NASA's MBSE Approach for Advanced Air Mobility

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March 8, 2022

Advanced Air Mobility (AAM) Mission

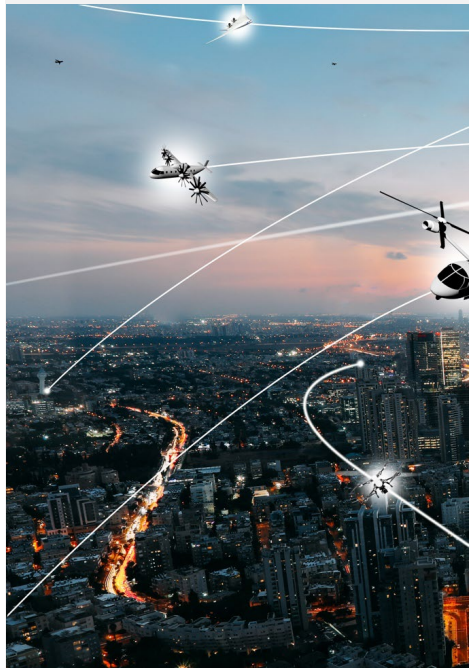
Urban Air Mobility (UAM) Maturity Levels (UML)

- UML-4 Medium Density/Complexity, Collaborative and responsible, automated systems
- UML-3 Low Density, Medium Complexity, Comprehensive safety assurance automation
- UML-2 Low Density/Complexity, Assistive automation
- UML-1 Conforming prototypes

Safe, sustainable, affordable, and accessible aviation for transformational local and intraregional applications

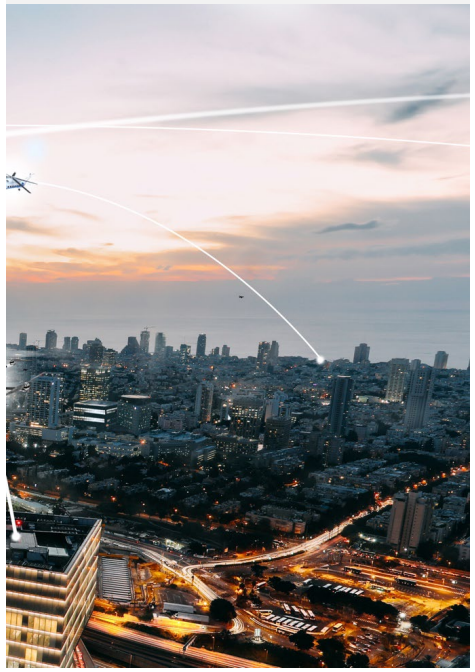
NASA Role to Address AAM Challenges

Vehicle Development and Operations



Airspace Design and Operations

Community Integration



NASA and key partners are collectively taking on the most difficult mission challenges to enable industry to flourish by 2030

- **Research and Development Portfolio**
- **Robust Ecosystem Partnerships**
- **AAM National Campaign (NC) Series**

NASA to deliver long term technical solutions and architecture requirements for industry, regulatory community

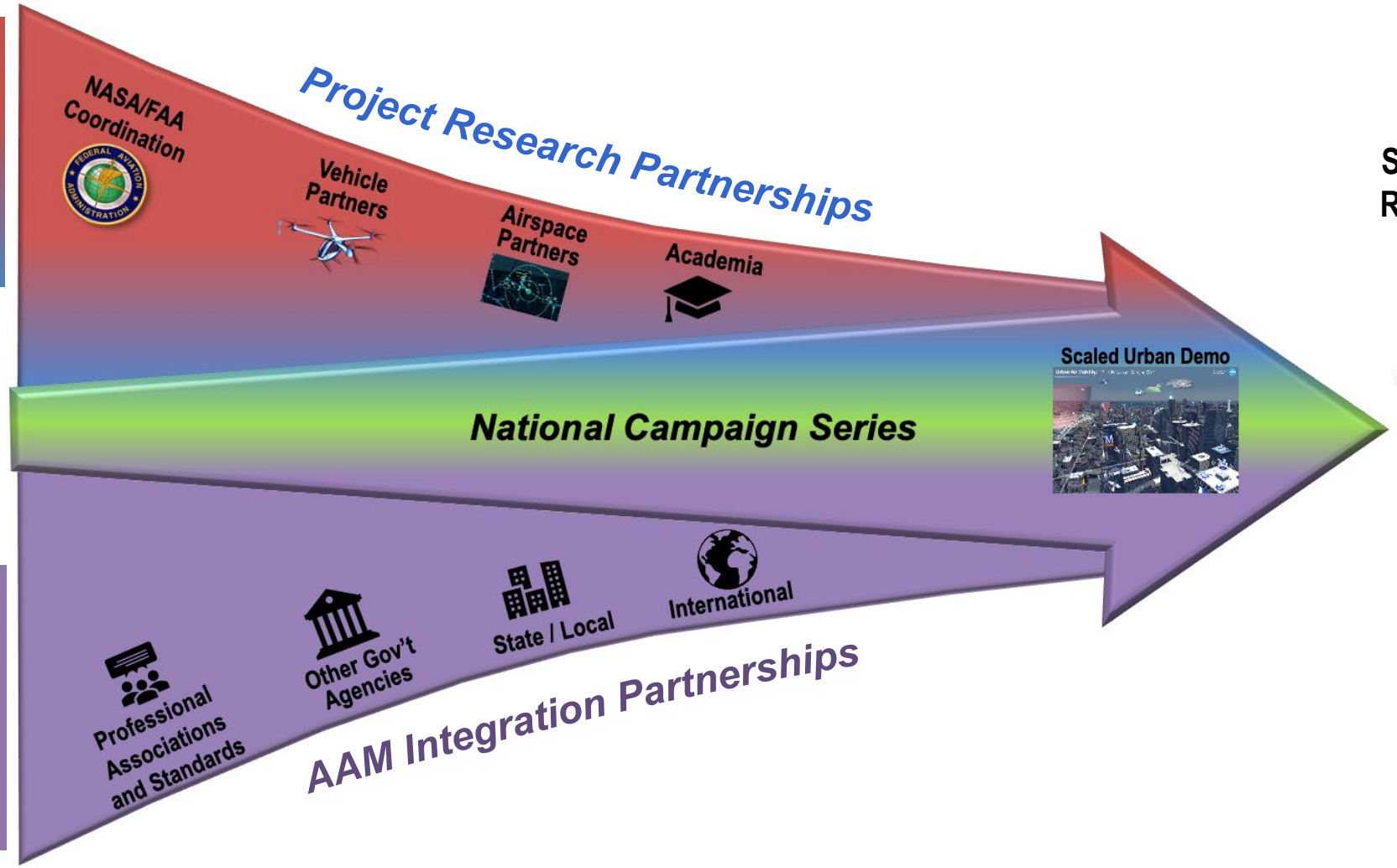
NASA AAM Ecosystem Partnership Strategy

NASA intends to establish partnerships with government, industry and academia to collaborate on the critical enabling technologies and vital research relevant to AAM.

- Foundational research partnerships in existence and developing
- NASA/FAA AAM Working Groups are beginning formal execution

- Continue to Leverage NC as a centerpiece of the partnership strategy

- AAM Ecosystem Working Groups (AEWG) are providing a valuable opportunity space for localities, international, and standards organizations



Community Outcome
System Architectures and Requirements for medium density operations

NASA must have a focused ecosystem-wide partnership strategy to enable UML-4

NASA plans to partner with Federal/State/Local authorities as well as international & professional associations to develop the policies, regulations and standards necessary to enable the UAM market.

Why is the AAM Mission using MBSE?

