ZUCROW LABS
2020
ANNUAL REPORT

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Then and Now

Propulsion researchers at Zucrow in the 1950s (below) probably never imagined they would be parking their cars on "Hypersonic Parkway." But that's exactly what happened in 2020, when the 176 acres around Zucrow Labs began their transformation into the **Purdue Aerospace District**. New roads have been built, land cleared, and a railroad bridge widened to make way for future aerospace facilities, both academic and industrial. Saab has taken residence of a new manufacturing facility right next door to Zucrow, where they will be building aero structures for the Air Force's newest supersonic training jet, the T-7 Red Hawk. Future plans include a hypersonics center of excellence with a "quiet" Mach-8 wind tunnel, the first of its kind in the world.

*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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Maurice J. Zucrow Laboratories
500 Allison Road
West Lafayette, IN 47907-2014
Phone: (765) 494-1501
FAX: (765) 494-0530
purdue.edu/zucrow

Front cover photo: *It just takes a drop of oxidizer to activate the explosive green flash of ammonia borane, a new safer hypergolic propellant being studied by Prof. Steve Son.*

Rear cover photo: *In the Tebbe TDI Laser Lab, Prof. Carson Slabaugh measures the three-dimensional structure of turbulent combustion.*

From the Director

This last year has been one that none of us will never forget. I remember looking forward to this year with a great deal of anticipation last January. We had projects planned for renovation in the Propulsion Lab (ZL4) to install six new state-of-the-art fume hoods, to build two new test cells for compressor research in the Combustion Lab (ZL1), and finally for a much-needed renovation of the second floor and main office of Chaffee Hall. Our research programs seemed to be poised for even more rapid growth, including new initiatives in hypersonic research. The construction of the new Saab building and the project to widen and deepen the Newman Road underpass were both underway.

Then, of course, the pandemic started to hit the United States hard, and in March 2020, Indiana shut down and Purdue University decided not to let the undergraduate students come back from spring break. We also shut down operations at Zucrow Laboratories, except for research projects deemed to be critical. Looking back on that time, it now seems incredible how much progress has occurred at Zucrow Laboratories over the past year. I think we would all agree that the response of the Purdue University administration to the pandemic has been very effective. We were able to obtain the needed personal protective equipment to return to nearly normal experimental operations during the summer, although our graduate student offices are unoccupied per university policy. **The students, faculty, and staff at Zucrow have been very conscientious about wearing masks and maintaining social distance.** Maintaining social distance in particular is not easy to do for some of our testing operations, which typically require close communication and coordination with multiple personnel. However, we have maintained our experimental operations without, to our knowledge, a single case of COVID-19 transmission at Zucrow. The same generally applies to laboratory operations and in-person classes university-wide at Purdue, as the number of reported cases has been very low.

The projects to install new fume hoods in ZL4 and to build new high bay test cells in ZL1 are now complete and represent significant improvements to our research infrastructure. Check out the photographs and descriptions of new facilities in the annual report. The renovation of the second floor and main office of Chaffee Hall was put on hold, which was too bad because the building was very empty this last year. However, the project is slated to begin in July of this year. The Saab factory is close to beginning operations, the Newman Road project is complete, and Allison Road has been widened and improved. **The entrance to Zucrow Labs in now very impressive!**

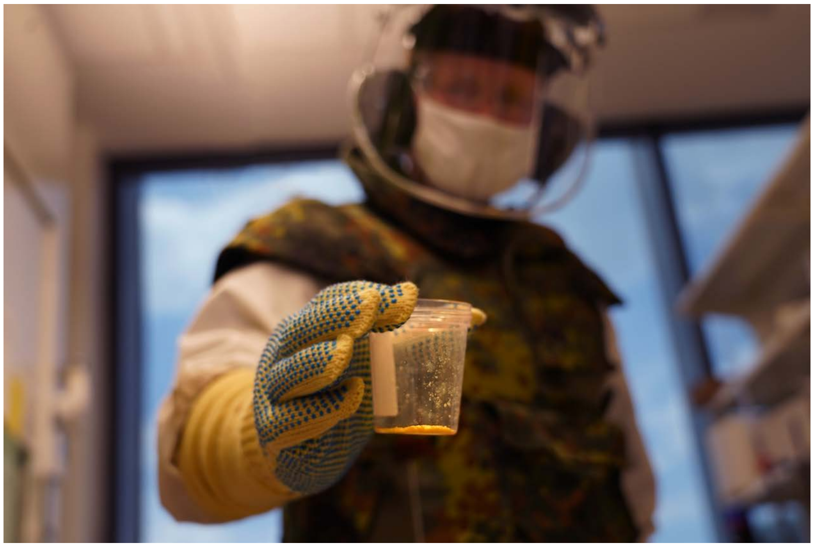
Our research programs have also come through this past year in fine shape. Our research expenditures fell slightly this year compared to the last two years, but the last three years overall have been exceptional. And we now have graduate students in residence! It is going to be a challenge to find enough office space in the fall when we anticipate that graduate student offices will again be occupied. We have also welcomed new professors to the Zucrow faculty, whom you'll read about later in this report: James Braun, Veeraraghava Raju Hasti, and Monique McClain.

Thank you so much for being part of the Zucrow family, and we can't wait to share with you all the breakthroughs that are coming in the 2020s!

Robert Lucht *Director, Maurice J. Zucrow Laboratories*

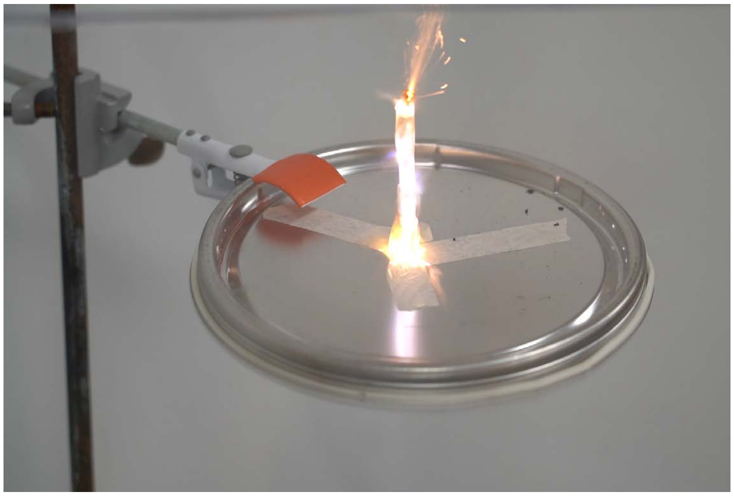
Next generation energetic materials

It began with a simple request: remove the lead from bullets, to make ammunition safer to handle and more environmentally friendly. Now, **Purdue and the US Army are joining forces** to modernize *all* of their energetic materials, in a multi-year $24 million project.



