National Aeronautics and Space Administration

Propulsion Technologies for Future Aircraft Generations: A NASA Perspective

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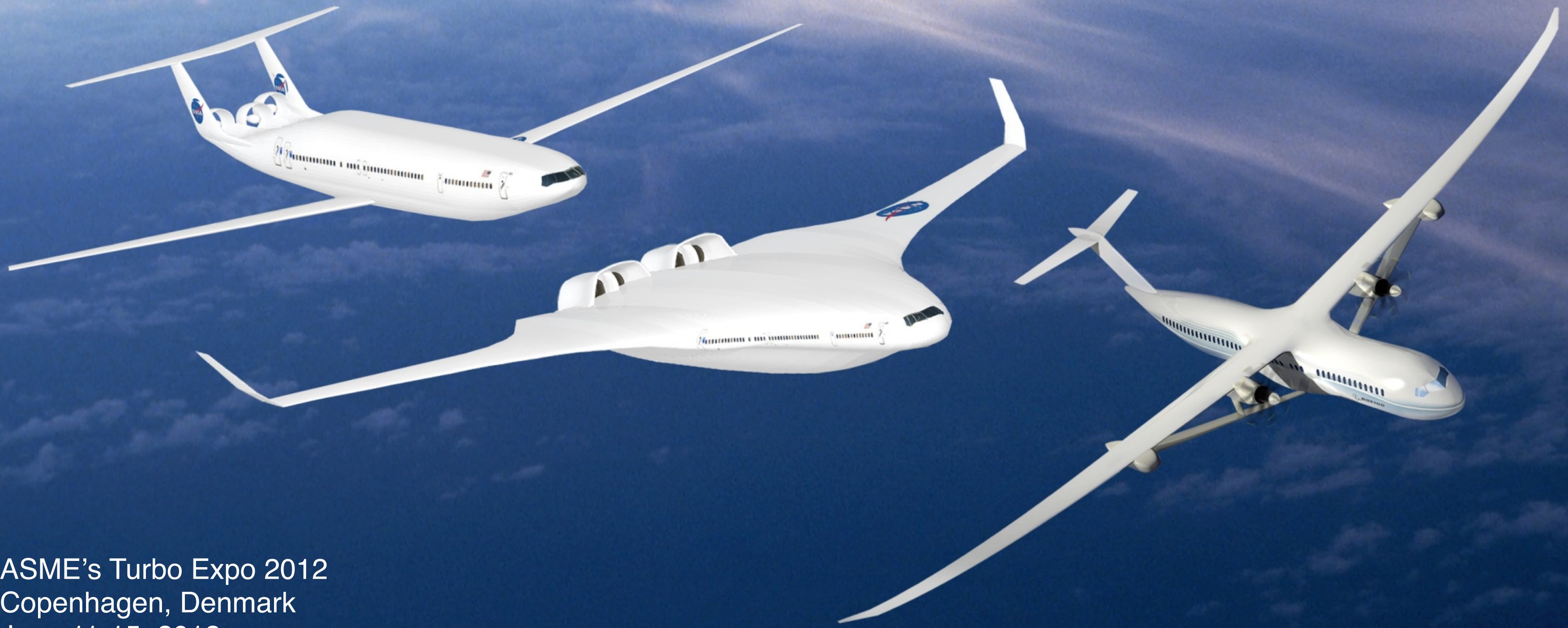


ASME's Turbo Expo 2012
Copenhagen, Denmark
June 11-15, 2012

SFW Strategic Framework/Linkage

Strategic Thrusts

1. Energy Efficiency

2. Environmental Compatibility

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-71 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

‡ CO_2 emission benefits dependent on life-cycle CO_{2e} per MJ for fuel and/or energy source used

Research addressing revolutionary N+3 Goals with opportunities for near term impact

