



# On-Demand Mobility

## Goals, Technical Challenges, and Roadmaps

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# Goals and Benefits

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## Goals

- Leverage and extend current investments in transport and UAS to **transform passenger, on-demand aviation**

## Benefits

- Transformative regional mobility (50-500 nm) that **complements traditional commercial aviation**
- Contribute to **solving top-3 NTSB aviation safety** concerns, while incubating autonomy frontier
- Increase **technology and certification uptake** rate of piloted-aviation with maturation **for transport aircraft**
- Expand **ARMD partnerships** to unconventional players who offer new technology opportunities

# Presentation Outline

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1. What is ODM?
2. Example ODM Mission: Thin-Haul Commuters
3. Summary of Barriers and Technical Challenges
4. Contributions to NASA ARMD Strategic Thrusts and Outcomes
5. Outcomes to Roadmaps
6. ODM Integrated Roadmap
7. Industry Steering Panel
8. Partnership Opportunities
9. Desired FY15 Funded Research
10. Summary

# High-Speed, On-Demand Mobility Defined

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**Mobility:** Movement of people and goods.

**High-speed Mobility:** Mobility at speeds significantly above typical surface transportation speeds ( $\gg 70$  mph). Enabled by aircraft (air-mobility) for distributed travel needs and high-speed rail for centralized, dense urban corridors.

**Scheduled Mobility:** Public transportation services aggregating the needs of many users with the specifics of a trip (origin, destination, and departure time) determined by service providers (e.g. bus, rail, airline operators).

**On-Demand Mobility:** Personal transportation capabilities in which the specifics of a trip (origin, destination, and departure time) are chosen by the user.

**High-Speed ODM:** ODM at  $\gg 70$ mph

- Enabled by small personal, charter, and high-frequency commuter aircraft (Thin-Haul)
- Includes manned and unmanned (passengers & cargo; “piloted” & autonomous)
- Currently a niche market due to cost, safety, and trip reliability considerations.

**ODM is shorthand for High-speed ODM within the aviation community**



# Example ODM Mission: Thin-Haul Commuters

**Thin-Haul Commuters** provide Essential Air Services (EAS) to small communities with 'thin' passenger trip distributions. New business models and technologies are developing across many industries to capture 'long-tail' markets instead of focusing only on dominant markets.

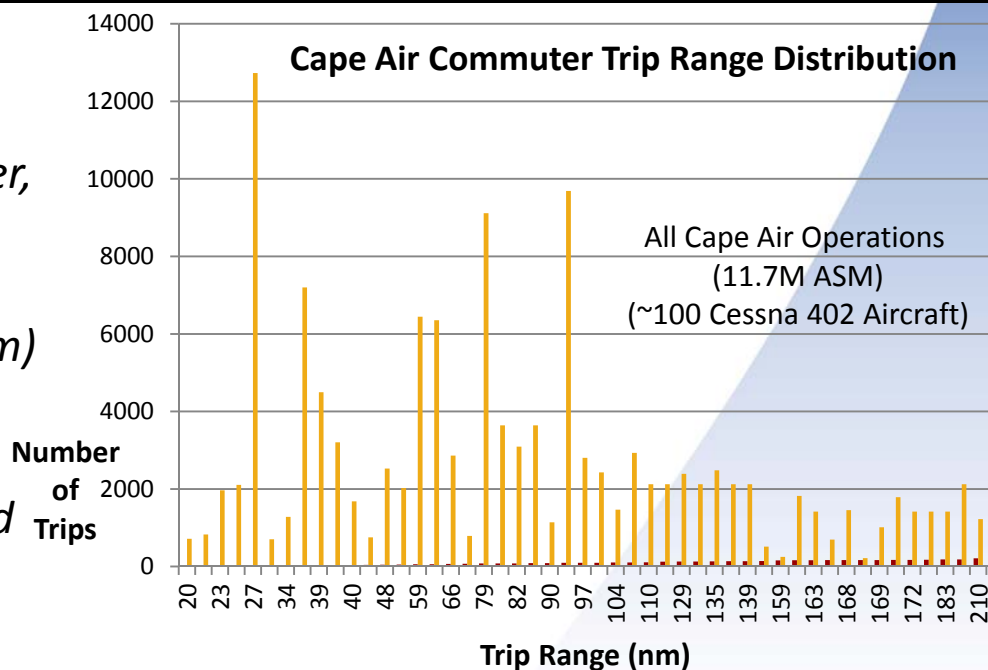
(see *The Long-Tail: Why the Future of Business is Selling Less of More*)

