National Aeronautics and Space Administration

NASA Electric Propulsion System Studies

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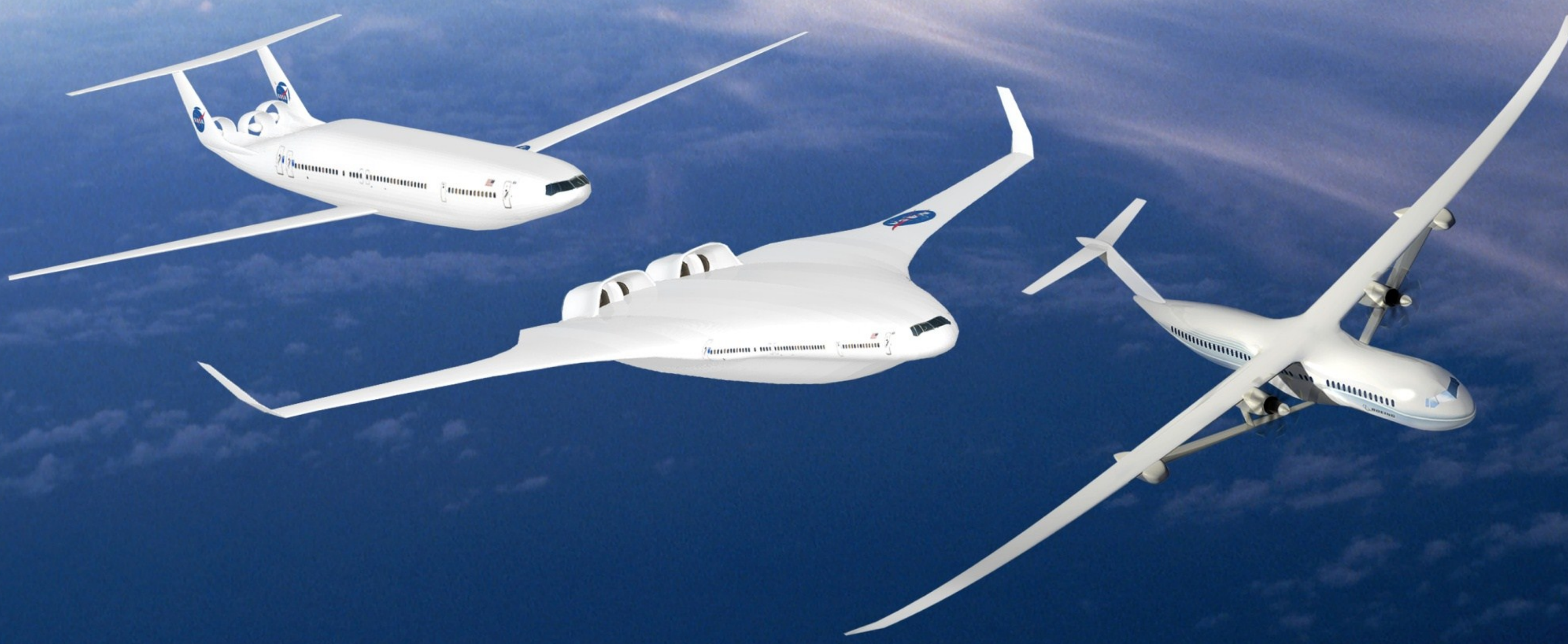
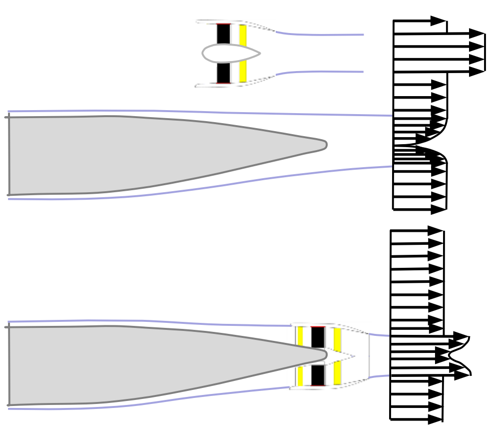


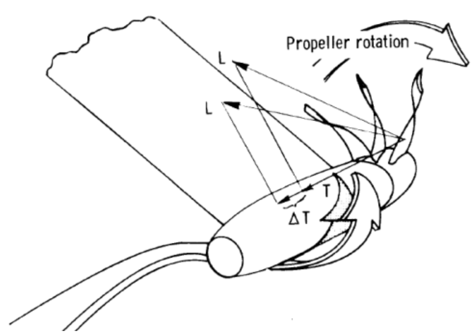
Outline

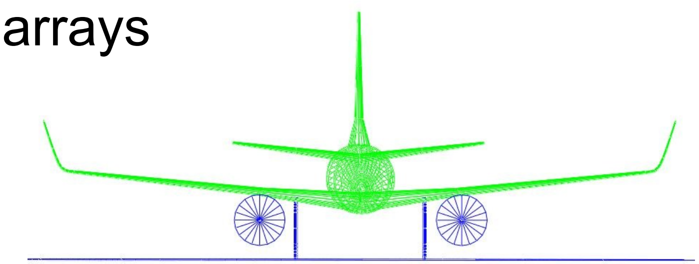
- Why Electric Propulsion
- Overview of Electric Propulsion architectures.
- Example Implementations.
  - Boeing SUGAR Volt
  - ECO-150
  - STARC-ABL
  - N3-X

