CASE STUDY: AEROSPACE, RESEARCH & ACADEMIA

Students Redefining Spaceflight: **EPFL's Gruyère Space Program**

How students achieved autonomous rocket landings with Chronos 2.1-HD high-speed camera

Key Results

- The Gruyère Space Program team successfully launched Colibri, a 1.25 kN thrust, student-built reusable rocket.
- Kron Technologies' Chronos 2.1-HD camera enabled critical diagnostics across ignition, injector testing, and vertical landing stability.
- The rocket completed over 53 flights, reaching an altitude of 105 meters and a top speed of 10m/s.

1. Introduction

Space transportation offers scientific, economic and technological opportunities. Yet, it is also a field of high complexity, steep challenges, and significant financial demands. Breaking through these barriers requires a well-coordinated, high-performing team with access to cutting-edge technology.

This is exactly what the **Gruyère Space Program (GSP)**, a student-led initiative from the prestigious Swiss Federal Technology Institute of Lausanne (EPFL), set out to prove. Despite the challenges, GSP aimed to show that advanced autonomous flight, precise navigation, and controlled rocket-powered landings were achievable; a feat that would make history as the first time accomplished by a student team.

As the complexity of their project grew, so did their need for visual testing tools.

This is where the **Chronos 2.1-HD High-Speed Camera** became indispensable, enabling the GSP team to capture high-speed phenomena, troubleshoot engine issues, and validate designs for repeatable rocket use.

Why Chronos 2.1-HD?

- **1000 FPS at full HD:** Capture events that are too fast to resolve by the naked eye
- **Compact, lab-ready design:** Perfect for field tests and academic use
- **Cost-effective:** Delivers lab-grade performance without breaking budgets

Chronos 2.1-HD High-Speed Camera

The Gruyère Space Program Team

The Gruyère Space Program and the Colibri Rocket

The Gruyère Space Program (GSP), a Swiss aerospace initiative founded in 2018 by students from EPFL (Swiss Federal Technology Institute of Lausanne), set out to do what had never been done before: design, build, and fly **Colibri**, a 100 kg, fully reusable, liquid-fueled vertical take-off and vertical landing (VTVL) rocket.

GSP sought to demonstrate that a student team could construct the world's first rocket hopper and accomplish navigation and closed-loop flight control with the capability of landing in a standing position. For the majority of the project, the core team consisted of five dedicated students. By the end of 2023, the team had grown to around ten members to support final testing phases and system refinements.

Despite being a small team, GSP achieved some remarkable milestones:

- **53+ successful free flights** at various altitudes and trajectories
- First free-flying reusable rocket hopper in Europe, and the world's first student-built hopper
- Precision landings from altitudes up to 105 meters
- Developed and validated closed-loop real-time control systems in actual flight conditions.
- Reliable rocket engine reuse across flights without major refurbishment
- Transition to a professional venture, now known as PAVE Space SA

What is Colibri?

It is a reusable vertical take-off, vertical landing (VTVL) rocket. Powered by a gimbaled N_2O/IPA bipropellant engine delivering 1.25 kN of thrust, Colibri stands 2.45 meters tall and can carry a payload of up to 3 kg (6.5 lbs).

Colibri in Motion

Test Platform for Colibri's GNC (Guidance, Navigation, and Control) System

2. Challenge

Developing a reliable and reusable liquid-propelled rocket engine was one of the most technically demanding aspects of the Colibri project.

For the GSP team, this wasn't just about launching a rocket; it was about designing an aerospace system capable of multiple flights, controlled landings, and repeatable performance.

Challenges That Emerged During Engine Development:

- **Ignition Sequence Tuning**
  Achieving reliable ignition required precise timing between propellant valve openings and ignition sources.

- **Combustion Chamber Cooling**
  Ensuring effective wall protection through a combination of film and regenerative cooling was essential to prevent thermal damage and extend engine life.

- **Propellant Phase Management**
  Understanding how nitrous oxide and isopropanol behaved at injection, particularly with phase changes, was key to maintaining stable combustion and efficient engine operation.

- **Injector Performance**
  Characterizing injection geometry and atomization efficiency was crucial to achieve high combustion quality and thrust stability.

- **Touchdown Dynamics**
  Observing the landing behavior of the legs during touchdown was important to perfect the engine shutdown conditions and ensure structural integrity.

KRON TECHNOLOGIES
HIGH-SPEED IMAGING

University
Swiss Federal Technology Institute of Lausanne (EPFL)

Team
Gruyère Space Program (GSP)

Use Case
Aerospace, Research & Academia

The Need for a High-Speed Camera

It became clear that key aspects of the Colibri launch process required precise synchronization between critical operations, such as propellant valve opening and activation of igniters.

