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Pyxis Project - Constellations Program

Concept Report

Skyward Experimental Rocketry
Politecnico di Milano

Author: *Skyward Team*
Editors: *Matteo Colombo, Federico Corallo, Nicolò Donghi, Federico Formentini, Nicolò Florio, Alberto Nidasio, Massimiliano Restuccia, Davide Rosato, Marco Tatangeli*

SKYWARD EXPERIMENTAL ROCKETRY

POLITECNICO MILANO 1863

Overview

Pyxis is a brand new COTS-propelled rocket from Constellations Program that aims at the 3000 meters apogee at the 2022 EuRoC edition. To achieve this goal, the successor of the 2021 Lynx will feature several upgrades and newly developed technologies that will pave the way for a 2023 hybrid engine powered rocket.

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1. Introduction

1.1 Team Introduction

Skyward Experimental Rocketry is a student association founded 10 years ago to add some practical activities alongside the theoretical teachings of the aerospace engineering course at Politecnico di Milano. Since its establishment, Skyward has designed, built, tested and launched several sounding rockets, holding the student record for highest apogee in Italy reached with Lynx, its first competition rocket, starting point of the Constellations Program.
The Pyxis team is now composed of 104 people coming from various engineering courses, divided into Integrated Teams, each of them guided by an Integrated Project Team Leader. In particular, the teams are: Structures, Aerodynamics, Structural Dynamics and Aeroelasticity, Control Systems, Electronics, Mission Analysis, Recovery Systems, Software, Logistics and Media.

1.2 Project Goals

Pyxis project is the outcome of what Skyward has put together over the last few years. The team has finally built a solid and organized association that aims at one goal: creating the best rocket possible by expanding its knowledge base on different aspects, developing new ideas, improving the ability to build a rocket in the span of one year and giving the possibility for the youngest members to make some experience.

1.3 Mission Objectives

- Reach the 3000 meters apogee as precisely as possible;
- Implement new features such as composite materials for the structure, an autonomously guided payload and an improved RF transmission system;
- Improve existing optimization algorithms and simulators and create new ones in order to deepen the understanding of the rocket during the design phase with studies such as the aeroelastic effects on the fins and on the whole structure;
- Give a consistent basis for future rockets both from a technical and an organizational standpoint;
- Start experimental campaigns with scientific payloads.

2. Description of the Rocket

2.1 CON-OPS

The rocket will be brought in a box to EuRoC in a ready-to-assemble form. As soon as the presentations to the jury and the FRR are done, the procedures can start. Pyxis is then brought to the launch site dismounted in few bays, only making it necessary to insert the motor, the electronics and the recovery systems and to screw together the modules.

- **Assembly**: 2 hours before ignition, the final integration of the rocket starts in order to prepare Pyxis for transportation to the launchpad;
- **Launchpad setup**: after the integration, the rocket is brought to the pad and lifted on the launch rail. The on-board avionics is powered on and the igniter is inserted. Once the procedure is complete all personnel leaves the launchpad;
- **Pre-flight procedure**: in the last 30 minutes before ignition all the pre-flight checks (telemetry, software, weather) are carried out and the rocket is configured for flight and armed;
- **Ignition**: at $t = 0$ a FIRE signal is sent to the igniter and the motor, a Cesaroni 7579 M1520-P, is ignited;
- **Lift-off**: at approximately $t + 0.5$ s the liftoff phase begins, clearing the launch rail in 0.6 s. As soon as it leaves the launch rail, the rocket is completely free from any ground support and it has the necessary velocity for the fins to provide aerodynamic stability;
- **Powered Flight**: the motor boost lasts until $t + 4.8$ s, during which the rocket reaches the maximum velocity of 313 m/s at around $t + 4.7$ s;
- **Coasting**: after motor burnout, the aerodynamic drag decelerates the rocket down to Mach 0.8 at $t \approx 7$ s, starting the air braking control;
- **Air braking**: when the Mach number is lower than 0.8, air brakes are activated by the avionics to increase drag in order to reach the correct apogee;
- **Apogee**: at $t \approx 24$ s the apogee is reached and detected by the apogee detection algorithm;
- **Nosecone Ejection**: once the apogee is detected the two expulsion systems are activated and the payload bay is ejected, pulling out the drogue parachute;
- **Drogue Descent**: the drogue parachute is completely deployed and it slows down the rocket to 34 m/s. At $t \approx 104$ s Pyxis reaches the altitude of approximately 350 m, at which the cutters on the 3 rings system are activated and the main parachute extraction starts. The same procedure is followed for the nosecone drogue chute, which instead descends at 26 m/s;
- **Parafoil Guidance Descent**: at $t \approx 105$ s the parafoil is deployed to carry the payload to a predefined landing target. Meanwhile, the main parachute is completely deployed and it slows down Pyxis at 7 m/s of vertical speed until touchdown;
- **Landing**: at $t \approx 160$ s the rocket lands and the recovery procedure can start.