Goal-Driven Advanced Vehicle Concept Studies (N+3)
purpose/approach

- Leverage external and in-house expertise
- Stimulate thinking to determine potential aircraft solutions to address significant performance, environmental, and operations issues of the future
- Identify advanced airframe and propulsion concepts and corresponding enabling technologies for commercial aircraft anticipated for 2030-35 EIS (market conditions permitting)
  - Develop plausible air travel scenario and define aircraft requirements
  - Generate advanced concept(s) that could thrive in future scenario
  - Anticipate changes in environmental sensitivity, demand, and energy
- Identify key driving technologies (traded at the system level)
- Prime the pipeline for future, revolutionary aircraft technology developments
- Use to inform and define SFW research portfolio and investments

Goal-Driven Advanced Vehicle Concept Studies (N+3)
summary

Advanced concept studies for commercial subsonic transport aircraft for 2030-35 EIS

Boeing, GE, GA Tech

154Pax
3500nm
M.70

NG, RR, Tufts, Sensis, Spirit

120Pax
1600nm
M.75

GE, Cessna, GA Tech

20Pax
800nm
M.55

MIT, Aurora, P&W, Aerodyne

354Pax
7600nm
M.83

180Pax
3000nm
M.74

Trends:

- *Tailored/Multifunctional Structures*
- *High AR/Active Structural Control*
- *Highly Integrated Propulsion Systems*
- *Ultra-high BPR (20+ w/ small cores)*
- *Alternative fuels and emerging hybrid electric concepts*
- *Noise reduction by component, configuration, and operations*

NASA, VA Tech, GT

305Pax
7730nm
M.85

NASA

300Pax
7500nm
M.84

Advances on multiple fronts are required to meet national goals - many broadly applicable features, some uniquely enabling.

2030 Fleet Scenario – Boeing

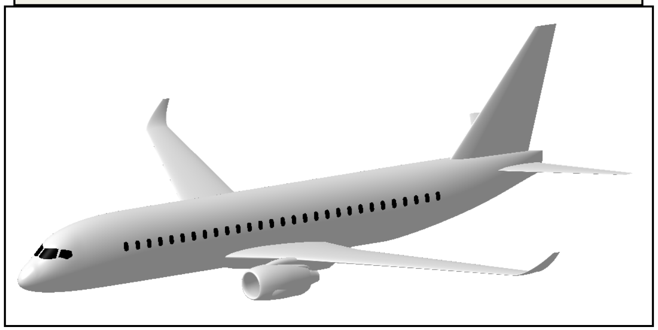
Boeing Current Market Outlook based; growth tied to GDP growth

	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

Medium/Large Single-aisle aircraft envisioned to dominate composition of 2030 transport fleet and miles flown

Scenario Driven Configurations – Boeing

N+3 Reference
"Refined SUGAR"



N+3 High L/D
"SUGAR High"

N+3 Electric Trade Aircraft
"SUGAR Volt"

- Fuel-Cell
- Batteries
- Hybrid

N+3
Reduced Noise HWB
"SUGAR Ray"

Awarded Phase II NRA to continue work on SUGAR Volt concept

N+3 Scenario and Requirements - MIT

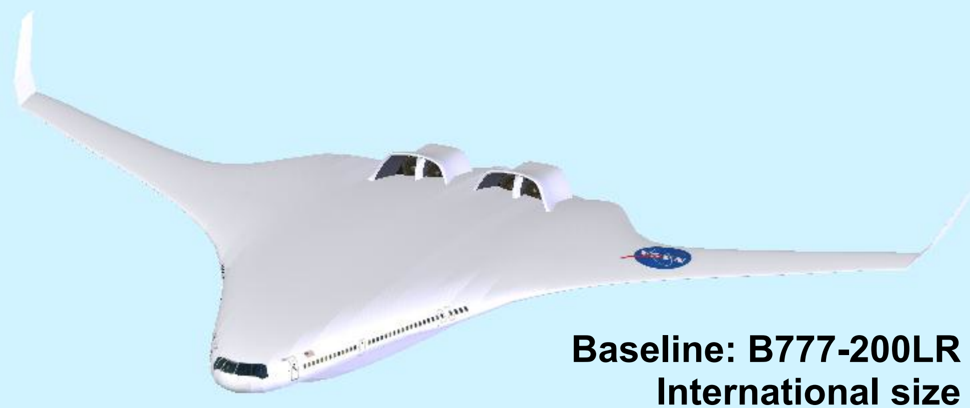
Size	• **Domestic**: 180 passengers @ 215 lbs/pax (737-800) • **International**: 350 passengers @ 215 lbs/pax (777-200LR) • Multi-class configuration • Increased cabin baggage
Range	• **Domestic**: US transcontinental; max range 3,000 nm with reserves • **International**: Transpacific; max range 7,600 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 stringency) • 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

