HIRONDELLE

FINAL PROJECT REPORT

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Abstract

Hirondelle is a multidisciplinary and long-term Startup project that aims to provide a complete packaged solution to address the need for 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 quadcopters 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 blazing fast 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

The Hirondelle project started two years ago at the start of our Robotics Engineering journey. Its scope is way beyond traditional yearly projects, and the present report aims to shine light on some of the critical and groundbreaking work that has been accomplished in the first half of our fifth and final year. As such, we will quickly recall preceding work to provide contextual clues to the reader, but many details will be skipped to focus on the last few iterations. This report is intended to be read by authorized people that have prior knowledge about the project, to fully grasp the scope and timeline of development.

I. Background and Preceding Work

1. Version 1.0 – ROB3

The very first Hirondelle prototype was conceived, assembled, tested, and discarded all in the seven months spanning from December 2023 to August 2024. It was meant to be an initial proof of concept, and testing ground for us to build our knowledge base and improve our engineering skills to a point where we felt comfortable moving forward to a more complex and advanced system architecture.

The chassis of this first prototype was entirely made from aluminum 30mm tubes, held together by large PETG 3D printed parts bolted to the tubes. The overall shape is reminiscent of a kite, similar to an elongated octagon. All of the structural tubes were coplanar to each other. These design choices made it a very sturdy and easy to build frame, but it was severely over-engineered and overkilled for the task. This resulted in a very heavy drone, with very large angular and linear momentum, making it harder to act accurately.

Speaking of actuators, we settled for standard issued Gear-boxed DC motors to control the 3D thrust vectored axis. The DC motors were rotationally coupled to the axis using 3D printed herringbone gears. For our purpose, we needed a precise angle control for all four degrees-of-freedom (DOFs); that was achieved by closing the feedback loop with a custom-made magnetic sensor PCB, and H-Bridge controllers. The result was a very fragile, resonating and overly complex actuation system, with disappointingly large backlash, and multiple critical failure points. It was just enough to get us through initial testing.

The overall electronic architecture was also sub-optimal, with a single ESP32 devkitcv4, multiple I2C ADC and GPIO expansion ICs to get around pin count limitations, and two different power circuits. The main power circuit consisted of two 6S LiPo batteries in series to provide adequate 48V power to the thrusters, while the secondary power bus was a 3S 11.1V LiPo battery, to power the actuator and the logic circuitry. A custom power dissipation board was made, but our lack of knowledge made it perform very poorly, and some design choices led to catastrophic failures: low-side N-Mosfet switching meant ground was effectively disconnected from the power bus, but current could still flow through the logic circuit via ESC's logic ground, effectively bypassing the Mosfets altogether.

The only part of the first prototype that was reused throughout the project, and still in service as of now, is the propulsion system. This is the critical choice that set up the scope of the entire project, effectively constraining the size of the drone. We opted for T-Motor V605 brushless VTOL series motors, with up to 3.2kW of continuous output each, paired with 22 Inches (54cm) carbon propellers for maximum thrust to size ratio. These propellers are specially made for heavy lift convertible drones, with a 7.4-inch pitch, that allows for fast horizontal flight and heavy stationary loads. Together, this motor-propeller combo provides up to 12.7 kg of static thrust, and amounts to 38 kg of total thrust, without any duct boost. That gives us adequate power margins for future developments, and this choice proved to be solid as it is still suited to today's context.

The first prototype is shown in **Figure I.1**.

Figure I.1 *First Hirondelle Prototype*

During the summer of 2024, we did all kinds of tests with this first prototype. The main goal was to achieve a good enough stabilization, with ample phase and gain margin. This was no easy task, as there is no readily available flight controller or control algorithm for this kind of drone. We had to build the flight control software from scratch, based on the Arduino framework. It was very simple, with a single outer PID loop that uses Euler angles (roll, pitch, yaw) to compute output thrust offsets directly. This implementation is very basic, but the performance was good enough for us to consider this as a success and move on to a more refined prototype.

2. Version 2.0 – ROB4

This brings us to the second version of the prototype. After gaining a lot of experience in all domains from the first prototype, we felt ready to undertake a much bigger challenge and actually build an advanced UAS system. The goal was to conceive and build a drone that would enable us to test the full flight envelope of the drone and unleash its full potential.

To do that, we had to depart from the previous design's paradigms, as there was almost nothing that could be taken from V1.0 and satisfy the aim of V2.0. We had to start over from scratch.

First order of business: weight savings. We designed the new version around a 3D triangular tubular frame, entirely made of carbon fiber tubes and composite reinforced 3D printed parts. This gave us a relatively sturdy structure, with the ability to absorb and damp some vibrations with compliant deformation, all while weighing at only 1.7 kg for the whole frame. This is a substantial decrease from the previous version. It was quite difficult to get the frame right, and we had to go through several iterations, material testing, and reinforcements struts to get to a satisfying result.

