LSU

School of Mechanical and Industrial Engineering

Water Spray Characterization for Cooling Rocket Engine Exhaust Plumes

Hansen Jones

Louisiana State University

70th Meeting of the APS Division of Fluid Dynamics

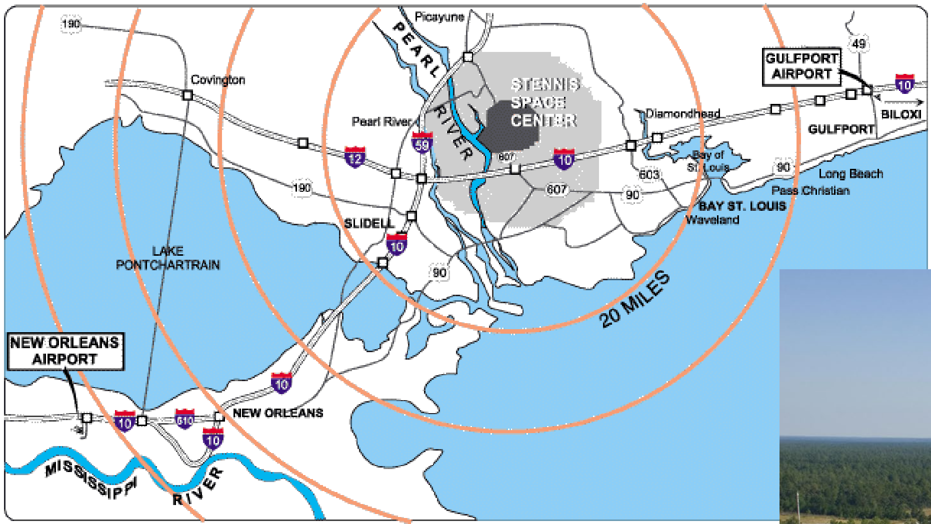
Denver, CO November 20, 2017

LOVE PURPLE
LIVE GOLD

Presentation Overview

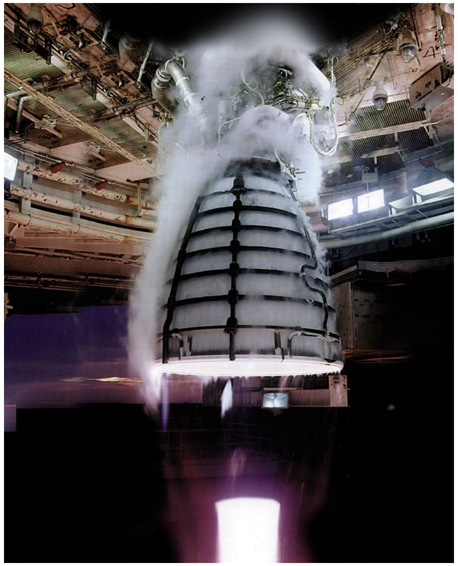
- Introduction to Stennis Space Center and motivation
- Introduction to computational method and validation steps
- Introduction to diagnostic techniques
  - Focusing Color Schlieren photography
  - Laser sheet visualization
  - Phased Doppler Particle Anemometry (PDPA)
- Cold flow water spray test rig overview
- Preliminary experimental results
- Introduction to hybrid rocket design
- Future work for combusting flow, application of diagnostic techniques

Stennis Space Center

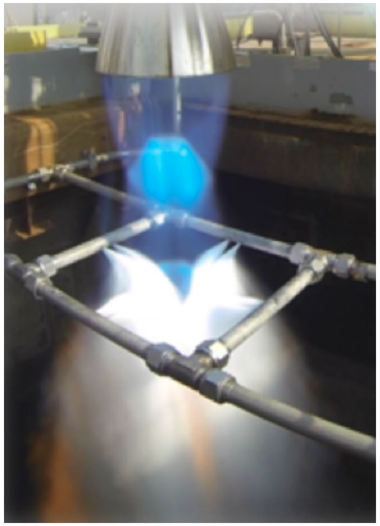


http://www.spaceflightinsider.com/wp-content/uploads/2015/06/NASA-Stennis-Space-Center-welcome-sign-Mississippi-photo-credit-Jason-Rhian-SpaceFlight-Insider-647x527.jpg
https://upload.wikimedia.org/wikipedia/en/4/4e/NASA_Stennis_test_complexes_on_display.jpg
http://sam.ucsd.edu/onr_jes/meetings/1999/regional.gif

Stennis Space Center



- Large scale stands have flame trenches that are cooled by ~300,000gpm of water.



- Small scale test stands require specialized cooling systems to protect nearby infrastructure.
- Flame trenches are uncooled.

https://www.nasa.gov/sites/default/files/thumbnails/image/s17-014_ssc-20170222-s00067_rs-25_engine_test.jpg

https://www.nasa.gov/sites/default/files/rs-25_engine_test_2_0.jpg

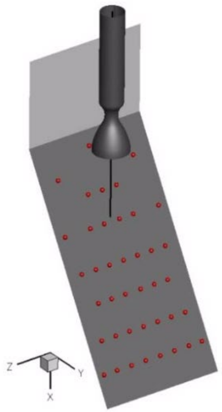
Project Motivation

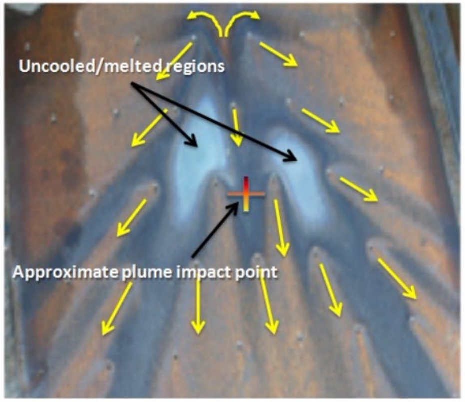
Damage to uncooled flame trench

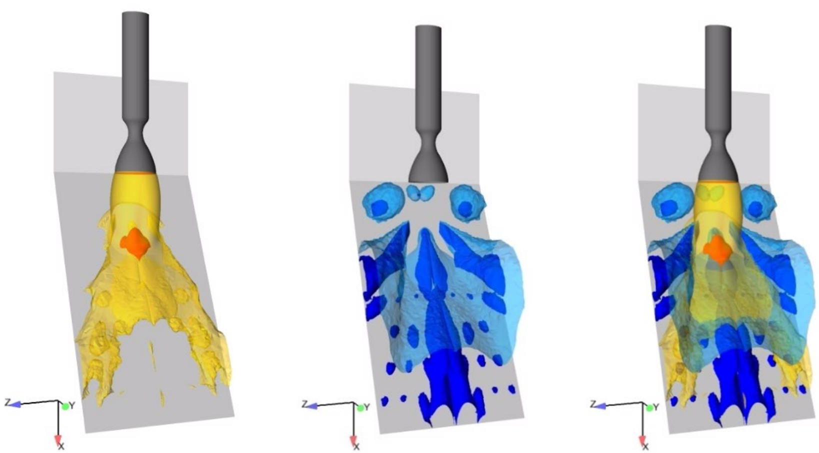
- We seek to improve rocket exhaust cooling in order to decrease facilities cost and improve life of test stand infrastructure

LOVE PURPLE
LIVE GOLD

Project Motivation







Project will serve to provide validation cases for a multi-phase CFD code used at NASA Stennis to design engine ground support hardware

Validation Steps

Cold Flow With Single Water Jet

- Gives time to determine most useful diagnostics and obtain confidence in their operation

Combusting Flow With Single Water Jet

- Allows for translation of laboratory experiments to full scale testing at NASA Stennis

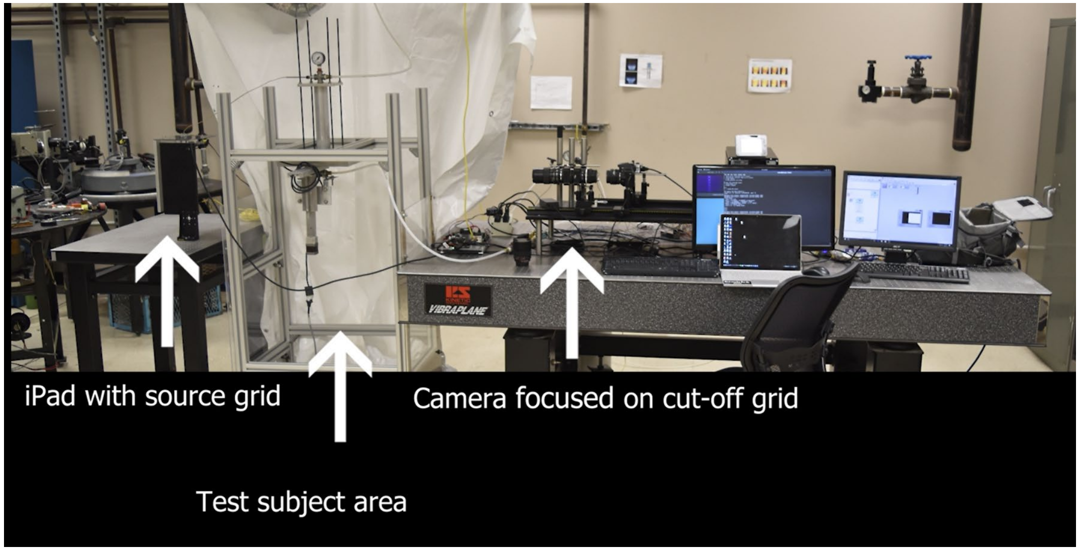
Alternate Water Spray Cooling Geometries

