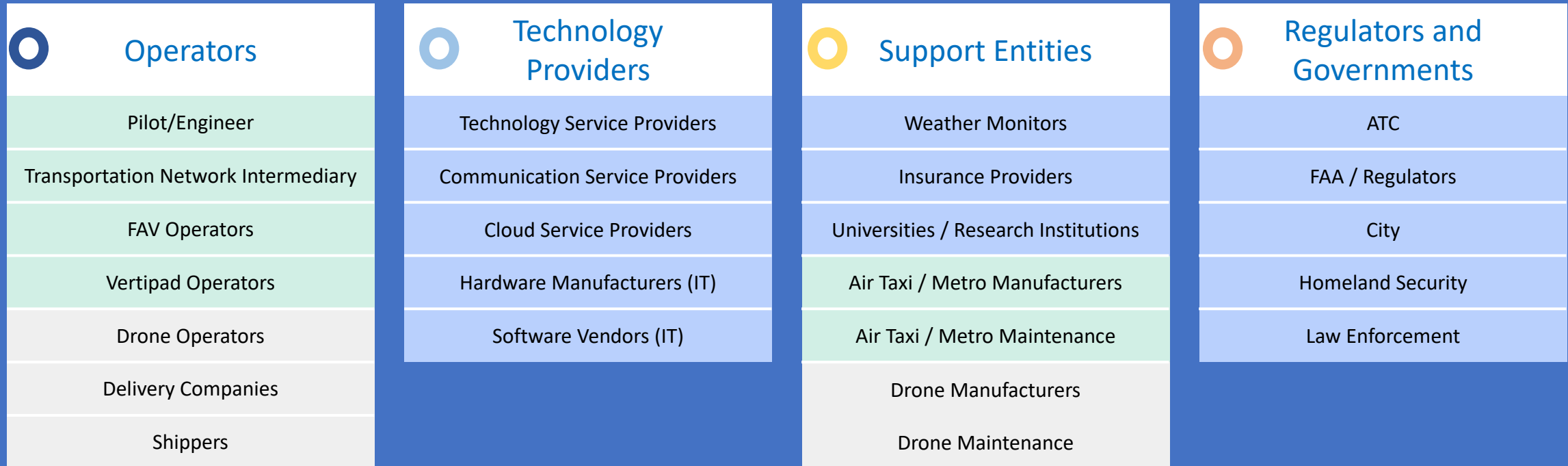
Flying things are use cases that represent the use of unmanned drones. Use cases include but are not limited to:

