ODM Technical Roadmap Report Out:

Simplified Vehicle Operations and Airspace Integration

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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

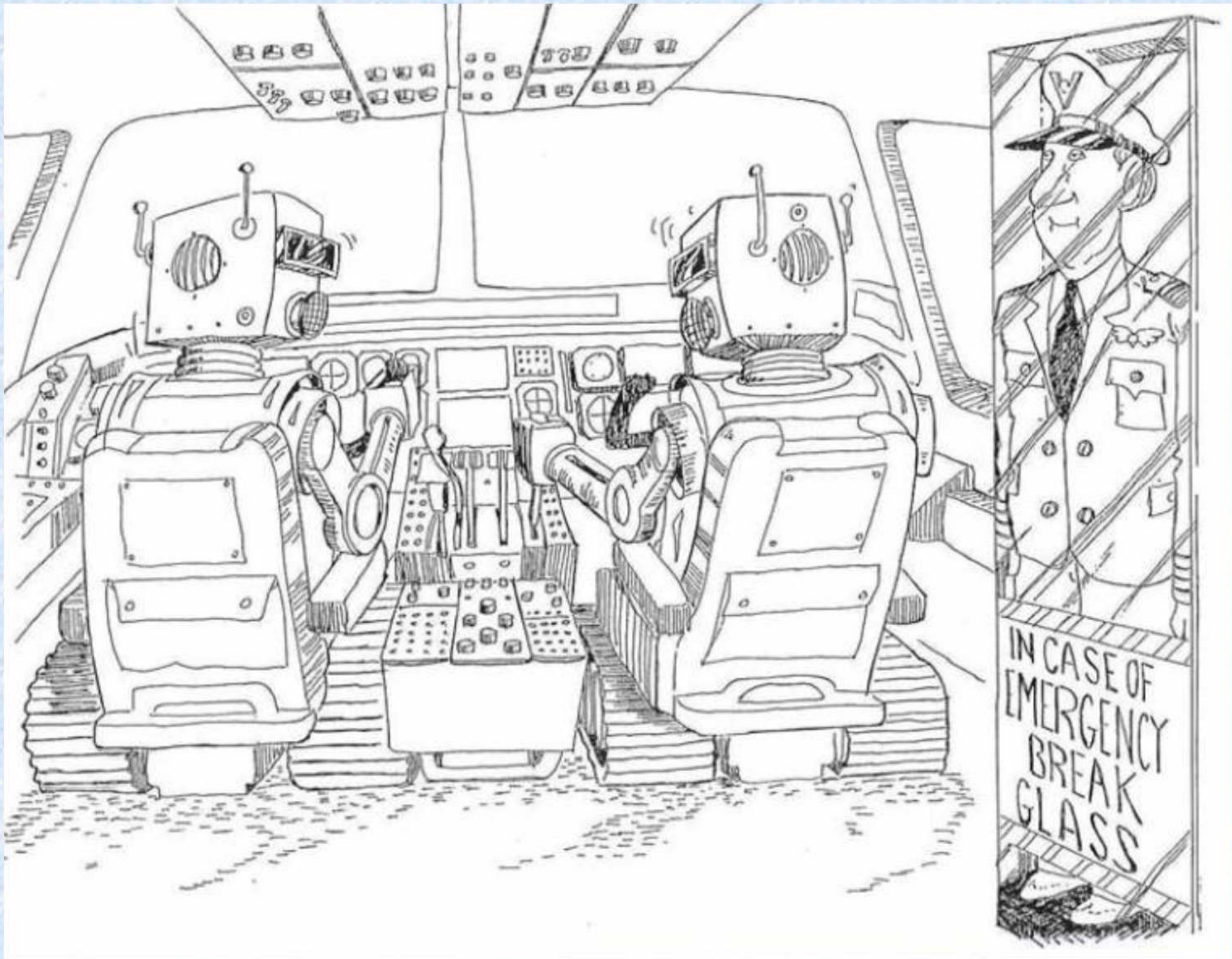
Technologies and certification path for practical, small, pilotless passenger aircraft

