Cruise Propulsion System Thermal Analysis for NASA's X-57 "Maxwell" Mod II Configuration

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Meet “Maxwell”

- X-57 is NASA’s Flight Demonstrator for *Distributed Electric Propulsion Technology (DEP)*
- **Project Goals**: generate data and procedures and share these with academia, industry, standards organizations, and regulators to enable design and certification of DEP concepts
- **Project Approach**: spiral development through multiple design “Mods”

Mod I: Baseline performance of gasoline-powered aircraft

Mod II: High-voltage powertrain integration, impact of electric retrofit

Mod III : Impact of cruise-sized wing, wingtip propellers

Mod IV: High-lift propeller takeoff, landing, handling qualities

Is the air cooling setup for the motors and associated control equipment adequate for Mod II?

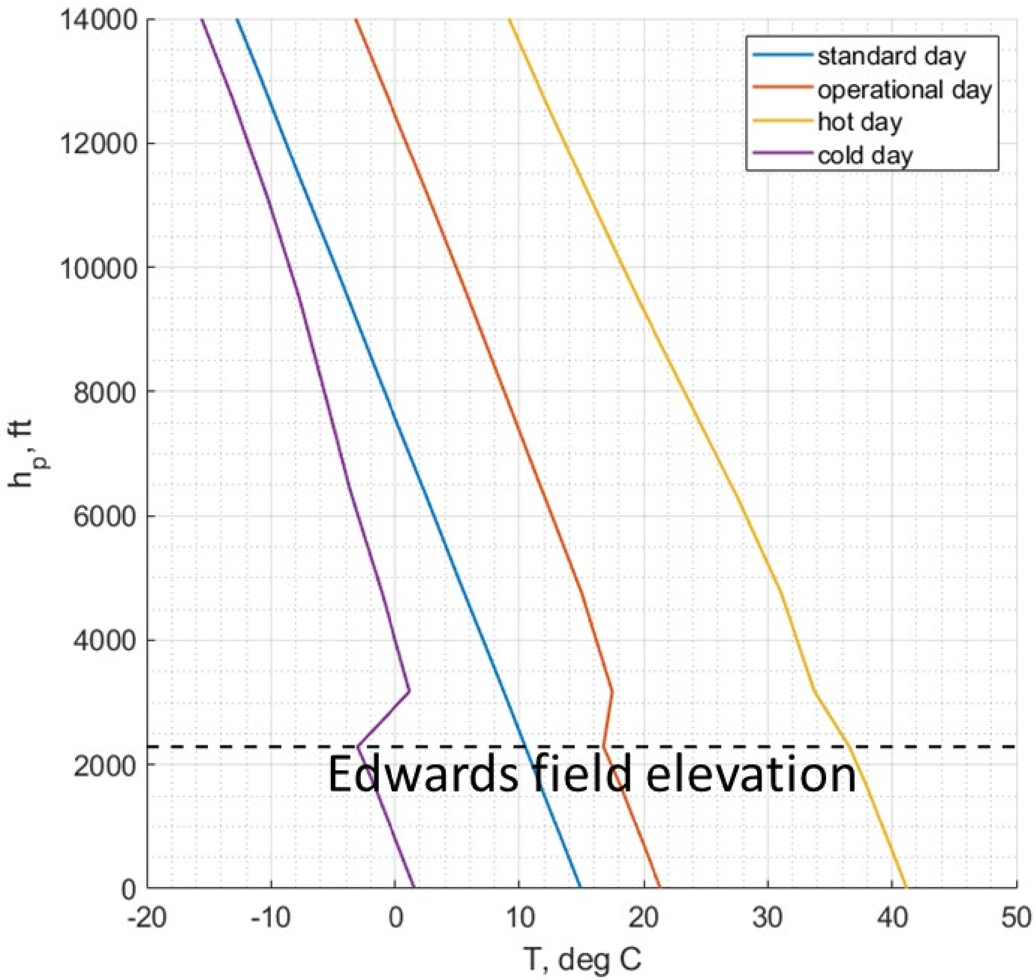
Cooling Requirements

- Maximum Continuous Power (MCP) setting
- Project reference atmosphere limits
- Component temperatures & margins

