On-Demand Mobility

Aviation’s Path to High Speed Regional Mobility

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Why Is NASA Here?

NASA Interest: Developing New Aviation Technologies

NACA/NASA: A Heritage of Bold Ideas and Risk Taking, Proving New Theories in Flight

X-31, 1990

Transformative Aeronautic Concepts Program

SCEPTOR CAS Sub-Project X-Plane

(Scalable Convergent Electric Propulsion Technology Operations Research)

Tecnam P2006T Light Twin General Aviation Aircraft

NASA Distributed Electric Propulsion (DEP) X-Plane

$15 million, 3-year project for the first Distributed Electric Propulsion manned X-plane

Electric propulsion is not just a new propulsion technology,
it's a very powerful integration technology

Transformative Aeronautic Concepts Program

SCEPTOR CAS Sub-Project X-Plane

Airbus E-fan: 46 miles in 37 minutes
74 mph average speed

Tecnam P2006T Light Twin
General Aviation Aircraft

NASA Distributed Electric
Propulsion (DEP) X-Plane

NASA SCEPTOR Primary Objective

- Goal: 5x Lower Energy Use (Comparative to Retrofit GA Baseline @ 150 kts)

NASA SCEPTOR Derivative Objectives

- 30% Lower Total Operating Cost (Comparative to Retrofit GA Baseline)
- Zero In-flight Carbon Emissions

NASA SCEPTOR Secondary Objectives

- 15 dB Lower community noise (with even lower true community annoyance) .
- Flight control redundancy, robustness, reliability, with improved ride quality.
- Certification basis for DEP technologies.
- Scaling study to provide a basis regional turbo-prop research investments.

Why Is NASA Here?

NASA's Objective is to Develop New Aviation Technologies

Small aircraft provide opportunities for new technologies to be introduced into aviation

Primary structure composites, Flat panel displays, etc…

Why?