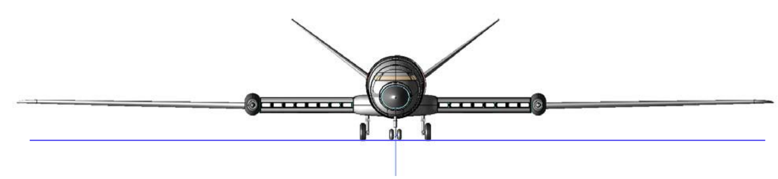
Why Electric Propulsion

- Allows the use of non-CO2 emitting terrestrial power sources in aviation
- High flexibility in moving power around the vehicle is a key enabler for several different ways to integrate propulsion into the aircraft in ways to further reduce the energy intensity of the vehicle
  - Boundary Layer Ingestion
  - Wingtip Propulsors
  - Highly distributed embedded propulsor arrays

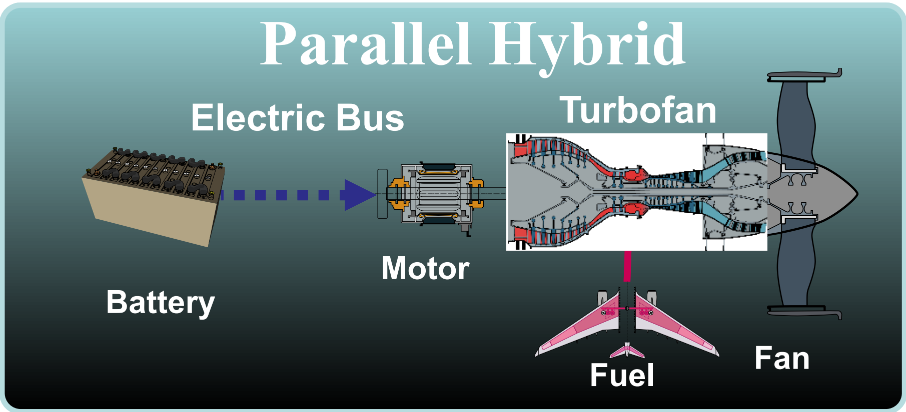


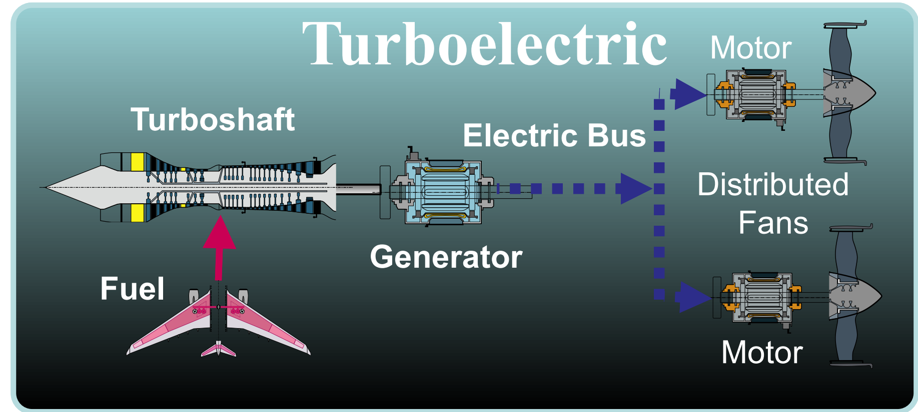


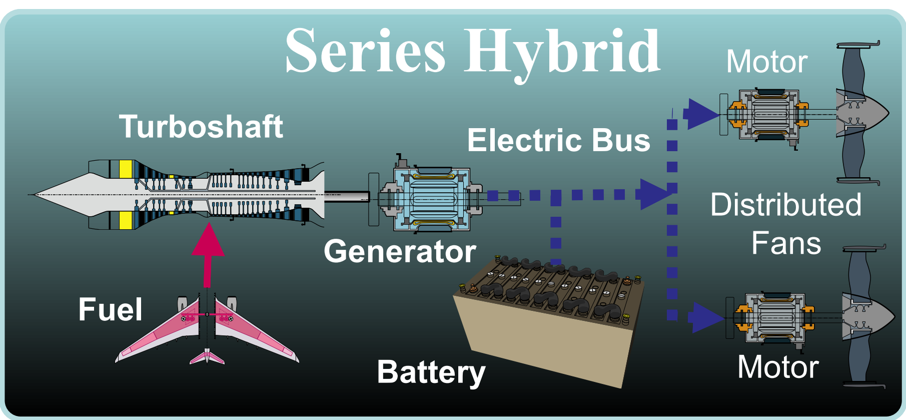


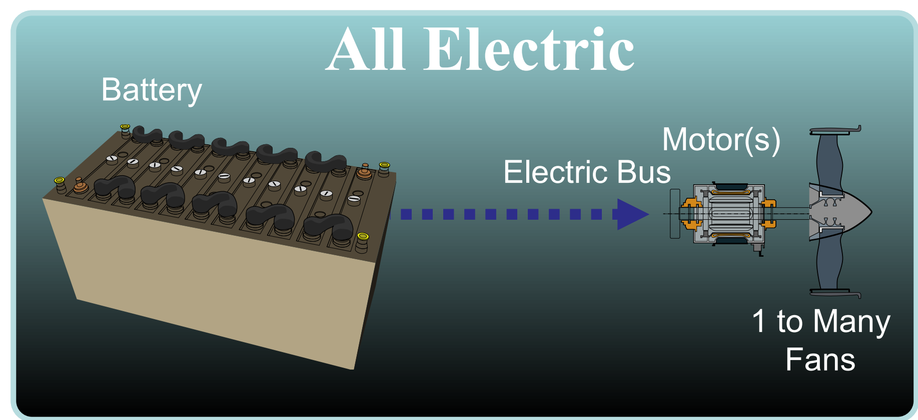


Four Cardinal Electric Propulsion Architectures

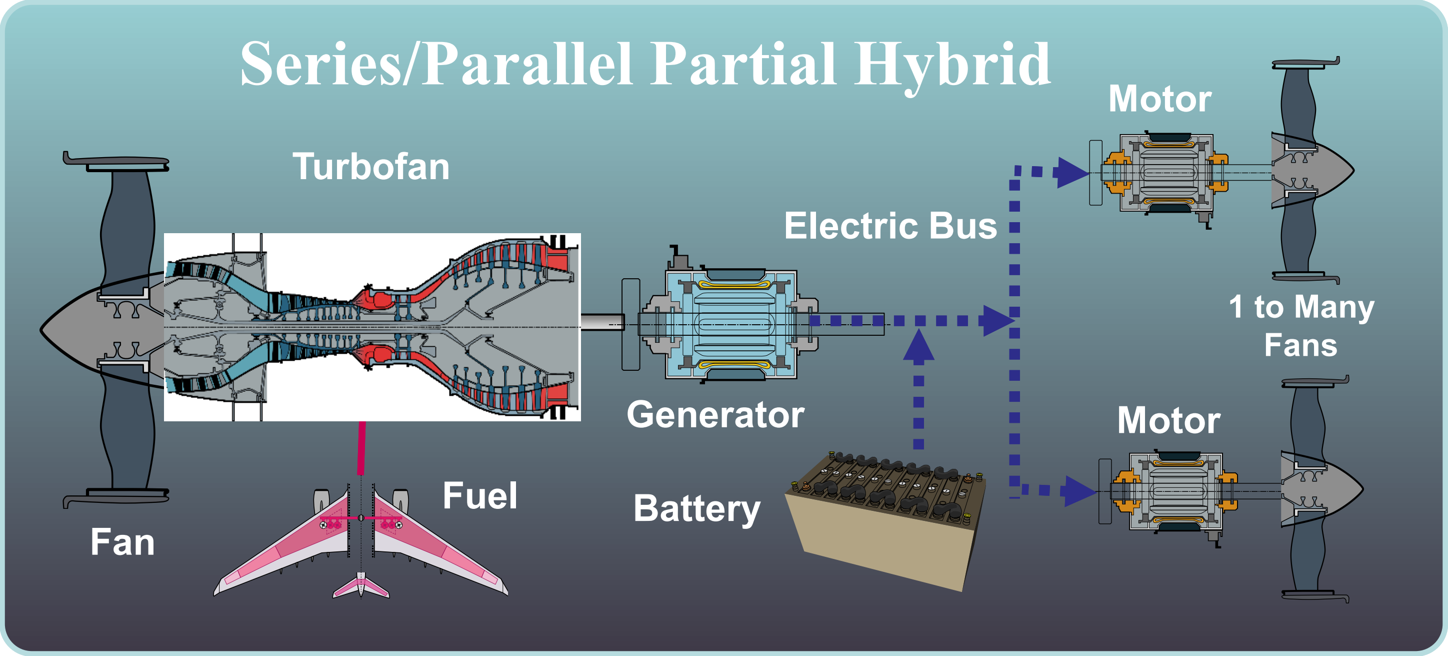




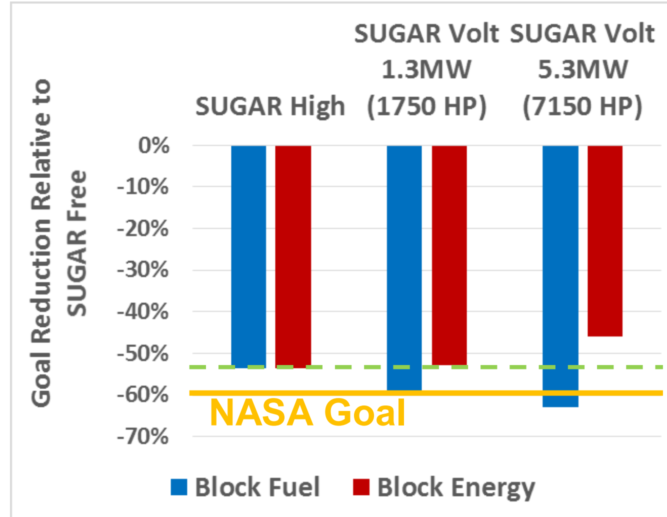




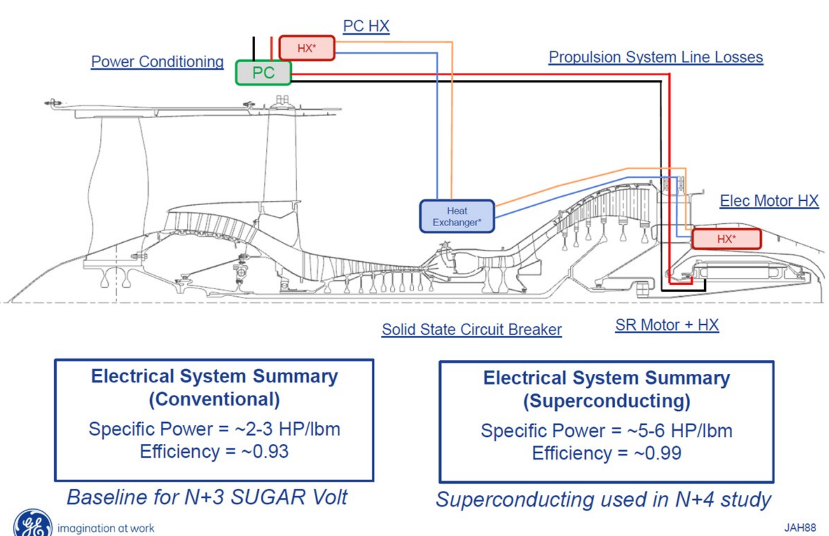
But Wait, There's More!



