ARMD 10-year Investment Strategy

Aeronautics and Space Engineering Board Meeting

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Aeronautics Research Mission Directorate
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Contents

Global Growth in Aviation: Opportunities and Challenges

Global Air Passengers by Region (% of Total)

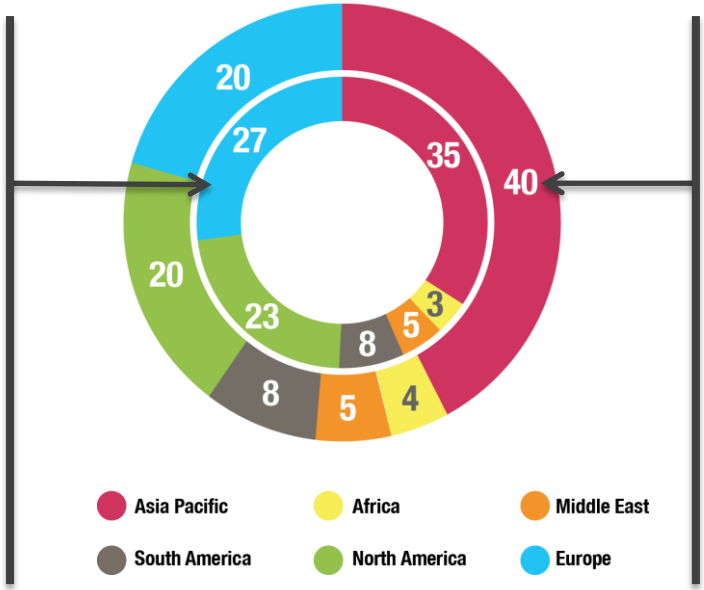
2014 Global Aviation Industry

3.3B Passenger Trips

North America and Europe combined is half of all Passenger Trips

58M Jobs

$2.4T GDP



2034 Global Aviation Industry, est.

7B Passenger Trips

Asia-Pacific Passenger Trips equal to North America and Europe combined

105M Jobs

$6T GDP

Over 36,000 New Aircraft required (replacement and growth) over the 20 year period ($4-$5T value)

Sources: International Air Transport Association, Air Transport Action Group, Boeing

Major Opportunities / Growing Challenges

Competitiveness—New state backed entrants, e.g., COMAC (China); Growing global R&D

Environment—Very ambitious industry sustainability goals; Large technology advances needed

Mobility—More speed to connect the worlds' major cities; Opportunity for commercial supersonic flight

U.S. Technological Leadership Required!

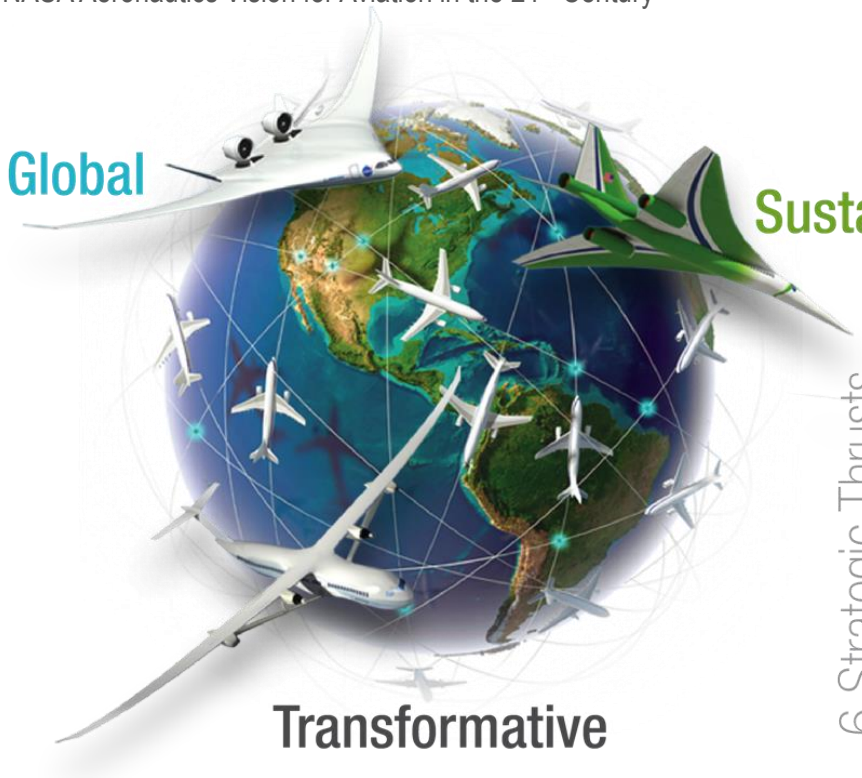
Real and Growing International Competition for the Future of Aviation

