

NASA Langley Research Center

Steve Bauer, Research Directorate

Where is NASA?

Langley is the first Research Center (1917)

Research Centers include **Ames**, **Glenn** and **Armstrong**



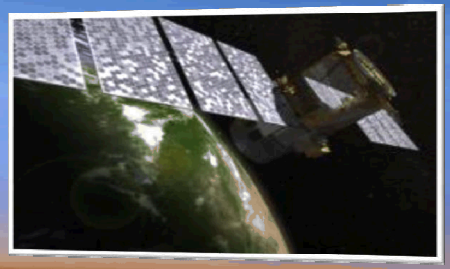
NASA Langley Research Center









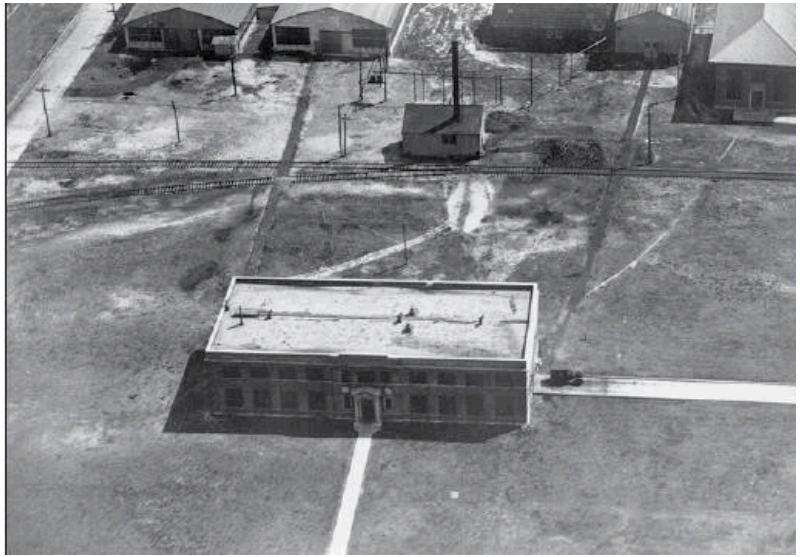


NACA / NASA Langley : Then and Now

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
LANGLEY FIELD, VA

1917

1918 $122 k



2017

2017 $992 m

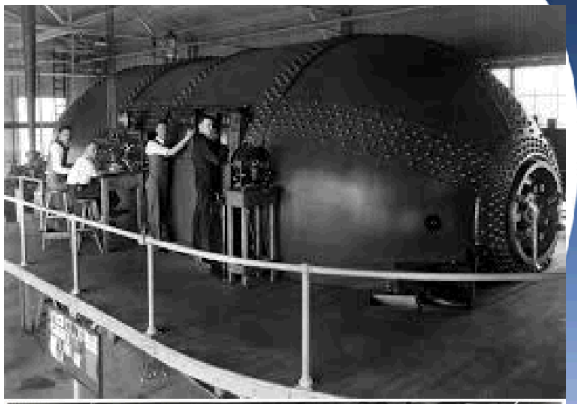
Langley Research Center

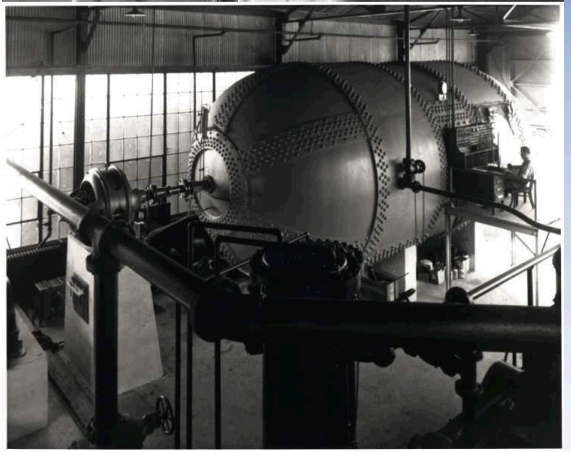


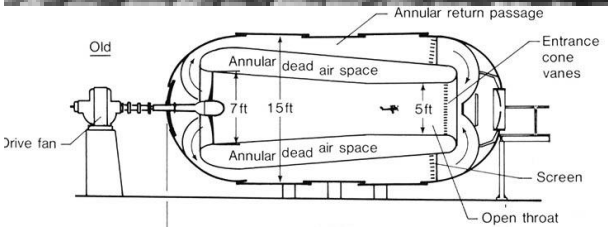
Budget : https://history.nasa.gov/SP-4103/app-c.htm

NACA : Variable Density Wind Tunnel

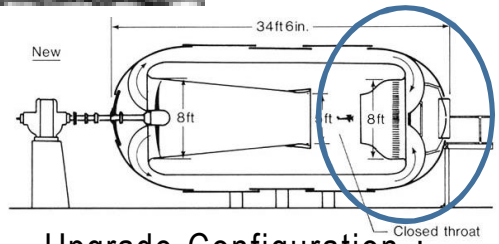






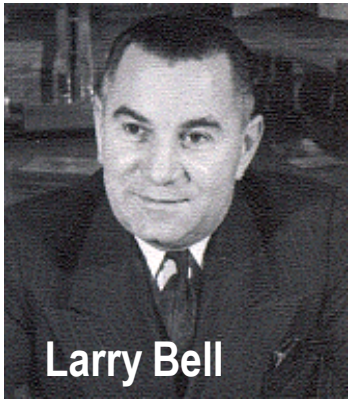


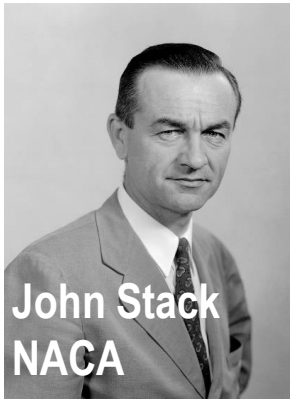
Initial Configuration : Turbulence

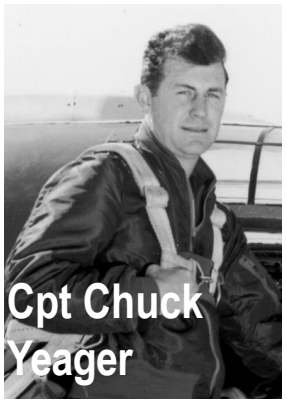


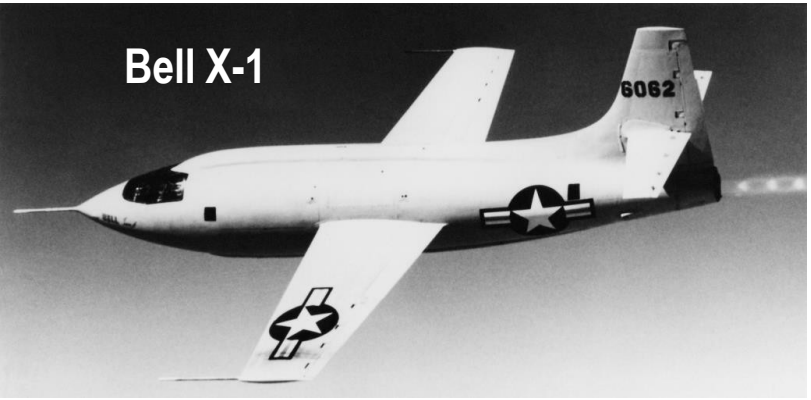
Upgrade Configuration : No Turbulence

NACA at Langley

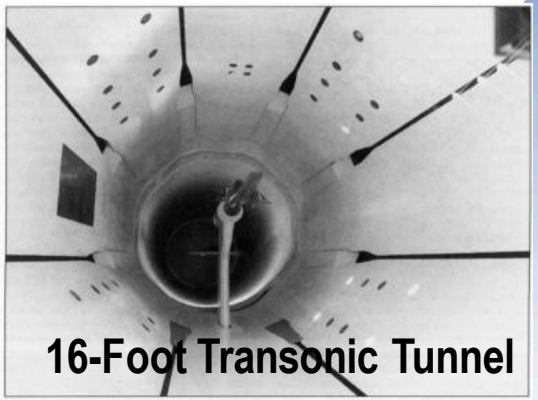








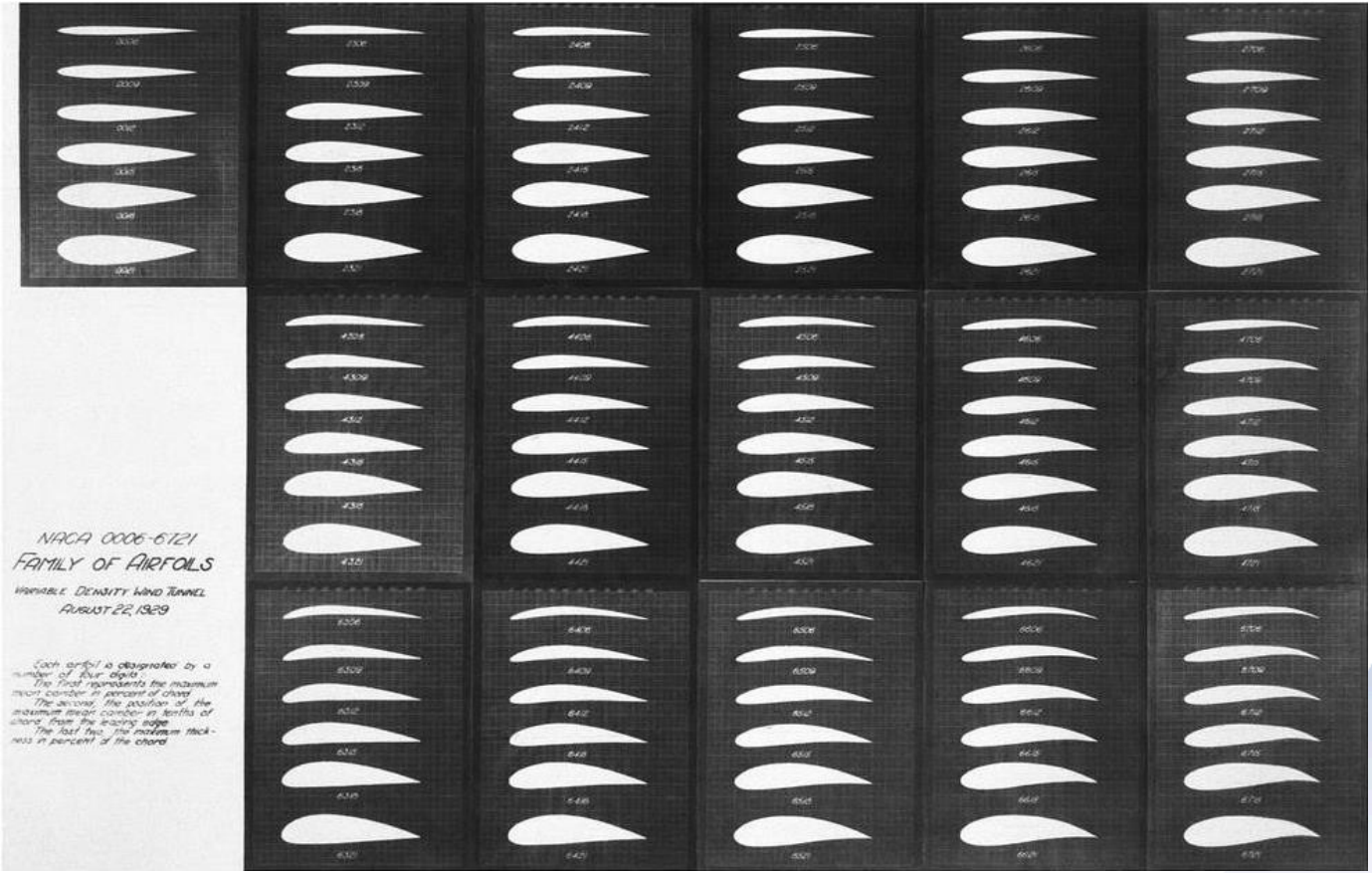
October 14, 1947 : Mach 1.06, at 43,000 feet.



