The Value and Challenges of Integrated Technology Demonstrations – Applying Lessons from the ERA Project

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Insight

Arguing with an engineer is like wrestling with a pig in the mud, after a couple of hours you realize the pig likes it

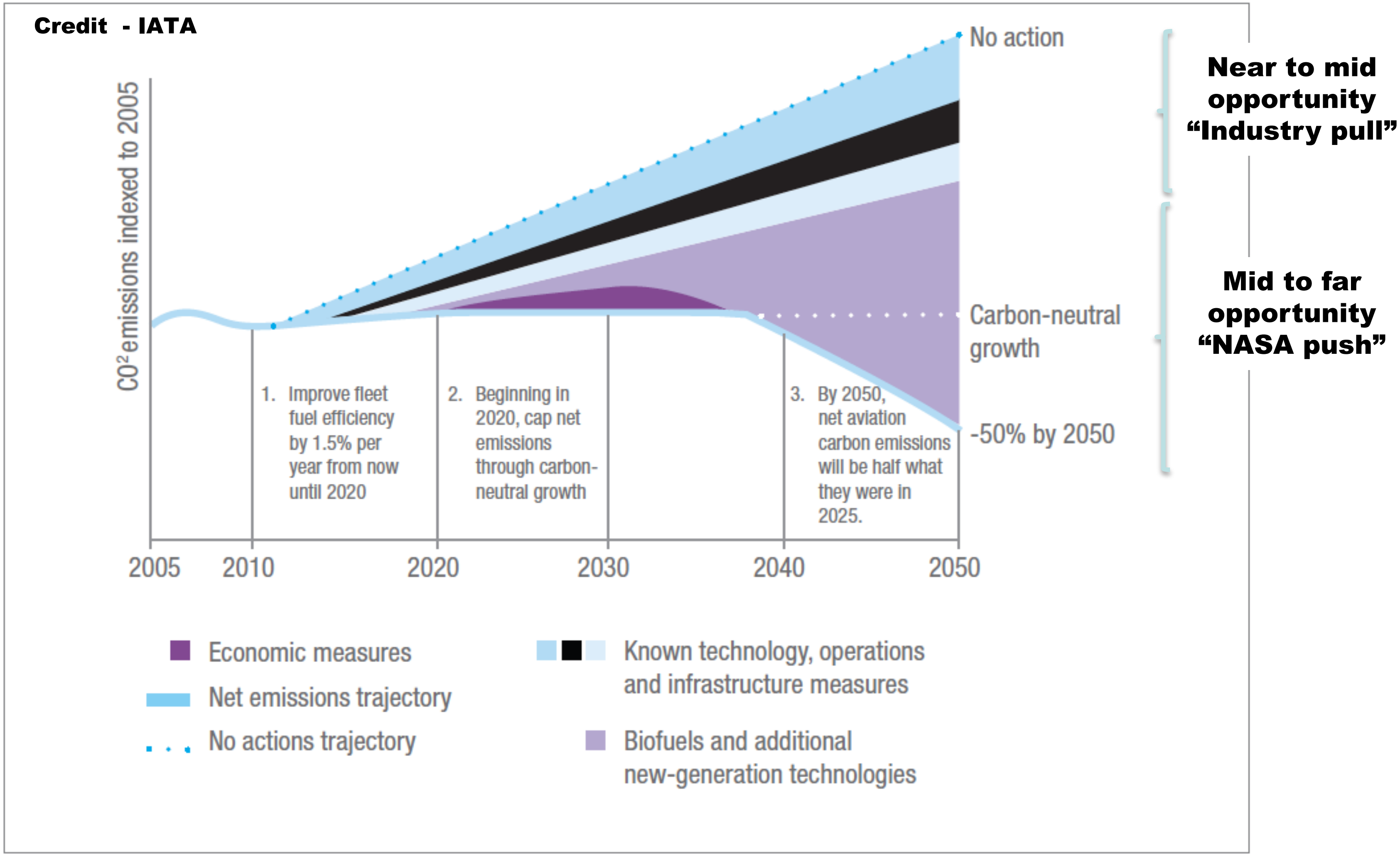
The role of technology demonstrators

- Separate the real from the imagined
- Advance/accelerate the technology readiness level
- Establish technical “performance” expectations
- Increase manufacturing readiness
- Address integration challenges & ”ilities”
- Inspire the next generation

Using the Environmentally Responsible Aviation Project as an Example

- Set aggressive, but achievable goals, & measure and report progress overtime
- Focused on a few technologies
- Use public/private partnerships for relevance
- Link research results to national goals
- Apply management rigor as needed – do not stifle, but ensure delivery