Boeing SUGAR Volt (Parallel Hybrid)



hFan Electrical System Walk-around



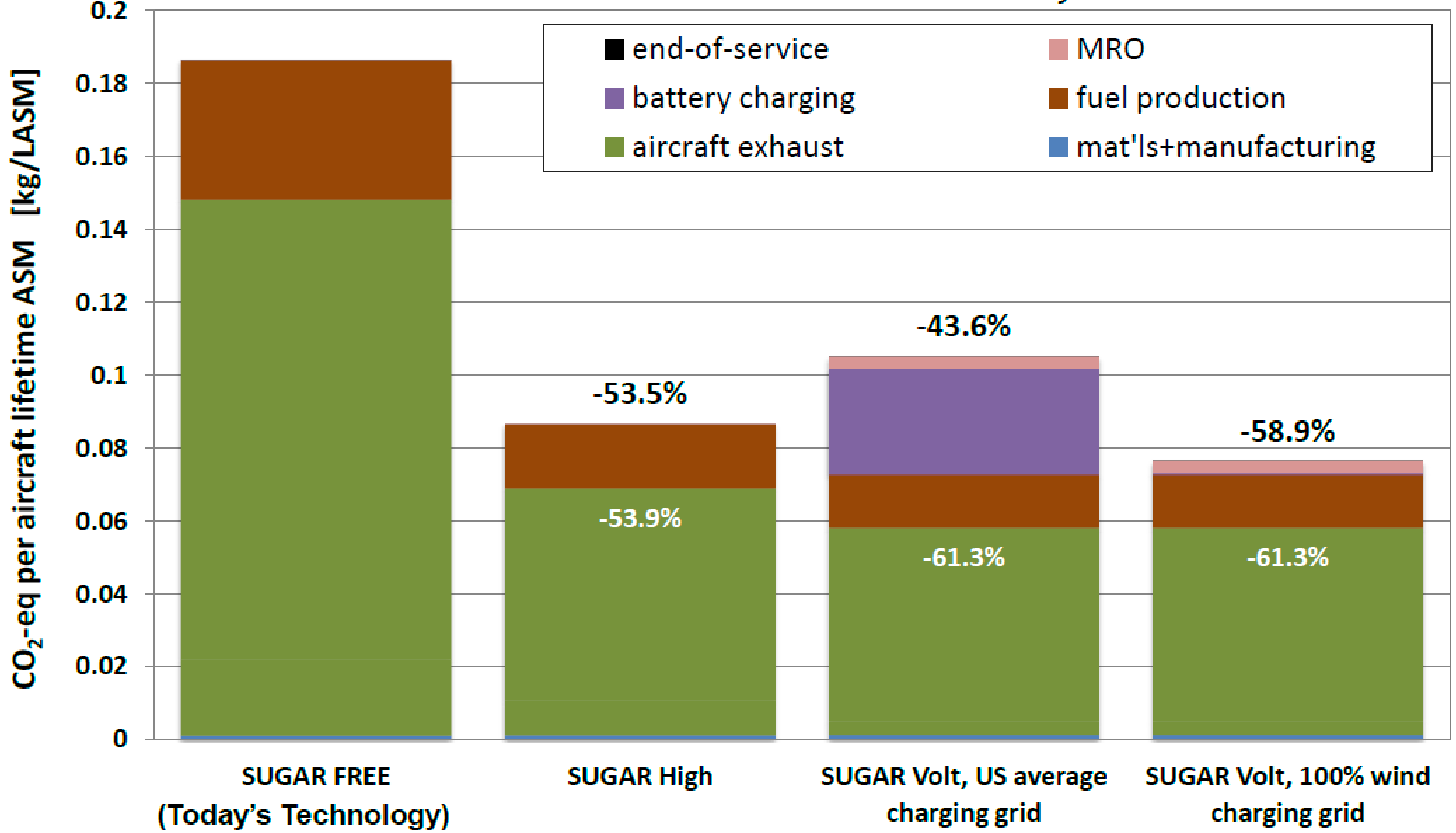
- 150 passenger
- 3500 nm range
- 750 Wh/kg battery energy density
- 1.3 MW motor meets NASA N+3 fuel reduction goal at the same energy consumption as SUGAR High
- 5.3 MW motor reduces fuel consumption further at the price of increased energy consumption compared to SUGAR High

Boeing Research & Technology, Boeing N+3 Subsonic Ultra Green Aircraft Research (SUGAR) Final Report

