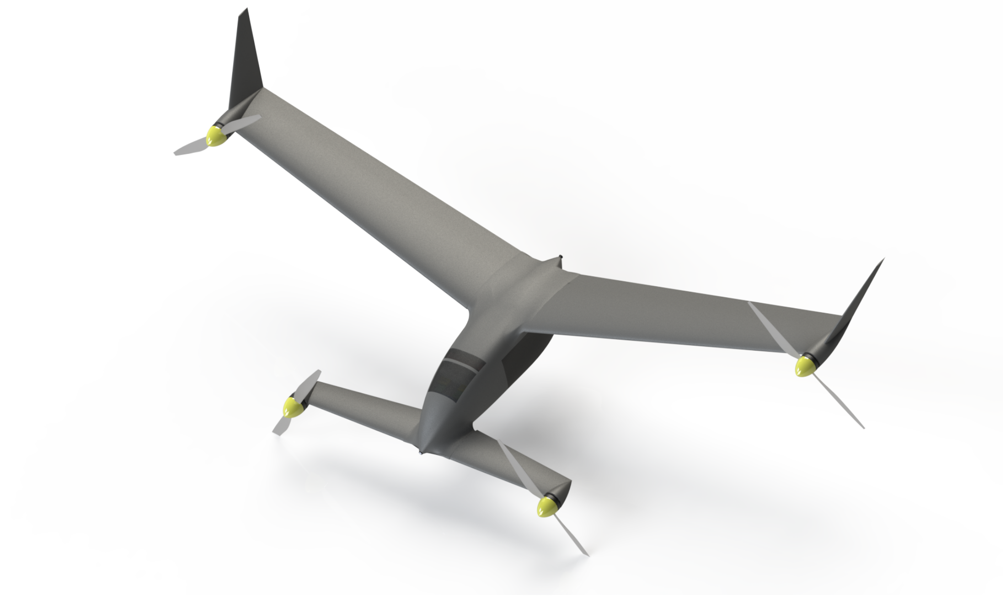
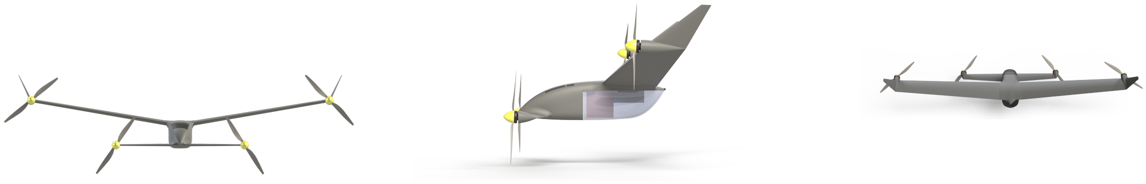
NASA / DLR Design Challenge 2020

BeeHive - The Urban Drone Delivery Concept





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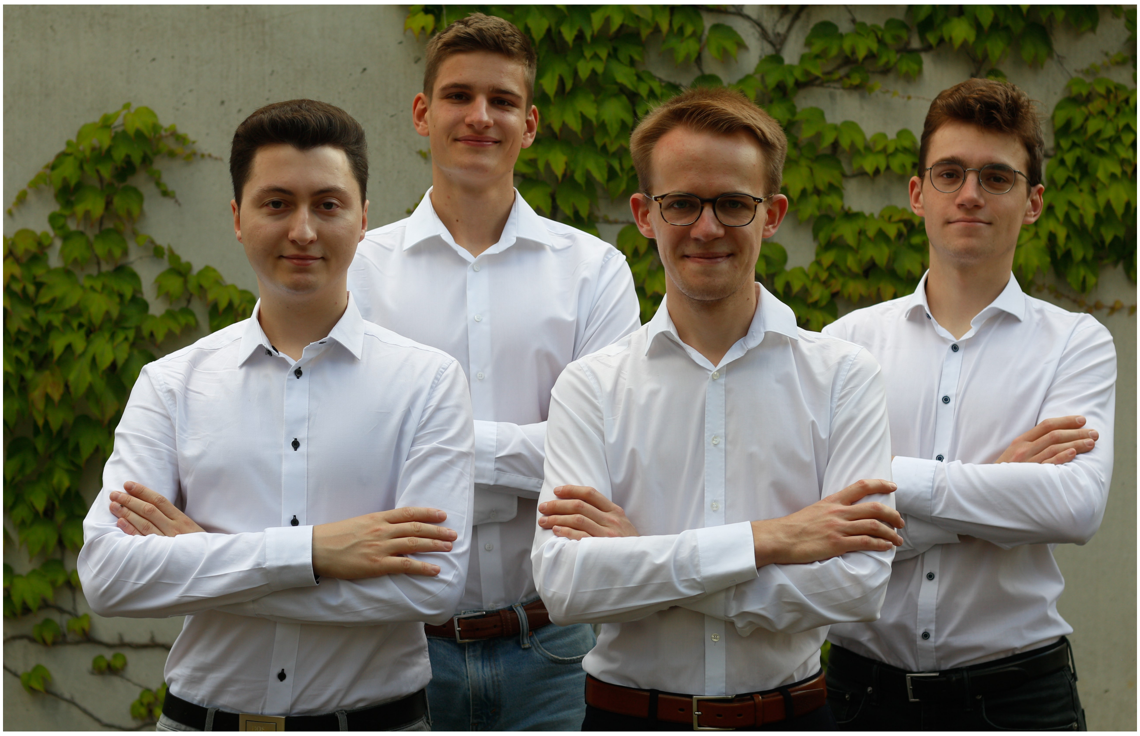

