Simplified Vehicle Operations Roadmap

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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 with 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

State-of-the-Art, Technically Advanced Aircraft

Flying that’s as Easy and Safer than Driving.

- Technical feasibility
- Airworthiness Certification
- Training and Operational credit
- Acceptance
Presentation Outline: Safety and Ease of Use

- Alignment of 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: Safety, Ease

- **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
Safety of Small Aircraft Compared to Alternatives

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<th>Mode</th>
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### Safety of Small Aircraft Compared to Alternatives

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<td>0.643</td>
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<td>Motorcycles</td>
<td>29.9</td>
<td>46x less safe</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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**Challenge:** Bring safety of small aircraft transportation up to level demonstrated by commuter airlines.
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
  - Higher component reliability
  - High-performance autopilots
  - Electronic flight bags / tablets
  - Access to information pre and in-flight
  - 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

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

- Significant improvement in accident rate by mitigating basic human errors and newer, more reliable systems
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 that typically reported...

2003, Honda offers active Lane keeping assist system
Definitely, but We Should Be Realistic

- Costs are plummeting (sensors, computers, data, connectivity)

But:

- Rate of progress more modest that 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
Function Allocation, Humans and Automation

Cummings, 2014; Rasmussen, 1983
Areas of Knowledge and Operation...

**Knowledge areas:**
- Federal Aviation Regulations
- Accident reporting, NTSB
- Radio, communication procedures
- Meteorology, weather product and NOTAM collection, dissemination, and use
- Recognition of critical weather situations
- Safe and efficient operation of aircraft, including collision and wake avoidance
- Visual charts, procedures, pilotage, nav.
- Air navigation under IMC
- Air traffic control procedures
- Aircraft loading, weight and balance, performance effects
- Principles of aerodynamics, powerplants, and systems
- Human and aeromedical factor
- Aeronautical decision making and judgment
- Crew resource management

**Operational areas**

**Preflight**
- Cross-country flight planning
- Preflight inspection
- Aircraft Loading
- Passenger safety, instruction, loading
- Engine start
- Taxiing

**In-flight**
- Airport Operations (surface, air)
- Takeoff, landing, go-arounds
- Ground reference, performance maneuvers
- Slow flight, maneuvering, stalls
- Navigation & flight by reference to instruments
- Instrument procedures
- Emergency operations
- High altitude operations

**Post-flight...**
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**
      - Simplified flight control and loss-of-control prevention, navigation, propulsion & systems management, communication
      - **Must** avoid Air France 447-like breakdowns
      - Initially use non-deterministic **autonomy as non-critical decision aids** and in contingency/emergency situations
    - Flight and contingency planning & monitoring, decision support
    - Independent monitoring, and possible action, for imminent threats & self-preservation (e.g. pilot impairment, unstable approach)
      - As trust develops, **transition tasks and responsibilities** from human to autonomy
    - Operator training, licensing must evolve with technology, but full credit lags behind
Flight Control Example, SVO

**Motivation:** “Stick to surface” manual control is significant component of flight training & loss of control greatest cause of fatalities

**Contributors:** Coupling, unattended operation, trim, envelope limits/non-linearities, complex dynamics

**Challenges:**
- Simplify control without depriving pilot of essential authority & awareness
- Graceful degradation
- Regulation of airplane & pilot
- Cost

**Potential approaches**
- "Pilotless" autonomy: safety-critical control and decision making moved to vehicle
- Full-time autopilot: human authority over flight parameters, flight tasks
- Fly-by-wire: authority over real-time maneuvering, but not control surfaces
Numerous flights by non-pilots demonstrated ease of use potential—ILS approaches flown to decision altitude on 1st flight

Envelope protection provided care-free handling at edges of envelope

Trained pilots almost universally complained about “car-like” stick response
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 impacts thin-haul commuter mission and 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 is responsible for real-time safety of flight; user involvement is optional and at the discretion of the automation
Simplified Vehicle Operation (SVO) Roadmap

2016
- Ultra-reliable automation
- Simplified Pilot Interaction & Interface
- Semi-autonomous aiding and self-preservation

2021
- Thin-Haul Focus
  - SVO-1 Flight Test, Demo
- SVO 1 Guidelines Certification Standards

2026
- 2nd generation flight systems
- Revised pilot, knowledge, training and certification
- SVO-2 Flight Test, Demo

2031
- Ab Initio Focus
- Simplified Pilot Certificate Consensus Standards

2036
- SVO 3 fundamental research, requirements analysis, UAS assessment
Next Steps, NASA

- Build community of interest and broad base of support
  - Participation of public, industry, academia and the FAA essential to technology strategy, execution, commercialization
    - Oshkosh forums
    - FAA-NASA Workshop this Fall

- Connectivity and partnerships with other NASA, DoD, DOT/FAA investments, programs

- Coordinate technology roadmap development
  - Preliminary roadmap report out to NASA Aero, early 2016
Questions
Backup Material
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
Top Ten GA Accident Causes

- 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
Technologies Critical to SVO-1 and 2, cont.

- 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
SVO-3 Technologies

- 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
      - 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