# 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


v2013.1

| 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**

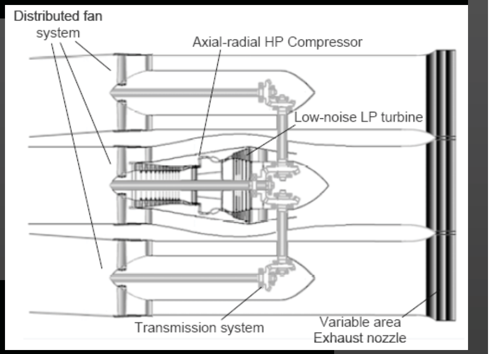
# Reference Aircraft – The Boeing 777-200LR

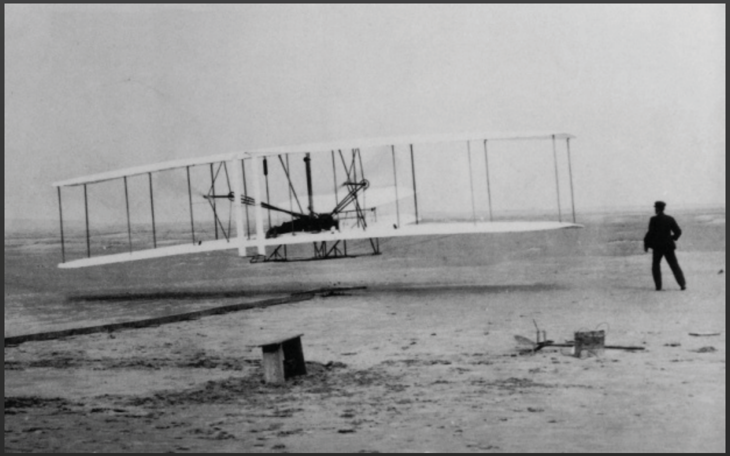
- **Passengers: 300**
- **Payload: 118,000 lbs (53.500 kg)**
- **Range: 7500 nm (14000 km)**
- **Cruise speed: Mach 0.84 @ 35k ft**
- **Fuel: 279,800 lbs (126.900 kg)**

# *Many Approaches to Distributed Propulsion*

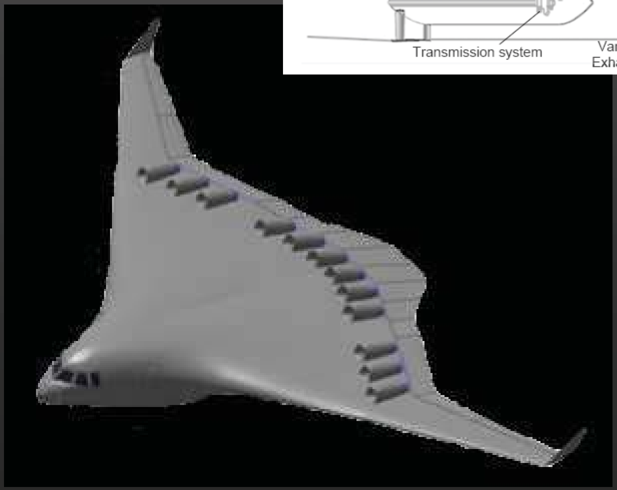
## Gas-Driven:

## Gear-Driven:



## Chain-Driven:



## Individual Engines:

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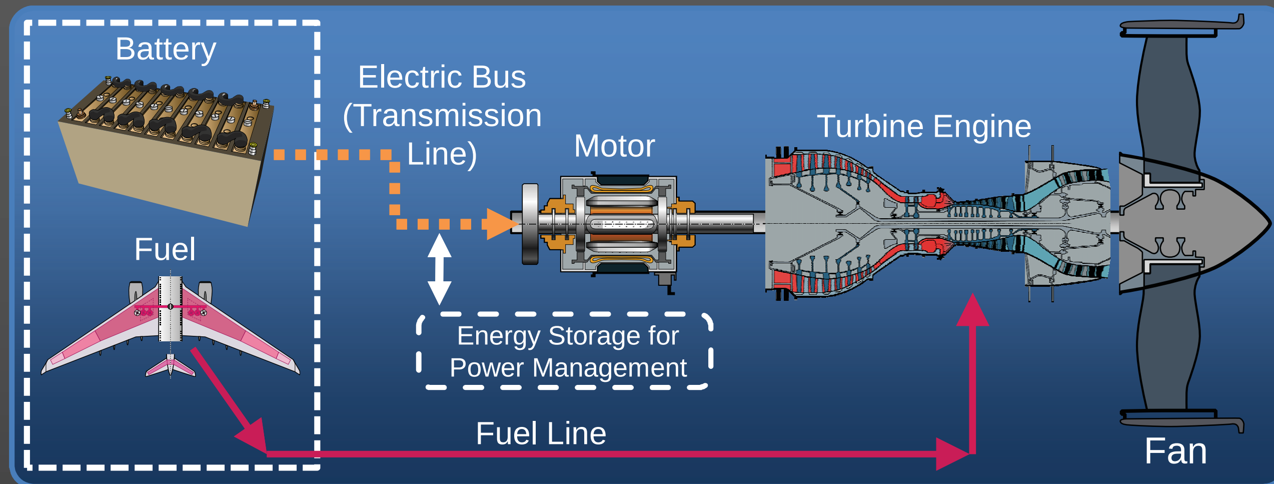
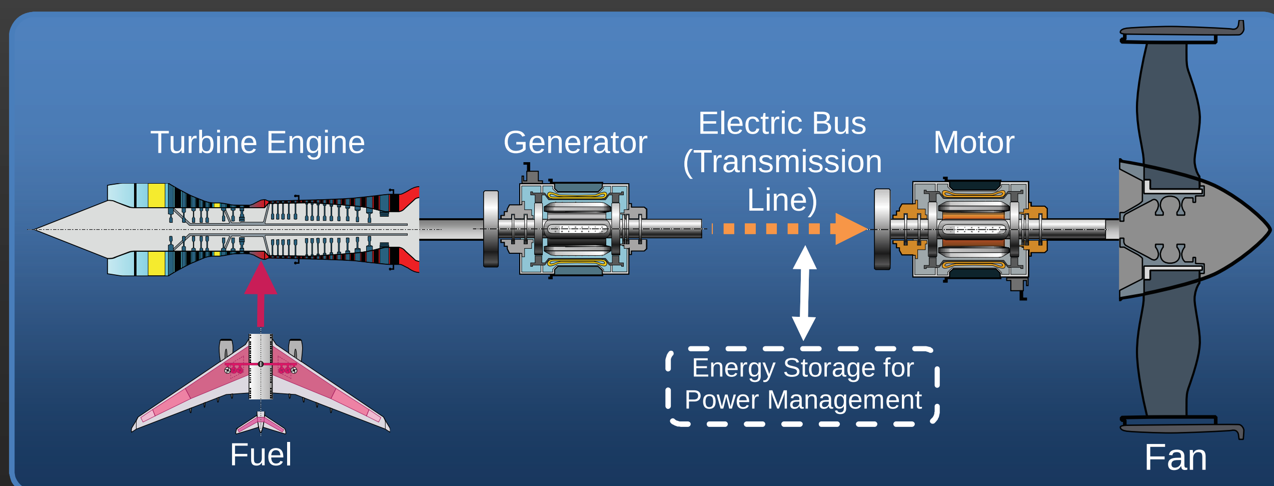
# Types of Electric Propulsion