- Last-Mile Delivery
- Public Safety
- Recreational / Personal / Hobbyist

Desirability - Market Analysis



DRF stakeholders are categorized into four primary UAM responsibility groups

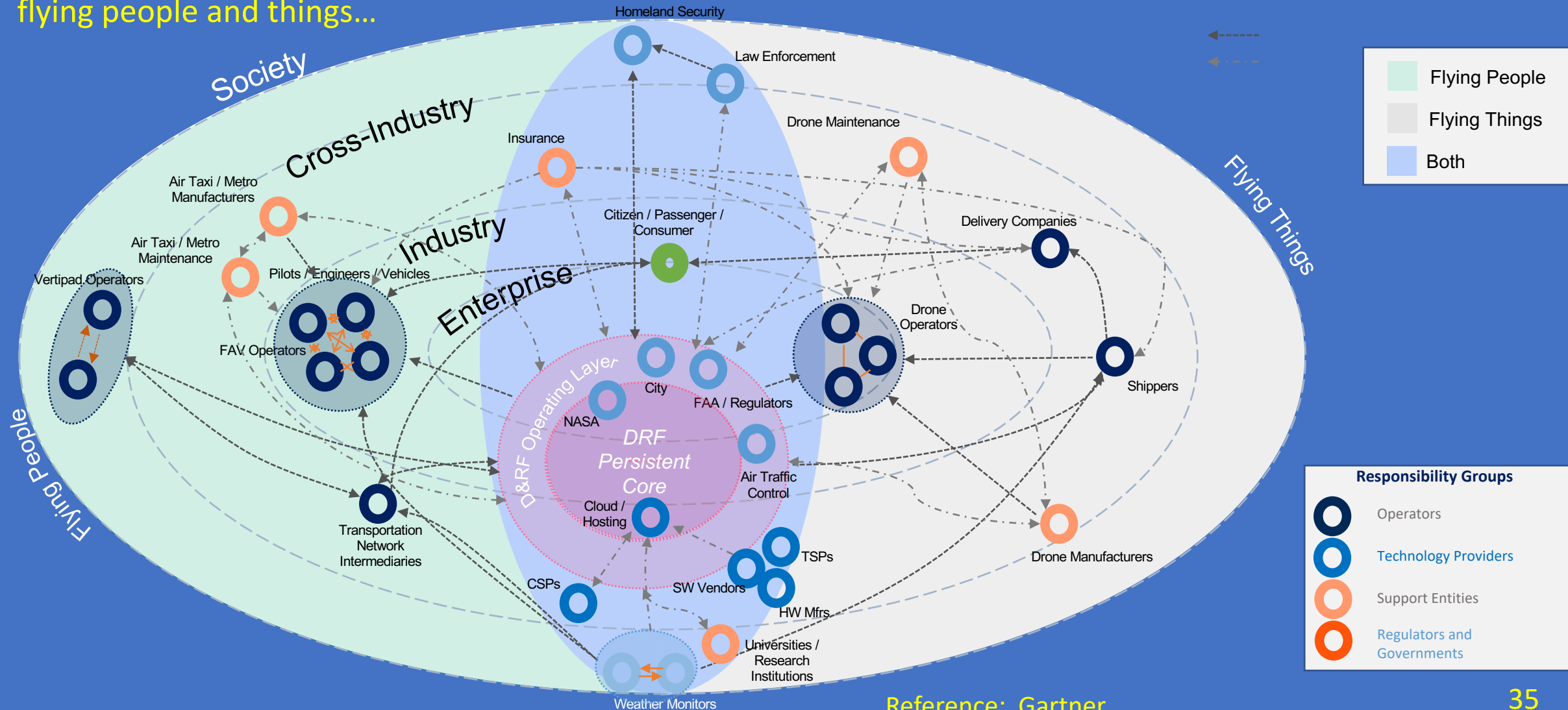


■ Flying People ■ Flying Things ■ Both

Desirability - Market Analysis



The ecosystem is comprised of a set of actors with evolving value relationships supporting use cases of flying people and things...



Reference: Gartner

Desirability - Market Analysis



Five barriers must be overcome before a widespread data and reasoning fabric can be adopted

Lack of data standardization

Mobility service data standards either do not yet exist (e.g., digital ridehail and car-share) or are incomplete (e.g., fixed-route transit)

Poor quality and incomplete data

Service availability information may be inaccurate, missing, infrequently published or unavailable digitally (e.g., vehicle location, fare data, or park-and-ride information)

Interoperability not designed into the system

Some legacy systems may still be used, and integration / interoperability was not considered when they were designed (e.g., booking and payment processing that spans modalities)

Lack of economic incentives

Private enterprises have an incentive to pursue a walled garden approach when possible (e.g., might not allow their real-time service data to be shown alongside competitors)

Inability to switch between different service providers

Personal preference data is often closely guarded by a single entity and cannot be shared with / switched to another service provider



Increased Barriers to Entry
Increased Cost
Decreased Competition
Stagnation

Desirability - Market Analysis



NASA should invest in the opportunity to shape and define the UAM Data & Reasoning Fabric ecosystem through recommendations, influence, and enablement activities

Ecosystem Overview

The Urban Air Mobility ecosystem is still in its infancy and the roles of its actors are still being defined; gaps exist within the ecosystem that can be addressed by the widespread deployment of a data & reasoning fabric

DRF Structure and Adoption

The DRF could support a door-to-door journey at full scale, but its architecture will need to be defined, gaps will need to be filled, and multiple barriers will need to be overcome before it can be fully deployed and adopted

NASA's Impact

NASA's impact on the overall ecosystem will be beneficial, though a robust assessment of growth by actor and industry vertical should be done to define the business case before pursuing any specific role

NASA's Role(s)

NASA can play several key roles to enable and grow the overall UAM ecosystem from a data and analytic governance, coordination, and orchestration standpoint

Desirability - Handoff / Infusion Path



	FY21-22	FY23-FYXX	FYXX+1 and beyond
Customer	TACP/CAS	ARMD (Mission Program)	Air Mobility Community Customers
Stakeholders	ARMD Air Mobility Community Stakeholder	ARMD Air Mobility Community Stakeholders	Air Mobility Community Stakeholders
End User	Air Mobility Community Beachhead User(s)	Air Mobility Community 2 nd Wave User(s)	Air Mobility Community Users
Potential Collaborators	ARMD Projects Companies with parallel domain and/or technology R&D/prototype interests	ARMD Projects Companies with parallel domain and/or technology demonstration interest	NASA/ARMD Activity Complete
Potential Commercial Carry Forward		DRF-related early MVP commercial investments	DRF-related service providers – standards, infrastructure, data & reasoning services, and air mobility services

MVSC Customer/Stakeholder/User Refinement for ARMD Context:

- Customer: Pays for product (prototypes)
- Stakeholder: Expresses priorities to Customer regarding Desirability
- End User: Uses product, final assessor of Viability & Feasibility

Viability

Realistic 'business' path forward

- Community Acceptance
- Regulatory Considerations

Viability - Community Acceptance



Community acceptance of DRF will be indirect and will depend on how the public experiences AAM

Safety

Longstanding expectation for safety in air transport will extend into AAM

Enabled by underlying DRF technologies for consistent, clear, secure, and timely exchange of data and reasoning services

Equitable Access

Expectation for more than just a net benefit to society

No community should suffer the detrimental impacts that other communities' benefits may cause

Environmental and Social Impacts

DRF should support AAM in creating a positive impact for the environment and for the vast majority of stakeholders, enabling affordable high-scale and high-density operations of diverse mission types.