Another big improvement for weight saving was the switch from two ready-made LiPo 6s batteries in series to two custom built Li-Ion 12S packs in parallel. This bumped the overall power density by more than 32%, all while greatly reducing electronic complexity. Indeed, having two 6S in series to achieve the full 48V meant that both batteries would have to always handle the full current load, but we now have two 12S batteries that can share the current load, to effectively halve the current flowing in each battery. This means less resistive power loss ($Pj = R*I^2$) and smaller cable gauge.

Next, we discarded the DC actuators for Brushless DC ones, the AKE60-8. That have incredible performance but are difficult to control efficiently. They worked for a time thanks to custom built FOC (field-oriented control) motor drivers but were eventually replaced by newer integrated motors. More on that later in the report.

Electronic architecture also saw a radical change in philosophy. We departed from the centralized ESP32 module, to go for a multiple STM32 mesh. We chose CAN (controller area network) bus for communication between the nodes of the mesh, mainly for its differential nature, proven reliability, high data rates (1 Mb/s for CAN2.0B) and noise immunity. The mesh had a lot of different PCBs, ranging from simple LED and Servo drivers to Flight Controllers, automated axis calibration IMUs, FOC drives, BMS...

The second prototype (early stage of development) is shown in **Figure I.2**.

Figure I.2 *Second Hirondelle Prototype (Early Stage of Development)*

II. Design Overhaul

The first task we gave ourselves before this school year even began was to come up with a new design for the drone. We had been using the first design since the very beginning, and an overhaul was way overdue. The goal was to create a signature look for the drone that could be displayed and shown to anyone interested in the project. You can see the visual in **Figure II.1**.

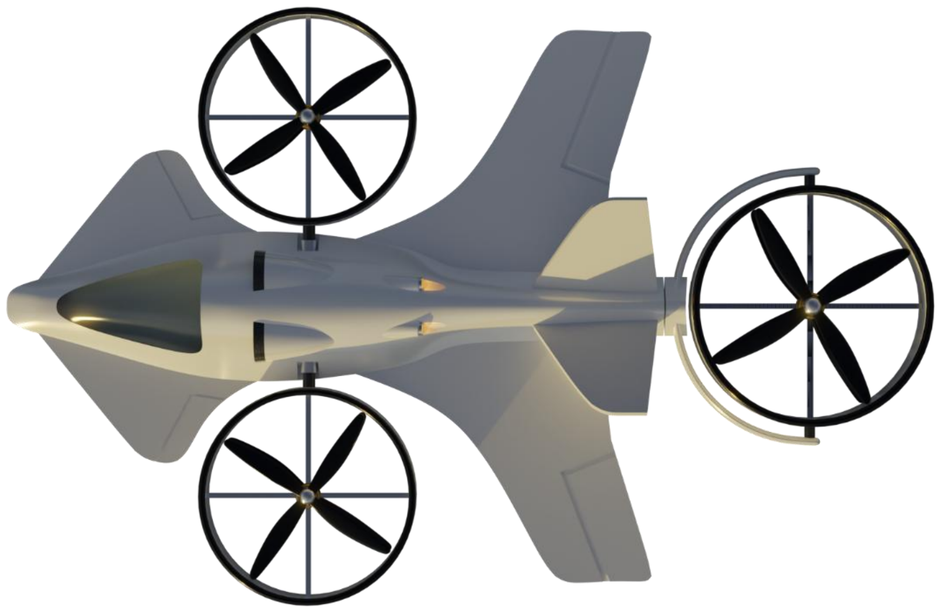

Figure II.1 First Hirondelle Design

The first step in the design process is to establish design codes and artistical choices that will serve as a guide all along the modelling work. We wanted to have a sleek design, with nice flowing lines, but also some hard surfaces, and sharp edges to really put the emphasis on the futuristic and serious look. We gathered a lot of reference images, artworks and inspiration, mostly from science fiction movies, video games like Star Citizen, and real-life aircraft like the Lockheed F22 Raptor, or the Dassault Rafale F4.

Next, we moved on to the sketching phase; we used the infamous paper and pen combo to draw dozens of shapes, lines, edges… until we got a clearer idea of what could or could not work. Some modelling was also done to see how the lines would interact with perspective, texturing and lightning, to get a better sense of the artistical direction.

Once we had a clear picture in mind, the time came to start modelling. This phase took place exclusively on Blender 4.3. Blender is an open-source software that has been developed by the community for over a decade now, and it is now at such a high level of feature integration that it is widely considered to be the best 3D modelling tool available. A good indicator of its maturity, is its growing userbase in industry applications like cinema, VFX, product rendering, architecture visualization… Blender also comes packed with an incredible amount of features like path traced rendering, smoke and water simulations, physics engine, node-based materials, sculpting…

Blender is a geometry-based modeler, as opposed to engineering tools like SolidWorks and Fusion360 that are parametric modelers. What is means is that instead of using sketches and mathematical operations, you instead model using primitive shapes (cube, sphere, plane…) and deform the shape by manipulating the vertices, edges and faces directly. This workflow is way more adapted to modelling objects that don’t need extreme precision or have mechanical constraints, that is to say, Blender is more adapted for actual Art.