Dec 6, 1950 : Mach 0.1 - 1.03 (1.3)

NASA Technical Paper (TP) 3521, September 1995

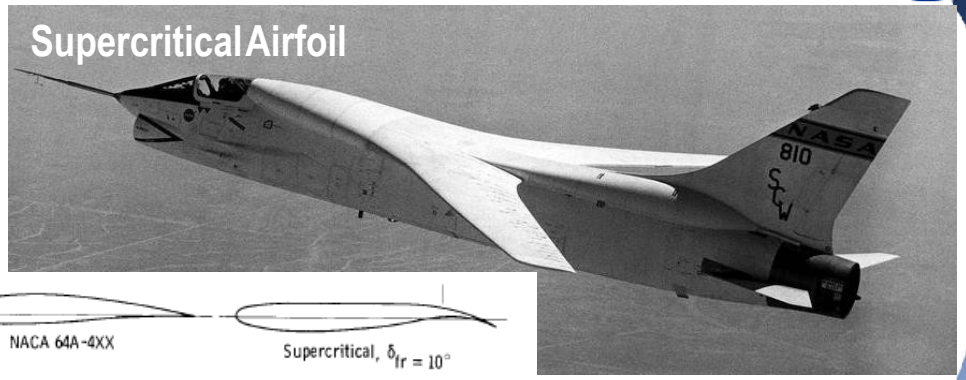
NACA at Langley : NACA Airfoils4/5



Digital Generator for airfoils : http://airfoiltools.com/airfoil/naca5digit

NACA-NASA at Langley : Richard Whitcomb







Conversion from NACA to NASA, July 29, 1958, The Space Race!

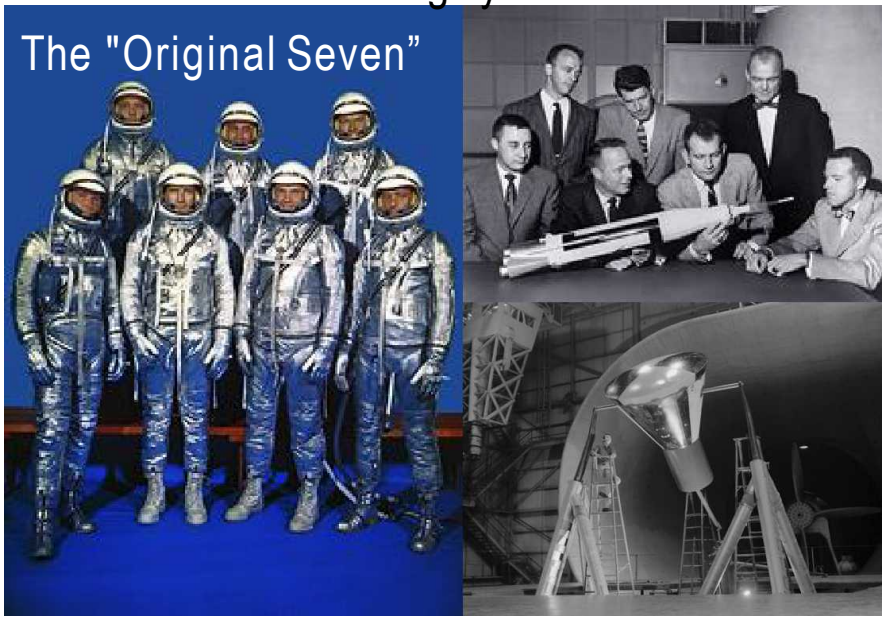




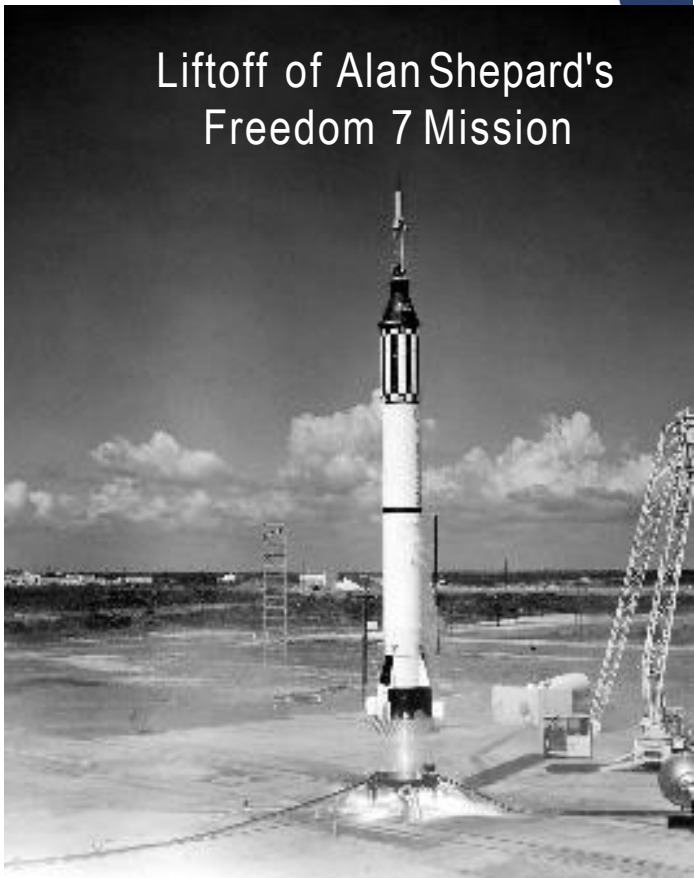


NASA Langley : Project Mercury

The original seven Mercury astronauts during training at The NASA Langley Research Center.



From left to right, back row they are Alan Shepard, Virgil "Gus" Grissom and L. Gordon Cooper; front row, Walter Schirra, Donald "Deke" Slayton, John Glenn and Scott Carpenter. The suits were the ones used by the astronauts during their Mercury space flights. https://www.nasa.gov/centers/langley/news/factsheets/Mercury.html?0



Yuri Gagarin : First Man in Space





The Huntsville Times

Man Enters Space

'So Close, Yet So Far,' Sighs Cape

U.S. Had Hoped For Own Launch

Soviet Officer Orbits Globe In 5-Ton Ship

Maximum Height Reached Reported As 188 Miles

Hobbs Admits 1944 Slaying

To Keep Up, U.S.A. Must Run Like Hell

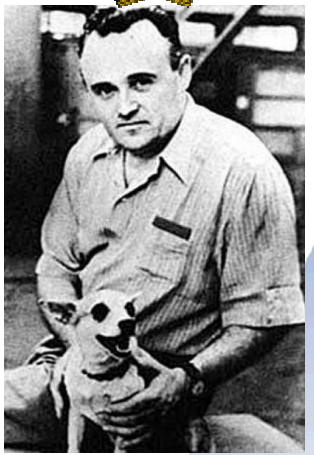
Praise Is Heaped On Major Gagarin

Worker Stands By Story

Reds Deny Spacemen Have Died

Reds Win Running Lead In Race To Control Space





Sergei Korolev and His Dog

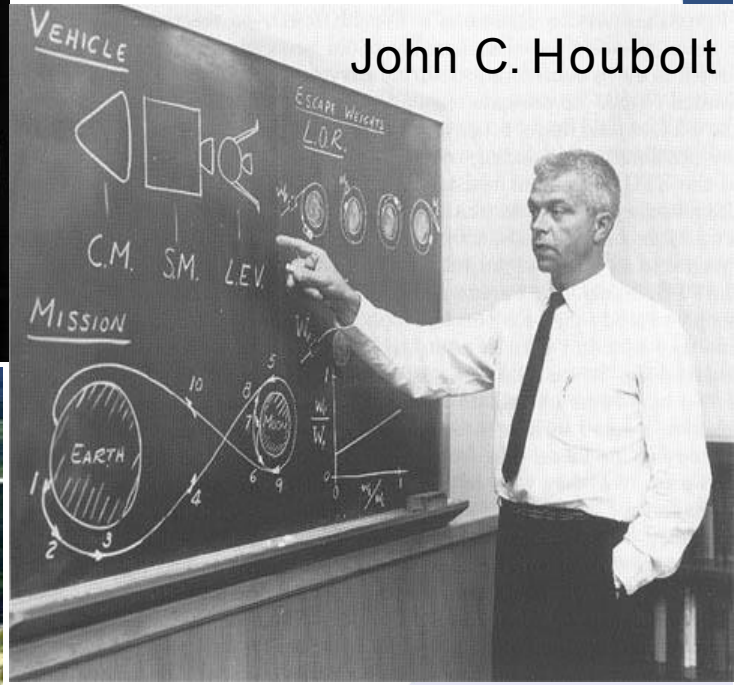
https://www.nasa.gov/mission_pages/shuttle/sts1/gagarin_anniversary.html

https://www.nasa.gov/audience/foreducators/rocketry/imagegallery/rp_dog.jpg.html

Apollo : Lunar-Orbit Rendezvous







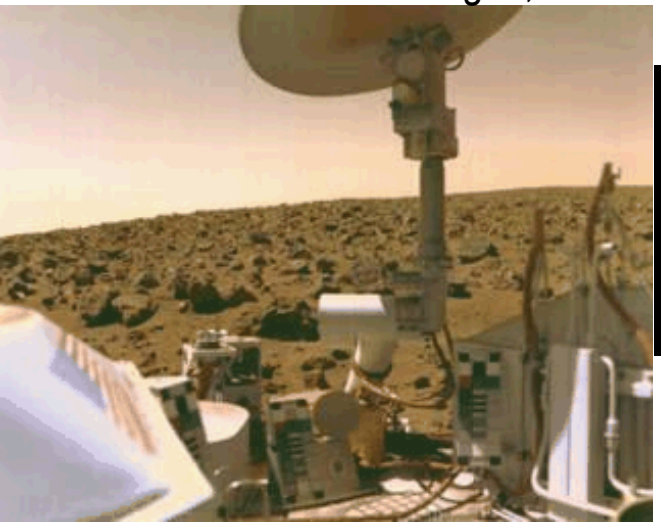


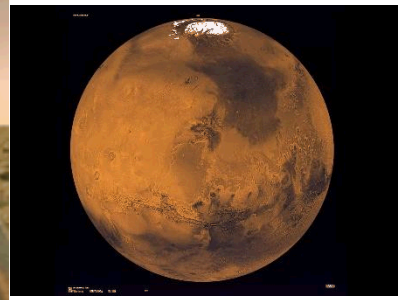


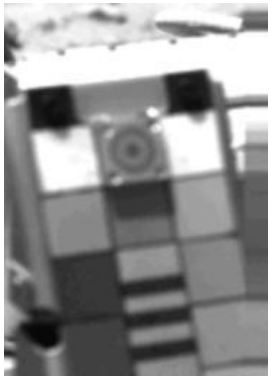
https://www.nasa.gov/centers/langley/news/factsheets/Rendezvous.html

NASA Langley : The Viking Program

Viking 1 was launched Aug. 20, 1975, and arrived at Mars on June 19, 1976. On July 20, 1976, the Viking 1 lander separated from the orbiter and touched down at Chryse Planitia. Viking 2 was launched Sept. 9, 1975, and entered Mars orbit Aug. 7, 1976. The Viking 2 lander touched down at Utopia Planitia on Sept. 3, 1976.









