Using Tomographic Imaging to Understand Hydrogen Combustion

Sallury Hernandez, Fabian Saldana, Kade Nygaard, Nicholas Nicolai, Malcolm Overbaugh, Vincent McDonell

Department of Mechanical and Aerospace Engineering, University of California Irvine, Irvine, CA

UCI Combustion Laboratory

UCI HYDROVISION

UCI Samueli School of Engineering

Executive Summary

- All major gas turbine engine manufacturers look to switch from fossil fuels to hydrogen.
- Hydrogen fuel is still being researched to reduce Nitric Oxides (NOx) emissions due to pollution.
- Using "micromixers" to make array of flames with good mixing the camera will capture the flame interactions.
- Current hypothesis is high-temperature regions of flame interaction lead to higher pollution emissions.
- Mechanical system allows a UV camera to rotate around a ring at certain intervals for imaging.
- UV camera snapshots will capture images of the reaction.
- Images will be processed using MATLAB to form a 3D map, similar to CAT scan.
- Map will highlight regions of high temperature and interaction for analysis.[1]

PURPOSE: Design a mechanical device & computational algorithm that will capture images of the flame interaction of hydrogen to create 3D reconstruction of the reaction.

Experimental design

(1) Key Features

- Round Turntable: Circular platform to rotates the camera around flame interaction.
- Fuel Injectors: The combustion process will involve seven fuel injectors mixing hydrogen and oxygen.
- Data Analysis & Visualization: The creation/implementation of MATLAB code will allow us to convert 2D images to a 3D tomographic map.
- DynaColor Camera: Camera that can capture Hydroxyl(OH), a product of hydrogen combustion with wavelengths at 308 nm

(2) Engineering Analysis

- MATLAB Code: Tested different MATLAB functions for transforming 2D images to tomographic maps using 3D reconstruction. [2]
- Heat Transfer Analysis: Conducted a heat transfer analysis on camera for high-temperature exposure
- Gear System: Custom designed gears fit on outer ring, mesh with pinion gear on motor
- Camera Precision: Calculations made to determine the camera would ideally work in ranges between 0.257 m and 18.2 m

