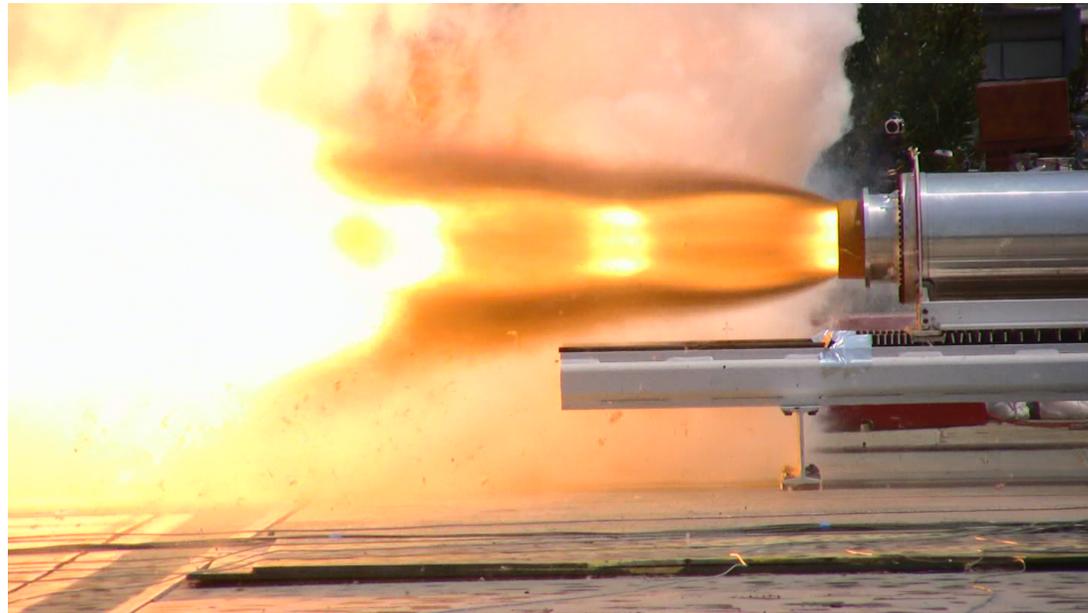# Stanford Propulsion and Space Exploration Lab

Vision – Advance the science and technology of clean, low-cost propulsion and energy

http://spase.stanford.edu

https://web.stanford.edu/~cantwell/

Brian Cantwell
Department of Aeronautics and Astronautics
Stanford University

SPaSE lab Alumni at JPL working on space exploration

Beth Jens
NASA – JPL

Perseverance cold gas
subsystem for dust removal

Ashley Karp
NASA – JPL

Propulsion Lead,Deputy Manager,
Mars Ascent Vehicle (MAV)

Tim Szwarc
NASA – JPL

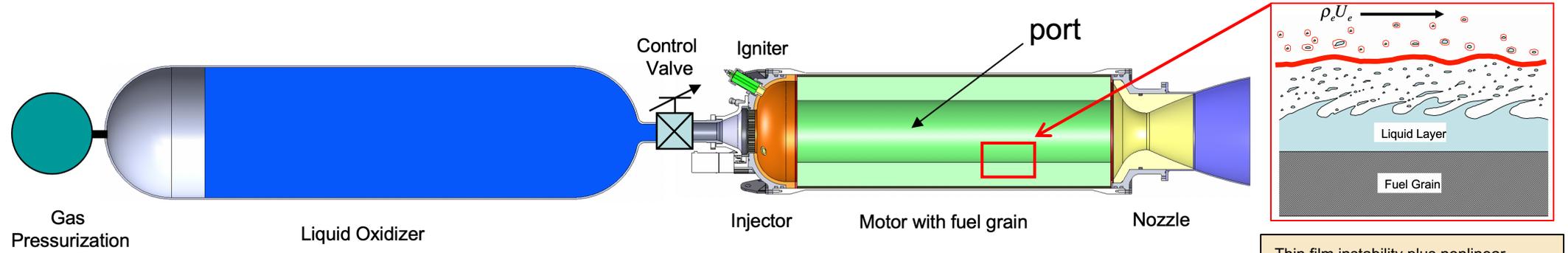Perseverance core
drilling system

William Hart
NASA – JPL

Cruise phase lead for mission Psyche

Flora Mechentel
NASA – JPL

Project Starshade

Liquifying fuels for hybrid propulsion - I

port

Control Valve

Igniter

$\rho_e U_e$

Liquid Layer

Fuel Grain

Gas Pressurization

Liquid Oxidizer

Injector

Motor with fuel grain

Nozzle

Thin film instability plus nonlinear growth and wave breaking leads to entrainment of droplets along the port

Karabeyoglu, Altman and Cantwell, "Combustion of liquifying hybrid propellants" parts 1 and 2, J. Prop. and Power, vol 18, 2002.

