Overview of the NASA N+3 Advanced Transport Aircraft Concept Studies

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Subsonic Fixed Wing Project
Fundamental Aeronautics Program

2nd UTIAS-MITACS
International Workshop on Aviation and Climate Change
Toronto, Ontario, Canada
May 27-28, 2010

Outline

- National and NASA Context
- Study Background
- Study Highlights by Team
- Concluding Remarks

The National and NASA context

- National Aeronautics R&D Policy (2006) and Plan (2007, 2010 update)
  - "Mobility through the air is vital…"
  - "Assuring energy availability and efficiency …" and "The environment must be protected…"
  - "Aviation is vital to national security and homeland defense"

National Aeronautics Research and Development Policy

December 2006

National Aeronautics Research and Development Plan

February 2010

- NextGen: The Next Generation Air Transportation System
  - Revolutionary transformation of the airspace, the vehicles that fly in it, and their operations, safety, and environmental impact

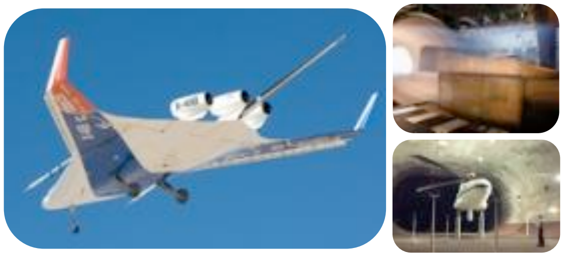
Next Generation Air Transportation System

Integrated Plan

- NASA Strategic Plan
  - Sub-Goal 3E: "By 2016, develop multidisciplinary analysis and design tools and new technologies enabling better vehicle performance in multiple flight regimes and within a variety of transportation system architectures." (updated)

2006 NASA Strategic Plan

NASA Aeronautics Programs in FY2010

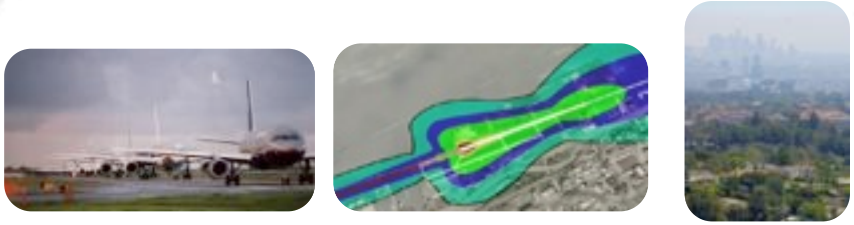


Fundamental Aeronautics Program

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

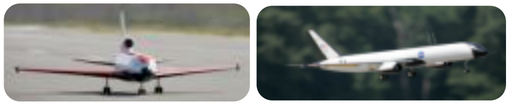
Integrated Systems Research Program

Conduct research at an integrated system-level on promising concepts and technologies and explore/assess/demonstrate the benefits in a relevant environment



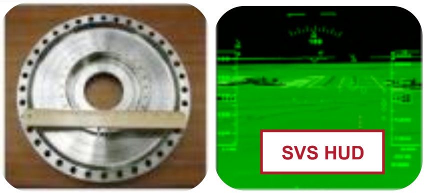
Airspace Systems Program

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.



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.



Fundamental Aeronautics Program
Subsonic Fixed Wing Project

Aeronautics Test Program

Preserve and promote the testing capabilities of one of the United States' largest, most versatile and comprehensive set of flight and ground-based research facilities.

Fundamental Aeronautics Program Overview

Goal: The overarching goal of the FA Program is to achieve technological capabilities necessary to overcome national challenges in air transportation including reduced noise, emissions, and fuel consumption, increased mobility through a faster means of transportation, and the ability to ascend/descend through planetary atmospheres. These technological capabilities will enable design solutions for the performance and environmental challenges of future air vehicles – vehicles that fly through any atmosphere at any speed.

Subsonic Fixed Wing (SFW)

Develop improved prediction methods and technologies that enable dramatic improvements in noise and emissions reduction, and increased performance (fuel burn and reduced field length) characteristics of subsonic/transonic aircraft.

Subsonic Rotary Wing (SRW)

Radically improve the transportation system using rotary wing vehicles by increasing speed, range, and payload while decreasing noise and emissions.

Supersonics

Eliminate environmental and performance barriers that prevent practical supersonic vehicles (cruise efficiency, noise and emissions, performance, boom acceptability).

Hypersonics

Enable airbreathing access to space and high mass entry into planetary atmosphere.

National Challenges: Energy and Environment

Fuel Efficiency

- In 2008, U.S. major commercial carriers burned 19.6B gallons of jet fuel. DoD burned 4.6B gallons
- At an average price of $3.00/gallon, fuel cost was $73B

Emissions

- 40 of the top 50 U.S. airports are in non-attainment areas that do not meet EPA local air quality standards for particulate matter and ozone
- The fuel consumed by U.S. commercial carriers and DoD releases more than 250 million tons of CO_2 into the atmosphere each year

Noise

- Aircraft noise continues to be regarded as the most significant hindrance to NAS capacity growth.
- FAA's attempt to reconfigure New York airspace resulted in 14 lawsuits.
- Since 1980 FAA has invested over $5B in airport noise reduction programs

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N+3 Advanced Concept Studies

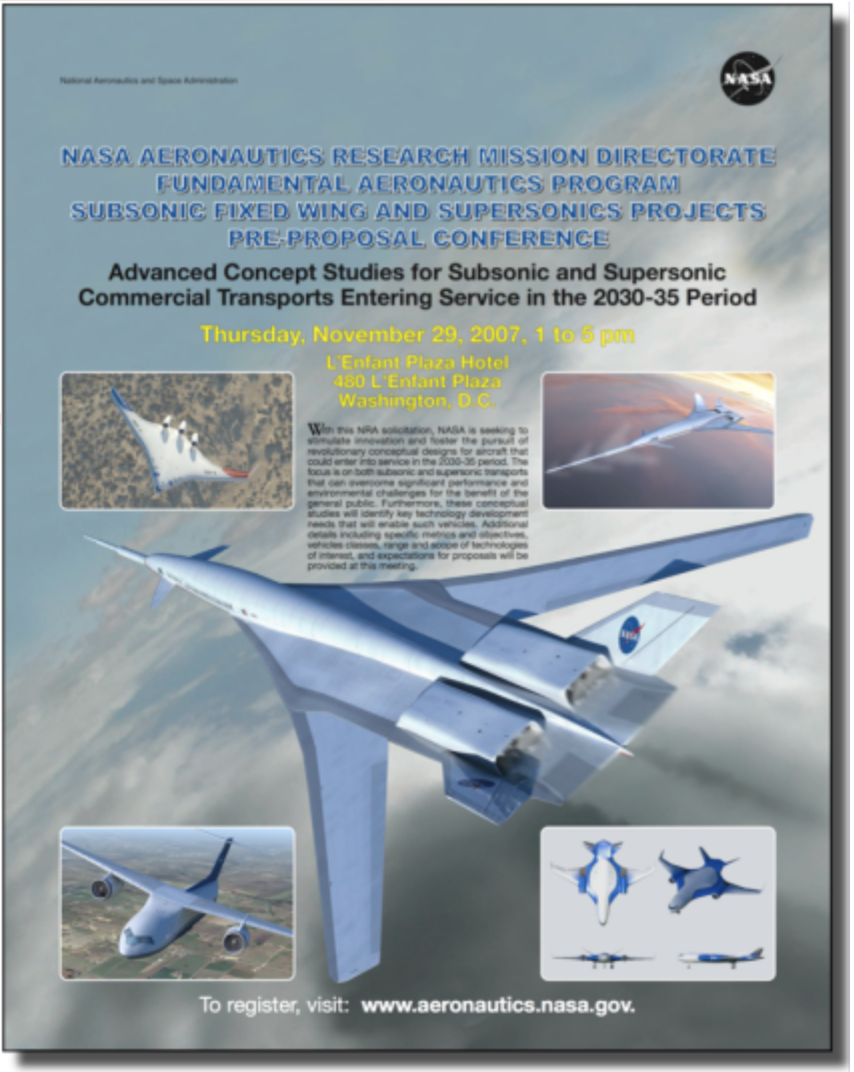
Fundamental Aeronautics Broad Objectives

- Stimulate thinking to determine potential aircraft solutions to significant problems of the future (performance, environmental, operations)
- 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
- Identify key driving technologies (traded at the system level) for fundamental research investments
- Prime the pipeline for future, revolutionary aircraft technology developments

N+3 Advanced Concept Study NRA

Fundamental Aeronautics: Subsonic Fixed Wing & Supersonics

- 29 Nov 07 bidders conf
- 15 Apr 08 solicitation
- 29 May 08 proposals due
- 2 July 08 selections made
- 1 Oct 08 contract start
- Phase I: 18 Months
  - 6 (4 SFW) awards
- Phase II: 18-24 Months with significant technology demonstration
  - details TBD



National Aeronautics and Space Administration

NASA AERONAUTICS RESEARCH MISSION DIRECTORATE
FUNDAMENTAL AERONAUTICS PROGRAM
SUBSONIC FIXED WING AND SUPERSONICS PROJECTS
PRE-PROPOSAL CONFERENCE

Advanced Concept Studies for Subsonic and Supersonic Commercial Transports Entering Service in the 2030-35 Period

Thursday, November 29, 2007, 1 to 5 pm

L'Enfant Plaza Hotel
480 L'Enfant Plaza
Washington, D.C.

With this NRA solicitation, NASA is seeking to stimulate innovation and foster the pursuit of revolutionary conceptual designs for aircraft that could enter into service in the 2030-35 period. The focus is on both subsonic and supersonic transports that can overcome significant performance and environmental challenges for the benefit of the general public. Furthermore, these conceptual studies will identify key technology development needs that will enable such vehicles. Additional details including specific metrics and objectives, vehicles classes, range and scope of technologies of interest, and expectations for proposals will be provided at this meeting.

To register, visit: www.aeronautics.nasa.gov.

NASA Subsonic Transport System Level Metrics

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

CORNERS OF THE TRADE SPACE	N+1 (2015)*** Technology Benefits Relative to a Single Aisle Reference Configuration	N+2 (2020)*** Technology Benefits Relative to a Large Twin Aisle Reference Configuration	N+3 (2025)*** Technology Benefits
Noise (cum below Stage 4)	- 32 dB	- 42 dB	- 71 dB
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%**	-50%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metroplex* concepts

*** 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 areas

N+1 "Conventional"

N+2 Hybrid Wing/Body

N+3 Generation

?

SFW N+3 Requirements

- Develop a Future Scenario for commercial aircraft operators in the 2030-35 timeframe

- 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
  - A 2030-35 technology conventional configuration vehicle and mission
  - A 2030-35 technology advanced configuration vehicle and mission

SFW N+3 NRA Teams

- BOEING | GE imagination at work | Georgia Institute of Technology
  - Subsonic Ultra Green Aircraft Research (SUGAR)
- NORTHROP GRUMMAN | Rolls-Royce | Sensis | Tufts UNIVERSITY | SPIRIT AEROSYSTEMS
  - Silent, Efficient, Low-Emission Commercial Transport (SELECT)
- GE imagination at work | Cessna A Textron Company | Georgia Institute of Technology
  - Small Commercial Efficient & Quiet Air Transportation for 2030-2035
- MIT Massachusetts Institute of Technology | Aurora FLIGHT SCIENCES | Pratt & Whitney A United Technologies Company
  - Aircraft & Technology Concepts for N+3 Subsonic Transport

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N+3 Advanced Concepts
NRA Phase 1 Studies (SFW)

Description: Completed four 18-month “Advanced Concept Studies for Commercial Subsonic Transport Aircraft Entering Service in the 2030-35 Period” intended to stimulate far-term thinking towards future aircraft needs, and identify key technology needs to meet the challenges.

