Aviation Impact on Global Climate: NASA Aeronautics Research Efforts

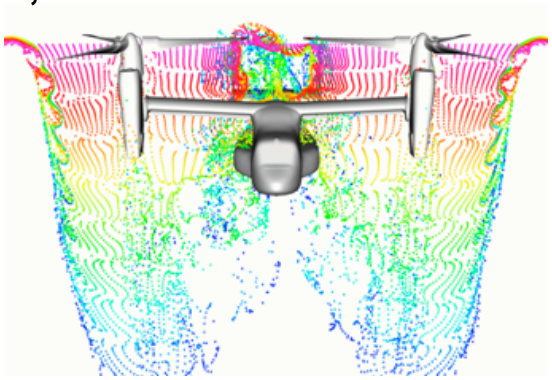
Aviation and Climate Change Workshop

Toronto

May 30, 2008

Fayette Collier

PI, Subsonic Fixed Wing Project, NASA Fundamental Aeronautics Program



Outline

- Introduction
- The current situation / understanding
- NASA / ARMD efforts to reduce impact on global climate
- Partnerships, ongoing, and future activities

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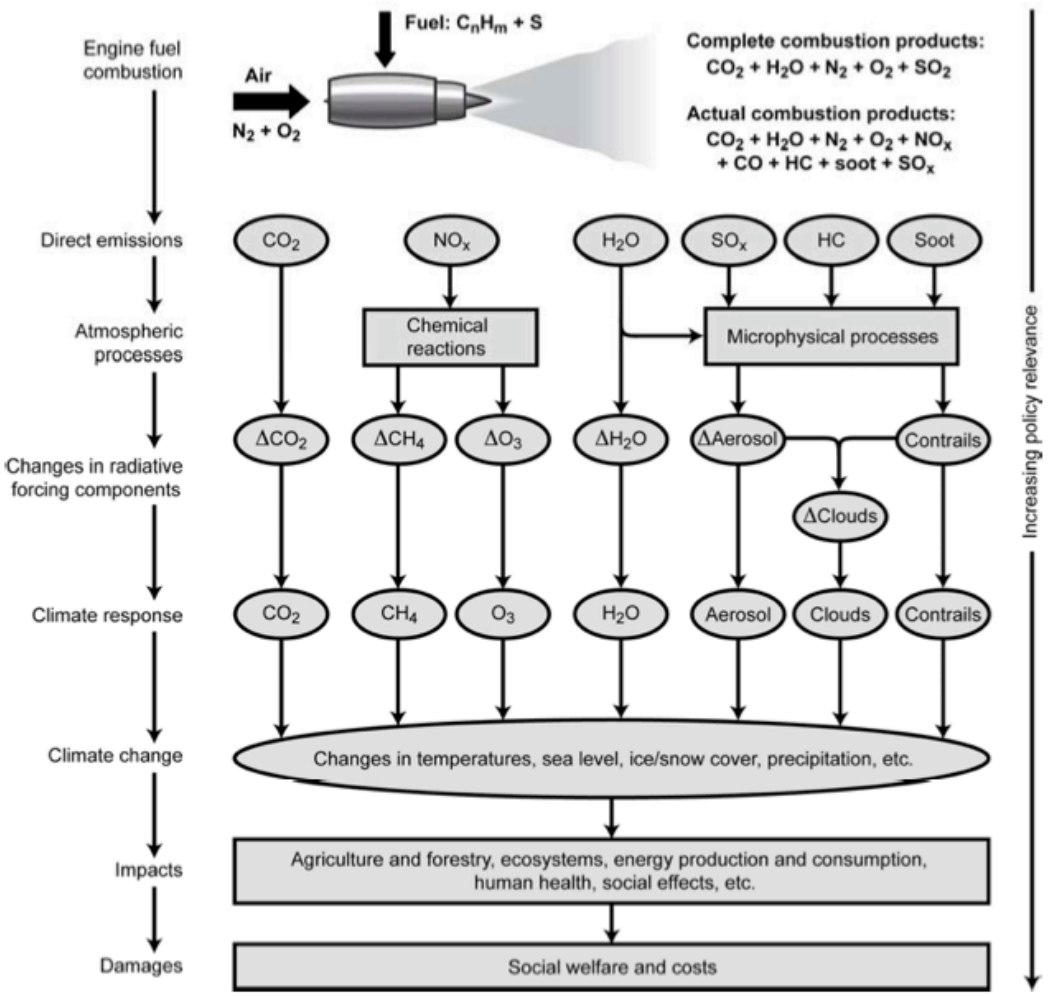
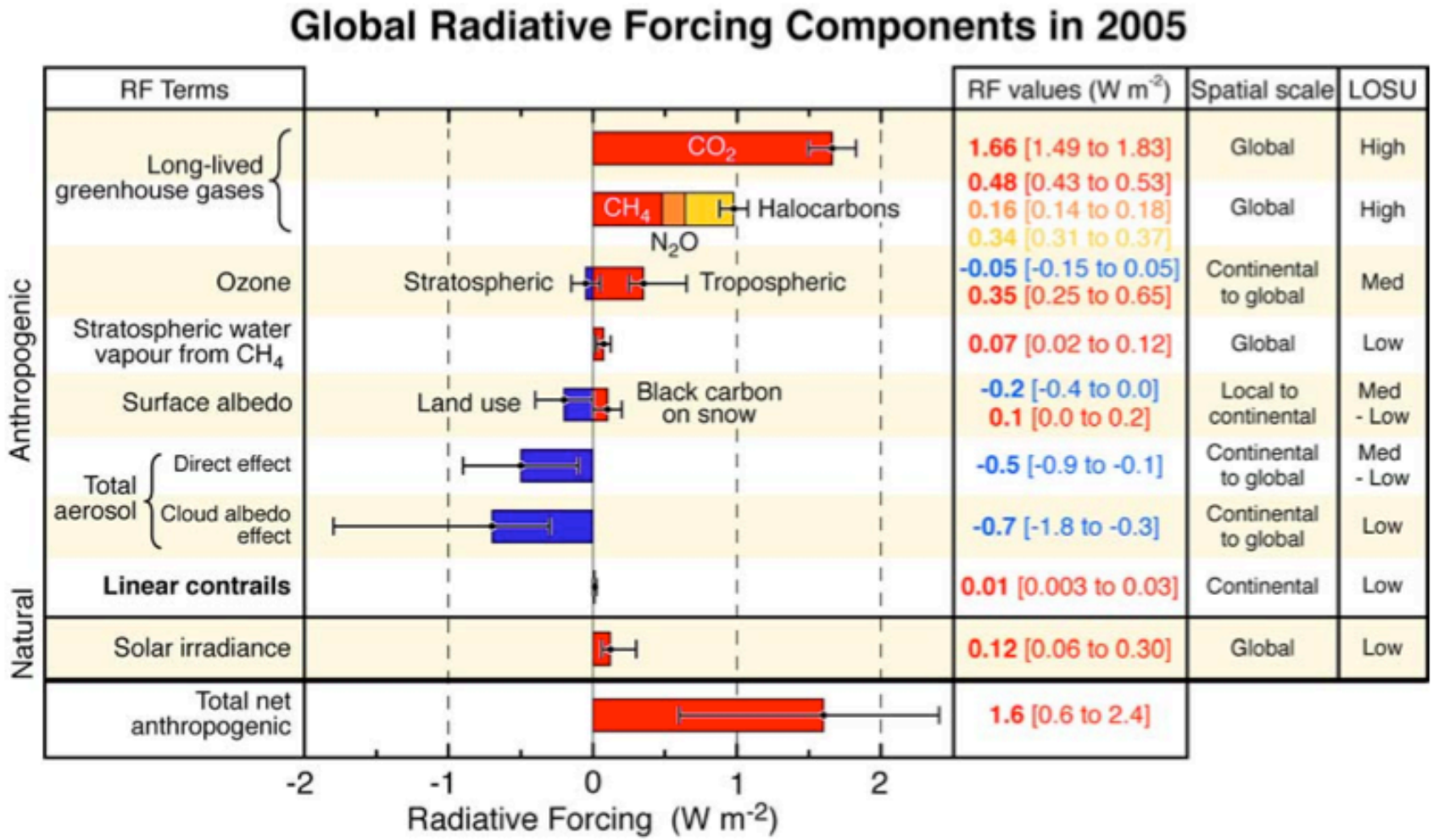
Aviation Emissions and Global Climate



