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RPPR Final Report
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Final Report for Period Beginning 08-Jun-2020 and Ending 07-Jun-2021
Title: Enhanced-Optical-Access Test-Section for Laminar Flame Studies in Shock Tubes
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STEM Degrees: 1
STEM Participants: 2

Major Goals: The goal of this project was to acquire new experimental facilities that would expand the capability of the shock-tube flame speed method to enable fundamental flame studies at high-unburned-gas temperatures. The project proposed the expansion of side-wall optical access to the shock-tube test section in order to provide transformational diagnostic capabilities for studying the dynamics of high-temperature flames at temperature conditions relevant to next-generation energy systems.

Accomplishments: During the reporting/award period, the goal of enabling game-changing side-wall optical access into the shock-tube test section was achieved under support of this and a parallel DURIP award (75723-EG-RIP). Specifically, this award provided for the acquisition of the custom-fabricated side-wall windows required to provide optical access into the cylindrical shock tube (see figures in report attachment).

Two forms of side-wall windows were acquired for the new test section. A UV-grade fused-silica window designed as an afocal cylindrical meniscus lens provides for ultraviolet chemiluminescence and laser-induced fluorescence imaging with low distortion. A second set of aberration-corrected cemented doublet windows incorporate a BK-7 glass crown cemented to a fused-silica base to provide for schlieren-compatible optical access with ultra-low distortion near the 530-nm design wavelength.

The award additionally provided for the purchase of electrical components needed to build an overdriven LED source for schlieren imaging. This source provides sufficient brightness to enable the short camera gating times (< 1 microsecond) necessary to eliminate motion blur from even the highest-speed transient events (e.g., shock waves) without requiring supplemental intensification that might otherwise degrade image quality. The award finally provided for machining of a supplemental flange used in the installation and removal of the windows from the test section.

The value of the capabilities provided for by this award have already begun providing valuable new insights not obtainable in previous facilities. Schlieren imaging over a 60-mm by 75-mm field-of-view enables the observation both of flame dynamics at much larger flame radii than was attainable through the previous 18-mm-diameter side-wall ports as well as aspects of auto-ignition phenomena not apparent in emission imaging alone. Simultaneous side- or end-wall emission imaging is additionally providing for direct comparisons of emission and density fields for the first time, with ongoing applications to both flame-speed and ignition experiments and future opportunities for measurements of high-speed, non-equilibrium flow fields.

Training Opportunities: This project has provided the senior student working on this project, Adam Susa, with a significant training opportunity related to all aspects of the project proposal, execution, and reporting. In this way, the project has supported his professional development as he approaches the end of his tenure, making him better prepared to pursue future endeavors. The project also supported the onboarding of a newer student on the project, Jackie Zheng, providing for his training on the relevant facility and methods and for additional mentoring experience for Adam Susa.

Results Dissemination: The results of this project are currently in preparation for dissemination through several conference and scholarly journal submissions. The optical design of the windows will be specifically described in an upcoming submission to Applied Optics; this work will include, as a supplemental material, the code necessary for the reader to generate designs of windows using the methodology developed through this project. The first experimental results obtained using the new optical test section are being prepared for the 2022 AIAA SciTech Conference (accepted abstract) and the 2022 International Combustion Symposium.

Honors and Awards: Combustion and Flame, special journal issue dedicated to Prof. R. K. Hanson (February, 2021)

Protocol Activity Status:

Technology Transfer: Nothing to Report

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Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
National Academy Member: Y

Participant Type: Staff Scientist (doctoral level)
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Project Contribution:
National Academy Member: N

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Project Contribution:
National Academy Member: N

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Project Contribution:
National Academy Member: N

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Person Months Worked: 1.00
Project Contribution:
National Academy Member: N

Funding Support:

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I certify that the information in the report is complete and accurate:
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Signature Date: 10/14/21 3:00PM

