NASA Update
FAA REDAC E&E Subcommittee Meeting

September 12, 2018

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Strategic Technical Advisor, Advanced Air Vehicles Program
NASA Aeronautics Research Mission Directorate

Fundamentals

- By 2050
  - 70% of the world's population will live in urban areas
  - Global GDP will likely double
  - Over half of the world's middle class will live in China and India
- Demand for mobility increases with income
  - Demand for high speed mobility increasing share
  - Inter and Intra Urban
- Convergence changes how we live and work
  - Physical, virtual and hybridized access anywhere, anytime

Global Growth in Aviation

2017

4 BILLION

PASSENGER TRIPS

2036

7.8 BILLION

PASSENGER TRIPS

41,030
New Aircraft Deliveries

$6.1 Trillion
Market Value

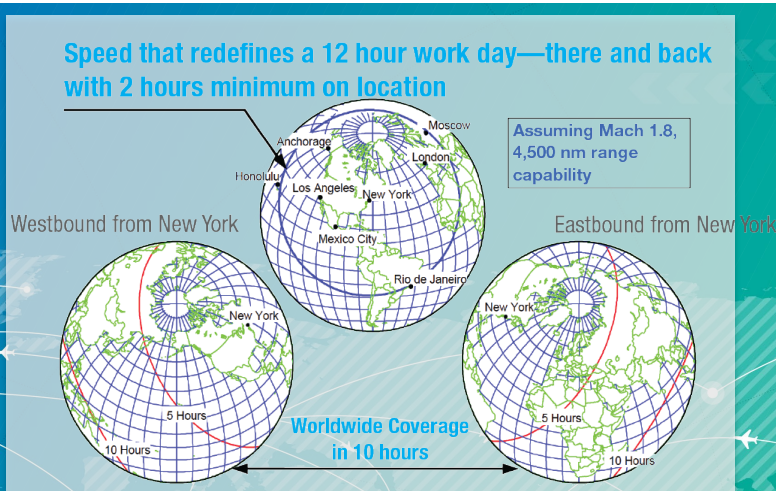
Asia-Pacific Market is Nearly **40%** of New Aircraft Deliveries

78% of New Aircraft Deliveries are Single Aisle Class (including Regional Jets)

Innovation in Commercial Supersonic Flight

WHY?

Commercial supersonic flight represents a potentially large new market for aircraft manufacturers and operators world-wide

