

Environmental Advantages of Additive Manufactured (AM) Micro-Turbine Engine

WP20-D4-5083

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Engineering Division, Air Force Life Cycle Management Center, Wright-
Patterson AFB**

Final Debrief

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14. ABSTRACT The technical objectives of this project are listed below: <ul style="list-style-type: none"> ● Demonstrate an AM micro-turbine for multiple applications, ensuring cost effectiveness and manufacturing sustainability of the newly developed AM turbine engine for DoD services; ● Demonstrate the potential for improved performance in thrust specific fuel consumption and noise emissions of AM micro-turbine engine by establishing baseline performance criteria and then recommending opportunities for optimization (as required); ● Validate reduced thrust specific fuel consumption and noise emissions of AM micro-turbine and provide recommendations for implementation at DoD installations. 					
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Project Team



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(UDRI)



James Smith, Eric Larson
(Belcan Engineering Group, LLC)

Technical Objectives

- 1) Demonstrate an AM micro-turbine for multiple applications, ensuring cost effectiveness and manufacturing sustainability of the newly developed AM turbine engine for DoD services;
- 2) Demonstrate the potential for improved performance in thrust specific fuel consumption and noise emissions of AM micro-turbine engine by establishing baseline performance criteria and then recommending opportunities for optimization (as required);
- 3) Validate reduced thrust specific fuel consumption and noise emissions of AM micro-turbine and provide recommendations for implementation at DoD installations.

Performance Objectives

➤ Engine Operation Performance Objectives

Performance Objective	Data Requirements	Success Criteria	Success Criteria Achieved?
Qualitative Performance Objectives			
Engine start-up procedure established	Procedure to reach idle speed (~30k RPM)	Fuel feed rate and ignition RPM shown to be repeatable	Successful
Stable engine operation achieved	Stable operation shown at idle (~30k RPM), 50% power (~38k RPM), and max power (~76k RPM)	Engine speed maintained for at least 5s at each point without fuel feed rate adjustment	Successful for idle and 50% power conditions. Max power result - further testing required

Performance Objectives

➤ Engine Operation Performance Objectives

Performance Objective	Data Requirements	Success Criteria	Success Criteria Achieved?
Quantitative Performance Objectives			
Thrust (N)	<ul style="list-style-type: none"> Measured at max power (~76k RPM) Via Loadstar® RAS1 S-type Load Cell on custom built thrust stand 	Comparable to CFD prediction*	Further testing required
Thrust Specific Fuel Consumption (TSFC) (kg / N hr)	<ul style="list-style-type: none"> Measured at idle (~30k RPM) and max power (~76k RPM) Via AliCat MCR-2000 Mass Flow Controller 	Comparable to CFD prediction* and commercially available micro-turbine**	Further testing required
Sound Pressure Level (dB)	<ul style="list-style-type: none"> Measured at idle (~30k RPM) and max power (~76k RPM) Via Rode VideoMic high quality directional microphone 	Comparable to commercially available micro-turbine*	Further testing required
* CFD (Computational Fluid Dynamics) analytical predictions developed by Belcan ** JetCat P400-Pro used as comparable commercially available engine for performance specs			

Performance Objectives

➤ Engine Manufacturing Performance Objectives

Performance Objective	Data Requirements	Success Criteria	Success Criteria Achieved?
Qualitative Performance Objectives			
Reduction in manufacturing complexity	Reduction in manufacturing sites and number of processes	Show reduction from traditional engine process*	Successful
Ease of assembly	Demonstrate reduction in assembly steps	Show simplification over traditional engine*	Successful
* Pratt & Whitney TJ-150 engine used for manufacturing comparison			

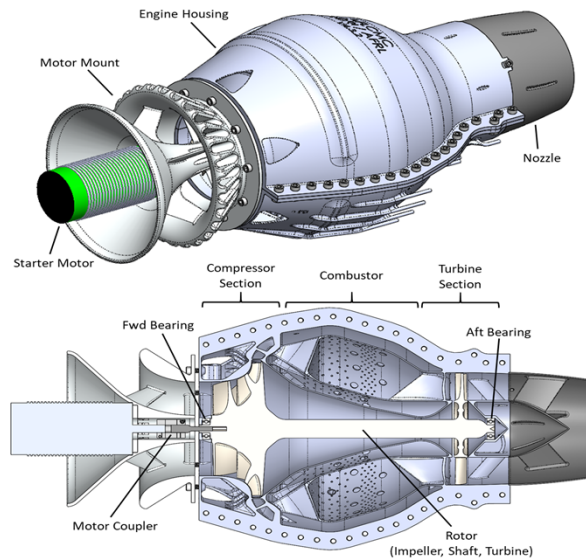
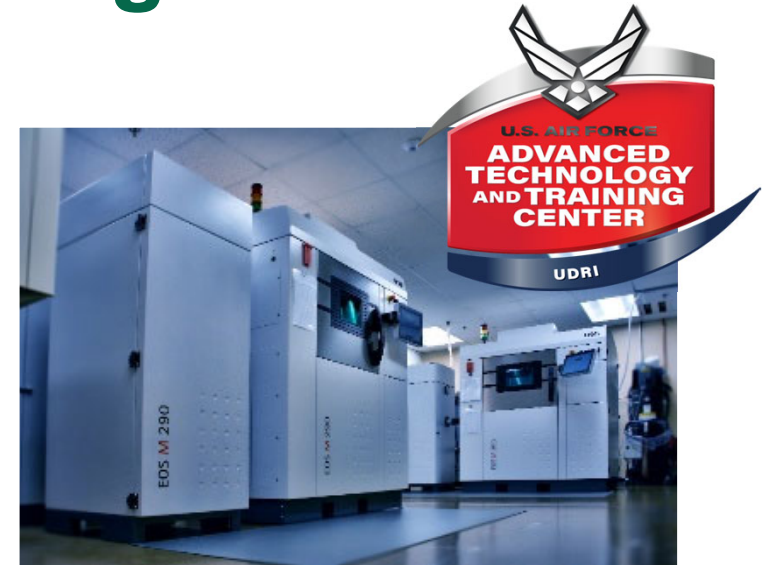
Performance Objectives

➤ Engine Manufacturing Performance Objectives

Performance Objective	Data Requirements	Success Criteria	Success Criteria Achieved?
Quantitative Performance Objectives			
Reduction of hazardous waste generated	Analysis of hazardous waste generated during manufacturing	Show reduction from traditional engine process*	Successful
Reduction of manufacturing costs	Analysis of cost of manufacturing methods	Show reduction from traditional engine process*	Successful
Reduction of manufacturing lead time	Lead time for manufacturing engine	Show reduction from traditional engine process*	Successful
* Pratt & Whitney TJ-150 engine used for manufacturing comparison			

