ZUCROW LABS
2025
ANNUAL REPORT

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"Reusability shouldn't feel cinematic." *That's the motto of the students of Purdue Space Program, who developed Purdue's first throttleable liquid rocket engine at the undergraduate level, as well as their first regeneratively-cooled hotfires.*

Read the full story...

Under Control

When Zucrow Labs began its earliest rocket tests in 1948, researchers gathered their data by remotely photographing Bourdon tube gauges. Then in 1967, **Dr. Charles Ehresman** (left) worked with Honeywell to design a new controls and data acquisition system, allowing researchers to observe critical measurements during a firing cycle, and also store data for later processing by the computers of the time.

Zucrow's control rooms continued to evolve throughout the decades, incorporating modern computers and remote-controlled television cameras.

Today's all-digital control centers enable full management of test rigs in multiple locations, while state-of-the-art sensors and cameras record millions of data points every second.

Read more about the 75-year history of Zucrow Labs...

From the Director

Here at the world's largest academic propulsion lab, the word of the year for 2025 was "ramp-up." Our newest facility, the $73 million High-Speed Propulsion Lab (also known as ZL9), is now open for business. It seems every day we are giving tours to groups who want to know more about its capabilities, and see its 34-foot-tall test cells and 9,000 cubic feet of high-pressure air storage. Scott Meyer is particularly fond of showing off the new berm that protects Purdue Airport's taxiways from our engine tests — what he calls our "half-million-dollar pile of dirt!"

Scott Meyer showcases Zucrow Labs facilities to members of the Indiana General Assembly in September 2025.

Hundreds of new researchers now conduct regular research in these magnificent test cells — not just Purdue faculty and students, but partners in industry, government, and defense. We can handle anything from the quietest flame to the loudest hypersonic engine.

We're also leading the way in characterization. Laser labs enable us to "see inside" combustors like never before. We are developing new energetic materials, manufacturing and testing them in unique ways. And you won't find better facilities to study gas turbines and compressors than right here at Zucrow.

Zucrow Labs was born 75 years ago, at the dawn of the Space Age. But with all the amazing advancements now happening on our campus, it feels like a new age is just getting started!

Robert P. Lucht
Director, Maurice J. Zucrow Laboratories

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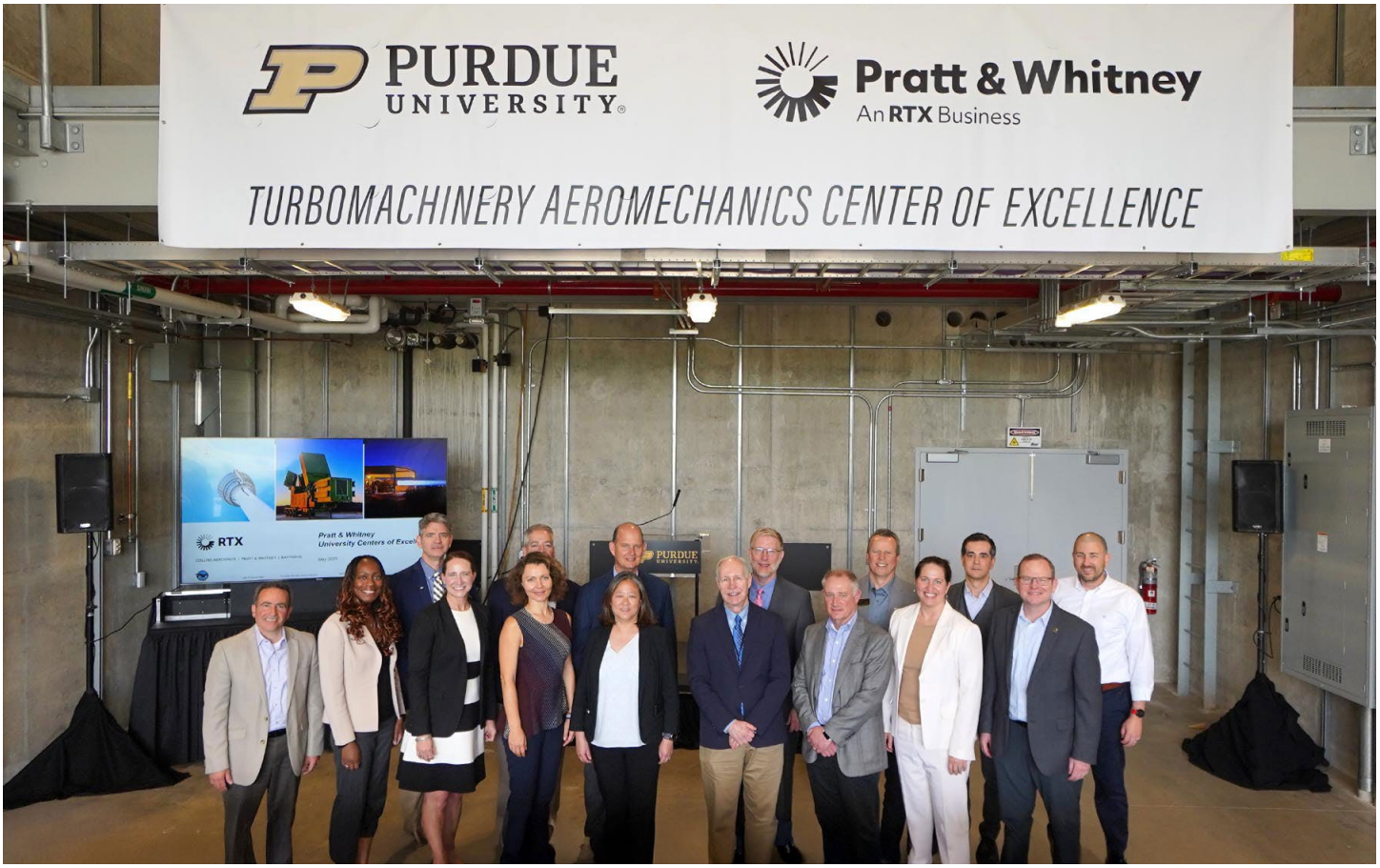
Pratt & Whitney joins Zucrow family