## Hybrid Electric




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

## Turbo Electric



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

Highly Efficient Gas Generator

Forward and Aft Fan Noise Shielding by Airframe

Superconducting Redundant DC microGrid

# 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

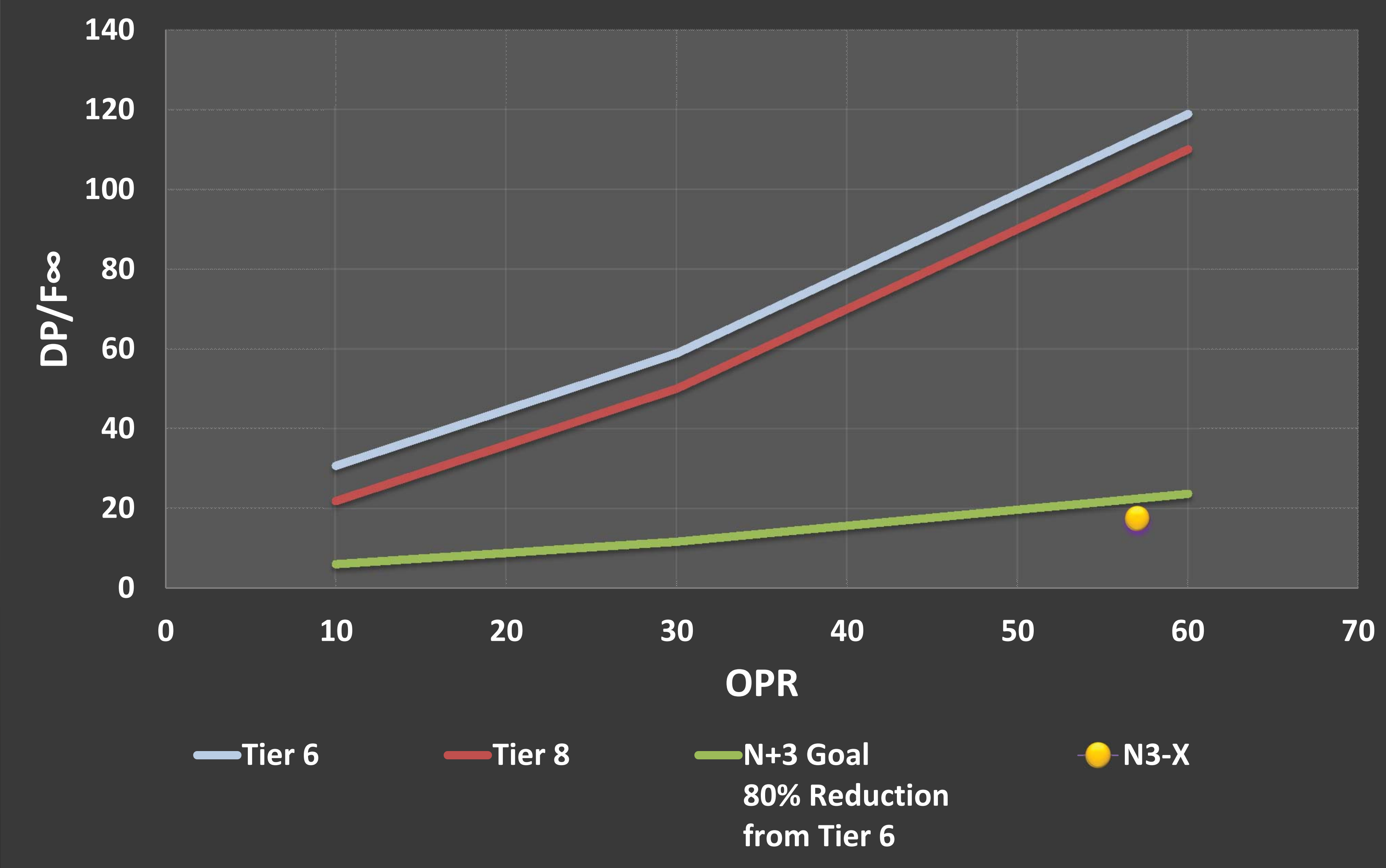
| | | BSCCO | $MgB_2$ |
|---|---|---|---|
| Turbogenerator | Turboshaft Engine & Nacelle – lbs (kg) | 4310 (1955) | 4070 (1846) |
| | Generator – lbs (kg) | 1180 (535) | 1090 (494) |
| | One Turbogenerator – lbs (kg) | 5491 (2491) | 5157 (2339) |
| Propulsor | Fan + Nacelle – lbs (kg) | 1562 (709) | 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% |