**Example of dominant (green) and long-tail (yellow) market distribution (with each being 50% of the total market share)**

NEW ENGLAND



- Congress provides \$241M of annual funding to subsidize this market.
- Cape Air is the largest commuter airliner, operating in the Northeast, Midwest, Western U.S., and Caribbean
- Stage lengths are short (max is <220 nm)
- Operating costs of existing Thin-Haul aircraft are very high.
- Load factors are typically low compared to commercial airlines.



# Congressional Testimony, Cape Air CEO Dan Wolf



” In every case when Cape Air’s 9-seat aircraft have taken over year-round EAS service at a community in the Continental US ridership increased (See Table 1). Combined ridership more than doubled. This is apparently paradoxical given that in most cases Cape Air’s 9-seat aircraft replaced 19 or 30-passenger aircraft. However, Cape Air’s model of high-frequency, non-stop, low-fare service in smaller aircraft consistently ends up attracting more passengers. ....”

” Cape Air’s model of high-frequency 9-seat scheduled airline service can be great air transportation for small communities in or out of the EAS program. This sector, however, is significantly challenged by a lack of suitable new aircraft and the burgeoning shortage of qualified pilots.”

## Current Cape Air Challenges are well matched to two key technology areas

- 1) **Electric propulsion** providing lower operating costs, higher safety, greater reliability (Cape Air is also one of the New England leaders pushing towards low carbon emissions)
- 2) **Autonomy** providing pilot aids that can reduce workload/training, with higher safety

**The Thin-Haul sector is largely unsupported by current NASA ARMD investment despite significant needs, risk tolerance, importance to Congress, and faster design cycles which are well suited for incubation of the new technologies and their certification rules (and at lower development cost).**



## ***Example 2025 Electric Thin-Haul Commuter***



9 Pax payload

<10,000 lbs gross weight

200 mile electric range

Near-all weather

Propulsion redundancy

High wing loading ride quality

Ultra low community noise

<2000 ft field length capable

250 mph cruise speed at high efficiency

400 mile range with hybrid-electric range extender

Single-pilot with Part 121-like safety

Robust low speed control

Low gust sensitivity

<\$3.00/mile operating cost

Dramatic reductions in life cycle carbon emissions promoting a path towards the use of renewable energy sources (wind, solar, etc)



***4-Seat NASA ARMD TAC/CAS 2017 CEPT Technology Demonstrator  
(supports both Zip and Thin-Haul commuter missions)***

# Other ODM Missions



## ***“Zip” Aircraft:***

<4000 lbs, 4 pax payload, <2000 ft runway, 200+ mph, 200-400 mile range, Near-all weather, Auto-like use of use and safety, < \$1.50/mile

*Zip Equivalency: Car*



## ***Hyper-Commuter PAVs:***

<1000 lbs, 1+1 pax payload, Helipad capable, 150mph, 200 mile range, VFR capability, Auto-like ease of use and safety, < \$0.75/mile

*HC-PAV Equivalency: Motorcycle*



## ***sUAS Package Delivery:***

<55 lb, 10 lb payload, Short range (<100 miles), Close proximity VTOL operations, Low noise and emissions

Note: While there’s already much Industry R&D for this mission, it shares similar vehicle/autonomy/airspace needs while providing limited life-critical risks for the developing and testing of these technologies.

