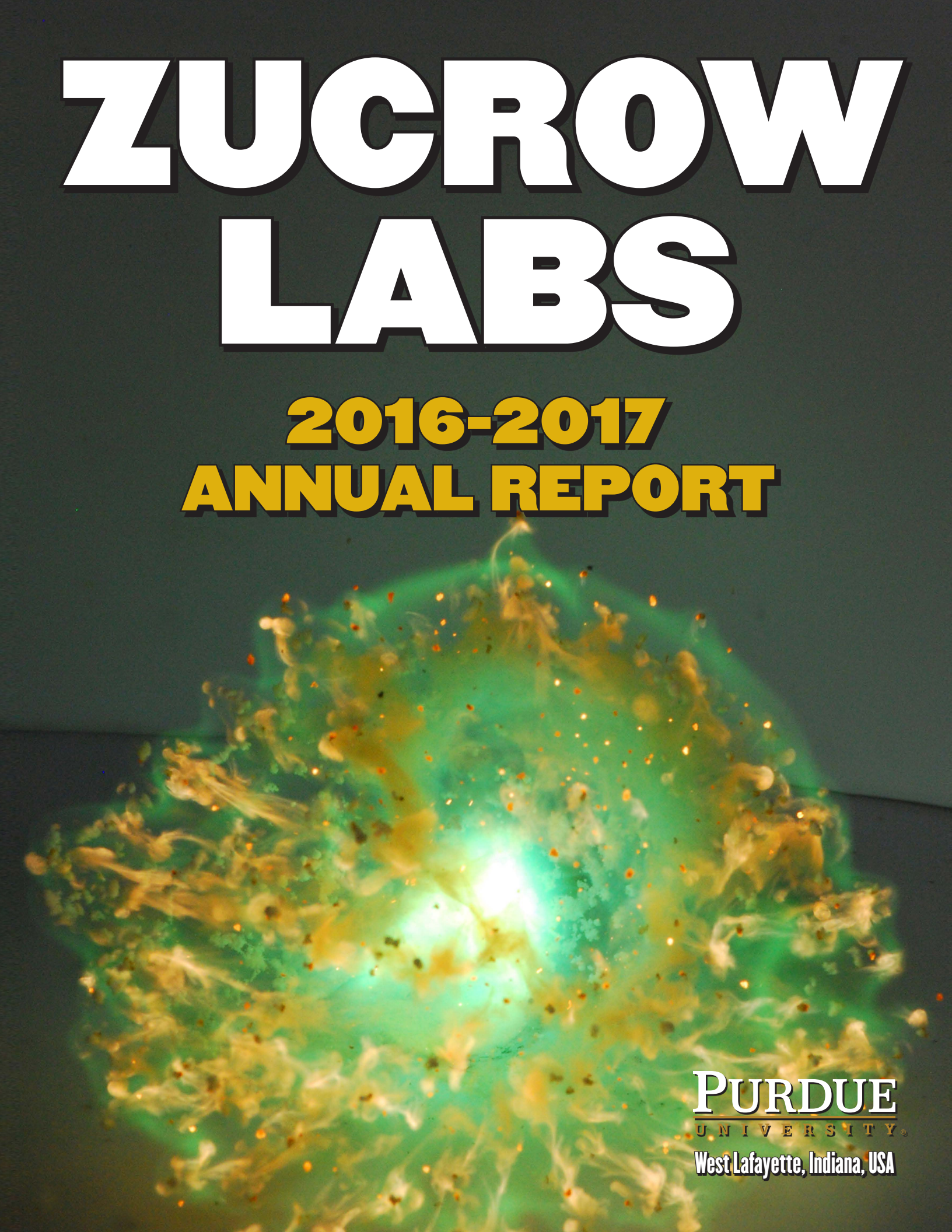
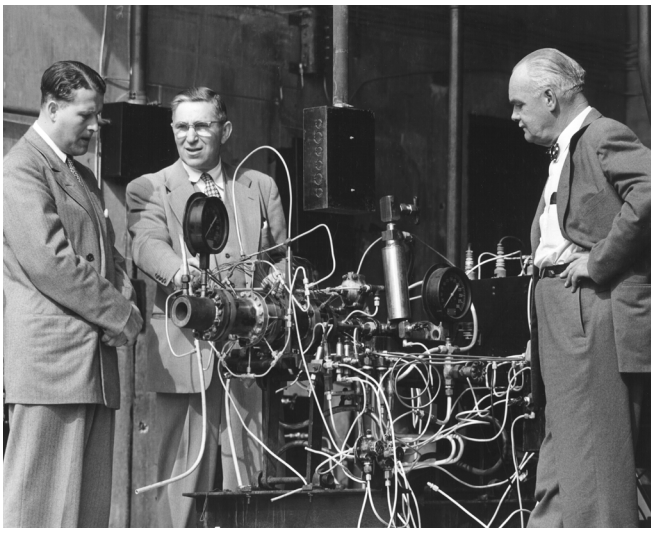
ZUCROW LABS