The modelling of the drone took us around a month, and it was an excruciating process of moving individual vertices around until the shape looked perfect. We had a lot of back and forth between us to iteratively improve small portions of the design. We also used the V2.0 frame to serve as a basis and mechanical ground truth.

After the raw model design was finished, we went on to do the texturing. We could have done it entirely inside Blender, but it was a nice opportunity to try out another tool (included in our student licenses): Autodesk Substance Painter. It is a tool that features parametric and paint-based texturing. We spent a lot of time adjusting the colors and the details to make the textures as realistic as possible. The texturing process really is the step that makes it all come together, and it is particularly satisfying to see the model start looking like what we had in mind (see **Figure II.2**).

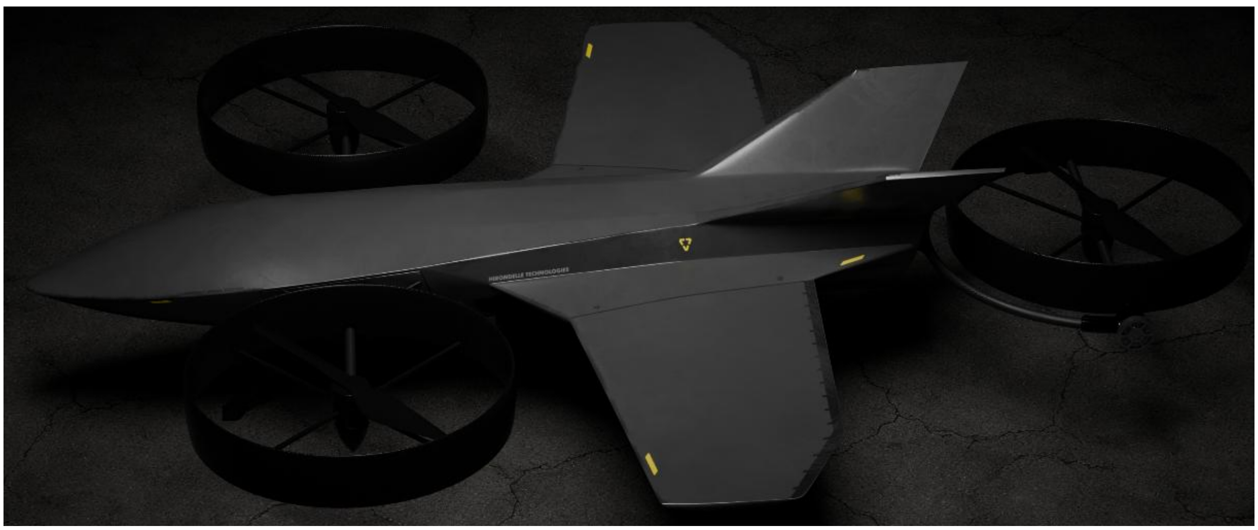

Figure II.2 Second Hirondelle Design

Once the model is finished, polished and textured, we can start making actual promotional materials with it and prepare the tools to make it come to be in real life. We used Blender and Unreal Engine 5 to make renders of the drone, whether static or dynamic videos, to then put on our website and PowerPoint presentations.

III. Mechanical Development

This section of the report focuses solely on the developments made since last year's final project report. A substantial amount of work has been carried out but is not detailed here; only the most significant new information has been retained for clarity.

1. New guidance motors

Hirondelle can tilt its axes in multiple directions to achieve thrust vectoring. This functionality requires strong and reliable actuators. Initially, the AKE60-8 motors (see **Figure III.1**) were used to actuate the axes. These motors were driven by an in-house–designed PCB and coupled with Hall-effect sensors to provide precise angular position feedback. While this solution was elegant and intellectually rewarding, it required a significant development effort before a first functional system could be achieved.

Figure III.1 *AKE60-8 Motor*

As the team size decreased, it was no longer feasible to both accelerate the overall project development and continue investing time in such complex custom systems. Consequently, we decided to adopt an alternative approach. We selected newly released AK45-36 motors (see **Figure III.2**) from T-Motor, which had just entered the market at the time of this work.

Figure III.2 *AK45-36 Motor*

These motors were chosen because they significantly accelerate the development process of Hirondelle. Indeed, they integrate their own controller and sensors, eliminating the need for custom-designed PCBs. Compared to the previous solution, they offer a far more "plug-and-play" integration.

The motors operate at 24 V, whereas the onboard batteries provide 48 V. Consequently, step-down (buck) converters were required to supply them with the appropriate voltage; suitable components were readily available on the market

Let’s compare these motors.