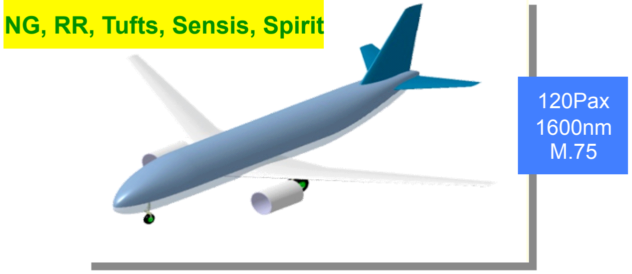
Results: Phase 1 final reports submitted March 31, 2010; final reviews held April 20-23, 2010

- Trends
  - Lower cruise speeds at higher altitude (~40-45k ft)
  - Heading toward BPR 20 (or propeller) with small, high efficiency core
  - Higher AR and laminar flow to varying degrees
- Uniquely enabling concepts/techs emerged (strut/truss, double bubble, hybrid-electric (battery) propulsion for example)
- Broadly applicable technology advances needed (for example lightweight materials, high temp materials, gust load alleviation)
- Energy: conventional/biofuel most prevalent, plus hybrid electric

Impact: Results will be used as key information to guide future investment in the SFW project, also basis for Phase 2 proposals currently under evaluation.

Boeing, GE, GaTech

154Pax
3500nm
M.70



NG, RR, Tufts, Sensis, Spirit

120Pax
1600nm
M.75

GE, Cessna, GaTech

20Pax
800nm
M.55

MIT, Aurora, P&W

354Pax
7600nm
M.83

180Pax
3000nm
M.74

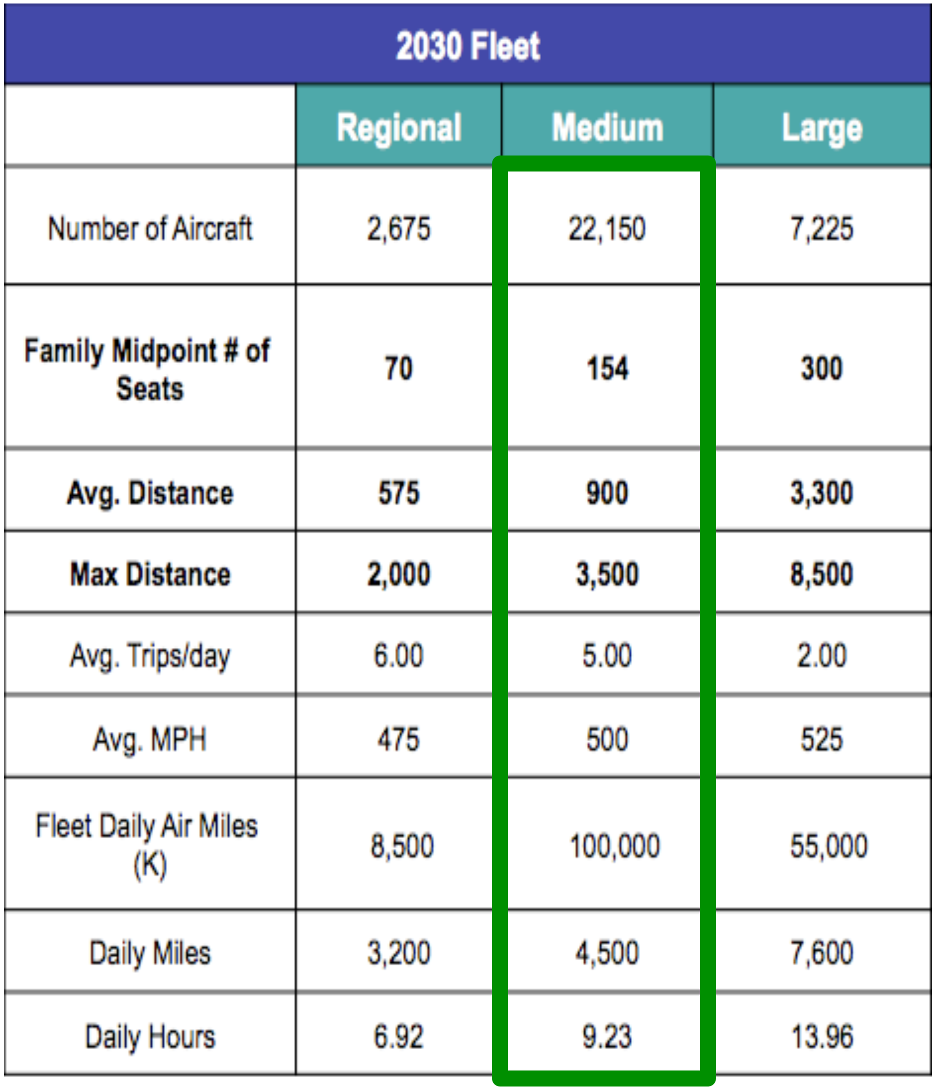
Boeing SUGAR

Credit: NASA/Boeing

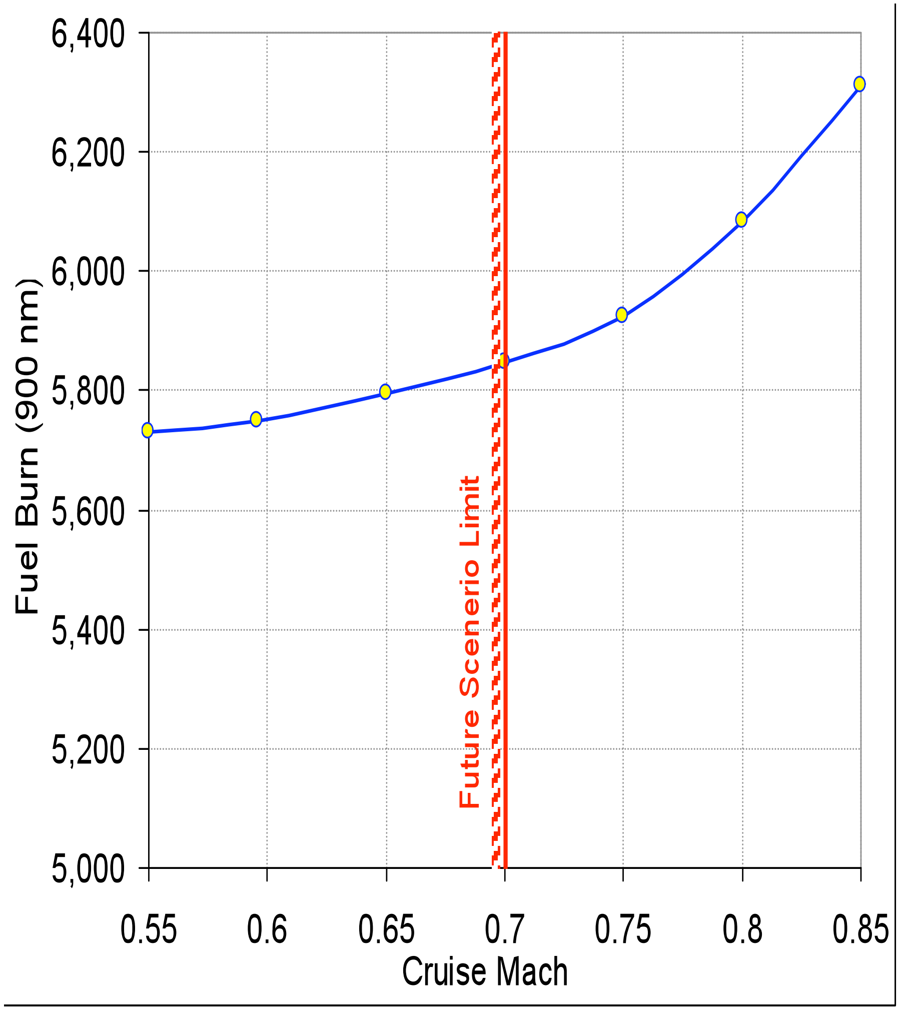
Boeing SUGAR

scenario derived vehicle requirements

Boeing Current Market Outlook based; growth tied to GDP growth (robust over time)



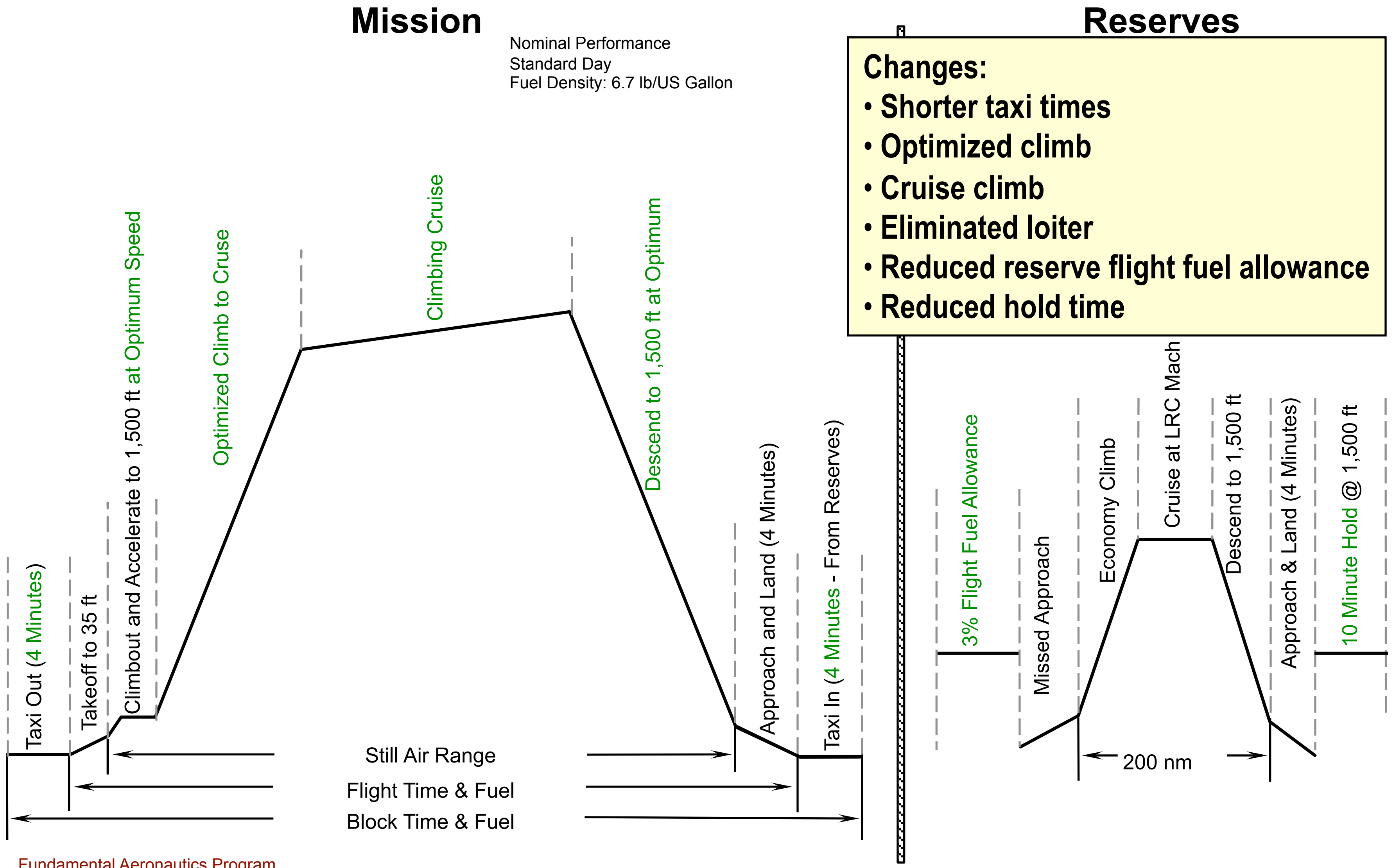
	2030 Fleet		
	Regional	Medium	Large
Number of Aircraft	2,675	22,150	7,225
Family Midpoint # of Seats	**70**	**154**	**300**
Avg. Distance	**575**	**900**	**3,300**
Max Distance	**2,000**	**3,500**	**8,500**
Avg. Trips/day	6.00	5.00	2.00
Avg. MPH	475	500	525
Fleet Daily Air Miles (K)	8,500	100,000	55,000
Daily Miles	3,200	4,500	7,600
Daily Hours	6.92	9.23	13.96