2016-2017 ANNUAL REPORT

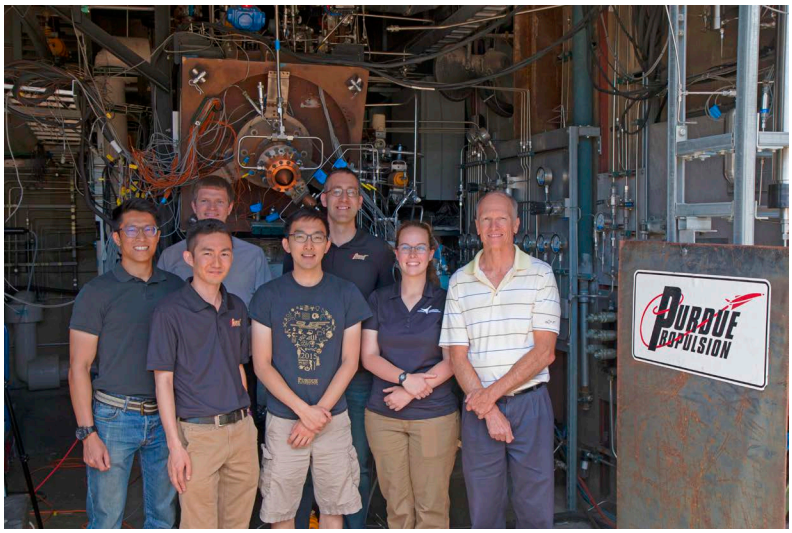


PURDUE UNIVERSITY
West Lafayette, Indiana, USA

Zucrow Labs
2016-2017 Annual Report



1953: Wernher Von Braun, Maurice J. Zucrow, and H.N. White examine an experimental rocket motor at the "Rocket Lab."



2017: Stephen Heister's research group poses in front of their experimental rocket motor at Zucrow Labs.

Dr. Maurice J. Zucrow joined Purdue University in 1946 to teach jet propulsion and gas turbines. He soon established a physical facility, adjacent to Purdue Airport, to run propulsion experiments. In the decades since, the "Rocket Lab" has expanded to 24 acres, including research on compressors, high-pressure combustion, thermal sciences, fluid mechanics, propellants and fuels, instrumentation and data collection. Now bearing his name, the **Maurice J. Zucrow Laboratories** have become the largest academic propulsion lab in the world.

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Front and back cover photos: Steven Son

From the Director


Bob Lucht

Dear colleagues, alumni, friends, and supporters of Zucrow Laboratories,

This is my first letter as Director of Zucrow Laboratories. I was appointed Interim Director on July 1, 2016 and then Permanent Director on July 1, 2017. For those of you who do not know me, I received my MS in 1979 and PhD in 1981 from the School of Mechanical Engineering at Purdue, and I performed my thesis research for both degrees in the Combustion Laboratory in what was at the time the Thermal Sciences and Propulsion Center (TSPC) under the direction of Profs. Normand Laurendeau and Donald Sweeney. I returned to Purdue in 2002 just after Profs. Steve Heister and Jay Gore received a $2M grant from the Indiana 21st Century Fund to renovate the High Pressure Laboratory and started working to get a program in high pressure gas turbine combustion started. I can say with pride that the return on investment for that initial grant from the State of Indiana has been tremendous.

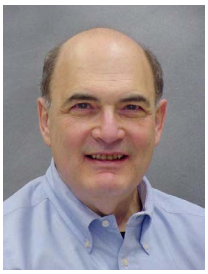
This is a very exciting period in the long history of Zucrow Laboratories. On September 22, 2017, we dedicated the first new building at Zucrow in over four decades, the High Pressure Combustion Laboratory, designated ZL8. The construction of this building is a testament to the foresight and leadership of Prof. Steve Heister, who was the Director from 2011 to 2016. This new building features four 500-square-foot test cells, a 1000-square-foot test cell, a 2100-square-foot laser laboratory, spaces for mechanical fabrication and electronics fabrication, and three control rooms for remote operation of experiments. This building provides the space and infrastructure needed for state-of-the-art research in gas turbine combustion for the next 20 or 30 years. The office space in the old High Pressure Laboratory was renovated and a new modern conference room was added. Thanks to the many individual donors who made this new addition possible, as well as the Lilly Endowment.

When I became Interim Director in July 2016, I assumed I would have to work hard at getting the funds to renovate Chaffee Hall. The auditorium in particular was in very bad shape. However, again because of a process that had been initiated by Steve Heister, we received funding from the university to renovate the auditorium and to make the bathrooms on the first floor accessible for the disabled. So the first floor of Chaffee Hall looks great now, although we still need to work on securing funds to renovate some of the office space on the first floor and to renovate the second floor.

As Zucrow Director at this time, my main problem is how to deal with the current rapid growth in our research activities. Our 2016 research expenditures were over $13M, and the number of graduate students has reached what I assume is an all-time high of 144. We literally are out of desks for the graduate students, and it is sometimes very hard to find a parking space. And the growth in research activity shows no signs of slowing, and may actually accelerate. The excellence of the faculty, staff, and graduate students, the excellent experimental facilities, and the Zucrow culture which encourages collaboration between research groups are powerful factors that are driving our current research growth. During the last year we developed a strategic plan and shared it with the Schools of Mechanical Engineering and Aeronautics and Astronautics and with the College of Engineering. Soon we will be working with an outside firm to develop a long-term plan for Zucrow Laboratories.