- 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

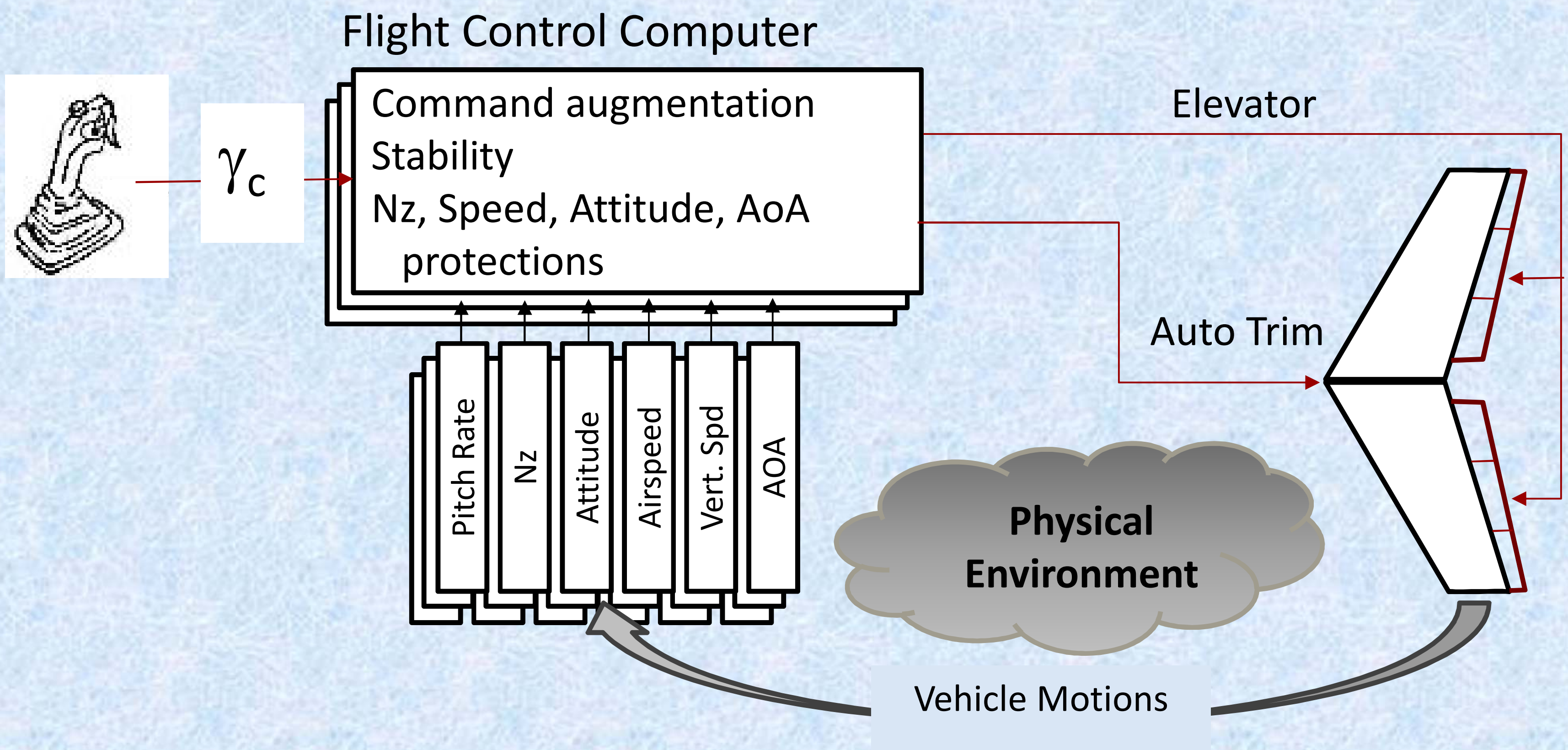
Challenge:



…Currently, pilots & controllers (aka humans) are failsafe for most systems & unknowns

