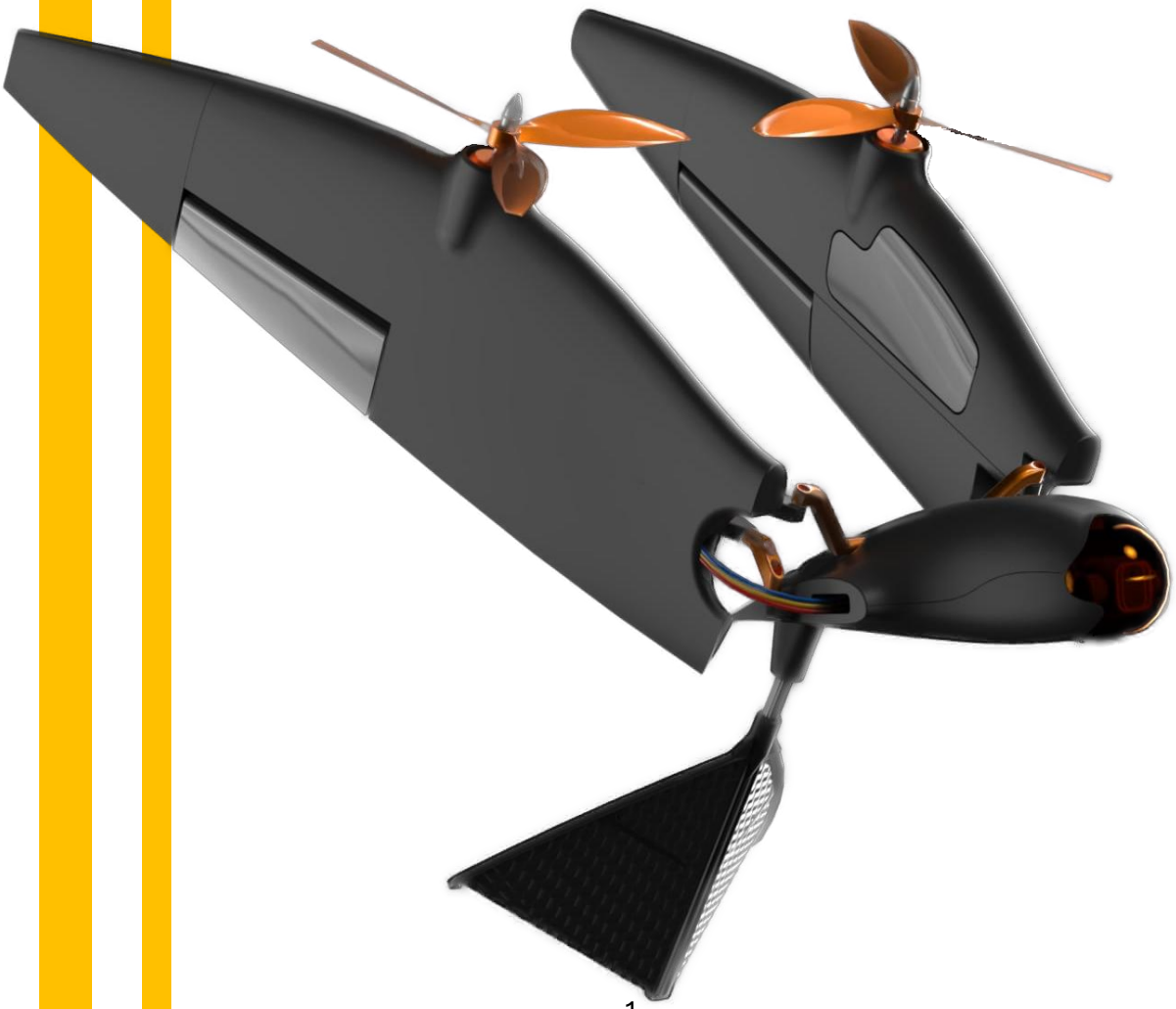
BIRDLIKE DRONE MANUFACTURING

UGent: Ontwerp van slimme producten

2025



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1. Introduction

Unmanned aerial vehicles (UAVs) have become an essential part across domains such as environmental monitoring, inspection, logistics, and surveillance. However, conventional drone typologies, primarily multirotor and fixed-wing systems, face persistent limitations related to noise, safety, maneuverability in cluttered environments, and robustness during close interaction with their surroundings. These challenges have motivated researchers and designers to explore alternative aerial paradigms inspired by biological flight, particularly that of birds. Among these approaches, bird-like drones, often referred to as ornithopters, represent a growing field of research that seeks to translate avian flight principles into engineered systems.

Birds have evolved highly efficient flight strategies that combine flapping, gliding, and perching, allowing them to operate in dense, unpredictable environments with remarkable agility and energy efficiency. Unlike conventional drones that rely on continuous rotor thrust or forward propulsion, bird-like drones generate lift and thrust through flapping wings, enabling flight modes that more closely resemble natural locomotion. This bio-inspired approach has been shown to reduce acoustic signatures, improve low-speed efficiency, and enable safer interaction with humans and wildlife. As a result, bird-like drones are increasingly explored for applications where discretion, environmental integration, and proximity to obstacles are critical.

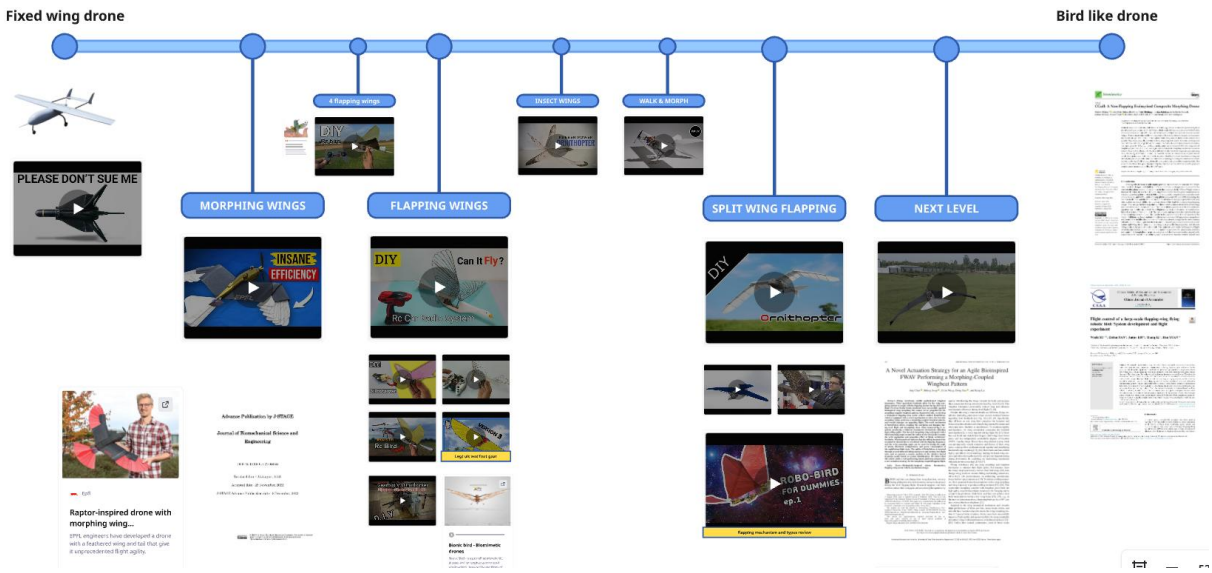
Beyond efficiency and aesthetics, bird-like drones address several structural and operational shortcomings of traditional UAVs. In environments such as forests, urban canyons, or indoor spaces, collisions are difficult to avoid and often lead to mission failure for rigid multirotor systems. Bio-inspired drones increasingly adopt compliant structures, articulated wings, and energy-absorbing materials, allowing them to tolerate or recover from impacts. Notably, research inspired by woodpeckers has demonstrated bird-like drones capable of surviving head-on collisions by dissipating kinetic energy through structural deformation rather than rigid resistance. This reframing of crashes as a design condition rather than an exception significantly improves operational robustness.

Bird-like drones occupy a distinct performance niche rather than competing directly with conventional UAVs on speed or payload. Studies comparing flapping-wing drones with fixed-wing and multirotor platforms indicate advantages in low-speed flight, hovering-adjacent maneuvers, and energy efficiency during intermittent flapping and gliding cycles. While challenges remain in control complexity, payload capacity, and manufacturing, bird-like drones offer a compelling solution to problems of noise, safety, resilience, and environmental compatibility. As such, they represent an important direction in the development of next-generation aerial systems that prioritize adaptability and coexistence with complex real-world environments.

This paper has as the challenge, the development of a fixed wing drone with bird-like features. The goal isn't to design a fully developed drone for the course, but rather a proof-of-concept. The goal therefore is to conduct thorough research, prototyping, and finalize the robustness and logistics involved in creating a final concept that addresses the challenging objectives. The committed work therefore works as the root to build and develop upon towards a finalized product.

2. State of the art

To initiate the project, a benchmarking study was conducted to map the current state of the art in bird-like drone development. The objective of this benchmarking was to identify existing typologies, design strategies, and technological trade-offs within the domain of bio-inspired aerial robotics. To structure this overview, the identified projects were positioned along a spectrum ranging from conventional fixed-wing drones to fully bird-like flapping-wing systems. This approach allowed for a clearer comparison of degrees of biomimicry, mechanical complexity, and functional ambition.



The benchmarking revealed a wide diversity of existing bird-like drone concepts. However, a clear pattern emerged: most systems tend to fall at one or two extremes. On one end of the spectrum are highly simplified bird-like drones that rely on minimal mechanical solutions, such as rubber-band-driven flapping mechanisms. While these designs are valuable as educational tools or proof-of-concept models, they typically achieve only very short flight durations and offer limited controllability and robustness. On the opposite end are highly complex research-driven platforms that incorporate advanced actuation, sensing, and control systems. Although these drones demonstrate significantly higher performance and flight stability, their complexity results in a bill of materials that often far exceed the financial constraints of this project, commonly surpassing a budget of €150.

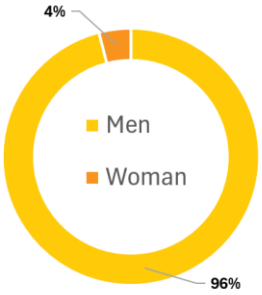
In addition to complete drone systems, several research publications were identified that focus specifically on the biomechanics and aerodynamics of bird wings. These studies provide valuable insights into flapping kinematics, wing deformation, and lift generation. However, due to the inherent complexity of avian flight, much of this research remains highly technical and difficult to translate directly into a feasible, low-cost, and buildable drone platform. As a result, this project positions itself between these two extremes by seeking a balance between biological inspiration, mechanical simplicity, and practical feasibility.

2.1 The main user

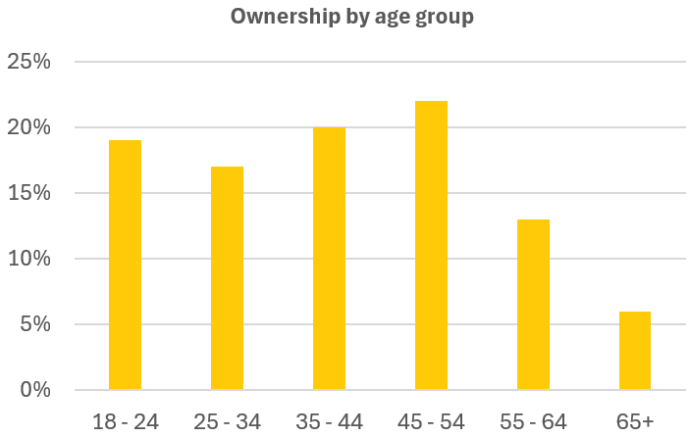
Drone technology is becoming a major industry of the 21st century. With this being a key player in innovation, it brings a lot to the table for not only users, but also world economics, legislations, power positions and work environments/systems. The sectors of agriculture, logistics, infrastructure, security and filmmaking will drastically evolve in the upcoming years. There is a whole wide world of usage, yet the market is narrow with only a few key players, with the biggest being China who holds 70-80% of the whole industry. Many key players are looking at other countries when they are going to step into the production of their own manufacturable drones to bring in the many sectors that were mentioned. For this project, there is the challenge of making a fixed-wing bird-like drone. Therefore, it is also important to have a main focus in a Macro-, Meso- & micro-economical vision to know in which type of domain the drone will be implemented.

User study

There are no statistics of the worldwide users for drones, but there are data sheets that go over some countries who became the biggest consumers of these gadgets. In the USA, the drone market is dominated by the male gender with a 96%. Only a small group of 4% of the total consumer market of drones is of the female sex, which brings a big imbalance.

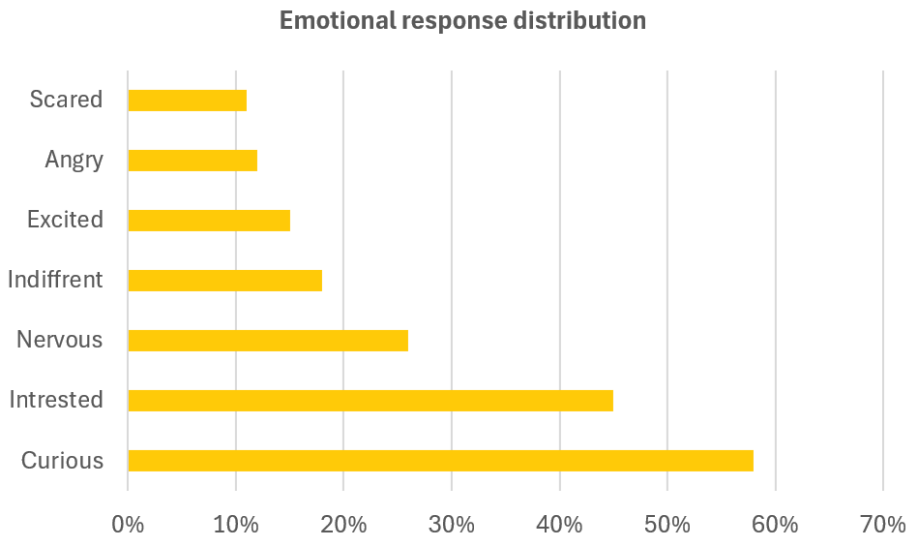


Drone users' age groups are distributed similarly, with the largest group around 45-54 years old, being 22% of the consumer market. Above that age, there's a sharp decline in users, but before that, there are many active groups who have an almost equal dominating position in the consumer field.



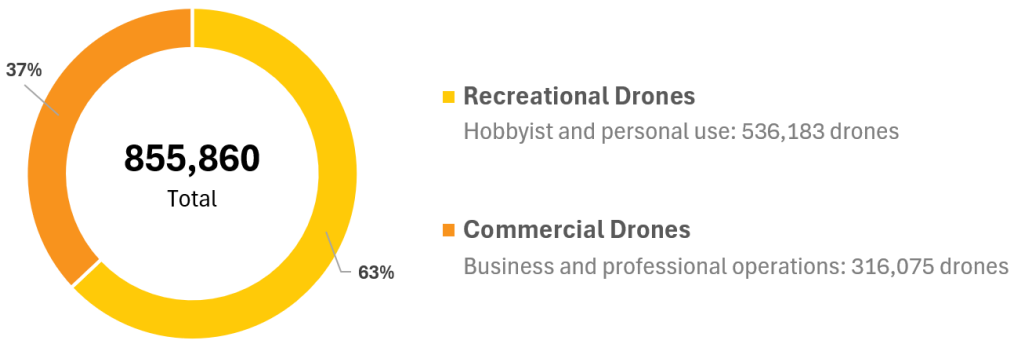
The user group can always be expanded upon as more people step into the consumer market of drones. Therefore, an insight into the public's opinions of drones is valuable information to take

into account. In general, many people are interested and curious about the drone world as a step into the future. However, about a fifth of the population is apprehensive about the implementation of drones and feels uneasy about the concept. This could be due to a feeling that privacy will be taken away, jobs will be replaced, etc.



The usage

The reason most companies switch to drones is to save time, improve quality and safety, and reduce costs. As these are very open examples for use, the implementation of these drones is also of key importance. In general, drones are used more for hobby/personal interest. This primarily involves photography enthusiasts, FPV racing pilots, and those interested in technology. This represents approximately 63% of total users, with 37% for commercial use for business and professional operations.



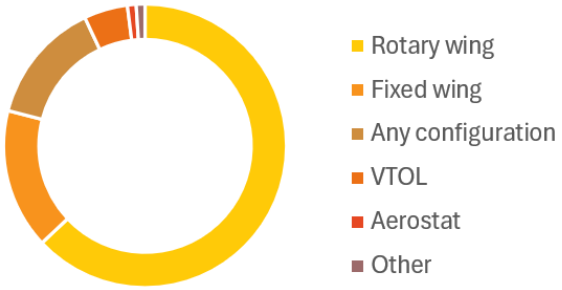
Most used types of drones

Most of the growth is currently occurring in FPV drones, but in terms of the number of companies, number of employees, and new applications, autonomous drones are leading the way. This is

primarily because they require significant investment in artificial intelligence, coding, and new technology.

	Growth rate (%)	Number of companies	Number of Employees	New Hires in the last Year
First-person view (FPV)	21,40%	395	4500	422
Underwater drones	14,60%	174	4500	366
Autonomous drones	17,30%	520	23800	3200

Though these diagrams show the investment, it doesn't say much about the type of drones that are used more often. In general, rotary-wing drones are the most dominant type as they share 63% of the market. The second most used type is fixed wing with 16% with other types following lower percentages in use.



Operator classes

In total, there are 3 operation classes: A1, A2 & A3. These classes are made with a focus on the mass of the drone, the distance criteria, demands of the pilot, technical specs and ID/registration. The higher the number is, the larger the library of drones to use from is.

Open category	CE class mass	Distance criteria	Demands for pilot	Technical specs	ID	Registration of operator
A1	250g max (without CE label or self-manufactured)	Allowed above people, but not above crowds	Read the manual	< 19 m/s in the case of self-manufactured or race drones	No	Only if the drone has a camera
A2	4kg max (drone class C2)	30 meters distance from people (or 5 meter in low speed mode)	Online course & exam (40 questions)	< 19 m/s, limited to max. 120 meters high	Yes	Yes
A3	All drones and model-planes without Cx label between 0.5 - 2 kg	+150 meters distance from people, buildings, and recreation areas	Online course & exam (40 questions)	/	No	Yes

2.2 Defining the user

As mentioned earlier, the challenge is to develop a fixed-wing, bird-like drone, which requires defining a specific user group. In terms of gender equality, the project does not rely on gender-based assumptions, as these have little relevance to the product architecture. Gender considerations would only become significant if the project involved ergonomics for the controller, which falls outside the scope of this project.

Users will need to have an A2 or A3 drone license, as the expected weight of the drone exceeds 1 kg, placing it within the C2, C3, and C4 categories. The primary target age group ranges from 18 to 54 years old. Individuals outside this range may also use the drone, but their needs and interests are not a central focus of this project.

In terms of usage, the primary focus will be on saving time and enhancing the overall user experience. Initially, the drone is intended for recreational purposes, targeting hobbyists and personal users. Over time, this foundation can be expanded into the commercial market. At this stage, the drone's main application lies in the entertainment sector. However, once the first model proves successful, its use can be extended to areas such as surveillance and mapping.

A further analysis was made of the different possible usages for these specific contexts. These contexts where chosen based off previous research on upcoming applications of drones.

Security

surveillance & security
- **Militaire verkenning:** Ze kunnen opgaan in de natuurlijke omgeving en vermijden detectie terwijl ze inlichtingen verzamelen.
- **Grensbeveiliging:** Patrouilleren langs de perimeter zonder indringers te alarmeren.
- **Stedelijke surveillance:** Mensenmassa's of gevoelige gebieden discreet in de gaten houden.

Law enforcement
- **Zoek- en reddingsacties:** Het vinden van vermiste wandelaars of personen in bossen of bergen.
- **Misdaadpreventie:** Het heimelijk observeren van gebieden die gevoelig zijn voor illegale activiteiten.

commercial use

Civil & commercial uses
- **Inspectie van infrastructuur:** het inspecteren van elektriciteitsleidingen, pijpleidingen of windturbines in gebieden waar traditionele drones mogelijk gevaar opleveren.
- **Rampenbestrijding:** het bereiken van moeilijk bereikbare gebieden (ingestorte gebouwen, bosbranden) zonder de aandacht te trekken.
- **Landbouw:** het monitoren van gewassen en vee op een natuurlijke, niet-verstorende manier.

Environment

Environmental & wildlife research
- **Dierenobservatie:** Vogels, wilde dieren of bedreigde diersoorten bestuderen zonder ze te verstoren.
- **Habitatmonitoring:** Gegevens verzamelen in gevoelige ecosystemen (bossen, wetlands, kliffen).
- **Verontreinigingsmonitoring :** Luchtkwaliteit, temperatuur of chemische concentraties in ecosystemen monitoren.

Intelligence

Intelligence & covert operations
- **Spionage:** Gebruikt door inlichtingendiensten voor het discreet verzamelen van informatie.
- **Monitoring van menigten:** Het in de gaten houden van grote openbare bijeenkomsten of protesten zonder zichtbare aanwezigheid van drones.

Media

Media & entertainment
- **Filmmaken:** Natuurlijke beelden van wilde dieren vastleggen zonder ze te verstoren.
- **Toerisme:** Meeslepende ervaringen creëren die natuurlijk aanvoelen (vogelperspectief zonder duidelijke drones).

To further define the different characteristics of the user, three personas were made each explaining different possible use cases of fixed wing drones. We specifically focused on the hobbyists-drone-enthusiasts, the young kids that are curious about the use cases of drones and the teenagers that have a passion for engineering and technology

Robin

Over

Leeftijd: 9 jaar oud
Woonplaats: Zeebrugge, België
Schoolgroep: groep 6
Situatie: enig kind, houdt van techniek en natuur

Context

Robin is een enorm nieuwsgierige en vindingrijke jongen van 9 jaar, die al van jongs af aan gefascineerd is door twee werelden: de natuurlijke wereld van vogels en de technische wereld van hoe dingen werken. Zijn kamer is een waar atelier, vol met zelfgemaakte vogelvoeder-plaatsen, tekeningen van verschillende vliegtuigen en modellen die hij in elkaar heeft gezet van constructies-peelgoed.

Hij brengt uren buiten door met een oude verrekijker van zijn opa, waarbij hij vogels observeert en probeert te begrijpen hoe ze vliegen en manoeuvreren. Thuis is hij niet weg te slaan van educatieve YouTube-kanalen die uitleggen hoe drones werken of hoe je zelf eenvoudige machines kunt bouwen. Zijn ouders, die zijn passie aanmoedigen, zijn constant op zoek naar manieren om zijn liefde voor natuur en techniek samen te brengen op een manier die veilig, leuk en écht leerzaam is.

Frustraties

- Veel educatief speelgoed is te simpel of saai
- Technisch speelgoed is vaak te complex zonder duidelijke uitleg
- Kan zijn interesses in natuur en techniek moeilijk combineren

Noden

- Leerzaam maar wel leuk en speels
- Duidelijke instructies die zelfstandig te volgen zijn
- Een tastbaar resultaat waar hij trots op kan zijn
- Combinatie van natuur (vogels) en techniek (drones)

Personaliteit

Extrovert	Introvert
Sensing	Intuition
Thinking	Feeling
Judging	Perceiving

Techniek

- Eenvoudige constructies
- Basis elektronica
- Bouwinstructies volgen

Educatie

- Nieuwe dingen leren
- Zelf iets kunnen bouwen
- Natuur begrijpen

Gebruikt merk

- Vorige: LEGO Technic, knutselpakketten

Lars

Over

Leeftijd: 34 jaar oud
Woonplaats: Rotterdam, Nederland
Beroep: Drone-specialist bij beveiligingsbedrijf
Situatie: Alleenwonend

Context

Lars werkt al 7 jaar als drone-specialist bij een toonaangevend beveiligings-bedrijf. Hij heeft een achtergrond in werktuigbouwkunde en is gespecialiseerd in onbemande vliegtuigsystemen. In zijn vrije tijd bouwt en programmeert hij graag zijn eigen drones en experimenteert hij met verschillende vlieg-configuraties.

Hij volgt actief alle technologische ontwikkelingen in de drone-industrie en bezoekt regelmatig vakbeurzen. Lars is altijd op zoek naar innovatieve oplossingen die de surveillance-mogelijkheden van drones kunnen verbeteren, vooral wat betreft stabiliteit en manoeuvreerbaarheid in complexe omgevingen.