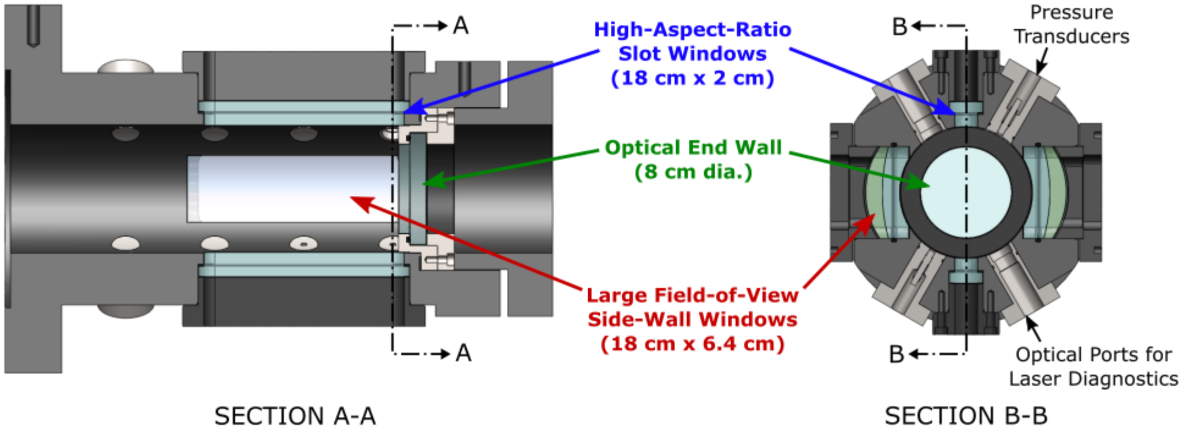

Figure 2: Cross-sectional views of the new, enhanced-optical-access test section. The large side-wall windows provide a significant expansion of optical access compared to the previously available 18-mm-diameter ports. Shown in Section B-B are the cemented-doublet windows, where the blue and green elements are comprised of different optical materials and cemented together to provide one aberration-corrected lens element.

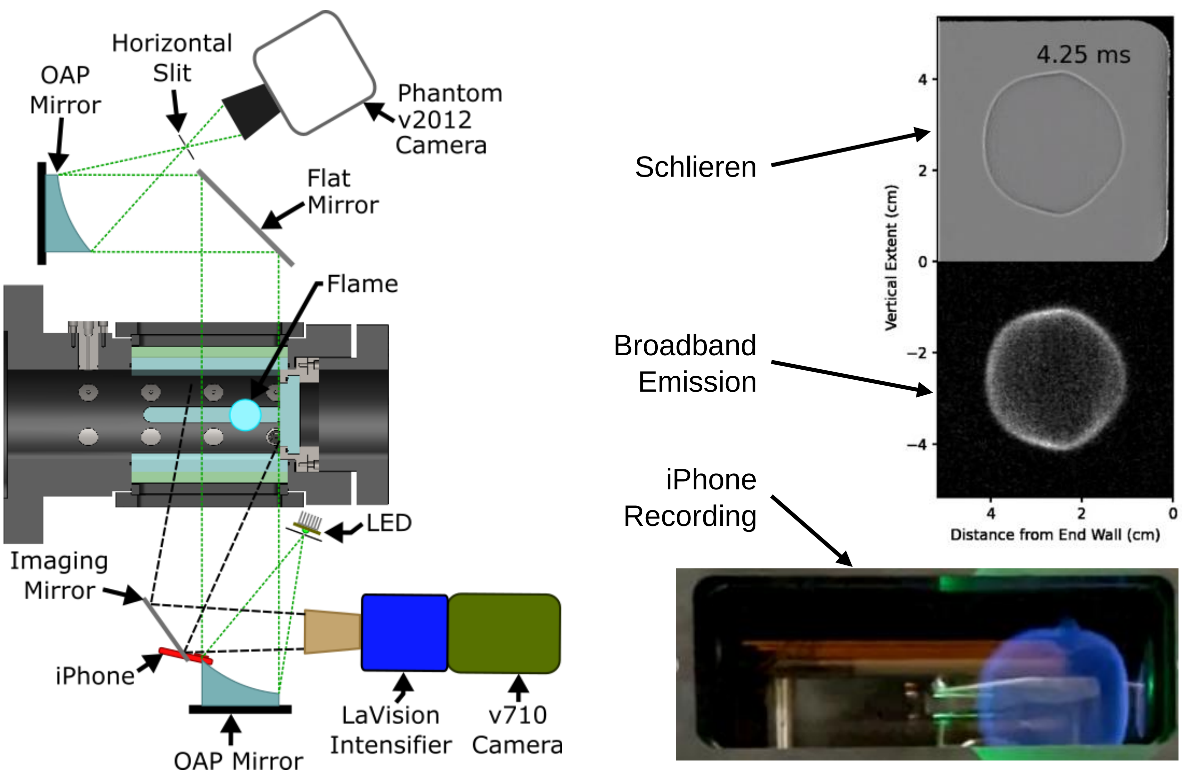

Figure 1: (Left) Schematic of the enhanced optical access shock tube configured for side-wall imaging using simultaneous schlieren, broadband UV emission, and color iPhone videography. (Right) Sample images of an expanding flame in the new test section. The schlieren and emission images were recorded in a reflected-shock experiment and are synchronous, distortion corrected, and shown at the same scale. The iPhone image is of a different static experiment.