Model Based Systems Engineering (MBSE) is the "utilization of dynamic models to complete standard systems engineering tasks in order to visually represent system functionality and hierarchy"

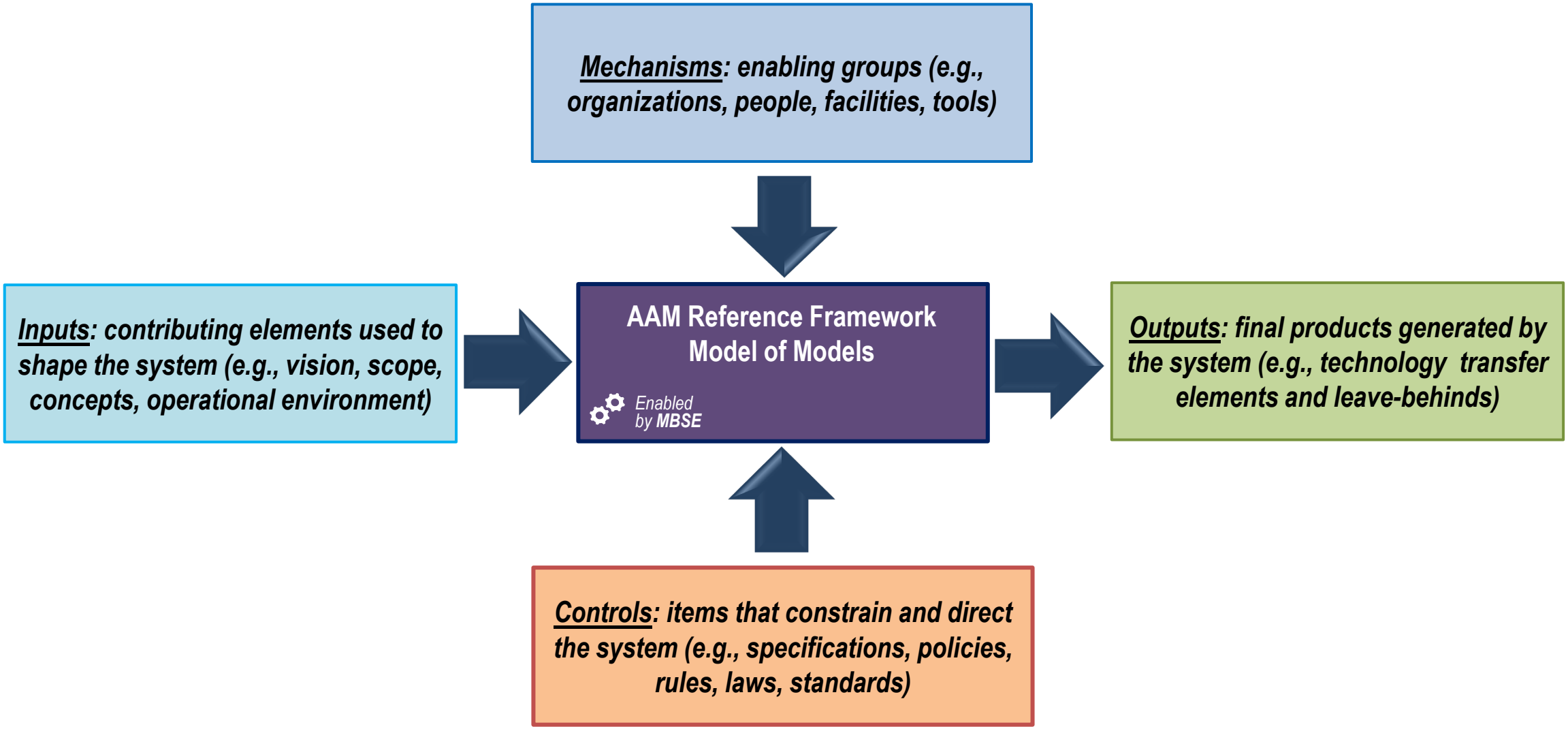
AMO Goals:

- To enable the AAM Mission by capturing, organizing, tracing, analyzing and validating representative AAM system architectures and requirements
- To grow and foster the use of MBSE practices across NASA Aeronautics

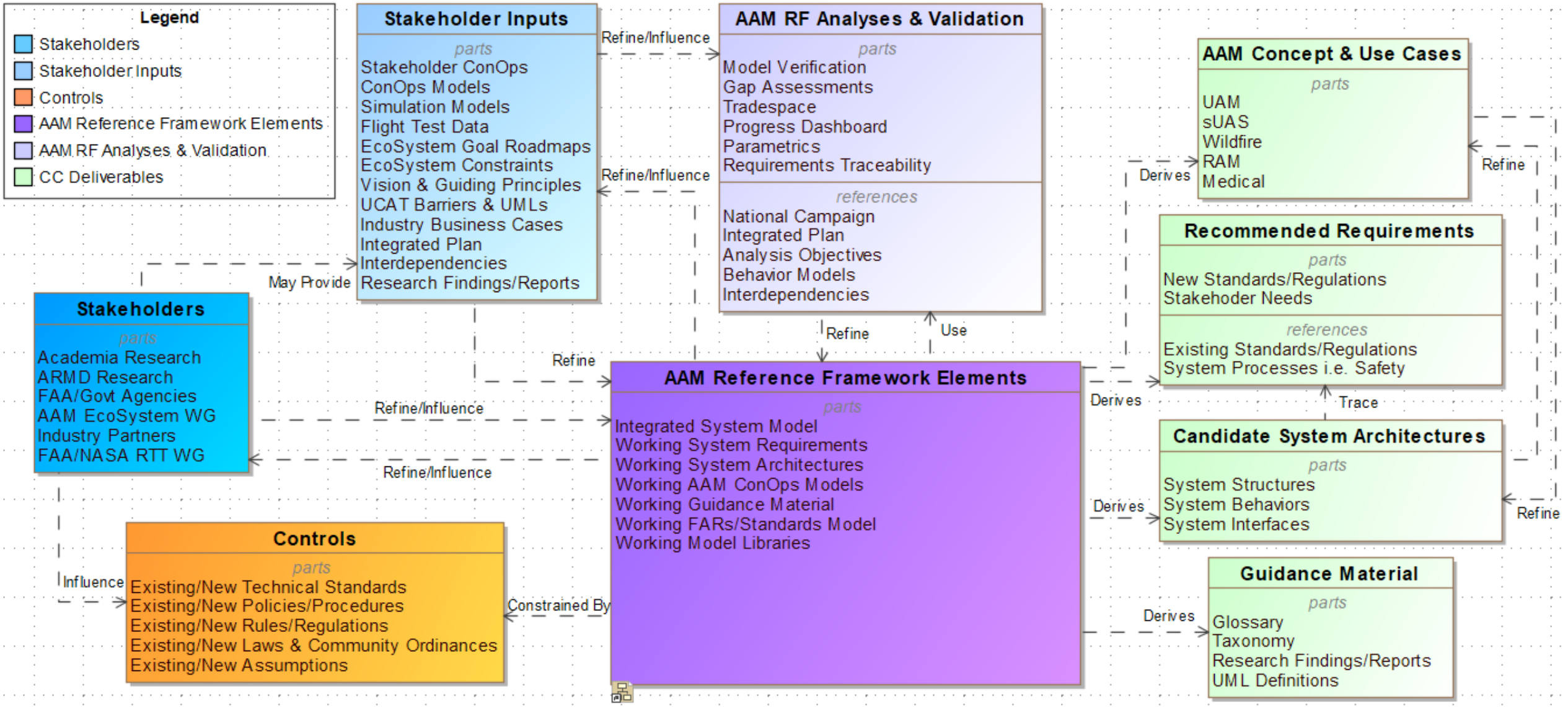
Objectives:

- Develop a centralized information database accessible by the AAM Ecosystem
- Improve ability to manage a very large and highly complex set of system concepts, architectures & reqmts
- Build a comprehensive representative AAM system architecture structure
- Capture the necessary data and requirements that define the UAM System Architecture
- Validate the AAM system architecture using research and test data
- Identify gaps in existing standards, regulations, and policies
- Improve communications and interoperability across the AAM Ecosystem
- Enable reusability of system elements that can be leveraged by other NASA Projects and external Stakeholders
- Enable scalable solutions to the problem
- Increase the use of modeling within AAM Mission Projects

AAM System Concept Meta-Model (Very High Level)

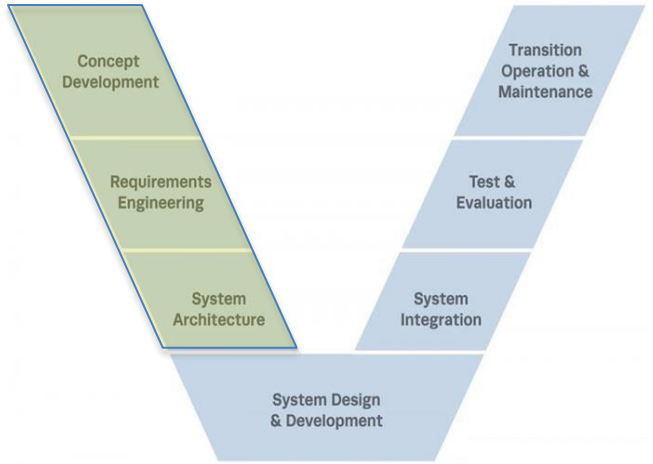


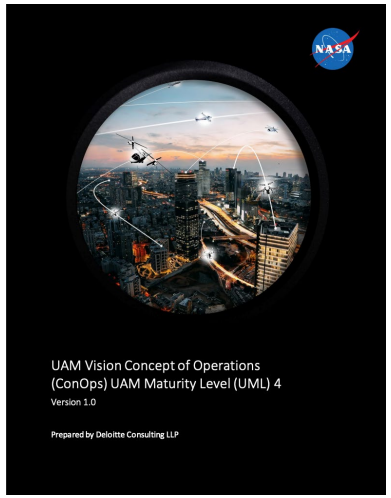
AAM System Concept Meta-Model in MBSE Format

