Annual Report

HIRONDELLE

Vahan KOMARYAN - Robin PERDREAU - Loïc LEROY

I. Introduction

Hirondelle is a **multidisciplinary and long term Startup project** that aims to provide a **complete packaged solution** to address the need of **military Spec-Ops Aerial support**. Hirondelle is classified as a **NATO UAS** (Unmanned Aerial System), and offers a disruptive design to the market segment of military drones.
We are using a completely **new airframe model**, with significant advantages over traditional quad-copters and fixed wing designs. Our **three thrust vectored propellers** allow for unmatched performance and radical maneuverability. Hirondelle is tailored to shine in any conflict zone, with **rapid deployment times**, **easy maintenance** and **low footprint** thanks to its VTOL (Vertical Take Off and Landing) enabled design. Hirondelle aims to bring a crucial asymmetric advantage to infantry and mission command in a variety of scenarios :

- Recon and Surveillance
- Target Designation
- Logistics and Cargo
- Tactical unit Cover
- Covert-Ops and Infiltration
- Air Dominance and anti-UAV/S
- Direct Strike and Ordonnance delivery
- Emergency Medical Delivery

II. Background and preceding work

As of the start of our 4th engineering year, Hirondelle enters its **second year of developpement**. We started working on it in September of 2023, and it has come a long way since the beginning.

Last year, we developed our **first prototype**, and we reached a lot of technological milestones. It was our first step into the robotics and engineering world, so we had to experiment with a lot of different techniques, materials and concepts. Finally, we **successfully developed a platform** suitable to model, test and review the basic capabilities of Hirondelle.

Before continuing our report to the current status of Hirondelle's development, it is important to **recall what was the state of the project** before the start of the year, to establish a basis of systematic comparison and benchmark.

1. Architecture

1.1. Frame

The V1's frame was made out of **30mm Aluminum tubes**, held together by **PETG 3D printed parts**. The choice of those basic materials was a result of our lack of knowledge in this field, and forced us to reinforce parts of the frame with heavy bolts and zip-ties.

It was very sturdy, but also **very heavy** (13.4 kg). The structure was arranged in a planar diamond shape, easy to work on, but providing no real structural benefits.

1.2. Actuators and Motors

We used **Direct Current Motors** with planetary gearboxes for our rotating propellers. They proved to be very easy to control, with plug-and-play H bridge drivers. 3D Printed gears were responsible for transmitting the torque from the motors to the propeller arms. Although very easy, this system was **very heavy**, necessitated a **lot of wiring**, and provided **poor accuracy** and significant **backlash**.

1.3. Electronics

The electronic design of our first prototype used a mix of **pre-made** and **custom made PCBs**. The system was very **inefficient**, sensitive to **noise**, and the wiring harness was very fragile.

The power design was very poor, we used two 6 cells Lipo batteries in series to provide the 48V to the propulsion motors. This means that both batteries had to sustain the full current load at any time, which significantly increased wire gauge requirements, heat dissipation and resistive power loss.

Another 3S lipo battery was used to supply the digital circuitry and the DC motors.
We used one ESP32 to control the whole drone.

2. Testing

After the end of the semester, we continued working on the drone during the summer. This additional time allowed us to **fully test the first prototype**, make some adjustments to the design, and create a controller from the ground up.

Testing the drone was done in a controlled **indoor environment,** with a strapping system that allowed us to test each degree of freedom individually, and limit the range of movements. Tuning the controller was a very tedious process, with a lot of trial and error. This is because the first prototype had 11 PID controllers, with some in cascade.

Eventually, we **got it working to a very acceptable degree**, the drone was able to fully stabilize around the Pitch and Roll axis, strafe in a 2D plane and recover from large external perturbations.

3. Key Takeaways

Developing this first prototype was an **important step to validate the design**, and gain knowledge. It was also a way for us to demonstrate the **feasibility** of such a drone. We were very satisfied with the design, and the performance of the systems used.

The next logical step was to **improve the drone in all possible metrics**. This meant that a big redesign of the prototype was in order. Working and testing the V1 had raised significant concerns regarding robustness, efficiency and weight, to name a few.

Thus, we decided to relinquish this V1, to **start from scratch and develop a better design**, more inline with our ambitions. This brings us to this year’s development timeline.