Scenario Driven Configurations - MIT

Double-Bubble (D series):
modified tube and wing with lifting body

Baseline: B737-800
Domestic size

Hybrid Wing Body (H series)



Baseline: B777-200LR
International size

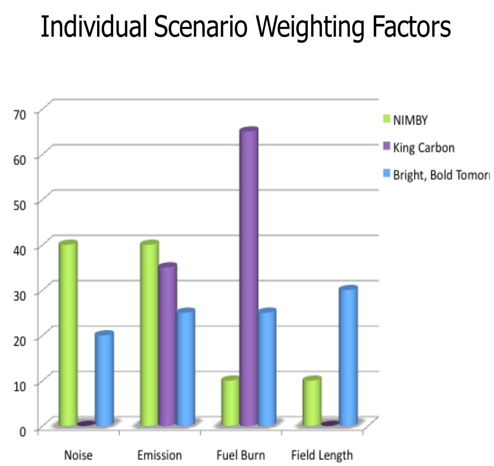
- Developed 2 aircraft based on domestic or international usage
- Awarded Phase II NRA to continue investigation of D-series concept

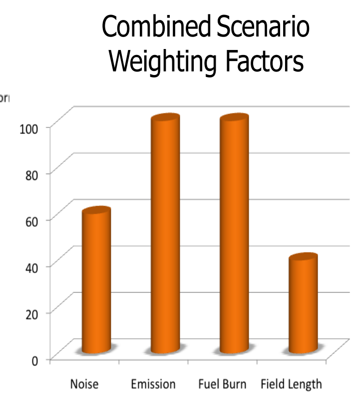
Scenario Analysis – Northrop Grumman

- Work entailed developing future scenario(s) that describe the challenges that may be facing commercial aircraft operators in the 2030-35 and beyond timeframe
  - Provides a context within which the proposer's advanced vehicle concept(s) may meet a market need/enter into service

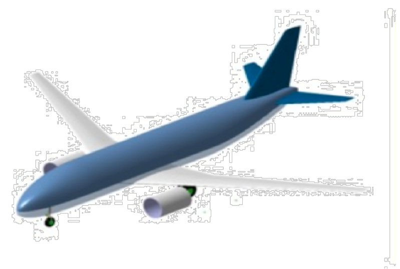
- N-G provided four scenarios that covered the range of possibilities
  - King Carbon
  - Not In My Backyard
  - Bright Bold Tomorrow
  - Doom and Gloom

- Scenarios used to develop weighting factors for use in design trade studies





Scenario Driven Configuration – Northrop Grumman



Preferred Concept Vehicle

		Target	Result
N+3 (2030-2035 Service Entry) Advanced Aircraft Concepts Goals (Relative to User-Defined Reference)	Noise (Cum below Stage 4)	-71 EPNdB	-70 EPNdB
	LTO NOx Emmissions (below CAEP/6)	-75%	-75%
	Performance: Aircraft Fuel Burn	better than 70%	64%
	Performance: Field Length	Exploit Metroplex Concepts	Exploit Metroplex Concepts
Mission Requirements Derived from Traffic Study	Range	1600nm	1600nm
	Passengers	120	120
	Field Length, TO and Ldg (SL, Std Day)	5,000 feet	5,000 feet
	Cruise Mach	0.75	0.75
	Cruise Altitude	< FL450	< FL450