Originally designed to function for 90 days, the Viking spacecraft continued collecting data for more than SIX YEARS!

NASA Langley : LDEF



Launched by STS Challenger.
Retrieved by STS Columbia 5.7 years later.

57 Experiments including;

- Materials, coatings and thermal systems
- Power and Spacecraft propulsion
- Optical fibers and crystals
- Electronics and optics.

In January 1990, the Long Duration Exposure Facility (LDEF), after five-and-one half years orbiting Earth, was retrieved during the STS-32 space shuttle mission and returned to Earth for close examination and analysis

The Langley Research Center Today

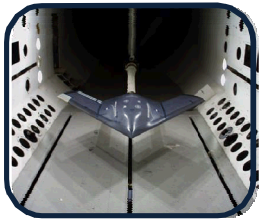
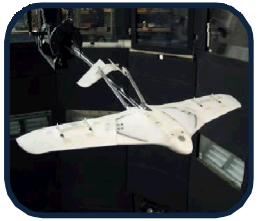


NASA Langley Research Center Organization



NASA Langley Product Lines

Aerosciences

Intelligent Flight Systems




Advanced Materials & Structural Systems



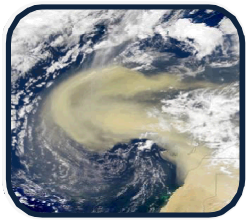

Measurement Systems



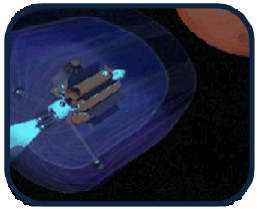
Entry, Descent & Landing



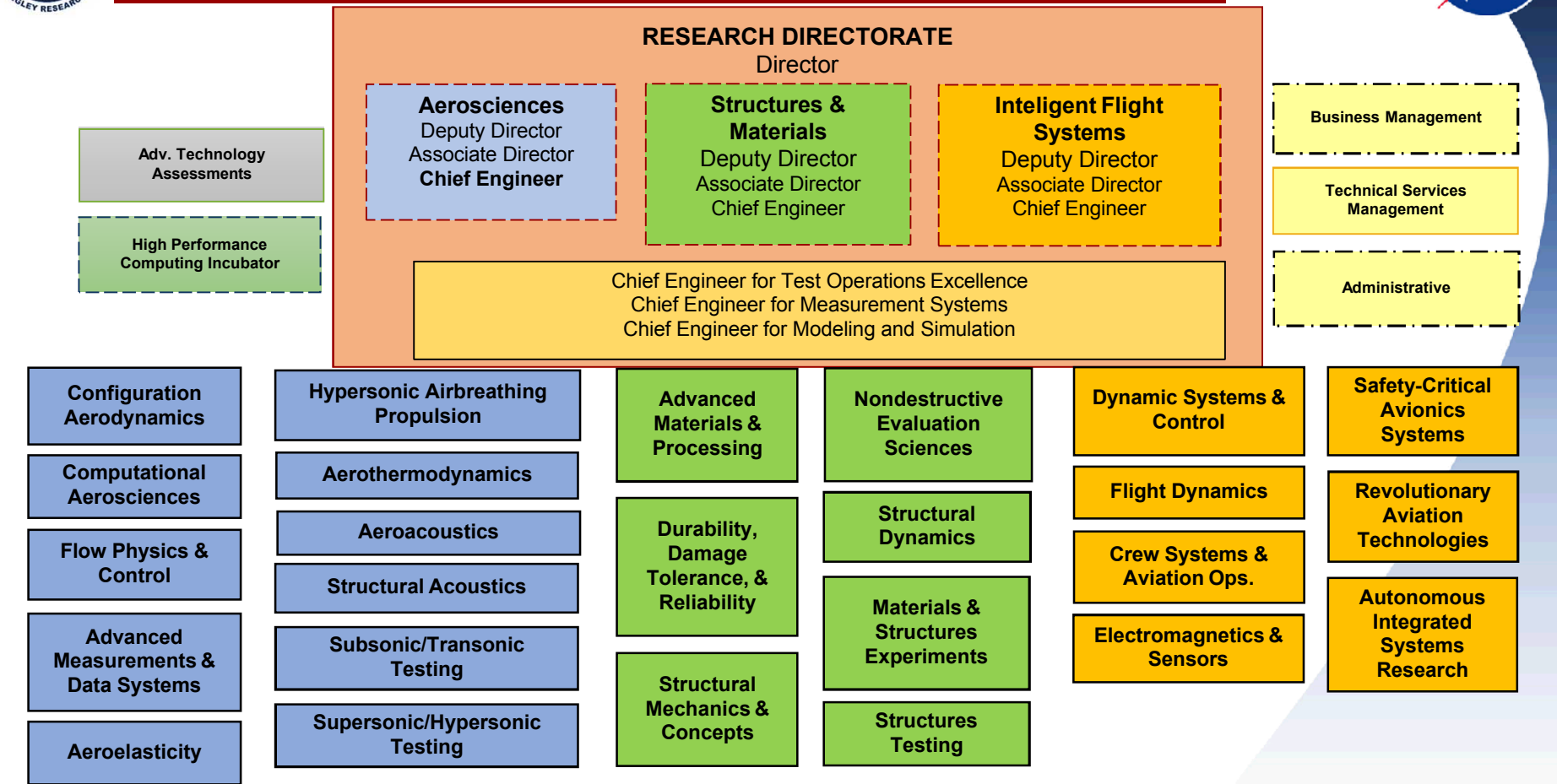

Atmospheric Characterization

Systems Analysis & Concepts




Research Directorate - Organization



Langley's - Research Directorate

What We Do



RD Workforce



Civil servants

Contractors on/near site

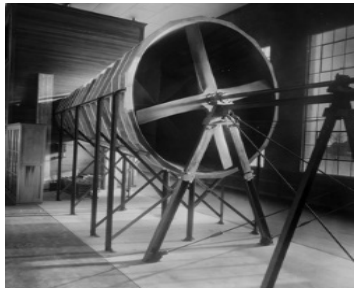
Areas of Expertise

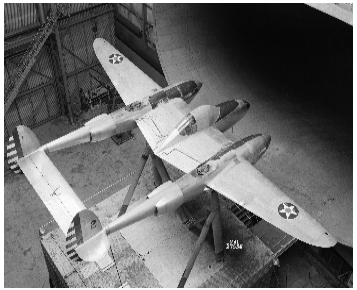
- Aerosciences
- Structures & Materials
- Intelligent Flight Systems

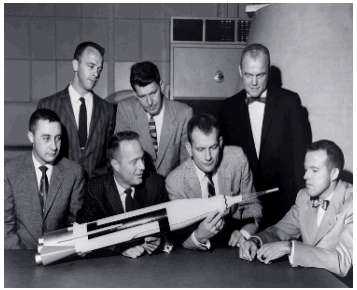
CELEBRATING 100 YEARS
NASA Langley Research Center 1917-2017

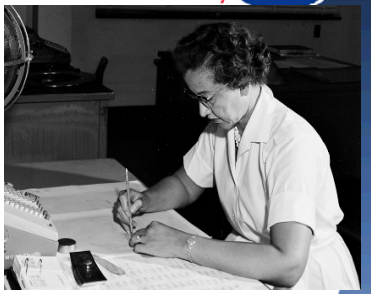
Langley's – Legacy

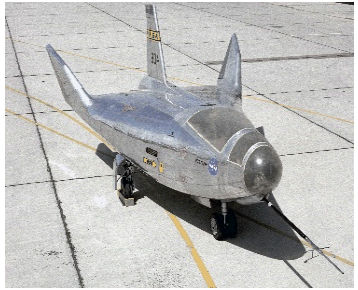
Aerospace Innovation 100+ Years

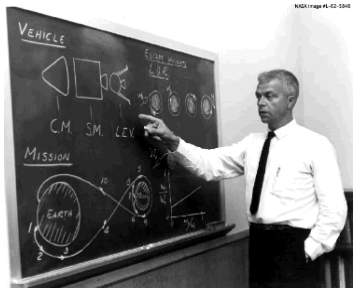








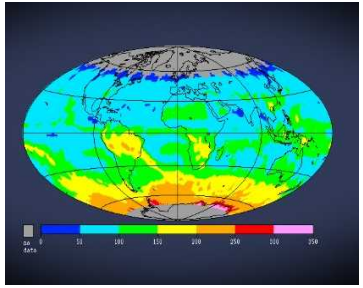














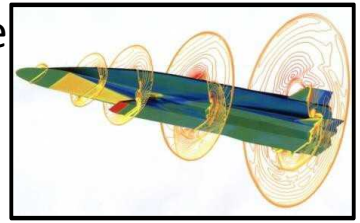


Aerosciences

Mission

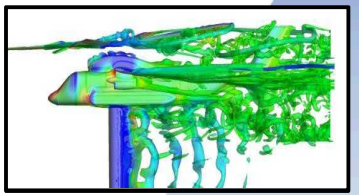
We provide the capabilities and technologies to make flight vehicles -- safe, reliable, efficient, maximizing speed while reducing noise & emissions.

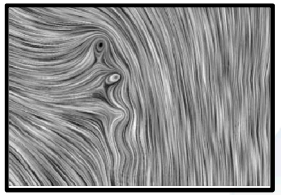




Technology Areas

Vehicle Level Design, Integration & Analysis
Hypersonic Technologies
Aeroelasticity/Aeroservoelasticity Technologies
Acoustic Design, Analysis & Control Technologies
Flow Control Technologies
Physics-Based Modeling, Simulation, Validation and Verification

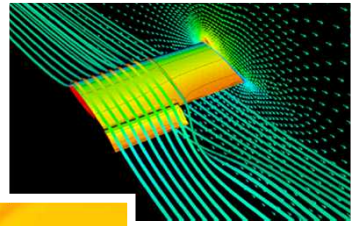


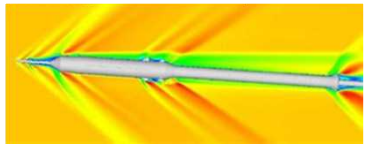


RD - Aerosciences
Aerodynamics

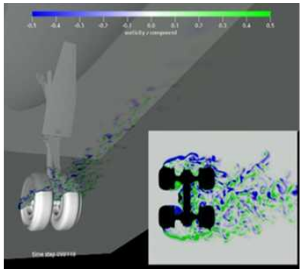
Configuration Aerodynamics

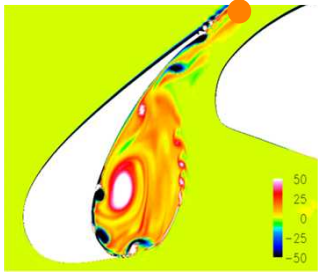




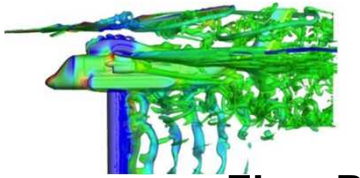


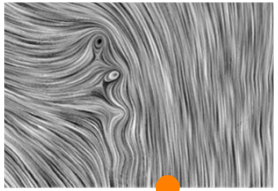
Computational Aerosciences





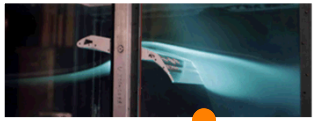
Flow Physics





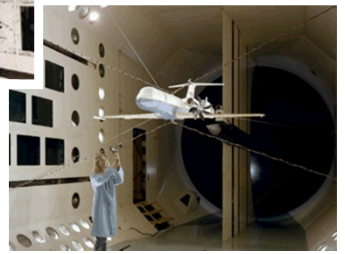
Flow Control











Aeroelasticity & Unsteady Aerodynamics

Designing Wings with Natural Laminar Flow

Why Natural Laminar Flow (NLF)?