From Wuebbles et al., 2007, IPCC, 1999, and Fuglestvedt et al., 2003

Global Radiative Forcing, 2005



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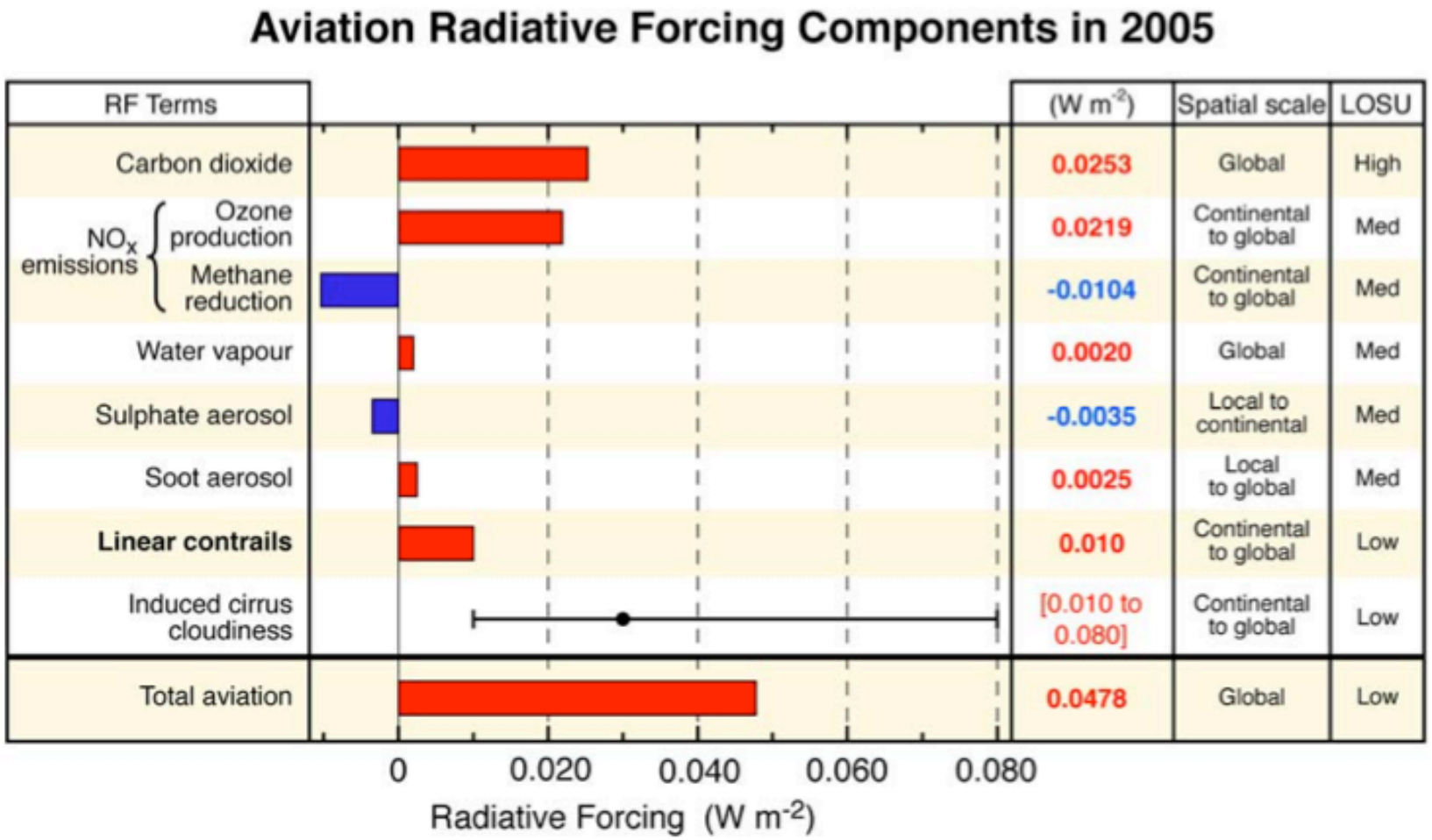