*sUAS Equivalency: Bicycle courier*



**ODM missions usually require extremely low noise and emissions, and high safety.**



# ODM Barriers: Vehicle



## Vehicle Barriers

- **High Vehicle Cost** due to small market, low utilization, expensive components and materials.
- **High Operating Cost** due to poor efficiency, high fuel cost, poor reliability and high maintenance.
- **Poor Safety** (~6x worse than cars, ~110x worse than airlines).
- Single engine aircraft have **Poor Perceived Safety** with a lack of redundancy across primary power.
- **Low Ease-of Use** due to high initial and recurring training and in-flight workload discourage non-enthusiasts.
- Communities object to **High Noise** and limited community benefit
- **Poor Emissions** don't promote sustainable or scalable operation
- **Low Trip reliability** due to weather, mechanical, pilot limitations
- Uncomfortable & fatiguing **Ride Quality** due to low wing loading



## *Airspace strategy note-*

- Initial ODM research is primarily vehicle centric
  - Until vehicle viability widely recognized, little ATM influence
- *Leverage concepts and research supporting other sectors (UAS, Commercial, legacy GA)*
- “Hardest” case and likely initial operating requirement is ATM 0, +1, +2)
  - Vehicle research must insure capability, efficiency with range of possible futures including ATM 1, 2, & 3 concepts

## Airspace system barriers

- Current and planned systems (ATM+1, +2) can't sustain > **3x growth** in operations despite ground infrastructure ability to accommodate
  - **Airspace not initially physically limiting, but contributes to technical challenges**
    - In particular, voice-based comm contributes to pilot workload, errors, and limits aircraft automation support

# NASA Aeronautics Strategic Thrusts



## Safe, Efficient Growth in Global Operations

- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks



## Innovation in Commercial Supersonic Aircraft

- Achieve a low-boom standard



## Ultra-Efficient Commercial Vehicles

- Pioneer technologies for big leaps in efficiency and environmental performance



## Transition to Low-Carbon Propulsion

- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology



## Real-Time System-Wide Safety Assurance

- Develop an integrated prototype of a real-time safety monitoring and assurance system



## Assured Autonomy for Aviation Transformation

- Develop high impact aviation autonomy applications

# Support for Agency Strategic Goals: Primary



**Outcome:** Pioneer low-carbon propulsion technology

**ODM Contributions:** Enable practical, wide-scale operational use of electric and hybrid-electric propulsion in manned aircraft with a strategy of incentivizing low carbon solutions through dramatic reductions in direct operating costs at shorter ranges.

(ODM Tech Challenge 1)

**Outcome:** Assured autonomy for aviation transformation

**ODM Contributions:** Significantly simplified piloting skills and training for manned aircraft while increasing system safety and capability by reducing pilot induced accidents (~70% of GA total).

(ODM Tech Challenge 2)

**ODM provides a technology introduction, validation path for transports**

## Support for Agency Strategic Goals: Secondary



**Outcome:** Develop technologies to substantially reduce aircraft safety risks.

**ODM Contributions:** Increase future small aircraft safety by >10x through combined vehicle propulsion robustness and trusted autonomy. (ODM Tech Challenge 3)

**Outcome:** Pioneer technologies for big leaps in efficiency and environmental performance.

**ODM Contributions:** Lower cost sub-scale demonstrations of multi-use technologies (i.e. high aspect ratio wing aeroelastic tailoring, fuselage boundary layer ingestion, distributed electric propulsion integration across disciplines, hybrid-electric power architectures, robust low speed control, spread frequency and phased acoustics, cruise efficient STOL, low cost robotic composite manufacturing, etc). (ODM Tech Challenge 4)

**ODM provides a technology introduction, validation path for transports**

# ODM Outcomes to Technology Roadmaps: Assured Autonomy and Increased Safety

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- **“Simplified Vehicle Operations” (SVO) research focuses on flight systems, human, and human-automation interaction**
  - Barriers: safety, ease-of-use, trip reliability, cost
  - Leverages, but very different focus than SASO Reduced Crew Ops (RCO).
    - SVO enables new class of pilot/ operator, RCO supports Airline Transport Pilots conducting new operations
  - Note: automation and autonomy are tools, not goal of SVO
  