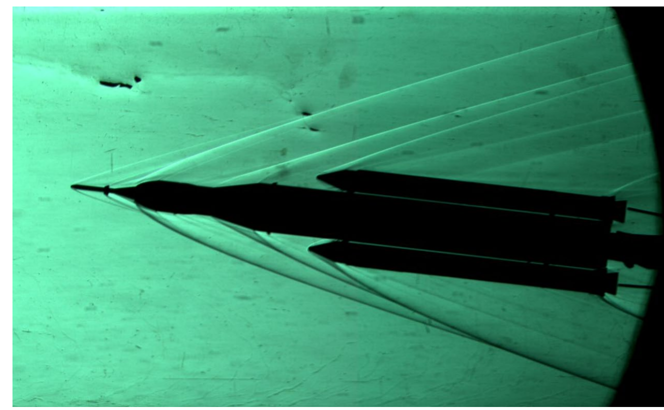
- Will explore other cooling water configurations present at Stennis including fanned sprays and spray rings. Effects on acoustics will be explored.

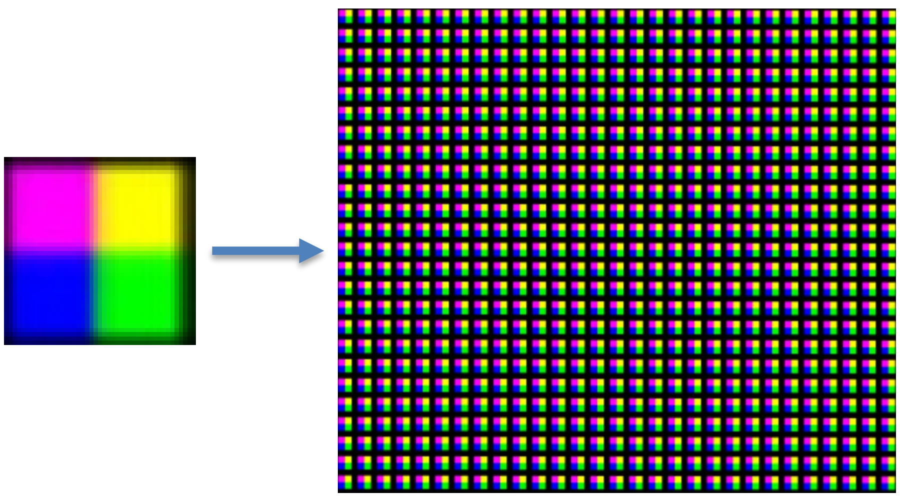
Diagnostics Theory

LOVE PURPLE
LIVE GOLD

Focusing Color Schlieren



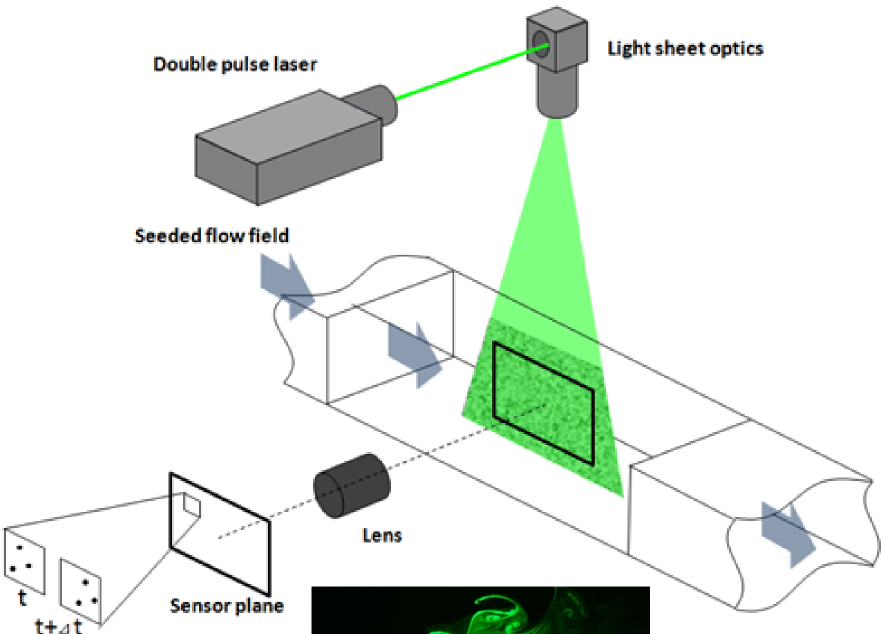


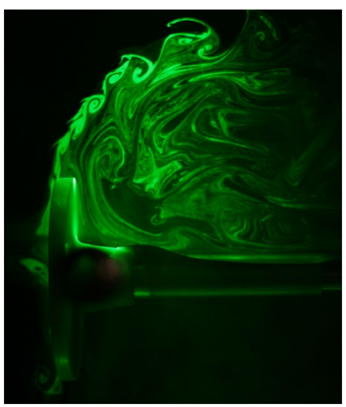


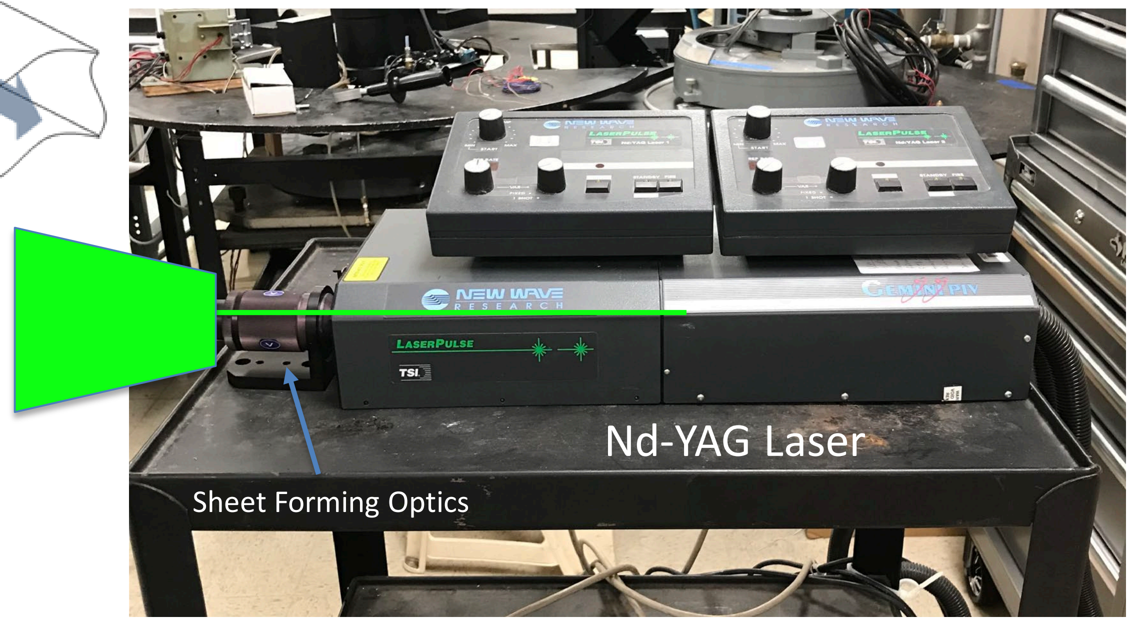
https://www.nasa.gov/sites/default/files/images/679684main_TWT_Schlieren_raw_full.jpg