Boeing SUGAR Volt CO2 Reduction Dependent on Terrestrial Charging Grid

Engineering, Operations & Technology | **Boeing Research & Technology**

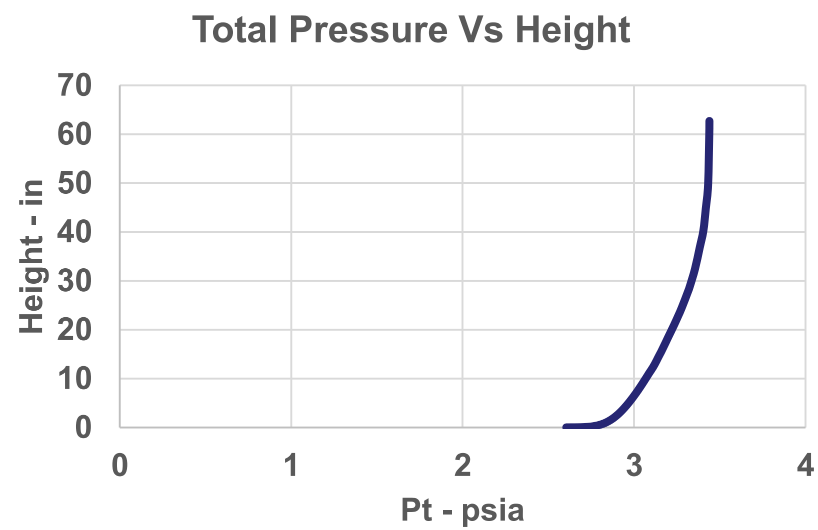
Non-contract analysis from SAE 2013-01-2277

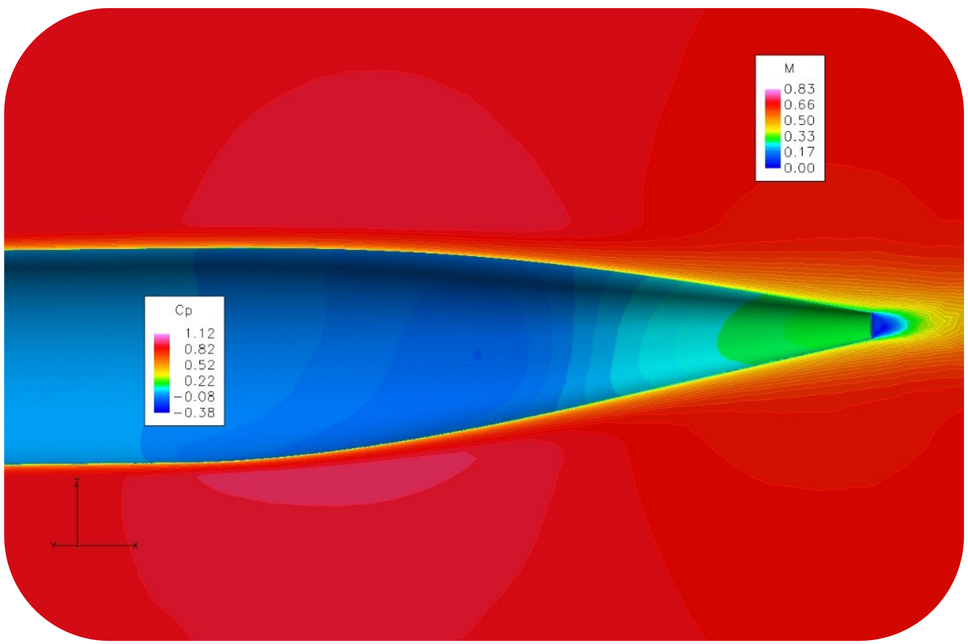


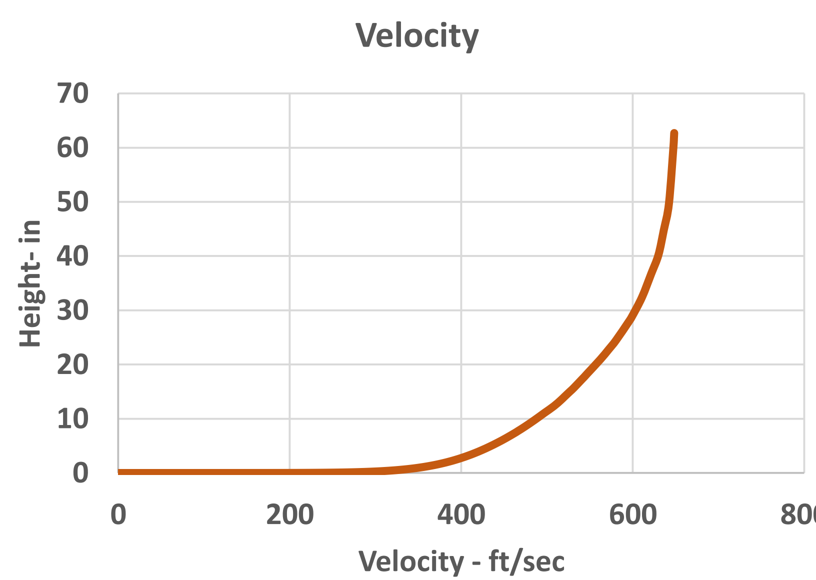
SUGAR Volt Hybrid Electric technologies provide additional benefits only if a renewable energy source is used to charge aircraft batteries