Davin Piercey

We will have a new faculty member starting in January 2018. Davin Piercey is a synthesis chemist who will be developing new types of energetic materials. He is being hired as a member of Purdue's Preeminent Team on Energetic Matetrials, and the Propulsion Lab (ZL2) will be extensively renovated to make it suitable for his experiments. The only other news on changes in the Zucrow faculty is sad news: Prof. Sandy Fleeter passed away in 2016 after a battle with cancer.


Sanford Fleeter

There have been several changes in the staff at Zucrow Laboratories since the last annual report. Long-time account clerk Edie Moffitt left to accept a new position in the College of Liberal Arts. We hired Tania Bell to replace her. We also recently hired Michelle Moody as a part-time, but permanent Clerk IV. Jen Ulutas was promoted from Secretary V to Administrative Assistant.

We're thankful for everyone who came before to make Zucrow the amazing place it is. We strive every day to continue making history!

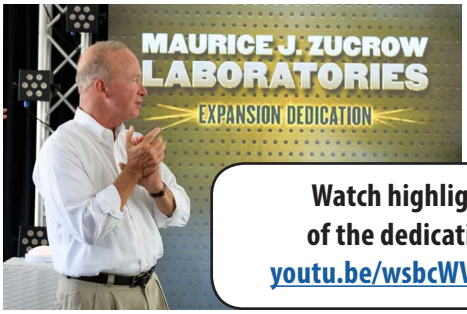
Robert Lucht
Director, Maurice J. Zucrow Laboratories

Let's celebrate!
Zucrow Expansion Dedication: Sep 22, 2017

It was the culmination of many years of effort, as Purdue celebrated the dedication of Zucrow's newly-expanded High Pressure Combustion Lab. This includes five brand new test cells, a 2,000 square-foot climate-controlled laser diagnostics lab, control rooms and offices, fabrication shop, and even a proper parking lot!

In spite of 95-degree temperatures, many VIPs attended the event, including the donors to the project, companies that work with Zucrow, current and former students and faculty, and Purdue's president, Mitch Daniels.

"Launching" the new expansion are Robert Lucht (director of Zucrow Labs); Tom Shih (head of the School of Aeronautics and Astronautics); Anil Bajaj (head of the School of Mechanical Engineering); Mung Chiang (dean of the College of Engineering); and Mitch Daniels (president of Purdue University).

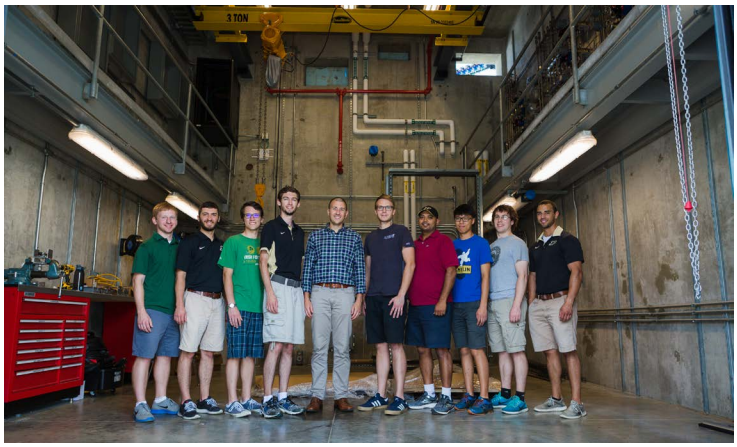


Watch highlights of the dedication: youtu.be/wsbcWVYDXA8

Now open!

ZL8: High Pressure Combustion Laboratory

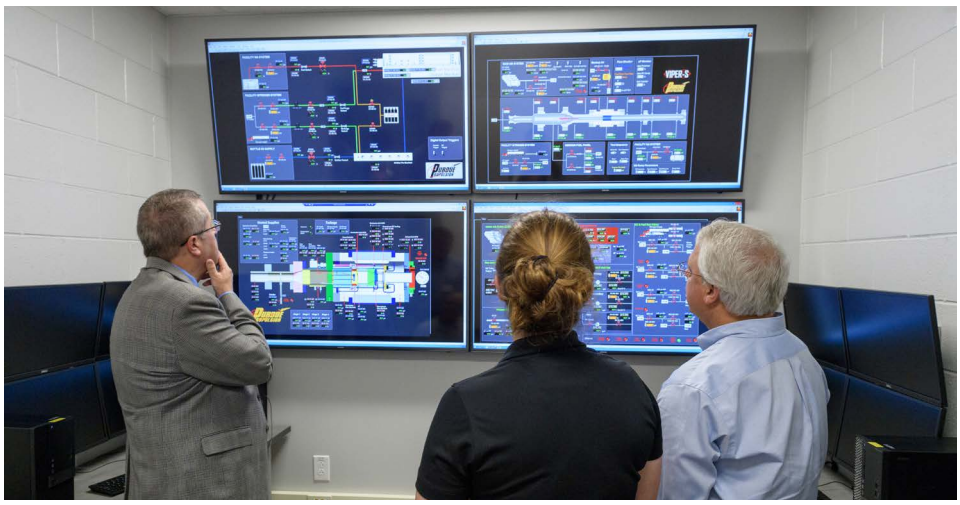
The new High-Pressure Combustion Laboratory (ZL8) features four 500 sq. ft. test cells to house airbreathing combustion and spray experiments. It also features one 1000 sq. ft. test cell with a state-of-the-art turbine lab for studying aerodynamics and heat transfer in advanced turbine systems. All cells are 20 feet high, to include all the necessary instrumentation and data acquisition. They also are connected to the new air heater, capable of delivering 1500-degree Fahrenheit air at 850 psi.



