# Ansys + German Institute of Technical Physics

"I'm quite sure we wouldn't have achieved ablation without the optimizations we performed in Ansys Zemax OpticStudio. We wouldn't have generated any meaningful data."

— **Raoul Lorbeer**
Research Scientist / Institute of Technical Physics, German Aerospace Center

Ansys

CASE STUDY

## Institute of Technical Physics Designs USB-powered Nanosatellite Laser Thruster

In 2020, the German Institute of Technical Physics (ITP) embarked on a project to prototype a new technology for maneuvering miniature satellites. The project's goal was to show how it's possible to propel nanosatellites with laser ablative propulsion, which generates thrust by evaporating material with a focused laser beam. Using Ansys Zemax OpticStudio, ITP conceived its design for laser-ablative propulsion and successfully demonstrated its viability under the strict requirements of satellite miniaturization.

## Challenges

The ongoing miniaturization of satellites has reached the level of a CubeSat, defined in the industry as a U-class spacecraft. Developing a single-unit CubeSat is challenging because its thrust mechanism should essentially contain no moving parts, consume no more than 2 watts of power, and make at least half of its volume available for other essential hardware. Just as with larger satellites, scientists have innovated thrust methods for CubeSat projects, including using electric, chemical, and cold-gas propulsion systems. But each of these methods brings with it certain limitations, particularly around the satellite's ability to maintain efficiency and maneuverability while operating at such a small scale.

ITP sought to design a thruster that would fit inside a single-unit CubeSat and use laser-ablative propulsion. The team's goal was to achieve thrust using a highly efficient, navigable system based on precision optics that would guide and control the laser activities and be a reliable source of propulsion for the satellite itself.

## Ansys Products Used

- Ansys Zemax OpticStudio

## Engineering Solution

One risk when building laser-ablative optics is contamination of the optical components by the ablative material. To mitigate this risk, ITP's optical design included a toroidal ellipsoid mirror that reimages the center of the deflected beam to a new location — effectively shifting the laser laterally within its mechanical housing and offsetting the angle at which it reaches the target surface. However, this additional step introduced aberrations in the beam that significantly diminished the focus efficiency required for ablation.

To offset the effects from shifting the beam via the toroidal mirror, ITP needed to include an additional aspheric lens that would correct the aberrations and preserve the beam's intensity. Most stock lenses of this type are designed for optimizing focus, not providing corrections to focus aberrations, so the new "corrective" asphere was custom-designed for the ITP project.

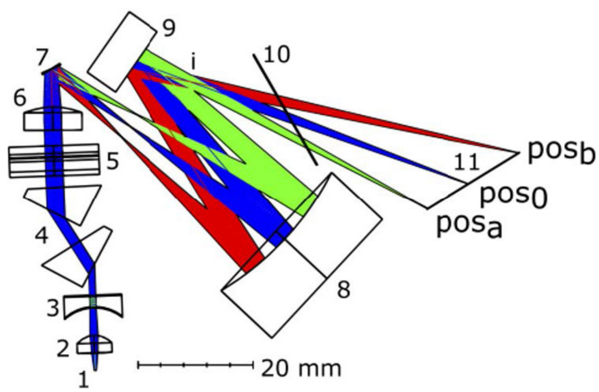


Figure 1. The ITP laser-ablative thruster design in OpticStudio. Optical components are shown in black; 0° MEMS mirror deflection angle beam path is shown in blue; and ±4° MEMS angle beam paths are shown in green and red. Source: CC BY (Creative Commons Attribution 4.0License) Toni Bauer, Sebastian Weixler, Raoul-Amadeus Lorbeer, and Hans-Albert Eckel, "USB-powered technology platform for laser ablative thrust generation," *OSA Continuum 4, 1304–1315 (2021)*

As illustrated in Figure 1, the laser-ablative thrust system designed by ITP (shown here with three example scanner tilt angles) comprises the following parts: 1. Laser diode (Dilas TL-0976-5000); 2. Aspheric lens for collimating the laser beam; 3. Cylindric lens for astigmatic correction; 4. Anamorphous prism pair for turning the elliptical beam into a circular profile; 5. Liquid lens for adjusting focal length; 6. Custom aspheric lens (25mm focal length) for correcting static system aberrations; 7. Microelectromechanical systems (MEMS) 3.6mmdiameter mirror with ±4° tilt (Mirrorcle A7B2.1-3600AU) for optionally deflecting the beam on both lateral axes; 8. Toroidal mirror for laterally shifting the MEMS mirror image to position i in order to prevent contamination or damage to the optical components by the ablated material; 9. Plain mirror for folding the beam path, complying with CubeSat mechanical housing standards by keeping the optical system footprint smaller than 10 x 10 cm; 10. Glass cover slip for further protecting the optical system from damage; 11. Propellant scanning plane (the target surface for ablation) that is tilted relative to the laser beam by the toroidal mirror.

When designing the custom asphere, ITP used the modeling functions in OpticStudio to experiment until finding the best possible result. Elsewhere in the design, ITP used stock optical components for collimating the beam and other preprocessing activities, such as astigmatic correction, as well as for turning the elliptical beam into a circular profile and adjusting its focal length. The team used the OpticStudio stock lens catalog and merit function editor to select and optimize these components within the design, entering parameters they knew would be necessary to adjust in a laboratory setup.

The small scale of the proposed thruster also meant that any physical rendering of the CubeSat would require precise placement during production. To test this precision, the team made use of the OpticStudio export capabilities to easily import the design into CAD. They then designed a mechanical housing and used a 3D printer to fabricate a model into which the optics could be placed.

In the end, ITP integrated a system with a volume of less than 10 x 10 x 5 cm, fitting within the 50% maximum volume for the thrust mechanism in a CubeSat. The system can perform 3D laser ablation of various materials, and can be powered using a standard USB port. With help from Ansys, the team achieved success at proving the viability of laser ablating material within a compact thrust system suitable for adoption in CubeSats.

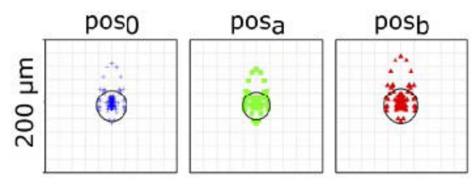


Figure 2. OpticStudio spot diagram simulations for the three example beam positions indicated in Figure 1. The dots show the intersection of ray-tracing rays with the scanning plane at each angle, relative to the expected airy diameter. Source: CC BY (Creative Commons Attribution 4.0 License) Toni Bauer, Sebastian Weixler, Raoul-Amadeus Lorbeer, and Hans-Albert Eckel, "USB-powered technology platform for laser ablative thrust generation," *OSA Continuum 4, 1304–1315 (2021)*

## / Benefits

- Designing custom aspheric optical elements using OpticStudio simulation tools.
- Simulation toolchain integration for effective software-based system modeling.
- Merit function tools for system optimization to systematically achieve a perfectly collimated beam.

## / Results

- Proved the viability of laser ablation as a thrust technology for nanosatellites.
- Achieved thrust generation within single-unit CubeSat limitations.
- Prototyped, miniaturized, and optimized complex optics that can be easily exported to CAD.

## / Company Description

The German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, or DLR) is Germany's national center for aerospace, energy, and transportation research. At the Institute of Technical Physics (ITP), an institute within DLR, scientists, engineers, and technicians pursue interdisciplinary research into key areas of laser application.

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