Facilitated by the application-agnostic nature of DRF enabling increase in scale, capability, and reach of AAM operations over time

DRF's inherent extensibility and flexibility will facilitate continuous learning and improvements to address community expectations as we gain experience with AAM

Viability - Regulatory Considerations



DRF will assist regulators in balancing public interest/safety with the pressure to improve the technologies driving the airspace system

Building Safety Cases

DRF offers the mechanisms to provide necessary (meta)data and conduct follow-on analysis on system conditions to support building safety cases

Management and Oversight of Ongoing Operations

DRF provides the framework and tools to establish data monitoring and collection protocols, and enables systems to be built on top of DRF that serve this mission requirement for regulators

Maintaining and Monitoring of Policies and Procedures

Through its policy framework, the DRF enables regulators to create, maintain, and monitor operating policies across the airspace system. DRF's extensible foundation of defined policies that propagate across systems and drive prescribed behavior enable policy changes to be quickly and accurately reflected across the airspace system

The purposeful, consistent, and extensible approach behind DRF enables regulators to make decisions that address the wellbeing of the broader stakeholder community

Feasibility

Technically appropriate and aligned to NASA

- NASA Appropriate (Why NASA?)
- Technical Approach
- Use Cases
- Minimal Viable System Concept

Feasibility - NASA Appropriate (Why NASA?)



- NASA is perceived as having the capability of listening to the concerns of all the market segments, including digesting complex technical considerations related to:
 - o Air vehicle constraints, performance, and operations
 - o Vehicle sub-systems (specifically, onboard avionics, autonomy software/hardware, communications),
 - o Communications (to/from vehicle, edge, and ground/cloud),
 - o Ground infrastructure design (such as airports, heliports, and vertipads)
 - o IT technologies (ranging from required data sources, to software and security architectures, to reasoning services).

Feasibility - NASA Appropriate (Why NASA?)



- NASA Collaboration Experience
 - NASA has decades of positive experience collaborating with elements of each of the DRF-related market segments
 - NASA needs to make extraordinary efforts to engage and stay engaged with the major companies in these areas.
 - Since conception, DRF has recognized this challenge and has taken steps to include team members with recent (or current) industry experience and contacts.
 - The DRF team has also made an extraordinary effort to engage with local governments as they are key to achieving advanced urban air mobility.
- NASA Neutral Broker Reputation
 - NASA is perceived as being a neutral broker capable of arriving at and proposing for community considerations DRF standards, protocols, and governance models to provide the optimal benefit to small-to-large members of all market segments, relevant government organizations, and academia.
 - This is not a technical skill per se, but a perceived attribute of NASA which allows it to perform functions, critical to DRF success, that no other organization can perform.

Feasibility - Technical Approach



Community Engagement

Work with the community through workshops, working groups and interviews, in order to refine representative use cases that can be used to validate DRF concepts



DRF Software

Develop a prototype implementation of the DRF framework and capabilities, in order to enable the rapid deployment of candidate data and reasoning capabilities



Data Services

Develop and functionalize data services and metadata models for DRF data life cycle



Reasoning Services

Leverage DRF Core and data services to develop AI/ML reasoning service demonstration cases

Feasibility – Use Cases



In order to guide the development of data models and reference reasoning services, an initial use case was developed.

- Before establishing a use case, we outline the emergency scenario that provides the backdrop for arriving at a relevant use of UAM assets that will exercise all the facets of the DRF and UML-6 characteristics.
- An emergency large-scale earthquake scenario and associated conditions were chosen so that they impact a large region, affecting a sizable population, and offer different types of mission response needs.



In this scenario, the general public would greatly benefit from the DRF framework to call upon UAM vehicles, operators, smart entities, and reasoning capabilities to offer solutions to the problem set

Feasibility – Use Cases



- The disaster scenarios and the corresponding use cases are designed to exercise the four technical areas that make up the DRF framework:
 - o Data services
 - o Reasoning services
 - o Communication needs
 - o Overall DRF system architecture
- The chosen use case for illustrating the DRF will focus on the movement of people from impacted region to a safe area where services can be rendered
- The use case has the following Operational Actions
 - Surveillance into critical zone identifies persons in need of immediate air evacuation
 - Emergency responders call on UAM operators for aerial evacuation
 - UAM operators respond to multiple rescue requests, deploying 100's of vehicles to various sites
 - Vehicles fly to assigned destinations
 - Vehicles take-off and fly back to designated mobile bases for evacuees
- Based on the Operational Actions, initial reasoning requirements have been developed