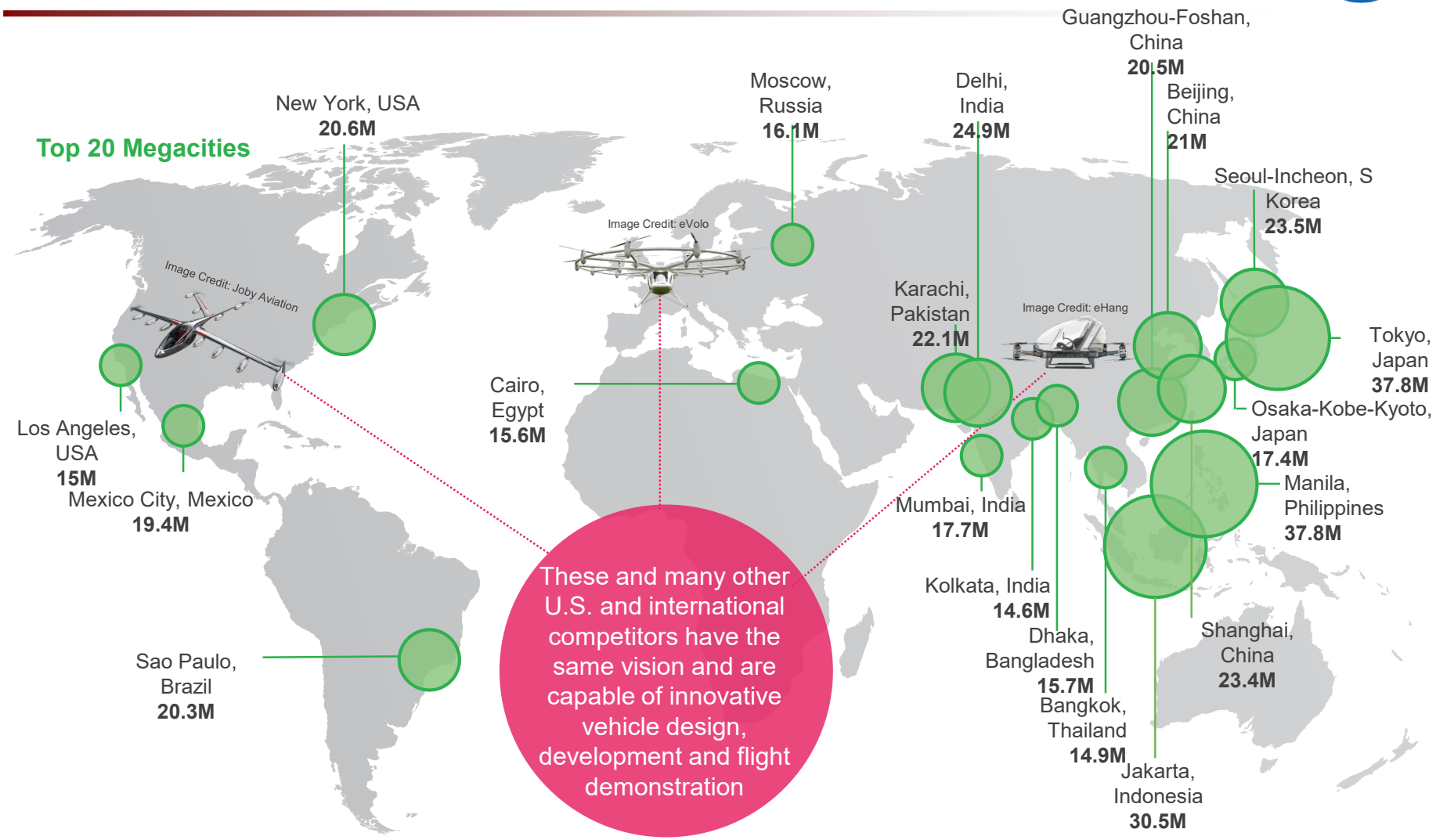


- Global demand for air travel is growing, which places a demand on speed
- Supersonic air travel offers many benefits including personal productivity and well-being for travelers; rapid for transport time-critical cargo
- Large potential market predicted: - business aircraft followed by larger commercial aircraft

www.nasa.gov

Urban Air Mobility

Global Race to Achieve Leadership



Large projected market–McKinsey analysis of demand by 2030 in 15 major U.S. cities:

- 500 Million annual UAS package deliveries
- 750 Million annual passenger trips

Extrapolation to the global market would likely increase demand by 5 to 10x

Top 20 Megacities by population data from allianz.com 03.16.15

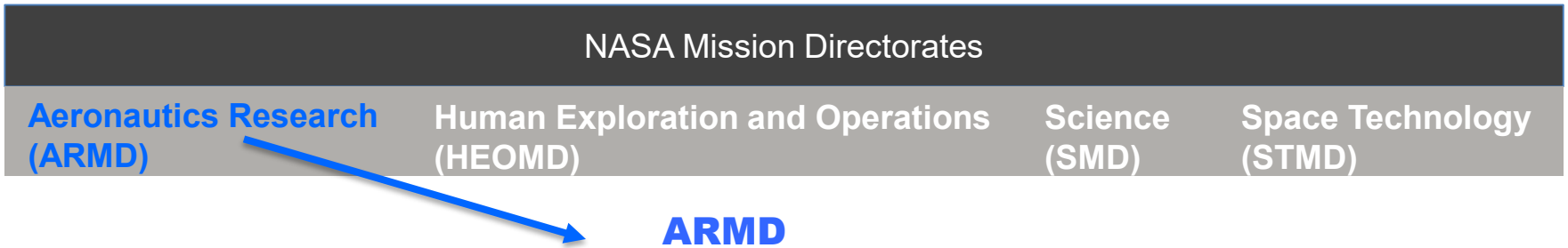
NASA Aeronautics Strategic Implementation Plan

Continues to Guide NASA Aeronautics Investment

Key Trends (Not Exhaustive)	Aviation Mega-Drivers	Analysis & Community Dialogue	Strategic Thrusts	Community Vision
Increasingly Urbanized World Rising Global Middle Class Driven by Asia-Pacific Urban Transportation Increasingly Congested	GLOBAL MOBILITY	 **Industry / Gov't Execs What's Needed?**	Safe, Efficient Growth in Global Operations Innovation in Commercial Supersonic Aircraft	
Continuing Pressure to Reduce Noise and Local Air Quality Impacts Aviation Industry Sets Challenging CO_2 Reduction Goals through Mid-Century	ENVIRONMENTAL CHALLENGES	 **Industry / Gov't SMEs What's Possible?**	Ultra-Efficient Commercial Aircraft Transition to Alternative Propulsion and Energy	
Networked Com and Sensors, Embedded Artificial Intelligence, and Big Data Converging with Traditional Systems and Technologies On-Demand Service Models Disrupting Traditional Industries	TECHNOLOGY CONVERGENCE	 **Systems Analysis**	In-Time System-Wide Safety Assurance Assured Autonomy for Aviation Transformation	