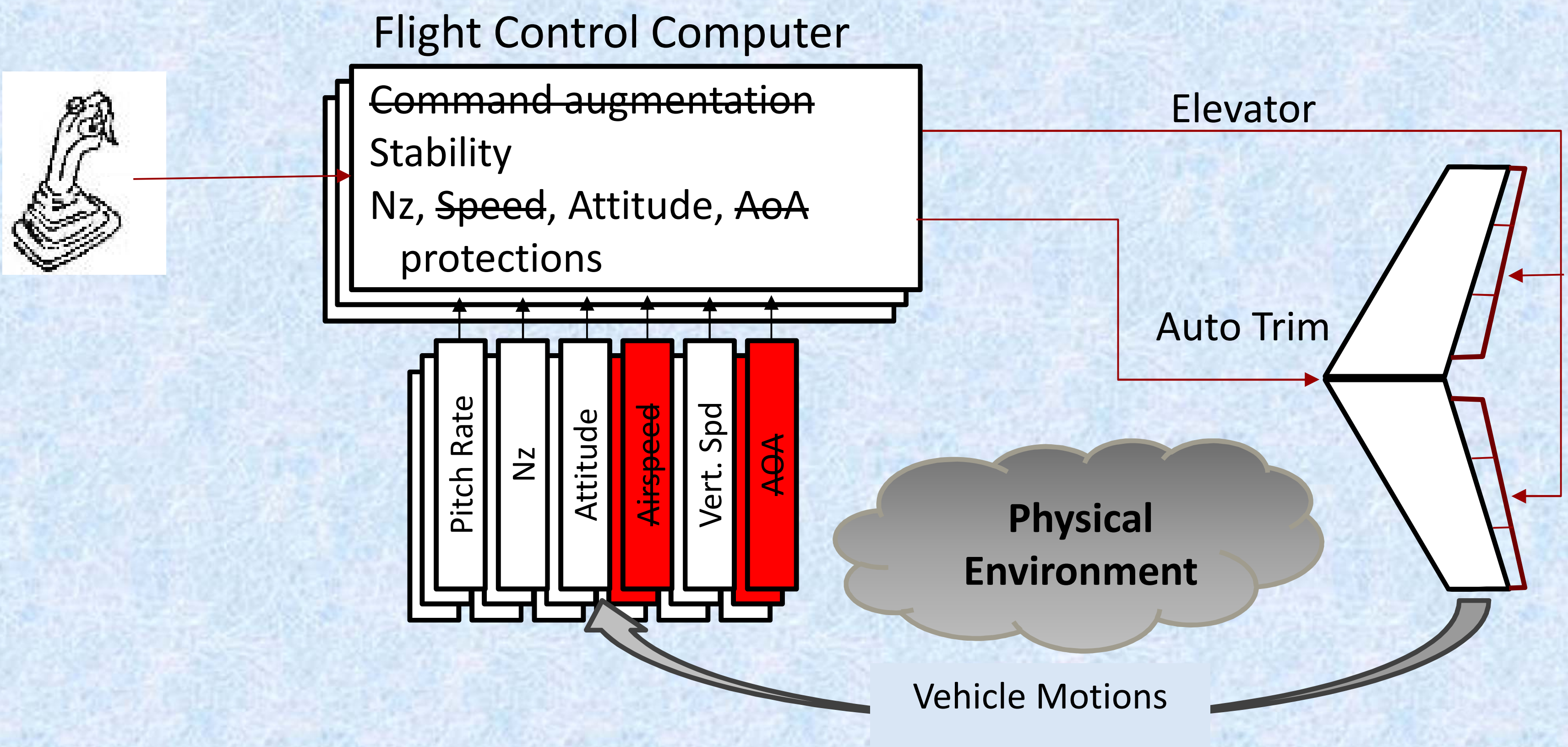
Failsafe Example: Fly-By-Wire

Normal Law: Hardware Assurance ~10^-4



Failsafe Example: Fly-By-Wire

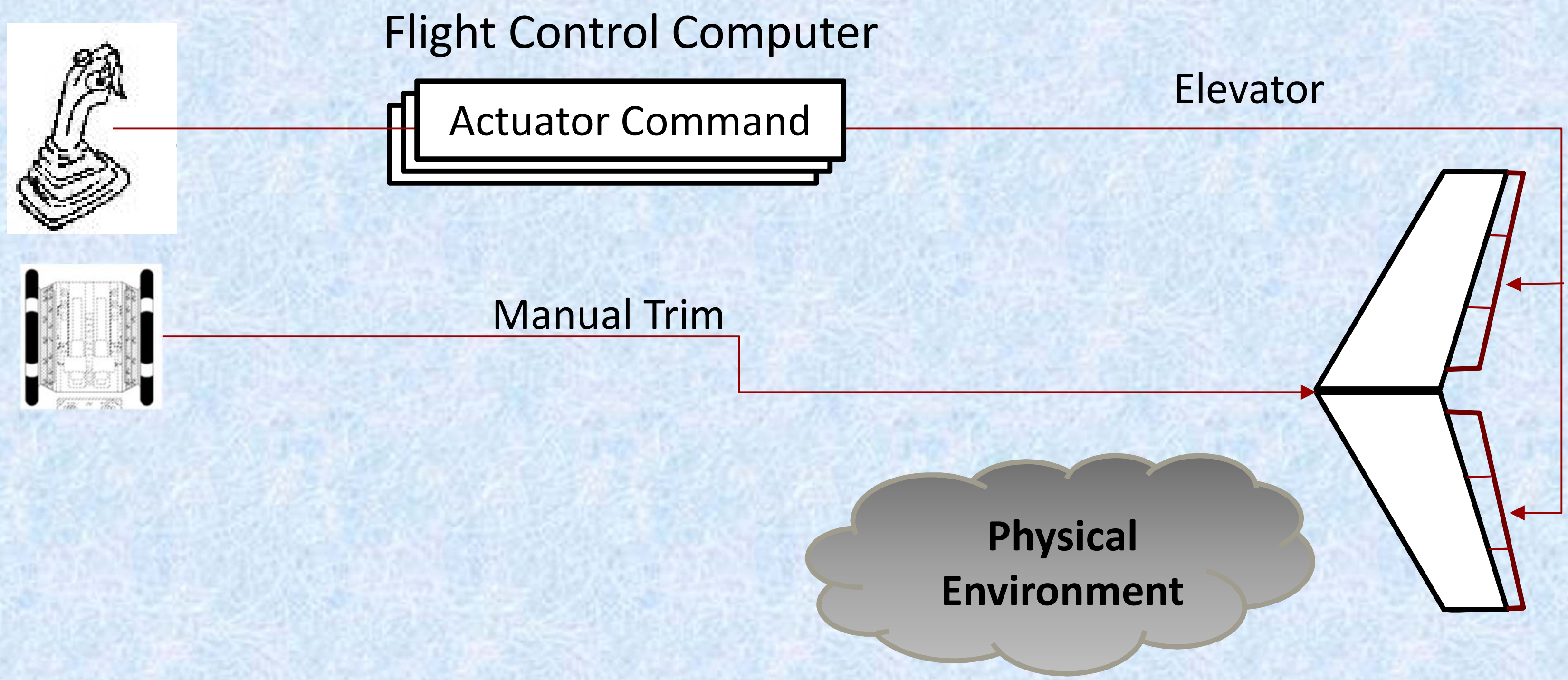
Alternate Law: Hardware Assurance ~10^-6



Note: loss of sensors may also degrade pilot displays and cause loss of autopilot

Failsafe Example: Fly-By-Wire

Direct Law: Hardware Assurance ~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

BASIC SKILLS AND SEAMANSHIP

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

HOME / TOP NEWS / U.S. NEWS

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

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

1 Comments Share Tweet Email Print

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

ARMD Strategic Thrusts

Proposed NASA Technology Investments

SPMR

ODM Barriers & Figures of Merit

Ease of Certification Metric Time/Cost Required	Affordability Metric Total Operating Cost/Pax Mile	Safety Metric Fatal Accidents per Vehicle Mile	Ease of Use Metric Required Operator Training Time & Cost	Door to Door Trip Speed Metric mph
Average Trip Delay Metric Time	Community Noise Metric Perceived Annoyance @ standoff	Ride Quality Metric Passenger Comfort Index	Efficiency Metric Energy/Pax Mile	Lifecycle Emissions Metric Total Emissions /Pax Mile