The time scale of these events was far too short to be captured by conventional imaging systems. Hence, these processes could only be analyzed and understood with the help of a high-speed camera capable of reaching a few 1000s frames per second.

Behind-the-Scenes: Chronos 2.1-HD high-speed camera alongside a standard camera. This setup allows for the capture of both slow-motion footage and regular FPS filming.

Colibri's Engine Performance Demonstration

3. Solution & Results

To overcome the challenges associated with building a reusable liquid-fueled rocket, GSP integrated the **Chronos 2.1-HD High-Speed Camera** into their propulsion development and testing workflow.

Operating at up to **1,000 frames per second at 1920 x 1080 (HD) resolution**, the Chronos 2.1-HD enabled frame-by-frame analysis, allowing the GSP team to understand crucial elements of the Colibri rocket, namely, reliability and performance of the rocket engine for reliable repeated flights.

> “The detailed frame-by-frame analysis provided by the high-speed footage proved critical in fine-tuning the propulsion system, solving ignition issues, and validating the design for repeated rocket reuse.”
>
> **Jérémy Marciacq, GSP Co-founder**

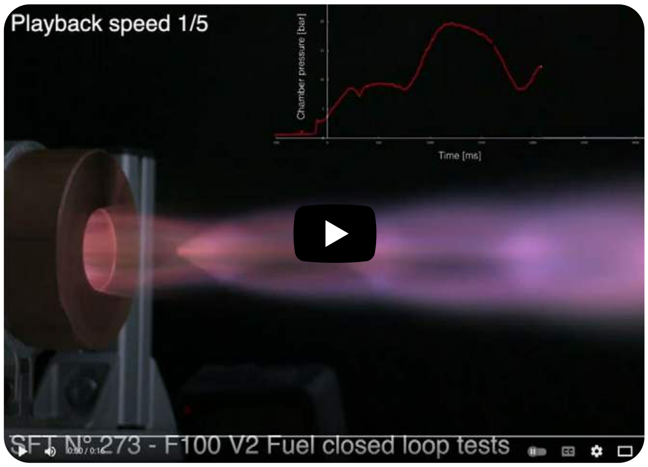
The high-speed camera was used during **three** main types of tests, each targeting a different aspect of rocket improvements:

1. Static Hot-fire Tests

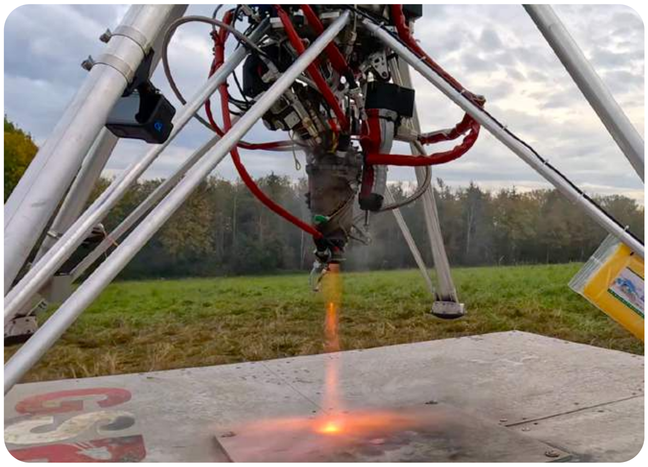
The early stages of the flame and flame-wall interaction provided the team with valuable insight to evaluate film cooling performance. The high-speed footage captured contained the elements to closely analyze flame stability, film integrity, and complex dynamics of flame-wall interaction that occur during the combustion process.

This data was instrumental in assessing how well the cooling film shielded the chamber walls from thermal stress. Additionally, it identified areas where cooling strategies can be optimized to improve the engine's combustion efficiency and structural resilience.

Another significant achievement was the team’s successful implementation of its first **fuel closed-loop control system**. This allowed them to assess combustion across different thrust levels, a critical step in assessing engine reliability and performance.



Video of Colibri's rocket engine filmed with the Chronos 2.1-HD to assess chamber pressure in slow-motion



Colibri rocket engine in action during liftoff

Engine Ignition Test

The goal was to analyze and optimize combustion efficiency. To accomplish that, the team synchronized an LED (for illumination) and the valve that allowed the fuel to flow into the chamber. Due to the fast nature of the process, the Chronos camera recording at 500 FPS provided sufficient temporal resolution for their analysis.

Why is this important?

