Turbo-electric Distributed Propulsion

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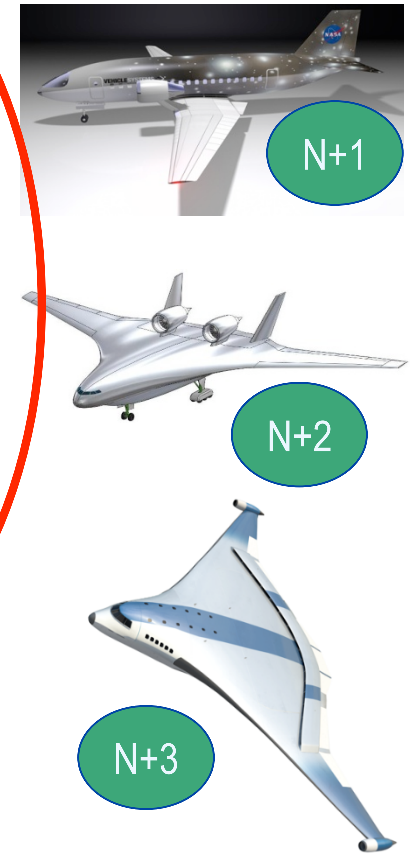
SFW System Level Metrics

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

CORNERS OF THE TRADE SPACE	N+1 (2015)*** Generation Conventional Tube and Wing (relative to B737/CFM56)	N+2 (2020)*** Generation Unconventional Hybrid Wing Body (relative to B777/GE90)	N+3 (2025)*** Generation Advanced Aircraft Concepts (relative to user defined reference)
Noise	- 32 dB (cum below Stage 4)	- 42 dB (cum below Stage 4)	55 LDN (dB) at average airport boundary
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%**	-40%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* 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 area



Approach

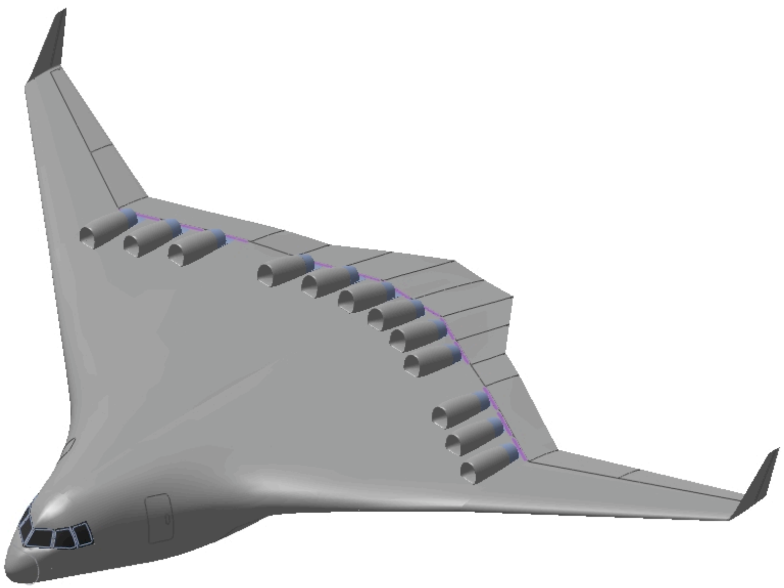
- Enable Major Changes in Engine Cycle/Airframe Configurations
- Reduce Uncertainty in Multi-Disciplinary Design and Analysis Tools and Processes
- Develop/Test/ Analyze Advanced Multi-Discipline Based Concepts and Technologies
- Conduct Discipline-based Foundational Research