III. Development

1. Hirondelle

The **initial plan** for the V2 was quite simple, **redesign everything with optimisation and efficiency** in mind. The goal was to make Hirondelle **closer to a preseries product**, and build a basis that could truly show the potential of the concept.

Starting in September 2024, we started working on **improving all of the major subsystems**, the development for each of them will be detailed below.

A. Frame

The frame is obviously one of, if not the **most important system** of the drone. It is meant to provide a strong structure, onto which every other system is fixed. It is also one of the heaviest and hardest to design. This is why the frame of the V2 underwent **multiple iterative designs**, with major setbacks along the way, before finally settling on a truly remarkable frame design.
One of the core requirements for this frame was to be as **lightweight and rigid** as possible. This was achieved with **composite materials** and a **3 dimensional tubular design**. The backbone of the frame was made out of 10mm Carbon Fibre tubes, held together by parts printed out of Carbon infused filaments.
The first iteration was very basic, with a minimum amount of tubes, the joints were made out of Nylon-CF, and the frame ended up being way **too flexible** (**Figure A.1**).

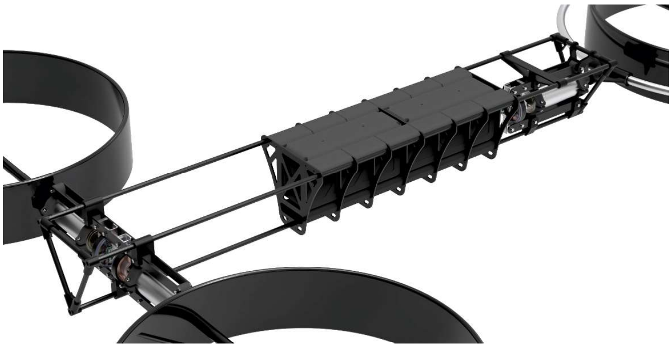


Figure A.1 *V2.0 of the frame*

To fix this issue, **additional tubes** were added to strengthen the frame, but another problem emerged : the joints were able to slide on the tubes, making the **chassis quite bendy** (**Figure A.2**).

Figure A.2 *V2.1 of the frame*

Another solution was found, involving **bolts and double sided adhesive** to grip on the tubes (**Figure A.3**). This solution was functional, but very **unpractical**, as any modification on any part forced the whole frame to be taken apart.

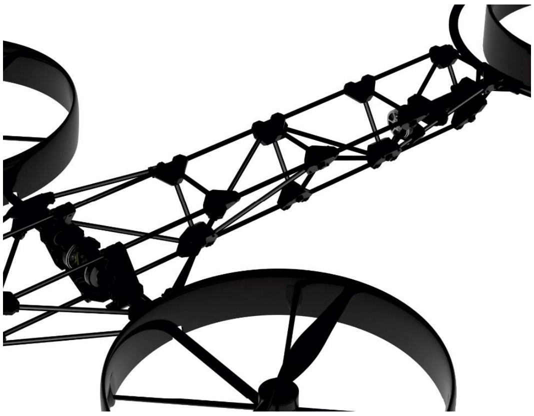
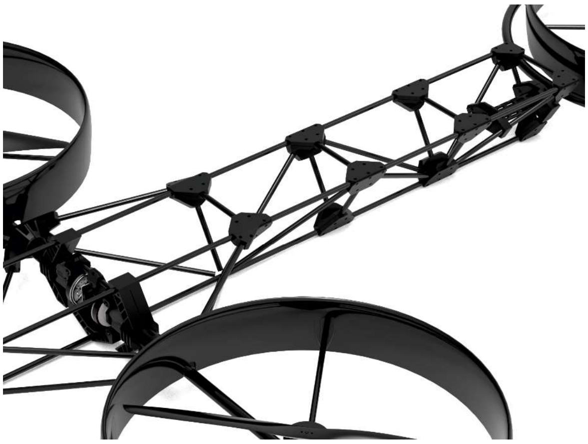


Figure A.3 *V2.3 of the frame*

In the final iteration, joints are no longer slid along the tubes, but **bolted in place** (**Figure A.4**). This solution provides great strength and easy maintenance. This final design weighs in at **1.7 kg, compared to the 7kg of the V1**.

