National Aeronautics and Space Administration

NASA N3-X with Turboelectric Distributed Propulsion

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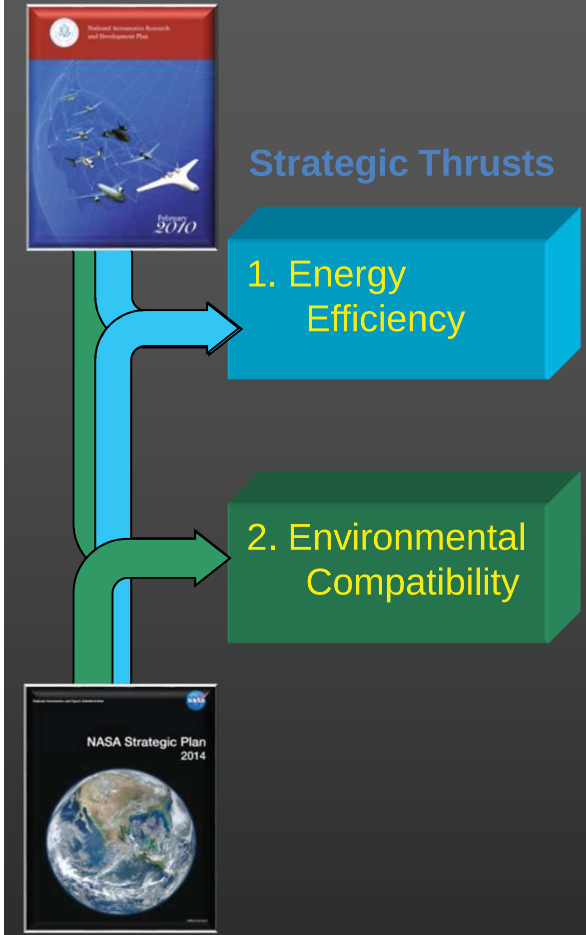
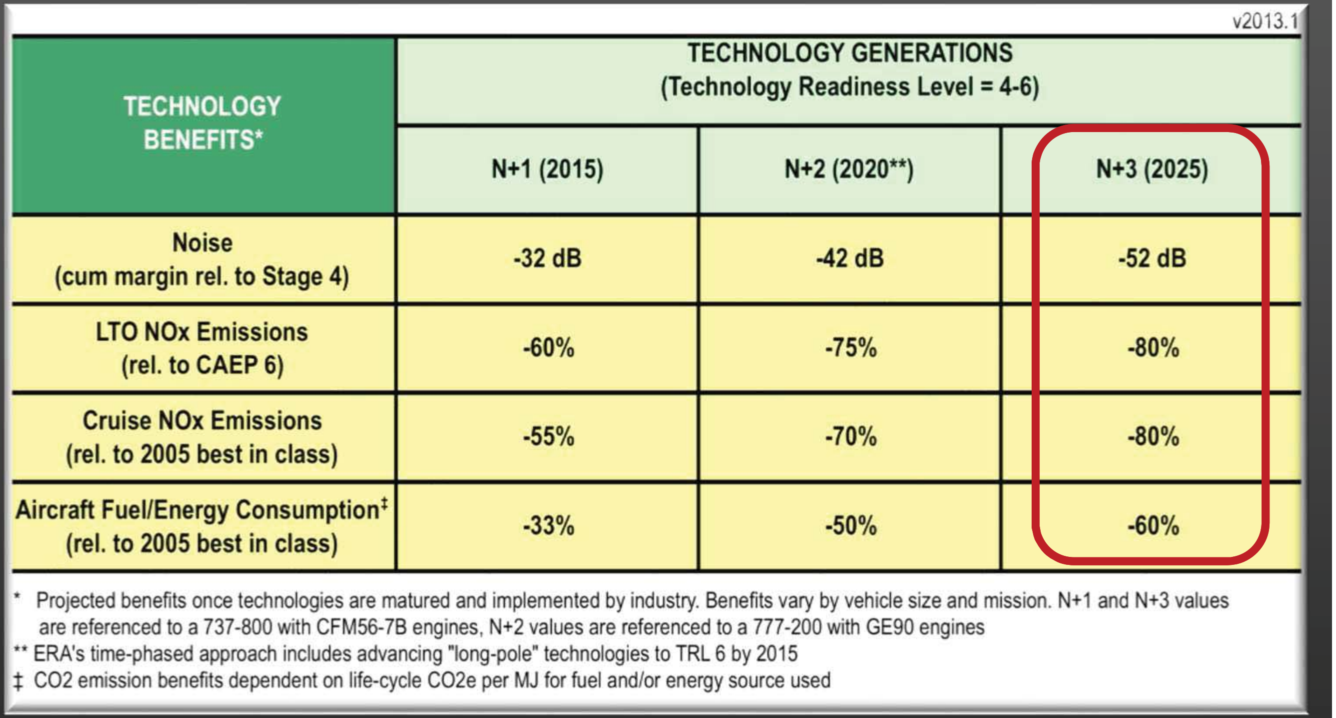
NASA Subsonic Transport System Level Metrics