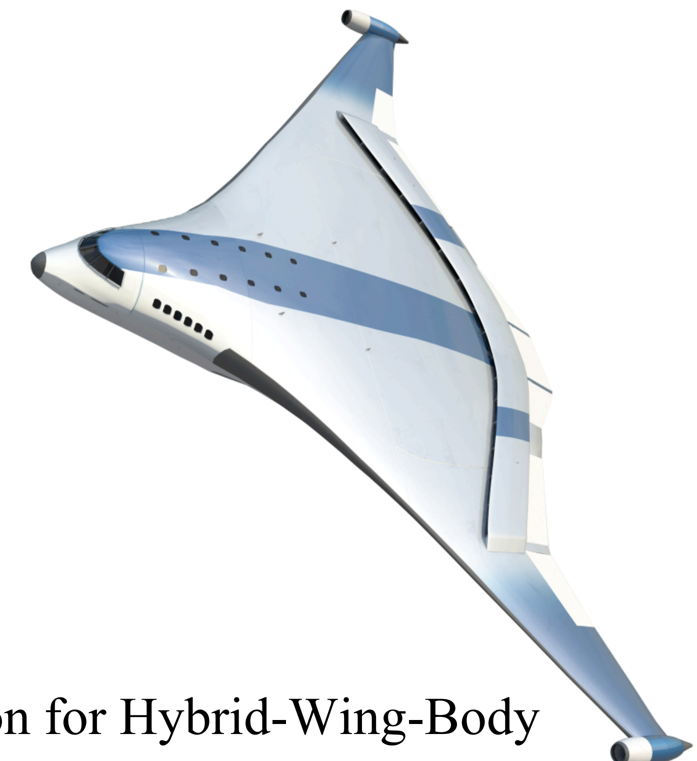
Single Vs Distributed Fans

- 1.35 FPR fans sized to provide 108,000 pounds rolling take-off thrust (SL/MN0.25/ISA+27) results in a total fan area of 1527 in^2
- Requires either 2 146 inch fans or 14 60 inch fans

Turbo-electric Distributed Propulsion CESTOL (N+3)

- Based on earlier baseline 12-engine configuration.
- ***Distributed turboelectric propulsion system*** with superconducting electric fans powered by two turbine-engine-driven superconducting electric generators.



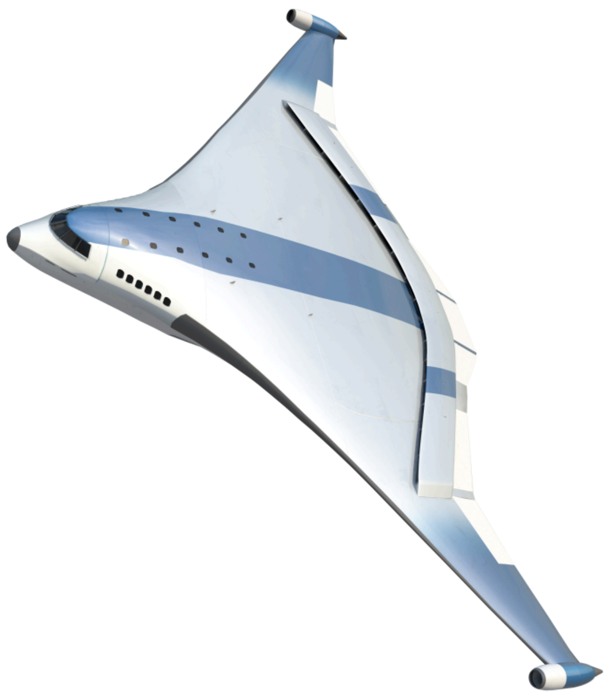


"Distributed Turboelectric Propulsion for Hybrid-Wing-Body Aircraft," 2008 International Powered Lift Conference.

Possible advantages of using a turboelectric drive system on an arbitrary "platform"

- Decoupling of the propulsive device from the power-producing device -> High performance and design flexibility
- High EBPR -> High fuel efficiency
- Speed of the power turbine shaft in the turbine engine is independent of the propulsor shaft speed. -> Electrical system as a gearbox with an variable gear ratio
- Minimal engine core jet noise due to maximum energy extraction
- Symmetric thrust with an engine failure
- Asymmetric fan thrust using fast response electric motors
- Cryogenic H2 as fuel and cooling fluid for superconducting system
- Large electrical power off-take for in-flight and ground use

Turboelectric Distributed Propulsion / HWB advantages



Fuel Burn and Emission:

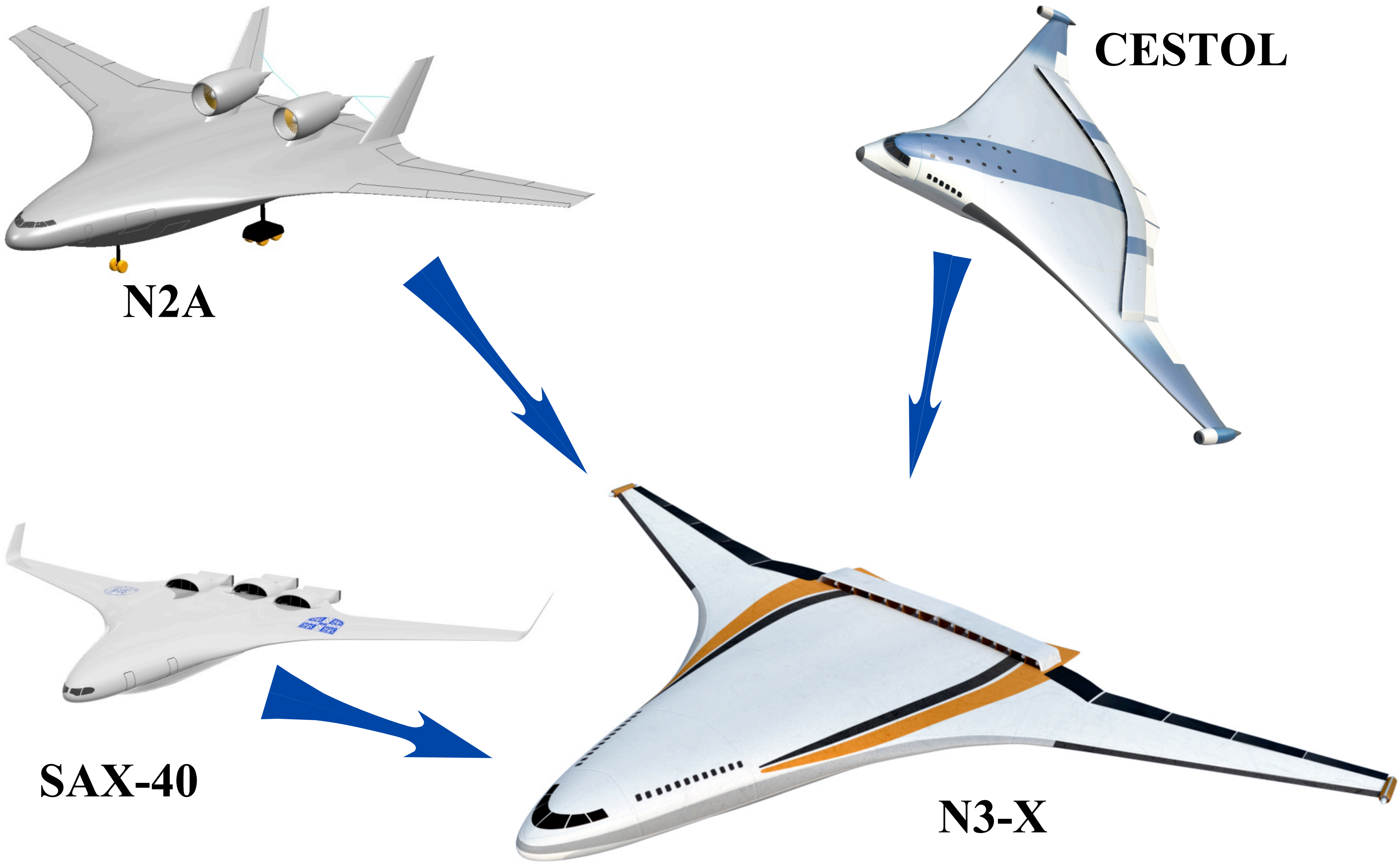
- 2 large engine cores and multiple motor-driven fans give very high bypass ratio.
- Higher propulsive efficiency via spanwise BLI and wake fill-in
- High engine core inlet pressure recovery

Noise:

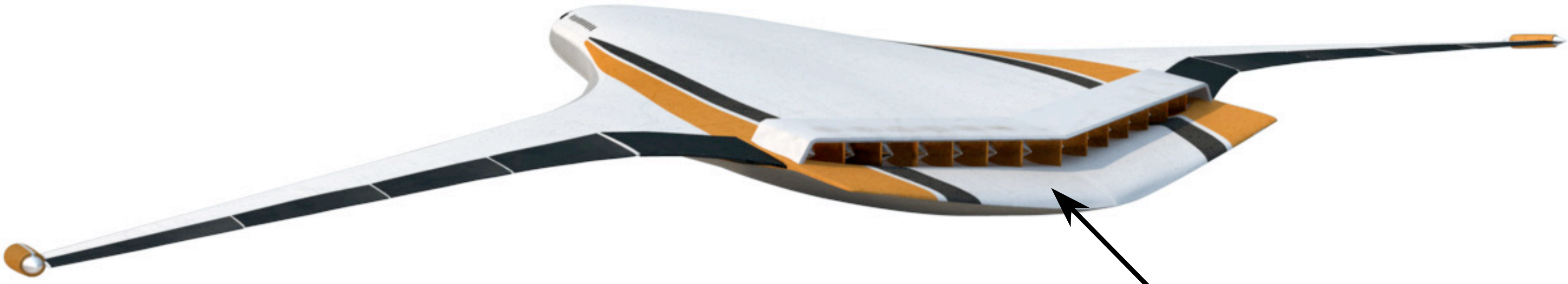
- Low community noise due to low pressure fans, airframe shielding, climb & descent profile
- Low core jet exhaust noise
- Low cabin noise due to remote location of propulsion systems

The turboelectric approach contributes to every corner of the NASA's SFW 'N+3' trade space!

Turbo-electric Distributed Propulsion Vehicle (N3-X)



N3-X Turbo-electric Propulsion System



Wing-tip mounted superconducting turbogenerators

Superconducting motor driven fans in a continuous nacelle

Turboelectric drive system could be applied to any other vehicle architectures

(e.g. HWB, Tube & Wing, V/STOL, Rotorcraft, Supersonic?)