Engine Manufacturing Site

- **AFLCMC/UDRI Advanced Technology Training Center (ATTC), Dayton, OH**
 - ◆ AM Powder Bed Fusion Technology - Direct Metal Laser Melting (DMLM) Process
 - ◆ AM Machine - EOS M290
 - ◆ Material - Inconel 718



Engine Assembly Model Views

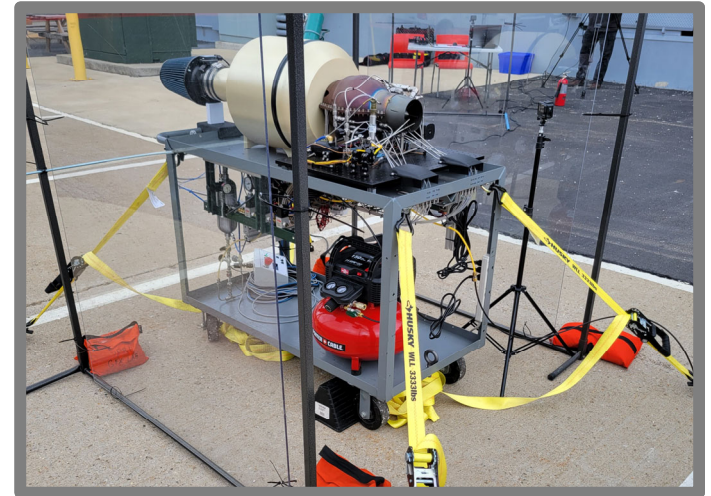
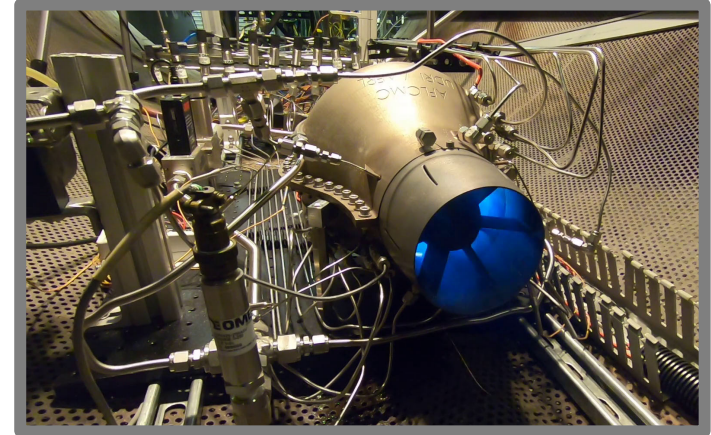


AM Printed Engine

Testing Sites

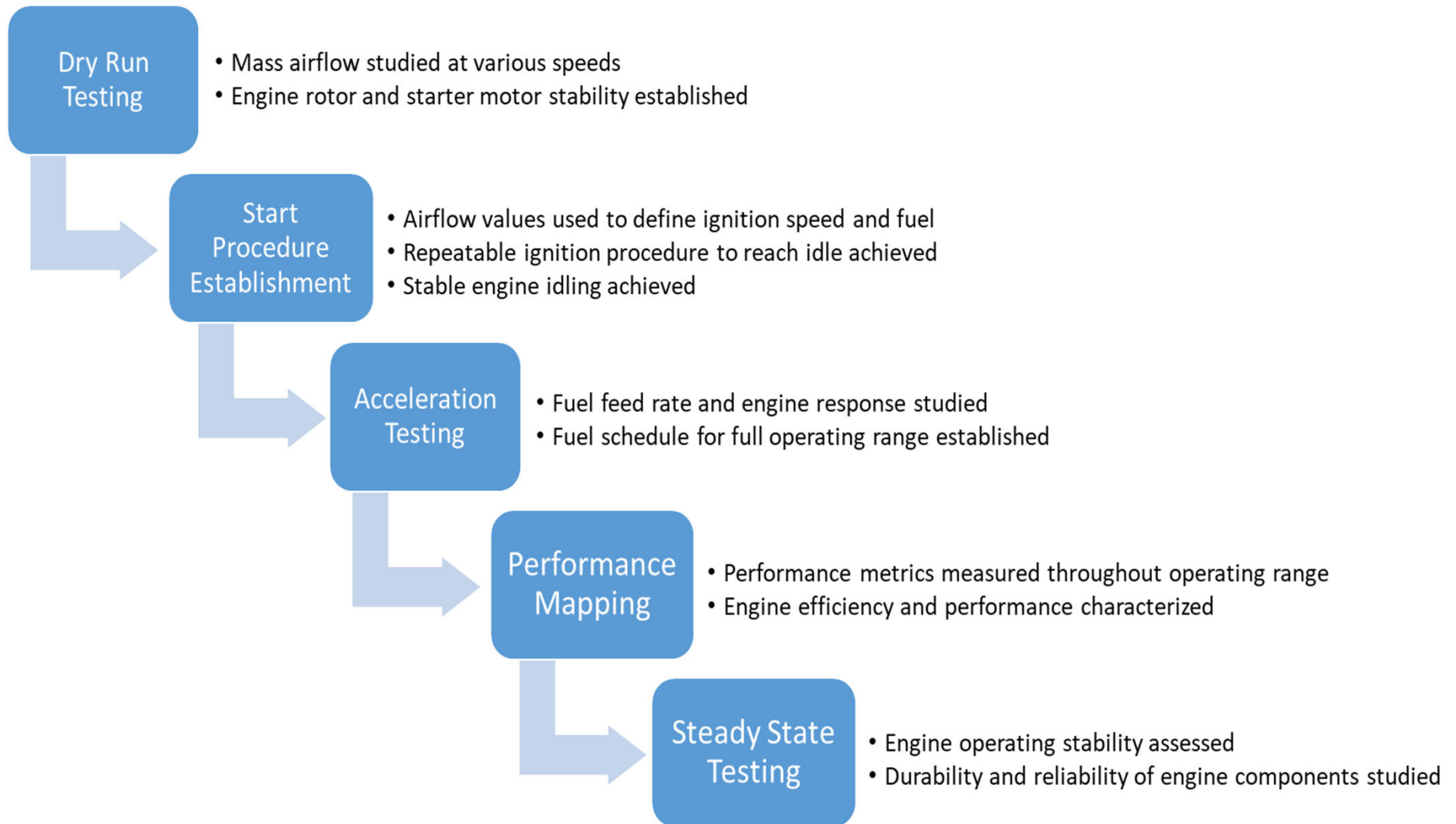
- **Air Force Research Laboratory (AFRL)**
Small Engine Research Lab/ Aerospace
Systems Directorate/ Wright-Patterson Air
Force Base WPAFB), OH:
 - Small Engine Test Cell

