Integration Concept
for a Hybrid-Electric Solid-Oxide Fuel Cell Power System into the X-57 "Maxwell"

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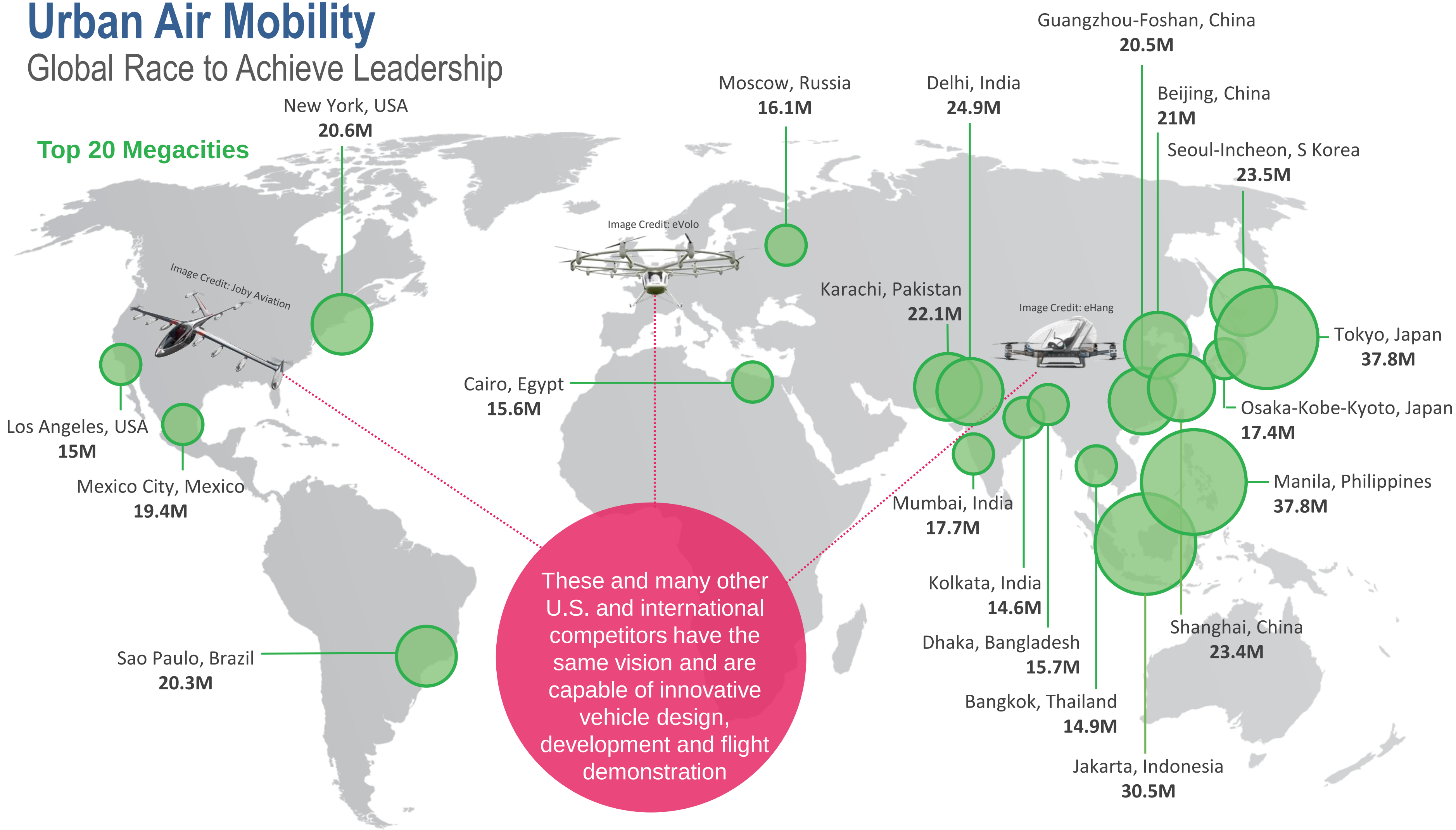
Urban Air Mobility

Global Race to Achieve Leadership



Large projected market–McKinsey analysis of demand by 2030 in 15 major U.S. cities:

- 500 Million annual UAS package deliveries
- 750 Million annual passenger trips

Extrapolation to the global market would likely increase demand by 5 to 10x

Top 20 Megacities by population data from allianz.com 03.16.15

NASA Aeronautics

NASA Aeronautics Vision for Aviation in the 21st Century

ARMD continues to evolve and execute the Aeronautics Strategy
https://www.nasa.gov/aeroresearch/strategy

6 Strategic Thrusts

Safe, Efficient Growth in Global Operations

Innovation in Commercial Supersonic Aircraft


Ultra-Efficient Commercial Transports

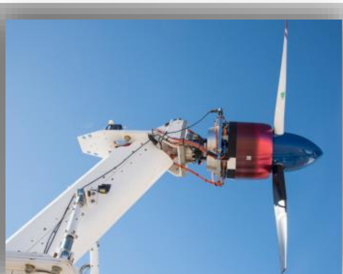

Transition to Alternative Propulsion and Energy


In-Time System-Wide Safety Assurance


Assured Autonomy for Aviation Transformation

U.S. leadership for a new era of flight

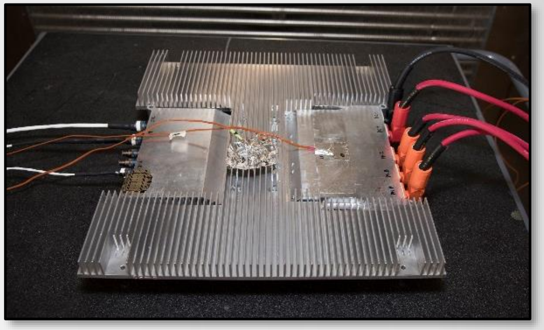
X-57 “Maxwell”



Motor and Propeller Endurance Test on Airvolt

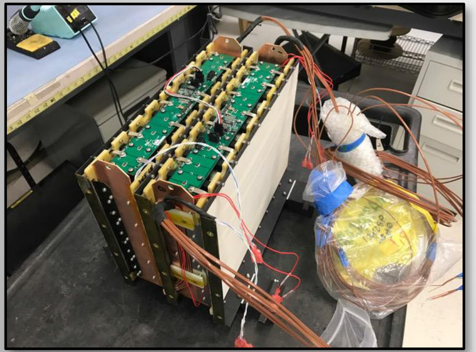
JSC Test Unit With Interstitial Barrier and Heat Spreader (Design Template)

X-57 Battery Module (¼ Pack) before Short Circuit Test

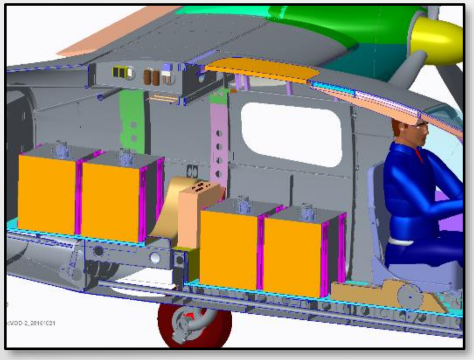


Cruise Motor Inverter Environmental Testing at NASA

Prototype Cruise Motor



X-57 Thermal Runaway Unit (2 Trays; ½ Module)



One Battery Pack (4 Module, ½ Ship Set)