The Army Research Office initially reached out to Purdue, asking to investigate potential replacements for the lead currently found in primary explosives, which are used to ignite powder inside most gun cartridges. "Right now, whenever you are shooting, you're going to be spreading lead into the air around you," said Prof. Davin Piercey. "Any use of lead is going to end up polluting the environment in small amounts. The more lead you remove, the better it is for the environment."

Piercey worked with the Army on a chemical structure that has not been used in primary explosives before. One material is made of silver salts while the other material contains no metal at all – just the basic ingredients for an explosive. These ingredients include carbon, hydrogen, nitrogen and oxygen. The chemical structure used in these materials makes them very dense, meaning that only a small amount of either material would be needed to create an explosion.



Piercey is part of the Purdue Energetics Research Center, an interdisciplinary group of Purdue researchers who are experts in energetic materials like propellants, explosives, and pyrotechnics. "Our motto is 'Molecules to Munitions,'" said Stephen Beaudoin, director of PERC and professor of chemical engineering. "There is no other university in the world that can do this every step of the way, all the way through. Energetic materials are not easy to work with. They have a tremendous amount of energy stored in just a molecule. The experiments have to be very precise, and you have to be very careful. You have to have people who are highly skilled to do this type of work."

As a result of this collaboration, the Army entered into a three-year cooperative research agreement with the Purdue Energetics Research Center to bring its munitions and energetics systems into the 21st century. "Right now, a lot of things are still being made by hand," said Jeffrey Rhoads, director of the Ray W. Herrick Laboratories, who shepherded the agreement. "They're not being manufactured in a modern way, and there are many safety concerns with that. Much of this could be done using automated processes where the operator is some distance removed."

There are currently 18 research projects and groups conducting energetics research as part of the project, including:

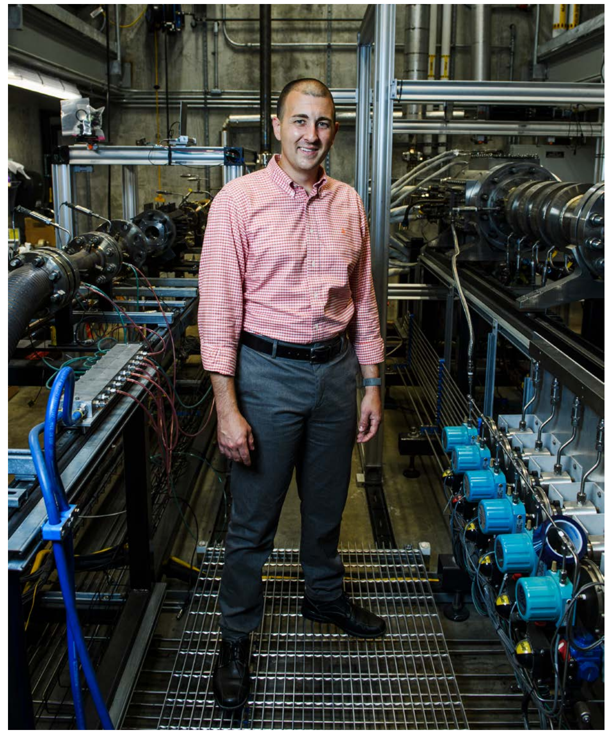
- Gaining a better understanding of how shockwaves interact with the microstructure and defects in energetic materials.
- Improving the performance of materials used in the aggressive service conditions such as gun launch and hypersonic flight.
- Developing inkjet-printed conductive energetic materials.
- Developing new manufacturing techniques to encapsulate metal or composite materials with embedded sensors to develop health-monitoring smart armor.

"It's an interesting project. On the one hand, it's trying to increase the effectiveness of these weapons, and on the other, it's trying to increase the safety and sustainability," Rhoads said.

Mission to Mars

Prof. Carson Slabaugh has his sights set on Mars – or more accurately, getting *to* Mars, and then returning to Earth. To make this dream happen, he's looking at not just the propellants, but also the method of igniting them.

"At the end of the day, the choice of methane and oxygen is definitely relevant to this long-term vision for Mars return trips. This propellant combination has benefits in terms of performance, simplicity and reusability that make it a good choice for lander ascent missions." Slabaugh said. "You can also find the things you need on the Martian surface and in the Martian atmosphere to manufacture these propellants and fuel the liquid rocket engine. Combine that idea with this ignition source ... and all that starts looking like a believable narrative."



Stanford University is leading the project, funded by a $16.5 million grant from the Department of Energy through the National Nuclear Security Administration's Predictive Science Academic Alliance Program, and will conduct all computational work. Slabaugh is Purdue's lead principal investigator, with Robert Lucht a co-PI. All of the experiments will be conducted at Zucrow Labs.

"We're unique at Zucrow in our ability to do things like this, especially as an academic lab." Slabaugh said. "The experiments will have many variables that must be controlled with surgical precision or the results will be impossible to interpret."

At Zucrow, Slabaugh will inject liquid oxygen and gaseous methane into a rocket combustion chamber at low initial pressures to simulate the vacuum of space. Then he will deliver a precisely timed pulse of laser radiation. The electromagnetic field will break down the fluid into a plasma, and the plasma will cause a chemical reaction. The laser allows a focused application of the ignition energy to a region that has the ideal mixture for combustion, away from walls that could burn up. Conventional igniters in rocket combustors are bulky and must be installed wherever they can fit on the combustor. There is a competing effect of getting the igniter energy to the propellants, but keeping the flame away from parts that could also burn up. A laser, however, allows the ignition energy to be put where it's needed. "Because of that, you only need a small fraction of it; you don't have to overwhelm the system," Slabaugh said. "Power requirements for laser ignition can be a lot lower because you can put that ignition kernel, that plasma kernel, in the flow where the mixture is at the right conditions."