N+3 Propulsion Technologies

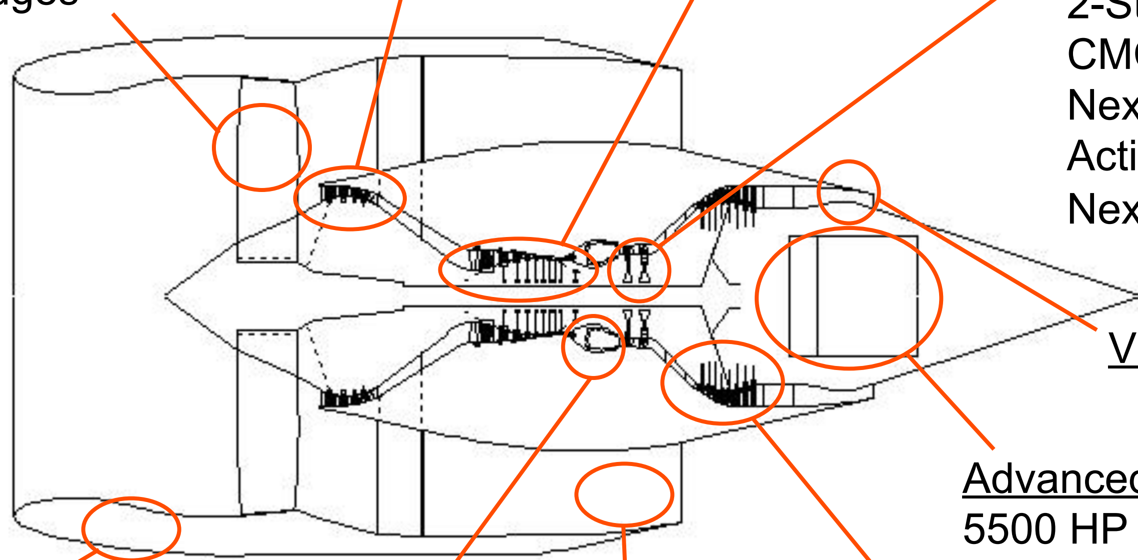
SUGAR Volt Engine Walkaround - hFan

<u>Advanced Composite Fan</u>
1.35 PR, 89.4” fan
Advanced 3-D aero design
Sculpted features, low noise
Thin, durable edges

<u>4-Stage Booster</u>

<u>Ultra-high PR core compressor</u>
59 OPR, 9 stages
Active clearance control

<u>HPT</u>
2-Stage
CMC nozzles + blades
Next-gen ceramic
Active purge control
Next-gen disk material