Figure A.4 *V2.4 of the frame*



The frame must also accommodate all the **actuators and the electronics**. One spot is of particular importance. In the middle of the two front propulsion units, there are two motors that need to be mounted very precisely and secured strongly, to **sustain the full torque** required **without deformation**. Hall Angle sensors also need to be mounted close to the motors, with **sub-millimeter accuracy**, to obtain accurate angle feedback.

The part responsible for securing all of those in place is referred to as the "**Nexus**".

The Nexus underwent significant changes during the development (**Figure A.5**).

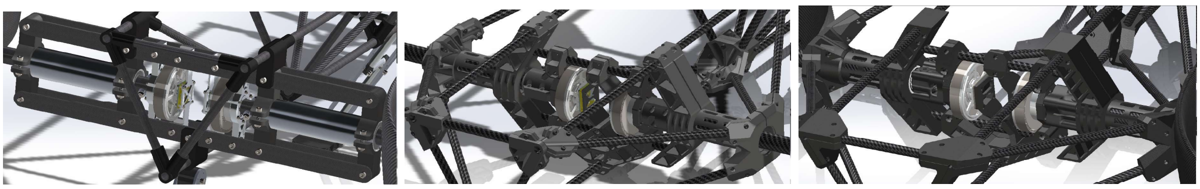


Figure A.5 *Evolution of the "Nexus"*

As we developed new fabrication techniques and gained knowledge, we improved the Nexus, following the same design principles as the frame.

The **rear propulsion unit**, with its **two degrees of freedom**, is one of the **most complex parts** of Hirondelle. We were able to make it very light and durable by using a rounded tube of aluminum, covered in Carbon Fiber and Kevlar, and then welded to the rear axle with epoxy resin and more composite fibers (**Figure A.6**).

Figure A.6 *Rear Propulsion unit of Hirondelle*

B. Actuators

One of the major improvements of the V2 comes from the choice of actuators. This is to be expected, as the actuators previously used on the V1 were very basic and had poor performance. Actuators play a crucial role in the overall performance of the drone. They are responsible for all of the degrees of freedom allowed by our design. A lot of parameters need to be taken into account for it to be coherent with the rest of the design.
For the V2, we tried several different actuator types : Servos, Brushed DC, Direct Drive BLDC…
Our final pick was the **CubeMars AKE60-8 (Figure B.1)**. This is a **Quasi-Direct-Drive Brushless DC motor**, with an integrated **8:1 planetary gearbox**, making it the best performer for our application.
Here are a few of its FoM (Figure of Merit) parameters :

- Weight : *260g*
- Stall Torque : *15Nm*
- No-Load Speed : *240 RPM*
- Stall Current : *12 Amps*

Figure B.1 *CubeMars AKE60-8*

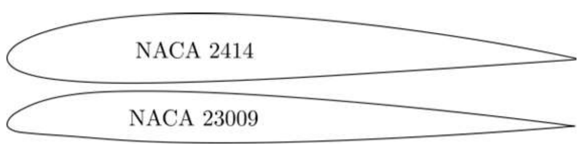
The most challenging part about those actuators is the driving. Brushless DC motors require three phase power signals to function. Generating those signals is very tricky, as it requires the knowledge of the absolute position of the motor, as well as its electronic position, magnetic flux and coil currents. All of that data can then be fed to an Algorithm called **Field-Oriented-Control** (FOC) to reconstruct the magnetic field of the motor, and apply the correct input signals.

C. Aerodynamics

One of the **special features** of the Hirondelle's aerodynamic formula is its ability to **take off vertically** and then **switch to an efficient horizontal flight mode**. Efficient horizontal flight requires wings in the style of traditional aircraft. The choice of wing profile takes into account the following constraints:

- Lighten the aircraft by at least 80% of its empty flight weight (≈ 10 kg)
- Efficiency at cruising speed (80 knots ≈ 150 km/h)
- Compact wing area for ease of transport (≤ 1 m²/unit)
- Profiles suited to our manufacturing methods (FDM printing, 3-axis CNC machining, fibering without evacuation)

According to the above-mentioned criteria, the **most suitable wing profiles** are NACA 2414 and NACA 23009 (**Figure C.1**), which are also standard airfoils commonly used in modern aeronautics for their excellent lift to drag ratio. We have chosen to use two distinct airfoils in our design because, to maximize wing efficiency, it is preferable to maintain a constant wing thickness, and the chord at the base of the wing is much greater than that at its tip (**Figure C.2**). It is therefore necessary to have a first profile for the base of the wing (elongated and thin) which transforms into a second profile (short and thick) as we approach the tip of the wing, in order to compensate for the difference in chord length.