Frustraties

- Standaard drones hebben beperkte manoeuvreerbaarheid
- Bestaande morphing-wing drones zijn moeilijk te besturen
- Weinig specialisatie-opties voor surveillance-toepassingen
- Tijdrovende programmeer-processen voor nieuwe functionaliteiten

Noden

- Precieze besturing voor complexe bewegingen
- Betere stabiliteit tijdens surveillance-missies
- Aanpasbare vleugelconfiguraties voor verschillende scenario's
- Robuust prototype voor praktijktesten

Personaliteit

Extrovert	Introvert
Sensing	Intuition
Thinking	Feeling
Judging	Perceiving

Techniek

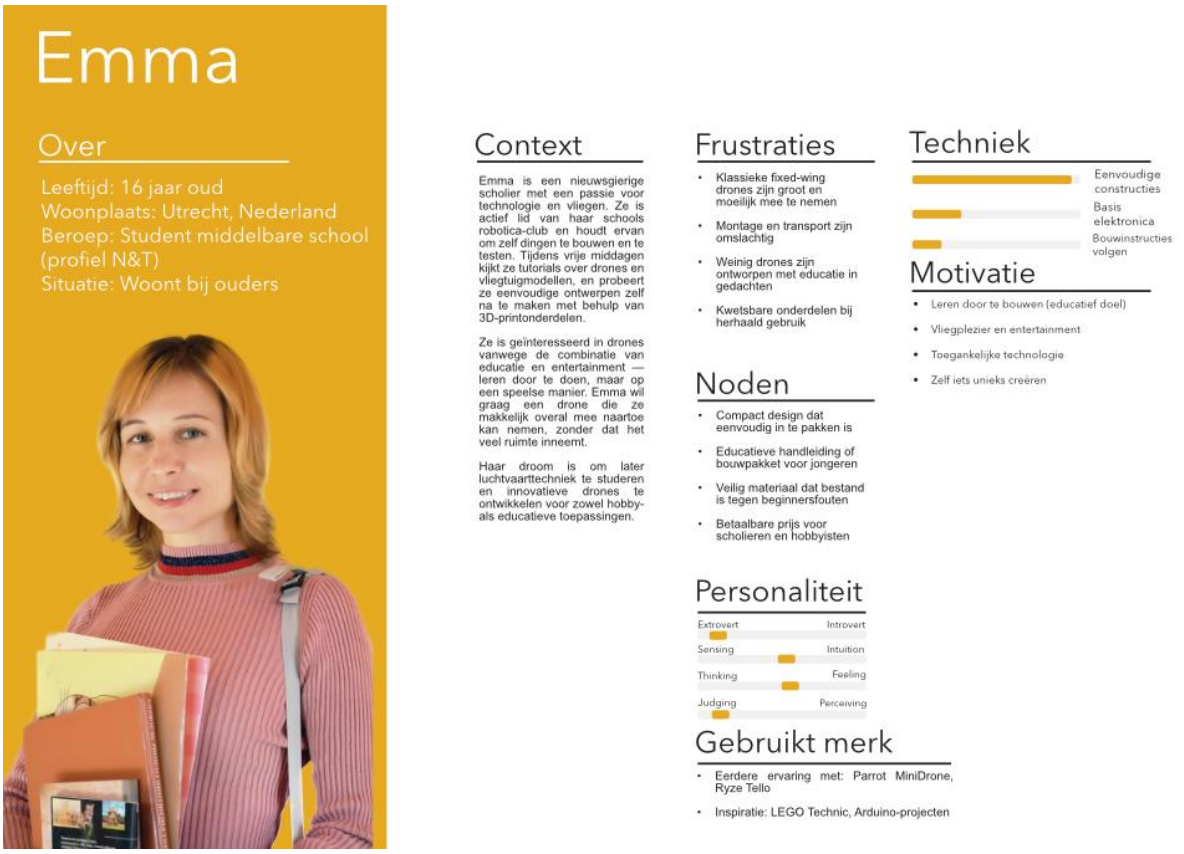
- Eenvoudige constructies
- Basis elektronica
- Bouwinstructies volgen

Motivatie

- Innovatie in drone-technologie
- Praktijkgerichte oplossingen
- Technische uitdagingen
- Betere surveillance-resultaten (bouwkunde)

Gebruikt merk

- Vorige: DJI Matrice series, Parrot Anafi



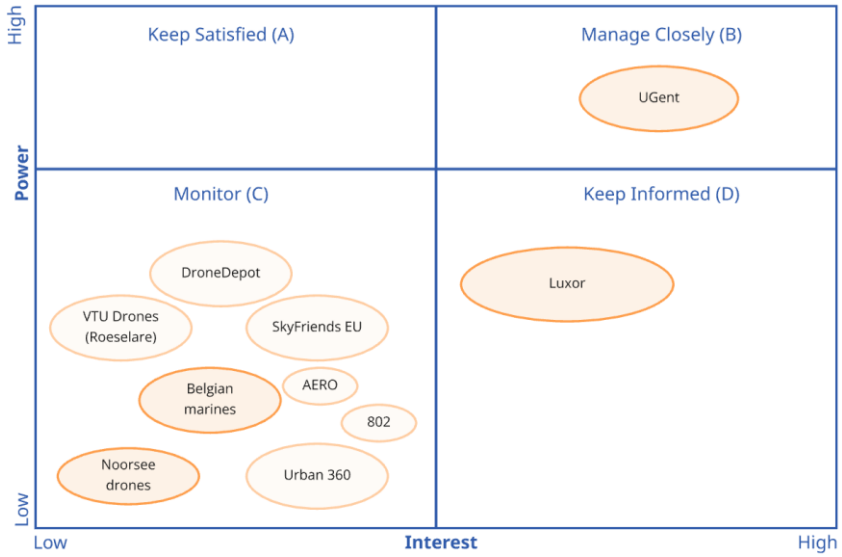
After investigating the different contexts in which drones can be used, we created a storyboard on how our drone could be used based off of these different contexts. The idea here is very simple that the drone needs to be able to be transported easily and can be remote controlled. To keep the system simple, we intend for the drone to be hand launchable.

2.3 Possible stakeholders

In order to hopefully get an extra budget for this project we visited a drone-expo during the open-company day in Zeebrugge. The two companies we visited, and where the expo was located are:

- **Noordzee drones:** Noordzee Drones is the European leader in drone training, consultation, and expert support for new drone pilots. Their mission is to provide the highest quality training in the field of Unmanned Aerial Systems to ensure the integration of drones into national airspace. They have assisted companies, police, and fire departments in implementing drone programs through training and consultation. In 2019, Noordzee Drones was nominated by Unizo as the promising SME of the year.
- **The Belgian marines:** The North Sea is one of the most closely monitored waters for threats. Military ships have radar systems and clear communication. The idea behind drones is to expand the radar network with a suit. Because these drones are shaped like seagulls or other birds that brave the seas, the idea of surveillance by other ships that are under suspicion is not recognized as a threat, allowing for better examination.

At the expo we also met a few other companies that are listed in the following stakeholder diagram:



During the expo, most of the drones were multi-rotor, as they are often seen as practical. These were used by the military, police, marine researchers, and regular consumers. When discussing drone design, many suggested fixed-wing drones as a good alternative, since they can be used 24/7 unlike multi-rotor drones. The drones were mostly intended for surveillance and entertainment, with only a few providing physical services such as cleaning or collecting samples.

Another remarkable thing was that most of these drones were produced in China instead of locally. There is a high demand for drones yet not enough companies find local businesses with the necessary requirements. Therefore, the market in Europe on drones themselves very small. Besides that, there was also a small training session in the expo on flying drones which could come in handy. With the Belgian marines however, not a lot on the drones were shown, but the ones who were are applied for surveillance. There is also a high demand for drone pilots making it more and more interesting for people to be introduced. Either way, the expos did have a purpose in the project.

There was one company in particular that was interested in our research:

- Luxor One is a Belgian deep tech company that develops advanced drone and sensor technology enhanced with artificial intelligence (AI). Founded by young engineers Thomas Sabbe and Simon Vervisch, the company focuses on creating autonomous drone systems capable of carrying out automated flight operations and complex sensing tasks without continuous human control.

We ended up having an online interview with this company, also asking for a possible partnership in this project, with the hopes of getting funded. There was unfortunately not enough common ground for them to fund or help us, however they did offer us some valid tips.

3. Material research

Before any prototyping was conducted, research was one on materials that could be of use. There are a few requirements necessary for these materials to be of use in prototyping:

- needs to be light to reduce weight.
- is resistible to impact
- is strong enough to carry weight.
- is low in cost

3.1 Wood research

Wood is one of the lightest materials in general and is often used for fixed wing prototypes. Besides that, wood is also easy to manipulate in a lot of ways and is one of the most sustainable materials. Still the structure of wood plays a big role as these cannot be changed and are therefore a big importance when used in prototyping.

Balsa Wood

Balsa wood is the lightest commercially available wood species, with a typical density of approximately 0.1–0.3 g/cm^3. It has an excellent strength-to-weight ratio (for its weight). Although it's very light, it is also very soft, making it vulnerable to impact damage or unsuitable for thin parts that must carry significant loads. It is also less stiff than heavier wood species.

For drone construction, it is ideal for components that experience minimal loads (e.g. decorative elements) or as an internal frame where weight is absolutely critical; however, sufficient thickness or reinforcement is required. Also, the pricing for samples of this wood is cheap being under 10 euro's. Still for the actual drone itself, the wood just isn't strong enough.

Kiri wood

Relatively new in lightweight construction; it is described as very light, easy to work with, and durable. The typical density is approximately 0.28–0.35 g/cm^3 according to a supplier list. This offers a good balance between weight and strength and is more readily available than exotic ultra-light woods.

The problem is that it may be slightly more expensive or harder to source in thin sheets suitable for laser cutting; consistency of quality can also vary.

Poplar wood

It is described as a lightweight hardwood (0.35–0.45 g/cm^3) that is easy to work with. It is widely available, relatively inexpensive, and well suited for laser cutting. However, it is not as light as balsa, so if weight is truly critical, lighter options are preferable.

Spruce wood

Spruce has a good strength-to-weight ratio and is often used for musical instruments and lightweight structures. Its typical density is about 0.40–0.47 g/cm^3, depending on the species and moisture content. It is suitable for structural parts while remaining relatively light. However, it is heavier than ultra-light woods, and care must be taken to ensure proper drying and to check for knots.

general conclusion for wood options

	density	Strength (bending)	Price	Good for use?
Balsa wood	0.1–0.3 g/cm^3	10–25 MPa	Below 10 euro's	Not strong enough
Kiri wood	0.28–0.35 g/cm^3	30–45 MPa	15 – 40 euro's	Too expensive
Poplar wood	0.35–0.45 g/cm^3	60–90 MPa	Around 18 euro's	Good
Spruce wood	0.40–0.47 g/cm^3	70–100 MPa	Around 15 euro's	Little bit heavy

In general, poplar wood would be the best choice. Although it isn't the lightest, it has a big difference in strength compared to the lighter wood types. Also, it is great to work with on prototypes and is still considered as light wood.

3.2 3D-print filament research

3D-filament, although having a higher density than wood, is one of the best ways to make lightwork prototypes. The reason is that it's easy to make structures that make the body thin. Besides that, it also adds more precision and a professional look for finalized prototypes.

PLA & PLA light

PLA has a density of about 1.24 g/cm^3, which is relatively high compared to many other plastics. Mechanically, it has a tensile strength of around 70 MPa and a Young's modulus of approximately 3.1 GPa. PLA is fairly stiff but brittle, with a low elongation at break of about 5–20%, and only moderate impact resistance (Izod/Charpy around 3.4 kJ/m^2). The price is typically around €18–20 per kg. PLA is very easy to print with high detail, making it ideal for prototypes or lightly loaded parts. However, due to its brittleness and limited thermal resistance, it is less suitable for highly loaded structural components or warm environments such as motor mounts or housings.

PLA Light (foaming PLA) is a modified PLA that expands during printing, producing much lighter parts. The effective printed density is typically around 0.4–0.8 g/cm^3, depending on print settings. Strength is significantly lower than standard PLA, with tensile strength around 20–40 MPa and stiffness of roughly 1–2 GPa. Like normal PLA, it softens at somewhere between 55–60 °C. PLA Light typically costs a bit more per kilogram than standard PLA (often around €25–30/kg, depending on brand and region), but because printed parts are lighter, the cost per part can be lower.

PETG

PETG has a density of about 1.27 g/cm^3. Mechanically, it has a tensile strength of around 53 MPa and a Young's modulus of approximately 3.0 GPa. PETG is more ductile than PLA, with an elongation at break of about 30%, and offers good impact resistance (around 4.5 kJ/m^2).

The price is usually around €15–20 per kg. PETG is stronger and tougher than PLA, making it suitable for structural parts that must tolerate some flex (such as arms or bodies), but it is slightly heavier and requires more careful tuning than PLA.

ASA

ASA has a density of about 1.05 g/cm^3, comparable to ABS. Mechanically, it offers a tensile strength of around 45 MPa and a Young's modulus of approximately 2.1 GPa. ASA has good impact resistance, with a Charpy-notched value of about 10.5 kJ/m^2.

ASA generally costs slightly more than ABS, roughly €25–30 per kg. It combines the mechanical advantages of ABS with much better UV and weather resistance, making it well suited for outdoor frames or enclosures and parts exposed to higher temperatures, though it requires a controlled printing environment.

Nylon

Nylon has a density of about 1.08 g/cm^3, depending on the specific type, with filled grades being heavier. Mechanically, it is very tough, with a tensile strength of around 79 MPa, a flexural modulus of about 2.4 GPa, and high elongation at break (30%+). It also has excellent wear resistance and good impact strength (Izod around 6.6 kJ/m^2).

Nylon is relatively expensive, usually costing around €35–70 per kg. It excels in durability, impact resistance, and heat and chemical resistance, making it ideal for parts such as brackets, mounts, fasteners, or gears. It is best used on printers with an all-metal hotend and preferably a closed build chamber and should be avoided in humid environments unless moisture control is ensured.

PC

Polycarbonate (PC) has a density of about 1.20 g/cm^3. Mechanically, it offers very high strength and stiffness, with a tensile strength of around 71 MPa and a Young's modulus of approximately 2.34 GPa. It is extremely impact resistant, standard Charpy tests at 23 °C show no break and it remains relatively tough even at low temperatures.

PC is expensive, usually costing around €35–40 per kg. It is an engineering-grade filament suited for the most demanding applications requiring high structural strength and heat resistance, such as motor mounts or heat-exposed structural parts. For simple builds or lightweight frames, PC is often overkill and carries a higher risk of print failure without proper equipment.

PP

Polypropylene (PP) has a density of about 0.90 g/cm^3, making it the lightest common 3D-printing filament. Mechanically, it has low tensile strength (9 MPa) and low stiffness (0.23 GPa), but it is extremely tough and flexible. It offers very high impact resistance (Charpy notched around 49 kJ/m^2) and excellent fatigue resistance.

PP usually costs around €30–50 per kg. It is extremely lightweight, flexible, and chemically resistant, making it interesting where weight is critical or flexibility is desired. However, due to severe warping and low stiffness, it is only practical if printing challenges can be managed. For most drone applications, other materials are generally more suitable unless a very light and flexible part is specifically required.

General conclusion for filament options

	Density	Tensile strength	Price (per kg)	Good for use?
PLA	1.24 g/cm^3	70 MPa	€18–20	Good for strong parts
PLA light	0.4–0.8 g/cm^3	20–40 MPa	€25–30	Good for parts that don't need a lot of impact
PETG	1.27 g/cm^3	53 MPa	€15–20	PLA is better for the price and weight
ASA	1.05 g/cm^3	45 MPa	€25–30	Not interesting for the price
Nylon	1.08 g/cm^3	79 MPa	€35–70	Way to expensive
PC	1.20 g/cm^3	71 MPa	€35–40	Not interesting for the price
PP	0.90 g/cm^3	9 MPa	€30–50	Not interesting

In general, PLA and PLA light are the best options for weight and strength. A good combination of these 2 materials could be great to get to the finished prototype desired for this project. Other filaments are either too expensive or too close for a change. Although the pricing of PLA light is high, through university these can be used freely.

3.3 Foam research

Foam is easy to sculpt complex structures of, but for final prototyping it is in general not the most interesting material. It can easily break when not applied with other materials or substances and is also a skill to perfect. Besides that, foam is very lightweight so even though sculptures wouldn't be perfect, they would still be of great use.

XPS

Extruded polystyrene (XPS), such as Depron or Styrodur, has a very low density of about 28–33 kg/m^3, making it an extremely lightweight material. It has low compressive and bending strength for its mass and is brittle under higher loads.

It is widely used in insulation and model-building applications (such as UAV wings, mock-ups, and lightweight panels) because of its low weight and reasonable stiffness. Depron in particular is popular among model builders for wings, fuselage skins, and flat structural surfaces.

XPS is widely available and inexpensive, commonly sold in sheet form. In Belgium, prices are typically around €3–6 per m^2 for sheets about 3–6 mm thick.

EPP

EPP foam (expanded polypropylene) has a density of about 30 kg/m^3, depending on the grade. It is flexible and highly impact-resistant, contributing to an excellent strength-to-weight ratio.

Mechanically, EPP is extremely tough, deforming elastically under load and largely recovering its shape afterward. It does not break under bending and absorbs impacts very effectively.

EPP is widely used for durable RC foam applications, such as airplane fuselages and bumpers, due to its combination of low weight, high impact resistance, and recyclability. It is generally available as blocks or sheets, with prices typically a few tens of euros for a 1x 0.6 m block of 50 mm thickness.

Rohacell

Rohacell® foam comes in several densities, typically 31, 51, or 75 kg/m^3, with the 71 IG-F grades around 75 kg/m^3. Ultra-light variants (~30 kg/m^3) are also available.

Mechanically, it has very high tensile strength and stiffness for its low density (for 75 kg/m^3, roughly 2.8 MPa tensile strength and 1.5 MPa compressive strength), giving it a much higher strength-to-weight ratio than XPS or EPP.

It is widely used as a high-performance core material in composites, for example in aeronautics, UAV wings, fuselage skins, race frames, and other lightweight sandwich constructions where high stiffness at minimal weight is required.

Rohacell is expensive, with 3 mm thick 75 kg/m^3 sheets (0.2 m^2) costing around €40 per sheet, available from composite suppliers such as Evonik or Easy Composites EU.

PVC-foam

PVC foam (e.g., Divinycell, EasyCell) typically has a density of 45–80 kg/m^3, with higher-density grades (200–400 kg/m^3) used for signage but heavier.

Mechanically, it is stiff and strong for a core material. At 75 kg/m^3, tensile strength is around 2.7 MPa and compressive strength about 1.6 MPa, with an elastic modulus of around146 MPa, making it much stiffer than polystyrene or EPP at the same weight.

It is widely used as a core material in sandwich constructions for aerospace, marine panels, and high-end model building, including RC frames and balsa-core applications. Brands like Raboesch supply thin PVC sheets for model building, and EasyCell/Foamcore is used in high-tech drones and composite panels.

PVC foam is relatively inexpensive, with 3 mm sheets (0.5×1.0 m) costing about €5–6 per sheet, or roughly €20–25/m^2 and is readily available from plastic and composite suppliers in the EU.

General conclusion for foam

	Density	Tensile strength	Price	Good for use?
XPS	0.028–0.033 g/cm^3	0.15–0.3 MPa	€3–6 per m^2	Good for lightweight prototypes
EPP	0.030 g/cm^3	0.3–0.5 MPa	Around 10 € per m^2	Same as XPS
Rohacell	0.075 g/cm^3	2.8 MPa	€40 for 0.2 m^2	Good for finalized wings but too expensive
PVC-foam	0.045–0.080 g/cm^3	2.7 MPa	€20–25/m^2	Good for finalized pieces

In general, foam isn't the best choice because of its weak strength when falling on impact. Still, for quick prototyping, this can be of great use. In general, XPS is best for simple crafts and lightweight results, though with high budget the rohacell could be of great use for finalized wings.

3.4 Fabric research

Fabrics in this case are only considered for wings and tail and serve to be strong, lightweight and easy to attach with sewing. For this research, the focus won't be on synthetic fibers like polyester. Either way, it is a good alternative that takes of weight.

Koverall

Koverall fabric has a low to moderate tensile strength, typically around 1–5 MPa, depending on the weave and thickness. It is not a structural material on its own but provides tear resistance and stress distribution when used as a covering over foam, balsa, or lightweight frames.

Polyester

Polyester parachute fabric is a lightweight, strong, and tear-resistant woven material. It typically weighs 30–70 g/m^2, has high tensile strength, low stretch, and is UV- and water-resistant. Used for parachutes, paragliders, kites, and ultralight wings, it offers an excellent strength-to-weight ratio and is easy to sew or heat-seal.

Siliconized ripstop

Siliconized ripstop fabric is a lightweight, durable woven polyester or nylon with a silicone coating for water repellency. Its ripstop weave prevents small tears from spreading, making it strong for its weight. Typically weighing 34-45 g/m^2, it is water- and wind-resistant, flexible, UV-stable, and can be sewn, heat-sealed, or bonded. Commonly used for ultralight tents, kites, paragliders, parachutes, and drone or RC aircraft coverings, it is valued for its combination of lightweight strength and tear resistance.

General conclusion for fabrics

	Density	Price	Good for use
Koverall	45 g/m^2	21.98 € for 1.52 x4.57 m	Not meant for sewing but still useful
Polyester	30–70 g/m^2	2.25 € for 1,50x1 m	Yes, durable material
Siliconized ripstop	34-45 g/m^2	1.60-3 € for 2x2 m	Well known for RC planes

In general, the option of polyester and ripstop are good options for attaching to the drone, though ripstop in general has a lower density reputation, making it have a more lightweight reputation. Koverall serves more for small prototyping and is in general expensive for what it is.

3.5 conclusion material research

For this project, a combination of poplar wood for structural components, PLA/PLA Light for detailed or load-specific parts, and ripstop or polyester fabric for coverings offers the best balance between weight, strength, cost, and workability. Foam like XPS or EPP can be integrated for lightweight internal structures or quick prototype iterations. This combination ensures a practical and efficient workflow for prototyping while maintaining structural integrity and minimizing weight.

Though this sounds nice on paper, in reality a combination like this is not feasible for this project. Although wood is a fine option to go with, 3D printing would be the best suited in combination with fabric sewing. Therefore, the materials chosen for this project at the end of the line are PLA, PLA light and polyester.

4. Different drone concepts

In order to find possible concepts, we started by creating a morphological diagram with all the previous information mentioned and some new ideas of course.

wings	Fixed wings	Morphing wings	Flapping wings	split wings	4 rotor (geen vleugels)	
position of the propellers	Front	Back	On wings			
Amount of propellers	1	2	3	4	5	
Control system	RC controller	Motion control	Teachable machine	Smarthphone	Zelf controller	
Context of user	Surveillance & security	Environmental & wildlife research	Civel & commercial uses	Intelligence & covert operations	Media & entertainment	Educatie

Out of this morphological chart we ended up creating a few interesting concepts. The concepts were chosen with the idea to be unique and different from one another.

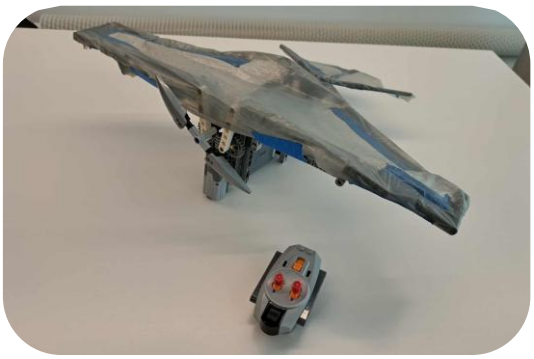
Concept 1	Concept 2	Concept 3
morphing wing bird-like drone: A drone controlled by a controller in the shape of a bird, intended for surveillance and security. The challenge here is programming the controller and prototyping the drone itself.	**fixed-wing drone controlled by gestures:** A classic fixed-wing drone powered by body gestures captured by a separate camera. The bird-like features are therefore found in the drone's controls. The aim here is education and entertainment.	**following pet drone:** A drone that follows the person. Ideally, this would be a fixed-wing drone, but realistically it would be a 4-rotor drone. A different animal characteristic would be assigned for this. This is purely for entertainment purposes.

Each concept also follows the necessary SMART ideology to make sure that the idea is achievable within the given timeframe.

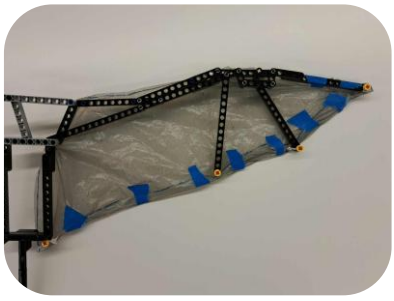
S	M	A	R	T
Specifiek	**Meetbaar**	**Acceptable**	**Realistisch**	**Tijd-gebonden**
Een fixed-wing drone met morphing (vormveranderende) vleugelprofielen en een controller die eruitziet en zich gedraagt als een vogel (bird-like controller). Toepassing: discrete surveillance en perimetersecurity. Kernfeatures: - Vleugelmechaniek voor aanpassing van camber/span (vereenvoudigde morphing: 2 standen: cruise / loiter). - Bird-shaped handheld controller met intuïtieve input (bijv. flapper-achtige joystick of tilt-based bediening). - Basis-sensorset: HD-camera (gimbal), IR/low-light optie, GPS, IMU, redundant communicatiekanaal (radio + LTE fallback). **Gesture-control mode (educatie & entertainment)** Ground-based camera of wearable sensor set die gestures detecteert en vertaalt naar vluchtcommando's (start, land, turn, speed change, hold). Bird-achtige handcontroller (tactiele/intuïtieve inputs) of alternatieve bestuurbare interface	**Snelheid:** Belangrijk voor prestaties, energieverbruik, safty en specs. **Liftkracht / liftgedrag:** real-time liftmetingen of afgeleide via accelerometers tijdens load-cases en transities; essentieel voor stabiliteit en voor morphing-transities. **Gewicht en gewichtsverdeling:** totale massa en CG-positie: weegscales en CG-meting op verschillende configuraties. **Wing geometry (span, chord, oppervlakte):** wingspan, wing-area per configuratie; gebruik CAD en fysieke meting. **Wing angle of attack (AoA) en lokale AoA tijdens vlucht:** met AoA-sensoren of afgeleide uit dynamische data. Belangrijk voor stall-gedrag, transitions en controller tuning.	Het project combineert drie normaal gescheiden domeinen: *biomimicry, human–drone interaction en autonome intelligentie*, in één modulair systeem. De combinatie maakt het een sterk onderzoeksplatform dat zowel in engineering als design uiterst relevant is. **Multi-markt potentieel**: security/surveillance, educatieve demonstraties voor STEAM, consumenten/entertainment (social media, events). Modulariteit maakt het inzetbaar voor meerdere klanten. **Unieke selling points**: bird-like esthetiek + morphing gedrag (camouflage en acceptatie), intuïtieve besturing (gestures/handcontroller), en follow-features voor engagement. Het is **educatief**: gebruikers leren over aerodynamica, sensorfusie, visiesystemen, interactieontwerp, robotica en natuur geïnspireerd design.	**Benchmarks & haalbare kwaliteitsniveaus** Prestaties vergelijkbaar met **basis fixed-wing DIY foamboard drones** (FliteTest-niveau). Gesture control op eenvoud (bijv. MediaPipe of basic OpenCV-tracking). Follow-mode op beginner-niveau (bijv. 2D-tracking, niet full autonomous waypoint AI). Bird-like design vooral visueel/aerodynamisch, geen complexe morphing. **Budget: maximaal €150** Dit betekent dat alle onderdelen **zeer low-cost** moeten zijn: Goedkope foamboard of EPP vleugels. Motor + ESC in budgetklasse. Basis flight controller (Arduino + gyro is mogelijk, of heel basic FC). Camera voor gesture input (USB camera of goedkope ESP32-cam). Minimaal aantal servo's. Geen dure GPS, LIDAR of high-end onboard vision.	Fase 0: Vooronderzoek & eisen (2 weken) ·Fase 1: Conceptontwerp & onderdelenlijst (3 weken) ·Fase 2: Mechanisch prototype (morphing vleugel) + framebouw (3 weken) ·Fase 3: Elektronica & integratie (flight controller) (3 weken) ·Fase 4: Software & controller 6 weken)

To test out the complexity of each concept we ended up making a few prototypes of each concept.