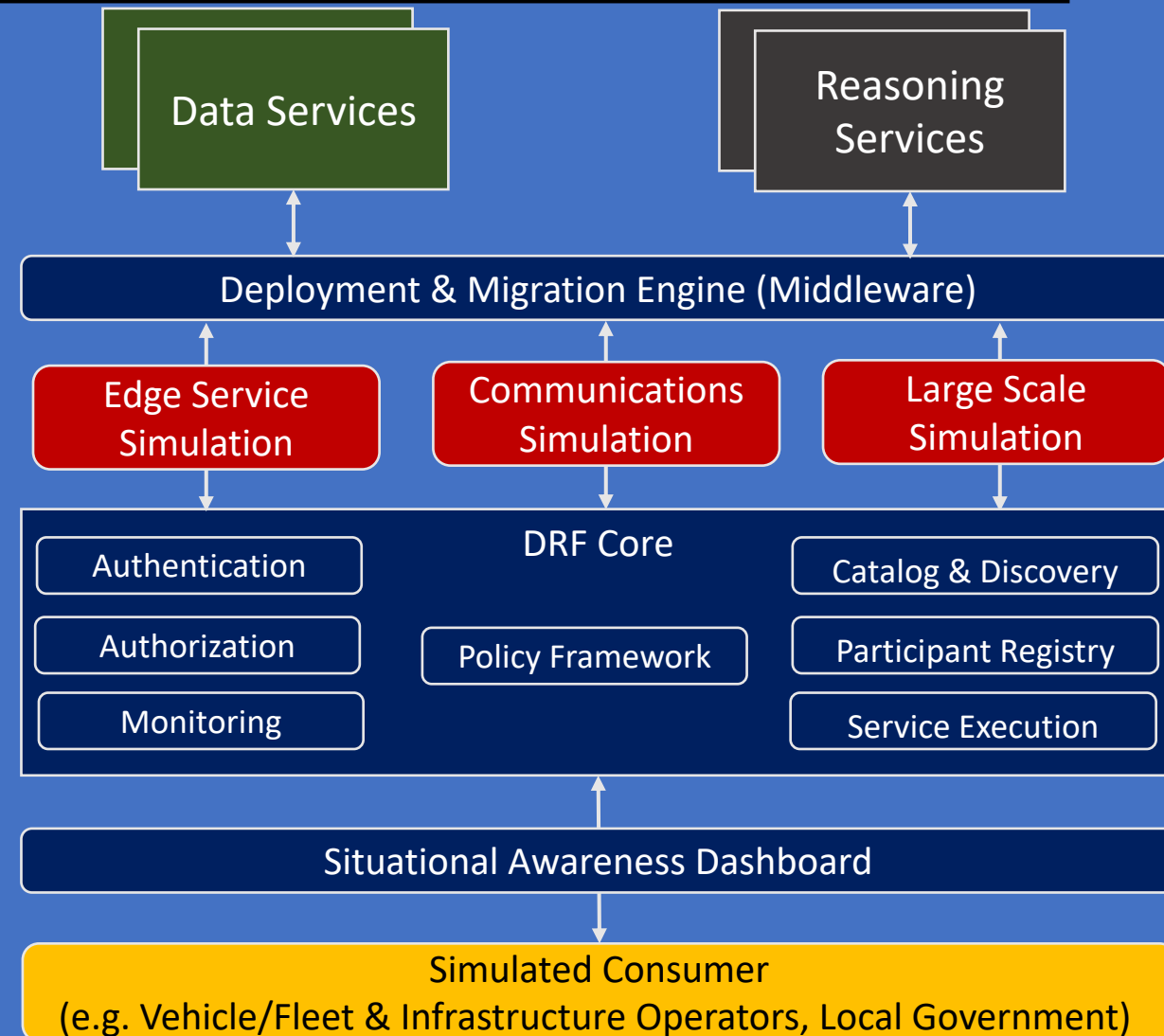


Minimal Viable System Concept – DRF Accelerator

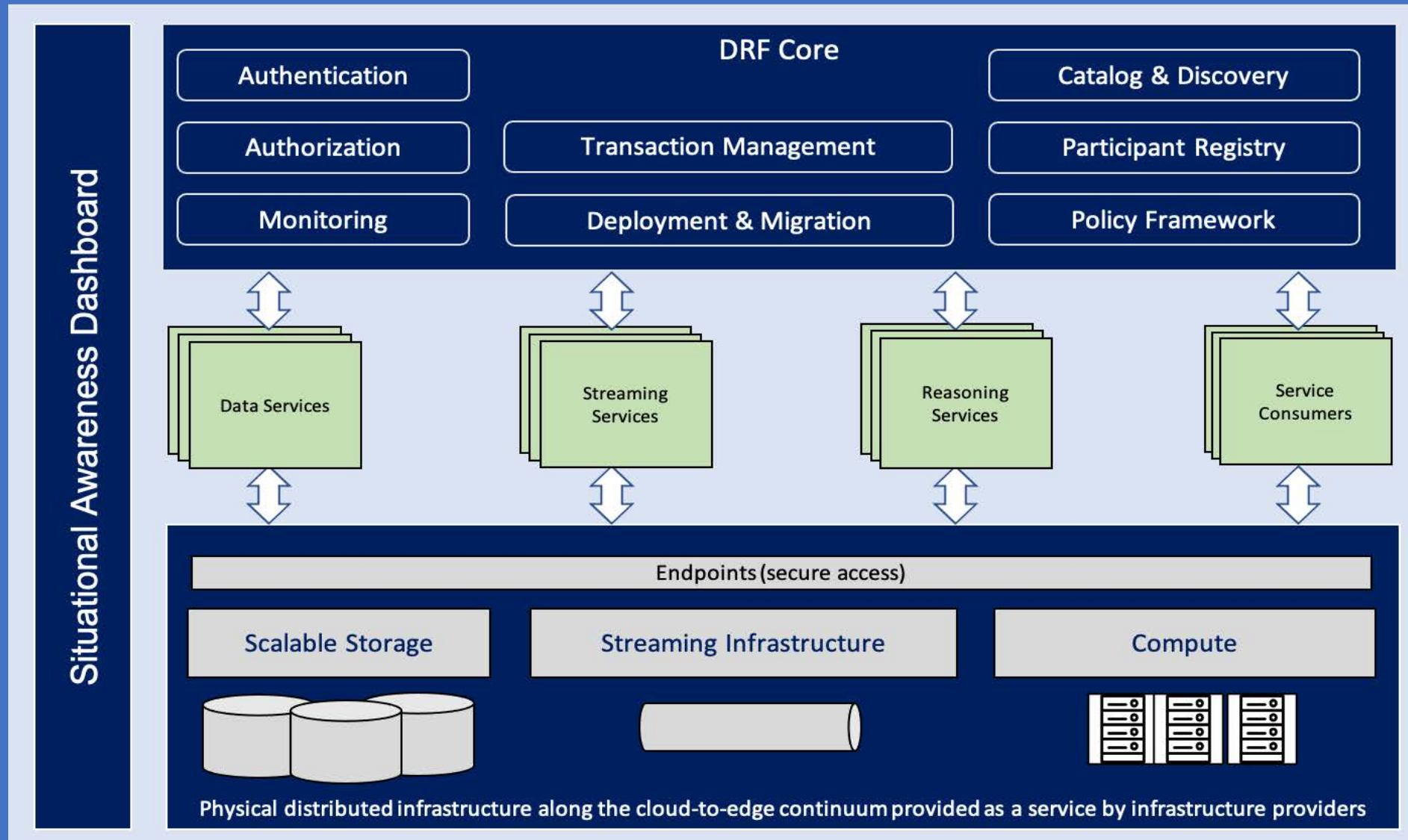


- Work with community stakeholders to refine the use cases that are used to evaluate the DRF and understand requirements needed to support advanced mobility
- Deliver DRF Accelerator
 - DRF Framework
 - DRF Core
 - Situational Awareness Dashboard
 - DRF metadata models and ontology
 - Reference data services
 - Reference reasoning services
 - Simulator
- Deliver a set of community best practices required to make the DRF successful

The DRF framework, data services and reasoning services will guide software development kits (SDK), with associated application program interfaces (API)



Minimal Viable System Concept – DRF Accelerator



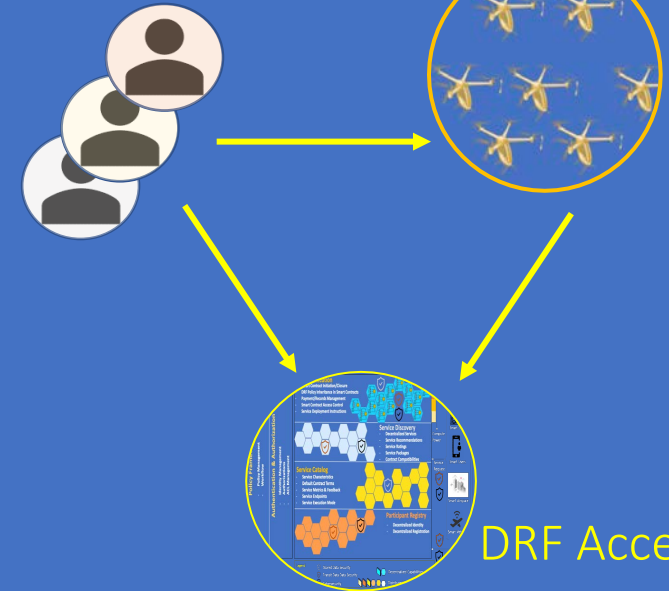
MVSC - Stakeholder Engagement and Use Case Refinement



- Stakeholders include external service providers and community stakeholders (local and city governments) and industry
- Work with stakeholders to refine the use cases, which will be leveraged to validate the DRF
- Engage with both government and industry:
 - o Assess the feasibility of the product
 - o Assess likelihood of DRF adoption
 - o Identify what data and services can be shared across the DRF

Stakeholder
Engagement

Use Cases



DRF Accelerator



Police

Fire



Medical



Utility



Business



Government



Citizens

Smart Airspace



Smart City



Smart Vehicles



Smart Entity





MVSC - Stakeholders Practices

- Engagement With Local Governments
 - o Based on candidates from Phase I, refine the nominal and emergency use cases, which will be leveraged to evaluate the DRF
 - o Identify the data is required to support local advanced air mobility