- **Laminar flow improves vehicle performance by reducing skin friction and profile drag**
- **NLF provides performance benefit without introducing a flow control system, such as suction, which increases weight, complexity, and cost**

Challenge with NLF:

- **NLF historically limited to slower vehicles with low wing sweeps because crossflow instabilities grow by increasing wing sweep**

NASA Concept:

- **Crossflow Attenuated NLF (CATNLF) designs the shape of the wing to delay transition by damping crossflow instabilities on highly swept wings**

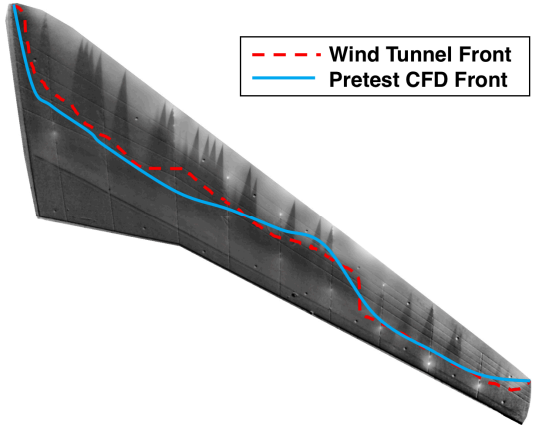


Validating the CATNLF Concept with a Wind Tunnel Test

- Designed a wing with the CATNLF method to be tested in the National Transonic Facility at the NASA Langley Research Center
- Painted model with Temperature Sensitive Paint to visualize extents of laminar flow
- Good agreement between pretest predictions and experimental extents of laminar flow suggest assumptions and design strategy/tools are valid
- Next step: design a flight test article to test CATNLF concept in flight



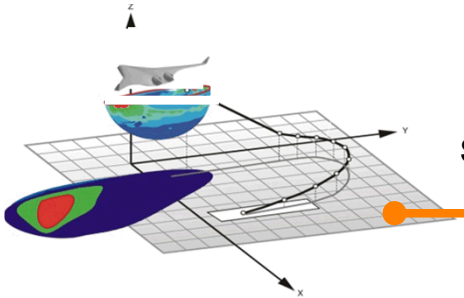
NASA researchers with model in the National Transonic Facility



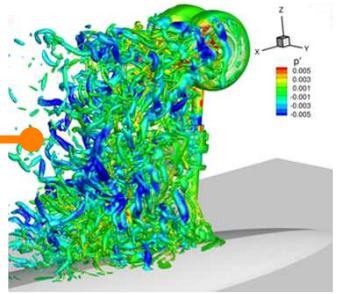
Transition visualization image from wind tunnel test overlaid with computational predications

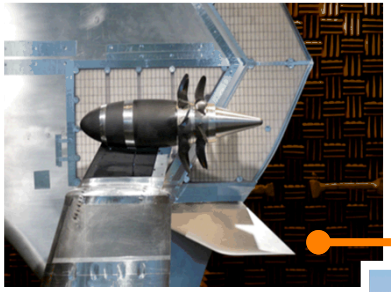
RD - Aerosciences
Acoustics

System Noise Prediction



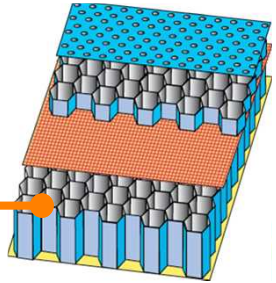
Computational Aeroacoustics

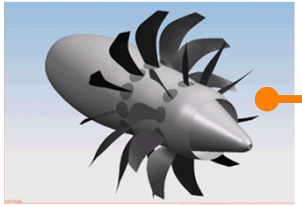




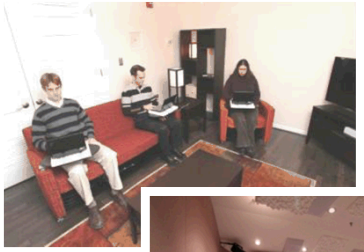
Propulsion-Airframe Aeroacoustics

Aircraft Liners

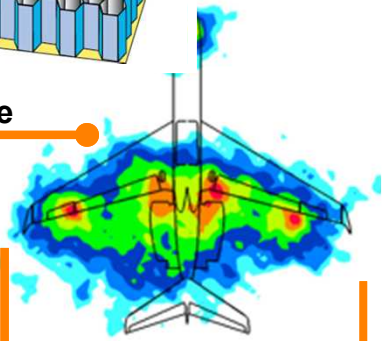




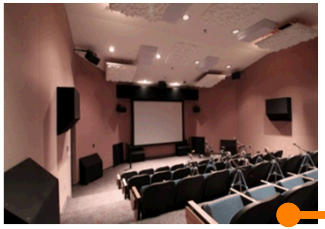
Rotor Noise



Airframe Noise







Human Response to Noise

UAS Acoustics



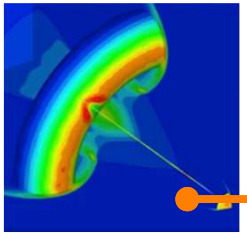
RD - Aerosciences
Hypersonics

Aerothermodynamics



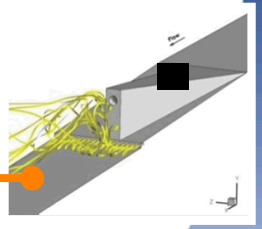


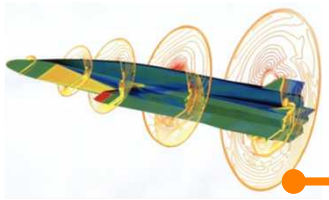
Hypersonic Airbreathing Propulsion



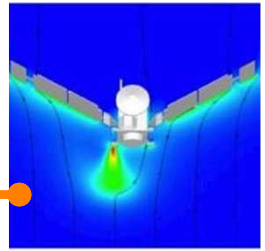
Computational Aerothermodynamics

Scramjet Combustion Modeling

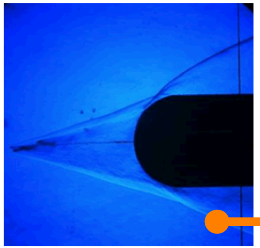




Propulsion Airframe Integration



Rarefied Flow Physics



Experimental Aerothermodynamics

Experimental Airbreathing Propulsion



Access to Space with Hypersonic Airbreathing Propulsion



Greater Efficiency • Reusable Hardware • Launch from Runway

Example Hypersonic Trajectory

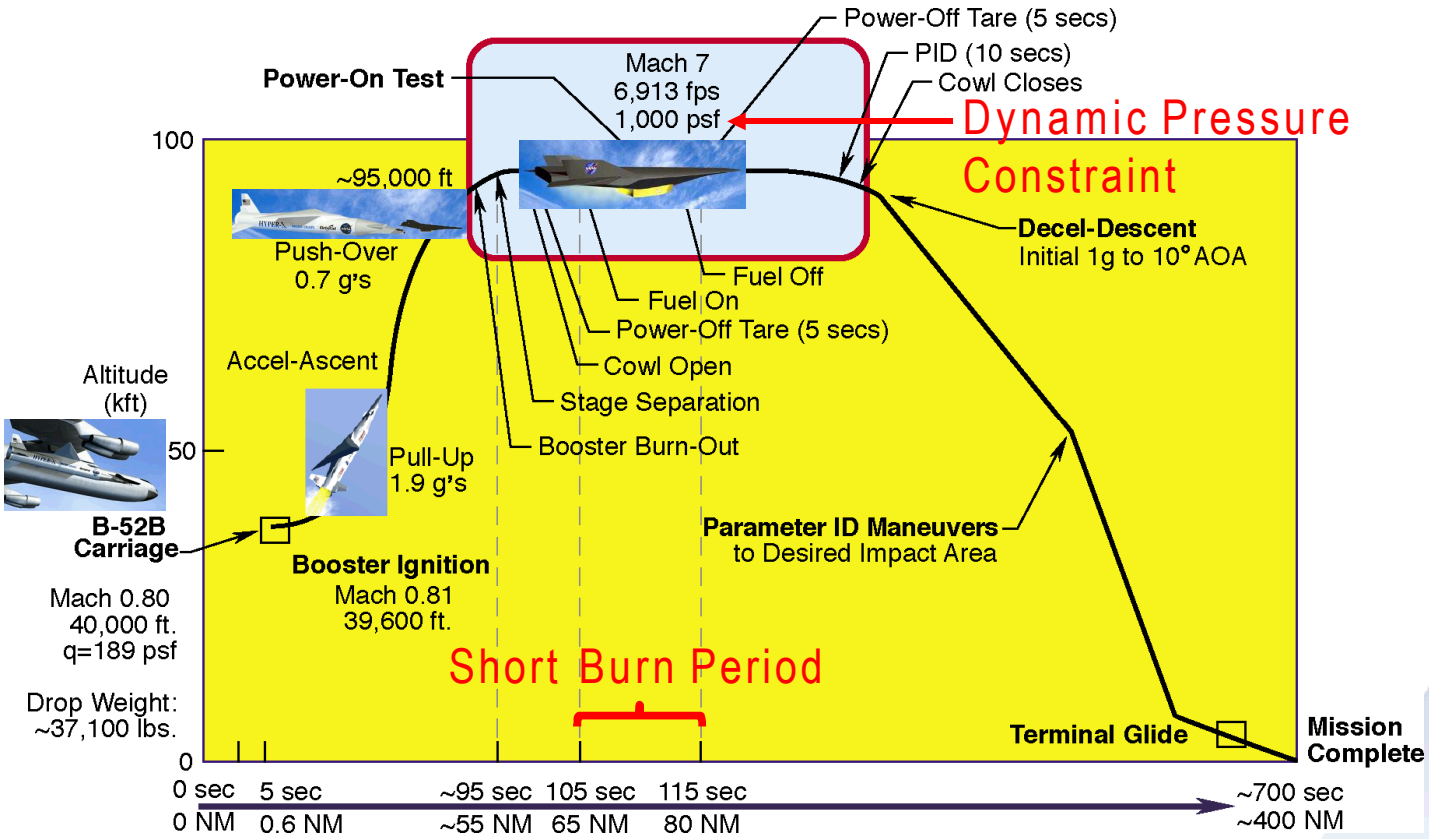
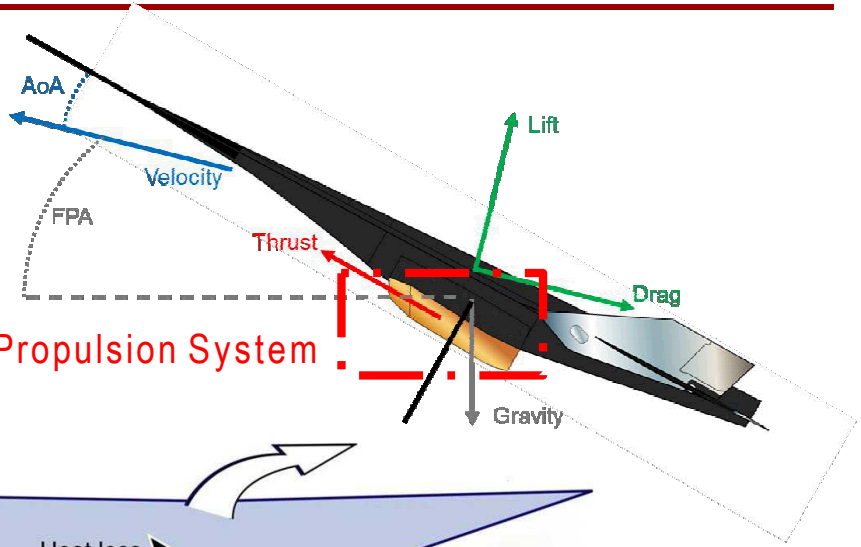