For the **flapping wing concept,** a simple prototype was made out of Lego-parts that can be controlled by remote. The weight of the Lego itself and the lack of tension in the fabric covering the wings make flying impossible. It remains an interesting prototype, but it became clear that in terms of control and weight, this would be an enormous challenge. Especially since the controls for this type of drone are not well known among drone experts.

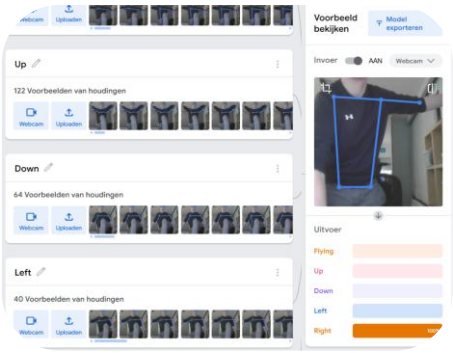


The **morphing wing concept** (concept1) was again made out of Lego. This prototype was created to test the folding mechanism with a plastic overlap that will serve as the future fabric to be attached to the drone. This system does not yet fold and unfold automatically, but rather manually. Due to the weight of the Lego and the lack of tension on the plastic overlap, it is not possible to test whether it can float. Therefore, this is only for illustration purposes and to highlight a possible mechanism.



The **final prototype** was (concept 2) in **teachable machines**. Here we created a simple system that could detect based on camera tracking whether the user wants the drone to go left or right by tracking the arm movement. The problem with this system is that sometimes the drone has problems detecting an upwards or balanced movement and this way of flying a drone would get quite tedious and physically difficult for a user.

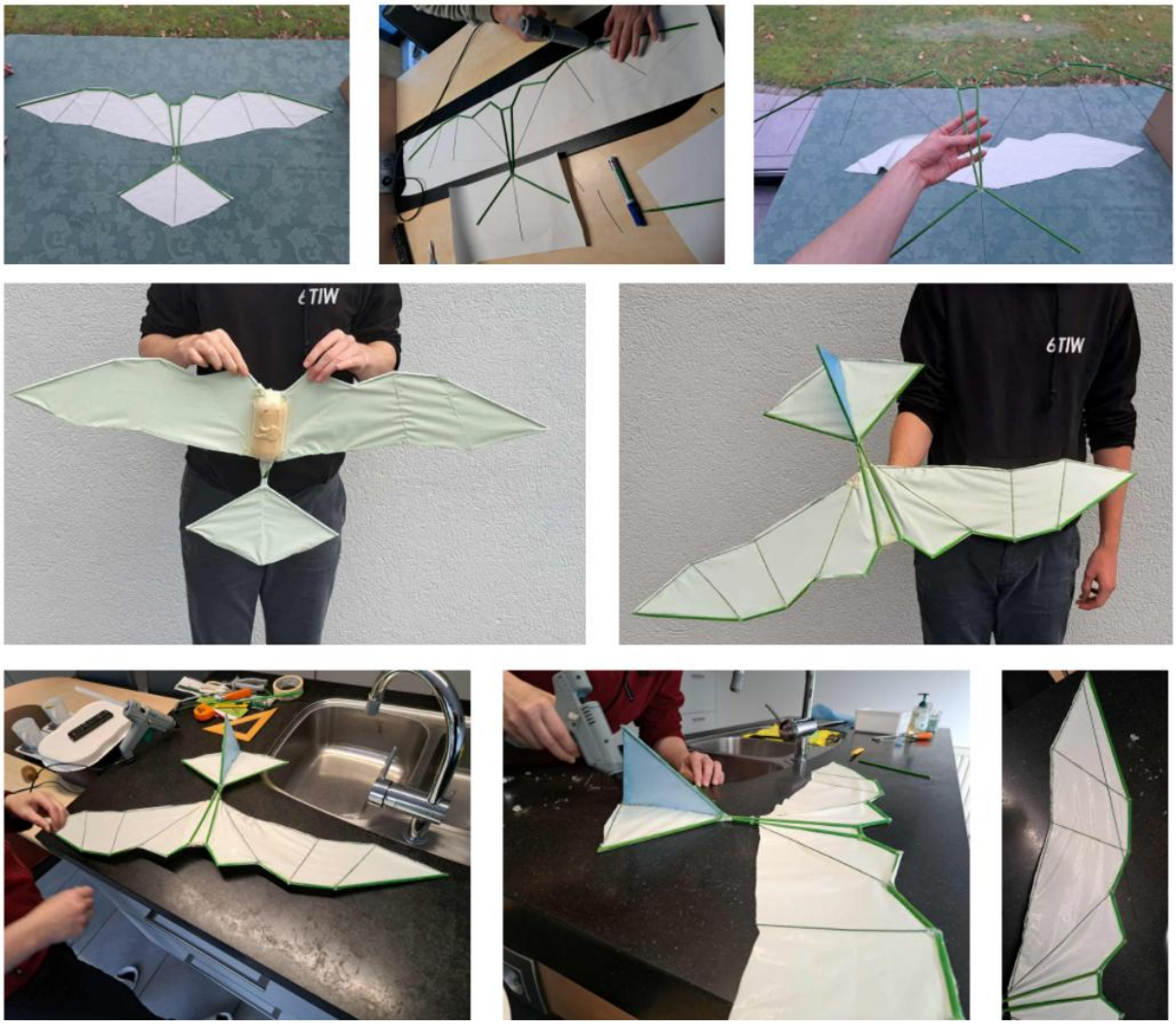
Concept 3 was not made considering this would be too difficult to prototype within a short period of time.



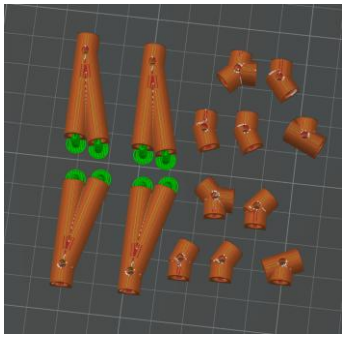
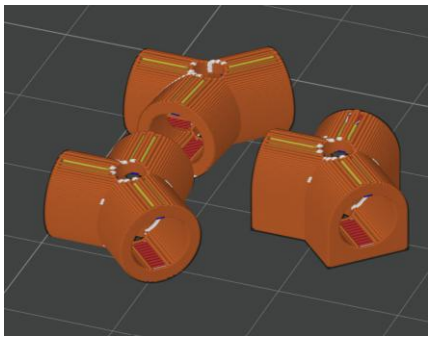
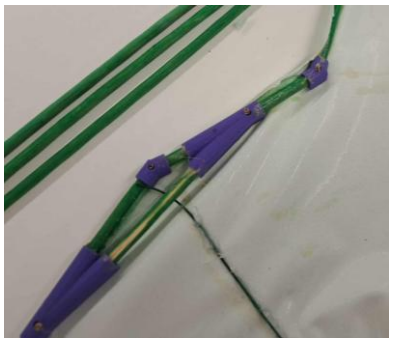
Out of all these prototypes, concept 2 simply seems the most viable to work further on so the next step was to try and make a flying model without the mechanism to reduce the weight. A **cardboard glider** model was designed as a quick-and-dirty prototype to test gliding. A cardboard profile was cut out to form a skeleton. Polyester was attached to the wings and tail with adhesive tape. Tests were then carried out around the campus. Later, a motor was added to test whether lift could be achieved. Because the cardboard was very weak and the motor itself was not securely attached, the tests were stopped and an improved prototype was sought that could generate more power.

Below is an improved prototype of the cardboard version used to conduct flight tests. The difference is that the wings have been reinforced by replacing the cardboard with light wooden sticks. These sticks were attached to the fabric using hot glue. The results of these tests again showed instability. One logical reason for this would be the fact that there is no rudder present in the tail and there is no weight to represent the fuselage of the drone but even with these additions the drone still couldn't balance itself during experiments.

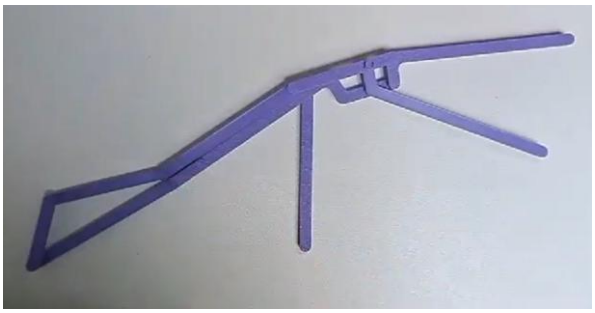
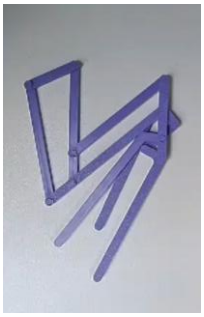
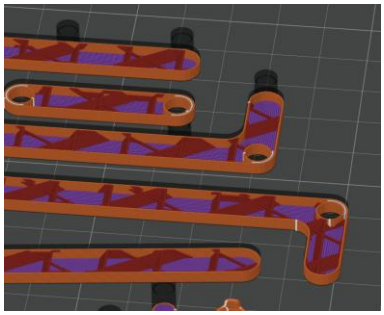
After many tests, there was also damage to the prototype's wings. This led to the idea of looking for support that would prevent these issues in future tests.



The PLA support was seen as the link for all the sticks in the drone's skeleton. This presented the problem that in some cases, the support was not long enough to properly place a complete link, and the wings were still not sturdy. Textile fastening was also applied, this time using screws. However, the screws made the design less user-friendly due to their pointed underside. It would therefore be interesting to look at other alternatives for fastening textiles in the future. Contrary to what was normally thought, the weight of the screws themselves did not add much extra weight to the drone.

The problem still however remains with this final iteration that the drone still could not fly due to too much instability. In one last effect we created a final prototype of the folding mechanism that was lightweight and stronger, however it remained clear that a new concept needed to be created in order for us to continue this project.

3.1 The final concept

Now that the iteration phase is done, the needs of the final drone concept are described through the MOSCOW method. To simplify the morphing system the idea will be to add one joint in the wings that allow the drone to dive like a falcon. This folding mechanism will therefore still be present but a lot smaller and subtle.

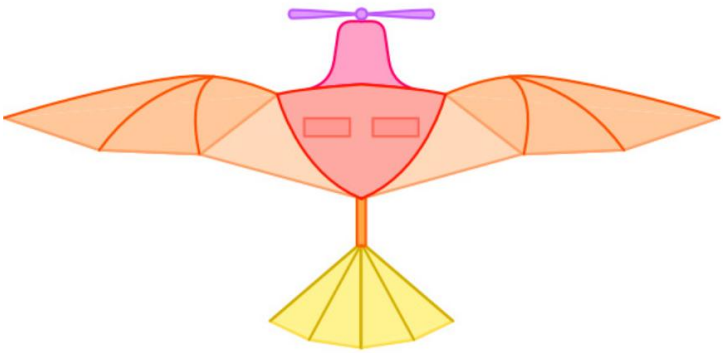
Must	Should	Could	Won't
• Bird-like uiterlijk van de drone (vanuit vleugels en staart) • invouwbare vleugels • fixed-wing • manuele besturing • energiebron: lithiuim-batterij • minstens 200m bereik • onder de 1.4 kg	• zou moeten vliegen • bestuurd worden via RC-controller • zou een systeem moeten hebben om de drone in evenwicht te houden • Zou langer moeten vliegen dan een kleine multi-rotor	• Kan beeldmateriaal weergeven vanuit de lucht • Kan een inwisselbare batterij hebben • Kan oplaadbaar zijn • Kan gebruikt worden in andere velden dan surveillance • kan gebruik maken van AI-herkenning	• Wordt niet gebruikt voor zaken te dragen • Wordt niet gebruikt in water • Wordt niet mee gevlogen over geboden gebied • wordt geen nieuw soort controller ontworpen voor uniek gebruik

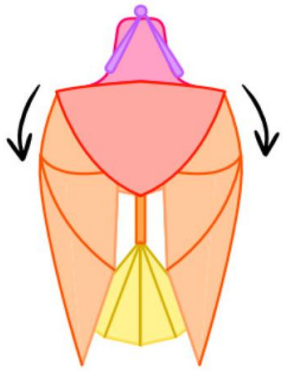
The person needs a fixed-wing drone that is not very conspicuous so that they can fly it. They also need a long range (200-500m) and controls that are recognizable to other fixed-wing drones.

The desire is to make the drone bird-like, or to incorporate a characteristic of birds so that the drone is less noticeable in its surroundings. This is to cause less disruption to other factors during use and, when filming, to make it appear more natural in, for example, nature, but also in surveillance.

The first product architecture can be described as follows: The wings have a winglike shape and are made out of textile, kept in shape by a strong beam system and are connected to the body with a rotating joint. The dark orange textile is fixed strong in place whilst the light orange textile is more flexible for proper movement. The tail is arch-shaped and in a T-configuration.

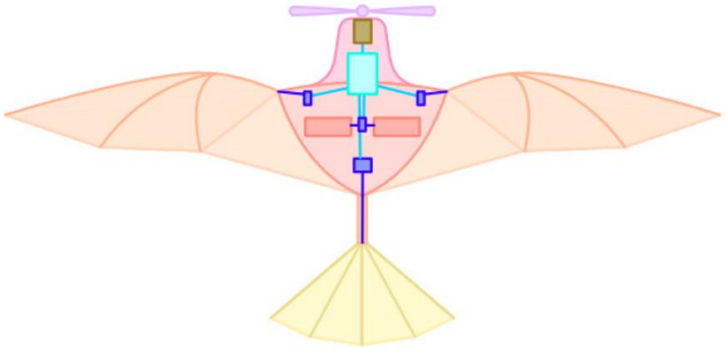
The actual electronics will be in the fuselage that would be 3D printed. Finally, the tail is connected to the fuselage with a rod and will act like a large elevator. This means there will be no rudder movement. This was chosen to simplify the design and to decrease the weight of the tail which will be later explained.

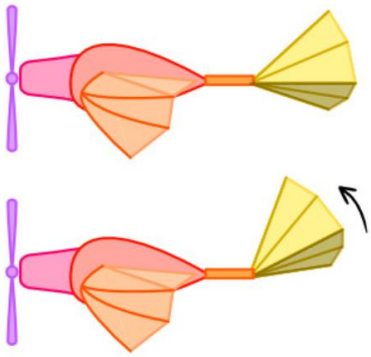




Stabilizor / Elevator & Rudder
Wings & Ailerons
Folding textile mechanisme
Propeller
Motor cell

Wings can fold in for easy transport and kamikaze attack





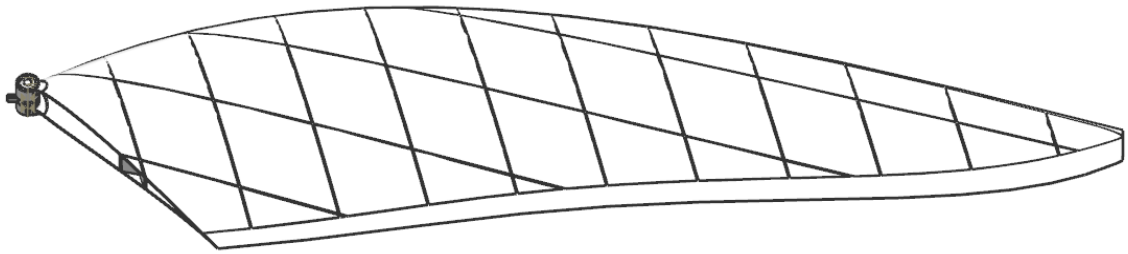
Brushless motor
Wings & Ailerons
Battery, ESC, ...

Ailrons and elevator in the back can move up and down.

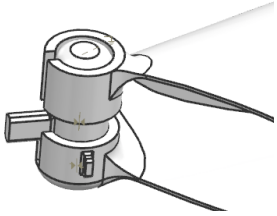
Unfortunately, this design has 2 major flaws:

1. The textile has is straight and does not have an airfoil shape. This is very negative considering lift is perhaps the most important thing for flight.
2. Working with textile makes It nearly impossible to add ailerons.

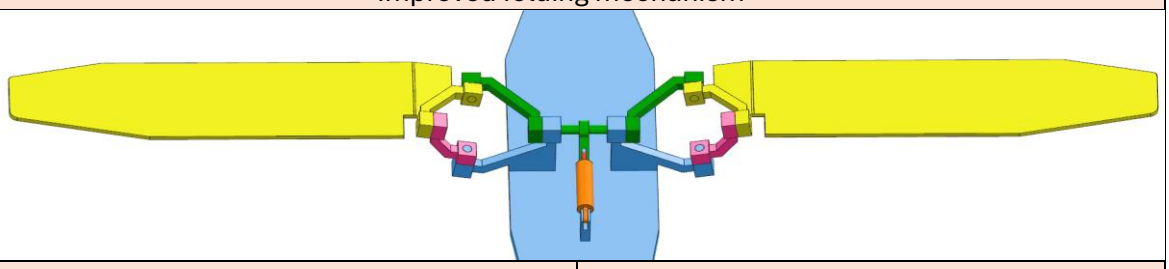
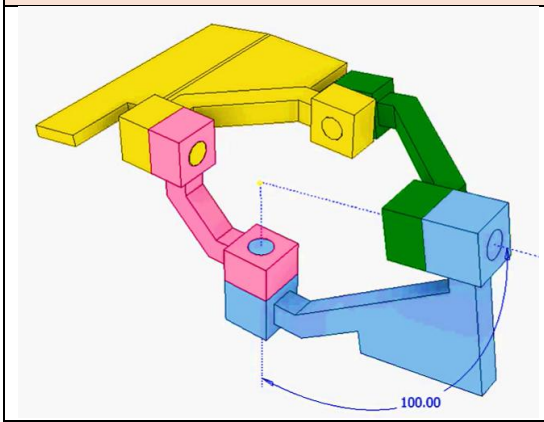
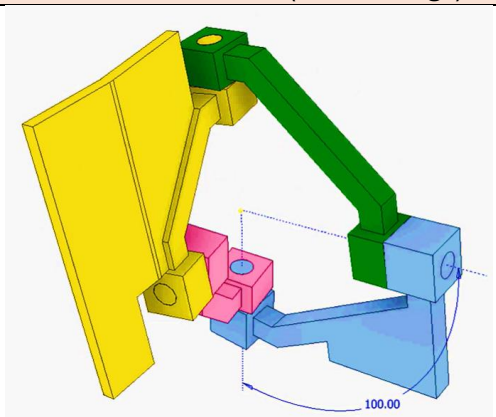
This is no problem for the tail because the entire tail acts like an elevator but for the wings this makes things much more difficult. A solution could be to add an internal rib structure, which gets wrapped with textile. but at that point, you might as well make the entire wing a sold 3D-printed structure.



In doing so, a new problem arises, since the wings have now become a lot heavier. This means that a much greater force ends up on the joint. This means the joint would have to be eater incredibly large or otherwise it would simply break due to the force of gravity, drag and lift on the wing.



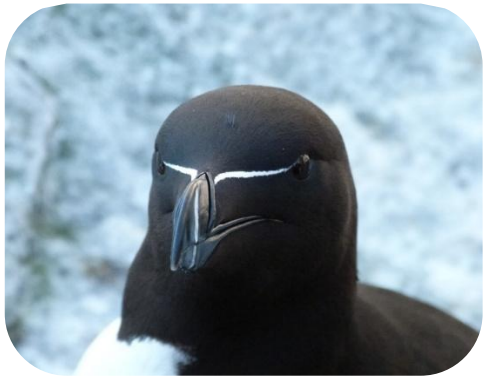
After some online research a viable solution was found where the wings would be connected to the fuselage using a 4-bar linkage. This would increase the amount of connection points to 2 and this mechanism would also be controlled from the center of the fuselage using a servo.

Improved folding mechanism	
	
Horizontal mode	Vertical mode (folded wings)
	

3.2 Brand identity

The brand identity of Razor is built around a balance between sportiness, precision, and natural elegance. Because the drone is designed for dedicated drone enthusiasts, the visual language avoids overly aggressive cues and instead draws inspiration from the aerodynamic grace of birds. The black body with subtle orange detailing reinforces this idea: it communicates speed and agility, yet remains refined and controlled rather than hostile or tactical.

The overall form retains bird-like characteristics to connect the drone's behavior and aesthetics with the fluid motion of flight found in nature. This direction aligns with the intended persona, enthusiasts who value performance but also appreciate design that feels organic rather than mechanical. The logo, based on the razorbill bird, further strengthens this connection by symbolizing streamlined power and precise maneuverability. Together, these elements create a cohesive identity that resonates with users who want a drone that feels fast and capable, but also approachable and visually harmonious.



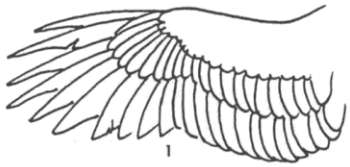
Besides that, the name Razer as the brand will develop this drone also has a meaning behind it, similar to the bird that gave the inspiration. Like a razor that goes over the skin, leaving its mark on the area as done, the drone does the same for the areas it flies over. It leaves behind its own mark in the information it receives from above as it cuts the sky at high speeds. That's, as mentioned earlier, the sportive qualitative performance that the drone is trying to present. To achieve this, the name alone will not suffice. The design needs to be in line with the message the brand wants to bring over.

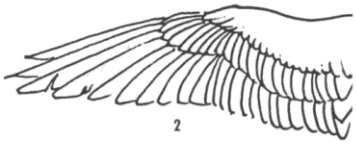
Biomimicry

To determine the aerodynamic shape of the Razer drone, we conducted research into different natural wing configurations. The image above illustrates the four primary bird wing types that occur in nature, each optimized for a different combination of speed, stability, and maneuverability. Studying these shapes helped us understand how subtle geometric changes influence flight performance and allowed us to translate biological principles into a functional drone design.

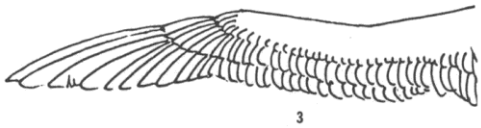
1. **Soaring Wings (Albatross-type):** These wings are long and narrow with a high aspect ratio, optimized for low-drag gliding over long distances. Birds such as albatrosses use this shape to maintain flight with minimal energy. While ideal for endurance and stability, this configuration offers limited maneuverability, making it less suitable for a sport-oriented drone that needs agile handling.

2. **High-Speed Wings (Falcon-type):** These wings are tapered, swept back, and relatively pointed. Falcons and other fast aerial predators use this shape for high-velocity dives, rapid directional changes, and precise control. The geometry enables excellent maneuverability and acceleration without introducing excessive drag. This category became a strong reference point for our design direction.

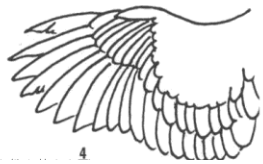




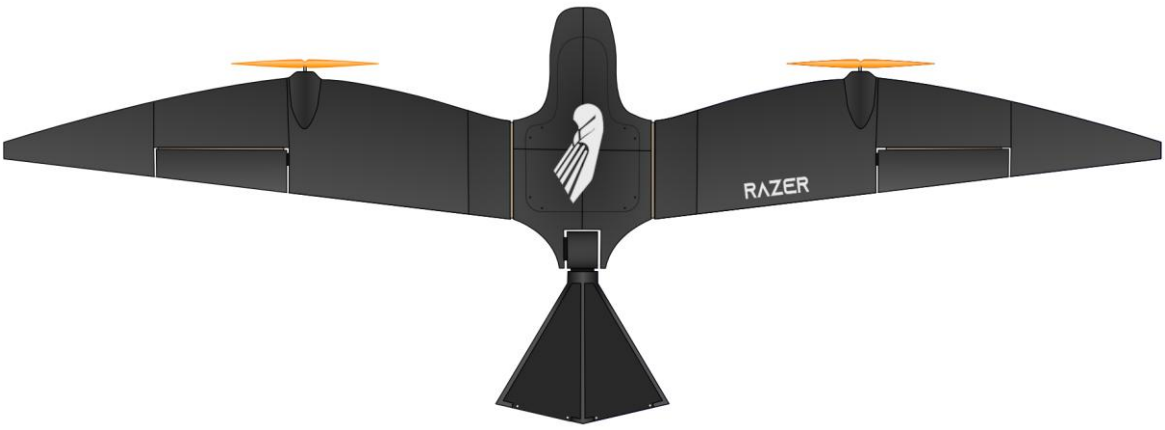
3. **Elliptical Wings (Hawk or Soaring Predator):** These wings provide a balance between lift efficiency and maneuverability. Common in birds like hawks and eagles, they allow stable soaring while still enabling controlled turns. Although effective for mixed-performance flight, their broader span and softer profile were less aligned with Razor's sleek, sporty identity.



4. **High-Lift Wings (Partridge-type):** Short, broad, rounded wings generate powerful lift during takeoff and rapid flapping flight. Birds such as partridges use them for quick bursts of speed and tight maneuvering at low altitude. However, this shape produces significant drag at higher speeds, making it less compatible with the aerodynamic goals of our drone.



After comparing the aerodynamic properties of all four wing types, we identified the lesser kestrel falcon as the most suitable biological model. Its wings fall within the high-speed category. These qualities aligned closely with Razor's brand identity: sporty, agile, and inspired by natural flight, without appearing overly aggressive. The kestrel's wing geometry provided a biomimetic foundation that supports both aesthetic coherence and aerodynamic efficiency.