 - o Identify the data that can be shared across the DRF
 - o Instantiate and test the features of a DRF, in collaboration with local governments
 - o Determine what metrics should be used to quantify adoption success
- Standards and Regulation Monitoring
 - o Monitor standards related to communications that are applicable to advanced air mobility
 - o Monitor FAA plans and regulations related to advanced air mobility



MVSC - Stakeholders Practices

- Industry Collaborations

- o Refine the features of the DRF that would enable an advanced air mobility data marketplace
- o Instantiate and test the features of a DRF, in collaboration with industry partners
- o Identify and instantiate what data and services can be shared across the DRF MVBP
- o Finalize the technology stack needed to support the MVBP and monitor evolving technologies that are applicable to the DRF
- o Identify the characteristics of communications networks within urban environments



Disciplined Entrepreneurship

Why “Disciplined Entrepreneurship” Process for DRF



The DRF opportunity has unique complexities:

Success is characterized by facilitating the emergence of a self-sustaining commercial DRF marketplace with appropriate academic and government roles. This is a more outward-facing opportunity than, for example, maturing a technology for eventual use on/in a NASA mission or by government partner.

DRF can best succeed by having an in-depth understanding of the relevant commercial IT and aerospace technologies and trends. The focus of DRF is on the viability of a technology stack to provide an increasing and relevant capability for advanced air operations, with individual technology layers being swapped in/out as the foundational IT technologies rapidly progress.