- **AFLCMC/UDRI Advanced Technology
Training Center (ATTC), Dayton, OH:**
 - Mobile Engine Test and Demonstration
Stand



Test Design

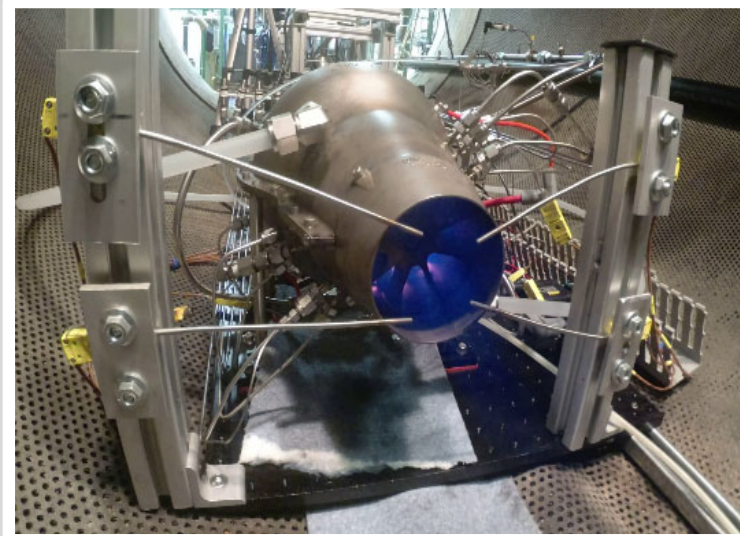
➤ Conceptual Experimental Design for AM Engine Performance



Test Design

➤ Pre-Demonstration Activities at AFRL lab

- Initial Testing at AFRL's Small Engine Test Cell (WPAFB, OH) - JetCat P400-Pro Engine Testing



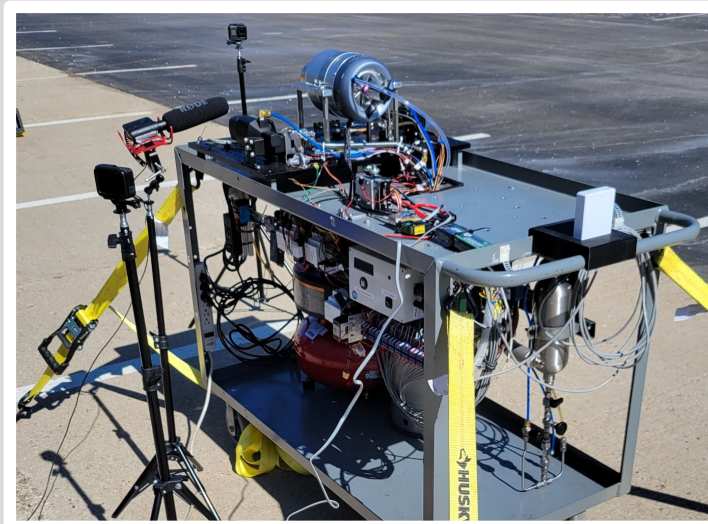
JetCat P400-Pro Engine Performance

Operating Conditions/Settings		Thrust (lbf)	TSFC ((lbm/hr) / lbf)	SPL (dB)
Operating Condition	Power Setting			
Idle (30% max)	30,000 RPM	3.7	6.4	79.8
Cruise (80% max)	78,400 RPM	46	1.8	111.1
Max Power (100% max)	98,000 RPM	83	1.6	114.7