	AKE60-8	*AK45-36*
No load speed [rpm]	**240**	52
Peak torque [Nm]	12.5	**24**
Peak consumption [W]	288	**156**
Price [$]	218.8	**135**
Weight [g]	**260**	340
Ease of integration	--	**++**

From a mechanical standpoint, these motors are slower than the previously used AKE60-8, but they provide significantly higher torque. This results in a more suitable compromise for Hirondelle, which does not require the high rotational speeds offered by the AKE60-8.

The AK45-36 motors are heavier than the AKE60-8, mainly due to the mass of their embedded controller and sensors, components that are not included in the AKE60-8 specifications, as it does not integrate them, as well as the presence of a reduction gearbox.

Finally, these motors are also more cost-effective, which is a significant advantage for small-series production.

These new motors must be properly integrated into the airframe to ensure correct operation. For this reason, entirely new mounting supports were designed within the structure (see **Figure III.3**).

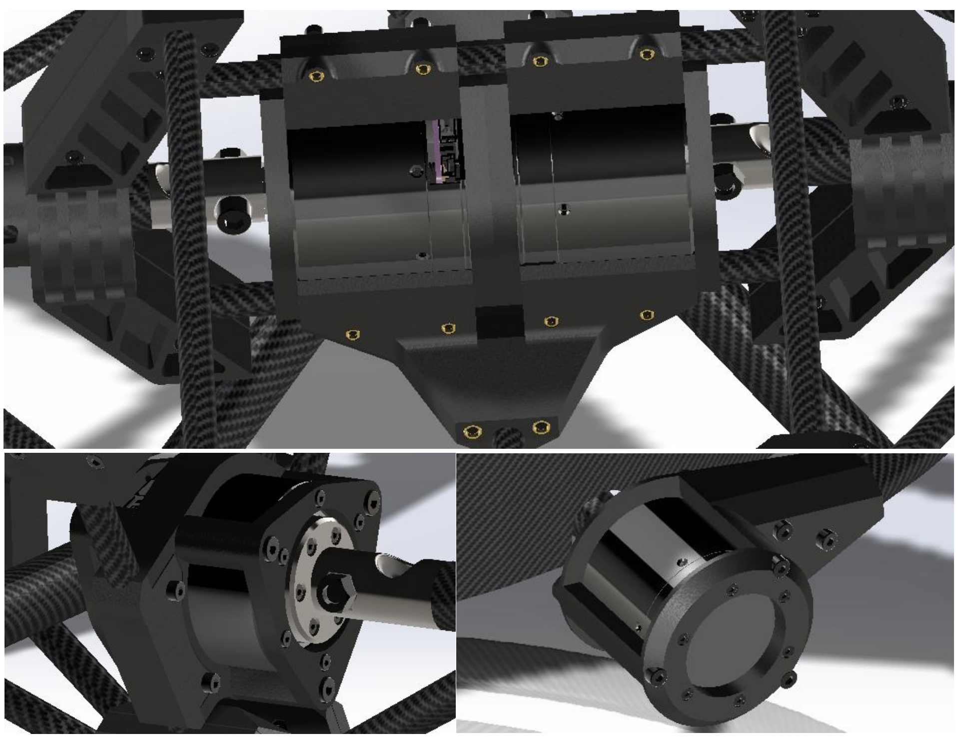

Figure III.3 *AK45-36 Integration on the airframe*

Overall, these new motors deliver performance equivalent to the previous solution while eliminating the need for custom PCB development and dedicated control algorithms, and at a fraction of the cost. This choice has resulted in a substantial gain in development speed and represents the most suitable option currently available for Hirondelle.

2. Couplers

Problem statement

Having addressed the actuation of the tilting axes, we now focus on the transmission of motor output power to the drone's axis. This subsystem is a key differentiating feature of Hirondelle compared to conventional drones and must be entirely developed in-house, as no equivalent solution exists on the market.

Since the beginning of the Hirondelle project, the coupling between the guidance motors and the tilting axes has never been fully successful or reliable. Transmitting the high torque of the AK45-36 motors (approximately 24 Nm) to the axis, while avoiding slippage, allowing internal cable routing, ensuring removability, and maintaining long-term reliability, represents a significant mechanical challenge.

Several coupling designs were iteratively developed and tested. Initial prototypes relied on 3D-printed components; however, it quickly became apparent that no conventionally FDM-printed material could withstand the applied mechanical loads. Before exploring alternative manufacturing methods, efforts were made to improve the existing approach using available resources.

Reinforced 3D-printed couplers were therefore designed, incorporating mechanical fasteners to compensate for deformations occurring along the print layer direction. This solution proved to be the most promising at this stage, enabling initial testing without immediate failure. Nevertheless, after several test cycles, plastic deformation and warping were observed due to repeated loading. As a result, this approach was deemed insufficiently reliable for long-term operation.