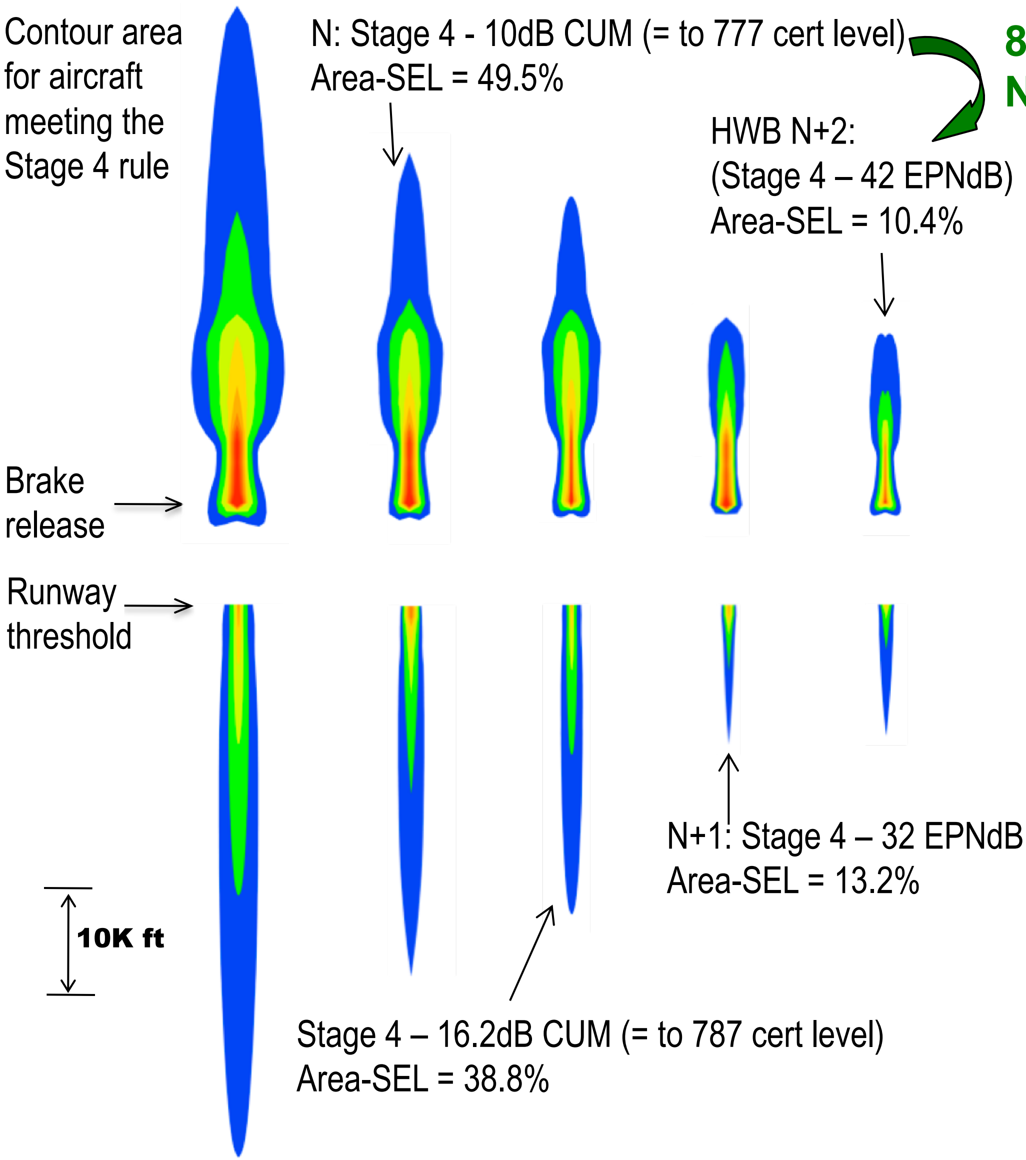
Grand Challenge for Commercial Aviation (1 of 2)
Reduce carbon footprint by 50 percent by 2050



…. in the face of increasing demand, and while reducing development, manufacturing and operational costs of aircraft & meeting noise and LTO NOx regulations

Grand Challenge for Commercial Aviation (2 of 2) Contain objectionable noise within airport boundary

Change in noise "footprint" area (within 85 dB) for a landing and takeoff



80% Reduction in Noise Footprint Area

- **All contours are for a 777-like aircraft weight and mission, N+2 achieved with HWB aircraft for same 777-like mission**
- **N and N+2 areas are rigorous predictions using analytical tool (ANOPP) with measurements for key installation effects**
- **Stage 4 and N+1 areas are computed from N aircraft to meet required EPNL**
  - **Source levels changed, assumed even distribution between three certification points**
- **Effects of source component directivity and aircraft configuration are included.**
- **Auralizations of ANOPP predictions for straight and level flight at conditions of takeoff and approach**

Thomas, R.H., Burley, C.L, and Olson, E.D., "Hybrid Wing Body Aircraft System Noise Assessment with Propulsion Aircraft Aeroacoustic Experiments," *International Journal of Aeroacoustics*, Vol 11 (3+4), pp.369-410, 2012.

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Commercial Transport System Level Metrics
The Score Card Part 1

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6) v2013.1		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines. N+2 values are referenced to a 777-

** 200 with GE90 engines.

‡ ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015
CO2 emission benefits dependent on life-cycle CO2e per MJ for fuel and/or energy source used

ERA Focus

Complete Alignment with the NASA Strategic Implementation Plan & The National Aeronautics R& D Plan

Environmentally Responsible Aviation Technical Challenges - The Score Card Part 2

TC1 **Innovative Flow Control Concepts for Drag Reduction**

– Demonstrate drag reduction of 8 percent, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, without significant penalties in weight, noise, or operational complexity

TC2 **Advanced Composites for Weight Reduction**

– Demonstrate weight reduction of 10 percent compared to SOA composites, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, while enabling lower drag airframes and maintaining safety margins at the aircraft system level

TC3 **Advanced UHB Engine Designs for Specific Fuel Consumption and Noise Reduction**

– Demonstrate UHB efficiency improvements to achieve 15% TSFC reduction, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, while reducing engine system noise and minimizing weight, drag, NOx, and integration penalties at AC system level

TC4 **Advanced Combustor Designs for Oxides of Nitrogen Reduction**

– Demonstrate reductions of LTO NOx by 75 percent from CAEP6 and cruise NOx by 70 percent while minimizing the impact on fuel burn at the aircraft system level, without penalties in stability and durability of the engine system

TC5 **Airframe and Engine Integration Concepts for Community Noise and Fuel Burn Reduction**

– Demonstrate reduced component noise signatures leading to 42 EPNdB to Stage 4 noise margin for the aircraft system while minimizing weight and integration penalties to enable 50 percent fuel burn reduction at the aircraft system level

Technology Selection and Key Performance Parameters - The Score Card Part 3

2025 Vehicle System Level Goals

Fuel Burn	NO_x	Noise
-50%	-75%	-42EPNdB

Technical Challenge

Progress Indicators

Innovative Flow Control Concepts	Advanced Composites	Advanced UHB Engines	Advanced Combustors	Airframe & Engine Integration
TC 1: 8% Drag Reduction	TC 2: 10% Structural Weight Reduction	TC 3: 15% TSFC and 15 EPNdB Noise Reduction	TC 4: 75% LTO NOx Reduction	TC 5: 42 EPNdB Cum Noise Reduction and 50% Fuel Burn Reduction

P2 Integrated Technology Demonstrations (TRL 4-6)

