Assessment of the Impact of an Advanced Power System on a Turboelectric Single-Aisle Concept Aircraft

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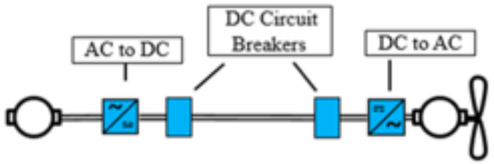
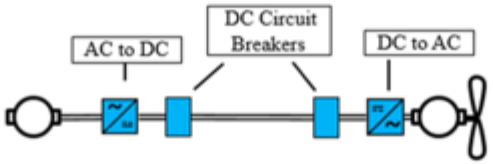
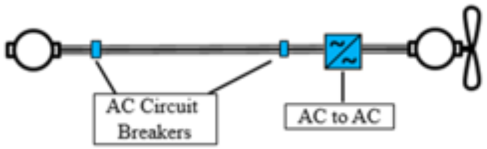
AIAA/IEEE Electric Aircraft Technology Symposium (EATS)

August 27, 2020

High-efficiency Electric Aircraft Thermal Research (HEATheR)

Problem: Current electrified aircraft concepts produce large amounts of **low-grade waste heat** and require **large, heavy thermal management systems** that cause drag.

Idea #1: Advanced Power System reduces heat to be rejected by a factor of 4

	National Academies of Sciences (NAS)	Advanced Air Transport Technologies (AATT)	HEATheR
			
Machine Efficiency, %	95.0	96.0	98.5
Converter Efficiency, %	95.0	98.0	99.0
Breaker Efficiency, %	99.5	99.5	99.5
Overall Efficiency, %	80.6	87.6	95.1
HEAT, %	**19.4**	**12.4**	**4.9**