Test Design

➤ Pre-Demonstration Activities at ATTC/ Test Set-up Validation

- Mobile Test Stand - JetCat P400-PRO Engine Testing

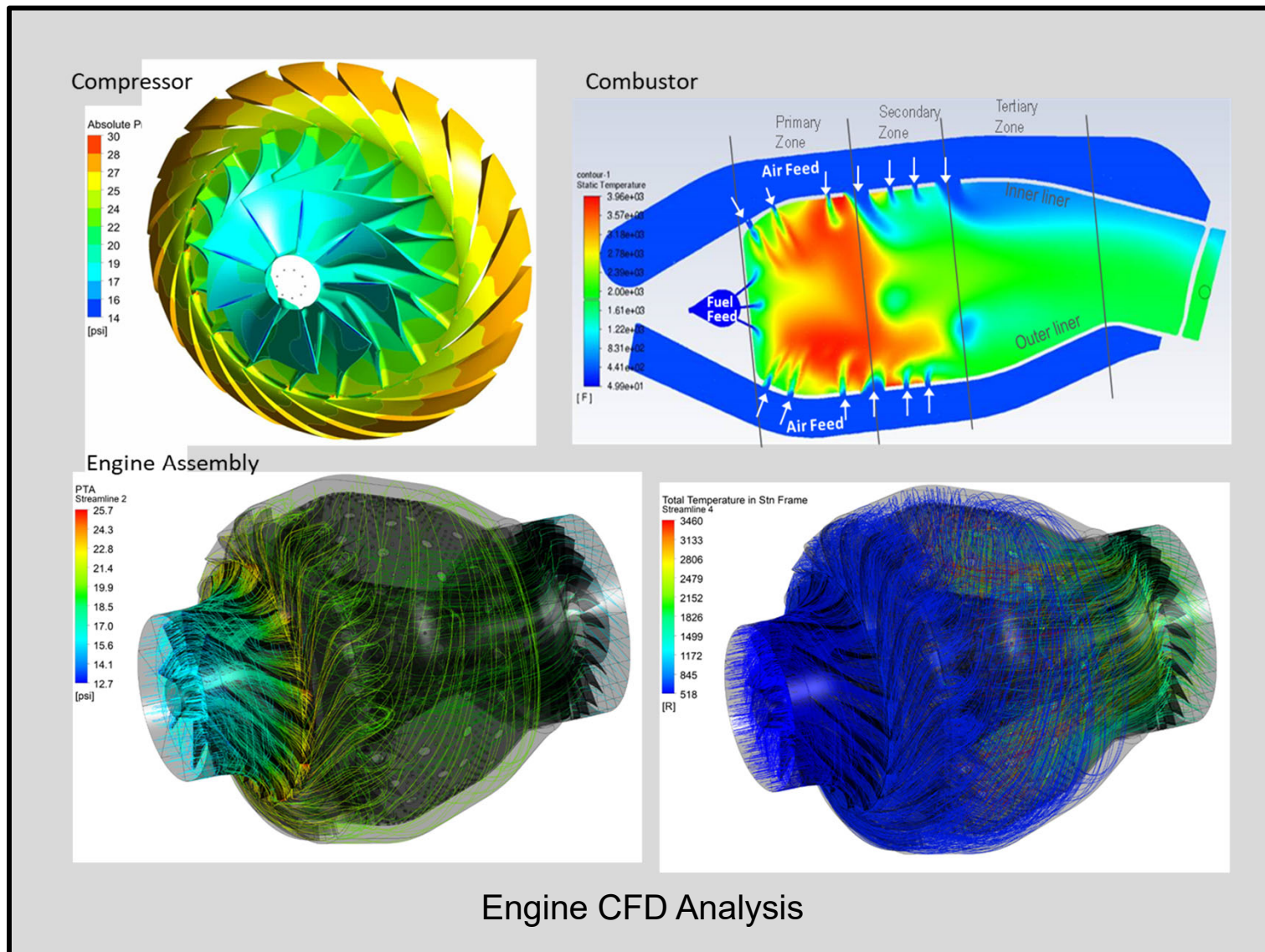


JetCat P400-Pro Engine Performance

Operating Conditions/Settings		Thrust (lbf)	TSFC ((lbm/hr) / lbf)	SPL (dB)
Operating Condition	Power Setting			