Boeing SUGAR

N+3 reference mission rules change due to projected NextGen ATS

17.5% fuel burn savings due both operational changes, and cycled vehicle changes



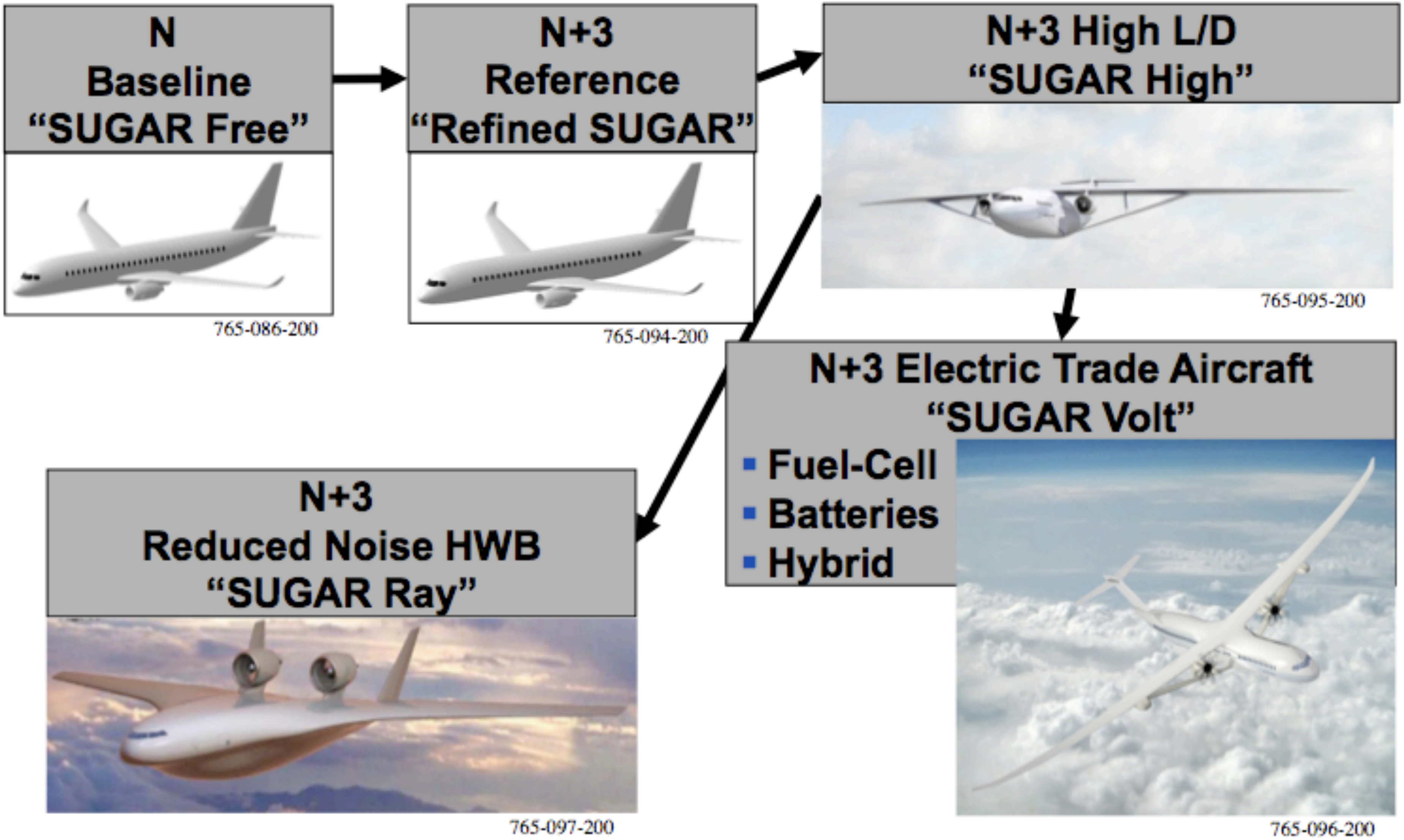
Nominal Performance
Standard Day
Fuel Density: 6.7 lb/US Gallon

Changes:

- Shorter taxi times
- Optimized climb
- Cruise climb
- Eliminated loiter
- Reduced reserve flight fuel allowance
- Reduced hold time

Boeing SUGAR focus concepts

Downselect to 5 concepts for detailed study; large number of trade/sensitivity studies within this set



N
Baseline
"SUGAR Free"

765-086-200

N+3
Reference
"Refined SUGAR"

765-094-200

N+3 High L/D
"SUGAR High"

765-095-200

N+3 Electric Trade Aircraft
"SUGAR Volt"

- Fuel-Cell
- Batteries
- Hybrid

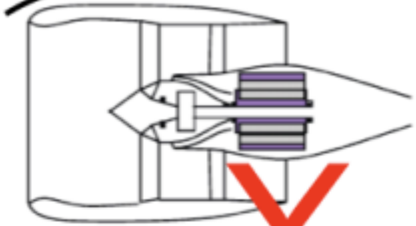
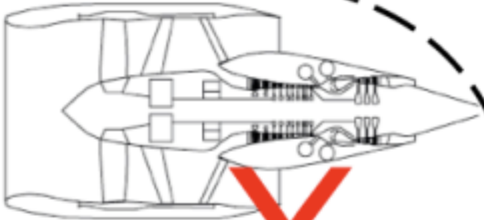
765-096-200

N+3
Reduced Noise HWB
"SUGAR Ray"

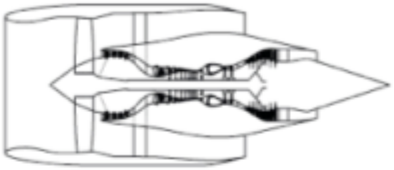
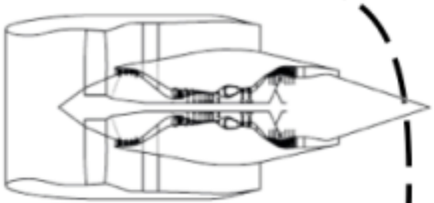
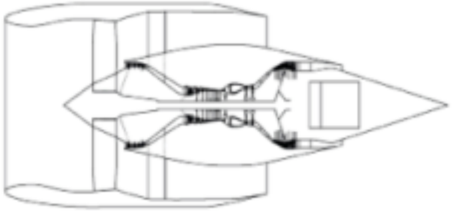
765-097-200

Boeing SUGAR Volt Propulsion Trades

Multiple propulsion concepts, including multiple electric variants

	CFM56	"eFan"	"fFan"
	Conventional GT	All-electric	GT-fuel cell hybrid
Airframe	SUGAR Free	SUGAR Volt	SUGAR Volt
Fan diameter / BPR	61" / 5	90" / 19	89" / ~10
Thrust (SLS/+27)	27,000 lbf	25,500 lbf	- - -
Cruise SFC	Base	-100%	-15-25% class
Propulsion system weight	Base	7,000 lb class	15-20K lb class
Emissions (relative to CAEP/6)	Base	-100%	TBD