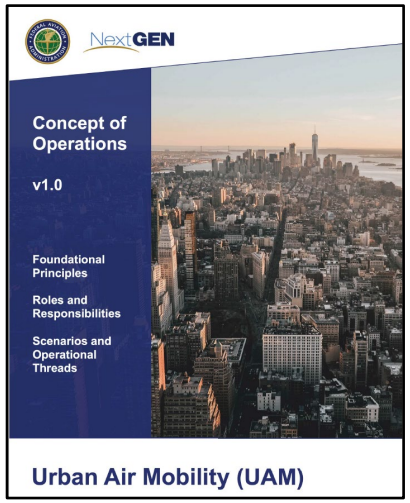


NASA UAM ConOps Modeling

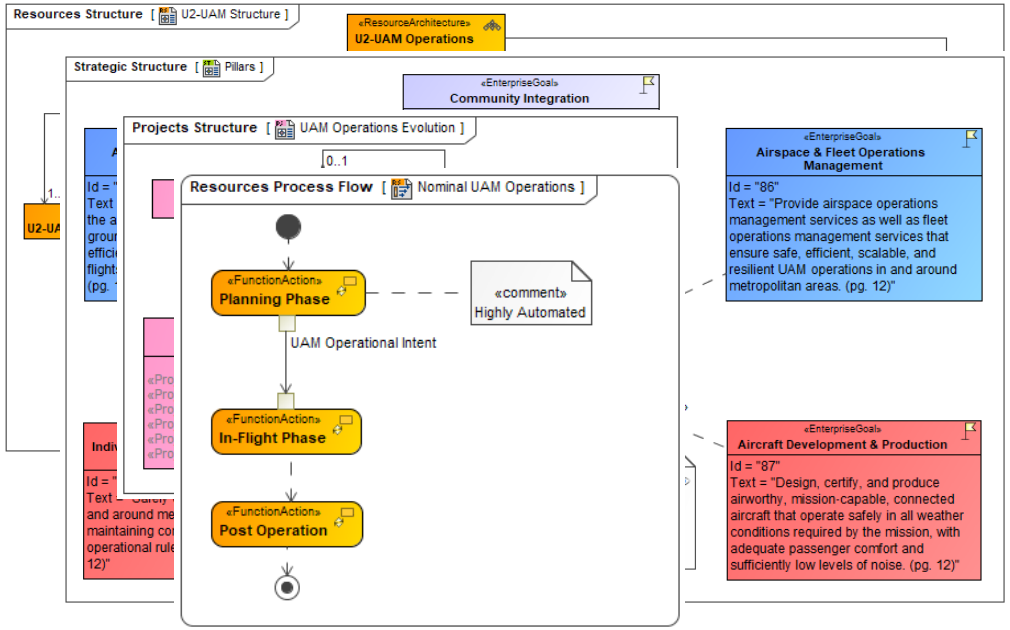
- Modeling effort started late 2020
- Working in the upper left-hand side of the Systems Engineering “V”
- Focus on commonality, reusability, and traceability through the ConOps







Document Representation

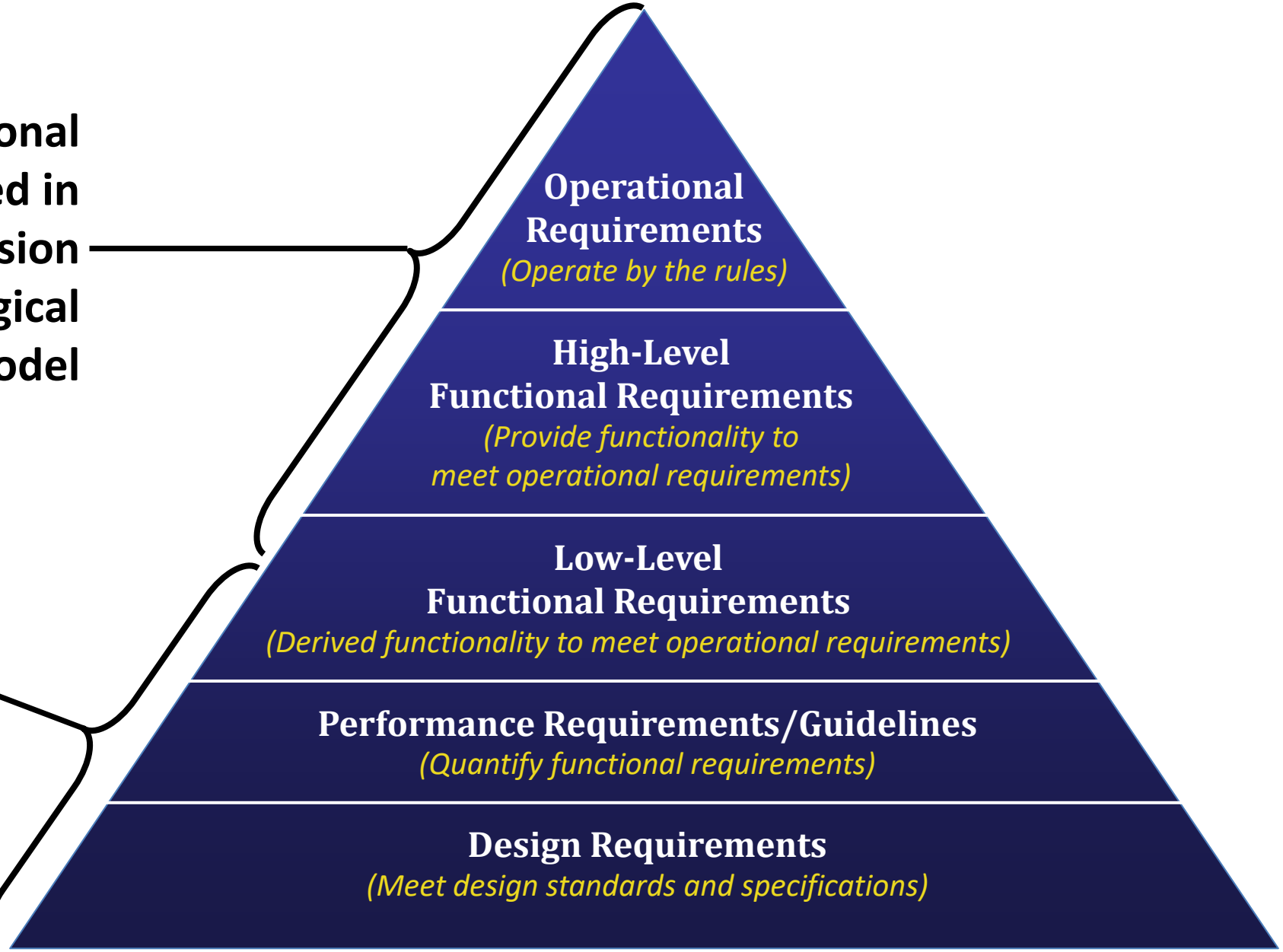


Model Based Representation

Requirement Hierarchy

Operational and Functional Requirements captured in the NASA "Mission Engineering" Logical Model

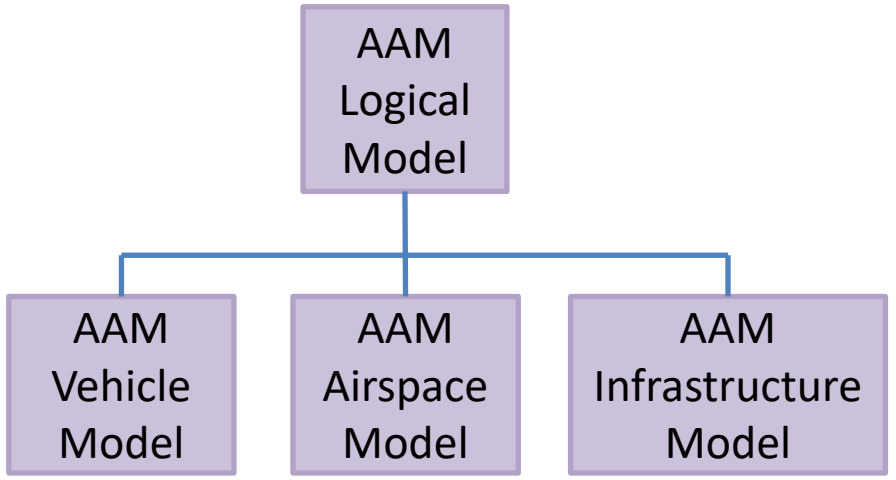
Low-level Functional, Performance, and Design Requirements captured in Partner and Flight-Test Physical Models



