# Visualization of Combustion Within a Hybrid Rocket Motor


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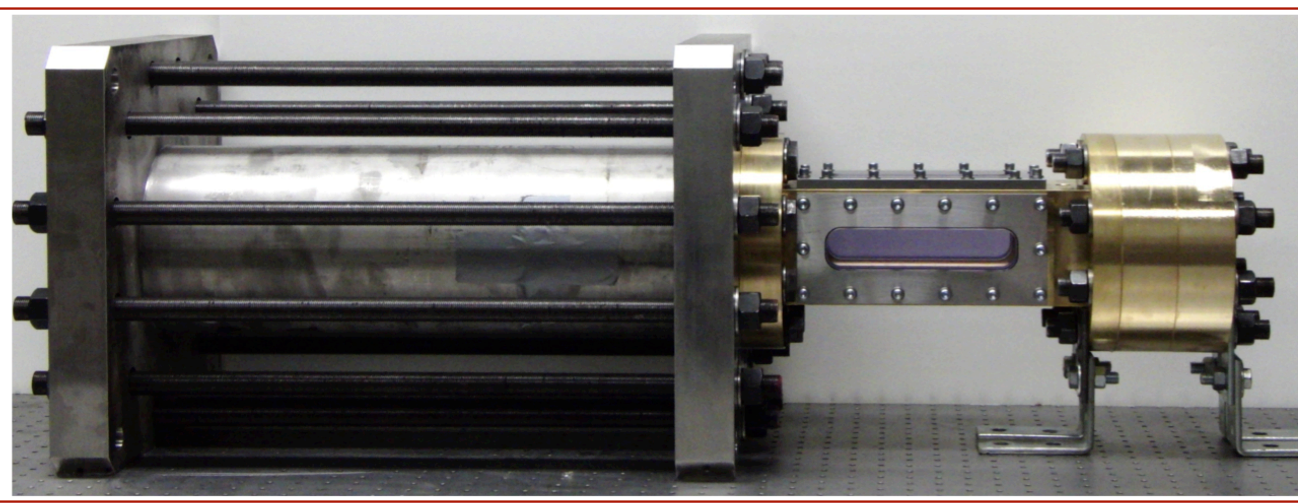
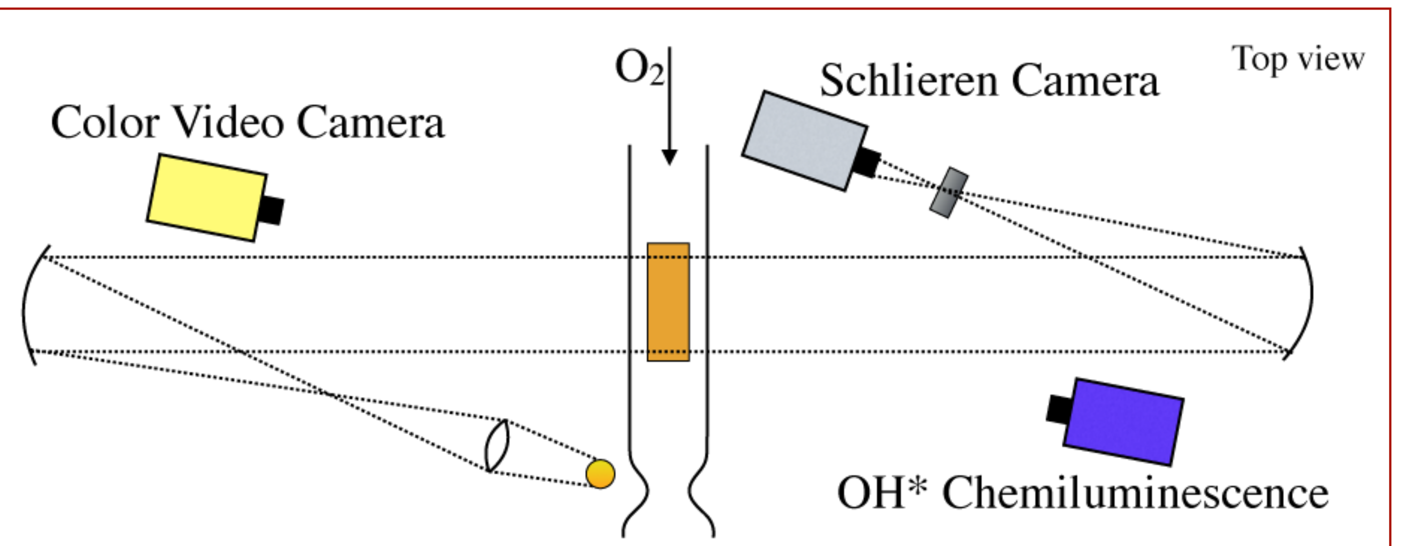
## Introduction