Flow around an aircraft tailcone

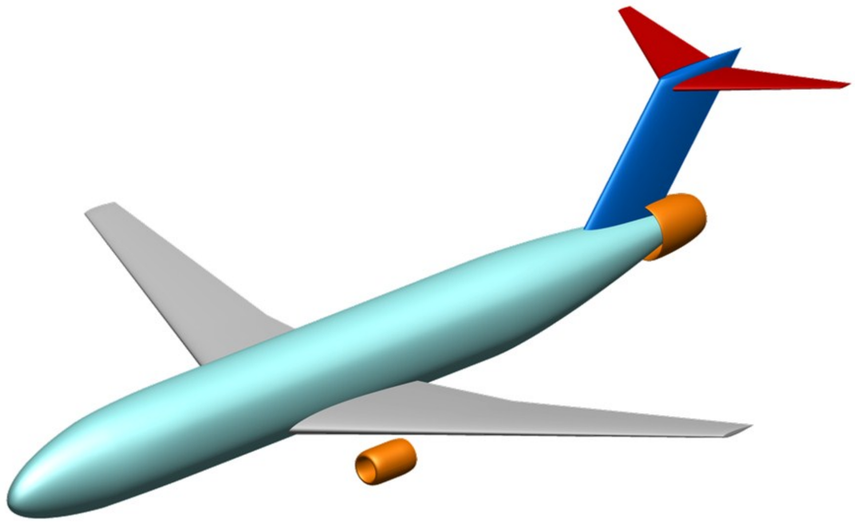
- Diffusion into the base region of the aircraft means the velocity profiles represent more than just the viscous boundary layer of the fuselage
- Velocity profile nearly uniform circumferentially, so distortion is nearly all radial



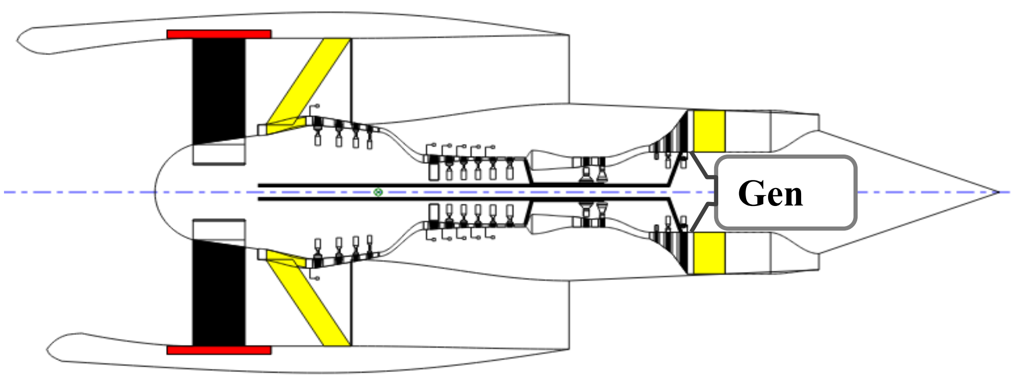


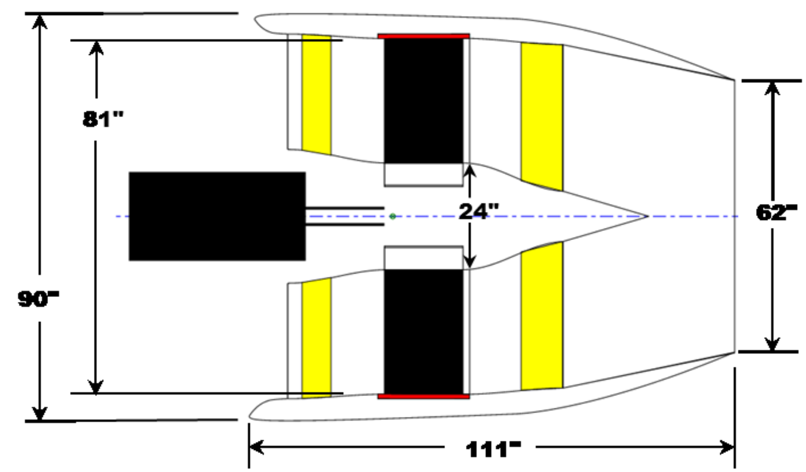


STARC-ABL*
(Partial Turboelectric/Fuselage BLI Fan)



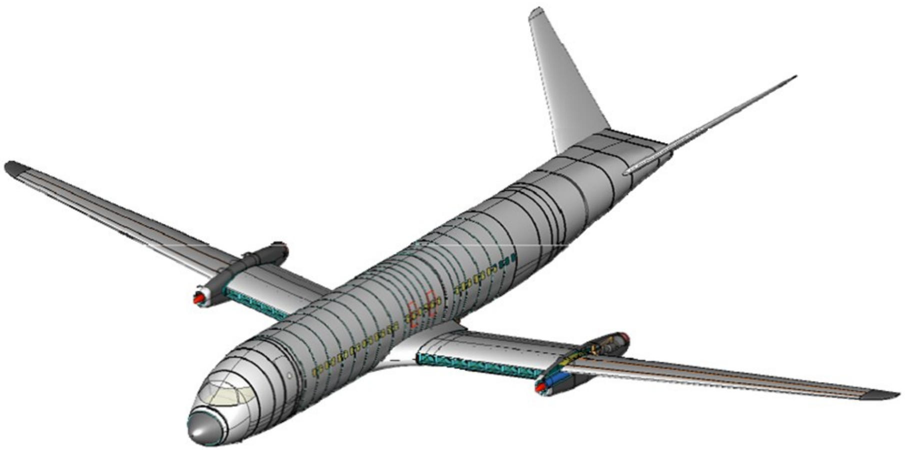
Passengers	**150**
Range	3500 nm
Cruise Speed	Mach 0.7
Tailcone Thruster Motor	2.6 MW (3500 hp)
Turbofan Generator	1.44 MW (1940 hp)
Turbofan Fan	1.95 MW (2615 hp)
Fuel Burn Reduction (vs same tech turbofan)	~10%