15,000 lb thrust hybrid motor test

Fast burning paraffin-based fuels for hybrid rockets first identified in the SPaSE lab at Stanford by Arif Karabeyoglu. Large scale tests at NASA Ames led by Greg Zilliac.

Not all tests are succesful!

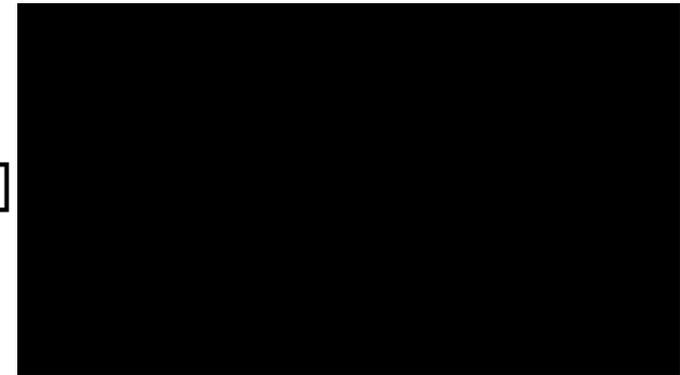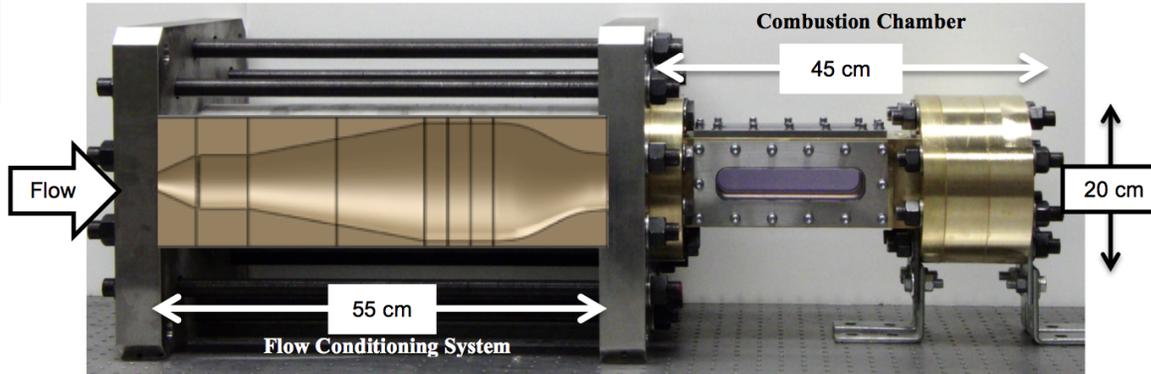**Visualization of hybrid rocket combustion, liquid layer instability and fuel droplet entrainment mechanism**

Oxygen compatible combustion visualization tunnel
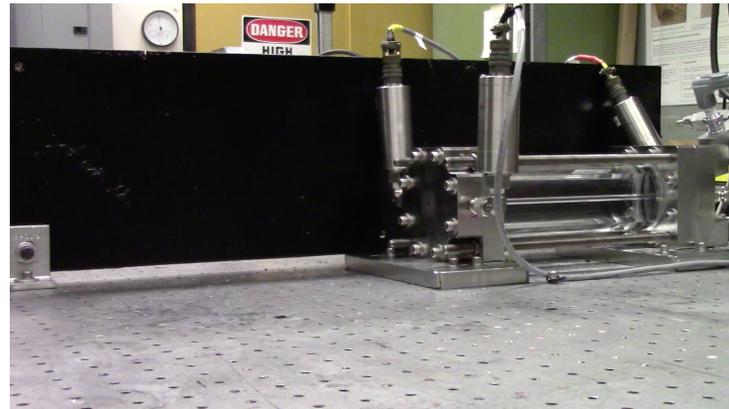
Ashley Karp
NASA - JPL

Beth Jens
NASA - JPL

Combustion Chamber

45 cm

Flow

20 cm

55 cm

Flow Conditioning System

Direct visualization of fuel regression in a clear-grain hybrid rocket

Flora Mechentel
NASA - JPL

05/17/2017
10.1 g/s oxidizer flow rate
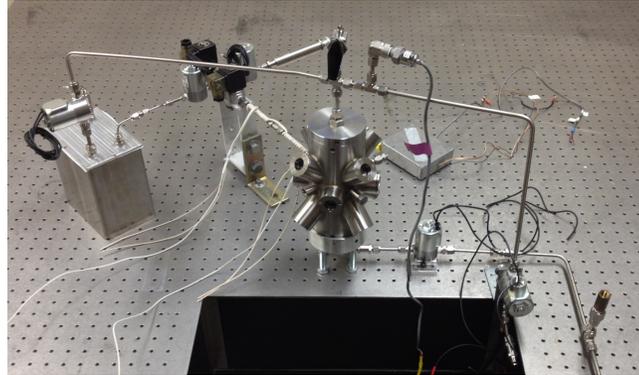20s set burn time