Risk: Lower consequence associated with the risks

Cost: Lower initial cost to test and introduce technologies

Certification Pathway: Early standards due to lower certification barriers

Small aircraft markets also permit early adoption markets

Lower capital costs

Early products promote faster technology acceleration rates

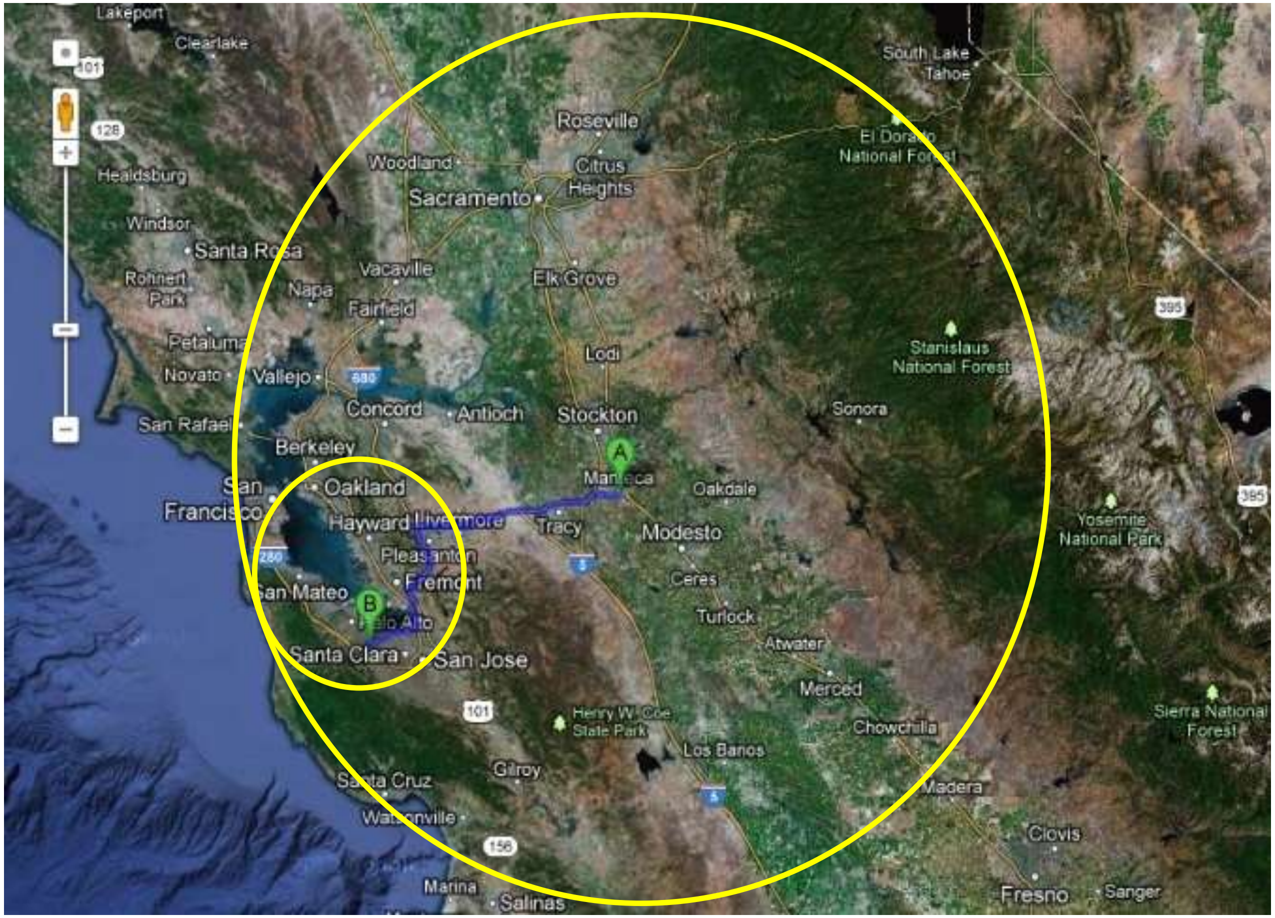
With scale independent technologies, start the path across all aviation markets

Convergent Technology Opportunity: On-Demand Mobility

NASA's Question: "Are there compelling new convergent technology opportunities that can transform small aircraft into on-demand mobility transportation?"

On-Demand Mobility (ODM) *combines the* ***<u>immediate and flexible</u>*** *travel access of automobiles with* ***<u>aviation's speed</u>*** *and ability to travel in a* ***<u>distributed fashion</u>****, independent of ground terrain and route infrastructure pathways. ODM is a new transportation choice that achieves* ***<u>greater regional productivity through high speed travel</u>*** *wherever and whenever users desire, with* ***<u>vehicles</u>*** *that offer levels of* ***<u>safety, efficiency, environmental and community friendliness, as well as affordability that is competitive to existing transportation</u>*** *solutions. Whether the payload is a package or people, this market will spring from sUAS and other technology frontiers as General Aviation is reinvented to impact society in far more meaningful ways to radically improve regional productivity.*

On-Demand Mobility Goal: Enable Greater Regional Mobility Reach



San Francisco Bay Area Daily and Regional Reach

Enable rapid, accessible personal mobility 'reach' for people and goods across large geographical regions.

- Provide ~4x increase in mobility speed compared to ground-based solutions.
- Eliminates in-route 1-D ground traffic congestion problems.
- Geographic constraints are removed (mountains, bridges, need for highways…).
- Scarce localized resource constraints are removed (land and housing cost…).
- Synergistic to telecommuting technologies, as new choices in mid-range transportation open up regional economic growth opportunities without increasing traffic congestion.

ODM Technology Challenges / Market 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 110x worse than airlines, 6x worse than autos per 100 million 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 are the New Technology Opportunities?

Electric Propulsion: Is this a new propulsion paradigm, similar to the advent of the turbine engine in the 1940's?