Idea #2: Outer Mold Line Cooling

New thermal management technology

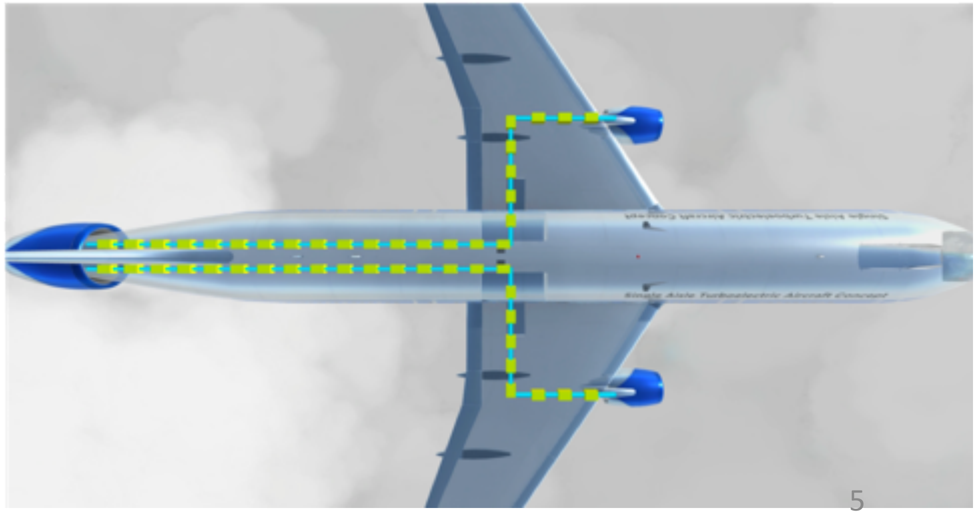
Fluid cooling

Air cooling

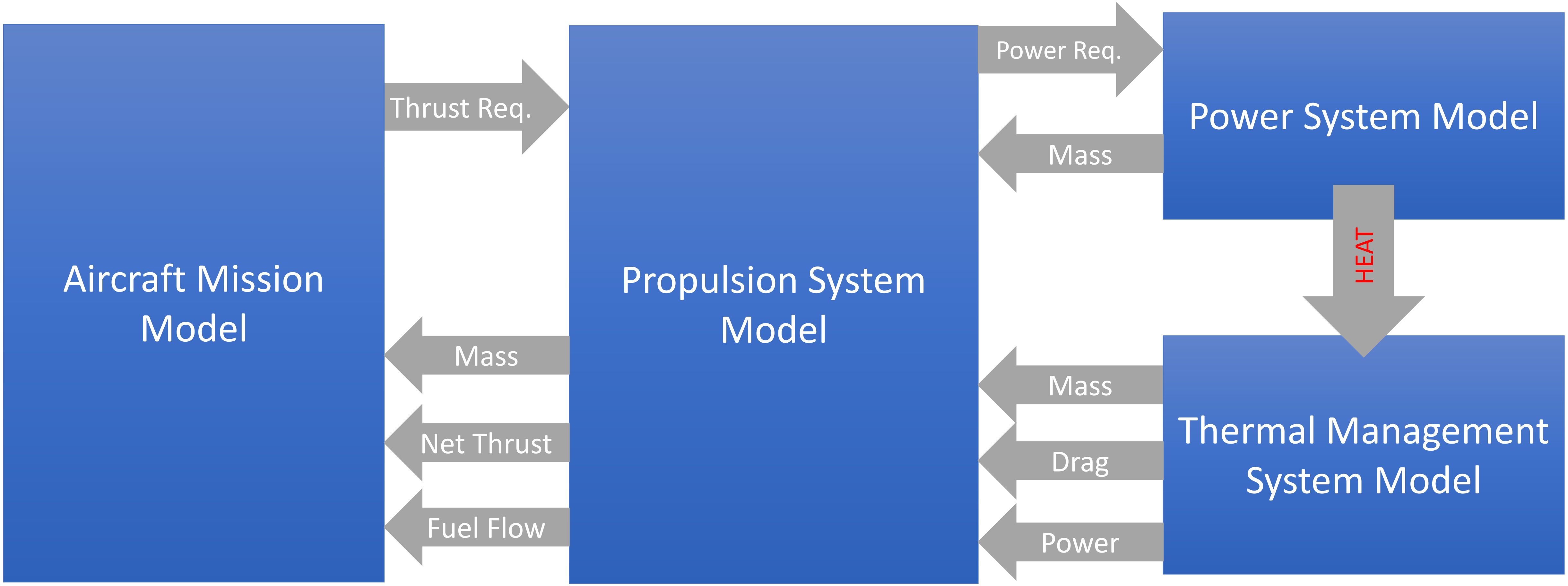
Outer Mold Line (OML) Cooling

Application: Single-Aisle Turboelectric AirCraft with Aft Boundary Layer propulsion (STARC-ABL)

- Conventional tube-and-wing EAP concept
- Key Mission Assumptions
  - 154 passengers
  - 37,000 ft cruise at Mach 0.785
  - 30-minute constraint on time to climb
- Turboelectric propulsion system
  - Traditional underwing jet engines with electric generators
  - Aft boundary layer ingestion (BLI) electric propulsor