STANFORD AERONAUTICS & ASTRONAUTICS

PaSE
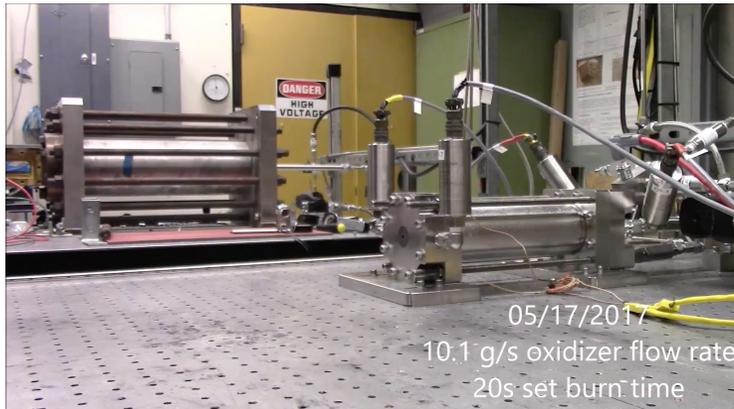
Lithium aluminum hydride (LAH) and LAH doped paraffin reacting with Reagent grade Nitric acid

LAH reacting with 70% nitric acid at one atmosphere

Paraffin/40%LAH + 70% nitric acid at 95C

Variable pressure droplet ignition chamber for studying ignition delay from vacuum to 3 MPa

Javier Stober
MIT

Ignition and combustion of Energetic Ionic Liquids (EILs) reacting with Nitric Acid


Anna Thomas
NREL

1 Hartree = 27.211 ev

Figure 6.5: Stills taken from high speed video data recording the reaction between an ionic liquid, BMPY$^+$DCA$^-$, and WFNA at 3000 fps in a droplet ignition chamber providing a nitrogen inert environment. The droplet of the ionic liquid can be followed from the tip of the syringe needle until contact, mixing, and, finally, ignition with the WFNA.

- Decomposition reaction pathways were determined using
  - Thermogravimetric Analysis (TGA)
  - Fourier Transform Infrared Spectroscopy (FTIR)
  - Computational chemistry (code Gaussian)
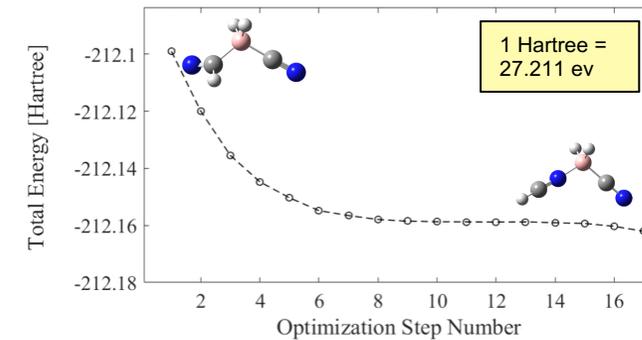
Density Functional Theory (DFT) used to find the lowest energy configuration

3/2/21

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Low power laser ignition of solid fuels for hybrid propulsion
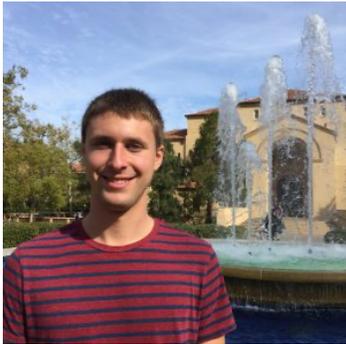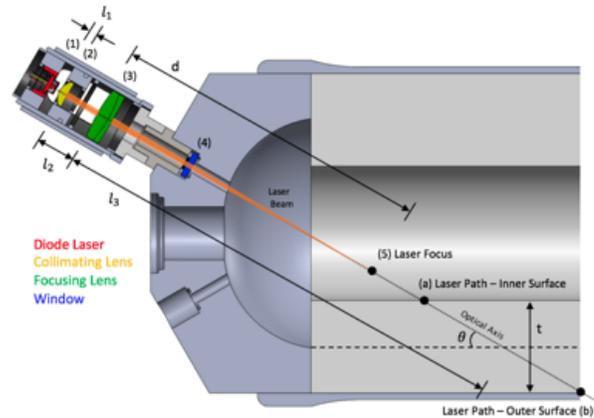
David Dyrda
Boeing Space Systems