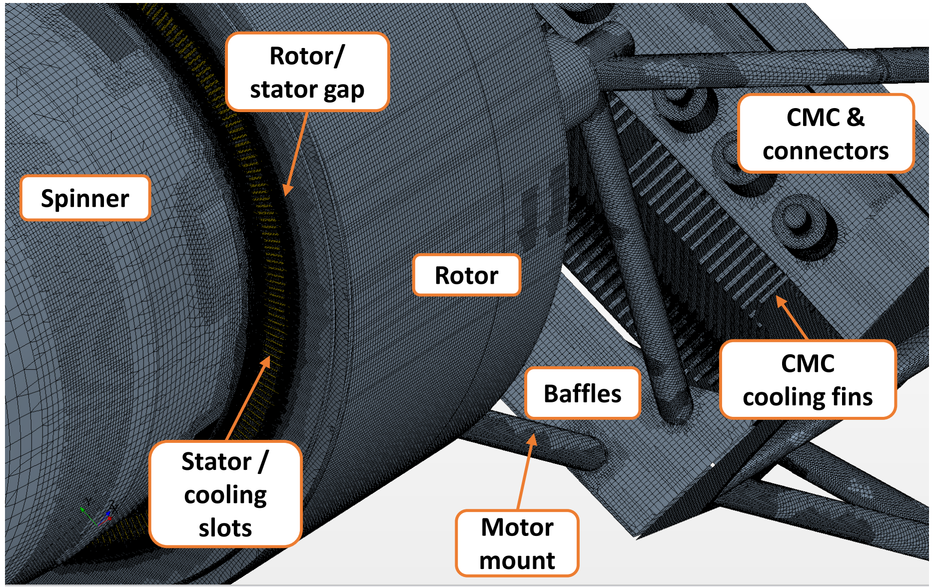
Component Temperature	Limit (°C)	Margined Limit (°C)
Cruise motor (CM) winding	135	124
CM magnet temperature	94	83
CM controller (CMC) field effect transistor (FET) junction (high voltage)	175	150
CMC low-voltage components	85 to 100	74 to 89

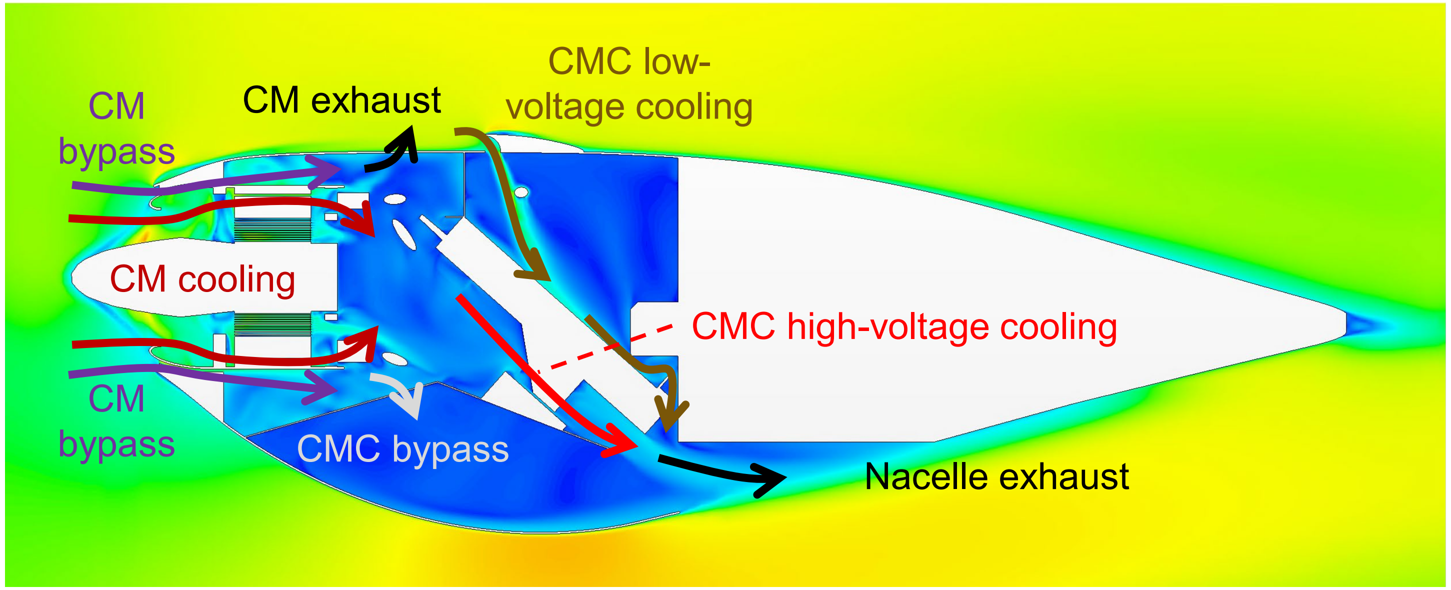
Flight Condition	Pressure altitude (h_p) / Airspeed (V)	Power Setting
Initial takeoff climb	2,500 ft / 70 KEAS	Peak (72.1 kW)
Cruise climb	2,500 ft / 81 KEAS	MCP (60.0 kW)
High-speed cruise	8,000 ft / 150 KTAS	Peak (72.1 kW)