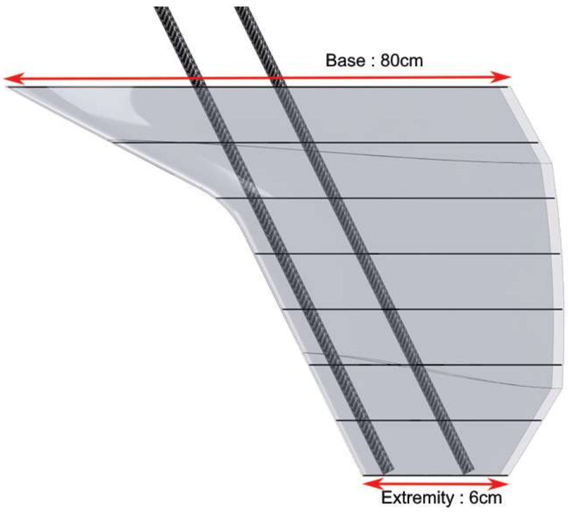


Figure C.1 *Comparison of selected profiles* **Figure C.2** *Wing chord*

To ensure that these two profiles were indeed the right ones, we carried out virtual wind tunnel simulations in SolidWorks, which enabled us to verify the wing's behavior under our flight conditions, as well as the performance we could expect from it.

The simulations showed that our choice of profile and wing shape was in line with our specifications. In the visuals below, we can see that our wing does indeed produce a **significant depression** on its upper section (visible in blue), which is the objective to be achieved with a wing. We can also see that our solution generates very **little drag and vortex** behind it, which is a sign of its effectiveness (**Figure C.3**).

