Overview: Simplified Vehicle Operations (SVO)

Ken Goodrich, Senior Research Engineer
Mark Moore, Senior Advisor for On-Demand Mobility

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SVO: Flying Easier and Safer than Driving

Challenge

- Safety record and difficulty of becoming & remaining a pilot are key barriers to utility of small aircraft, despite technology revolution over past 20 years

Goals

- Flight systems, interfaces, and operations that make ODM aviation as accessible & practical as driving
- Simple, carefree handling of novel and conventional aircraft
- Proving ground for technology and operations beneficial to transport and other aircraft classes

Technical Approach

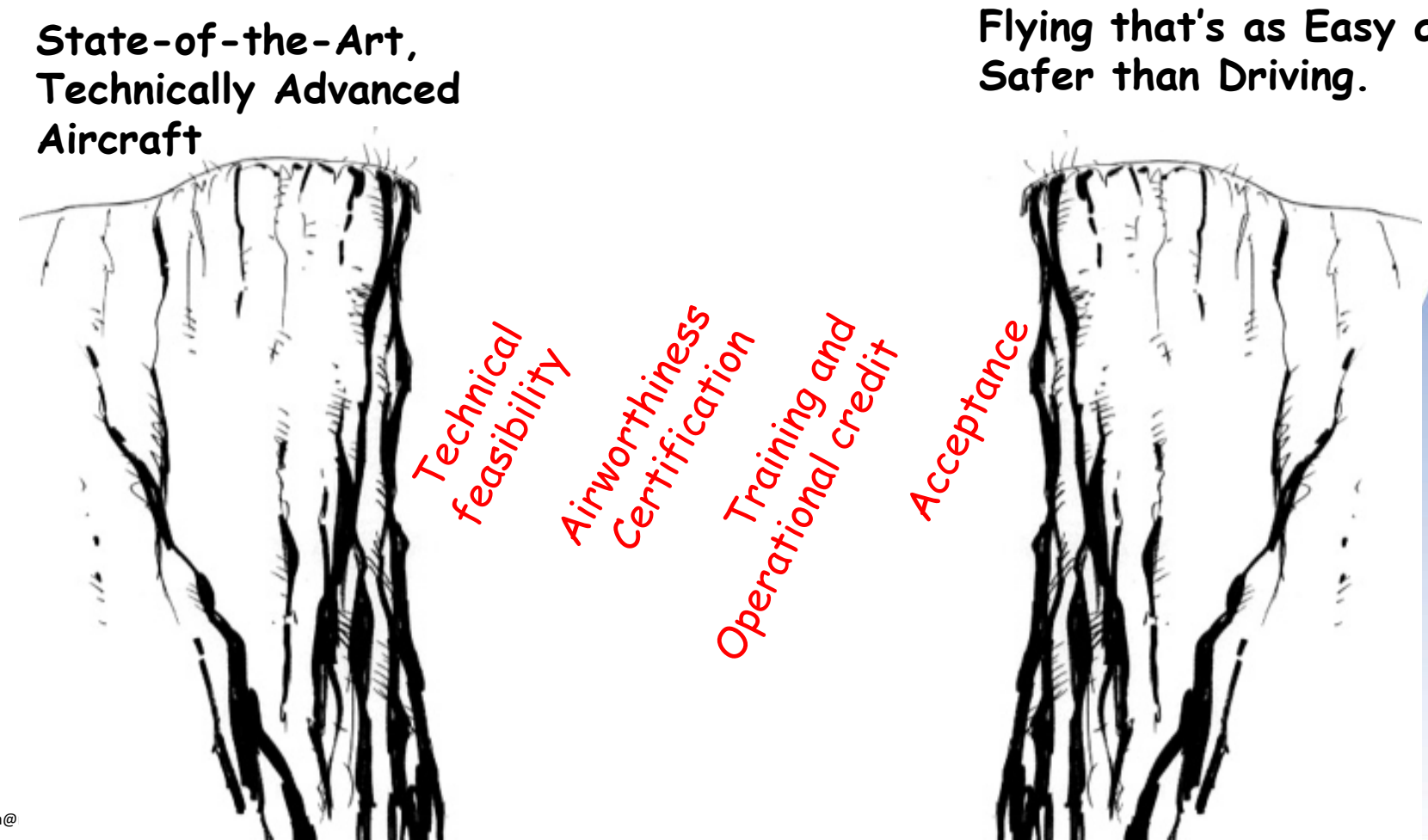
- Incremental revolutions: Expert -> Operator -> User
- Initial steps: 1) Reduce specialized skills and training by allocating select, demanding tasks to ultra-reliable automation and 2) mitigate the human as single-point of failure
- Increasing reliance on technology as operational experience, confidence gained

SVO Design Space

- **Pilot**
  - Required skills & knowledge
  - Workload and resource constraints
  - Mitigate human as single pilot of failure
- **Aircraft and systems**
- **Off-board support (e.g. dispatch, ground-pilot)**
- **Airspace System & Operations**
  - Least flexible element in the near-term
  - Must design for the present and possible futures
  - Some near-term operational simplification possible by limiting navigation and operation options (…with some negatives)

What are the Challenges?