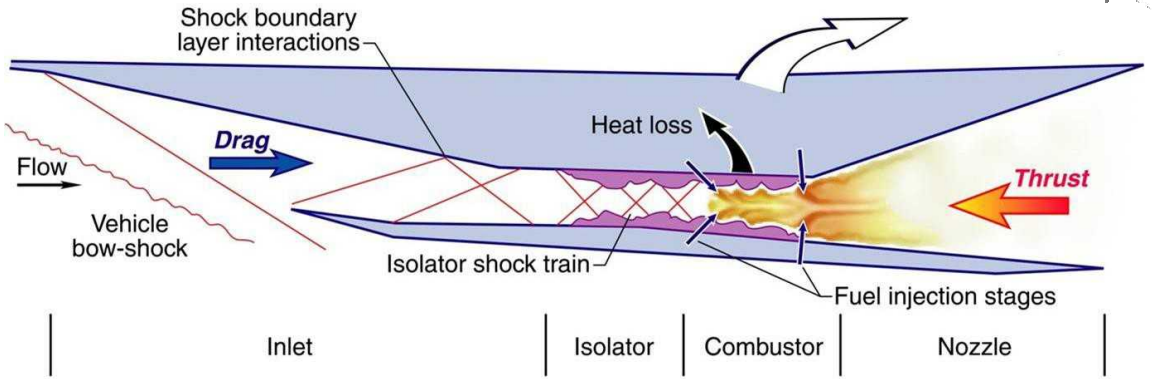
Image Credit: Voland, R et al., "Hyper-X Mach 7 Scramjet Design, Ground Test and Flight Results," 13th AIAA Hypersonic Technology Conference, Capua, Italy, May 19th, 2015.

Hypersonic Propulsive Flight

Control Parameters

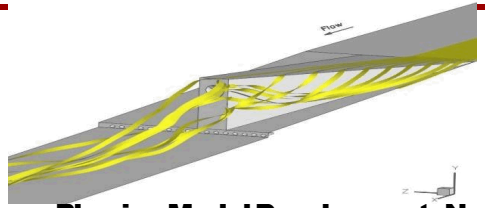
- AoA
- Fuel ER

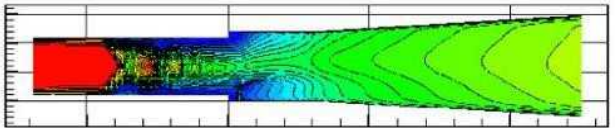




Images Credit: Tony Landis, "X-43A 3-view", NASA Dryden Flight Research Center Graphics Collection, April 6th, 2004; Heiser, W.H. and Pratt, D.T. "Hypersonic Airbreathing Propulsion", AIAA Education Series, 1994.

Hypersonic Airbreathing Propulsion Branch





Physics Model Development, Numerical Methods, and Code Development



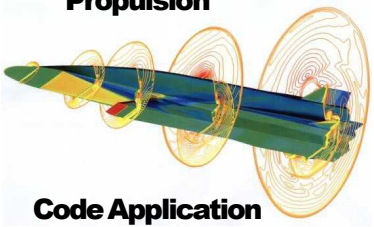
Experimental Airbreathing Propulsion

MISSION

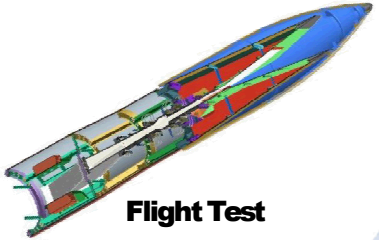
Conduct multidisciplinary research to develop advanced technology for hypersonic airbreathing propulsion systems for aerospace vehicles.



Vehicle Configuration Development and Optimization



Code Application



Flight Test



Aeronautics – LaRC Major Wind Tunnels



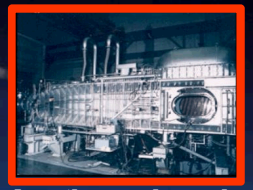
14 x 22 Foot Subsonic Tunnel
Subsonic, Alternate Uses



National Transonic Facility
High Reynolds Number Flow
Nationally Unique



LaRC Unitary Plan Wind Tunnel
Supersonic Speed Range



Aerothermodynamic Complex
Exploration Workhorse

Subsonic **Transonic** **Supersonic** **Hypersonic**

National Assets needed to meet the needs of the Agency, DoD and Industry



20-Foot Vertical Spin Tunnel
Spin Characteristics & Dynamic Stability
Nationally Unique



Transonic Dynamics Tunnel
Aeroelasticity & Flutter
World Unique



8-Ft High Temperature Tunnel
Large-scale Hypersonics & Propulsion

RD - Aerosciences

Major Wind Tunnels



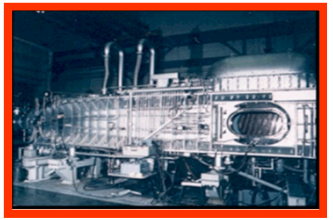
14 x 22 Foot
Subsonic Tunnel



National Transonic
Facility

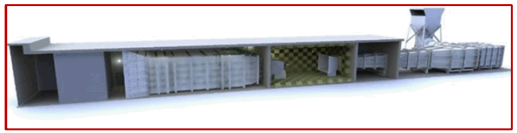


LaRC Unitary Plan
Wind Tunnel



Aerothermodynamic
Complex

Subsonic **Transonic** **Supersonic** **Hypersonic**



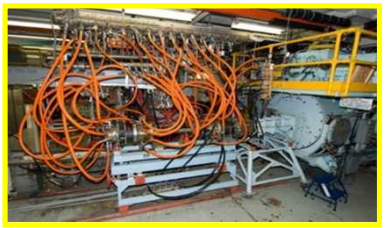
Low Speed Aeroacoustic
Wind Tunnel



20-Foot Vertical Spin
Tunnel



Transonic Dynamics
Tunnel



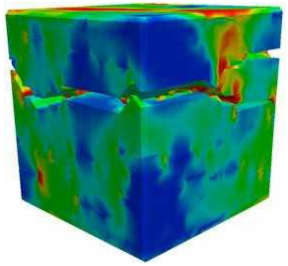
ScramJet
Complex



8-Ft High Temperature
Tunnel

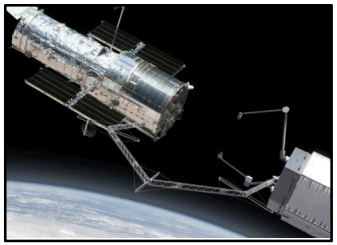
Advanced Materials and Structural Systems

Mission



We innovate new materials and structural concepts that enable future aviation & space exploration, and develop the foundational technologies essential for manufacturing, design, validation & sustainment.

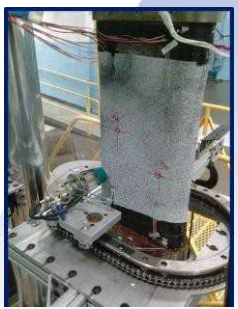




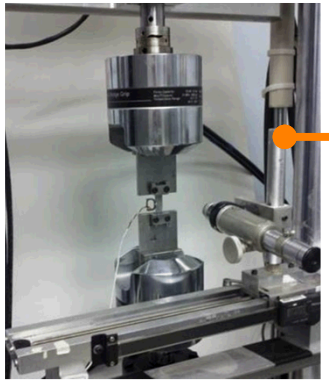
Technology Areas

Materials
Structures
Mechanisms/Manipulators
Advanced Manufacturing Technology
Flight Qualified Structures
Advanced NDE and SHM Technology





RD - Structures & Materials



Durability & Damage Tolerance



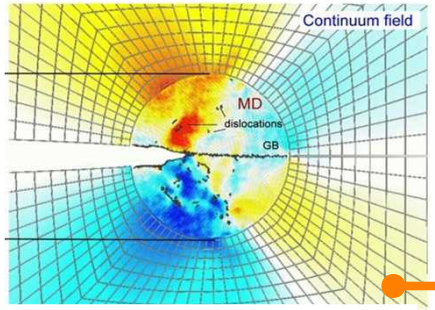
Impact & Landing Dynamics



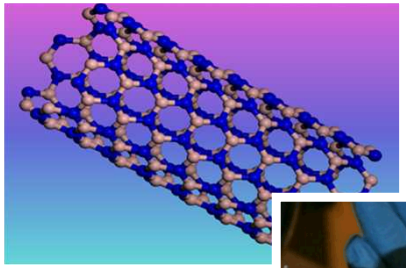
Structural Concepts

Materials Synthesis & Processing





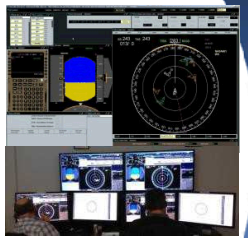
Computational Materials Design





Nanostructured Materials

Intelligent Flight Systems



Mission

We develop and validate new architectures, technologies, and approaches to advance flight systems toward increasingly autonomous capabilities and operations for air and space.