LOVE PURPLE
LIVE GOLD

Laser Sheet Visualization



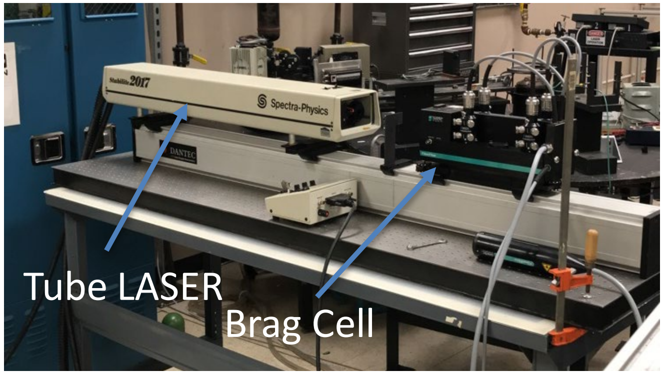


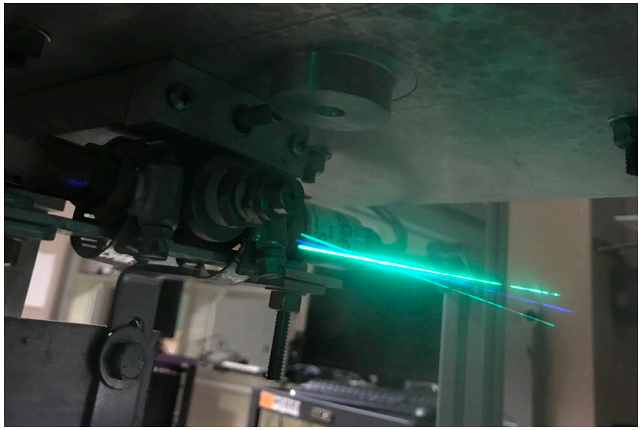


http://www.steveohalloran.com/blog/archives/flow_vis_6-16-06_high.jpg

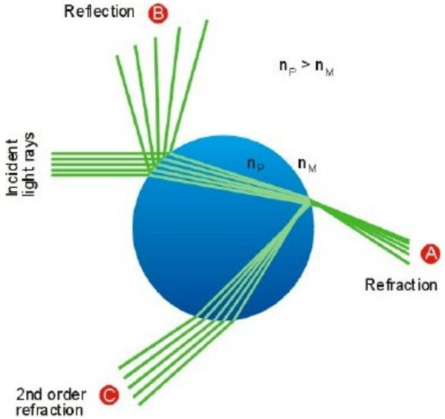
http://www.seika-mt.com/product/piv-en/img/img-Optical_setup.gif

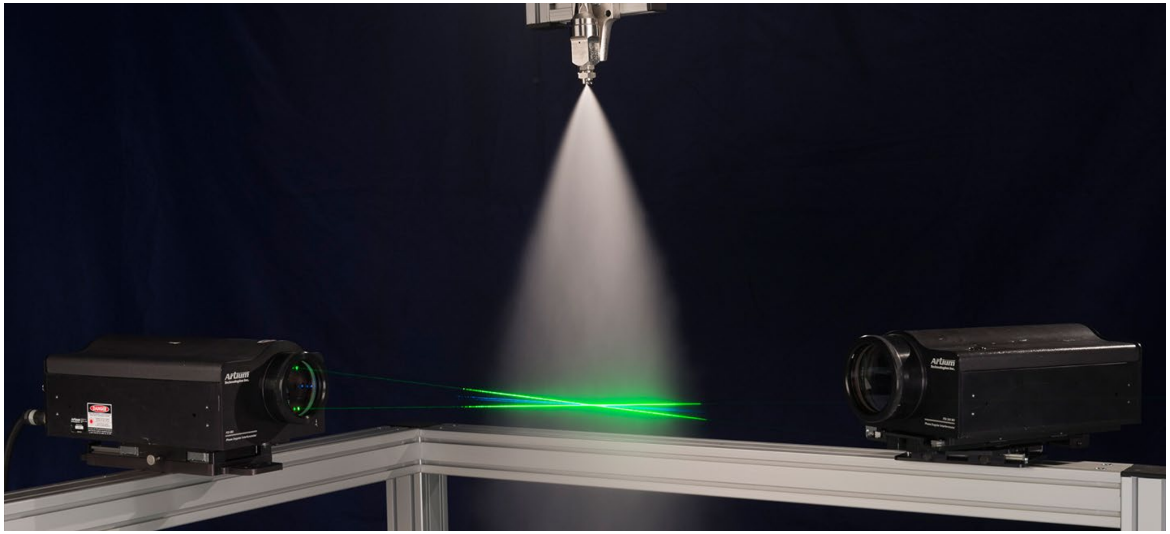
Phase Doppler Particle Anemometry (PDPA)