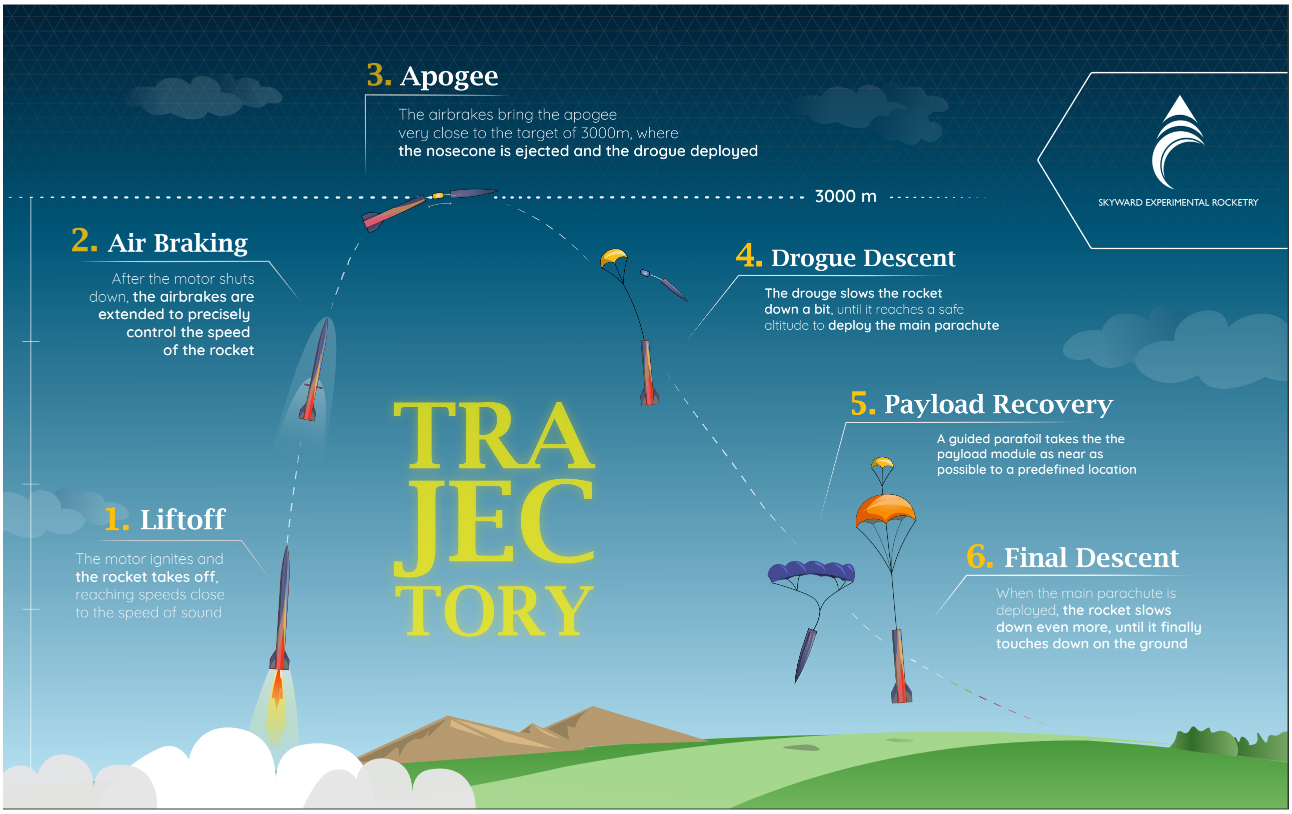

Figure 2.1: Pyxis CON-OPS

2.2 System Concept

Pyxis is organized into different compartments, each of them assigned to a specific subsystem. Even though the concept is similar to Lynx, everything has been re-designed and enhanced both with solutions for problems that arose during EuRoC 2021 operations and brand new, custom designed features.