Now open!

Tebbe TDI Laser Lab

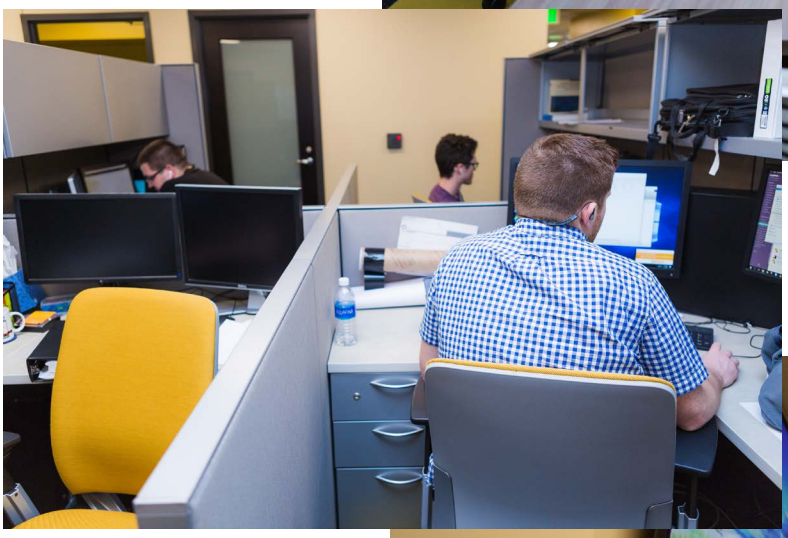
The Tebbe TDI Laser Lab offers 2,000 sq ft of climate-controlled space for experiments, with windows directly connected to the five test cells. This allows optimal inclusion of laser diagnostic measurements. The laser lab also includes two control rooms, an instrumentation room, mechanical room, and fabrication shop.



Now open!

ZL3 Offices, Control Room, and Conference Room

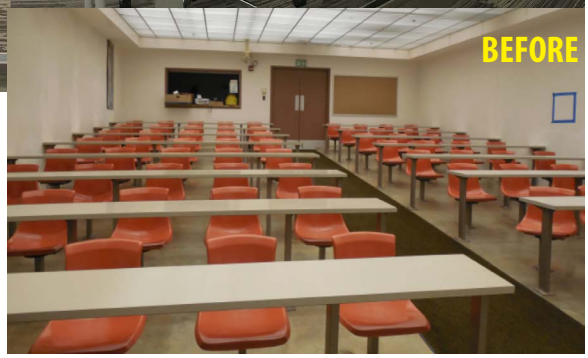
It's the little things that make our students and faculty happy: like a proper conference room! Groups can meet on-site, show videos of their experiments on the flatscreens, and discuss how to move forward with their research.

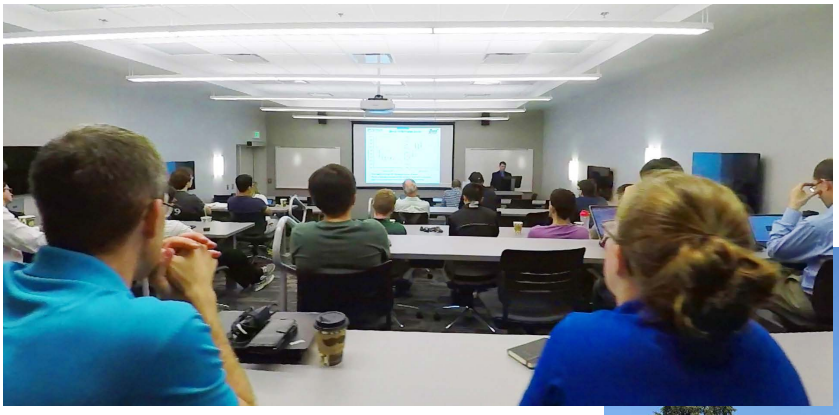


ZL3 also now has proper offices, control rooms, a break room, modern restrooms, and even a paved parking lot. So happy to be out of that trailer!

Now open!

Chaffee Hall remodeled





Chaffee Hall also received an upgrade this summer. The old auditorium, with its squeaky orange chairs, is no more. Now, small groups can collaborate around their own individual flatscreen TVs, or focus on the presentation on the big screen. The building's interior has been renovated to include accessible entrances and restrooms, and even some new artwork on the walls. The building's exterior has also been updated, and new signage out front brings Zucrow into the 21st century!

Congratulations Loral O'Hara!

2017 Astronaut Class

Zucrow Labs alumna Loral O'Hara (MSAAE '09) has been selected for the 2017 NASA Astronaut Class. O'Hara is one of five women and seven men selected from more than 18,000 applicants.