- **SVO transitions from expert pilots -> trained operators -> users**
  - Key steps:
    1. Demanding flight-critical, but **deterministic tasks** transitioned from human to **ultra-reliable automation**: component failures must not effect performance
      - State of the art example: current FBW failure modes require reversion to stick to surface piloting (e.g. Air France 447): unacceptable for SVO
    2. Initially use non-deterministic **autonomy as non-critical decision aids** and in emergency situations (e.g. landing with incapacitated pilot) to gain operational experience, confidence
    3. As trust develops, **transition tasks and responsibilities** from human to autonomy
      - Operator training, licensing must evolve with technology, but full credit lags behind



# 3 Epochs of Simplified Vehicle Operation (SVO)



- **SVO + 1 (2016 – 2026): Key deterministic tasks relegated to automation**
  - Current FAA training required (e.g. ab initio-to IFR in minimum of 70 hours)
  - But, unlike present new pilots, capable of safe, confident, near-all weather ops.
  - Expect only incremental airworthiness certification accommodations
  - Despite constraints, can dramatically simplify low-level tasks that dominate current training and workload and allow focus on high-level (harder to automate) perception and judgment skills
  - Technology mitigates pilot as single-point of failure, greater than automotive safety
  - Immediately benefits thin-haul commuter and grows latent small aircraft market
  
- **SVO + 2 (2021 – 2036): SPC, Simplified Pilot Certificate**
  - Simplified training and licensing based on research and operational experience from SVO + 1
  - New flight system, interfaces, and operation standards that allow updates to training and operational regulations in Part 61, 91, and 135 taking full advantage of technology
  - Goal ab initio to near-all weather “pilot” in <40 hours (similar to driver training)
  
- **SVO +3 (2031 - 2051): Autonomous operation**
  - Autonomy fully responsible; user involvement in flight is optional, restricted

