Simplified Vehicle Operations Roadmap

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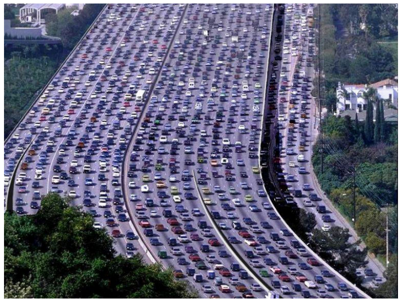

Goals and Benefits
ODM Safety and Ease of Use

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

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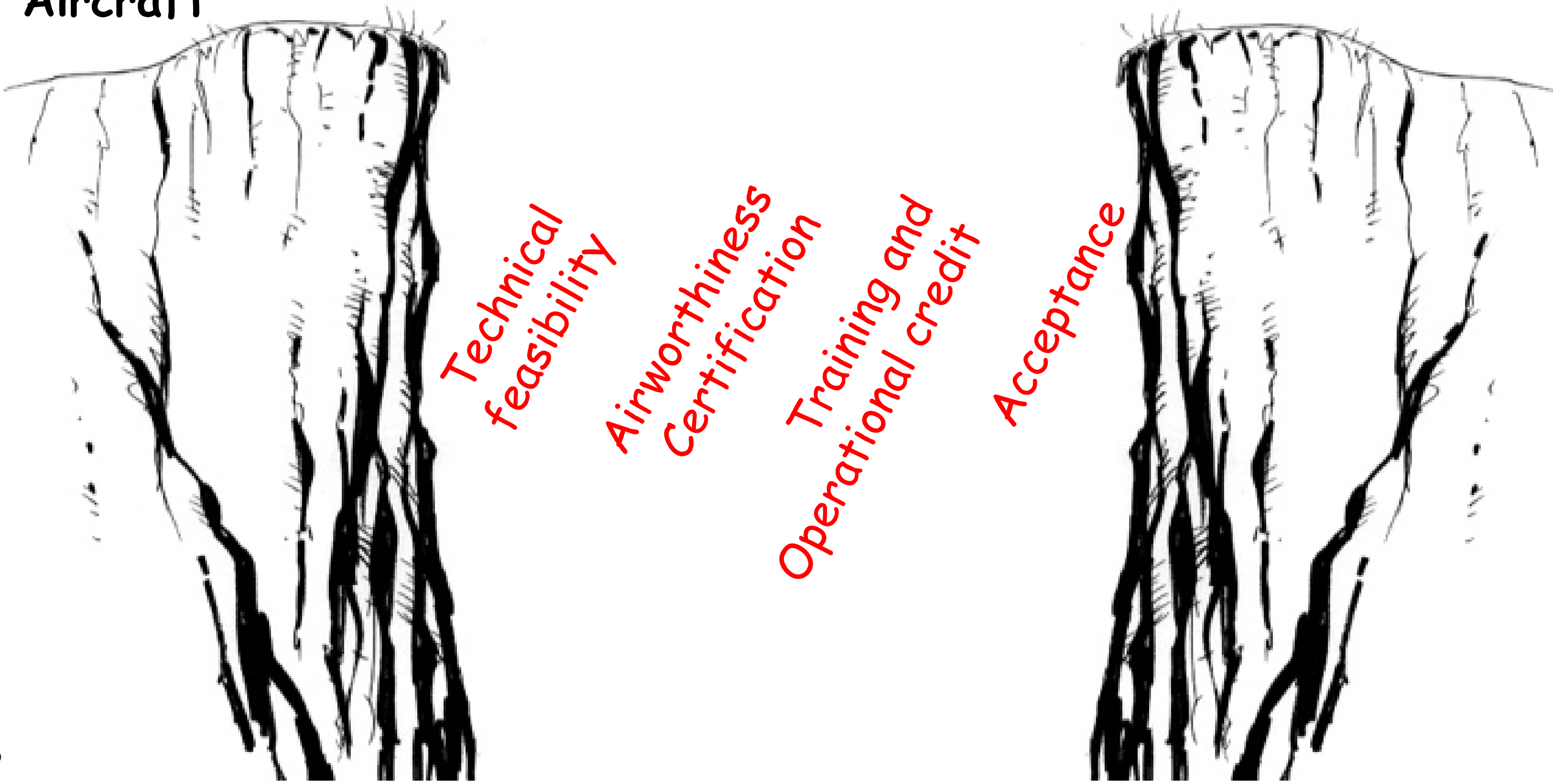
What are the Challenges?