By visualizing the slow-motion footage of the ignition system, the team could:

- Measure delays between valve actuation and actual fuel or gas appearance.
- Understand the timing of the ignition spark and ensure the timing is accurate to within +/-2 ms
- Analyze the injector behavior in slow motion to catch any delays or oddities.
- Refine the system/practice, if required. For instance, when to trigger injection vs when ignition happened.

This is an important step in rocket development for multiple reasons, such as precise fuel delivery timing to achieve combustion stability. For instance, even small delays (e.g., 2-5 ms) between **valve actuation and actual spray** can cause **poor ignition timing** or **inefficient combustion**.

The LED and valve are triggered at time 0 ms. By counting frames between the LED flash and visible ignition, the team measured ignition delay with ±1–2 ms resolution.

Relevance: The GSP team proved that it is possible to create a reusable rocket with limited resources. This type of technology has important applications shortly due to the revival in interest in space exploration. Chronos is proud to support such self-driven and ambitious individuals who are attacking problems of significant social relevance.

2. Cold Flow Tests

A key component of rocket performance is its ability to make the best use of the propellant energy. The fuel spray pattern produced by the fuel injectors is directly related to fuel burning efficiency.

To evaluate this, the **spray pattern** and **propellant phase behavior** were recorded. Due to the rapid ejection speed of the propellant, high-speed images elucidate the series of events that affect the propellant phase change, especially nitrous oxide behavior, at the exit of the injector.

Additionally, the footage enabled the detailed analysis of injection geometry efficiency, including atomization quality and propellant mixing, both of which are crucial for optimizing injector design and enhancing burn consistency.

Close-up view of fuel ejection from pintle injector, filmed with the Chronos 2.1-HD

Set Up

- **Camera:** Chronos 2.1-HD High-Speed Camera, Color, 32 GB
- **Lens:** Tokina 11-20mm f2.8, Sigma 24-70 f2.8, Tokina 100mm Macro f2.8
- **Lens Adapter:** Nikon F-C, CS-C Adapter
- **Camera Equipment:** Trigger Switch Cable

Camera Equipment used with the Chronos 2.1-HD by the GSP Team

3. Dynamic Take-off and Landing Tests

One of the most critical moments in any rocket flight is the **first and final few seconds**: ignition, takeoff, throttle-down, and landing. For GSP, capturing these stages in detail was essential to improve flight control and ensure safe and upright landings.

Using the Chronos 2.1-HD High-Speed Camera, the team filmed take-off and landing sequences in slow motion. This footage revealed subtle yet important behaviors, such as the precise moment of engine ignition, the release of the umbilical, and the throttle-down response leading to touchdown.

Video of the Colibri rocket take-off, filmed with the Chronos 2.1-HD

> “The high-speed camera was a key asset during the Colibri project, used extensively across different types of ground tests to gather insights that conventional equipment could not provide.”
>
> **Jérémy Marciacq, GSP Co-founder**

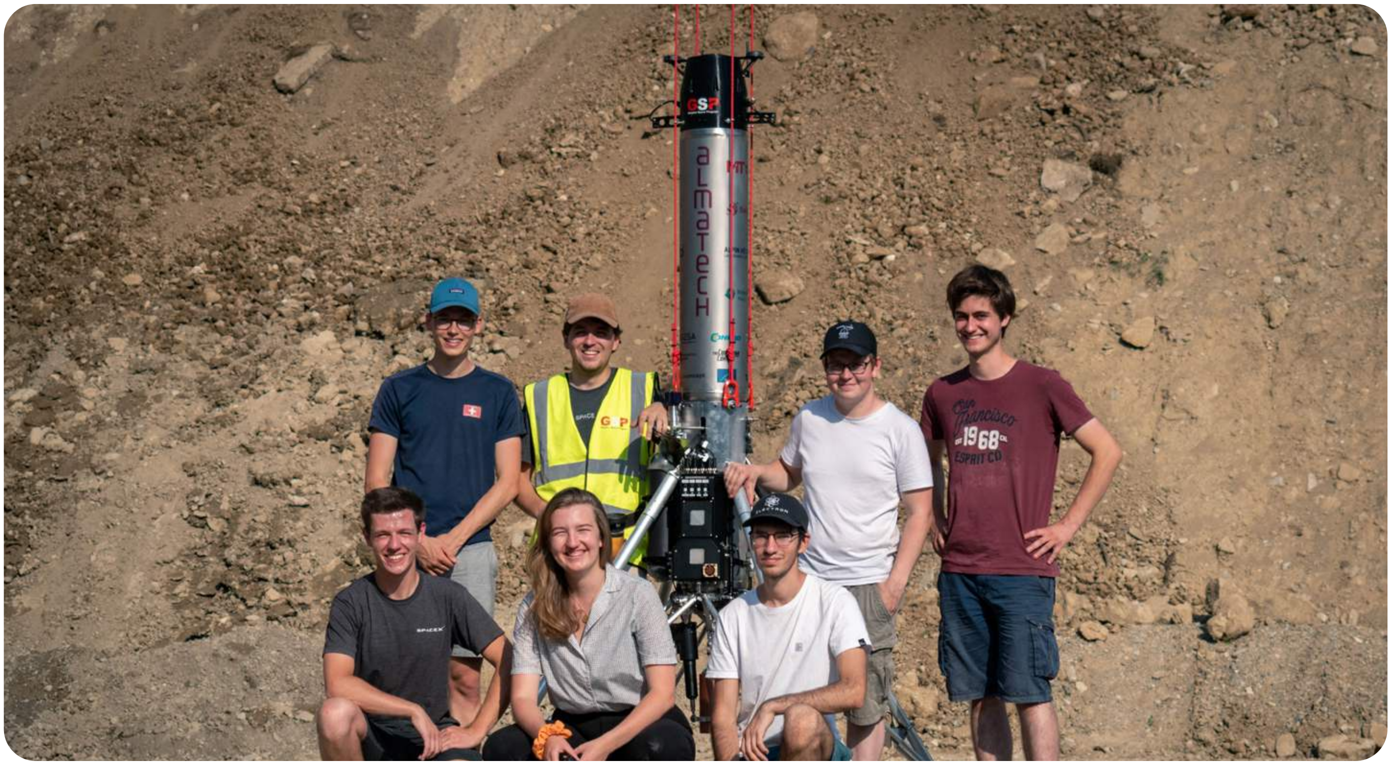
From Technical Troubleshooting to Communication and Marketing