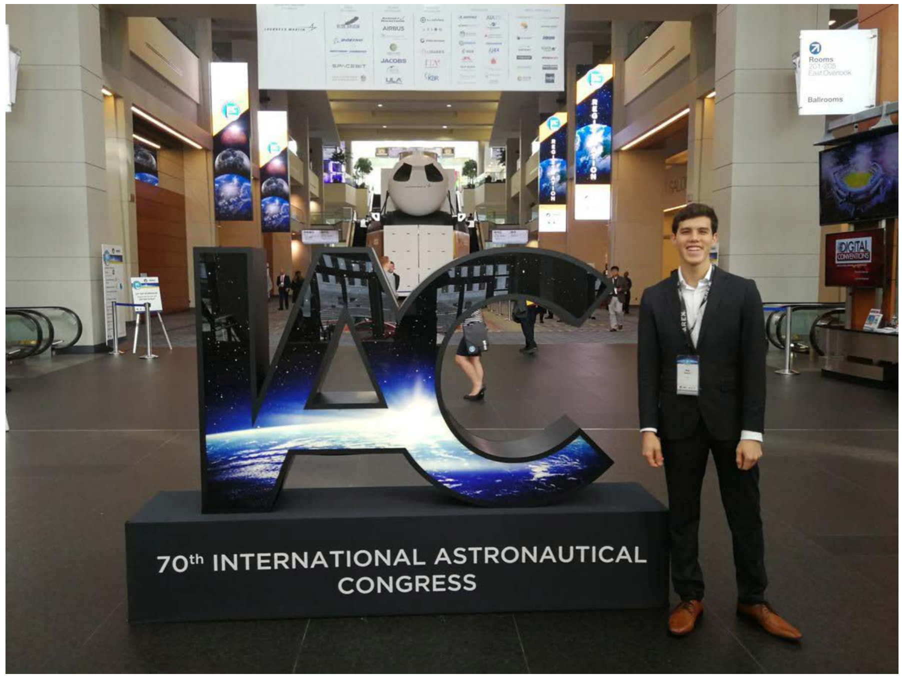
Hypergols burn as soon as they come in contact with each other under any conditions, and those toxic propellants then have to be carried on the spacecraft in tanks. If the chamber needs to be ignited again — or numerous times on a very long space mission — that means the vehicle needs to carry more of that propellant on the mission. This adds mass, which means less payload. That's the current approach for space exploration. But it's a process that makes some sort of electronic form of ignition look more favorable. Solar panels could be taken to recharge batteries and also be used for whatever other electronics are needed on the mission, a mass benefit if the supporting infrastructure is common between the ignition system and other things.

Zucrow can run experiments with liquid oxygen at real rocket propellant flow conditions, a one-of-kind capability for a university. Slabaugh will run his tests in the High Pressure Combustion Lab, next to the facility's laser lab, which will enable the laser ignition component of the work and the measurements that he and Lucht will take. "The infrastructure at Zucrow is most certainly a source of pride for us, but I think at least equally important is that the people at Zucrow Laboratories are there to use it and are not afraid to go after problems like this, that have a ton of uncertainty and a lot of risk and, frankly, if you're not used to it like we are, can be quite terrifying," Slabaugh said. "It's a lot to take on. We only work on problems that are worth working on. This is a pretty challenging one. It'll be cool."

This story originally appeared in the [Fall 2020 issue of Aerogram.]

Passion for propulsion

It's been a busy year for **Roy Ramirez**, senior in Aeronautics & Astronautics. Not only did he design and build the first liquid-fueled rocket ever in Central America, but he also became stranded in France after having his passport stolen, and travel shut down because of the COVID pandemic.



But first things first. After conducting research at Zucrow Labs, Roy decided he wanted to share his passion for propulsion with his homeland of Costa Rica, by designing and building the first ever liquid-fueled rocket in Central America. "The point of doing it back home in Costa Rica is so people can actually do it with off-the-shelf components," Ramirez said. "It's to encourage Costa Rican people to dream a little bigger."

The theoretical work alone took about 18 months, and **his prototype (which he called the P-5) underwent extensive testing at Zucrow Labs**. He obtained 300 quotes from 48 manufacturing companies in 16 different countries for the manufacturing. He compared his options to make sure that he could get the items he needed for a low cost while retaining good quality. The actual assembly took place in his home country.

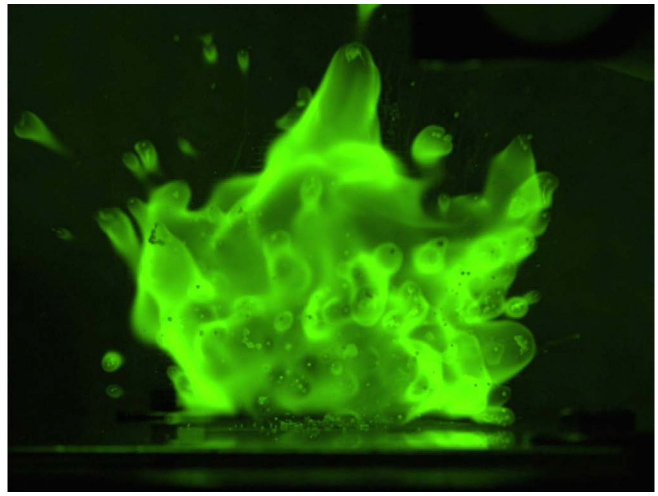
"The P-5 was not meant to be a powerful engine, but rather a way to understand what are the financial, manufacturing and technical implications of building the simplest device that can still be categorized as a liquid rocket engine," Ramirez said.

In 2020, Roy had planned to study abroad at ESTACA University in France; he ended up getting a more immersive experience than he bargained for. His passport was taken from his backpack while out in the city, and because the COVID-19 pandemic had closed most embassies, he was effectively stranded in France. But Roy took advantage of the opportunity, maximizing his time during the lockdown by studying, and expanding his French language abilities and knowledge of French culture. He also secured an internship position with a French aerospace company called ThrustMe, where he worked on propulsion systems for satellites.