Idle (30% max)	30,000 RPM	4.5	5.6	70
Cruise (80% max)	78,400 RPM	38	2.2	80
Max Power (100% max)	98,000 RPM	79	1.7	94

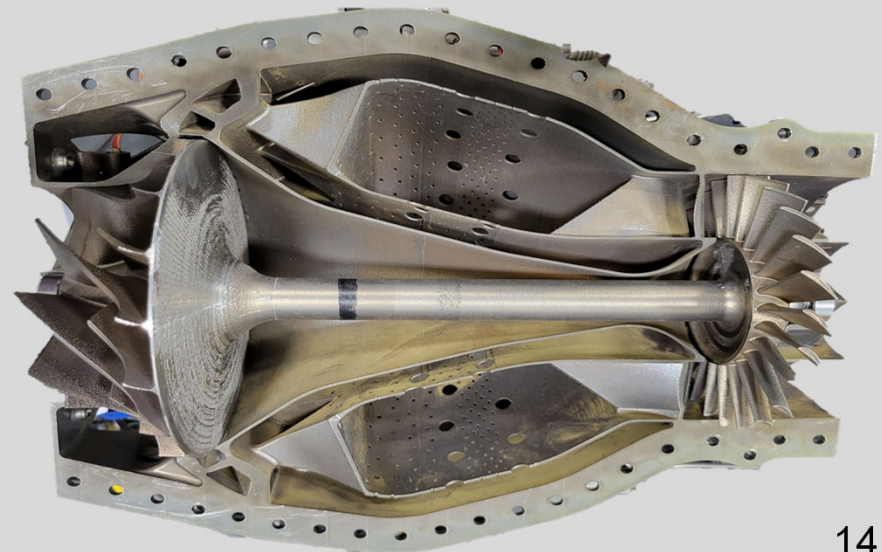
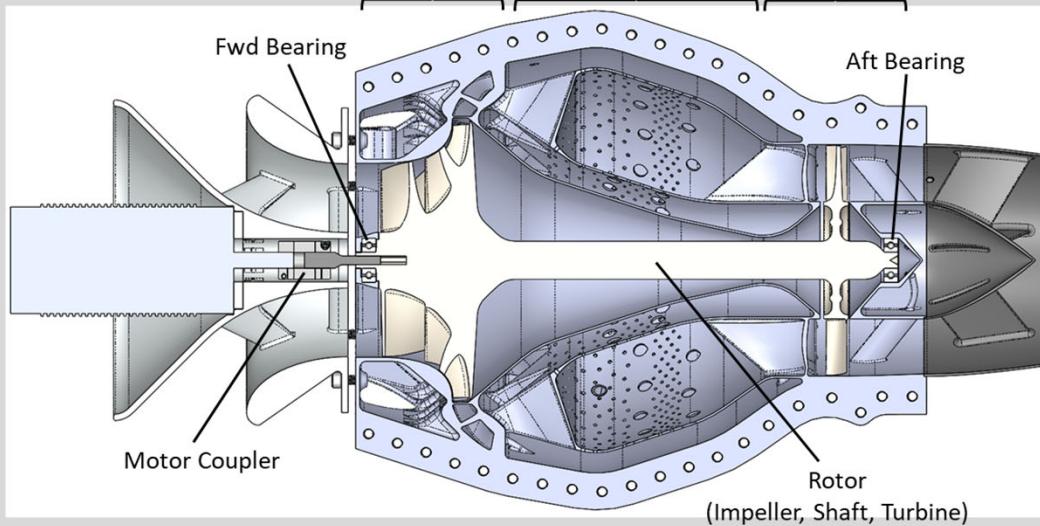
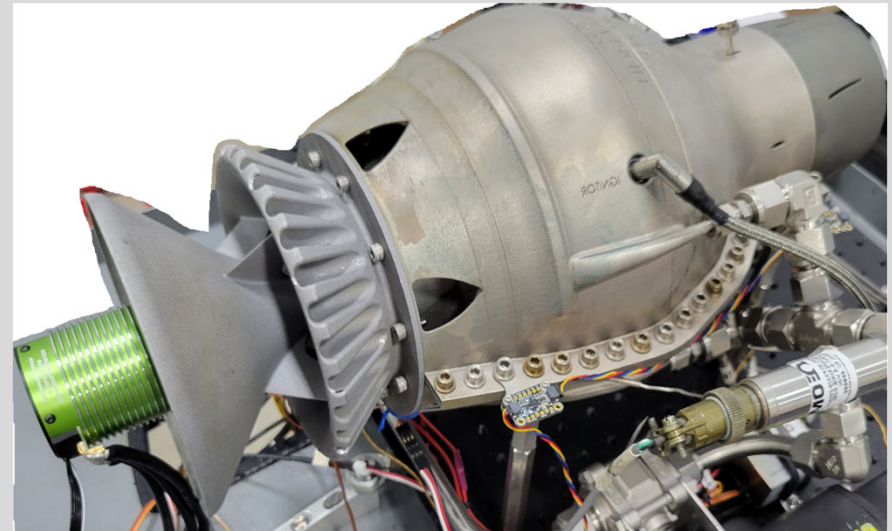
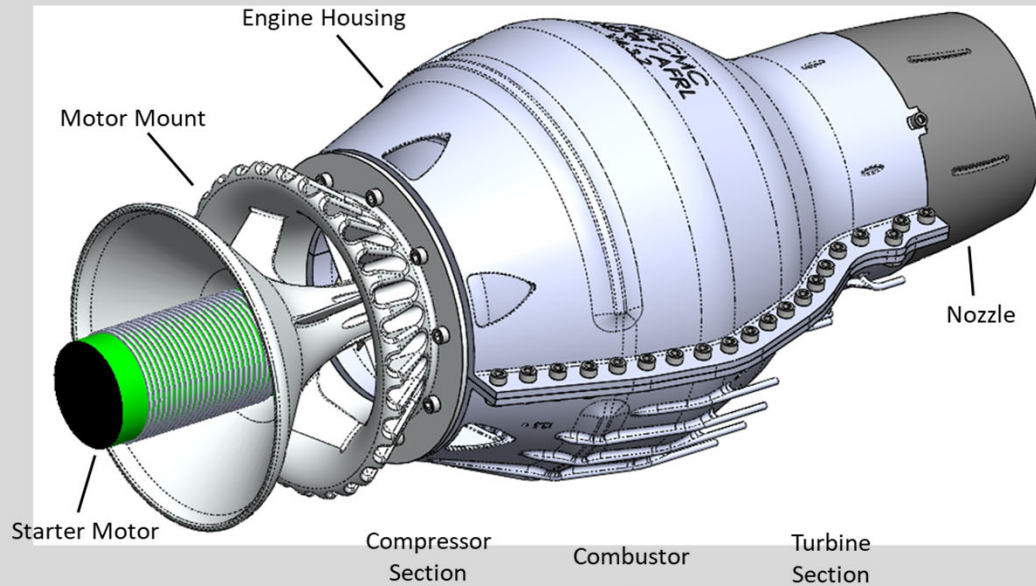
Performance Assessment