Pratt & Whitney, one of the world's largest jet engine manufacturers, has collaborated with Purdue University to establish a **Turbomachinery Aeromechanics Center of Excellence** — advancing the research of turbines, compressors, and other propulsion technologies.

Pratt & Whitney is part of the aerospace conglomerate RTX, which also includes Collins Aerospace and Raytheon. The partnership with Purdue was announced in May 2025 at a ceremony in one of the new ZL9 test cells.

Pratt & Whitney have identified four key Purdue collaborators conducting propulsion-related research: **Nicole Key**, whose research is focused on high-speed compressors; **Guillermo Paniagua**, who studies turbines; **Carson Slabaugh**, who develops combustors and rotating detonation engines; and **Dianyun Zhang**, who focuses on materials like organic matrix composites.

Beyond research collaborations, the partnership also provides a stable, long-term relationship between academia and industry; a reliable funding platform; and an enhanced network of recruiting opportunities for Purdue students.

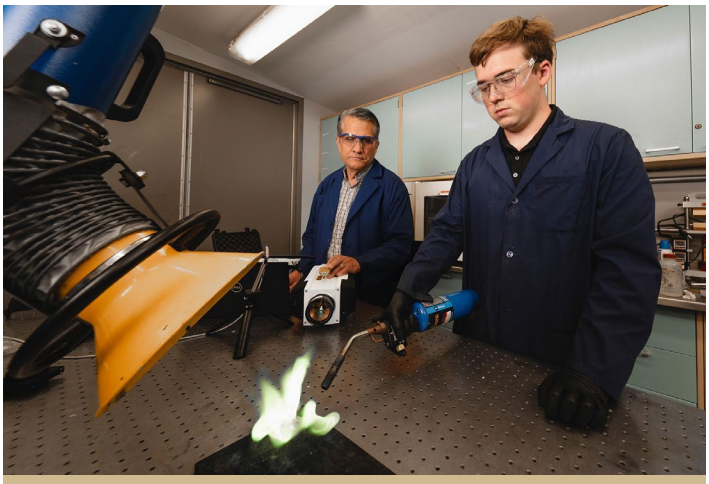
"RTX has hired more than 300 Boilermakers in the past ten years," said Dan DeLaurentis, Purdue University's executive vice president for research. "Purdue faculty have conducted more than $9.5 million of research projects from RTX over the last 10 years. We clearly work well together, and having this Center of Excellence just cements a wonderful partnership."

Read the full story...

Guillermo Paniagua showcases Zucrow Labs' high-pressure air storage facility to visitors from Pratt & Whitney.

Switchable explosives

Purdue University researchers have made a significant advancement in the field of energetics by **creating a switchable explosive, which can be turned "off" to enhance safety during handling and transportation, and turned "on" to detonate when needed.**



The Purdue Energetics Research Center (PERC) has developed a "switchable explosive", which can enhance its safety during handling and transportation.

Steve Son, Alfred J. McAllister Professor of Mechanical Engineering, worked with Metin Ornek, research scientist at Zucrow Labs, and a team of other researchers to create the explosive. They started with RDX, a common explosive, encased in a rubberized polymer binder. They then injected thermally-expandable microspheres (TEMs).