Figure 4: A representation of the proposed laser ignition concept for use in single port hybrid rocket motors. The laser system is composed of a single diode laser, a collimating and focusing lens, and a transparent window. The beam focuses to a point within the motor a distance d away from the focusing lens.
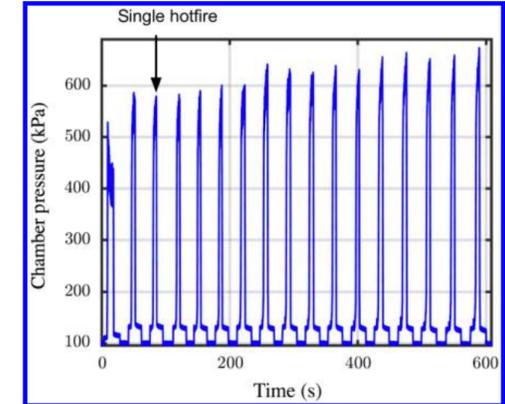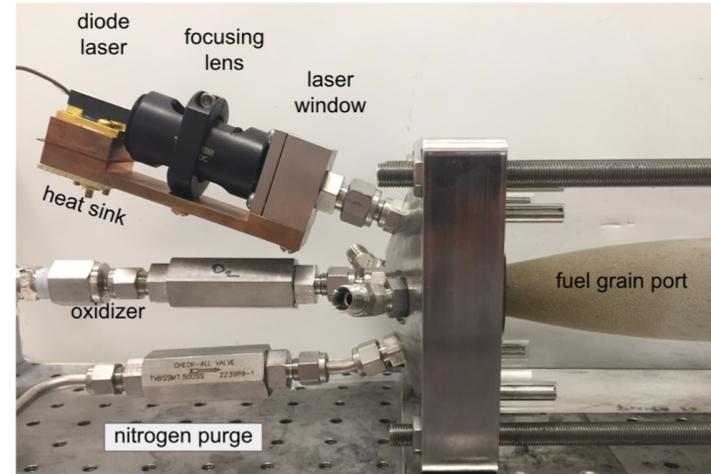
Fig. 4 Hot fires 1–17 on fuel grain 1, intended to mimic a series of restarts without motor adjustment. Chamber pressure data from individual tests have been stitched together.

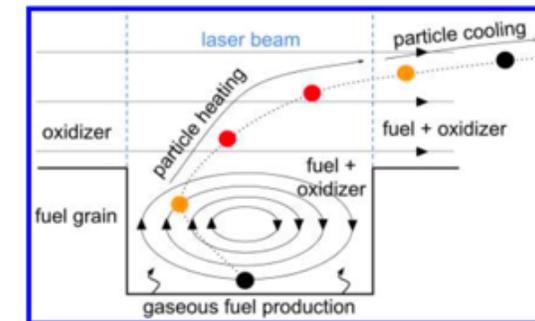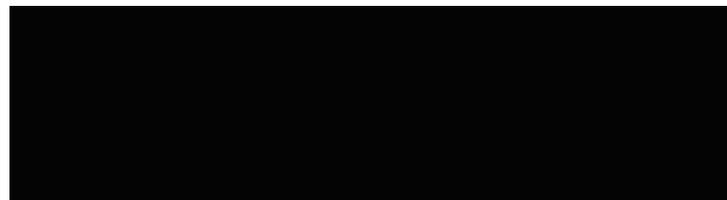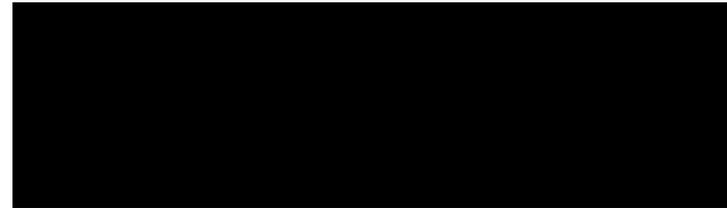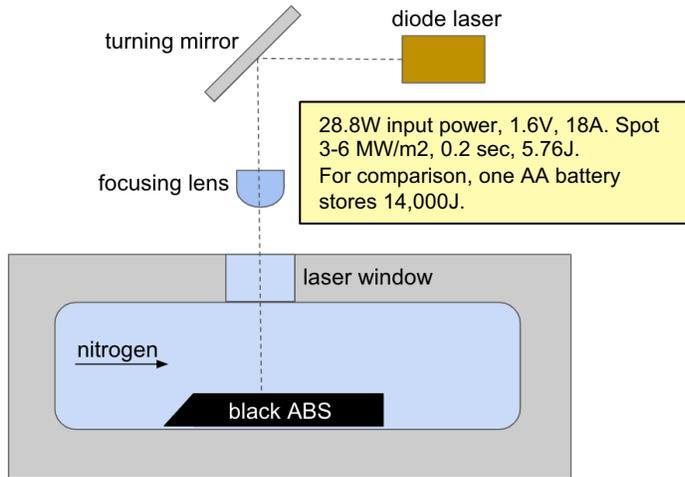## Ignition mechanism – Soot particle entrainment and heating

28.8W input power, 1.6V, 18A. Spot 3-6 MW/m2, 0.2 sec, 5.76J. For comparison, one AA battery stores 14,000J.