- **CFD Analysis to Validate the Design & Performance of the AM engine**



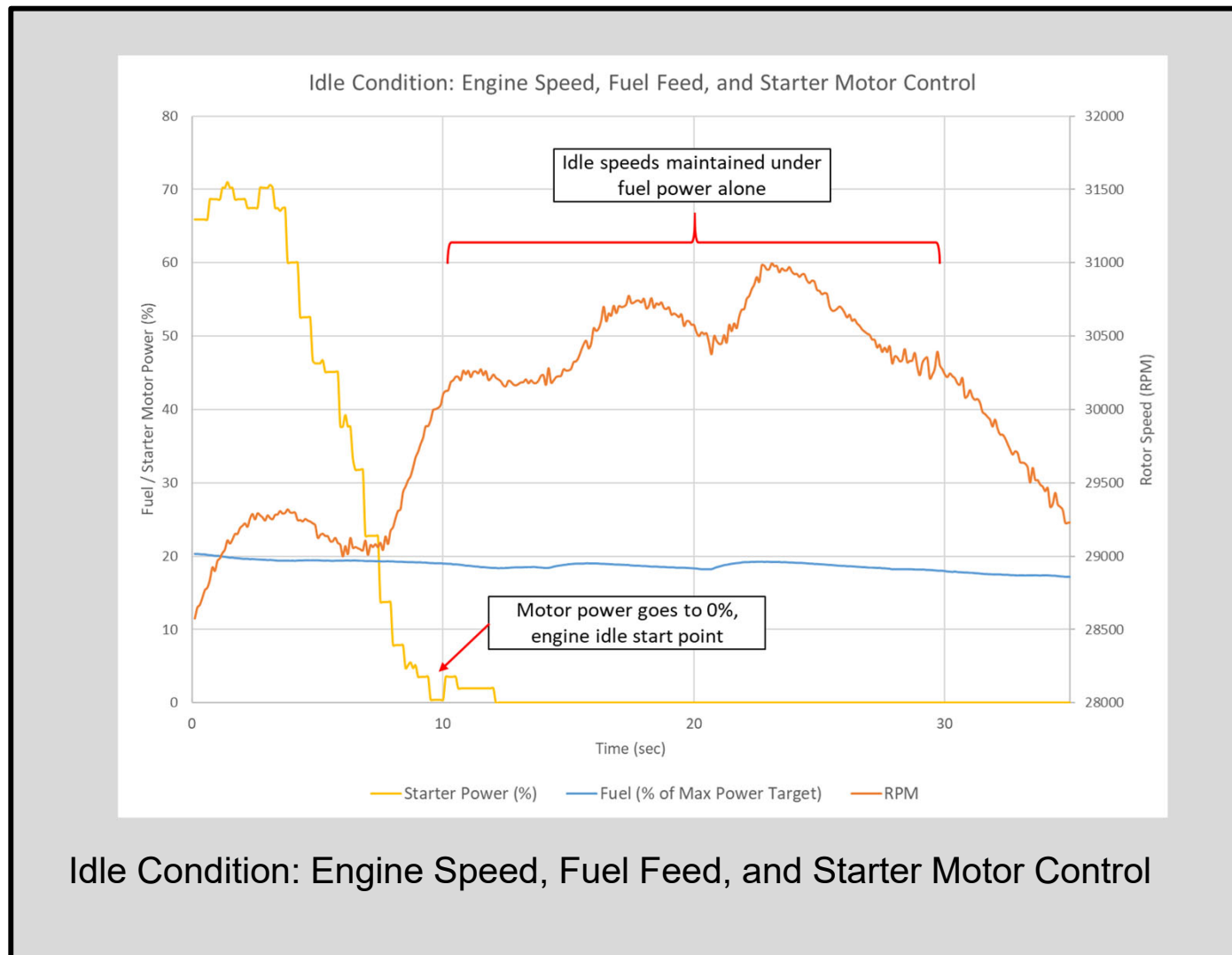
Performance Assessment

➤ Engine Assembly Model Views



Performance Assessment

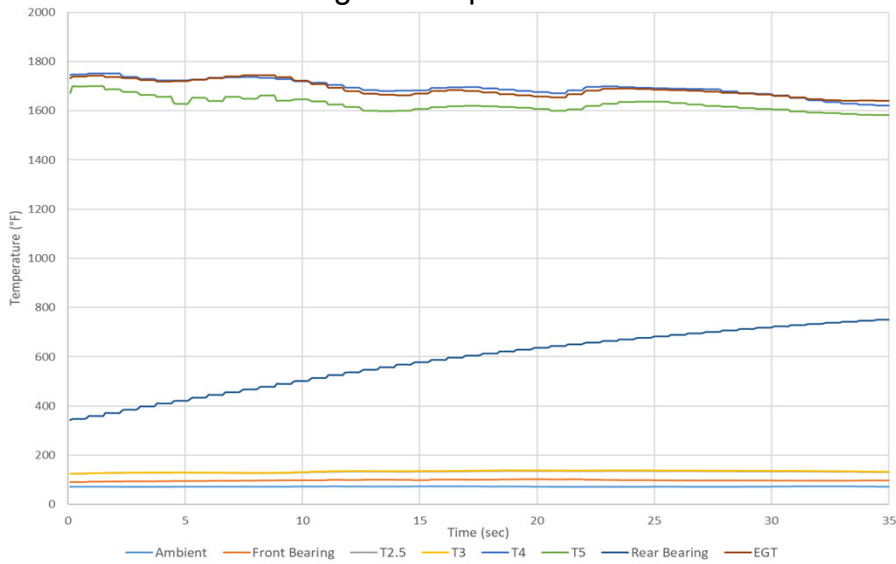
➤ AM Engine Testing: Idle Condition



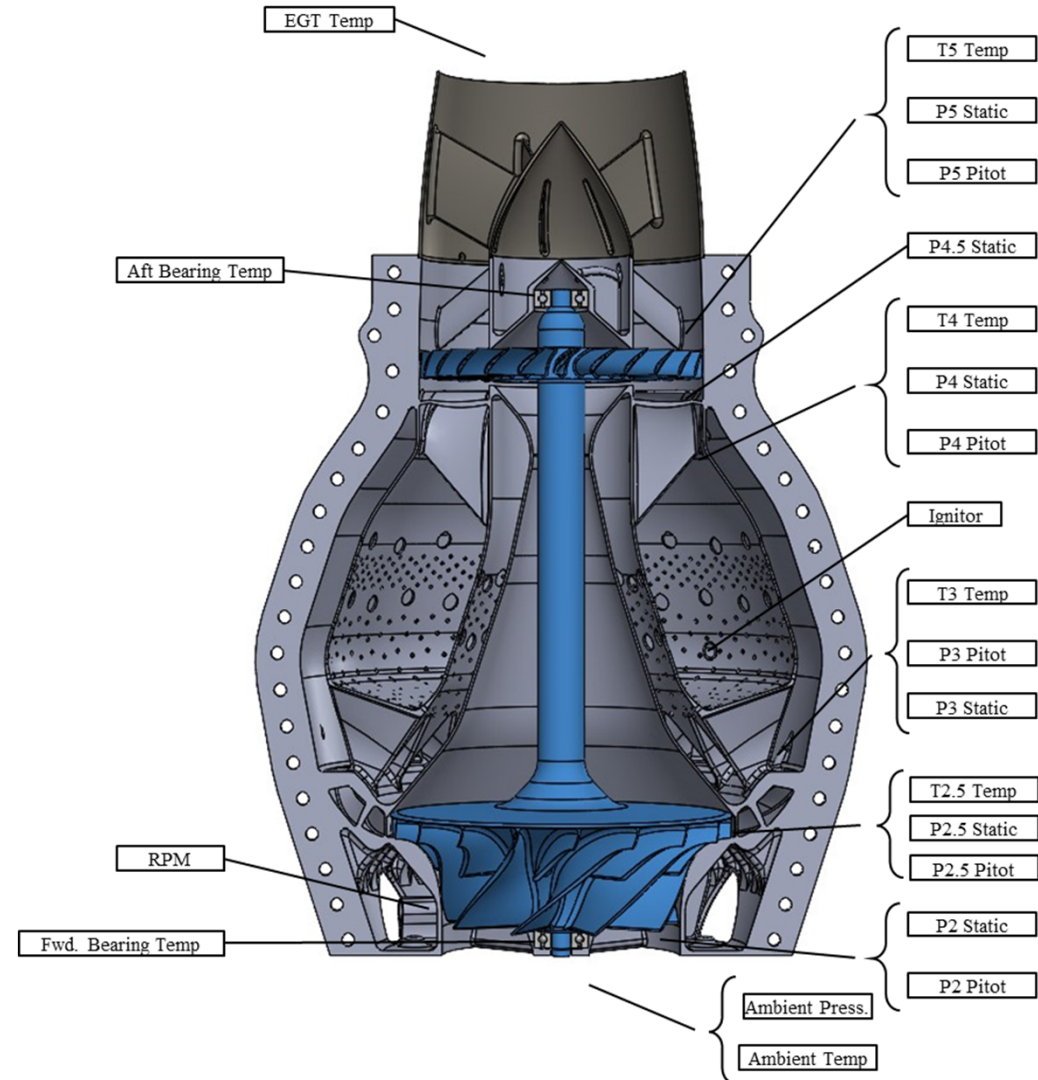
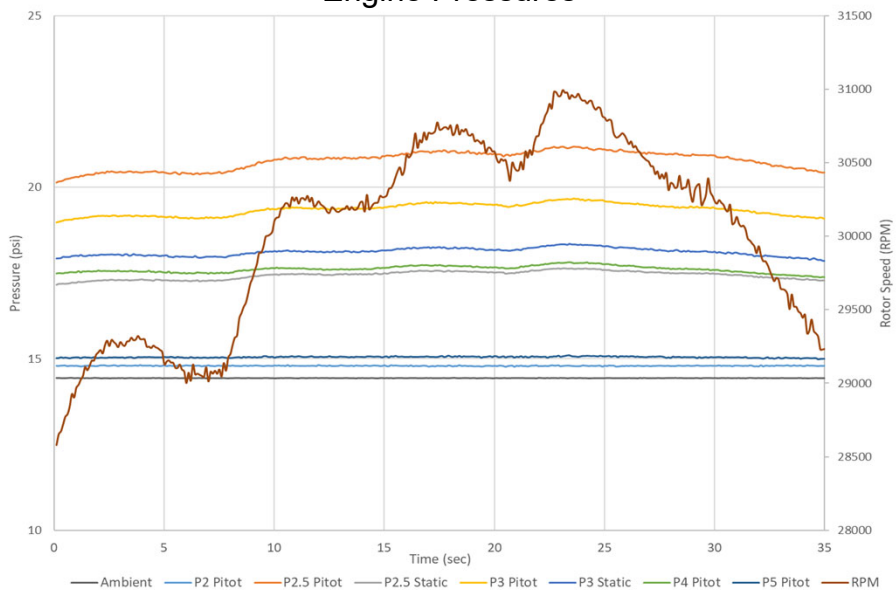
Performance Assessment