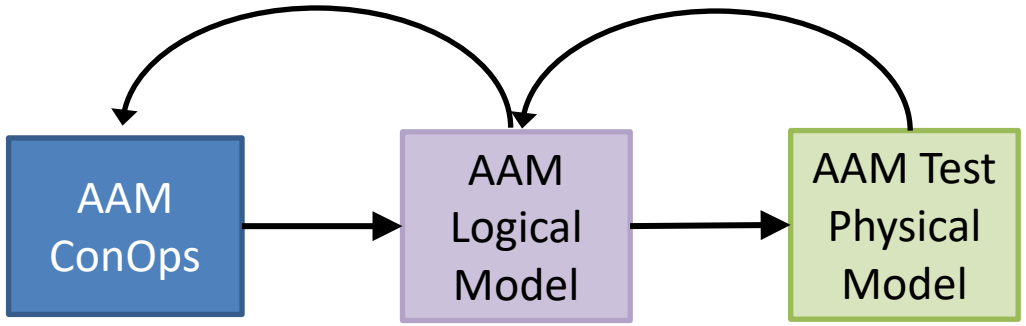
System Architecture Model Development Steps

- Initial AAM concept development
- Integrate content from SMEs
  - Based on initial AAM concept
  - Derive baseline architecture and requirements from concept with inputs from SMEs
  - *Logical model*
- Mature AAM model and concept
  - Use logical model as basis for AAM research and National Campaign *physical models*
  - Update logical model based on research and testing outcomes
  - Logical model changes inform concept changes
- Validate AAM model and concept
  - Determine validation strategy
  - Collect data from research and National Campaign
  - Analyze results

AAM Model of Models



Concept to Model Progression



Ex: National Campaign

FAA NextGen's v1.0 UAM Research ConOps

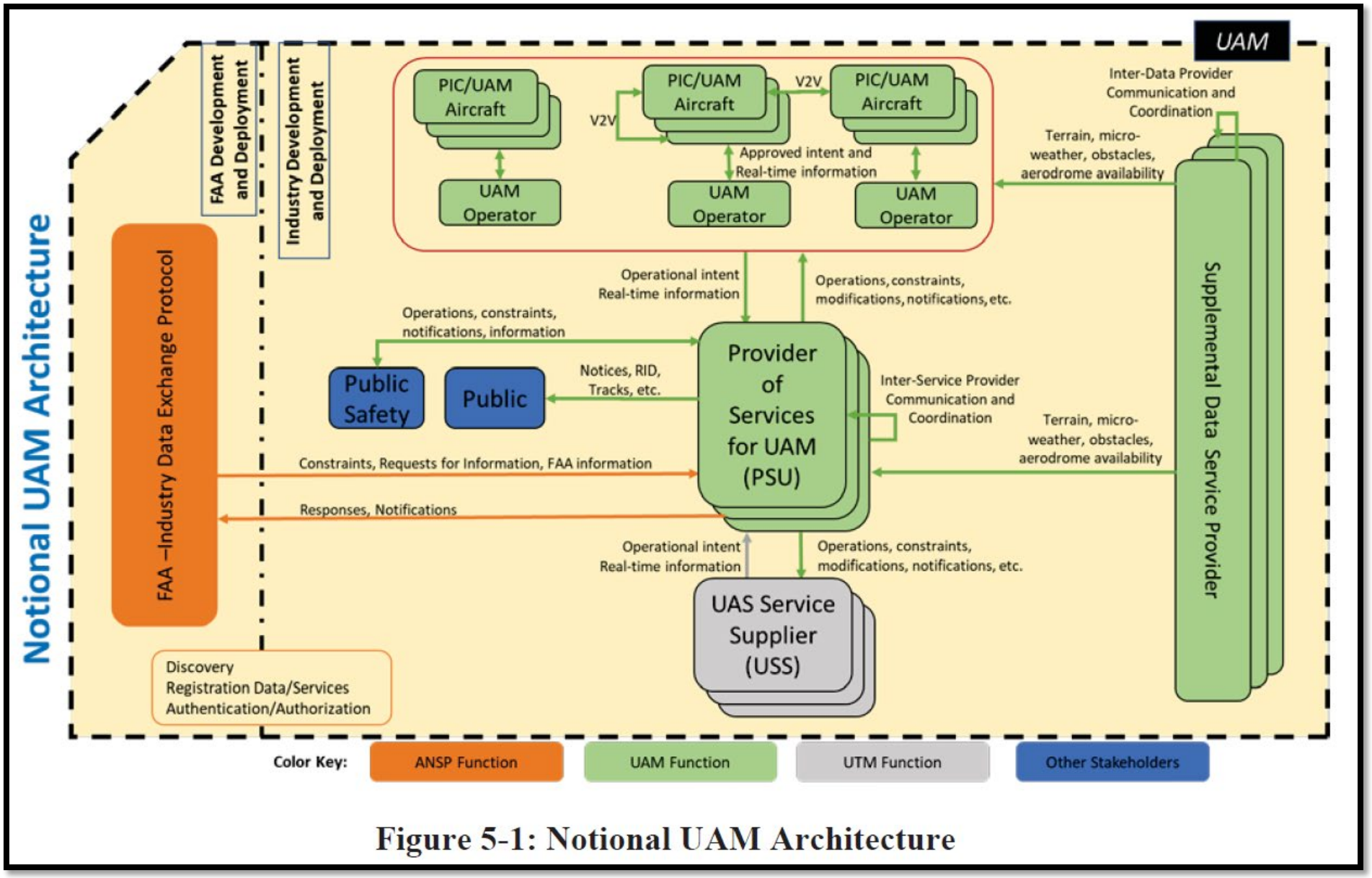
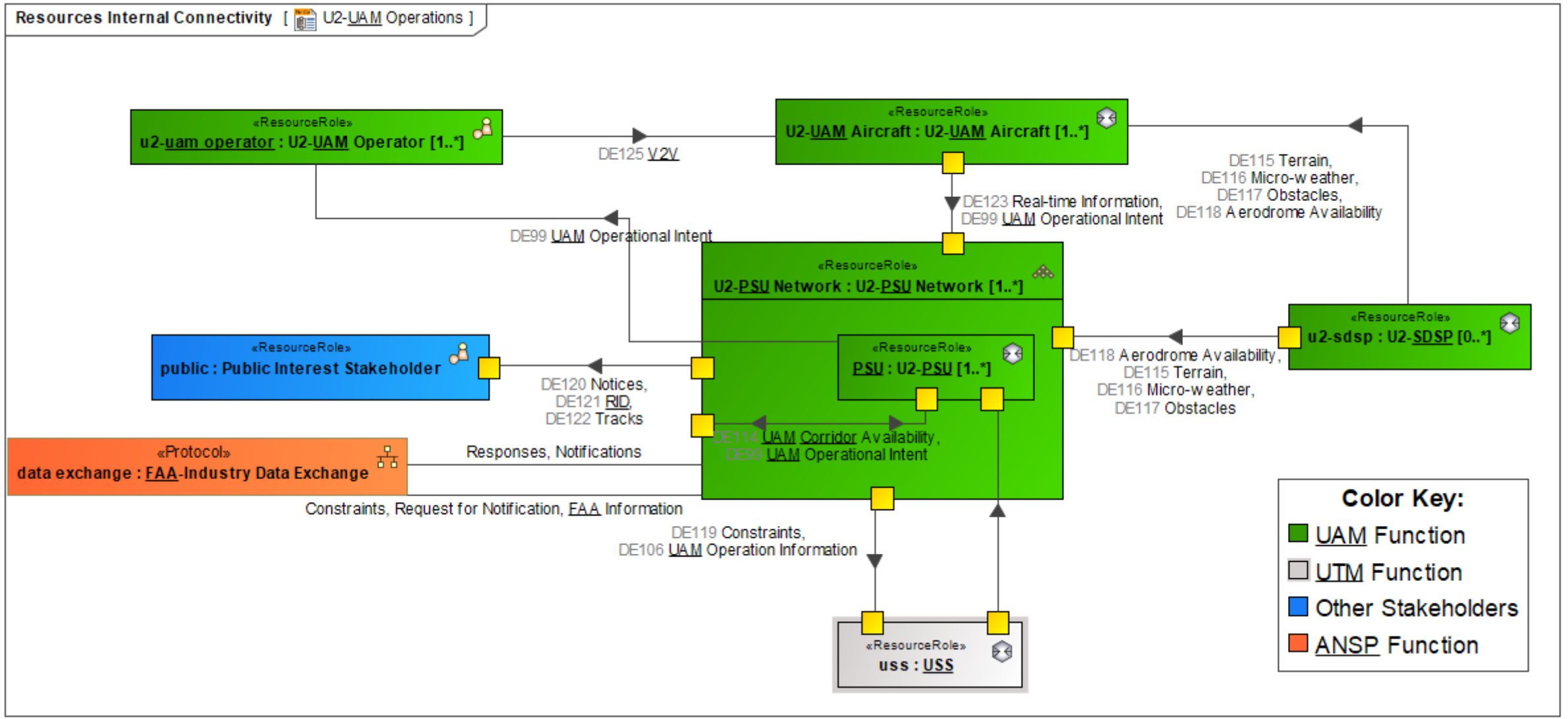