Point measurement which can measure particle velocity and diameter



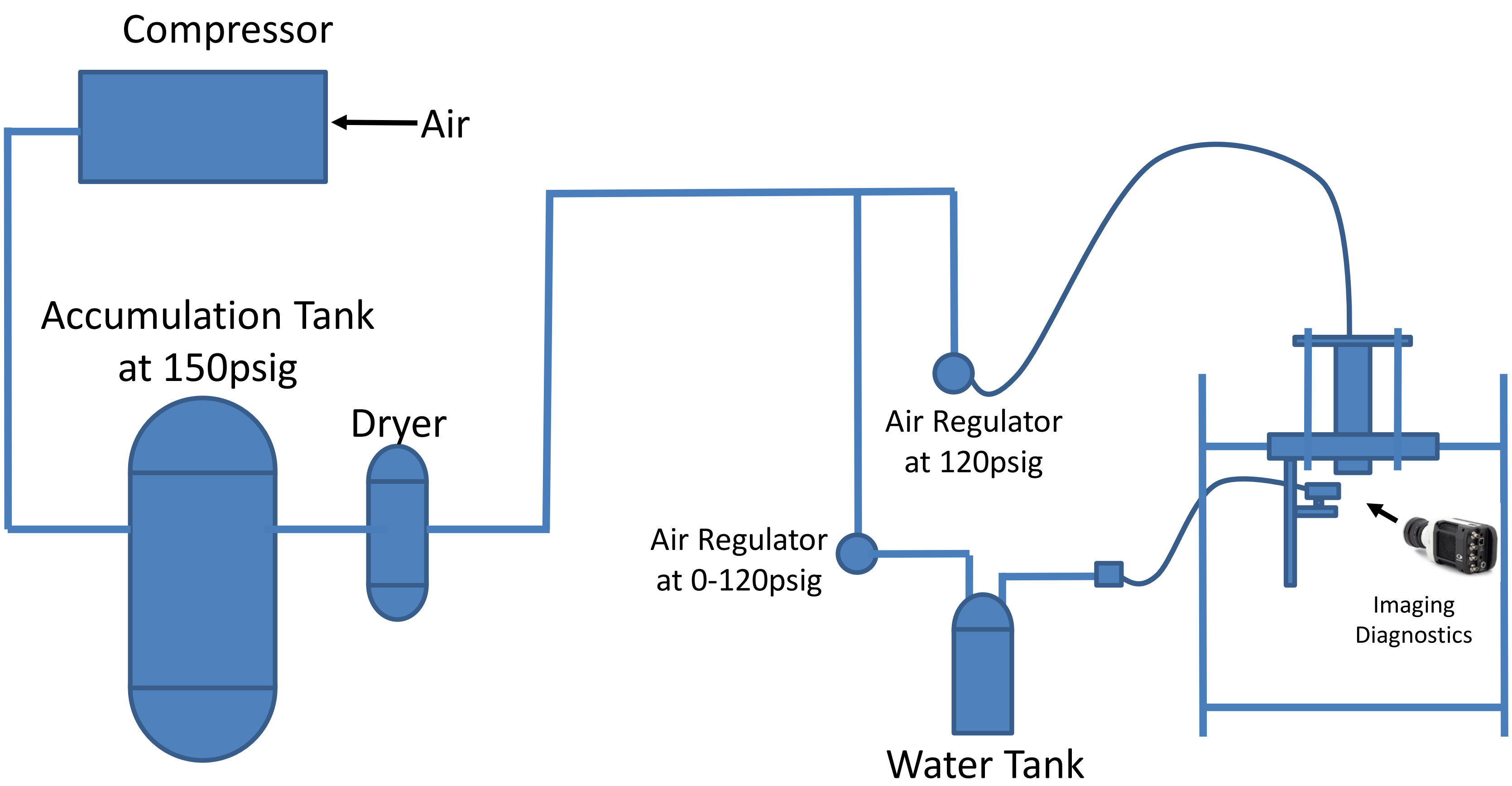


http://www.sprayanalysis.com/images/pdi_lg.jpg

Love Purple Live Gold

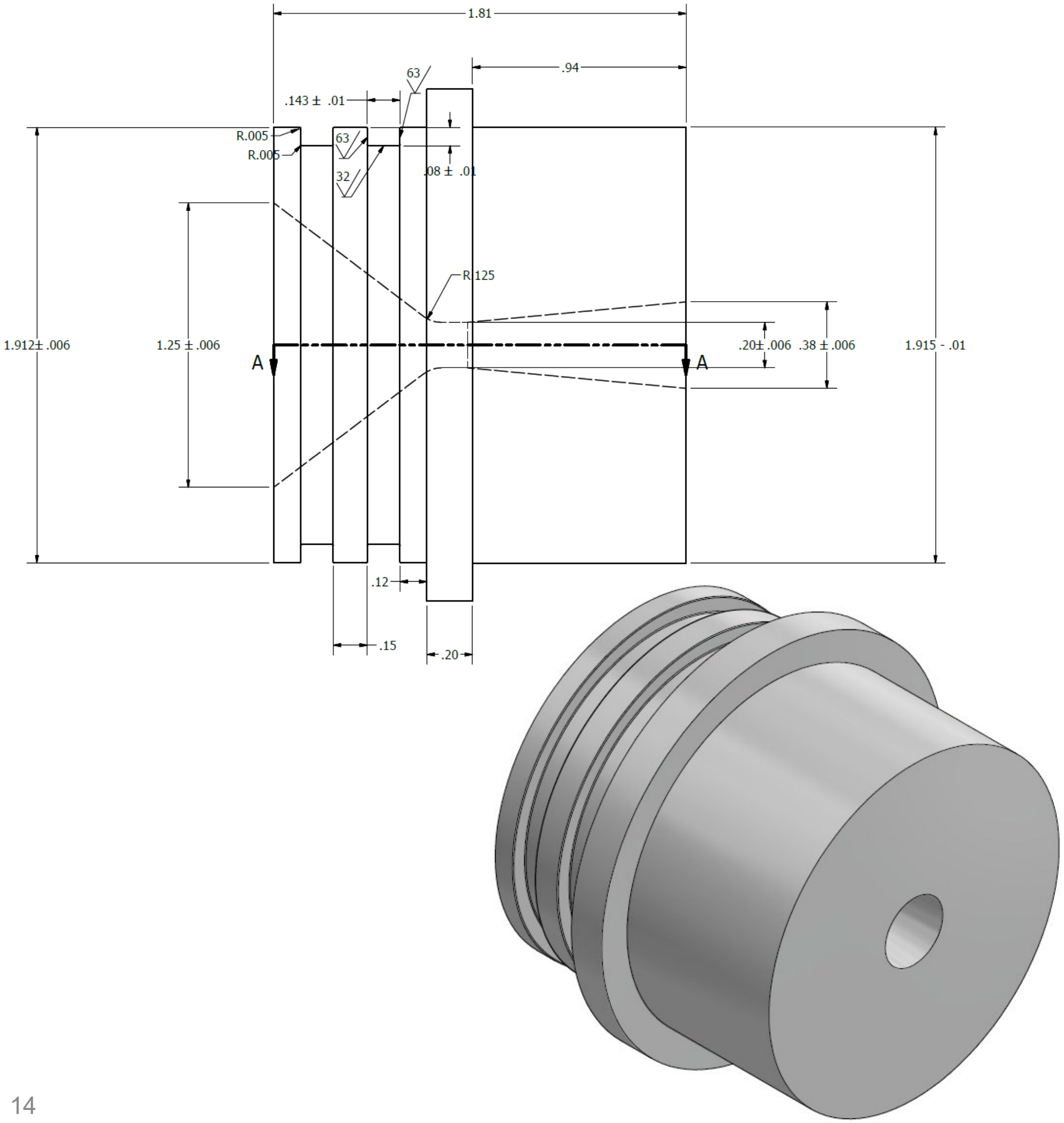
Test Results

Cold Flow Test Rig Overview



LOVE PURPLE
LIVE GOLD

Cold Flow Test Rig Overview

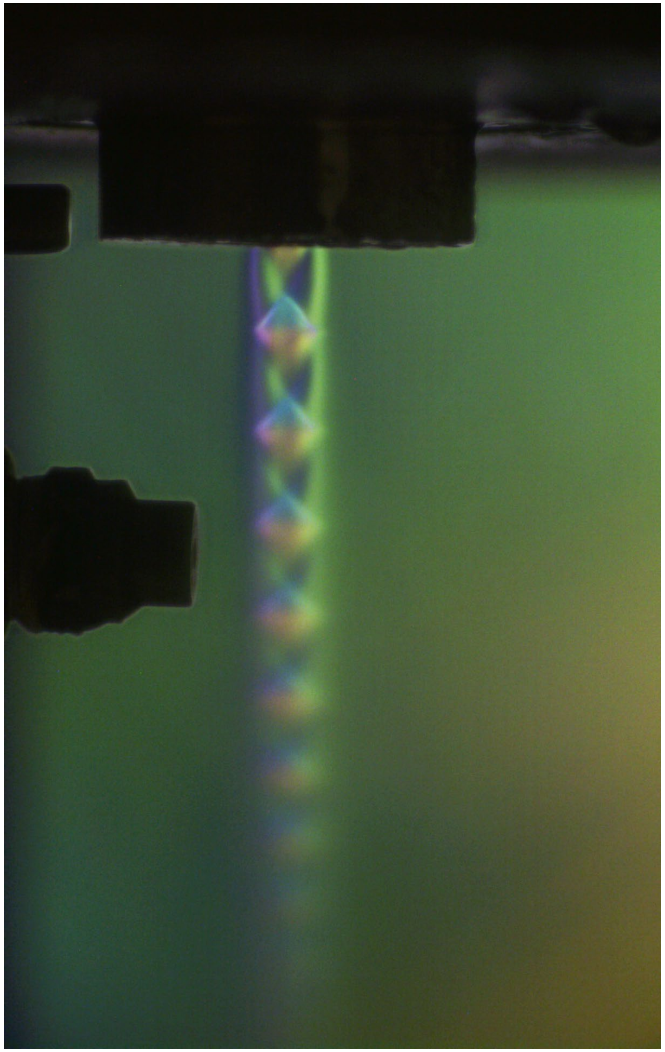


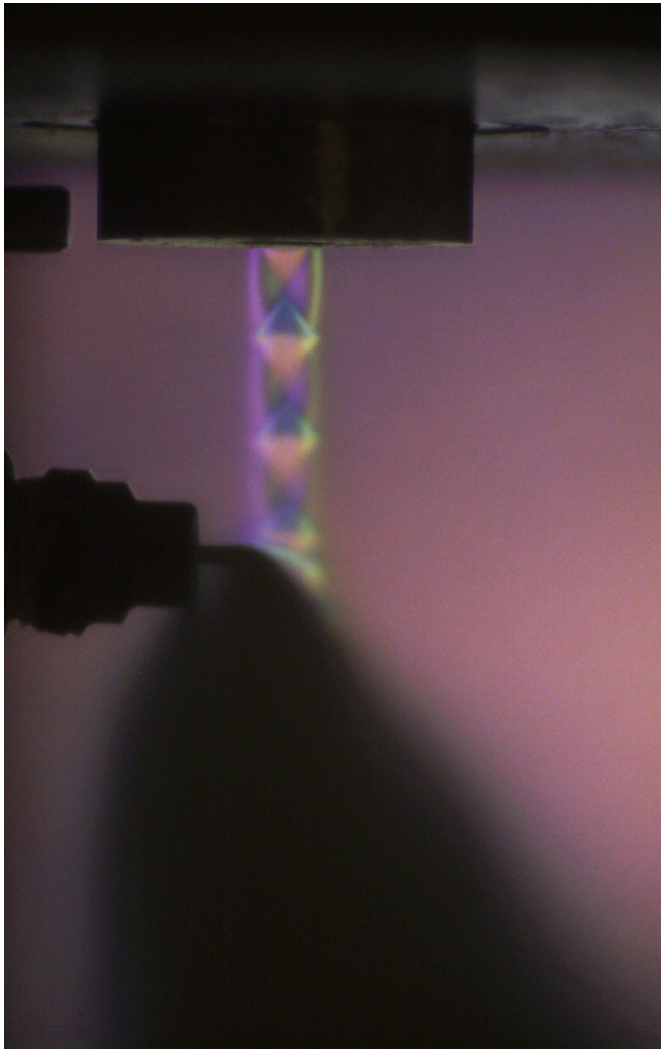
Testing Conditions:

- Compressed air at 65°F, 120psig, ~75 SCFM flowrate
- Water at 65°F, 80psig, ~5.6gpm flowrate through .06in orifice diameter

