INVESTIGATIONS OF THE COMBUSTION AND EMISSIONS CHARACTERISTICS OF JET-A FUEL IN A SINGLE STAGE TURBO JET ENGINE THROUGH NUMERICAL AND EXPERIMENTAL ANALYSIS

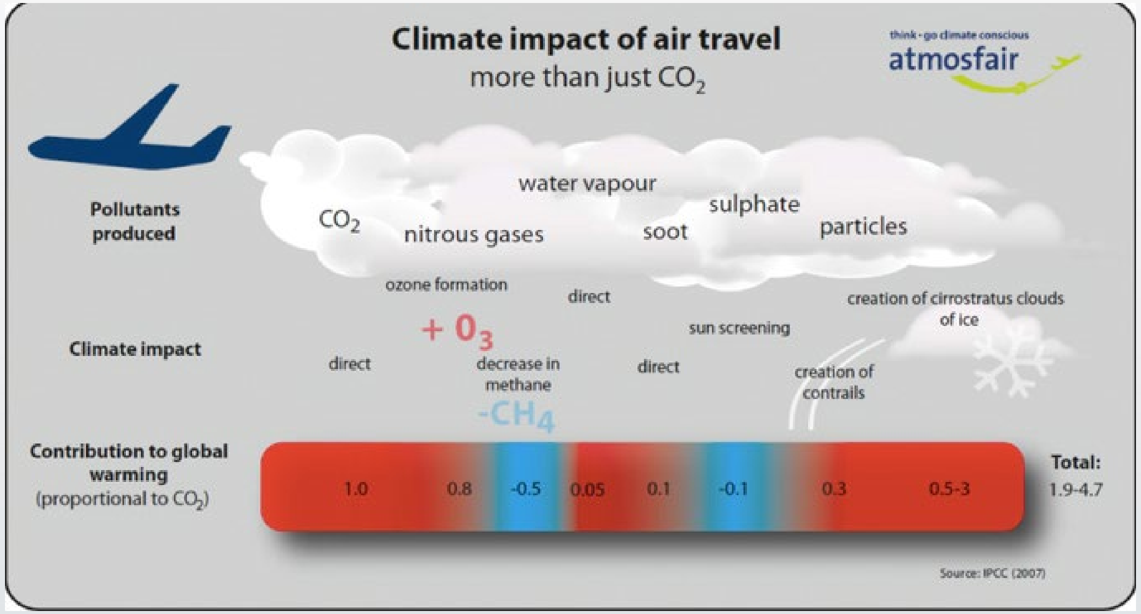
NSF-REU Milestone

Amanda Weaver and Richard C. Smith III

DoD-NSF Assure REU Site Award: 1950207

Introduction/Objectives

- Investigate the effect of increasing RPM on combustion efficiency in a single stage turbo jet engine
- Develop numerical model for the single stage jet engine based on Jet-A combustion
- Evaluate the experimental and numerical model for efficiency and emissions

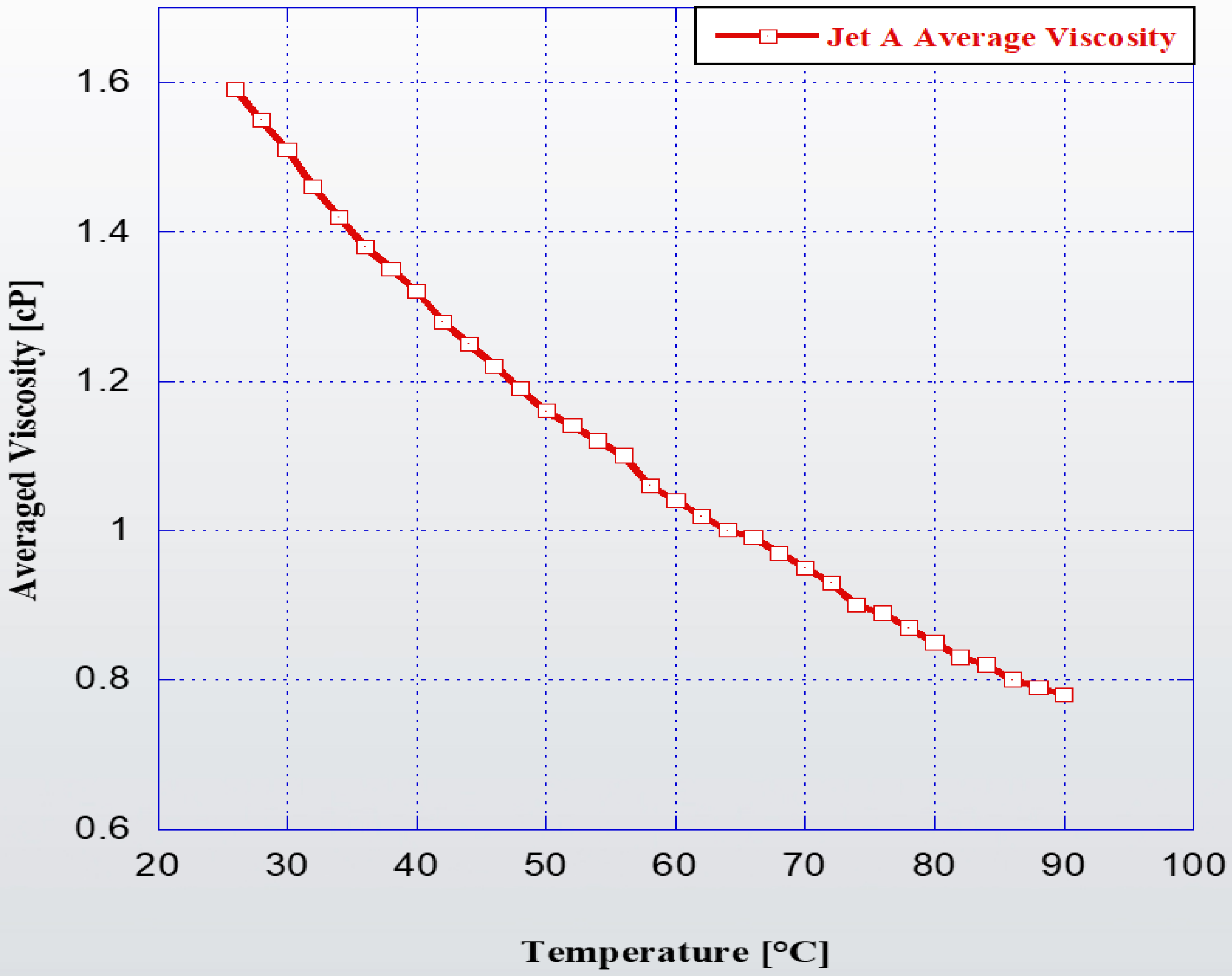


Thermophysical Properties of Jet-A

Lower Heating Value	41.88
Derived Cetane Number	48.0
Avg. Ignition Delay (ms)	3.26
Avg. Combustion Delay (ms)	5.01
Viscosity @ 40° C (cP)	1.32