"TEMs have a thermoplastic shell and are filled with a low boiling point hydrocarbon," said Son. "When heated, the hydrocarbon vaporizes and the TEMs expand to 60 to 80 times their original size. An RDX-based rubberized explosive is perfect for this application, because the polymer allows for expansion."

Heating the explosive in a specific way results in microstructural changes, which causes the TEMs to become hot spot locations. When shocked, these hot spots sustain a detonation wave fully throughout the material. Without that heating process, the TEMs do not detonate unintentionally. This is what creates the switchable explosive.

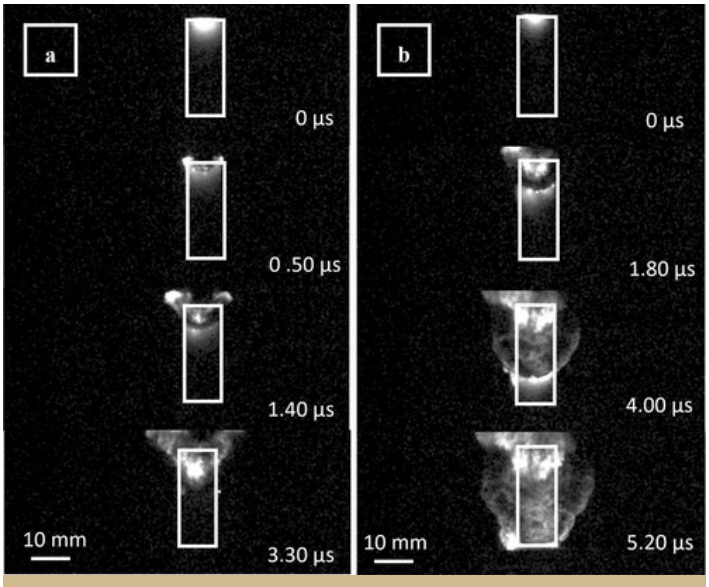
The team began by mixing the explosives, changing the amount of TEMs in each sample. Afterward, they were left with five different samples containing TEMs, and one baseline sample without any TEMs. They heated each sample (either to 95°C or 125°C), held that temperature for 30 minutes, and then cooled them back to their original temperature.

Following that, micro CT was used to study the microstructural differences of the unheated and heated samples. The 95°C samples increased in size and in porosity due to the expansion of the TEMs. However, the heated 125°C sample showed little to no expansion, as the TEMs deflated back to their original size due to the higher temperature. This process of expanding and deflating was also confirmed through hot-stage microscopy, a powerful analytical technique that allowed the researchers to look at changes in the material.

The samples were then tested to see if they could sustain a detonation wave. A brass witness plate and high speed video were used to conclude whether each sample was successful. Each sample was ignited and none of the 95°C samples were able to sustain a detonation wave fully. However, the 125°C samples had different results.

"The high temperatures allowed the TEMs to completely expand, melt, rupture, and deflate within the explosive formulation," said Ornek. "This caused critical hot spots to form, allowing the sample to detonate fully throughout the material."

Read the full story...



High speed imaging of the TEMs unheated and heated at 125°C.

Two Zucrow-born companies take off

Two startups created by Zucrow Labs alums are looking to be game changers in the world of small-scale hypersonic testing and in-space rotating detonation engines.

Pluto Aerospace was founded by Chris Nilsen (BSIDE '19), who helped restart SEDS at Purdue as a student, and today works at Zucrow Labs as an associate propulsion engineer. He envisioned a rocket system that makes high-speed flight research more accessible to small businesses and startups. His prototype vehicle, Dash, completed its second successful flight with customer payloads in June 2025.

The goal of Pluto Aerospace is to bring hypersonic testing within reach of small businesses and startups.

"I hear it from people all the time," says Nilsen. "We'd love to prove our tech but we can't afford to wait three or four years to get on a flight. So we know it's the right answer because it doesn't exist anywhere else. We're proud to be that bridge."

Read more about Pluto Aerospace...