https://www.nasa.gov/aeroresearch/strategy

NASA Aeronautics Programs and Projects



ARMD PROGRAMS

Jay Dryer: Director

Advanced Air Vehicles

Projects
- Advanced Air Transport Technology
- Advanced Composites
- Revolutionary Vertical Lift Technology
- Commercial Supersonic Technology
- Hypersonic Technology

Akbar Sultan: Director

Airspace Operations and Safety

Projects
- Airspace Technology Demonstrations
- UAS Traffic Management
- System-Wide Safety
- ATM-X

Dr. Ed Waggoner: Director

Integrated Aviation Systems

Projects
- Unmanned Aircraft Systems Integration in the National Airspace System
- Flight Demonstrations and Capabilities
- Low Boom Flight Demonstrator

Dr. John Cavolowsky:Director

Transformative Aeronautics Concepts

Projects
- Convergent Aeronautics Solutions
- Transformational Tools and Technologies
- University Innovation

Aerosciences Evaluation & Test Capability Office

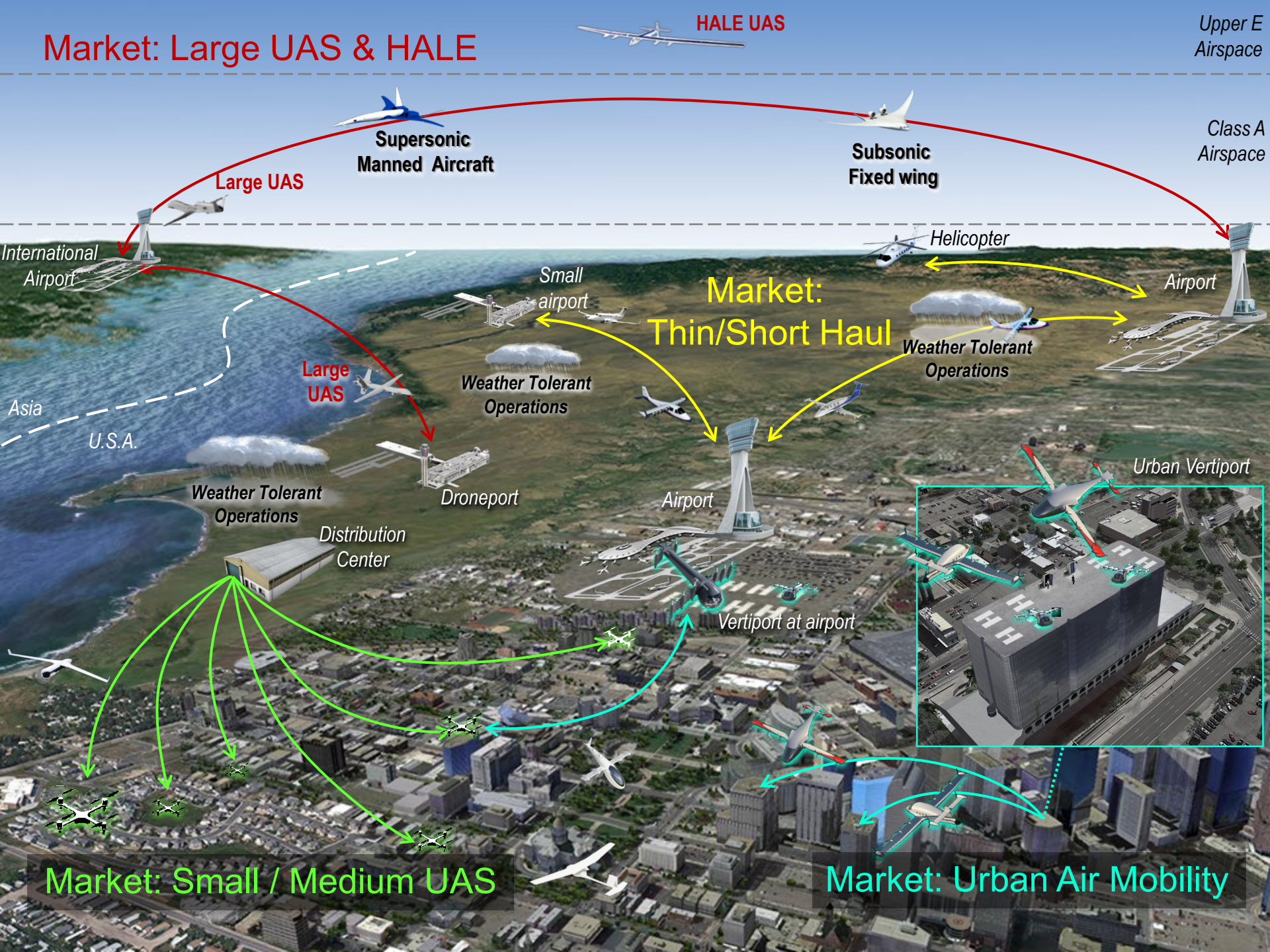
X-planes/test environment

Critical cross-cutting tool development

FY 2019 Budget Request - Aeronautics

$ Millions	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Aeronautics	**$656.0**	**$685**	**$633.9**	**$608.9**	**$608.9**	**$608.9**	**$608.9**
Airspace Operations and Safety (AOSP)	140.6		90.8	96.2	120.4	122.7	122.9
Advanced Air Vehicles (AAVP)	274.6		230.6	248.5	257.1	257.8	258.3
Integrated Aviation Systems (IASP)	125.0		189.2	154.1	106.6	103.3	102.5
Transformative Aeronautics Concepts (TACP)	115.8		123.3	110.1	124.9	125.1	125.1

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.


Market: Large UAS & HALE
HALE UAS
Upper E Airspace
Class A Airspace
Supersonic Manned Aircraft
Subsonic Fixed wing
Large UAS
International Airport
Helicopter
Small airport
Market: Thin/Short Haul
Airport
Weather Tolerant Operations
Large UAS
Weather Tolerant Operations