Fig. 5 Oxidizer flow over the laser cavity results in a recirculation zone that facilitates carbon particle entrainment. These particles are also heated by the laser.
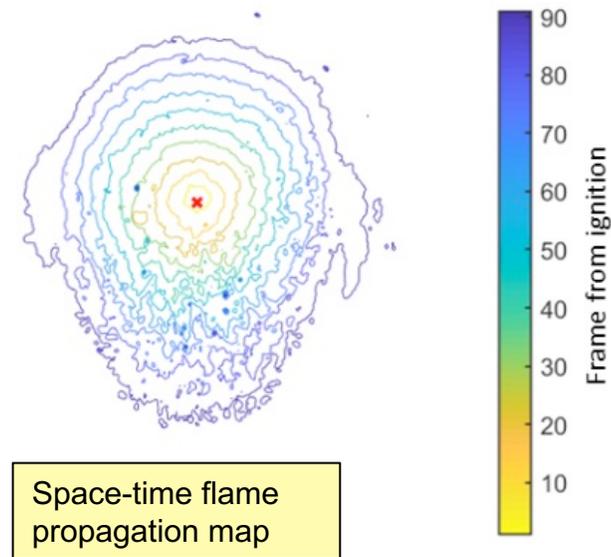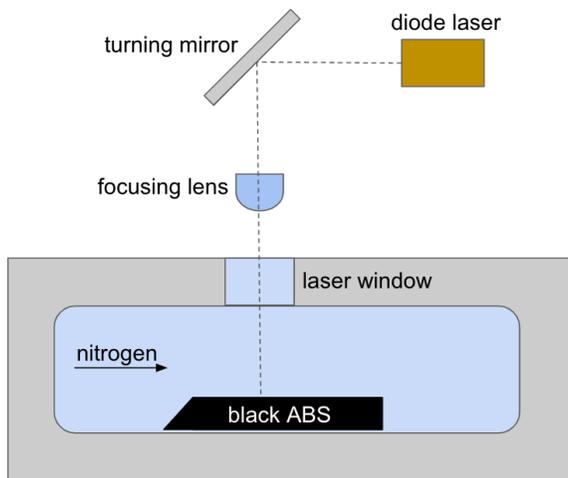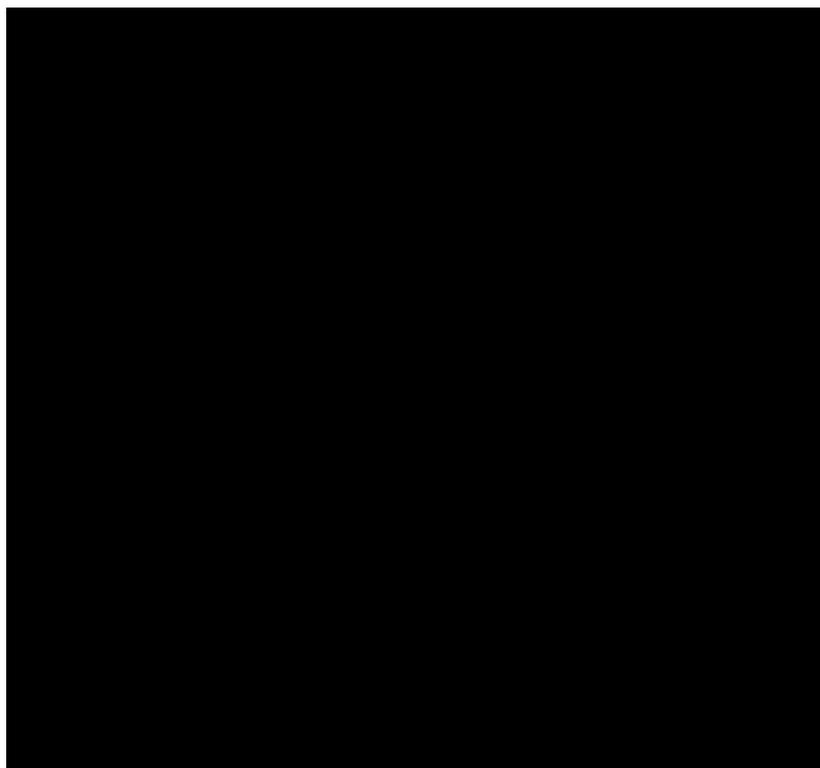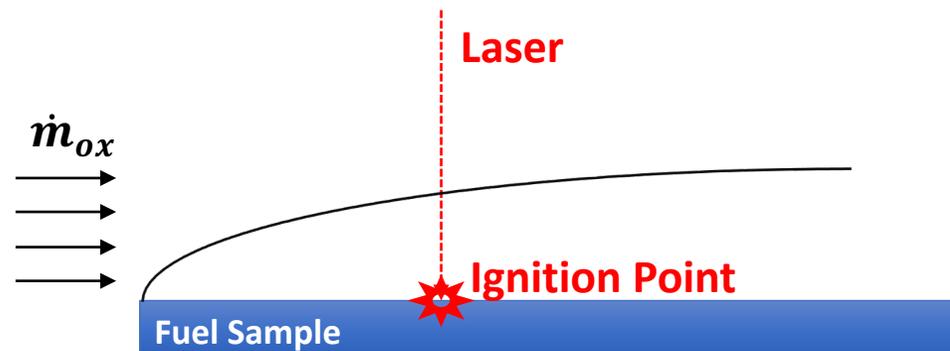
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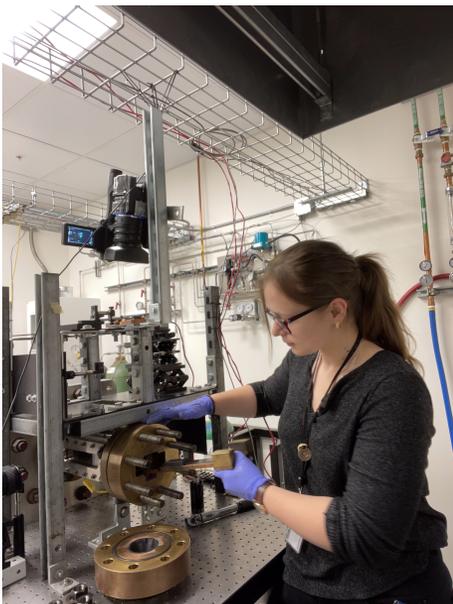
Veronika Korneyeva
Stanford AA