We are not the only game in town anymore

- COMAC C919 nearing flight test
- Airbus acquired a US patent for a Mach 4+ supersonic aircraft concept. (July 2015)
- JAXA tested supersonic aircraft concept (July 2015)
  - World's first successful drop test of a low boom supersonic design
- Airbus E-Fan flew across the English Channel (July 10, 2015)
- Airbus proposed a formation of electric aircraft consortium between EU and US (September 2015)
- Siemens is leading high power electric motor for airplanes
- Toyota and Nissan are eyeing development of electric aircraft
- Drone Market is rapidly growing – by 2020, the civil market will be as large as the military
  - Israel is the world's largest drone exporter ($4.6B in the last 8 years)
  - Chinese DJI is the world's biggest consumer small UAS maker by revenue

NASA Aeronautics

NASA Aeronautics Vision for Aviation in the 21st Century



6 Strategic Thrusts

- Safe, Efficient Growth in Global Operations
- Innovation in Commercial Supersonic Aircraft
- Ultra-Efficient Commercial Vehicles
- Transition to Low-Carbon Propulsion
- Real-Time System-Wide Safety Assurance
- Assured Autonomy for Aviation Transformation

U.S. leadership for a new era of flight

Environmentally Responsible Aviation Project

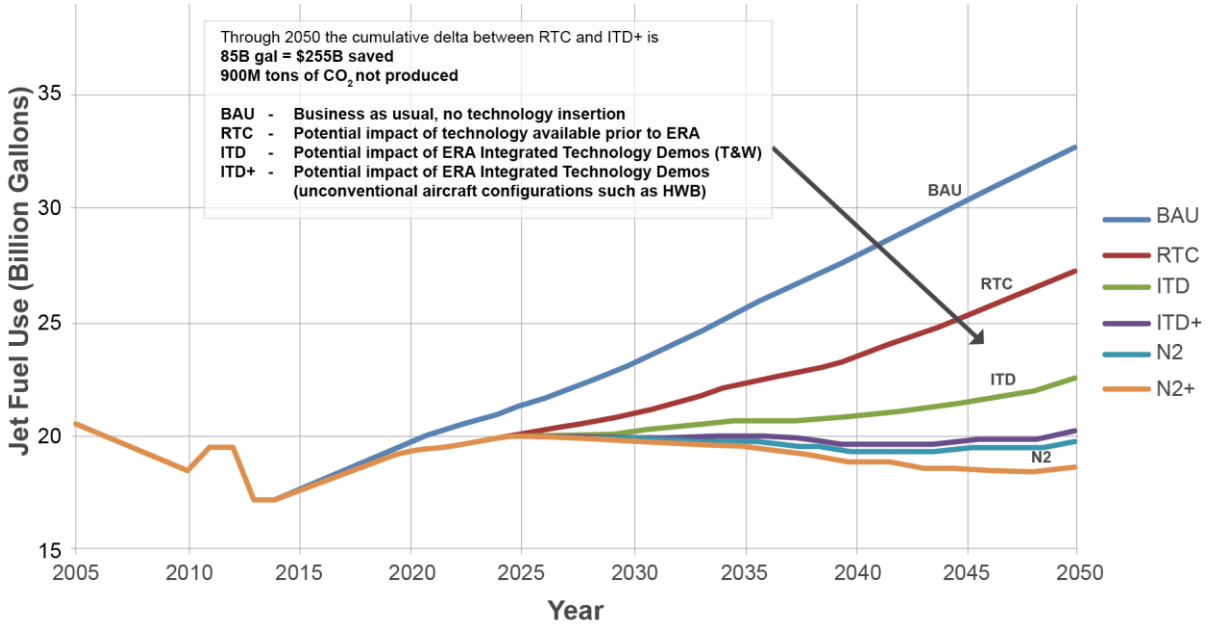
Completed in FY 2015

Image Credit: Boeing

www.nasa.gov

Potential Impact of ERA

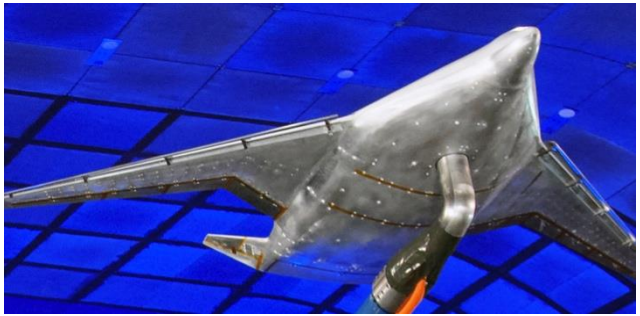
Ultra-Efficient Commercial Vehicles-Subsonic Transport