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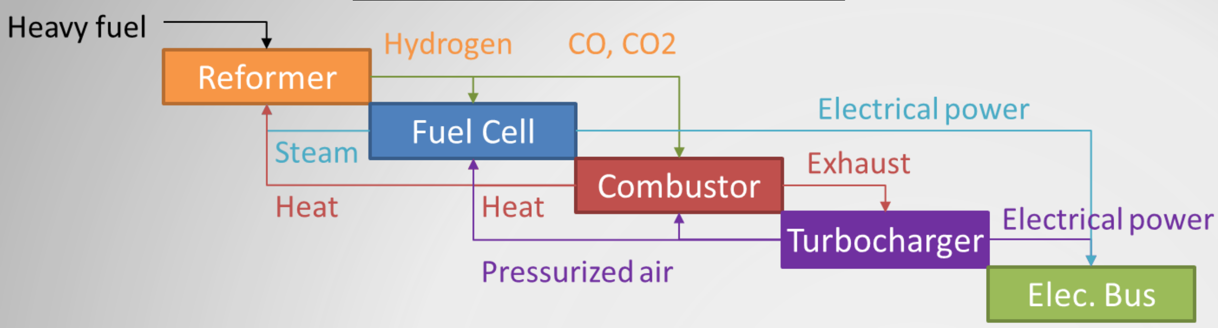
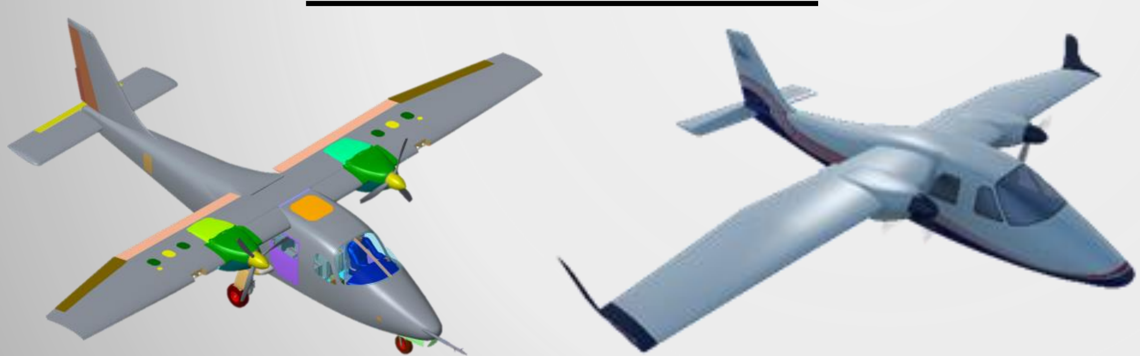
Fuel Cell Variant of X-57 “Maxwell” – X-57-F “FUELEAP”