Asia
U.S.A.
Droneport
Weather Tolerant Operations
Distribution Center
Airport
Urban Vertiport
Vertiport at airport
Market: Small / Medium UAS
Market: Urban Air Mobility

supersonics

value via speed at cruise

NASA Supersonics Strategy

STRATEGIC THRUST, OUTCOME, & CRITICAL COMMITMENT

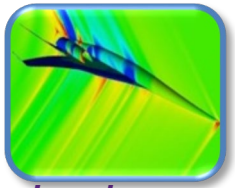
Strategic Thrust 2: Innovation in Commercial Supersonic Aircraft
Outcome (2015 – 2025): Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise
Critical Commitment: Deliver a flight validated community response database to ICAO

Integrated Design Solutions for Revolutionary High Speed Aircraft
Research & development of validated analysis tools and technologies that enable the low-sonic boom design of supersonic aircraft

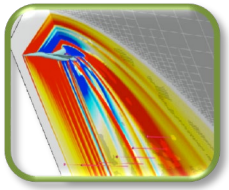
Design & Build Low Boom Demonstrator Aircraft
Design and build a first-ever low-boom demonstrator aircraft that can be utilized to generate the necessary boom data

Understanding & Measuring Community Response to Sonic Booms
Research, development, application of validated methodologies for a field study of community response to enable development of overland sonic boom standards

DELIVER DATABASE

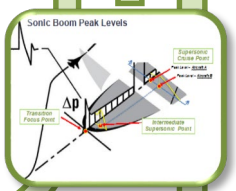


Low boom design tools (complete)



Prediction Validation

Sonic boom community response metric & methodologies

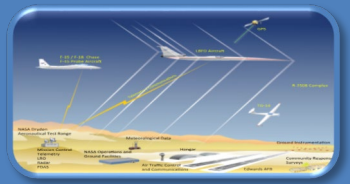


Community test planning

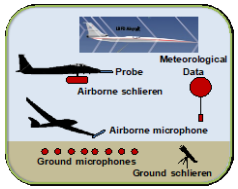
Community tests

LBFD Project

Design & build aircraft with low noise sonic boom signature characteristics



Verify aircraft low boom acoustic signature



Flight validation data measurement methodology

NASA'S LOW-BOOM FLIGHT DEMONSTRATOR

Design Parameters
- **Length:96 ft**
- **Span: 29.5 ft**
- **Speed: Mach 1.42 (940 mph)**
- **Altitude: 55,000 ft**