Technologies and study vehicle concepts that together can simultaneously meet the NASA Subsonic Transport System Level Metrics for noise, emissions, and fuel burn in the N+2 timeframe

Examples of Recent Progress in Developing Ultra-Efficient Subsonic Transport Concepts

TTBW Aeroservoelastic • FY14
Langley Transonic Dynamics Tunnel

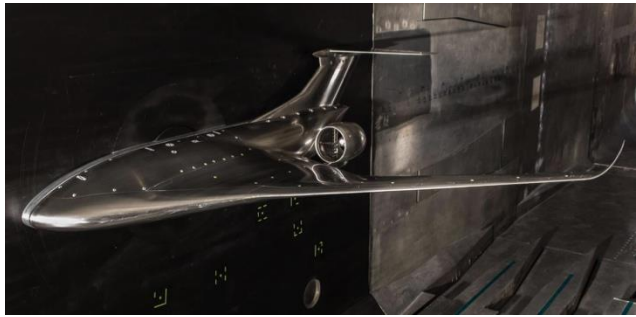


BWB/UHB Low Speed Operability • FY15
National Full-Scale Aerodynamic Complex at Ames

D8/BLI Integrated Benefit • FY13&14
Langley 14- By 22-Foot Subsonic Tunnel

TTBW Aerodynamic Integration • FY16
Ames 11-Foot Transonic Wind Tunnel

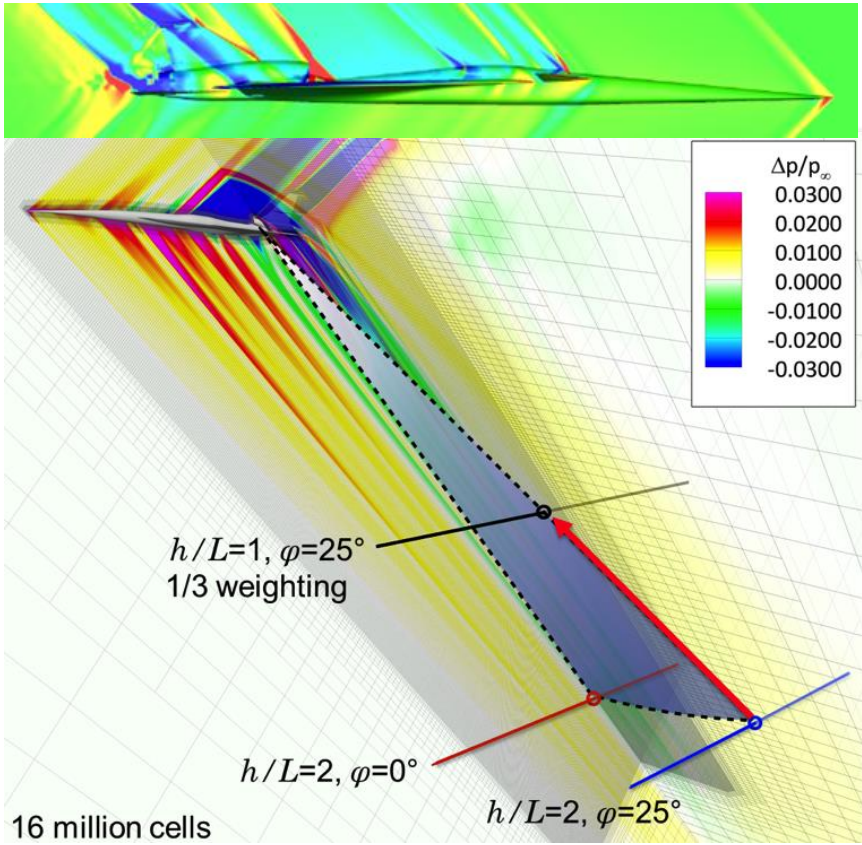
BWB Non-circular Fuselage • FY15
Langley Combined Loads Test System (COLTS)



HWB/OWN Performance • FY15
Langley National Transonic Facility

Paving the Way for Supersonic Flight

Completion and transfer of design tools to industry

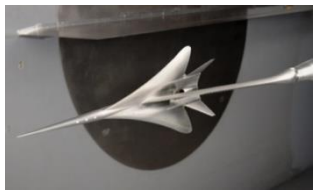


Computational design tools developed that help shape the aircraft based on desired signature on the ground.