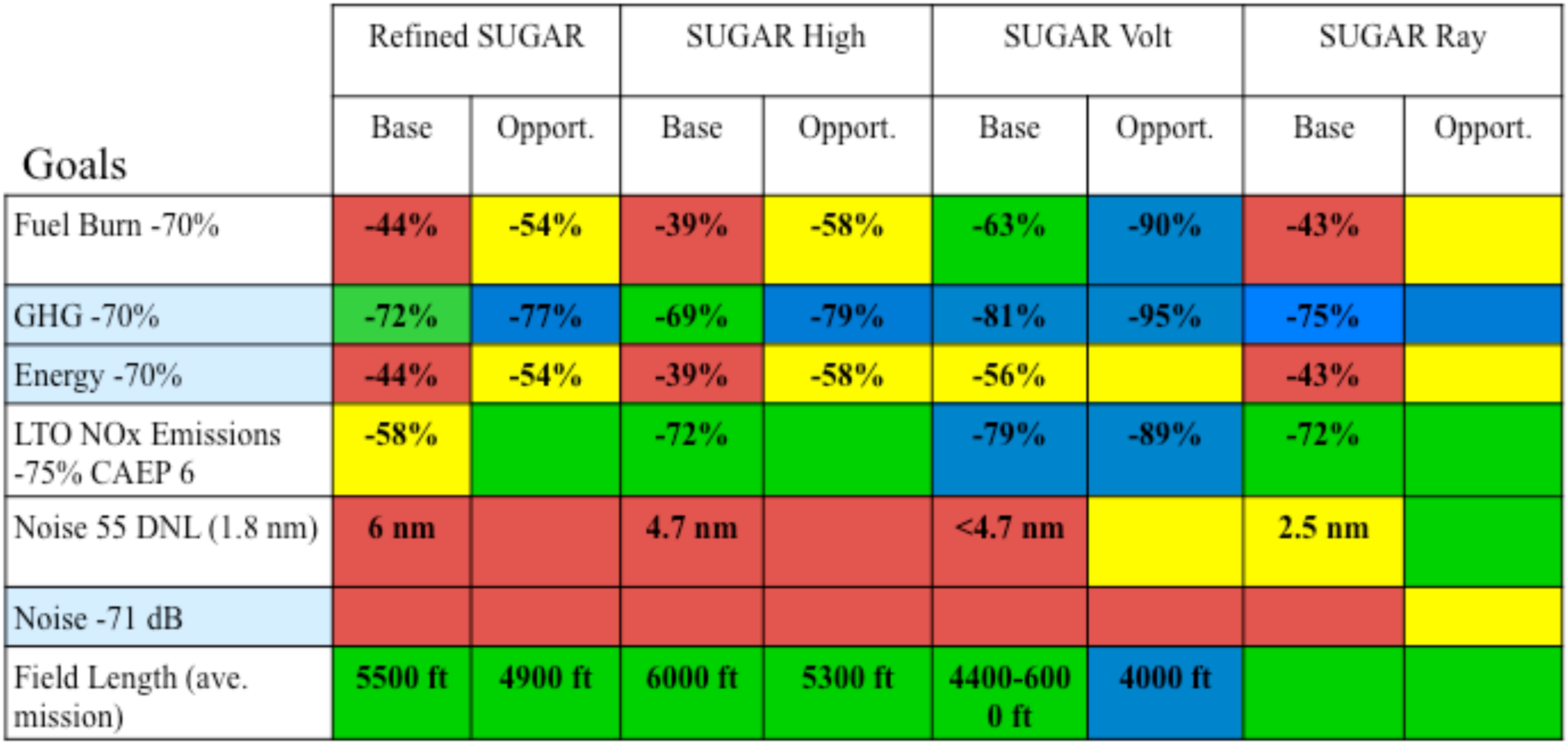
Selected

	"gFan"	"gFan+"	"hFan"
	Gas turbine	Advanced GT	GT-electric hybrid
Airframe	Refined SUGAR	SUGAR High	SUGAR Volt
Fan diameter / BPR	70" / 9	77" / 13	89" / 18
Thrust (SLS/+27)	18,900 lbf	18,900 lbf	25,600 lbf
Cruise SFC	-21%	-28%	-28% GT mode (–100% elec. Mode)
Propulsion system weight	6411 lb	7096 lb	10475 lb
Emissions (relative to CAEP/6)	-58%	-72%	better than –72%

Boeing SUGAR

Summary against Goals

SUGAR Volt offers the most potential



Goals	Refined SUGAR		SUGAR High		SUGAR Volt		SUGAR Ray	
	Base	Opport.	Base	Opport.	Base	Opport.	Base	Opport.
Fuel Burn -70%	🟥 **-44%**	🟨 **-54%**	🟥 **-39%**	🟨 **-58%**	🟩 **-63%**	🟦 **-90%**	🟥 **-43%**	🟨
GHG -70%	🟩 **-72%**	🟦 **-77%**	🟩 **-69%**	🟦 **-79%**	🟦 **-81%**	🟦 **-95%**	🟦 **-75%**	🟦
Energy -70%	🟥 **-44%**	🟨 **-54%**	🟥 **-39%**	🟨 **-58%**	🟨 **-56%**	🟨	🟥 **-43%**	🟨
LTO NOx Emissions -75% CAEP 6	🟨 **-58%**	🟩	🟩 **-72%**	🟩	🟦 **-79%**	🟦 **-89%**	🟩 **-72%**	🟩
Noise 55 DNL (1.8 nm)	🟥 **6 nm**	🟥	🟥 **4.7 nm**	🟥	🟥 **<4.7 nm**	🟨	🟨 **2.5 nm**	🟩
Noise -71 dB	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨
Field Length (ave. mission)	🟩 **5500 ft**	🟩 **4900 ft**	🟩 **6000 ft**	🟩 **5300 ft**	🟩 **4400-6000 ft**	🟦 **4000 ft**	🟩	🟩

🟥 Far from goal

🟨 Does not meet goal

🟩 Nearly meets or meets goal

🟦 Exceeds goal

Boeing SUGAR Technology Ranking

Top 2 recommendations center on additional study of hybrid electric propulsion & strut/truss bracing

Ranking	Technology or Technology Group	Goals
Game-Changing	Hybrid Electric Propulsion & High Performance Modular Batteries	Noise, Emissions, Fuel Burn, TOFL
Critical	Advanced Combustors	Emissions
Critical	Biofuels	Emissions
Critical	NextGen ATM	Emissions, Fuel Burn
Critical	Engine Noise Treatments	Noise
Critical	Aero Technologies (Inc. Laminar Flow)	Noise, Emissions, Fuel Burn, TOFL
Important	Engine Technologies	Fuel Burn
Important	Airframe Acoustic Technologies	Noise
Important	Airframe Materials & Structures	Fuel Burn
Important	Advanced Subsystems	Emissions, Fuel Burn

"A wide portfolio of technologies is needed to achieve the NASA N+3 goals"

Northrop Grumman SELECT

Credit: NASA/Northrop Grumman

NORTHROP GRUMMAN Rolls-Royce Sensis Tufts UNIVERSITY SPIRIT AEROSYSTEMS

Northrop Grumman SELECT

scenario derived vehicle requirements

Weighted scenarios/goals (King Carbon, NIMBY, Bright Bold Tomorrow), exploit metroplex for capacity

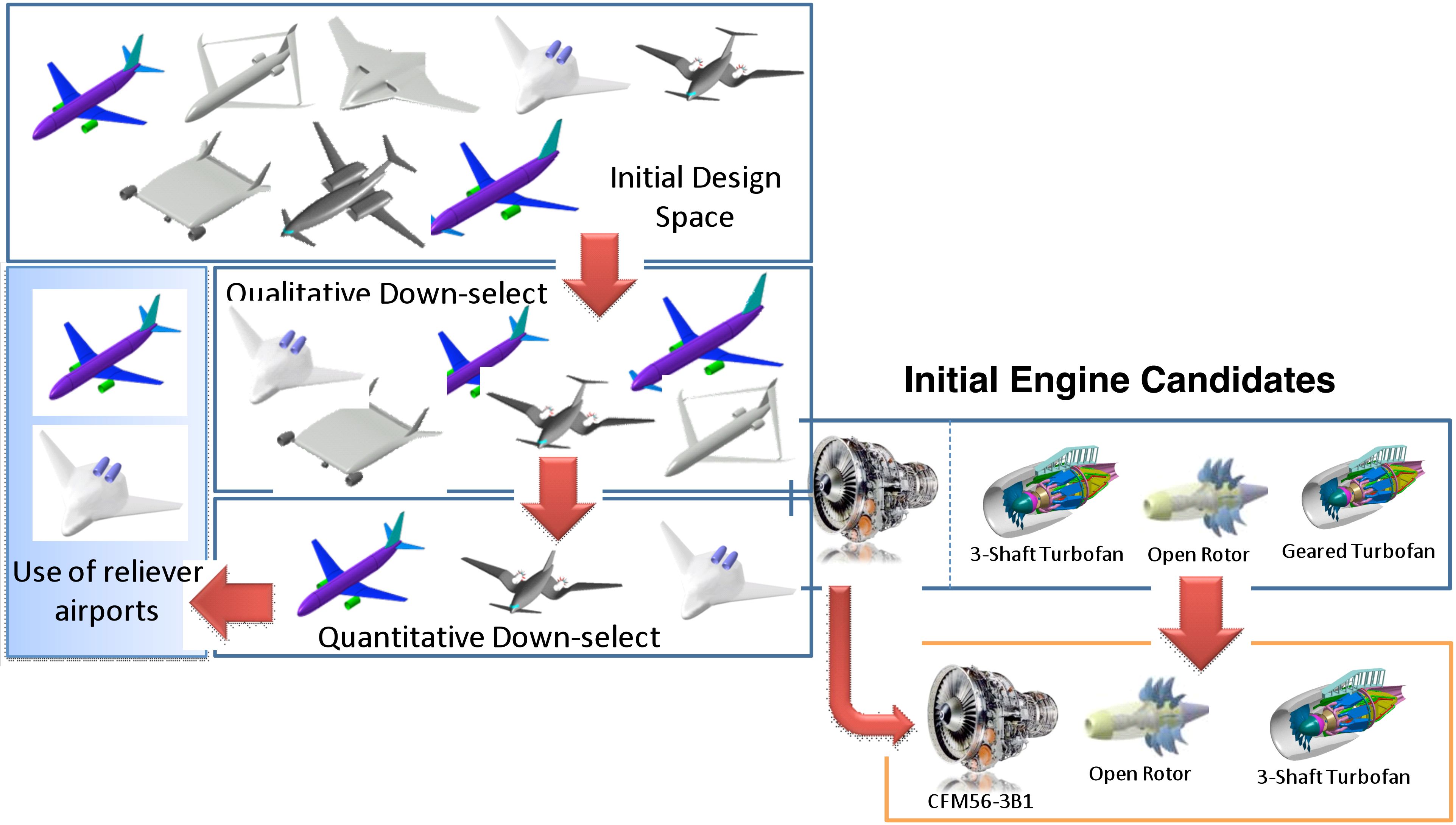
- NextGen alone is not sufficient
- By engaging Metroplex fields with 5000’ runways (or greater), a huge addition in capacity and attendant reduction in delay is achieved
- Substantial future delays will be seen (or attendant price increases, congestion, frustration) if not implemented soon
- For the broadest capability, a range of 1600 nm is sufficient
- Passenger count of 120 will serve primary Metroplex mission
- Cruising at Mach 0.75 or greater will best utilize N+3 airframes

Mission Requirements	
Range (with reserves):	1600 nm
Passengers:	120
Balanced Field Length (Sea Level/Standard Day):	5000 ft
Landing Distance (Sea Level/Standard Day):	5000 ft
Minimum Cruise Mach:	0.75