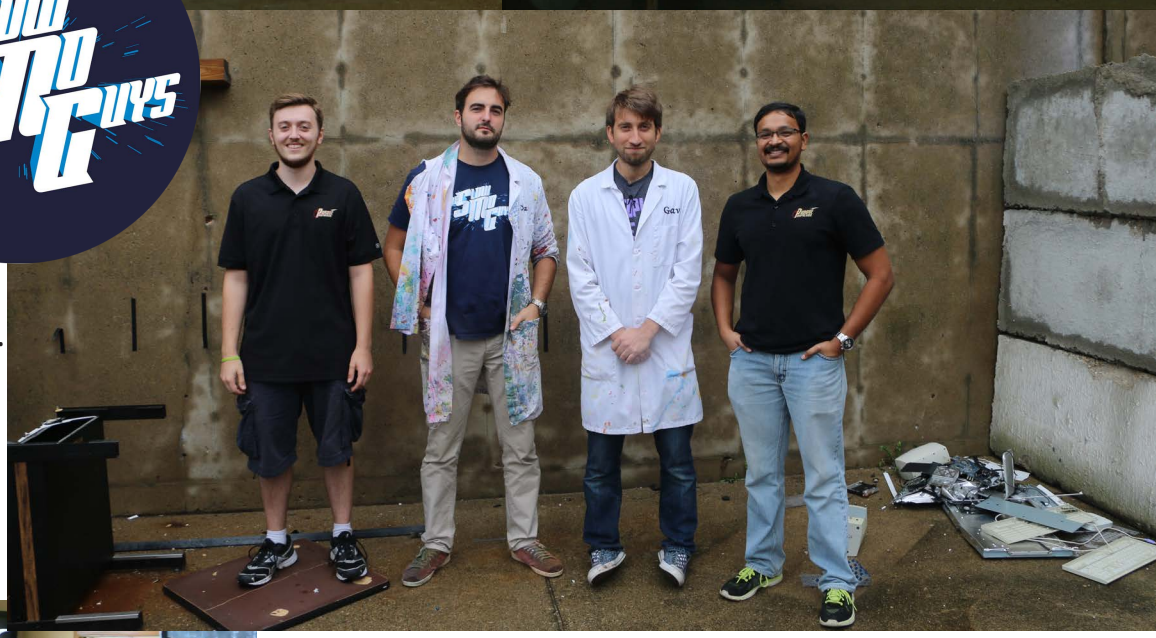
O'Hara began flying planes as a teenager. She built subscale rocket engines at Zucrow Labs, with Professor William Anderson, measuring temperature and pressure at different injector sizes, combustor sizes, chamber pressure, and propellant combinations. She also led groups at Purdue Space Day! O'Hara earned her master's from Purdue's School of Aeronautics and Astronautics in 2009. **She is the 24th Purdue graduate to be selected by NASA to become an astronaut**. O'Hara is currently a Research Engineer for Woods Hole Oceanographic Institution in Massachusetts.

The new astronauts must complete two years of intensive training at the Johnson Space Center before they will be qualified for assignment to future space missions.
[Read more about Loral O'Hara at purdue.edu...]

Slow Mo Guys Visit Zucrow

Internet superstars The Slow Mo Guys visited Purdue in October 2016 to film some of their award-winning YouTube videos. They spent an entire day at Zucrow Labs.

They filmed in both Steve Son's lab and in Timothee Pourpoint's lab, focusing on hypergolic propellants. The shoot culminated with a visit to Sally Bane's Sandia combustion tube, which utterly destroyed an old computer (bought at the Purdue Surplus Store!)



The Slow Mo Guys filmed the combustion tube's deflagration-to-detonation transition in high definition at 28,500 frames per second. The resulting video now has 2.6 million YouTube views!

Watch all the Slow Mo Guys videos at Purdue:

purdue.edu/ME/slowmo

Building Indiana's Bicentennial Torch

To mark Indiana's 200th birthday, the state organized a month-long torch relay through all 92 counties. The high-tech torch was designed and built at Zucrow Labs, by a team of Purdue engineers under the direction of Timothee Pourpoint.

Gabby Feldman and Timothee Pourpoint assemble the torches.

Each torch contained GPS, Wi-Fi, and a built in camera. Aero/Astro students designed the body, while Ag/Bio students pinpointed the E85 Indiana ethanol used as fuel. With the help of Alcoa in Lafayette, Materials Engineering students manufactured 130 torches, as well as 10 smaller flameless torches for children. The torch relay came to Tippecanoe County on October 12, 2016, visiting Purdue's campus and Zucrow Labs.

Top: Astronaut and Purdue alum David Wolf carries the torch in Neil Armstrong's symbolic steps.

Right top: President Mitch Daniels was one of several Purdue dignitaries to carry the torch through campus.

Right bottom: During the relay, the Boilermaker Special drove the torch to its home at Zucrow Labs.

More News

Rolls-Royce, Purdue University, and the state of Indiana announced a new $24 million public-private partnership to develop and test next-generation turbine airfoils. The research will be housed at Guillermo Paniagua's lab, the Purdue Experimental Turbine Aerothermal Laboratory (PETAL), in the new ZL8 building. This program provides Purdue with the nation's most advanced turbine lab for compact gas turbine engines.