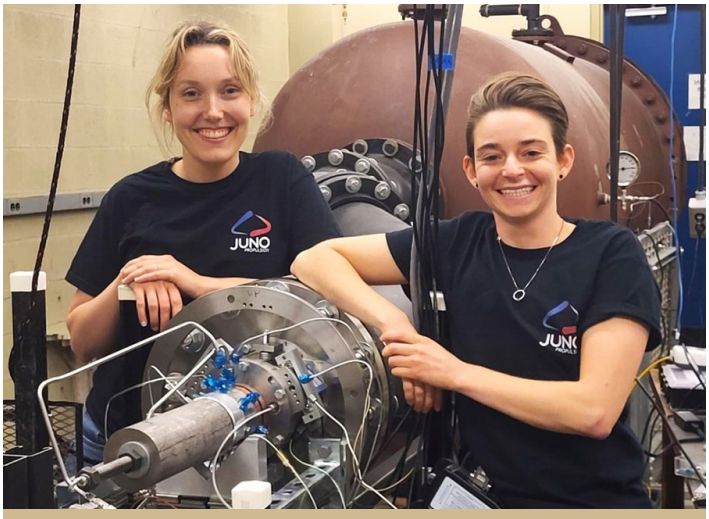
Juno Propulsion, a small startup in Washington State, hopes to be the first organization to ever test a rotating detonation rocket engine (RDRE) in space. Co-founders Alexis Harroun (MSAAE '19, PhD AAE '23) and Ari Martinez (BSAAE '17, MSAAE '19, PhD AAE '23) both studied under Purdue propulsion legend Steve Heister at Zucrow Labs.

"We're going to build the full propulsion system — everything from tankage to fuel delivery, to thruster and controller," says Harroun. "Obviously the thruster is the secret sauce, and we're putting in all the experience we got at Zucrow into building this."

Juno Propulsion's design uses nitrous oxide and ethane as fuel to create a rotating detonation wave. They expect to achieve specific impulses 5% to 10% greater than traditional rocket engines of the same size, according to Harroun. Smaller engines mean space vehicles can have more capacity for payloads and fuel. If it proves viable, the company's engine may allow companies to wean themselves off toxic hydrazine fuels, which are dangerous and costly to handle.

"There are other non-toxic and green solutions on the market, but because they're not using a performance-enhancing tech like ours, they're not going to be able to compete performance-wise," Harroun said. "We're trying to bridge that gap."

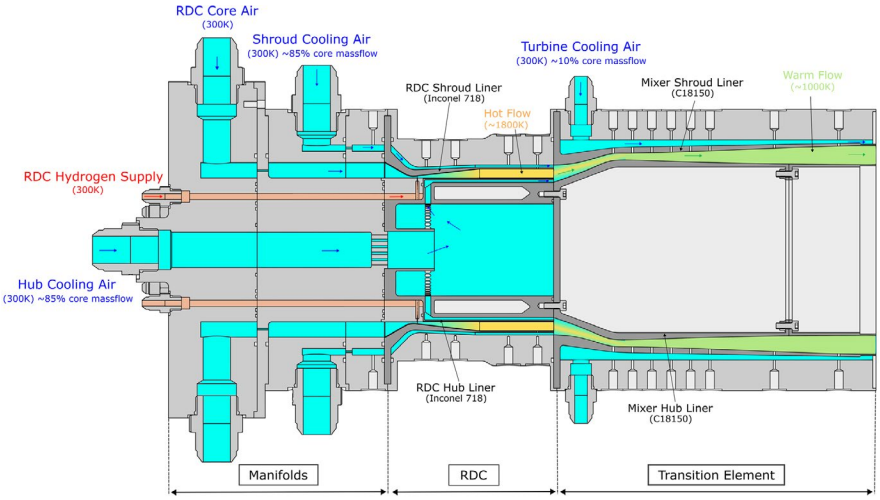
Read more about Juno Propulsion...



The co-founders of Juno Propulsion, Alexis Harroun (left) and Ari Martinez (right), are both Zucrow alums.

RDE turbines for Rolls-Royce

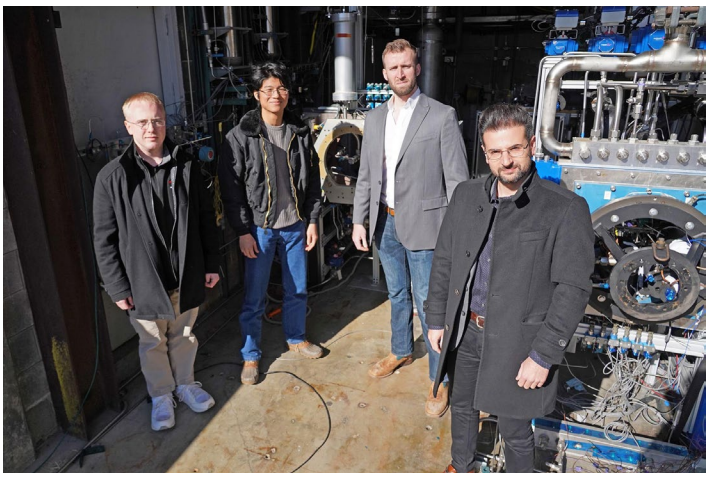
Rotating detonation engines (RDEs) are a promising technology with the potential to significantly enhance thermodynamic efficiency and reduce the footprint of propulsion and power generation systems. However, the inherent fluctuations in flow properties, caused by the motion of the detonation wave, result in strong, unsteady behavior. This dynamic characteristic, combined with the extreme power density of RDEs, leads to a compact combustor size but presents considerable challenges for effective thermal management.