Gulf of Technology, Policy, and Acceptance

State-of-the-Art, Technically Advanced Aircraft

Flying that's as Easy and Safer than Driving.



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

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 small aircraft transportation up to level demonstrated by commuter airlines

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Safety of Small Aircraft Compared to Alternatives

Mode	Fatalities per hundred million passenger miles	Rate relative to passenger cars
Passenger Cars	0.643	1.0
Motorcycles	29.9	46x less safe
US Airline Flights	0.0038	167x safer
Commuter Airlines (<10 passengers)	0.102	6.7x safer
General Aviation	7.8 (estimated)	12x less safe

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?

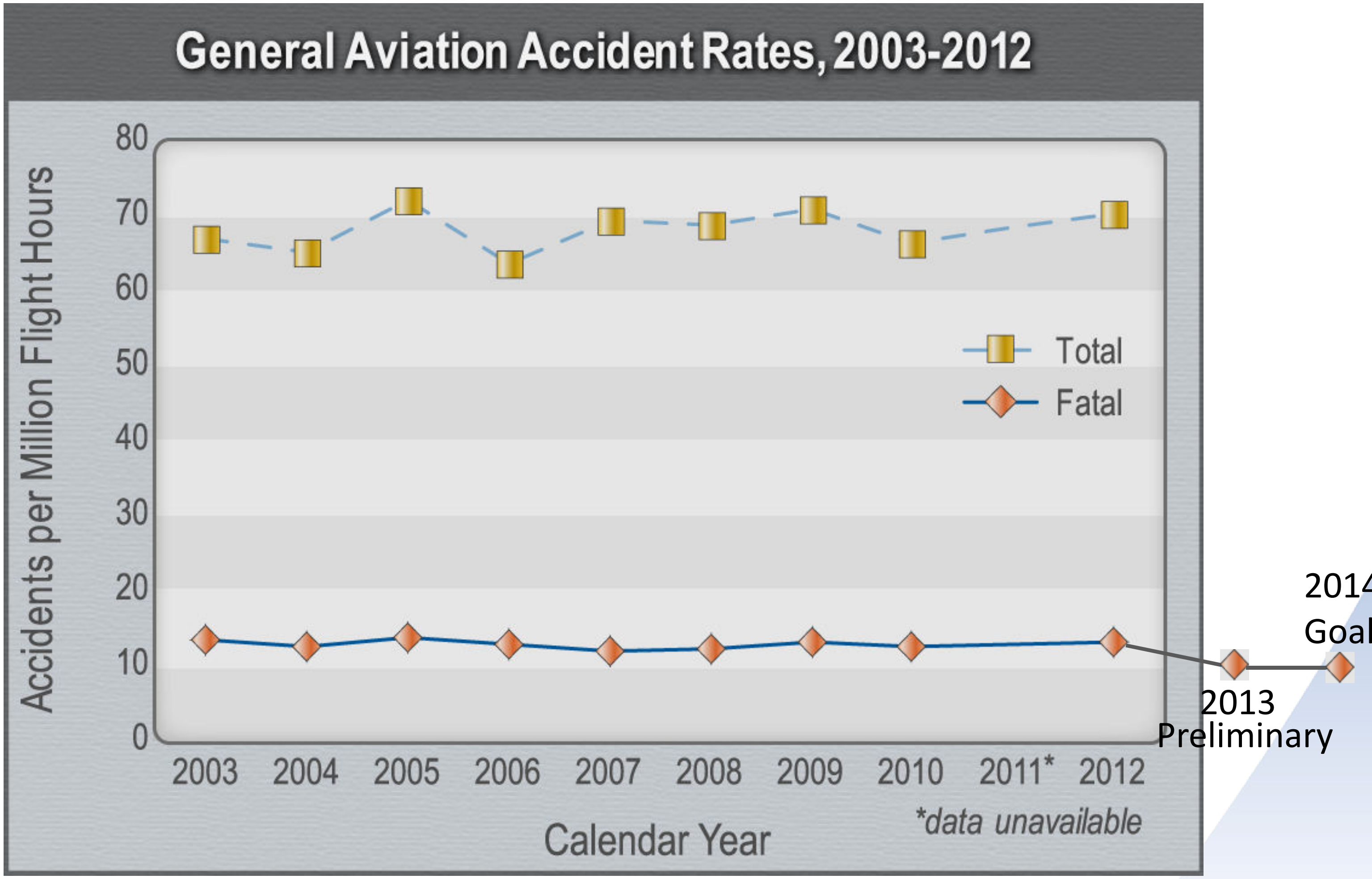
- **Operationally the change has been tremendous, improving utility, efficiency, average workload, comfort, potential safety, etc.**
  - Navigation / position awareness
  - Higher component reliability
  - High-performance autopilots
  - Electronic flight bags / tablets
  - Access to information pre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