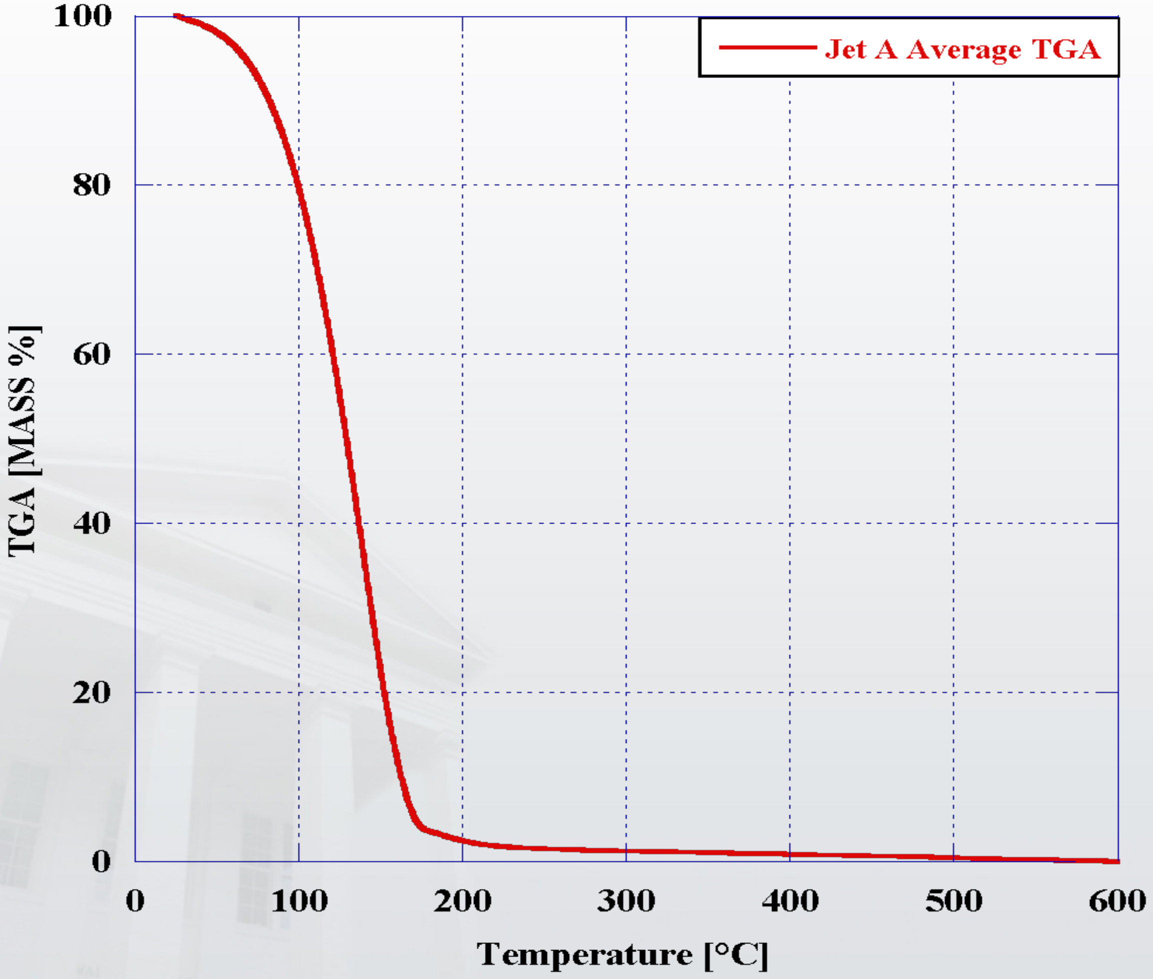
Viscosity

- Temperature was increased from 26°C to 90°C
- Viscosity of Jet-A at 40°C is 1.32 cP



Viscosity vs Temperature

Thermogravimetric Analysis



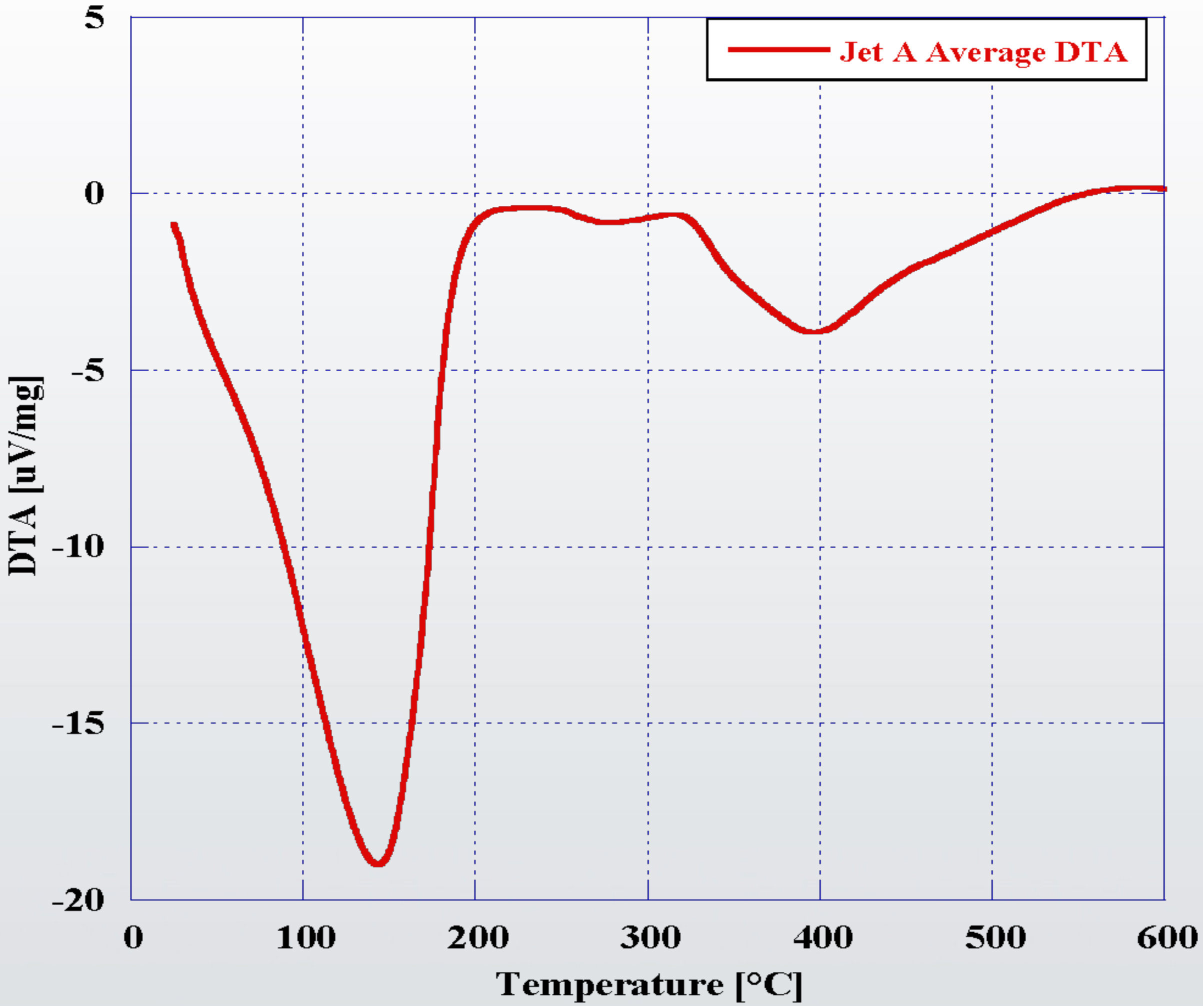
Jet-A Mass Percentage vs Temperature

- Volatility of the fuel was determined using a Thermogravimetric Analysis, Shimadzu DTG-60 Device

TA%	Average
TA (10)	83°C
TA (50)	130°C
TA (90)	164°C

Differential Thermal Analysis

- Energy absorption rate is catalogued alongside the increase in temperature
- More volatile fuels will absorb energy at a faster rate