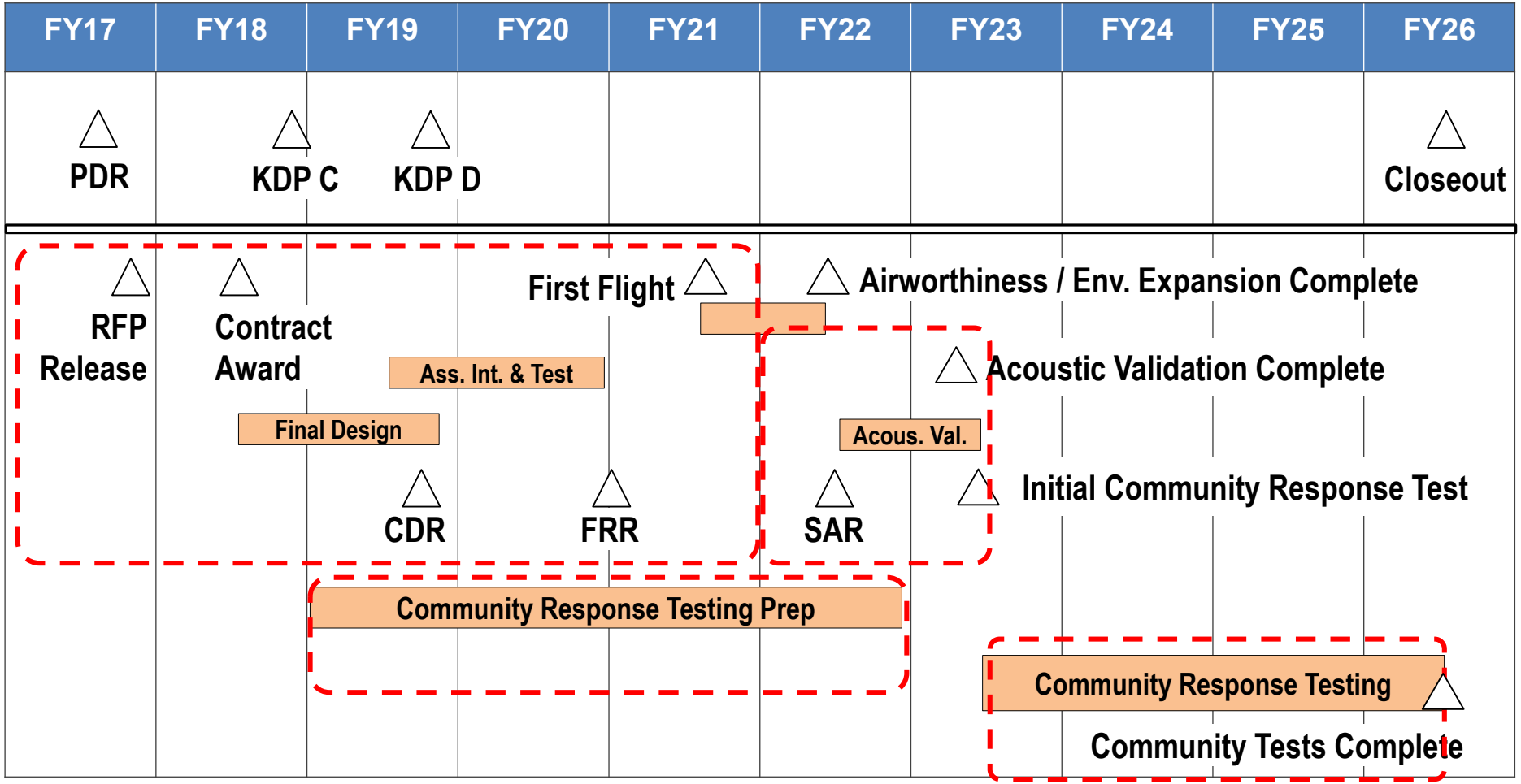
X plane approach focuses efforts on defining minimum set of key requirements that can be met in the most cost effective design

X-59 QueSST (Quiet SuperSonic Technology)

Key Requirements
- The acoustic signal of the X-plane must effectively replicate that of future larger supersonic commercial aircraft.
- The X-plane must conduct community overflight tests in a manner representative of typical flight operations of future aircraft.