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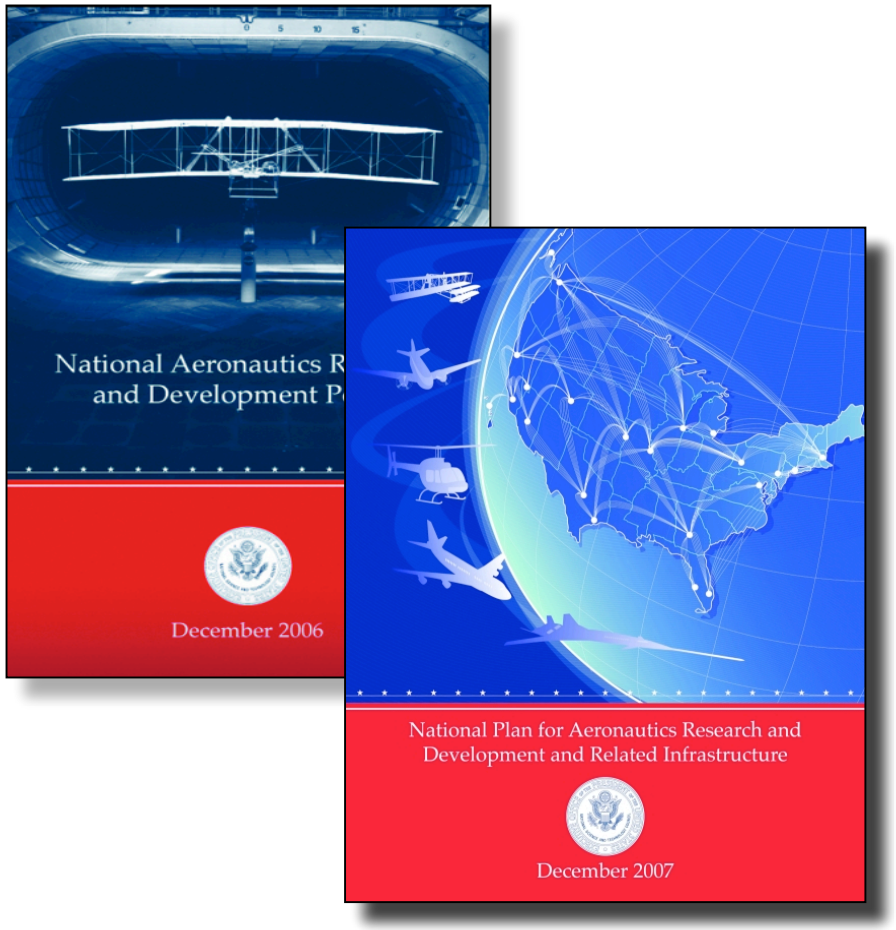
Global Climate Addressed in National Aeronautics R&D Policy and Plan Objectives

- **Policy**
  - Executive Order signed December 2006
  - Outlines 7 basic principles to follow in order for the U.S. to "maintain its technological leadership across the aeronautics enterprise"
  - Mobility, national security, aviation safety, security, workforce, energy & efficiency, and environment

- **Plan (including Related Infrastructure)**
  - Plan signed by Pres. Bush December 2007
  - Goals and Objectives for all basic principles (except Workforce, being worked under a separate doc)
  - Summary of challenges in each area and the facilities needed to support related R&D
  - Specific quantitative targets where appropriate
  - More detailed document/version to follow later in 2008



Executive Order, Policy, Plan, and Goals & Objectives all available on the web

For more information visit: http://www.ostp.gov/cs/nstc/documents_reports

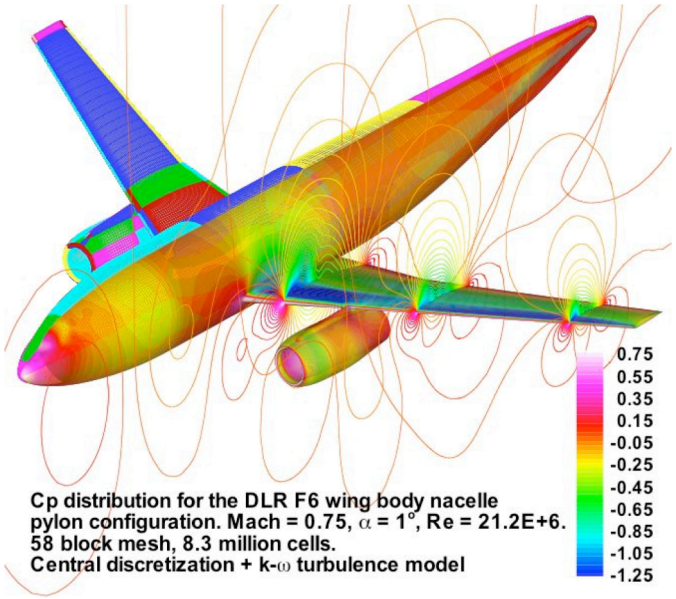
Aeronautics Programs

Fundamental Aeronautics Program
- Subsonic Fixed Wing
- Subsonic Rotary Wing
- Supersonics
- Hypersonics

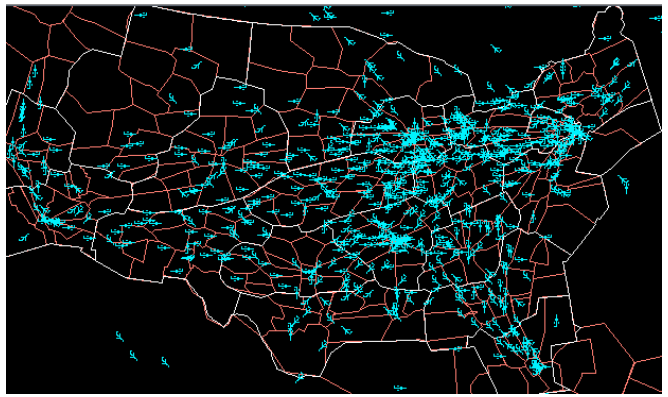
Aviation Safety Program
- Integrated Vehicle Health Management
- Integrated Resilient Aircraft Control
- Integrated Intelligent Flight Deck
- Aircraft Aging & Durability

Airspace Systems Program
- NGATS Air Traffic Management: Airspace
- NGATS Air Traffic Management: Airportal

Aeronautics Test Program
- Ensure the strategic availability and accessibility of a critical suite of aeronautics test facilities that are deemed necessary to meet aeronautics, agency, and national needs.



Cp distribution for the DLR F6 wing body nacelle pylon configuration. Mach = 0.75, α = 1°, Re = 21.2E+6. 58 block mesh, 8.3 million cells. Central discretization + k-ω turbulence model



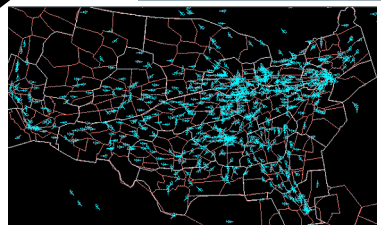
Aeronautics Programs

Fundamental Aeronautics Program

Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for vehicles that fly in all speed regimes.

Aviation Safety Program

Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft.



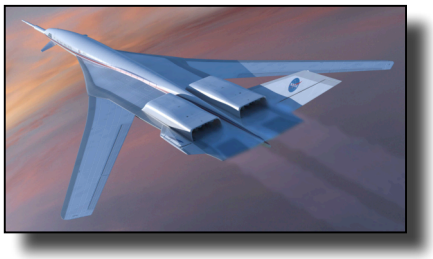
Airspace Systems Program

Directly address the fundamental ATM research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.