Completed Design Tool TC in FY15

Multiple flight tests to examine areas such as efficiency and also help study community response measurement techniques.

Several comprehensive wind tunnel campaigns conducted to validate performance of designs and help develop tools.



New methods to image the shocks from an aircraft in flight have been invented.

NASA Aeronautics Ready for Flight

Accomplishments and Planning

NASA Aero Vision and Strategy Established

Roadmaps Completed

2008-2013	2014/15	2016/17	2018-2026

N+3 Subsonic & Supersonic Concept/Technology Studies

Ground Testing of N+3 configurations and technologies

LBFD PDR Completed

UEST PDR Completed

N+2 Environmentally Responsible Aviation (ERA) Project Initiated

8 Integrated Tech Demos Completed, Tech transitioned to industry. HWB ready for Flight Dem/Val.

Ready for X-Plane Integration & Demonstration

NASA FAA NextGen Research Transition Teams (RTTs) Initiated

Technology Transitions to FAA: MSP, EDA, PDRC, TSAS

ATD-1 Completed and transferred to FAA

ATD-2, 3 Completed & Transferred to FAA

Ready for NextGen TBO Integration & Demonstration

FY 2017 Budget

$ Millions	FY 2015	Enacted FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Aeronautics	**$642.0**	**$640.0**	**$790.4**	**$846.4**	**$1,060.1**	**$1,173.3**	**$1,286.9**	**$1,294.2**	**$1,307.6**	**$1,218.1**	**$829.7**	**$839.5**
Airspace Operations and Safety	154.0		159.4	159.2	176.2	189.1	221.5	198.7	200.9	193.2	175.5	167.8
Advanced Air Vehicles	240.6		298.6	277.4	308.8	311.6	312.6	321.3	315.0	318.9	317.7	326.7
Integrated Aviation Systems	150.0		210.0	255.4	381.4	493.0	556.7	591.5	612.2	525.0	203.8	210.6
Transformative Aeronautics Concepts	97.4		122.3	154.4	193.8	179.7	196.2	182.8	179.4	181.0	132.7	134.4

Ten Year Investment Plan–FY 2017 Budget Accelerates Key Components of NASA Aeronautics Plan

Fund the Next Major Steps to Efficient, Clean and Fast Air Transportation Mobility

New Aviation Horizons

Start a continuing series of experimental aircraft to demonstrate and validate high impact concepts and technologies. Five major demonstrations over the next 10+ years in the areas of Ultra-Efficiency, Hybrid-Electric Propulsion, and Low Noise Supersonic Flight

Major New Initiative within IASP

Enabling Tools & Technologies

Major series of ground experiments to ready key technologies for flight

Research and ground demonstration for an advanced small engine core for very high bypass engines and as a hybrid-electric propulsion enabler

Development of next generation physics-based models needed to design advanced configurations

Increases to AAVP & TACP

Build off of major current developments and accomplishments

Revolutionizing Operational Efficiency

Accelerate demonstration of full gate-to-gate Trajectory Based Operations

Increase to AOSP

Fostering Advanced Concepts & Future Workforce

Increased investment in new innovation through the NASA workforce and Universities

Leverage Non-Traditional Technology Advances

Pursue challenge prizes in areas such as energy storage, high power electric motors, advanced networking and autonomy

Increase to TACP

Continue to incentivize new innovation

UAS

Strong continued research leadership in enabling UAS integration into the National Airspace. Extending the UAS in the NAS project for an additional 4 years

Hypersonics

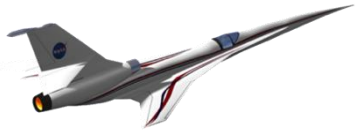
Increased investment to ensure a strong National fundamental research capability