Engine Performance – SLS/ISA+27

SLS/ISA + 27	N2A Turbofan	N2B Multi-fan	N3-X TurboElectric
Fn (total)	69687	51779	78942
Fn (core)	8849		4361
Specific Fn	27.7	27.2	21.9
SFC	0.2894	0.2880	0.1884
BPR	9.7	11.5	20.1
OPR	41.7	45.0	58.8
Fan PR	1.574	1.468	1.287
Fan Vj	940	839	700
Core Vj	1315	946	800
Wfan	2299	1756	3437
Wcore	215	147	171

N2A – 2 Pylon Mounted Turbofans

N2B – 3 Embedded Multi-fan Engines

N3-X - 2 Wing-tip Turbogenerators / 14 Embedded Motor Driven Fans

Engine Performance – 35k/MN0.8/ISA

35,000 ft/ MN0.8	NASA Pax300 (GE90 Class)	N2B Granta	N3-X TurboElectric
Fn (total)	19015	7458	16131
Fn (core)	3909		1759
Specific Fn	13.6	9.9	10.0
SFC	0.5368	0.5342	0.4654
BPR	8.3	11.3	17.2
OPR	45.6	43.0	82.4
Fan PR	1.520	1.500	1.456
W	1396	752	1606

N2A – 2 Pylon Mounted Turbofans

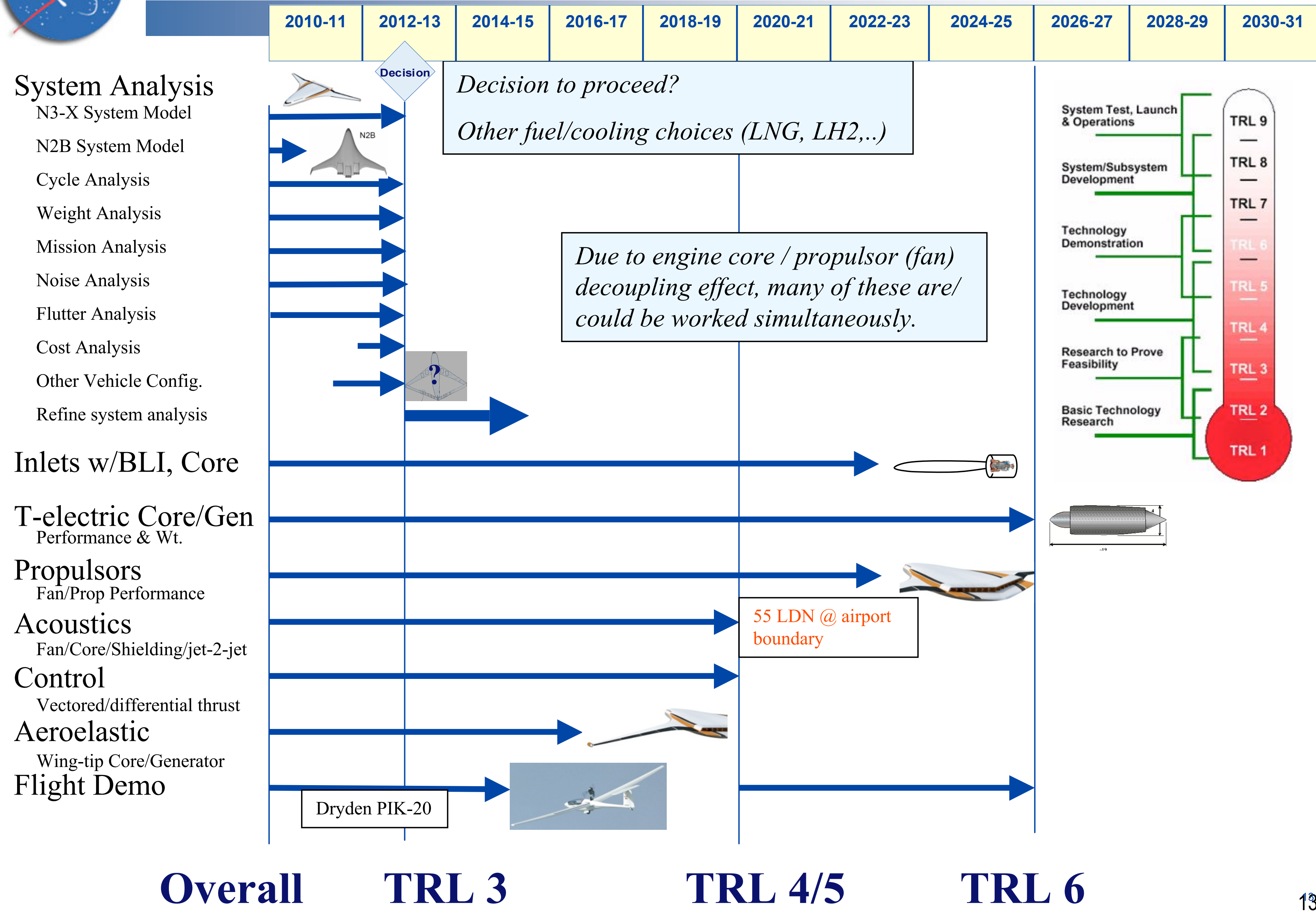
N2B – 3 Embedded Multi-fan Engines

N3-X - 2 Wing-tip Turbogenerators / 14 Embedded Motor Driven Fans

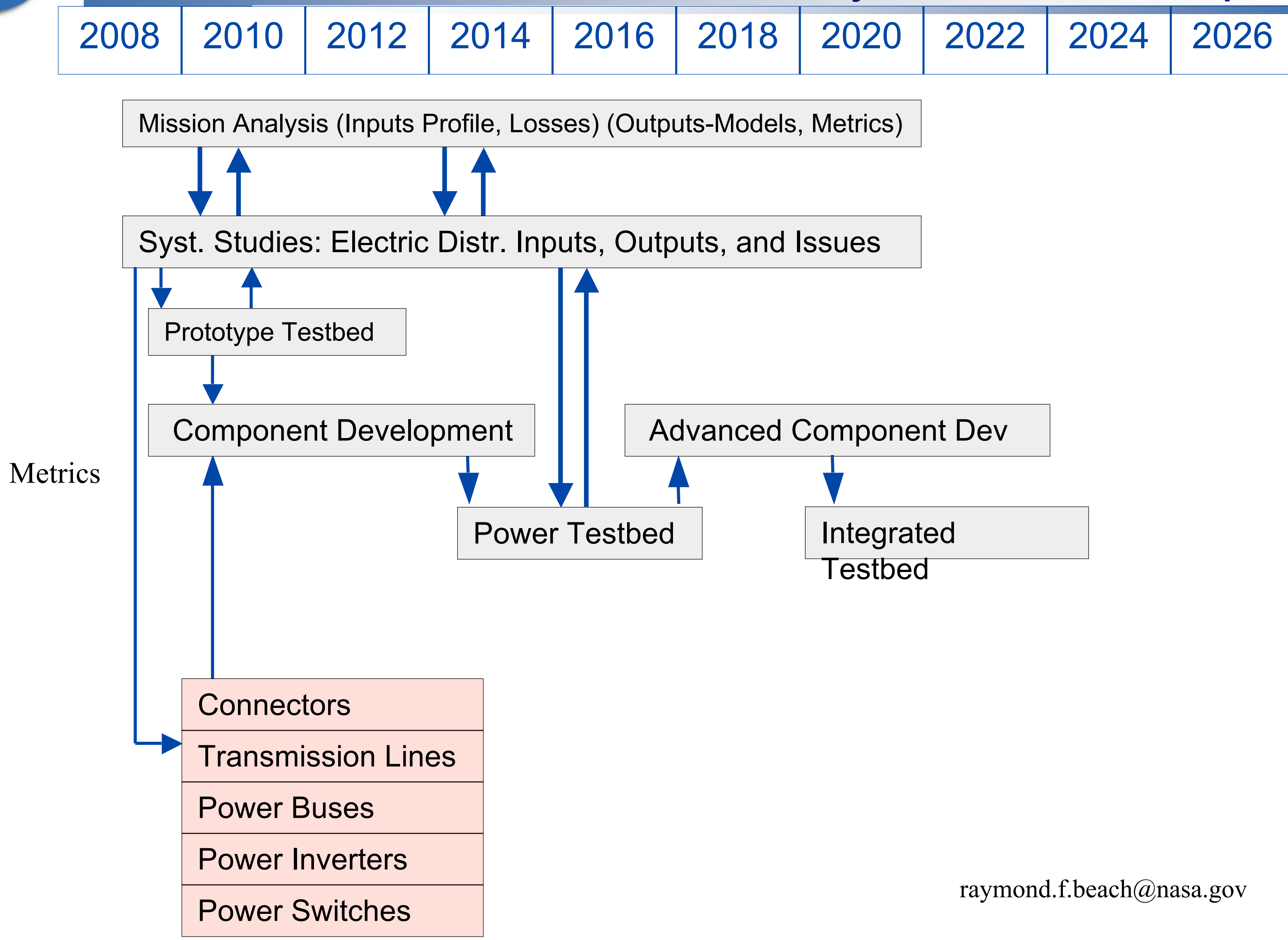
N3-X Electrical System Weights

Propulsion System	Components	Weight, lbs (kg)	Efficiency, %
Turboelectric distributed fans (refrigerated)	2 - 54,000 hp generators (including refrigerators)	3,600 (1,600)	99.7
	2 - 54,000 hp inverters (including refrigerators)	10,600 (4,900)	98.8