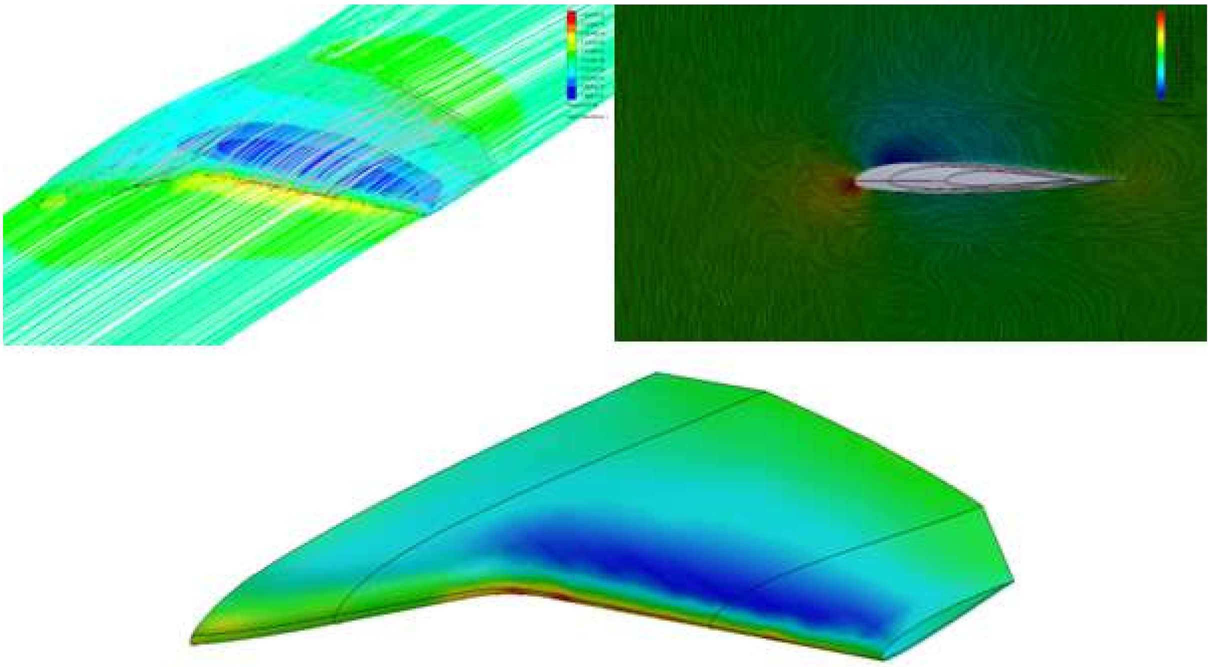


Figure C.3 *Aerodynamic simulation results (1. Airflow trajectory; 2. Airflow verticality around the wing; 3. Air pressure on the wing surface)*

Let's turn now to the practical aspects of wing architecture and construction. In aeronautics, in order to make wings light and rigid at the same time, they are most often made of a **fiberglass** or even **carbon fiber shell**, reinforced with ribs. The wings also contain one or more spars to stiffen them and attach them to the aircraft.

For our wings, we used a very similar architecture, simply replacing the spars with carbon tubes for reasons of scale and ease of installation (**Figure C.2)**. We built a 1:3 scale wing ourselves, starting with the creation of a polyurethane foam mold machined by 3-axis milling (**Figure C.3)**. The mold was then covered with a film to allow easy removal from the mold. We then applied two layers of fiberglass cloth (2x2,200 g/m²) impregnated with epoxy resin (**Figure C.5)**. Once the resin had cured, the part was sanded and re-varnished twice to obtain a polished surface as free of defects as possible. We repeated these operations a second time for the second half of the wing. For the ribs, we opted for laser-cut 3 mm plywood. Finally, we assembled the ribs on the carbon tubes and closed the two half-shells around them (**Figure C.6)**.

Figure C.4&5 *Mould machined and fiber-forming in progress*

Figure C.6 *Final assembly*

The aerodynamic development of the Hirondelle has resulted in a wing that combines vertical take-off with efficient horizontal flight at 80 =knots. The NACA 2414 and NACA 23009 airfoils optimize the lift/drag ratio, while respecting the constraints of lightness and compactness. The manufacturing process, based on CNC machining, vacuumless fiberglassing and the use of fiberglass, **validated the design and methods** at 1:3 scale. These approaches will be **re-used for full-scale manufacture**, confirming their effectiveness for the rest of the project.

D. Batteries

Moving on to batteries, we also had some **significant improvements** between the V1 and the V2. We completely reworked the system, as it was clearly one of the weakest points of the drone. We decided to build our own battery pack, to tailor it to our needs. We kept the same battery voltage, **12S** (48v), but we rearranged the pack as **two individual batteries** of 12S3P, in parallel, as opposed to the previous two 6S put in series. This means that the load for each battery is halved, reducing power dissipation and wire gauge. We also switched from a Li-Po to a **Li-Ion chemistry**. We chose cells with a unit-cap of **5000mAh** and peak current of **60A**. This allows each battery to deliver up to 180A, which is an acceptable safety margin.
Each battery is assembled with **Nylon-CF** printed brackets, soldered with a pure Nickel sheet, and secured in a **Carbon-Kevlar case**. Each battery features a **LED display** for voltage monitoring, a ON-OFF switch, a “armed” switch, a **MOLEX connector** with high current capability, a cooling fan and a dual quick release system for easy battery removal.