Northrop Grumman SELECT

vehicle and engine concepts

Downselect from many ideas to a few concepts for detailed study



Initial Design Space

Qualitative Down-select

Quantitative Down-select

Use of reliever airports

Initial Engine Candidates

3-Shaft Turbofan

Open Rotor

Geared Turbofan

CFM56-3B1

Open Rotor

3-Shaft Turbofan

Final Engine Candidates

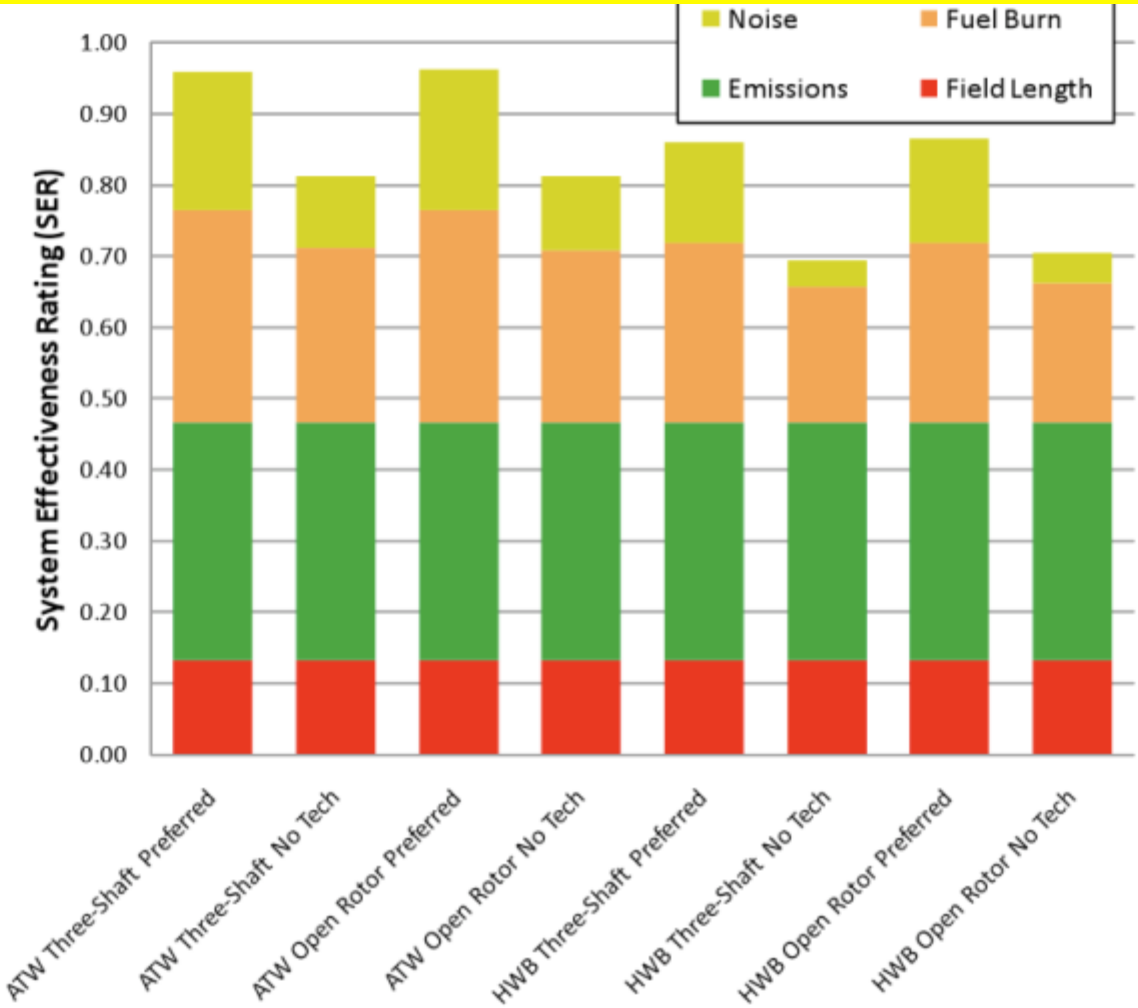
Northrop Grumman SELECT

ATW (Adv Tube/Wing) is preferred concept for this mission; open rotor if < ~3 EPNdB over 3-shaft TF

- The ATW exhibits better system-level performance than the HWB

- The ATW open rotor configuration performs slightly better than the ATW three-shaft turbofan
  - Assuming the two engines have the same noise output

The ATW is the preferred configuration

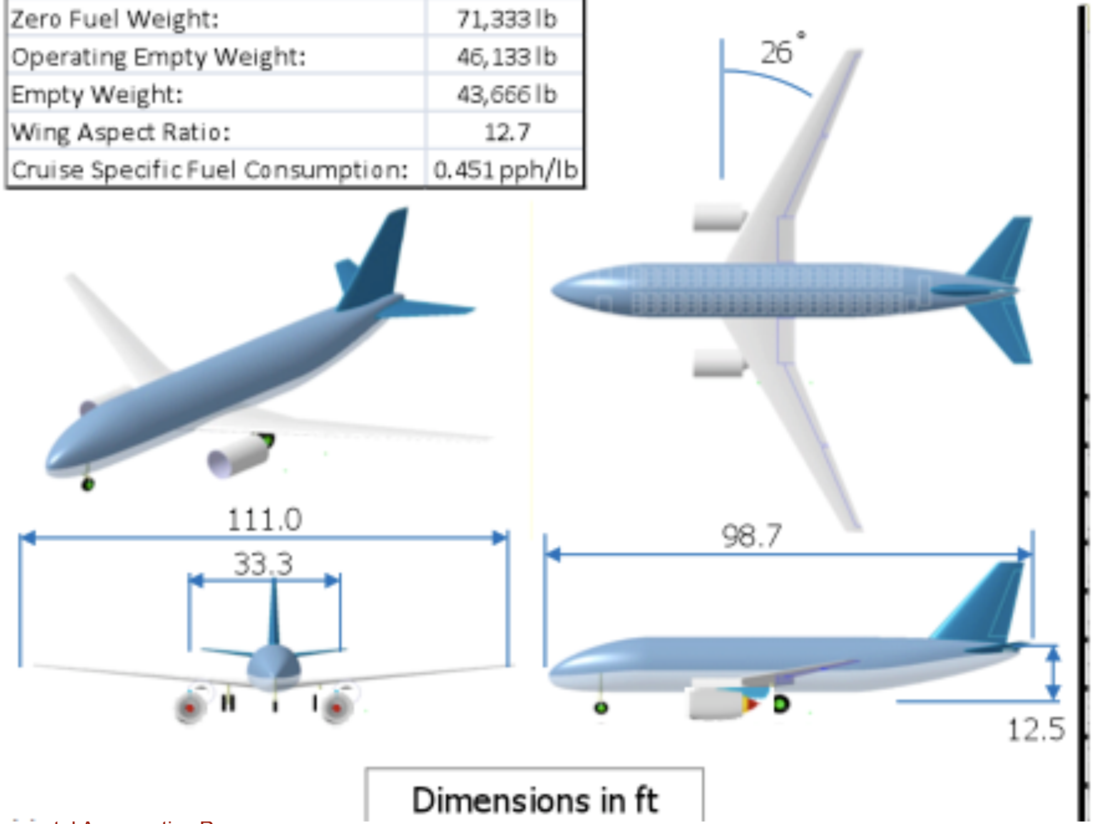


Northrop Grumman SELECT

preferred concept

“revolutionary in performance, if not in appearance”

Phase 1 Preferred Configuration Summary	
Range (With Reserves):	1,600 nm
Passengers:	120
Field Length Capability:	5,000 ft
Cruise Altitude:	45,000 ft
Design Mach Number:	0.75
Ramp Gross Weight:	80478 lb
Zero Fuel Weight:	71,333 lb
Operating Empty Weight:	46,133 lb
Empty Weight:	43,666 lb
Wing Aspect Ratio:	12.7
Cruise Specific Fuel Consumption:	0.451 pph/lb



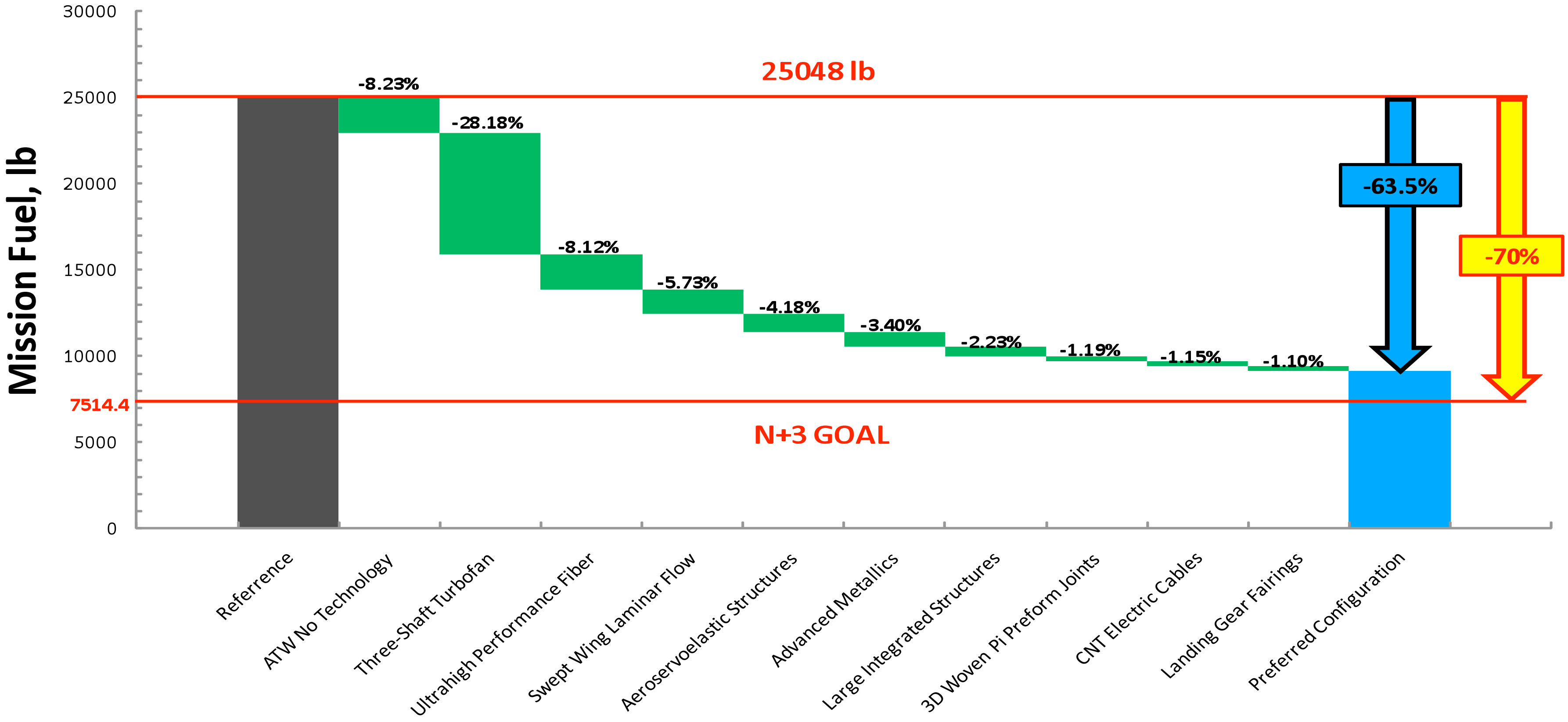
Technology Suite
Three-Shaft Turbofan Engine
-Ultra-High Bypass Ratio ~18
-CMC Turbine Blades
-Lean-Burn CMC Combustor
-Intercooled Compressor Stages
-Swept Fan Outlet Guide Vanes
-Fan Blade Sweep Design
-Lightweight Fan/Fan Cowl
-Compressor Flow Control
-Active Compressor Clearance Control
-Shape Memory Alloy Nozzle
Swept Wing Laminar Flow
Large Integrated Structures
Aeroservoelastic Structures
Ultrahigh Performance Fibers
Carbon Nanotube Electrical Cables
3-D Woven Pi Preform Joints
Advanced Metallics
Landing Gear Fairings
Advanced Acoustic Inlet Liner

Northrop Grumman SELECT

fuel burn reduction and technology suite

large overall benefit from many "smaller" technologies cycling into design together; propulsion largest

- Overall fuel reduction represents technology set applied as a group
- Propulsion system resulted in largest overall fuel burn reduction
- Aerodynamics, structures, and propulsion disciplines all important towards achieving fuel burn reduction



Northrop Grumman SELECT

Summary against Goals

Once again – revolutionary in performance, if not in appearance – need to understand

Performance Criteria	N+3 Goal (2030-2035 EIS) Relative to Reference Vehicle	Phase I Achievement		
		Absolute	% of Goal	
Noise (Cum Below Stage 4)	-71 dB	-70 dB	98%	🟢
LTO NOx Emissions (Below CAEP/6)	Better than -75%	-91%	121%	🟢
Fuel Burn	Better than -70%	-64%	91%	🟡
Field Length	Exploit Metroplex	Exploited Metroplex		🟢