Guillermo Paniagua's team, in collaboration with Carson Slabaugh, undertook a study to provide a thorough design methodology for an air-cooled RDE that can be integrated into the Rolls-Royce M250-C40B gas turbine engine. Their research has been published in the *Journal of Turbomachinery*.

Read the full research article...

HySonic Technologies receives contract



HySonic Technologies, LLC, founded by associate professor of mechanical engineering Carlo Scalo, recently received an award from the US Army **to advance the fundamental understanding of the effects of compressible turbulence on the external and internal flow dynamics of hypersonic air breathing propulsion devices.** The $1.31 million Phase 2 contract comes from the Army Research Office, via the Small Business Innovation Research (SBIR/STTR) program.

"This is tremendous news," said Scalo, whose academic research focuses on nonlinear acoustics, compressible turbulence, and hypersonics. "This contract will enable us to track every step experienced by the air flow around and through a hypersonic air-breathing vehicle. We appreciate the emphasis on the fundamentals that the Army is placing, especially at a time when my group is deepening our understanding of the mechanics of hypersonic transition and hypersonic turbulence."

For the experimental combustion aspect of the project, Scalo will be collaborating with Carson Slabaugh at Zucrow Labs. For the external aerodynamic investigations, they will work with Nicholaus Parziale at Stevens Institute of Technology.

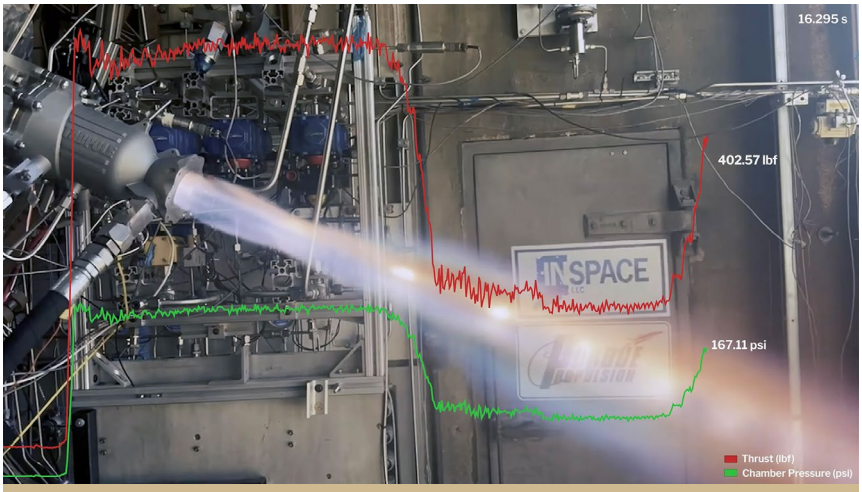
Read the full story...

Giant leap, soft landing

Purdue Space Program (PSP) is the largest student rocketry chapter in the world. Their Active Controls team features 80 undergraduate students dedicated to vertical takeoff and vertical landing (VTVL) technology, aiming to build a fully reusable lander vehicle to compete in the Collegiate Propulsive Lander Challenge.

In Spring 2025, the Active Controls team won $15,000 by demonstrating throttling capability in their liquid rocket engine, TADPOLE.

They partnered with Elementum 3D to use a proprietary Al6061-RAM2 alloy, previously tested by NASA. Suddenly, professionals were watching to see if undergraduates could deliver on an ambitious technical promise.



As demonstrated by the burn data, TADPOLE became Purdue's first throttleable liquid rocket engine and first regeneratively cooled hotfire at the undergraduate level.

For almost a year, they waited for a spot on the 10k Stand at the Maurice J. Zucrow Laboratories. When they finally secured it for a month in April 2025, they arrived ready to fabricate, assemble, and test for as many hours as the facility allowed.

Throttle tests brought forth the engine's true capability. A lander vehicle must go up, hover, and come down gently, requiring mastery of the steady state and transient engine behavior. Firing with integrated throttle valves was the heart of the challenge, where they could prove engine controllability. Over a month of tests, the engine proved itself capable and reliable.