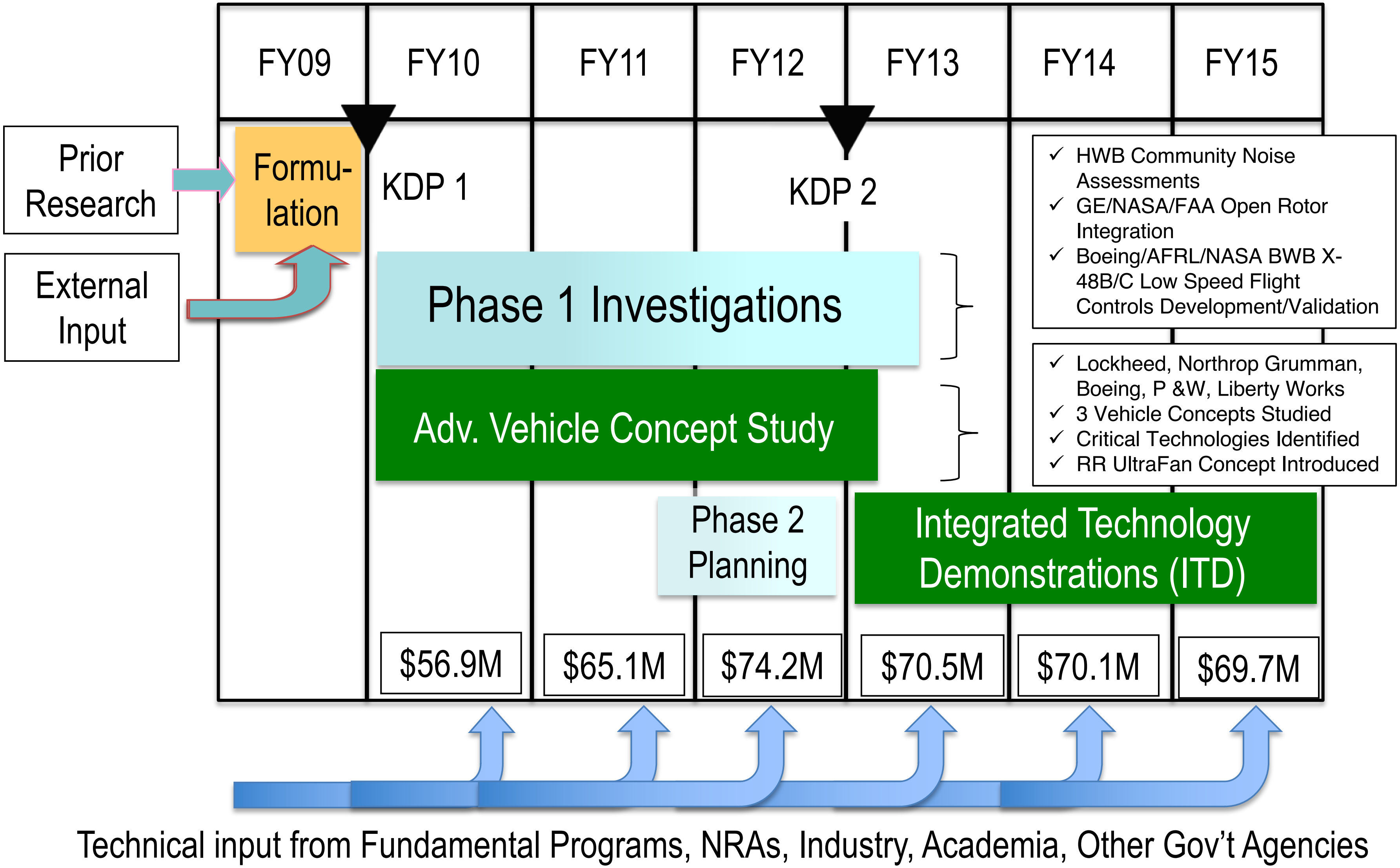
Demonstration	KPP_{2025}
12A+ AFC VT & Advanced Wing	•Cruise Drag Reduction
21A PRSEUS	•Structural Weight Reduction
21C ACTE	•Wing Weight Reduction
30A Front Block Compressor	•TSFC
35A UHB Propulsor	•TSFC •Cumulative Noise Reduction
40A Low LTO NOx, Fuel Flex Combustor	•LTO NOx
50A Low Noise Flap Edge & Landing Gear	•Airframe Component Noise Reduction
51A UHB Engine Integration on HWB	•Fuel Burn Reduction •Cumulative Noise Reduction