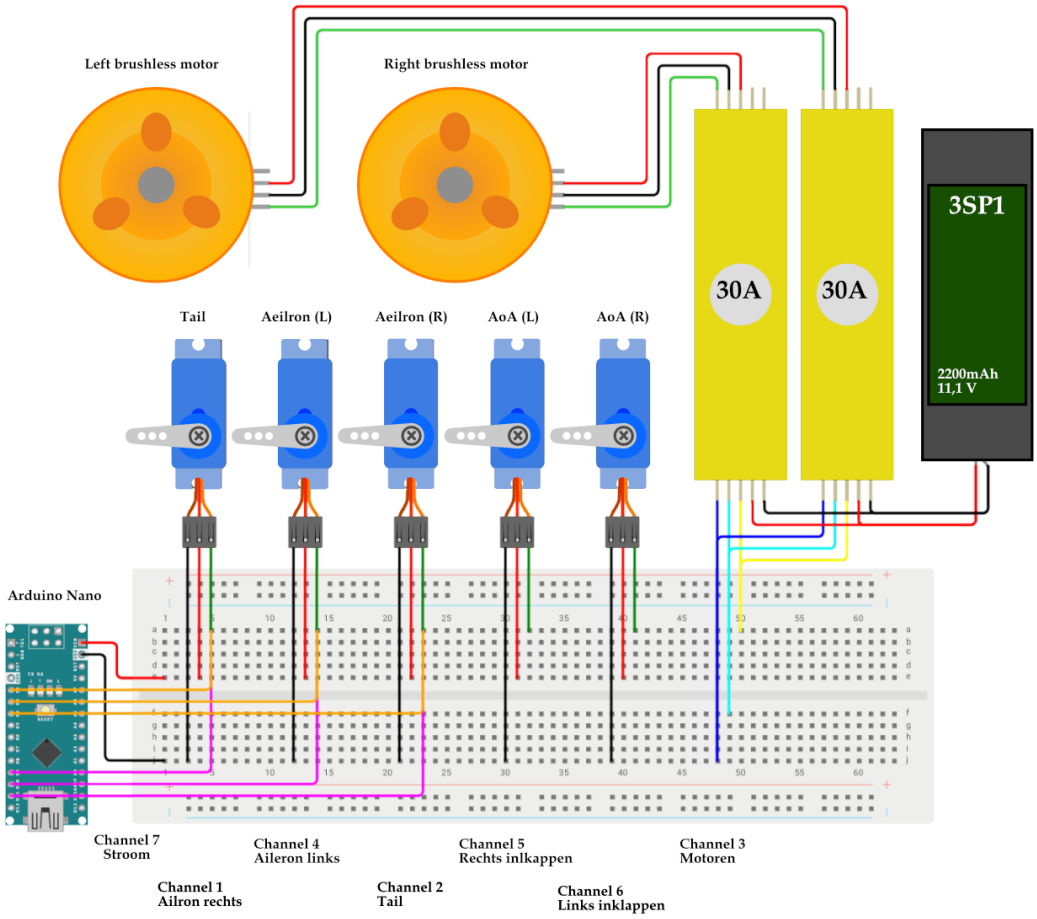
4. Electronics

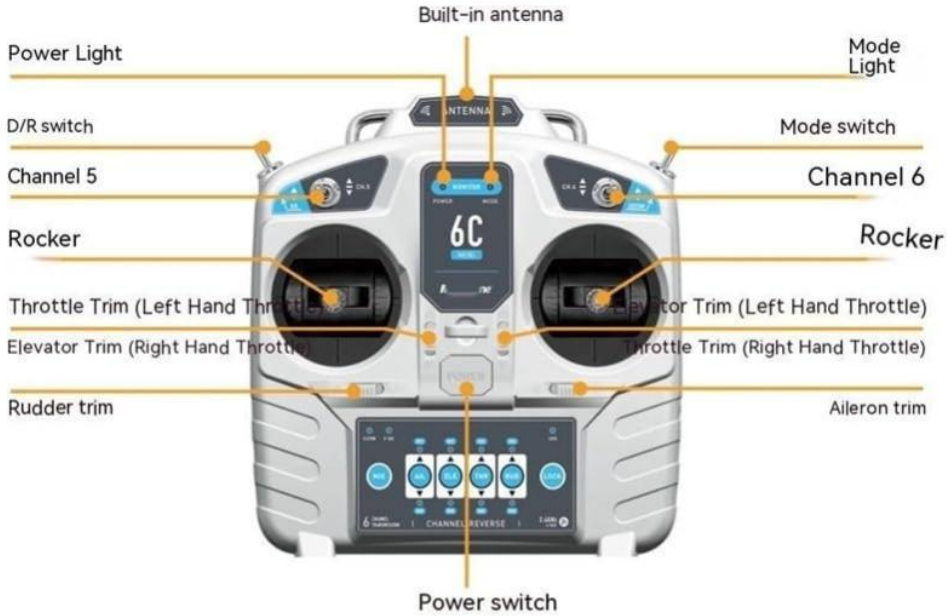
At the center are the two brushless motors, on which the propellers are mounted. These motors generate the lift that keeps the drone in the air and are connected to electronic speed controllers (ESCs) that regulate the motor voltage. Five servos are implemented for the control elements: two for the ailerons that control the drone's roll movement, two for the wing folding mechanisms that can tilt the wings in and out, and one for the movement of the tail.

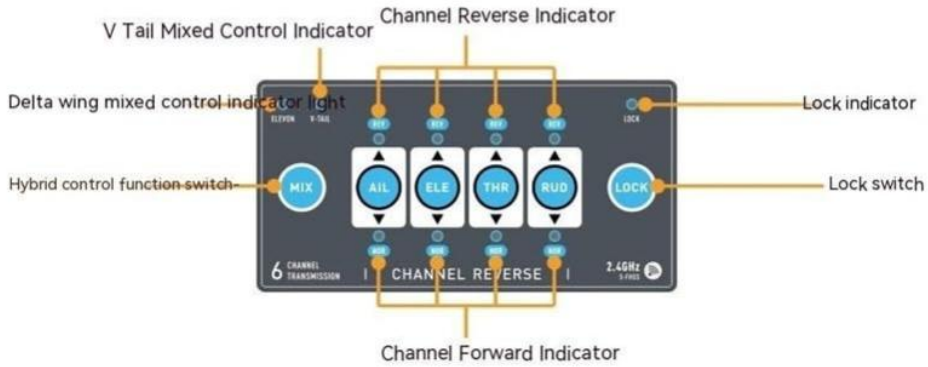
Power is supplied by a LiPo battery (3S1P, 2200 mAh, 11.1 V), which powers both the motors via the ESC and the Arduino and servos. An Arduino Nano is used for control and stabilisation, which is responsible for the drone's auto-balancing. The Arduino reads signals from the built-in gyro sensor, processes them and controls the servos and motors to achieve the desired flight stability.

When selecting components, the cheapest brushless motors that still provides sufficient power to lift and move the drone was chosen. For the servos, the priority was compactness, low weight and easy availability so that they fit well into the limited internal volume of the drone without affecting aerodynamics. All in all, this internal setup offers a balance between power, precision and compact design, which is essential for a lightweight and manoeuvrable drone.

The internal connections can be seen in following scheme:







Looking at the controller. The left rocker's vertical movement serves to adjust the tail positioning. The right rocker vertical movement serves the motors, the horizontal movement controls the roll of the plan. Channels 5 and 6 serve to fold the wings in and out. The controller itself needs four AA-batteries making it last a long while.

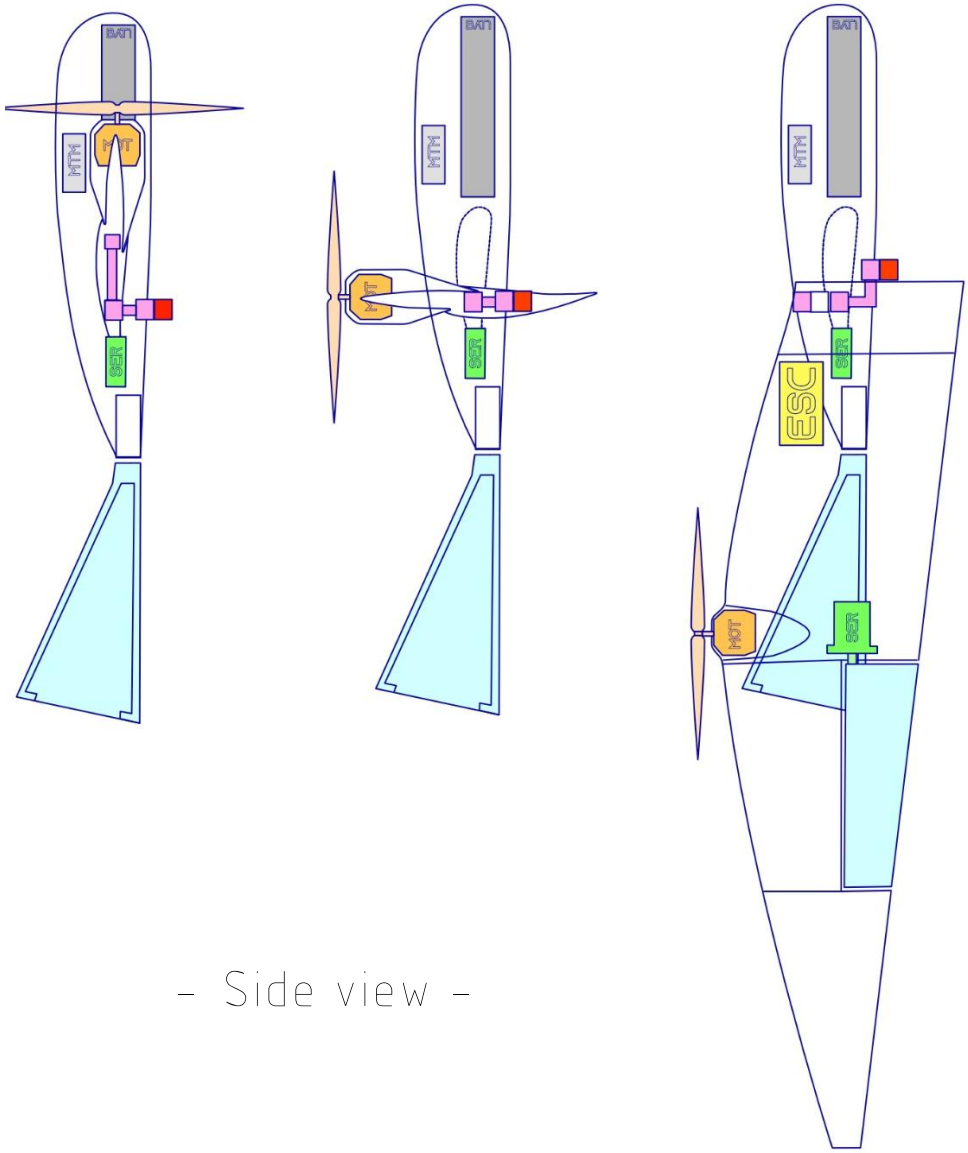
4.1 Battery choice

We utilize two A2212 2200KV motors, each featuring a peak load current of 21.5A and operating at 11.1V. Since each individual battery cell provides 3.7V, a 3S battery configuration is required to achieve the necessary 11.1V total. In terms of power consumption, the combined motors draw a maximum peak current of 43A. However, because the throttle is rarely held at 100% during flight, we can estimate an average operational draw of approximately 30A. By selecting a 2200mAh battery, we expect a flight duration of roughly 4 to 5 minutes. To ensure the battery can safely discharge this power, we must consider the C-rating, which defines the maximum current delivery. While the setup requires a minimum of 50A to cover the motors, auxiliary components, and a safety margin, implying a minimum C-rating of 22.7 for a 2200mAh pack, the chosen battery features a 50C rating, providing more than sufficient overhead for stable performance.

5. Product architecture

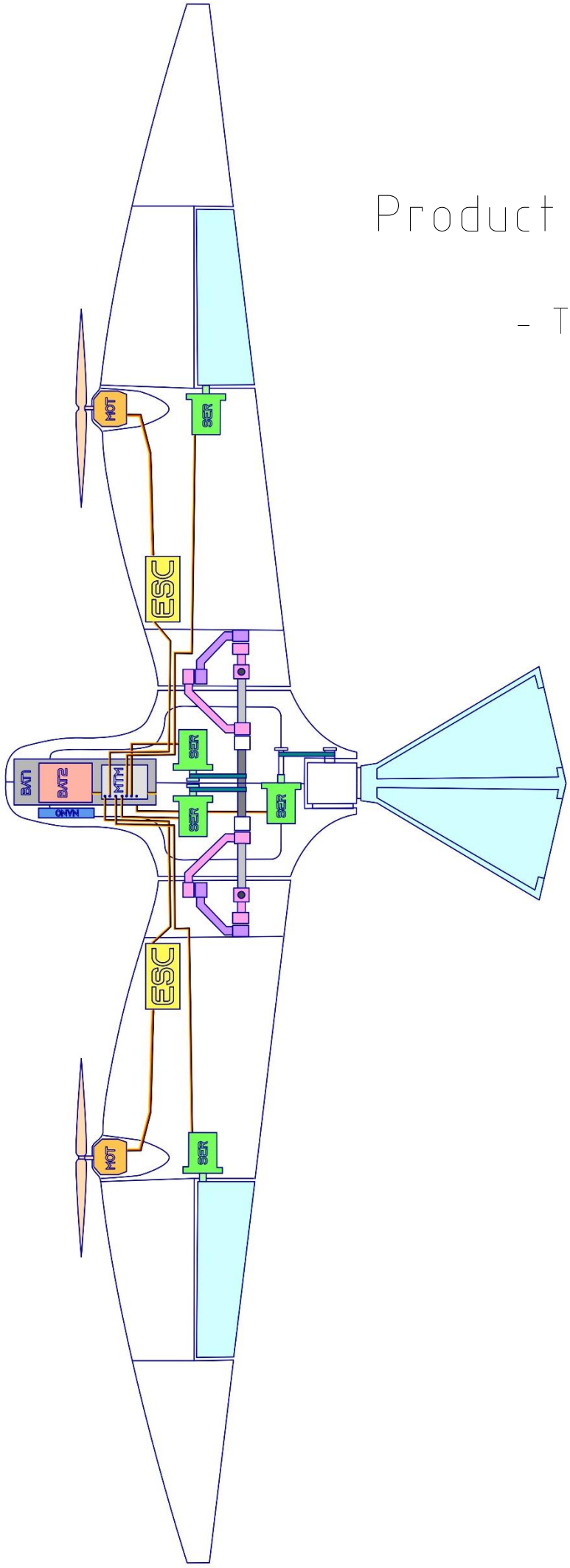
This mechanism would allow much more rigidity but also increases the complexity within the fuselage and begs the question of how all the components could even be arranged. At the same time, the fact that the wings fold inwards and rotate vertically at the same time does offer a new advantage. If the motors are attached to the wings this would mean that when the wings are folded in, the propellers will be facing upwards, theoretically allowing the thrust force to be used for vertical landing and take-off, if everything is perfectly balanced when folded inwards.

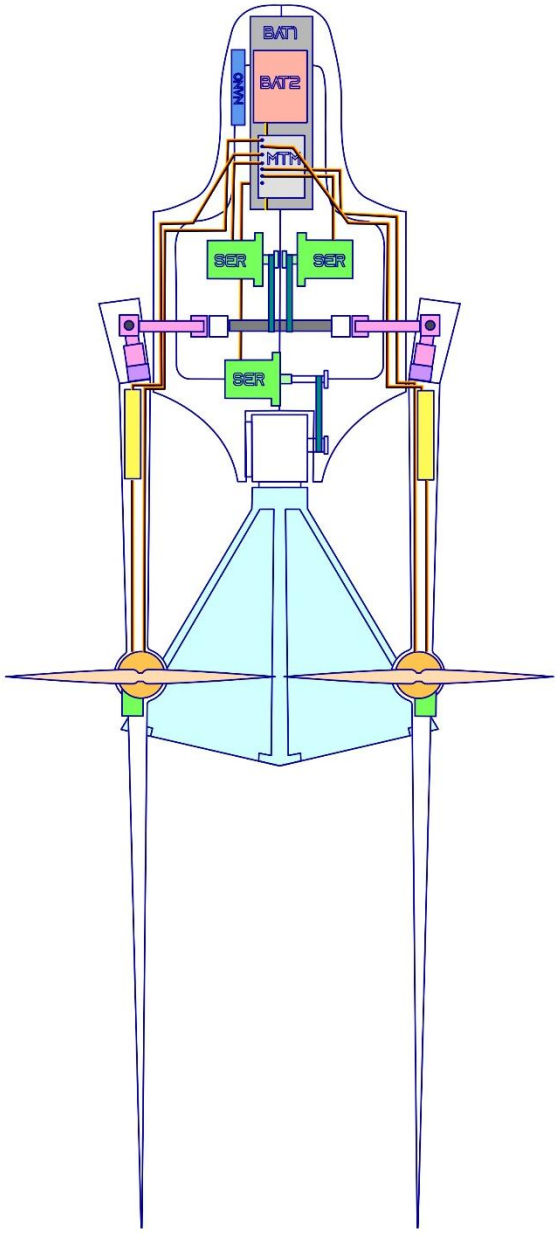
From a side view this drone folding mechanism would look somewhat like described below. The wings are bigger than expected when folded inwards, however this is necessary for the lift force. It does seem like there is not enough space in a fuselage of normal size unless making the mechanism smaller but that would drastically reduce the strength of the system. The red beam in this case falls under the bottom of the fuselage which is not optimal for landing. To solve this the mechanism would ideally poke out the top of the fuselage where it cannot be damaged when landing.



Product architecture

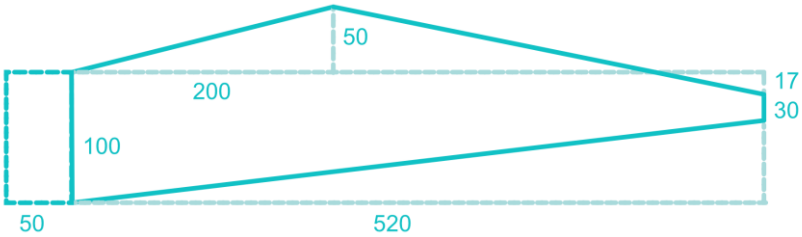
- Top view -





5.1 Calculating the wing and tail design

The product architecture shows how the mechanism and electronics would be arranged inside the body of the drone. In order to fit everything nicely, the drone has to be a certain size, so the total wingspan currently is 120cm, making each wing 520cm long. To test if everything would fit inside of the drone, the product architecture is fully modeled in the correct size. The chosen chord of the wing is 100 mm, and the area is roughly 50 000mm^2 for each wing.



- $ailron\ chord = 20\%\ Chord = 20\ mm$
- $ailron\ span = 30\%\ semispan = \ 156\ mm$
- $tail\ length = 2\ Chord = 200\ mm$

For a T-shaped tail:

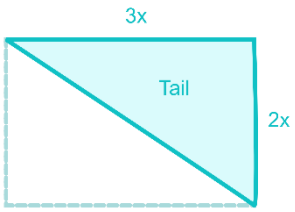
- $A_{hozriontal} = \frac{50\ 000mm^2}{4} = \ 25\ 000\ mm^2\ (per\ side)$
- $A_{vertical} = 35\%\ \left(\frac{25\ 000}{2}\right) = 4375\ mm^2$

For a V-shaped tail the optimal angle is 30° so for a triangular shape it can be said that:

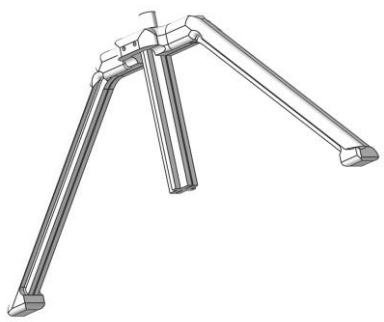
- $A_{tail} = \frac{25\ 000}{\sin(30)} = 28800$

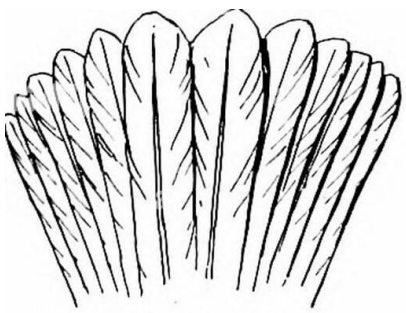
$$28800 = 2x \cdot 3x$$

$$x = \sqrt{\frac{28800}{6}} = 70\ mm$$



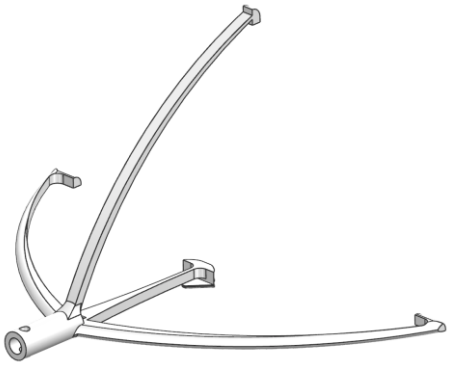
For the tail, we experimented with a few designs. The first idea was to create a flat tail that is clamped between two beams creating a perfectly flat tail, just like most birds have. The downside of this design is that the lack of a rudder creates very little stability.



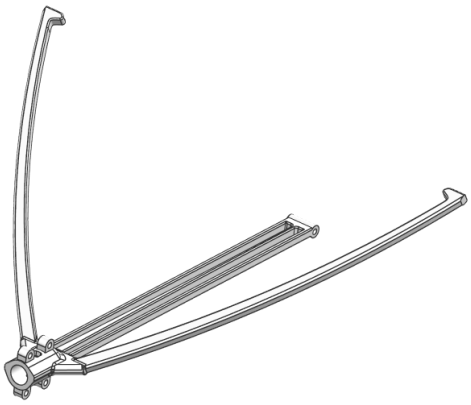


Rounded tail

The second design solves this problem and now has a T-structure that includes the rudder. To make it more lightweight, instead of the clamping mechanism, the idea would be to wrap and sew the textile around the beams. The downside of this second mechanism is that the T-structure makes it difficult to connect the textile to the beams. Such T-shape prototype was previously tested, it was impossible to create without a lot of sewing or glue.



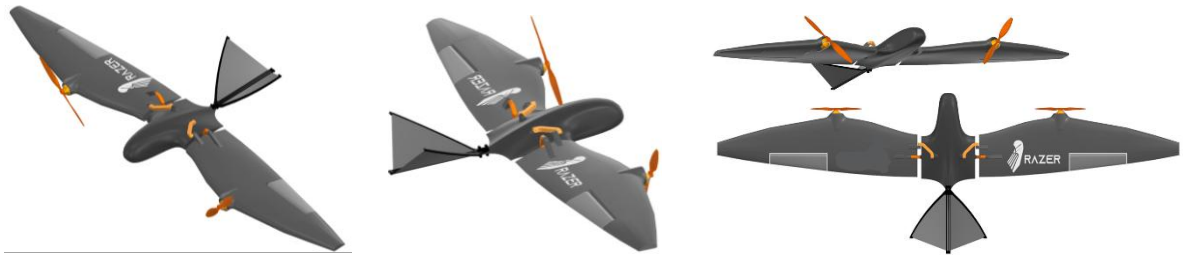
The final design is a V-tail instead of the traditional T-structure. In this case the elevator and rudder are mixed as one. V-tails and T-tails are different from one another, both have their advantages and disadvantages, however in this case selecting a V-tail will simply add more benefits.



	V-Tail	T-Tail
Drag	Low	Medium
Weight	Low	High
Pitch Control	Medium	High
Yaw Control	Medium	High
Pitch Stability	Medium	High
Yaw Stability	Medium	Good
Aerodynamic Efficiency	Good	Good
Risk of Deep Stall	None	High
Structural Complexity	Low	High
Manufacturing Difficulty	Low	Higher

The First CAD model

Based on the final product architecture, the first CAD model was designed that contained the outside structure of the drone. Internal components where not added since there needs to be a balance check in place first, however this model will be valuable to estimate the weight considering the wings and fuselage are hollow. The CAD model can also help to simulate whether the folding mechanism will be able to hold the weight of the wings, using a CAE analysis.

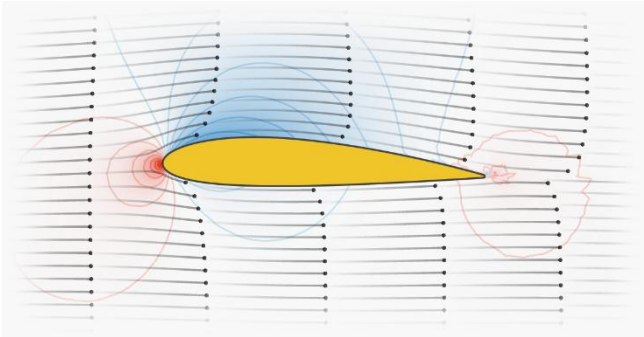


5.2 steering of product

There are many ways to make a drone fly, but in order for an object heavier than air to remain airborne, it must generate a sufficient amount of lift and thrust. Lift is the upward force generated by the wings as air flows around them, allowing the drone to counteract its own weight. Thrust, on the other hand, is the forward force produced by the propeller, enabling the drone to overcome drag and maintain airflow over the wings.

In a fixed wing drone, the wings and the stabilizer at the rear are the most important components for generating lift. The wings were designed in a way that allows them to efficiently split the airflow while minimizing turbulence. Depending on their shape, the wings also create pressure differences: areas of high and low pressure. This effect can be used to the drone's advantage, as high-pressure zones naturally move toward low-pressure zones, generating a forward-propelling force when designed correctly.

The optimal wing profile for maximizing lift and ensuring stable flight is called an airfoil, as shown in the image below. While airfoils always share the same droplet-like shape, there are hundreds of variations. The key is to select the right airfoil depending on the intended application.



Thrust in fixed-wing drones can be generated in two main configurations: puller and pusher. In a puller plane, the propeller is placed at the front, pulling the aircraft forward and creating a smooth airflow over the wings. In a pusher plane, the propeller is mounted at the rear, pushing the aircraft through the air. This configuration can reduce drag around the nose, improve visibility, and protect the propeller during take-off and landing. The main difference lies in where the thrust is applied, which influences airflow and stability, but both systems can achieve efficient and stable flight when properly designed.

Generating enough lift is unfortunately only half of the story. A drone always needs a proper weight distribution for proper flight. If the back of the plane is for example to heavy than the plane will become increasingly unstable and hard to control while of the front is too heavy, manoeuvrability and stability will be reduced. The trick of making a good fixed-wing drone is to make sure the front of the plane weights just as much as the back and must be fully symmetrical. Besides weight distribution there are also a lot of other factors that impact the stability of the drone during flight. The angle of the wings, size and profile of the stabilizer in the back and shape of the body or wings will carry benefits and downsides that usually effect the stability in some way.