<u>Variable core nozzle</u>

<u>Advanced Motor & Gearbox</u>
5500 HP power output
Advanced gear box

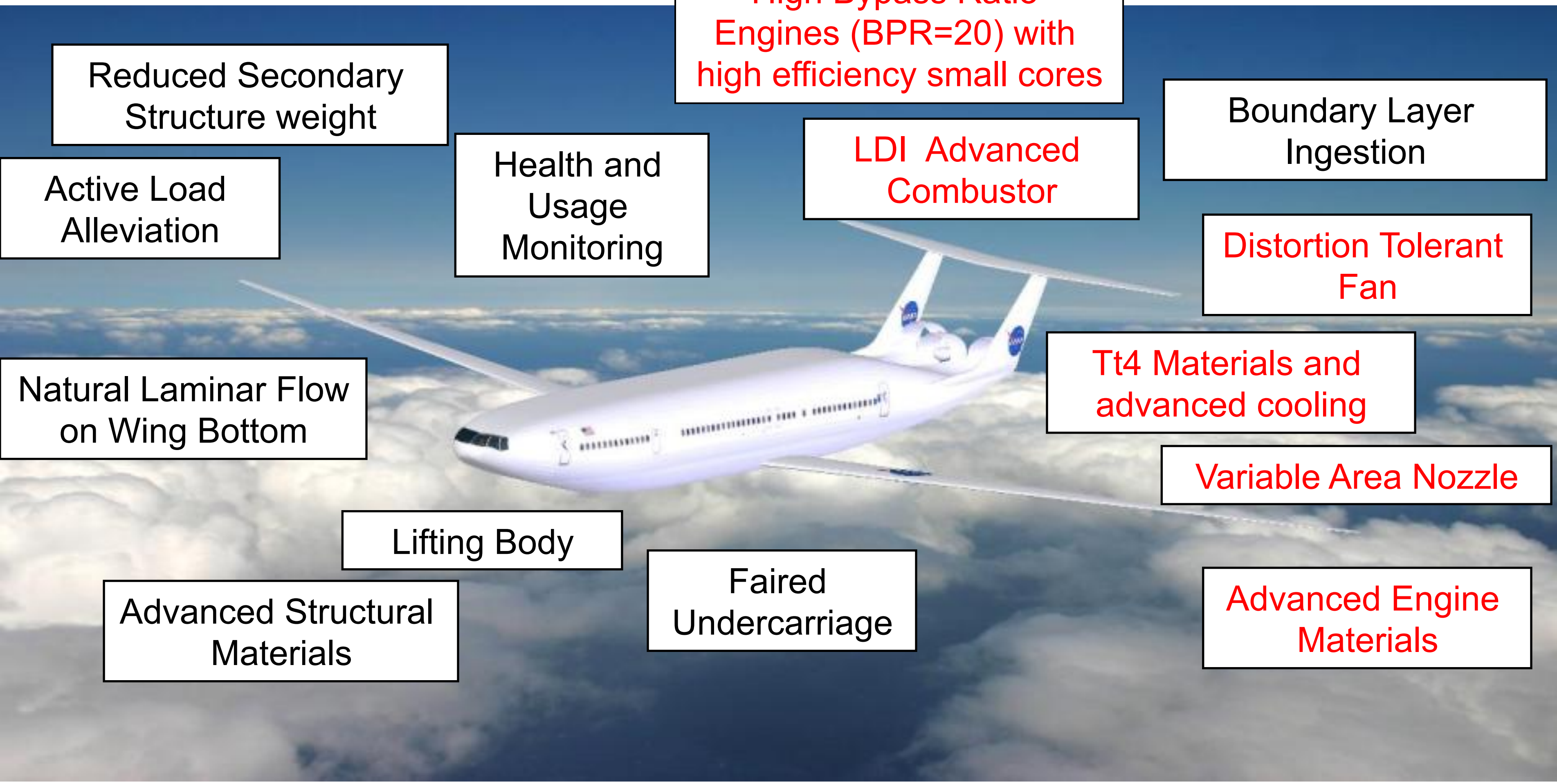
<u>Advanced nacelle</u>
Slender OD
Unitized composite
Advanced acoustic features

<u>Advanced combustor</u>

<u>Integrated thrust reverser/VFN</u>
Highly variable fan nozzle

<u>LPT</u>
8-Stage
Highly Loaded Stages
CMC blades/vanes (weight)

D8 Airframe & Propulsion Technology Overview



Key Propulsion Technologies listed in Red

Northrop Grumman Advanced Engine Architecture

Three-Shaft Turbofan

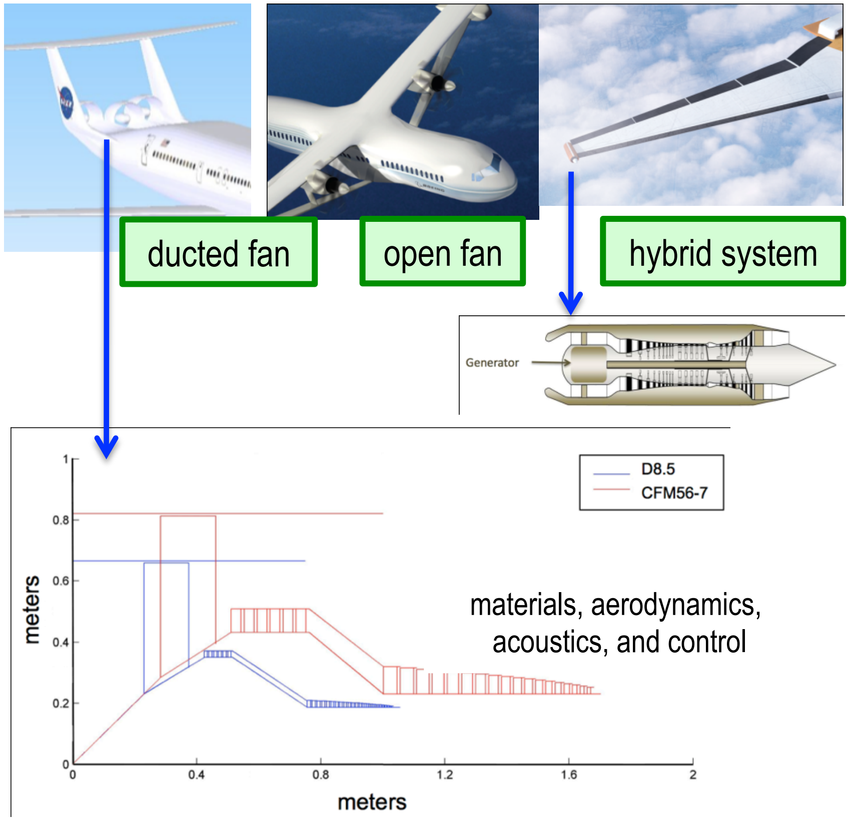
- High BPR (~18) = propulsive efficiency
- High OPR (~50) = thermal efficiency
- Low noise
- Low weight