Solution

Our objective was to obtain a definitive solution to this problem, one that would be sufficiently reliable to require no further development effort. This motivated the exploration of manufacturing technology that we had previously considered but never implemented: metal additive manufacturing.

Unfortunately, Polytech does not have access to metal 3D printing equipment, whose cost typically exceeds €300,000 per machine. However, several companies worldwide offer metal additive manufacturing services at reasonable prices, making this approach feasible for our application.

As the team had no prior experience with metal additive manufacturing, the new coupler was designed using information gathered from online resources and design guidelines, as well as iterative design support from ChatGPT. Within a few hours, this process led to the development of the following coupler designs (see **Figure III.4**)

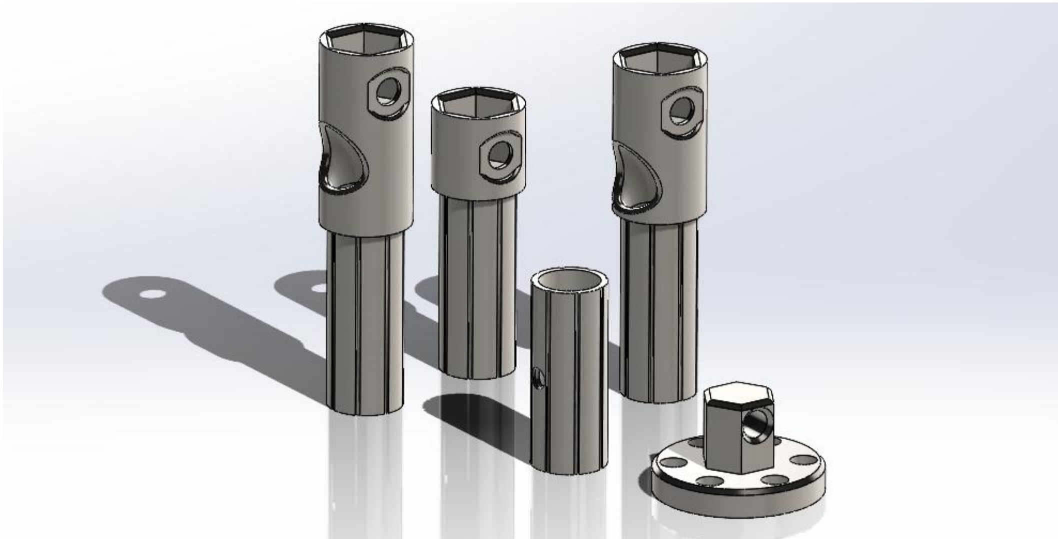

Figure III.4 *New Inox 304 Couplers*

These couplers were specifically designed to:

- Allow internal cable routes to supply power to the propulsion units
- Enable easy removal of the axis, which is why the coupler is split into two separate parts
- Most importantly, withstand the torque generated by the AK45-36 motors

The couplers operate as follows. Three different variants were developed: one located at the rear of the propulsion unit that does not require cable routing, a longer version intended for the first axis of the rear propulsion unit mounted on the frame, and a third version designed for the lateral propulsion unit.

Each motor is equipped with a dedicated adapter while the second part of the coupler is permanently bonded to the carbon tube of the axis using epoxy resin. This bonding method helps prevent carbon tube fracture under high dynamic loads. The two parts are then assembled using an M6 fastener.

The finalized 3D models were sent to the manufacturer, and the parts were received one week later. The initial tolerance assumptions and geometric design proved accurate, allowing the couplers to be directly integrated into the prototype without requiring further modifications.

3. Fairing

During this summer, we developed a completely new design for Hirondelle.

The goal of this phase was to turn the new Hirondelle design into a tangible prototype, a significant undertaking. Every aspect of producing such a large component had to be carefully considered, including cost, ease of fabrication, and the level of expertise required. After evaluating various methods, we decided to use vacuum molding with epoxy resin and fiberglass.

The first step was to create a full-scale, one-to-one mold of the new Hirondelle design. To achieve this, the design was first remodeled in SolidWorks, previously it existed in Blender, allowing us to assign accurate real-world volumes and dimensions (see **Figure III.5**).