Roy also formed his own aerospace startup called AREX, which combines all of his efforts with the overall mission of globalizing space exploration. One of his initiatives, Project Polaris, brings together personnel from Costa Rica, France, and Purdue to collaborate on a rover designed to operate on Saturn's moon, Titan. He hopes to present the technology at the International Astronautical Congress in Paris in 2022.

Roy believes that if someone feels as if they are under-qualified for an opportunity, they should still go for it. He says, "Doors are already closed. You don't lose anything by knocking on them. If you knock and they don't open, the door was already closed, however, if they open the door, you know you didn't miss out."

The Green Flash: a safer hypergolic



In August 2020, SpaceX's Crew Dragon capsule splashed down off the Florida coast following its first crewed mission. But the two astronauts inside could not exit the capsule immediately; technicians outside had to confirm there were no airborne vapors from hydrazine, a highly toxic fuel used by the vehicle's hypergolic thrusters. Now, Zucrow researchers are investigating a **safer and less toxic hypergolic propellant**, studying its explosive reaction with a new technique involving both visible and infrared high-speed cameras.

"Hypergolics have been used all the way back to the Apollo era and before," said Steven Son, the Alfred J. McAllister Professor of Mechanical Engineering. "We want to develop hypergolic fuels that have good performance, but are also much less toxic."

Unlike most other hypergolic fuels, ammonia borane (NH_3BH_3) is a solid material, stable in typical atmospheric conditions. Because of its hydrogen density, it was first developed as a solid-state storage medium for hydrogen. But combustion researchers have recently discovered its hypergolic properties, which could be used as part of a hybrid propellant.

"Before this can be used in the real world, we have to understand the fundamental combustion science governing its behavior," said Chris Goldenstein, Assistant Professor of Mechanical Engineering. "We are using a new approach which combines visible and infrared imaging to characterize the combustion process." Their work has been published in *Proceedings of the Combustion Institute.*

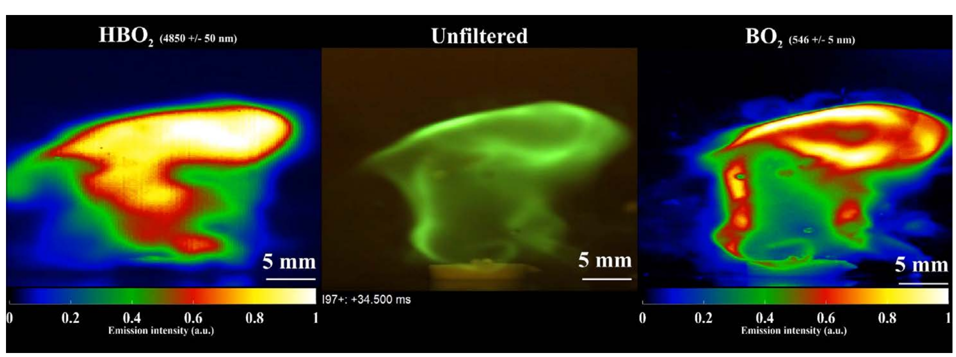
Infrared imaging allows researchers to see the chemical composition of the flame throughout the combustion process. "Every molecule has a unique spectral fingerprint," said Goldenstein. "By looking for specific wavelengths of light, we can identify where in space certain molecules are distributed, and know how complete the combustion process is. Many of the desired wavelengths are not visible to the naked eye, and infrared imaging is the only way to see them."

Because the reaction takes place in just a few milliseconds, they use specialty cameras capable of capturing at least 2,000 frames per second. The high-speed video reveals a remarkable and rapidly expanding green flash, demonstrating the power of hypergolic substances.

"Thanks to infrared imaging, we saw a lot of BO2 signal, which was surprising to us," said Son. "This indicates that ammonia borane is achieving complete combustion even better than conventional boron fuels."

"To be able to handle these materials safely and work with these kinds of propellants is unique," said Son. "Purdue is one of the few places that is able to do this kind of research."

"Combustion is a complex process involving hundreds of chemical compounds," said Goldenstein. "Each one tells their own unique story about the reaction sequence. With this method, we can see those individual stories."



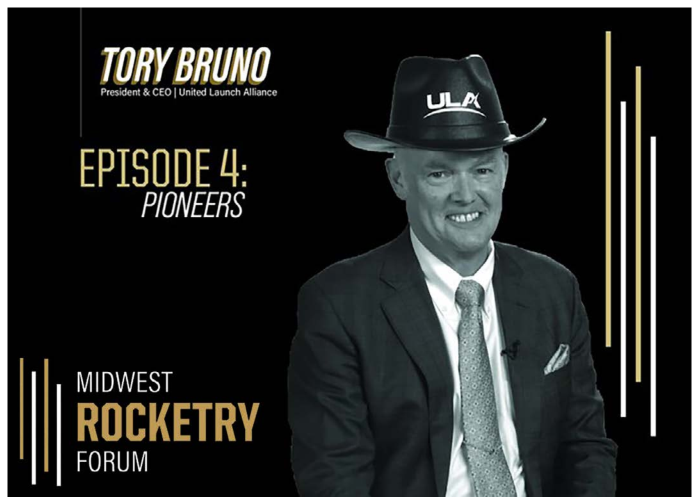
Rocket outreaches

The capabilities of Zucrow Labs are too good to be kept inside our own walls. Students, staff, and faculty often reach out to offer their expertise to others, spreading the good news of combustion and propulsion around the world.

Hybrid rocket during a quarantine

Propulsion students at the University of Illinois at Urbana-Champaign faced numerous obstacles in 2020, working together across five time zones, and having their own experimental facilities shut down because of COVID. However, they successfully designed a hybrid rocket engine that uses paraffin and a novel nitrous oxide-oxygen mixture called Nytrox. They connected with Zucrow graduate student Chris Nielson, who did preliminary over-the-phone design reviews, and they were eventually invited to conduct their hydrostatic and cold-flow testing at Zucrow's high-pressure combustion test cells. The team has its sights set on launching a rocket with the new engine at the 2021 Intercollegiate Rocketry and Engineering Competition in New Mexico.