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 loads
  - Pilot expected to detect, troubleshoot & backstop wider range of non-normals
  - Average workload is much lower, but peaks remain high, if not higher

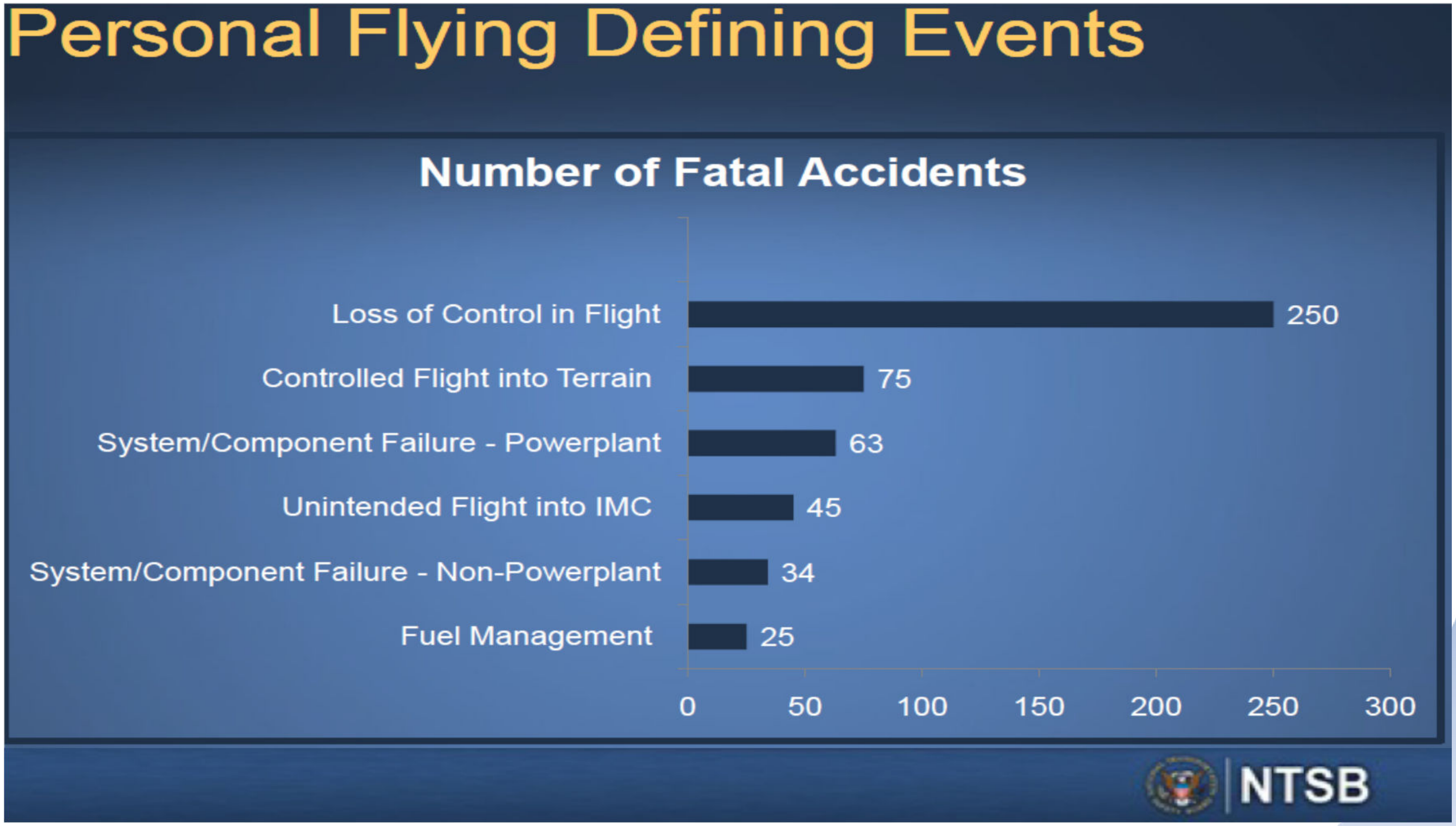
How Has Technology Simplified Piloting ?