Gulf of Technology, Policy, and Acceptance



Outline

- ODM missions, potential operators
- Barriers: where are we now, safety & ease of use?
- Emerging technology and trends
- Simplified Vehicle Operations (SVO) strategy

On-Demand Mobility (ODM)

On-Demand Mobility *leverages rapidly developing convergent technologies to offer the potential to transform shorter-range transportation to achieve vibrant aviation markets that dramatically increase regional productivity and accessibility.*

Thin Haul Commuters: *Regional 9 passenger aircraft connect smaller cities directly with point to point aviation services. The Essential Air Service Program subsidizes this market with $251M/year, yet Electric Propulsion and Autonomy technologies offer the ability to decrease total operating costs by 30%, with lower community noise and emissions.*

Thin Haul Commuter

Advanced General Aviation: *Enables technology demonstration at sub-scale to achieve more rapid/low cost X-planes that can also pioneer the required new certification standards while re-energizing the GA market as an early adopter of advanced aviation technologies.*

Distributed Electric Propulsion X-Plane

Revolutionary Vertical Flight: *New VTOL flight concepts are being enabled that increase efficiency by 10x with quieter operations.*

Revolutionary Vertical Flight Concepts

Small UAS Market: *New markets such as Package Delivery are quickly evolving for aerial robots of <55 pounds to provide remarkable new on-demand aerial services. But solutions require new highly integrated VTOL flight concepts capable of robust/redundant/reliable control, ultra-low community noise, high cruise efficiency, and ultra-high safety.*

Small UAS GL-10 VTOL Demonstrator

On-Demand Mobility supports existing and emerging aviation markets to achieve transformational capabilities.

SVO Barriers

Current General Aviation (GA) Aircraft compared to Commercial Airliners

- **Poor Aerodynamic and Propulsive Efficiencies**
  - Aerodynamic efficiency measured as Lift/Drag ratio is 9-11 compared to 17-20.
  - (Thermal) x (propulsive efficiency) of 20-24% compared to 36-40%.
- **Poor Emissions**
  - High Hydrocarbon, Green House Gas emissions, particulates and lead pollution.
- **Poor Community Noise**
  - Similar levels and certification compliance with few improvements for the past 50 years.
- **Poor Comparative Safety**
  - **Accident rate 56x worse than airlines, 15x worse than autos per 100 million vehicle miles traveled**.
- **Poor Ride Quality**
  - Low wing loading leads to bumpy ride along with gust sensitivity.
- **Poor Dispatch Reliability Rate**
  - Maintenance and weather sensitivity result in <70% rate for trip completion.
- **Substantially Higher Operating Costs**
  - Compared to all other transportation options (car, airline, train).
- **Onerous Training Requirements**
  - Currently only 0.18% of the U.S. population is capable of flying GA aircraft compared to 69% who have a driver's license.

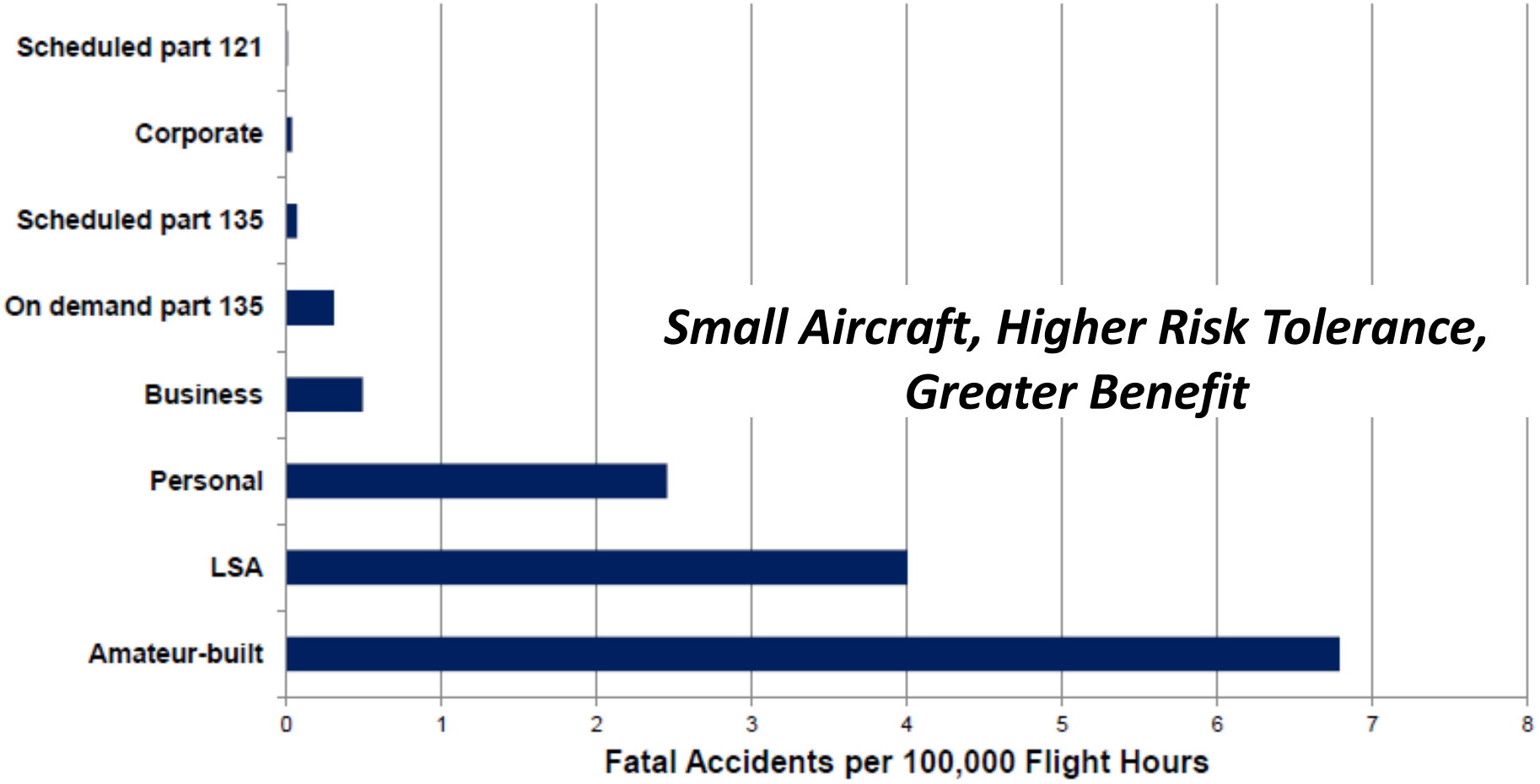
What is Safe Enough and is it Realistic?