Product of Kansas City Workshop, Oct. 2015

ODM Barriers & Figures of Merit

SVO Contributions

Ease of Certification <u>Metric</u> Time/Cost Required	Affordability <u>Metric</u> Total Operating Cost/Pax Mile	Safety <u>Metric</u> Fatal Accidents per Vehicle Mile	Ease of Use <u>Metric</u> Required Operator Training Time & Cost	Door to Door Trip Speed <u>Metric</u> mph
Average Trip Delay <u>Metric</u> Time	Community Noise <u>Metric</u> Perceived Annoyance @ standoff	Ride Quality <u>Metric</u> Passenger Comfort Index	Efficiency <u>Metric</u> Energy/Pax Mile	Lifecycle Emissions <u>Metric</u> Total Emissions /Pax Mile

Primary **Secondary**

12

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		Timescale
Over the horizon Awareness, mission planning	**Mission Layer** Objectives, destination Flight plan & route Contingencies, continue/stop	Several Minutes to End of flight
Real-time perception, action formulation	**Maneuver Layer** Local factors of flight Immediate goal, objectives Desired trajectory, actions	Seconds to Several Minutes
Execution of action plan	**Motion / Physical Layer** Stick, rudder, throttle, systems	< Seconds

Aircraft Strategy: Managed Revolution

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

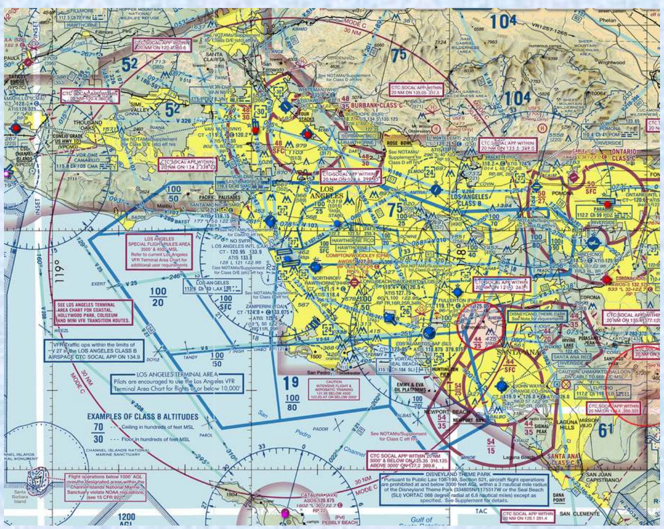
- Critical but deterministic tasks transitioned to automation with **high, simultaneous functionality, reliability & availability**
  - Augmented flight control, guidance, navigation, propulsion & systems management, communication, ("Motion Layer" functions)
  - Required for aircraft with or without 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

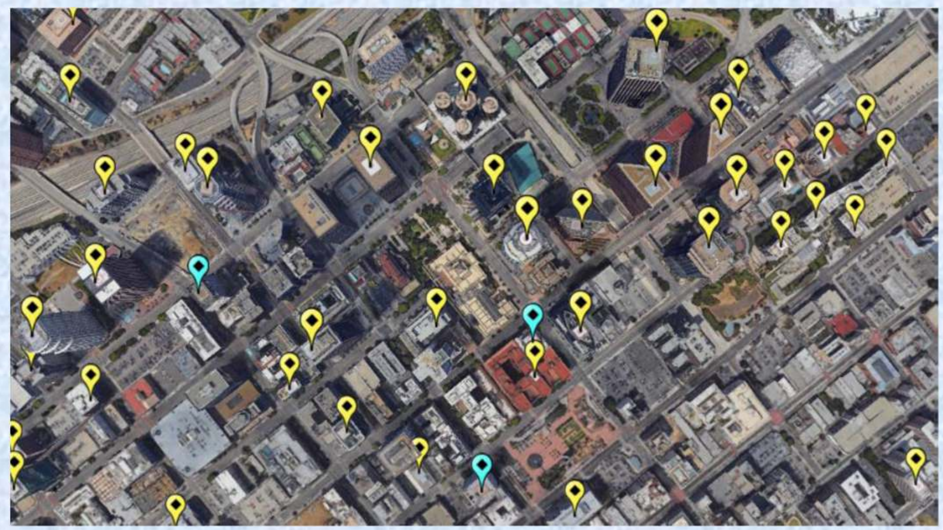
Efficient, operations in all airspace classes, surface to flight levels, runway and runway-independent, low-visibility, unprecedented numbers of manned-aircraft, compatible with highly automated vehicles/operations