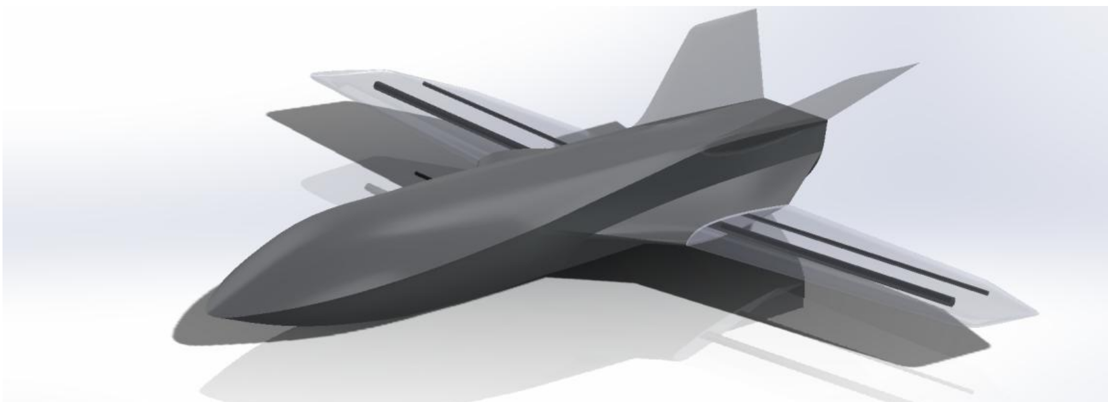

Figure III.5 *Remodeled version of the new design on SolidWorks*

Using the full-scale model, we then designed the individual mold sections to be 3D printed on our K1 MAX printer. The 2-meter-long upper fairing mold was divided into twelve separate segments, each measuring 30 × 30 cm (the lower fairing required twelve additional segments). The same procedure was applied to the wings and V-tails. After several weeks of printing and assembling the molds, we obtained the complete set ready for the next stage of fabrication (see **Figure III.6**).

Figure III.6 *Assembled Mold*

With the molds prepared, we proceeded to fabricate the fairing using epoxy resin and fiberglass. The process was relatively straightforward: fiberglass sheets were cut to cover the entire mold, followed by the application of epoxy resin. Multiple layers were then consolidated by vacuum-sealing the assembly using specialized bags and a vacuum pump. To accelerate curing, the components were kept as warm as possible during the process. After approximately one day, the resin had fully hardened, allowing us to remove the mold from the vacuum bag, demold the part, trim the edges, and sand the surfaces. After painting, we got this result (see **Figure III.7**).

Figure III.7 *Final Fairing*

4. Batteries

The Hirondelle batteries are in-house-designed 48 V packs, operating with custom-developed PCBs. The objective of this phase was to protect the cells from external mechanical and environmental threats. To achieve this, a carbon-fiber casing was selected, following the same approach previously used for Hirondelle's propulsion ducts.

The cells are first housed within a PA-CF structural frame and then inserted into a multilayer carbon-fiber shell. This shell is securely closed using 3D-printed carbon-reinforced components. The final assembly is shown in **Figure III.8**. These structural elements also support the PCB, electrical connections, and the active cooling system.

The battery modules are ultimately secured to the airframe using Velcro straps.

Figure III.8 *3D model and real versions of Hirondelle batteries*

5. Landing gears

During the development of the first prototype versions, the integration of retractable landing gear was considered for an extended period. However, designing a system capable of supporting the mass of such an aircraft while ensuring flawless reliability under all conditions proved to be particularly complex. Additionally, the motivation for retracting the landing gear was primarily driven by design considerations rather than aerodynamic performance.

With efficiency and rapid development in mind, we therefore chose to completely rethink the landing gear system. The design was transitioned to fixed landing gear, which is significantly more robust and reliable, while maintaining careful attention to aesthetics to ensure visual coherence with the overall design. The landing gear is shown in **Figure III.9**.

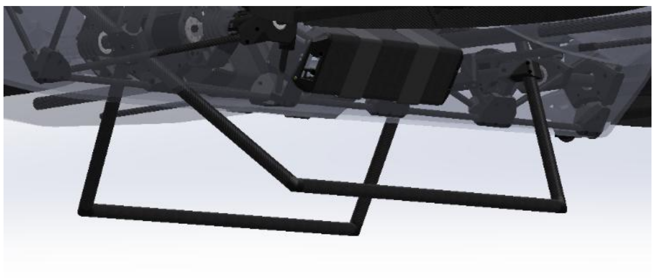

Figure III.9 *New Fixed Landing Gear*

6. Test setup

It was not conceivable to test Hirondelle directly outdoors by simply placing the drone on the ground and conducting trials without a defined framework or methodology. An extensive preliminary testing phase was therefore essential, with Hirondelle firmly secured, to finely tune the PID controllers to stabilize the vehicle under controlled conditions and to verify that the mechanical structure could already withstand moderate loads. Only after this critical step did it become relevant to consider more advanced outdoor testing, building on a technical foundation that had already been validated.

To achieve this, we developed a test rig (see **Figure III.10**) that allows Hirondelle to be suspended at four points, from both the top and the bottom, thereby fully constraining its motion. This configuration enables extensive testing under conditions that are safe, controlled, and easy to implement.

Figure III.10 *Hirondelle Indoor Test Setup*

IV. Electrical systems

1. Overall Architecture

The new electrical system has been designed with requirements that differ radically from what came before. We are now optimizing to reach maximum efficiency, augmented modularity and reduced development time, all while keeping performance an upmost requirement. We need PCBs that can adapt to our needs and be as future proof as possible. This means breaking out unused pins, providing bypass paths in case of failure, keeping complexity low and predictability high.