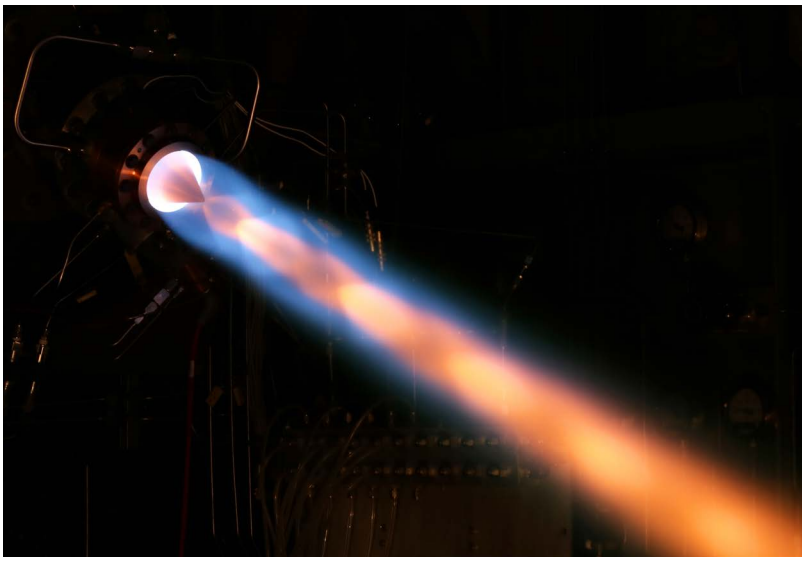
Read more at purdue.edu...

Adranos Energetics is marketing a high-performance environmentally friendly solid rocket propellant, developed at Zucrow Labs. Brandon Terry (Ph.D. '15) studied energetic materials under Steve Son, formulating an aluminum-lithium composite that dramatically reduces the amount of hydrochloric acid produced during a launch. Brandon formed a company, Adranos Energetics LLC, and has since once won numerous business and entrepreneurship awards.

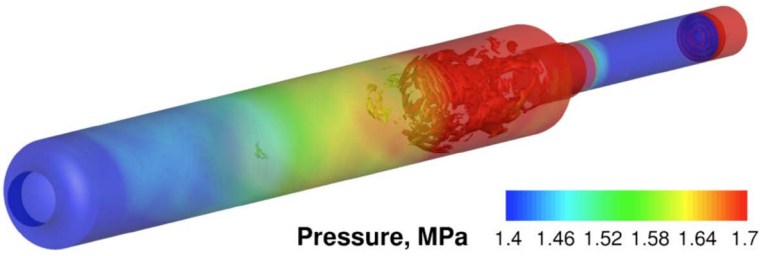
Read more and watch a video at purdue.edu...

Zucrow is privileged to host exciting research in **rotating detonation engines**, thanks to grants from the Department of Energy and the Air Force Office of Scientific Research. About 10 students and staff support this work, developing a high pressure combustor infrastructure, and conducting hundreds of tests at thrust levels exceeding 1,000 lbf and chamber pressures exceeding 400 psi. The DOE aspect focuses on stationary power generation, with large scale hotfire tests being partially supported by Aerojet-Rocketdyne.

Watch a test fire of the RDE engine on YouTube...



More News



Purdue, Michigan, and MIT were chosen to form a multi-university **Center of Excellence in Multi-Fidelity Modeling of Combustion Dynamics**, thanks to a $4.2 million grant from the Air Force Research Laboratories and the Air Force Office of Scientific Research. "Combustion instability is one of the most complex problems that can be encountered during the development of chemical propulsion systems," says Professor William Anderson, who serves as the principal investigator at Purdue. Enabled by recent and rapid advances in high-fidelity computational fluid dynamics, adaptive reduced models, and data-driven modeling, the Center will develop and demonstrate mathematically-derived reduced order models and physically-inspired reduced fidelity models to efficiently and accurately predict combustion dynamics.

Sigmar Wittig won a lifetime achievement award at the International Society for Air Breathing Engines (ISABE) conference in Manchester. Sigmar taught at Purdue in the 1960s and 70s, and helped to establish the Global Engineering Alliance for Research and Education (GEARE). Sigmar is now the Chairman of the German Aerospace Center.
At the same conference, Natalie Smith (MSAAE 2011, PhD 2015) and professor Nicole Key co-authored the Best Paper Award winner, "Effects of blade row interactions on unsteady stator surface pressures in an embedded compressor stage."

(L to R) Natalie Smith, Sigmar Wittig, Nicole Key

David Helderman (BSAAE '06, MSAAE '09) received the Purdue College of Engineering's 2017 **Young Alumnus Award**. David serves as a manager for test facility engineering at Blue Origin. During his time in AAE, Helderman's areas of concentration were propulsion and design. He was active in Purdue Solar Racing, and conducted research at Zucrow Labs for his MS requirements under the supervision of Prof. William Anderson.

(L to R) Tom Shih, Bill Anderson, David Helderman, Scott Meyer, Mung Chiang

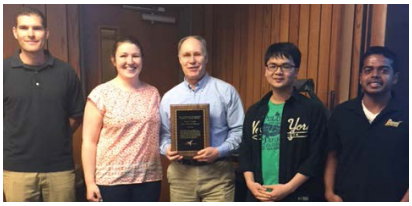
Faculty Updates

Congratulations to **Chris Goldenstein** and **Carlo Scalo**, who received grants from the AFOSR, Air Force Office of Scientific Research. Each grant is $450,000 over three years. Chris will study Characterization of Nanopropellant Combustion and Agglomerate-breakup Physics via Infrared Laser-absorption Imaging. Carlo's research area is Direct Numerical Simulation of Hypersonic Boundary Layer Transition over Distributed Surface Porosity.


