ODM Technical Roadmap Report Out:

**Simplified Vehicle Operations and Airspace Integration**

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Transformative Vertical Flight Workshop
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Hartford CT
SVO System Scope

User (traveler)
- Required skills & knowledge
- Workload and resource constraints
- Human as single-point-failure

Aircraft and systems

Crew, support personnel (as needed)
- on or off-board (e.g. dispatch, remote-pilot, ground handler)

Airspace & Operations
- Cannot implement independently: design for the present and work toward desired future
SVO Vision

Technologies and certification path for practical, small, pilotless passenger aircraft

- Transformative, high-speed regional and urban transportation
- Aircraft maintains safety in presence of sub-system failures, non-normal, unforeseen
- User focuses on decisions affecting travel/mission outcome

Airspace concepts & requirements enabling full benefit of ODM & integration with other users

Proving ground for tech scale-up and down
Challenge:

...Currently, pilots & controllers (aka humans) are failsafe for most systems & unknowns
Failsafe Example: Fly-By-Wire

Normal Law: Hardware Assurance $\sim 10^{-4}$

Flight Control Computer

Command augmentation
Stability
$N_z$, Speed, Attitude, AoA protections

Elevator

Auto Trim

Physical Environment

Vehicle Motions

$\gamma_c$
Failsafe Example: Fly-By-Wire

Alternate Law: Hardware Assurance  $\sim 10^{-6}$

Flight Control Computer
- Command-augmentation
- Stability
- Nz, Speed, Attitude, AoA protections

Vehicle Motions

Physical Environment

Note: loss of sensors may also degrade pilot displays and cause loss of autopilot
Failsafe Example: Fly-By-Wire

Direct Law: Hardware Assurance $\sim 10^{-9}$

Pilot flies stick-to-surface with manual trim. Airplane may have marginal handling qualities.
Failsafe Example: Unknowns

Airmanship predicated on general Intelligence, knowledge

The General Responsibility Rule

Rule 2 is the General Responsibility Rule, which has two principal aspects.

THE RULE OF GOOD SEAMANSHIP

Part (a) of the General Responsibility Rule has been called the Rule of Good Seamanship. It says, simply, that nothing in the Rules excuses you from failure to follow the Rules or to practice good seamanship. In situations not covered by the Rules, take the action required by the special circumstances.

THE GENERAL PRUDENTIAL RULE

Part (b) of the General Responsibility Rule is sometimes called the General Prudential Rule. It directs you to consider all the dangers to navigation when applying the Rules, evaluating and responding to any special circumstances that may make you depart from the Rules to avoid immediate danger. “Immediate danger” means more than just the mere perception of a risk of collision. It means, rather, that a collision is imminent unless you act immediately to avoid it. In such a circumstance, Rule 2(b) says, you must depart from the Rules to avoid the collision.
Leverage UAS, but not Panacea

Air Force facing drone and jet pilot shortage due to 'insatiable demand'

By Andrew V. Pestano | March 17, 2016 at 9:21 AM

A U.S. Air Force MQ-9 Reaper, an unmanned aerial vehicle, at Kandahar Airfield in Afghanistan. The Air Force is looking to recruit 300 more drone operators, but says it will still be 500 operators short of its ideal staffing level. File photo by Tech. Sgt. Robert Cloys/U.S. Air Force
ODM Roadmapping Process

Stakeholders
Industry, FAA
NASA

ODM Barriers,
Figures of Merit

Outcomes & Vision

Technology
Survey, Candidates

Research Themes

Roadmaps,
Technical Challenges

Proposed NASA
Technology Investments

ARMD
Strategic Thrusts

Industry, FAA
NASA

SPMR
## ODM Barriers & Figures of Merit

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Product of Kansas City Workshop, Oct. 2015
## ODM Barriers & Figures of Merit
### SVO Contributions

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**Primary**

**Secondary**
SVO Targeted Outcomes

Safe, easy to use, pilotless, small, passenger aircraft

Aircraft responsible for flight safety & execution
- Plan & execute flights based on user directives, constraints, preferences
- Detect, avoid, mitigate internal & external hazards on-ground & in-flight
- Safety maintained in unforeseen situations
- Novel aircraft using full capabilities of airframe

