Enabling Autonomous Flight and Operations

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Objectives for Aviation Autonomy

- Address pilot shortage and international competitiveness with increasingly automated cockpit, flight and operations
  - Reduced crew operations for long-haul
  - M:N operations for small to mid-size
  - Fully autonomous drones and urban air mobility (UAM)
- Substantially increase airspace system capacity without overloading air traffic control (ATC) and controller workload
- Enable new emerging market pilots to receive certification with order-of-magnitude reductions in training
- Enable aircraft to auto-land anywhere and under any conditions
- Maintain and enhance safety of individual flight and airspace

Traditional and Emerging Markets

1. Long-haul reduced crew operations for civil markets and DoD
2. High altitude long endurance operations
3. Autonomous cargo aircraft
4. UAM and thin haul operations for passengers and cargo
5. Small Unmanned Aircraft Systems (sUAS)





Needs

- Success of high-scale UAM and overall advanced air mobility(AAM) depends on:
  - Airspace operations concepts and technologies that will not overload air traffic management
  - Battery technologies
  - Manufacturing and supply chain network for high-scale operations
  - Aircraft designs and operations with acceptable noise
  - Infrastructure – charging, vertiports, etc.
  - Passenger experience and acceptance

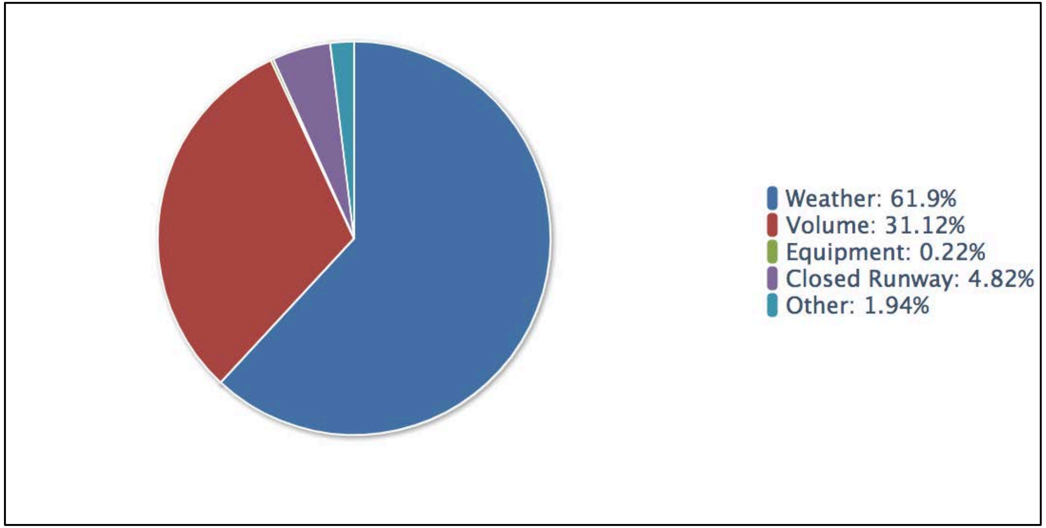
Airspace Operations

- Forecast for commercial, small non-model UAS fleet: nearly triple from 277,386 in 2018 to 835,211 in 2023, an average annual growth rate of 24.7 percent (FAA, 2019 Forecast)
  - Reference: https://www.faa.gov/news/updates/?newsId=93646
- Forecast for UAM and AAM is not yet available but business predictions are in millions
- Current take-off and landing operations are about 60,000/day and peak traffic 5 – 7K

Delay Statistics

Causes of National Aviation System Delays
National (April, 2019)

More Topics:
- On-time arrival performance
- Flight delays by cause
- Weather's share of delayed flights
- Weather's share of national aviation system (NAS) delays