Strategic Thrusts



1. Energy Efficiency

2. Environmental Compatibility



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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	-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

Research addressing revolutionary far-term goals with opportunities for near-term impact

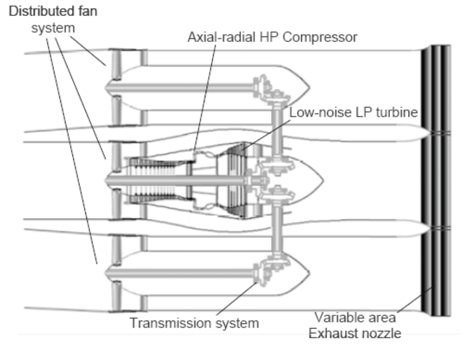
Reference Aircraft – The Boeing 777-200LR

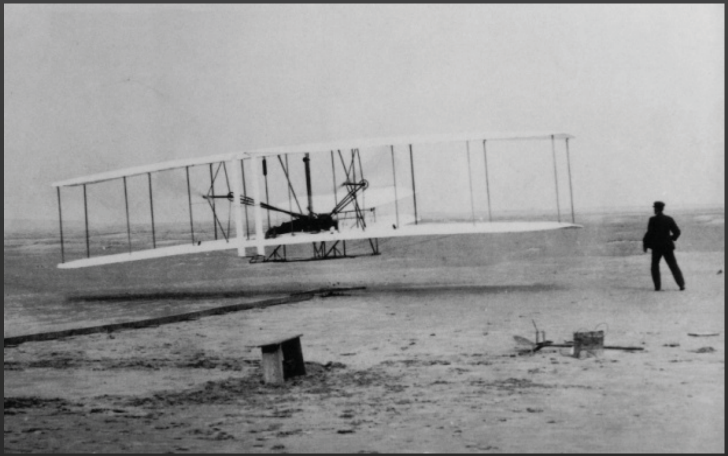
- **Passengers: 300**
- **Payload: 118,000 lbs (53.500 kg)**
- **Range: 7500 nm (14000 km)**
- **Cruise speed: Mach 0.84 @ 35k ft**
- **Fuel: 279,800 lbs (126.900 kg)**

Many Approaches to Distributed Propulsion

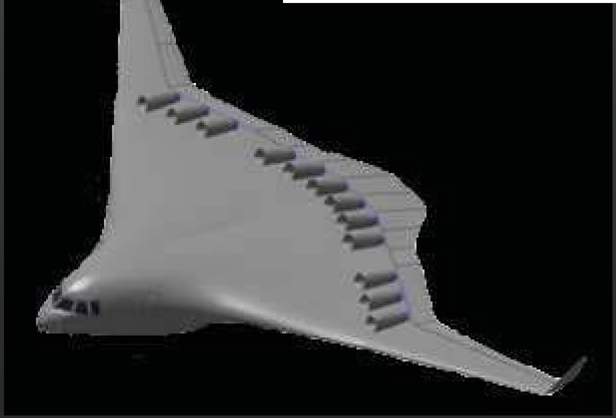
Gas-Driven:

Gear-Driven:





Chain-Driven:



Individual Engines:

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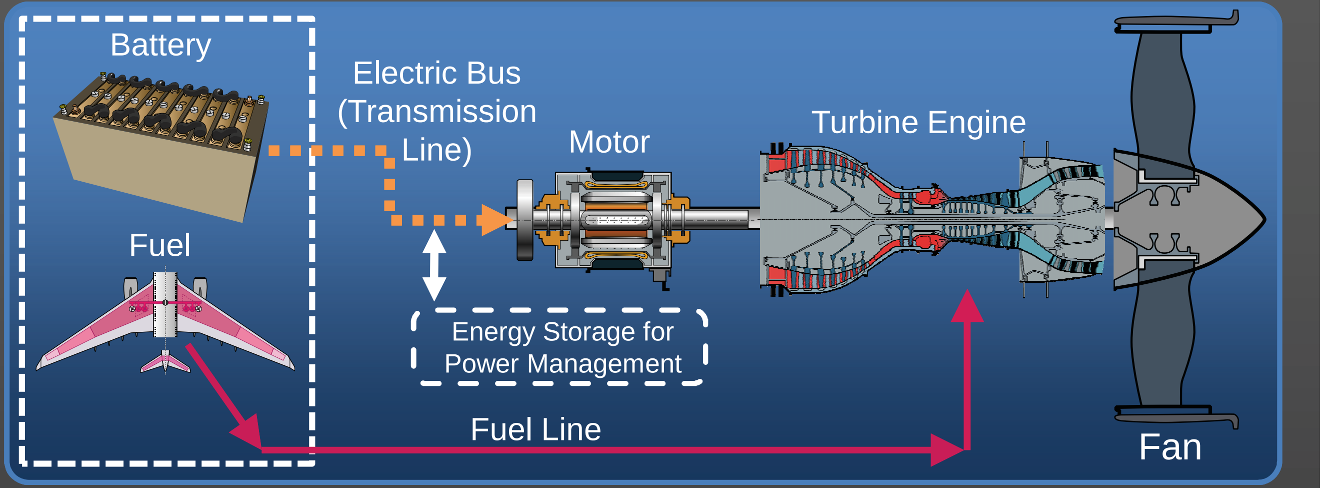
Types of Electric Propulsion

Hybrid Electric



Battery

Fuel

Electric Bus (Transmission Line)