# Technologies Critical to SVO 1 and 2



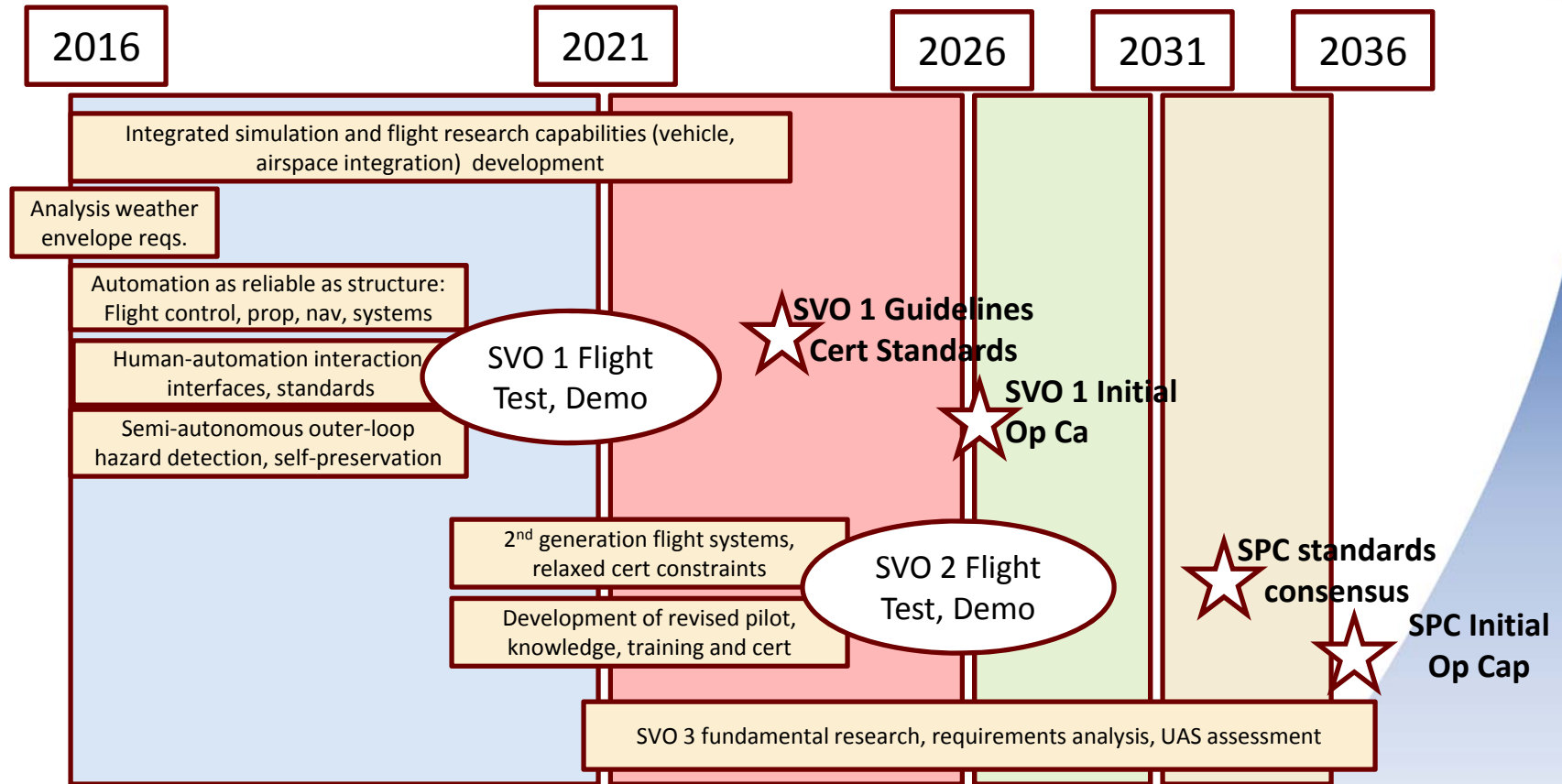
- **Underlying safety-critical technologies enabling SVO 1 & 2 are resilient automation, not non-deterministic machine intelligence**
  - Human retains overall responsibility for safety of flight, but is **totally relieved** from many low-level tasks and responsibilities that 1) increase training, 2) often bite (e.g. stall awareness)
    - Integrate existing, near-existing technologies to create deterministic **automation as reliable as structure**
    - Machine intelligence introduced, but not for safety-critical tasks; gain experience before critical reliance
  - Sub-component failures, rare-normals must not require novel piloting skills, for example
    - Engine-out
    - Ice encounter
    - Loss of GPS
  - Automation capable of emergency landing if pilot incapacitated
    - Digital parachute
    - Much less demanding than full-mission automation due to special handling by other elements of the system (e.g. traffic cleared away) and relaxed cert requirements due to rarity of use (back-up to a rare event, not primary capability)
  - Dissimilar strengths and limitations of human and automation increase joint system safety and performance while reducing costs and certification risk

# SVO +3 Technologies



- **Final convergence of UAS and manned aviation**
  - Passenger carrying UAS
  
- **Requires fundamental breakthroughs in machine intelligence**
  - Time horizon unknowable
  - Current reliability of autonomous aircraft maybe 99.9% (in benign weather), but carrying humans as cargo requires 99.9999% or better
    - Full autonomy is estimated to be > 3-4 orders of magnitude more challenging than required for SVO 1 or 2
    - Incremental introduction still needed validate safe operation in real-world, novel situations
      - UAS experience will useful, but sUAS likely to take advantage of options not appropriate for manned aircraft and larger UAS likely to rely on remote pilots
  
- **SVO 3 leverages SVO 1, 2 and of course, advance autonomous vehicle research**
  - Ideally, common-core across vehicle classes, applications