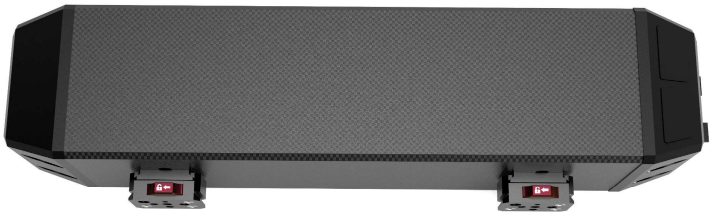


Figure D.1 *Dual quick release system on the side of the battery*

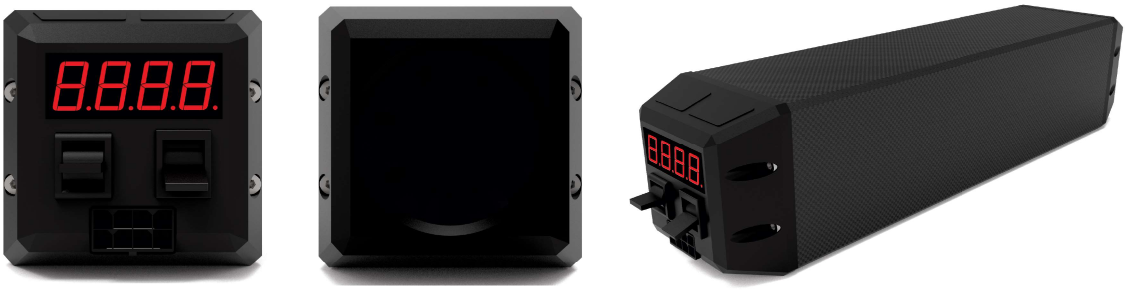


Figure D.2 *Battery front panel, back panel, ¾ view*

E. Electronics

Electronic design is of **utmost importance** to sustain the **heavy current** loads, **harsh environment**, and **high processing power**. For this V2, we completely reworked the electronic design. The first step was to create guidelines that would allow for cross-compatibility and reliable operation.

Those guidelines include the choice of connectors, provided by **Molex**; those range from 0.8mm pitch high density signal connectors to 10mm+ pitch high current connectors.

Next, we needed a strong physical to application standard protocol to allow the circuits to communicate. We chose **CAN** (Controller Area Network), a very reliable and noise-immune protocol used in aerospace and automotive industries. It uses a differential pair, and standalone transceivers, allowing for very high common mode voltage and interference resistance all while maintaining a bitrate north of 1Mbps on cables reaching hundreds of cumulated length.

Microcontroller selection was quite a bit trickier. There is a wide panel of readily available microcontrollers from all of the major electronics brands. One very popular choice for industrial applications is the **STM32** family of 32bit specialized MCUs. They are based on the ARM architecture, and come in all shapes and sizes, ranging from tiny low-power to 600 pins multi-core powerhouses. The peripherals included are also application dependent.

We spent the first few months experimenting with the STM32s. They are easy to integrate in any design, but proved to be hard to debug and develop for. This is why we later switched to **ESP32S3** Microcontrollers from Espressif. They are dual RISC cores, clocked at 240Mhz and they are packed with all of the peripherals we need.

The design principles also evolved dramatically from the V1 to the V2. **Every PCB** that needs logic to function **integrates an MCU**. This makes it easier to develop and test, as every PCB is independent and can be tested as such. The nervous system of the drone now features **more than 15 individual MCUs**.
Because we switched the battery architecture, we now have to step the battery voltage down. This is done on almost all PCBs. Each PCBs must **generate its own voltages**. This is done to make the overall architecture more manageable.
Each PCB is **assembled**, fully brought up, benchmarked and **stress tested** to ensure longevity and trustworthiness.

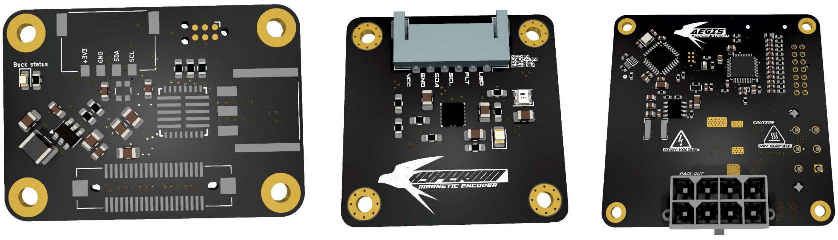


Figure E.1 *Some Example of PCBs used on the V2*

F. Landing gears

Like every other aircraft, Hirondelle must land in safe conditions, this is why we developed a unique landing gear system with **special kinematics** allowing it to fold in and out the landing pads using only **two simple actuators**. The goal of having foldable landing gears is to **avoid the drag** that fixed landing gears would generate. The main challenge is to get solution with the following characteristics:

- Lightweight
- Resist an impact from a 1 m drop
- Fold inside the aircraft fairing

The “legs” are made with **two carbon fiber tubes** allowing some damping in case of a rough landing held together with **high strength resin parts** (Formlab Tough 1500 resin). The end of each leg is covered with a TPU pad offering a non-slip surface, high abrasion resistance and cushioning. The “legs” are moved by a **linear actuator** which is very convenient to use, lightweight and very compact in size.