ERA Technology Development & Maturation Plans – Phase 1 and 2

Environmentally Responsible Aviation Vision, Mission, & Scope

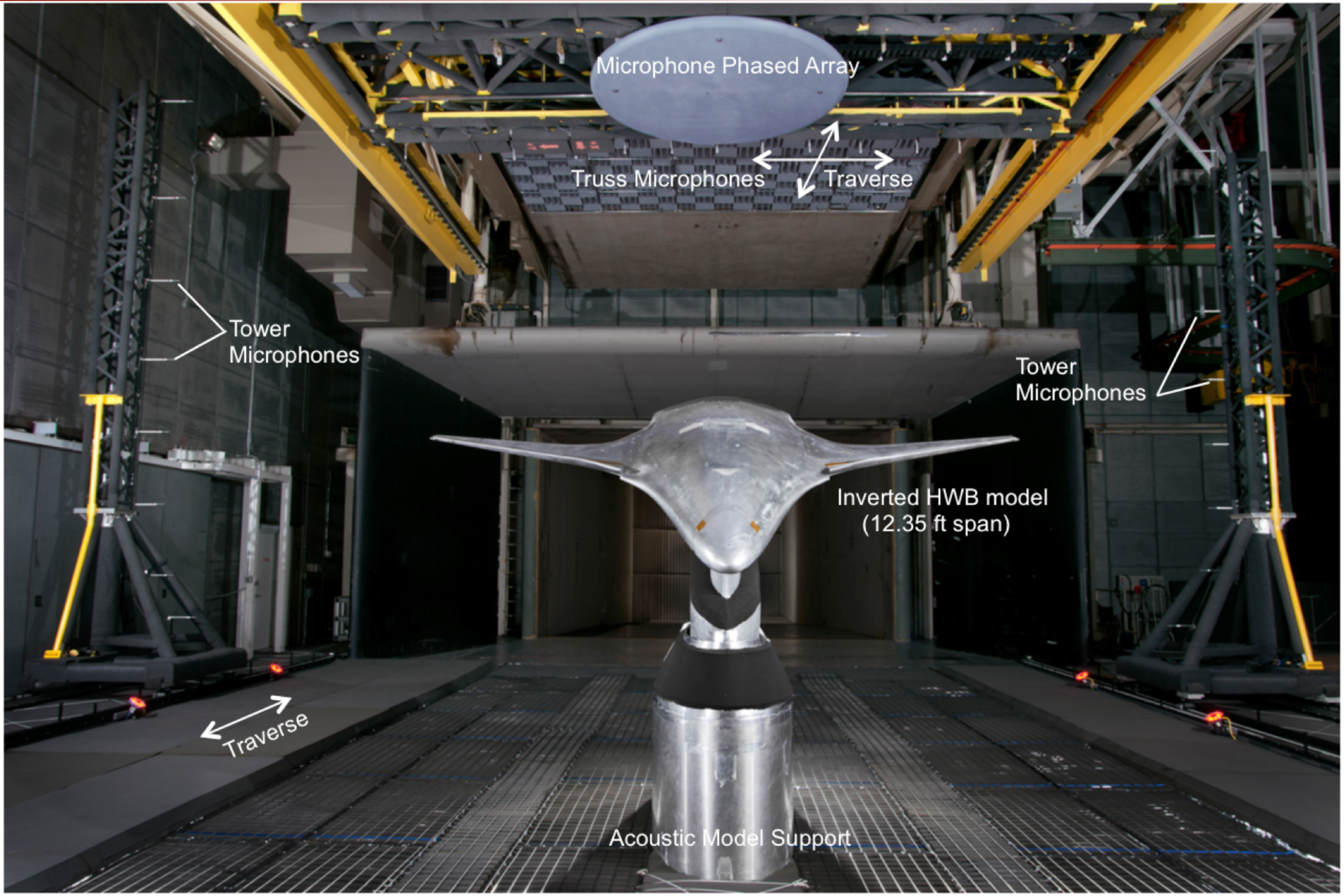
- Vision
  - expand the viable and well-informed trade space for commercial transport design decisions
  - enable simultaneous realization of national noise, emissions, and performance goals (N+2 timeframe)
- Mission
  - Execute integrated technology demonstrations
  - Partner w/Industry/Academia/OGA and transfer knowledge
- Scope
  - Mature technology for application in the 2020+ time frame
    - Advance the state-of-the-art, reduce risk of application
  - Perform system/subsystem research in relevant environments

Environmentally Responsible Aviation Project Flow



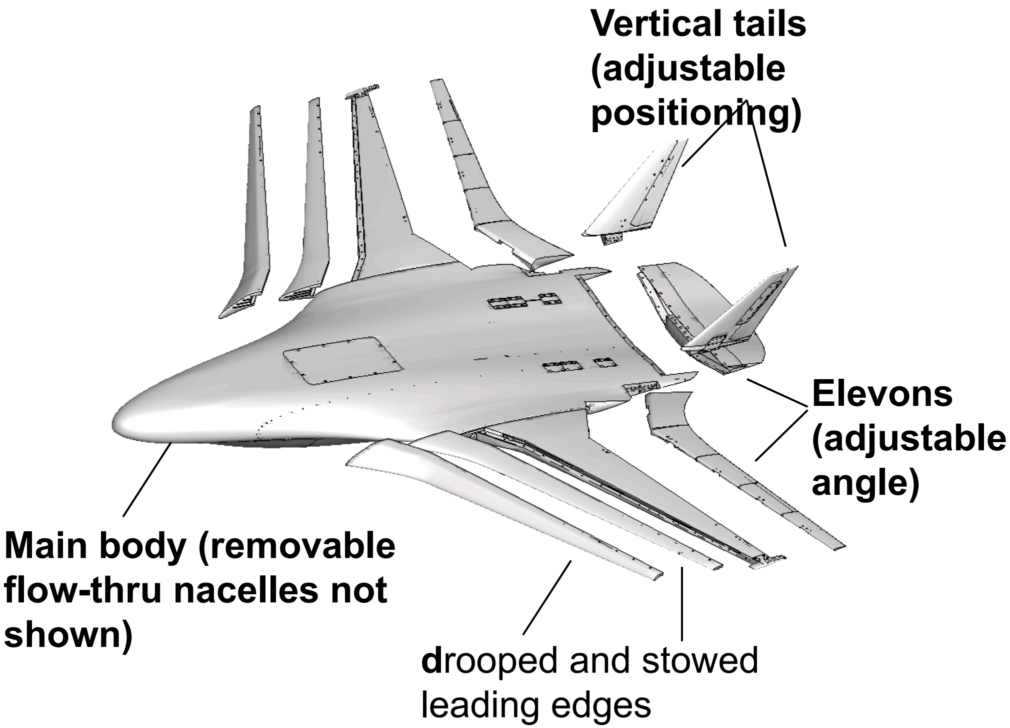
HYBRID WING BODY ACOUSTIC TEST

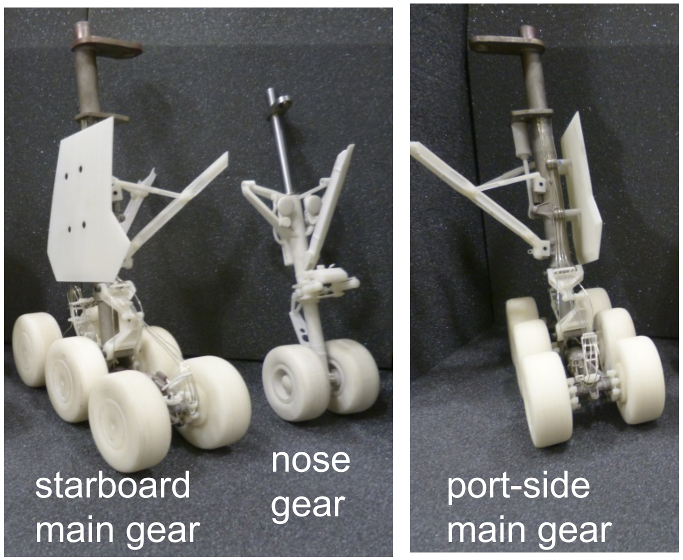
LaRC 14x22 ft. Subsonic Wind Tunnel



- Noise measurements were obtained from Tower and Truss microphones, and from Microphone Phased Array at key streamwise locations.