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



Current LA Sectional



Downtown LA, existing helipads

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 crowed 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
    - Trip planning with uncertainty, e.g. origin/destination, timing, route, in-flight diversions, return-trip considerations)
  - Emergency authority (e.g. parachute deployment)
    - 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

2016	2021	2026
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


Scale-Up Tech

SVO System Concepts
Safety-Critical Avionics and Systems
Highly Augmented Flight & Trajectory Control
Automated Perception and Planning

SVO Research Areas 2/2

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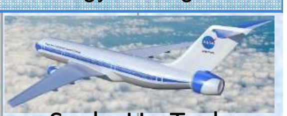
Scale-Down Tech Integration


Initial Operational Vehicles


Scale-Up Tech

Current and Planned NAS Integration

Beyond NextGen Integration

Airspace Integrated Test, Evaluation, & Demonstration

Validated Guidelines, Standards, Cert Methods

Simplified Vehicle and Airspace Operations 1/2

2016	2021	2026
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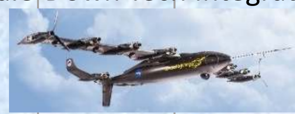
Scale-Down Tech Integration



Initial Operational Vehicles

Scale-Up Tech

SVO System Concepts

- Thin Haul Flt Deck, Ops
- Air Taxi CONOPS
- PSSA FCS Piloted Air Taxi
- FHA, Pilot/AC System
- Environment Model for Autonomy
- Human Perform & Error Model, Term. Ops
- PSSA Auto Air Taxi

(PSSA = Preliminary System Safety Assessment)

Safety-Critical Avionics and Systems

- Architecture for S-C flight control augmentation
- Cert Guidelines Autonomous Perception In-flight Weather, Hazards
- Cert Guidelines, Maneuver Planning, Hazard Avoid
- Cert Guidelines Autonomous Perception Surface
- Cert Guidelines, Mission Planning, Monitoring ,Contingencies

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 Reqs. Auto Air Taxi
- Thin-Haul, Plt 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

Simplified Vehicle and Airspace Operations 2/2

2016 | **2021** | **2026**

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


Scale-Up Tech

Current and Planned NAS Integration

- VFR Urban Air-Taxi CONOPS
- Piloted, VFR Urban Air-Taxi Integration
- Piloted, VFR Urban Air-Taxi Demonstrations
- Auto. Detect and Avoid to Asst. VFR Urban Air-Taxi Ops.
- Automated VFR Urban Air-Taxi Integration
- IFR Applications of Commercial Digital Networks
- Advanced, Automated Airport Management Module + DAA for Higher Vol IFR at Non-towered Airports
- Automated VFR Urban Air-Taxi Sub-Scale Demo
- Automated VFR Urban Air-Taxi Demo Operations

Beyond NextGen Integration

- Advanced ATM Working Group
- Autonomous, Regional Enroute ODM Simulation(Air-Taxi, CTOL., Legacy, UAS)
- Preliminary CONOPS,CNS reqs. For Auto ODM
- ODM Metroplex CONOPS and Preliminary Integ. Sim
- Autonomous, Sub-Scale Metroplex Hyb Sim-Flt Test (Air-Taxi, CTOL., Legacy, UAS)

Airspace Integrated Test, Evaluation, & Demonstration

- Thin Haul Pilot in Loop Sim
- Thin Haul X-Pln
- Scale-up, Single-Pilot 121 Simulation
- Pilot in Loop Sim Air-Taxi
- Automated VTOL User / Remote Op in Loop Sim
- Piloted Air-Taxi System Integ. Lab
- Automated Air-Taxi System Integ. Lab
- Piloted Air-Taxi Demonstrator / Prototype
- Sub-Scale Piloted VTOL Flt
- Automated Air-Taxi Operational Flt Prototype
- Automated Air-Taxi Flt Research Platform

Validated Guidelines, Standards, Cert Methods

- **Human Perfom. & Error Rates** ☆
- **Draft DEP MEL Rating & FCS Reqs.** ☆
- **Draft Safety-Critical FC Augmentation & Simplified Piloting** ☆
- **Draft reqs. For Auto Air-taxi and Airspace integration.** ☆
- **Prelim. Autonomous Metroplex CONOPS, CNS** ☆
- ☆ **Draft Reqs. Autonomous, High-Volume IFR at Nontowered**