Video

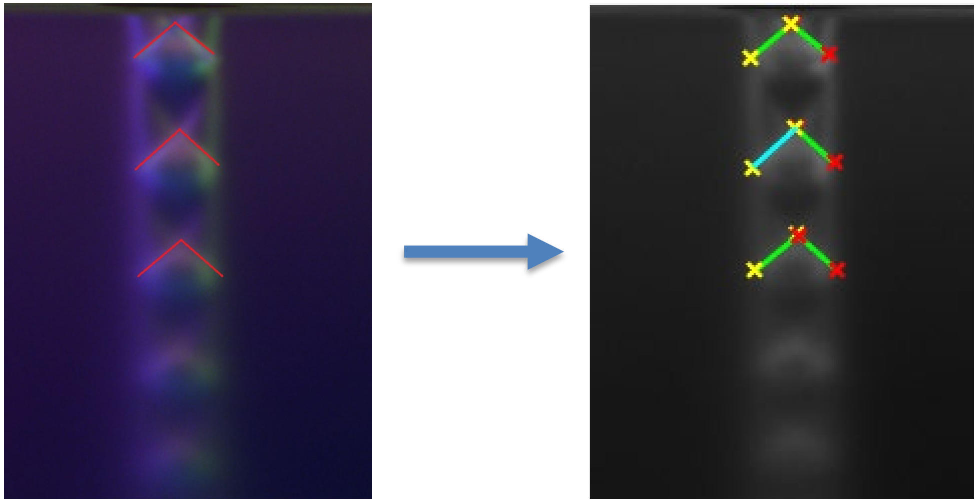
Focusing Color Schlieren

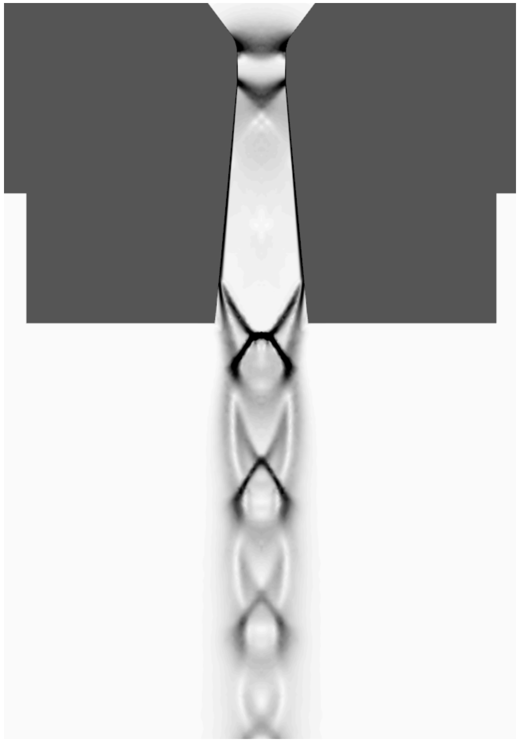




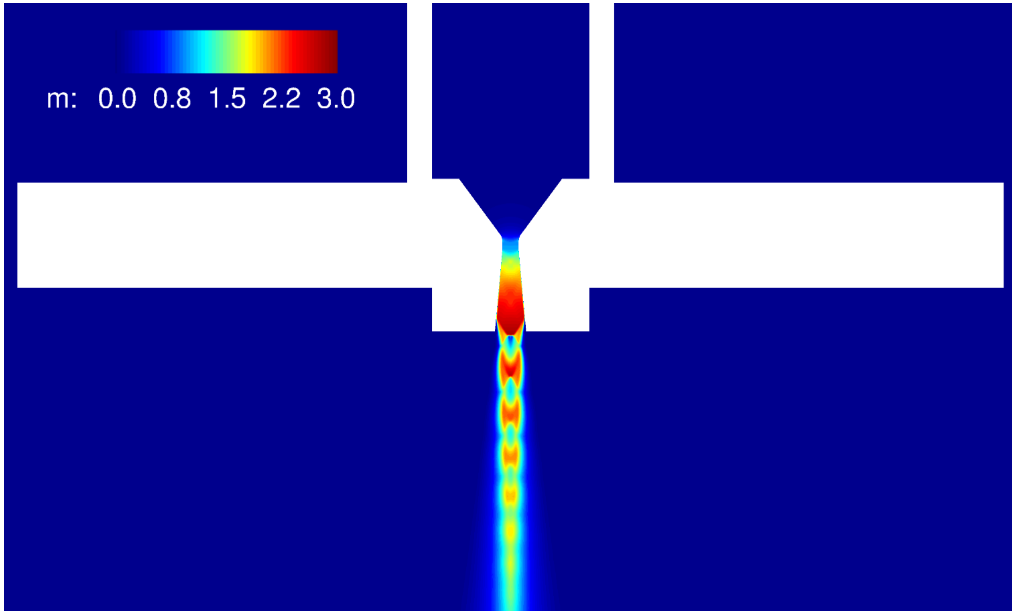
Love Purple
Live Gold

Focusing Color Schlieren



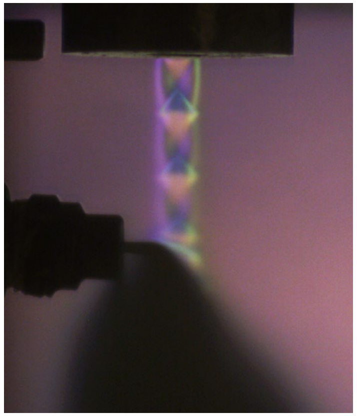


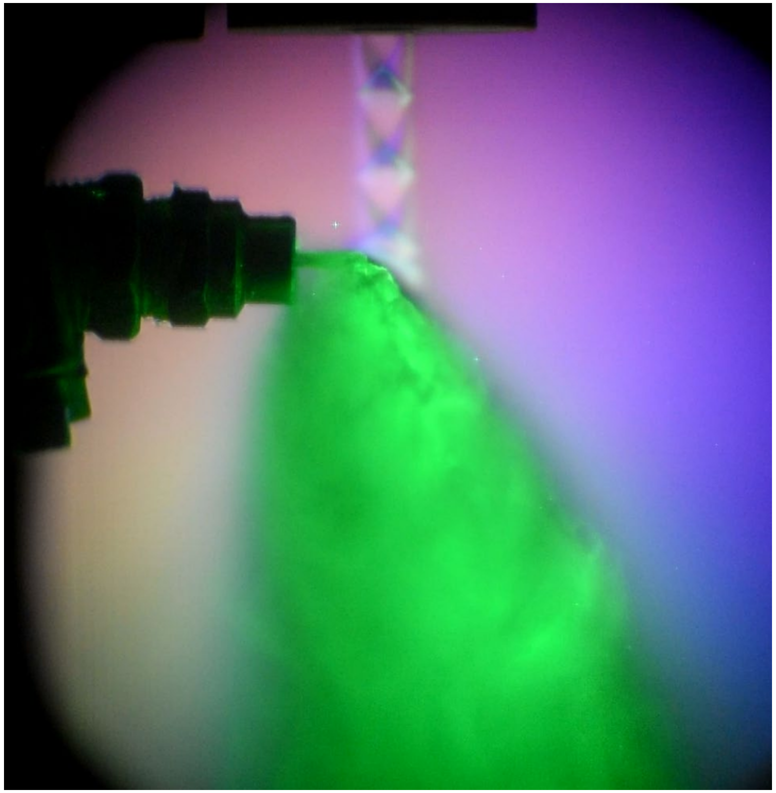
Density gradient magnitude plot

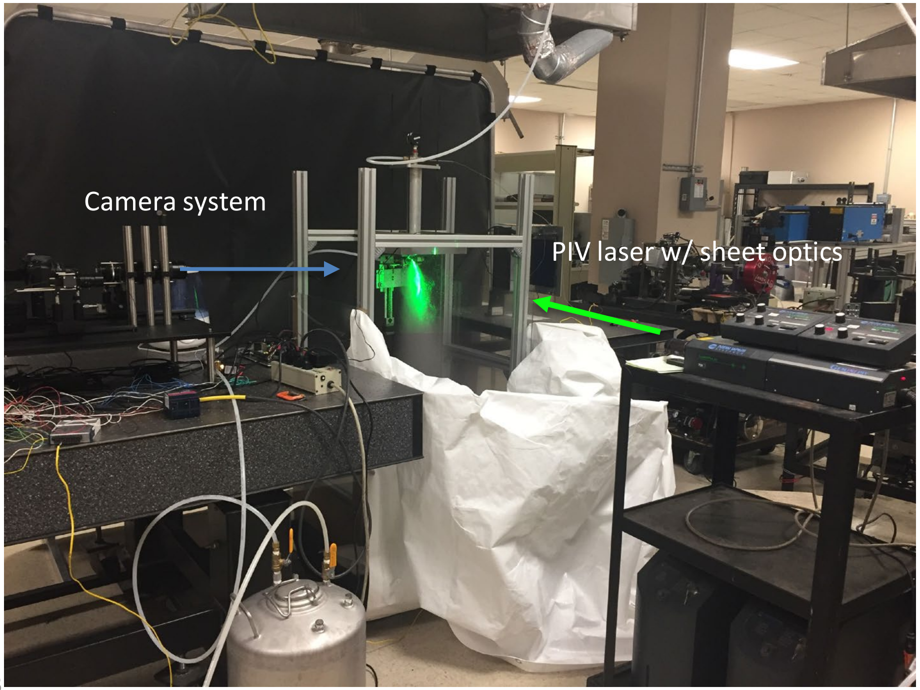


Mach number contour plot

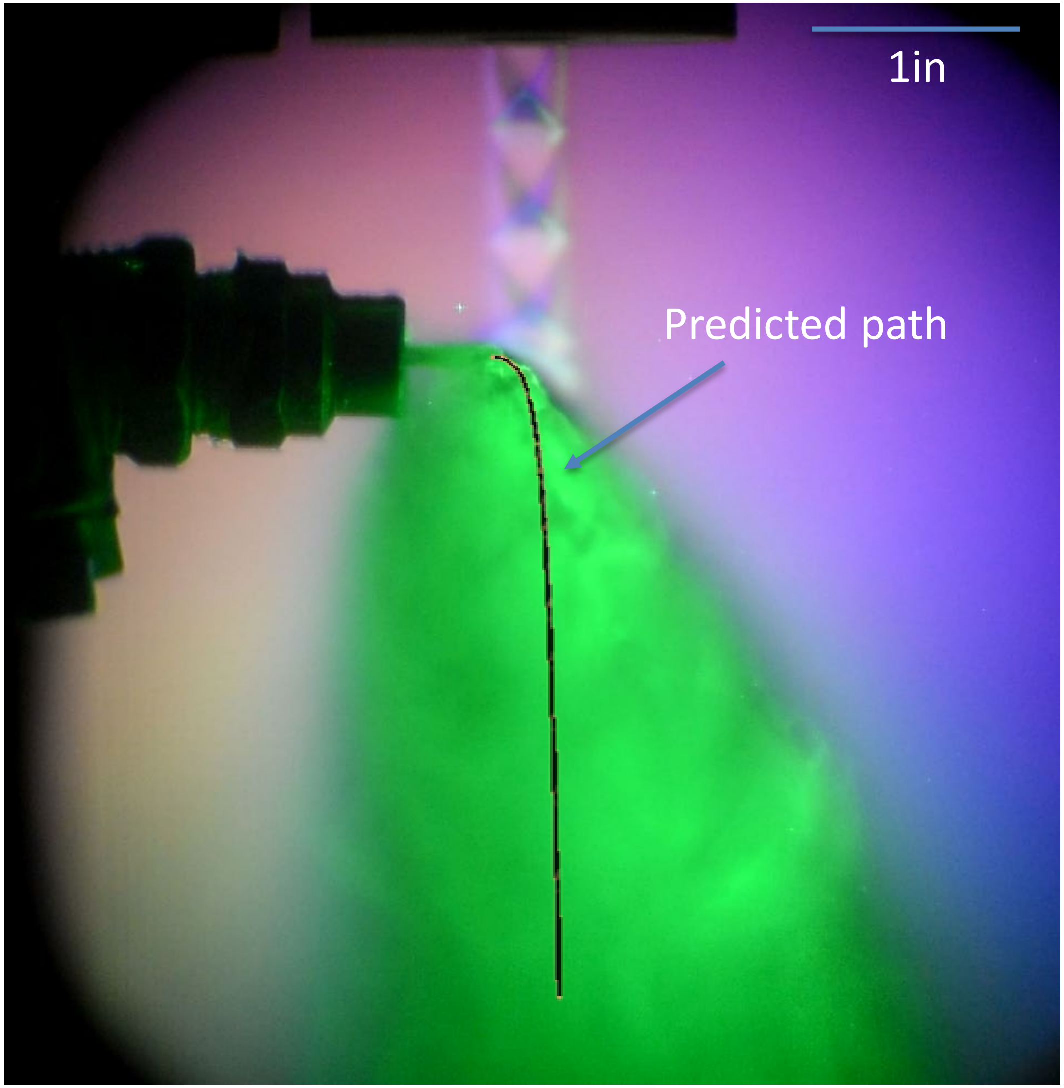
Laser Sheet Visualization

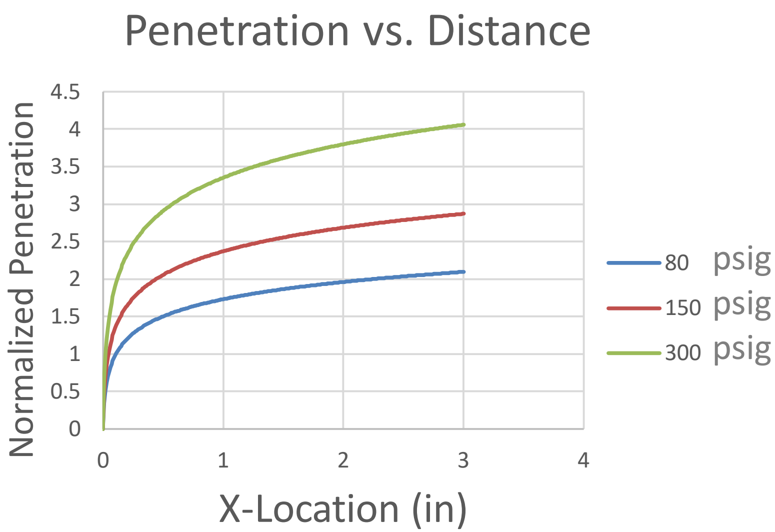






Laser Sheet Visualization

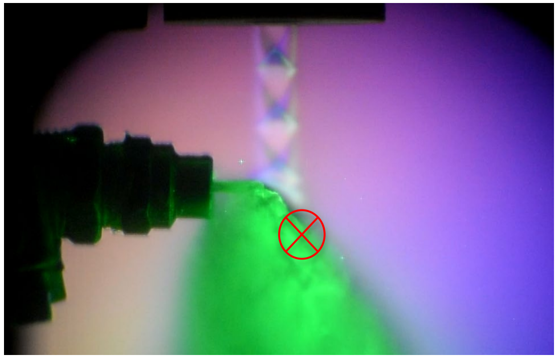




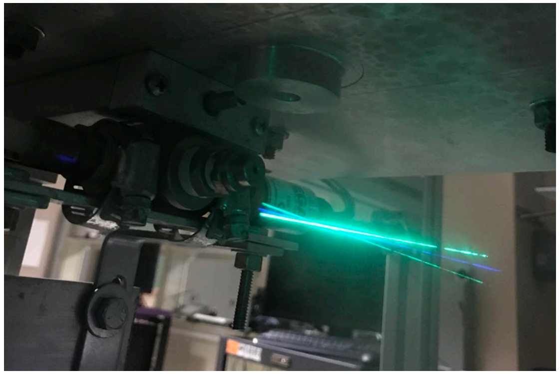
$$\bar{y}_B/d_e = 1.1\, q^{0.5} \ln(1 + 10\,\bar{x}/d_e).$$

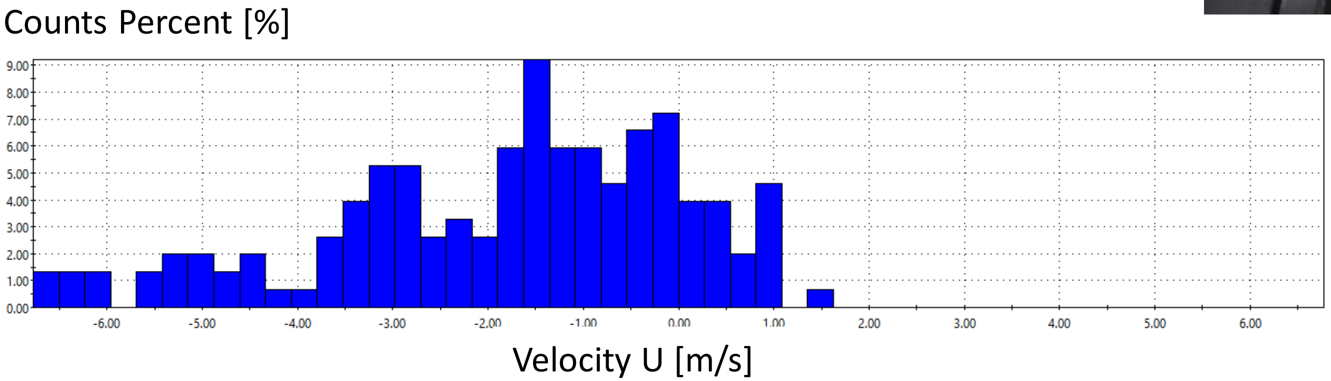
- Relates total pressures and exit diameters to penetration distance
  - Valid for injection into supersonic wind tunnel from flat plate, but extended for initial design and sizing

Phase Doppler Particle Anemometry (PDPA)

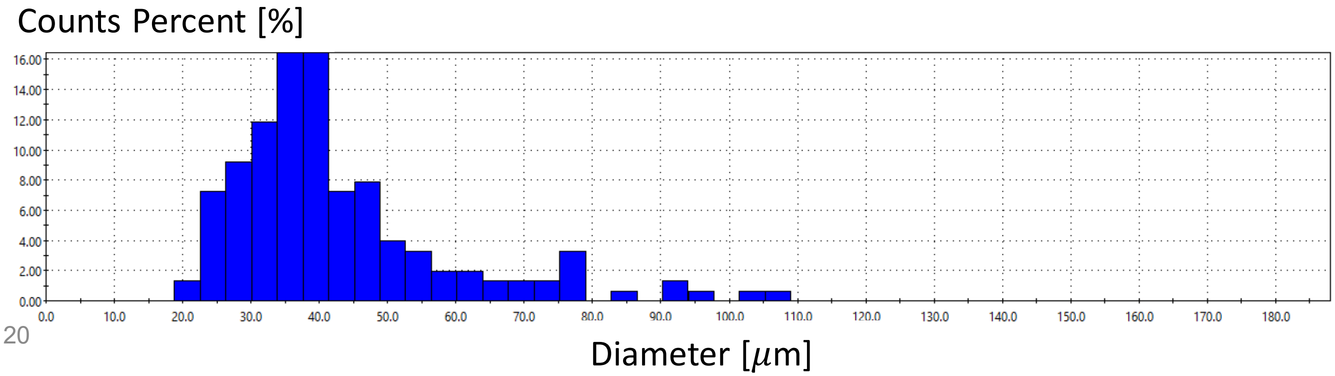


Location:
- 2.5in from nozzle exit
- .22in radially from longitudinal axis



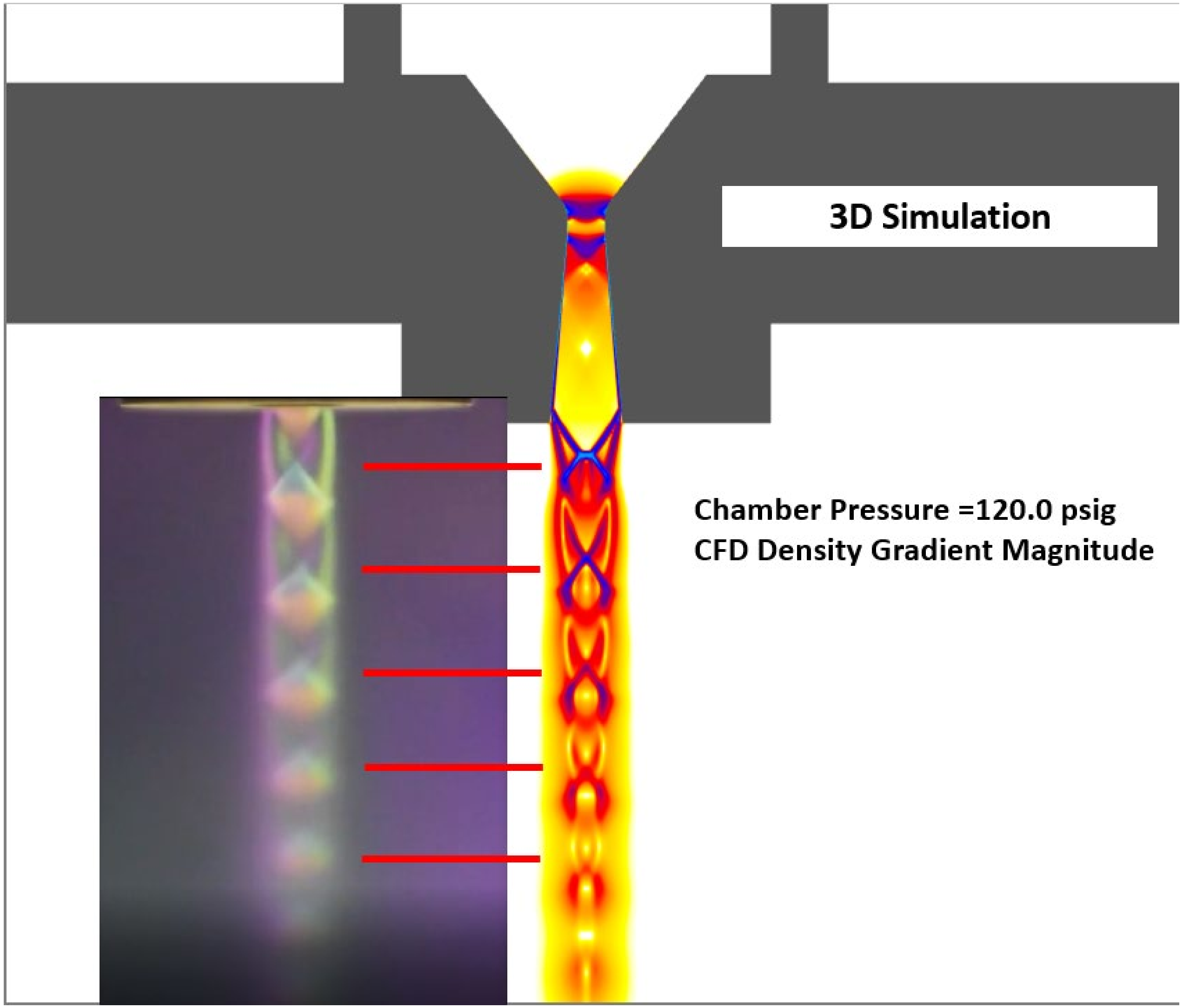


- Loose grouping for vertical velocity likely due to recirculation in test section and unsteady, cyclic flow behavior.



