On-Demand Mobility (ODM) Technical Pathway:

Enabling Ease of Use and Safety

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Goals and Benefits
ODM Safety and Ease of Use

Goals

- Improved ease of use and safety
  - Long-term goals: automotive-like training and workload & better-than automotive safety
  - Ease-of-use encompasses initial and recurrent training, preflight & in-flight workload

Benefits

- Necessary (but not sufficient) for practical aircraft-based ODM
- Faster, less risk averse, lower-cost proving ground for new technology and operations beneficial to transport aircraft
- Technologies that help address NTSB’s Most-Wanted aviation safety improvements
  - General aviation loss of control
  - Public helicopter safety
  - Procedural compliance
What are the Challenges?

Gulf of Technology, Policy, and Acceptance

Contemporary, Highly Automated Aircraft

Flying that's as Easy (…or Easier) and Safer than Driving.

Technical feasibility
Airworthiness Certification
Training and Operational credit
Acceptance
Alignment of proposed ODM research with NASA Strategic Thrusts

Performance requirements and current state of the art
  - How safe is safe enough and is it achievable?
  - How has technology simplified piloting already?
  - Emerging automation technologies

“Simplified Vehicle Operations” (SVO), proposed research strategy
  - Planned evolution & incremental revolution
  - Pilots -> Trained operators -> users

Next steps
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
NASA Aeronautics Strategic Thrusts: Safety, Ease

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**Assured Autonomy for Aviation Transformation**
- Develop high impact aviation autonomy applications
Outcome: Assured autonomy for aviation transformation

ODM Contributions: Significantly simplified piloting skills and training for manned aircraft while increasing system safety and capability. (ODM Tech challenge 2)

Outcome: Develop technologies to substantially reduce aircraft safety risks.

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

ODM provides a technology introduction, validation path for transports
2013 Total aviation fatalities: 443, 420 in general aviation and Part 135 operations....95% of total
### Performance: How Safe is Safe Enough?

#### Challenge:
Bring the safety of all transportation by small aircraft up to the level demonstrated by commuter airlines.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Fatalities per hundred million passenger miles</th>
<th>Rate relative to passenger cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Cars</td>
<td>0.643</td>
<td>1.0</td>
</tr>
<tr>
<td>US Airline Flights</td>
<td>0.0038</td>
<td>167x safer</td>
</tr>
<tr>
<td>Commuter Airlines (&lt;10 passengers)</td>
<td>0.102</td>
<td>6.7x safer</td>
</tr>
<tr>
<td>General Aviation</td>
<td>7.8 (estimated)</td>
<td>12x less safe</td>
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How Has Technology Simplified Piloting?

1990’s

2015

+ tablet-based electronic flight bag for additional pre and in-flight awareness
How Has Technology Simplified Piloting?

- Operationally the change has been tremendous, improving utility, efficiency, average workload, comfort, potential safety, etc.
  - Navigation / position awareness
  - Coupled autopilots
  - Access to information pre and in-flight
  - Electronic flight bags / tablets
  - System monitoring, failure detection

- But...
...Becoming and remaining proficient & vigilant is as, if not more, challenging than ever before

- Typically, greater than 500 hours and $30,000 required to become experienced instrument pilot
- Required knowledge and skills have increased, not decreased
- System and mode complexity has increased
  - Variations between aircraft, software loads
- Pilot expected to detect, troubleshoot & backstop wider range of non-normals
- Average workload is much lower, but peaks remain high, if not higher
How Has Technology Simplified Piloting?

- Realized safety has not significantly changed.

General Aviation Accident Rates, 2003-2012

Accidents per Million Flight Hours

Calendar Year


2013 Goal

Preliminary

http://www.ntsb.gov/investigations/data/Pages/2012%20Aviation%20Accidents%20Summary.aspx
Top Accident Categories

- Significant improvement in accident rate by addressing basic errors
- Automotive-level safety achievable by improving relatively deterministic functions
- Age of current fleet contributes to component failure rate
Are Autonomous Systems a Light on the Horizon?
Definitely, but We Should Be Realistic

- Costs are plummeting (sensor, computers, data algorithms)
- But:
  - Rate of progress more modest than typically reported...

2003, Honda offers active lane keeping assist (0.2 lateral g)
Function Allocation, Humans and Automation

Cummings, 2014; Rasmussen, 1983
Definitely, but We Should Be Realistic

- Costs are plummeting (sensors, computers, data, connectivity)
- But:
  - Rate of progress more modest than typically reported...
  - Performance in complex, novel situations likely to remain brittle
  - Less capable but more reliable systems may have better return on investment
    - It’s the corner cases that drive skills, training, monitoring, and costs not the nominal
  - Regulators need statistically significant operational histories before approving critical reliance on new technologies & operations without reversion to proven
    - One revolution at a time
Pathway to Simplified Vehicle Operations (SVO)

Transition from expert pilots -> trained operators -> users

- Key steps:
  1. Demanding flight-critical, but deterministic tasks transitioned from human to ultra-reliable automation: sub-system failures must not effect performance
     - Simplified flight control and loss-of-control prevention, navigation, propulsion and systems management
     - Must avoid Air France 447-like scenarios
     - 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
  2. 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
  - Technology mitigates pilot as single-point of failure
  - Immediately benefits thin-haul commuter ops and latent small aircraft markets
  - Expect only incremental airworthiness certification accommodation, but lays foundation for future
  - Current FAA training required (e.g. ab initio-to IFR in minimum of 70 hours)
  - New pilots capable of comfortable, confident, near-all weather ops.

- **SVO-2 (2021 – 2036):** SPC, Simplified Pilot Certificate
  - Simplified training & 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 operations
  - Autonomy fully responsible; user involvement in flight is optional
Simplified Vehicle Operation (SVO) Roadmap

2016

- Ultra-reliable automation
- Simplified Pilot Interaction & Interface
- Semi-autonomous aiding and self-preservation

2021

- Thin-Haul Commuter Demo
  - SVO-1 Flight Test, Demo
  - SVO 1 Guidelines Certification Standards

2026

- Ab Initio Demo
  - SVO-2 Flight Test, Demo
  - Revised pilot, knowledge, training and certification
  - Simplified Pilot Certificate Consensus Standards

2031

2036

SVO 3 fundamental research, requirements analysis, UAS assessment
Next Steps

Build community of interest and consensus

- Effort includes building a community, not just technology
  - Participation of industry, academia and the FAA essential to project formulation, execution, commercialization
  - Oshkosh forums, July 21 (public) and 22 (Industry)
  - Kansas City workshop in collaboration with FAA
    - Nominally late October

- Connectivity and partnerships with other ARMD, NASA, DoD, DOT investments, programs
Questions
Performance: How Safe is Safe Enough?

- Small, commuter airline record highlights that even current small aircraft can conduct scheduled operations with safety higher than cars.

- Note, equivalent safety per mile may not be societally sufficient if new mode is used to travel many more miles.
  - Annual or life-time risk given typical exposure might be more appropriate.
    - E.g. 12.5K miles/ per year by car for 80 years = 1,000,000 miles and a 0.63% lifetime risk of fatality.
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 relived 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
    - Possibility of support from off-board personal, for example
      - Pre-flight, loading
      - Dispatcher-like support
Underlying safety-critical technologies enabling SVO 1 & 2 are resilient automation, not non-deterministic machine intelligence

- 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 (and/or physical) 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
Final convergence of UAS and manned aviation
• Passenger carrying UAS

Requires fundamental breakthroughs in machine intelligence
• Time horizon uncertain
• 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
    o 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