Figure F.1 *The different iterations of the rear landing gears*

At the front, the “leg” is exactly the same as the rear ones but what differs is the **locking mechanism** which keeps the front landing gear in position when it is deployed. This mechanism is needed because the front led has an **angle when it is open** and the linear **actuator is not strong enough** to keep the front landing gear from folding under the weight of the aircraft. The locking mechanism is composed of a servo motor with a latch attached to it. When the front leg is fully deployed, the latch is turned in a groove inside the **two carbon forged parts** (recognizable by their curvy shape) so when Hirondelle lands, the front landing gear cannot fold under the weight and the linear actuator is protected against any overload.

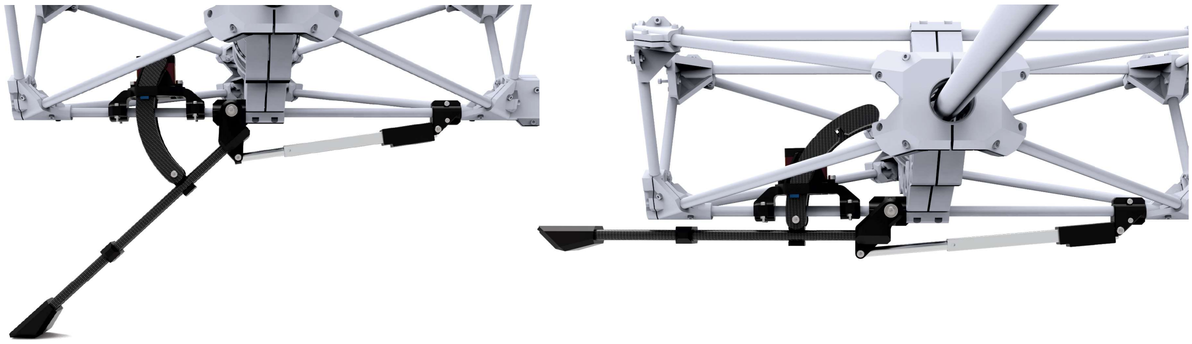


Figure F.2 *The front landing gear in opened and closed positions*

2. Accessories

A. Gimbal and mounting points

Figure B.1 *Gimbal overview*

Hirondelle is designed to be as **modular** as possible, adapting to all **types of terrain and missions**. That's why we've designed the Hirondelle with a number of attachment points for different modules. The “Strix” gimbal is one of these modules. It's a **2-axis camera** that can be placed at the front of the chassis. “Strix” could be considered a project in its own right, given the complexity of what needs to be done - electronically, optronically and mechanically - but it's a crucial part of Hirondelle. Once airborne, “Strix” will be **Hirondelle's eyes** and will enable fluid navigation, whether by manual guidance with **headtracking** or **autonomous piloting** with SLAM.

A number of **other payload options** are currently under development, such as a **geolocated transport case** that will enable Hirondelle to exploit its full payload potential and transport equipment completely autonomously

B. Remote control

To control the drone, we started the prototyping and research to build **our own remote control**. This remote allows the end user to **customize parameters**, **plan operations**, and **pilot Hirondelle** remotely, with a secured uplink.
We are developing our own **control software** called “**Harfang**”. This software runs on a **lightweight LINUX** distribution.
The processing power to run the OS comes from a **raspberry pi compute module 5**, directly driven by a custom made PCB. The remote runs on Li-Ion batteries, and offers more than 8 hours of runtime on a single charge.
The exterior is made out of **forged Carbon Fiber**, to be shock resistant and durable.

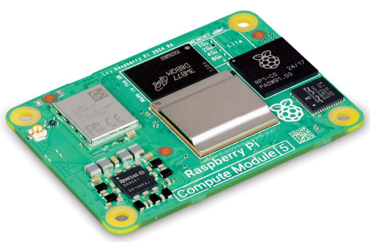


Figure A.1 *Raspberry pi compute module 5*