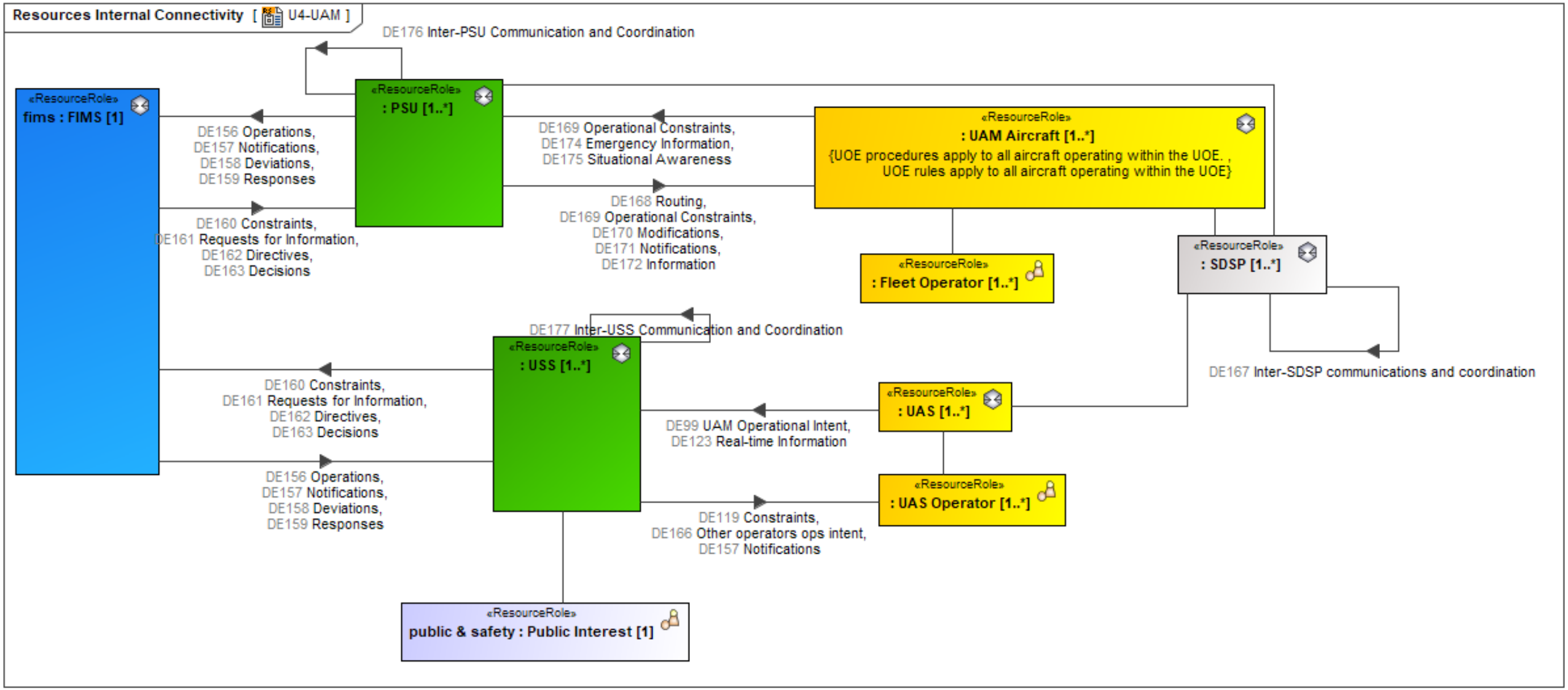
Figure 5-1: Notional UAM Architecture

Figure from FAA NextGen's v1.0 UAM ConOps document: https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf

FAA Nextgen's V1.0 UAM Research ConOps: Model



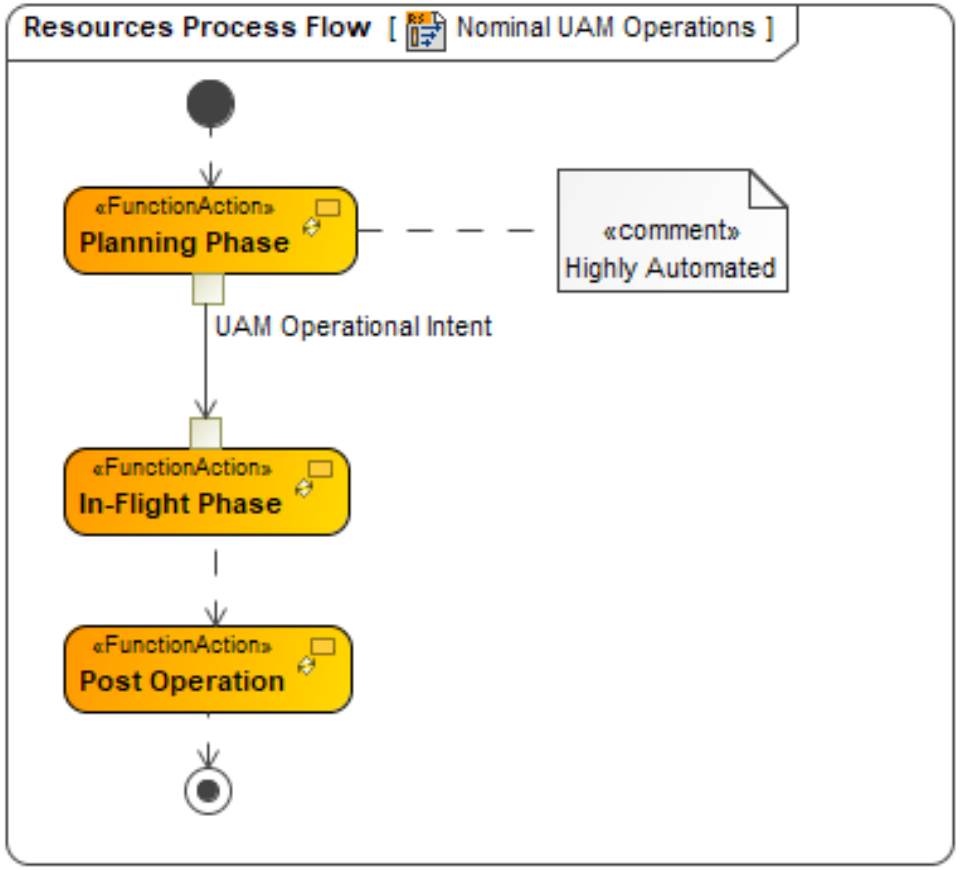
NASA UAM UML-4 ConOps Model



NASA Modeling Environment = NASA Models (Reference Architecture, ConOps, FARS, etc.) on TWC & interactions between

Nominal UAM Operations (Part 1)