- ...Realized safety has not significantly changed



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

Top Accident Categories

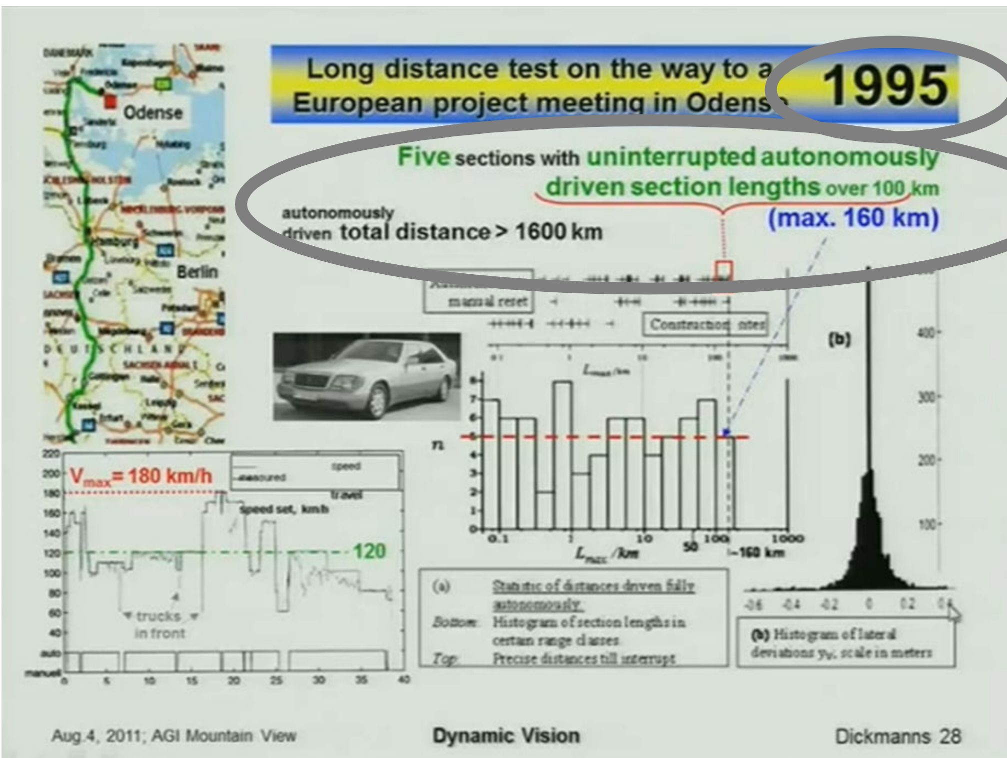


- Significant improvement in accident rate by mitigating basic human errors and newer, more reliable systems

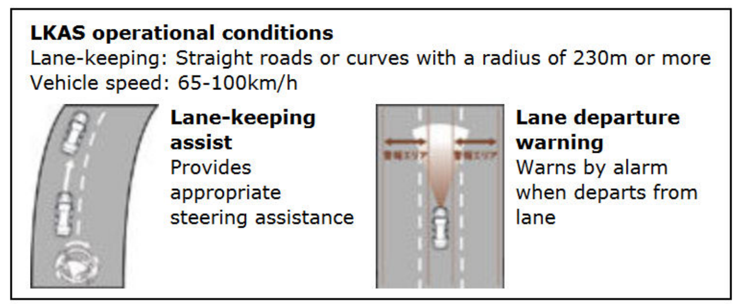
Are Autonomous Systems a Light on the Horizon?