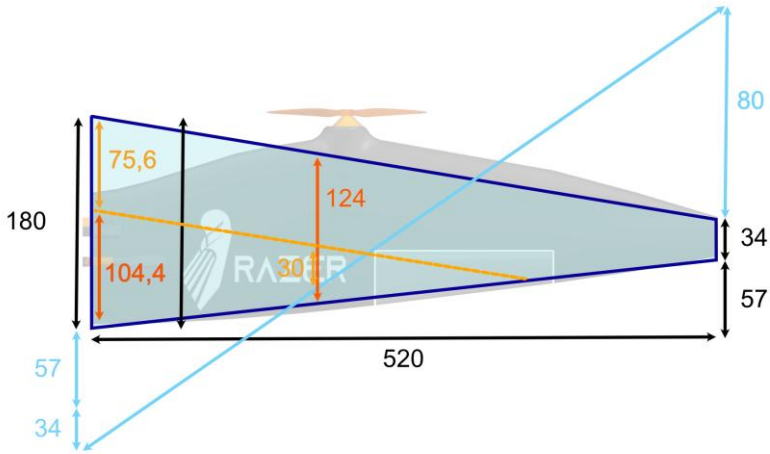
Finally, the drone's maneuverability allows it to move up, down, left, and right while maintaining control. This is achieved using ailerons on the wings and stabilizer, which rotate up or down to change drag and lift, enabling controlled turning and altitude changes.

5.3 Balancing the drone

Since the wings are now fully designed and no more major adjustments will be made, the next step is to find the centrum of lift (CL). The centrum of lift will determine the exact balancing point. The current shape of the wing is very organic so to simplify the calculations we will assume the shape of the wing is a simple trapezoid with these specific measurements:

- Root cord $C_r = 180\ mm$
- Tip cord $C_t = 34\ mm$
- Semi-wingspan $b = 520\ mm$

The following calculations determine the centrum of lift to be about 10 cm from the trail edge:



solution:

Taper ratio: $\lambda = \frac{C_t}{C_r} = \frac{34}{180} = 0{,}1889$

Mean aerodynamic Chord (MAC): $MAC = \frac{2}{3}\ C_r\ \frac{1+\lambda+\lambda^2}{1+\lambda} = 123{,}6\ mm$

Vleugeloppervlak: $S = \frac{C_r+C_t}{2}\ b = \frac{180+34}{2}\ 520 = 55640\ mm^2$

Aspect ratio (AR): $AR = \frac{b^2}{S} = \frac{520^2}{55640} = 4{,}86$

Ligging van MAC on wingspan: $y_{M\ AC} = \frac{b}{6} \cdot \frac{1+2\lambda}{1+\lambda} = 100{,}44\ mm$

$x_{AC} = 0{,}25\ MAC = 30{,}9\ mm$

Centrum of lift: $CL = 75{,}6\ mm\ (leading\ edge)$

$= 104{,}4\ mm\ (from\ trail\ edge)$

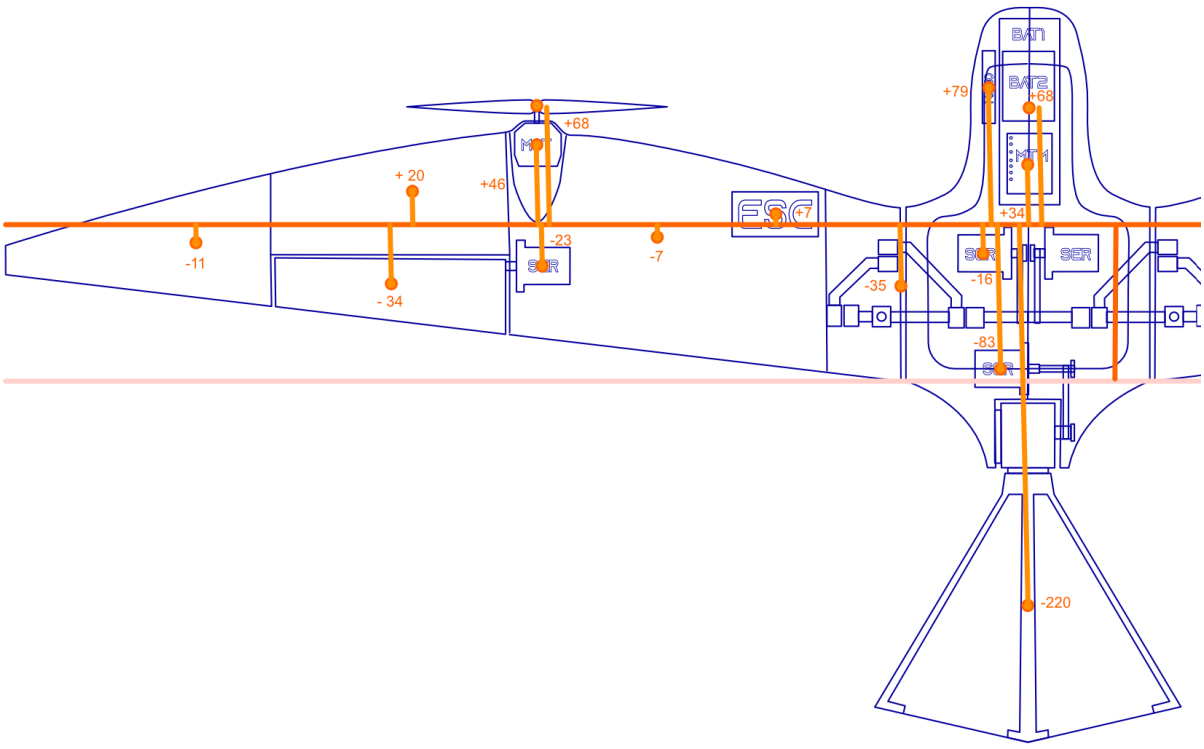
To balance the drone, the centrum of gravity (CG) needs to be as close as possible to the LG. To make the calculations easy we will not calculate the CG but assume the CG and LG are the same, in order to find the moment created around this shared point.

The drone was designed to be nearly perfectly symmetrical meaning, we only have to calculate the moment created by each component around the CG/CL axis.

$$M = F\,.r = 9{,}81\,m\,.r$$

Since the current drone is still under development and the details of the drone design have not yet been determined. For now, the following calculations will simply be a rough estimation of whether the drone is front heavy or back heavy.

A rough estimation of the centrum of mass was made on the product architecture sheet, and the distance to the CG/CL was measured.



For the weight we assumed all the components are printed out of PLA (not PLA light). The total weight currently comes down to just under 1kg and the drone seems to be mainly front heavy, creating a momentum of around 12170 gram mm forward rotation. This is very positive considering the fact that front heaviness is easier to balance out than back heaviness.

In the current product architecture, the angle of attack in the wings can be increased from 0° to at least 30°. The larger the angle of attack the larger the backwards momentum gets created, therefore balancing out the drone further.

Component	mass (g)	amount	Y-coordinate	Moment
3D-printed parts				
Tail structure	20	2	-220	-5200
Wing P1	65	2	-7	-910
Wing P2	23	2	20	920
Wing P3	20	2	-11	-440
Fuselage	100	2	10	2000
Rods	8	2	-35	-560
Ailerons	15	2	-34	-1020
Total	**482**	**gram**		482
Electronics				
Battery	190	1	68	12920
mic7re	8	2	34	272
propeller	6	2	68	816
ESC	24	1	7	336
motor	54	2	68	4968
servo AE	12	2	-23	-552
servo BA	12	1	-83	-996
servo WI	12	2	-16	-384
Nano	5	1	79	68
Total	**426**	**gram**		
Final results				
Weight	**908**	**gram**		
Moment	**12170**	**gram mm**		

There is however a valid concern that this forward moment will be larger in reality. Truthfully the current calculations are an estimation. This means following things:

1. The center of Lift might be slightly more forward or backwards largely impacting the final balance. This is because it is very difficult to calculate the center of lift for such an organic shape.
2. The center of mass of the fuselage could be more forward in the final prototype depending on the infill.
3. The weight and exact passion of the cables have not been taken into account but will however be in front of the drone.

All these things indicate that the balance point might be too far forward. The largest moment forward gets created by the motors, battery and fuselage, and there simply is not much that can be done to decrease this. The only way to counterbalance this is by adding more weight to the back. A simple way to fix this is by adding metal rods in the tail or adding a metal or wood connection piece between the tail and the fuselage.

To fully balance the drone an extra weight has to be added of about 80g between the tail and the fuselage. For now, we will assume the drone has passed the weight distribution test and we can continue with this design.

5.4 The power of lift

Balancing the drone is important during flight but if the wings don't generate enough lift the drone will not fly at all. The battery in total has a capacity of 2.2 Ah, a C-rating of 50C, and a voltage of 11.1V. The power of the battery is crucial as it is the one who gives power through the motors. To know the power of both motors, the maximum amount of Watt needs to be calculated.

The maximum current the battery can deliver is calculated as following:

- Data: Capacity = 2.2 Ah, C-rating = 50C
- Formula: $I_{max} = Capacity \cdot C - rating$
- Calculation: $I_{max} = 2.2 \cdot 50 = 110A$

This results in around 1200W:

- Data: $I_{max} = 110A,\ Voltage = 11.1\ v$
- Formula: $P_{max} = I_{max} \cdot Voltage$
- Calculation: $P_{max} = 110A \cdot 11.1v\ =\ 1221\ W$

The motor itself has a power between 250-260 W, but the drone having 2 motors, the power the system demands is generalized to 550W for both motors.

With this data, the power of lift can be calculated using the following formula:

$$T = \left(P\sqrt{2\rho A}\right)^{\frac{2}{3}}$$

Since the diameter of the propeller is around 0.15m and creates a rotating disc-surface of 0.0176m^2 the max amount of power will be about 550 W, taking the air density into account.

- $D = 0.15\ m$
- $A = \pi \cdot r^2 = \pi \cdot 0.075^2 = 0.01767\ m^2$
- $\rho_{air} = 1.225\ \frac{kg}{m^3}$
- $P_{max} = 550\ W$

With all this data, the power of lift can be calculated:

From an optimistic view, it can be concluded that the max drone weight is 2.4kg

$$T\ = \left(550\ W \cdot \sqrt{2 \cdot 1.225\ \frac{kg}{m^3} \cdot 0.01767\ m^2}\right) = 23.57\ N \text{ --> } mass\ =\ \frac{23.57\ N}{9.81\ \frac{m}{s^2}} =\ 2.4\ kg$$

From a realistic view, it can be concluded that the max drone weight is 1,9kg

$$P_{eff} =\ 0.7 \cdot 550\ W = 385\ W$$

$$T = \left(385W \cdot \sqrt{2 \cdot 1.225\ \frac{kg}{m^3} \cdot 0.01767\ m^2}\right) = 18.6\ N \text{ --> } mass\ =\ \frac{18.6\ N}{9.81\ \frac{m}{s^2}} = 1.89\ kg$$

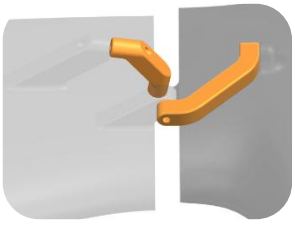
From the optimistic view, the maximum mass of the drone is 1.89 kg.

It is with this that we set the maximum mass of the drone to 2 kg. A higher mass could cause a risk that the drone won't fly as the motors wouldn't give enough power. If there is a wish for more power, it isn't the battery that needs replacement but rather the motors. The battery itself still has a margin on how many Watts it can give compared to the motors' demand.

In Table 1 it is clear that the current weight is around 1kg, however this will with no doubt increase as the inner structure gets further refined. For now, these calculations indicate that the drone will be able to fly, considering the weight will not double during the final drone refinements phase.

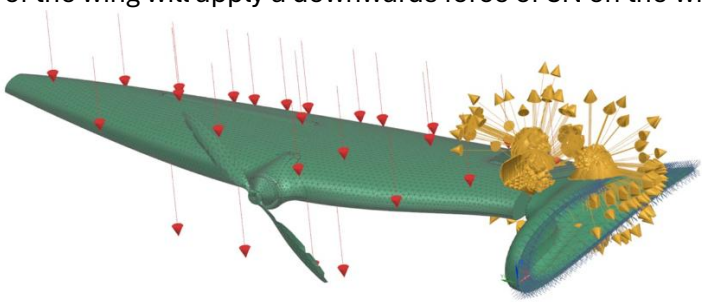
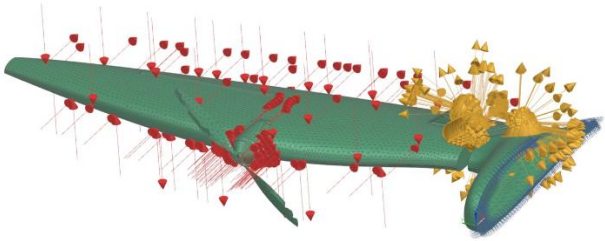
6. Simulating the folding mechanism

6.1 Testing the strength of the folding mechanism



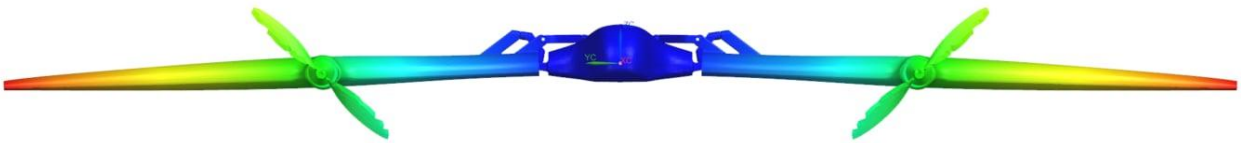
In the current design of the drone there is a lot of worry on whether the mechanism will be able to fully hold the weight of the wings. All the forces on the wings will essentially come down on these 2 rods, and the connection mechanism in the wings and fuselage. This means that 2 things are without a doubt incredibly important:

1. Can this mechanism withstand the weight of the wings, the lift force and the drag resistance?
2. If the drone crashes ideally the 2 hook beams should brake and not the mechanism on the fuselage and wings. This begs the question of where the weakest point in the mechanism is located (the hook beams or the connection points)

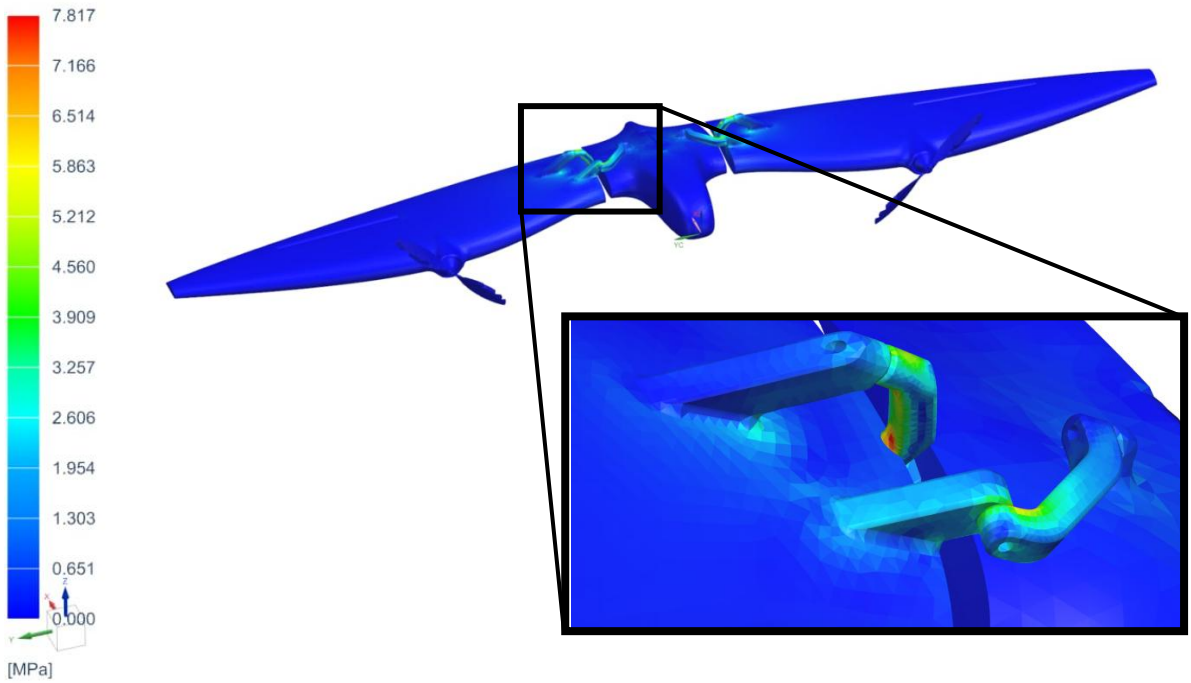
Simulation 1	In the first test the drone is in a stationary position and held by the fuselage meaning that the weight of the wing will apply a downwards force of 3N on the wing surface. 
Simulation 2	In the second scenario the drone is flying and a 9N of lift force is being generated (equal to about half of the max weight) and the drag force is 5N in opposite direction to the flight direction. 

Scenario 1

In this case the drone wings will bend down with a maximum of 1,9 cm in the tips. Overall, no significant deformation can be observed, and everything seems fairly normal.

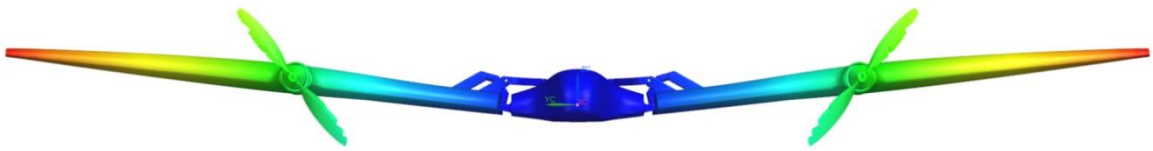


The maximum inner tension is about 8MPa and takes place in the hook-beams. No major internal tension, above 5Mpa is found in the wings or fuselage.

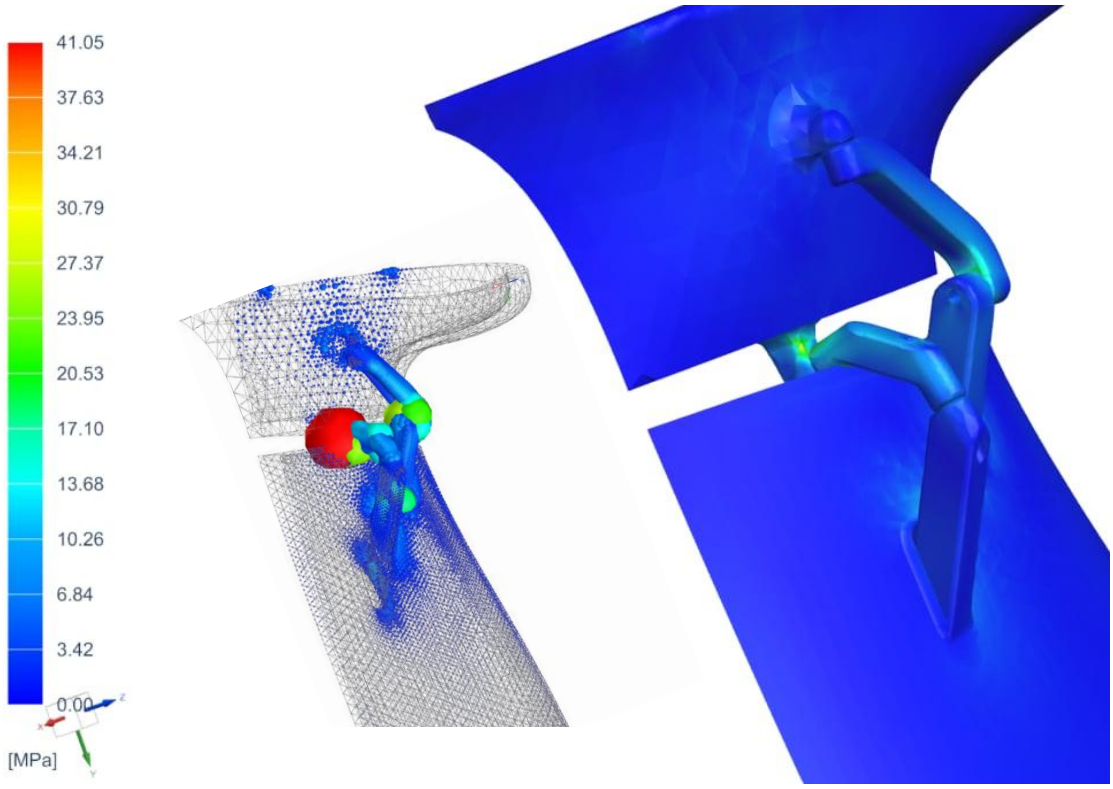


Scenario 2

In scenario 2, the lift force causes the wings to bend upward by 4.4 cm. This increases the dihedral angle of the wings, which is generally positive because it creates a more stable configuration.



The disadvantage is that the internal stress in the rods increases to a maximum of 40MPa. However, this stress is very localized and is probably a peak stress at the lower connection point. The actual maximum stress will be between 25 and 30MPa.



The most important question now is whether the mechanism will break. Unfortunately, there is no clear answer to this question. For the time being, the drone has been fully simulated in ABS because PLA does not exist in the NX database. The simulation also does not take into account the fact that this material is 3D printed. In reality, the rods will probably be slightly stronger (PETG) while the connection points are made of PLA.

The tensile strength of these materials is as follows:

Tensile strength of printed material	
FDM printing	
PLA	50 – 70 MPa
PETG	40 – 55 MPa
ABS	30 – 45 MPa
PLA	20 – 30 MPa
SLS printing	50 MPa
SLA printing	30 – 60 MPa

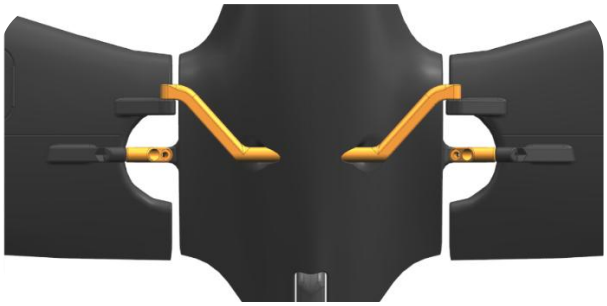
Of course, this tensile strength also depends somewhat on the type of filament, so these values should be taken with a grain of salt.

Even though the material has not yet been finalized, the simulation shows that the rod mechanisms and connection systems need to be made slightly stronger. These simulations at least make it clear where the potential breaking points will be.

In the current folding mechanism, there where however 2 major flaws.

1. The large rods connected to the fuselage cannot be controlled by the servo within the fuselage and are currently separated from each other.
2. The mechanism would not work right now because there would be interference in the wings.

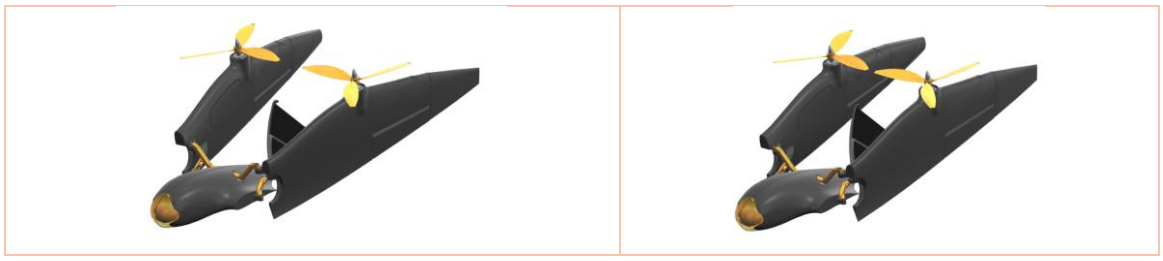
To solve these problems, a large circular cutout was made in the wings ensure the mechanism has enough room between the fuselage and wings for rotation and the rods are connected with each other in the middle of the fuselage.



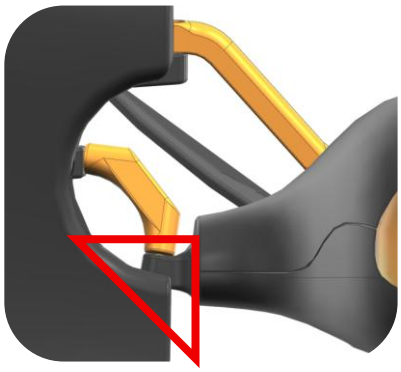
6.2 Simulating the motion of the folding mechanism

Now that we know that the folding mechanism works, the next step is to see if the mechanism works within the drone without causing any interference. This can be done by animating the motion.

Step 1	**Step 2**
Step 3	Step 4
Step 5	Step 6
Step 7	Step 8



Doing this animation proved to be quite helpful because this indicated an interference between the wing and the connection point with the fuselage. This means that the circular cutout needs to be further to the back.



7. Drone design

Besides the practicalities of the drone, the design is also essential when being launched on the consumer market. Most of the drones already look the same lines of identity, though the front still lacks some character. Therefore, research was done on how this could be more interesting to look at for whoever comes across this drone.

7.1 Body paint

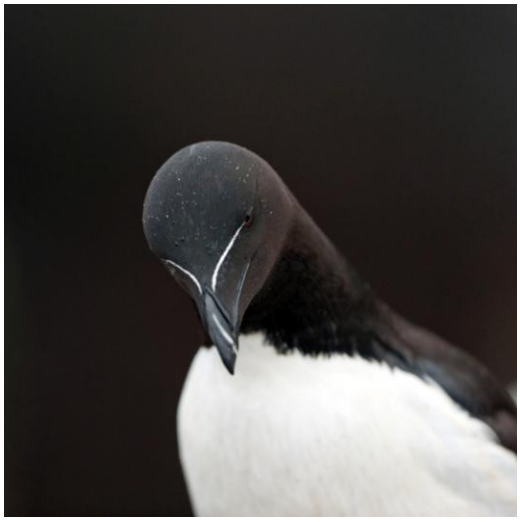
One of the first designs was to apply an orca-white pattern to the front. The reason was the already inflated shape of the drone's front, which is quite similar to that of orcas, belugas, pilot whales, etc. The idea itself isn't all that strange; marine life is often associated with life in the sea.

An example of where it has already been applied is military aircraft. There are two reasons:

Psychological impact: the aggressive appearance of a shark with bared teeth was intended to intimidate and instill fear in the enemy.

Identity: helped soldiers bond with their vehicle and strengthened squadron unity.

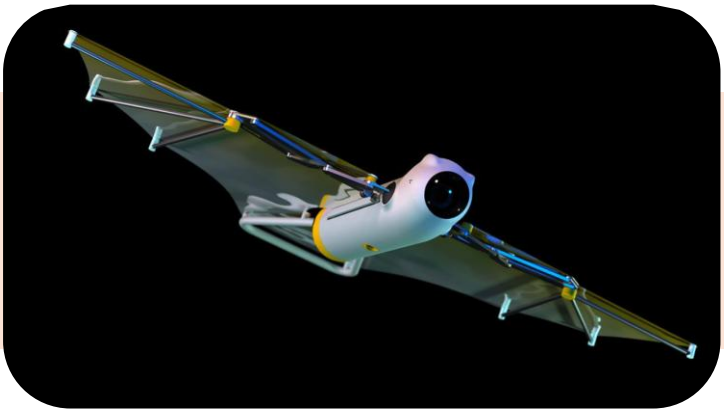
The second idea was to switch to the identity the team had previously envisioned, namely the razorbill stork. Looking at the shape of the razorbill's head, it's very narrow and precise, which is the opposite of the drone's frontal snout. Therefore, we considered fine-tuning this to make the lines longer and more flexible. Although some iterations came of this, in the end the frontal area didn't fit the description of the bird.