Motor

Turbine Engine

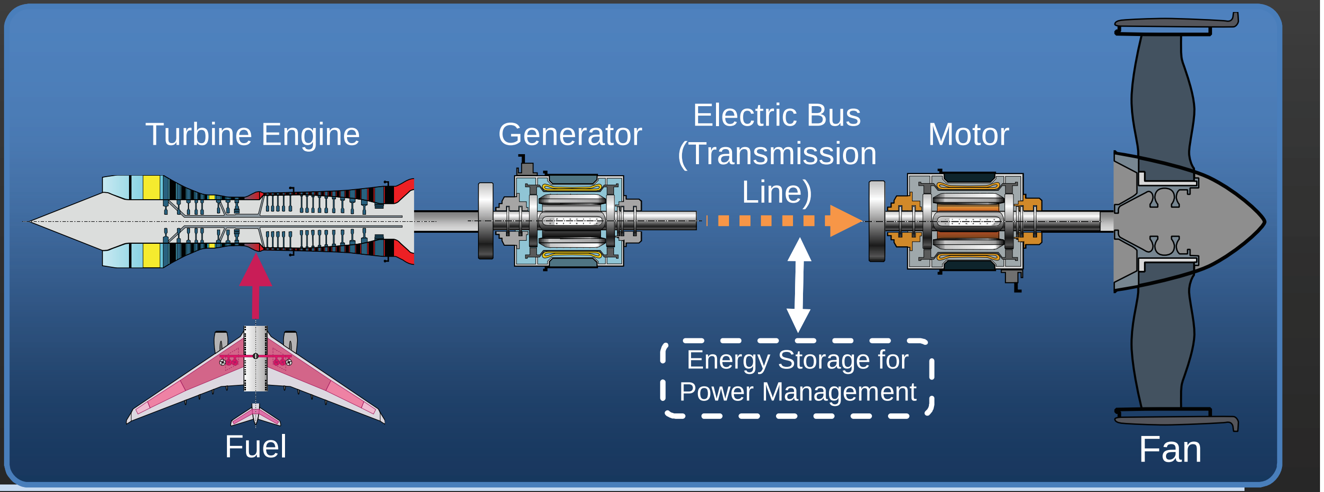
Energy Storage for Power Management

Fuel Line

Fan

Both concepts can use either non-cryogenic motors or cryogenic superconducting motors.

Turbo Electric



Turbine Engine

Generator

Electric Bus (Transmission Line)

Motor

Energy Storage for Power Management

Fuel

Fan

Many Small, Distortion-Tolerant Fans Yields Large Total Area and High Effective Bypass Ratio

Wide Propulsor Array Maximizes Boundary Layer Ingestion & Wake Filling

Superconducting Motors/Generators

Forward and Aft Fan Noise Shielding by Airframe

Superconducting Redundant DC microGrid

Highly Efficient Gas Generator

N3-X

N+3 Technology Cycle Design Values

Propulsor

Fan Pressure Ratio = 1.3
Fan Efficiency = 95.3% (podded)
= 94.3% (embedded)
1% embedded distortion efficiency penalty
Inlet Total Pressure Loss = 0.2%

Turboshaft Engine

Polytropic Efficiencies:
- LPC/HPC = 0.9325
- LPT/HPT = 0.93
- PT = 0.924

Temperature Limits:
- T3 = 1810 R (1006 K)
- T4 = 3360 R (1867 K)

Cooling *(Uncooled CMC rotors/stators)*:
- HPT = 4% (nonchargeable)
- LPT = 2% (nonchargeable)
- PT = 1% (chargeable)

Electrical System (N3-X/TeDP)

BSCCO	Motor Eff	=	99.94%
	Generator Eff	=	99.93%
	Tmax	=	50 K
MgB2	Motor Eff	=	99.97%
	Generator Eff	=	99.98%
	Tmax	=	30 K
Inverter	Efficiency	=	99.93%
	Tmax	=	100 K
Cryocooler	% of Carnot Eff	=	30%
	Tsink	=	Tamb

TeDP Cycle Results

	RTO		TOC	
	BSCCO	MgB_2	BSCCO	MgB_2
Total Vehicle Thrust - lbf	**94,200**	**85,800**	**35,500**	**33,400**
Specific Fuel Consumption - lbm/hr/lbf	**0.236**	**0.217**	**0.341**	**0.313**
Specific Energy Consumption - BTU/s/lbf	**1.216**	**1.194**	**1.761**	**1.727**
Effective bypass ratio	**35**	**36**	**29**	**30**
Overall pressure ratio	**57**	**57**	**84**	**84**
Max compressor exit temperature -°R	**1,800**	**1,800**	**1,680**	**1 ,680**
Maximum turbine inlet temperature - °R	**3,360**	**3,360**	**3,26 0**	**3,260**
Fan nozzle exit velocity - ft/s	**610**	**600**	**990**	**990**
Turboshaft nozzle exit velocity - ft/s	**760**	**750**	**1,370**	**1,360**