Congratulations to **Li Qiao**, **Timothee Pourpoint**, and **Steve Son,** who were selected as Associate Fellows of the American Institute of Aeronautics and Astronautics (AIAA).



Congratulations to **Robert Lucht**, who received recognition as the 2017 Outstanding Mentor of Engineering Graduate Students given by the Official Mechanical Engineering Graduate Student Association (OMEGA).

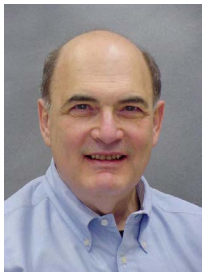


Congratulations to **Nicole Key** and **Guillermo Paniagua**, who were both promoted to full Professor in the School of Mechanical Engineering. Nicole Key and **Terry Meyer** were also recently named fellows of American Society of Mechanical Engineers (ASME).



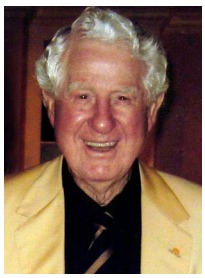
[Read more news at purdue.edu/zucrow](purdue.edu/zucrow)

Sanford Fleeter (1944-2016)



Sandy Fleeter was the McAllister Distinguished Professor of Mechanical Engineering. He had a distinguished academic career of nearly 38 years at Purdue, after ten years at Allison Gas Turbines (now Rolls Royce). He conducted research in turbomachines and wind turbines, eventually becoming Director of the Purdue Thermal Sciences and Propulsion Center (now known as Zucrow Labs). Professor Fleeter was a Fellow of both ASME and AIAA. He had authored more than 350 technical publications and served as the major professor for nearly 85 M.S. and Ph.D. thesis graduates.

Ralph Bailey (1924-2017)



Ralph E. Bailey, 92, passed away on February 1, 2017. He was President and CEO of Consolidation Coal Company (now Consol Energy), and became chairman and CEO of Conoco in 1979. He was a great friend to Purdue Mechanical Engineering. In 2000, he endowed the *Ralph and Bettye Bailey Chair of Combustion Engineering*, a position initially held by Normand M. Laurendau. Now the *Ralph and Bettye Bailey Distinguished Professorship of Mechanical Engineering*, Robert P. Lucht currently holds the position.

Zucrow Student Association (ZSA)

The Zucrow Student Association (ZSA) organizes educational and social events, promoting an inclusive lab for all Zucrow students. We host monthly 'Lunch and Learns' where students listen to interesting lectures about a wide range of topics. Every three weeks, ZSA brings coffee and donuts to the whole of Zucrow (in summer, it's ice-cream and sorbet!) We also love having picnics and beach volleyball at Pickett Park, and this semester we organized a volleyball team, football team, and a basketball team. We fund these activities with sales of Purdue Propulsion apparel, mugs, lanyards, and souvenirs -- so that everyone can proudly represent Zucrow Labs!

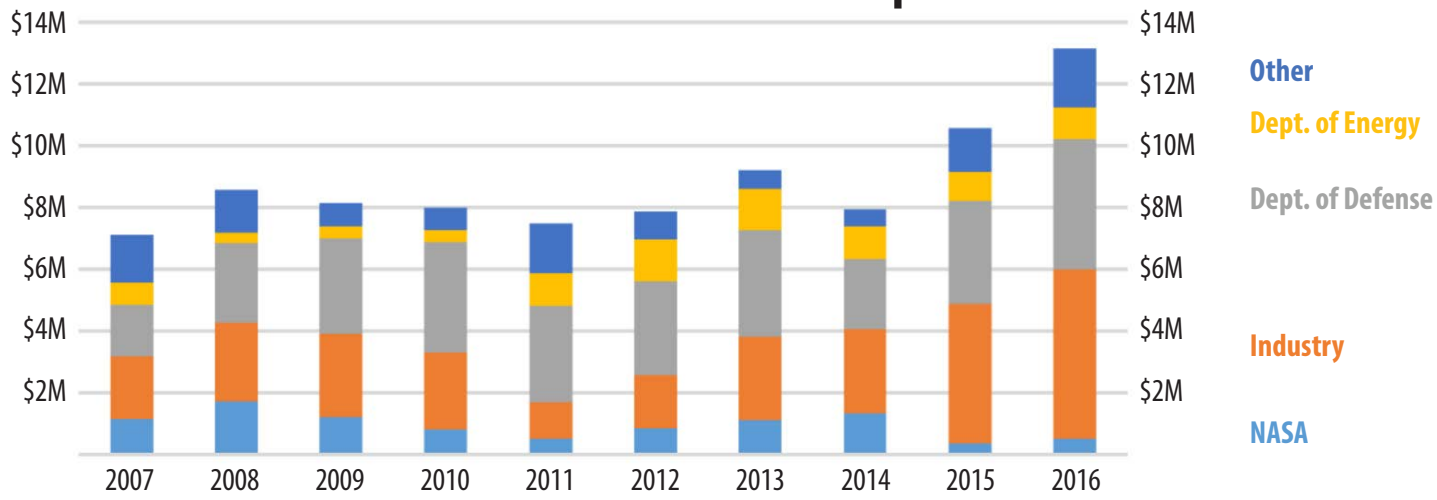
One of our biggest roles is to give tours of the facilities, so that visitors can see our research. From scientists to schoolchildren, the more people that see the work of Zucrow Labs, the more advancements will be made in the propulsion field!