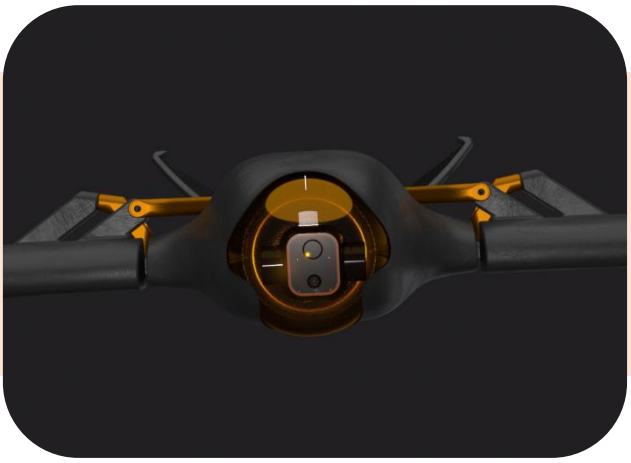
In the end it was decided to leave the body paint idea as it made the drone come off as less serious as intended for its audience. The drone itself also needs something that is worth the change. It is better to explain the customer the design with a strong "why?" with an answer that sounds strong instead of "it looks aesthetically pleasing." Therefore, the next thing that was looked into as an option for a frontal design was the functionality the drone will have.

7.2 Implementation of vision

When the team took a recap into what was already done in the project, a crucial element came back and that was the intended usage. The drone is set to be placed in the market of surveillance tasks which means that it eventually has to analyze its environment. Therefore, the drone will need good camera placement. Inspiration on Pinterest was found on how this could be implemented



Eventually the design was implemented in the design. Though for now in the project only serves as an aesthetic, in future work it will be implemented as a function of the drone in this way. From that point on, this was the defined way of showing the frontal character of the Razor drone.



7.3 A user-friendly design

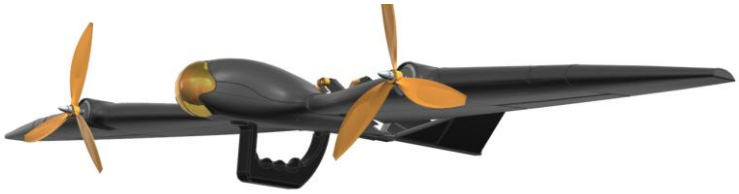
Besides the aesthetic itself, the drone also needs to have a positive usage. It is also one of the most important aspects of this project to have a product that sits well with the users, not only from a technical point (functionality, technology) but also from the practical side (holding the drone, taking the drone with you, throwing the drone).

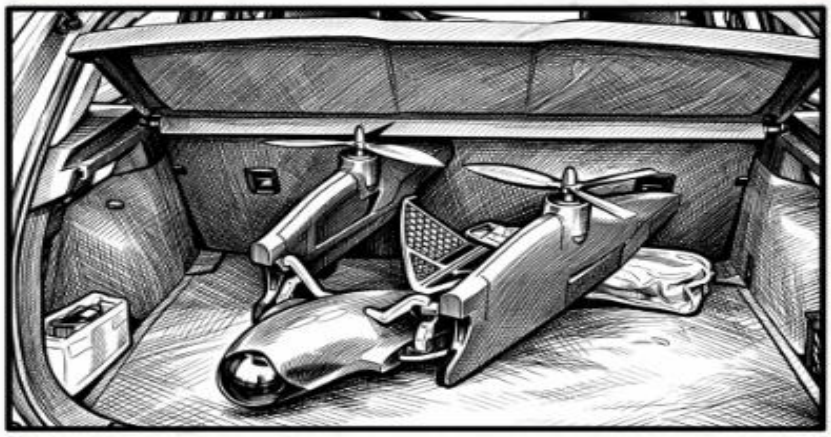
For now, it is already defined that the drone has folded wings, which brings transportation a lot easier for the user. In general, the drone will also be on the light side so when holding it and throwing it, the focus of issues wouldn't be on the strength of the user but rather the skill of launching the drone itself. In general, fixed wing drones are thrown with bare hands with no extra handle or helping device to make it easier.

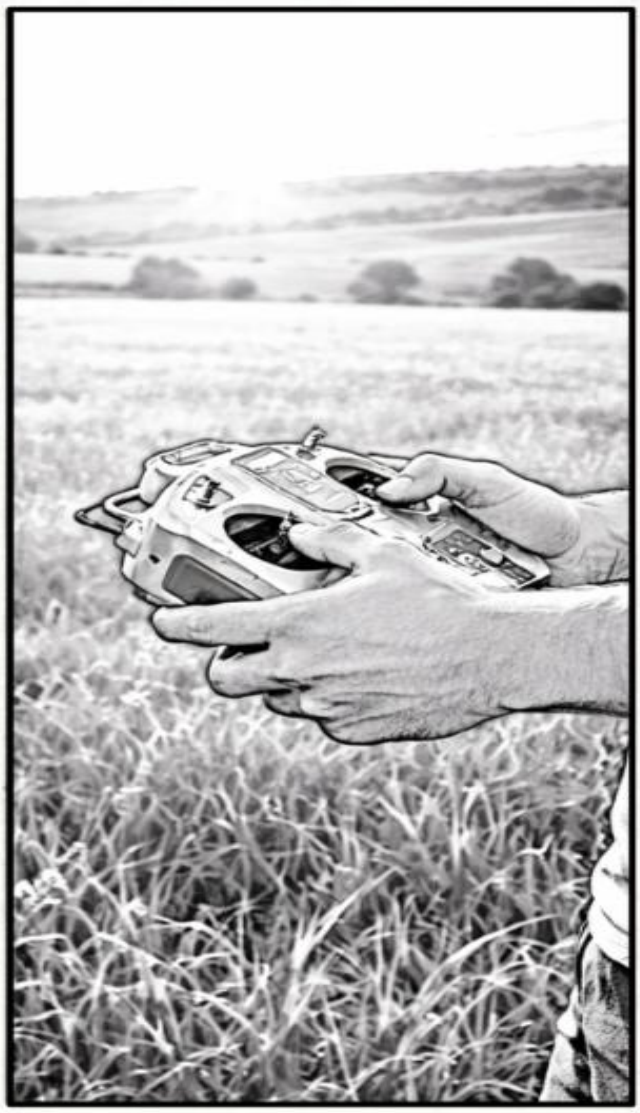
As an extra to make the usability of the drone more friendly is the addition of a launch handle. The principle is that the handle gets locked on the underside and by the power of the launch itself comes lose. In other words, the handle slips out when the drone gets pushed well enough.

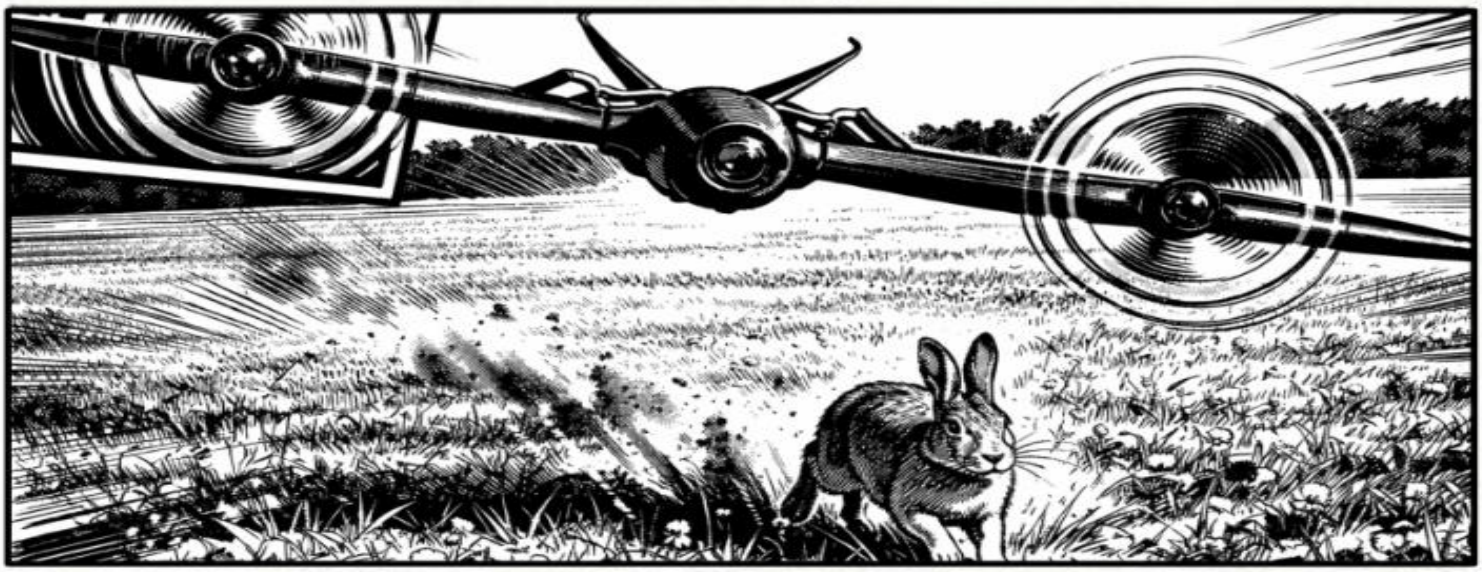
The final model's design is very much inspired by the silhouette of a swan, giving bird characteristics of birds in parts as well as a small detail. This serves as a helping hand and isn't the biggest necessity of the drone to use. It just helps the user give more precision when throwing the drone.

When a full assembly of design will be shown of a final design of this project, most will resemble the design shown in the pictures below. In the prototyping phase, some adjustments will be made to make the drone more compatible with the goals that have to be achieved. Therefore, this only serves as the final conceptual design.









8. Final prototypes

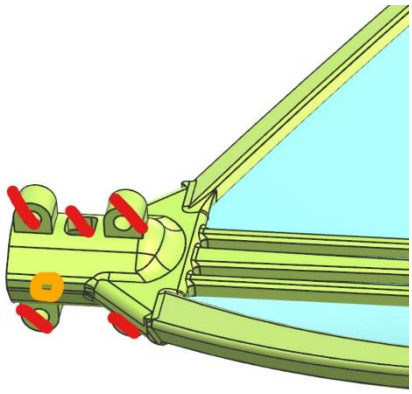
To make a final prototype, the assembly will mostly consist of 3D-printed part made of PLA or PLA light as was selected in the material research. The parts printed consist of the fuselage, tail frame and wing parts.. The reason not everything was printed with PLA Light was due to print failures but also to enforce strength in critical areas. All these parts would then be glued together with a strong epoxy adhesive. After printing, these parts were also weighed for calculations to show forces more realistic than the hypothetical masses. This was done to re-evaluate the balancing of the drone. The results showed that the drone was front-heavy, giving the signal that the battery needs to be placed as far in the back as possible. If needed, the tail could also be placed further from the body to receive more balance. Either way, to make a full prototype, adjustments had to be made to the tail, fuselage and wings to finalize the use of it.

8.1 Finalized Tail

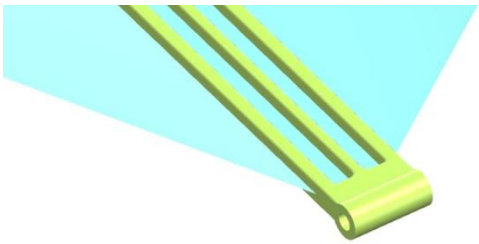
With the tail, a few iterations were done on the last concept of the V-tail before actually producing it. As mentioned earlier on the conceptualization of the tail, The V-tail was to the go-to type for the drone that was visioned for the project. In general, the idea was to attach 2 parts of the tail together with either strong glue or screws. The evolution of decisions made for the various attaching methods will be discussed through the evolution of the V-tail.

Version 1: screw-oriented

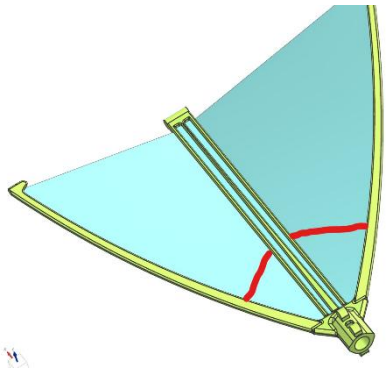
The first iteration had four holes for M3 screws. These holes were very small, which could cause problems with the final bond. The hollow space at the top serves as an additional connection to the rest of the drone. This also prevents the drone from shifting too much. Besides that, the model wasn't fully smoothed out, making it more possible to get destroyed when given a certain impact. The reason for these connections is because the drone exists in two parts.



Besides the holes at front, the back end originally also had a hole for an M3 screw, making the tail fully attachable with screws, which is a pleasing thing when considering modularity. Though not only was the design a bit overwhelming, but also the amount of screws needed as well.

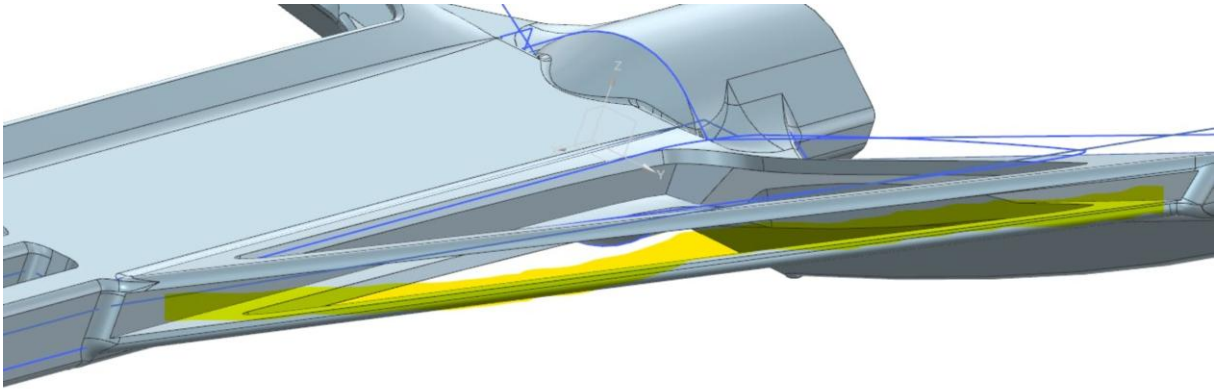


The tail itself in the first version also had issues with stability. The tail itself only focuses on strength from the 2 side ends without real attachment to the center part which makes it vulnerable for bending. Besides that, the end of each side has a very closed form that limits the way the fabric will be going in the direction of the middle part.

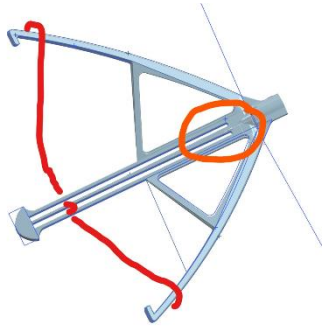


Version 2: re-enforced simplified

The connection holes have been simplified to a single connection at the front and the rest of the body; the plan is to glue the two sections together. Reinforcement was also added, with a hole in the middle for both weight and the option to allow the fabric to pass through. This was later modified. The same applies to the tail; currently, it has a curved shape, but ultimately, this will not be necessary. Though glue is seen as non-modular, this is simply for prototyping purposes. For a final product, the tail will be one body with no parts.



Aside from some shape errors, there were also some measurements out of place for the placing of the fabric, as for unnecessary detail in the tail. Most of the tail has better smoothness than version 1, but there were the little details that would be of importance to finalize this tail for the prototyping aspect of it.



Version 3: finalized design

The final model includes minor adjustments, such as the padding on the reinforcement, and a repositioned round shape at the tail. The corners at the ends are also more curved towards the center of the tail. The end of the tail itself is also minimized in design, for it isn't necessary as the fabrics will just pass through.

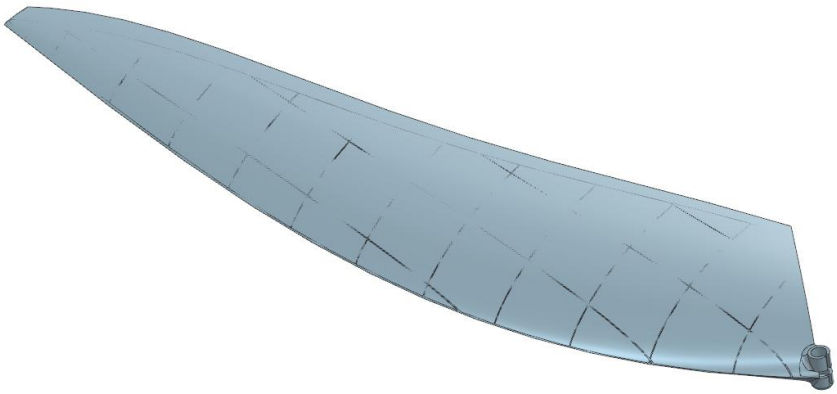
Prototyping of the tail

The finalized tail was printed out in PLA and then glued together as one tail. Though this was just the base for polyester still had to be sewed on it. For this a sew kit was used. At first, the fabric was sewn in to separate parts but when redoing, everything was being sewed together as one. The sew this, a double string was used for extra strength where needed. With this a definite prototype was finalized for the tail.

8.2 Evolution of the wings

Version 1

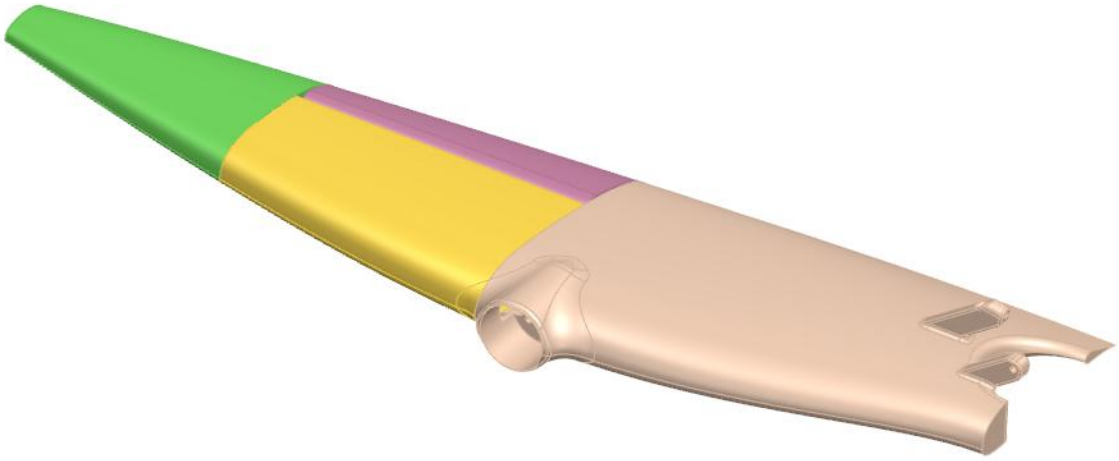
The first version of the wings was a concept. At that point, the hinge system wasn't yet decided on, and we weren't yet planning on including motors in the wings. It did, however, give us a general idea of the shape and the direction we wanted to go in. The structure exists out of a thin outside shell, with ribs giving the wing the necessary strength.



Version 2

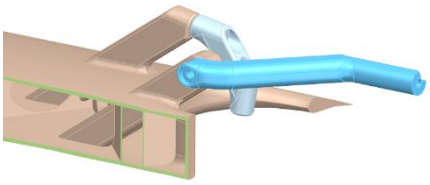
The second iteration of the wings were meant to be printed and tested. Since the first concept of the wing was made quickly, the surfacing wasn't built up properly. This CAD model had to be rebuilt to allow us to add more features.

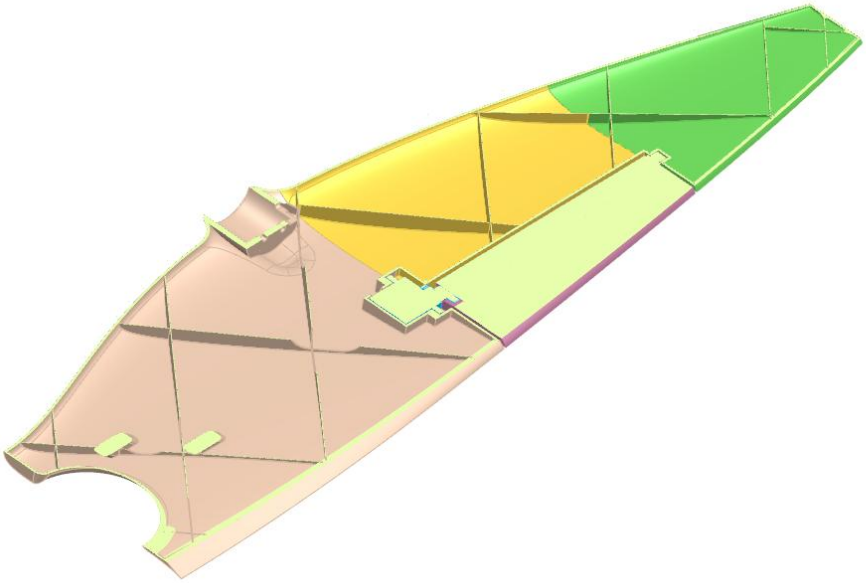
This version was split into 4 parts, one of which is the aileron, since the entire wing is too large to fit in a build volume. When splitting up the part, the print orientations were kept in mind. The print orientation of the inside part of the wing was suboptimal, as the layer lines would make the small beams of the mechanism weak. If possible, the 2 small links should be the weak link, as those would be easier and cheaper to replace if necessary. This could be fixed by strengthening the 2 rods with textile and resin, basically adding a composite sleeve. The same technique can be used to fuse the parts together.



Similar to the first version, this design also exists of a shell, this time 3 walls thick, and ribs to provide the necessary strength. However, since the motor and servo were now included, some cable routing holes were necessary, as well as holes to allow for mounting the motors. The flaps are solid in the design, as this is a simple shape that will get a shell and ribs during the slicing process.

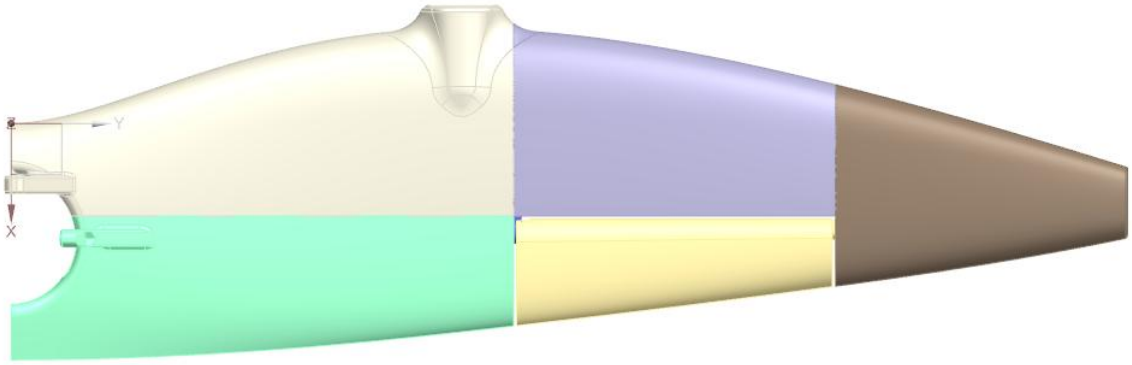
The final major change of this version is the addition of the updated hinge design. Since these links need to be strong as discussed earlier, they were made quite thick compared to the small links. The links were extruded through the top shell all the way to the bottom and intersect with some ribs, to give it the necessary support and strength.

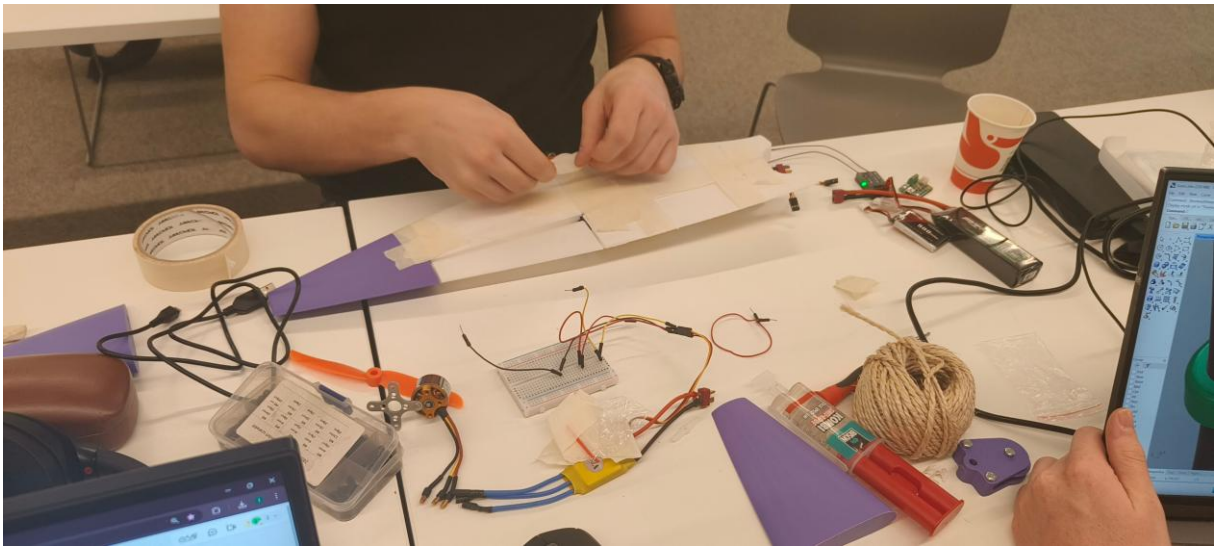




After some failed attempts at printing the biggest part, the inside of the wing, the decision of splitting this part into 2 was made. This came with the benefit of easier printing, a better print orientation for the links, easier wire routing and mounting the ESC in the wing, while introducing an extra seam, possibly compromising the strength.