Direct, efficient human-automation interaction
- User focuses on decisions relevant to trip/mission outcomes, probabilities, preferences
- Dispatcher/supervisor oversees fleet operations

Airspace & procedures for large numbers of on-demand autonomous, manned-sized aircraft (>1,000,000 aloft)
- All airspace classes, weather
- All types of aircraft (commercial, legacy GA, sUAS, UAS)

Aircraft & airspace system requirements, guidelines, compliance methods for practical applications
Outcome: Pilotless, Manned Aircraft

Decision & Control Hierarchy

Functional Emphasis
- Over the horizon
- Awareness, mission planning
- Real-time perception, action formulation
- Execution of action plan

Mission Layer
- Objectives, destination
- Flight plan & route
- Contingencies, continue/stop

Maneuver Layer
- Local factors of flight
- Immediate goal, objectives
- Desired trajectory, actions

Motion / Physical Layer
- Stick, rudder, throttle, systems

Timescale
- Several
- Minutes to
- End of flight
- Seconds to
- Several
- Minutes
- < Seconds
Aircraft Strategy: Managed Revolution

Architecture for full-automation that supports incremental reliance during transition from present to pilotless future

- Critical but deterministic tasks transitioned to automation with high, simultaneous functionality, reliability & availability
  - Augmented flight control, guidance, navigation, propulsion & systems management, communication, (“Motion Layer” functions)
  - Required for aircraft with or without pilot/operator
- Automated outer-loops (e.g. mission and maneuver layers) may initially have restricted authority to support pilot/operator. Authority increased in specific situations.
  - Independent monitoring, and possible action, for imminent threats & self-preservation (e.g. pilot impairment, unstable approach)
  - Significant human-machine interaction challenges (e.g. human-automation CRM)
- As experience/trust is earned, transition tasks, responsibilities, authority from human to aircraft, Pilot -> Operator -> User
  - Operator training, licensing follows trust
Outcome: ODM Airspace Integration

Efficient, operations in all airspace classes, surface to flight levels, runway and runway-independent, low-visibility, unprecedented numbers of manned-aircraft, compatible with highly automated vehicles/operations

Example, Greater Los Angeles, population 18.7 million, 34,000 sq miles

- 3 International airports
- 27 Non-international airports
- 4 Military airfields
- ~24,000 vertistops (.7 per sq mile, 1 per 785 people)
- > 72,000 ODM aircraft operating during rush hour... + legacy traffic & UAS
Airspace Strategy: Design for Present, Create Future

Present: work within the ATC system we have, not the one we’d like to have...
- Dependable transportation: Combination of IFR and VFR
  - CTOL routinely flies IFR, urban VTOL initially mainly VMC/VFR
- Plenty of ground infrastructure, but voice-based communication challenging: workload, training, safety
- Integration of urban VTOL into crowded metroplex airspace early demonstration opportunity for high-volume autonomous self-separation

Create future: develop & validate airspace system architecture and requirements for widespread growth, integration of ODM
- Efficient, on-demand routing, sequencing to all runways and vertipads
  - (ARMD ST 6: Dynamic, fully autonomous trajectory services enabling rapid adaption to meet user demand or respond to system perturbations)
- Compatible with highly-automated aircraft
- Coexist with current and leverage emerging users (e.g. UAS)
- ~1 Million ODM vehicles aloft nationwide (current peak ~10,000); 100x
  - Vast majority short-distance, runway-independent operations
Validated Guidelines and Cert. Standards

- Establish equivalent total-system and human performance, safety in current system
- Target safety and performance for ODM
- Comprehensive environment model for design & validation
- Technical system performance, reliability requirements
- Predicting, validating safety & performance in dramatically different human-automation systems
Human-Aircraft Interaction Challenges
Human roles, authority, information reqs., and interfaces

Potential human roles--

• User
  ▪ Directives to outer-loop for desired travel
    o Trip planning with uncertainty, e.g. origin/destination, timing, route, in-flight diversions, return-trip considerations)
  ▪ Emergency authority (e.g. parachute deployment)
    o Insight into proper functioning, safety of overall vehicle and flight
  ▪ Intermodal connectivity
  ▪ Aircraft loading, boarding