AIAA paper 2020 – 3731
Experimental Studies of Flame Propagation on
Planar Hybrid Fuel Samples in Opposed Flow

AIAA Propulsion and Energy Forum Aug 2020

$\dot{m}_{ox}$

Laser

Ignition Point

Fuel Sample

turning mirror

diode laser

focusing lens

laser window

nitrogen

black ABS

Frame from ignition

Space-time flame
propagation map

Stanford AeroAstro Visit Day March 4-5, 2021

A Universal velocity profile for near-wall flows
AIAA SciTech Conference Jan 2021

A universal velocity profile for smooth wall pipe flow

Brian J. Cantwell†

Department of Aeronautics and Astronautics, Stanford University, Stanford, CA 94305, USA

(Received 21 January 2019; revised 11 August 2019; accepted 11 August 2019)

AIAA 2021 - 0061

Matt Subrahmanyam
Stanford AA

A new turbulent boundary layer velocity profile is used that is uniformly valid from the wall to the free stream for all Reynolds numbers

MATTHEW A. SUBRAHMANYAM, BRIAN J. CANTWELL, JUAN J. ALONSO

A NEW MIXING LENGTH MODEL HAS BEEN DEVELOPED TO ACCURATELY DESCRIBE WALL-BOUNDED FLOWS

| Flow	a	b	k	m	n
Channel	22.8673	0.4649	0.4086	1.2569	1.3972
Pipe	20.0950	0.3195	0.4092	1.6210	1.6190
ZPG Boundary Layer	24.8462	0.1771	0.4193	1.2043	2.4331

Stanford University
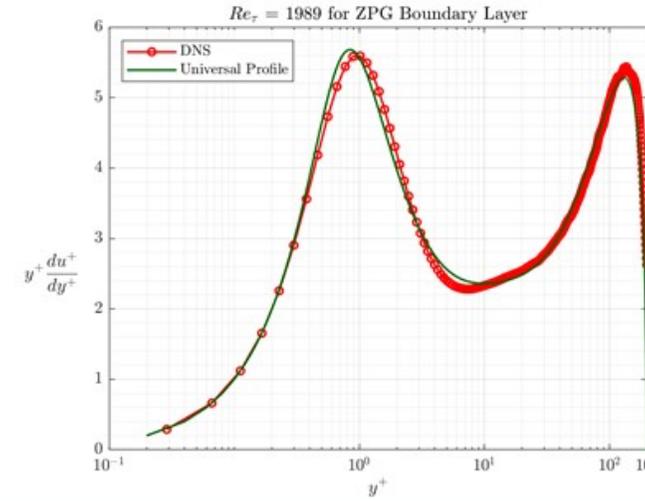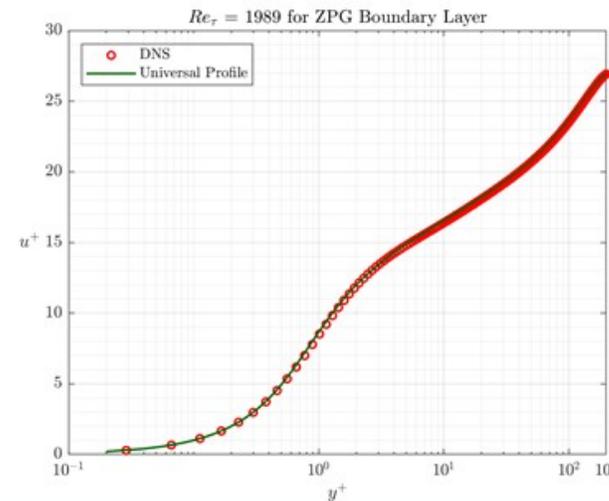
Stability of thin liquid films subject to shear flow
AIAA Propulsion and Energy Forum Conference Aug 2020

Eylul Bilgin
Stanford AA

- AIAA-2020-3730

- Combustion of Liquefying Hybrid Propellants: Long-Wave Instabilities of Sheared Liquid Films Subject to Blowing

- Eylul Bilgin (ebilgin@stanford.edu) Prof. Brian Cantwell (cantwell@stanford.edu)

- **Summary**

  - Investigation of the long wave stability characteristics of pressure and shear driven liquid layers forming over liquefying hybrid propellants and the introduction of a mathematical technique for solving over-posed stability problems.

- **Key results**

  - **A new method (method of variational iterations) was used for the first time to solve a hydrodynamic stability problem.**

  - **The sensitivity of long wave stability characteristics to velocity curvature was demonstrated through both a numerical scheme and theoretical analysis.**

Energy from waste nitrogen
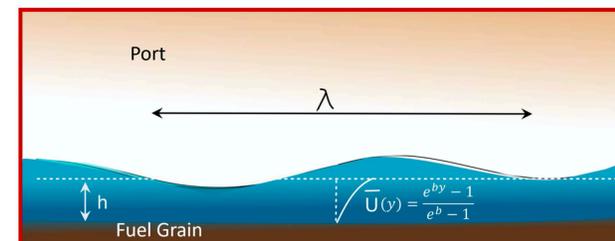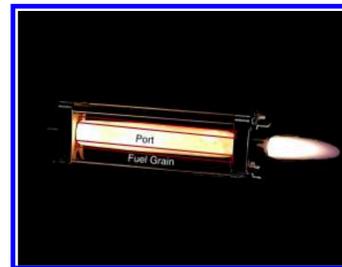
In collaboration with Prof. Craig Criddle of the Stanford Department of Civil and Environmental Engineering (CEE), This is the first project to propose a new process for recovering waste nitrogen from waste water for energy production.

Energy & Environmental Science

RSC Publishing

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Nitrogen removal with energy recovery through N_2O decomposition†

Yaniv D. Scherson,*[ae] George F. Wells,[b] Sung-Geun Woo,[d] Jangho Lee,[d] Joonhong Park,[d] Brian J. Cantwell[c] and Craig S. Criddle[be]

Broader context

The release of reactive forms of nitrogen is a major environmental threat causing hypoxia and eutrophic zones in water bodies. Globally, rising energy costs and increasingly stringent discharge regulation are major drivers for efficient wastewater treatment processes that lower costs and increase recoverable energy from waste. While many processes recover energy from carbon waste as CH_4, none recovers energy from waste nitrogen. This work introduces a new wastewater treatment process that removes and recovers energy from nitrogen waste by exploiting the thermodynamic properties of N_2O for energy recovery. The proposed process, referred to here as *C*oupled *A*erobic–anoxic *N*itrous *D*ecomposition *O*peration (CANDO), involves three steps: (1) partial aerobic nitrification of NH_4^+ to NO_2^-, (2) partial anoxic denitrification of NO_2^- to N_2O, and (3) N_2O conversion to N_2 with energy recovery *via* catalytic decomposition of N_2O or use of N_2O as an oxidant in CH_4 combustion. If successfully scaled-up, this process has the potential to lower aeration and biosolid production (the two major operational costs), increase CH_4 recovery from "freed" organic matter, and introduces a new renewable energy source from CH_4 combustion with N_2O.

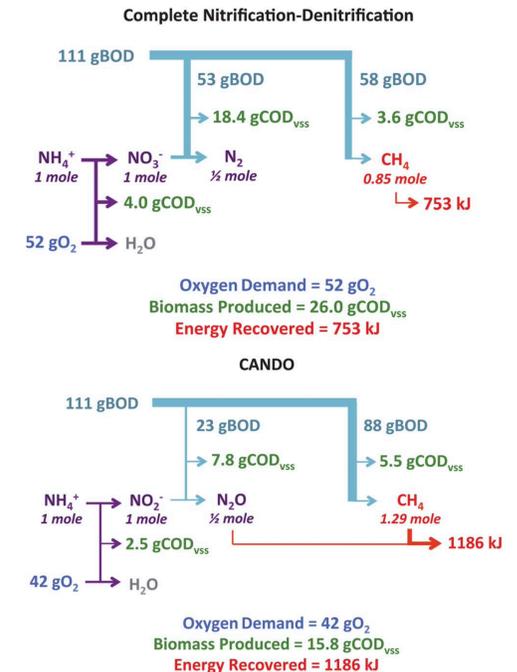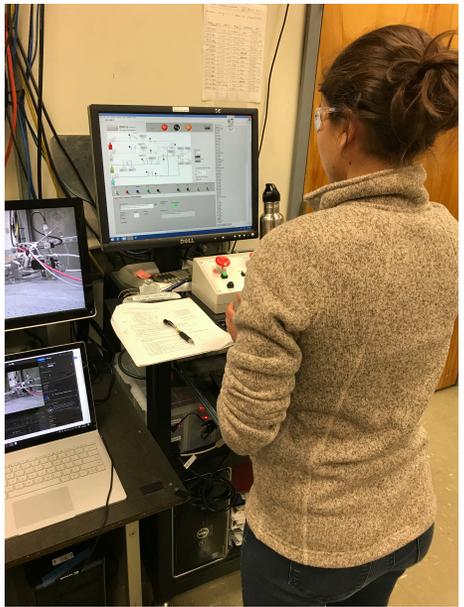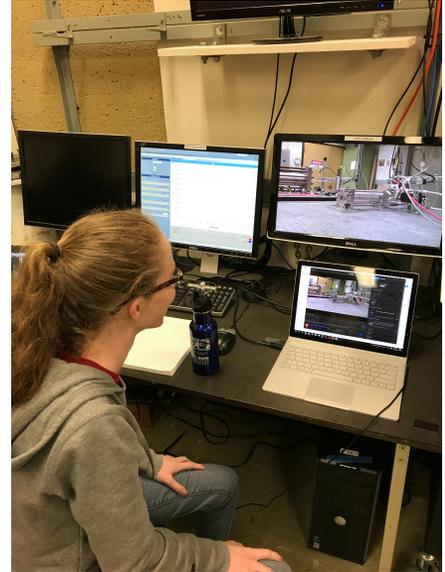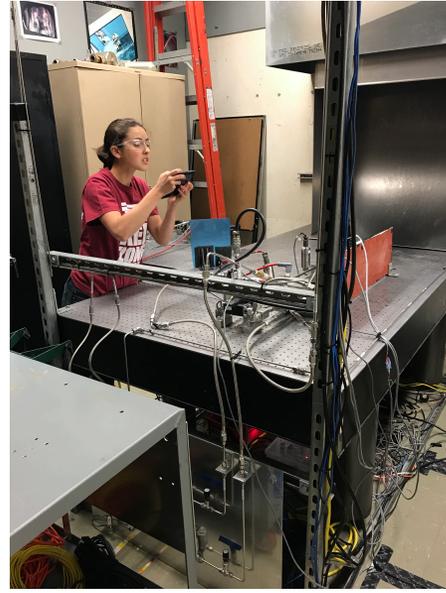Prof. Craig Criddle

Yaniv Scherson
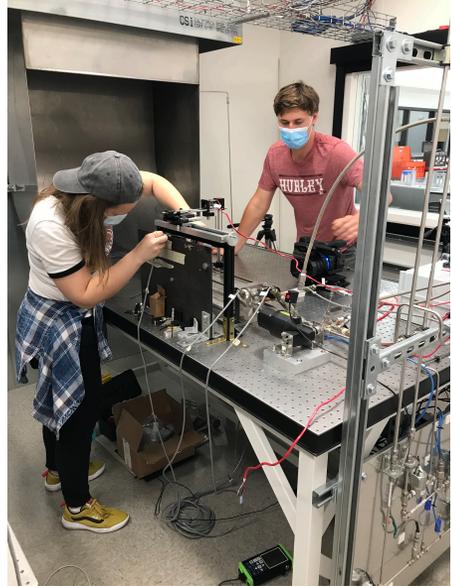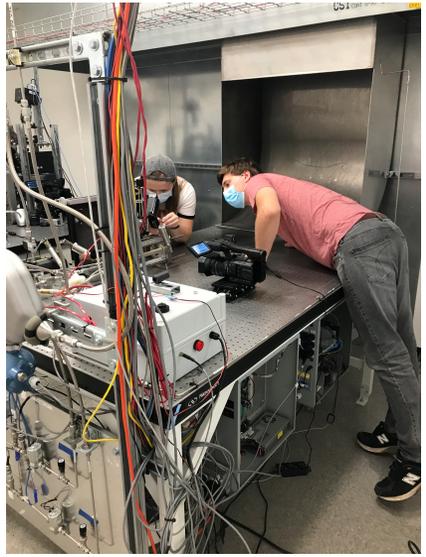Anaergia

Complete Nitrification-Denitrification

CANDO

Fig. 8 Comparison of complete nitrification–denitrification to CANDO with respect to oxygen demand, biomass production, and energy recovery.

Stanford AeroAstro Visit Day March 4-5, 2021

People

Recent PhD grads

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Blue Origin

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NASA - JPL

Beth Jens
NASA - JPL

Yaniv Scherson
Anaergia

David Murakami
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Ben Waxman
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Anna Thomas
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AshleyMicks
Ford Motor Co

Laura Simurda
Stanford AA

Javier Stober
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Flora Mechentel
NASA - JPL

Ashley Coates
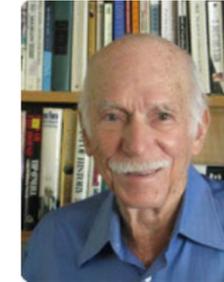NASA Ames

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