➤ AM Engine Testing: Idle Condition

Engine Temperatures

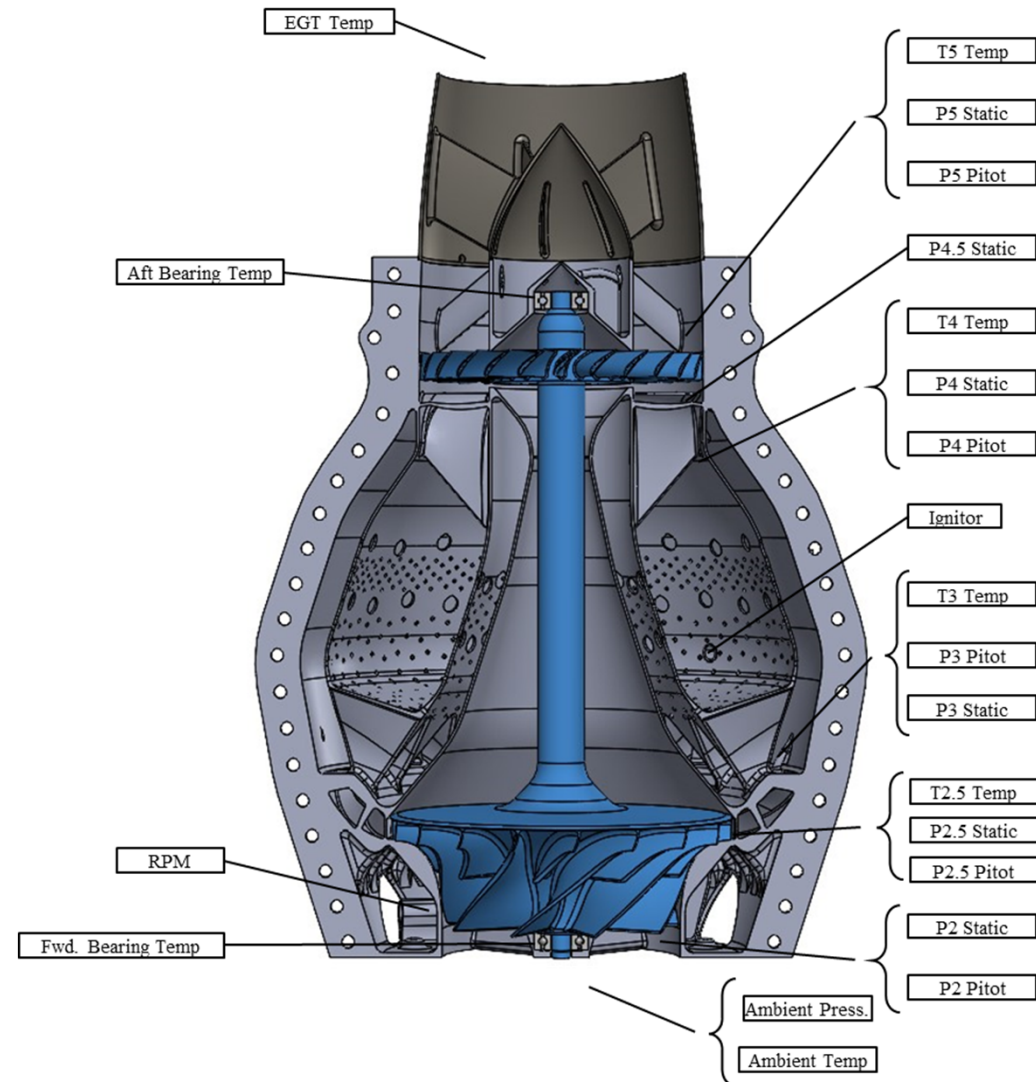
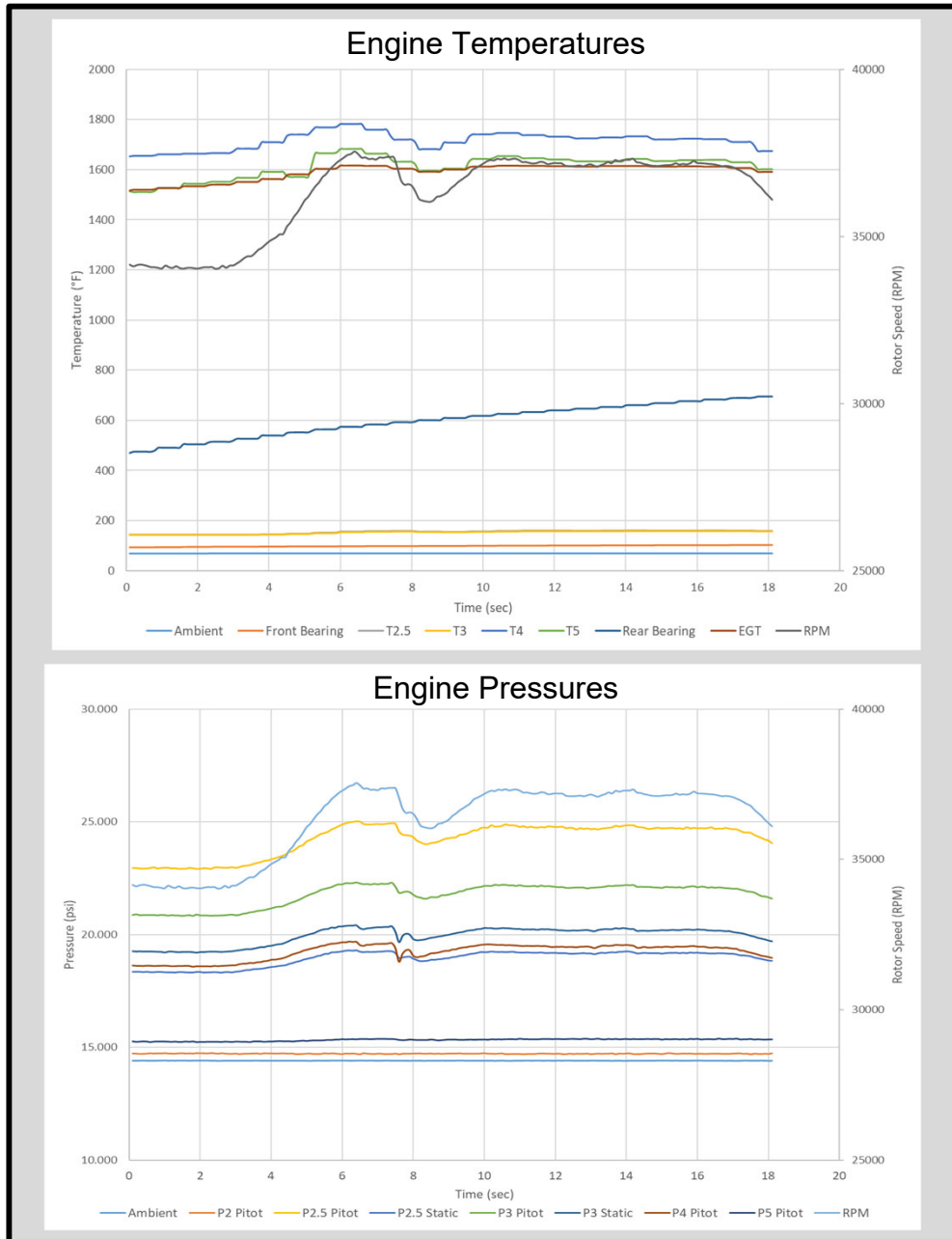