Reusability shouldn't feel cinematic. By the tenth test, it should feel routine. When firing a liquid engine becomes second nature, that's when real progress begins.

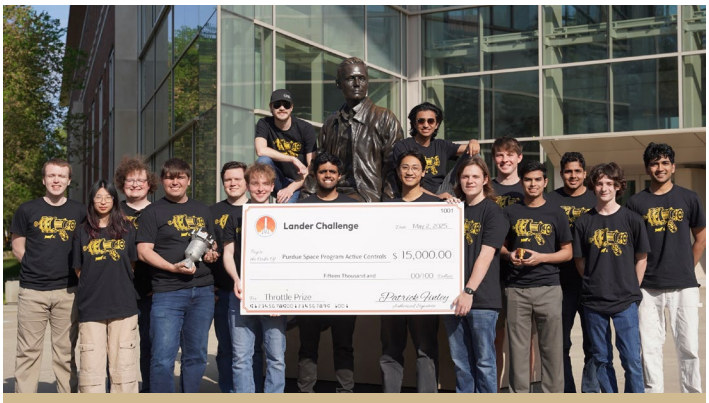
Other teams were also racing toward the same milestone. Purdue secured the final throttle prize by just one day. The results speak for themselves: TADPOLE became Purdue's first throttleable liquid rocket engine and first regeneratively cooled hotfire at the undergraduate level. They accumulated more than 160 seconds of burn time, including multiple continuous twenty-second hotfires.

While winning the milestone prize validated their work, the bigger impact was realizing that undergraduates can achieve complex goals. This campaign unified years of mechanical, electrical, aerospace, and computer science work. TADPOLE now guides the design for its successor, superTADPOLE, with all design, control, and cooling strategies informed by real test data.

This effort is possible because of Purdue. Few universities give undergraduates direct access to propulsion facilities like Zucrow Labs, and even fewer encourage pushing student teams to the limits. At Purdue, propulsion isn't reserved for graduate school. It's something you can do your freshman year, on a Tuesday afternoon, supported by mentors who treat student hardware professionally.

Liquid propulsion is no longer something students admire online. It is something that they build, test, analyze, and iterate on themselves. As the aerospace industry accelerates, students will increasingly be part of that growth, not spectators of it.

Read the full story...



Active Controls presents the $15,000 prize awarded by the Lander Challenge in front of Armstrong Hall.

Blue duo: twins work at Blue Origin

Identical twin sisters Dayle and Claire Alexander basically did everything together while growing up — including attending Purdue, getting degrees in aeronautics and astronautics, and conducting hypergolic propellant research at Zucrow Labs with Prof. Timothee Pourpoint.

Today, they are both senior propulsion engineers at Blue Origin, responsible for New Glenn's upper-stage BE-3U engines. In January 2025, they were both on consoles at Cape Canaveral monitoring New Glenn's inaugural launch.

"It was the first time for that rocket, this team and for the company — the first time that Blue Origin got into orbit, so it was a very big deal," explains Claire.

"This was a way different rocket, a more complicated rocket, than I'd worked on before," said Dayle. "But it felt like I was prepared to be there."

Read the full story...

The Olympic skiing rocketeer

Which is more difficult: slaloming down a ski slope at 50 miles an hour, or designing a rocket to travel 1,000 miles an hour? William Flaherty, a Purdue mechanical engineering student, has done both! Growing up in Puerto Rico, he became one of the few Winter Olympians from the island when he competed in slalom and giant slalom at the 2022 Beijing Winter Olympics. He then fell in love with rocketry, and decided to attend Purdue to pursue it.

"Purdue has facilitated my learning like no other school could," said William, now a junior in mechanical engineering. "They have top level academics, and world-class facilities. There's really no better place in the world for rocketry."

William is a member of Purdue Space Program (PSP), the country's largest chapter of SEDS (Students for the Exploration and Development of Space). These ambitious undergraduates design, build, and launch liquid-propellant rockets, solid rockets, hybrid rockets, satellites, and more — all on their own time. Their latest creation, Cratermaker Special, is a 10-foot long composite beast currently undergoing testing. It will feature another "first" for a university: a bang-bang solenoid system to maintain tank pressures throughout the flight.

It also enabled William to get an internship at SpaceX's Starbase, working on the launch tower. "Doing mechanical engineering and PSP is tough," he said. "It's a lot of late nights. But you can't argue with their placement rate!"

Read the full story...

Awards and honors

Venkat Athmanathan, Senior Research Scientist, was recognized by Purdue's College of Engineering with the Outstanding Research Staff Award for 2025.

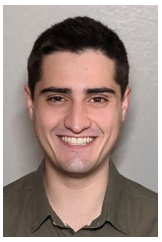
More info...