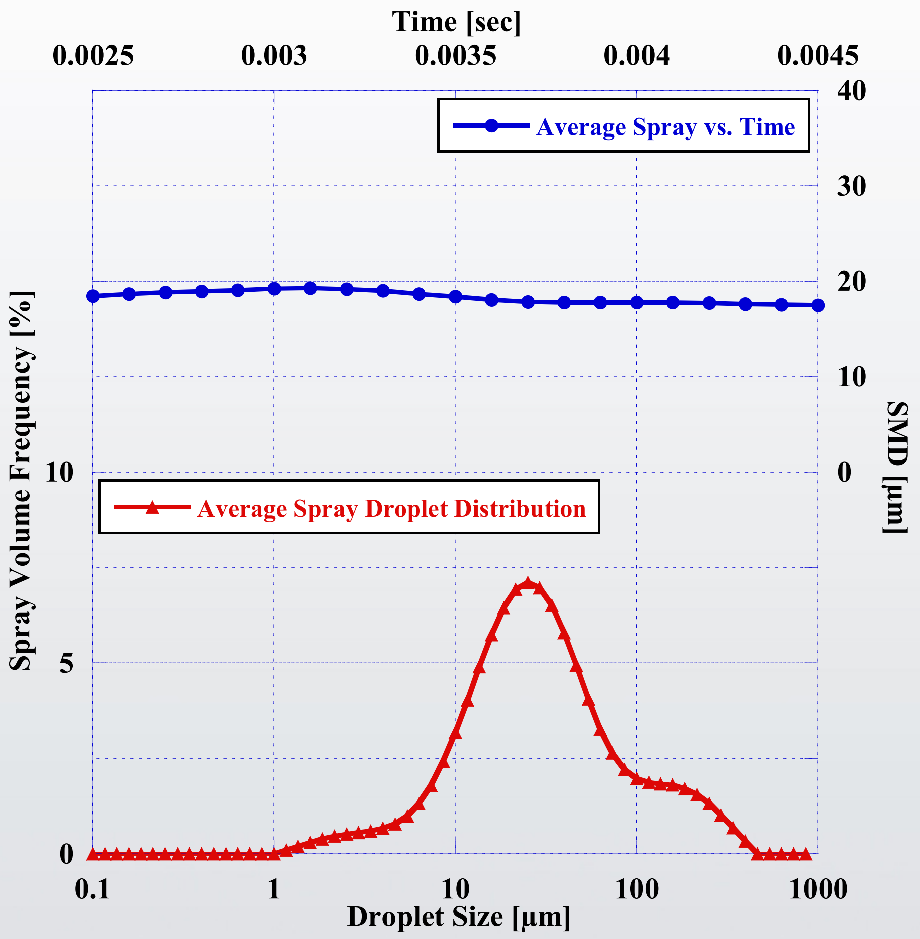


Energy Exchange Rate vs Temperature

Spray Analysis

- Droplet size and distribution characterize fuel atomization
- SMD, Sauter Mean Diameter is a measurement of droplet size

(µm)	Average
Dx (10) (µm)	9.85
Dx (50) (µm)	30.11
Dx (90) (µm)	133.45
SMD (µm)	18.54
Most Prominent Droplet Size (µm)	25.12
% V < 10 µm	14.3%



Spray Droplet Size and Distribution

DCN Determination

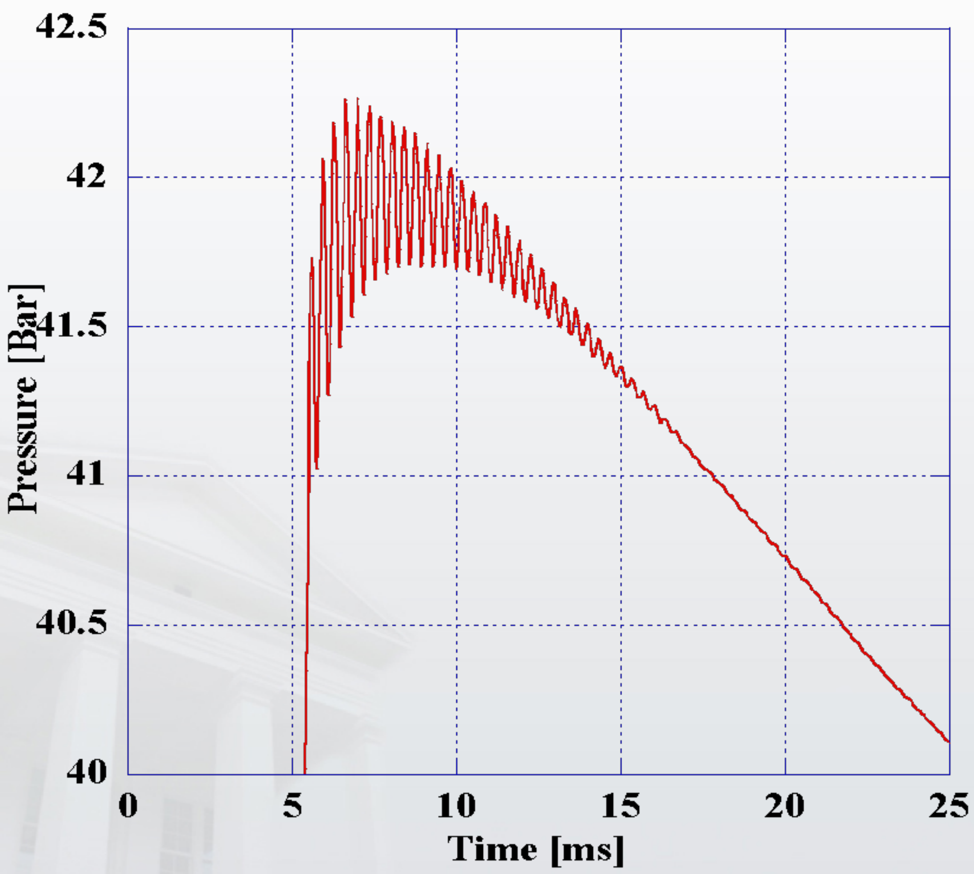
ASTM Standard D7668-14.a

- Derived Cetane Number is a representation of the autoignition characteristics of the fuel
- The DCN equation uses the ignition delay and combustion delay to calculate this value