NASA Green Flight Challenge, 2011
Pipistrel G4 Taurus $1.5 Million Prize Winner

Rui Xiang RX1E
China

FEATHER
JAXA

Electric Cri-Cri
Airbus

Pipistrel Watts Up
Slovenia
(Ready for Production)

E-Genius
Airbus

DA-36 E-Star
Airbus

E-Fan
Airbus

What are the New Technology Opportunities?

Autonomy: Is this a technology for military UAVs and R/C hobbyists, or the next step in the digital revolution, completely changing small aircraft safety and the user base?

Google Project Wing

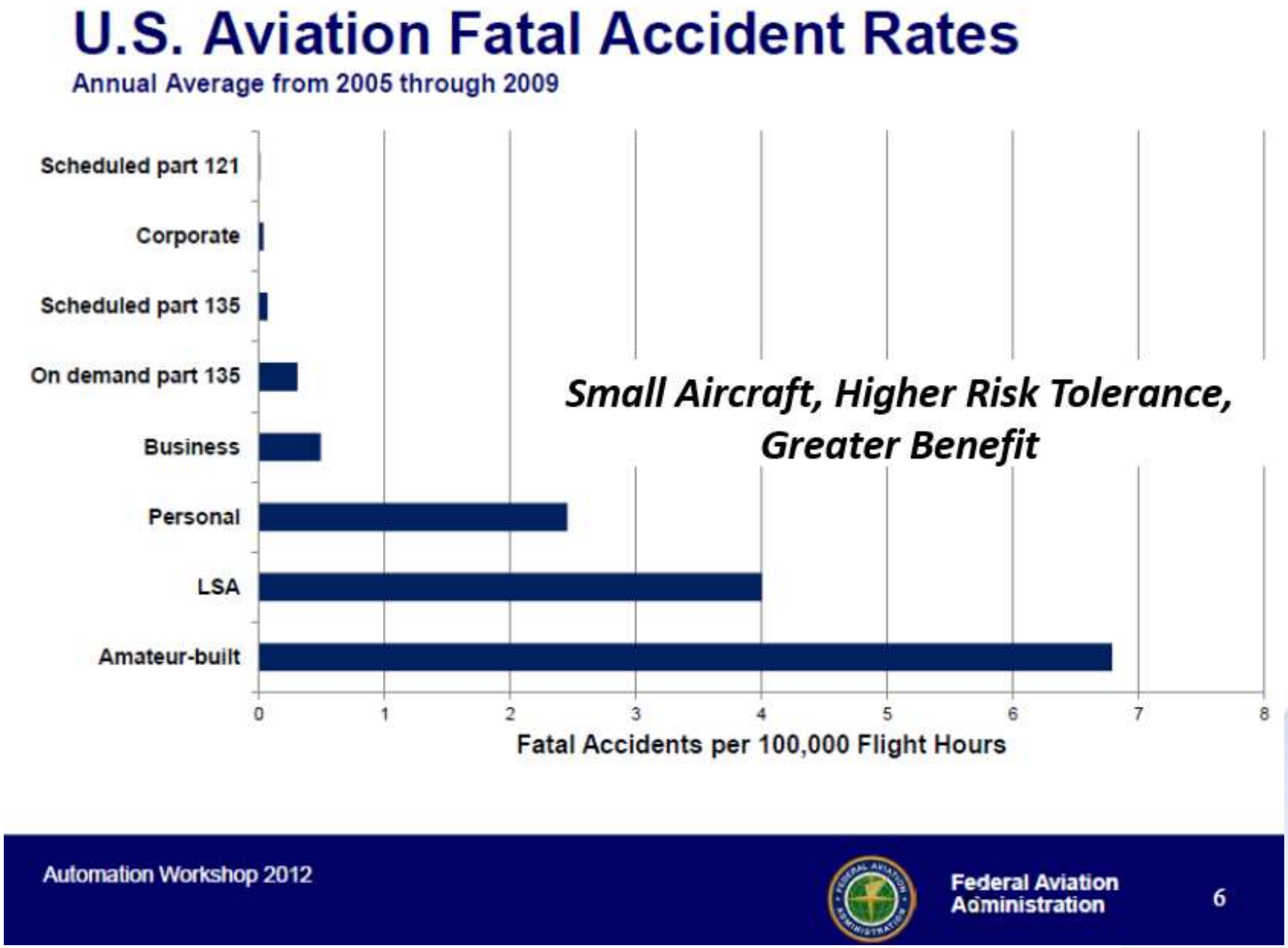
Google Self Driving Car

Self flying aircraft, are a far simpler challenge than self driving cars, due to the different in close proximity clutter and required reaction time for the autonomy.

But the consequence of failure is much greater, and therefore requires an evolutionary path that the FAA and the public can embrace.

Enabling Safety through Autonomy

Autonomy offers the greatest benefit to small aircraft, while also providing the opportunity to build FAA statistical proof of it's effectiveness.



Wes Ryan, FAA Small Aircraft Directorate, "General Aviation Automation"

ODM Technology Enablers

Electric Propulsion + Autonomy: Technologies that Close the Gaps

- **Propulsive Efficiency:** Energy to thrust conversion efficiency improved from 22% to 84%.
- **Aerodynamic Efficiency:** Lift/Drag ratio improved from 11 to 18.
- **Emissions:** Life cycle GHG decreased by 5x using U.S. average electricity.
- **Community Noise:** Certification noise level from 85 to <70 dB (with lower true annoyance).
- **Safety:** Robust, Reliable, Redundant control, increased effectiveness at lower speeds.
- **Ride Quality:** Wing loading increased by 2-3x.
- **Dispatch Reliability:** Lower maintenance, high wing loading offers less gust/weather sensitivity.