Sally Bane, Associate Professor of Aeronautics and Astronautics, is the PI on a $743,000 NSF project using virtual reality to teach large-scale engineering lab courses to undergraduates.

More info...

Elizabeth Bradshaw, senior in aeronautics and astronautics, was named a 2025-26 Purdue Engineering Fellow. Elizabeth is President of Purdue Space Program (PSP).

More info...



Antonio Castillo, Research Scientist, received the 2025 Sustainability Bursary Award from Rolls-Royce, for his contributions to reducing the environmental impact of turbomachinery. He also won the 2025 ASME Turbo Expo Early Career Engineering Award. *More info...*

Diane Collard, Research Scientist for the Purdue Energetics Research Center (PERC), received the 2025 Kristina Bross Mentor-Mentee Award from Purdue's John Martinson Honors College.

More info...

Chris Goldenstein is now the Avrum and Joyce Gray Rising Star Professor in Entrepreneurship and Innovation. His team also received an Honorable Mention from AIAA for Best Paper in Aerospace Sciences for their paper characterizing the Sandia National Laboratories hypersonic shock tunnel. *More info...*

Jay Gore, the Reilly Professor in Combustion Engineering, has received the James Harry Potter Gold Medal from ASME, recognizing distinguished service in the science of thermodynamics.

More info...

Lukas Inhestern, Research Scientist, has received the Purdue Bravo+ Award, recognizing stand-out accomplishment or over-the-top achievement by a Purdue staff or faculty member.

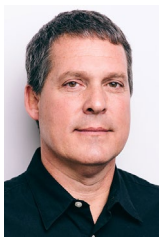
More info...

Joseph Jewell, the John Bogdanoff Associate Professor of Aeronautics and Astronautics, has been nominated by President Donald Trump to be the next Assistant Secretary of War for Science and Technology.

More info...

Nicole Key has received a named professorship; she is now the Avrum and Joyce Gray Professor in Entrepreneurship and Innovation. She also received the 2025 AIAA Ground Testing Award for her work in advanced high-speed compressors.

More info...

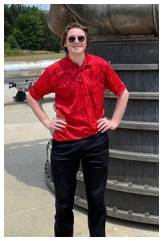


Scott Meyer, Managing Director of Zucrow Labs, was recognized by Purdue's College of Engineering with the Staff Long-Term Impact Award for 2025.

More info...

Guillermo Paniagua has received a named professorship; he is now the Reilly Professor of Mechanical Engineering. He also won Best Paper Award in Diagnostics & Instrumentation at the 2025 ASME Turbo Expo.

More info...

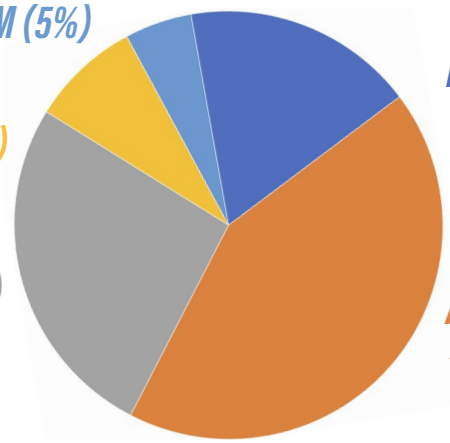


Two Zucrow students have been chosen for NASA's Space Technology Graduate Research Opportunities (NSTGRO). **Devin Johnson,** a Ph.D. student working with Terrence Meyer, is developing CFD simulations to quantify how a revolving detonation wave impacts fuel injection performance within a rotating detonation engine. **Joseph Ligresti**, studying with Timothee Pourpoint, is characterizing the effects of extended exposure to vacuum and thermal gradient conditions on the reactivity of combustion intermediates for low-temperature storable propellants.