Definitely, but We Should Be Realistic

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



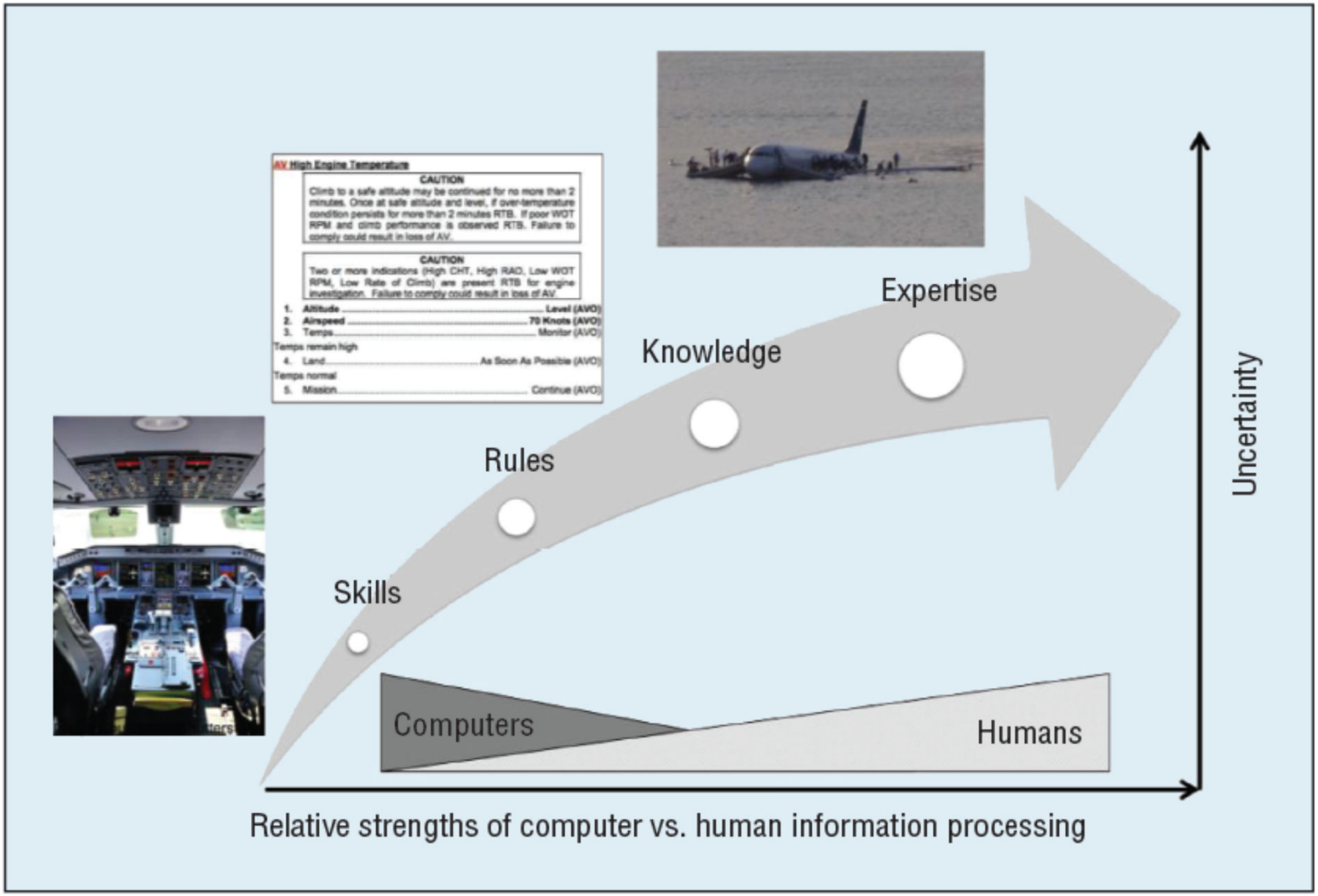
2003, Honda offers active Lane keeping assist system