# Simplified Vehicle Operation (SVO) Roadmap



# ODM Outcomes to Roadmaps: Pioneer Electric Propulsion

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- **Electric propulsion provides a method of addressing multiple barriers with a single technology that integrates across many disciplines.**
  - Propulsive and aerodynamic efficiency, emissions, noise, control, ride quality, and structural characteristics can be significantly improved through tight coupling of distributed electric propulsion.
- **New integration strategies that maximize synergistic cross-disciplinary coupling benefits to achieve optimal vehicle system solutions**
- **Advanced electric motors and controllers**
- **Redundant and robust high voltage (>400 volts) architectures**
- **Advanced batteries and integration solutions**
  - Feasibility for ODM markets is at the 400 to 500 Whr/kg battery pack level
  - Multi-functional structural batteries to reduce battery installation weight while meeting aerospace safety standards.
- **Hybrid-electric range extenders**
  - Practical ranges of 300 to 600 nm in the near-term require hybrid-electric systems with small power systems to augment energy storage.

# ODM Outcomes to Roadmaps: Pioneer Techs for Leaps in Efficiency + Environment

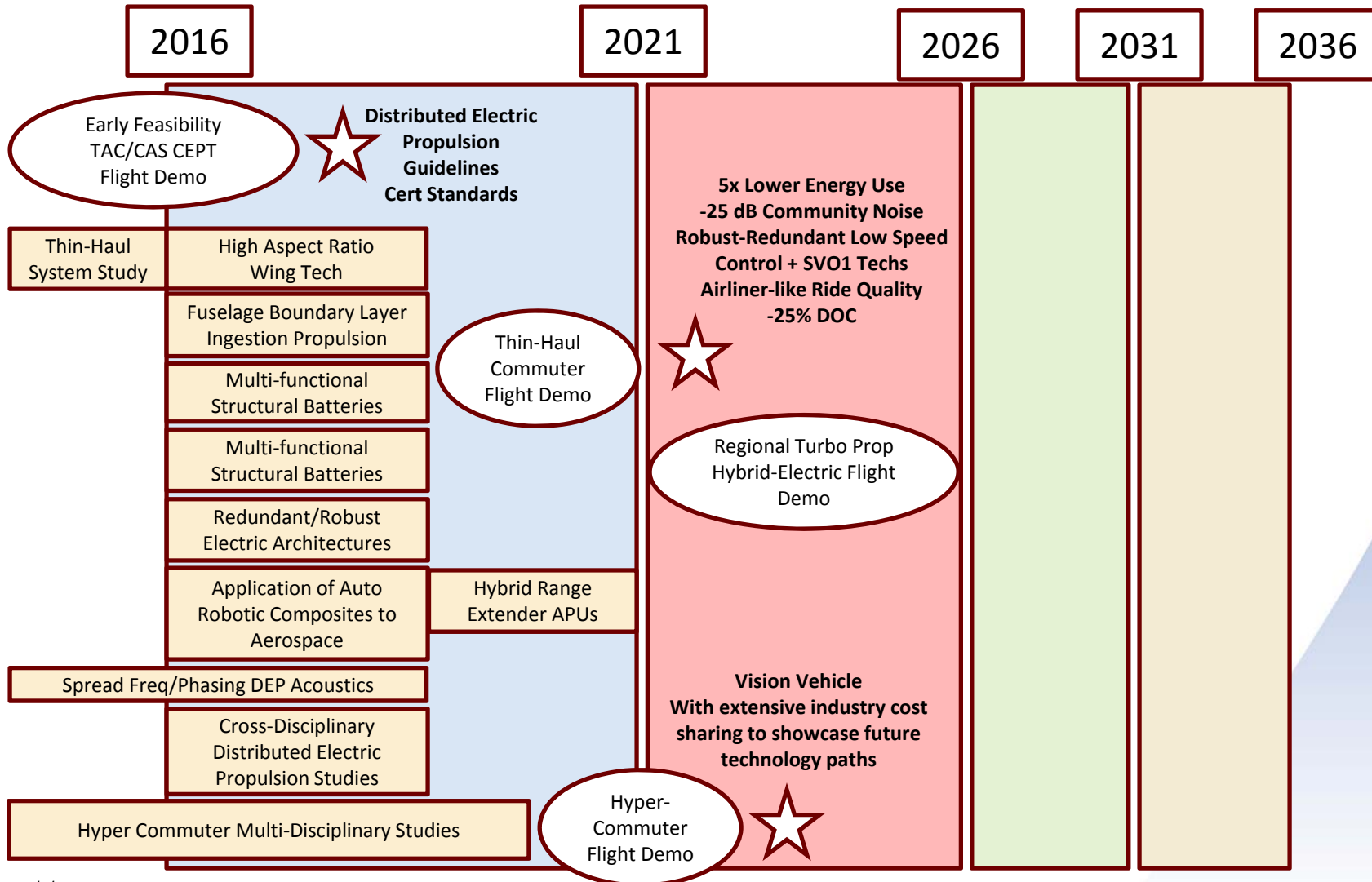
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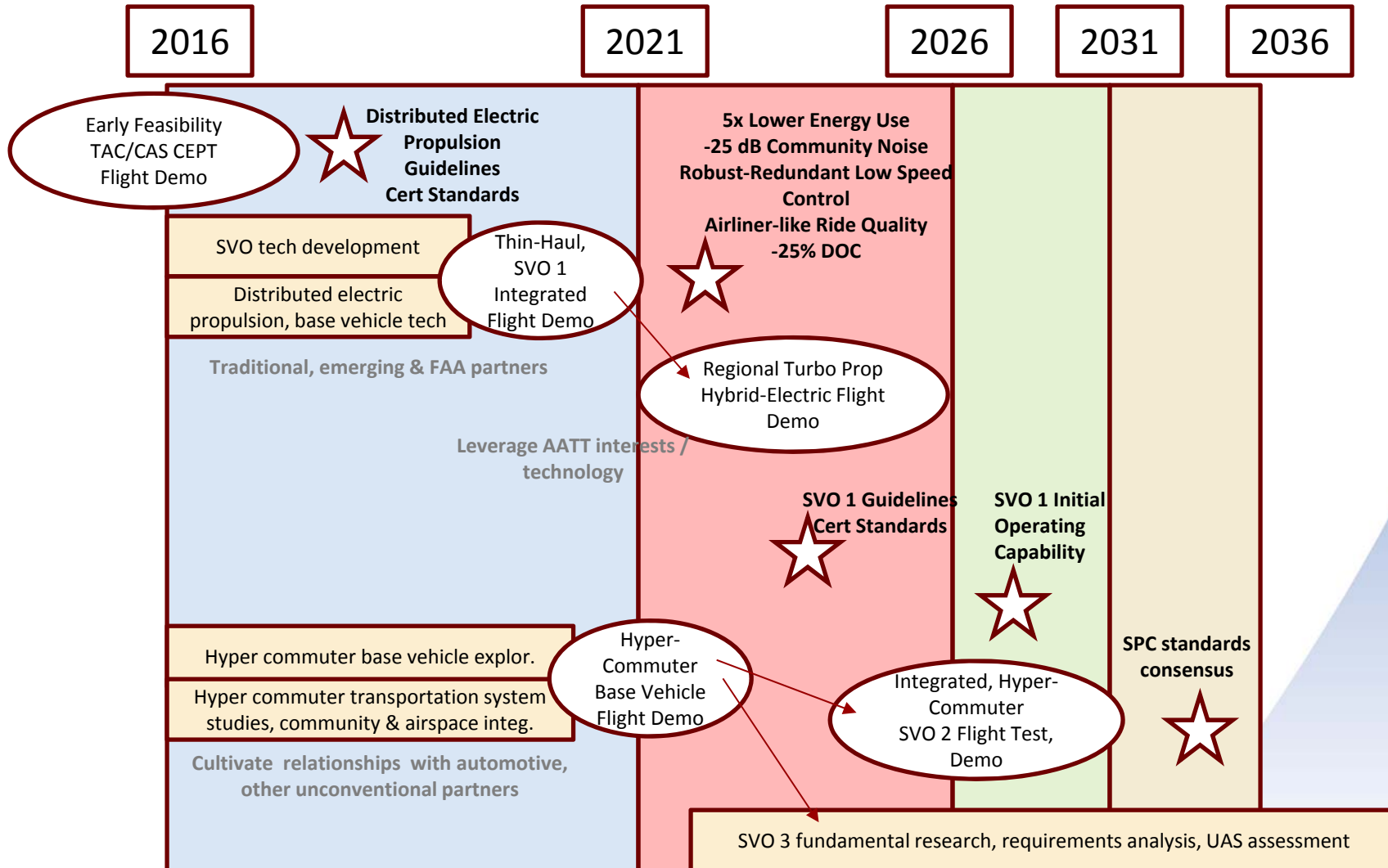
- **Many of the key technologies for improving efficiency and environmental friendliness can be investigated collaboratively with AAV program and demonstrated in an integrated manner with ODM aircraft that act as sub-scale demonstrators for commercial aviation (but at significantly lower cost)**
  - Distributed spread frequency and phasing acoustics with improved community annoyance modeling
  - Aero elastically tailored wings able to achieve high aspect ratio with minimal weight penalties
  - Fuselage boundary layer ingestion supplementary propulsion to improve propulsive efficiency
  - Application of robotic composite manufacturing methods from automotive to aerospace for dramatic cost reductions
  - Robust and redundant integrated propulsion that can achieve either cruise efficient STOL or high wing loading with improved ride quality.
  - Application of advanced materials that have properties enabling smart capabilities leading to improved safety (sensing, improved margins, etc)