GE/Cessna

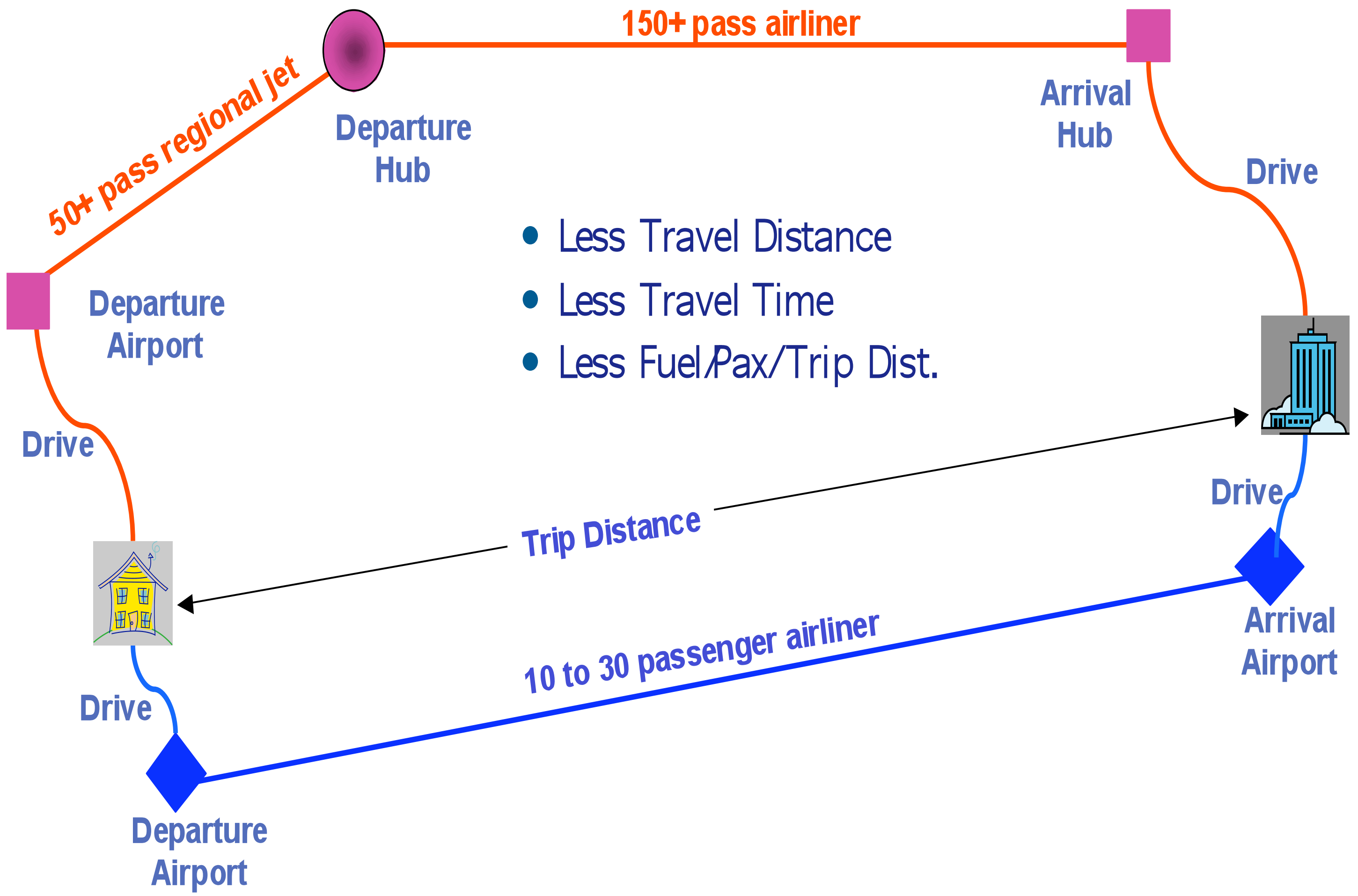
Credit: NASA/General Electric

GE/Cessna

scenario derived vehicle requirements

Distributed point to point to off load overwhelmed hub and spoke, min 3X price to garner 14% air market

Point-to-Point Travel for 2035

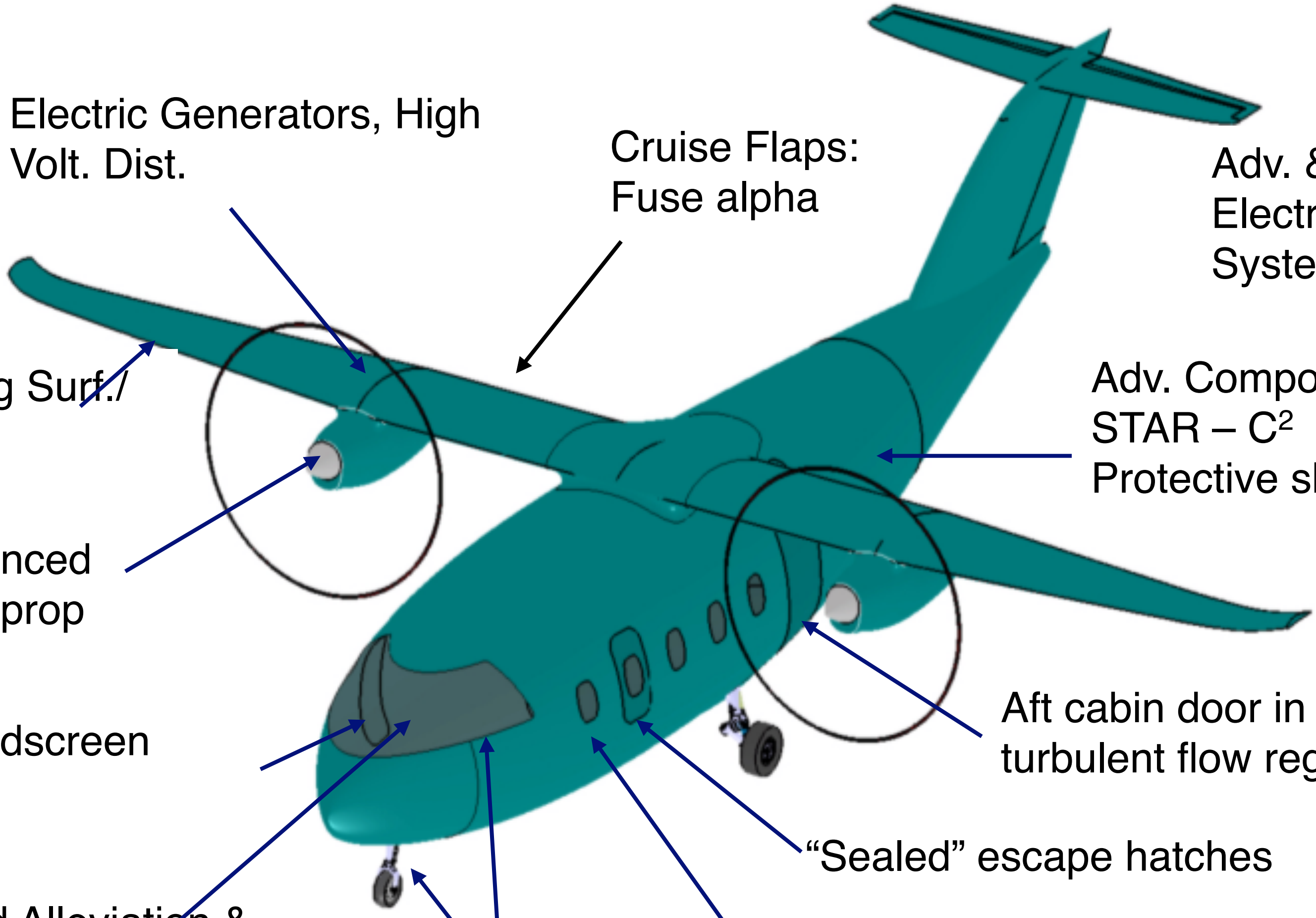


- Less Travel Distance
- Less Travel Time
- Less Fuel/Pax/Trip Dist.

GE/Cessna

technologies

Laminar flow and techs for lightweight structure, systems, propulsion
M.55, 800nm, 20pax



Electric Generators, High Volt. Dist.

Cruise Flaps: Fuse alpha

Adv. & Electric Systems

Self-Cleaning Surf./ with Ice Prot

Adv. Composites STAR – C^2 Protective skin

Advanced turboprop

Aft cabin door in turbulent flow region

Integral windscreen

“Sealed” escape hatches

Gust Load Alleviation & Ride Control

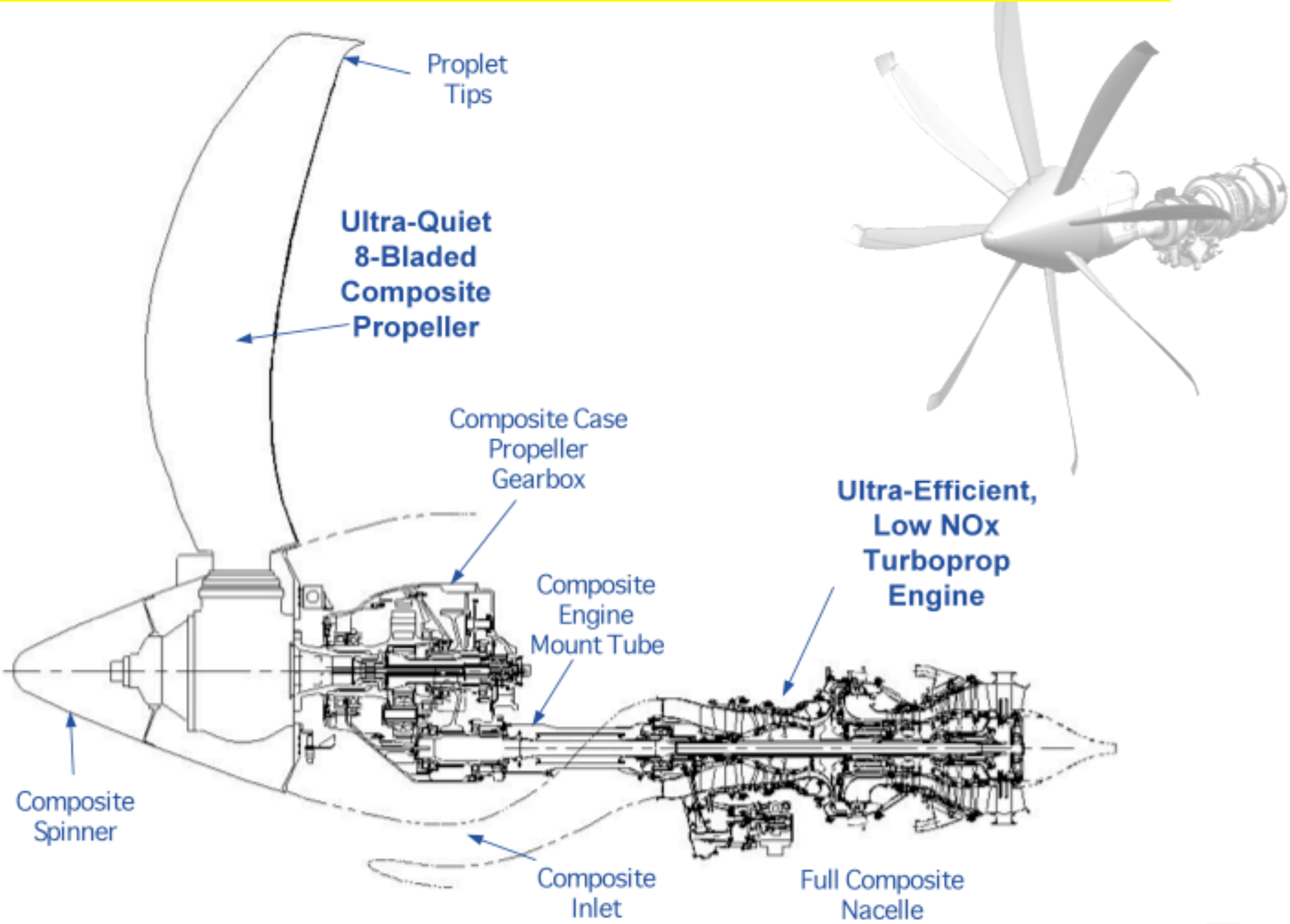
Virtual reality or “sealed” windows

HLFC

GE/Cessna

engine concept – Ultra Quiet and Efficient Turboprop (UQETP)