The team’s systematic approach and attention to detail allowed them to use the footage captured by the camera to produce professional-quality video.

Beyond scientific and academic relevance, the videos produced were also used to report technical progress and featured in media and presentation materials. This enabled them to attract and maintain sponsor support and engagement, as well as find other sources of funding.

The table below summarizes when and how the Chronos 2.1-HD High-Speed Camera was used to address engineering challenges during the Colibri project.

Challenges:	Camera Used During:	The Camera Helped the Team to:
Ignition Sequence Tuning	Static hot-fire tests Closed-loop tests	• Tune and verify ignition sequences. • Precisely time valve actuation and ignition spark to optimize combustion onset. • Measure key timings such as ignition delay, valve response times, and flame establishment
Combustion Chamber Cooling	Static hot-fire tests	• Assess film cooling performance • Analyze the cooling film stability and flame-wall interactions during combustion.
Propellant Phase Management	Closed-loop tests	• Evaluate propellant phase changes (especially nitrous oxide behavior) at the injector during cold flows.
Injector Performance	Cold Flow Tests	• Analyze injection geometry efficiency • Ensure proper atomization and effective mixing of propellants during cold flows.
Flight Dynamics	Dynamic Take-off and Landing Tests	• Understand touchdown dynamics • Improve engine throttle-down profiles and landing resilience.



4. What is next for GSP?

After the successful conclusion of Colibri, which involved 53 precision landings, autonomous control, and full engine reusability, GSP has transitioned to **PAVE Space SA**, a Swiss aerospace company led by GSP alumni.

Though Colibri's flight campaign has ended, its legacy continues through PAVE Space SA. They are now focused on developing a kickstage, an orbital transfer vehicle, to move satellites rapidly to their final orbits by building upon the propulsion systems developed during Colibri, with the intent of having higher thrust levels, longer burns, and the operational demands of spaceflight.

The new endeavour, although more complex, is based on the knowledge gained and tools used during the student-led era, which includes the important function of **high-speed imaging**.

5. Conclusion

The success of Colibri is a remarkable achievement in student-led aerospace innovation. Through the team's determination and ambition to push boundaries, the Gruyère Space Program not only built and flew a reusable rocket but also laid the foundation for a professional aerospace venture.

The **Chronos 2.1-HD High-Speed Camera** played a key role in this journey, providing the insight needed to improve ignition sequences, validate injector behavior, and capture dynamics of flight and landing.

Kron Technologies is proud to support such an ambitious group of individuals and will continue to do so. The students behind GSP are a true inspiration, and their story serves as a testament to what's possible in the student-led aerospace field.

About Kron Technologies

Kron Technologies is a Canadian high-speed imaging system design and manufacturing company located in the heart of the Greater Vancouver Area. Kron aims to make high-speed imaging accessible to everyone.

Kron Technologies serves a broad range of customers – from R&D and industrial to media production – anything one might want to have slowed down beyond the human eye's capability.