Top: Beach volleyball is a great way to get together with your friends and work out that stress during the summertime.

Left: We know what fuels grad students... free donuts and coffee!

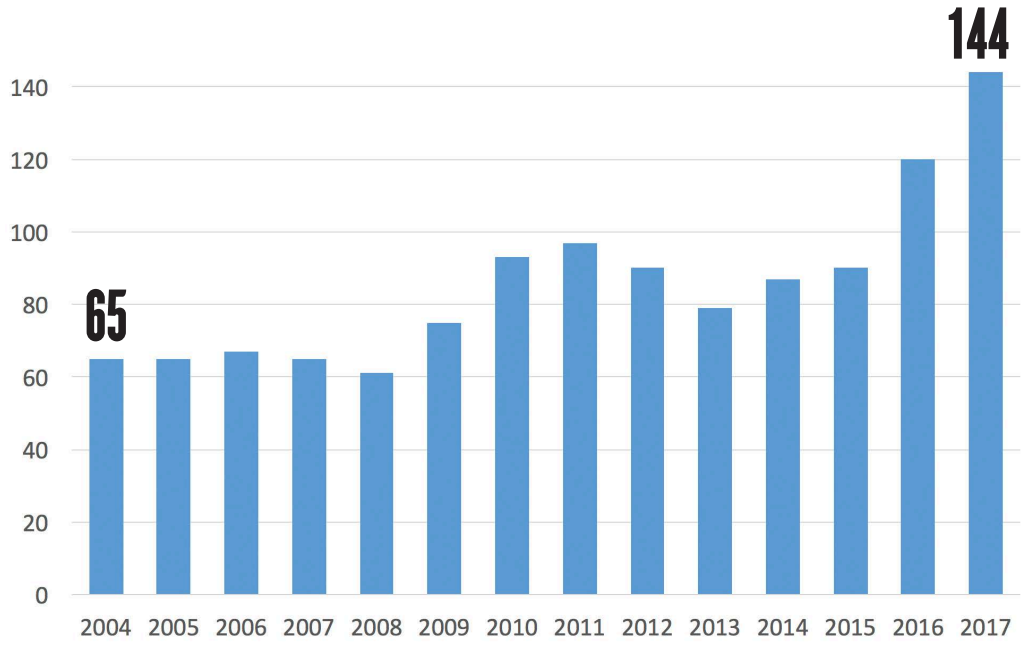
Statistics

Zucrow Labs Annual Research Expenditures



Research expenditures now exceed $13 million annually. This is dominated by large increases in industrially sponsored work.

Number of graduate students working at Zucrow Labs



Our growth has been phenomenal. In less than a decade, we have more than doubled the number of graduate students who conduct research at Zucrow Labs. This doesn't include all the undergraduates, post-docs, visiting scholars, and others who also make up the Zucrow family.

Fare Thee Well

Here's where our graduating students end up.

2016

Zachary Adams	USAF (TX)
Hatem Mohamed Belal	Military Technical College (Egypt)
Gina Bishop	Promontory (UT)
Cis De Maesschalck	Rolls-Royce plc (Derby, UK)
Jeffrey Engerer	Sandia National Laboratory (NM)
Lou Fangyuan	Post Doc at Purdue University
Aalok Gaitonde	3D Systems (SC)
Rohan Gejji	Post Doc at Purdue University
Trey Harrison	Continuing on at Purdue
Jake Harry	Blue Origin (TX)
Steve Hunt	Aerospace Corporation (CA)
Naga Kalipi	
David Kittell	Sandia National Laboratory (NM)
Dan Konopa	US Army (NY)
Yujun Leng	Post Doc at Purdue University
Jesus Mares	National Research Council - RAP (FL)
Jeanne Methel	Continuing for Ph.D. in Toulouse, France
Jacob Miller	Lawrence Livermore National Labs (CA)
Luke Mishler	United Technololgies Research Center (CT)
Aye-Addo Nyansafo	Continuing on towards PhD
Raghav Ramachandran	
Jonathan Rocha	
Jiayun Shao	
Jorge Sousa	Stanford University (CA)

2017

Andrei Anghelus	SpaceX (TX)
Cory Back	Lockheed Martin (VA)
Michael Bedard	SpaceX (FL)
Sayan Biswas	Sandia National Laboratory (CA)
Arly Black	
Cameron Davis	Pratt & Whitney (CT)
Rohan Dudany	Aerojet Rocketdyne (CA)
Jeremiah Graham	Aerojet Rocketdyne (CA)
Tyler Graziano	flight simulator company in FL
Ryan Griffin	Orbital ATK (AZ)
Joel Hey	Sandia National Laboratory (NM)
Galen Jackson	PC Krause and Associates (IN)
Andrew Justice	The Eaton Corporation (OH)
Brandon Kan	SpaceX (CA)
Kevin Koch	Northrop Grumman (CA)
Thomas Liu	Aerodyne Industries (AL)
David Stechmann	SpaceX (CA)
Nicole Vaughn	Jacobs Engineering (AL)
James Wallace	Pratt & Whitney (CT)
Heather Wiest	Blue Origin (FL)

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