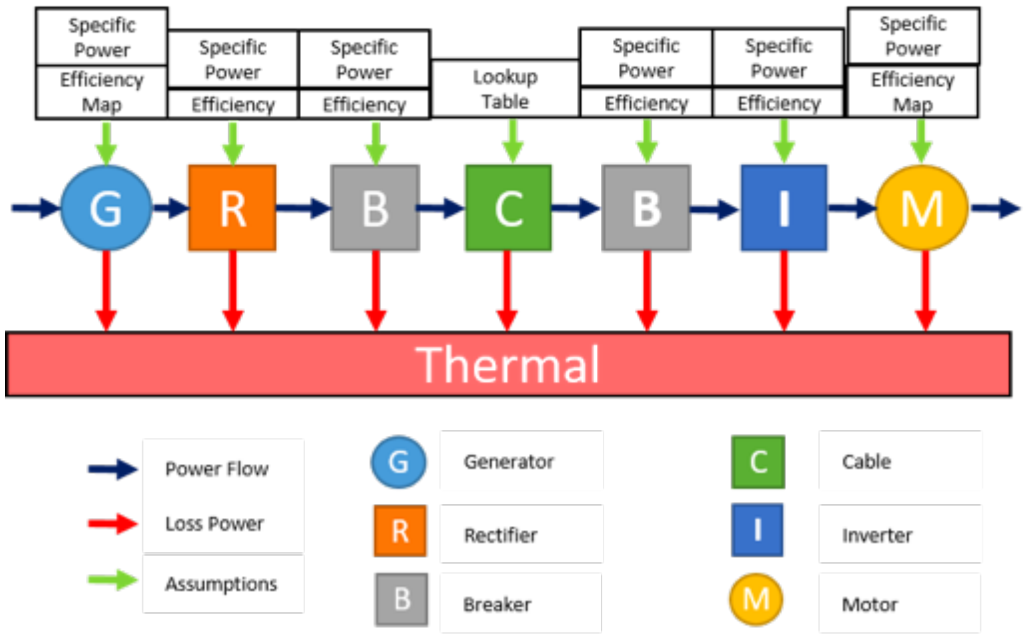


HEATheR developed power system and TMS models for STARC-ABL



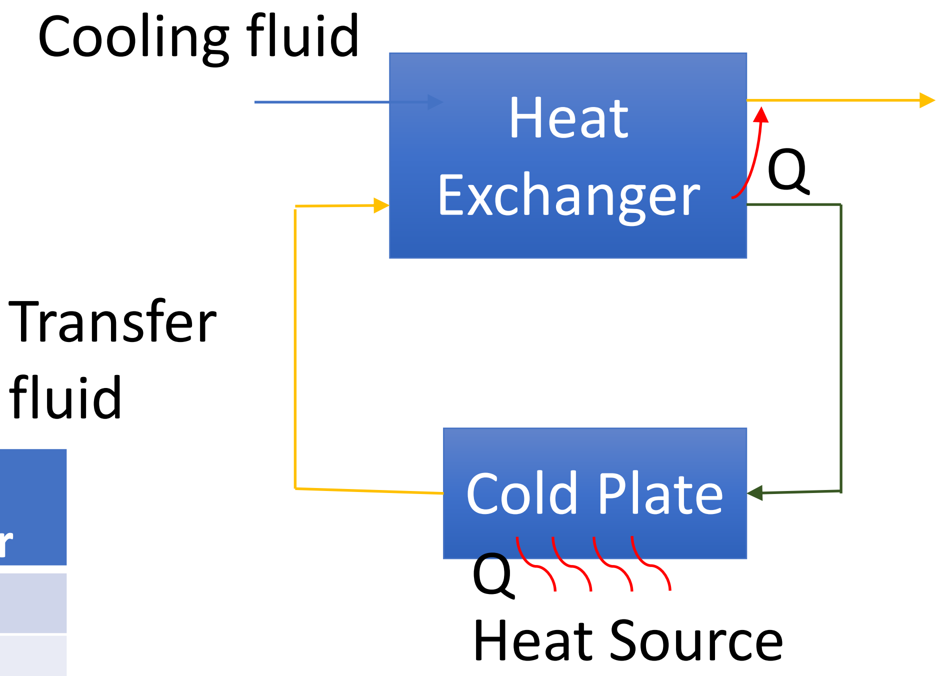
Power system modeling approach includes advanced cable modeling.

- Electrical Power System – Sizing and Analysis Tool (EPS-SAT)
- Used to perform power system studies
  - Calculate mass
  - Calculate efficiency
  - Perform system trades
  - Expose strengths and weaknesses of designs



Conventional TMS modeling assumes liquid-based plate fin heat exchangers.

- Uses an OpenMDAO based tool with optimization capabilities
- Designed at rolling takeoff steady state
- Uses conventional Kays and London sizing methods

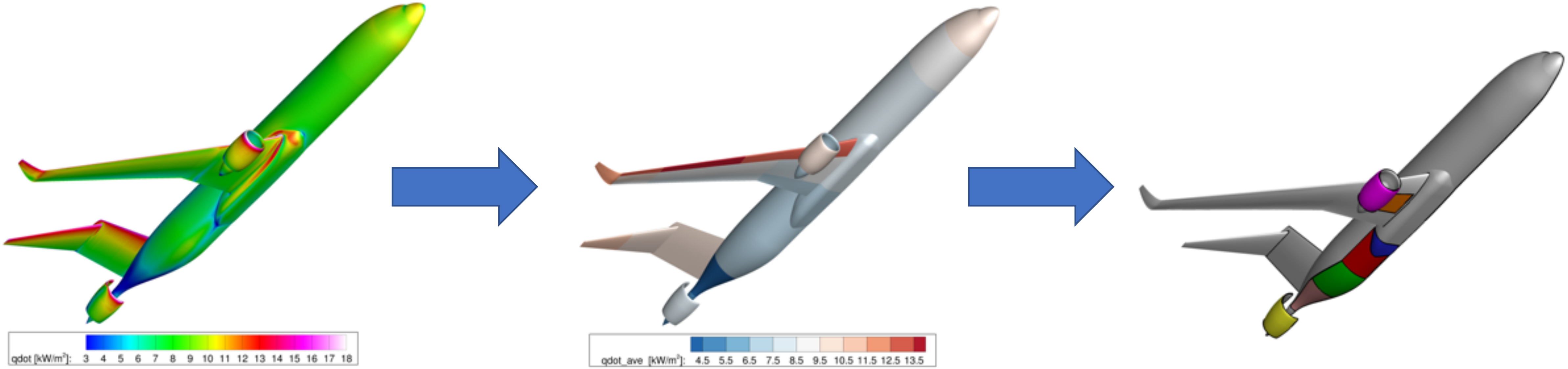


		Motor/ Generator	Electric Converter
Enhanced Baseline Loop Temperature	Coolant In (C)	106	54
	Coolant Out (C)	150	60
HEATheR Loop Temperature	Coolant In (C)	60	54
	Coolant Out (C)	68	60

Outer Mold Line Cooling

Two steps to consider:

1. How much heat can be rejected at the OML
2. How to transfer that heat from the component to the OML



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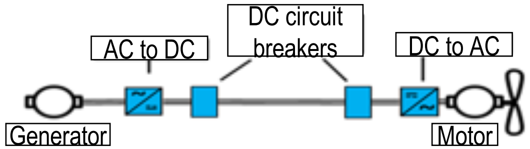
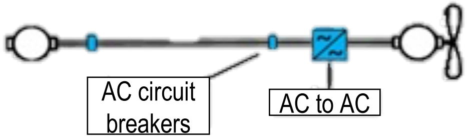
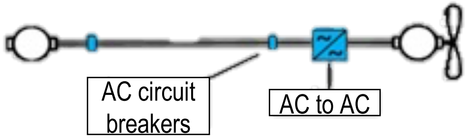
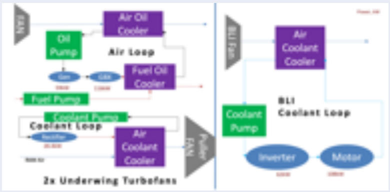
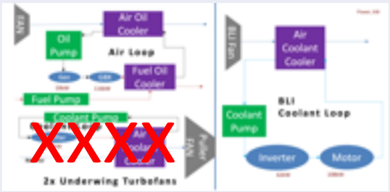
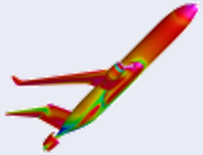
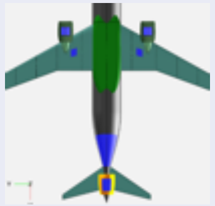
Wicked Heat Pipes → Oscillating Heat Pipe Panels

Aircraft and Propulsion System Modeling

- Weight, power, and drag estimates were added to the Numerical Propulsion System Simulation (NPSS) and Weight Analysis of Turbine Engines (WATE) models
- Engine decks and weight are provided to Flight Optimization System (FLOPS) model
- Sensitivity of aircraft was provided for TMS optimization:

Change in Block Fuel Burn	Change in System Parameter
1%	530 lbm of weight
	34 lbf of drag
	13 lbm/hr of fuel flow

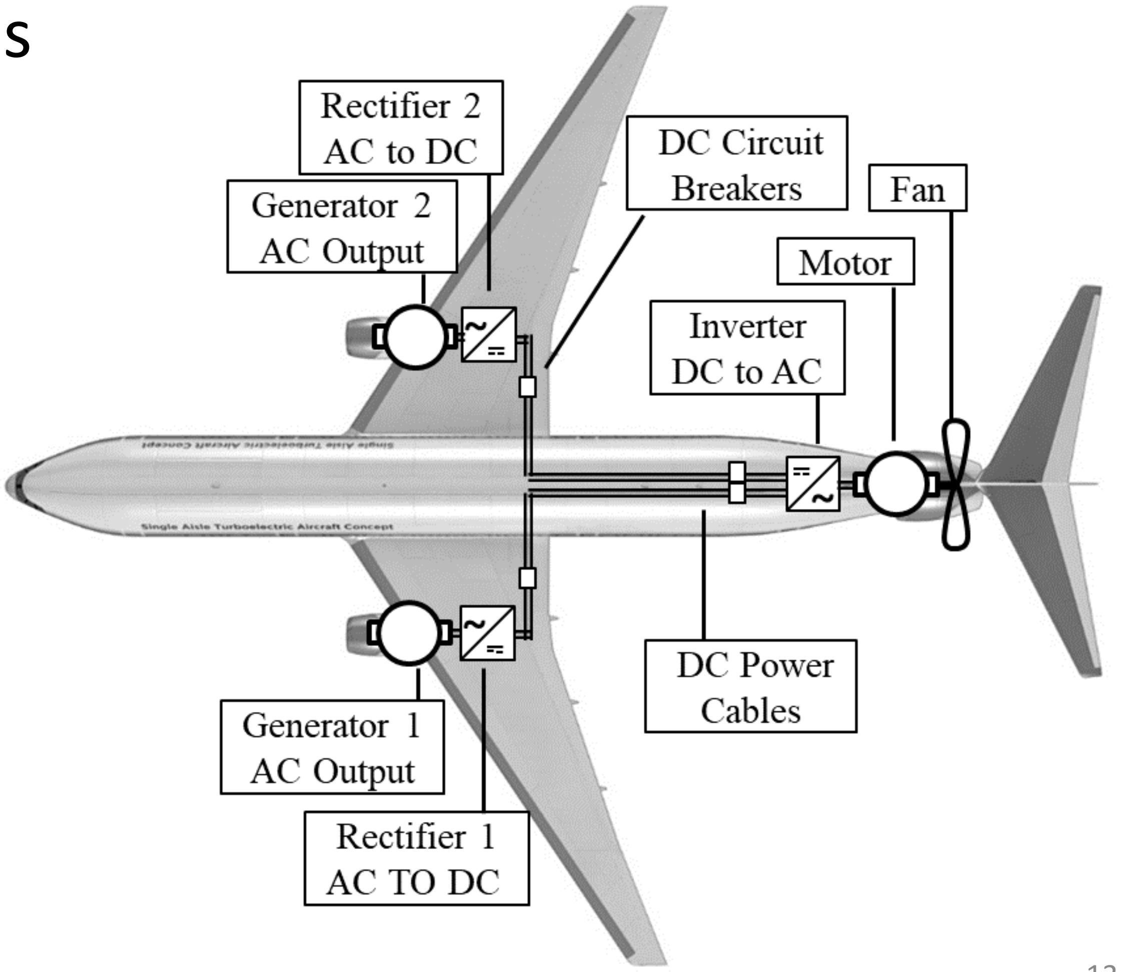
Aircraft Conceptual Models

	Enhanced Baseline	HEATheR with Conv. Cooling	HEATheR with OML Cooling
Description	Baseline aircraft model with enhanced power and TMS modeling	Aircraft model with optimal power system and cooling loops	Aircraft model with optimal power system and OML Cooling
Aircraft	FLOPS	FLOPS	FLOPS
Propulsion	NPSS	NPSS	NPSS
Electric	DC transmission 	AC transmission 	AC transmission 
Thermal	Baseline Cooling Loop 	Cooling loop, low loss, AC-AC 	CFD and OML Cooling  