Derived Requirements
- New airframe design to achieve desired acoustic signal, with smallest size that meets key acoustic requirements
- Use of components from existing aircraft to reduce cost (F-18 engine, T-38 canopy and cockpit, F-16 landing gear, etc.)
- Payload capacity: single pilot/flight test instrumentation

LBFD Project Life Cycle



Major Reviews

PDR, Preliminary Design Review
CDR, Critical Design Review
FRR, Flight Readiness Review
SAR, System Acceptance Review

vertical lift

value through accessibility

Emerging Aviation Markets

Global Race to Achieve Leadership

Urban Air Mobility Example

Ehang - China

E-Volo - Germany

Joby - US

And many other U.S. and international competitors have the same vision and are capable of innovative vehicle design, development and flight demonstration

The race to capture the market will be won based on…

- Ability to safety certify innovative aviation technologies and configurations
- Achieving equitable community noise standards
- Enabling safe airspace access at high densities
- Achieving safe vertiport infrastructure standards

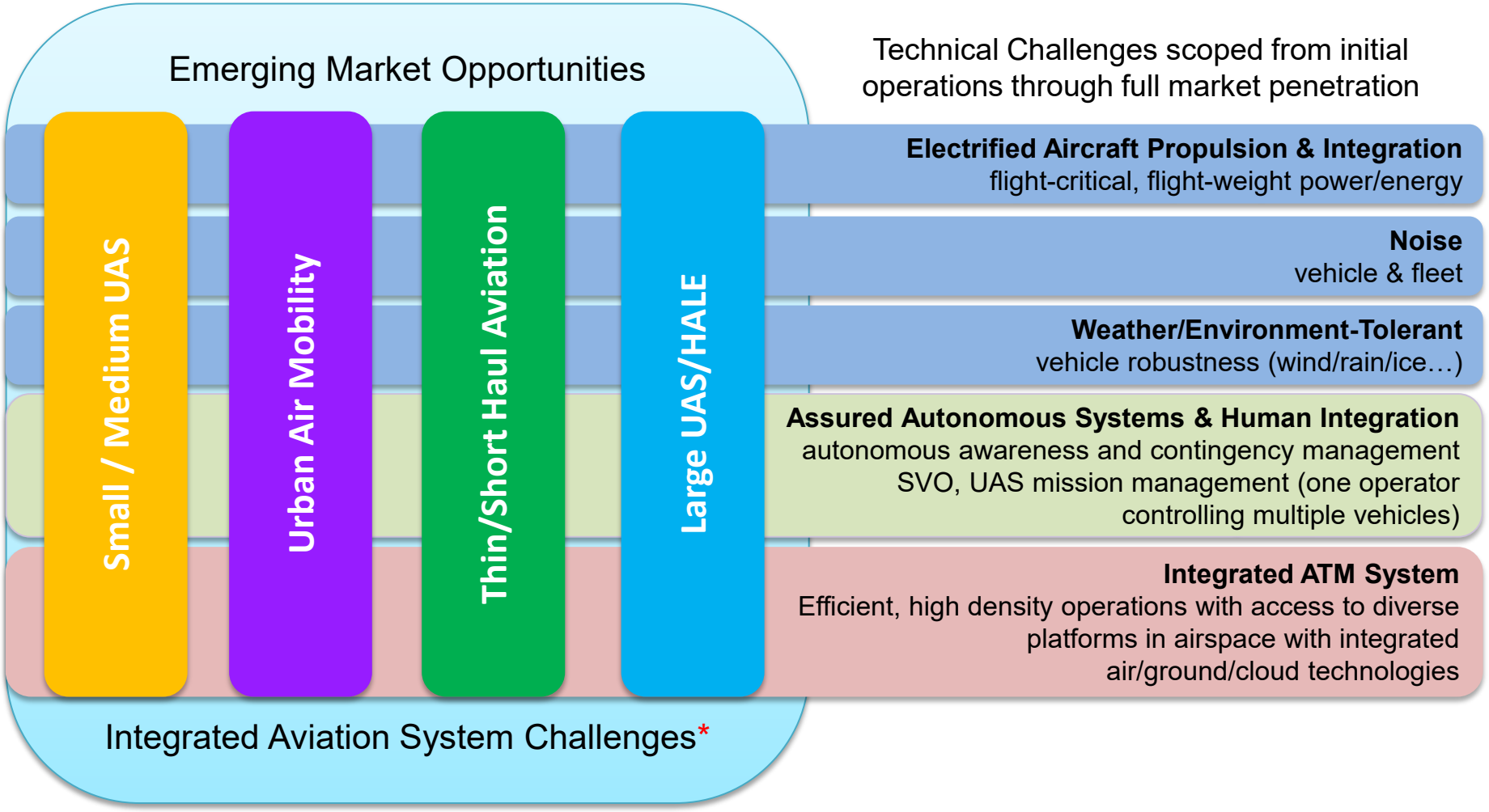
But most demonstrations and early market growth are overseas – all four key issues easier to manage in many other countries. The U.S. must lead or fall behind.