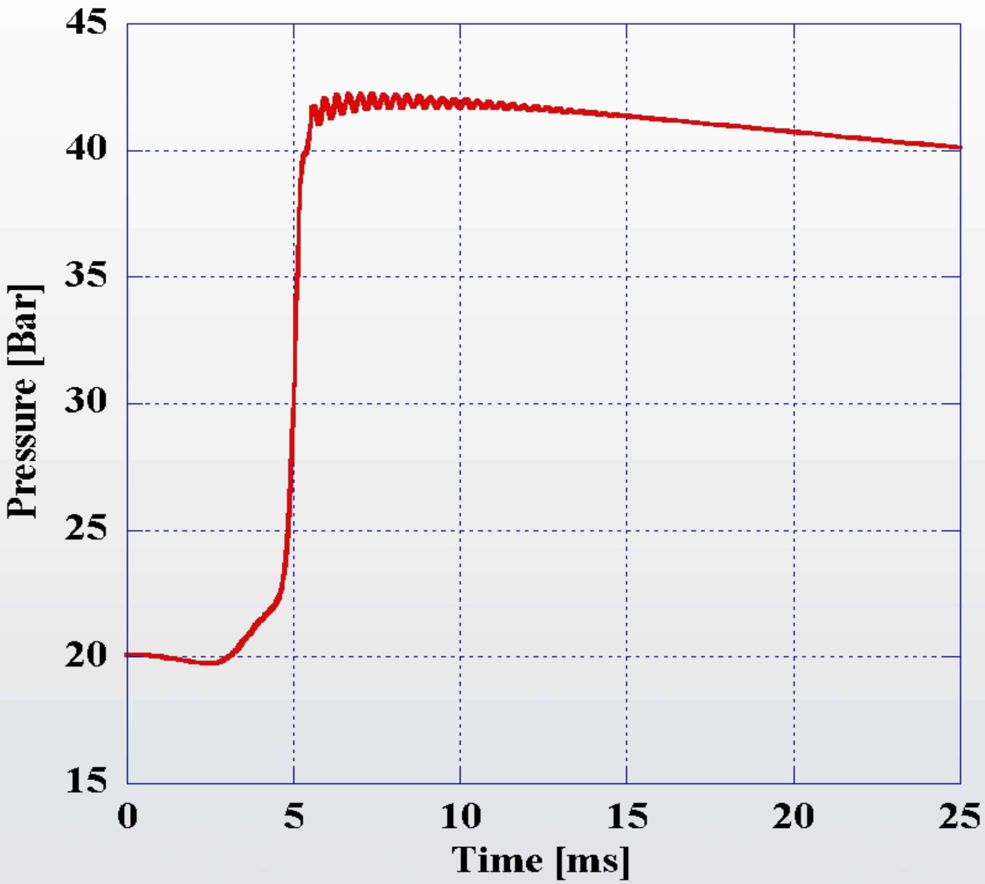
Wall Temp.	Fuel Injection Pressure	Coolant Temp.	Injection Pulse Width	Chamber Pressure
595.5 °C	1000 Bar	50 °C	2.5 ms	20 Bar

$$DCN = 13.028 + \left(\frac{-5.3378}{ID}\right) + \left(\frac{300.18}{CD}\right) + \left(\frac{-12567.90}{CD^2}\right) + \left(\frac{3415.32}{CD^3}\right)$$