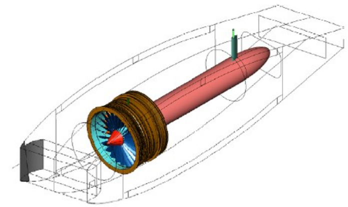
*STARC-ABL: Single-aisle Turboelectric AirCRaft – Aft Boundary Layer

ESAero ECO-150 (Fully Turboelectric/Distributed)

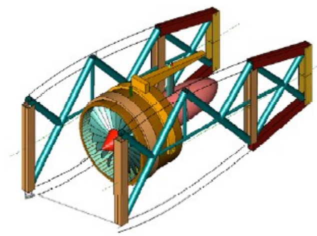


Propulsor

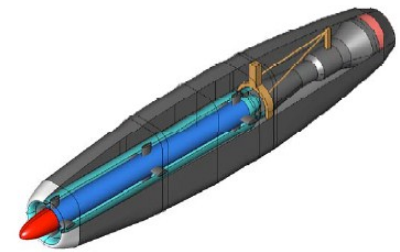
non-cryo motor

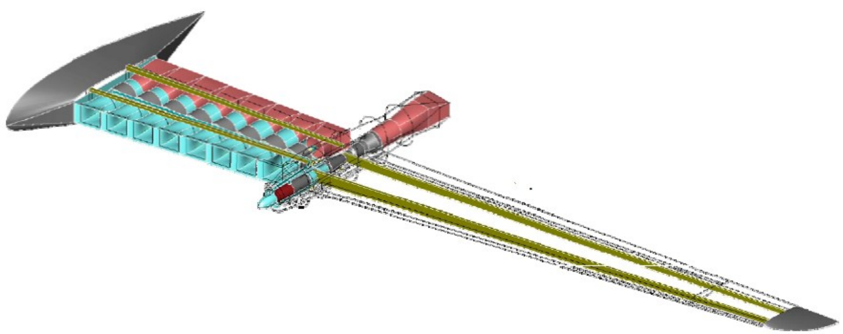


cryo motor



Turbogenerator with non-cryo generator





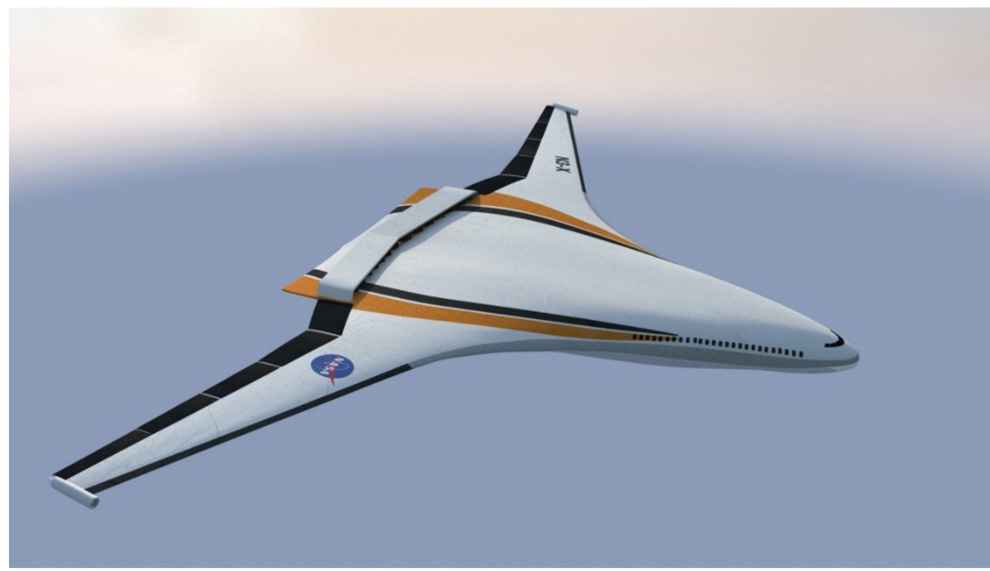
- 150 Passenger/35k lbs Payload
- 3500 nm range
- Mach 0.8 Cruise
- 2 8-MW turbine driven generators
- 16 1-MW motor driven fans
- Fuel reduction from 737-700
  - 44% Non-cryo
  - 59% Cryo (with LH2 cooling)

Empirical Systems Aerospace: SBIR NNX13CC24P Phase I 2013 / NNA10DA88Z Task 6 2012 / SBIR NNX10CC81P Phase I 2009 / SBIR NNX09CC86P Phase I 2008

NASA N3-X
(Fully Turboelectric/Distributed/BLI)

Baseline: B777-200LR/GE90-115B	
Passengers:	300
Range:	7500 nm
Payload:	118,000 lbs
Cruise Speed:	Mach 0.84
Fuel:	279,800 lbs

N3-X Superconducting	
Passengers:	300
Range:	7500 nm
Payload:	118,000 lbs
Cruise Speed:	Mach 0.84
Fuel:	76,000 lbs (-72%)
Generators:	30 MW
Motors:	4.3 MW