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

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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-nonlinearities, 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

Example Simplified Control

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

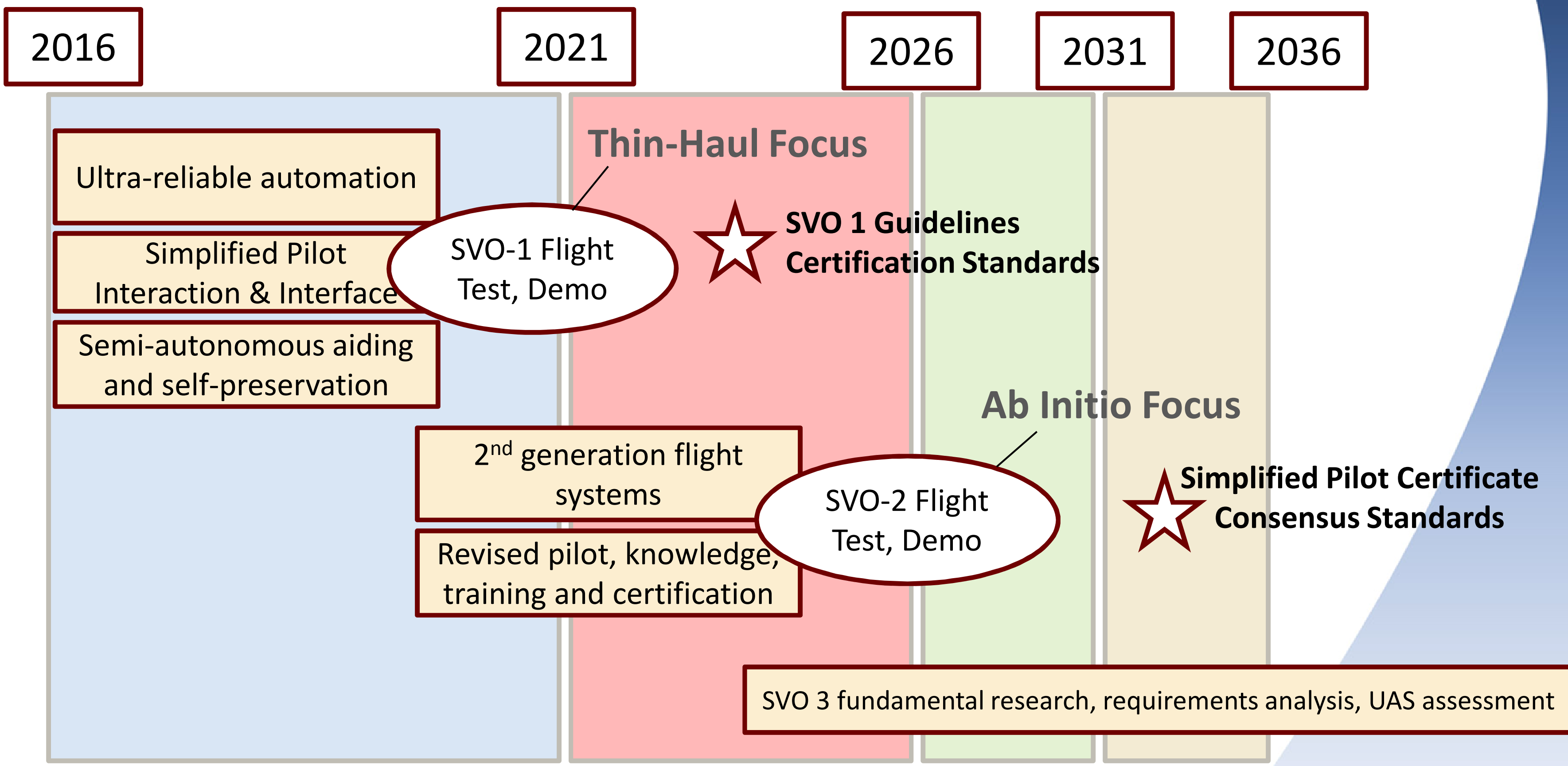
3 Epochs of Simplified Vehicle Operation (SVO)

- **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



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?