	14 - 7,700 hp motors (including refrigerators)	6,700 (3,100)	99.5
	Total Electrical System Weight	**20,900 (9480)**	**98.0**
Turboelectric distributed fans (LH2 cooled)	2 - 54,000 hp generators (LH2 cooled)	2,300 (1,100)	99.9+
	2 - 54,000 hp inverters (LH2 cooled)	5,300 (2,400)	99.8
	14 - 7,700 hp motors (LH2 cooled)	4,600 (2100)	99.9+
	Total Electrical System Weight	**12,200 (5533)**	**99.8**

Turboelectric Distributed Propulsion (TDP) Aircraft Roadmap



Turboelectric Aircraft Electrical Systems Roadmap



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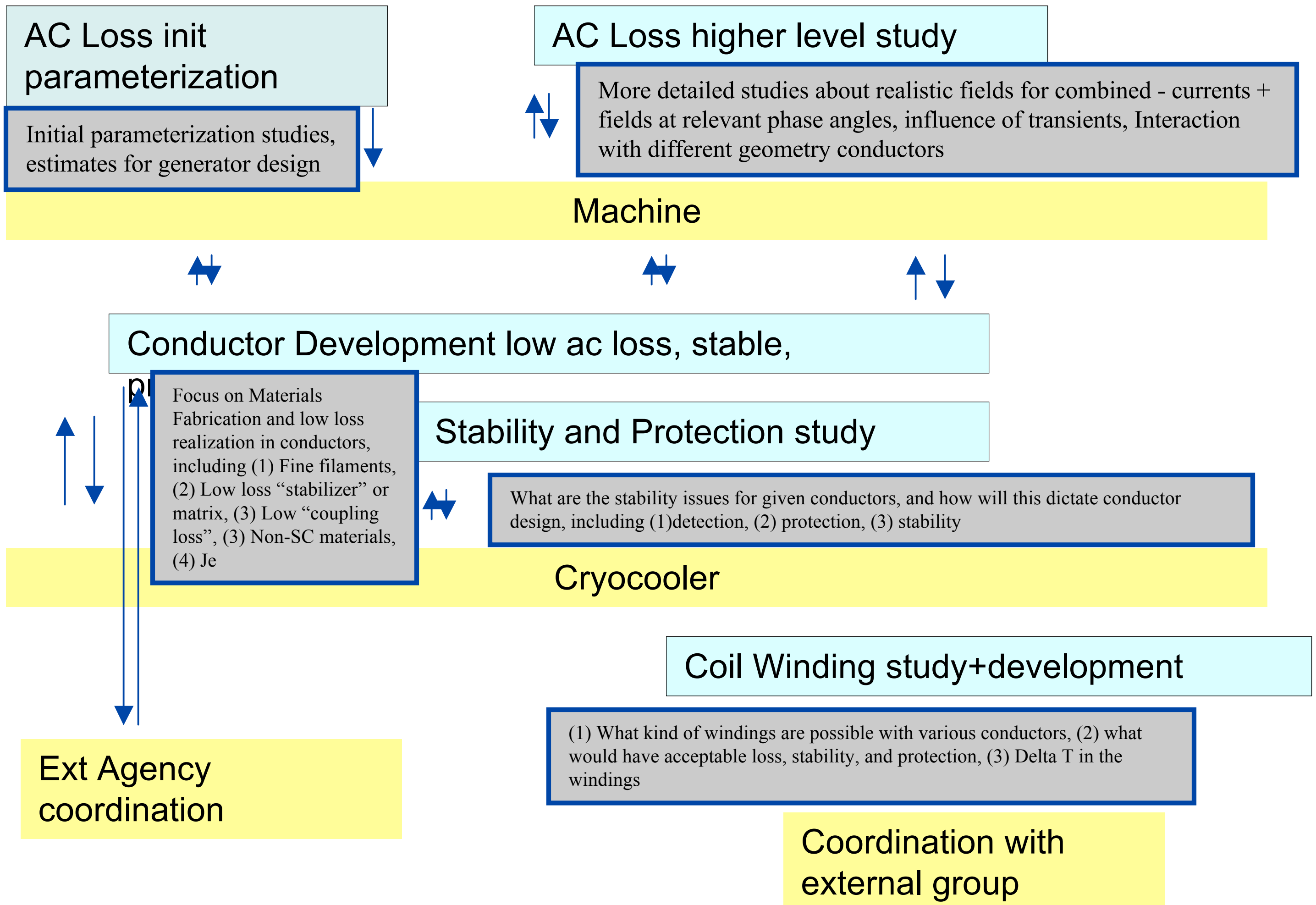
Low AC Loss Roadmap