NASA Fundamental Aeronautics Program

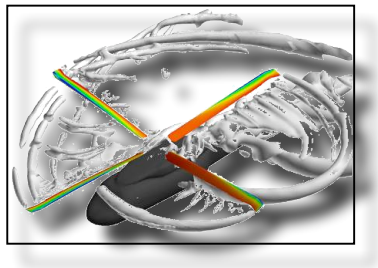
- ***Hypersonics***
  - Fundamental research in all disciplines to **enable very-high speed flight** (for launch vehicles) and **re-entry into planetary atmospheres**
  - High-temperature materials, thermal protection systems, advanced propulsion, aero-thermodynamics, multi-disciplinary analysis and design, GNC, advanced experimental capabilities

- ***Supersonics***
  - **Eliminate environmental and performance barriers** that prevent **practical supersonic vehicles** (cruise efficiency, noise and emissions, vehicle integration and control)
  - Supersonic deceleration technology for **Entry, Descent, and Landing** into Mars



- ***Subsonic Fixed Wing (SFW)***
  - Develop revolutionary technologies and aircraft concepts with highly **improved performance** while satisfying **strict noise and emission constraints**
  - Focus on **enabling technologies**: acoustics predictions, propulsion / combustion, system integration, high-lift concepts, lightweight and strong materials, GNC, alternative fuels

- ***Subsonic Rotary Wing (SRW)***
  - Improve **civil potential of rotary wing vehicles** (vs fixed wing) while maintaining their unique benefits
  - Key **advances** in multiple areas through **innovation** in materials, aeromechanics, flow control, propulsion

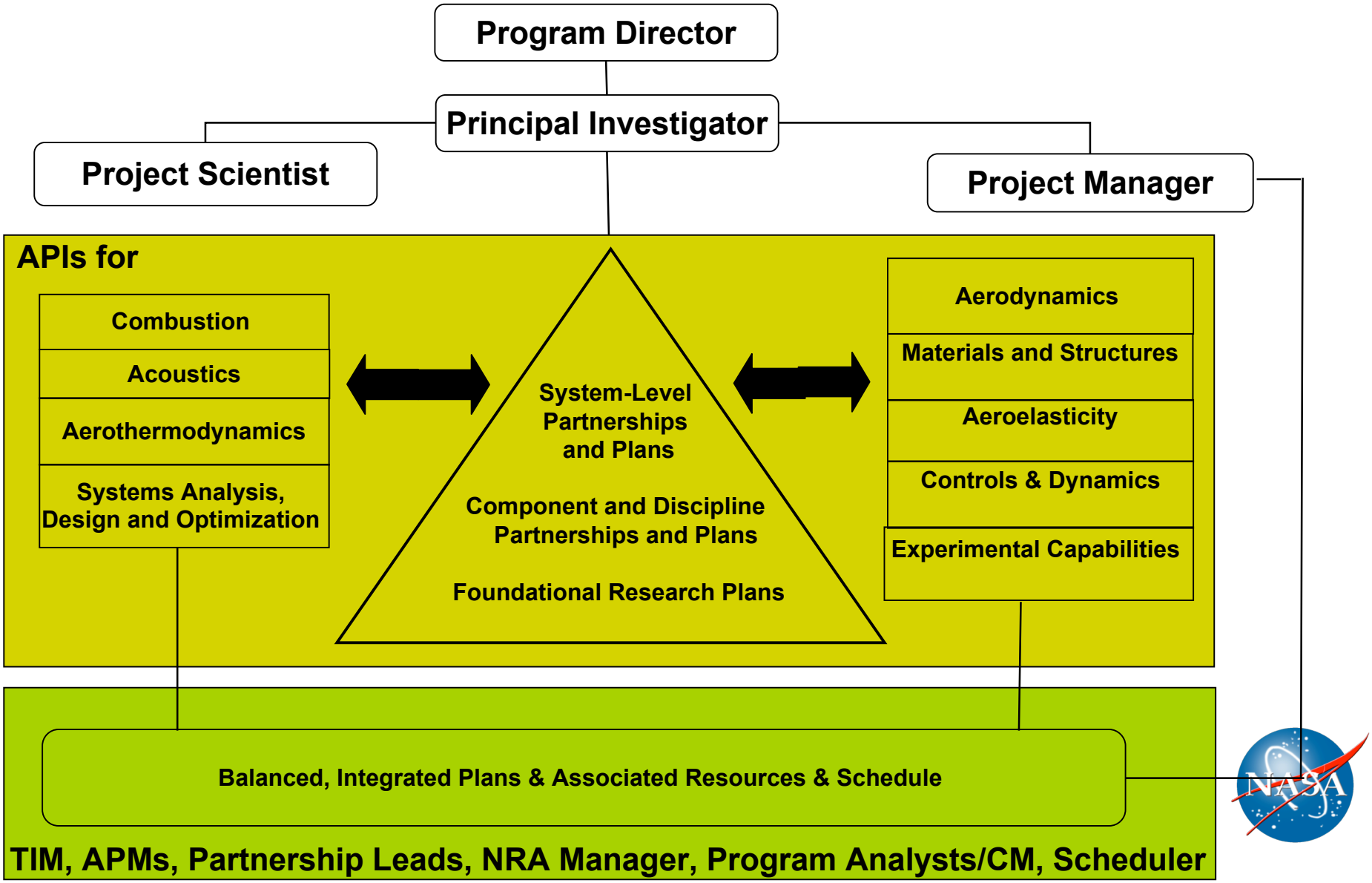


Subsonic Fixed Wing Project

…. technology for dramatically improving noise, emissions, & performance

- ***Objectives***
  - Development of prediction and analysis tools for reduced uncertainty in design process
  - Development of concepts/technologies for enabling dramatic improvements in noise, emissions and performance characteristics of subsonic/transonic aircraft
- ***Relevance***
  - Direct impact on future designs of a wide range of subsonic aircraft relevant to industry, DoD, and OGA
  - Direct impact on JPDO & NextGen operational and environmental goals and objectives

Organization of SFW Project

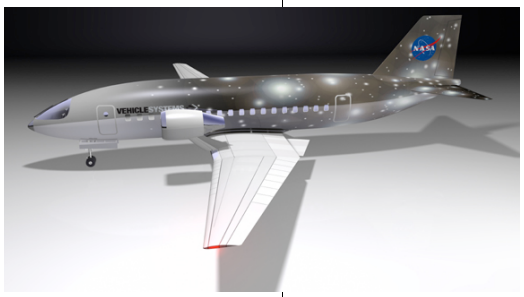


System Level Metrics

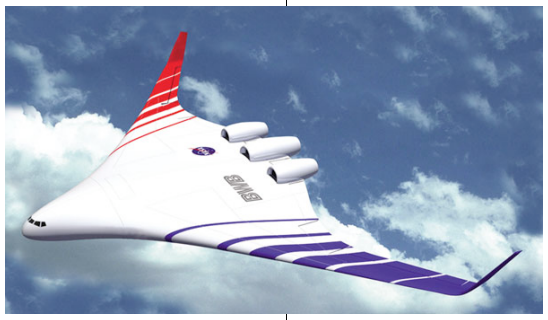
.... technology for dramatically improving noise, emissions, & performance

CORNERS OF THE TRADE SPACE	N+1 (2015 EIS) Generation Conventional Tube and Wing (relative to B737/CFM56)	N+2 (2020 IOC) Generation Unconventional Hybrid Wing Body (relative to B777/GE90)
Noise (cum below Stage 4)	- 32 dB	- 42 dB
LTO NOx Emissions (below CAEP 6)	-60%	-75%
Performance: Aircraft Fuel Burn	-33%***	-40%***
Performance: Field Length	-33%	-50%