These unique complexities require a formulation process that:

- Focuses on NASA priorities, but is informed by a deep understanding of commercial practices, priorities, technologies, and trends.
- Is understood by industry, as there needs to be extensive ongoing dialog with industry using term and processes common in industry.

Entrepreneurship processes meet these needs:

- There are many, mostly hosted by major universities, such as MIT, Stanford, and UC Berkeley.
- The MIT Disciplined Entrepreneurship process is among the best documented with an impressive history of MIT success:
 - MIT alumni have started over 25,000 companies (900 per year), employ 3+ million people, with annual revenue of ~\$2 trillion.

Disciplined Entrepreneurship Themes

- ### Key characteristics on the Disciplined Entrepreneurship Process:

-

Source: Aulet, Bill, *Disciplined Entrepreneurship: 24 Steps to a Successful Startup*, Wiley, 2013, p. 12



Disciplined Entrepreneurship – The 24 Steps in 6 themes

DE Themes

Who is your customer?

What can you do for your customer?

How does your customer acquire your product?

How do you make money off your product?

How do you design and build your product?

How do you scale your business?

Step 1: Market Segmentation

Step 2: Select a Beachhead Market

Step 3: Build an End User Profile

Step 4: Calculate the Total Addressable Market(TAM) Size for the Beachhead Market

Step 5: Profile the Persona for the Beachhead Market

Step 6: Full Life Cycle Use Case

Step 7: High-Level Product Specification

Step 8: Quantify the Value Proposition

Step 9: Identify Your Next 10 Customers

Step 10: Define Your Core

Step 11: Chart Your Competitive Position

Step 12: Determine the Customer's Decision-Making Unit (DMU)

Step 13: Map the Process to Acquire a Paying Customer

Step 14: Calculate the Total Addressable Market Size for Follow-on Markets

Step 15: Design a Business Model

Step 16: Set Your Pricing Framework

Step 17: Calculate the Lifetime Value (LTV) of an Acquired Customer

Step 18: Map the Sales Process to Acquire a Customer

Step 19: Calculate the Cost of Customer Acquisition (COCA)

Step 20: Identify Key Assumptions

Step 21: Test Key Assumptions

Step 22: Define the Minimum Viable Business Product (MVBP)

Step 23: Show That “The Dogs Will Eat the Dog Food”

Step 24: Develop a Product Plan

Disciplined Entrepreneurship Process Tailoring for DRF

The NASA DRF team learned and then tailored the MIT 24-Step Disciplined Entrepreneurship (DE) process to this assessment. Key aspects of this tailoring involves:

- o Phase I: Emphasis on customer discovery and value creation

- *Using a combination of steps 1, 3, 7, 10, 20, and 22 from the Disciplined Entrepreneurship process*

Why we need DRF?

- o Phase II: Focus on customer acquisition and minimum viable business product identification

- *Using a combination of steps 5, 9, 12, 20*, and 22* from the Disciplined Entrepreneurship process*

What should DRF look like?

- o Phase III: Target on market economics, business model, and product plan

- *Using a combination of steps 7*, 8, 9*, 15, 21, 23, and 24 from the Disciplined Entrepreneurship process.*

How to enable a DRF?

**Revisited steps between phases*



Disciplined Entrepreneurship Approach in Phase I



MIT 24-Step DE Process

Who is your customer?

1. Market Segmentation
2. Select a Beachhead Market
3. Build an End User Profile
4. Calculate the TAM Size for the Beachhead Market
5. Profile the Persona for the Beachhead Market
9. Identify Your Next 10 Customers

What can you do for your customer?

6. Full Life Cycle Use Case
7. High Level Product Specification
8. Quantify the Value Proposition
10. Define Your Core
11. Chart Your Competitive Position

How does your customer acquire your product?

12. Determine the Customer's Decision-Making Unit (DMU)
13. Map The Process to Acquire a Paying Customer
18. Map the Sales Process to Acquire a Customer

How do make money off your product?

15. Design a Business Model
16. Set Your Pricing Framework
17. Calculate the Lifetime Value (LTV) of an Acquired Customer
19. Calculate the Cost of Customer Acquisition (COCA)

How do you design and build your product?

20. Identify Key Assumptions
21. Test Key Assumptions
22. Define the Minimum Viable Business Product (MVBP)
23. Show That "The Dogs Will Eat the Dog Food"

How do you scale your business?

14. Calculate the TAM Size of Follow-On Markets
24. Develop a Product Plan

LEGEND:

Useful for NASA opportunity assessment
May be useful for NASA project formulation
Profit Focused

NASA Opportunity Assessment Process

Selected Step from the DE Process

1. Market Segmentation
3. Build an End User Profile
7. High Level Product Specification
10. Define Your Core
20. Identify Key Assumption
22. Define the MVBP

Tailored Approach Used to Carry Out the Step

- Used prior knowledge of ATM and UTM
- Stakeholder interviews & summarization
- Based on stakeholders' technology pull
- Assessment of NASA capabilities
- Used market studies and advisor notes
- Identification of 5 product definition thrusts (role, data, software, reasoning, and comm.)