Technology Areas

Smart Systems for Vehicles
Human-Machine Teaming & Interfaces
Modeling and Control of Complex Systems
Methods to Ensure Trusted Autonomy
High Confidence Safety-Critical Systems
Intelligent Sensory Systems

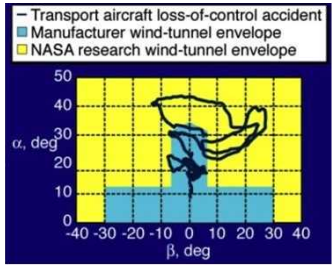




RD - Intelligent Flight Systems

Dynamics & Controls





Control Upset Characteristics & Safety-of-Flight Prediction







Entry and Launch Vehicle Flight Dynamics



Trajectory Analysis and Control

Robust, Adaptive/Autonomous Control
Distributed, Decentralized Control









Static and Dynamic Stability & Control

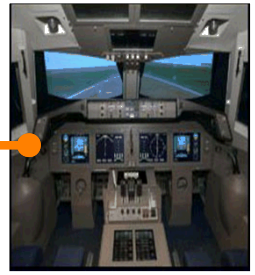


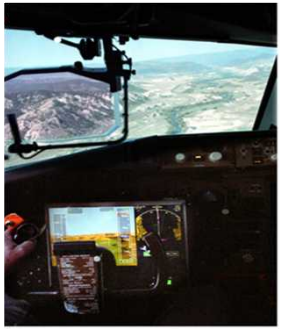
Flying/Handling Qualities

RD - Intelligent Flight Systems
Crew Systems & Aviation Operations



Autonomous & Crewed Research Simulation







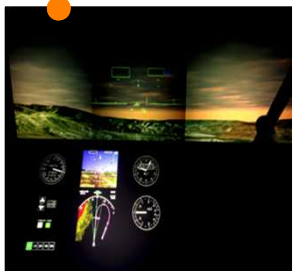
Flight Test for Advanced Sensing, Avionics, Crew & Autonomous Research, and NAS Improvement

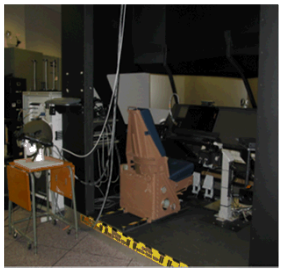
Air Traffic Operations Laboratory





Visual Imaging Simulator for Transport Aircraft Systems





RD - Intelligent Flight Systems
Safety-Critical Avionics Systems

RF Threats





Neutron Particles

Design Error





Components/System Failure

Design Integrity, Operational Integrity, and V&V



- Requirements
- High-level design
- Low-level design
- Code
- Executable

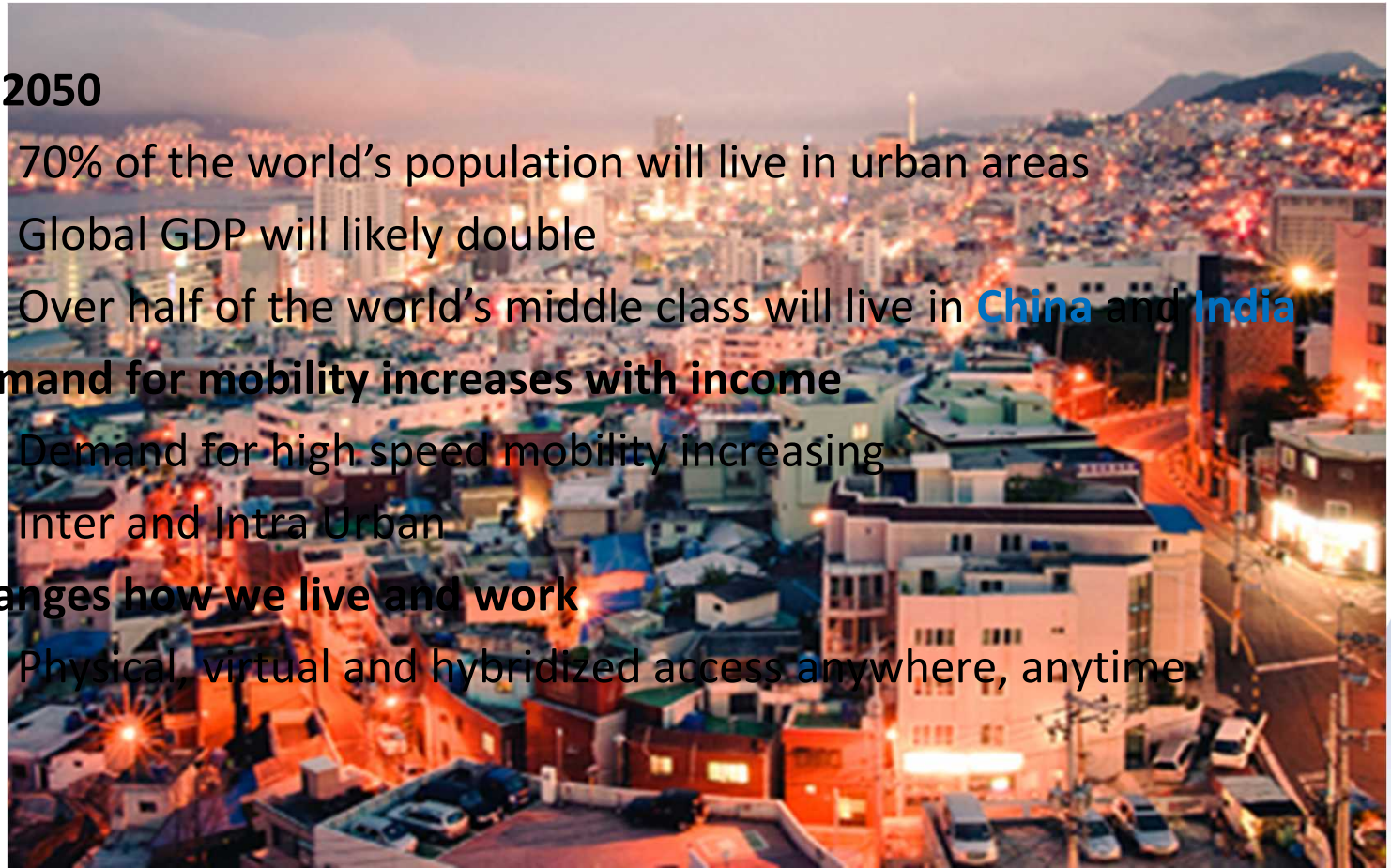
Software Design, Certification, & Data Integrity for Avionics systems



Algorithm Design & Certification for Air Traffic Separation & Autonomy

Global Challenges Are Opportunities

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
  - Inter and Intra Urban
- **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

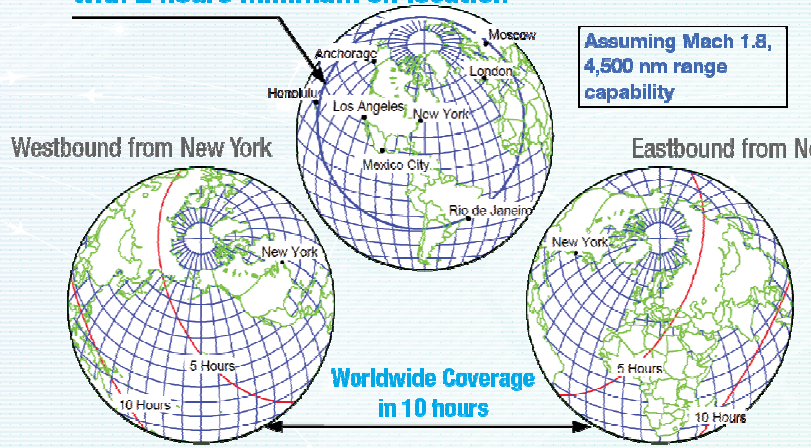
78% of New Aircraft Deliveries are Single Aisle Class (including Regional Jets)

Commercial Supersonic Flight

WHY?

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

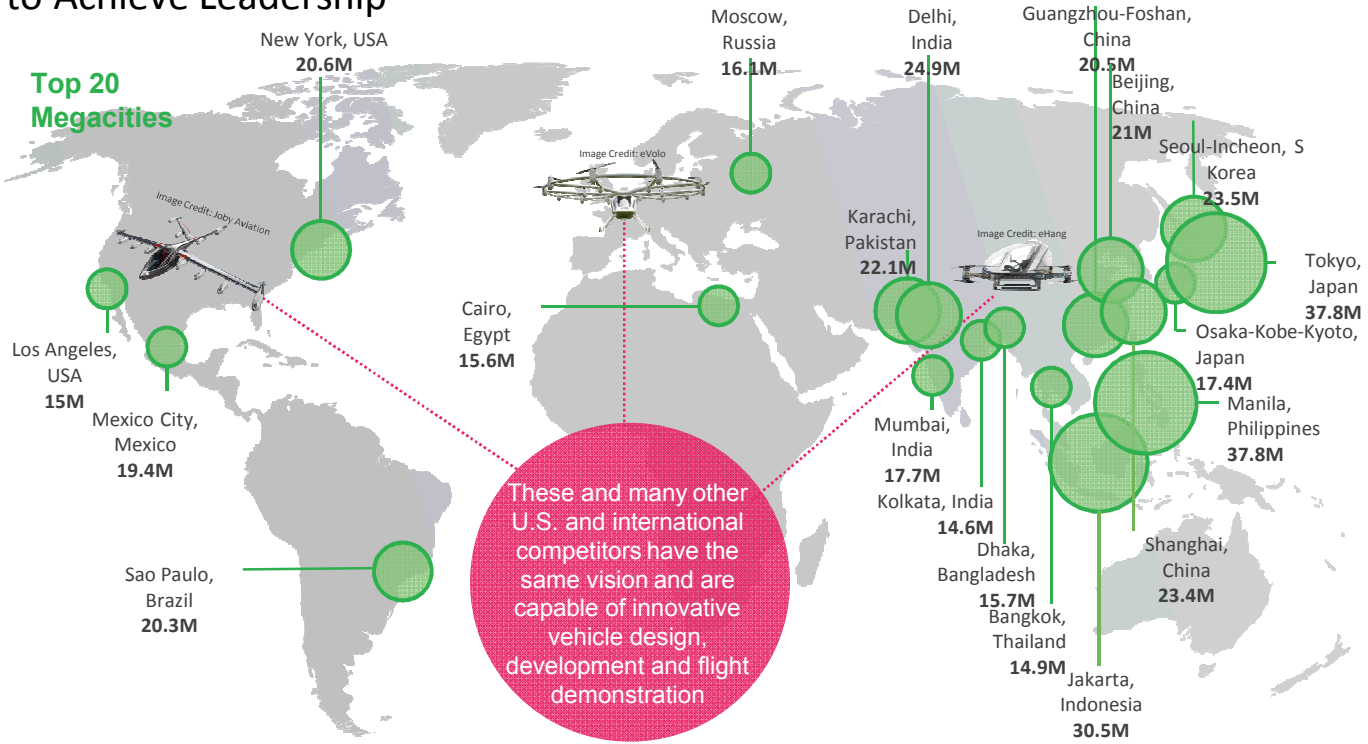
Speed that redefines a 12 hour work day—there and back with 2 hours minimum on location