The power of podcasting



Purdue students had big plans to celebrate the 25th anniversary of their chapter of SEDS (Students for the Exploration and Development of Space) with an in-person event called the Midwest Rocketry Forum. COVID might have changed their plans, but not their ambition! They changed the format to feature online videos, as well as podcast interviews with notable people in rocketry, including team members from NASA, SpaceX, Virgin Orbit, Boeing, and Rocket Lab. **The biggest get was Tory Bruno, President & CEO of United Launch Alliance**, who spent two hours talking with the Purdue team. Beyond just talking rockets, the Midwest Rocketry Forum also offers practical tips for other schools or organizations that want to start their own rocketry programs: from safety procedures and best practices, to getting sponsorships, and even how to photograph launches.
Check out all their resources at purdueseds.space

New program for Morgan State University

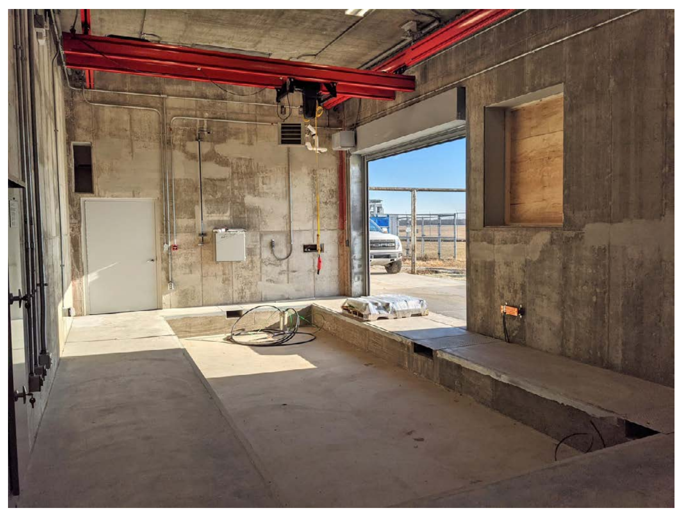
Purdue has formed a partnership with Morgan State University in Baltimore, Maryland, to create the **first ever liquid-fueled rocketry program among Historically Black Colleges and Universities**. The partnership began when three Morgan State students worked as interns at Zucrow Labs in the summer of 2019. Now, Morgan State engineering students will have the opportunity to complete a 3+2: three years at Morgan State followed by two years at Purdue, resulting in bachelor's degrees in distinct majors from both institutions.

Test cell updates

Vacuum chamber for high pressure combustion

This past semester the build-up of Stand V was completed in ZL3. This test cell features a vacuum chamber and ejector system capable of testing 100-lbf thrusters at simulated 100,000 ft altitude conditions. Additionally, feed systems are in place for testing with gaseous hydrogen, gaseous oxygen, RP-1, peroxide, MON-25, and AFM-315E. Future feed systems will even include hydrazine. The gaseous hydrogen and gaseous oxygen feed systems enable propellant conditioning with the use of tube-in-tube heat exchangers with hot water and liquid nitrogen outer jacketing. While at vacuum, a force measurement system enables the acquisition of thrust data for the test article. An independent data acquisition system features a plethora of channels for pressure, temperature, and other important measurements.

New home for compressors



ZL1 has been renovated with the addition of 2 new test cells, control stands, and a build room to the High Speed Compressor Lab. A new military fan project funded by the Office of Naval Research was the motivation for the new space. The ONR funded a new 3,000-hp electric motor and Variable Frequency Drive through a DURIP grant and a 4-year research contract to study fan casing treatments on military fans. Honeywell generously donated an 18-inch diameter fan rig to Purdue for this project. The research team includes PhD students William Brown (ME) and Andrew Cusator (ME) and Masters student Yuning Dai (AAE). Their objective is to develop fan casing treatments without efficiency penalties. These test cells feature several improvements over the existing spaces in the compressor lab including tall ceilings with overhead cranes for ease of assembly, bedplates flush-mounted to the floors, and an overhead fan to prevent hot air from accumulating in the test cells. With research equipment being delivered in the next couple of months, the team expects to accomplish the first spin of the rig this year.

Test cell updates (cont'd)

New liquid monopropellant test stand

As the aerospace industry sees a wave of new commercial launch providers, Zucrow Labs has been involved in many projects related to the development of new launch vehicles. Through a contract with an industry sponsor, a new liquid monopropellant test stand was built to handle high pressure, high flowrate hydrogen peroxide applications. Design started in late 2019 with first propellant flow achieved in August 2020, despite hurdles caused by the ongoing COVID-19 pandemic and its impacts on Zucrow Labs. Used to test an RCS system for an upcoming launch vehicle, "Stand A" can measure thrusts up to 3000lbf and

features a 6 degree of freedom force measurement system with calibration systems in 5 axes. Fed by a 14-gallon tank, flow rates up to 30 pounds per second of high-test peroxide are achieved through a new high flowrate nitrogen pressurization circuit. Additionally, expanded capability was added to the existing rocket cell data acquisition system to read further high frequency and low frequency data channels. The stand also makes use of Coriolis flow measuring devices which provide density and flow rates in real time. Hotfires conducted on Stand A have already provided the test sponsor with data that has resulted in marked improvement of the sponsor's development articles.