NASA is adjusting its portfolio to address the issues, support FAA and industry to accelerate U.S. competitive posture, and do it through a technically sound, sustainable and scalable approach

Emerging Markets - Integrated Challenges

NASA ARMD Programs pivoting to address complex challenges

ARMD has developed a holistic understanding of the challenges for enabling the enormous potential of emerging aviation global market opportunities



*** Only showing small a/c emerging markets; fully integrated aviation system captures all air vehicles**

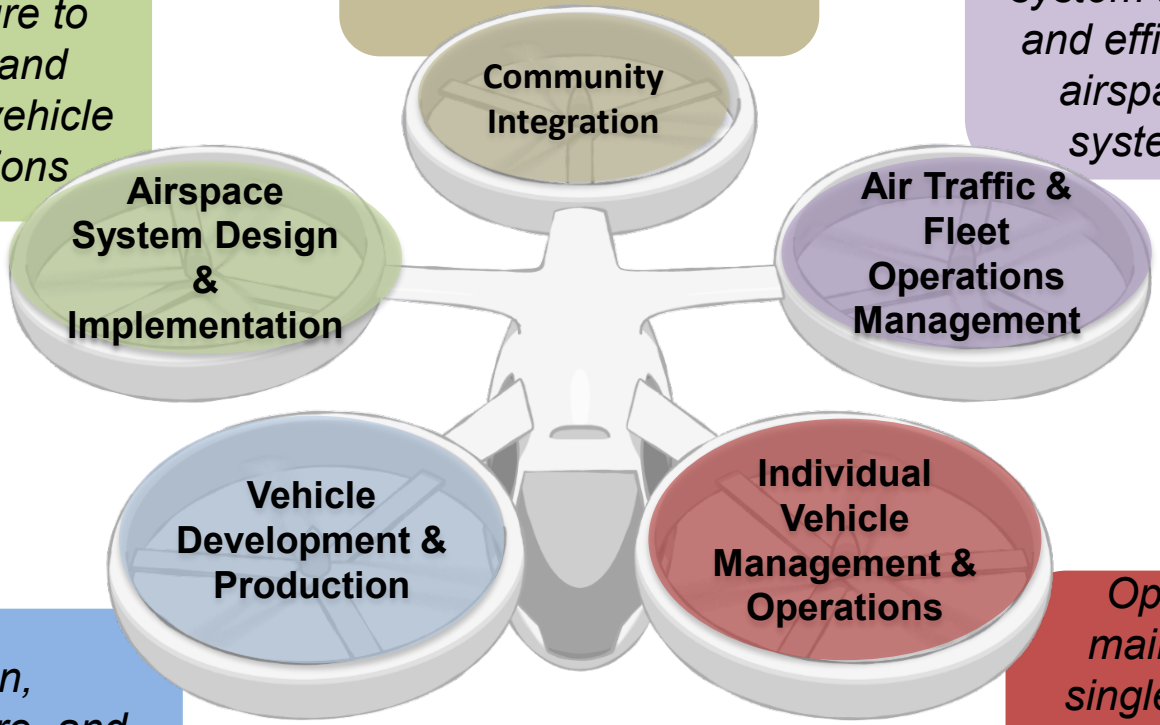
NASA UAM Vision and Framework

Policy, Certification, and Technical Challenges For Operating in the National Airspace System

Societal integration and acceptance of UAM operations

Design, development, and implementation of infrastructure to enable safe and efficient multi-vehicle UAM operations

Operations and management of multiple vehicles within a UAM system that enable safe and efficient sharing of airspace and other system resources



Design, manufacture, and system readiness of UAM vehicles

Operations and maintenance of a single UAM vehicle, independent of the sharing of airspace or other system resources

Urban Air Mobility (UAM) Vision
Revolutionize mobility within metropolitan areas by enabling a safe, efficient, convenient, affordable, and accessible air transportation system for passengers and cargo

"Development" ←

→ "Operations"

Open, publicly-available reference configurations for Urban Air Mobility

NOT "BEST" DESIGNS; NO INTENT TO BUILD AND FLY

- Cover a wide range of technologies and missions
- Provide focus for trade studies and system analysis
- Assess failure modes and hazards of concept vehicle EAP architectures

Quadrotor "Air Taxi"

- One passenger (250-lb payload)
- 50-nm range
- electric quadrotor

Tilt wing "Airliner"

- Fifteen passengers (3000-lb payload)
- 8x50 = 400-nm range
- turbo-electric tiltwing

Lift+Cruise Air Taxi

- Six passengers (1200-lb payload)
- 2x37.5 = 75nm range
- turboelectric Lift + Cruise VTOL