	Annual Fleet Utilization				Normalized Fatality Rates		
Vehicle Type	Vehicle Hours (1,000)	Vehicle Miles (Million)	Passenger Miles (Million)	Average Annual Fatalities	Per 100,000 Vehicle Hours	Per 100 Million Vehicle Miles	Per 100 million Passenger Miles
Passenger cars	50,300,000	1,510,000	2,340,000	14,701	1x (0.030)	1x (0.997)	1x (0.643)
Airlines	18,600	7,891	579,000	16	3.9x	0.277x	0.006x
Commuter Operations	307	47	235	0.25	2.77x	0.539x	0.167x
Motorcycle	600,0000	18,000	19,800	4,809	28.6x	28.6x	40.2x
General Aviation	22,400	3,370	6,740	511	77.1x	15.4x	12.0x

Data period 2005-2012
Automobile average speed and vehicle occupancy assumed to be 30 mph and 1.55
Commuter average vehicle occupancy assumed to be 5
GA average speed and vehicle occupancy assumed to be 150 mph and 2.0

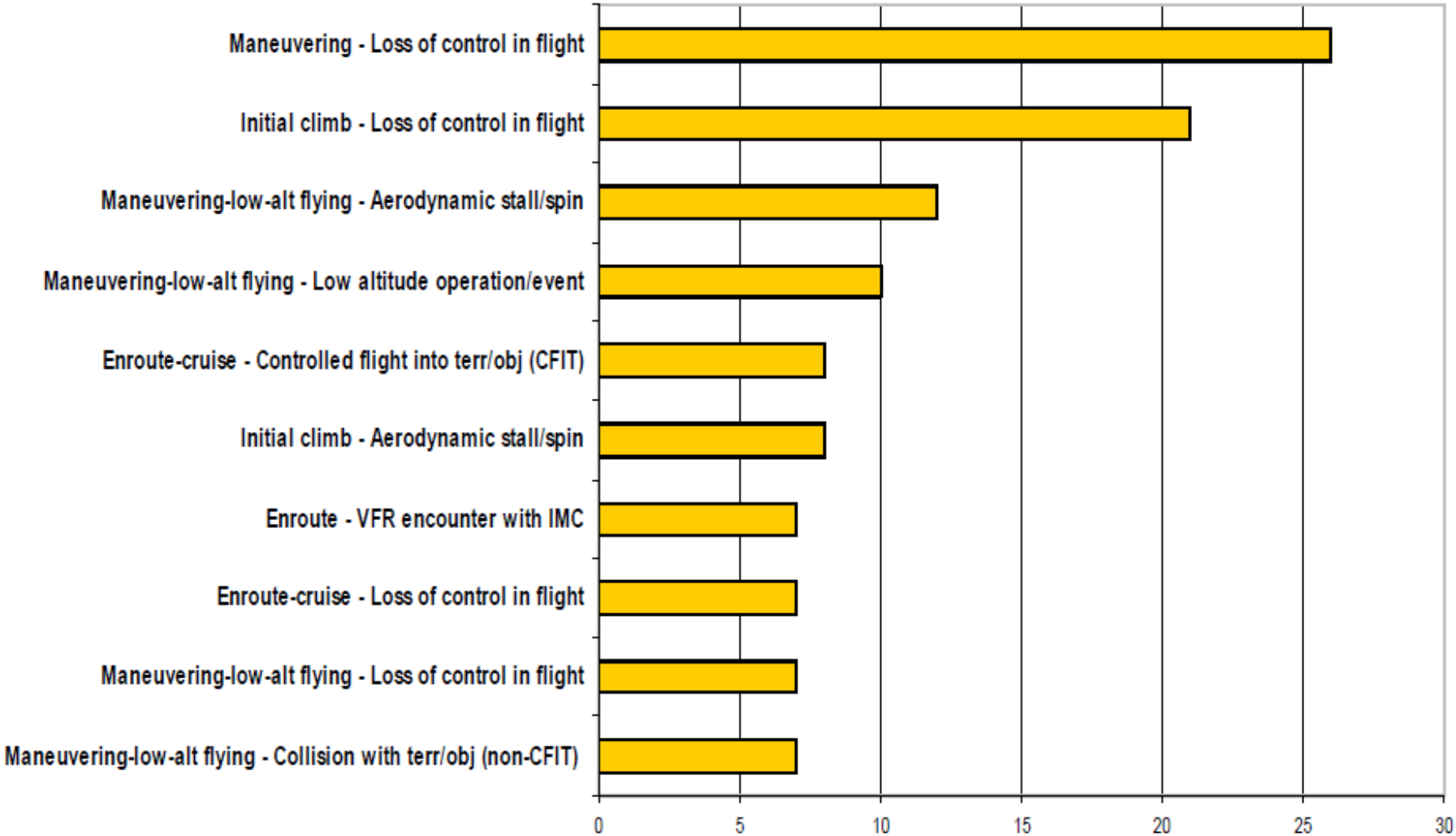
U.S. Aviation Fatal Accident Rates

Annual Average from 2005 through 2009



Small Aircraft, Higher Risk Tolerance, Greater Benefit

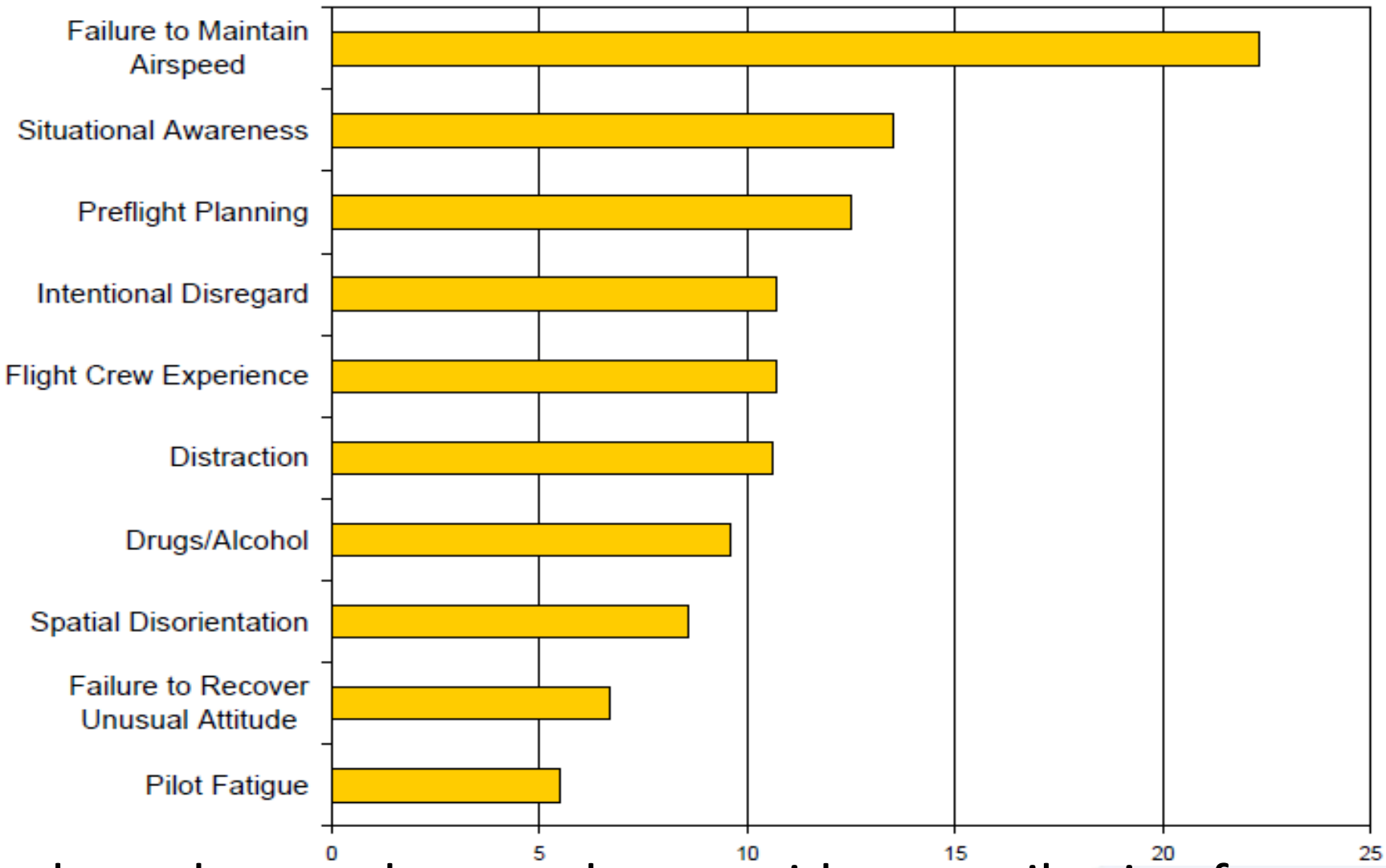
Top Ten GA Accident Causes, Transforming GA Safety, Five-Year Strategy, 2011



* 2008-2009. Data consistent with the 2009 Nall Report.

Significant improvement by addressing basic errors

Top Ten GA Accident Contributing Factors, Transforming GA Safety, Five-Year Strategy, 2011



…but, also need to need to consider contributing factors

Potential ODM "Pilots & Flyers(?)"

- **Commercial operations and pilots**
  - Thin-haul commuter, cargo, charter/air-taxi, training
  - Historically motivated by career potential
  - Current requirement for Part 135 IFR Pilot in Command: >1200 hours total time & Commercial + IFR or ATP license (~ $60K from ab-initio)
- **Early adopters and enthusiasts**
  - Motivated by combination of utility, learning, and pleasure
  - Constrained by costs, time
  - Active private pilots
  - Inactive private and former student pilots (>70% of student pilots don't complete training)
  - Techies, professionals, others
- **Frequent travelers**
  - Motived by cost-benefit, but willing to make investment if ROI is +
- **Occasional travelers**
  - Motivated by cost-benefit with high sensitivity to entry barriers due to limited use

Increasing Technology Support

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?