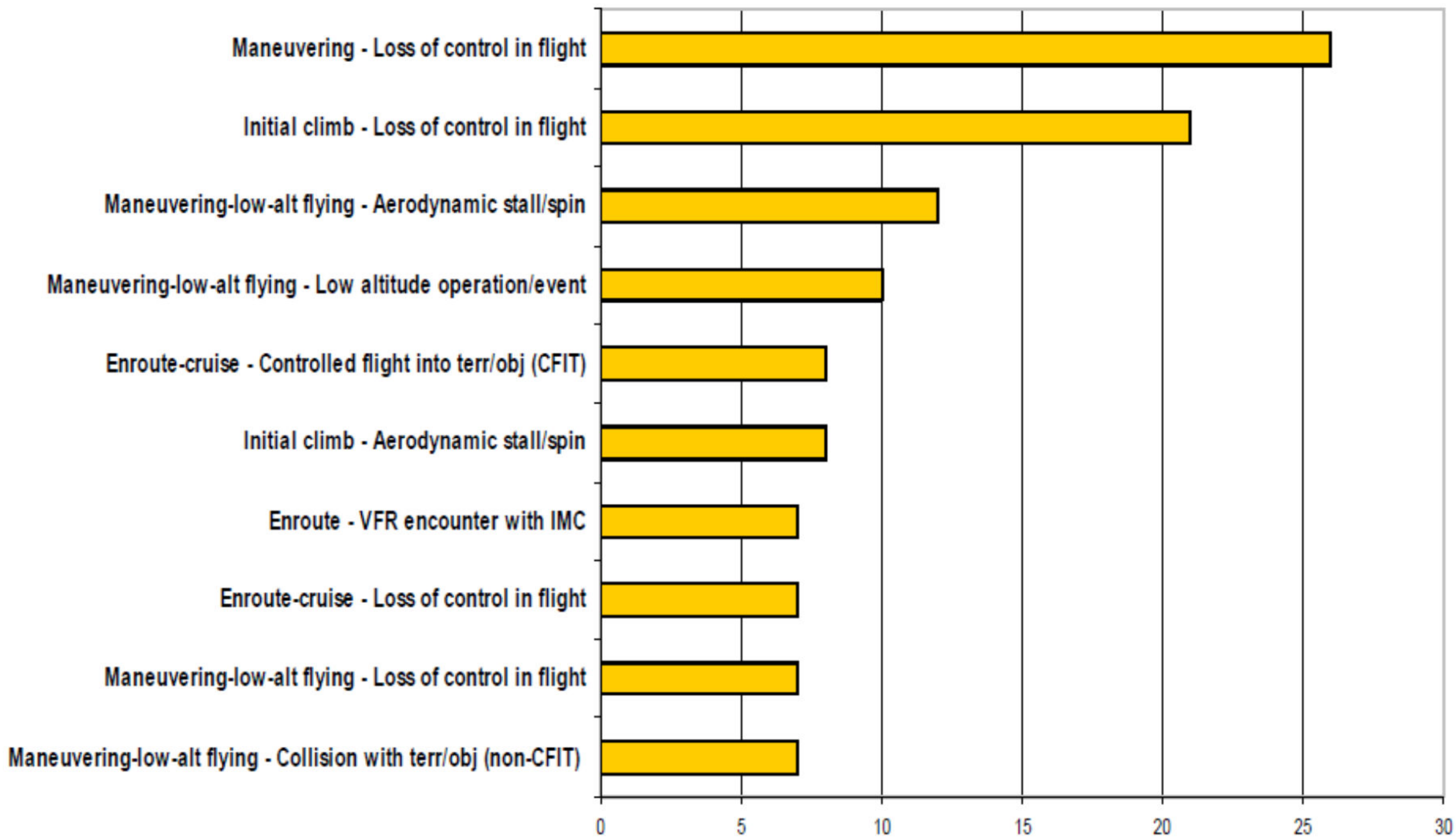
- Small, commuter airline record highlights that even current small aircraft can conduct scheduled operations with safety higher than cars

- 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



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

- 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