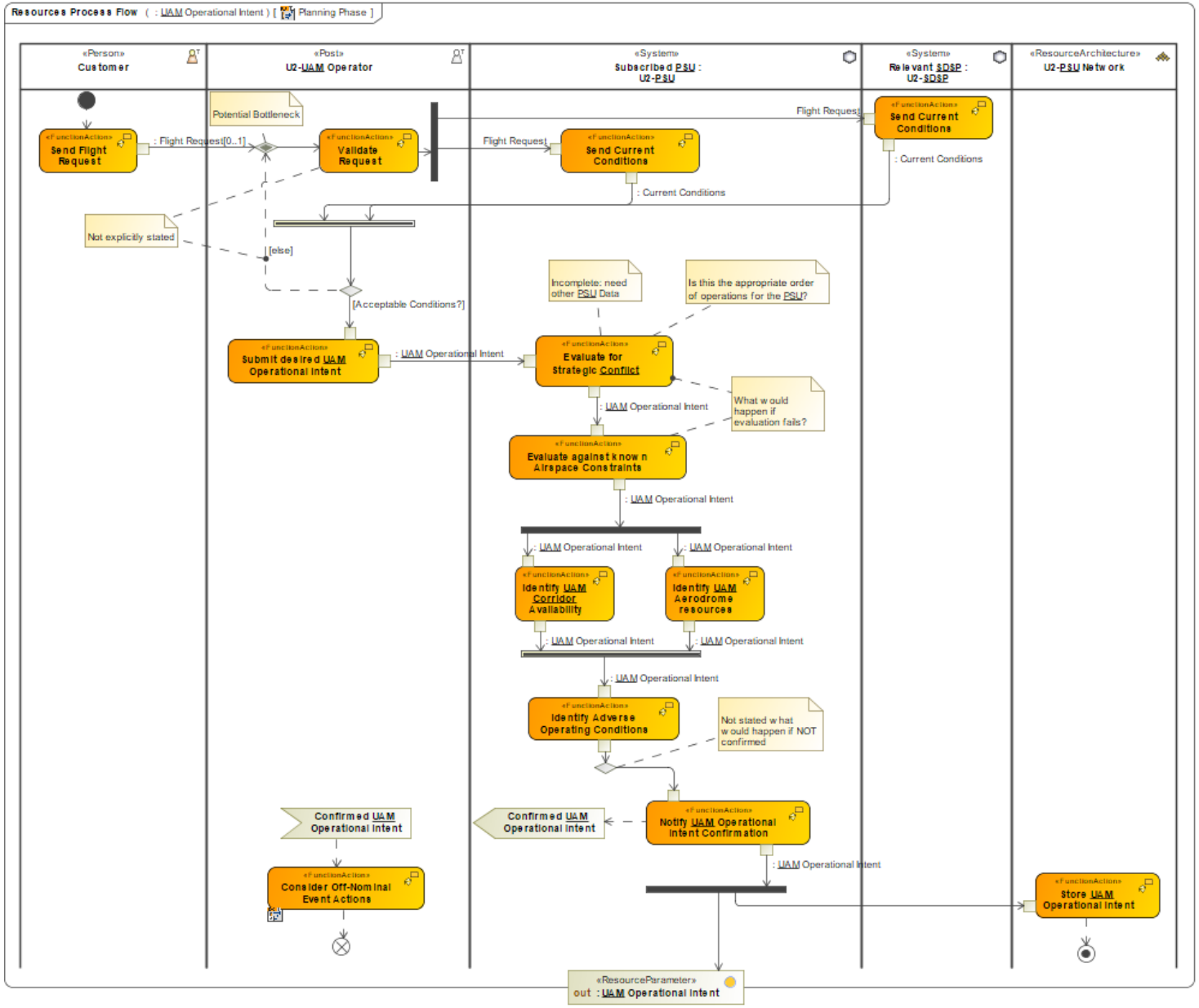
- Resource Process Flow shows functions and their step-by-step workflows in the Resource Domain
  - Resource domain is used to define the resources needed to implement the architectures to realize desired capabilities
- Diagram shows the Functional flow during Nominal UAM Operations
- UAM Operational Intent data flows between Planning Phase and In-Flight Phase
- Lower Levels exist to describe functional decomposition and allocation to UAM Participants



Nominal Operations based on Section Headers in Section 6

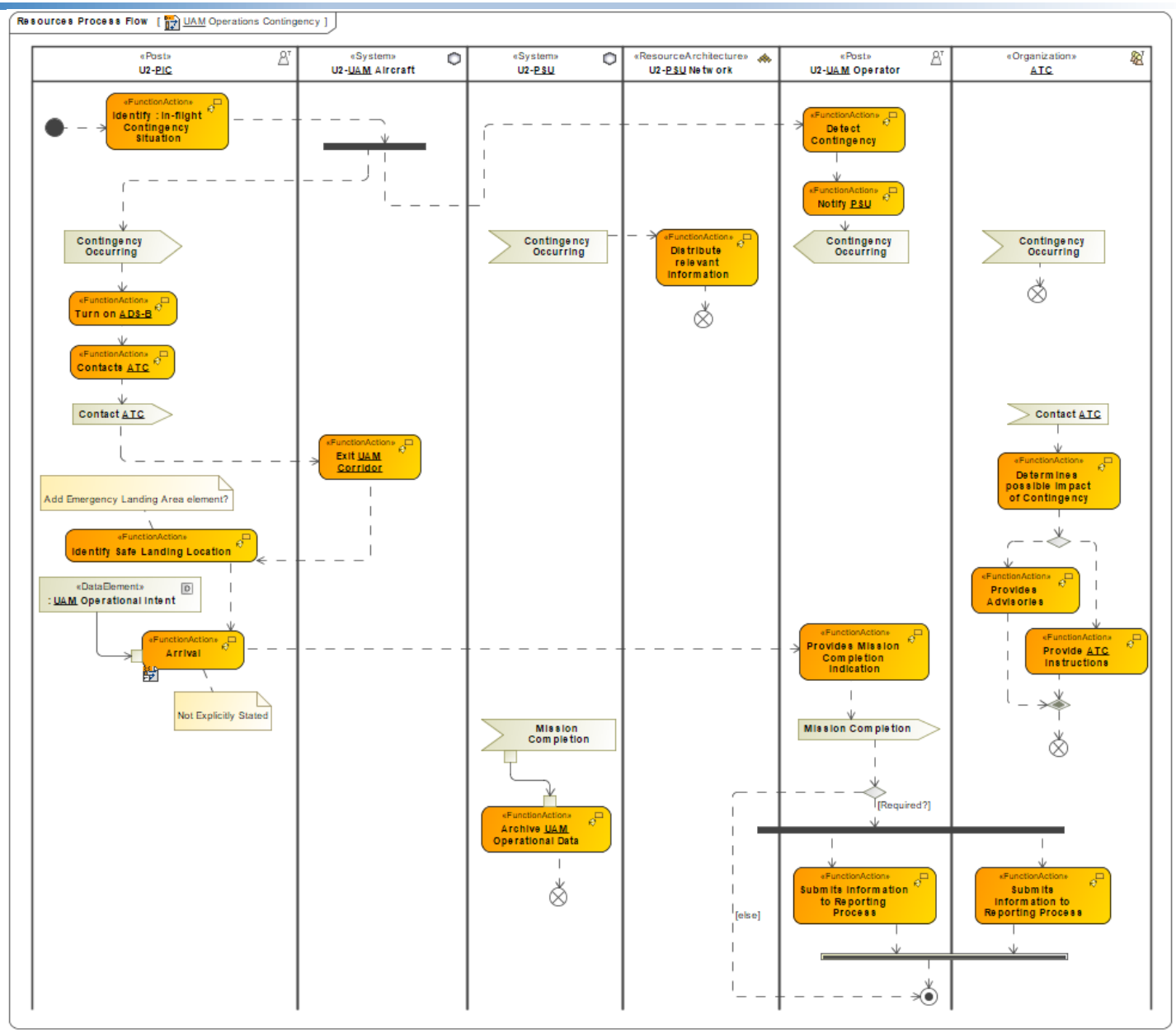
Nominal UAM Operations (Part 2)

- Diagram shows the functions occurring during Planning Phase of Nominal UAM Operations (Section 6.1.1.1)
  - Row shows the Participants
  - Column (a.k.a. Swimlanes) shows functionality expected for each Participant
- Captured *as written* in the documentation
- Notes on the diagram for added description but also highlights need for clarification



UAM Operations Contingency

- Separate Diagram for Off-Nominal Scenario (Section 6.2)
  - Row shows the Participants
  - Column shows functionality expected for each Participant
- Captured *as written* in the documentation
- Last Swimlane brings in ATC and their functions during the UAM Operations Contingency



Federal Aviation Regulations Modeling

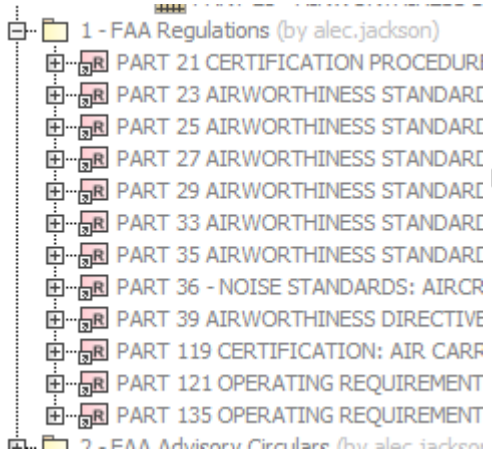
Add New | Add Existing... | Delete | Remove From Table | Columns | Export