RTO (sea level, M0.24, ISA+27 °R) ***TOC (3 4,000 ft, M0.84, ISA)***

Electrical System

		BSCCO	MgB_2
Generator X 2	Power – hp (MW)	41080 (30,6)	37840 (28,2)
	Power/Weight – hp/lb (kw/kg)	35 (57)	35 (57)
	Weight – lbs (kg)	1180 (536)	1090 (494)
Motor X 14	Power – hp (MW)	5920 (4,42)	5280 (3,94)
	Power/Weight – hp/lb (kw/kg)	14 (23)	14 (23)
	Weight – lbs (kg)	410 (186)	365 (166)
Inverter X 14	Power/Weight – hp/lb (kw/kg)	18 (30)	18 (30)
	Weight – lbs (kg)	323 (147)	299 (136)
Cooling System	Total Cryocooler Wt – lbs (kg)	5130 (2327)	
	LH2 Tank Wt – lbs (kg)		1510 (685)
Grid	Cable + Protection – lbs (kg)	3570 (1619)	3290 (1492)

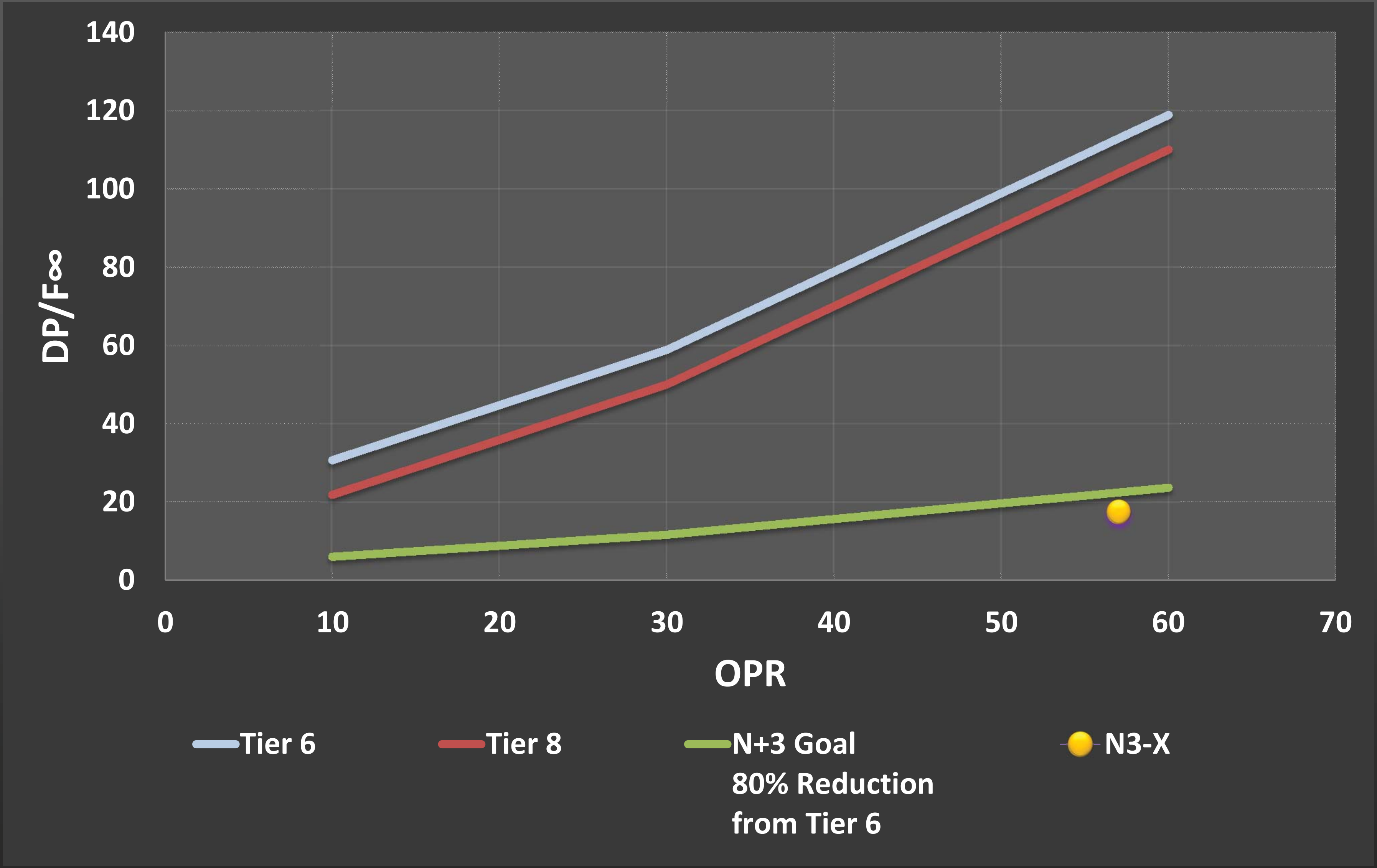
Propulsion System Weight

		BSCCO	MgB_2
Turbogenerator	Turboshaft Engine & Nacelle – lbs (kg)	4310 (1955)	4070 (1846)
	Generator – lbs (kg)	1180 (535)	1090 (494)
	One Turbogenerator – lbs (kg)	5491 (2491)	5157 (2339)
Propulsor	Fan + Nacelle – lbs (kg)	1562 (709)	1424 (646)
	Motor + Inverter – lbs (kg)	733 (332)	664 (301)
	One Propulsor – lbs (kg)	2295 (1041)	2088 (947)
Cooling System	Total Cryocooler Wt – lbs (kg)	5130 (2327)	
	LH2 Tank Wt – lbs (kg)		1510 (685)