KEAS: Knots Equivalent Airspeed
KTAS: Knots True Airspeed



Mod II Nacelle Components & Airflow





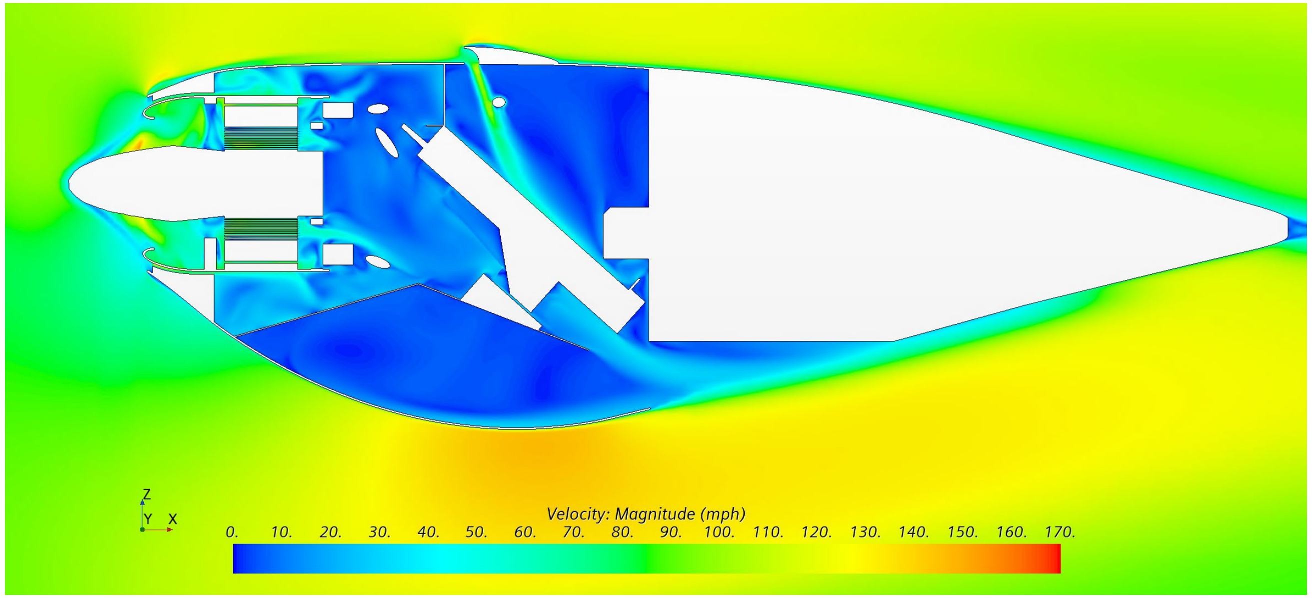
Initial Takeoff Climb, Project Hot Day

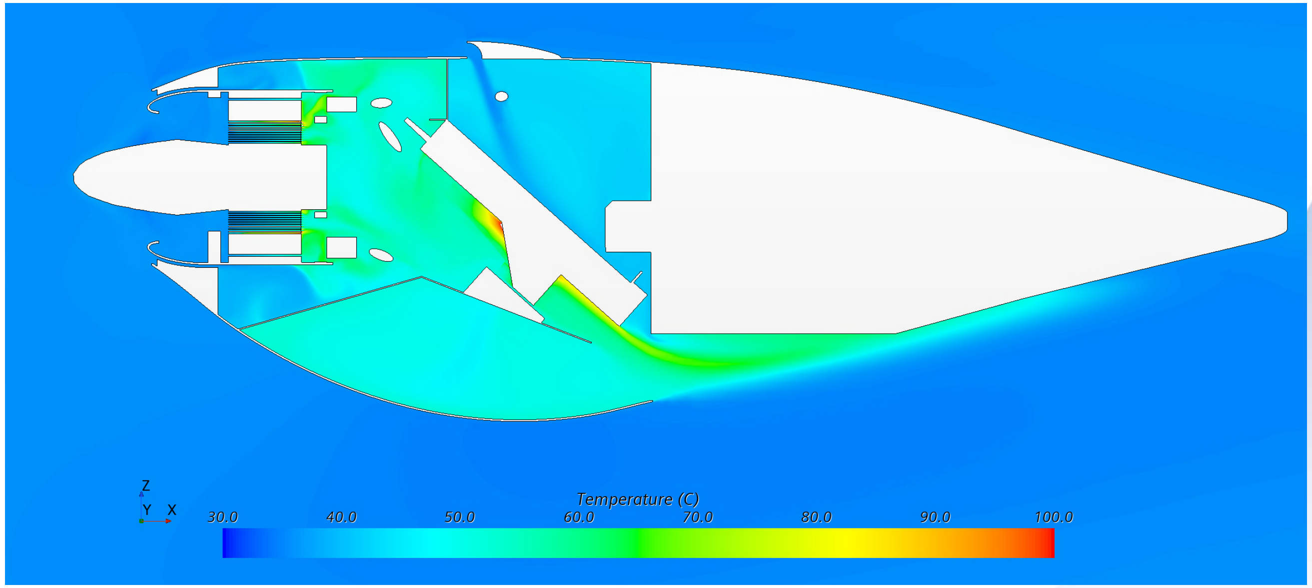
- Highest heat loads, lowest airspeed, hottest ambient conditions

Component	Heat (W)	Efficiency
CM stator windings	5,237	92.53%
CM rotor magnets	582	
CMC high-voltage heat sink	810	97.96%

- CM cooling flow: 67.2 deg C
- CMC high-voltage flow: 62.1 deg C
- CMC low-voltage flow: 46.7 deg C

- “Mickey Ear” jet over 100 mph at high-speed cruise condition





Component Temperature Estimates

Component	Initial takeoff climb		Cruise climb		High-speed cruise	
	T (°C)	Additional margin (°C)	T (°C)	Additional margin (°C)	T (°C)	Additional margin (°C)
CM winding	109.4	14.6	92.2	31.8	85.6	38.4
CM magnet	45.4	37.6	43.1	39.9	31.9	51.1
CMC FET junction	104.9	45.1	91.7	58.3	85.3	64.7
CMC FPGA	75.9	13.1	73.2	15.8	58.5	30.5
CMC driver board	76.2	12.8	73.6	15.4	59.2	29.8
CMC AC/DC board	75.6	-1.6	73.1	0.9	58.7	15.3
CMC CPU board	75.1	-1.1	72.4	1.6	57.7	16.3
MDAU case	61.4	12.6	57.0	17.0	44.8	29.2
FOBE case	55.7	18.3	51.3	22.7	39.9	34.1

- All components within margined limits other than two low-voltage CMC components
  - Both components within 2 deg C of margined limits
  - Project considering additional testing to confirm margin, planning to set early operational limits below maximum hot day extremes by 2 deg C in the meantime

Summary

- Developed thermal models for X-57 Mod II nacelle and cruise motor components
- Identified sizing flight conditions and environments
- Determined that cooling design was mostly adequate
  - Some additional scrutiny needed for low-voltage side of CMC
  - Identified mitigations as necessary
- Just because it’s efficient, doesn’t mean it’s not hard to cool!

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