- **Operating Costs:** Energy costs decrease from 45% of Total Operating Cost to 6%
- **Training Requirements:** Digital propulsion control is highly convergent to autonomy technologies to enable the equivalent ease of use as automobiles with similar safety rates.

ODM Technology Enablers

Many additional transformative technologies are becoming available that can fundamentally alter On-Demand Mobility feasibility through the use of small aircraft for regional transportation.

- Robotic composite manufacturing processes to achieve lightweight vehicle cost reductions, and quality improvements.
- Additive manufacturing (for both metals and plastics)
- Material coatings that can improve operational feasibility of laminar flow and simplified icing solutions.
- Aerodynamic morphing that improves the mismatch of requirements across low and high speed cruise conditions.
- Peer to peer airspace management, detection, and crash avoidance.
- GPS denied navigation through low cost complementary sensors.
- On-demand weather information availability with improved regional resolution and forecasting.

Why Is NASA Here?

NASA's Objective is to Develop New Aviation Technologies

<u>Markets and Missions</u>
Aviation markets and missions drive what technologies are required

<u>Advanced Concept Integration</u>
Advanced concepts integrate technologies to provide market/mission context

"How much will technology X help versus technology Y"

NASA needs to understand the markets, missions, and integrated concepts in order to understand which technologies can best meet aviation needs.

Small aircraft enable technologies to be developed
As quickly as possible
As safely as possible
At the lowest cost