Criteria

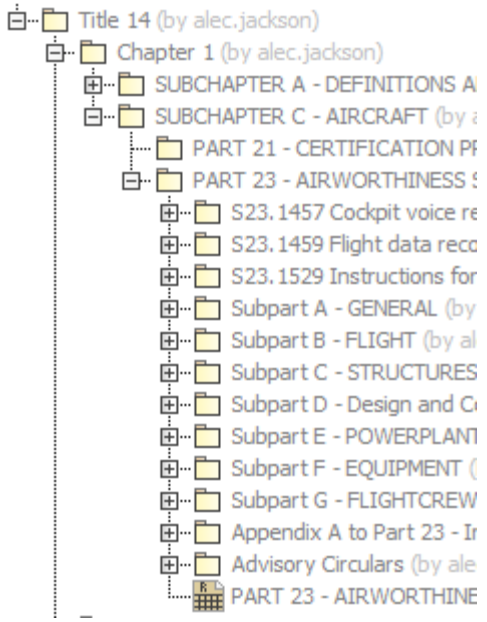
Element Type: Drag elements from the Model Browser ... Scope (optional): S1.1 General Definitions ... Filter:

#	Term	Description
1	Administrator	Federal Aviation Administrator or any person to whom he has delegated his authority in the matter concerned.
2	Aerodynamic Coefficients	Non-dimensional coefficients for aerodynamic forces and moments.
3	Air Carrier	A person who undertakes directly by lease, or other arrangement, to engage in air transportation.
4	Air Commerce	Interstate, overseas, or foreign air commerce or the transportation of mail by aircraft or any operation or navigation of aircraft within the limits of any Federal airway or any operation or navigation of aircraft which directly affects, or which may endanger safety in, interstate, overseas, or foreign air commerce.
5	Air Traffic	Aircraft operating in the air or on an airport surface, exclusive of loading ramps and parking areas.
6	Air Traffic Clearance	Authorization by air traffic control, for the purpose of preventing collision between known aircraft, for an aircraft to proceed under specified traffic conditions within controlled airspace.
7	Air Traffic Control	Service operated by appropriate authority to promote the safe, orderly, and expeditious flow of air traffic.
8	Air Transportation	Interstate, overseas, or foreign air transportation or the transportation of mail by aircraft.
9	Aircraft	Device that is used or intended to be used for flight in the air.
10	Aircraft Engine	Engine that is used or intended to be used for propelling aircraft. It includes turbosuperchargers, appurtenances, and accessories necessary for its functioning, but does not include propellers.
11	Airframe	Fuselage, booms, nacelles, cowlings, fairings, airfoil surfaces (including rotors but excluding propellers and rotating airfoils of engines), and landing gear of an aircraft and their accessories and controls.
12	Airplane	Engine-driven fixed-wing aircraft heavier than air, that is supported in flight by the dynamic reaction of the air against its wings.
13	Airport	Area of land or water that is used or intended to be used for the landing and takeoff of aircraft, and includes its buildings and facilities, if any.
14	Airship	Engine-driven lighter-than-air aircraft that can be steered.
15	Alert Area	Inform pilots of a specific area wherein a high volume of pilot training or an unusual type of aeronautical activity is conducted.
16	Alternate Airport	Airport at which an aircraft may land if a landing at the intended airport becomes inadvisable.
17	Altitude Engine	Reciprocating aircraft engine having a rated takeoff power that is producible from sea level to an established higher altitude.
18	Amateur Rocket	Unmanned rocket that: (1) Is propelled by a motor or motors having a combined total impulse of 889,600 Newton-seconds (200,000 pound-seconds) or less; and (2) Cannot reach an altitude greater than 150 kilometers (93.2 statute miles) above the earth's surface.
19	Appliance	Any instrument, mechanism, equipment, part, apparatus, appurtenance, or accessory, including communications equipment, that is used or intended to be used in operating or controlling an aircraft in flight, is installed in or attached to the aircraft, and is not part of an airframe, engine, or propeller.
20	Approved	Unless used with reference to another person, means approved by the FAA or any person to whom the FAA has delegated its authority in the matter concerned, or approved under the provisions of a bilateral agreement between the United States and a foreign country or jurisdiction.
21	Area Navigation	Method of navigation that permits aircraft operations on any desired flight path.
22	Armed Forces	Army, Navy, Air Force, Marine Corps, and Coast Guard, including their regular and reserve components and members serving without component status.

Show hyper link capabilities



Model structure aligns with FAR model



Glossary

- Common Glossary defined and used across models to ensure consistent terminology
- Acronyms and Terms are populated throughout the model
- Able to access the description of a word/phrase from the Glossary as it appears in the model

#	△ Term	Description	Synonyms
1	Air Traffic Management	The dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management — safely, economically and efficiently — through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions. (Source: ICAO Doc 4444 PANS-ATM)	
2	Conflict	A point in time in which the predicted separation of two or more aircraft is less than the defined separation minima. (Source: FAA UAM_ConOps_v1.0 pg.31)	
3	Constraint	An impact to the capacity of a resource. Constraints can be natural (e.g., weather), circumstantial (e.g., runway construction), or intentional (e.g., TFR).	
4	Cooperative Separation	Separation based on shared flight intent and data exchanges between operators, stakeholders, and service providers and supported by the appropriate rules, regulations, and policies for the planned operations. Air Navigation Service Providers (ANSP) do not provide tactical ATC separation services for UAM operations.	
5	Demand Capacity Balancing	Flight intent adjustments during the planning phase to ensure that predicted demand does not exceed the capacity of a resource (e.g., UAM Corridor, aerodrome).	
6	Human-on-the-Loop	Human supervisory control of the automation (systems) where the human actively monitors the systems and can take full control when required or desired.	
7	Human-over-the-Loop	Human informed, or engaged, by the automation (system) to take actions. Human passively monitors the systems and is informed by automation if, and what, action is required. Human is engaged by the automation either for exceptions that are not reconcilable or as part of rule set escalation.	
8	Human-within-the-Loop	Human is always in direct control of the automation (systems).	
9	In-time System-wide Safety A	Systems that monitor data, make assessments, and perform or inform a mitigating action.	
10	Nominal UAM Operation	A nominal UAM operation is a single UAM operation that executes in accordance with the established performances, rules, policies, and procedures.	
11	Off-Nominal Operation	An off-nominal operation deviates from nominal operations.	
12	Operational Tempo	The density, frequency, and complexity of operations.	
13	Providers of Services for UAN	An entity that assists UAM operators with meeting UAM operational requirements to enable safe and efficient use of UAM Corridors and aerodromes. This service provider shares operational data with stakeholders and confirms flight intent.	
14	PSU Network	A collection of PSUs with access to each PSU's data for use and sharing with their subscribers.	
15	Route		Corridor
16	Safety Management System	Systematic, top-down, organization-wide approach to mitigating risks and hazards and ensuring the effectiveness of risk management controls and safety assurance techniques.	
17	Strategic Deconfliction	Deconfliction of UAM Operational Intent via advanced planning and information exchange.	
18	Tactical Separation	UAM operator responsibility for tactical conflict and collision avoidance.	
19	UAM Aerodrome	A location from which UAM flights arrive and depart	
20	UAM Aircraft	An aircraft that can execute UAM operations.	
21	UAM Corridor	An airspace volume defining a three-dimensional route segment with performance requirements to operate within or cross where tactical ATC separation services are not provided.	
22	UAM Operating Environment	Flexible airspace area encompassing the areas of high UAM activity.	
23	UAM Operation	The transport of people or goods from one aerodrome to another using UAM Corridors.	
24	UAM Operational Intent	Operation specific information including, but not limited to, UAM operation identification, the intended UAM Corridor (s), aerodromes, and key operational event times (e.g., departure, arrival) of the UAM operation.	