Pressure Trace



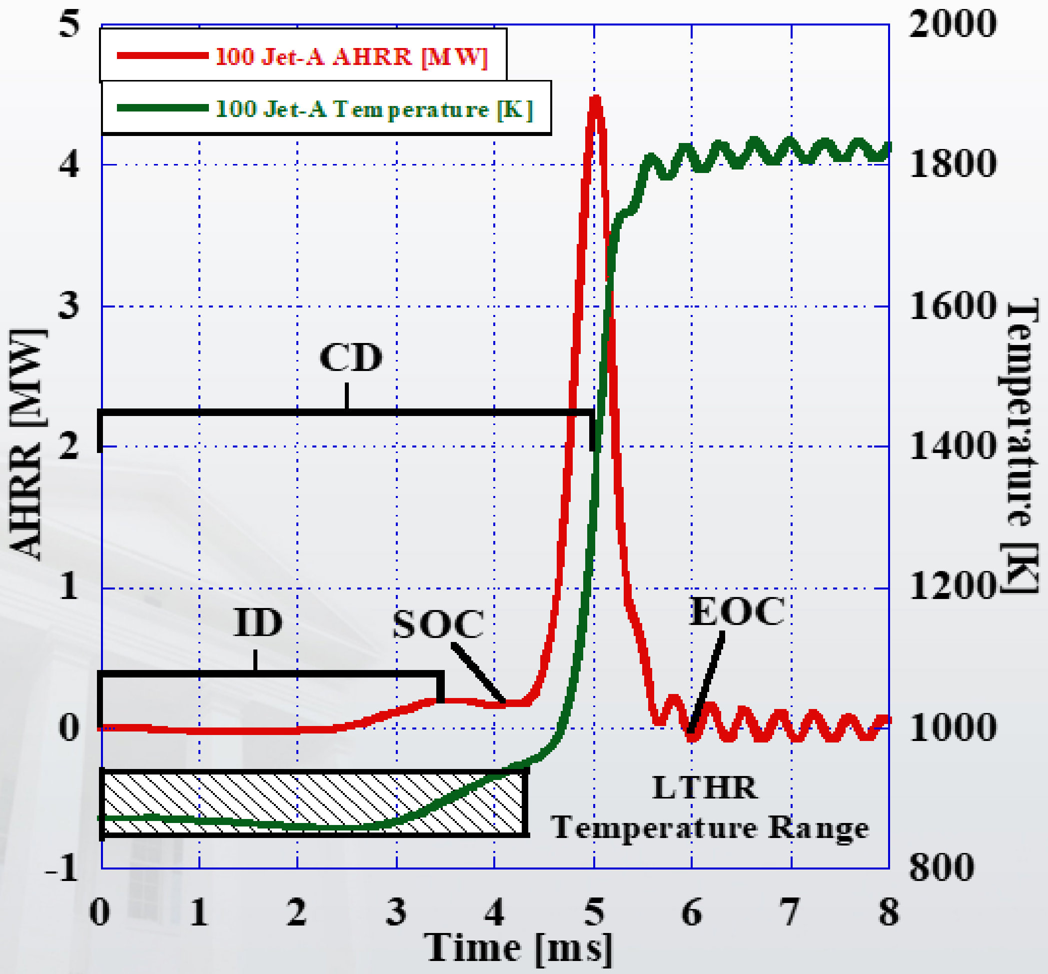
Pressure Trace for Jet-A

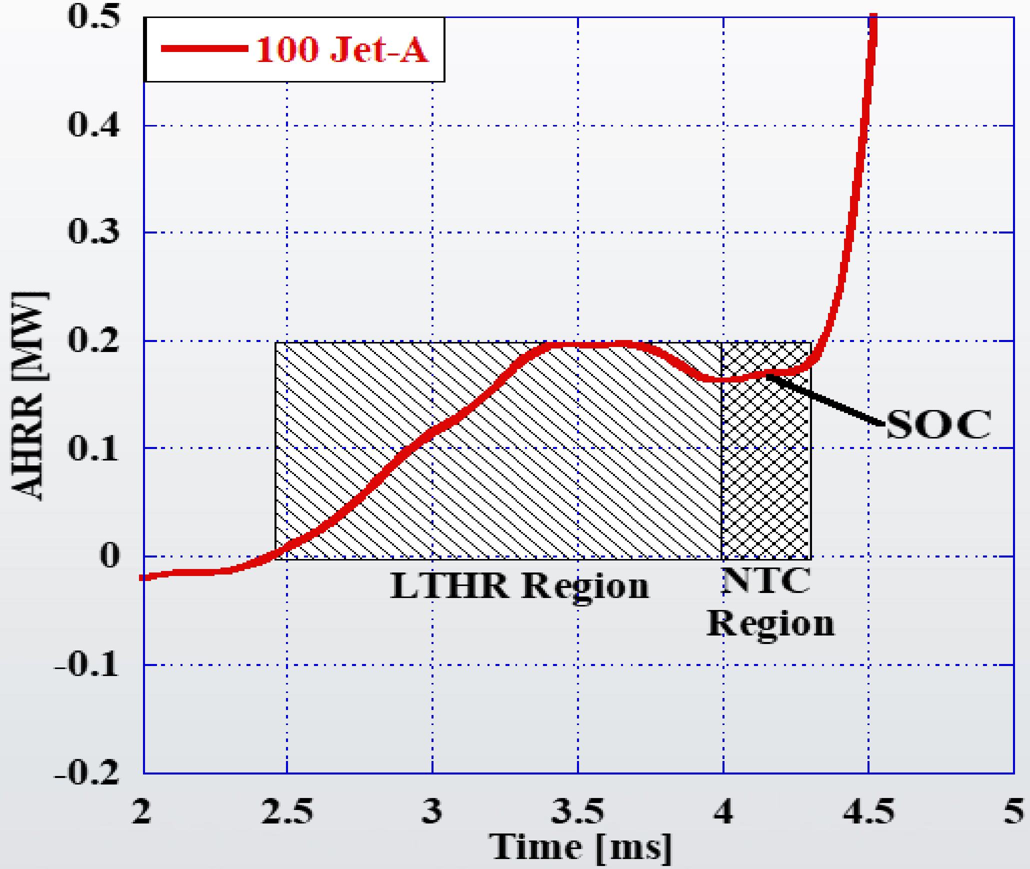


Pressure Trace for Jet-A

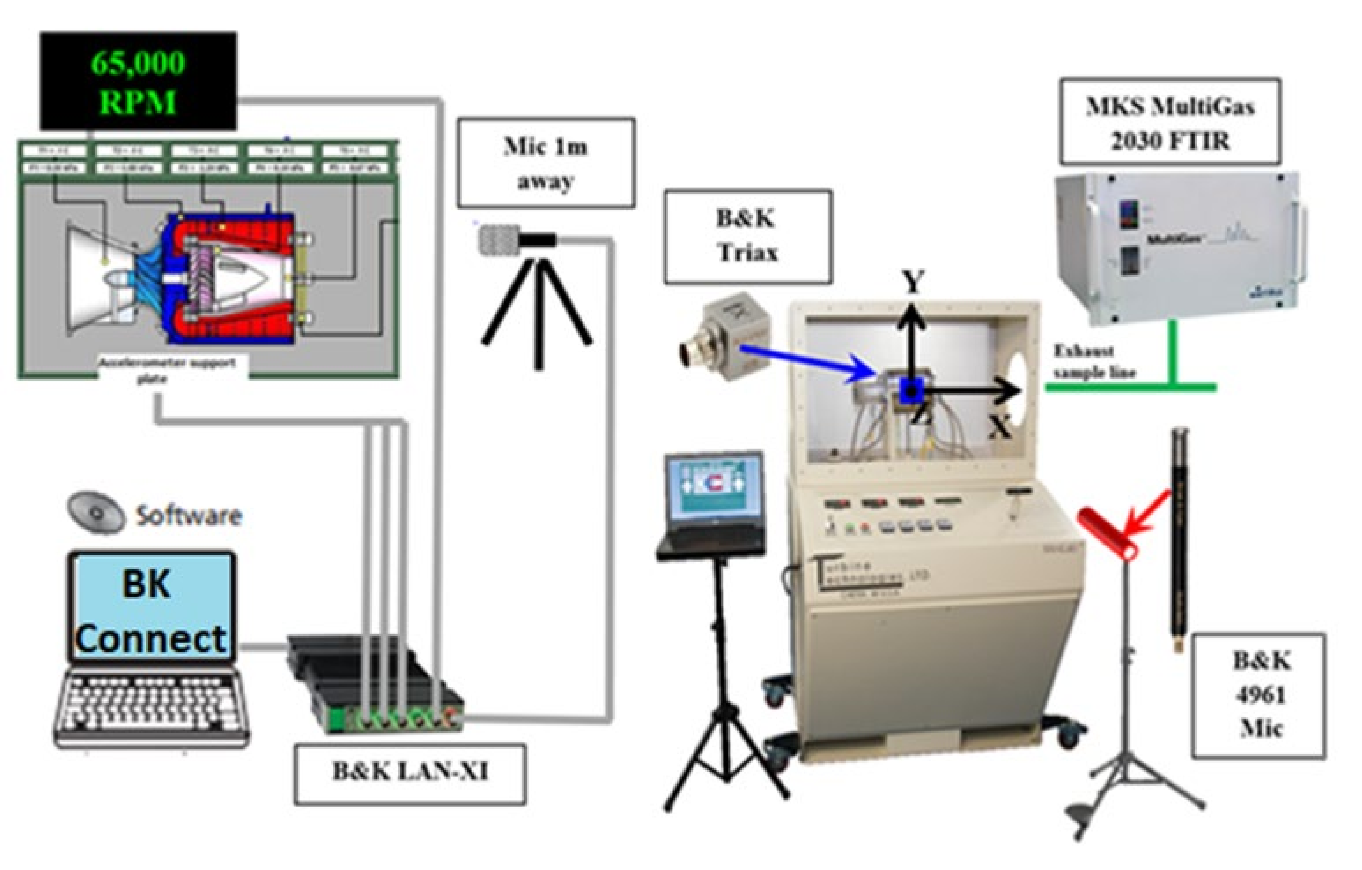
Peak Pressure is 42.6 Bar

Apparent Heat Release Rate



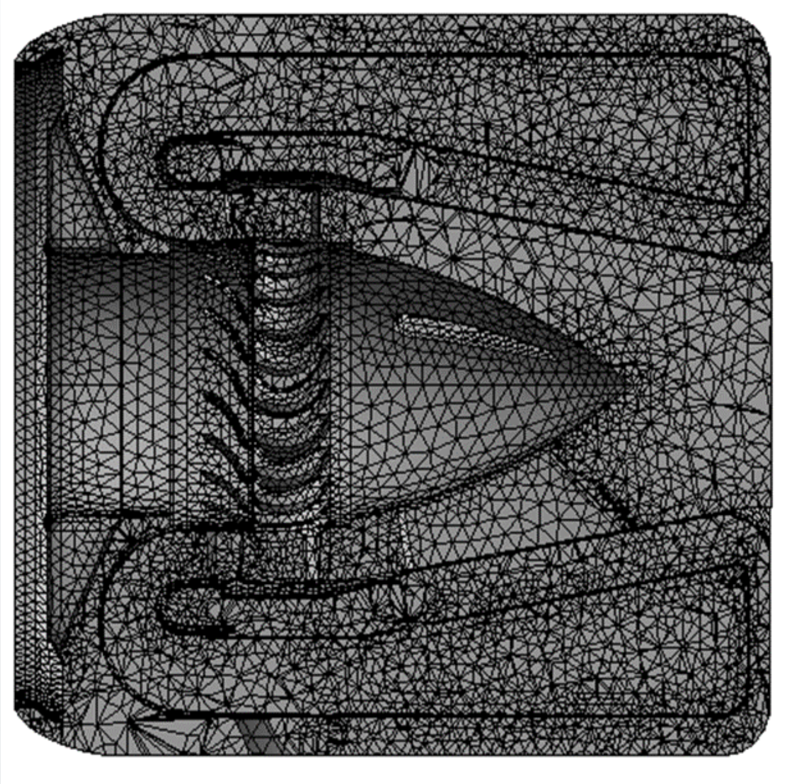


Experimental Set Up

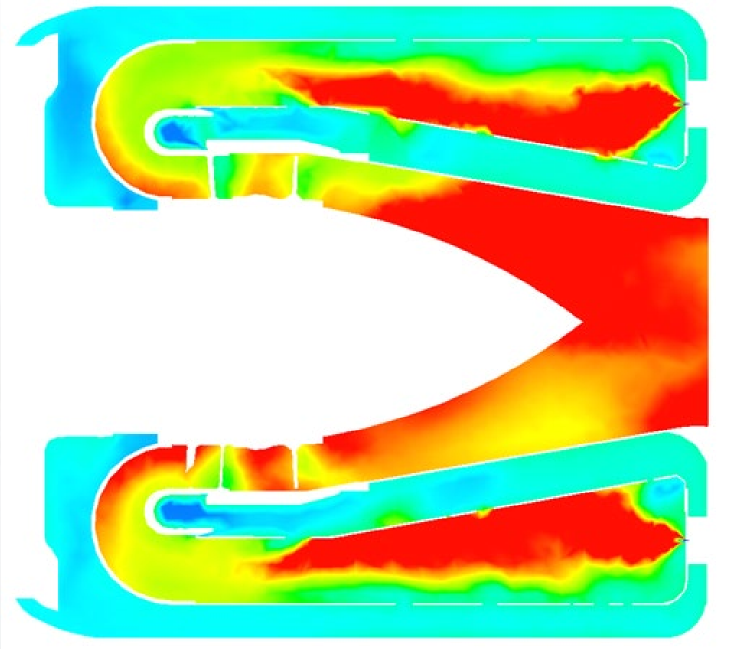


Meshing and Grid Convergence

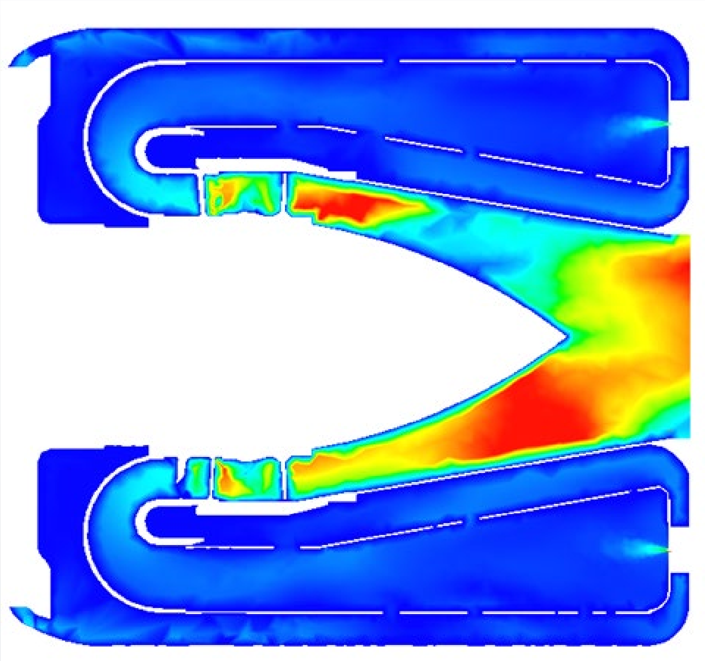