Grid	Cable + Protection – lbs (kg)	3570 (1619)	3290 (1492)
Total System	2 TurboGen + 14 Props + Cooling + Grid	51,820 (23.505)	44,335 (20.110)
777-200LR	2 GE90-115 "Dry" + Nacelle + Pylon	47,300 (21.455)	

Mission Fuel/Energy Consumption

	Weight lbs (kg)	Mission Fuel Consumption lbs (kg)	Mission Energy Consumption BTU(MJ)	Mission Energy Reduction
777-200LR Class Aircraft	768,000 (348.400)	280,000 (127.000)	5.2E+09 (5.5E+06)	
N3-X BSCCO/Cryocooler	515,000 (233.600)	85,000 (38.560)	1.6E+09 (1.67E+06)	70%
N3-X MgB_2/LH_2	496,000 (229.800)	76,000 (34.470)	1.5E+09 (1.55E+06)	72%

N3-X LTO NOx Comparison



Noise Reduction

- Exposed Turboshaft Engine
    - Primary Noise Source
    - Inadequate nozzle length for Noise Treatment
- Flush Vectoring Propulsor Nozzle
    - Eliminates Scrubbing Noise
    - Aft Fan Noise Much Smaller Than Turbomachinery and Approach Flap Noise

- **Estimated 32 EPNdB Cum Below Chapter 4**

- Buried Turboshaft Engine
    - Moved to wing root
    - Leading Edge S-Duct Inlet
    - Upper Wing Surface Exhaust
- Setback Propulsor Nozzle
    - Eliminate Vectoring Nozzle at Price of Some Scrubbing Noise
- Low-noise Slotless Flaperons