Enhanced Baseline Power System

- DC system with AATT assumptions
- Total weight: 2883 lbm
- Total loss: 413 kW

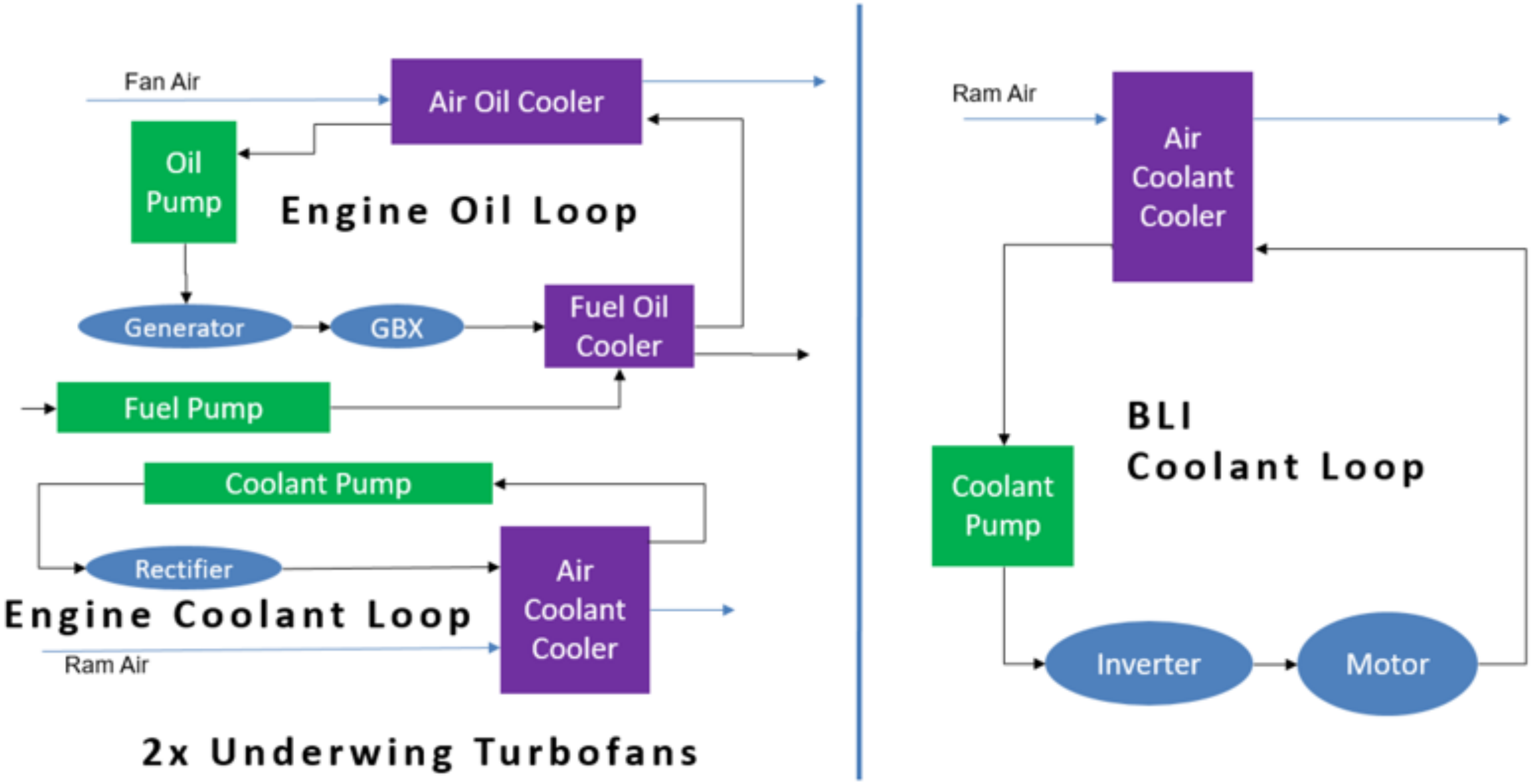
Component	Specific Power (kW/kg)	Efficiency (%)
Motor	13.15/1.4	96.0
Generator	13.15/1.4	96.0
DC Breaker	200	99.5
Rectifier	19.1	98.0
Inverter	19.1	98.0
Cable	3 max parallel, 5% tol.	