The first obvious choice is to depart from the STM32 microcontrollers. They are great, very efficient, and very optimized for certain tasks, but they are significantly less flexible; the pinout is fixed and cannot be changed after the PCB is ordered. Peripherals are tied to certain pins and cannot be reassigned. They are also more difficult to program; mainly due to ST's horrible proprietary tools and software. The hardware integration itself is pretty easy, but overall, they cannot realistically be used for rapid prototyping. They are also very expensive, often hitting 7€ per chip.

Fortunately for us, Espressif recently released a new microcontroller with a lot of desirable features: the ESP32-S3. This chip comes with two RISC-V cores clocked at 240MHz, which is already very impressive. It also has an "IO-MUX" and a "GPIO MATRIX"; this allows us to route almost any peripheral to any GPIO pin, at runtime. This is an incredible feature that saves a lot of time and avoids hardware mistakes. It also has a solid ecosystem with reliable and fast programming tools. Speaking of programming, it does not need an external programmer (the STM32 requires a ST-LINK programmer), it directly embeds a USB-OTG PHY that can be used to program and debug the chip with standard USB. Moreover, hardware development is even simpler, with no need of ANY external component apart from optional capacitors and quality-of-life switches. These microcontrollers even come in surface mount module packages, that already embed crystals, antennas, filter caps, reset logic and up to 16MB of Flash and 8MB of SRAM. For comparison, a top-of-the-line, 13€ STM32 has 256kb of flash and RAM. All of this comes at an incredible price of only 3€ per chip.

2. Flight Controller

The Flight Controller needs to be redesigned from the ground up, as it has not been changed since V1.0. It now embeds the new ESP32-S3, along with a high performance 6-axis IMU from BOSH: the BMI088. It also has a 24bit high precision barometer, that provides excellent altitude estimations, a magnetometer from ST, and the ability to add an external GPS receiver. The flight controller comes with extensive I/Os: 3x ESC ports, 1x UART Camera port, 1x SBUS/ELRS port, 4x AUX, USB-C, and 2x CAN2.0B. The whole pinout of the ESP is used and exposed for modularity. It also features a 5V power rail that can supply up to 3.5 Amps for external servo drives or future expansions.

The controller embeds a new flight control firmware that we developed entirely in-house during this semester, as no other firmware supports the unusual shape of our drone. This control software is a major improvement compared to everything we've used before. We implemented a cascade PID controller for maximum phase and gain margin. The outer PID loop uses a Madgwick filter to get attitude estimations of the drone based on accelerometer and gyroscope data. The output is then used as angular rates setpoints for the inner PID loop, that uses the raw gyroscope data to manage the thrust of each motor.

To accommodate the two flight regimes (i.e. hover and forward), we had to invent a new controller design that could seamlessly merge the two regimes without instabilities. This is done using a clever system: every actuator (motors and axis actuators) has two vectors, the hover and forward vector, each of these vectors tells the controller how an actuator should react to the controller's output. For example, in hover mode, only motors are used to stabilize pitch and roll. The controller then needs to blend between these two response vectors. This is done thanks to trigonometry; we can multiply one vector by $\sin^2\theta$ and the other vector by $\cos^2\theta$ where θ is the blend is for the side actuators. Let's recall that $\sin^2 x + \cos^2 x = 1$ for all x. This ensures that the overall gain of the controller is always the same, and both flight regimes can blend nicely without instabilities. The final controller is shown in **Figure IV.1**.

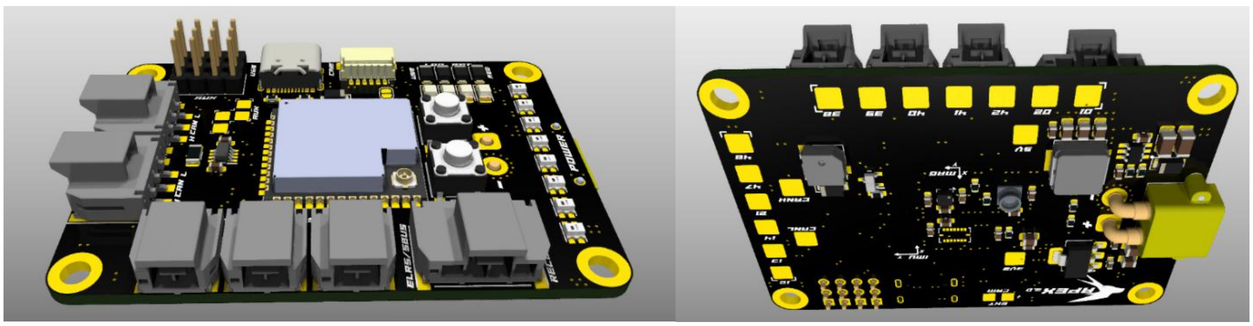

Figure IV.1 *Hirondelle Control Board*

3. Battery Management System

The Battery Management System or BMS for short is a circuit responsible for ensuring that the batteries always remain in safe operating condition. Basically, a BMS should embed multiple thermistors to get the battery temperature, a current sensor to know the current, an ADC for voltage sensing, and a way to disconnect the load as fast as possible in case of failure.