Mesh Refinement	Nodes	Elements
Coarse	157,703	748,591
Medium	284,570	1,400,105
Fine	713,024	3,652,420



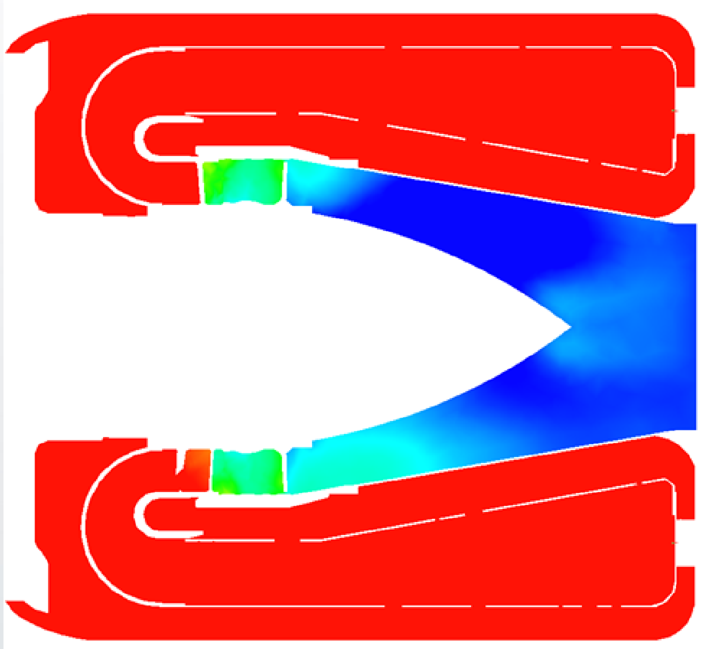
Simulation at 70,000 RPM



Temperature Plane

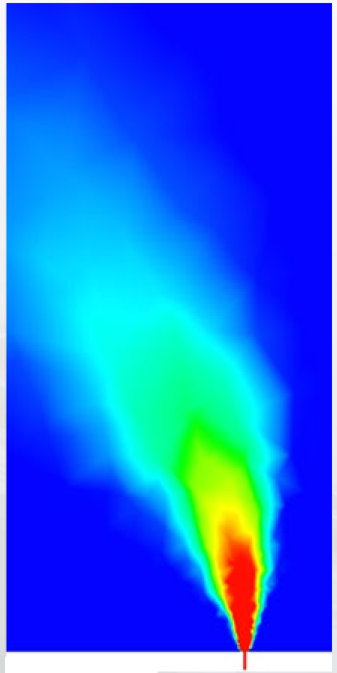


Velocity Plane



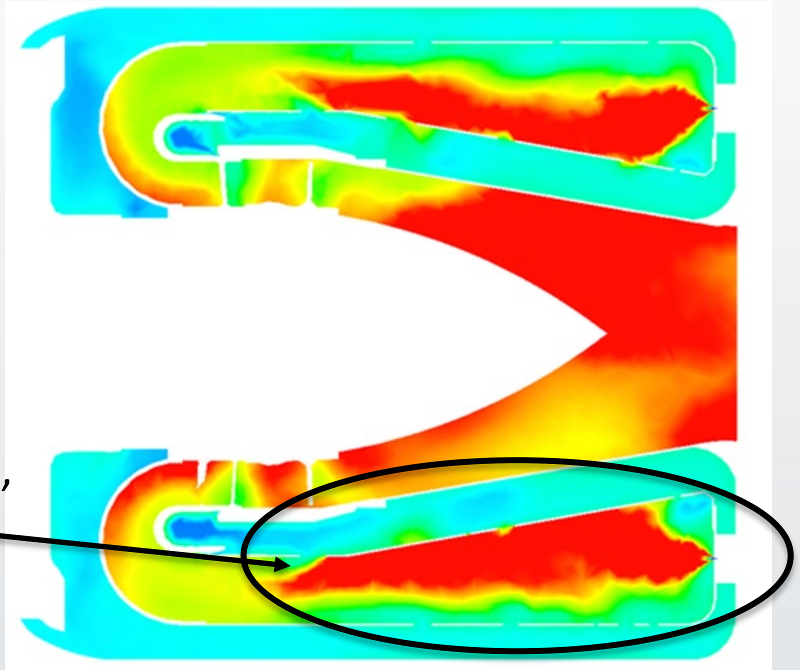
Pressure Plane

Injector Spray Penetration and Distribution



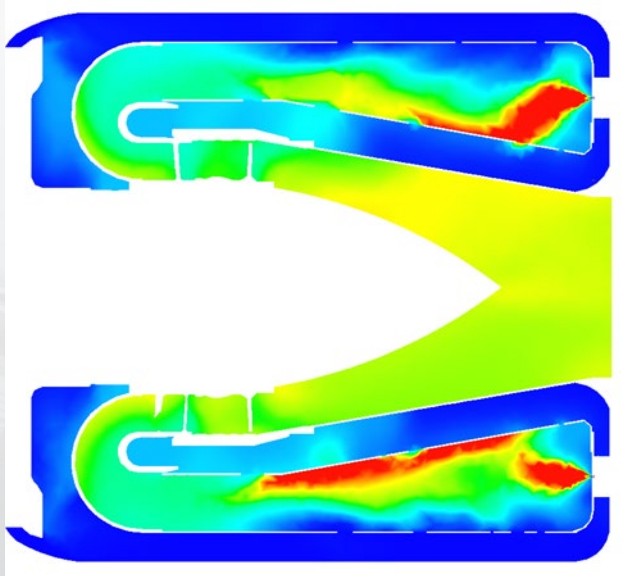
Injector Spray Penetration and Distribution