Enhanced Baseline Thermal Management System

Enhanced baseline used engine oil loop for gearbox cooling, but only electric system cooling is accounted for

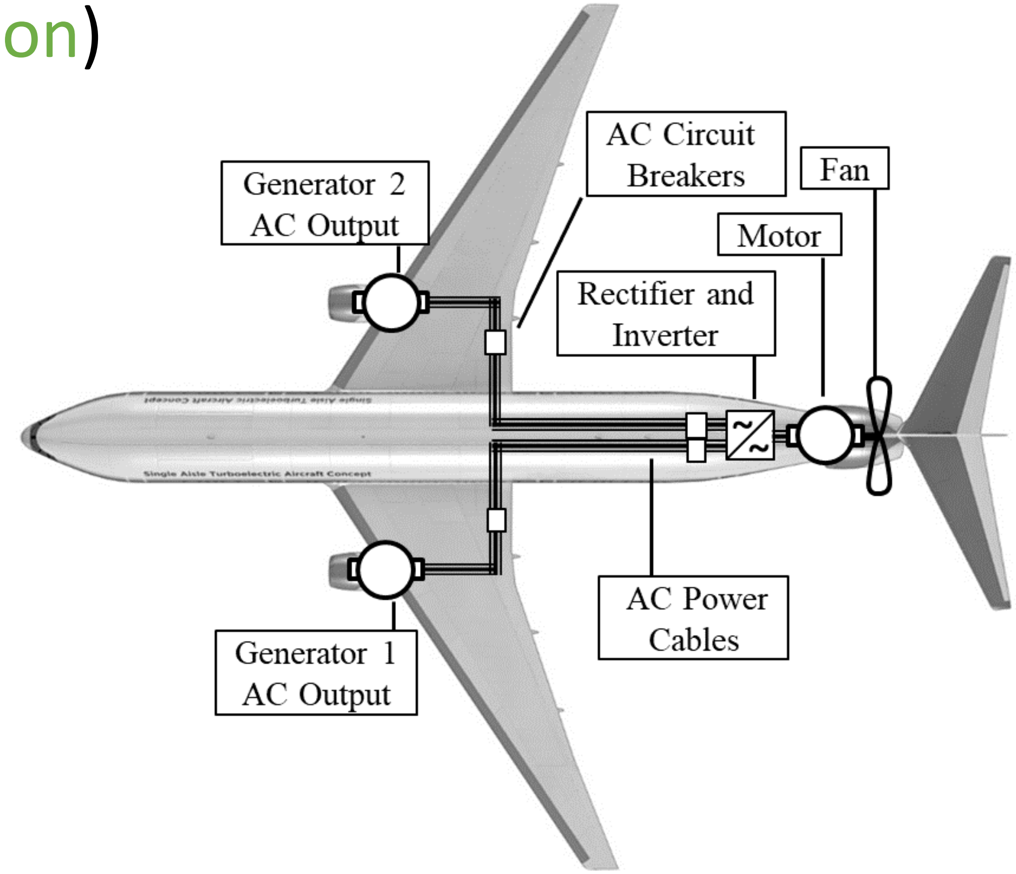
- Weight: 241 lbm
- Power: 200 W
- Drag: 12 lbf



HEATheR Power System

- Total weight: 2039 lbm (29% reduction)
- Total loss: 180 kW (56% reduction)

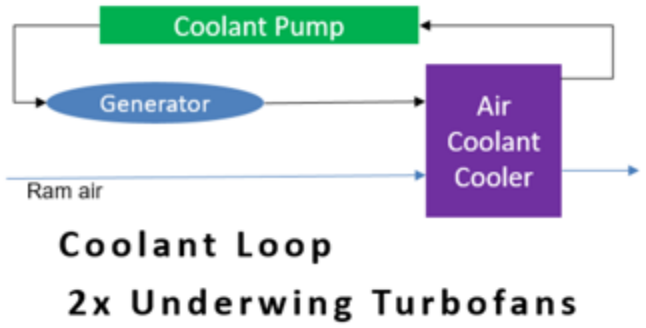
Component	Specific Power (kW/kg)	Efficiency (%)
Motor	16/1.4	98.5
Generator	16/1.4	98.5
DC Breaker	350	99.5
Rectifier	20	99.5
Inverter	20	99.5
Cable	3 max parallel, 5% tol.	