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NASA/DLR Design Challenge: Approval and support of report submission

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and support the submission to the NASA/DLR Design Challenge 2020. We further declare that the report is the result of the above-listed students' own work.

Best regards

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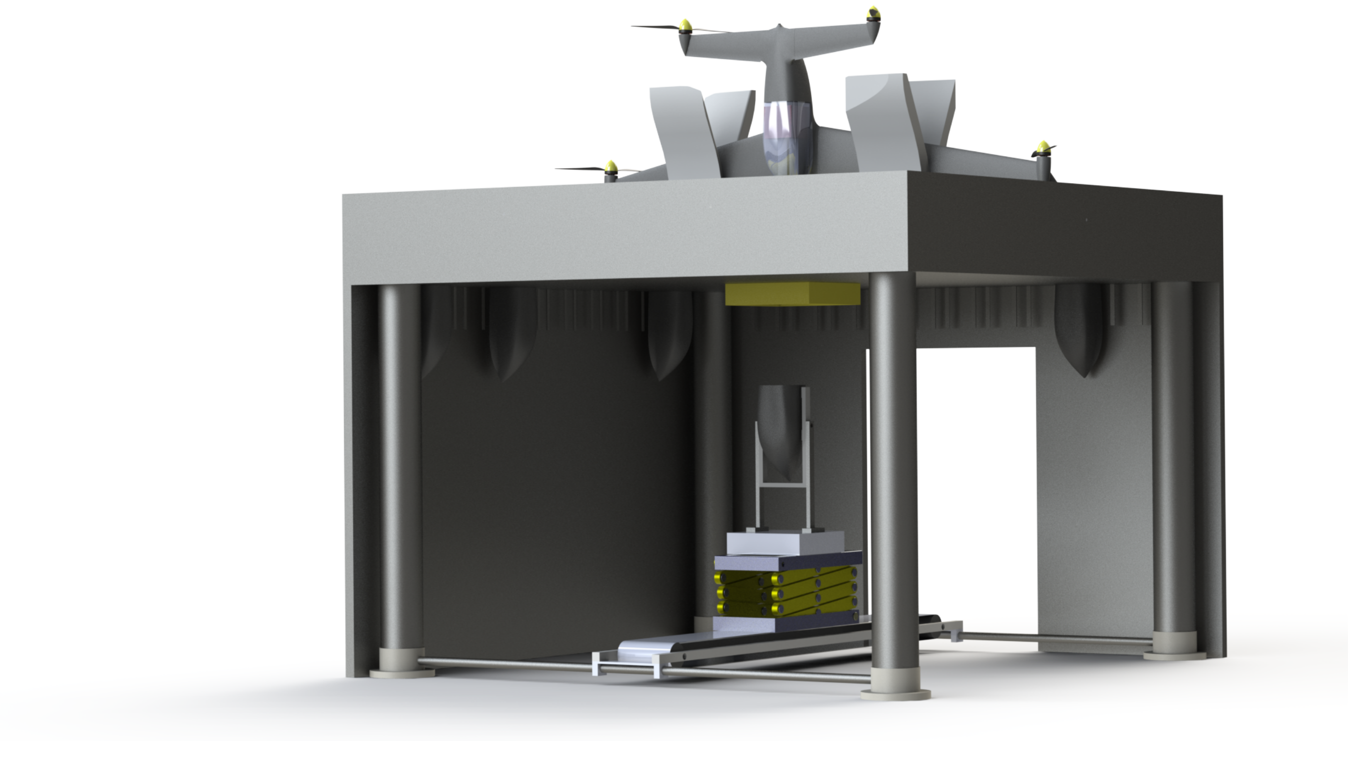
Abstract