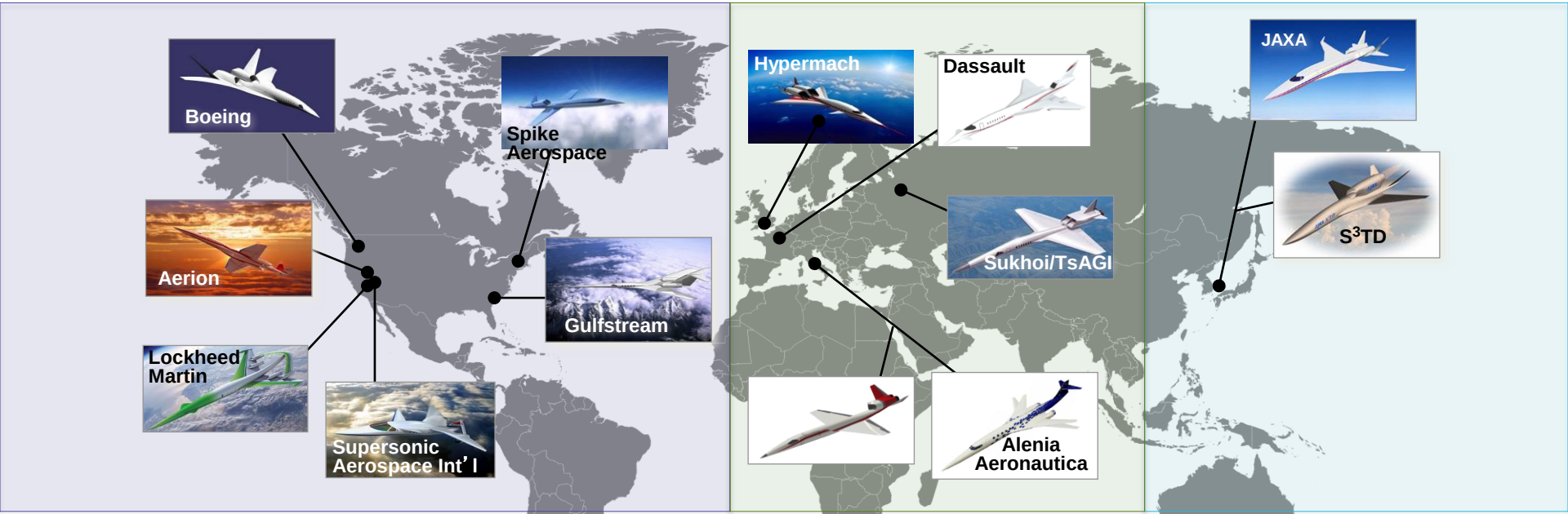
Increases to IASP & AAVP

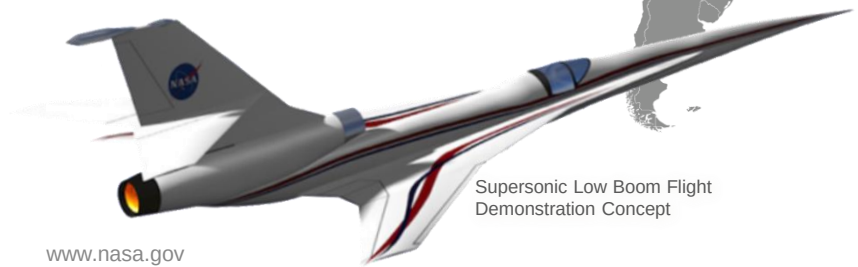
Ultra-Efficient Subsonic Demonstrators

Low Noise Supersonic Flight

First Step to Unlocking a Global Market







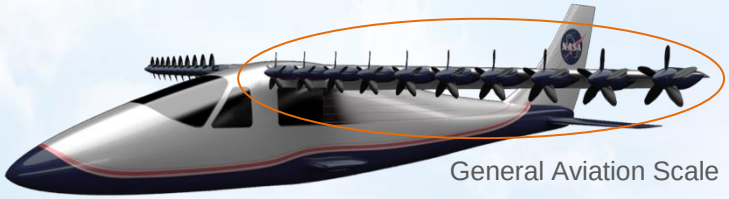
Supersonic Low Boom Flight Demonstration Concept

Low Boom Flight Demonstrator

- Demonstrate that noise from sonic boom can be reduced to a level acceptable to the population residing under future supersonic flight paths.
- Create a community response database that supports an International effort to develop a noise based rule for supersonic overflight.
- **Establish U.S. Leadership for this New Global Market**

Hybrid Electric Propulsion (HEP) Flight Demonstrators—Examples

Concept Exploration and Scaling



General Aviation Scale

Aircraft Concept Description

- Electric propulsion distributed along the wing
- High aspect ratio / high wing loading

Benefits

- 5X increase in energy efficiency (compared to conventional General Aviation (GA) configurations)
- Major potential improvement in GA safety
- Enables NASA, Industry and FAA learning on the integration, certification, and operation of HEP systems

Status

- 2017 Phase 1 First Flight

Aircraft Concept Description

- Motor driven tail cone (aft, integrated BLI) propulsor is used to improve propulsive efficiency of aircraft
- Motor driven from generators installed in optimized turbofans

Benefits

- Applicable to conventional transport configurations, enables potential for early adoption of HEP technology
- Ingests fuselage boundary layer, reducing drag and increasing propulsive efficiency
- 5-10% energy reduction, depending on mission range