Proof of Concept

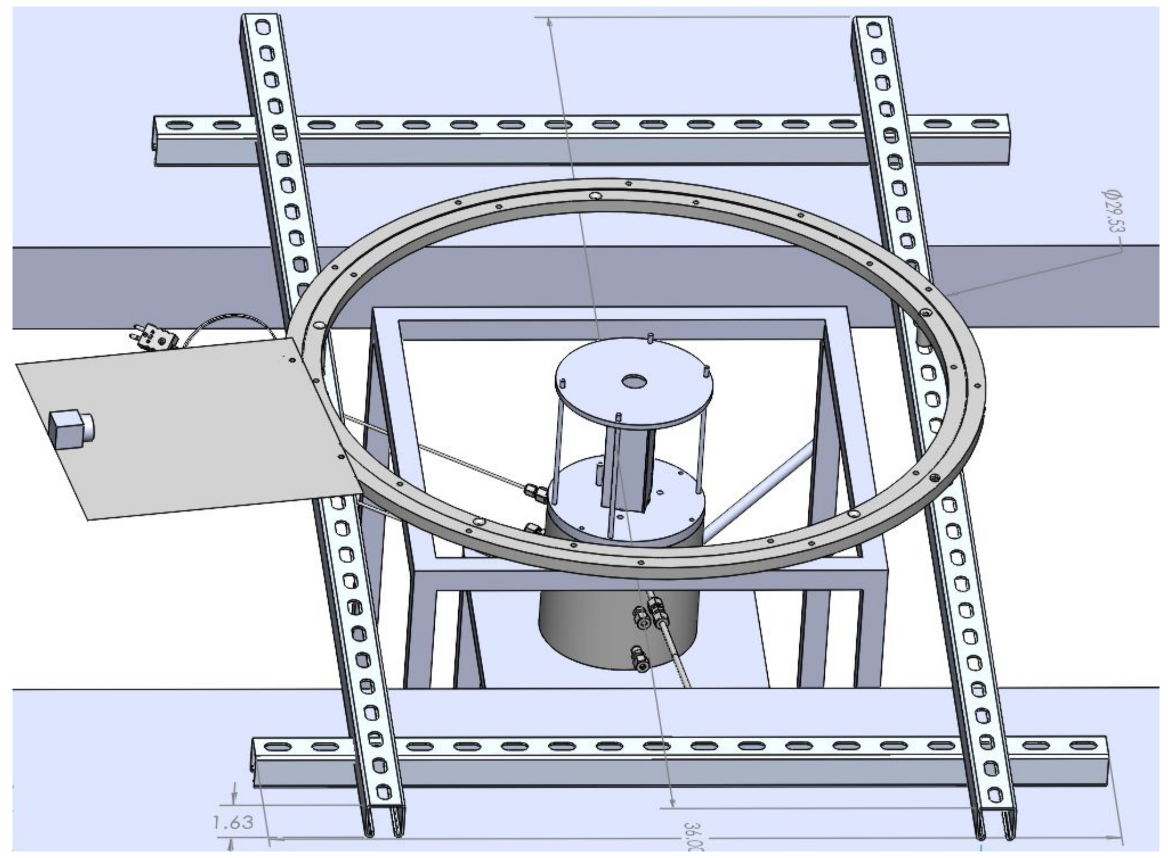

Figure 1: CAD assembly of camera mount stand, gear system, unistruts, and rotational platform.

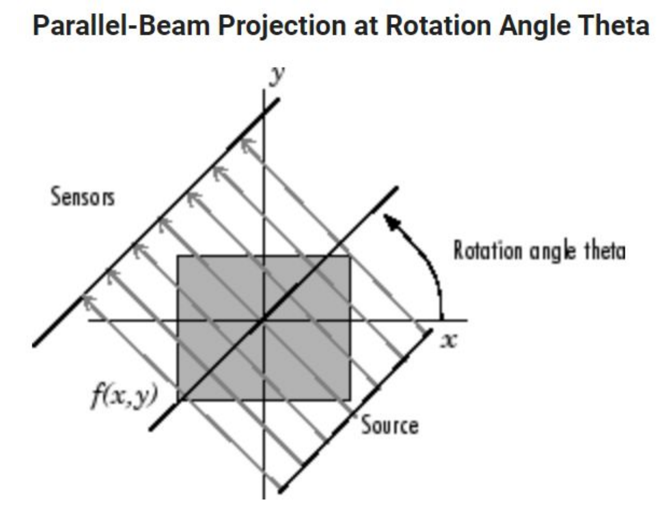

Figure 2: Radon Transform graphic that displays parallel beam projections, which are conducted from 0-180°.[2]

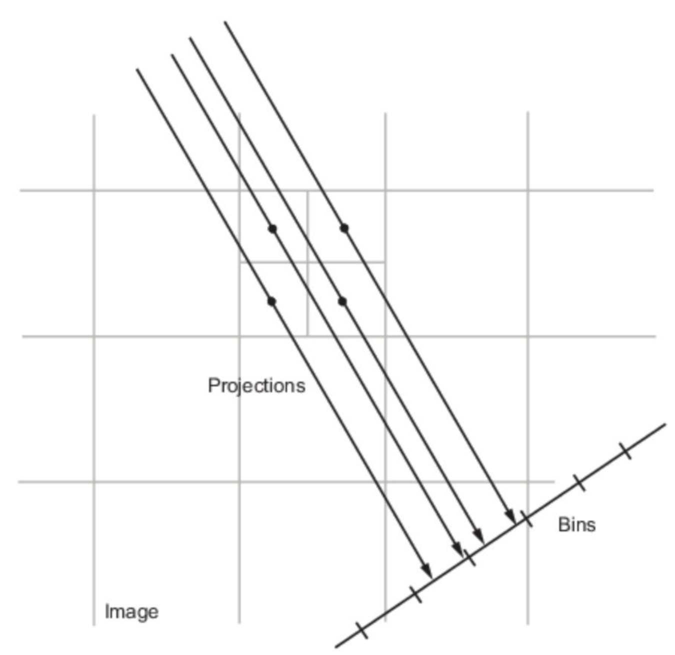

Figure 3: Graphic that displays how Matlab's radon function obtains data through pixels, micropixels and bins.[2]

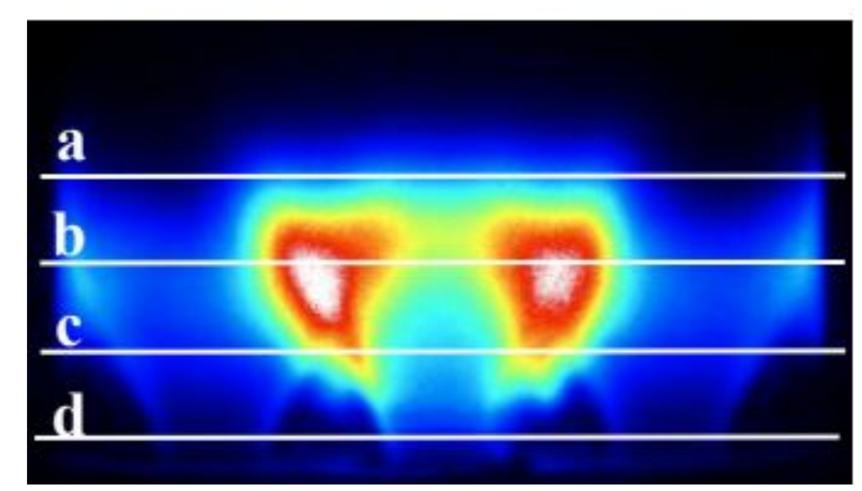

Figure 4: Example from Penn State of how horizontal slices will be made on each flame image using the Radon Transform, so they can be used to make a tomographic map. [1]

Discussion

Thus far, our team has made significant progress during the design phase of this project. We have conducted heat transfer analysis, developed CAD designs, experimented with the camera system, and developed code that will help create a tomographic map. We plan to carry out our designs into an action phase, where we build and utilize our code in order to create a tomographic map with an automated imaging system. Some future improvements revolve around being able to make the process fully automated, a major goal in mind to make this process easier to recreate and analyze. Developing tomographic maps allows for a deeper analytical approach to understanding the chemical properties and nature of a hydrogen flame, which is vital in understanding the nature of hydrogen combustion.

Contributions

- The project team provided the detailed CAD, the finished MATLAB code, the heat shield design and analysis, the gear and motor system, and the camera mount and ring support.
- The sponsor helped provide an initial CAD of the flame injectors, some previous MATLAB scripts, and provided ideas and calculations for the heat shield design, the gear system, and camera mount and ring support.
- Both the camera and ring were provided by the sponsor
- In the future, we will add the heat shield to protect the camera from the high temperatures and add the gear and motor system so the camera moves autonomously and precisely.
- This program will allow a more detailed analysis into the formation of NOx from hydrogen combustion, enabling discovery of how to reduce NOx emissions from hydrogen turbines.

Acknowledgements

A special thanks to the University of California, Irvine, for allowing us to use all these resources available anywhere, from labs to personnel. Our sponsor, Vincent Mcdonell, not only a professor, but also the director of the Combustion Lab at UCI, has many years of experience and was able to guide us in the right direction. We worked very closely with Malcolm Connor Overbaugh, a Ph.D. student at UCI, from whom we received lots of feedback and resources.

References

1) Samarasinghe, J, Peluso, S, Szedlmayer, M, De Rosa, A, Quay, B, & Santavicca, D. "3-D Chemiluminescence Imaging of Unforced and Forced Swirl-Stabilized Flames in a Lean Premixed Multi-Nozzle Can Combustor." *Proceedings of the ASME Turbo Expo 2013: Turbine Technical Conference and Exposition. Volume 1B: Combustion, Fuels and Emissions*. San Antonio, Texas, USA. June 3–7, 2013. V01BT04A053.
2) "Radon Transform." *Radon Transform - MATLAB*, www.mathworks.com/help/images/ref/radon.html. Accessed 27 Feb. 2024.
3) Flebbe, Saskia, et al. Munich, Germany, 2023, *EXPERIMENTAL 3D ANALYSIS OF FLAME PROPAGATION IN A LEAN-PREMIXED SWIRL BURNER OPERATED WITH HYDROGEN.*