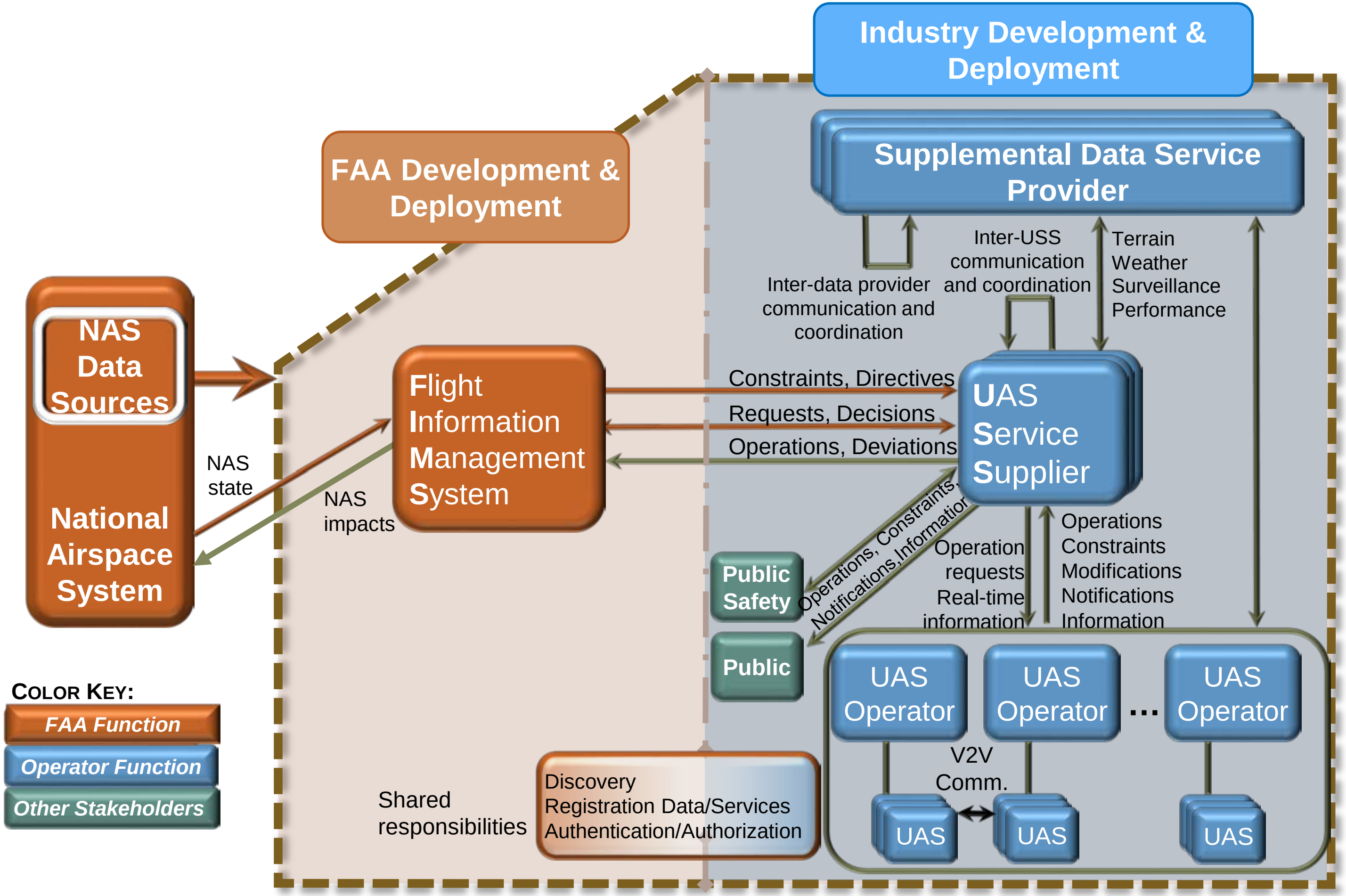


Reference: https://www.transtats.bts.gov/OT_Delay/ot_delaycause1.asp?type=5&pn=1

Enabling Future Operations

- Clearly, we need new ways to accommodate new entrants – drones and urban air mobility
- Scalability is key – however that needs to be interoperable as well; we can’t segregate airspace for every new entrant
- Integration where possible and segregation where necessary (e.g., commercial space launches)
- Flexibility where possible and structure where necessary to ensure safety and high capacity (e.g., bike lanes vs cars)

UTM Service-Based Architecture



Flight Information Management System
- → Enables airspace controls
- → Facilitates requests
- → Supports response in emergencies impacting NAS

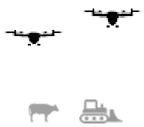
UAS Service Supplier
- → Federated Structure
- → Cloud-based system
- → Automated System
- → Supports UAS with services (e.g. separation, weather, flight planning, contingency management, etc.)