Urban mobility and urban cargo delivery are some of the most pressing issues for urban centers around the world. Cities are often plagued by congested infrastructure and heavy restrictions on freight delivery causing delays and inefficiencies in the last mile delivery of items to both consumer households and enterprises. These inefficiencies incur heavy costs as the last mile often makes up a significant portion of the costs associated with urban cargo delivery.

To address these issues the student team of the *Technische Universität Dresden* has developed a design proposal for a low cost, reliable cargo delivery drone able to transport small and lightweight cargo at high speeds within an urban environment called *BeeHive*. This report demonstrates the economic sustainability and profitability of the concept, its adherence to the guidelines established by the NASA/DLR Design Challenge 2020 as well as the highest standards for safety, noise reduction, and efficiency.

BeeHive is an autonomous system consisting of two components, the associated delivery drone called *Bee* and the landing infrastructure called *Hive*. *Bee* is driven by four electrical motors enabling vertical take-off and landing as well as the delivery of a payload weighing 2.5 kg over a distance of 15 km. Power is supplied to the motors through electrical batteries which are replaced between landing and take off. *Hive* is a fully automated landing-platform. It is capable of autonomously handling the resupply and recharging of the drone without human intervention.



BeeHive Concept - for better visibility only two side walls are shown

Contents

Nomenclature

Symbol	Description	Unit
Abbreviations		
AC	Aerodynamic center	
AFC	Autonomous Flight Control	
B2B	Business-to-business	
BSW	backwards swept wing	
CAD	Computer Aided Design	
CAS	Calibrated Airspeed	
CFR	Code of Federal Regulations	
CFRP	Carbon Fiber Reinforced Polymer	
CoG	Center of Gravity	
DDC	Direct Operating Costs	
DHL	DHL International GmbH	
DOC	Direct Operating Costs	
DTGW	Design Takeoff Gross Weight	
EAS	Essential Air Service, Equivalent Airspeed	
ESC	Electronic Speed Controller	
FAA	Federal Administration of Aviation	
FSW	forwards swept wing	
GFRP	Glass Fiber Reinforced Polymer	
GPS	Global Positioning System	
GRP	Glass-Reinforced Plastic	
ICA	Initial Cruise Altitude	
LCC	Life Cycle Costs	
LiPo	Lithium Polymer	
Li-ion	Lithium Ion	
MTOW	Maximum Take-off Weight [kg]	
OC	Operating Costs	
PC	Production Costs	
RC	Radio Controlled	
STOL	Short Take-Off and Landing	
UAS	Unmanned Air System	
UAV	Unmanned aerial vehicle	
UPS	United Parcel Service of America, Inc.	
VTOL	Vertical Take-Off and Landing	
Greek		
α	angle of attack	rad or °
γ	flight path angle	rad or °
Γ	dihedral angle	rad or °
η	efficiency	–
λ	taper ratio	–

Λ	aspect ratio	–
ρ	density	kg/m^3

Latin

b	span, coefficient	m, –
$C, C_1, C_2, ...C_5$	coefficients for mass estimation	–
$\bar{C}$	mean chord length	m
C_D	drag coefficient	–
C_{Di}	lift-induced drag coefficient	–
$C_{L\alpha C}$	lift coefficient curve slope of the canard	–
$C_{L\alpha W}$	lift coefficient curve slope of the wing	–
C_L	lift coefficient	–
D	drag force	N
F_{max}	maximum motor power	N
g	gravitational acceleration 9.81 m/s^2	m/s^2
H	altitude	m
h	physical location of the center of gravity	m
h_{AC}	physical location of the aerodynamic center	m
L	lift force, length, tail moment arm	N, m
L/D	lift-to-drag ratio	–
l_{CW}	arm between the aerodynamic center of the canard and the wing	m
m	mass	kg
p	pressure	MPa
P	power	kW
r	radius	m
S	reference area	m^2
S_C	planform area of the canard	m^2
t	time	s
T	thrust force	N
V	velocity, airspeed	m/s
v_{cruise}	cruise velocity	km/h
x, y, z	spatial coordinates	–