- 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

Urban Air Mobility

Global Race to Achieve Leadership

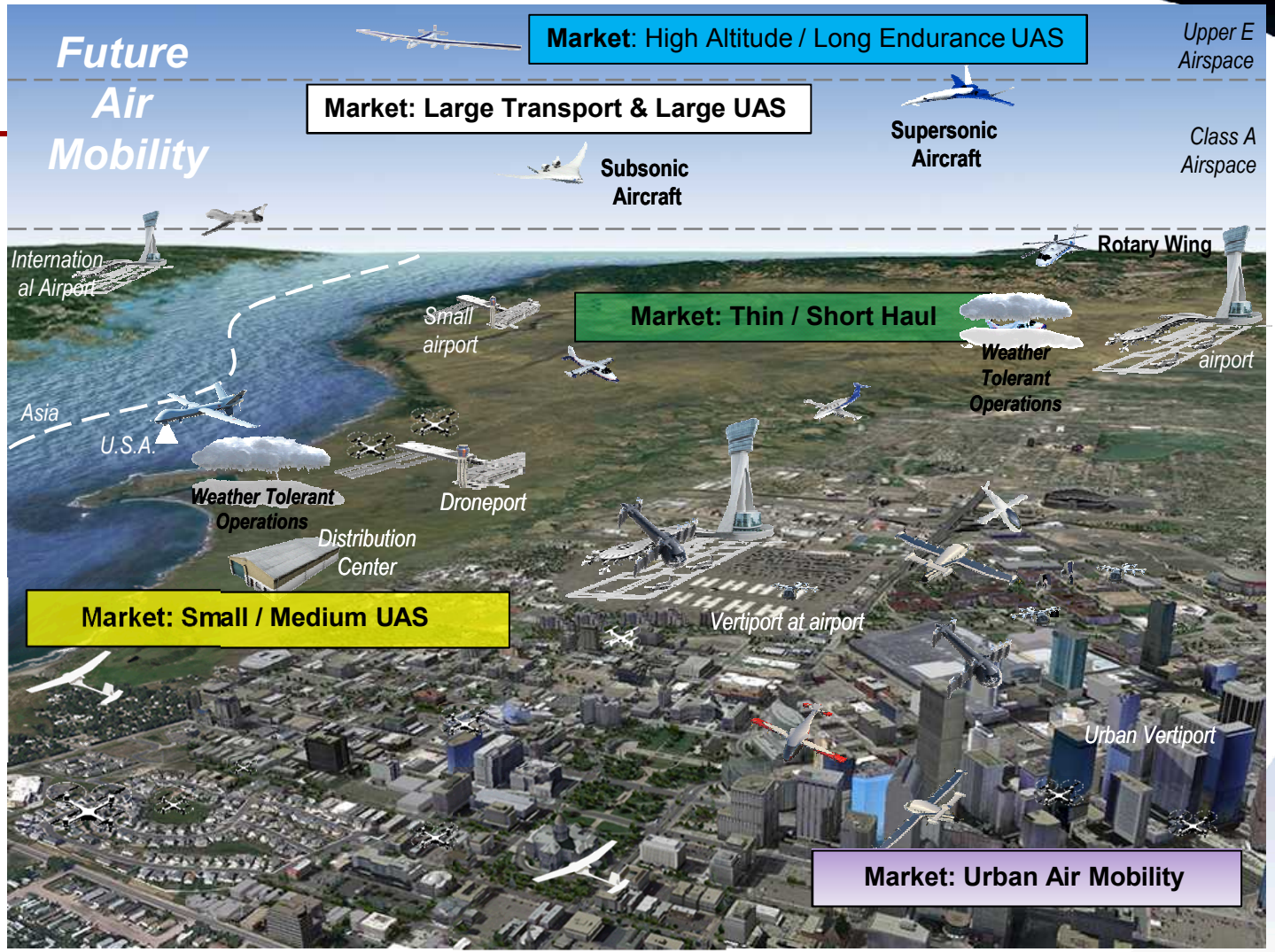


Large projected market–McKinsey analysis of demand by 2030 in 15 major U.S. cities:

- 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


Future Air Mobility
Market: High Altitude / Long Endurance UAS
Upper E Airspace
Market: Large Transport & Large UAS
Supersonic Aircraft
Class A Airspace
Subsonic Aircraft
Rotary Wing
Internation al Airport
Small airport
Market: Thin / Short Haul
Weather Tolerant Operations
airport
Asia
U.S.A.
Weather Tolerant Operations
Droneport
Distribution Center
Market: Small / Medium UAS
Vertiport at airport
Urban Vertiport
Market: Urban Air Mobility

Traditional Market - Challenges

NASA Subsonic Transport System Level - Measures of Success

v2016.1

Valued Mission Capability:

Payload-Range-Speed-Accessibility, Economical, Safe, Sustainable

TECHNOLOGY BENEFITS	TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)		
	Near Term 2015-2025	**Mid Term** 2025-2035	**Far Term** beyond 2035
Noise (cum below Stage 4)	22 – 32 dB	32 – 42 dB	42 – 52 dB
LTO No_x Emissions (below CAEP 6)	70 – 75%	80%	>80%
Cruise No_x Emissions (rel. to 2005 best in class)	65 – 70%	80%	>80%
Aircraft Fuel/Energy Consumption (rel. to 2005 best in class)	40 – 50%	50 – 60%	60 – 80%



Evolutionary



Revolutionary

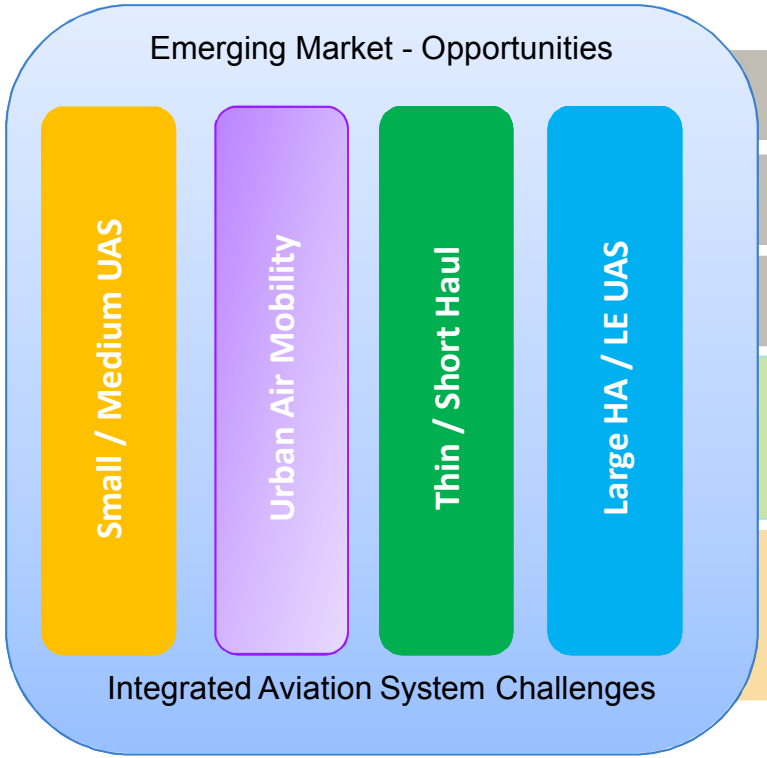


Transformational

Emerging Markets - 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



Technical Challenges scoped from initial operations through full market penetration

Electrified Aircraft Propulsion & Integration
flight-critical, flight-weight power/energy

Noise
vehicle & fleet

Weather/Environment-Tolerant
vehicle robustness (wind/rain/ice…)

Assured Autonomous Systems & Human Integration
autonomous awareness and contingency management
SVO, UAS mission management (one operator controlling multiple vehicles)

Integrated ATM System
Efficient, high density operations with access to diverse platforms in airspace with integrated air/ground/cloud technologies

NASA Aeronautics

Strategy and Program Structure

NASA Aeronautics - Strategic Implementation Plan

Strategic R&D Thrusts



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 Alternative Propulsion and Energy

- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology



In-Time System-Wide Safety Assurance

- Develop an integrated prototype of an in-time safety monitoring and assurance system



Assured Autonomy for Aviation Transformation

- Develop high impact aviation autonomy applications

NASA Mission Directorates

Aeronautics Programs and Projects

Mission Directorates

Human Exploration & Operations	Aeronautics Research	Science	Space Technology

Aeronautics Programs

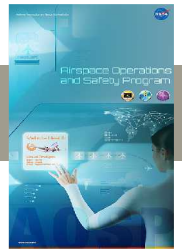
Advanced Air Vehicles

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



Airspace Operations & Safety

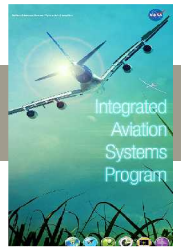
Projects
- Airspace Technology Demonstrations
- UAS Traffic Management
- System-Wide Safety
- ATM-X



Integrated Aviation Systems

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

X-planes/test environment



Transformative Aeronautics Concepts

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

Critical cross-cutting tool development



“Far-Term” Goal-Driven - Adv. Air Vehicle

Concept Studies and Trends for commercial subsonic transport aircraft for 2030-35

Boeing, GE, GA Tech





MIT, Aurora, P&W, Aerodyne







GE, Cessna, GA Tech



NG, RR, Tufts, Sensis, Spirit



NASA, VA Tech, GT

Trends:

- Tailored/multifunctional structures
- High aspect ratio/laminar/active structural control
- Highly integrated propulsion systems
- Ultra-high bypass ratio (20+ with small cores)
- Alternative fuels and emerging hybrid electric concepts
- Noise reduction by component, configuration, and operations improvements



NASA



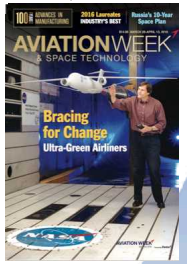
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Future UEST X-Plane Concepts







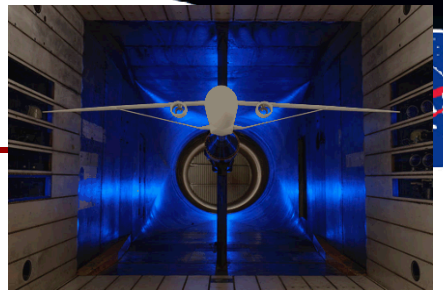




Approved for
Public Release

Technology Maturation for UEST

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



Very High Aspect Ratio Wing



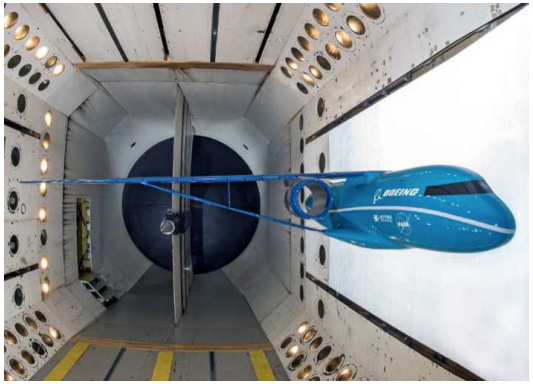
Boundary Layer Ingestion



Electrified Aircraft Propulsion

Ultra-Efficient Subsonic Transport (UEST)

Concepts - Examples of Ground Testing Progress Through FY16



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)



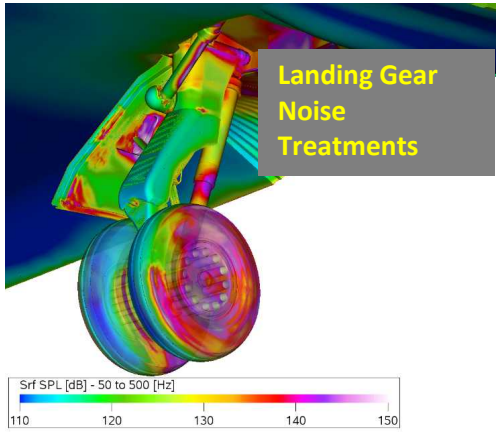
HWB/OWN Performance • FY15
Langley National Transonic Facility

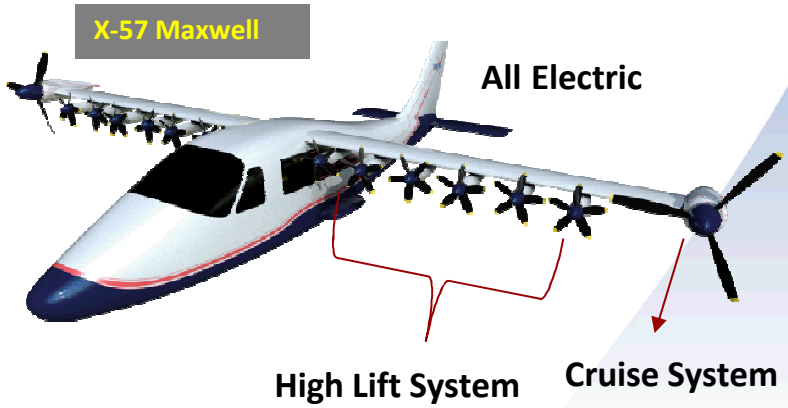
Flight Research and Demonstrations

Recent and ongoing









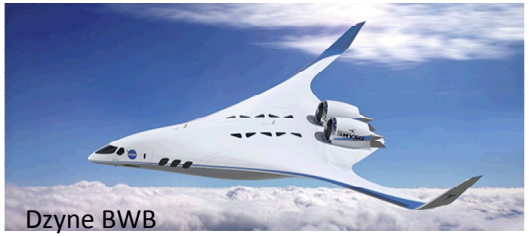
Overcoming the PAI Challenge

Subsonic Transport – opening a range of future possibilities?