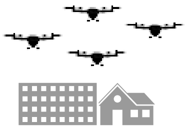
Supplemental Data Service Provider
- → Supplies supplemental data to USS and UAS Operator to support operations

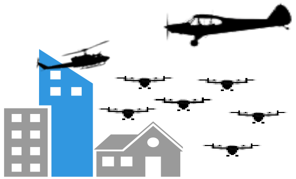
UAS / UAS Operator
- → Individual Operator
- → Fleet Management
- → On-board capabilities to support safe operations

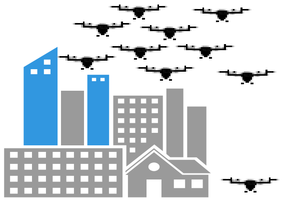
Technical Capability Levels (TCL)

Risk-based development and test approach along four distinct TCL









TCL1

What: Concept for management of airspace in lower risk environments and multiple visual line-of-sight (VLOS) UAS operations

When: Aug 2015, May 2016

Outcomes: Validation of cloud-based service oriented architecture

TCL 2

What: Complex multiple beyond visual line of sight (BVLOS) UAS Operations in lower risk environments

When: Oct 2016, May 2017

Outcomes: Information sharing between operators, and established federated 3rd party service model

TCL 3

What: Technologies needed for BVLOS UAS Operations over populated areas and near airports

When: March-June 2018

Outcomes: Technologies for detect and avoid, comm. and nav., and data exchange between multiple USS

TCL 4

What: Complex BVLOS operations in urban environment, nominal and contingency situations

When: Summer 2019

Outcomes: Operational concept, vehicle technologies, and data exchanges for operations near large structures and in highly populated areas

UTM Construct

- Roles and responsibilities – air navigation service provider (ANSP), operator, third party service suppliers
- Digital
- Interoperable
- Intent sharing
- Cooperative
- Manage by exception paradigm

UTM and ATM Environments

- UAM aircraft will operate where drones are operating in low altitude and where manned aviation is operating
- Interoperability will be key
- UAM aircraft could be dual capable for near future – they will interact inside UTM environment using UTM construct and inside current ATM environment with ATC