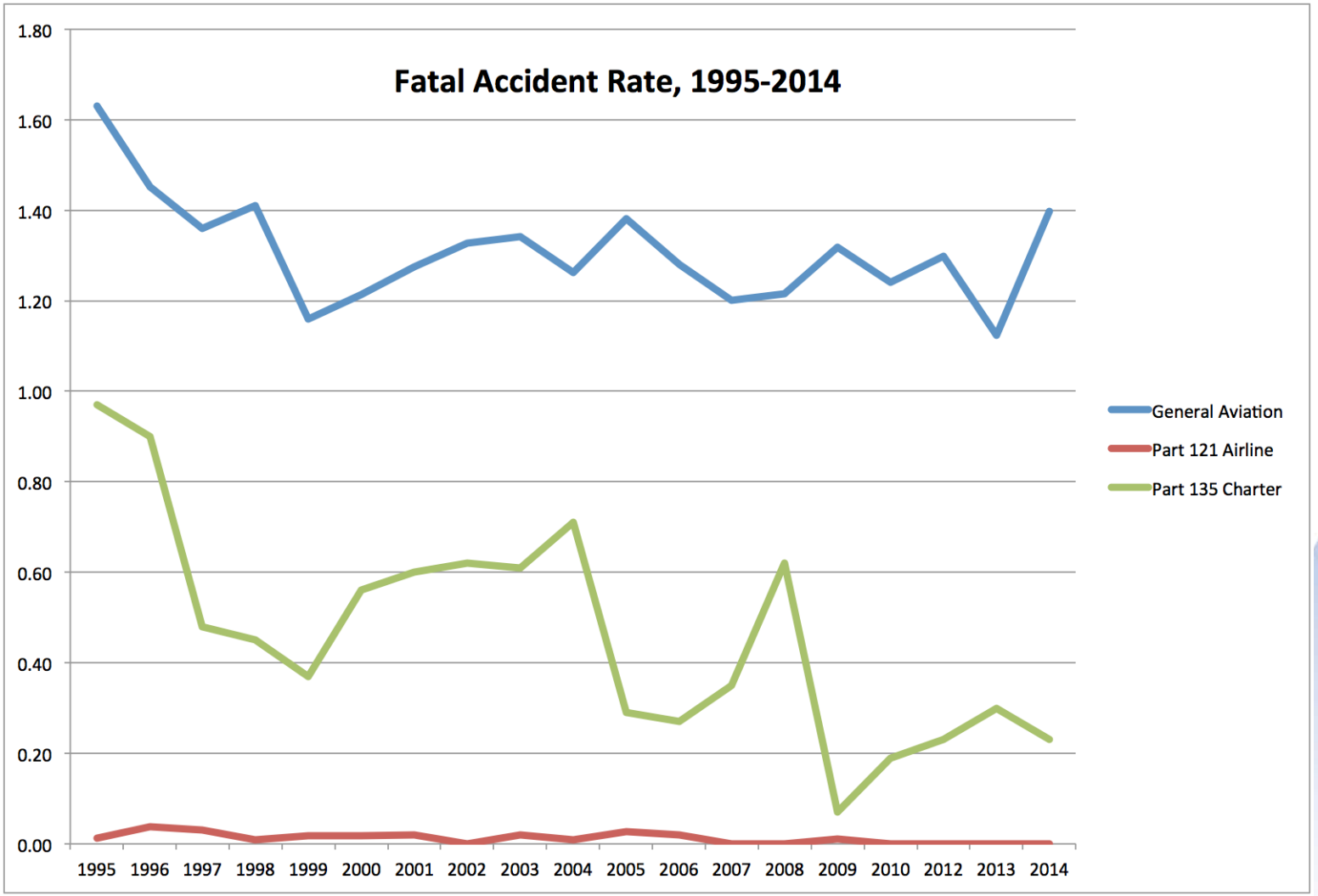
- **Operationally the change has been tremendous, improving utility, efficiency, average workload, comfort, potential safety, etc.**
  - GPS navigation / pervasive position awareness
  - High-performance autopilots
  - Terrain / obstruction awareness
  - Electronic flight bags / tablets
  - Weather information pre and in-flight
  - Higher component reliability (e.g. solid-state IMU vs vacuum)
  - Improved system monitoring, failure detection
- **But…**

How Has Technology Simplified Piloting?

- **…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 versions
  - 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 ?