Welcome to the hood

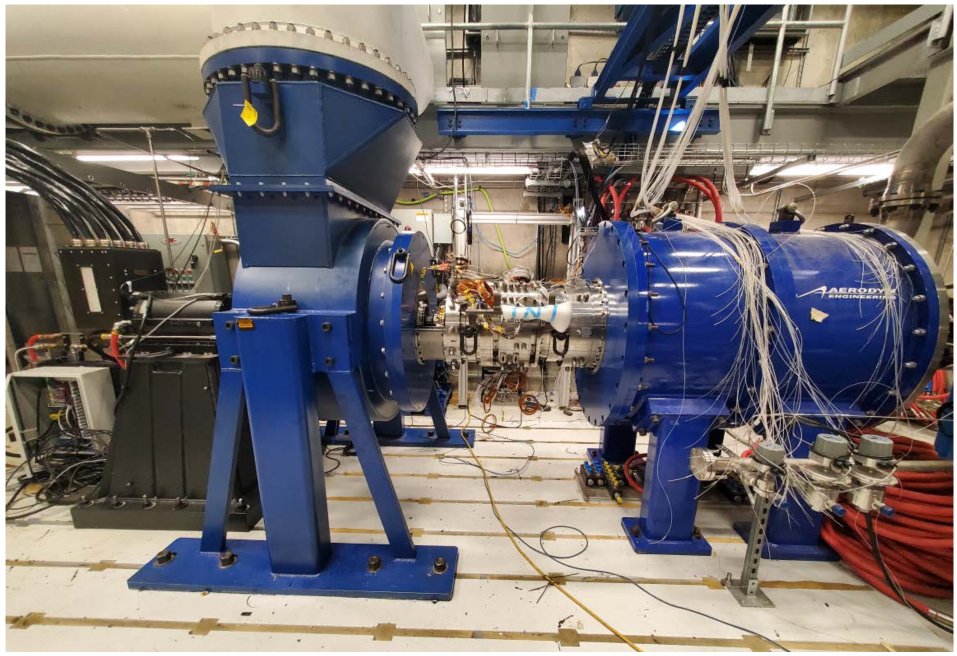
Our propulsion lab, known as ZL4, is one of Zucrow's original buildings -- and it showed. Walking through it, you'd be forgiven for thinking that you'd been transported back to the "Rocket Lab's" humble beginnings in 1948. But our piecemeal fume hoods are no more, as we've replaced them with a brand new state-of-the-art facility for students and faculty to conduct experiments and test new propellants. These infrastructure replacements aren't the sexiest projects, but they make a huge difference in how efficiently and effectively we can do our research.

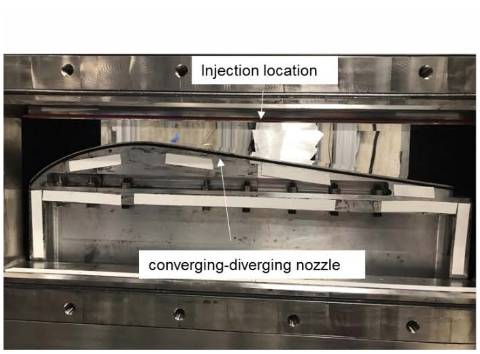
Test cell updates (cont'd)

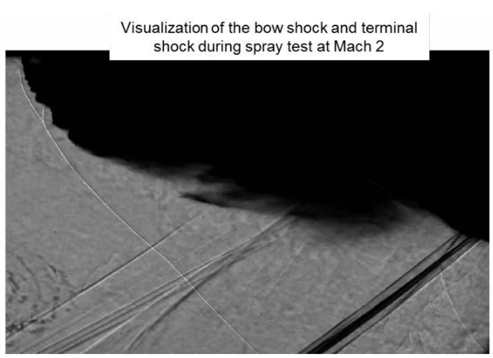
Purdue Experimental Turbine Aerothermal Lab (PETAL)

2020 was an exciting year for Guillermo Paniagua's turbine lab. They collaborated with the Air Force Office of Scientific Research on a program for Low-Pressure Turbines and Hypersonic research. They also are working on a new Department of Energy program to develop a Coal Syngas Oxy-Combustion Turbine for use in Advanced sCO_2 Power cycles, led by the Southwest Research Institute, in cooperation with GE, Air Liquide, University of Central Florida, the Electric Power Research Institute, and 8 Rivers.

Paniagua's team completed their first experiments in the **Small Turbine Aerothermal Rotating Rig (STARR)**. The first testing in rotation represented a significant milestone in their cooperation with Rolls-Royce Corporation with the Indiana Economic Development Corporation's support. This new facility enables the simultaneous acquisition of about 1,000 sensors to evaluate the turbine efficiency with unprecedented accuracy. The electrical dyno is based on Formula 1 technology, suitable to break about 1,000 HP at high speed, over 20,000 RPM without a gearbox.

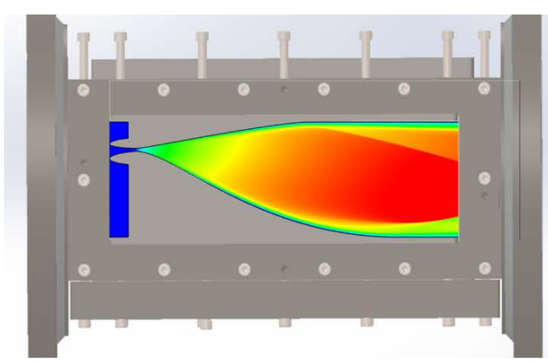


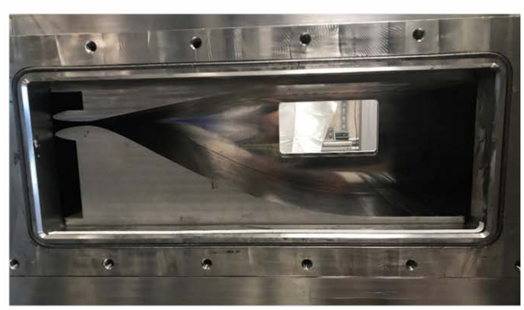




Research is underway at a more fundamental level at Mach 2 to characterize sprays in a fully optical accessible test section. The liquid jet is monitored using multiple techniques such as kHz shadowgraphy, backlit imaging, and Mie Scattering. This figure shows some experiments performed in the Linear Experimental Aerothermal Facility (LEAF).

Additionally, a Mach 5.5 test section is currently being commissioned to perform fundamental research at Hypersonic conditions.

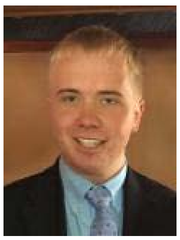




Students receive NASA Fellowships

Four Zucrow students have been chosen to collaborate with NASA on world-changing research, as part of the NASA Space Technology Graduate Research Opportunities (NSTGRO). Since 2011, NASA's Space Technology Mission directorate has sponsored the research of graduate students who show significant potential to contribute to NASA's goal of creating innovative new space technologies for the nation's science, exploration and economic future. Five of the 2020 NSTGRO recipients come from Purdue; four of them work at Zucrow.