- **Estimated 64 EPNdB Cum Below Chapter 4**

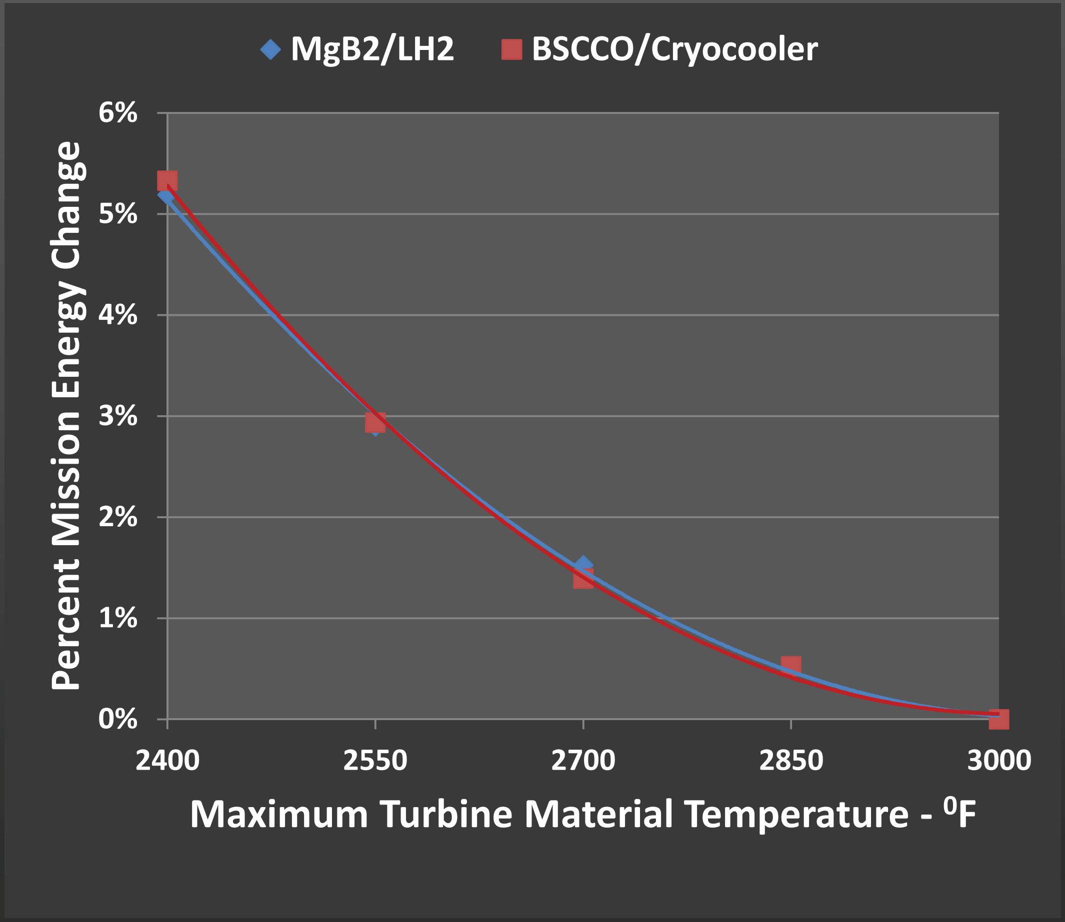
Comparison of N3-X to FW Metrics

Metric	N+3 Goal	N3-X
Noise (Cum Margin Rel to Chapter 4)	-52 db	-32db/-64 db
LTO NOx Emissions (Rel to CAEP Tier 6)	-80%	-85%
Cruise NOx (Relative to 2005 best in class)	-80%	
Aircraft Fuel/Energy Consumption (Relative to 2005 Best In Class)	-60%	-70% / -72%