N+1



N+2



*** An additional reduction of 10 percent may be possible through improved operational capability

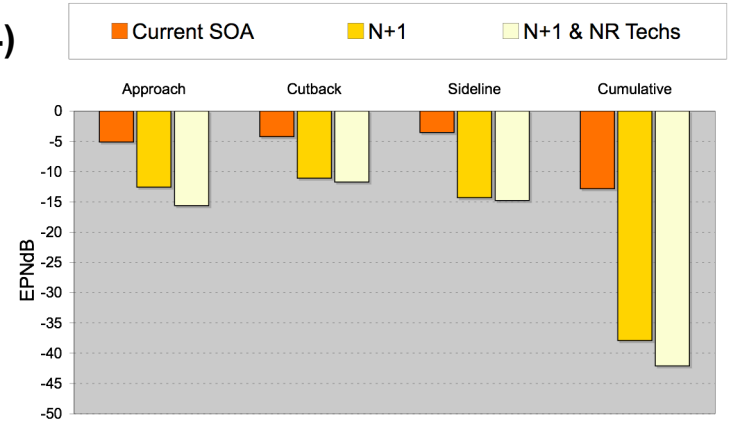
Approach

- *Enable Major Changes in Engine Cycle/Airframe Configurations*
- *Reduce Uncertainty in Multi-Disciplinary Design and Analysis Tools and Processes*
- *Develop/Test/ Analyze Advanced Multi-Discipline Based Concepts and Technologies*
- *Conduct Discipline-based Foundational Research*

Noise Reduction

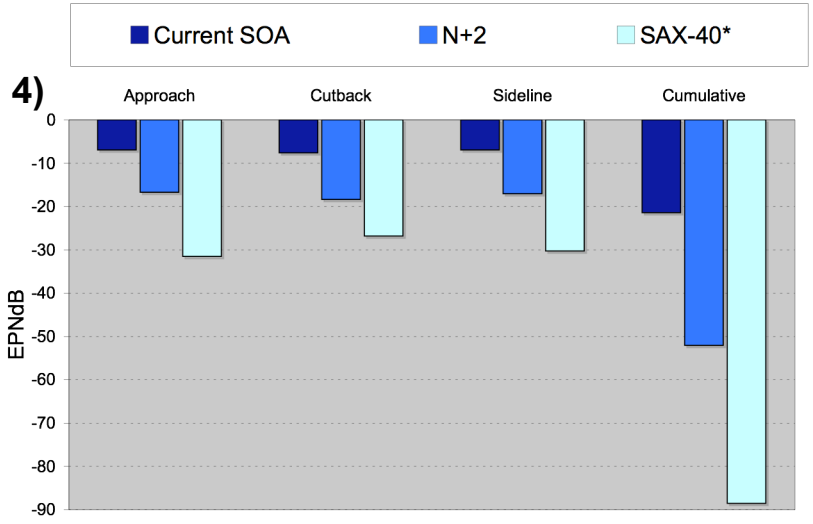
"N + 1" Conventional Small Twin

- 42 EPNdB cumulative below Stage 3 (32 wrt Stage 4)
- Target Next Generation Single Aisle (NGSA)
- Ultra-High Bypass (UHB) engines
- Noise Reduction (NR) technologies for fans, landing gear, propulsion airframe aeroacoustics
- Light weight acoustic treatment in multi-functional structures



"N + 2" Hybrid Wing/Body

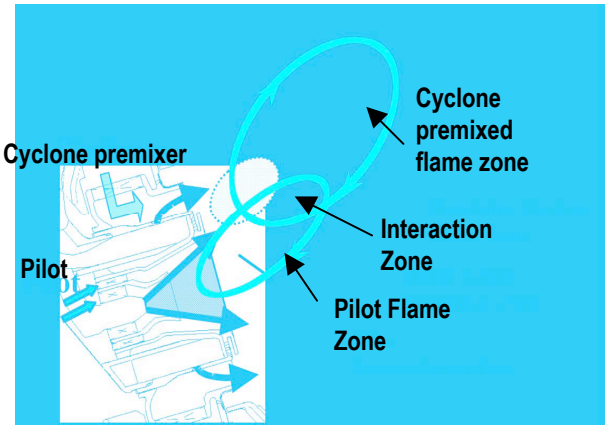
- 52 EPNdB cumulative below Stage 3 (42 wrt Stage 4)
- Will achieve significant noise reduction from wing shielding of engines
- Drooped leading edge
- Continuous mold line flaps
- Landing gear fairings
- Long duct, low drag acoustic liners
- Distortion tolerant fans with active noise control



NOx Emissions Reduction

Conventional Small Twin: N+1

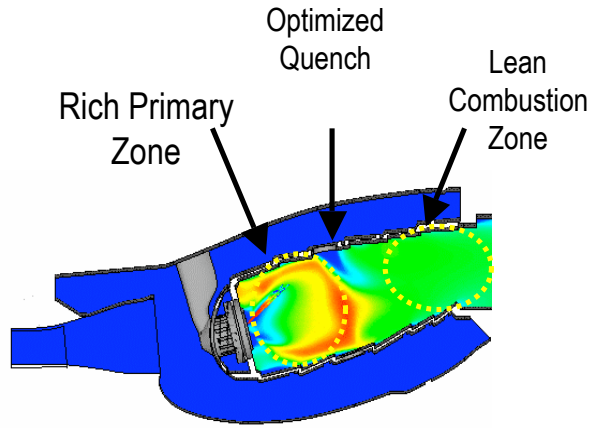
70% LTO NOx reduction below CAEP/2
- Target Next Generation Single Aisle (NGSA)
- Annular combustor TAPS (GE)
  - Improved fuel/air mixers
- TALONX (P&W)
  - Optimized quench section for improved mixing
  - Improved fuel/air mixing in rich zone



Cyclone Main with Pilot Concept

Hybrid Wing/Body: N+2

80% LTO NOx reduction below CAEP/2
- Improved CFD Modeling
- Advanced combustor concepts
- Advanced fuel/air mixers
- Active combustion control
- High temperature liners
- Alternative fuels