Zach Ayers studies laser diagnostics of high-pressure combustion, with Terrence Meyer. His project is titled "A study of propellant mixing effects on rotating detonation rocket engines using high-speed measurements of temperature and mixing dynamics." This study aims to provide the modeling community with experimental data with mixing conditions ranging from non-premixed to fully premixed. Laser-based diagnostic techniques including fuel tracer planar laser-induced fluorescence (PLIF) and coherent anti-stokes Raman scattering (CARS) will be used to evaluate these effects in an optically accessible engine.



Nathan Ballintyn's research centers around the advancement of rotating detonation engines (RDEs), a powerful propulsion method with the capability to improve the performance of air-breathing and rocket engines. Working with Stephen Heister, Ballintyn is responsible for designing and testing a hypergolic rocket RDE with potential applications to orbital maneuvering, reaction control systems, planetary descent/ascent and deep space exploration.

Amanda Braun researches with Terrence Meyer. Her project is titled "In-situ temperature, velocity, and density measurements in high-speed flows using burst-mode filtered Rayleigh scattering." Further characterization and understanding of the high-speed flow dynamics in transonic to hypersonic regimes is important for the development, testing, and improvement of complex space and rocket vehicles. The study will investigate the feasibility and performance of a wavelength-agile, burst-mode FRS system for quantitative measurements of temperature, velocity, and density at kHz-MHz rates in transonic to hypersonic flows.

Josh Ludwigsen is co-advised by Steve Son and Terrence Meyer. His project is "Non-Intrusive Measurements of the Effects of Small Particulates on Near Surface Rocket Exhaust Plumes." The impingement of rocket exhaust plumes with lunar and Martian surfaces results in a significant amount of dust propelled at large speed outward. Their research aims to utilize state of the art laser diagnostics within rocket exhaust plumes to measure the velocity and distribution of dust particles as they interact with the plume as well as measure the difference within the plume structure caused by the introduction of the dust particles.

Adranos update

A slate of good news for **Adranos Inc.**, the Purdue-affiliated startup that developed a novel solid rocket fuel at Zucrow Labs. In February 2020, they secured $1 million of venture capital, and hired vice president of business development Stefan Coburn, who previously worked at Blue Origin. In August 2020, they received another $1.1 million from the US Army's Aviation and Missile Center to conduct hypersonic research. In November 2020, another $2.1 million came from the Department of Defense to qualify their rocket fuel for use in long-range firing systems. Finally, they announced the intention to **build a manufacturing facility in West Lafayette**, creating 50 new jobs by 2025.

To learn more about Adranos and its novel solid rocket fuel, visit adranos.com.

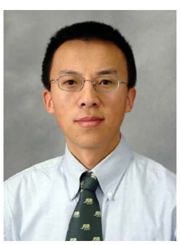
Meet our new faculty

James Braun is a Research Assistant Professor of Mechanical Engineering. After a BS and MS from KU Leuven in Belgium, James got his PhD at Purdue while working at Zucrow Labs. He studies pressure gain combustion, turbomachinery, and high-speed internal flows with an aero-thermal focus on the integration of experiments with computational fluid dynamics. Working under Terrence Meyer and Guillermo Paniagua, he modeled rotating detonation engines, and then tested his models experimentally; he also studied turbines in subsonic, supersonic, and hypersonic conditions.

Hasti Veeraraghava Raju is a Research Assistant Professor of Mechanical Engineering. After a BS from Sri Venkateswara University in India, he finished an MS and PhD at Purdue, studying under Jay Gore. His areas of expertise are application of artificial intelligence in engineering for autonomous intelligent systems; energy, propulsion, emissions; computational fluid dynamics; and high-performance computing. His research has involved the streamlining of power plants; online health monitoring of engines; and reducing emissions from jet engines.

Monique McClain is a Research Scientist in Mechanical Engineering, scheduled to become Assistant Professor in August 2021, after completing her postdoctoral research at Oak Ridge National Laboratory. After a BS at the University of California San Diego, she finished her MS and PhD at Purdue. Her research focuses on additive manufacturing, including quality control, dissimilar material 3D printing, and additive manufacturing of energetic materials. She collaborated with Jeff Rhoads, George Chiu, Emre Gunduz, and Steve Son to develop a method to print extremely viscous materials, including solid rocket fuel.

Faculty honors



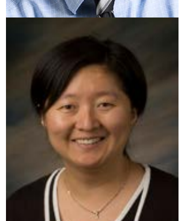
Jun Chen was elected as a Fellow to the American Society of Mechanical Engineers (ASME).

Chris Goldenstein received a $200,000 NASA Space Technology Research Grant through their Early Career Faculty program, for Ultrafast Laser Absorption Spectroscopy for Characterizing Shock-Heated Gases.

Jay Gore became a Global Advisor for the Smart Campus Cloud Network, a project of the Terre Policy Centre that contributes to United Nations Sustainable Development Goals.

Guillermo Paniagua was selected to receive the 2021 American Institute of Aeronautics and Astronautics (AIAA) Ground Testing Award, for "significant contributions in aerothermal highspeed flow instrumentation and novel wind tunnels to support the aerospace industry." Paniagua has also received the American Society of Mechanical Engineers IGTI Aircraft Engine Technology Award, for sustained personal creative contributions to aircraft engine technology.

Timothee Pourpoint has been selected for the University Faculty Scholars Program by the Office of the Provost. He also received the C.T. Sun Excellence in Research Award from the School of Aeronautics and Astronautics.