Status

- High industry interest
- Leading candidate for large scale flight demonstration in the mid 2020's
- Wind tunnel, powertrain, and integration simulation, testing, and analysis required to validate benefits, explore technical challenges, and reduce the risk of flight test

New Aviation Horizons Flight Demo Plan

"Purpose-Built" Ultra-Efficient Subsonic Transport (UEST) Demonstrators

Hybrid Electric Propulsion (HEP) Demonstrators

Transport Scale
Ground Test Risk Reduction

Small Scale "Build, Fly, Learn"
Design & Build
Flight Test
Design & Build
Flight Test

DP
Preliminary Design
Design & Build
Flight Test

Validated HEP Concepts, Technologies And Integration for U.S. Industry to Lead the Clean Propulsion Revolution

Ground Test Risk Reduction
Preliminary Design
Design & Build
Flight Test

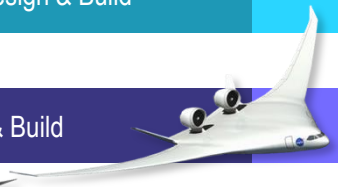
DP

Potential Candidates

Ground Test Risk Reduction
Preliminary Design
Design & Build
Flight Test

DP

Preliminary Design
Design & Build
Flight Test



Validated ability for U.S. Industry to Build Transformative Aircraft that use 50% less energy and contain noise within the airport boundary

Fully integrated UEST Demonstrator

DP

Design & Build
Flight Test

Enables Low Boom Regulatory Standard and validated ability for industry to produce and operate commercial low noise supersonic aircraft

FY17 FY18 FY19 FY20 FY21 FY22 FY23 FY24 FY25 FY26

TBO: Concept to Demo

Next Step in NASA Research and NextGen Development

Develop and Demonstrate NextGen Capabilities:
Reducing fuel use and flight delays

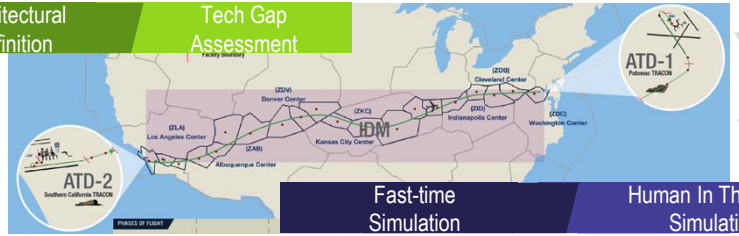
Gate-to-Gate Optimization

Gate-to-Gate Trajectory Based Operations

Gate-to-Gate 4DT TBO: Complete gate-to-gate flight optimization incorporating system constraints and user request.

Concept Validation | Technology Maturation | Demo

Architectural Definition | Tech Gap Assessment



Enables airlines to operate increasingly efficient 4D "gate-to-gate" trajectories

Fast-time Simulation | Human In The Loop Simulation | Integrated Field Demo

RTT deliverable

Initial Integrated Demand Management

Concept Validation | Technology Maturation

IDM TBO: Integrates departure, en route, and descent flight operations for greater optimization

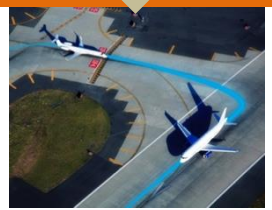
Complex Terminal Area Trajectory Management

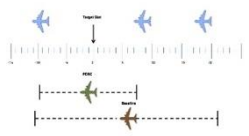
ATD-2

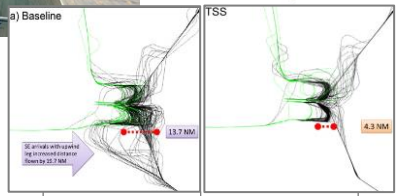
Initial Concept Demo

Fully Integrated Field Demo

RTT deliverable







ATD-2: Coordinated preflight, taxi, takeoff, and departure paths for all outbound flights at an airport

Enables airlines to optimize efficient operations into and out of busy airports and terminal area airspace

ATD-1

Ground Side Demo

Flight Side Demo

RTT deliverable

ATD-1: Efficient descent, approach, and landing for all flights inbound to an airport