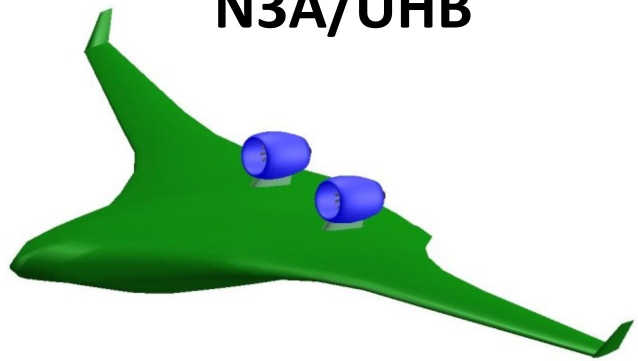


Turboelectric distributed propulsion benefits on the N3-X vehicle, Kim H.D. et al, Aircraft Engineering and Aerospace Technology Journal, Vol 86 Iss 6 pp. 558-561 2014 (http://dx.doi.org/10.1108/AEAT-04-2014-0037)

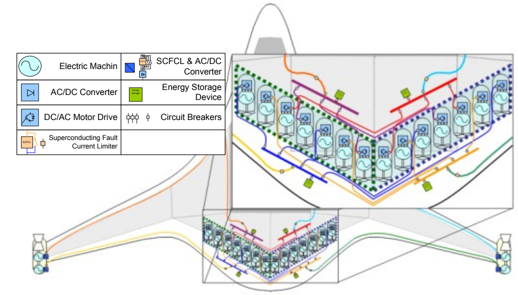
NASA N3-X Propulsion System Weight

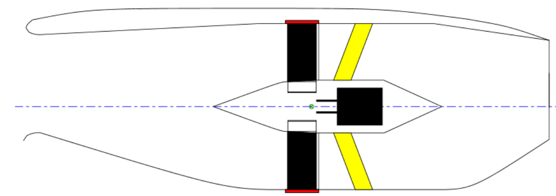
B777-200LR

N3A/UHB

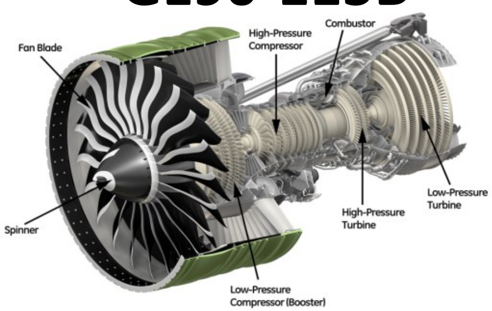


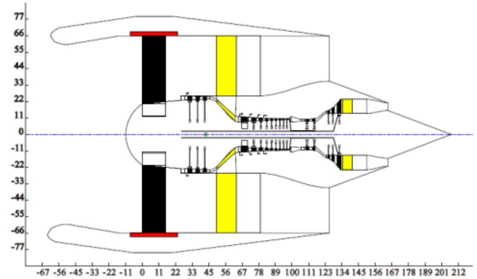
N3-X

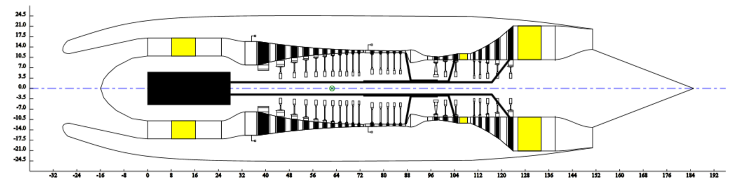




GE90-115B







	GE90-like	UHB	TeDP/Cryo	TeDP/LH2
Thrust – RTO	180,400	139,000	94,200	85,800
Non-electrical System - lbs		58,600	30,500	28,100
Electrical System/Gearbox - lbs		1800	21,300	16,300
Total Weight - lbs	**47,300**	**60,400**	**51,800**	**44,400**

Timeline of Machine Power With Application to Aircraft Class

2015	2020 (N+2)	2025 (N+3)	2030 (N+4)	2035

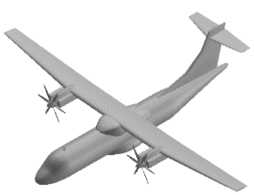
Largest Electrical Machine On Aircraft

Non-Cryo: 100 kW | 1 MW

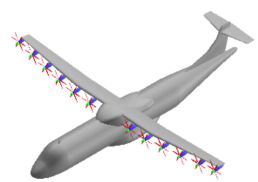
Super Conducting: 3 MW | 10 MW | 30 MW

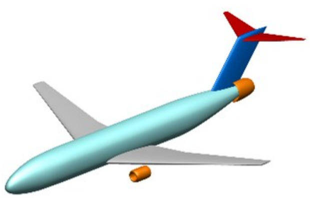
9 Seat/0.5 MW Total
50 kW – 250 kW

19 Seat/2 MW Total
100 kW – 1 MW

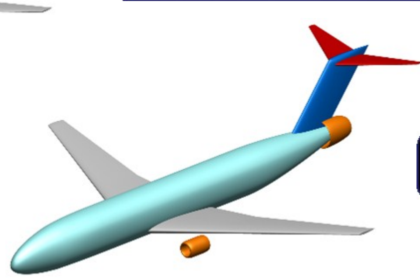


50 Seat/3 MW (prop)/ 12 MW(jet) Total
300 kW – 6 MW





150 Seat/22 MW Total
1 MW – 11 MW



300 Seat/60 MW Total
3 MW – 30 MW

For the power range bar for each aircraft class

- The left side is the smallest electrical machine in a partially electrified system
- The right side is the size of the generator in a twin engine fully electrified system

NASA