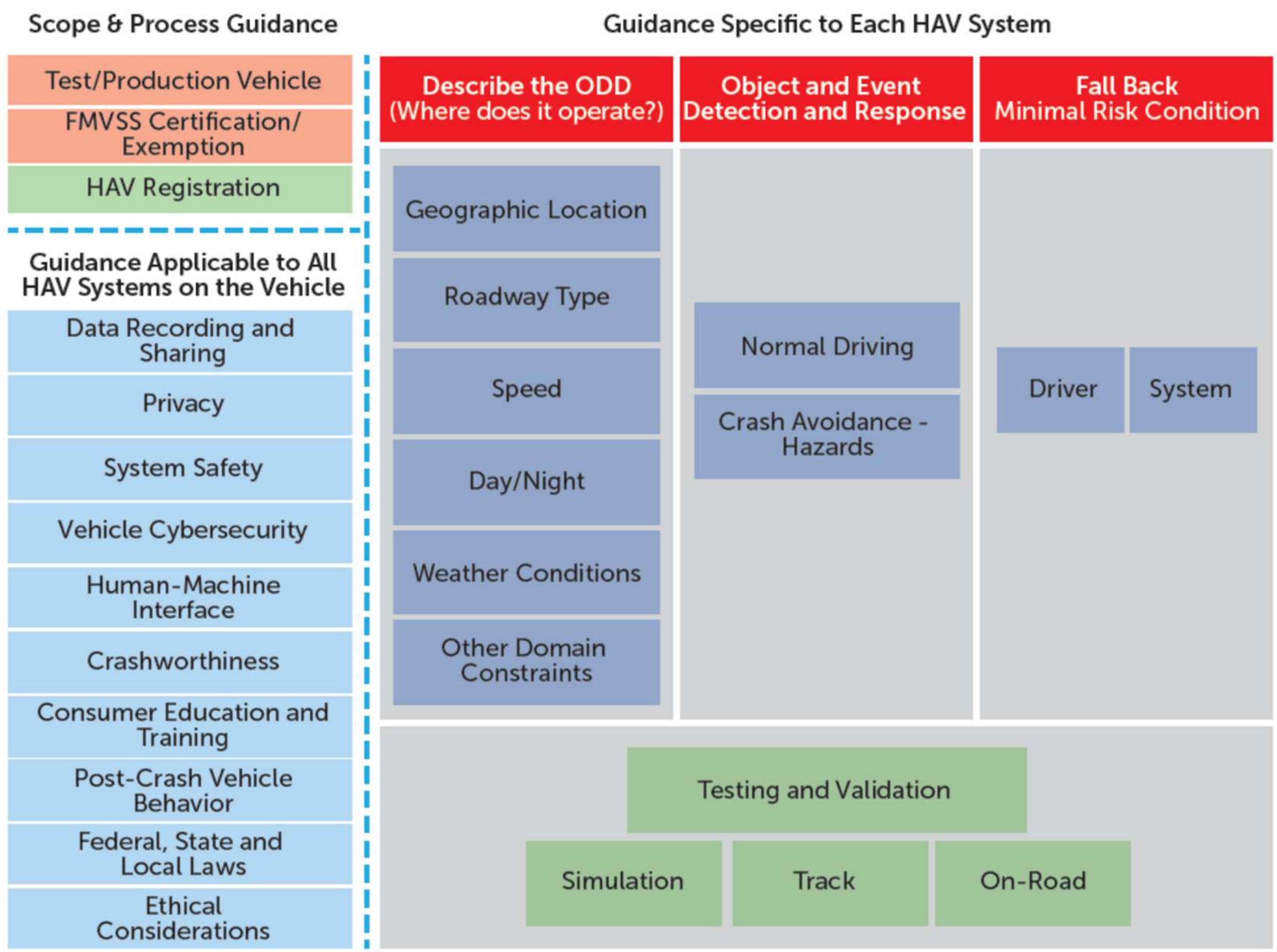
Next Steps

- 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



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…