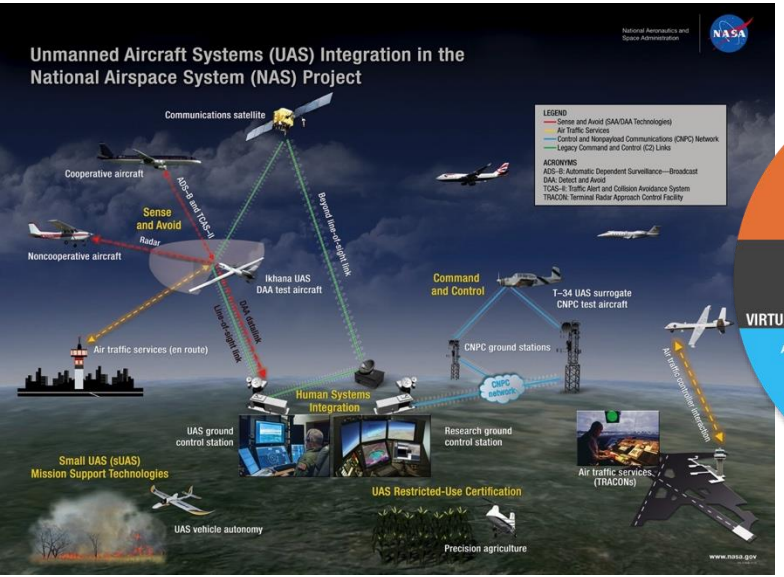
2015 | 2017 | 2020 | 2025

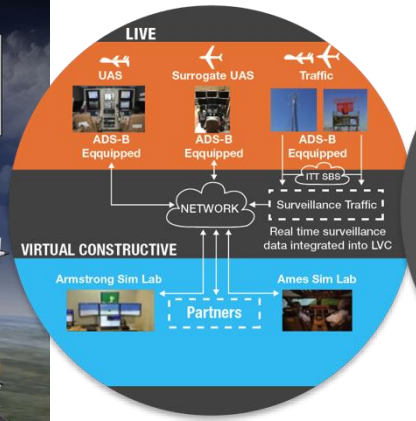
Extend UAS in the NAS Project

Phase 2 MOPS Project Goal and Technical Challenges (TC)

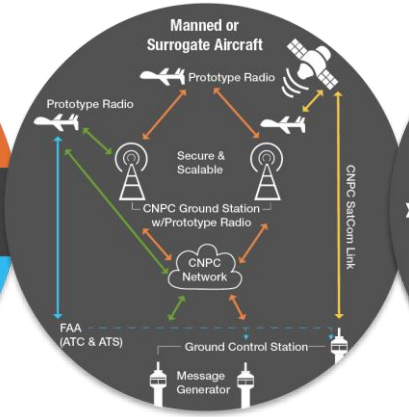
Extend the UAS Integration in the NAS Project (UAS-NAS) through 2020 to support FAA and RTCA in the development of Phase 2 Minimum Operational Performance Standards (MOPS)

SC228 Phase 2 Goal: Develop Minimum Operational Performance Standards for Detect and Avoid and Command and Control equipment for extended operations of UAS in Class D, E, and perhaps G airspace.

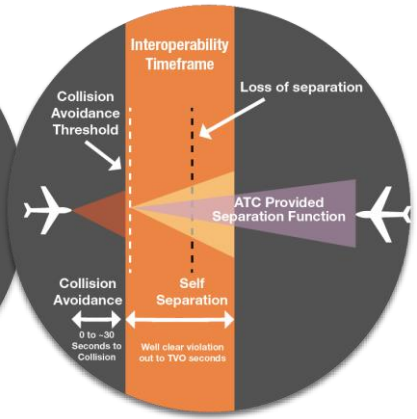




Integrated Test and Evaluation (IT&E)



Satellite Communications (SatCom) Performance Standards

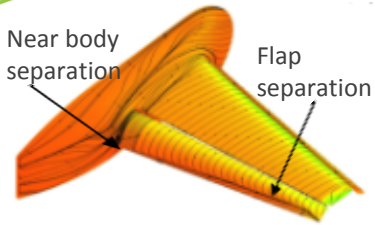


Detect and Avoid (DAA) Performance Standards

UAS-NAS Phase 2 MOPS continues to support the RTCA SC-228 MOPS development

Accelerate Development of Advanced Physics Based Design and Analysis Capabilities

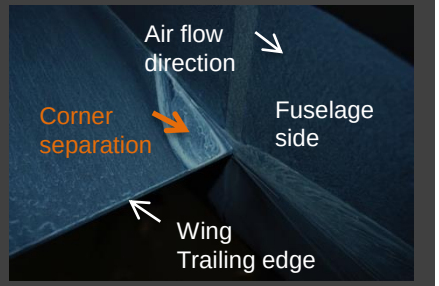
Simulation of Physics—Advanced Models



With the request, ARMD fully funds new design tools called for in NASA's recent Computational Fluid Dynamics 2030 study