A visualization facility has been developed at Stanford University in order to study flow in a turbulent combustion boundary layer. The facility has been used to image the combustion of various fuels with gaseous oxygen. Five classical fuels have been tested, specifically Hydroxyl-Terminated PolyButadiene (HTPB) with 0.5% by mass carbon black, HTPB without carbon black, High Density PolyEthylene (HDPE), Acrylonitrile Butadiene Styrene (ABS), and PolyMethyl MethAcrylate (PMMA) as well as a liquefying high regression rate fuel, specifically neat paraffin with 0.5% by mass of black dye, referred to as Blackened Paraffin (BP).



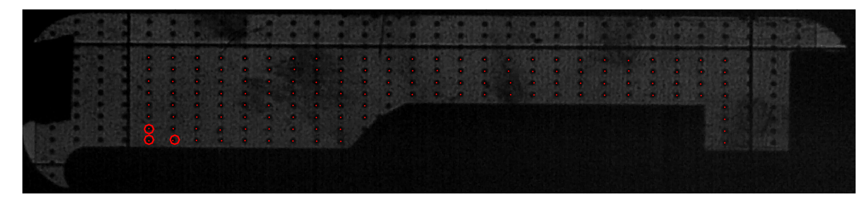
## Background

29 hot fires were successfully conducted in the combustion visualization facility in 2014. High speed color, schlieren and OH* chemiluminescence videos were recorded. Color videos are recorded with Casio Exilim EX-F1 cameras at 1200 frames per second with a resolution of 96 x 336 pixels. A MotionPro X3 Plus camera and a 105 mm Nikon lens with an f-number of f/2.8 capture the schlieren images at 3000 frames per second with a resolution of 1080 × 236 pixels. Images of OH* chemiluminescence are acquired at 3000 frames per second using a Photron APX ii2 intensified camera, a 105 mm Nikkor UV lens, and a high-transmission bandpass filter centered at 313 nm with a full-width half-max of 5 nm. For each test 14,206 schlieren images and 16,384 OH* chemiluminescence images were collected. The aim of this work is to develop a systematic approach to, and tools for, analyzing these images.

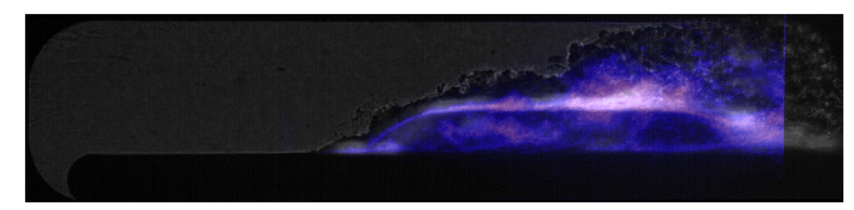



## Methodology

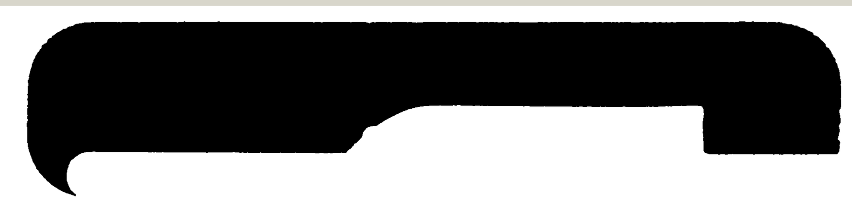
**Project Images** – Remove projection error and ensure consistent alignment of OH* and schlieren images regardless of their original scale



**Align Images** – Minimize squared difference per pixel between the images in the region around the fore end of the fuel grain