Report Generation

- Can Generate Reports directly from the model in Office (.docx, .xlsx) format
- Enables up-to-date elements to be output quickly
- Customizable Templates for Stakeholder needs
  - Could export full model or only select diagrams

Appendix D: Acronyms List

Term	Description
AAM	Advanced Air Mobility
AAVP	Advanced Air Vehicles Program
AC	Aircraft
ACO	Announcement of Collaborative Partnership Opportunities
ADS-B	Automatic Dependent Surveillance – Broadcast
AFB	Air Force Base
AFS	FAA Flight Standards Service Organization
AFSRB	Airworthiness Flight Safety Review Board
AGL	Above ground level
AI	Artificial intelligence

Snapshot of Template

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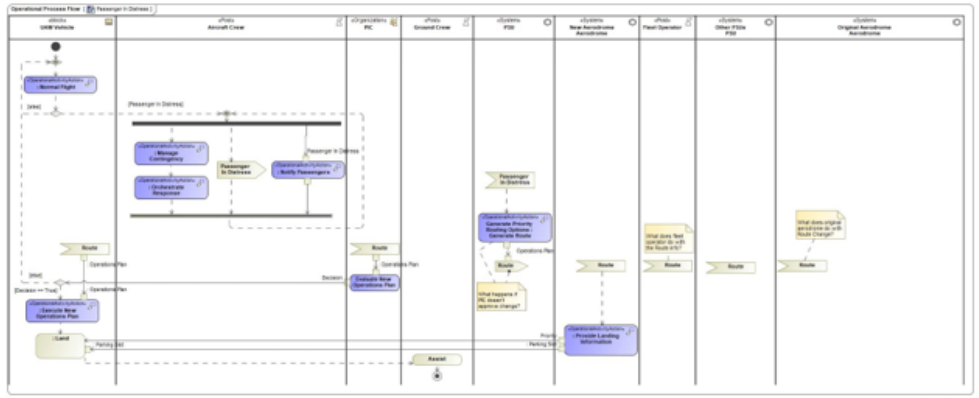
#macro(printHeading $element)
#       if($element.hasQualifiedName())
#               set($depth = $element.qualifiedName.split("::").size())
#               if($depth == 3)
$element.name
#               elseif($depth == 4)
$element.name
#               elseif($depth == 5)
$element.name
#               elseif($depth == 6)
$element.name
#               end
#       end
#end
#macro(printPackagesRecursively $package)
#       printHeading($package)
#       printRequirement($package)
#       printDocumentation($package)
#       printDiagrams($package)
#       printTables($package)
#       foreach($pack in $sorter.humanSort($report.filterElement($package.packagedElement, ['Smart Package'])))
#               printPackagesRecursively($pack)
#       end
#end
#macro(printRequirement $pkg)
#       foreach($req in $sorter.humanSort($report.filterElement($pkg.additionalContentCalc, ['Requirement'])))
    • $req.text
```

Exported Report

role during this type of emergency, but incident reports are likely filed afterwards.



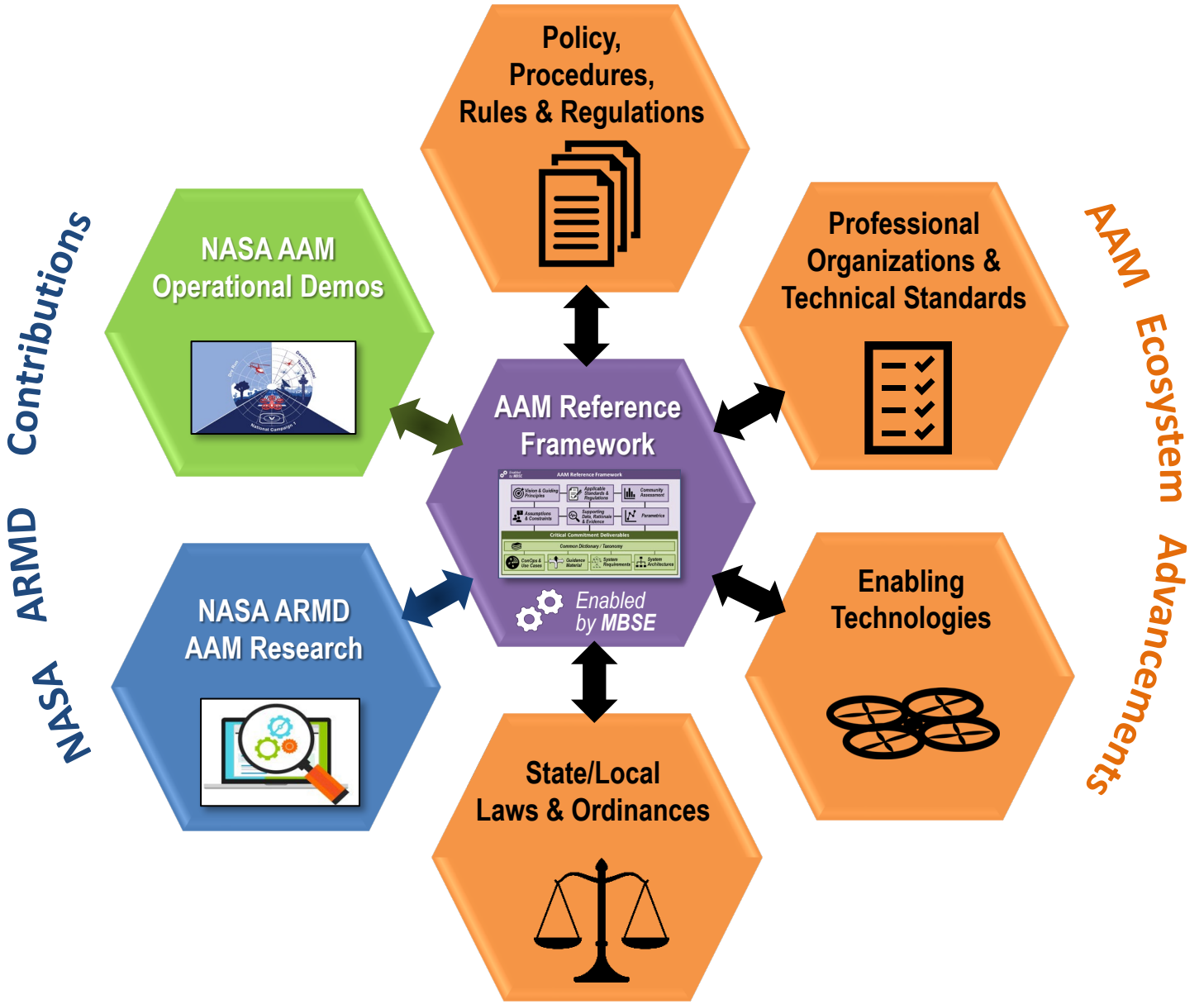
UAM Aerodrome Closure

If a UAM aerodrome is closed for any reason (safety criteria, weather, gate contention, etc.), it is the onus of the UAM aerodrome operator to inform the PSU. UAM aerodrome operators have established procedures for notifying PSUs that they are closed when communications links are broken. The PSU pushes this information to other PSUs, the fleet operators, other UAM aerodrome operators, and SDSPs, and identifies proposed route plans for airborne aircraft scheduled into the closed UAM aerodrome,

AAM Reference Framework External Engagement

- Inputs:
  - Concepts and Use Cases
  - Validation Support:
    - National Campaign Test Models
    - Research and test results
    - Sub-system models from Industry
  - Candidate Standards, Regulations, and Ordinances

- Outputs:
  - Model of Federal Aviation Regulations
  - Interim Releases of Reference Framework
    - Model Structure
    - ConOps and Use Cases: Including Glossary
    - System Architectures and Requirements
      - ConOps Model
      - Reference Architecture
    - Modeled Candidate Standards, Regulations, and Ordinances



Backup Slides

Backups

AAM System Concept Meta-Model Overview

Stakeholder Inputs

Contributing elements from the Stakeholders used to shape and test the AAM system under development. These include concepts, architecture models, system assumptions, and planned research.

Stakeholders

The organizations and people that enable and influence the AAM system (e.g., NASA Projects, Other Govt. Agencies, Industry Partners, etc.)

Controls

Materials that constrain and direct the definition of the system (e.g., specifications, policies, rules, laws, standards, etc.)

AAM Reference Framework (RF)

AAM Reference Framework Analyses/Validation

Activities (tests, assessments, etc.) and their results supporting the verification, validation, and traceability of the components within the Reference Framework. These may be executed by NASA Projects or external partners.

AAM Reference Framework Elements

The collection of material, models, and data used to organize and develop the Critical Commitment content.

AAM Critical Commitment Deliverables "Book of Requirements and Guidelines"

AAM Concept and Use Cases

The high-level vision that provides a common understanding that supports the development of the system-level requirements and architecture for the reference missions.

Recommended Requirements

System-level specifications used to define and bound candidate characteristics and constraints of an operational AAM system.

Candidate System Architectures

Organization of the elements of the system, supporting the understanding of the roles, relationships, dependencies, and interfaces of the reference mission systems.

Guidance Material

Applicable AAM RF Element content that directly supports or adds clarity to the other Critical Commitment content. (e.g., glossary, research findings/reports, UML definitions)