Fuel Cell Architecture

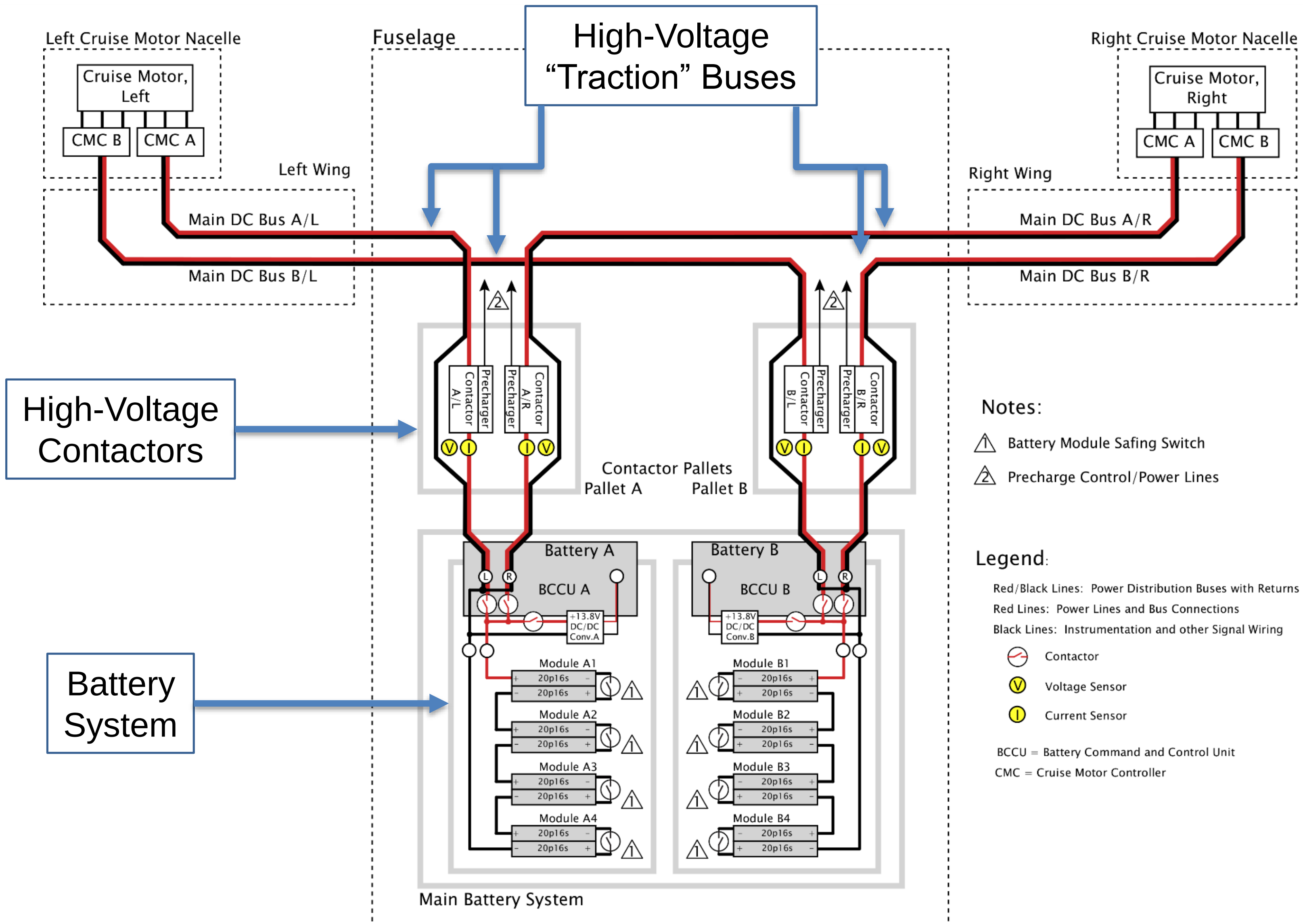


X-57 “Maxwell” MOD II

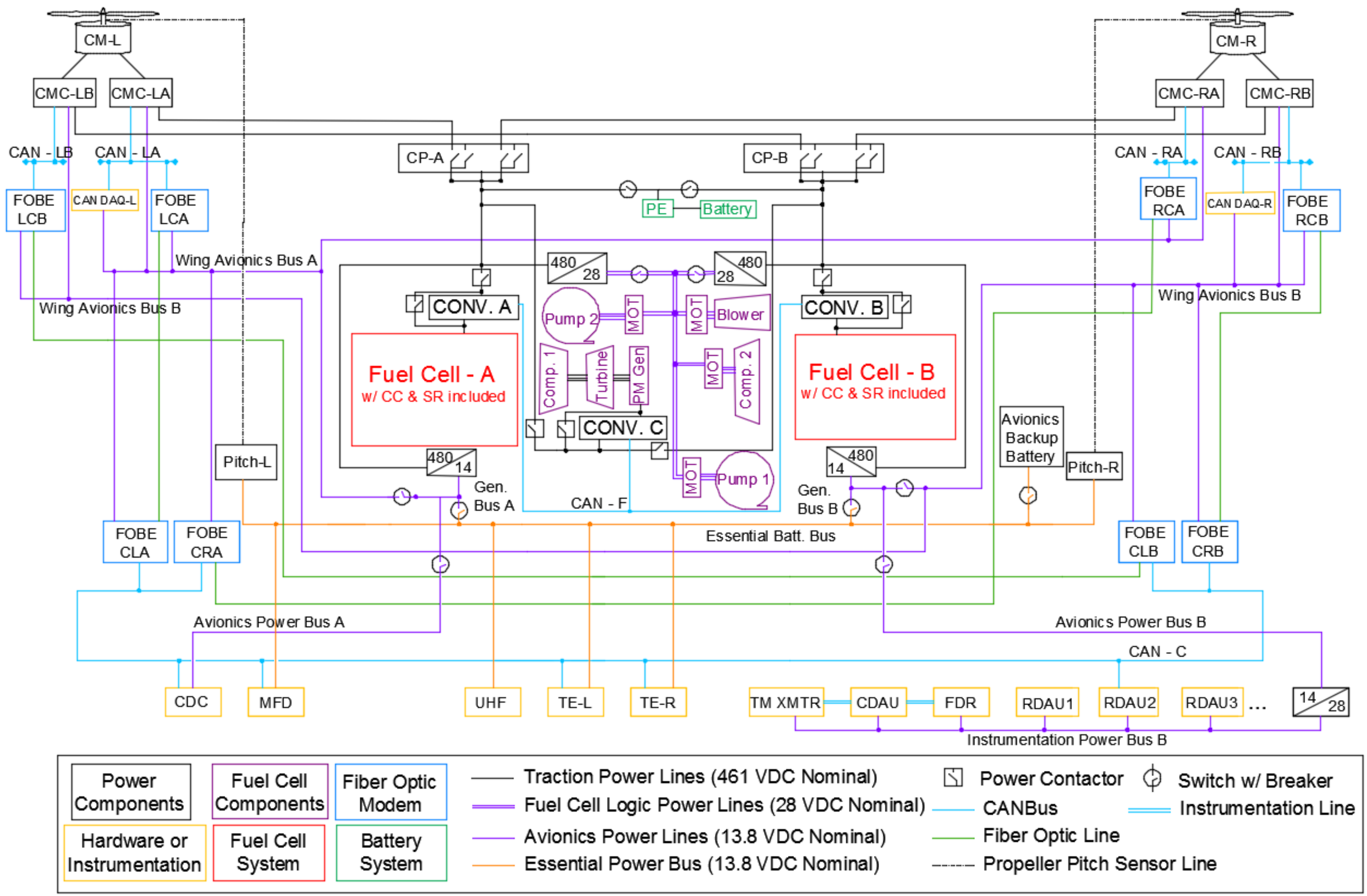


- Steam reformer provides ability to utilize heavy fuels instead of carrying H_2 onboard
- Goal is to provide 60% overall efficiency with 3+ hr range
- Baseline aircraft is the X-57 “Maxwell” MOD II, an all-electric airplane

X-57 "Maxwell" Power Architecture



X-57-F "FUELEAP" Power Architecture



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Power Requirements and Technology Gaps

Each Fuel Cell produces approximately 60 kW

Mission segment	Motor power	Power demand	Battery power*
Takeoff (2 min)	144 kW	158 kW	38 kW
Cruise Climb (10 min)	120 kW	131 kW	11 kW
Cruise (fuel dependent)	100 kW	110 kW	-10 kW

*When the battery system is discharging, the value is (+); when charging, the value is (-).

Option	Efficiency	Weight	Notes
Reference system: Hot recycle blower	-	-	Represents a material and reliability challenge
Option 1: Warm recycle blower	-6%	+50 lbm	• Add two heat exchangers, plumbing and an air scoop (drag) • Frontal area of ram air heat exchanger is 0.7 ft^2
Option 2: Carry water	-12%	+94 lbm*	• Volume and mass for water tank • Mass for more stacks (25% more stacks) • Additional heat exchanger required to produce steam • No recirculation is necessary