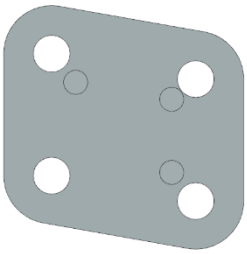
Some parts of the wing were printed in lightweight PLA, which is a bit harder to print. This filament behaves like PLA when printing at 200°C, but foams up when printed at 220 or higher. We decided to print at 240°C, as this makes the filament expand to double its volume. Because of this foaming effect, this filament has more and stronger strings than regular PLA. The stringing and filament expanding in the Z direction can cause the nozzle to catch the print and push it over. The higher the print, the bigger the leverage. This caused the biggest part of the wing, the one housing the engine to fail multiple times. The decision to split this part into 2 separate parts was made. This came with the benefit of easier printing, a better print orientation for the links, easier wire routing and mounting the ESC in the wing, while introducing an extra seam, giving up some strength.





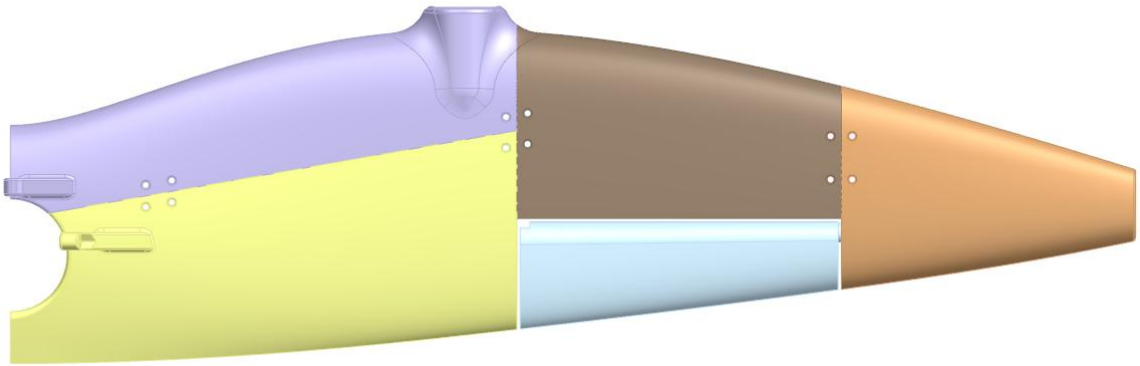
As usual with the first prototype, there were some issues. While the servo itself fit, the hole for the cable was in the wrong place. The axes on the ailerons were too small, which meant they could easily come loose. The engines must be mounted from the back, but since there is barely any room for an Allen key to move around, this can take quite a while. Finally, the holes provided for the cables were rather small.

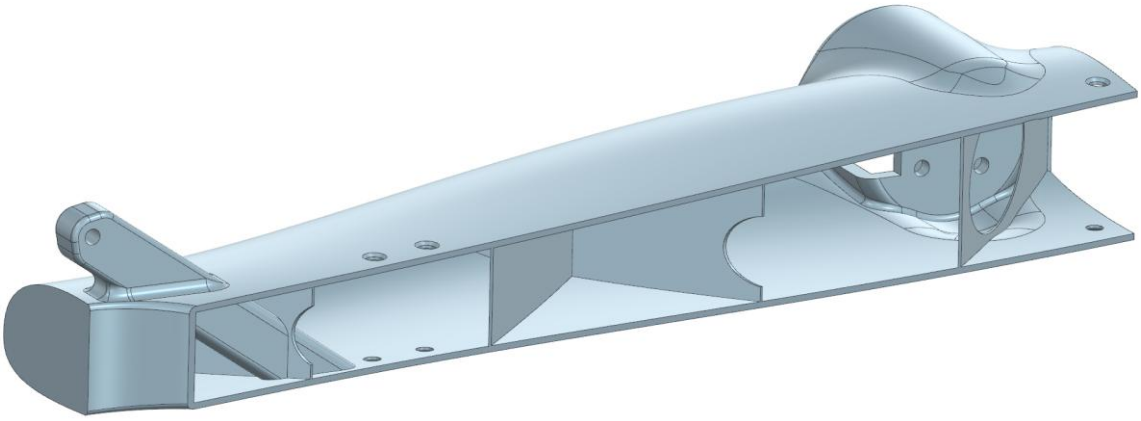
Version 3 – Finalized design



For the final design, the split line behind the motor was moved up into a more diagonal position, allowing for easier access to the screws that hold the motor in place. Some connection pieces were provided for modular mounting, replacing the epoxy composite concept. This means every part can be replaced after unscrewing a couple of bolts. Each of these connection pieces has a unique pattern applied to make sure its identifiable during the assembly process.

Finally, there were some smaller changes, such as making the axis of the ailerons a bit longer, securing them properly in place. Some tolerances were refined, to ensure the motor doesn't scrape the housing and the servo can properly be mounted. The holes in the ribs were reworked for improved cable mounting and screw access. The cutout that prevents the wings to clip the mechanism while folding in was rescaled and repositioned.

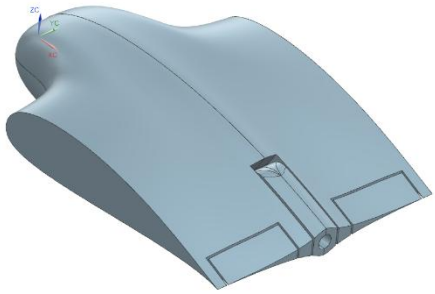




8.3 Evolution of the fuselage

Version 0 – Concept

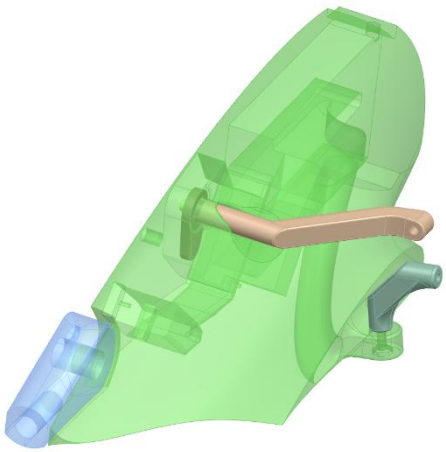
In an attempt at reducing drag, the fuselage is the shape of an airfoil as well. The tail mechanism is a cutout in this shape, ensuring a smooth transition. The initial concept had ailerons in the fuselage, to avoid having to put servo's in the wings. The motor was supposed to be mounted in the front.



Version 1

The first worked out version was a big step forward compared to the initial concept. First of all, the ailerons and motor(s) have been moved to the wings. Not only does the wing have more room, allowing for a bigger aileron surface, having the ailerons further from the center of rotation gives them more leverage. Having 2 motors gives the drone more potential power, but also the potential of yaw control without the need for an extra control surface, like a vertical stabilizer.

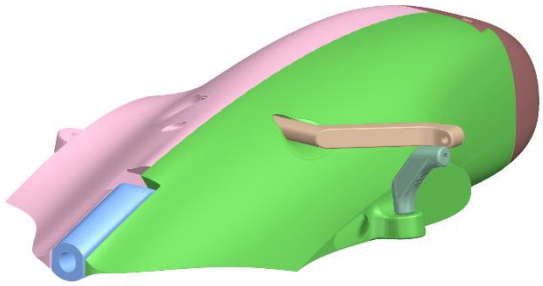
At the front, the fuselage has room for the battery and electronics. There are 3 servos housed, 2 for the folding mechanism of each wing and 1 for the tail mechanism, all of which have cables that need routing to the front. The cables coming from the servo's and ESC in the wings also need routing. For that, cable tunnels were routed through the fuselage.

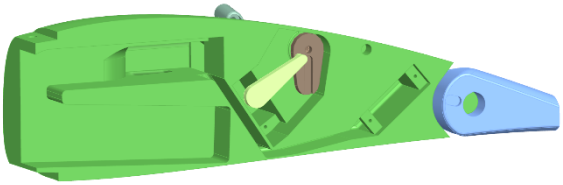


The fuselage exists of 3 separate parts that are each printed separately: the left, right and a nose. The 2 halves can be mounted with a screw through the left side of the fuselage, which screws into a heated insert on the other half. The nose is also mounted with 2 screws and heated inserts, screwing in from the top.

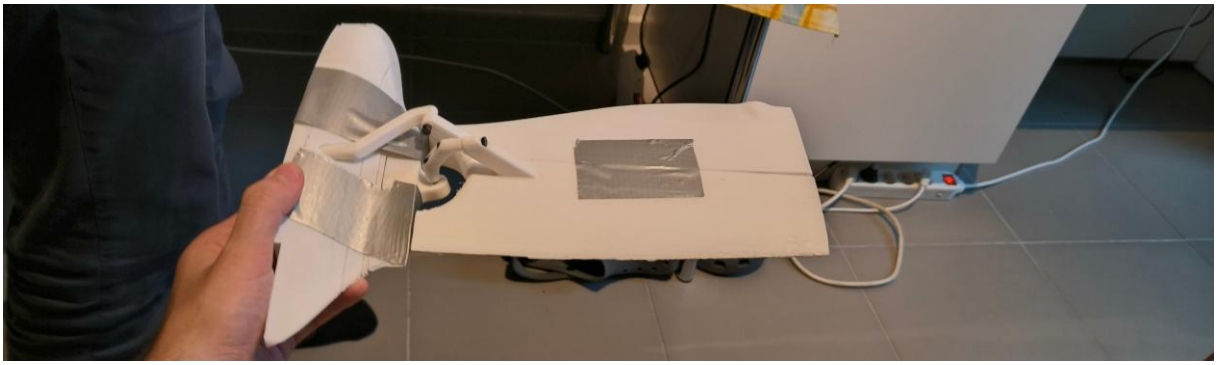
Fitting all the electronics in the fuselage was a tough task. The model became corrupted at some point, which meant it was suddenly impossible to resize the fuselage without starting from scratch. The entire fuselage was printed in PLA. This makes the fuselage much easier to print, but

also stronger in case of an impact. Lightweight PLA has a lot of solid stringing, which would be impossible to remove in some of the cable guides.





This model went through a test fit, despite a failed print due to a partial clog, hence the extra duct tape. This test revealed a lot of issues, most of which were fixed in the upcoming versions.



Version 2&3&4

Version 2, 3 and 4 will be discussed together. Most of the big changes were implemented in Version 2, while the remaining changes between these versions are smaller solutions, like tolerances, or slightly wrong dimensions.

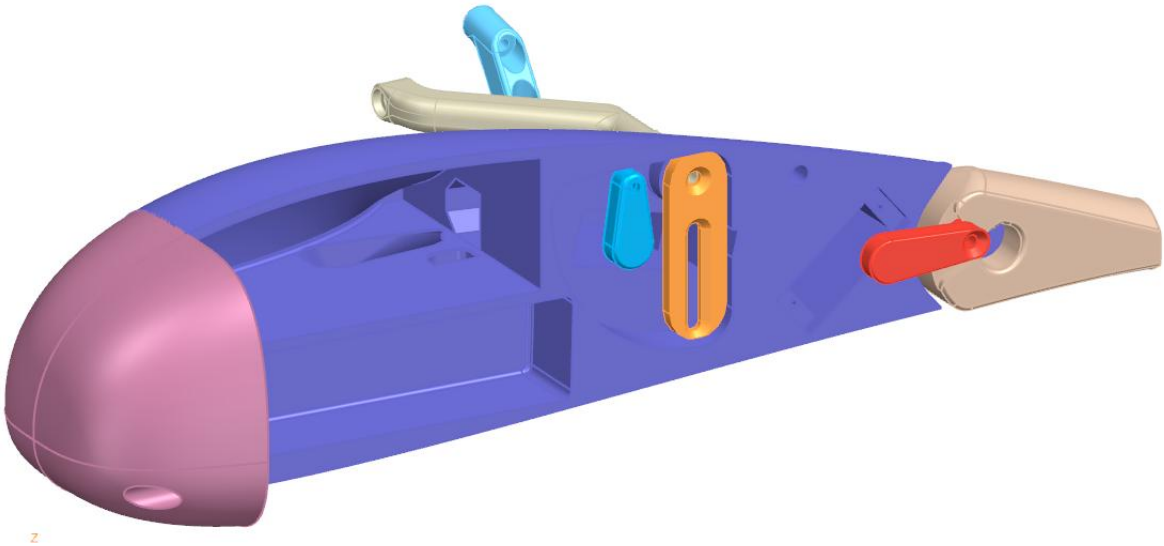
One of the biggest issues of version 1 was the lack of room for electronics and the wires of the battery. This was improved in version 2, by using offset surfaces of the outside shape. This came at the sacrifice of slightly less sturdy walls. For these changes, the mounting mechanism of the nose had to change as well. The nose is now mounted from the front. This was a nice change, as some parts of the first version of the nose were too thin and ended up breaking. This change fixed that issue as well.

To make more room for the battery and its wires, the compartment had to be elongated towards the trailing edge. This meant that the cable guide of the tail servo had to be moved deeper into the fuselage, behind the folding wing mechanism. Speaking of cable guides, the tunnel that houses cables coming from the wings were enlarged. A smoother start and end of the tunnel was implemented as well, because the initial bend was too tight for the thick wires to go through.

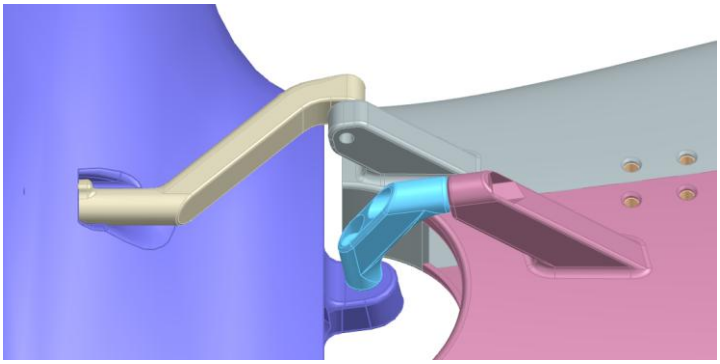
In version 1, the servo responsible for folding the wing didn't have nearly enough force to control the wings. This was partially caused by bad positioning, leading to the servo having terrible leverage on the mechanism. To give the servo more leverage, it was slightly repositioned. The mechanism now makes use of a screw for a more secure hinge point, as the first version was too flimsy and kept failing.

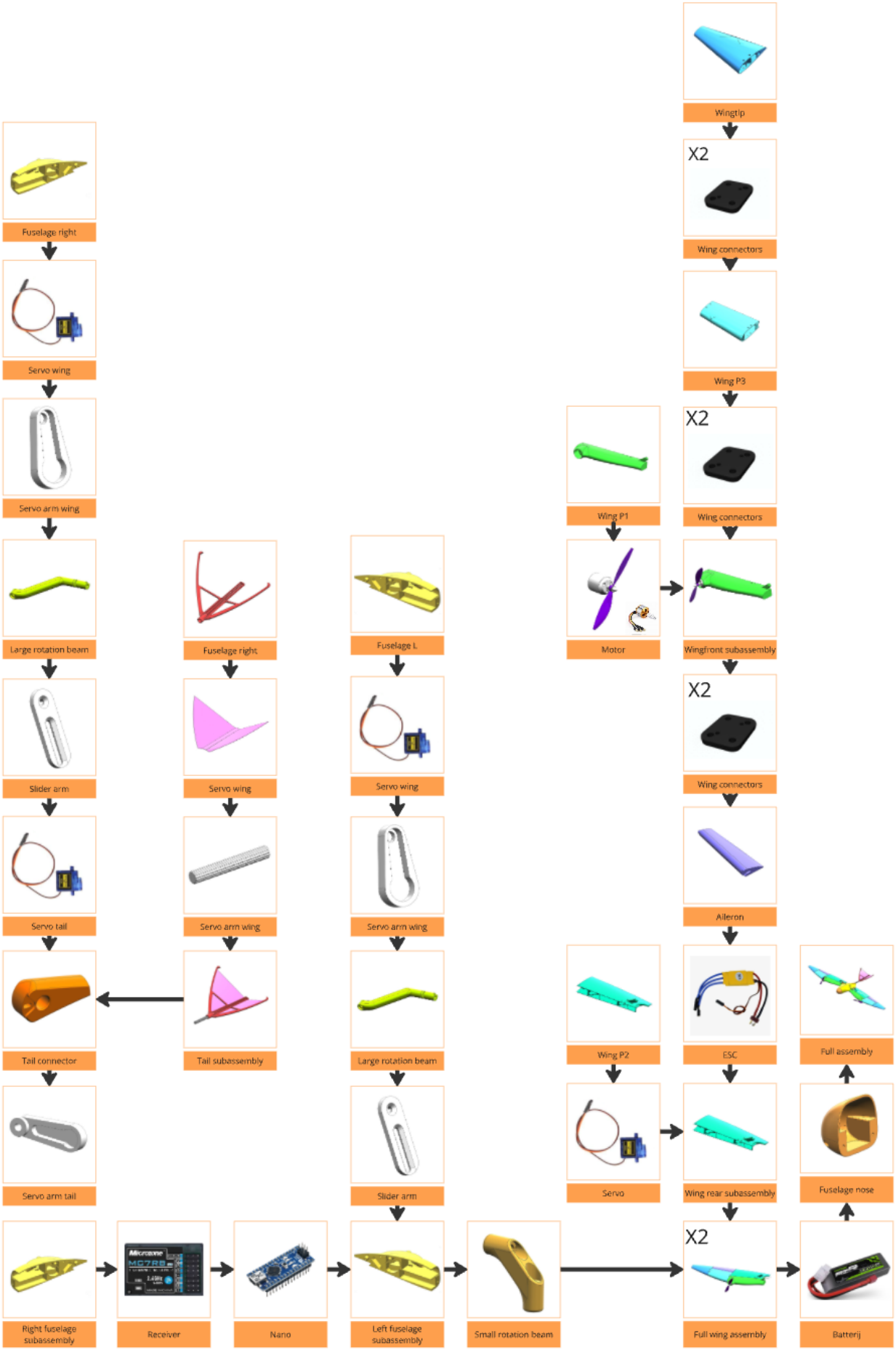
In an attempt to give the servo that controls the tail movement more leverage, the tail section was made a little bit larger. The trade-off is a smaller degree of movement in the tail. In hindsight, since the servo struggles with holding the tail up, the leverage should have been made even bigger. There is a little bit of room to move this servo backwards.

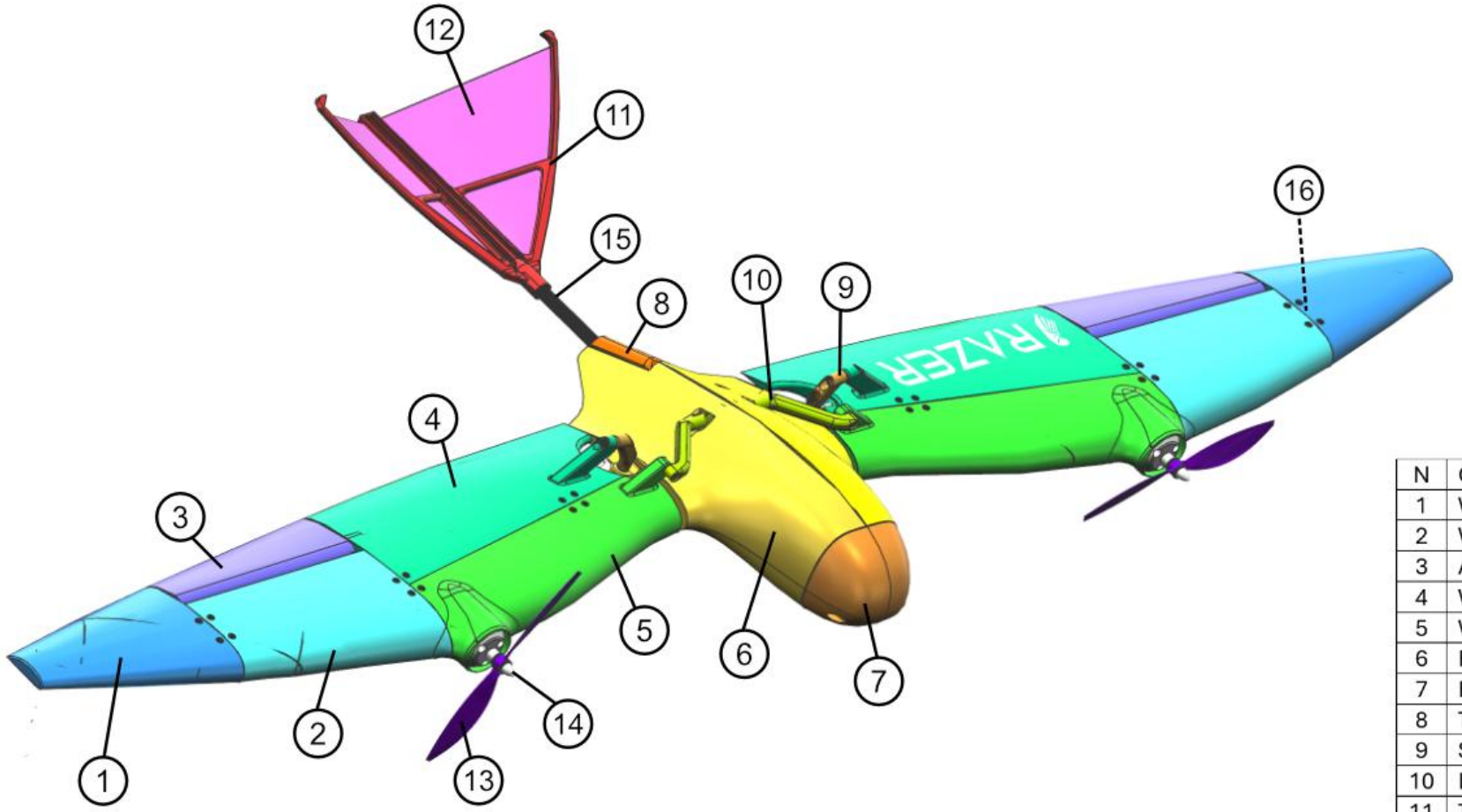
As discussed earlier, the FEM-analysis showed that that the mounting point of the small link on the fuselage is the weak point of the mechanism. This isn't helped by the fact that the layer lines are in a suboptimal orientation. One of the changes in the iterations of the fuselage is that this point has been beefed up, including larger edge blends in the hopes of limiting the amount of peak stress. During the preparation of the gcode in Cura, a modifier was positioned on this area to define more walls/perimeters. Another optimization for the printing process was the small chamfer on the end of the axis of the tail component. This prevents the need for post-processing in case of a elephants foot.



Finally, in version 1, the long top link could move freely towards the inside of the fuselage, but not outwards. It's however crucial that both movements are restricted. A small edge was added to this link, while the fuselage was changed accordingly. This little edge also limits how far the link can turn, in addition to the mechanism on the inside. Note that the 2 inside links were printed with the least amount of perimeters. This means that if the wings crash, these pieces are the first one to fail. Not only are these easiest to repair, but they also take the least material, time and money to reproduce.




Wingtip
X2
Wing connectors
Wing P3
X2
Wing connectors
Wing P1
Motor
Wingfront subassembly
X2
Wing connectors
Aileron
ESC
Wing P2
Servo
Wing rear subassembly
Full assembly
Fuselage nose
X2
Full wing assembly
Batterij
Fuselage right
Servo wing
Servo arm wing
Large rotation beam
Slider arm
Servo tail
Tail connector
Servo arm tail
Fuselage right
Servo wing
Servo arm wing
Tail subassembly
Fuselage L
Servo wing
Servo arm wing
Large rotation beam
Slider arm
Right fuselage subassembly
Receiver
Nano
Left fuselage subassembly
Small rotation beam



N	Component	#
1	Wingtip	2
2	Wing P3	2
3	Aeilron	2
4	Wing P2	2
5	Wing P1	2
6	Fuselage	2
7	Fuselage nose	1
8	Tail connector	1
9	Small rotation beam	2
10	Large rotation beam	2
11	Tail structure	1
12	Tail textile	1
13	Proppeller	2
14	Motortips	2
15	Tail extention beam	1
16	Wing connectors	12

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CAMPUS KORTRIJK

SCALE:	PART NAME:	NAME:
1:1	Mechabird	Tom, Louik, Willem, Viktor

NORM:	MATERIAL:	GROUP:	DATE:	
ISO2768mK				A3

ID PART: mechabird

9. Total cost

The first costs included in this calculation are the material costs of the 3D prints. Printing 1 drone on a Bambu Lab A1 would take 45 hours and uses 772g PLA, which results in 687g in PLA parts. This means the cost of the PLA would be €19.28, if we calculate €25/kg. The electronics in the drone amount to a total of €138.5, while the other various materials add another €7.21. This brings the total material cost to €164.99.

For the final product, we're also going to include the cost of printing (€5/h) and assembly (€10/h). This respectively adds €225 and €20 to the final cost, resulting in a final cost of €410.