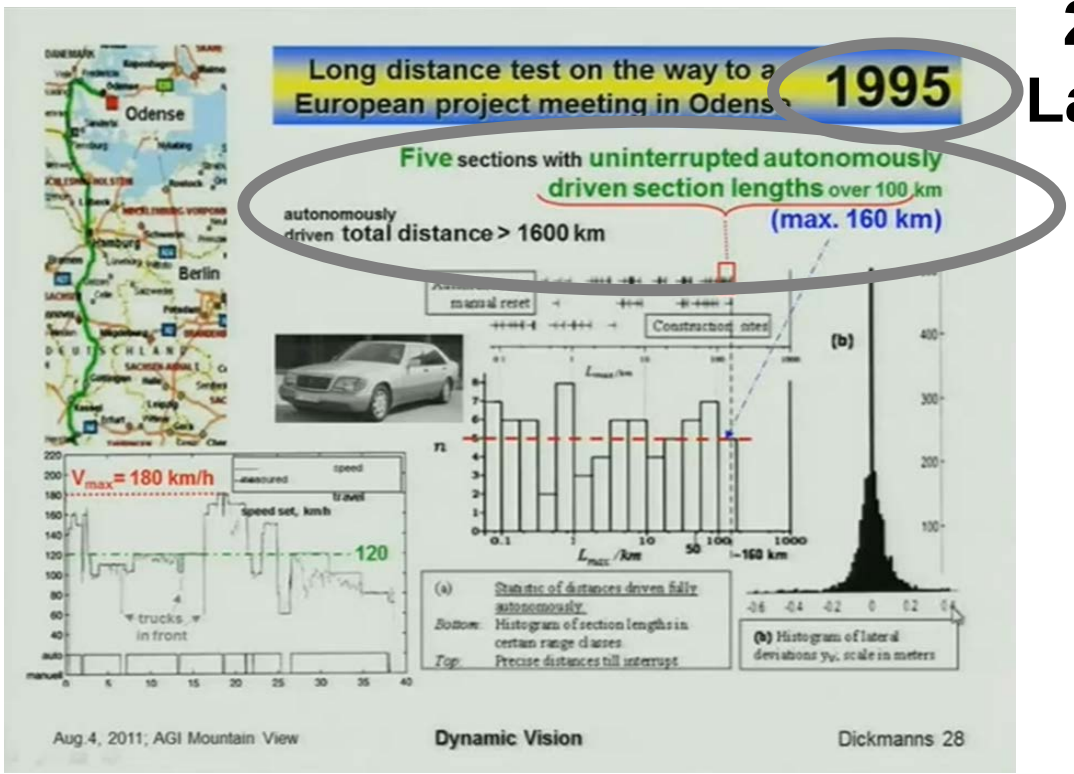
- …Realized GA safety has not significantly changed



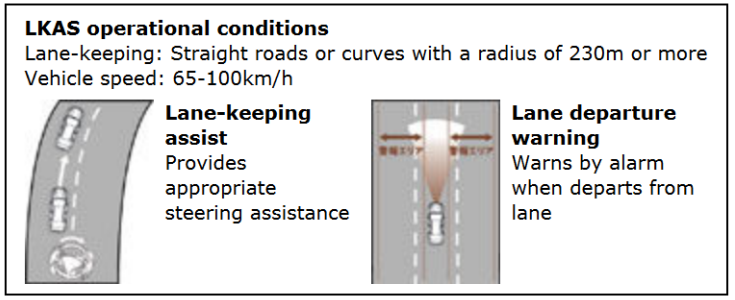
Are Autonomous Systems a Light on the Horizon?

Definitely, but We Should Be Realistic

- **Costs are plummeting (sensors, computers, data, connectivity)**
- **But:**
  - Rate of progress more modest than 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 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

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

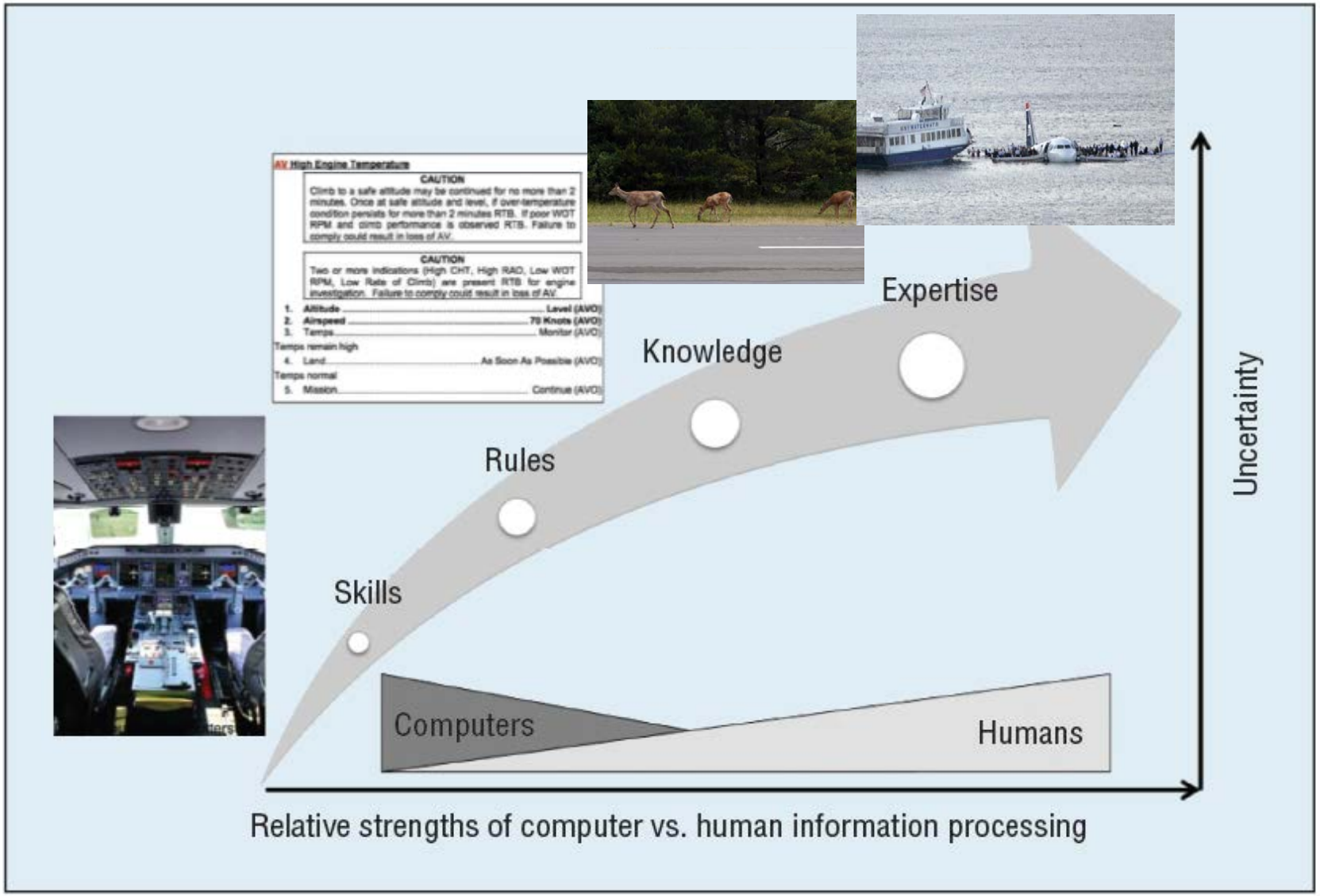
- Cross-country flight planning
- Preflight inspection
- Aircraft Loading
- Passenger safety, instruction. loading
- Engine start
- Taxiing