We developed a custom BMS system that is suited for our drone, as no commercial alternative exists for such amounts of power and UAV requirements. Our BMS is based on an ESP32-S3 that manages all the parameters of the battery. The heart of the system is the BQ74200PW from Texas Instruments, it is a battery front-end IC that can drive High Side N-Channel Mosfets to connect or disconnect the load based on GPIO inputs. We chose to only populate the discharge Mosfets to limit thermal losses; so only discharge can be interrupted but not charging. This won't be an issue for us as we use an external charger. We use two Mosfets in parallel, specifically the IQDH88 Series from Infineon. They feature the absolute lowest RDSON resistance on the market, with only 500µOhms when fully on. They also have a direct-die exposed metal cooling surface on their topside, which is a bit unusual but allowed us to put a small heatsink on top. According to calculations, this would allow us to push the BMS to 300+ amps of burst discharge, and we validated 70A of continuous current in tests.

A hall effect current sensor has been chosen over a more traditional shunt resistor sensing method, as even a few mOhms of resistance will happily start a bonfire when presented with 100+ Amps. We went for the ACS 72981 from Allegro, with a 150 Amps bidirectional sensing capability.

We also implemented multiple HMI systems to communicate the state of the batteries to the user, including LEDs and a very loud buzzer (110dB). You can see the BMS system in **Figure IV.2**.

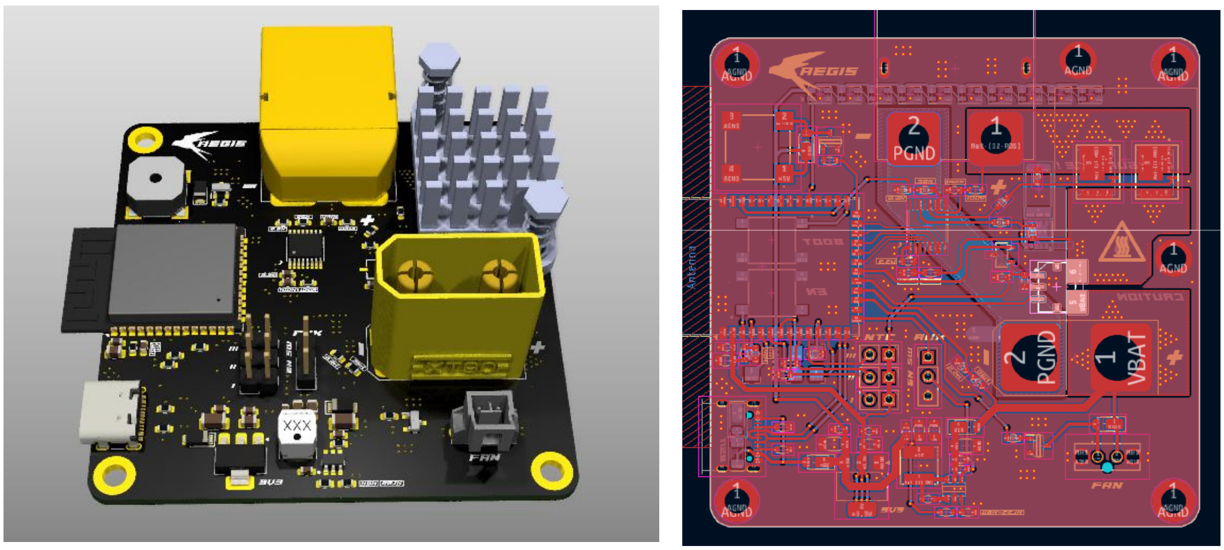

Figure IV.2 *Hirondelle BMS System*

4. Power Distribution

The Power Distribution system is the spinal cord of the drone. It is responsible for transmitting power to every component. We redesigned everything from the ground up to meet the new requirements. The power distribution system was developed alongside the mechanical aspects to make sure that every PCB was in an optimal spot on the chassis. We have 6 different PCBs that are specifically designed for a purpose and supply power to other subsystems. They are interconnected using 12AWG silicone wire and XT90 / 60 / 30 connectors depending on the current requirements. The main power comes from the two batteries, that are connected to a single PCB stack in the center of the drone. This PCB is designed with exposed copper pad, so that we can add a lot of solder to decrease trace resistance. The power then goes to the endpoints in cables. We also have a 24V power bus for the axis actuators. That bus is generated by four synchronous buck regulators.