Innovative low noise propeller is key to minimizing noise and community acceptance



GE/Cessna

summary against goals

Combination of advanced configuration and technologies - significant progress against all goals

	TOGW	**Thrust**	**Fuel Burn**	**LTO NOx**	**LTO Noise**	**Field Length**
	lb	lbf	lb/mission	g/LTO/Pax	EPNdB Cum	Landing, T/O
Baseline Airliner	24973	4557.5	3516	43	-20	4000
B20 w/ 2008 TF	**BASE**	**BASE**	**BASE**	**BASE**	**BASE**	**BASE**
Advanced Airliner	14550	3203.8	1088	10.5	-75	
A20 w/ 2030 ATP	**-42%**	**-30%**	**-69%**	**-75%**	**-55**	**-9%**
Adv Reference Airliner	17511.1	4090.4	1669	17.3	-41	
AR20 w/ 2030 ARTF	**-30%**	**-10%**	**-53%**	**-59%**	**-21**	**-8%**
Advanced Propulsion Only	22267	5197	1800	20.6	-62	
B20 w/ 2030 ATP	**-11%**	**+14%**	**-49%**	**-52%**	**-42**	**+23%**
Advanced Airframe Only	16437.6	3287.8	2135	31.9	-32	
A20 w/ 2008 TF	**-34%**	**-28%**	**-39%**	**-25%**	**-12**	**+6%**

MIT

Credit: NASA/MIT

Credit: NASA/MIT

Massachusetts Institute of Technology

Aurora Flight Sciences

Pratt & Whitney
A United Technologies Company

MIT

scenario derived vehicle requirements

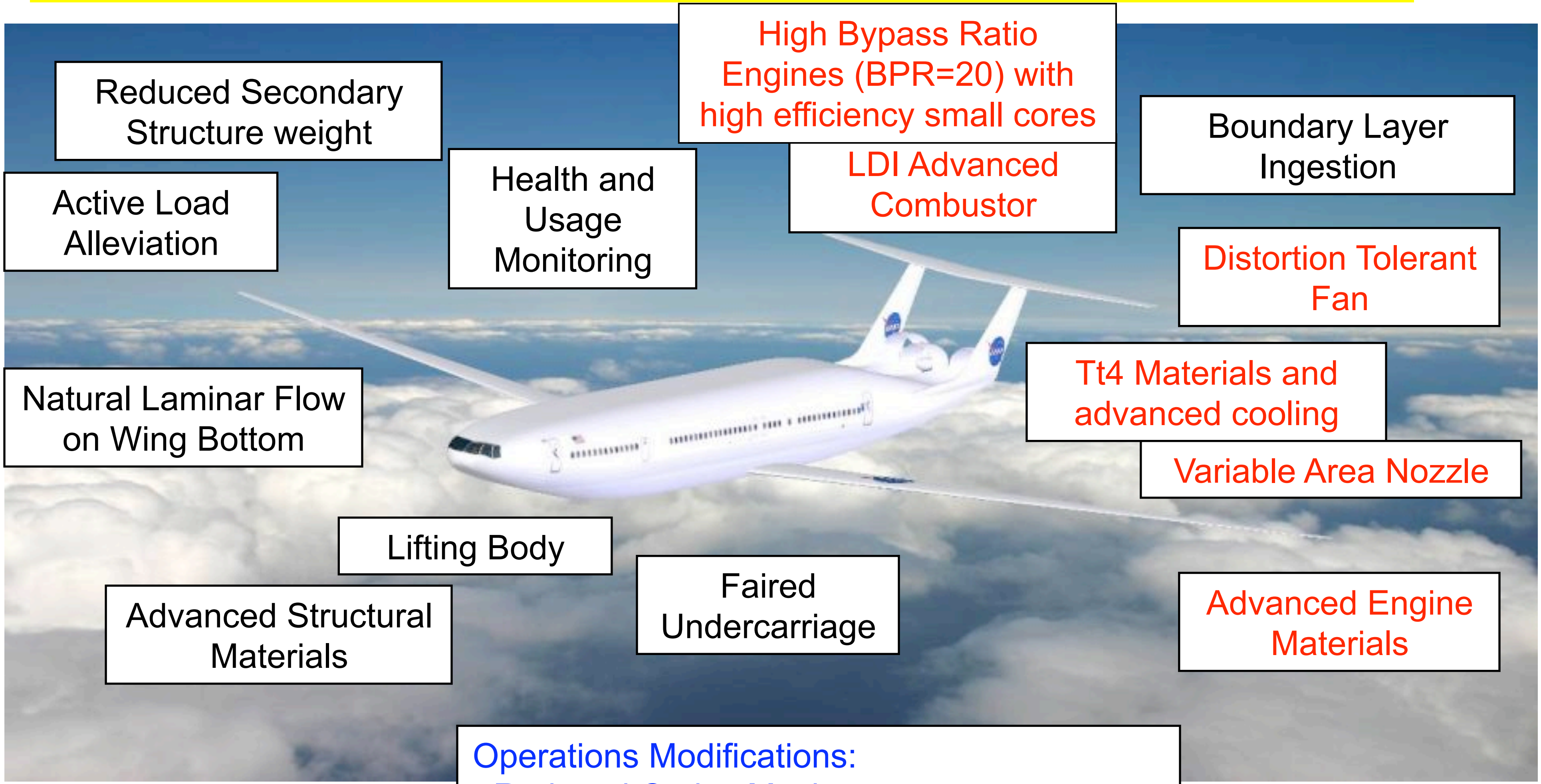
GDP based growth, similar to Boeing Current Market Outlook; detailed assessment metroplex field length

Size	▪ **Domestic**: 180 passengers @ 215 lbs/pax (737-800) ▪ **International**: 350 passengers @ 215 lbs/pax (777-200LR) ▪ Multi-class configuration ▪ Increased cabin baggage
Range	▪ **Domestic**: US transcontinental; max range 3,000 nm with reserves ▪ **International**: Transpacific; max range 7,600 nm with reserves
Speed	▪ **Domestic**: Minimum of Mach 0.72 ▪ **International**: Minimum of 0.8 ▪ Driven by fuel efficiency
Runway Length	▪ **Domestic**: 5,000 ft balanced field ▪ **International**: 9,000 ft balanced field
Fuel & Emissions	▪ N+3 target: 70% fuel burn improvement ▪ Meet N+3 emission target (75% below CAEP/6 NOx restriction) ▪ Consider alternative fuels and climate impact
Noise	▪ N+3 target: (-71 dB cumulative below FAA Stage 4 limits)
Other	▪ Compatibility with NextGen ▪ Wake vortex robustness ▪ Meet or exceed future FAA and JAA safety targets

MIT

D8.5 Airframe & Propulsion Technology Overview

Novel configuration plus suite of airframe, propulsion and operational characteristics combined



Reduced Secondary Structure weight

Active Load Alleviation

Health and Usage Monitoring

High Bypass Ratio Engines (BPR=20) with high efficiency small cores

LDI Advanced Combustor

Boundary Layer Ingestion

Distortion Tolerant Fan

Tt4 Materials and advanced cooling

Variable Area Nozzle

Natural Laminar Flow on Wing Bottom

Lifting Body

Faired Undercarriage

Advanced Structural Materials

Advanced Engine Materials

Operations Modifications:
- Reduced Cruise Mach
- Optimized Cruise Altitude
- Descent angle of 4º
- Approach Runway Displacement Threshold