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…

Function Allocation, Humans and Automation



Cummings, 2014; Rasmussen, 1983

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
         - Example, simplified control…

Example Simplified Flight Controls

- **Motivation:** Manual, "stick to surface" control is significant component of flight training & loss of control greatest single contributor to fatalities
- **Contributors:** Coupling, divided attention/disturbances, trim, envelope limits/non-nonlinearities
- **Challenges:**
  - Simplify control without depriving pilot of essential authority & awareness
  - Graceful degradation
  - Regulation of airplane & pilot
  - Cost
- **Potential solution path: full-time command augmentation system (CAS) for direct flight path control**
  - Pilot has direct command over vehicle's instantaneous maneuver within design envelope
  - CAS manages control surfaces/power as need to achieve pilot's commands
  - Also essential to ground-pilot interface or advanced on-board automation

Example Simplified Flight Controls

Simplified control evaluation with non-pilots ~2001

- 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

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 controls 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

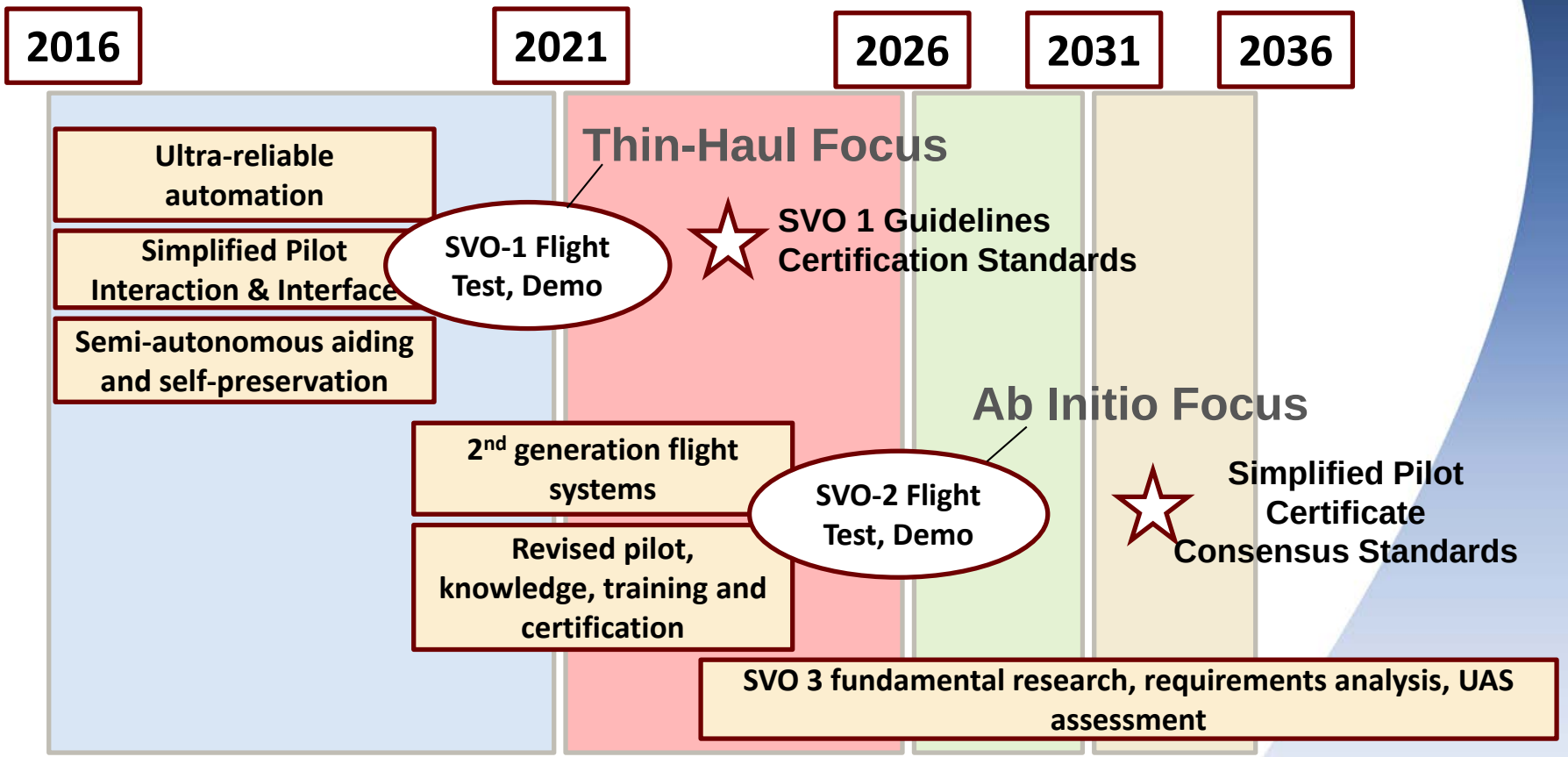
3 Epochs of Simplified Vehicle Operation (SVO)