Note:

- Both step 6: Full Life Cycle Use Case and step 7: High Level Product Specification are useful for NASA opportunity assessment. In our study, we referred to UTM and UML 4 as the starting points and then assessed the efficacy of DRF enabling UML 6 / Vision 2045 from these starting points. As there has been substantial work already done in the UTM, including discussions on potential use case, our emphasis was primarily on the high level product specification for DRF that would pave the pathway from UML 4 to UML 6 / Vision 2045. In this regard, the Steps 6 and 7 were exercised in conjunction.
- Similarly, we combined the step 10: Define Your Core and step 11: Chart Your Competitive Position, with the notion that NASA is not a competitor rather a facilitator for DRF, in which case much of the competitive position charting would essentially refer to NASA's core capabilities in ensuring the establishment and functioning of a reliable, inclusive, and efficient DRF.

Disciplined Entrepreneurship Approach in Phase II



MIT 24-Step DE Process

Who is your customer?

1. Market Segmentation
2. Select a Beachhead Market
3. Build an End User Profile
4. Calculate the TAM Size for the Beachhead Market
5. Profile the Persona for the Beachhead Market
9. Identify Your Next 10 Customers

What can you do for your customer?

6. Full Life Cycle Use Case
7. High Level Product Specification
8. Quantify the Value Proposition
10. Define Your Core
11. Chart Your Competitive Position

How does your customer acquire your product?

12. Determine the Customer's Decision-Making Unit (DMU)
13. Map The Process to Acquire a Paying Customer
18. Map the Sales Process to Acquire a Customer

How do make money off your product?

- 15: Design a Business Model
- 16 Set Your Pricing Framework
17. Calculate the Lifetime Value (LTV) of an Acquired Customer
19. Calculate the Cost of Customer Acquisition (COCA)

How do you design and build your product?

20. Identify Key Assumptions
21. Test Key Assumptions
22. Define the Minimum Viable Business Product (MVBP)
23. Show That "The Dogs Will Eat the Dog Food"

How do you scale your business?

14. Calculate the TAM Size of Follow-On Markets
24. Develop a Product Plan

NASA Opportunity Deep Dive Process (Phase II)

Selected Step from the DE Process

Tailored Approach Used to Carry Out the Step

- | | |
|---|---|
| 5. Profile the Beachhead Market Persona | - Understand current practice and limitations |
| 9. Identify Your Next 10 Customers | - Identify 2 to 3 early adopters and/or use cases |
| 12. Determine the Customer's DMU | - Identify initiators, influencers, deciders, & users |
| 20. Identify Key Assumptions | - Identify the resources/infrastructures that can be leveraged to enable DRF, and their future trends |
| 22. Define the MVBP | - Select one or more use cases that can sufficiently describe DRF's relevance, efficacy, and impact among its anticipated future stakeholders |

Disciplined Entrepreneurship Approach in X2



MIT 24-Step DE Process

Who is your customer?

1. Market Segmentation
2. Select a Beachhead Market
3. Build an End User Profile
4. Calculate the TAM Size for the Beachhead Market
5. Profile the Persona for the Beachhead Market
9. Identify Your Next 10 Customers

What can you do for your customer?

6. Full Life Cycle Use Case
7. High Level Product Specification
8. Quantify the Value Proposition
10. Define Your Core
11. Chart Your Competitive Position

How does your customer acquire your product?

12. Determine the Customer's Decision-Making Unit (DMU)
13. Map The Process to Acquire a Paying Customer
18. Map the Sales Process to Acquire a Customer

How do make money off your product?

- 15: Design a Business Model
- 16 Set Your Pricing Framework
17. Calculate the Lifetime Value (LTV) of an Acquired Customer
19. Calculate the Cost of Customer Acquisition (COCA)

How do you design and build your product?

20. Identify Key Assumptions
21. Test Key Assumptions
22. Define the Minimum Viable Business Product (MVBP)
23. Show That "The Dogs Will Eat the Dog Food"

How do you scale your business?

14. Calculate the TAM Size of Follow-On Markets
24. Develop a Product Plan

NASA Opportunity Assessment Process

Selected Step from the DE Process

9. Identify Your Next 10 Customers
7. High Level Product Specification
8. Quantify the Value Proposition
21. Test Key Assumptions
15. Design a Business Model
23. Show "The Dogs Will Eat the Dog Food"
24. Develop a Product Plan

Tailored Approach Planned to Carry Out the Step

- Establish collaborations with 2 to 4 potential end-users, and 2-6 data and reasoning service providers
- Prioritize specific DRF services based on use case demand
- Compare demonstrated benefits of DRF over alternatives, identify key evaluation metrics demonstrating benefits
- Confirm key assumptions through application of DRF accelerator to end user use cases
- Study exactly how to enable a self-sustaining marketplace (such as: IP protection, educating stakeholder on best DRF practices, and so on)
- DRF MVBP evaluated by external end-users/customers
- Identify the set of, for example, SDK, open source libraries, and other similar DRF-end-product plan for follow-on activities

Note:

- In addition to evaluating the technological efficacy of DRF over other contemporary capabilities, in the proposed phase III of the project focus will be put on assessing the viability of DRF as a commercial product through identifications of agile development process for continuous integration continuous delivery (CICD), technology transition pathways, and distribution channels.