• Pilot / operator (on-board or remote)
  ▪ Insight, authority, interaction with middle- and inner-layers

• Dispatch / fleet manger

• Ground handler
## SVO Research Areas 1/2

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### X-57
- Thin-Haul X-Plane
- VTOL X-Plane

### SVO System Concepts
- Scale-Down Tech Integration
- Initial Operational Vehicles
- Scale-Up Tech

### Safety-Critical Avionics and Systems
- Highly Augmented Flight & Trajectory Control

### Automated Perception and Planning
- Safety-Critical Avionics and Systems
- Highly Augmented Flight & Trajectory Control
- Automated Perception and Planning

### NASA Logo
### SVO Research Areas 2/2

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Proof of Feasibility, Concept Exploration, Certification Requirements, Basis

Design, Development, Certification, Validation of Operational Prototypes

Early Operations, Maturation, Redesign, Extension, and Technology Scaling

X-57

Thin-Haul X-Plane

VTOL X-Plane

Scale-Down Tech Integration

Initial Operational Vehicles

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Airspace Integrated Test, Evaluation, & Demonstration

Validated Guidelines, Standards, Cert Methods
### Simplified Vehicle and Airspace Operations

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#### SVo System Concepts
- Thin Haul Flt Deck, Ops
- Air Taxi CONOPS
- PSSA FCS Piloted Air Taxi
- Environment Model for Autonomy
- PSSA Auto Air Taxi

#### Safety-Critical Avionics and Systems
- Architecture for S-C flight control augmentation
- Cert Guidelines, Autonomous Perception Surface
- Cert Guidelines, Autonomy Perceptual Control
- Cert Guidelines, Maneuver Planning, Hazard Avoid

#### Highly Augmented Flight & Trajectory Control
- Thin-Haul Int. Flight & Prop Control
- Piloted Air-Taxi Highly Augmented Flight and Trajectory Control
- Automated Air-Taxi Auto Takeoff, Landing w/Abort, Contingencies
- Real-Time Performance Monitoring, Modeling

#### Automated Perception and Planning
- Perception Req. Auto Air Taxi
- Thin-Haul, Ptt Incapacitation, Emergency Autoland
- Traffic Dect Avoid, Self-Separate Algorithms, Air-Taxi
- Sensor, Perception Development Traffic, Obstructions, Weather,
- Automated Pre-flight Airworthiness, Wt and Bal. Check
- Auto Air Taxi, Mission & Maneuver Contingency Planning Algorithms
- Sensor, Perception Development Navigation, Surface Ops

(PSSA = Preliminary System Safety Assessment)
### Simplified Vehicle and Airspace Operations

#### 2016
- Proof of Feasibility, Concept Exploration, Certification Requirements, Basis

#### 2021
- Design, Development, Certification, Validation of Operational Prototypes

#### 2026
- Early Operations, Maturation, Redesign, Extension, and Technology Scaling

#### X-57
- Thin-Haul X-Plane
- VTOL X-Plane

#### Scale-Down Tech Integration
- Initial Operational Vehicles

#### Scale-Up Tech

#### Current and Planned NAS Integration
- VFR Urban Air-Taxi CONOPS
- Pilot, VFR Urban Air-Taxi Integration
- Auto. Detect and Avoid to Asst. VFR Urban Air-Taxi Ops.

#### Beyond NextGen Integration
- Advanced ATM Working Group
- Autonom. Regional Enroute ODM Simulation (Air-Taxi, CTOL, Legacy, UAS)

#### Airspace Integrated Test, Evaluation, & Demonstration
- Preliminary CONOPS, CNS reqs. For Auto ODM
- Advanced ATC CONOPS

#### Airspace Integrated Test, Evaluation, & Demonstration
- Thin Haul Pilot in Loop Sim
- Pilot in Loop Sim Air-Taxi
- Pilot Taxi System Integration Lab
- Sub-Scale Piloted VTOL Flight