Swirling, Spray Penetration, and Distribution

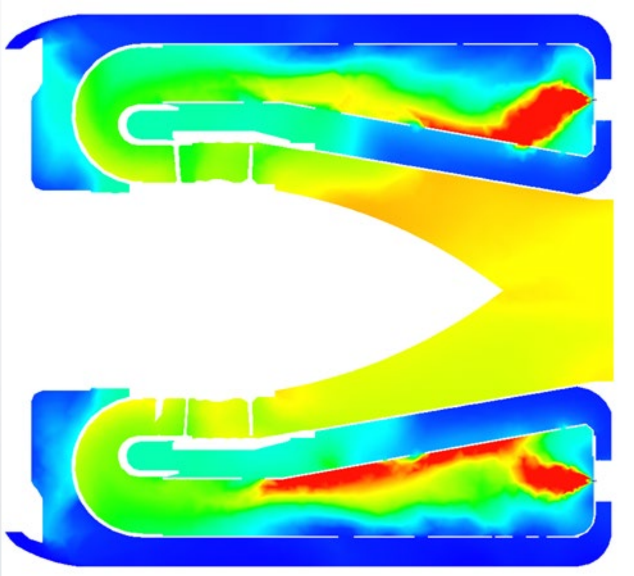


Temperature Plane

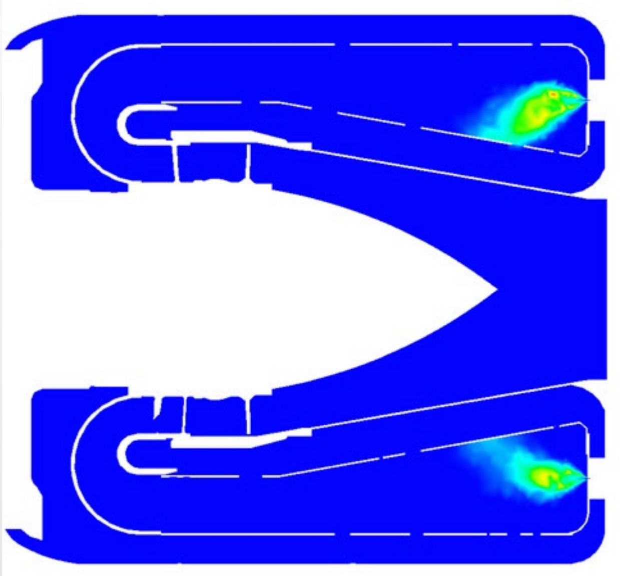
Emissions at 70,000 RPM



CO_2 Mass Fraction

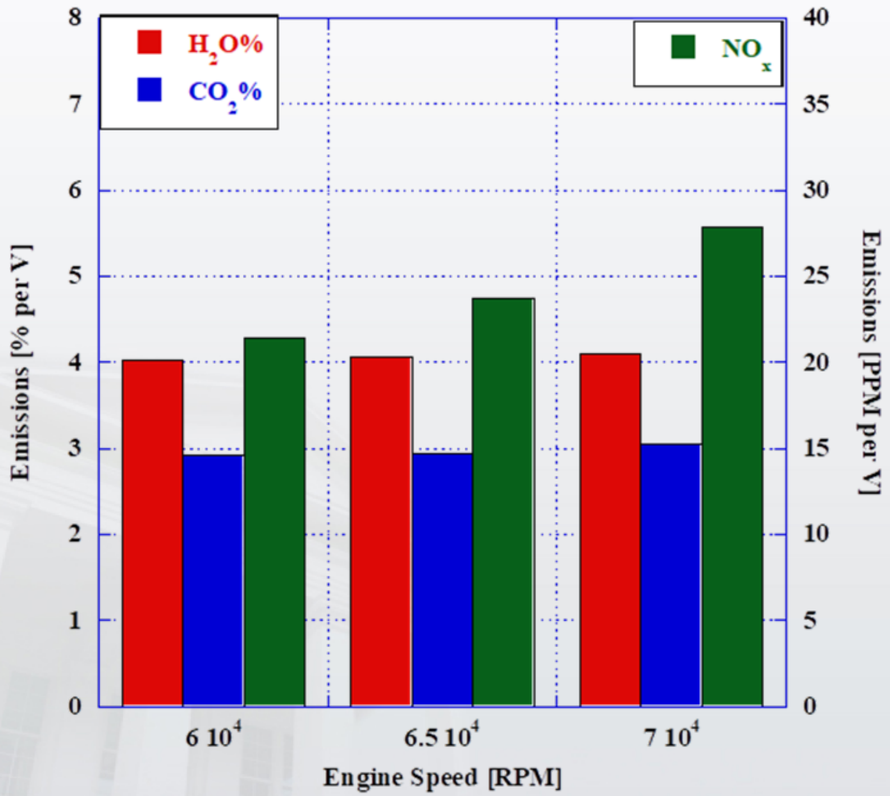


H_2O Mass Fraction

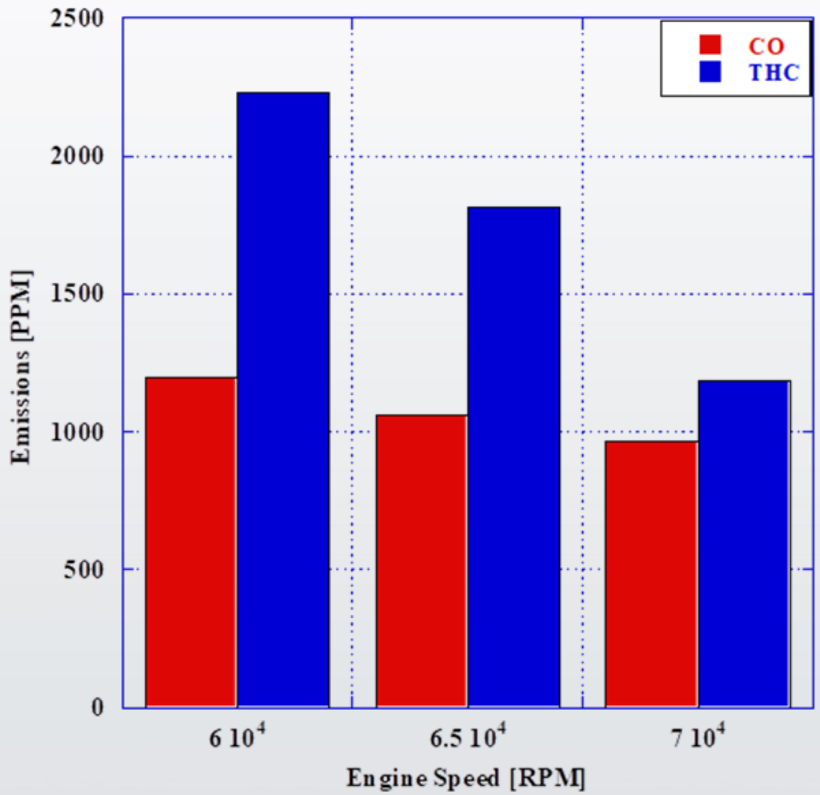


CO Mass Fraction

Emissions, Calculated

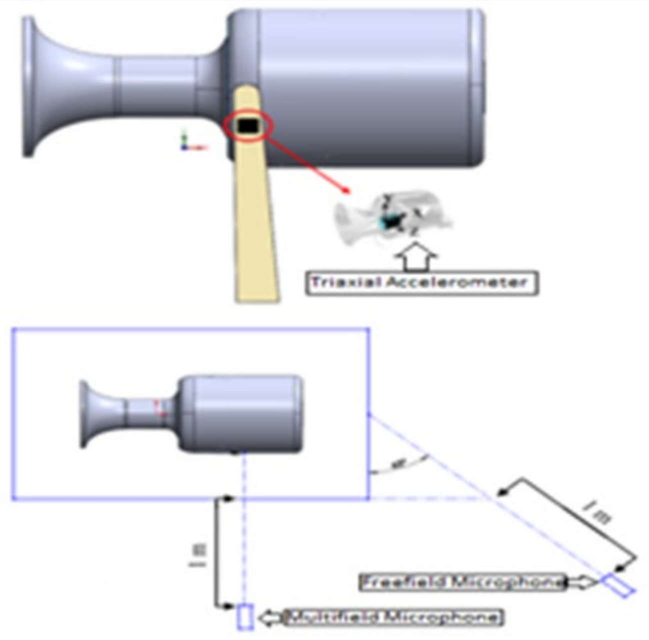


Average Jet-A H_2O %, CO_2 %, and NO_x Emissions vs RPM



Average Jet-A CO and THC Emissions vs. RPM

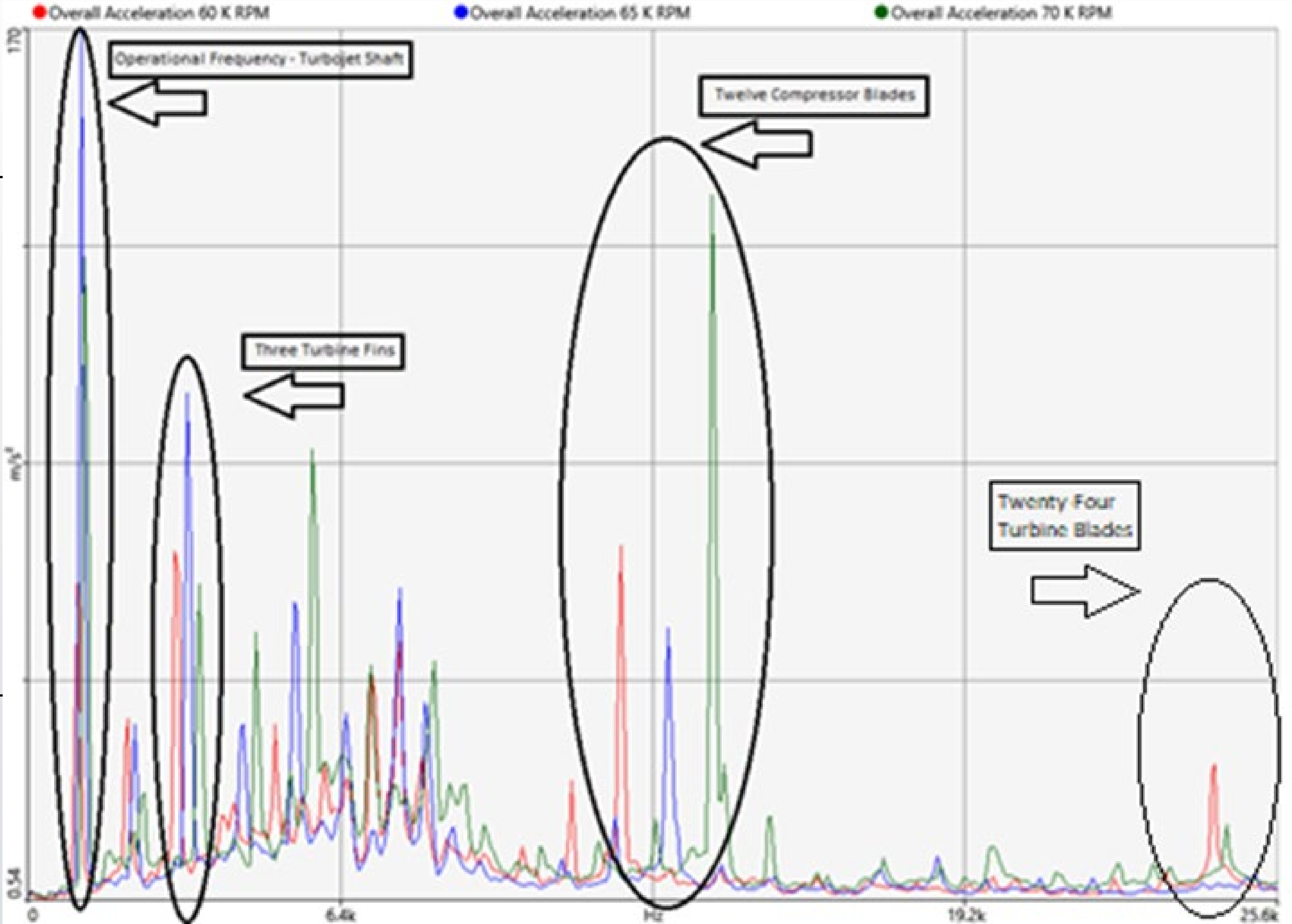
Noise, Vibrations, and Harshness



Operational RPM	60,000	65,000	70,000
Operational Frequency -Turbojet Shaft	1.02 kHz	1.09 kHz	1.15 kHz
Frequency from Three Exit Fins of the Turbojet	3.01 kHz	3.26 kHz	3.52 kHz
Frequency from Twelve Compressor Blades	12.16 kHz	13.12 kHz	14.02 kHz
Frequency from Twenty-Four Turbine Blades	24.32 kHz	24.06 kHz	24.58 kHz

NVH of the Different Regions of the Turbine

Operational RPM	60,000	65,000	70,000
Operational Frequency - Turbojet Shaft	1.02 kHz	1.09 kHz	1.15 kHz
Frequency from Three Exit Fins of the Turbojet	3.01 kHz	3.26 kHz	3.52 kHz
Frequency from Twelve Compressor Blades	12.16 kHz	13.12 kHz	14.02 kHz
Frequency from Twenty-Four Turbine Blades	24.32 kHz	24.06 kHz	24.58 kHz



Conclusion

- ***The numerical emissions were shown to exhibit comparable trends to the experimental data thus indicating the validity of the numerical model***