HWB AIRFRAME MODEL





5.8% scale (12.35 ft span)

Modular components (control surfaces and landing gear)

High fidelity of geometric details

Designed by a team led by Boeing under a NASA Research Announcement

TEST RESULTS

This was a large and successful multi-year effort which resulted in:

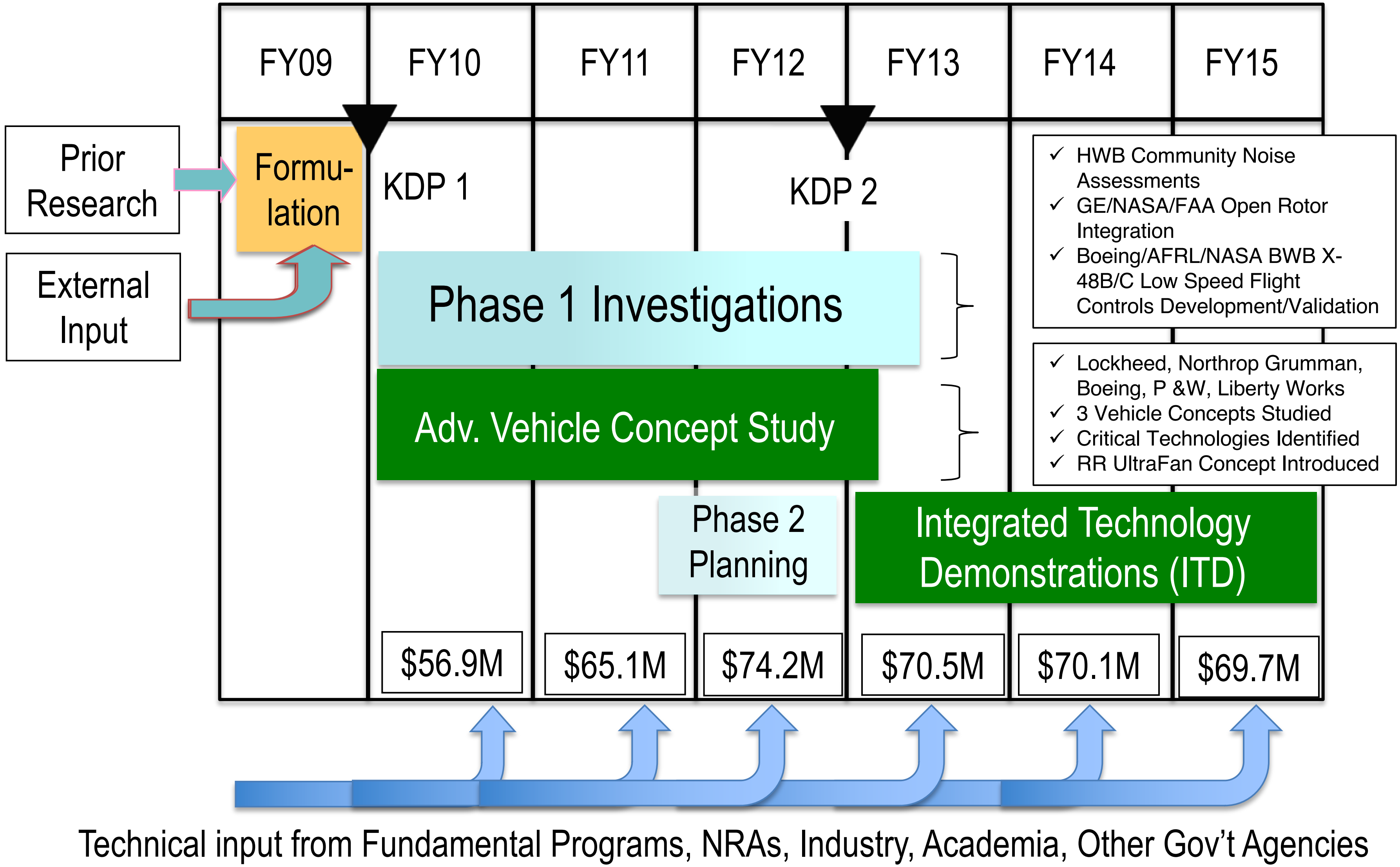
- Detailed characterization of :
  - Jet noise and its shielding
  - Airframe noise
  - Broadband noise shielding

  on a full span, high fidelity HWB aircraft configuration

- Acoustic database for system noise analysis and validation/development of noise prediction capabilities to assess Environmentally Responsible Aviation (ERA) Project noise goals

- Improved testing capabilities of NASA Langley's 14 by 22-Foot Subsonic Tunnel

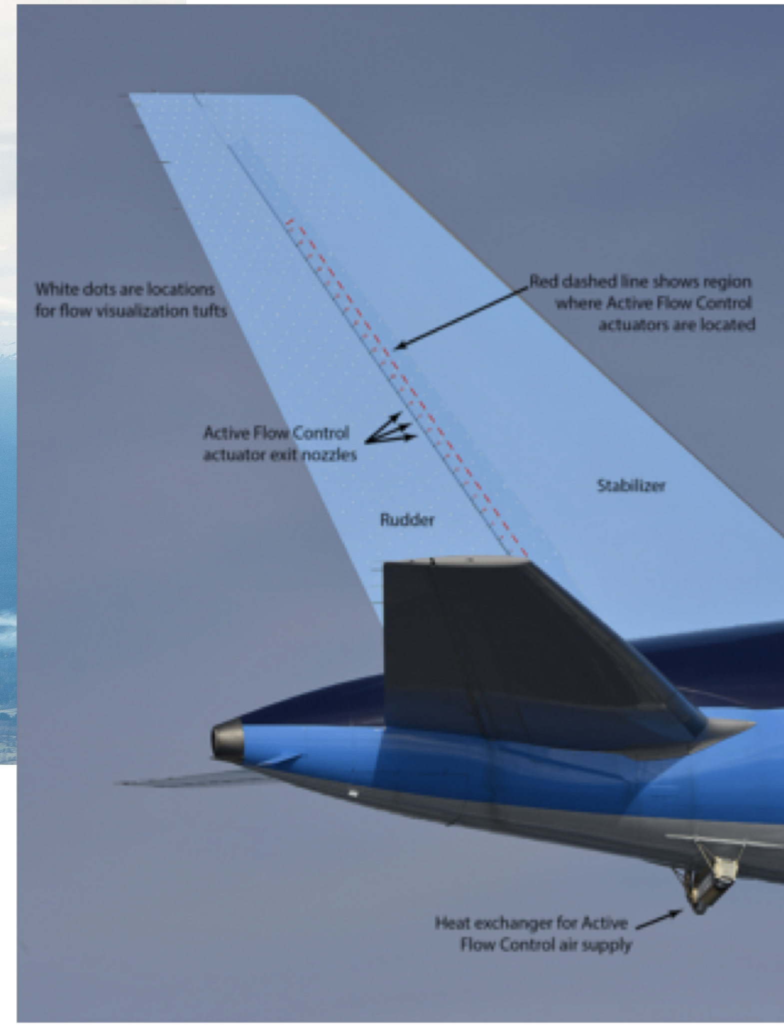
Environmentally Responsible Aviation Project Flow