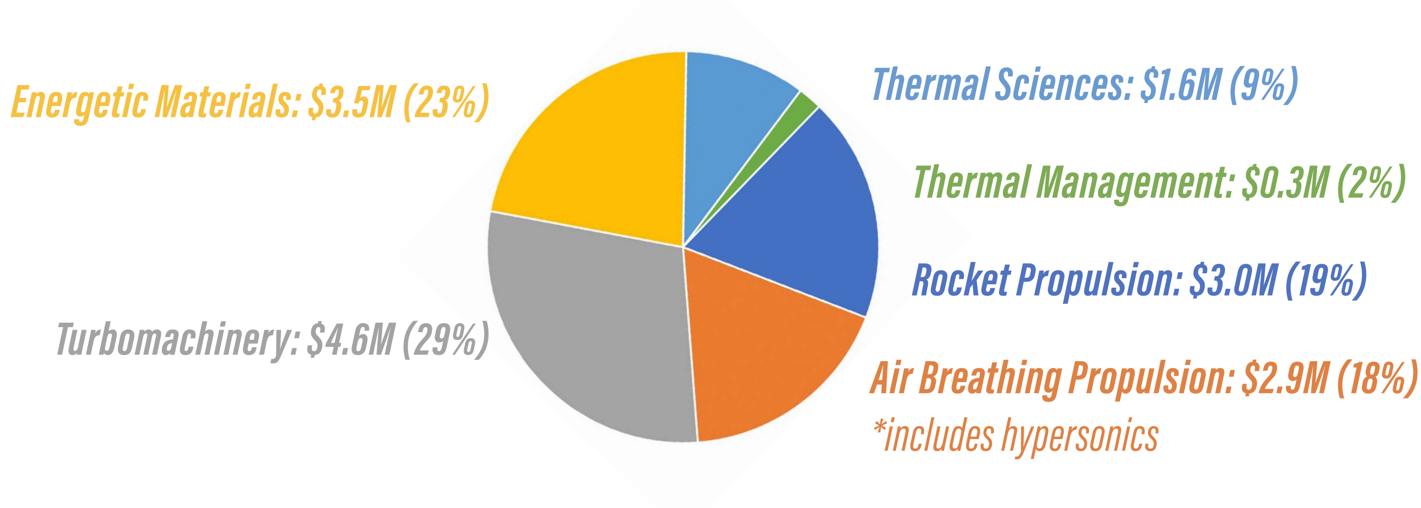


Li Qiao started a six-year term on July 17, 2020 as member on The Combustion Institute's Board of Directors.

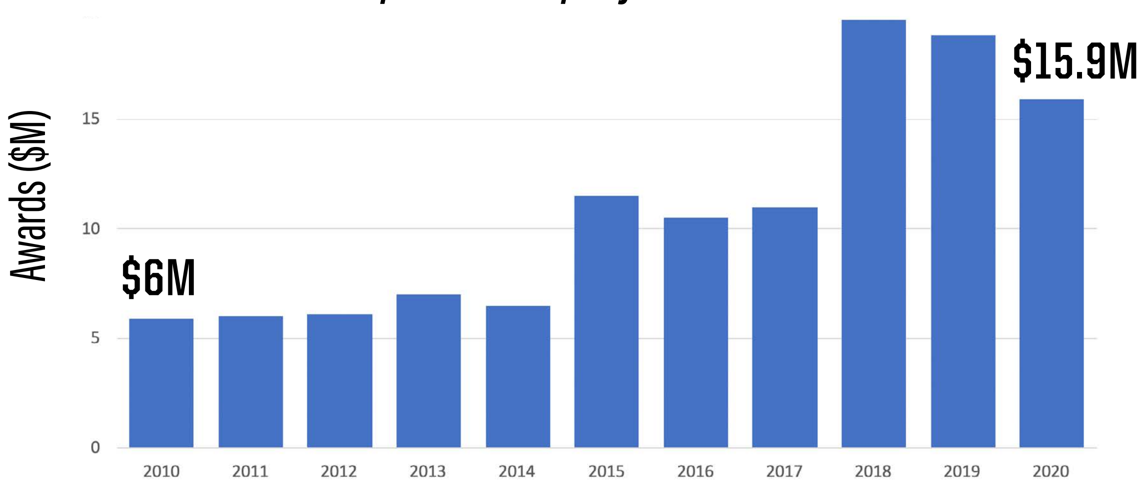
Steve Son was elected as a Fellow to The Combustion Institute, and received their Research Excellence Award. He was also elected as a Fellow to the American Society of Mechanical Engineers (ASME).

Zucrow by the numbers

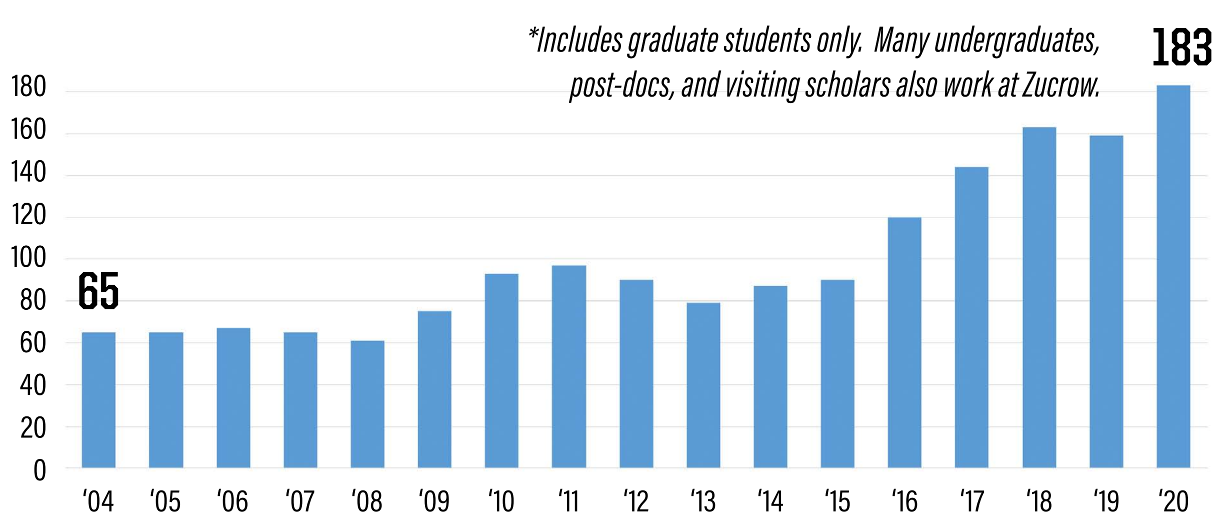
Total expenditures at Zucrow for calendar year 2020: ***$15.9 million***



Growth in sponsored projects at Zucrow Labs



Growth in number of graduate students working at Zucrow Labs



ZUCROW LABS 2020 ANNUAL REPORT

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