Indices

F	fiber
i	counter variable
L	landing
max	maximum
min	minimum
TO	takeoff
W	wing

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1 Introduction

More than half of today's world population lives within urban environments. The level of urbanization is projected to further increase to 68% by the year 2050 [1]. While in 1950 746 million people lived within urban environments this number has grown to 3.69 billion by 2014. Meanwhile, the amount of megacities with more than 10 million inhabitants continues to grow [2].

Due to this development congestion has become a major issue and particularly within cities larger than 1 million inhabitants. This has been caused by both an increase in cargo moving through cities due to globalization and a high dependency on the automobile [3].

Urban freight distribution is commonly the last mile in contemporary supply chains. However, this happens in a setting where due to the urban environment certain problems are exacerbated. Congestions reduce both the reliability and time of the process. The rise of e-commerce has also further increased the demand for home delivery parcels and as such the logistical strain on urban infrastructure. Additionally, the increase of freight-related traffic within cities may be a source of competition for scarce urban land [4].

Those issues, while not completely resolved may, be reduced in severity by the move of low range freight distribution from the roads to the air. Delivery drones promise to decrease urban congestion by taking home delivery trucks from the roads and moving the logistics into the unused airspace. Furthermore, time-sensitive deliveries can be completed fast and more reliable through aerial delivery services due to the lack of obstruction by congestion and general urban traffic.

2 Business Concept

The consequence of the rising interconnectivity of workflow is the growth of data and goods flow. Especially for the latter, even modern cities do not have appropriate solutions for a fast and reliable transport. In the highly urbanized city of London commercially used transport options such as cabs, equally cars and trucks, are nearly 40% slower than a ride by bike. How is it possible, that in 21th century an over 200 years old invention is overtaking modern cars? The time has come for an autonomous aircraft cutting travel time in urban areas to just under 13 minutes for a 15 kilometer journey - more than 80 percent faster than driving the same distance in London by car.

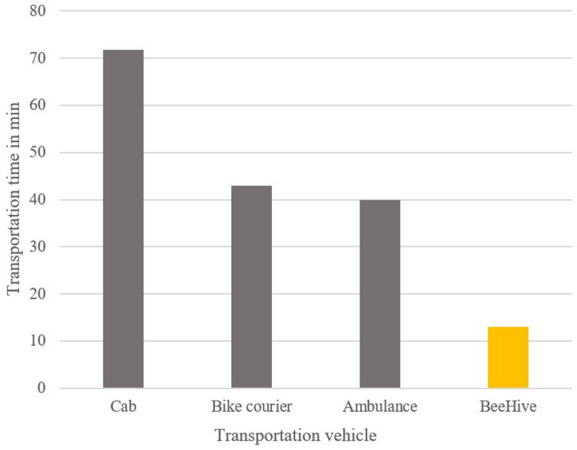

Figure 1: Transportation time for a distance of 15 km in the city of London during mid day

2.1 Executive Summary

BeeHive is going to revolutionize the market of fully automatised urban miniature freight delivery. This will be achieved by providing cheap low range air delivery drones together with a stackable and highly integrated infrastructure which operates without any human interaction. The results are highest levels of safety and most significant reduction of time at an acceptable cost. These are the prerequisites for a wide range of possible applications with which a vast and diversified client base can profit from the benefits of this concept.
Therefore *BeeHive* consists of two pivotal parts: The rectangular shaped *Hive* provides the landing infrastructure and cargo station, from which a payload cartridge, including the payload itself and recharged batteries, are loaded into the aircraft. Underneath the platform, an equally automatized cargo network unloads the delivered cargo in a storage system and provides *Bee* with new cargo. There is no need for any human interaction, aside maintenance. Depending on the customer requirements and needed transportation capacity multiple of those platforms can be combined providing even more capacity.
Bee realizes the transport between two *Hives* and links businesses in urban areas or beyond. Therefore, the aircraft is built as lightweight and efficient as possible, using only renewable sources of energy for its propulsion to have a minimum impact on the environment and to avoid any kind of pollution in populated areas. Moreover, *Bee* is equipped with a reliable emergency system to avoid damage or injury of inhabitants, buildings and the payload itself after the unlikely event of a system failure. The decision was made to use only commercially available components commonly used in RC (remote controlled) aircraft. Thereby, the disproportional high costs for custom made components can be avoided and a fast entry into the market is possible due to the omission of additional development time for those parts. Additionally the dependence of a supplier is bypassed, allowing a solid negotiation position and faster delivery times of components.
Because *BeeHive* targets to connect and improve a wide variety of businesses, the whole maintenance will be assured by the *BeeHive*-Company that leases the system to its customers. Without actual selling, the company has full control over the development and use of the delivery concept and can expect higher long term profits. Moreover, this concept aims for a minimal barrier of entry for interested companies to participate from all the advantages the delivery concept has to offer as fast as possible, without tying up a significant amount of capital in a new technology.
Therewith the *BeeHive*-Network can be expanded as fast as possible to win trust in its reliability and to operate even more efficient.
The high level of automation *BeeHive* strives towards, will ensure that personnel costs and requirements will stay at an absolute minimum so it can be operated by every employee of the lessee without specific training. Thereby, the target group includes all businesses that want to transport time-sensitive goods in urban areas, including health care, delivery services targeting private customers and B2B-activities.

2.2 Mission Statement

The world is becoming more urbanized creating new and expanding existing urban environments. The problems large cities are faced are increasing and exacerbated by this process. The goal of *BeeHive* is to connect urban areas with reliable, fast, and cheap aerial freight distribution infrastructure for everyone to raise productivity and livability to a completely new level.

3 Design Overview

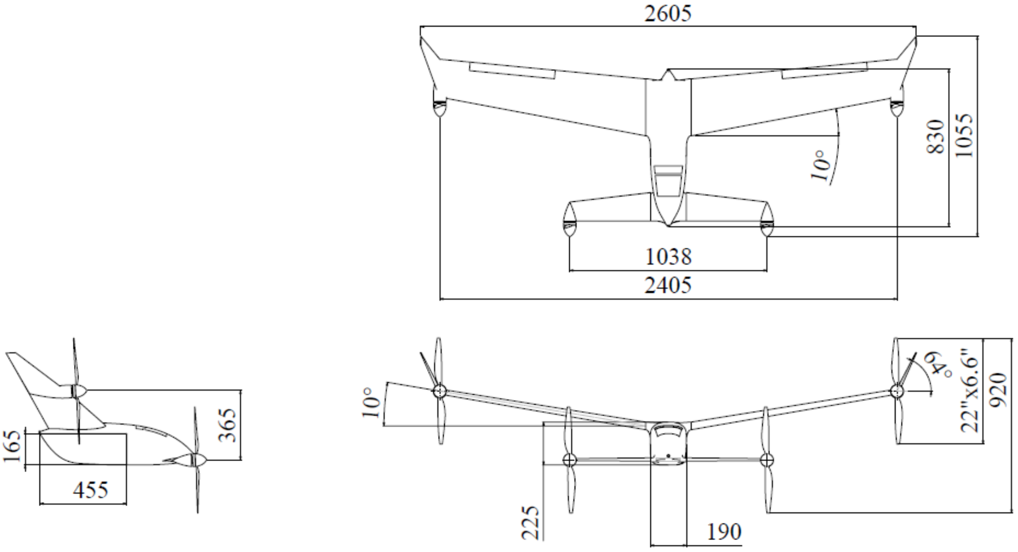

Figure 2: Multiview Orthographic Projection of *Bee*
All measurements are in mm unless specified otherwise.

Bee is a small sized VTOL unmanned aerial vehicle (UAV). It is capable of transporting a payload of up to 2.5 kg safely at a range of 15 km from one *Hive* (landing/starting platform) to another. Using one pulling propeller on each wing tip, to pitch and yaw the design does not use a vertical tail. Winglets at the tip of the main wing increase the efficiency and stabilize the aircraft during horizontal flight. To pitch *Bee* into a vertical nose up flight position the canard wing and front motors will rotate. The aircraft is constructed out of lightweight and durable materials, making it efficient and robust. A removable *Payload Cartridge* contains the payload and batteries and will be autonomously exchanged after each mission by *Hive*.

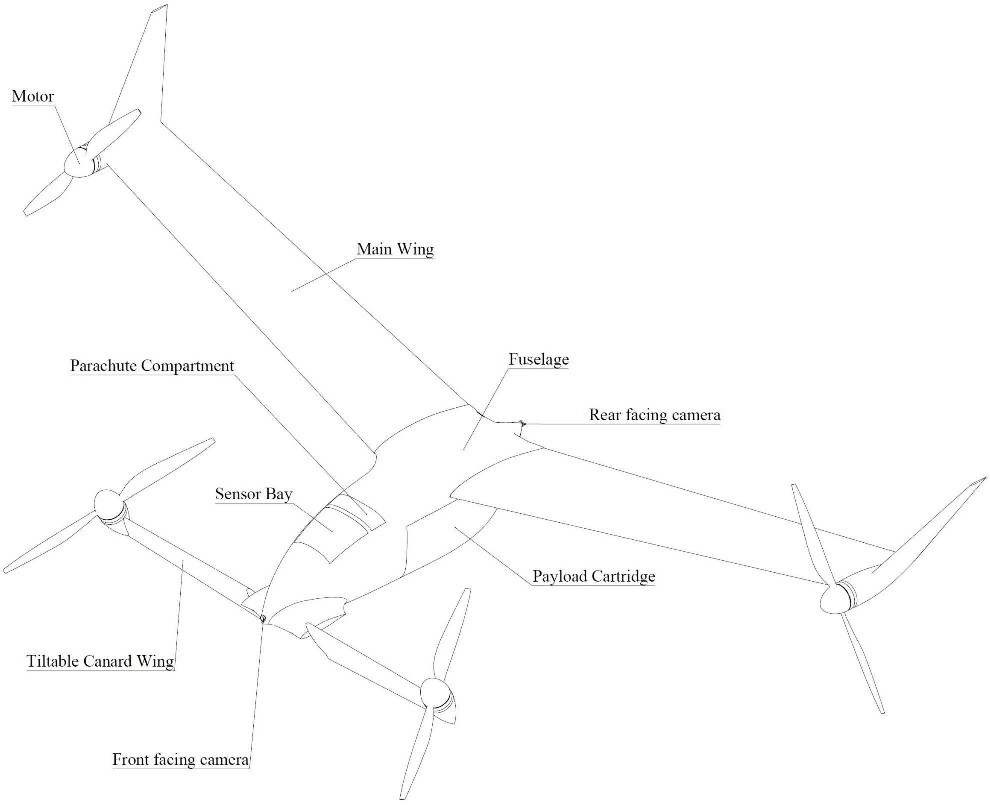

Figure 3: Perspective view of *Bee*

3.1 Approach

Analysing the $MTOW$ to Payload ratio of other drones such as the Wingcopter, *Bees* $MTOW$ was estimated to be about 10 kg. The calculations and modelling started from this point. Due to *Bees* size and requirements being similar to a RC aircraft the design process partly based on Radio controlled aircraft (RC aircraft) experience as well as on Snorri Gudmundssons book: "General Aviation Aircraft Design: Applied Methods and Procedures" [5] and material provided for the lectures of the ILR institute of the TU Dresden [6].
The first Wing configurations were tested and modified using the software package FLZ VORTEX [7], which includes a 3D modelling software that helped defining wing parameters, such as size, profile, glide ratio, lift coefficient, angle of attack etc.
Additionally, eCalc [8] was used to support the design of propulsion system and power train. After comparing a box-wing and canard aircraft, the canard configuration was chosen. Solidworks was then used to design *Bee* and *Hive* (Landing platform + servicing module) before calculating the drag coefficient of the fuselage (C_{Df}) using the Solidworks flow simulation (see Appendix, Figure 15). For the following calculations MathCad and Excel were used.

3.2 Wing Configuration

Due to the limited size of each landing platform, the ability to start and land vertically was considered to be necessary. Nevertheless, *Bee* is a winged aircraft instead of a multicopter version. Using wings to create lift instead of only relying on rotors increases both efficiency and safety.
Unlike other drones *Bee* does not utilize fully rotatable engines nor two fully rotatable Wings

for the take-off or landing. Instead it lands and starts in a vertical, nose up position with all engines generating lift. Rotating the canard wing with its front motors enables *Bee* to switch flight modes from horizontal to vertical and vise versa.
According to the current pitch angle, the canard wing rotates into a position at which lift is either created by the wings, the motors or a combination of both. The decision to only rotate the whole aircraft was made due to two main reasons.
At first, rotating the front and back engines or both wings results in requiring a complex tilting mechanism and having higher requirements on the structure. Both increase the overall complexity, mass, price and result in a higher risk of malfunction.
Only rotating the smaller and less lift-creating canard wing moderates those issues, in cost of having to perform a rotational land/start maneuver.
Secondly, the upright position allows *Bee* to land on its tail instead of its belly. In an early project phase a stand on the winglets and the tail empennage was planned but replaced by landing in a Y shaped device of the landing platform that will hold *Bees* main wings. The abundance of a fixed landing gear therefore lowers drag and weight.

- During the early design phase, a canard design competed against a box-wing design. Both configurations were modeled and the aerodynamic coefficients were approximated using the simulation software Vortex [7]. The comparison was focused on the L/D ratio and is shown in Appendix A.3. Comparing the two designs the box wing showed a slightly superior L/D, but decisive were constructive parameters.
- A VTOL requires rotors that enable all flight scenarios. Having separate rotor pairs for vertical and horizontal flight means additional weight, which leads to the exclusion of that propulsion system. Meaning, that *Bee* needs a rotational pair of rotors, which are far more easily placed on the wingtips of a canard than on a box-wing configuration. Furthermore it was planned to land on the winglets, which wouldn't have been possible with the boxwing either.
- Constructing and replacing the wings is significantly easier done on a canard than on the boxwing.
- The next question to consider, regarding the canard configuration, has to do with stability and control. A horizontal lifting surface placed in front of the main wing will result in a stabilizing pitching moment, if the CoG is placed in front of the aerodynamic center.
  One of the consequences is stalling at the canard wing due to a high pitch angle before stalling at the main wing. This will cause the nose of the drone to swing down into a stable position without stopping the main wing from creating lift.

There are also some downsides of the canard.
The canard wing creates a relatively high drag due to the high angle of attack. This problem can be minimized by making the canard wing smaller and the main wing bigger.
Due to its forward position the canard wing normally worsens the airflow on the main wing. For *Bee* this is not a big issue because the two wings are offset in height.

3.3 The Wings

After the decision of using a canard configuration, the next step was to optimize the geometry of the wings. For this Vortex was used once again. The optimization was an iterative process. The goal was to maximize the L/D ratio.
But the aerodynamic characteristics were not the only sticking points. The leverage arms

between the CoG and the motors have to be large enough to control pitching and yawing moments during the VTOL. This is fulfilled by the vertical offset between the wings and a dihedral angle of the main wing.
The determination of the airfoils took place in a similar manner to the configurations. The airfoils MH200 and MH201 [9] were selected. The comparison is shown in Appendix A.3.
The main wing is equipped with winglets. This causes better side stability and a reduced lift-induced drag. They also increase the L/D without increasing the wingspan.
The wings are built of expanded polypropylene [10] with CFRP rods which are placed at the center of the wing as can be seen in Figure 18 Appendix A.2. EPP, which is widely used to construct RC planes, was chosen because of its favorable mechanical characteristics.
Firstly it has a low density of about 9 g/mm^3 resulting in a very light weight.
Additionally the shell is very elastic and shock resistant which ensures that a minor landing mistake does not result in damaging the wing or a nearby person.
Furthermore the EPP layer acts as a thermal insulation, protecting the electronics from either heat or cold and therefore ensuring a working system even in rough conditions. The motors and the cables are attached on one tip of the rod. The wing is manufactured by first placing the rod in the center of the wing form and then spraying the foam into the form. Afterwards the wing is coated with a GFRP fabric which is attached with epoxy resin.