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FUELEAP Failure Modes and Effects Analysis

Failure Scenario (FUELEAP-specific)	SOFC (x2)	Turbine	Compressor (primary)	Compressor (backup)	Pump (primary)	Pump (backup)	Recycle Blower	Converter A	Converter B	Converter C	CAN - F	Battery System	Criticality
Nominal													
Single Fuel Cell								I					Mission
Dual Fuel Cell	F			D		D	I	I	I				Safety
Turbine Failure		F	I		D					I			Mission
Primary Compessor		D	F										Mission
Secondary Compressor	D			F									Mission
Primary Pump					F								Negligible
Secondary Pump						F							Negligible
Recycle Blower	D						F						Mission
Converter A	I							F					Mission
Converter B	I								F				Mission
Converter C		D								F			Mission
CANBus - F								I	I	I	F		Negligible
Battery System												F	Mission

LEGEND						
	(green)	Nominal Operations	D	Degraded Performance	I	Inoperable
	F	Failed Component	Safety	Land as soon as possible		
	Mission	Land as soon as practical	Negligible	Assess during flight		

- Only FUELEAP-specific failures addressed
- System designed to be fault tolerant
- Even with Dual Fuel Cell Failure (“Safety Critical”), the system will have enough power from the turbine and the battery system for steady-level flight

Backup Slides

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