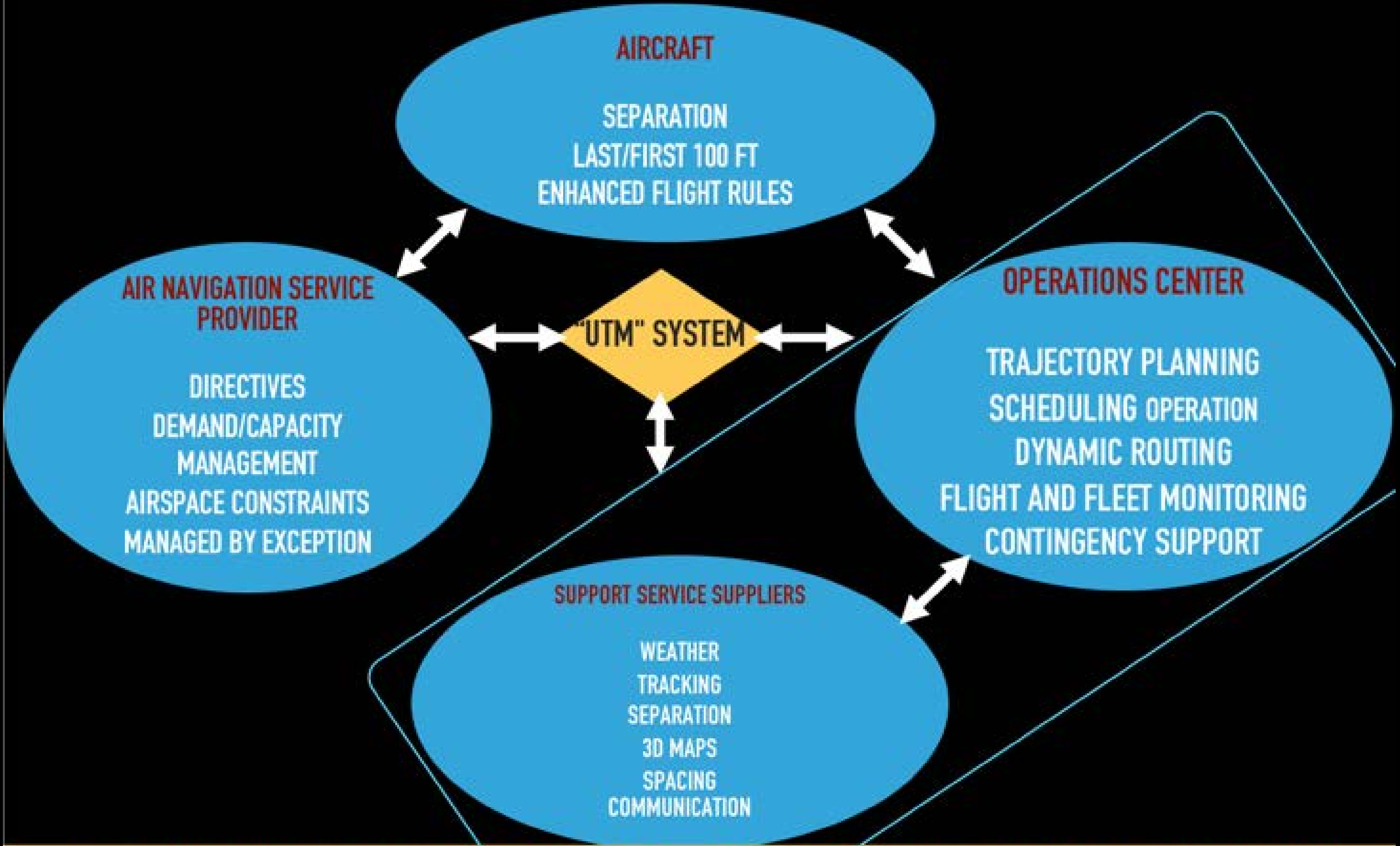
Concept of Operations

- Building comprehensive concept of operations that includes piloted, autonomous, and remotely operated UAM-type vehicles
  - Accommodate various use cases (e.g., point-to-point, healthcare related)
  - Nominal operations (e.g., corridors, routes, etc.)
  - Interoperability
  - UTM-ATM environment (there is separate effort underway for future UTM inspired ATM)
  - Off-nominal conditions and contingencies (e.g., energy depletion, bird strike)
- Example: Reserve fuel requirement for GA

Vertipads and Vertiports

- Developing vertiport and vertipad concept of operations
  - Multiple ports at a vertipad
  - Multiple pads in the vicinity
  - In/out routes
  - Infrastructure to operate under IMC conditions

FLEXIBILITY WHERE POSSIBLE, STRUCTURE WHERE NECESSARY



RESEARCH TO DETERMINE SERVICES, PERFORMANCE NEEDS, AUTOMATION CAPABILITIES FOR SCALED OPERATIONS

UTM-Like-ATM Airspace Operations Environment

- Cooperative
- Intent-sharing
- Digital: data exchanges among operators
- Standardized application protocol interfaces
- Air/ground integrated
- Service-oriented architecture
- Role for third parties

Space Traffic Management

High Altitude UTM (Upper E)

Conventional Manned Aviation (Class A, B, C, D, E)

Urban Air Mobility

Low-altitude small UAS

Current ATM

All services are provided by the FAA

- Traffic flow management
- Airspace directives/constraints
- Scheduling, sequencing, and spacing
- Separation management
- Off-nominal management
- Every vehicle interaction in real-time.

FAA Systems

Humans address off-nominal and contingencies

Airspace User

Airspace User

Airspace User

Airspace User

Airspace User

Airspace User

Very little interaction among users and third-party services

- Human in the epi-center of information integration
- Every data moves through FAA systems for every vehicle
- Each change focused on domain-specific FAA system.

UTM-inspired ATM

Some services are provided by the FAA

- Airspace directives/constraints
- Resource availability and changes to resources (e.g., arrival/departure rates, resource schedules)
- Separation (research question)

FAA Systems

User or third-party services

- Flow management
- Sequencing and spacing
- User participation strategic separation (e.g., oceanic).