MIT D8.5 – Double Bubble Configuration

summary against goals

D8.5 configuration w/ adv techs meets 3 of 4 goals

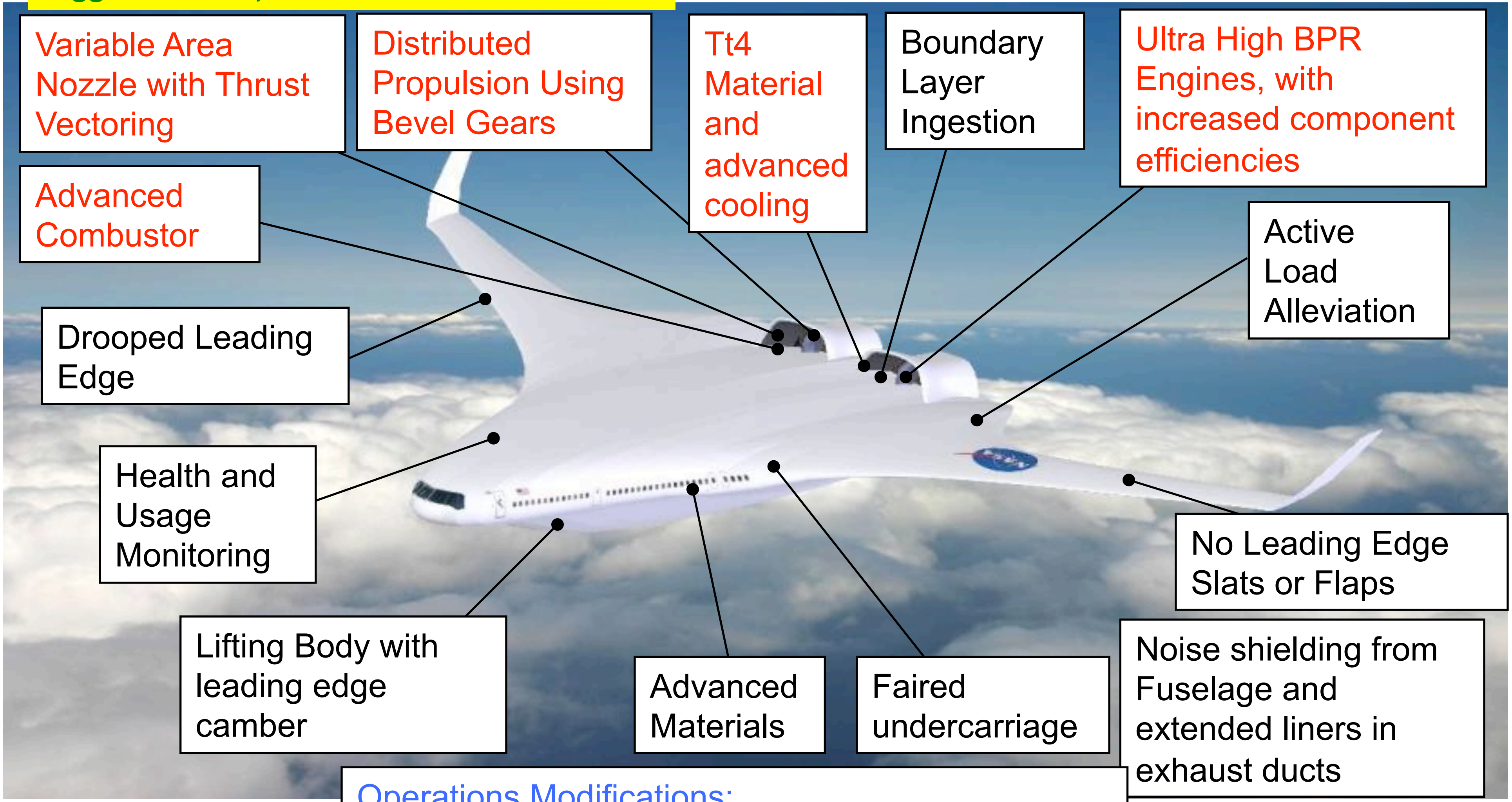
Mission
Payload: 180 PAX
Range: 3000 nm

Metric	737-800 Baseline	N+3 Goals % of Baseline	D8.5
Fuel Burn (PFEI) (KJ/kg-km)	7.43	2.23 (70% Reduction)	*2.17* *(70.8% Reduction*)
Noise (EPNdB below Stage 4)	277	202 (-71 EPN db Below Stage 4)	213 (-60 EPNdB Below Stage 4)
LTO Nox (g/kN) (% Below CAEP 6)	43.28 (31% below CAEP 6)	75% below CAEP 6	*10.5 (87.3% below 6)*
Field Length (ft)	7680 for 3000 nm mission	5000 (metroplex)	*5000 (metroplex)*

MIT

H3.2 Airframe & Propulsion Technology Overview

Bigger is better, and faster is better for HWB



Variable Area Nozzle with Thrust Vectoring

Distributed Propulsion Using Bevel Gears

Tt4 Material and advanced cooling

Boundary Layer Ingestion

Ultra High BPR Engines, with increased component efficiencies

Advanced Combustor

Active Load Alleviation

Drooped Leading Edge

Health and Usage Monitoring

No Leading Edge Slats or Flaps

Lifting Body with leading edge camber

Advanced Materials

Faired undercarriage

Noise shielding from Fuselage and extended liners in exhaust ducts

Operations Modifications:
- Optimized Cruise Altitude
- Descent angle of 4°
- Approach Runway Displacement Threshold

MIT H3.2 Hybrid Wing Body Configuration

summary against goals

H3.2 configuration w/ adv techs further from goals, but studied at lower fidelity than D-series

Mission
Payload: 354 PAX
Range: 7600 nm

Metric	777-200 LR Baseline	N+2 Goals % of Baseline	N+3 Goals % of Baseline	H3.2
Fuel Burn (PFEI) (KJ/kg-km)	5.94	3.58 (40% Reduction)	1.79 (70% reduction)	***2.75 (54% reduction)***
Noise (EPNdB below Stage 4)	288	246 (-42 EPNdb)	217(-71 EPNdB)	242 (-46 EPNdB Below Stage 4)
LTO Nox (g/kN) (% Below CAEP 6)	67.9	24.5 (75% below CAEP 6)	>24.5 (75% below CAEP 6)	*18.6 (81% below CAEP 6)*
Field Length (ft)	10,000	4375 (50%)	metroplex	*9000*

N+3 Advanced Concepts
NRA Phase 1 Studies (SFW)

Description: Completed four 18-month “Advanced Concept Studies for Commercial Subsonic Transport Aircraft Entering Service in the 2030-35 Period” intended to stimulate far-term thinking towards future aircraft needs, and identify key technology needs to meet the challenges.

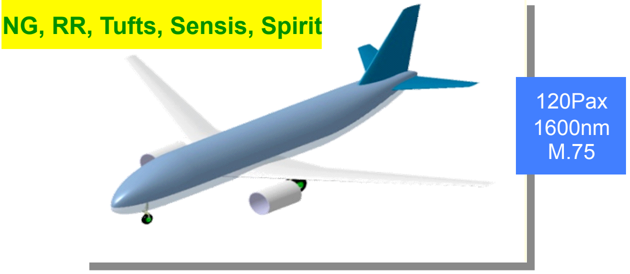
Results: Phase 1 final reports submitted March 31, 2010; final reviews held April 20-23, 2010

- Trends
  - Lower cruise speeds at higher altitude (~40-45k ft)
  - Heading toward BPR 20 (or propeller) with small, high efficiency core
  - Higher AR and laminar flow to varying degrees
- Uniquely enabling concepts/techs emerged (strut/truss, double bubble, hybrid-electric (battery) propulsion for example)
- Broadly applicable technology advances needed (for example lightweight materials, high temp materials, gust load alleviation)
- Energy: conventional/biofuel most prevalent, plus hybrid electric

Impact: Results will be used as key information to guide future investment in the SFW project, also basis for Phase 2 proposals currently under evaluation.

Boeing, GE, GaTech

154Pax
3500nm
M.70



NG, RR, Tufts, Sensis, Spirit

120Pax
1600nm
M.75

GE, Cessna, GaTech

20Pax
800nm
M.55

MIT, Aurora, P&W, Aerodyne

354Pax
7600nm
M.83

180Pax
3000nm
M.74

Outline

- National and NASA Context
- Study Background
- Study Highlights by Team
- Concluding Remarks

SFW N+3 NRA Phase 2

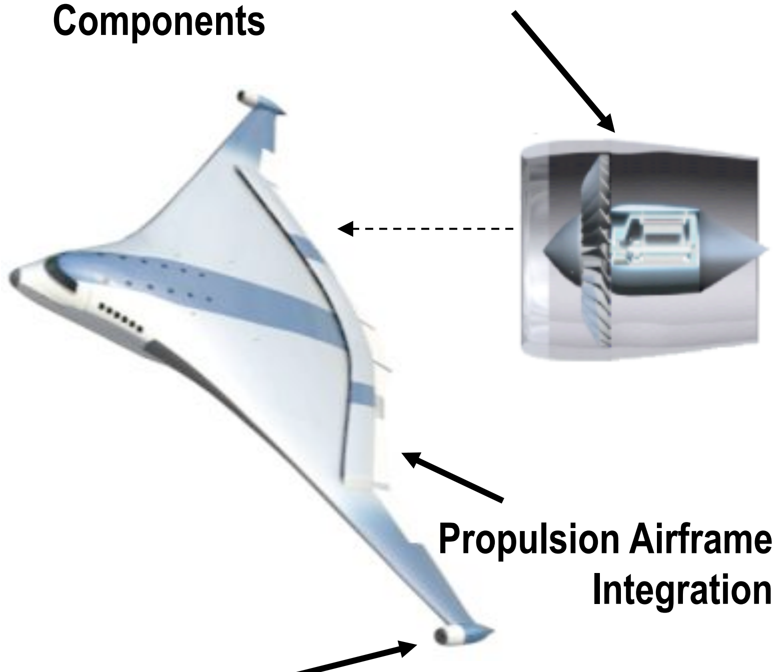
what's next?

- 5 Proposals Submitted by April 19, 2010
- 3 Task Areas
  - Experimental and Higher-Fidelity Exploration of Key Technologies
  - N+3 Advanced Vehicle Concept Study
  - N+4 Advanced Vehicle Concept Study
- Start work October 2010
  - 2-3 years, total $5-6M/year

Additional N+3 Studies

Distributed Turboelectric Propulsion

NASA In-house



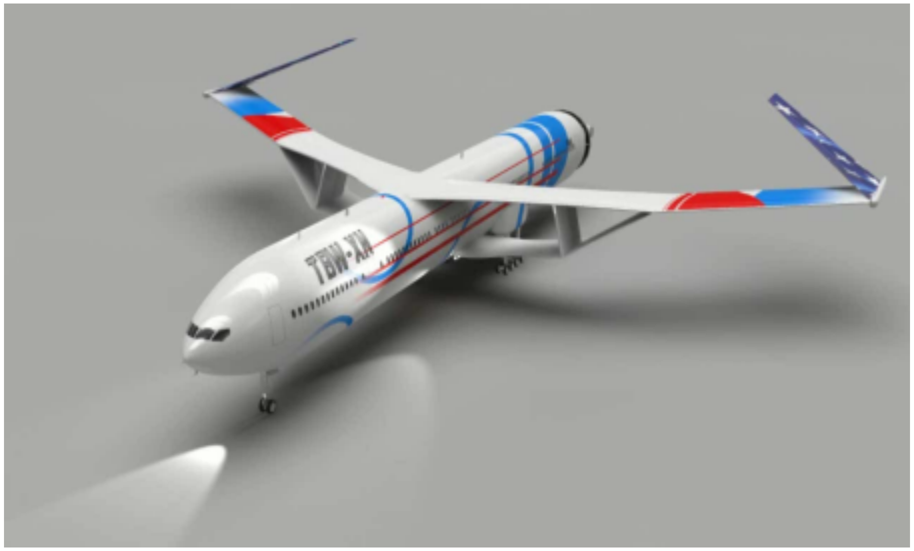
Lightweight High Temperature Superconducting Components

Propulsion Airframe Integration

Turboelectric Engine Cycle

Truss-Braced Wing (TBW) Research

NASA In-house, NIA, Virginia Tech, Georgia Tech



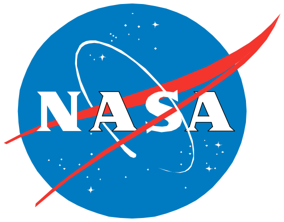
High Span Truss-Braced Wing with Fold

Goldschmied Propulsor

Laminar Flow

SFW N+3 Goals – Final Thoughts

- Noise – tied to regulation, Stage 4
  - Drive towards National goal of noise within airport boundaries
  - Review -71 dB cum below Stage 4 –*is it the right level in this timeframe?*
- Emissions – LTO NOx tied to regulation, CAEP 6
  - Other emittants not regulated, yet
  - CO2 - a global climate change metric…
  - H2O, contrail, cirrus
  - NOx at cruise
  - …. *add additional environmental metrics, but what levels?*
- Fuel Burn – no regulation
  - -70% from current day reference, user defined depending on mission
  - MIT energy intensity metric, added climate impact metric
  - Boeing, added life cycle CO2
  - ……… *split energy efficiency and CO2/GHG into 2 goals*
- Field Length – exploit metroplex
  - Idea = enhance capacity/availability by accessing under utilized existing airports/runways to off load hub in metro area
  - 5000' field length for domestic operations (payload/range) seems to be worthy goal to have a positive impact on capacity/availability
  - ……. *probably a lower level metric, but 5000' is a good target*


NASA