Part	Part Weight (g)	Total weight (g)	Print time (min)	Material cost (€)	#
Fuselage	97,14	118,61	365	2,96	2
Long beam	5,33	5,37	21	0,13	2
Short beam	2,36	2,36	16	0,06	2
Aileron	20,06	20,3	120	0,51	2
Wing (P2)	42,7	42,84	128	1,07	2
Connection	7,3	7,3	33	0,18	2
Tail	17,98	23,58	139	0,59	1
Wing (P3)	29,43	30,03	99	0,75	2
Wing (P1)	51,32	61,91	227	1,55	2
Wing (P4)	61,13	66,56	181	1,66	2
Tail connector	7,26	7,42	29	0,19	1
Extra beams	3,29	3,29	20	0,08	2
Nose	21,81	23,99	82	0,6	1
Som	687,17 g	772,13 g	2670 min	€19,28	

	Weight (g)	**Price (€)**	**#**
Controller	485	40	1
Battery	190	26	1
Mic7re	8	5	1
Propeller	6	0,5	2
ESC	24	7	2
Motor	54	11	2
Servo AE	12	3,6	2
Servo BA	12	3,6	1
Servo WI	12	3,6	2
Nano	7	12,5	1
Som	325 g	€138,5	

	Price	#
Textile	1,01	1
Screws	0,025	68

Spray paint	4,5	1
Solder	/	/
Tape	/	/

Total cost	€ 410
Total weight	1019g
Total print time	45h

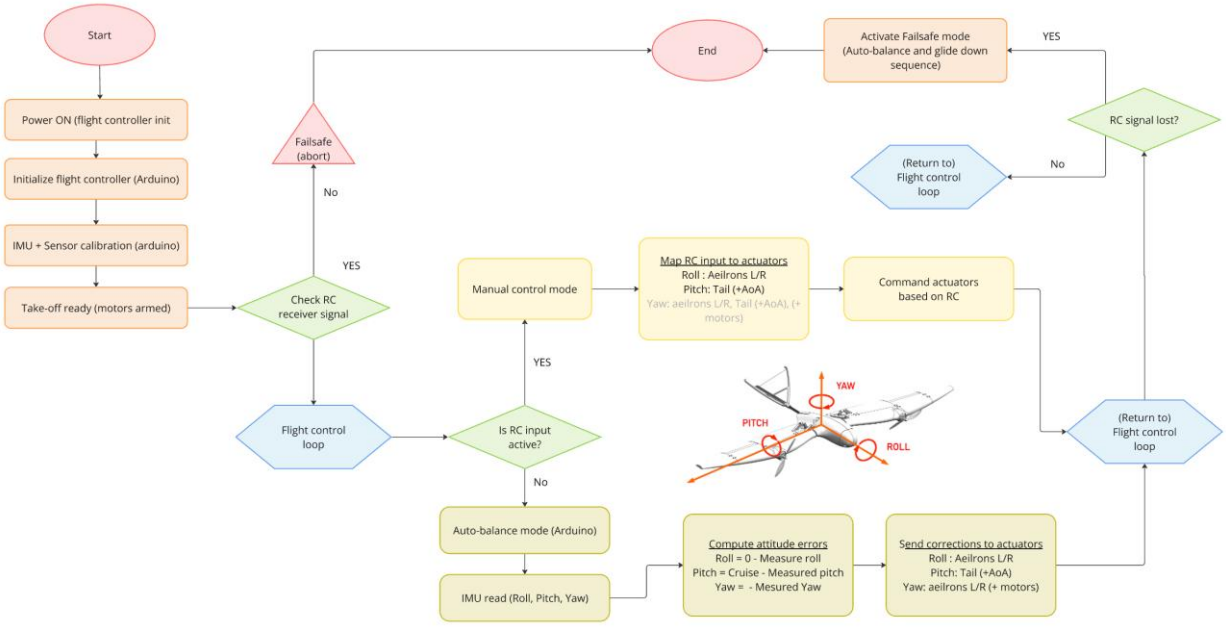
10. Programming

Development began with extensive testing of the MPU6050 sensor, in which roll and pitch angles were calculated for the first time based on raw accelerometer and gyroscope data. Although calibration, drift correction and a complementary filter initially appeared to give stable results, longer drift measurements revealed that the MPU was structurally unreliable. The sensor exhibited inconsistent behavior, unnatural offsets and unexplained drift, making further optimization pointless. This led to the decision to completely replace the MPU with the Arduino Nano's internal LSM6DS3 IMU, which, despite having fewer axes, provided much more stable and reproducible data.

The first real stabilization controller was developed using the internal IMU. This version combined accelerometer angles with gyro integration via a complementary filter and controlled the servos according to aerodynamic logic. This iteration made it clear that the internal IMU was sufficiently accurate, but also that filtering, offset correction and servo limitation were essential to avoid vibrations, noise and mechanical overshoot.

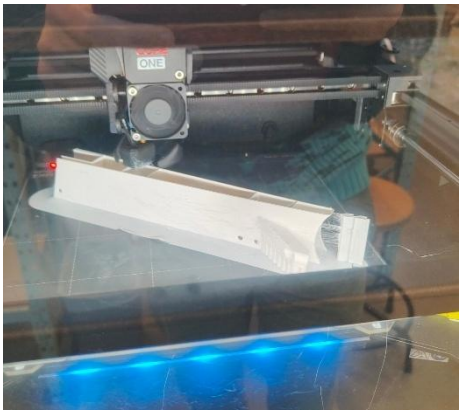
Next, a pure RC controller was built, without any form of stabilization. This version served as a debugging and reference tool: it made it possible to test servo mapping, pulse detection, deadbands and mechanical limits without being influenced by sensor data. During this phase, errors such as jitter in the RC pulse measurement, incorrect servo inversions and overly aggressive mapping came to light. These problems were resolved before integration with auto-levelling.

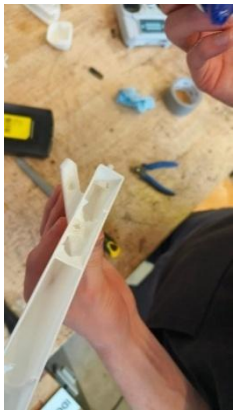
The final iteration combined both worlds: RC control and automatic stabilization in a single system. A deadband is used to determine whether the pilot is actively steering; if not, the IMU takes over. A preliminary calibration determines pitch and roll offsets, after which gyro and accelerometer data are filtered to stable angles. This iteration solved previous problems such as servo overshoot, unstable transition between modes and inaccurate zero positions. The result is a robust controller that switches smoothly between manual input and automatic levelling, making it the most complete and error-free version of the system.



11. Assembly

This was followed by the final assembly of the drone. Even though the shapes were compatible, there were no problems yet. One of these examples was a wing component with an unreinforced connection to the fuselage. It was considered to fill the cavity of the unreinforced section with adhesive.



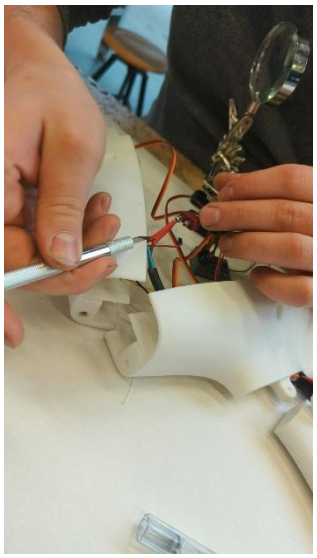


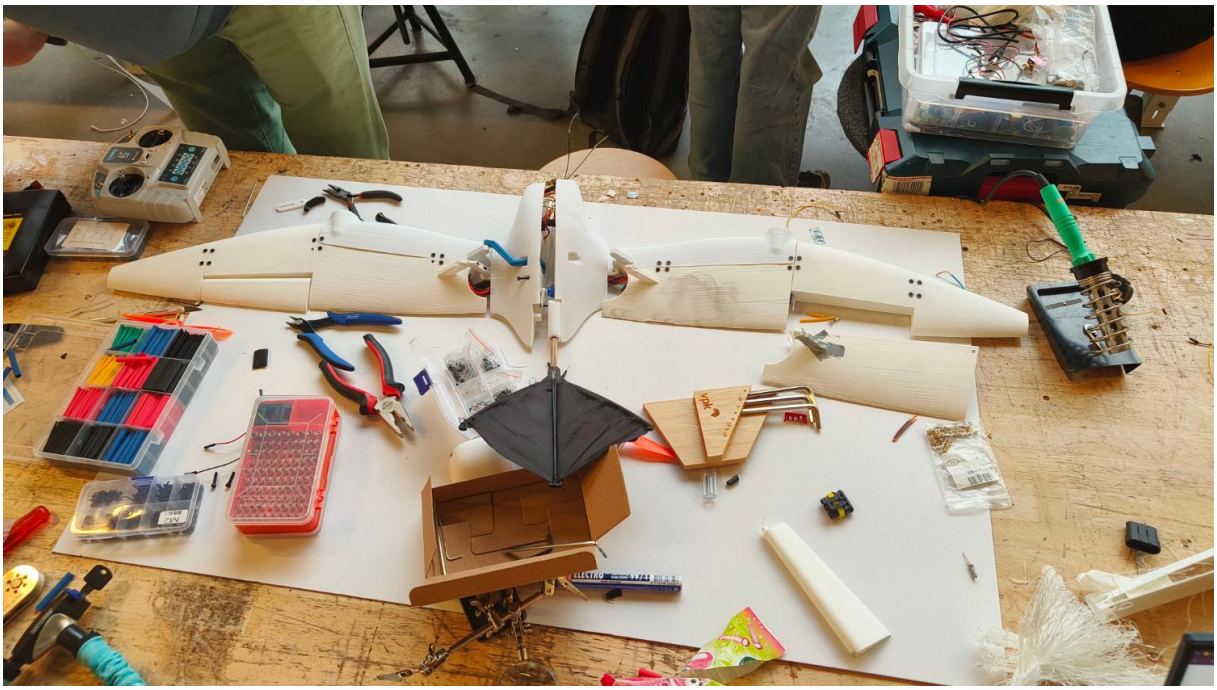
This was seen a mistake, as it would easily make the component more flexible and thus less rigid. This resulted in reprinting a part, delaying the full assembly. Although this lost the team some time, after the failure of the first re-print it was finally time for a full assembly of the parts with the electronics integrated.

The final model is made in a modular way so that parts could be repaired like mentioned earlier. These are brought together by screw-parts, which are used for the motors, 3d-printed parts and servos. Although it sounds simple, the process was frustrating when integrating the electronics, because of the lack of space and the lack of certain connectors. The wings were first to get assembled because these have none of the programming aspects that need focus integration.

11.1 Integrating cables

To integrate the cables, there had to be skill in soldering and attaching the cables in place. Besides that, they also had to be integrated well into the product architecture and the receiver. Also, the larger cables of the battery take a lot of space in the fuselage, giving limited freedom for positioning electronics. When fully integrated the battery was left disconnected to safe energy for testing. The arduino also had to be programmed so this was integrated later in the process.



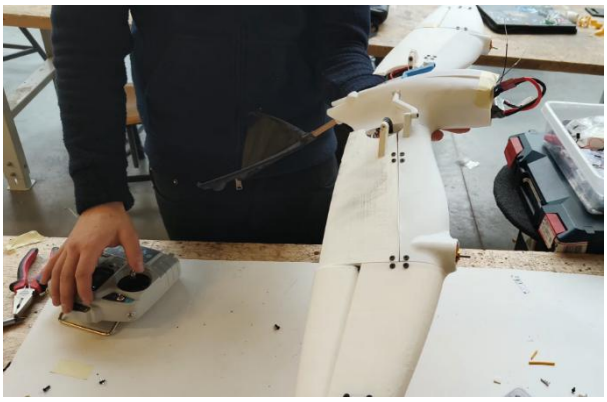


11.2 Paintjob

To test the black spray paint, small pieces of PLA were used to test upon. This existed out of an orb, a plate and a spare wing part to see if the paint would stick well. The result gave a clean black color, though it was best to keep some distance between the object and the spray can.

To add the same result to the assembly, the drone would have to be painted in 2 sessions with 6 hours waiting time between them. This would be to give the black color for the top and bottom.

12. Testing



According to new European drone regulations, UAS geographical zones (so-called "geozones") have been created since 31 December 2020[1]. These zones are only accessible to drones complying with technical and operational criteria as well as restrictions with regard to the use of these drones. Therefore, Skeyes implemented a web application to facilitate planning, coordination and information flow procedures between drone operators/pilots and Air Traffic Control.

There are 2 zones above Kortrijk. If you are in the zone above/around Flanders National Airport, it's necessary to apply for flight authorisation at least 8 days prior to the flight. It's also necessary to report the flight 3 hours before take-off. The maximum permitted height is 120m.

The second restricted area is a broader area around the airport. Just like the other zone, the maximum height is 120m and the flight needs to be reported 3 hours beforehand. While this zone requires that the start and the end of each flight must be reported in such a way as prescribed by the zone manager, it's not necessary to apply for flight authorisation 8 days prior.

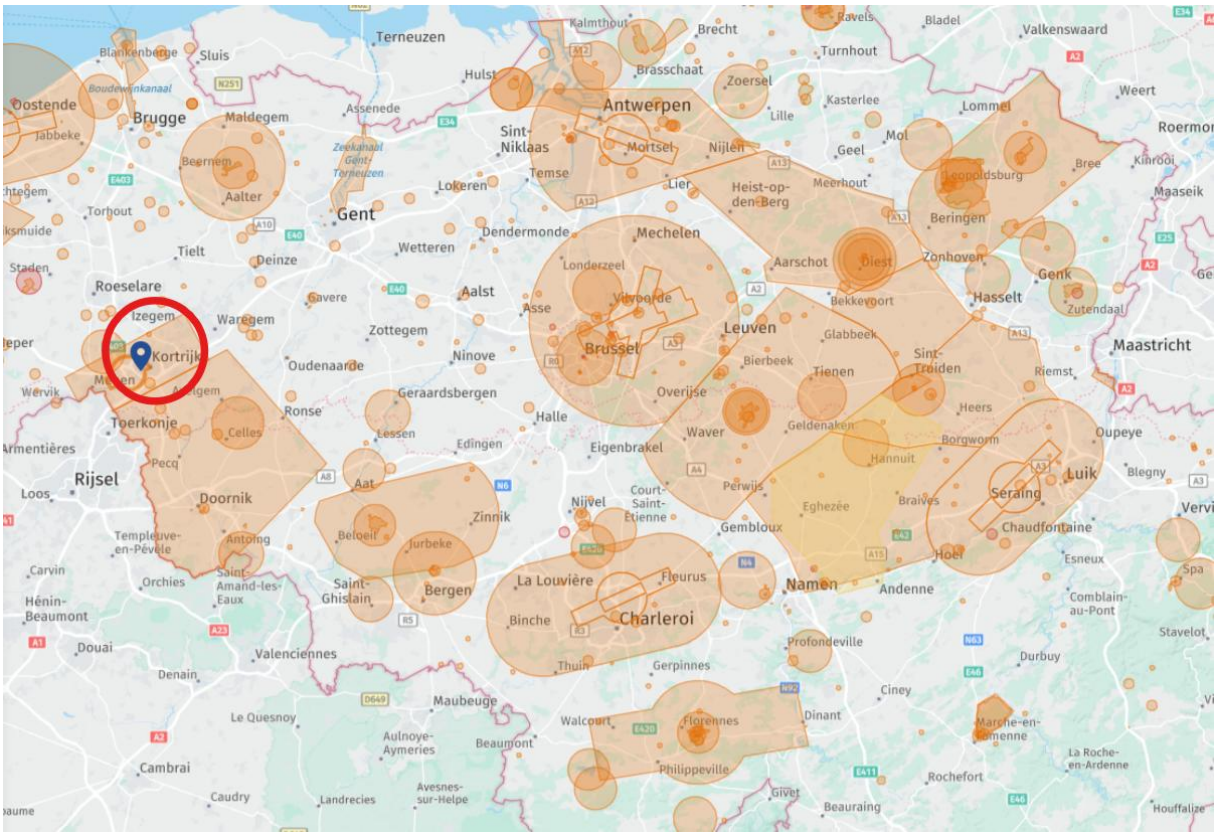
However, both zones require the drone to have a geo-awareness system, which can alert the pilot when a potential breach of a restricted geo-zones is detected. Since our drone doesn't have such a system, making it fly in Kortrijk would be illegal. The Skeyes website mention that deviations for model aerodromes can be granted by Skeyes, but it's not clear which rules these apply to.

If we decide to fly the drone elsewhere outside of restricted geo-zones, the law dictates that it must be registered since it's heavier than 250g. This can be done through the drone portal of the Directoraat-Generaal Luchtvaart (DGLV).

On top of this, it's necessary to acquire an A2 certificate if we intend to fly a 1 kg drone near buildings or people, such as in the urban areas of Kortrijk. The basic A1/A3 license restricts us to open fields at least 150 meters away from residential or industrial zones. To obtain this, we must first hold the A1/A3 license, complete practical self-training and pass an additional theoretical

[1] https://www.skeyes.be/en/services/drone-home-page/you-and-your-drone/drone-service-application/

examination through an authorized entity.



12.1 Feature testing

Besides the possible location, tests were also already focused on doing in the workplace. These tests were to see the performance of the airfoils, the tail, the rotors and the motors. Besides that, also understanding the controls is essential for the drone. With the tests that were done, these were proven easy to understand and use.

12.2 Zipline test

Because we do not have the skill nor experience to fly with a drone, a safe testing system needed to be designed. The idea is to hang the drone on a zipline so that it cannot crash. At the same time, we can still test the mechanism and see if it can generate some lift for proper flight.

What we need for our test environment is an open field where a rope can be attached at two points, so it stays balanced in the air. We also need permission to use the field and the field itself must be nearby. These fields are open and because the drone itself won't fly, but just practice the ability to move forward.

The closest fields to test upon are located in the following locations:

50.818221127105026, 3.239488448010524
50.82249568341012, 3.2515475758056827

Eventually, we decided to test in a backyard that was plenty long for this test. The drone was able to pull itself forward without any help. However, because only 1 mounting point was used, the drone was able to rotate freely, which couldn't be prevented while locked in the harness. This meant we weren't able to test full power without the risk of damaging the drone.

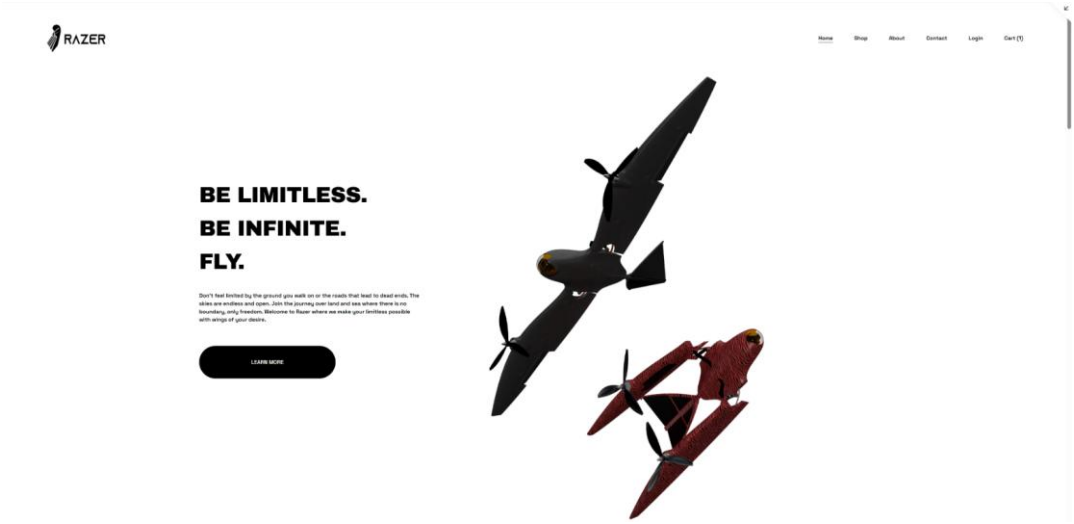
The test had to be cut short, as the right motor started failing and the ESC started beeping. This error message could mean that the ESC wasn't getting a signal from the receiver. However, upon opening the drone, no bad connection was found.

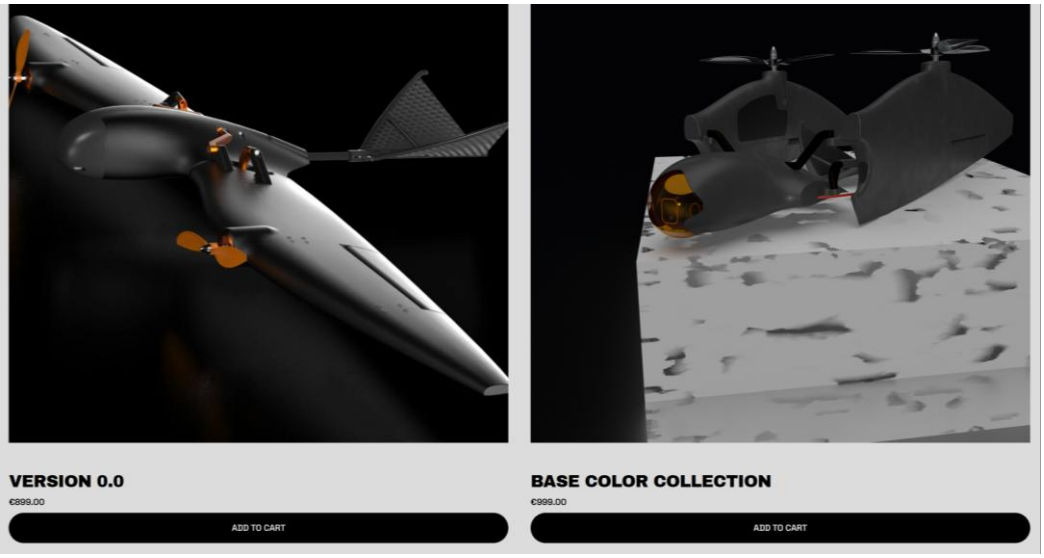
12.3 Results from tests

From the feature tests, it was shown that the airfoils still have some work to do before it will work smoothly. Now they feel sticky on some occasions. Besides the airfoils, the tail worked well, though it could not stick in place and has to be positioned stuck with the joystick-position. With that, the servo for it also sounded like the tail felt heavy. The biggest issue concerning the servos is with the folding mechanism. The wings are just way too heavy for the servos to actually turn. A stronger servo should have to be placed for it to actually work. For now, it needs assistance by hand to get in the folded position.

13. Marketing

To test if users would like our project in future works, a website was made on Squarespace. This website gives information about the group and project, the tools they could buy when they would become a real market product and also contact registrations to get in connection with the team. With this, the price of drones were also defined to be placed in the global market once finalized. This price ranges from 999-1499 EUR.





14. Conclusions

Our final drone had 772.13 g in printed 3D printed parts, which took our team 44 hours and 30 minutes to print. This cost 19.28 EUR to realize. Our electronics in total had a mass of 325 g and cost 138.50 EUR making it the biggest costs of the drone. This in total brought us to a drone with a total mass of 1018.97 g. For the calculations on power of lift, this is positive as the maximum weight possible for take-off is around 1.89 kg. This shows that the drone in general is lightweight for its size. Still, for strength and sturdiness it still has to be improved upon for the wings to stay perfectly aligned for flying. Besides that, also stronger servos in the fuselage would be a great implementation as the ones that are placed in now are too weak for folding the wings.

Another thing that could be concluded is that the drone is a highly valuable product concept and would be a great addition to the market once it is ready for flight. Out of benchmarks for fixed-wing drones, the folding wing integration is almost unseen in the usual drone, making it stand out. Besides that, costs and prices are also favorable for most drones can cost way more than the price placed in this essay. This makes our project not only an opportunity to continue upon but also a learning experience to try things that rarely have been done before.

As mentioned in our tests, it was difficult to really test the drone in a safe environment where it could bring in full potential. Also with that current battery, the drone on maximum settings could only fly for 5 minutes, making it risky to lose all power with no charging station as back-up. Also, malfunctions could happen with the servo's and rotors in some instances, making chances of finding new errors still possible in future testing.

In general, the conclusion is that the concept and proof of flight are there in theory, making testing and better electronics essential for future work in this project. Also, better product architecture for a more modular touch would improve the overall adjustments of electronics in the drone which could make the project faster.

15. Reflection

This project brought forth a lot of engineering competences needed to succeed. Early in this essay it was mentioned that the goal was to made a proof-of-concept bird-like drone. In the big picture, this was seen as a success but looking closer, even the proof still has a lot to be worked on. Things like affordances, cleaner prints and stronger servos and electronic implementations would help convince the public more about the project. Still, in a semester time we had many different iterations and given the research in this paper, the scale to make a flying drone with a safe landing with a budget of 150 EUR and a lack of expertise in the drone profession we do see this as a success overall.

The biggest difficulty overall was high demand prices for electronics and materials, which made prototyping of more minimum viable prototypes not possible. This also makes it harder to test the drone given the lack in replaceable prototypes and the difficulty of doing it in a safe, non-risk way. Besides that, another big challenge was implementing the electronics in the fuselage. Things also became more difficult as the files for the CAD model became corrupt, making the process take longer. Another challenge we had to face was the folding mechanism, as it had to be strong enough for the weight of the wings and wouldn't bring a lot of resistance to the servo so that it can deliver enough moment for the wings to turn. Auto-balancing also became frustrating as gyro drift occurred early in the process. The last difficult task that is worth addressing was in the ideation phase when thinking of the flexibility and movement-possibilities of the wings and tail without losing strength in the design.

When starting this project, we didn't fully understand what we were getting ourselves into with all the different tasks in hand and the limitations we had. When thinking about what could've been done differently, the controller is one of the most important factors to talk about. The controller costed 38.99 EUR, which took a big part of the project. If we could've lent it, we could focus that budget on implementing a camera for surveillance which could add to the smart features of the drone. Another factor that could've been looked better into was the modularity of the drone. For now, the drone consists of too many screws which takes a lot of time for disassembly and assembly. Focusing on a more efficient way for this could make the drone more user-friendly and repairable in the grand scheme of things. At last, we came into the project with two of our members having knowledge on composite drone manufacturing in a summer school program, though making a bird-like drone demands more knowledge on the steering. Our teams knowledge only reached that of fixed-wing drones, which brought our competences for the project lower. Gaining more knowledge of this beforehand could've been very useful to get a better direction on where to further improve.

There were many challenges, definitely in the concepting and prototype phase. We therefore hope this will inspire more groups to make a challenge for themselves and try to make something while having these limitations. For the future, the group would give more time on making the folding wing realizable without manual touch and implement the camera for surveilling. Besides that, real flying tests would be a great way to see how far the model is prepared to be used for the consumer. It's difficult to build an electronically "smart" product within a product that's already structurally very technically complex. Looking back, we're proud of what we achieved, but within the realm of smart products, we might have wanted to make the electronics and coding a bit more complex. Besides that, more time and a higher budget would make the project more realizable for a working result with more potential.

The biggest challenges we faced are concluded below:

1. Manufacturing a drone requires a very high budget for electronics and materials, which makes it impossible to prototype multiple minimum viable prototypes. This makes it difficult to test the drone in a safe, risk-free manner.
2. Fitting all the electronics into the fuselage was not easy, as this had to be done in a compact, lightweight housing with low aerodynamic drag. This problem was exacerbated by the fact that the CAD model became corrupted. As a result, the surfacing and scale of the fuselage could not be adjusted.
3. Developing an implosion mechanism in the wings that:
   -Is strong enough to withstand the weight of the wings and the lift + drag forces on the wings.
   -Causes little resistance on the servo, so that the servo can deliver the necessary torque to turn the wings.
4. The Arduino program linked to the servos had difficulty performing uniform auto-balancing in the ailerons and tail. Uneven auto-balancing causes gyro drift, causing the drone to lose its balance.
5. During the ideation phase, it was difficult to achieve flexibility and range of motion in the wings and tail of the drone without reducing structural strength and still being able to generate enough lift.