Automation addresses off-nominal and contingencies

Airspace User

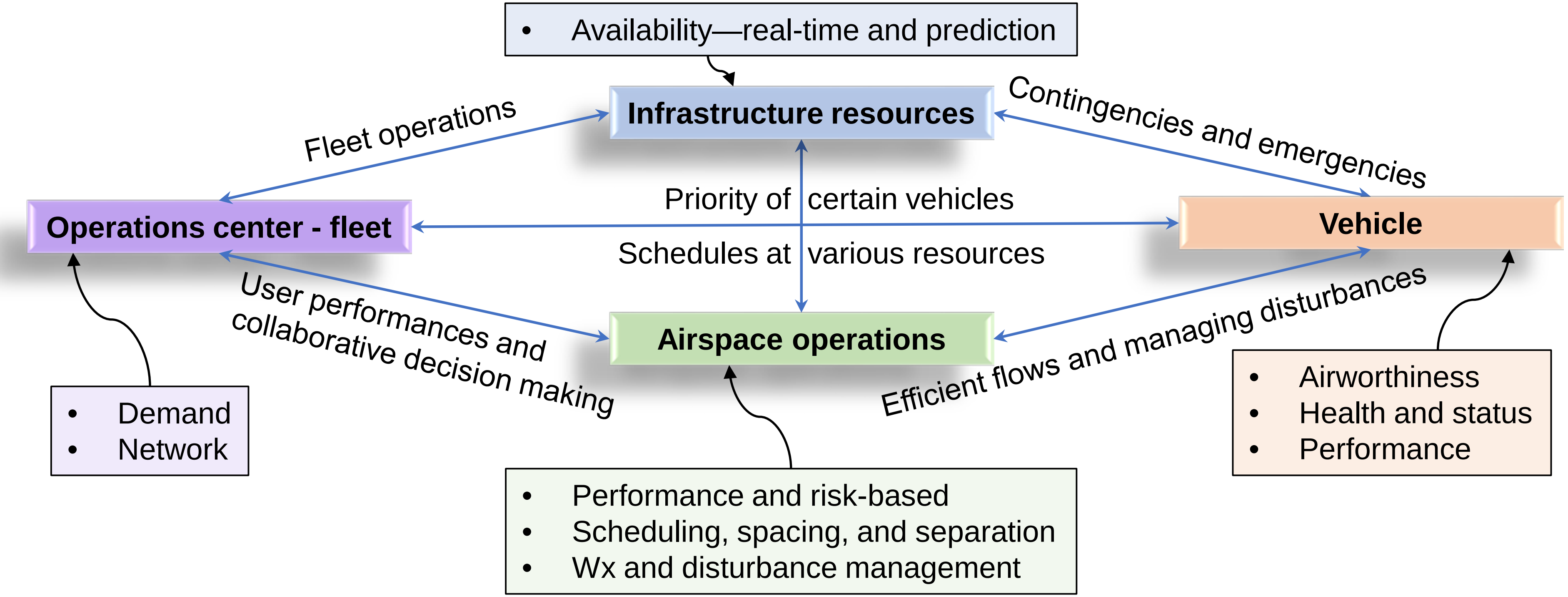
Airspace User

Users collaborate/cooperate for efficiency, intra-user preferences for flights into constrained resources.

- Automation in the epi-center of information integration
- New paradigm: digital and connected ecosystems—outside apps, scalability.

NASA's unique role: architecture, data exchange, service allocation/roles/responsibilities, rules of engagement, service performance requirements, automation for contingency management and disruption handling, machine learning environment and algorithms for continuous improvement, safety assurance, certification/acceptance approaches and technology transition.

Connectivity is Key



Autonomy alone will not lead to efficiency and large-scale disturbance management.
Connectivity is crucial: air/ground/cloud/infrastructure integration will be key.

Key Research Areas and Contributions

- Concept of operations (NASA, industry, Deloitt, etc)
- Simulations to demonstrate feasibility of UTM construct to scale the operations – nominal and off-nominal
- Develop third-party UAM service suppliers and their requirements
- UAM Maturity Levels (UMLs): aircraft, airspace, infrastructure/community – low to high density and complexity
- Support grand challenge series to assess UAM state of maturity
- Demonstrate services – helicopter and drones to scale, and eVTOLs
- NASA-FAA-industry collaboration

UAM Maturity Levels (UML)

Vehicles | Airspace | Community

INITIAL STATE	UML-1	• Late-Stage Certification Testing and Operational Demonstrations in Limited Environments
	UML-2	• Low Density and Complexity Commercial Operations with Assistive Automation
INTERMEDIATE STATE	UML-3	• Low Density, Medium Complexity Operations with Comprehensive Safety Assurance Automation
	UML-4	• Medium Density and Complexity Operations with Collaborative and Responsible Automated Systems
MATURE STATE	UML-5	• High Density and Complexity Operations with Highly-Integrated Automated Networks
	UML-6	• Ubiquitous UAM Operations with System-Wide Automated Optimization

* UML indicates operational system capability, not ”technology readiness”

Airspace Operations Classics

- Operations under VMC and IMC conditions
- RNP requirements in dense congested operations
- Weather integration and impacts, and disturbance management
- Trajectory definitions and rerouting
- Tracking (accuracy)
- CNS services and requirements
- Separation among cooperative and non-cooperative (aircraft, buildings, etc.)
- Spacing and scheduling
- Large-scale disturbance handling (e.g., GPS failure, comm failure, weather problems)

Airspace Operations: UTM, UAM, and Beyond

- Scalable – increasingly autonomous
- Cooperative – information needs, and technologies for cooperation among vehicles, and operators, and service providers
- Digital – data exchanges and standardized application protocols
- Resilient – technologies and procedures for faster recovery from disruptions
- Manage by exception – flexibility where possible and structure where necessary
- Safety assurance – in-time data, prognostics, V&V of increasingly autonomous systems
- Air/ground/cloud integrated
- Service oriented architecture – third party

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Airspace operations….

….enabling beyond possible!