Rich Burn Quick Quench Lean Burn Concept

Lean Direct Injection Multipoint Concept

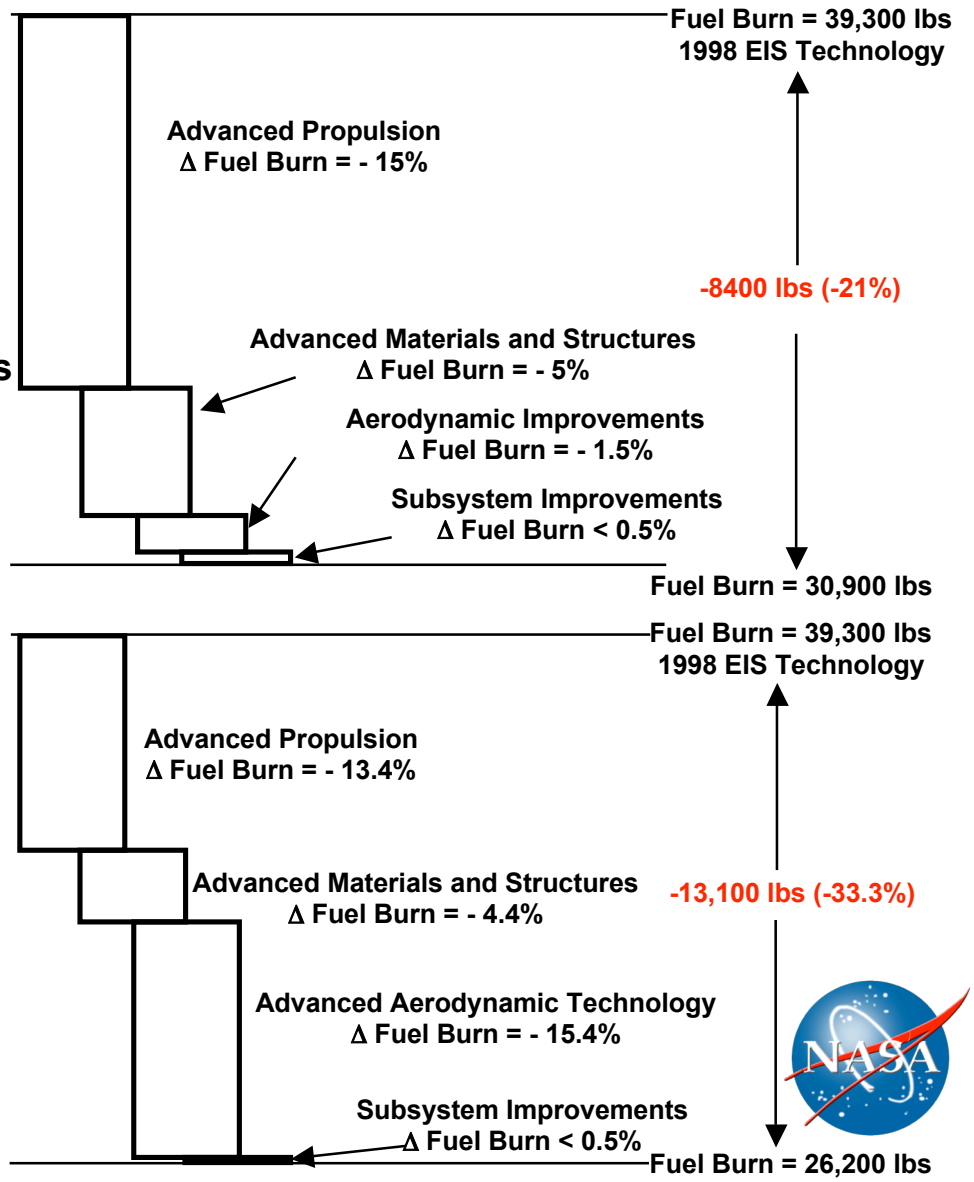
Performance - Fuel Burn - N+1

"N + 1" Conventional Small Twin

- 162 pax, 2940 nm mission baseline
- Ultra high bypass ratio engines, geared
- Key technology targets:
  - +1 point increase in turbomachinery efficiencies
  - 25% reduction in turbine cooling flow enabled by: improved cooling effectiveness and advanced materials
  - +50 deg. F compressor temperatures (T3)
  - +100 deg. F turbine rotor inlet temperatures
  - -15% airframe structure weight
  - -1% total vehicle drag
  - -15% hydraulic system weight

"N + 1" Advanced Small Twin

- All technologies listed above plus:
  - Hybrid Laminar Flow Control
    - 67% upper wing,
    - 50% lower wing,
    - tail, nacelle
  - Result = -17% total vehicle drag



Performance - Fuel Burn - N+2

Hybrid Wing Body - 300 pax, 7500 nm

Dominant Configuration - Tube and Wing 1997 Baseline

Fuel Burn = 237,000 lbs
1997 EIS Technology

Hybrid Wing Body configuration with composite fuselage
Δ Fuel Burn = - 10%

Advanced Propulsion (Podded) and Airframe Technologies (composite wings)
Δ Fuel Burn = - 10%

-95,900 lbs (-40%)

Advanced Propulsion (Embedded) and BLI inlets
Δ Fuel Burn = - 14%

Aerodynamic Improvements (Hybrid Laminar Flow Control)
Δ Fuel Burn = - 6%

Fuel Burn = 147,595 lbs

Subsonic Fixed Wing
Major Activities - FY08

UHB Geared Turbo Fan Tests (Noise, Performance and Alternate Fuels)
- Partner = Pratt and Whitney

UHB Open Rotor Tests (Planning Phase)
- Partner = GE Aviation

Airframe and engine noise tests
- Partner = Gulfstream and Honeywell

Cruise Efficient STOL Concept Tests
- Partners = AFRL and Northrop Grumman, Boeing PW, LM

BWB X-48B Low Speed Vehicle Flight Tests, Acoustic Testing, and System Studies
- Partners = AFRL/Boeing Phantom Works

Laminar flow strategy and tests
- Partners = AFRL and Boeing Phantom Works

MDAO strategy, framework and requirements documents complete
- Validated GEN 1 Capability - low to medium fidelity (FY09)
- Validated GEN 2 Capability - medium to high fidelity (FY11)
- Validated GEN 3 Capability - high fidelity (FY13)

Subsonic Fixed Wing
Noise Reduction and Performance

Collaborative Test with P & W in NASA 9' x 15' Acoustic Wind Tunnel (FY07)

22" Subscale Rig Demonstrated:

- Noise reduction benefits of an advanced (UHB) cycle fan
- Fan efficiency that exceeded predictions
- Overall performance advantage of a low PR, low tip speed fan
- High efficiency fan design translates into decreased noise
- Data from rig test used to define fan aerodynamics for FY08 test

FY08 Accomplishments

Performance and Noise Tests

Alternative Fuels Tests

Installation Testing in Ames 11-foot

Pratt & Whitney
A United Technologies Company

NASA

Subsonic Fixed Wing
Prior Laminar Flow Demonstrations

Significant US Experiences

- Jetstar Hybrid Laminar Flow Wing Simulated Airline Service
- B757 Natural Laminar Flow Flight Experiment
- F-14 Variable Sweep Transition Flight Experiment
- B757 Hybrid Laminar Flow Control Flight Experiment
  - The “Crossflow” Experiment in the Langley 8-ft TPT
- A320 Hybrid Laminar Flow Nacelle Demonstration

Significant European Experiences

- Dassault Falcon 50 Hybrid Laminar Flow Flight Demonstrator
- VFW 614 European Natural Laminar Flow Nacelle Demonstrator
- European Laminar Flow Investigation
  - VFW-61 HLFC Wind-tunnel Experiment
  - Fokker 100 Natural Laminar Flow Glove Flight Experiment
  - The A320 Laminar Fin Program

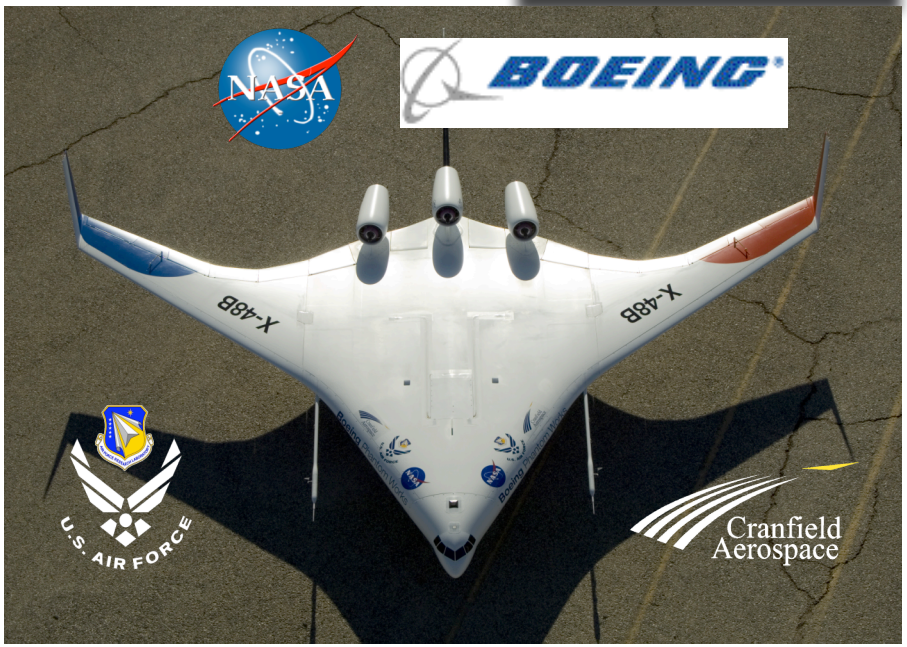
Subsonic Fixed Wing
FY08 Laminar Flow Restart

- Ground test strategy
- Natural laminar flow
  - How far can we push Distributed Roughness Elements
  - Other approaches for passive control
- Relook at The HLFC “Crossflow Experiment” Database
- Develop flight test or demonstration strategies

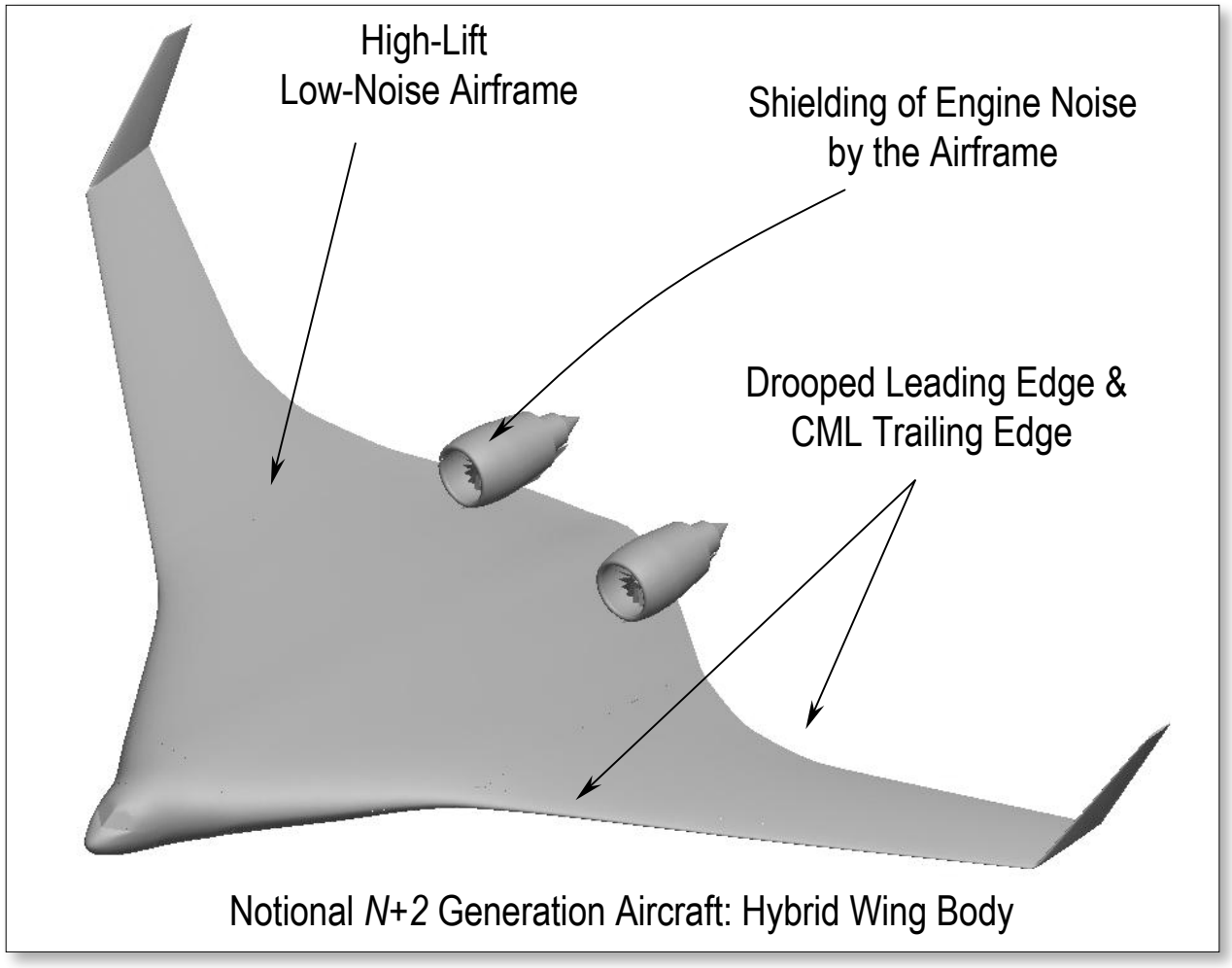
Subsonic Fixed Wing
Technical Highlight: X-48B Flight

First flight July 20, 2007
- X-48B
- 500 lb, 21 ft wing span
- 31 minute flight
- Low-speed flying/handling qualities experiment
- Potential future use for acoustics tests (ground and flight) and transonic experiments

13 Flights Completed



Subsonic Fixed Wing Technology Path - N+2



Notional *N+2* Generation Aircraft: Hybrid Wing Body

Potential ASM Session

-Low Speed S & C

-Transonic Aerodynamics

-Acoustics Characterization

-Structural Developments

-Advanced CE STOL Concept Vehicle

-Risk Assessment and Systems Study

-X-48B Flight Test Results

NASA N+3 NRA Pre-Proposal Conference

- ***Advanced Concept Studies for Subsonic and Supersonic Commercial Transports Entering Service in the 2030-35 Period***
- Proposals expected 29 May, 2008
- Details at http://www.aeronautics.nasa.gov/fap
- Stimulate innovation and foster the pursuit of revolutionary conceptual designs for aircraft that could enter service in the 2030-35 time period. Overcome significant performance and environmental challenges for the benefit o the public.
- Phase I: 18-Months, Phase II: Two Years, with significant technology demonstration
- Awards expected by end of summer

SFW System Level Metrics

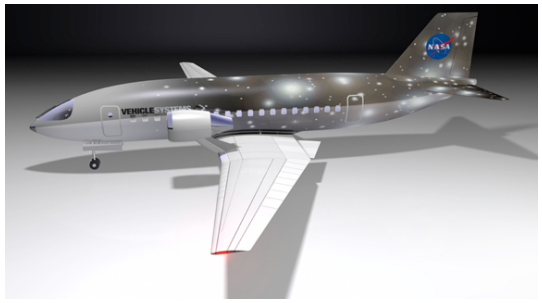
CORNERS OF THE TRADE SPACE	N+1 (2015 EIS) Generation Conventional Tube and Wing (relative to B737/CFM56)	N+2 (2020 IOC) Generation Unconventional Hybrid Wing Body (relative to B777/GE90)	N+3 (2030-2035 EIS) Generation Advanced Aircraft Concepts (relative to user defined reference)
Noise	- 32 dB (cum below Stage 4)	- 42 dB (cum below Stage 4)	55 LDN (dB) at average airport boundary
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%**	-40%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

** An additional reduction of 10 percent may be possible through improved operational capability

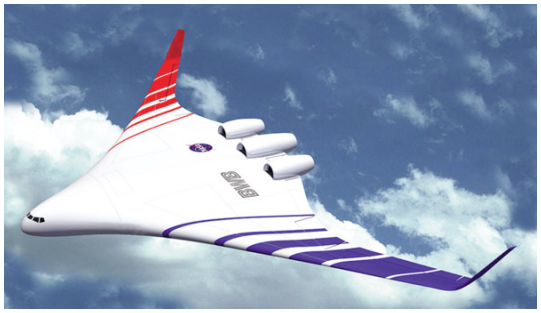
* Concepts that enable optimal use of runways at mutiple airports within the metropolitan areas

EIS = Entry Into Service; IOC = Initial Operating Capability

N+1 Conventional



N+2 Hybrid Wing/Body



N+3 Generation

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Summary of Contributions

- Focus on fuel burn reduction / performance improvement:
  - Balanced investment between N+1, N+2, and N+3 generations
  - Contributions from propulsion system, airframe, combustors, integration, revolutionary configurations, alternative fuels, operations

- Current understanding of global climate is one of the guiding principles for goals/targets/objectives in NASA/FAP/SFW but a balanced approach is needed (global climate, noise, emissions, performance)

- Aircraft emissions and alternative fuels are the keys to reduction of GHG emission reduction

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Key Partnerships

- ***FAA Office of Energy & Environment***
- Aviation Climate Change Research Initiative
- Commercial Aviation Alternative Fuel Initiative
- NASA Science Mission Directorate
- OGAs (NOAA, EPA, DoE, NCAR, etc)
- International collaborations

Learn more about NASA Aeronautics…..

www.aeronautics.nasa.gov

Overview of the entire NASA Aeronautics Program

- Fundamental Aeronautics Program
- Aviation Safety Program
- Airspace Systems Program
- Aeronautics Test Program

www.aeronautics.nasa.gov/fap/index.html

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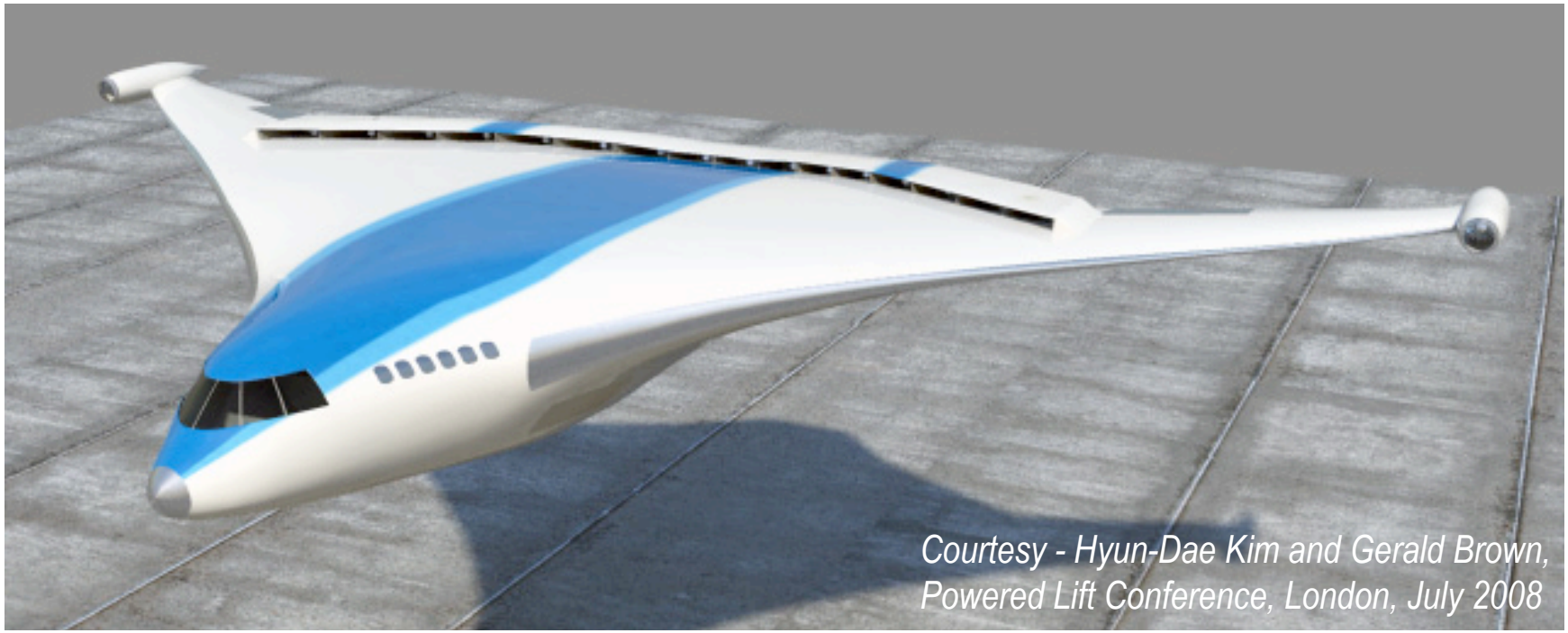
Questions



Courtesy - Hyun-Dae Kim and Gerald Brown,
Powered Lift Conference, London, July 2008