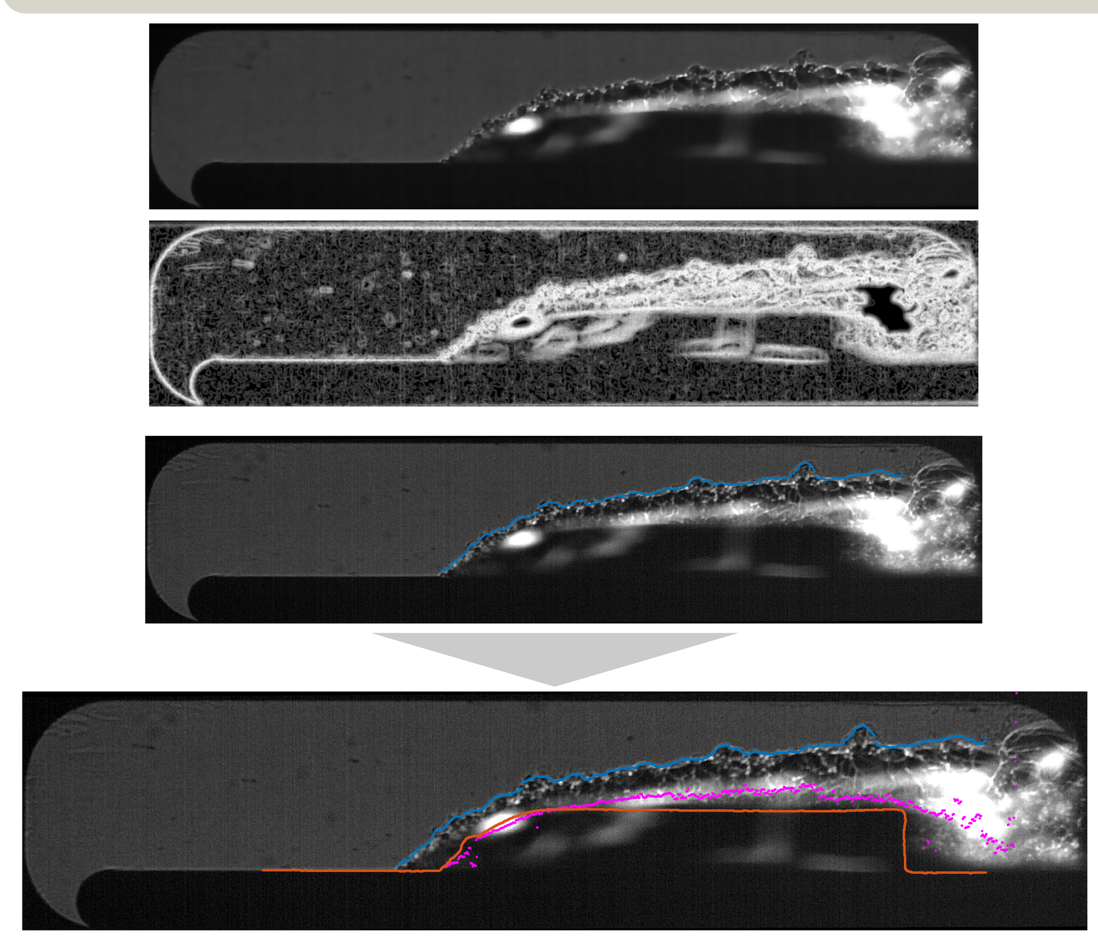


**Detect Fuel** – Detect the original fuel grain edge prior to combustion



**Detect Flame** – Locate the peak in OH* chemiluminescence within each column

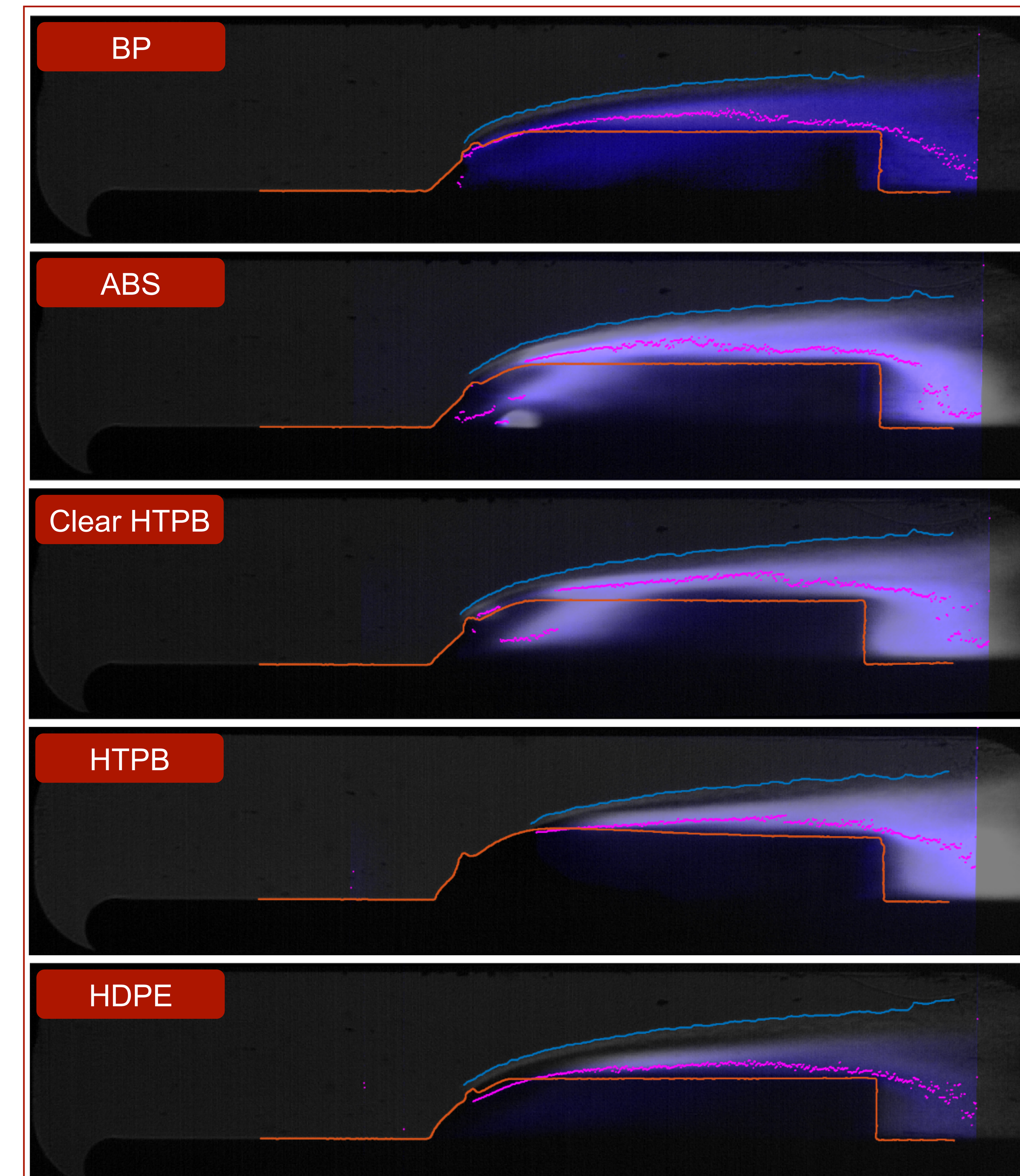
**Detect Boundary Layer** – Evaluate the edge of the boundary layer in the schlieren images



**Quantify Burn Time** – Calculate mean OH* pixel intensity throughout each test in order to quantify burn times for each test

## Results

The algorithm was successfully applied to all tests conducted at atmospheric pressure. To minimize computation time, mean images of 50 consecutive images were analyzed. Examples of the results for various fuels are shown below. The algorithm could not be applied to mean images for pressurized tests as the boundary layer became too indistinct in these cases. For pressurized tests the algorithm was successfully applied to individual images.




## Future Work

- Estimate the transient fuel grain location using hybrid rocket combustion theory
- Run the edge detection code over a large number of pressurized images and evaluate how the profiles change with increasing pressure
- Quantify the boundary layer profiles as a function of Reynolds number


## Acknowledgments

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