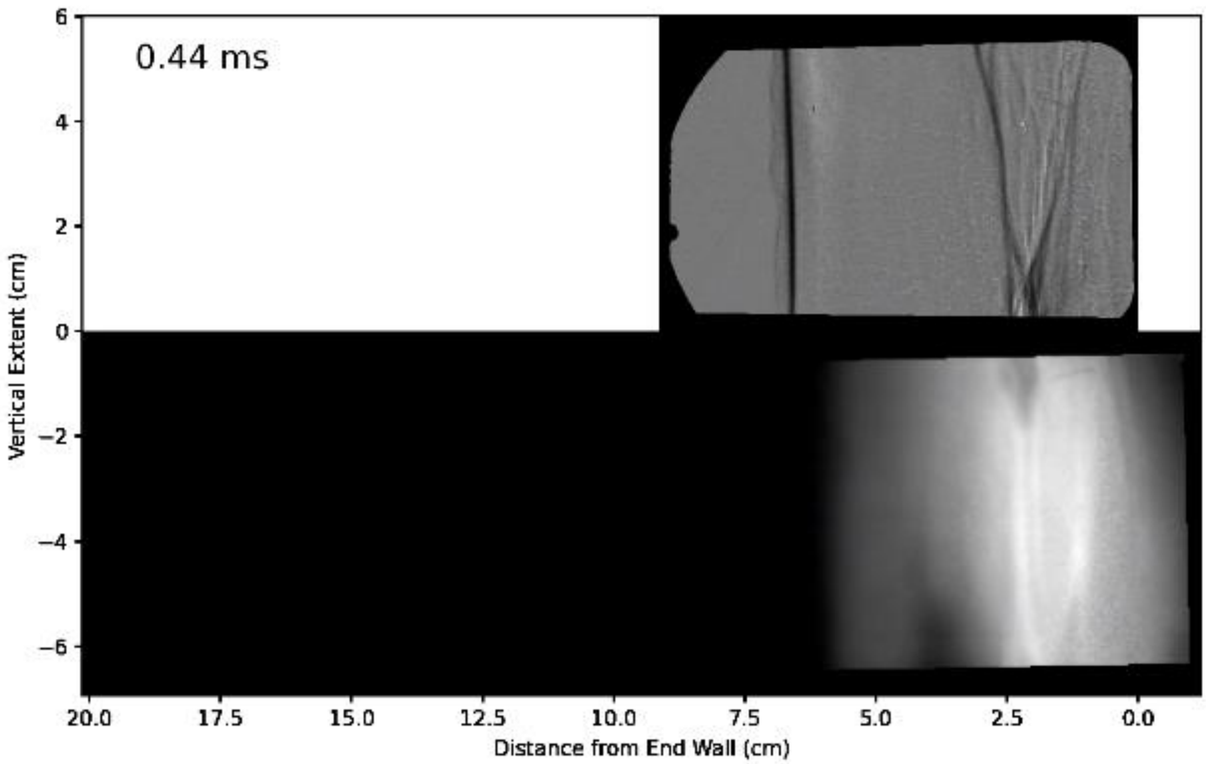

Figure 3: Synchronous image pair of schlieren (top) and emission (bottom) imaging of a strong autoignition event in a shock tube. The vertical black line in the schlieren image (~7 cm) is the reflected shock wave. The weaker waves seen to the right are a result of ignition and reveal dynamics not apparent in the emission image.

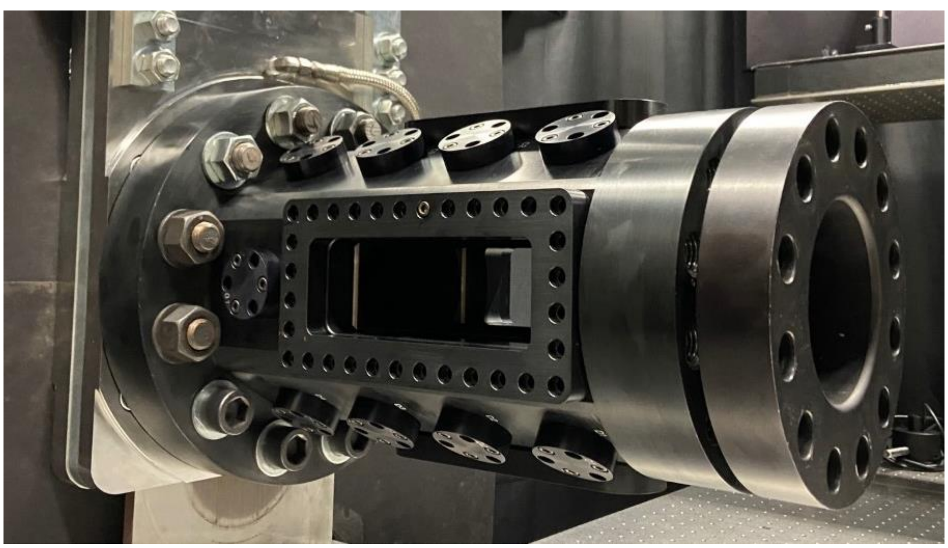

Figure 4: Enhanced optical access test section installed on the shock tube. The test section was manufactured of 6061 aluminum and features a black, hard-anodized coating to reduce stray reflections and enhance the quality of images.