EVALUATE feasibility and benefits of fully cryogenic motors and generators based on realistic conductors. *



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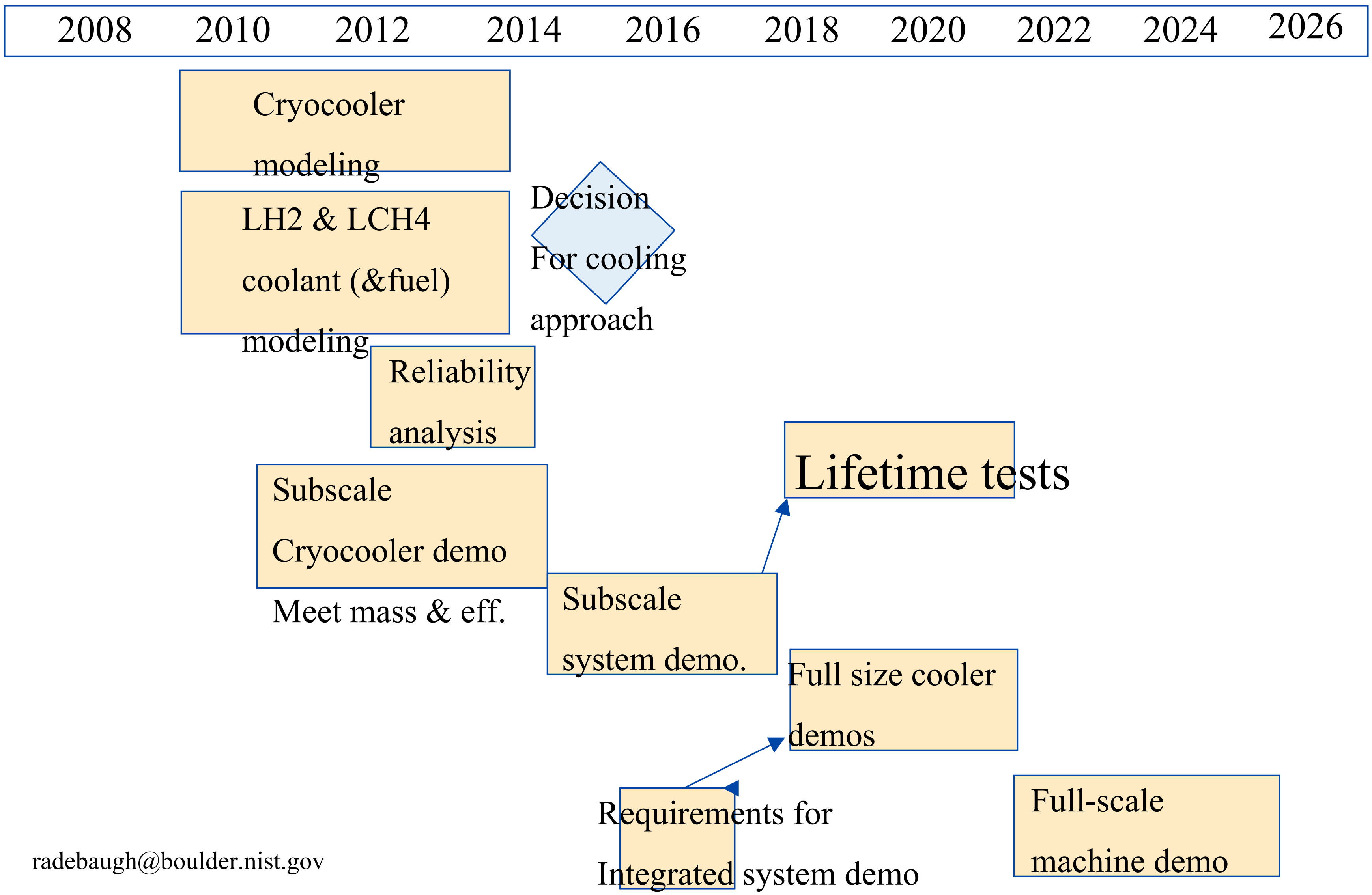
***All conductor tasks will be closely coordinated with the “Superconducting Machines” area.**

Cryocoolers Roadmap



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SUPERCONDUCTING MACHINES

Road Map Proposal for superconducting machine development for turbo-electric propulsion