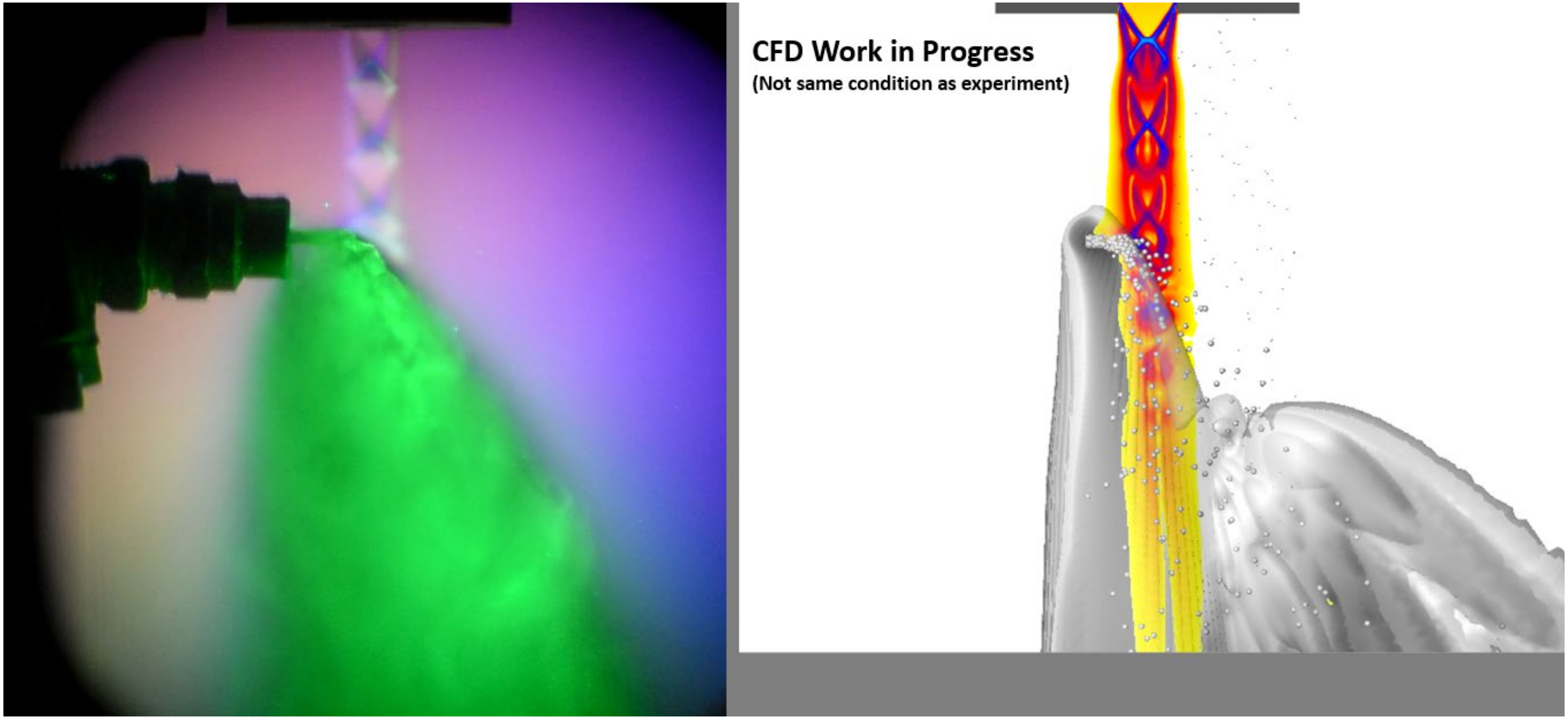
LOVE PURPLE LIVE GOLD

Simulation Results

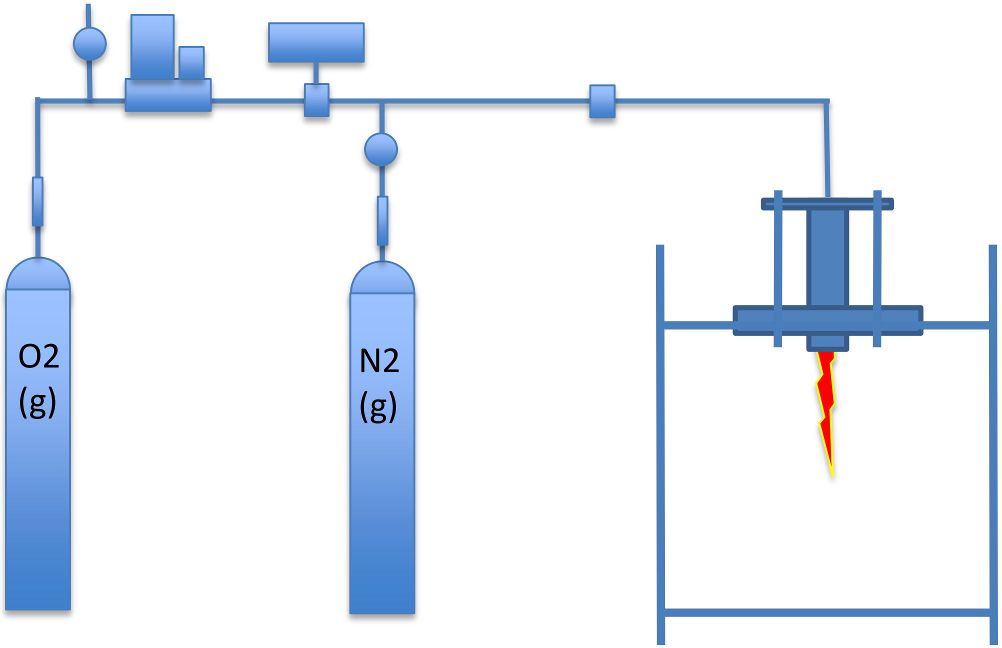


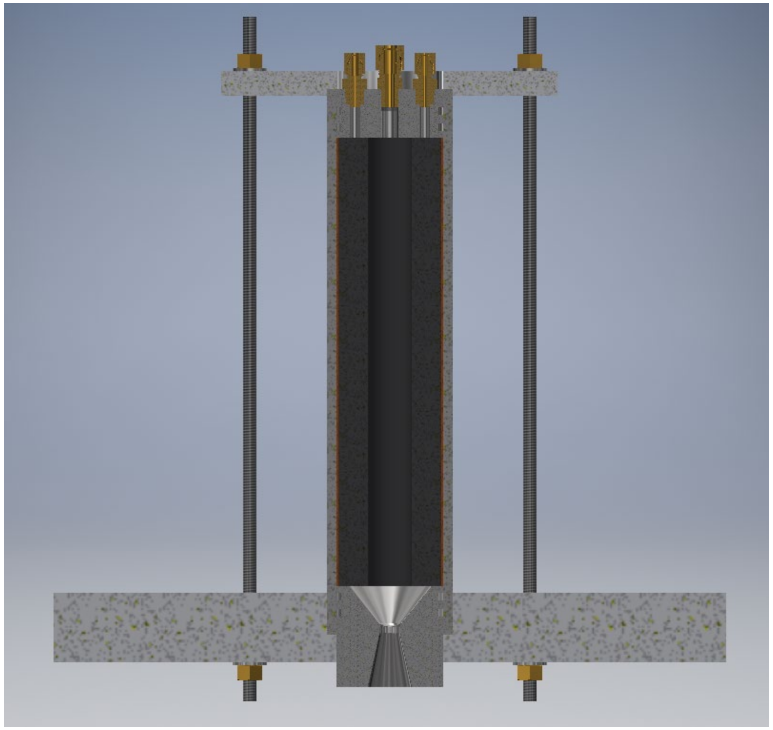
LOVE PURPLE
LIVE GOLD

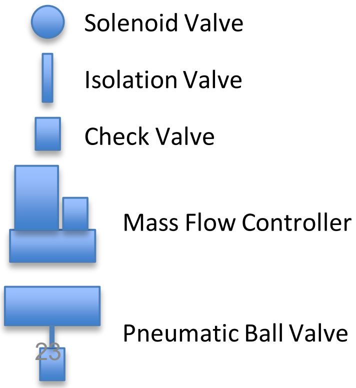
Simulation Results



Hybrid Rocket Design



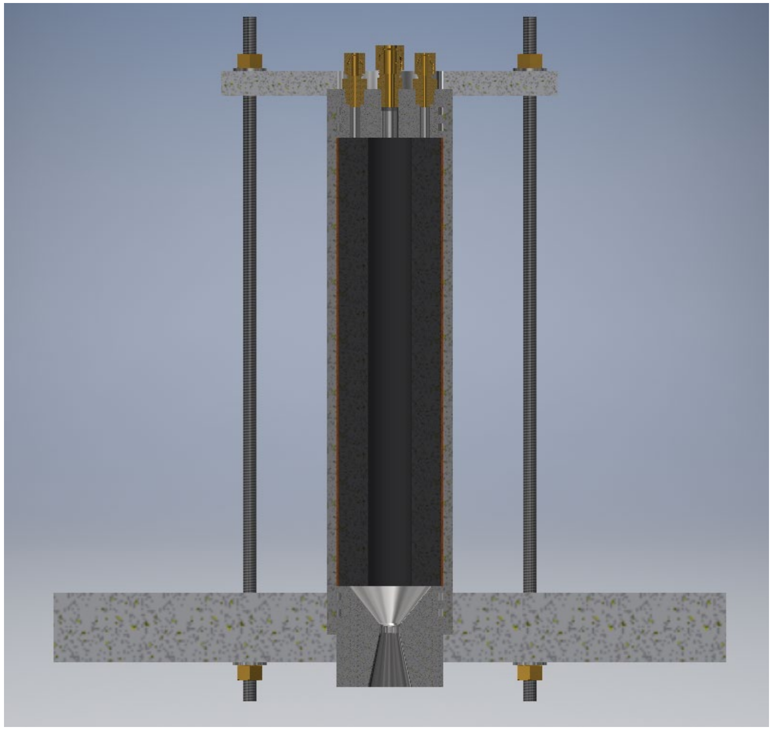




- Cylindrical HTPB fuel grain with phenolic inhibitor
- Electronic ignition with restart capability
- Nitrogen gas purge system

Future Work

- Same laser based diagnostics will be implemented
- Different water spray patterns will be explored
- Stand will be used on future work including tomographic diode laser absorption spectroscopy (TDLAS) to measure temperature in exhaust plume
- Will serve as a repeatable, safe, and simple rocket engine for future combustion diagnostics work



LOVE PURPLE LIVE GOLD

Thank you!

Special thanks to:
Dr. Shyam Menon, LSU
Dr. Daniel Allgood, NASA Stennis
Christopher Jeansonne, LSU Undergraduate

Funding for this project is provided by:
The Louisiana Space Consortium (LaSPACE)

Hansen Jones
Graduate Research Assistant
Louisiana State University, Baton Rouge, LA
hjone15@lsu.edu

LOVE PURPLE LIVE GOLD