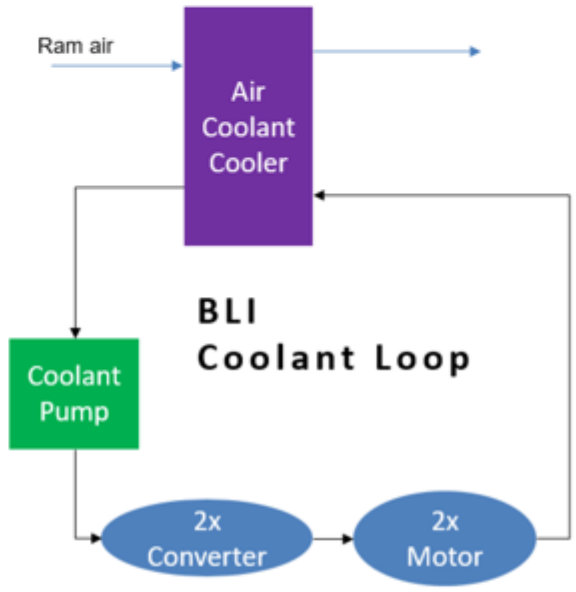


HEATheR with Conventional Cooling

The High Efficiency Megawatt Motor (HEMM) is designed to run on the same loop as the converters

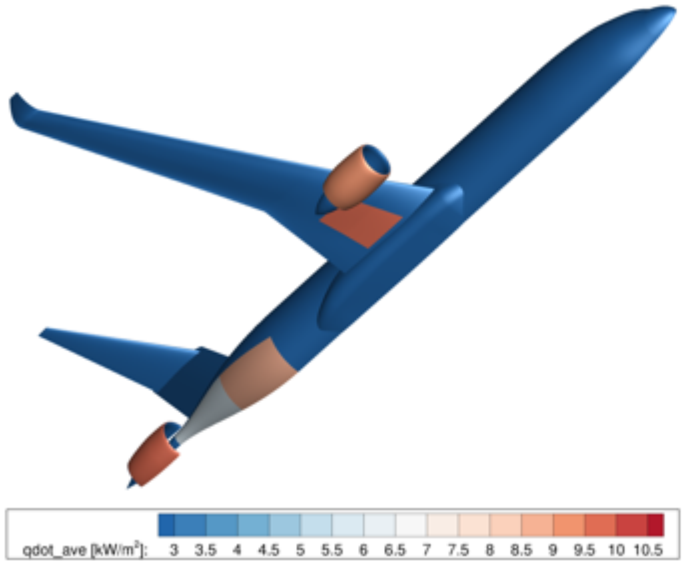
- Weight: 112 lbm (53% reduction)
- Power: 300 W (50% increase)
- Drag: 4.5 lbf (62% reduction)