PJMasson- 02/23/2009

Task	Year 1				Year 2				Year 3				Year 4				Year 5			
Analysis and Simulation																				
System studies	■	■																		
Technology trade-off			■	■	■															
Preliminary design					■	■	■	■												
Detailed design								■	■	■										
Component testing																				
AC losses in stator	■	■	■	■	■	■														
Mechanical behavior of litz wires				■	■	■														
Rotor quench management	■	■	■	■	■	■														
Build and test sub-scale rotor				■	■	■	■	■	■											
Cold bearing and seals				■	■	■	■													
PMAD							■	■	■											
System testing																				
Build sub-scale machine									■	■	■	■								
Balance testing											■	■								
Full load/torque testing													■	■						
Transient testing													■	■						
Build full scale generator													■	■	■	■				
Build full scale motor													■	■	■	■				
Build ducted fan															■	■	■			
Full system testing																		■	■	■

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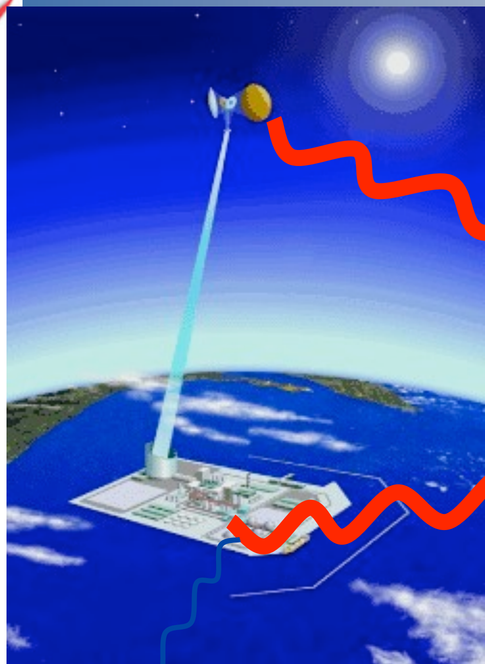
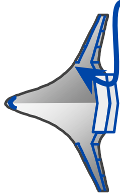
Beyond N+3?

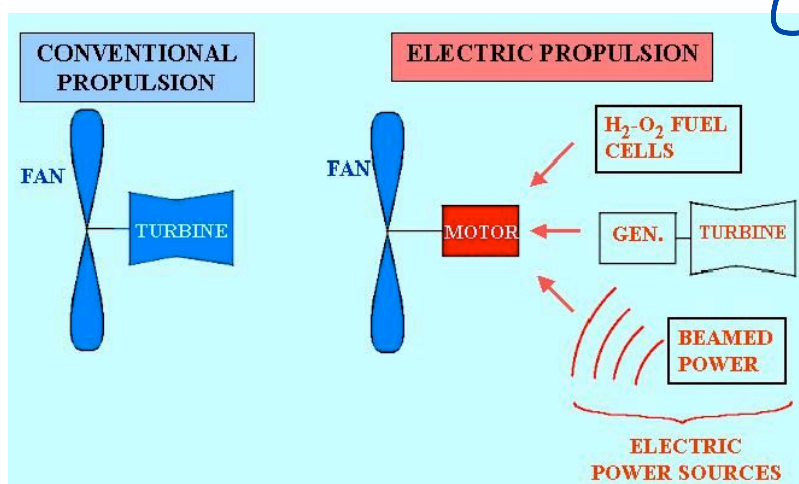




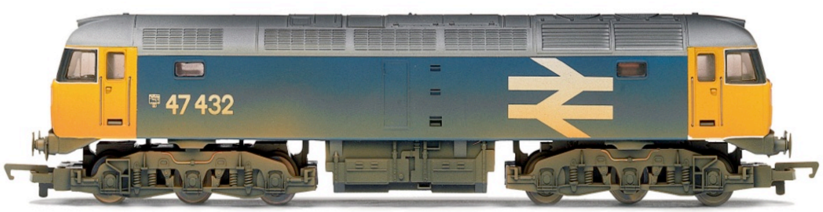
$$R = \frac{V}{g}\frac{1}{SFC}\frac{L}{D}\ln\left(\frac{W_i}{W_f}\right)$$

0

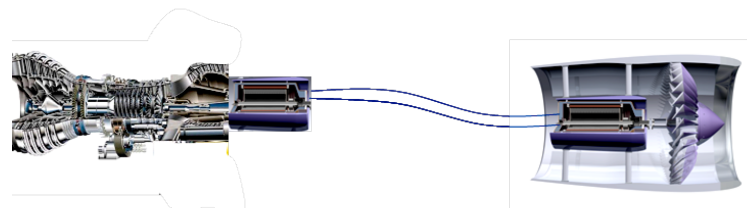
0



Ships, Trains & Cars Already Benefit From Hybrid Electric Power Systems



Why not Airplanes?



Q & A