Thin Haul Commuter ODM Markets / Missions

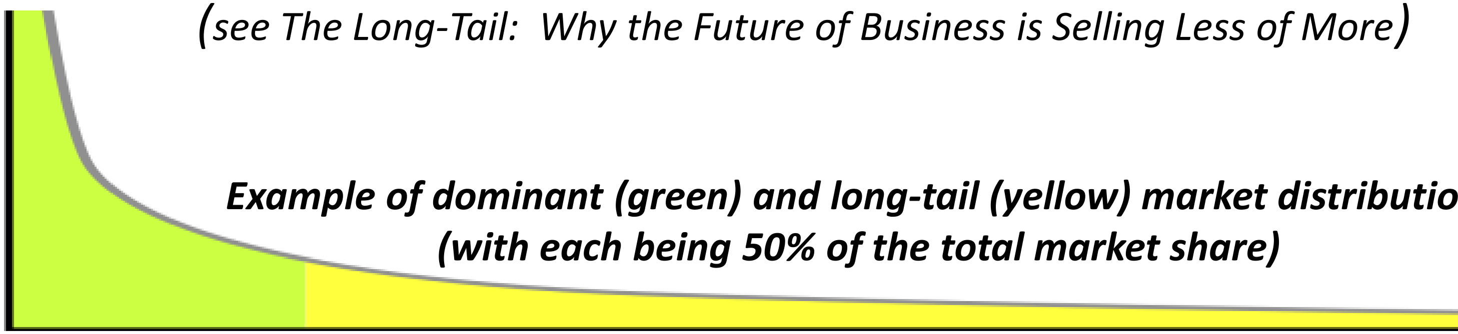
9 Passenger Distributed Electric Propulsion Commuter Concept

Commuters: *Regional 9 passenger aircraft connect smaller cities directly with point to point, adaptive scheduling aviation services. Electric Propulsion and Autonomy technologies offer the ability to decrease total operating costs by 30%, with lower community noise and emissions.*

Thin-Haul ODM Commuters

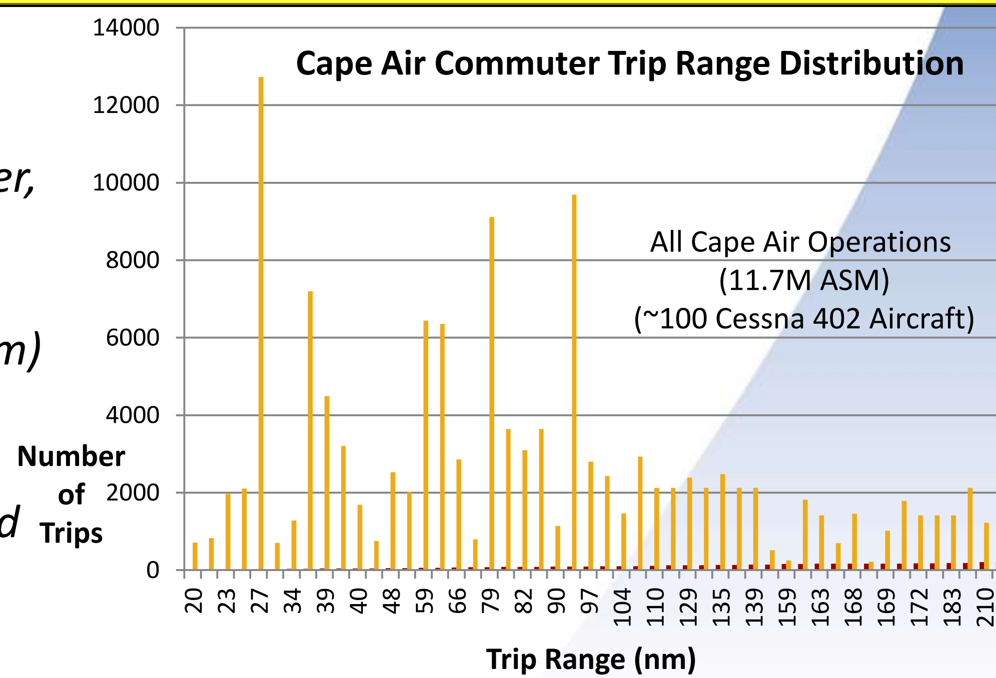
Thin-Haul Commuters *provide Essential Air Services to small communities with 'thin' passenger trip distributions. New business models and technologies are developing across many industries to capture 'long-tail' markets instead of focusing only on dominant markets.*

(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)

- *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.*



sUAS Package Delivery ODM Markets / Missions

Small UAS GL-10 VTOL Distributed Electric Propulsion Demonstrator

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.*

sUAS Package Delivery ODM Markets / Missions

Redundant, Reliable, Robust Control

VTOL with 4x the Lift/Drag aerodynamic efficiency

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)