- Experimental emissions data showed that H_2O , CO_2, and NO_x experienced an increase of 1.9%, 4.0%, and 30% respectively, while CO and THC emissions decreased by 19% and 47% respectively.

- The fluctuations in emissions experienced an internal engine temperature change of 15% when operating from 60,000-70,000 RPMs.

- The vibration's signatures produced by the turbojet main shaft, three exhaust exit fins, twelve compressor blades, and twenty-four turbine blades, the overall frequency produced by each component increased by 1.13%, 1.17%, 1.15%, and 1.01% respectively as the RPM increased to 70,000 RPM from 60,000 RPM.

Acknowledgements

- This research was supported by DoD-NSF Assure REU Site Award: 1950207 and the experimental fuel was provided by the Air Force Research Laboratory.

- We acknowledge also the technical support of the following: Perry Kuznar, Tom Kutrieb, Jason Hoff and Kevin Carlson from Turbine Technologies LTD, Charles McGuffy and Janusz Waszkielewicz from PAC, Tanner Smith, Tony Frazer, Ryan Salmon, and Alfonso Moreira from Brüel and Kjær, and Joseph Wolfgang from Malvern Lasers, Timothy Martin from MKS Instruments Inc.

- We would finally like to acknowledge Richard Locke, Don Apple, Matthew Tuttle, James Heiler, and Chris Williams from AVL.