Mission Energy Sensitivity to Propulsion System Parameters

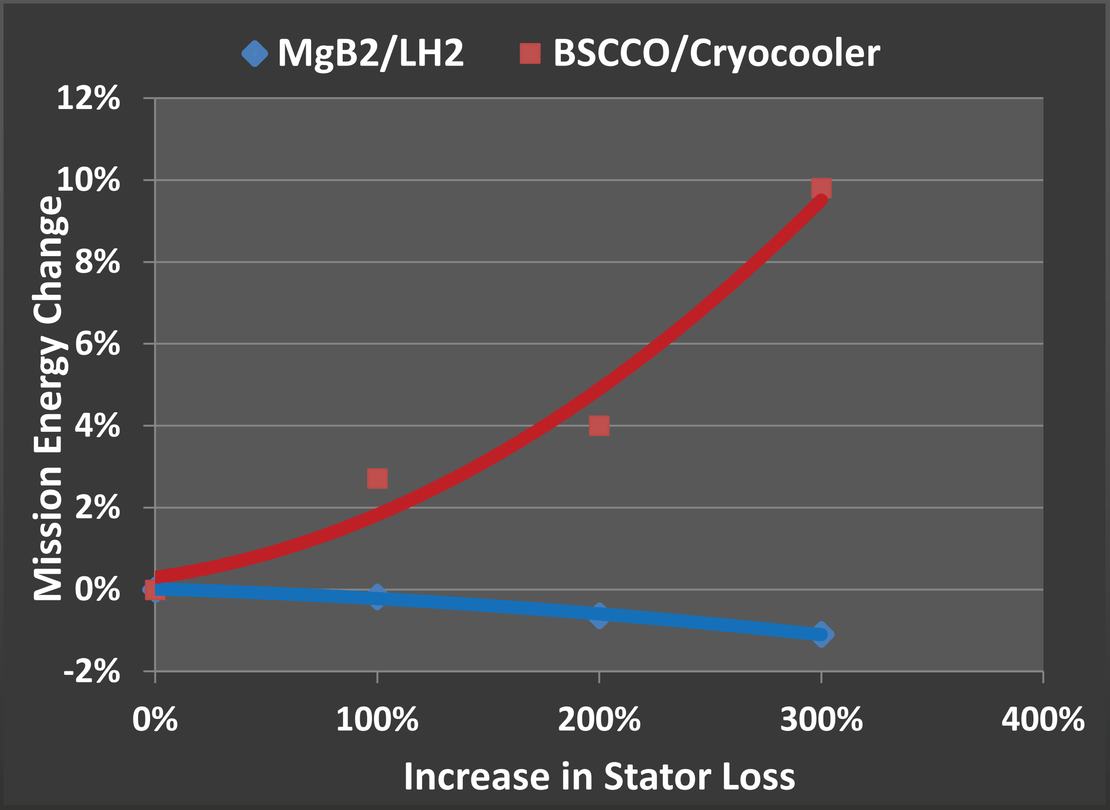
Parameter	Change	Mission Energy Sensitivity
TSFC	+1.15%	+1.0%
Propulsion System Weight	+10%	+0.8%
Inlet Total Pressure Loss	+1.0%	+3.0%
Fan Efficiency	+1.0%	+1.0%
Fan Pressure Ratio	+0.05	+2.0%
Compressor Discharge Temp	-50 ^{0}R	+1.0%
LPC Polytropic Efficiency	-1.0%	+0.81%
HPC Polytrophic Efficiency	-1.0%	+0.43%
HPT Polytrophic Efficiency	-1.0%	+0.72%
LPT Polytrophic Efficiency	-1.0%	+0.43%
PT Polytrophic Efficiency	-1.0%	+0.27%

Sensitivity to Turbine Rotor Inlet Temperature



- Current SOA CMC Temperature Limit is 2400 ^{0}F
- Technology development roadmap to get to 2700 ^{0}F has been defined
- **300 ^{0}F reduction from baseline only increases mission energy by 1.5%**
- Using cooled metallic blades for the HPT rotor one blades could allow TIT to remain at 3000 ^{0}F with CMC in subsequent rotors

Sensitivity to Stator Loss



- Stator Loss Effected By Superconducting Filament Size
- Assumed 10 micron
- SOA is 40-50 micron which results in 200% higher loss
- Addition loss in BSCCO/Cryocooler results in increased cryocooler size and power yielding 4% increase in mission energy
- Counterintuitively MgB2/LH2 Mission Energy DECREASES with increasing stator loss.
- This is due to more LH2 required for cooling which REDUCES total fuel weight which reduces mission energy

Questions?