DE Steps Left Out from the DRF Planning

The DE steps not included in the DRF planning and evaluation are:

- Step 4: Calculate the Total Addressable Market (TAM) Size for the Beachhead Market
- Step 13: Map The Process to Acquire a Paying Customer
- Step 14: Calculate the Total Addressable Market Size for Follow-on Markets
- Step 16: Set Your Pricing Framework
- Step 17: Calculate the Lifetime Value (LTV) of an Acquired Customer
- Step 18: Map the Sales Process to Acquire a Customer
- Step 19: Calculate the Cost of Customer Acquisition (COCA)

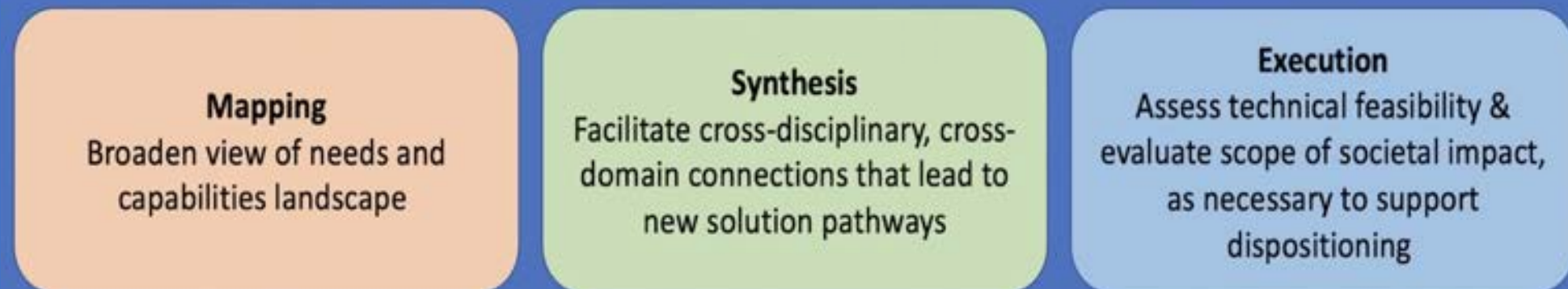
Justification:

- Steps 4, 13, 14, 16, 17, 18, and 19 are explicitly profit focused and thus they are best conducted by the for-profit entity/entities eventually taking over the commercial implementation of DRF.
- NASA's interest is primarily in the impact of DRF on the future integrated airspace operation efficiency and safety.
- Wide-scale market for DRF simply does not exist today and potential stakeholders are still evaluating their service models for advanced air mobility and corresponding market entry strategies.

NOTE: "Step 24: Develop a Product Plan" will continue from the planned phase III activity to the refinement and execution of the identified product plan beyond phase III. It is anticipated that, if Phase-III is successful, ARMD will issue an authority to plan the project, for which the foundational work done in phase III will be carried forward in the subsequent phase.

Mapping the CAS-R Lifecycle to the DE Process

- The CAS Project designed a lifecycle (process) to discover, identify, and characterize high-value system-level Opportunities for ARMD.
- The lifecycle has three core technical functions – Mapping, Synthesis, and Execution – in alignment with CAS Reimagined (CAS-R) strategies for achieving transformational change.
- Under the CAS-R lifecycle concept, DRF is identified as an Opportunity.
- The CAS-R lifecycle is envisioned as highly iterative in practice and intends to transform the Opportunity as it matures.
- The three core technical functions of CAS-R are shown in the diagram below:



Mapping the CAS-R Lifecycle to the DE Process

- Some of elements of the DE process are independent of the CAS-R process.
- The DE-specific elements focus on how to enable a DRF in a UAM environment.

	Mapping	Synthesis	Execution	DE-Specific
Approach in Phase-I 1. Market Segmentation 3. Build an End User Profile 7. High Level Product Specification 10. Define Your Core 20. Identify Key Assumption 22. Define the Minimum Viable Product	•	• •	• • •	
Approach in Phase-II 5. Profile the Beachhead Market Persona 9. Identify Your Next 10 Customers 12. Determine the Customer's DMU 20. Identify Key Assumptions 22. Define the Minimum Viable Product			• • •	• •
Approach in Phase-III 9. Identify Your Next 10 Customers 7. High Level Product Specification 8. Quantify the Value Proposition 21. Test Key Assumptions 15. Design a Business Model 23. Show "The Dogs Will Eat the Dog Food" 24. Develop a Product Plan			• • •	• • • •

DE Summary of Lessons Learned



Advantages:

DE provides a very detailed process focused on understanding and designing products to customer/market needs:

- o Very frequently found the DE process pulling the DRF Team back to gather additional information regarding:
 - Customer/market for DRF
 - Industries' perceived role of NASA related to DRF
 - IT industries ecosystems that DRF needs be aware of and make best use of
 - Aerospace/Airspace ecosystems that DRF needs to blend with

DE provides a framework and “vocabulary” for quick and in-depth engagement with industry:

- o Provides a common language - Very helpful in allowing NASA CS to understand industry processes and for NASA CS to explain ourselves to industry.

Challenges:

DE includes some steps/processes focused on assurance of a viable money-making company:

- o DRF team needed tailor these steps either by shifting measure of value to national benefit, or excluding those steps.

Recommended Future Use:

DE is a proven and detailed framework for designing products in response to customer/market needs :

- o DRF team would recommend continuing to use DE in Phase III/X2 to assure a continued focus on customer/market needs and the many industry-NASA touch points critical to DRF success.