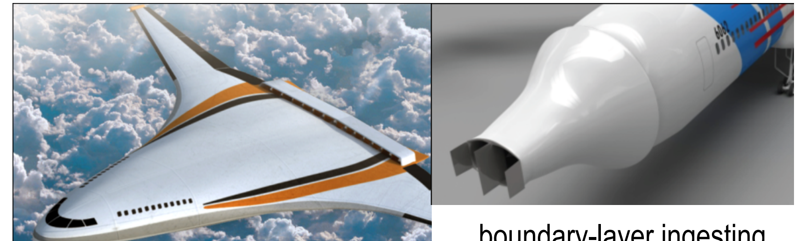
Technology Suite
Three-shaft Turbofan Engine
Ultra-High Bypass Ratio of ~18
CMC Turbine Blades
Lean-Burn CMC Combustor
Intercooled Compressor Stages
Swept Fan Outlet Guide Vanes
Fan Blade Sweep Design
Lightweight Fan/Fan Cowl
Compressor Flow Control
Active Compressor Clearance Control
Variable Geometry Nozzles

- Geared turbofan dropped due to similarities with three-shaft turbofan
- Open rotor had best sea level static fuel consumption
- Open rotor potential noise not quantified in time to be included

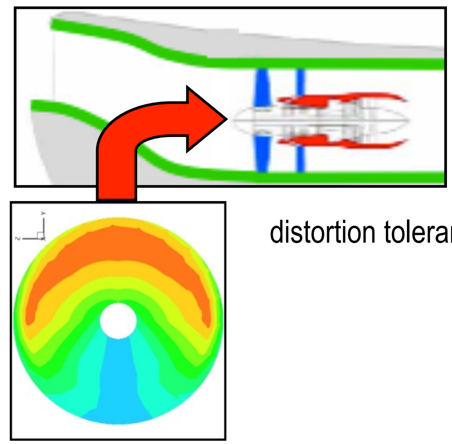
Propulsion Related Research Elements

versatile core applicable to variety of propulsion systems/installations

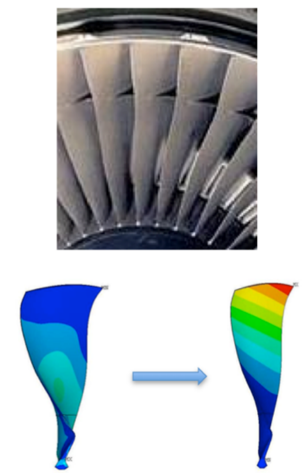




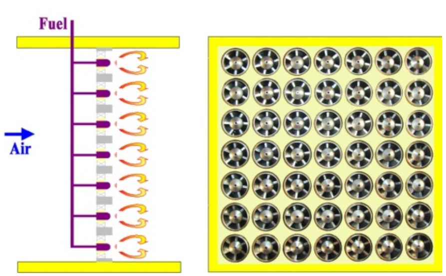
boundary-layer ingesting
concepts thrust vectoring



distortion tolerance



adaptive fan blades



multi-point
lean direct injection

jet/surface interaction acoustics