- Enable tools to advance on schedule with the Ultra-Efficient Subsonic Transport (UEST) X-Planes
- Utilize tools in UEST design studies
- Acquire flight validation data from the UEST Flight Tests

High Fidelity Experiments on Complex Flow Physics



Experimental Aircraft Flight Validate Advanced Models

Increase Investment in New Innovation

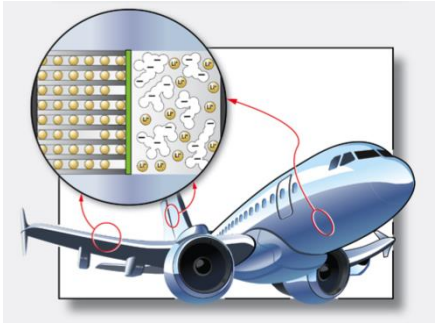
Internal NASA Researcher Driven and External University Driven

University Leadership Initiative

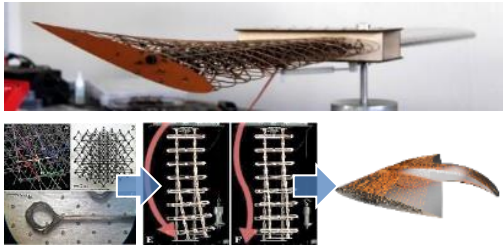
- Expand and Accelerate “University Aeronautics Leadership” research initiative
  - Help solve most complex challenges associated with High Efficiency, Clean Aviation;
  - Leverage capability of universities to bring together best and brightest minds across many disciplines;
  - Universities propose their own technical challenges undertaking an innovative, multi-disciplinary research portfolio to address those challenges.

Convergent Aero Solutions

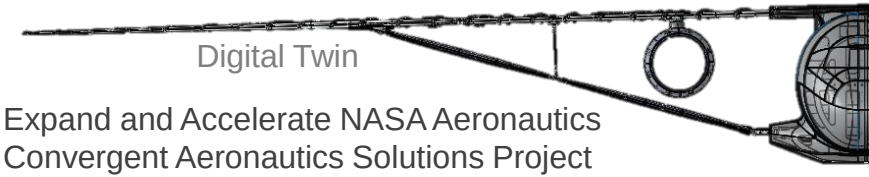
Multi-Function Structures



Adaptive Digital Materials



Digital Twin



- Expand and Accelerate NASA Aeronautics Convergent Aeronautics Solutions Project
  - Targeted increase to support rapid feasibility assessments for transformative technology concepts for High Efficiency, Clean Aviation
  - Project initiation in FY15 – many more high quality concepts than could be funded – high confidence in project expansion

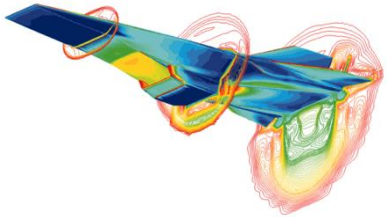
NASA Hypersonics

Increased investment to sustain National capability

NASA

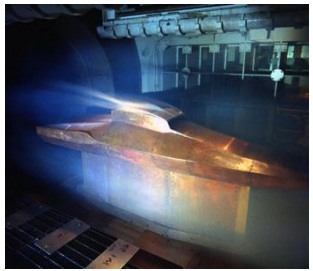
- Focus on fundamental research (long term emphasis with near term impact)
- Fully utilizes data from DoD demonstrations to advance and validate methods and technologies
- Performs independent studies to assess technical readiness for advanced capabilities
- Maintains unique facilities & skills with unique expertise to benefit broad community (OGA, industry & universities)

Fundamental research base for country & future missions



Share valuable data that NASA cannot afford to create

Provide subject matter experts and key facilities



DoD

- Focus on operational mission (especially in near-term)
- In-house expertise aligned with mission need
- Enhancing test capabilities
- Significant investment (especially in demonstrations)

Develop new military capability

New Era For NASA Aeronautics

Investing In Our Future - Investments in NASA's cutting edge aeronautics research today are investments in a cleaner, greener, safer, quieter and faster tomorrow for American aviation:

- A future where Americans are working in stable, well-paying jobs.
- A future where we fly on aircraft that consume half as much fuel and generate only one quarter of current emissions.
- A future where flight is fueled by greener energy sources.
- A future where our air transportation system is able to absorb nearly four billion more passengers over the next 20 years without compromising the safety of our skies.
- A future where our airports are better neighbors because they contain noise within the airport boundary.
- A future where people can travel to most cities in the world in six hours or less in an airplane that can fly faster than the speed of sound on bio-fuels.