#### Validated Guidelines, Standards, Cert Methods
- Human Perfom. & Error Rates
- Draft Safety-Critical FC Augmentation & Simplified Piloting
- Draft reqs. For Advanced ATM Working Group
Next Steps

- Electrified Aircraft RFI, SBIR subtopics
- Thin-haul and air-taxi working groups develop SVO, Airspace reference concepts
- Preliminary university study funded on urban air-taxi focusing on vehicle automation, remote supervision & “Pilot In Command” considerations
- Expect to fund 1-2 similar preliminary studies in FY17
- Enduring ODM research proposal to ARMD by Jan 2017 for possible FY18 start
Backup
Emerging DOT Driverless Car Guidance

Figure I: Framework for Vehicle Performance Guidance

Scope & Process Guidance
- Test/Production Vehicle
- FMVSS Certification/Exemption
- HAV Registration

Guidance Applicable to All HAV Systems on the Vehicle
- Data Recording and Sharing
- Privacy
- System Safety
- Vehicle Cybersecurity
- Human-Machine Interface
- Crashworthiness
- Consumer Education and Training
- Post-Crash Vehicle Behavior
- Federal, State and Local Laws
- Ethical Considerations

Guidance Specific to Each HAV System
- Describe the ODD (Where does it operate?)
  - Geographic Location
  - Roadway Type
  - Speed
  - Day/Night
  - Weather Conditions
  - Other Domain Constraints
- Object and Event Detection and Response
  - Normal Driving
  - Crash Avoidance - Hazards
- Fall Back Minimal Risk Condition
  - Driver
  - System

Testing and Validation
- Simulation
- Track
- On-Road
**Automation Overarching Technical Challenges**

**Motion layer**: core aircraft systems that combine high-level functionality, reliability, and availability

- All systems needed for normal operation such as flight and trajectory control, propulsion-power, communication, navigation, etc...
- Failure detection, recovery not dependent on human monitoring, action
- Highest availability requirement: control augmentation system for stability, envelope protection, simplified trajectory management
  - Interface to maneuver and mission layers (including human user or supervisor)
  - Accurately estimate current, achievable flight performance envelope for trajectory, mission planning functions
Automation Overarching Technical Challenges

**Maneuver layer:** autonomous perception, situation awareness, trajectory analysis, planning, and selection capability for safety and tactical maneuvering

- Real-time perception, awareness of factors relevant to flight and surface operations (mission, clearance, winds, weather, traffic, obstructions, terrain, airspace, crew, passengers, cargo, etc...)

- Algorithms for autonomous situation analysis, decision making, and trajectory generation for safety and flight execution
  - Priorities: safe, legal, advance plan
  - Independent, robust flight-safety monitoring, reaction
  - Self-separation, sequencing in VFR, future IMC

- Human-automation interaction
  - Limited and high-authority automation
Automation Overarching Technical Challenges

**Mission layer:** Automation that develops, monitors, maintains flight and contingence plans, clearances that are safe, legal, support mission & preferences

- Many aspects already available, emerging in electronic flight bag/tablet apps—need guidelines for credit
- Integrated analysis of flight information services (weather, NOTAMS, etc)
- Assist user with forecast uncertainties and travel options
- Autonomously maintain alternate & bail-out, contingency plans
- Preflight-airworthiness, load plan, on-board weight
- Managing ATC communications
Airspace Technical Challenges

Current airspace (current + ADS-B out, NextGen)

Reduce skill and workload associated with

• Speech to digital combined with support for simplified ATC communication, clearance analysis/negotiation
• Support deployment of small aircraft appropriate digital datalink between ATM, aircraft, crew/users
  • Assess suitability of private networks for early capability
• Autonomous sense and avoid to assist high-density VFR operations
  • Demonstrate self-separation, sequencing with manned back-up
• Integration of initial VFR VTOL operations in targeted, early markets
  • Suitable weather, travel demand, airspace flexibility, ground infrastructure, community integration / support

Desired, future airspace

• Operational CONOPS and requirements for efficient utilization of runways, vertipads, airspace in normal and non-normal conditions
• Flow/resource management, Separation, sequencing, merging, collision avoidance, flight procedures, communication, navigation, surveillance, etc...