ITD 12A+ AFC Enabled Vertical Tail and Advanced Wing Flight Demonstration

Functional Check Flight – March 2015

Active Flow Control Setup



Results – When activated, the AFC system enabled 30 percent increase in rudder side force at full deflection

ITD 21A Damage Arresting Composites Demonstration Stitched Resin Infusion



NASA Super Guppy Aircraft picked up the MBB at the Long Beach Airport in Calif. and delivered it to NASA LaRC




Where it was moved to COLTS and installed between the platens for testing

Results – The test article was loaded to design ultimate load in up-bending, down-bending, internal pressure and combinations of pressure and mechanical load in the pristine condition, with barely visible impact damage and with discrete source damage.

ITD 21C Adaptive Compliant Trailing Edge (ACTE) Flight Demonstration

NASA Armstrong Gulfstream GIII Subsonic TestBed Aircraft w/Chase Plane

Results – The 2015 flight test program demonstrated flight worthiness of ACTE Flap System thru Mach number 0.75

Integrated Technology Demonstrators Summary Performance

	Integrated Technology Demonstrators	Partner(s)	Min Success	Full Success	Impact (2025)
12A+	AFC Enabled Vertical Tail and Advanced Wing Flight Test	Boeing			-1.5 % Tail Drag -3 % Wing Drag (NLF)
21A	Damage Arresting Composites Demonstration	Boeing			-20 % Structural Weight
21C	Adaptive Compliant Trailing Edge Flight Test	AFRL FlexSys			-5 % Wing Weight
30A	Highly Loaded Front Block Compressor Demonstration	General Electric			-2.5 % TSFC
35A	2nd Generation UHB Propulsor Integration	Pratt & Whitney FAA			-9 % TSFC -15 EPNdB
40A	Fuel Flexible, Low NOX Combustor Integration	Pratt & Whitney			-75 % LTO NOX
50A	Landing Gear and Flap Edge Noise Reduction Flight Test	Gulfstream			LG -1.0 EPNdB FE -3.0 EPNdB
51A	UHB Integration on Hybrid Wing Body Aircraft	Boeing			-42 EPNdB -50 % Fuel Burn

Technical Accomplishments - Summary

- It is feasible that Open Rotor Systems will meet current noise standard
- Laminar flow applications have been applied by Boeing to B787
  - Main wing, high Rn applications are the final challenge
- Active flow control applications are still being investigated
- Compliant wing technology is feasible. Large impact on tube & wing
  - Aviation Partners has teamed with FlexSys
- A scalable low NOX, fuel-flexible combustor that exceeds the current regulation with an engine w/advanced fan blade system is feasible
  - Application to future engine products are being explored
- Highly loaded compressor blading is feasible
  - Application to future engine products are being explored
- The Rolls Royce UltraFan engine concept shows great promise
- Feasible noise reduction technologies for engine and airframe emerged
- The NASA/Boeing HWB / GTF configuration was matured further
  - Low speed aero, structures, and operability issues solved
- Less mature, over the wing configurations also show promise toward goals

Potential Impacts
Vehicle Level – AIAA 2016-1030 & 0863

Table 13. N+2 Large Twin Aisle class T+W and HWB Concepts

		Large Twin Aisle			
					
	Units	T+W301-DD	T+W301-GTF	HWB301-DD	HWB301-GTF
TOGW	lb	570,195	570,533	537,641	534,491
OEW	lb	265,290	270,084	251,281	253,326
Payload	lb	118,100	118,100	118,100	118,100
# Pax		301	301	301	301
Range	nm	7500	7500	7500	7500
Total Fuel	lb	186,805	182,349	168,259	163,065
Block Fuel	lb	168,687 (-39.1%)	164,748 (-40.6%)	151,597 (-45.3%)	147,011 (-47.0%)
Wing Area	ft^2	4664	4670	10169	10169
Wing Span	ft	226.5	226.6	250	250
Wing Aspect Ratio		11	11.0	6.2	6.1
Wing Loading	lb/ft^2	122.2	122.2	52.9	55.9
Cruise Mach		0.84	0.84	0.84	0.84
Start of Cruise L/D		22.1	22.0	23.8	23.7
Number of Engines		2	2	2	2
Thrust per Engine	lb	71800	74,000	65,989	69,398
Start of Cruise SFC		0.483	0.467	0.49	0.475

Notes – (1) Impacts also modeled all other seat classes. (2) HWB- GTF vehicles provided the best overall performance

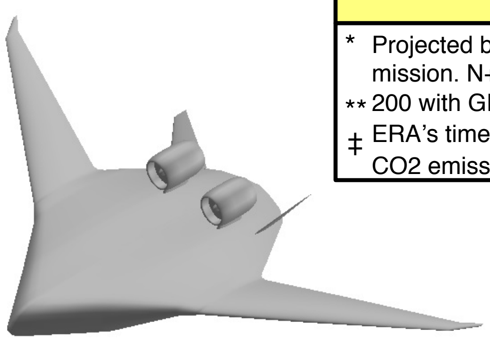
Potential Impacts
Vehicle Level - Best Performers

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6) v2013.1		
	N+1 (2015)	N+2 (2020**) (rel B777/GE90)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	**-42dB / -40.3dB**	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	**-75% / -79%**	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	**-70% / -75.4%**	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	**-50% /-47%**	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines. N+2 values are referenced to a 777-200 with GE90 engines.