2.3 General Arrangement

As said, from the bottom to the tip the rocket is organized in different modules. First, the engine bay houses the COTS solid motor and keeps the three carbon fiber fins fixed and correctly aligned. The air brakes are an optimized version of Lynx's, weighting 40% less with larger exposed surface and better actuation. The connection with the electronics bay is ensured by an aluminum flange featuring three cameras and a set of LEDs, used to precisely know the state of the electronics, which is stored inside a glass fiber fuselage with an octagonal antenna system. Moving upwards, the recovery bay has a redundant expulsion system, one SRAD and one COTS, and stores two double stage recovery systems, one for the rocket and the other for the payload, with a guided parafoil. Finally, the payload bay houses the electronics to control its descent, a 1U cubesat and a pitot tube on the tip.

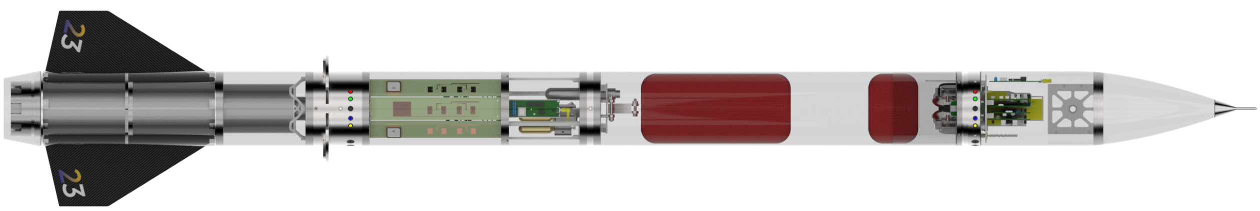

Figure 2.2: Pyxis side section view

2.4 Dimensions

Parameters	Specifications
Length	2511 mm
Diameter	150 mm
Fins Geometry	3 trapezoidal fins
Propellant Weight	3.6 kg
Propulsion Type	Solid
Motor Case	Cesaroni Pro98 3G gen2
Reload	Pro98 M1520-P
Liftoff Mass	20.5 kg
Payload Mass	1.2 kg
Stages	1

Table 2.1: Pyxis specifications.

2.5 Main Performance Figures

Parameters	Specifications
Peak thrust	1827 N
Total impulse	7579 Ns
Burning time	4.8 s
Peak Mach	0.94 Ma
Peak Velocity	313 m/s
Peak acceleration	8.5g
Launchpad exit velocity	39 m/s
Minimum stability margin	1.9 $calibers$

Table 2.2: Pyxis main performance figures.

2.6 Main Systems Description

2.6.1 Electronics

The avionics comprehends two systems: one handling the rocket and the other guiding the payload descent. The main flight computer, an improved version over last year's design, and the auxiliary computer, a simpler board to control the cameras and air brakes, are stored inside the electronics bay. The major improvement is a new dual frequency transceiver system with an octagonal array of antennas that allows a solid data transmission. As for the payload bay, Pyxis will use Lynx boards as they worked properly and still meet the mission requirements, while mitigating chip shortage supplying issues. Each of the two systems has an Eggtimer TRS Flight Computer as a backup.
The onboard computers are able to communicate during the ascent through the CAN bus protocol with a cable that is later disconnected at the separation of the payload from the rest of the rocket. This connection allows, for example, the main flight computer to receive the air speed measured by the payload computer through the pitot tube to improve the position estimate.
Pyxis electronics is powered by six LiPo batteries, three for the payload bay and three for the main system, to grant separate power supplies to the SRAD and COTS electronics and to the cameras.

2.6.2 Software and Control

The software powering the rocket has different objectives. Regarding the main system, the electronics need to control the air brakes to reach the target apogee. To do so, a specific control algorithm is developed in order to achieve the goal in the most precise way possible improving the performance of last year. The full state estimator of the rocket was also updated to integrate the pitot tube and to gather more accurate data.
Concerning the payload, the computer uses a dedicated autonomous guidance, navigation and control system to control the parafoil and safely reach a specific landing area. The sensors fusion algorithm was improved and adapted for Pyxis specifications.

2.6.3 Recovery System

As the rocket reaches the apogee, the nosecone is expelled thanks to the pressure released by two CO_2 canisters and completely detached from the main body. Thus, Pyxis is equipped with two different double-stage recovery systems. At first, the rocket descent is slowed down and stabilized by a drogue chute, which then pulls out the main cross parachute from the deployment bag. Meanwhile, the nosecone is slowed down by a drogue chute that around 400 m of altitude extracts a parafoil which is able to correct the descent direction thanks to two actuators. The transition between the two different recovery stages is obtained through pyro-cutters acting on a three-ring system.
A strain gauge is added to one of the anchoring points in order to collect data on the parachute opening shock force which is hard to estimate with accelerometers.