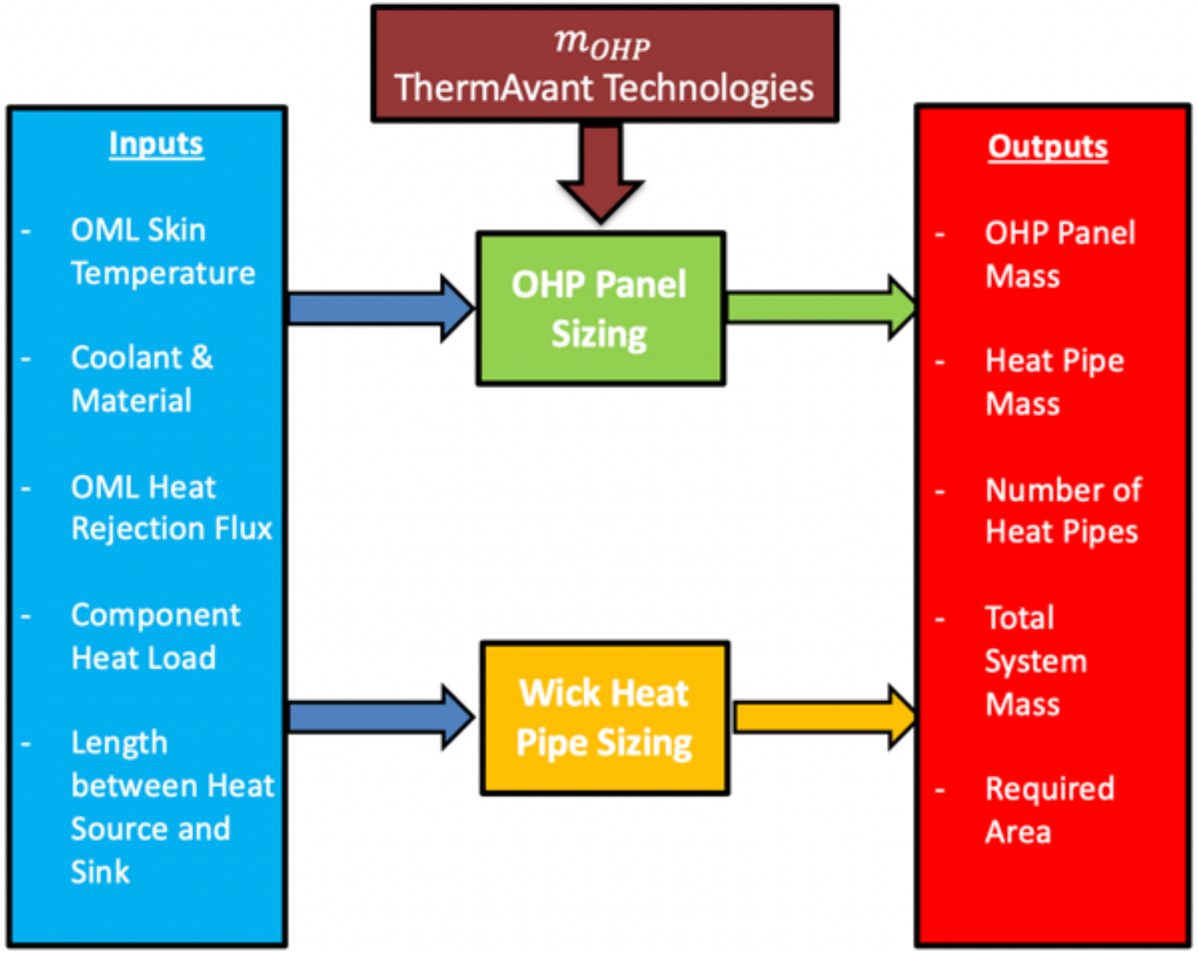




HEATheR with OML Cooling

- Weight: 229 lbm (4.9% reduction)
- Power: 0 W (100% reduction)
- Drag: 0 lbf (100% reduction)



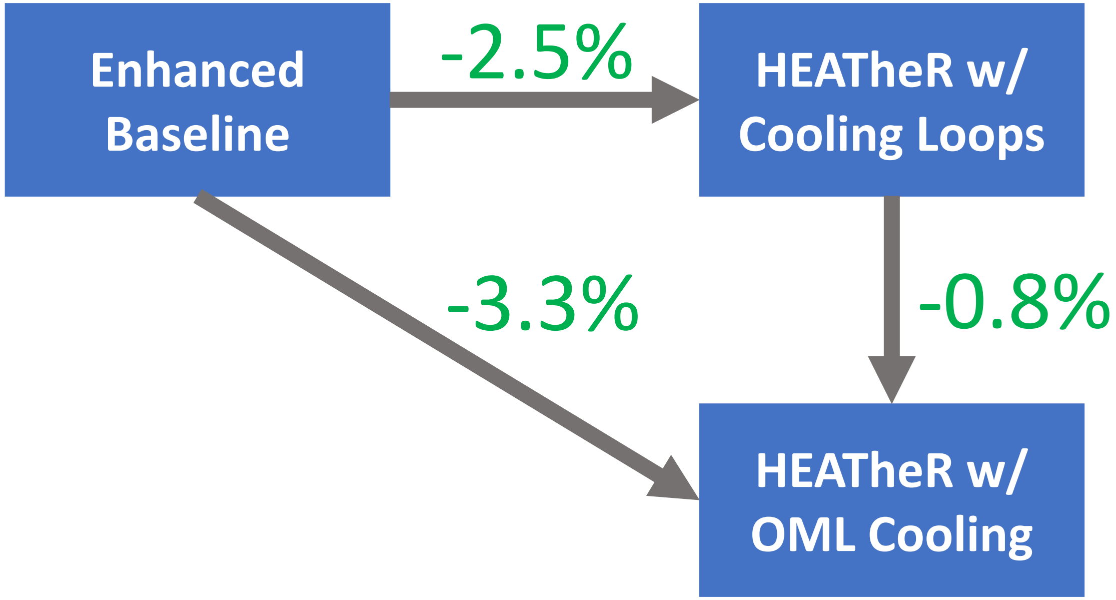


Conceptual Level Aircraft Results

	Units	Enhanced Baseline	HEATheR with Conv. Cooling		HEATheR with OML Cooling	
Turbomachinery	lbm	9837	9837	-	9837	-
Gearbox	lbm	99	0	-100%	0	-100%
Power System	lbm	2883	2039	-29%	2039	-29%
TMS	lbm	241	112	-53%	229	-4.9%
Total Prop. Weight	lbm	13,061	11,988	-8.2%	12,105	-7.3%
Gross Weight	lbm	135,790	133,506	-1.68%	133,312	-1.83%
Operating Empty Weight	lbm	78,918	77,350	-1.99%	77,402	-1.92%
Block Fuel (Design Mission)	lbm	23,143	22,490	-2.82%	22,267	-3.78%
Block Fuel (Economic Mission)	lbm	6352	6195	-2.47%	6143	-3.29%

Conclusions

- **Benefits shown are in addition to BLI effects**
- Estimated fuel burn benefit of an advanced power system is 2.5%
- OML cooling has a potential additional benefit of 0.8%
- Overall, HEATheR Technologies could potentially reduce block fuel burn by 3.3%



Thank you!

The authors would like to acknowledge the NASA Convergent Aeronautics Solutions project for funding this project. We would also like to thank our partner Charles Lents of United Technologies Research Center for his expertise in EAP thermal management systems, our partners at ThermAvant Technologies for their contributions to the OML cooling analyses, and finally Dr. Massoud Kaviany (University of Michigan) for his contributions to the wicked heat pipe work.