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO2 emission benefits dependent on life-cycle CO2e per MJ for fuel and/or energy source used



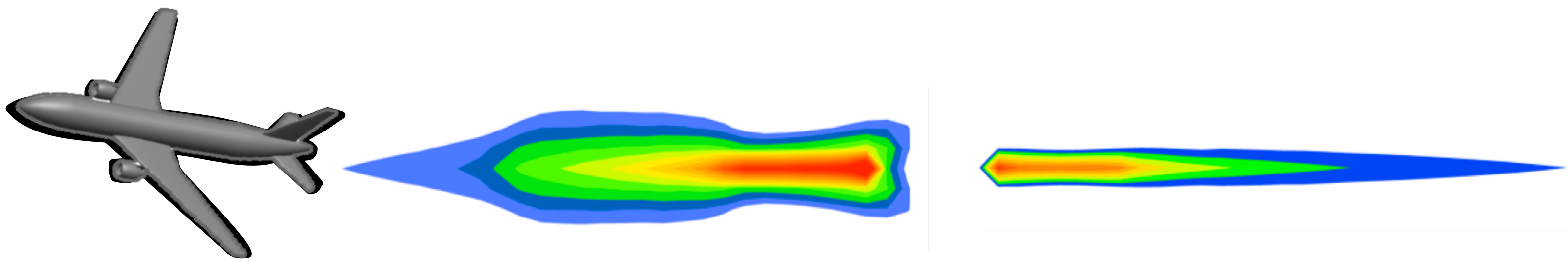
HWB 300 / GTF

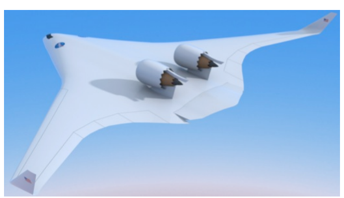
Goal versus Actual

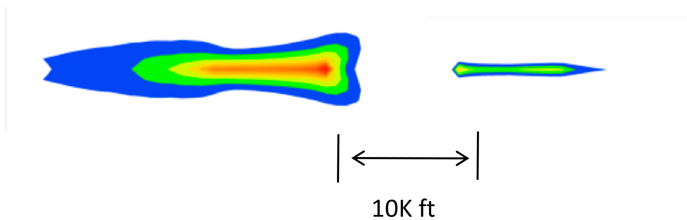
Documentation:
AIAA 2106-1030
AIAA 2016-0863

Potential Impacts
Vehicle Level - Best Performers

PREDICTED NOISE IMPACT – TAKEOFF AND LANDING CYCLE
AURALIZED NOISE IMPACT – STRAIGHT AND LEVEL FLIGHT AT TAKEOFF AND LANDING CONDITIONS







80% Reduction in Noise Footprint Area

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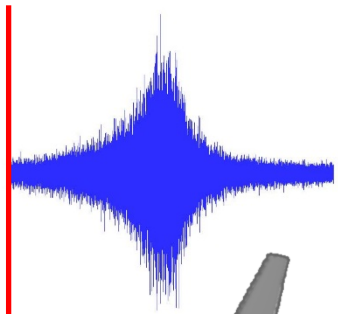
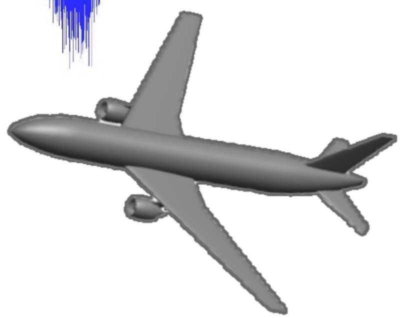
Rizzi, S.A., Aumann, A.R., Lopes, L.V., and Burley, C.L.., "Auralization of Hybrid Wing Body Aircraft Flyover Noise from System Noise Prediction," AIAA Paper 2013-____, January*, 2013.*

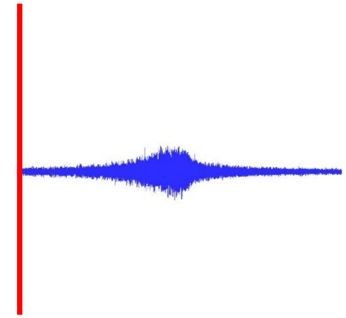
Potential Impacts
What does Stage 4 - 40 EPNdB sound like?