National Aeronautics and Space Administration

# 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**

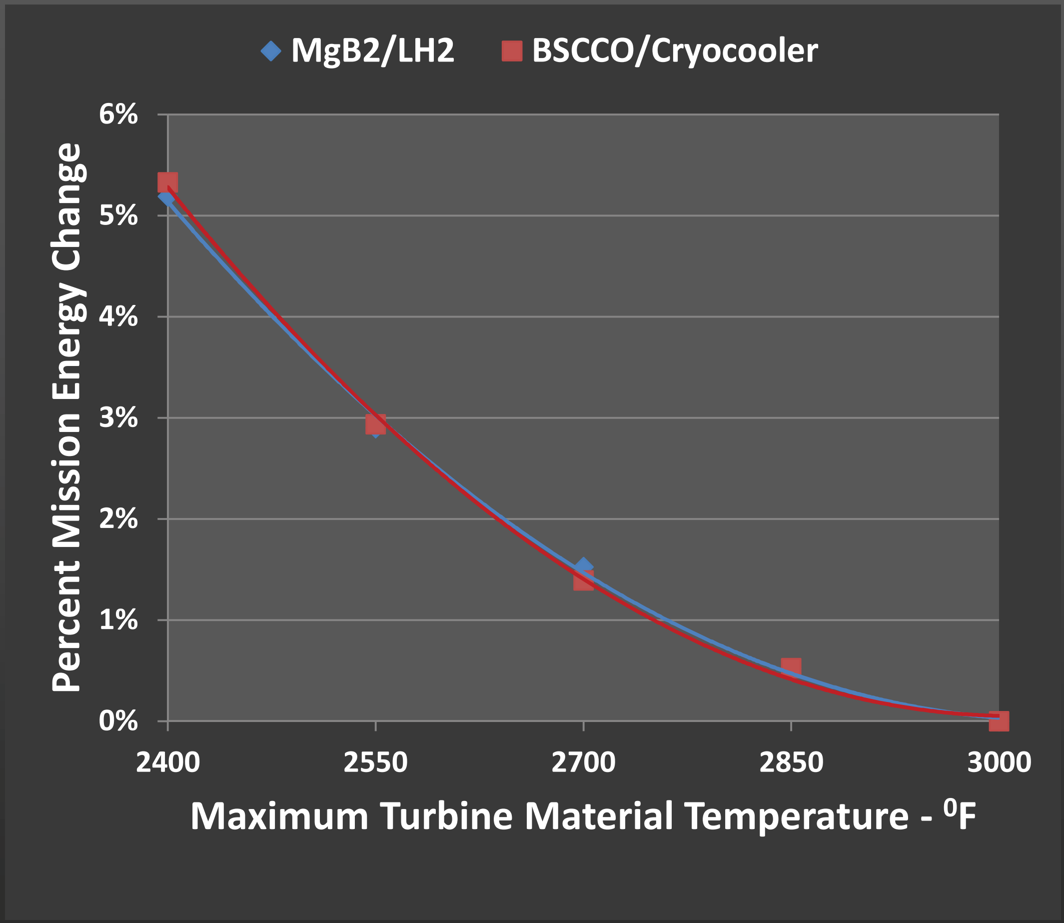
# Comparison of N3-X to FW Metrics

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

# Mission Energy Sensitivity to Propulsion System Parameters

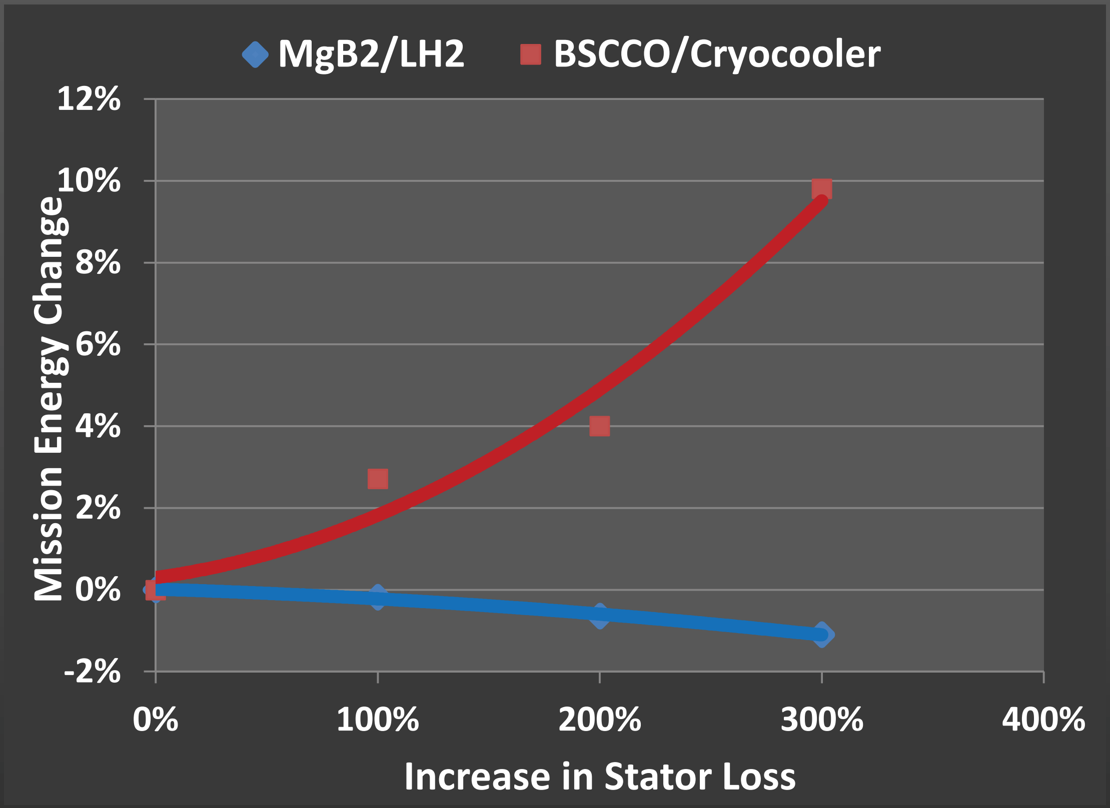
| Parameter | Change | Mission Energy Sensitivity |
|---|---|---|
| TSFC | +1.15% | +1.0% |
| Propulsion System Weight | +10% | +0.8% |
| Inlet Total Pressure Loss | +1.0% | +3.0% |
| Fan Efficiency | +1.0% | +1.0% |
| Fan Pressure Ratio | +0.05 | +2.0% |
| Compressor Discharge Temp | -50 $^0$R | +1.0% |
| 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?