- **SVO-1 (2016 – 2026): Foundational Precedents & Capabilities**
  - Demonstrate transition of key skill/capability from pilot to aircraft,…simplified controls?
  - Moderate workload peaks and specialized skills
  - Mitigate pilot as single-point of failure (…automation back-stops pilot)
  - 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 with combined private-instrument curriculum), but new pilots capable of more confident, near-all weather ops.
  - Benefits/grows thin-haul, air taxi, early adopter personal aviation markets
  - Operational experience for SVO-2, Part 121, and UAS applications

- **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**
  - Aircraft and off-board board support shoulder command responsibilities; nominally accommodates user direction, but may modify or inhibit

Simplified Vehicle Operation (SVO) Roadmap



NASA ODM Roadmapping Next Steps

- **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, July 2015
    - FAA-NASA Workshop Oct 21 and 22

- **Representative system concept(s) and ConOps**
  - Detailed analysis of technology, regulatory gaps and approaches

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

- **Coordinate technology roadmap development**
  - Preliminary report out to NASA Aero, early 2016

Questions

Backup Material

How Has Technology Simplified Piloting ?

- …Realized safety has not significantly changed

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

135 and 121 Regulatory Breakpoints

Operation	Scheduled	Negotiated by customer	Turbojet		7500lbs or less		Seats	Solely within US	Notes
Commuter	✓		✗	and	✓	and	<10		
On Demand									
Scheduled	✓		✗	and	✓	and	<10		
Non-Sched		✓			✓*	and	<30*		*For common carriage
Cargo					✓				
Supplemental									
Turbojet		✓	✓			and	1-30		
Prop		✓	✗			and	10-30		
All AC that..		✓				and	31+		
Cargo									
Domestic	✓		✓	or	✗	or	10+	✓	
Flag	✓		✓	or	✗	or	10+		

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**

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

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

- **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

Roadmap Elements

Goals: a clear and concise set of targets that, if achieved, will result in the desired outcome; quantified goals (e.g. "improve energy efficiency in commercial buildings by 25% in ten years") provide the most specific guidance.

Milestones: the interim performance targets for achieving the goals, pegged to specific dates (e.g. "improve the energy efficiency of commercial buildings by 2% per year during the next five years without slowing economic growth").

Gaps and barriers: a list of any potential gaps in knowledge, technology limitations, market structural barriers, regulatory limitations, public acceptance or other barriers to achieving the goals and milestones.

Action items: actions that can be taken to overcome any gaps or barriers that stand in the way of achieving the goals; typical solution actions include technology development and deployment, development of regulations and standards, policy formulation, creation of financing mechanisms, and public engagement.

Priorities and timelines: a list of the most important actions that need to be taken in order to achieve the goals and the time frames, taking into account interconnections among those actions and stakeholder roles and relationships

Safety of Small Aircraft Compared to Alternatives

Mode	Fatalities per hundred million passenger miles	Rate relative to passenger cars
Passenger Cars		
Motorcycles		
US Airline Flights		
Commuter Airlines (<10 passengers)		
General Aviation		

Challenge: Bring safety of all small aircraft ops up to level demonstrated by commuter airlines and move commuters toward airline

Safety of Small Aircraft Compared to Alternatives

Mode	Fatalities per hundred million passenger miles	Rate relative to passenger cars
Passenger Cars	0.64	1.0
Motorcycles	30.	47x less safe
US Airline Flights	0.0038	168x safer
Commuter Airlines (<10 passengers)	0.10	6.4x safer
General Aviation	7.8 (estimated)	12x less safe

Challenge: Bring safety of all small aircraft ops up to level demonstrated by commuter airlines and move commuters toward 121 airlines

Elements of SVO

- **Pilot / operator**
  - Human capabilities/limitations
  - Prior experience
  - Specialized training
- **Vehicle**
- **Off-board support**
- **Airspace & Operations**

Elements of SVO

- **Pilot / operator**
- **Vehicle**
  - Base-vehicle
    - Weather envelope
    - Non-normal with graceful degradation
    - High-integrity systems / avionics
  - Automation
    - Simplified trajectory control
    - Hazard awareness and avoidance
    - Information and decision-support
  - Human-machine interface
- **Off-board support**
- **Airspace & Operations**

Areas of Knowledge and Operation…

- **Note, many of regulations implicitly assume underlying human abilities and judgment,**

  e.g: 91.113 - Right-of-way rules: "…regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear."