Progress toward aviation's environmental goals and objectives - a vehicle perspective

Presented by - Fay Collier, Ph.D., M.B.A.
PI, Subsonic Fixed Wing Project
Fayette.S.Collier@nasa.gov

Green Aviation Workshop

Ames Research Center, CA

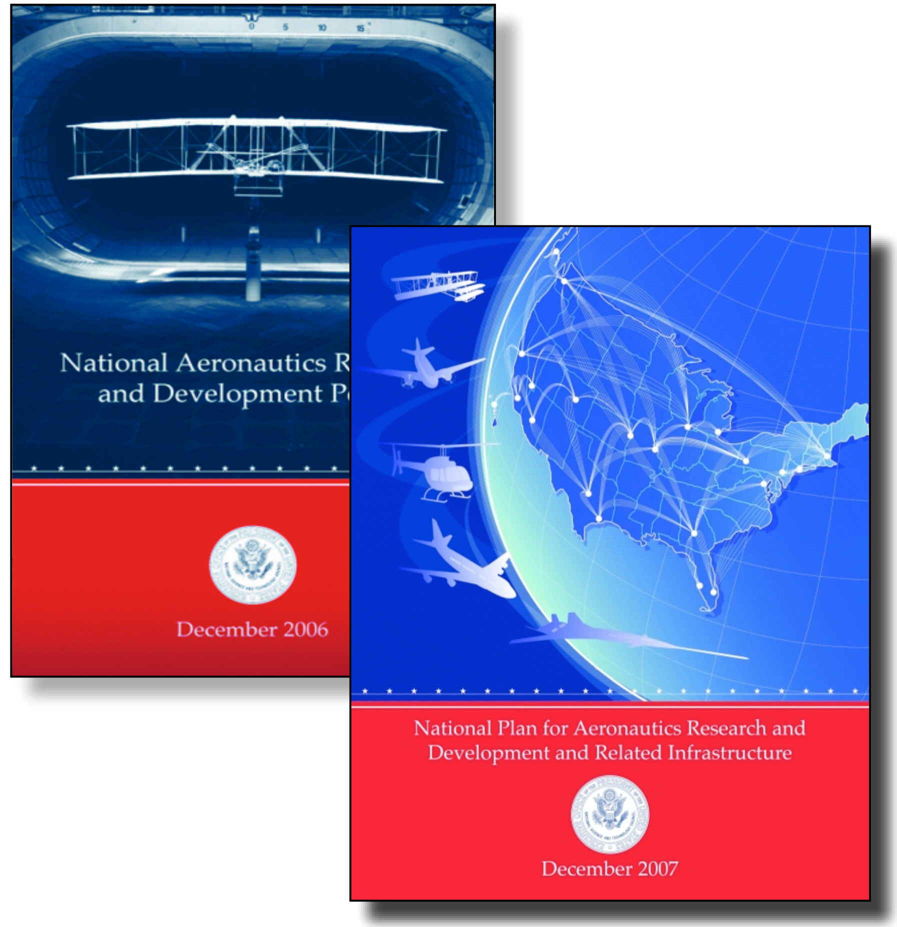
April 25, 2009

Outline

- Introduction
- N+1 Vehicle Themes and Progress
- N+2 Vehicle Themes and Progress
- N+3 Vehicle Themes and Progress
- Alternative Fuels Research
- Wrapup

National Aeronautics R&D Policy and Plan

- **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 President 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

SFW System Level Metrics

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

CORNERS OF THE TRADE SPACE	N+1 (2015)*** Generation Conventional Tube and Wing (relative to B737/CFM56)	N+2 (2020)*** Generation Unconventional Hybrid Wing Body (relative to B777/GE90)	N+3 (2025)*** Generation Advanced Aircraft Concepts (relative to user defined reference)
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Performance: Aircraft Fuel Burn	-33%**	-40%**	better than -70%
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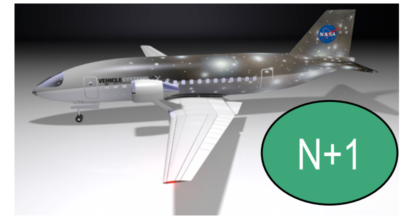
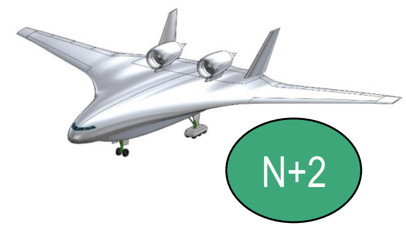
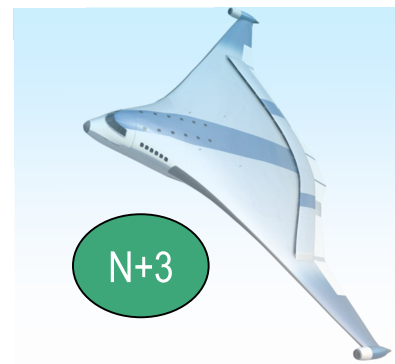
*** Technology readiness level for key technologies = 4-6

** Additional gains may be possible through operational improvements

* Concepts that enable optimal use of runways at multiple airports within the metropolitan area







Approach

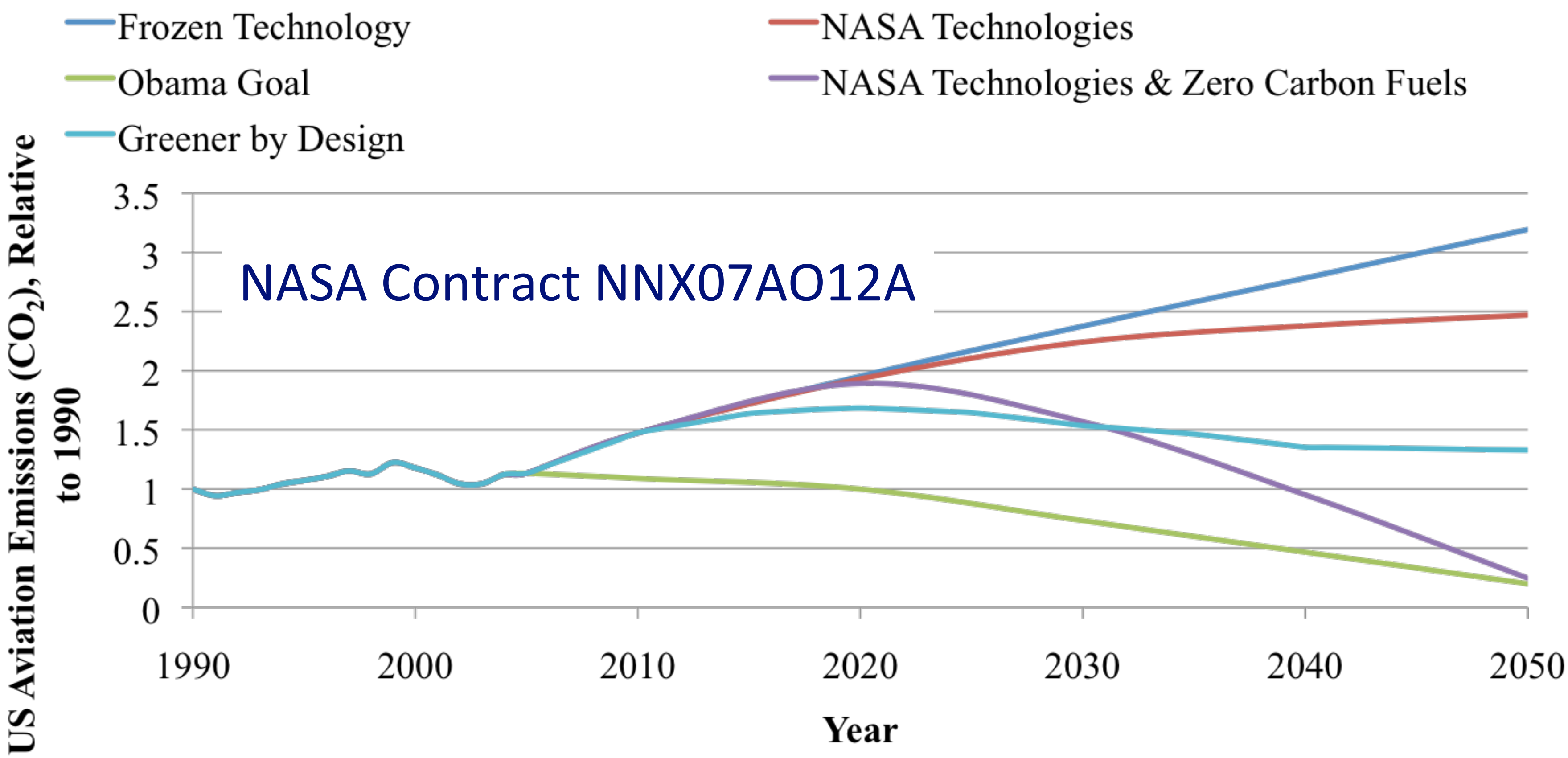
- Enable Major Changes in Engine Cycle/Airframe Configurations

- 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

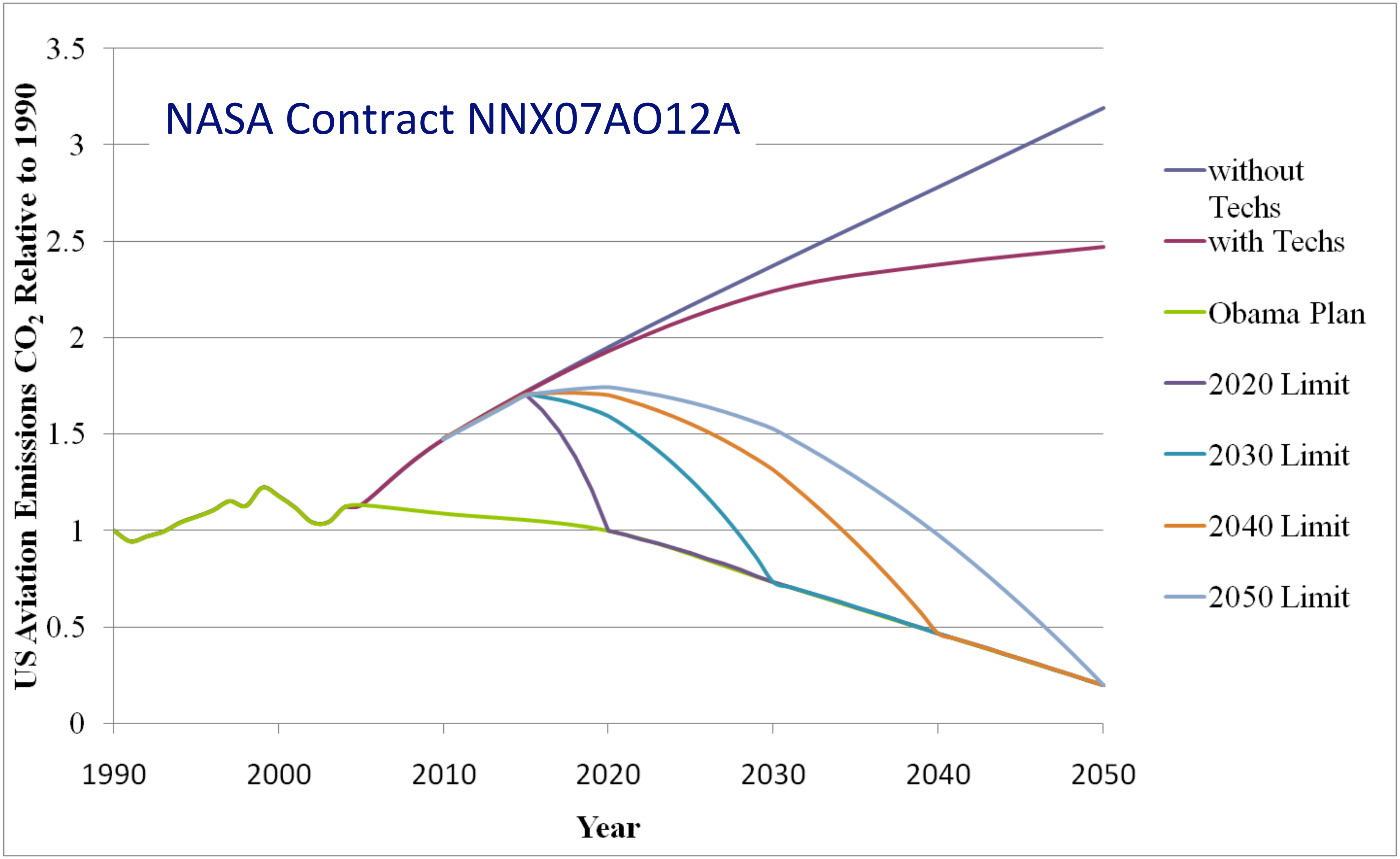
The Obama Campaign CO2 Goal and Aviation Emissions



Magnitude of emissions growth and goal gap is dependent upon aviation traffic growth assumptions, and introduction rate of adv aircraft technologies, & net carbon zero alternative fuels

Mavris, Pfaender, Hollingsworth, et al

The Obama Campaign CO2 Goal and Aviation Emissions with accelerated introduction rates of carbon zero alt fuels



Mavris, Pfaender, Hollingsworth, et al

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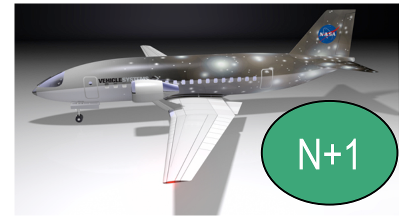

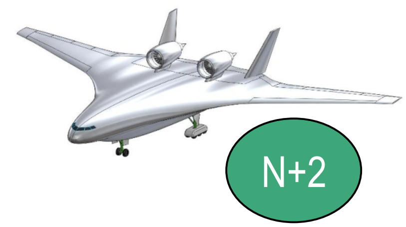

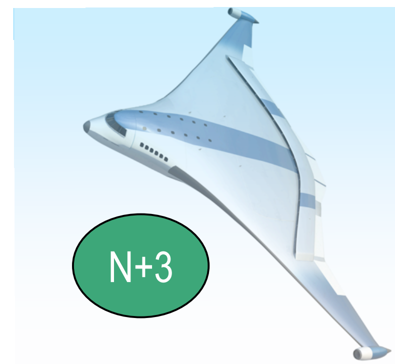

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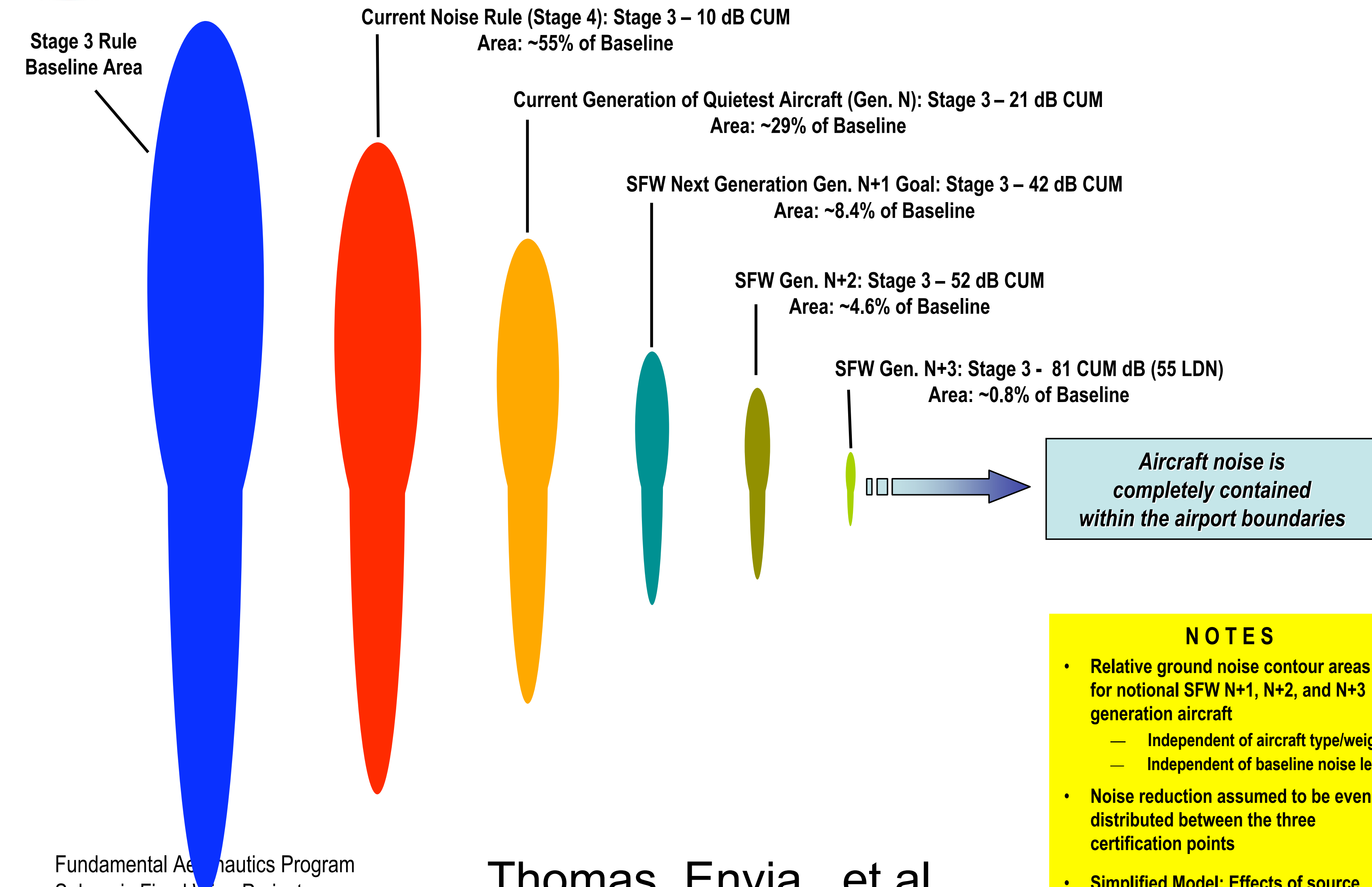
Change in noise "footprint" area based on Subsonic Fixed Wing Project goals for a single landing and takeoff



NOTES

- Relative ground noise contour areas for notional SFW N+1, N+2, and N+3 generation aircraft
  - Independent of aircraft type/weight
  - Independent of baseline noise level
- Noise reduction assumed to be evenly distributed between the three certification points
- Simplified Model: Effects of source directivity, wind, etc. not included

Thomas, Envia, et al

Performance - Fuel Burn - N+1

Detailed System Analysis

"N + 1" Advanced Small Twin

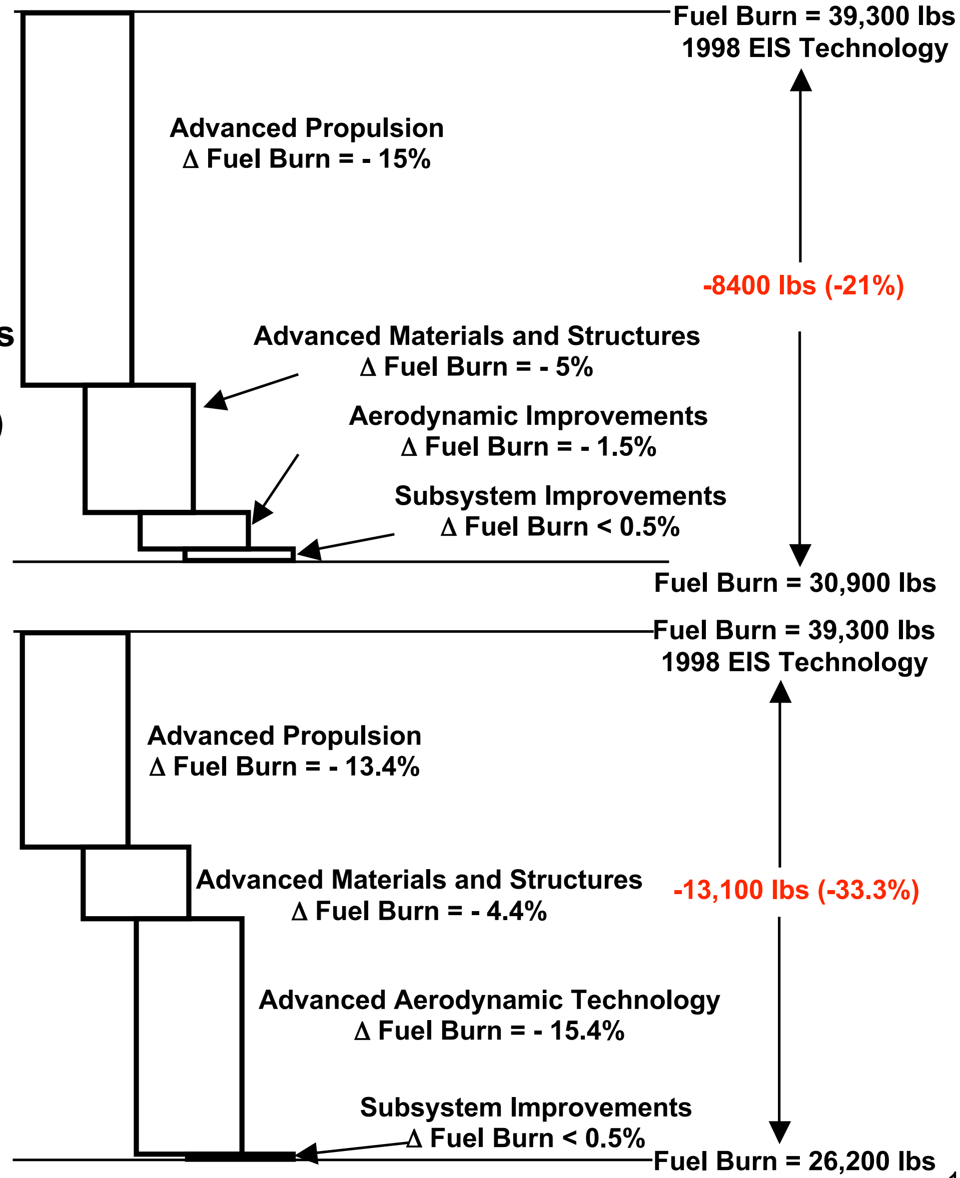
- 162 pax, 2940 nm mission baseline
- Ultra high bypass ratio engines, geared
- Key technology targets:
  - +1 point increase in turbomachinery efficiencies
  - 25% reduction in turbine cooling flow enabled by: improved cooling effectiveness and advanced materials
  - +50 deg. F compressor temperatures (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 - Plus

- All technologies listed above plus:

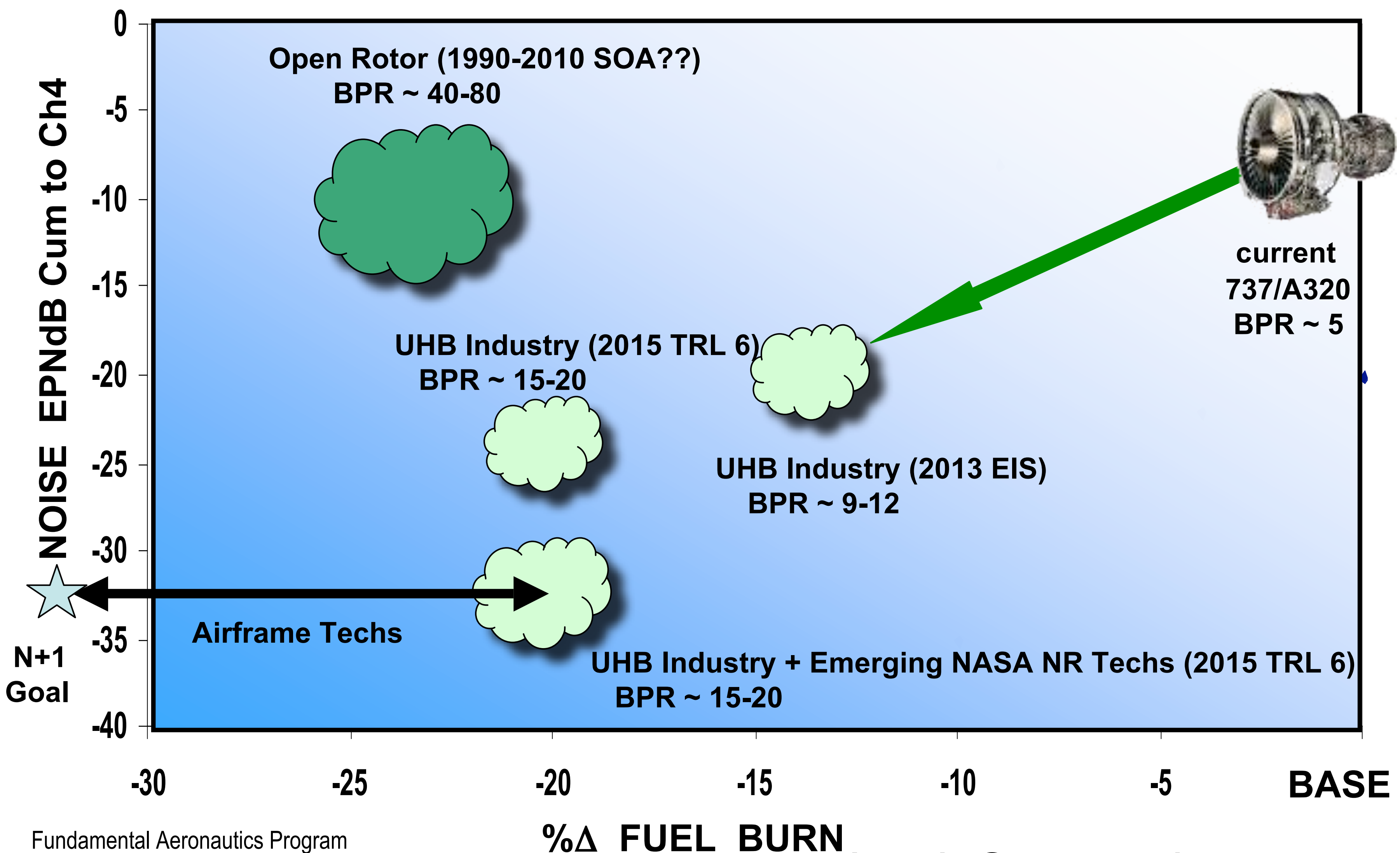
  Laminar Boundary Layer over
  - 67% upper wing,
  - 50% lower wing, tail, nacelles

  Result = -16.8% total vehicle drag
  - wing upper surface: 5.7%
  - wing lower surface: 3.8%
  - horizontal tail upper and lower surface: 2.2%
  - vertical tail both sides: 1.9%
  - nacelles: 3.2%



Guynn, Nickol, et al

UHB Engine Research

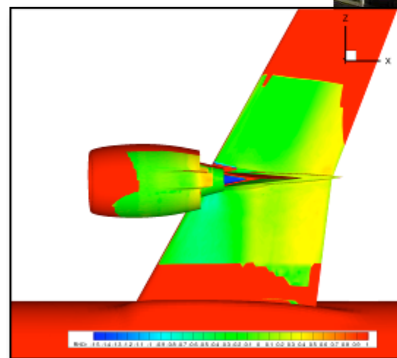


Lord, Sepulveda, et al

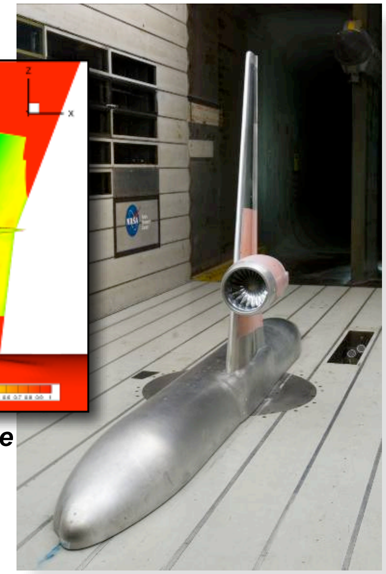
Ultra High Bypass Engine Cycle Collaborative Research

➢ *Pratt & Whitney Geared Turbofan*

- **Nacelle/Wing Interaction Test**
  - **Highly successful collaboration between Industry Partner and three NASA centers**
  - **Test data provided design confidence for nacelle-wing integration at BPR = 12**



Pressure Sensitive Paint results

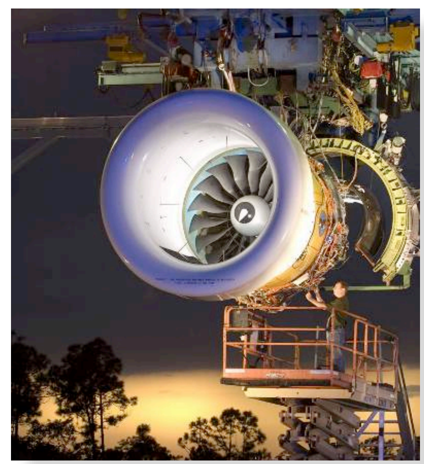


Powered half-span model test in Ames 11' wind tunnel

- **Geared Turbofan Demonstrator Engine**
  - **Successful ground demonstration of Geared Turbofan concept completed May 2008**
    - **Predicted fan performance verified**
    - **Acoustic characteristics within expectations**

- **Future Collaboration**
  - **Space Act Agreement negotiations initiated for continued research collaboration into next generation Geared Turbofan, starting with system analysis and design studies in 2009**

GTF Demonstrator Engine ground test



Flamm, Lord, Hughes, et al

General Electric Open Rotor

- **Space Act Agreement**
  - Signed August 2008
  - Initiates collaborative research on Open Rotor propulsion concepts in NASA Glenn 9'x15' and 8'x6' wind tunnels in 2Q 2009

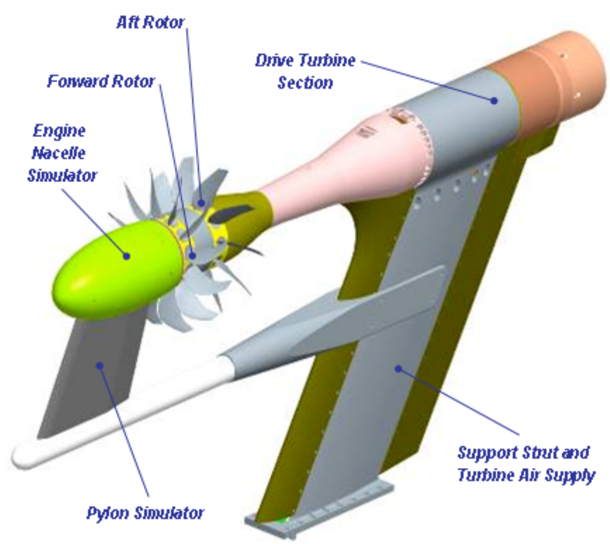
Test Objectives

- Investigate performance and noise
- Produce shareable open rotor fan design
- Generate shareable database of test results

Plan

- NASA refurbish 1980s counter-rotation propfan drive rig
- GE will design, fabricate and test 1980s technology based open rotor fan as Historical Baseline

GE Open Rotor Concept



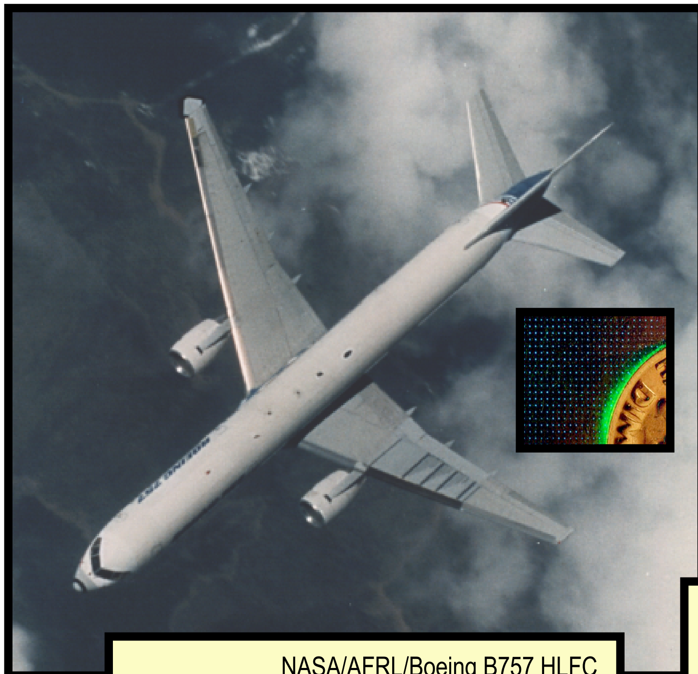
NASA Glenn Open Rotor Propulsion Rig

Hughes, GEAE, et al

Historical Collaboration in Laminar Flow

a few examples

NASA/Lockheed/Douglas JetStar HLFC
Simulated Airline Service - 1983-86



NASA/AFRL/Boeing B757 HLFC
Flight Experiment - 1990

NASA/Boeing HLFC Wing Model
8' TPT Wind Tunnel - 1995

- History/experience/solutions on which to build
- Today, fuel cost share of DOC is significantly higher
- Global environmental concerns widely acknowledged

Laminar (Boundary Layer) Flow Research

NLF (and DRE=distributed roughness elements)

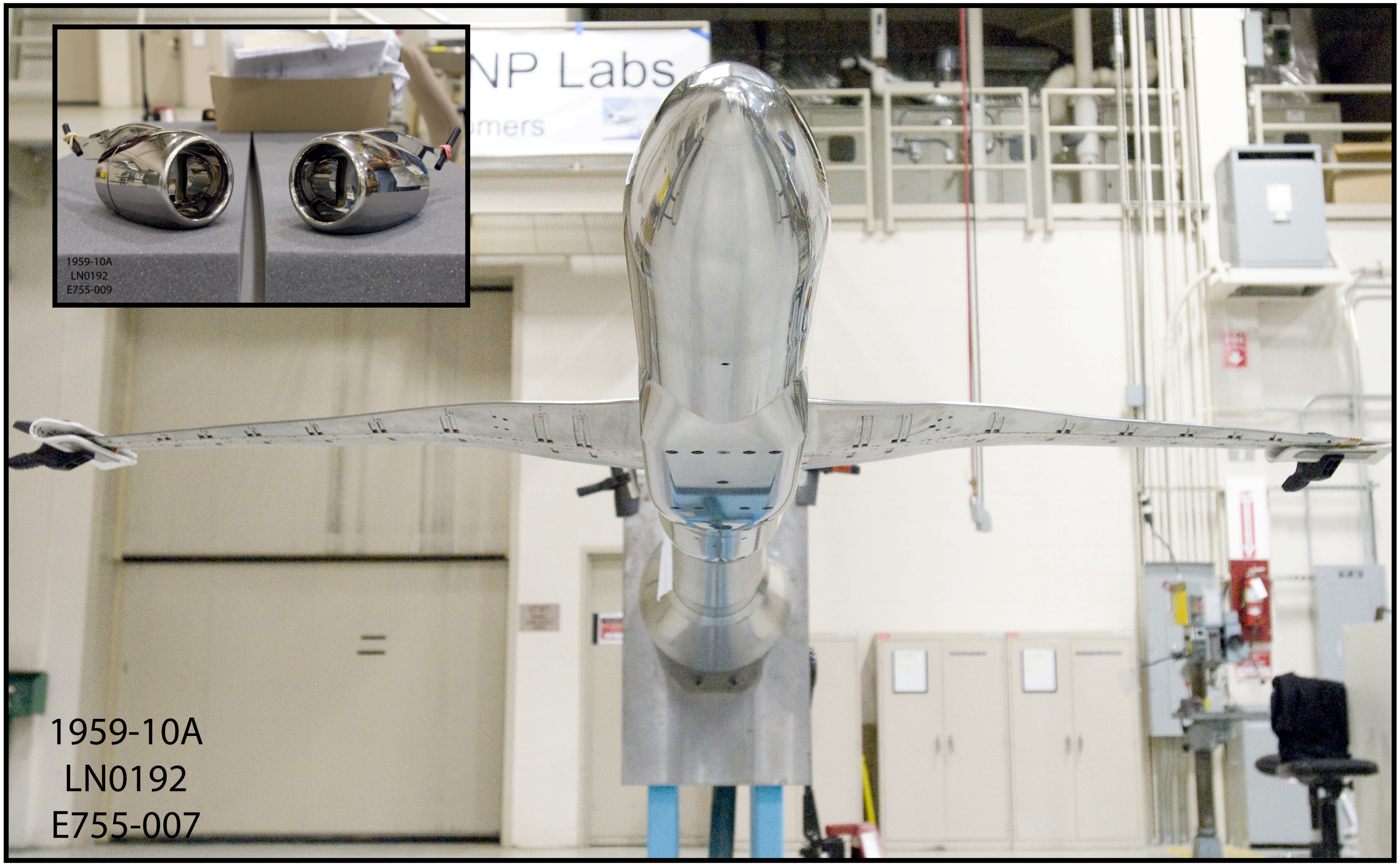
- Characterizing/evaluating the NTF as LF aircraft research/development facility
- Exploring the limits (in terms of Reynolds number) for DRE (with Saric, et al)

HLFC

- Re-visit and datamine the “crossflow” experiment
- Developing strategy/seeking partners for HLFC in-service demonstration

Laminar (Boundary Layer) Flow Research

High Rn LF wind-tunnel model for NTF



Rivers, Campbell, BCA, et al

Laminar (Boundary Layer) Flow Research

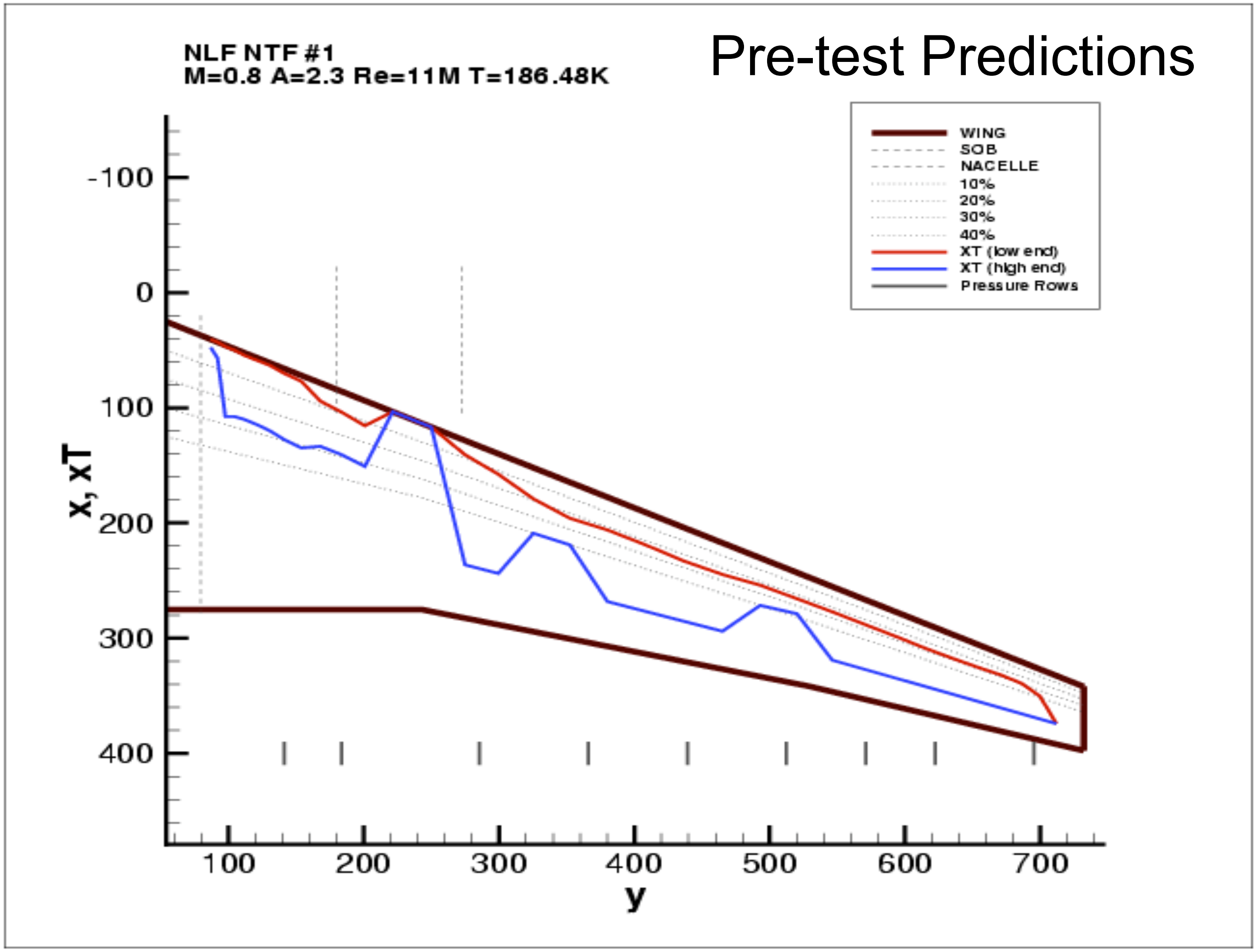
Aero Objectives for NTF Tests

- Determine LF extent relative to predictions
- Determine effectiveness of TSP for transition detection
- Determine the suitability of the NTF for NLF testing
- Determine the effectiveness of small scale model manufacturing quality for NLF testing
- Determine drag (increments) for NLF relative to predictions

Stability and Control Objectives for NTF Tests

- View the LF in sideslip and understand how to analyze the test practice
- Find the transition location (where the flow becomes turbulent)
- Ensure that the flow transition does not have adverse effects
- Correlate the LF wing with other WTs at lower Rn

Laminar (Boundary Layer) Flow Research



Rivers, Campbell, BCA, et al

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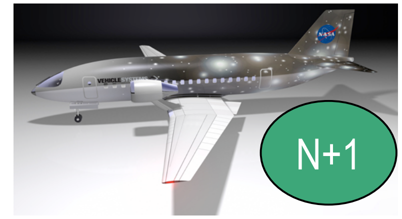

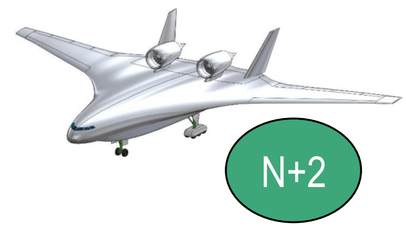

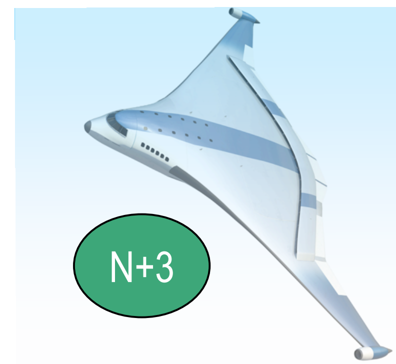

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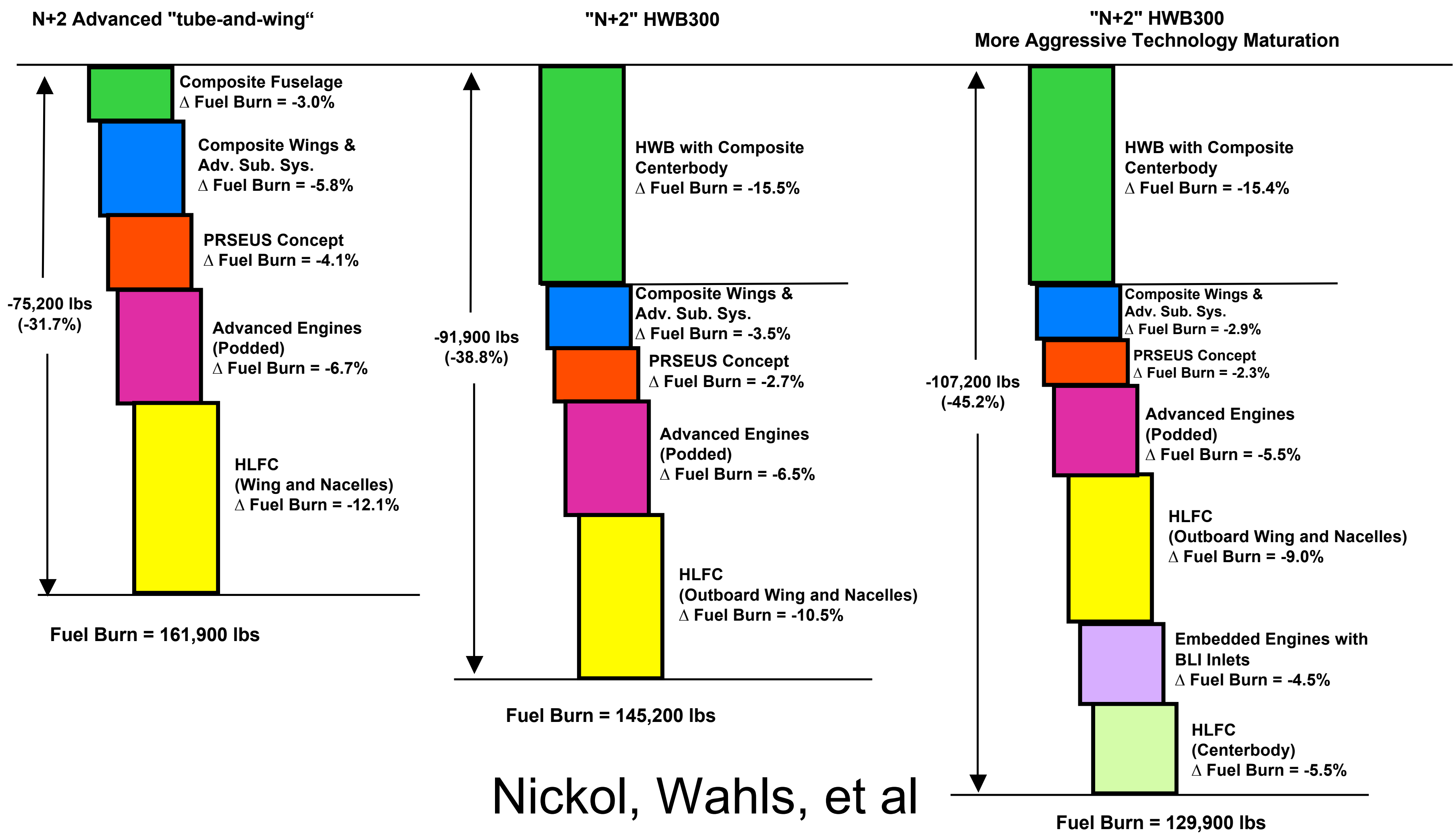
POTENTIAL REDUCTION IN FUEL CONSUMPTION
N+2 Advanced "tube-and-wing" and Hybrid Wing Body Transports

Reference Fuel Burn = 237,100 lbs
"777-200ER-like" Vehicle

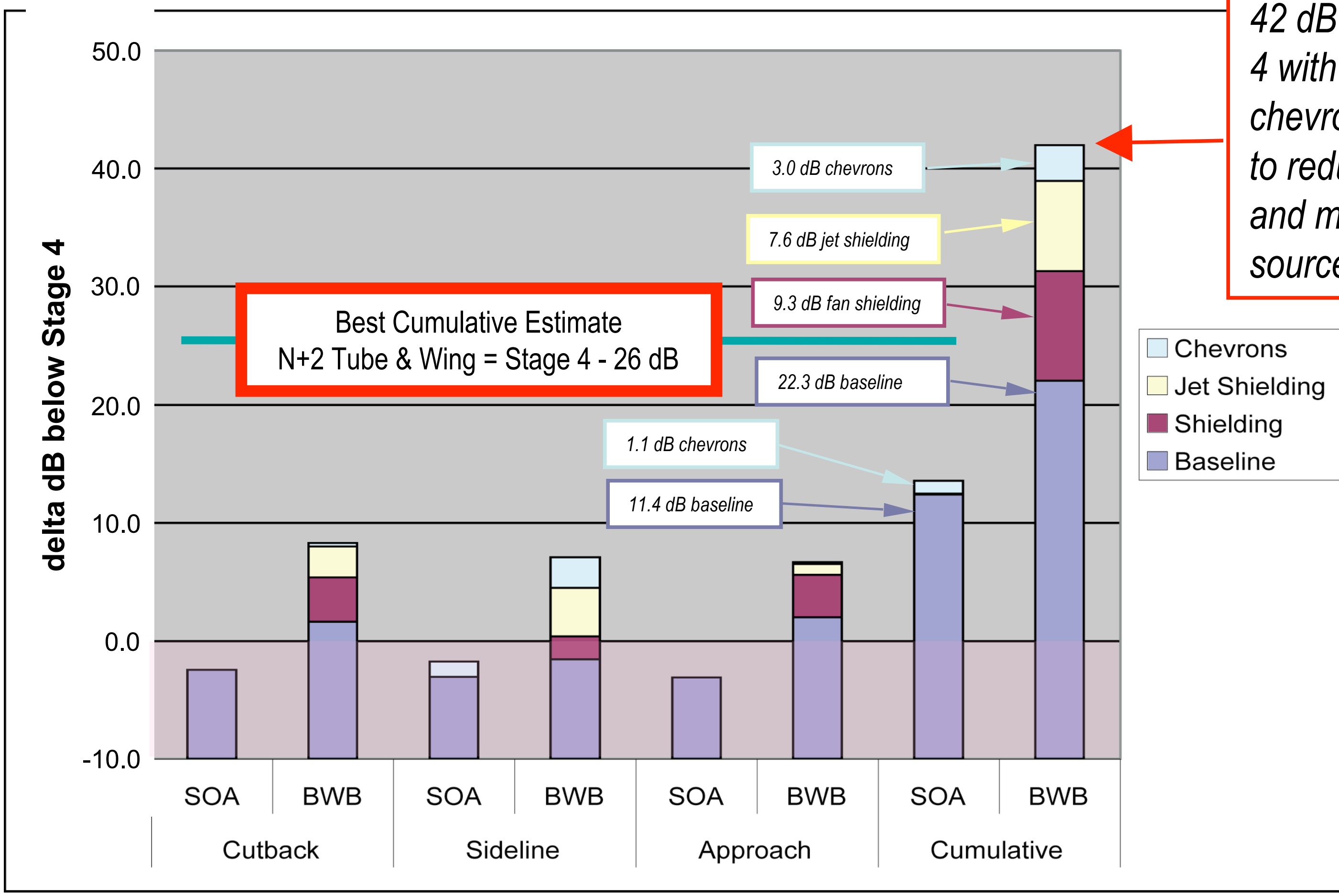


Nickol, Wahls, et al

POTENTIAL NOISE REDUCTION

Advanced N+2 "tube & wing" and N+2 “Hybrid Wing Body” Transports

Include estimate of maximum jet noise shielding (estimated from suppression maps) from moving engines two diameters forward on aircraft



42 dB below Stage 4 with aggressive chevrons (or other) to reduce jet noise and move jet sources upstream

Fundamental Aeronautics Program
Subsonic Fixed Wing Project

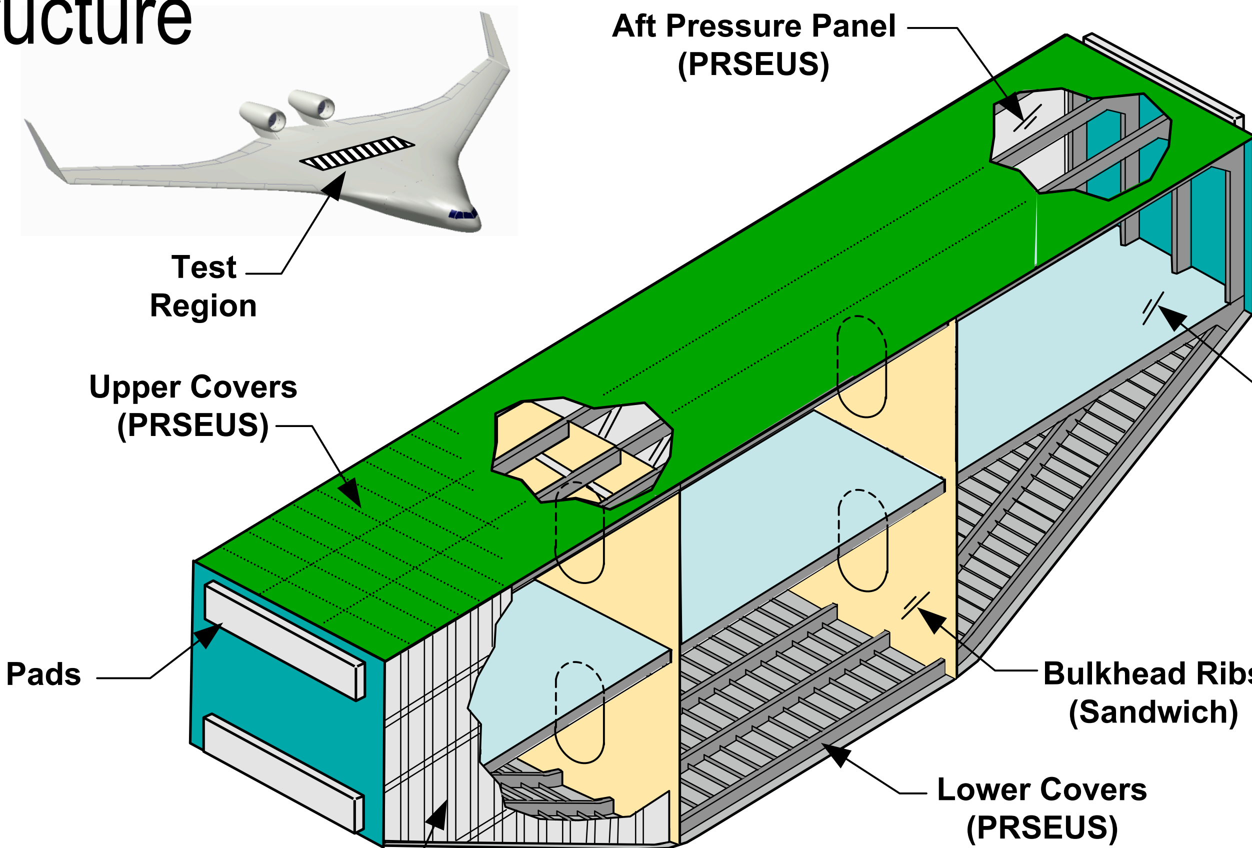
Thomas, Berton, et al

Working Long Poles - Low speed flight controls

Risch, Vicroy, Princeon, et al

Progress (2)

Working long poles - Non-circular pressurized fuselage structure

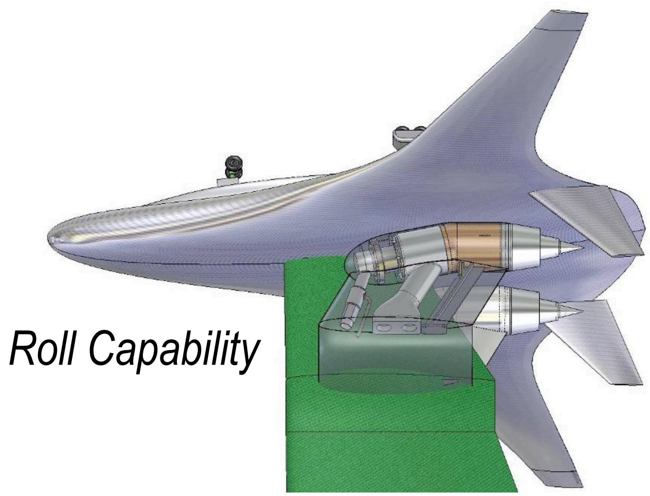


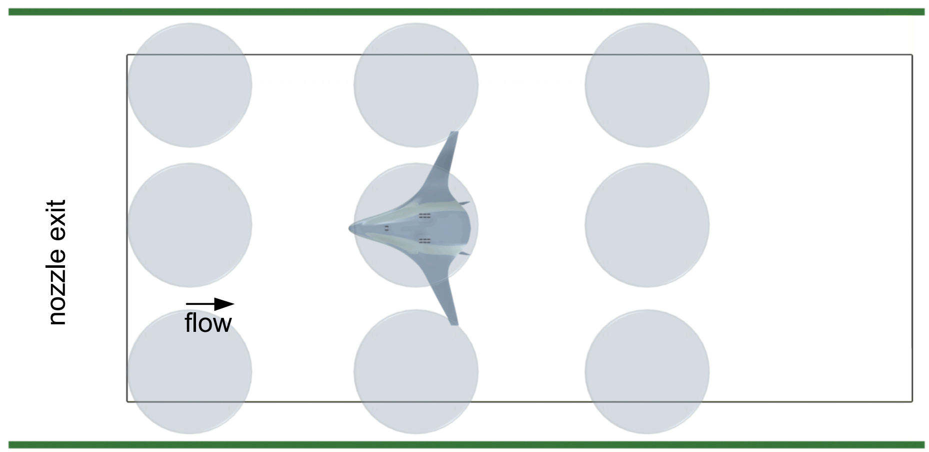
Primary Structural Components

Jegley, Velicki, Vivek, Zoran, et al

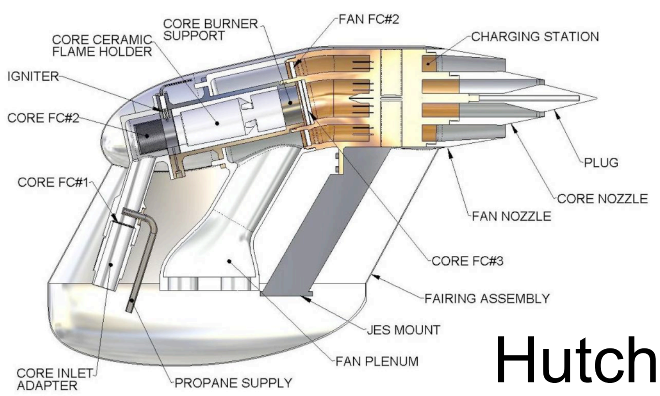
Working long poles - noise characteristics

- Twin High Bypass Ratio Jet Simulators
- Simplified Fan Noise Simulator
- Instrumentation and Processing for Low Noise Levels





Top view with some array positions



Phased Array (DAMAS type) processing to measure low noise levels in 14 x 22

Hutchinson, Gatlin, Kawai, et al

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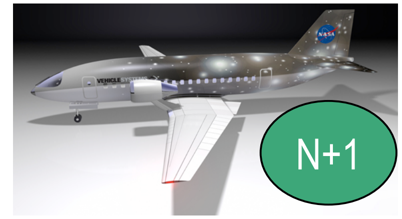

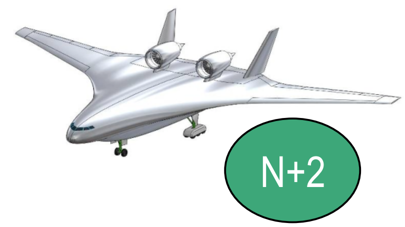

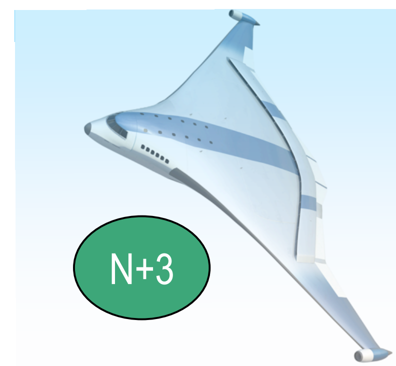

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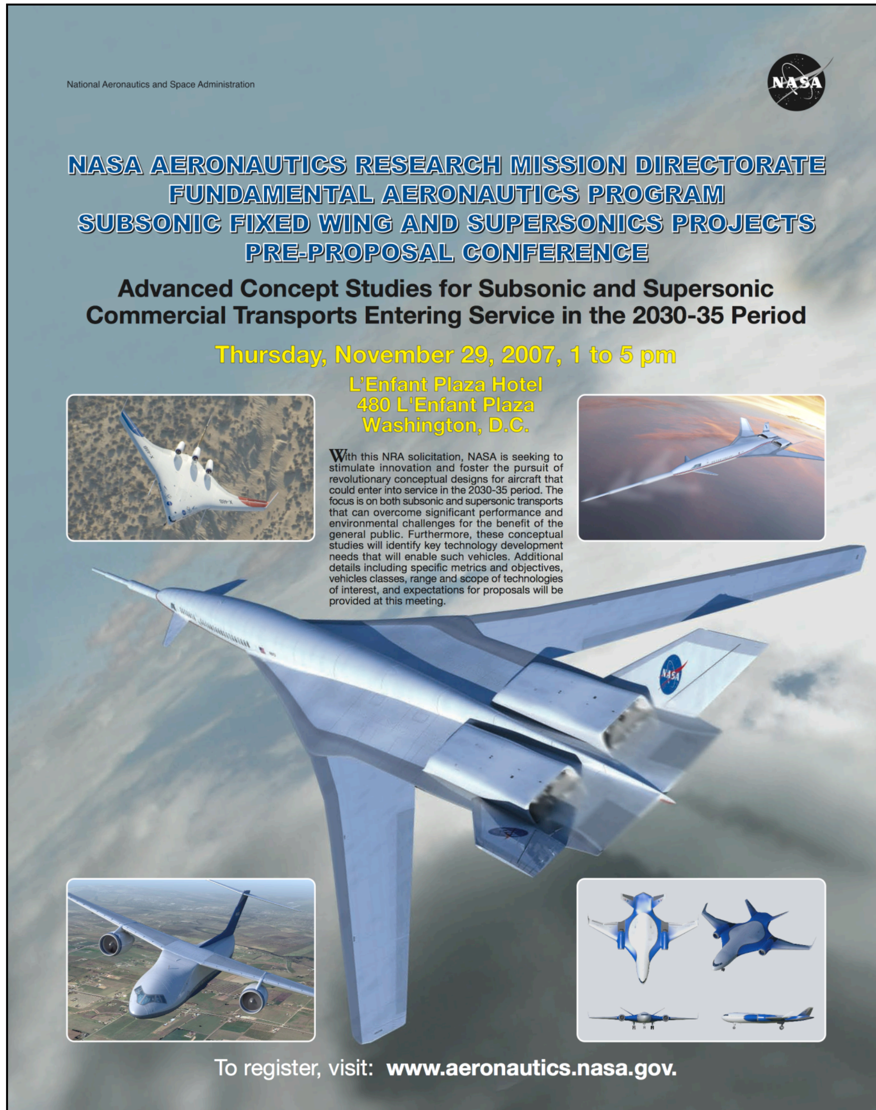
SFW N+3 NRA Objectives

- Identify advanced airframe and propulsion concepts, as well as corresponding enabling technologies for commercial aircraft anticipated for entry into service in the 2030-35 timeframe, market permitting
  - Advanced Vehicle Concept Study
  - Commercial Aircraft include both passenger and cargo vehicles
  - Anticipate changes in environmental sensitivity, demand, & energy
- Results to aid planning of follow-on technology programs

N+3 Advanced Concept Study NRA

- 29 Nov 07 bidders conference
- 15 Apr 08 solicitation
- 29 May 08 proposals due
- 2 July 08 selections made
- 1 Oct 08 contract start
- Phase I: 18 Months
  - NASA Independent Assessment @ 15 months
- Phase II: 18-24 Months with significant technology demonstration



SFW N+3 NRA Requirements

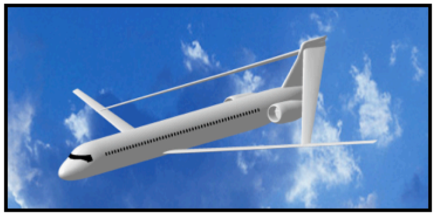
- Develop a Future Scenario for commercial aircraft operators in the 2030-35 timeframe
  - provide a context within which the proposer's advanced vehicle concept(s) may meet a market need and enter into service.
- Develop an Advanced Vehicle Concept to fill a broad, primary need within the future scenario.
- Assess Technology Risk - establish suite of enabling technologies and corresponding technology development roadmaps; a risk analysis must be provided to characterize the relative importance of each technology toward enabling the N+3 vehicle concept, and the relative difficulty anticipated in overcoming development challenges.
- Establish Credibility and Traceability of the proposed advanced vehicle concept(s) benefits. Detailed System Study must include:
  - A current technology reference vehicle and mission
    - to be used to calibrate capabilities and establish the credibility of the results.
  - A 2030-35 technology conventional configuration vehicle and mission
    - to quantify improvements toward the goals in the proposer's future scenario due to the use of advanced technologies, and improvements due to the advanced vehicle configuration.
  - A 2030-35 technology advanced configuration vehicle and mission

Boeing

Subsonic Ultra-Green Aircraft Research (SUGAR)

A Wide Variety of Concepts Will Be Considered

Engineering, Operations & Technology | **Phantom Works** **Platform Performance Technology**

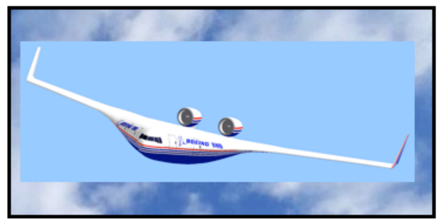


Joined Wing

Hydrogen Powered

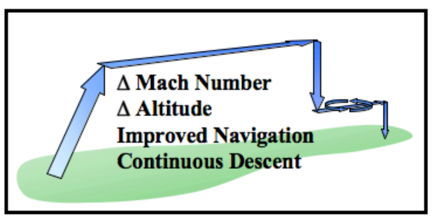
Strut-braced Wing

Aerial Refueling

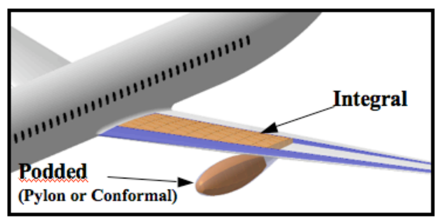


Hybrid Wing Body

Formation Flight



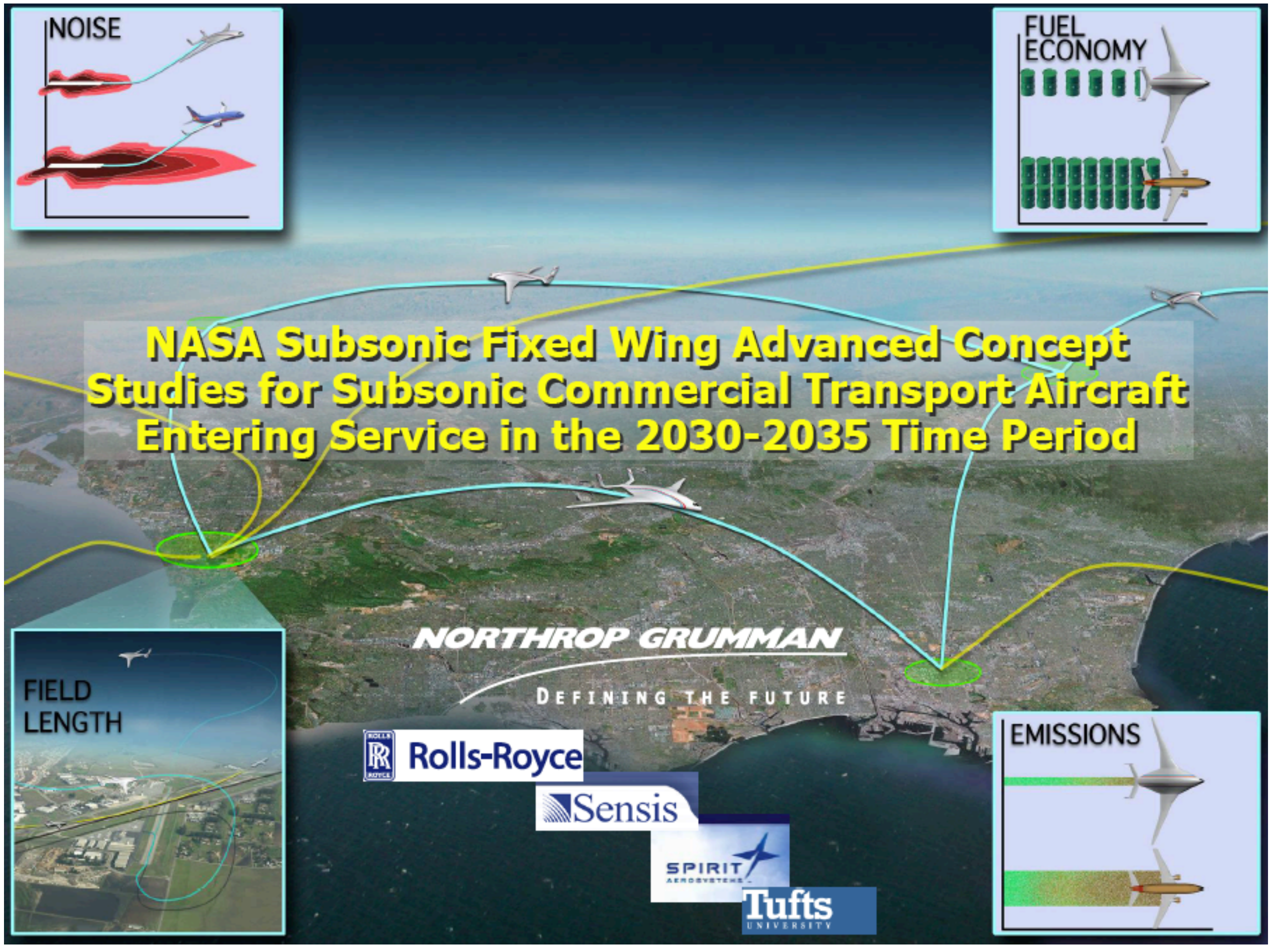
Changes in Mission & Operation



Podded or Integral Batteries

Other Concepts from Worksl

Northrop Grumman



Massachusetts Institute of Technology

Aircraft & Technology Concepts for an N+3 Subsonic Transport

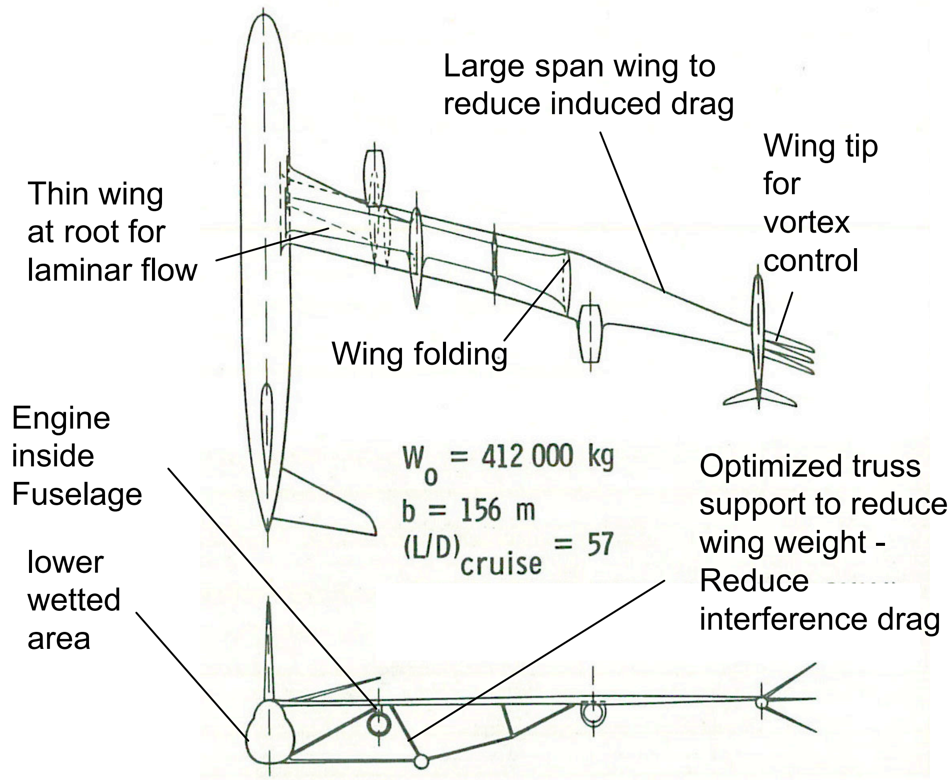
- MIT
- Aurora
- Aerodyne
- Pratt & Whitney
- Boeing PW

General Electric

Truss-Braced Wing (TBW) Research

NASA In-house, NIA, Virginia Tech, Georgia Tech N+3 Study

- What: Develop and design a revolutionary Truss-Braced-Wing (TBW) subsonic transport aircraft concept.
- Why: In 1988, Dennis Bushnell, Langley Chief Scientist challenged the aeronautic community to develop a passenger transport aircraft with Lift/Drag ratio of 40. BWB & Pfenninger's TBW have the potential to meet this challenge.
- How: Develop full Multidisciplinary Design Optimization (MDO) analysis tool for TBW design to increase span, reduce weight and drag with thin wing for natural laminar flow, reduced wetted area, folding wing & flight-control, vortex control, advanced composite, efficient engine in fuselage, bio-fuel, fly below 27000 ft to prevent cirrus creation



- Revolutionary: If successful, this design will Double the Lift/Drag ratio of a conventional transport aircraft
- Bushnell will status the community at the Green Aviation Workshop at NASA Ames
- Collier and Bushnell planning roadmapping workshop for Langley in the near term

Bushnell, Vivek, Schetz, Mavris, et al

Truss-Braced Wing (TBW) Research

Work in Progress

Configuration Comparison, Max. L/D

- Increasing L/D by:
  - No trim constraint – negative stability margin
  - Add riblets, 95% of turbulent C_f

70% LFC

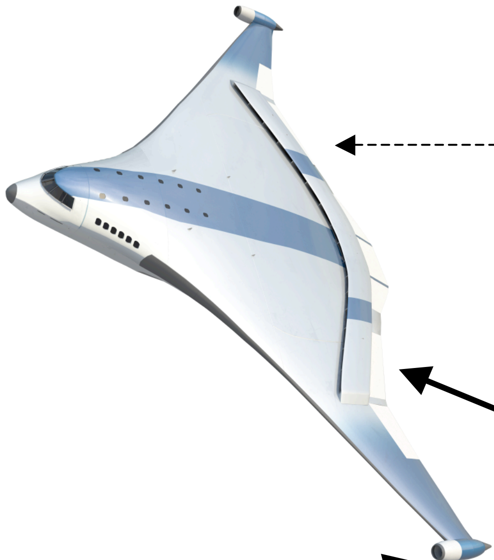
	TOW [Klb.]	W_{wing} [Klb.]	W_{fuel} [Klb.]	L/D	b/2 [ft.]	S_W [kft^2]	c_{Avg} [ft]	AR	H_{Cr} [kft]	W/S_W [psf]
Cantilever	705.0	240.7	182.9	36.1	177	6.14	17.3	20.3	43.0	99.9
SBW	613.1	193.1	150.8	41.3	210	6.75	16.1	26.1	48.2	79.7
TBW	623.3	215.0	129.7	49.8	268	9.91	18.4	29.0	55.0	56.4
TBW No Trim	692.3	271.5	138.0	52.8	269	10.4	19.3	27.9	54.6	59.9
TBW No Trim, Riblets	669.4	258.1	130.2	54.7	267	10.1	18.9	28.3	54.7	59.8

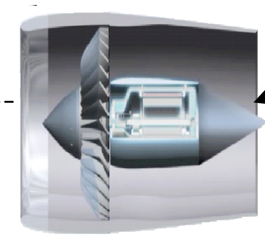
VirginiaTech Invent the Future | Georgia Institute of Technology

Multidisciplinary Analysis and Design Center for Advanced Vehicles 4

Distributed Turboelectric Propulsion Vehicle

NASA In-house N+3 Study (Just completed roadmapping workshop)





Lightweight High Temperature Superconducting (HTS) Components

- Superconducting motor and generator structures
- Low-loss AC superconductor
- Compact cryocooler
- LH2 tankage (if desired)
- HTS electric power distribution components

Turboelectric Engine Cycle

- Decoupling of the propulsive device (fans) from the power-producing device (engine core) -> High performance and design flexibility of aircraft
- High effective bypass ratio -> High fuel efficiency due to improved propulsive efficiency and maximum energy extraction from the core
- Distributed power to the fans -> Symmetric thrust with an engine failure

Propulsion Airframe Integration

- Large BLI high aspect ratio short inlet and vectoring nozzle
- Distributed fan noise reduction through wing and jet-to-jet shielding
- Engine core turbomachinery noise suppression
- Direct spanwise powered lift
- Aircraft control using fast response electric fan motor and/or vectoring nozzle
- Wing-tip mounted engine core/generator
    - Aeroelasticity, tip vortex interaction

Kim, Felder, Brown, et al

Outline

- Introduction and Effects of “Technology on the ATS”
- N+1 Vehicle Themes and Progress
- N+2 Vehicle Themes and Progress
- N+3 Vehicle Themes and Progress
- Alternative Fuels Research
- Wrapup

Alternative Fuels

- Goals:
  - Characterization of FT and biomass fuels against ASTM standards
  - Fuel - flexible combustor design

Alternative Fuels - Biofuels Roadmap

▲ In House
△ With Partner

FY08	FY09	FY10	FY11	FY12	FY13

Biomass Feedstock Selection

- Initial Halophyte Species Identified
- Algae and Halophyte species identification and growth parameters optimized to meet aviation fuel requirements.
- 5 Halophyte species Down-selected for optimization
- Initial assessment for carbon-negative plant species
- Open-pond algae optimization 1000 gals of algae oil for testing. – Seambiotic,Inc. (SAA)

Computational Transport and Process Analysis

- Open-pond algae systems - Seambiotic (SAA)
- Process modeling for photobioreactor systems – Biofuel Producers of America (SAA)
- Halophyte life cycle support systems model - Seawater Foundation

Oil/Fuel Characterization

- Salicornia oil analysis (Seawater Foundation / ASU / NASA / Boeing / AFRL)
- Oil/fuel characterization of algae and halophytes - DOE (SAA)
- Thermal Stability testing of Boeing biofuel

Combustion Flametube Experiments

- LDI low emissions concept with Boeing Supplied Biofuel
- AFRL/NASA Sector Rig Combustion/Emissions Testing
- Advanced high pressure SFW combustor concept with biofuel

Ground/Flight Testing

- NASA DC-8 ground testing with 2 biofuels
- Potential Salicornia fuel flight demonstration
- Flight Testing of biofuels with partners

Alternative Fuels - FT, GTL, CTL Roadmap

△ In House
△ With Partner

FY08	FY09	FY10	FY11	FY12	FY13

Fischer-Tropsch Reactor Studies

- **Alt Fuels Laboratory Completed**
- **Baseline F-T reactor studies**
- **Evaluate 4 catalysts for Jet Fuel Yield**
- **Advanced catalyst development for improved aviation fuel yield**
- Product Upgrade Studies for Improved Yield

Chemical Kinetics Model Development

- **Reaction Design Initial Chemical Kinetics Mechanism Development for F-T and Biofuels**
- CWRU Kinetics Mechanism Development for F-T fuels
- CFD Predictions of LDI Combustor with Alt Fuel

Fuel Characterization

- Thermal Stability testing of GTL alt fuel
- **Thermal Stability testing of CTL alt fuel**
- **Thermochemical and Physical Property Database.**
- **Ignition Energy Measurements of GTL and CRL Fuels**
- Thermal Stability testing of newly acquired Alt Fuel

Combustion Flametube Experiments

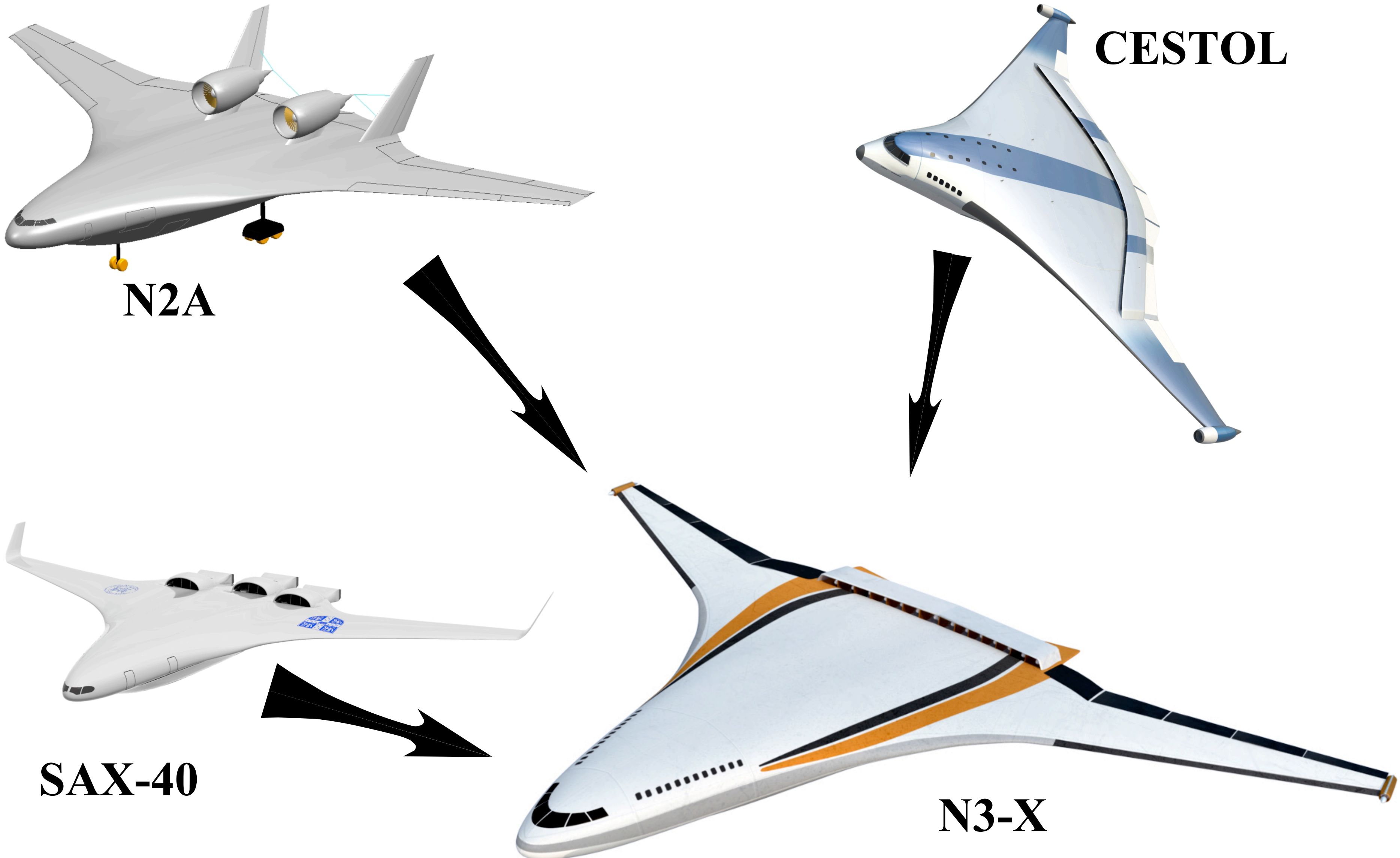
- LDI low emissions concept with GTL and CTL Alt Fuel
- **GE complex multi-swirler concept with CTL Alt Fuel**
- Advanced Low Emissions Concept with alt fuel
- **Advanced high pressure SFW combustor concept with Alt Fuel**

Engine Testing

- P&W GTF Alt Fuel
- **NASA DC-8 ground testing with 2 F-T fuels**
- **Potential engine testing with industry partner**
- **Potential Flight Testing of synthetic fuels with partners**

Bulzan, Anderson, et al

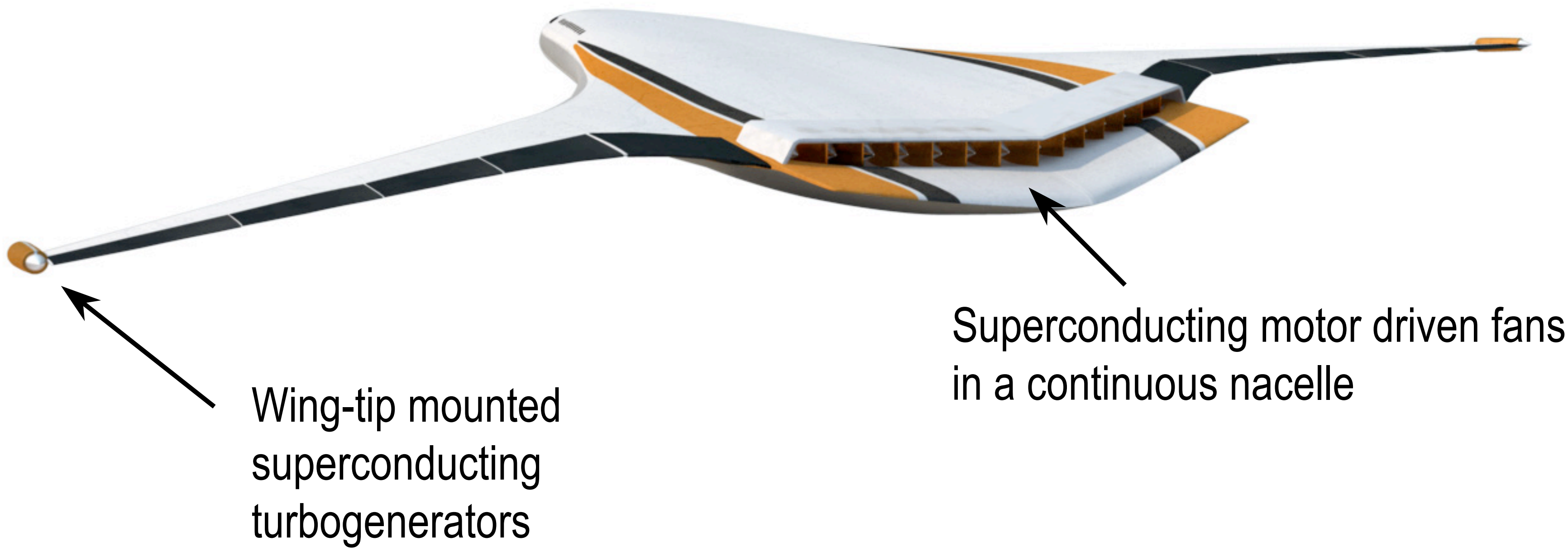
Alternative Fuels - What about hydrogen you say?



Felder, Kim, Brown

Alternative Fuels - What about hydrogen you say?

N3-X Distributed Turboelectric Propulsion System



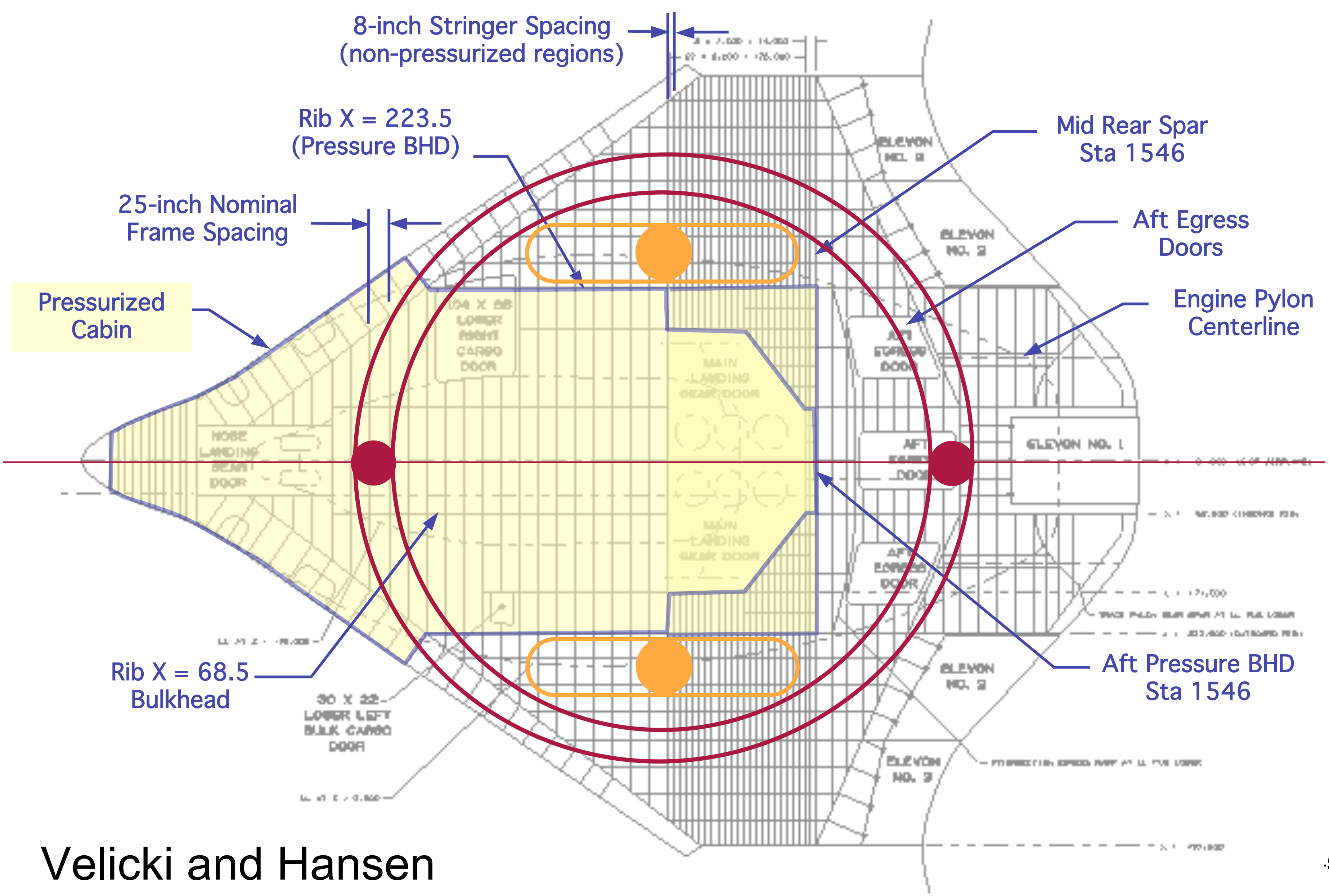
Felder, Kim, Brown

Alternative Fuels - Cryogenic Cooling Options

- Jet fuel with Refrigeration
  - Jet-A fuel weight is baseline for comparison
- Liquid Hydrogen cooled and fueled
  - No refrigeration required
  - 4 times the volume & 1/3 the weight of the jet fuel baseline
- Liquid Methane cooled and fueled
  - 5% of the baseline refrigeration
  - 64% larger volume & 14% less weight the jet fuel baseline
- Liquid Hydrogen cooled and Hydrogen/Jet-A fueled
  - No refrigeration required
  - 32% larger volume & 6% less weight than the jet fuel baseline
- Liquid Methane/Refrigeration cooled and Methane/Jet-A fueled
  - 5% of the baseline refrigeration
  - 17% larger volume & 2% less weight than the jet fuel baseline

Felder, Kim, Brown

Structural Concepts for Storing the LH2



Velicki and Hansen

Outline

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Comments or Questions?

The stakeholders say they want it all - ultra low emissions and “nearly silent”

N3-X Distributed Turboelectric Propulsion System