LTA Ref (NASA model of 777-GE90-110B) on Approach

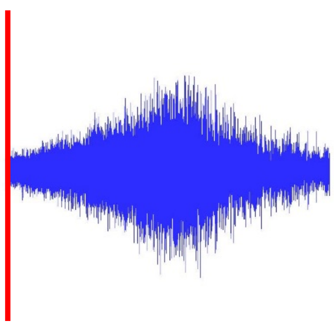




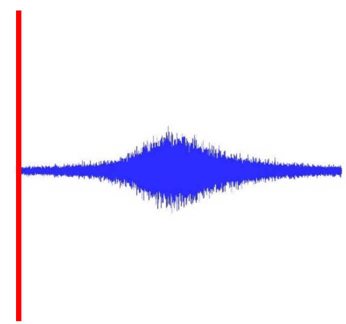
HWB301-GTF w/ITDNR on Approach



LTA Ref (NASA model of 777-GE90-110B) on Sideline

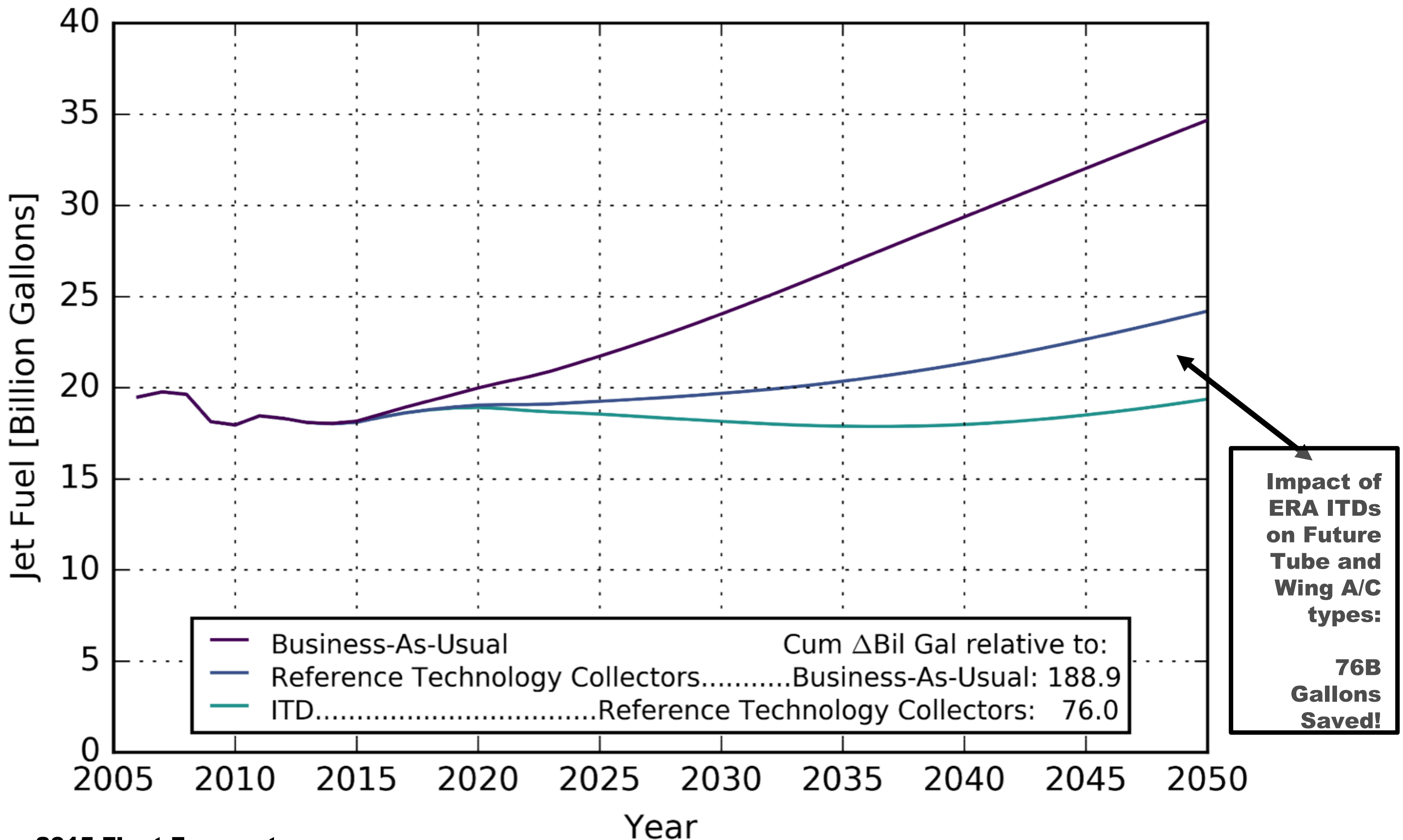


HWB301-GTF w/ITDNR on Sideline



"Auralization of NASA N+2 Aircraft Concepts from System Noise Predictions," Rizzi, Burley, and Thomas, 22nd AIAA/CEAS Aeroacoustics Conference, 30 May – 1 June, 2016, (accepted for publication).

Potential Impacts
US Fleet Level – Jet Fuel Consumption



2015 Fleet Forecast
Gradual Introduction of ITD-enabled tech to future (2020 and beyond) Tube & Wing aircraft types

Useful skills for executing technology demos

- Proactive risk management
- Change management
- System engineering
- Uncertainty quantification
- Communication and “Ego” management

Subsonic 1 - Status
X-Plane System Requirements Definition

- In 2017, 5 contracts awarded, work completed
  - expand the viable and well-informed trade space for commercial, high subsonic transport design decisions
  - enable simultaneous realization of national noise, emissions, and fuel burn goals for MIDTERM timeframe (2025 – 2035) and beyond
  - to further mature technology developed in ERA and other projects
  - to help prepare NASA for potential future X-Plane programs

Contractor	Aircraft Architecture
– Aurora	- Double Bubble D8
– Boeing	- Blended Wing Body
– Boeing	- Transonic Trussed Braced Wing
– DZYNE	- Blended Wing Body
– Lockheed	- Hybrid Wing Body

Boeing TTBW X-Plane Concept
The Boeing Company

Objectives

- Demonstrate aerodynamic and structural benefits of Transonic Truss-Braced Wing (TTBW) technology
- Validate cruise performance can be achieved that enables fuel burn reduction goals
- Demonstrate a certification path for non-traditional structures

Aurora D-8 X-Plane Concept
Aurora Flight Sciences

Objectives

- Demonstrate the operability of the D8 integrated double-bubble fuselage & boundary layer ingesting engines
- Verify feasibility of D8 conceptual design (lightweight structures, fabrication methods, ease of operations, lifecycle cost savings)
- Substantiate the fuel savings, noise reduction, and emissions reduction of the D8 configuration

Lockheed HWB X-Plane Concept
Lockheed Martin

Objectives

- Demonstrate HWB Aerodynamics and Propulsion Efficiency
- Characterize HWB Acoustics and Emission Reduction Potential
- Mature Technology to Next Generation Opportunity

DZYNE BWB X-Plane Concept
DZYNE

Objectives

- Demonstrate at full-scale flight the combination of BWB-X integrated technologies (pitch-pivot landing gear, semi-buried propulsion, BWB aerodynamics, BWB flight controls, BWB acoustics) has the ability to evolve into the disruptive Ascent 1000 Vision System aircraft
- Substantiate the performance benefit projections of *(-60% fuel burn, -86% NOx*) of the Ascent 1000 112 seat aircraft compared to the ERJ-190AR with *-39 dB cum to stage 4* noise reduction.
- Prove the viability of manufacturing processes and operational benefits in the ATM leading to Ascent 1000 product development; opening new US manufacturing market

Boeing BWB X-Plane Concept
The Boeing Company

Objectives

- Validation Of Aerodynamic Performance (L/D)
- Validation Of Engine Noise Shielding (Takeoff & Landing)
- Demonstrate Damage Tolerant Composite Center-body For Flight Loads And Proof Loads During Ground Testing
- Validate Full-Flight Envelope Stability & Control Assessment
- Validate Flight Control Secondary Power Requirements