2.6.4 Payload

A custom designed and manufactured 1U Cubesat accommodates two different systems.
The first comes from a collaboration with the secondary school "Cigna-Baruffi-Garelli" of Mondovì (CN), to let the students design, build and test an experiment. The high schoolers will choose and program some Blebricks, commercial modules for IoT and rapid prototyping, to record different environmental parameters and reconstruct the flight afterwards. This experience will teach them how to work together towards a common goal and make them taste what a STEM career looks like, far beyond simple technical aspects.
The other part of the cubesat is used to test and validate some concepts for next year's rocket. Finally some dummy masses will be added to be compliant with EuRoC rules.

2.7 Materials and Manufacturing Techniques

With Pyxis, the application of composite materials has been extended to all the parts that could fit it. Carbon fiber (CFRP) is used for the boat tail, the motor bay outer shell, the recovery bay fuselage and the fins. Fiberglass has been chosen for all the parts containing components that need to communicate through radio signals with the outside world, such as the electronics bay shell, the coupling tube and the nosecone. Even though composites are the main characters, aluminum has not been discarded. In fact, all the other structural parts featured in the rocket are machined out of aluminum (connections, flanges, etc.). A notable mention is the motor flange: it has been modeled using topology optimization and then 3D printed in AlSi10Mg, a manufacturing technology never used before in our rockets. Lastly, 3D printed PETG has been used for all the plastic parts that are not structural but serve as supports, mounts or spacers.

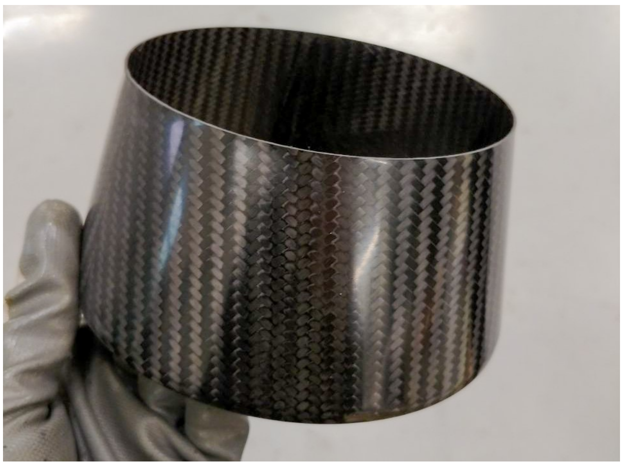

Figure 2.3: CFRP Boat Tail

2.8 Unique Characteristics

This project brought along a lot of new features that allow the team to expand the technical knowledge and undergo new challenges.
The new array of antennas makes it possible to have a much reliable transmission to the ground station. This, in the year to come, is going to make it possible to transmit the video to the ground station and, possibly, to a live stream.
Topological optimization is applied on some components, from the motor head flange in metal, to other pieces 3D-printed in plastic materials. This, together with the usage of composites makes the rocket structurally lightweight.
The most important unique feature of Pyxis is the parafoil, which autonomously guides the payload while collecting flight data. It was necessary designing a completely new system which must satisfy all the requirements imposed by the team and the jury, developing and integrating old components and new ones into a single efficient design, which also mitigates the risk of collision between the main chute and the payload bay by completely detaching it.

Figure 2.4: Helicopter Drop Test of the Parafoil

3. Difficulties and Criticalities

The main expected difficulties are related to the new features and to external factors.
The major criticality is for sure the testing phase of the payload module recovery with the parafoil. This kind of systems are known to be complex and only a strong test campaign can make them reliable enough to be used during flight. Several drop tests from buildings and three helicopter drop tests have already been performed to validate the system, but many others are expected to take place until September, when a complete flight test will be carried out.
Other complex features are the optimized motor head flange and the antenna array, which must be thoroughly tested. The former will be produced in two copies: one will undergo a complete qualification test at more than twice the nominal thrust of the engine while the other, which is the actual flight hardware, will simply be subjected to an acceptance test. Some components of the latter are being tested right now, and the final antenna array will be certified in an anechoic chamber.
Another aspect which should not be underestimated is the composite parts lamination and gluing to the aluminum components. Composites are fairly new to Skyward, since last year the team only used them for the fins, the nosecone and the coupling tube; this means that our understanding of the design and manufacturing of such materials must improve, and tests have to be carried out to make sure that everything is flight ready.
External factors should be taken into account, too: chip shortage, raw materials price increases and COVID forced us to accurately organize the purchasing and production phase by using strict deadlines for the design to compensate for possible delays and components supply issues.

Figure 3.1: Outside Unpainted View of Pyxis