Engine Pressures



Performance Assessment

➤ AM Engine Testing: 50% Power (38,000 RPM) Condition



AM Engine Manufacturing Environmental Impact

- ◆ The comparison analysis to the Pratt & Whitney TJ-150 turbojet engine (MALD and SPEAR missiles) vs AM micro-turbine engine by AFLCMC/UDRI team
- ◆ Casting Process (investment casting, post processing, transportation) vs AM (gas atomized powder, AM, post processing) for eight (8) design/development iterations

Process	Total Particulate (lbs)	Sox (lbs)	Nox (lbs)	VOC (lbs)	One (1) Engine		Eight (8) Engines	
					kWh	CO ₂ (lbs)	kWh	CO ₂ (lbs)
Investment Casting Process								
Investment casting emissions	0.26	0.92	0.472	0.067		22.83		182.66
Transportation (5-ton truck/castings)	6.20		11.20	1.60		219.68		1,757.40
Total — Investment Casting					15,867.97	15,926.41	126,943.79	127,411.31
Additive Manufacturing Process								
Total — Additive Manufacturing					3,895.41	3,850.22	31,163.28	30,801.78

Cost Comparison and Lead-time

- ◆ The comparison analysis to the Pratt & Whitney TJ-150 turbojet engine (MALD and SPEAR missiles)
- ◆ Casting Process (investment casting, post processing, transportation) vs AM (gas atomized powder, AM, post processing)

Process	kWh	Cost (\$)	CO ₂ (lbs)
Investment Casting	126,943	7,617	127,411
Additive Manufacturing	31,163	1,870	30,801

- ◆ The lead-time comparison (in weeks) for eight iterations of design, design modification, and build for both investment casting (with SLA tooling) and additive manufacturing

Estimated Lead-time (weeks)	Iteration								Total (weeks)
	1	2	3	4	5	6	7	8	
Investment Casting									
Investment casting design/SLA mold pattern/build	5.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36	
Casting/post processing	15	15	15	15	15	15	15	15	
Total Casting Lead-time	20.36	18.36	18.36	18.36	18.36	18.36	18.36	18.36	148.91
Additive Manufacturing									
Additive design/build	6.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	
Post processing	4	4	4	4	4	4	4	4	
Total Additive Lead-time	10.35	8.35	8.35	8.35	8.35	8.35	8.35	8.35	68.83

Implementation Challenges and Successes

We came a long way....

- **Engine Design**

- ◆ Initial test run failures
- ◆ Belcan consulting - engine redesign using computational fluid dynamics (CFD); **Success - a digital twin!**

- **Printing**

- ◆ First attempt to print a case - 76 machine stops
- ◆ **Success - got it down to one stop!** (to refill powder hopper)!

- **Testing**

- ◆ Lost access to the engine test cell at AFRL
- ◆ **Success - designed and built Mobile Engine Test Stand!**

Award: 1st Place in Technical Advanced AM Concepts and the Members Choice Award at the *2023 Additive Manufacturing Users Group Conference* (AMUG 2023, March 19-23, Chicago, IL)

Future Work Recommendations

- Additional developmental work is needed
- Performance verification testing needs to be completed to demonstrate engine performance as expected
- Completion of these steps will aid in identifying appropriate ground and air applications for the engine

Technology Transfer

- **USAF – UDRI Cooperative Research and Development Agreement (CRADA) is in progress**
- **UDRI – To extend these efforts using internal funds to identify a potential commercial application**
- **1st Place in Technical Advanced AM Concepts and the Members Choice Award at the 2023 Additive Manufacturing Users Group Conference (AMUG 2023, March 19-23, Chicago, IL)**
- Environmental Advantages of Additive Manufactured (AM) Micro-Turbine Engine, *ESTCP DoD Symposium, Dec 2020, poster*
- Environmental Advantages of Additive Manufactured (AM) Micro-Turbine Engine, *ESTCP DoD Symposium, Dec 2021, briefing and poster*
- Environmental Advantages of Additive Manufactured (AM) Micro-Turbine Engine, *ESTCP DoD Symposium, Dec 2022, poster*

Key Points

- There is a need to further mature the AM engine technology
- The engine articles and test facilities developed under this project are readily available for further development work
- Opportunities exist to further optimize the AM engine design and performance

Awards

*2023 Additive Manufacturing Users Group Conference
(AMUG 2023, March 19-23, Chicago, IL)*

◆ **1st Place in Technical
Advanced AM Concepts**

◆ **Members Choice Award**



BACKUP SLIDES

WP20-5083: Environmental Advantages of AM Micro-Turbine Engine

Performers:

- *AFLCMC, AFRL, UDRI, Belcan*

Technology Focus

- *Additively Manufactured (AM) Micro-Turbine Engine*

Demonstration Site

- *USAF/UDRI ATTC (Dayton, OH); AFRL/WPAFB, OH*

Demonstration Objectives

- *Demonstrate an AM micro-turbine for multiple applications, ensuring cost effectiveness and manufacturing sustainability of the newly developed AM turbine engine for DoD services*

Project Progress and Results

- *Engine start-up procedure established*
- *Stable engine operation achieved: Successful for idle and 50% power conditions. Max power result - further testing required*
- *Manufacturing complexity reduced*
- *Ease of assembly achieved*

Implementation

- *Additional developmental work and verification testing is needed to aid in identifying appropriate ground and air applications for the engine*