Side by Side "Vanpool"

- Six passengers (1200-lb payload)
- 4x50 = 200-nm range
- hybrid side-by-side helicopter

subsonics (transports)

the 24/7 global backbone
of air transportation
now and into the foreseeable future

Subsonic Transport Technology Strategy

Prove out transformational, integrated propulsion and airframe technologies

Energy usage reduced by more than 60%

Harmful emissions reduced by more than 90%

Objectionable noise reduced by more than 65%

Current Generation

Next Generation -Transitional-

Future Generations -Transformational-

Image Credit: Denis Fedorko

Create technology pathway for new capabilities

Image Credit: pjs2005 from Hampshire, UK

2040

Image Credit: Weimeng

2030

Image Credit: Don-vip

2020

Technology Maturation for UEST Markets

- Suite of 5 Key Technologies coupled into Transformative Configurations will have a tremendous impact:
  - Light Weight, Very High Aspect Ratio Wings
  - Tailored Unconventional Structures
  - Propulsion – Airframe Integration, especially Boundary Layer Ingestion
  - Electrified Aircraft Propulsion
  - Small Core Turbine Engines
- ARMD is advancing these key technologies to create market opportunities

Very High Aspect Ratio Wing

Boundary Layer Ingestion

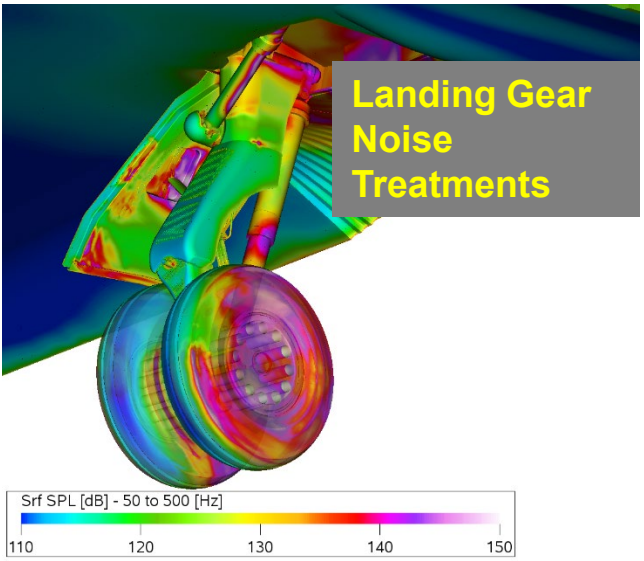
Electrified Aircraft Propulsion

Flight Research and Demonstrations

recent and ongoing

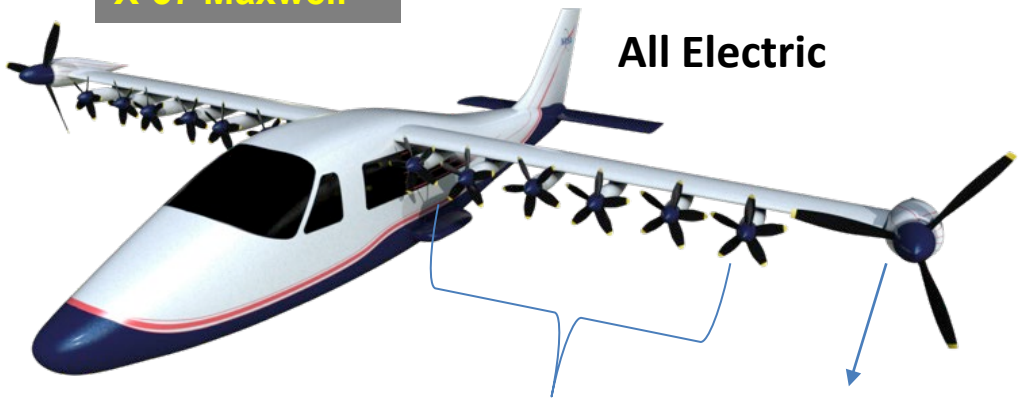
X-56 Performance
Adaptive Aeroelastic Wing

Adaptive Compliant Trailing Edge II



Landing Gear
Noise
Treatments

X-57 Maxwell



All Electric

High Lift System

Cruise System

DAWN OF NEW ERA OF AVIATION

Exciting times

- Investing in our future - laying the groundwork for Aviation in 2040
- Many challenges… present many opportunities… across many markets

Technologies

- Many broadly applicable and some uniquely enabling technologies
- Convergence from other sectors into aviation

Vehicles, Operations, Energy, Smart Systems

- Bringing new value through the air