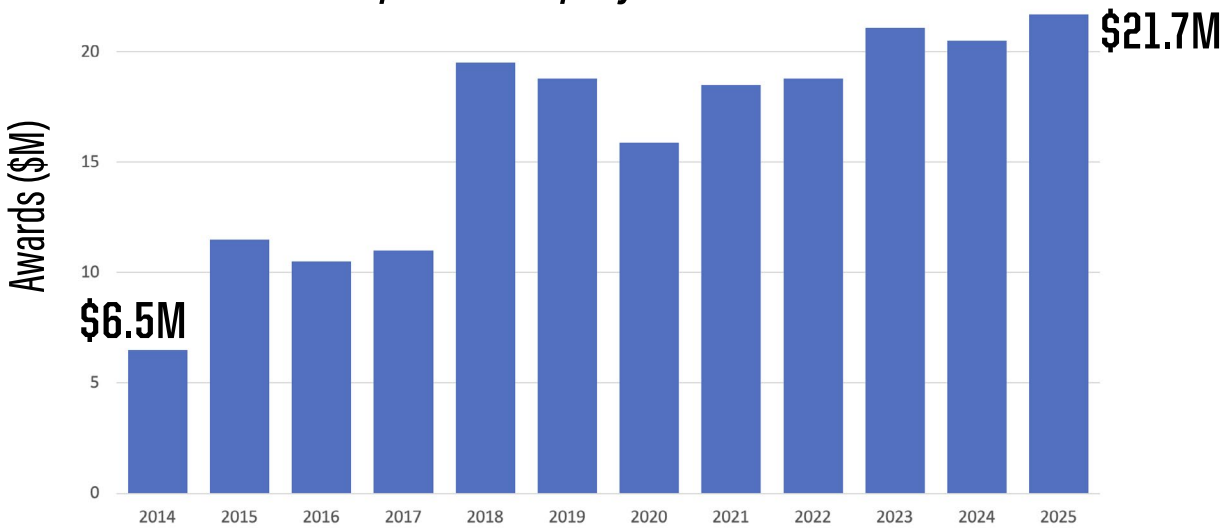
More info...

Zucrow by the numbers

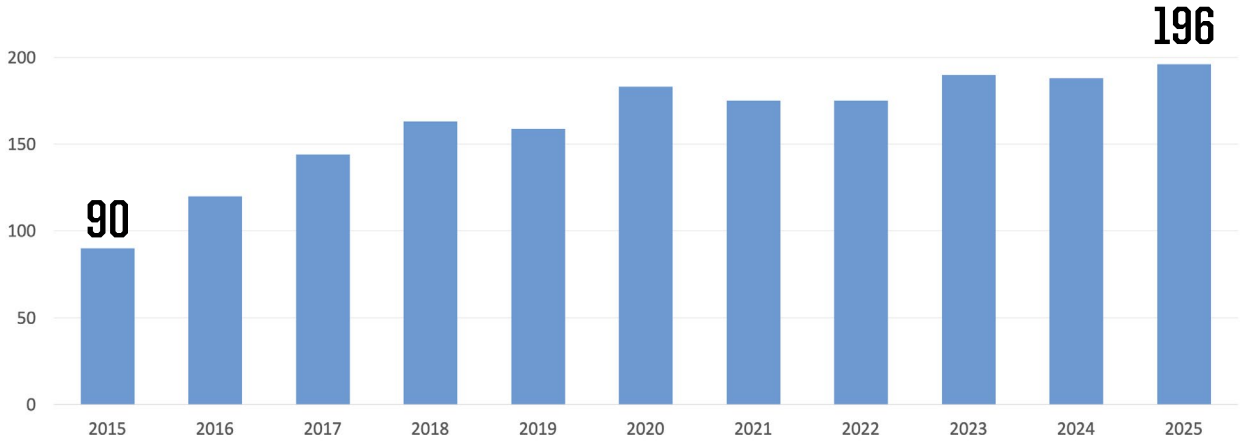
Total expenditures at Zucrow for calendar year 2025: **$21.7 million**



Growth in sponsored projects at Zucrow Labs



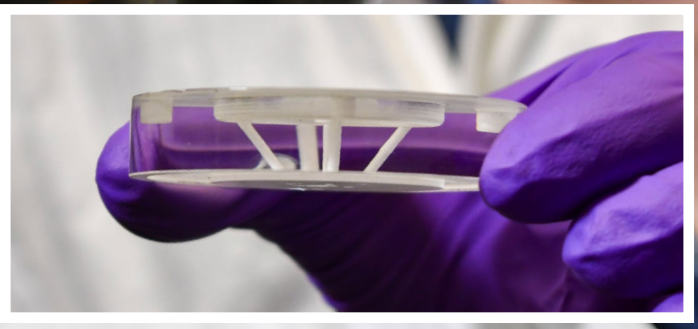
Growth in number of graduate students working at Zucrow Labs



Seeing is Believing

*Timothee Pourpoint challenged the students in his Propulsion Design, Build, and Test class to create a **fully transparent rocket engine**: tanks, feed lines, valves, injectors, manifolds, combustion chamber, and nozzle. With support from NASA and Formlabs, they 3D-printed a suite of optically clear components, assembled them, and successfully hotfired the result at Zucrow Labs.*

Read the full story...



The transparent design enabled them to see a nitrogen bubble entering the manifold, which would have been impossible to observe otherwise.

Watch the video here!

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