- **Sample configuration possibilities with different PAI challenges**



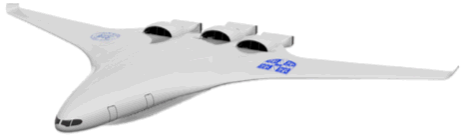




- **Sample configuration possibilities with novel PAI including BLI**



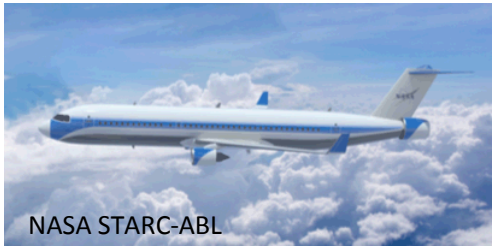
- Type II Distortion



MIT/Cambridge SAX-40









Revolutionary Vertical Lift Technology

value through accessibility

Why? Urban Air Mobility (UAM)

Massive Congestion





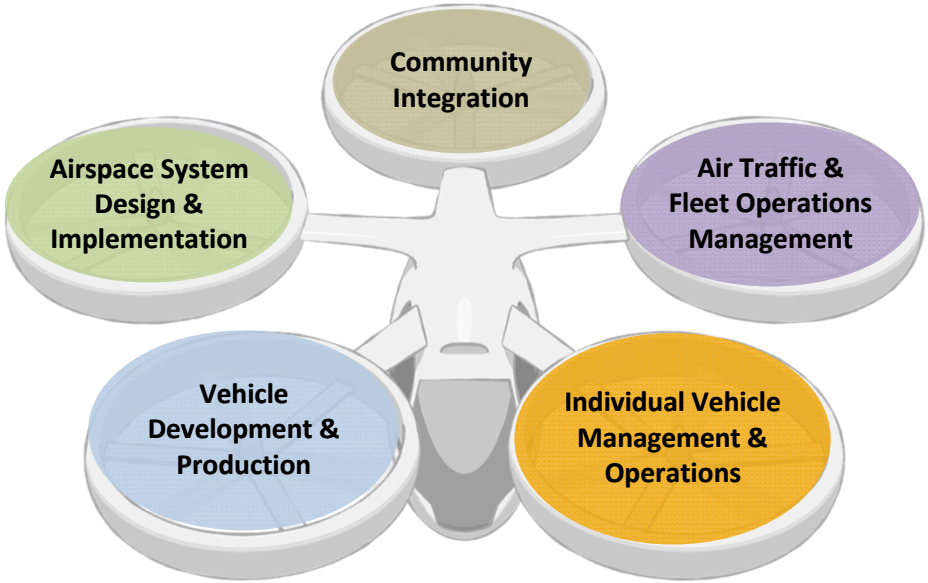
Time Demands

NASA Urban Air Mobility (UAM) Framework and Vision

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

Societal integration & acceptance of UAM operations

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



Design, manufacture, & system readiness of vehicles

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

"Development" ← → "Operations"

Vision

Revolutionize mobility within metropolitan areas by enabling a safe, efficient, convenient, affordable, & accessible air transportation system for passengers and cargo

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 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



Side by Side "Vanpool"



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

Lift+Cruise Air Taxi



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

Safe, Efficient, Quiet Vertical Lift Aircraft

“Traditional” helicopter design is already challenging “Emerging” eVTOL designs present even more challenges

Wide range of concepts in development up to and including in flight test (Hirshberg, www.vtol.org, July 2018 list surpassed 100!)







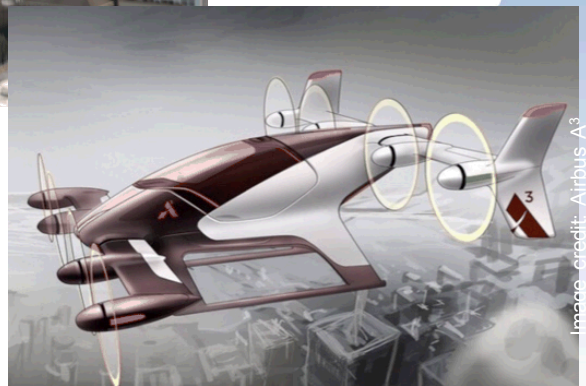


Image credit: Airbus A³

Commercial Supersonic Technology

value via speed at cruise

Commercial Supersonic Flight

The emerging potential market has generated renewed interest in civil supersonic aircraft

- Evidenced by the appearance of several commercial programs even with existing restrictions on overland flight and other challenges



Overland Flight Restrictions based on unacceptable sonic boom noise are viewed as the main barrier to this vision

The vision of the Supersonics Community is a future where fast air travel is available for a broad spectrum of the traveling public.

- Future supersonic aircraft must be able to fly overland without creating an “unacceptable situation” but compared to Concorde more efficient, affordable and environmentally responsible



Supersonic Technical Challenge:

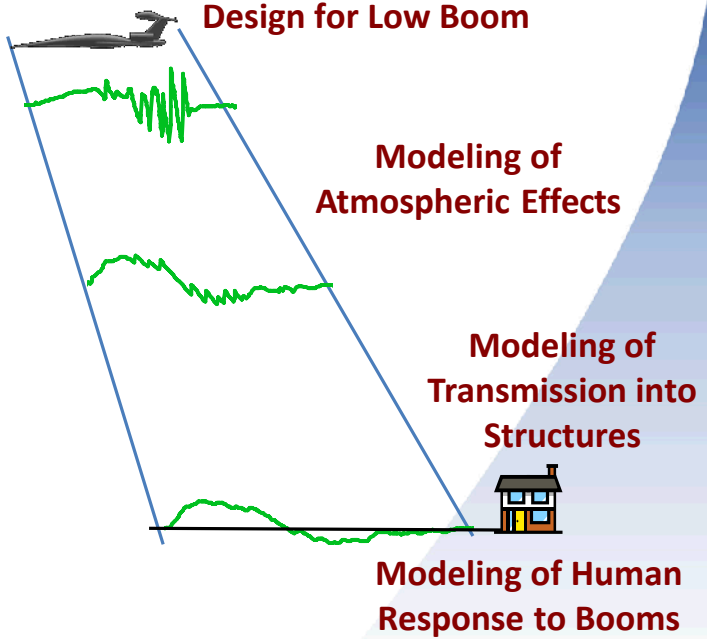
Understand and overcome the environmental barrier of sonic booms to civil supersonic flight. Improve understanding of the impact of reduced sonic boom noise on community residents.

Design for Boom Reduction

- Low boom design techniques
- Multidiscipline tools for practical application
- Flight validation approaches

Response to Low Noise Sonic Boom

- Effects of atmosphere
- Structural response & modeling
- Human response & modeling
- Community exposure testing
- Extrapolation to general population



NASA Low-Boom Flight Demonstrator

X-59 QueSST (Quiet SuperSonic Technology)



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

Design Parameters

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

Civil Supersonic Aircraft

examples of current aircraft development programs heading towards flight test







Concluding Remarks

Disruption has happened

Primary Mode of Transportation (horse is replaced by automobile)

Easter morning 1900: 5th Ave, New York City. Spot the automobile.



Source: US National Archives.

Easter morning 1913: 5th Ave, New York City. Spot the horse.



Source: George Grantham Bain Collection.

Disruption continues to happen

Science Fiction - 1965



Becomes Reality - 1989



The **first** the **clamshell** design was the MicroTAC, created in 1989 (Motorola)

There are many more!

DAWN OF NEW ERA OF AVIATION

Exciting times

- Laying the groundwork for future Aviation
- Many challenges, present many opportunities across many markets

Technologies

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

Vehicles, Operations, Energy, Smart Systems

- Bringing new value through the air via aviation

Questions?



NASA – Aerosciences Assets

Specialty Tunnels | Subsonic | Transonic | Supersonic | Hypersonic



Icing Research Tunnel



9x15-Ft Low-Speed Wind Tunnel



Unitary Plan Wind Tunnels



8x6-Ft Supersonic Wind Tunnel



10x10-Ft Supersonic Wind Tunnel



8-Ft High Temperature Tunnel**



Propulsion Simulation Laboratory



14x22-Ft Subsonic Tunnel



Transonic Dynamics Tunnel***



National Transonic Facility**



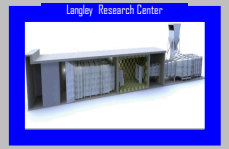
4-Ft Supersonic Wind Tunnel



Aerothermodynamic Laboratory Complex*



Flight Dynamics Research Facility



Low-Speed Aeroacoustic Wind Tunnel



0.3-m Transonic Cryogenic Tunnel



20-In Supersonic Wind Tunnel

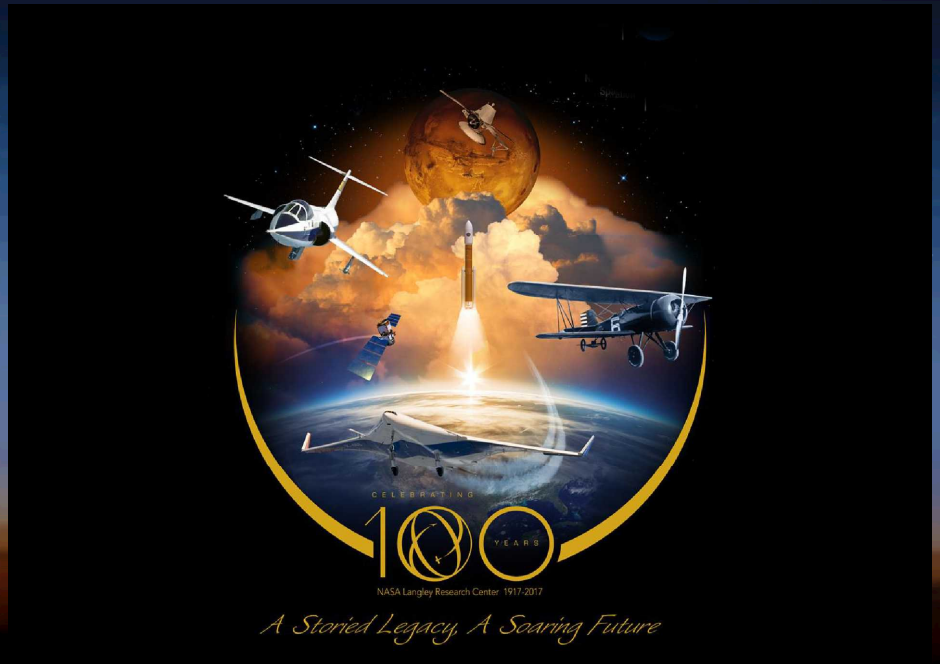


SCRAMJET Complex

Langley Wind Tunnels

* NASA Unique, ** Nationally Unique, *** World Unique


RESEARCH DIRECTORATE
RD
NASA LANGLEY RESEARCH CENTER


CELEBRATING
100
YEARS
NASA Langley Research Center 1917-2017
A Storied Legacy, A Soaring Future