# Electric Propulsion, Efficiency and Environment Technologies Roadmap



# ODM High Level Integrated Roadmap



# Next Road Mapping Steps

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## Build consensus across the community of interest

- Program is about building the emerging ODM community, not just technology.
- The technology goals, strategy, and decomposition to roadmaps is based on the expertise of ODM planners.
- Review and participation by industry, academia and the FAA will greatly improve the ODM research strategy.
- The AIAA Transformational Flight Program Committee was created 3 years ago as an open, broad-based community of interest with ~50 members actively participating. ODM content will be reviewed with this professional society to bring in as many perspectives as possible.
- Developing formal partnerships is desired to guide further strategic planning by conducting preliminary system studies.
  - Ad-hoc steering panel for overall strategy and plan formulation
  - Individual agreements to study specific concepts, opportunities
- **Connectivity and partnerships to other ARMD, NASA, DoD, DOT investments, programs**

# Industry Steering Panel

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- **Discussions with ARMD have suggested formation of an industry steering panel to provide guidance on ODM research priorities.**
- **An initial participant list has been shared that includes U.S. large aerospace companies, General Aviation companies, emerging ODM aviation companies, universities leading ODM related research, small companies leading relevant new tech development, as well as other industries that have interest in participating in ODM including automotive companies.**
- **An initial meeting will be planned once initial roadmaps are in place and initial ODM resources are provided.**
- **FAA involvement in the steering panel is desired, and the initial meeting location will likely be selected to enable FAA participation. Prior contact with the FAA has shown significant interest in electric propulsion and autonomy at the GA aircraft scale for incubation of certification standards.**
- **Participation across NASA centers and ARMD will be encouraged to build a single NASA vision for the future needs of ODM research.**

# Summary

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- **ODM provides high-leveraged benefits**
  - Transformative regional transportation
  - Path to operational introduce advanced technologies that benefit commercial transports
  
- **Enabled by multidisciplinary integration of autonomy, distributed electric population, and automated fabrication**
  - Vehicle feasibility is initial focus
  - Integrate current and future ATM ops and research
  
- **Actively building ODM community for further road map development and advocacy**