3.4 Fuselage

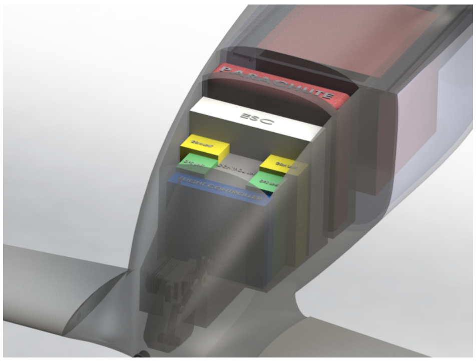

Figure 4: Main components

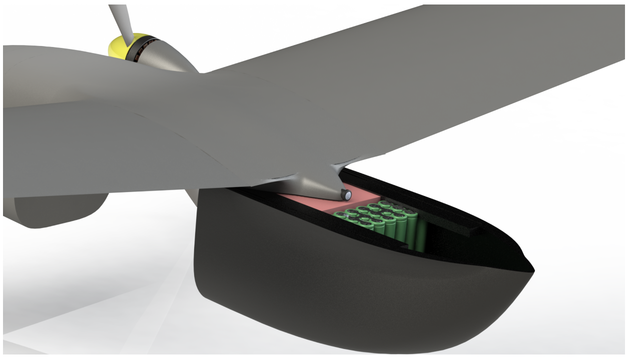

Figure 5: Payload cartridge - Red (Payload); Green (Battery)

The dimensions of the payload and the lowest possible drag are the main factors that are driving the design of the fuselage.
To optimise the aerodynamics the cubic package with a edge length of 150 mm is fit into the fuselage instead of being mounted externally. Additionally, *Bees* fuselage is kept short to lower the Center of Gravity (CoG) while standing vertically. At first, an autonomous landing on a flat surface was planned, which would have required a low CoG and a short canard wing to improve the stability during side winds. Although the landing concept changed, a low CoG is still very beneficial.
The fuselage consists of an expanded polypropylene (EPP) shell and a carbon fiber reinforced polymer (CFRP) frame (see Figure 18, Appendix).
The streamlined shell ensures the low drag of the fuselage as well as physical protection of its internals. Even though EPP is water repellent [10], the fuselage will have an additional coating to minimize the surfaces roughness and to reduce drag.
The CFRP frame mainly serves as the mechanical structure, it bears the loads and forces and

therefore provides the needed stability. To fit vital components such as the servo actuators, regulators, flight controls, the parachute etc., the frame is build around them.
Very important to note is how *Bee* carries the payload and batteries in an exchangeable Payload Cartridge.

3.5 Payload Cartridge

The *Payload Cartridge* as shown in Figure 5, slides onto *Bees* rail-system and is locked in place until being removed. Similar to the fuselage the cartridge is constructed out of EPP and reinforced with a CFRP frame.
The rail system acts as the mount, as well as the electrical contact for the batteries that are placed in the far end to ensure *Bees* Center of Gravity is placed within the stability range.
After touching down on *Hive*, the landing infrastructure will autonomously replace the cartridge with a fully charged one. *Bee* is then ready for flying its next mission.

3.6 Power train

Due to the positive aspects of a vertical take-off and landing aircraft, the decision to go with a multi-rotor concept was done right at the beginning. *Bee* is powered by 4 brushless motors which are located at each wingtip. The front left and left front and rear motor are displayed in Figure 20 and Figure 21 in Appendix A.2. The energy storage consists of 4 separate battery packs which are located inside the payload cartridge.

3.6.1 Why using a multirotor concept?

Urban areas are highly populated, on this account a VTOL aircraft is the perfect opportunity to minimize the length of the flight path. The high density of buildings in city centers and CBDs (Central Business Districts) forces the drone concept to minimize required space on the ground and during flight.
A vertical take off results in a minimized landing space.
A VTOL aircraft also provides high landing accuracy and good maneuverability in all axes. During landing, the drone can always adjust itself and the electric power train makes sure that changes in speed and direction are made nearly immediately. In comparison, combustion engines always have a small delay until they reach full power and thereby are not suitable for fine maneuvers on smaller aircraft.
Multirotor aircraft also minimize the length of the landing path; conventional airplanes have to use their glide path to land at a specific landing site.

3.6.2 Advantages and disadvantages of a 4 rotor drone

The conclusion to use four motors was made to find the perfect spot between high efficiency and a lightweight design. The thoughts of using even more motors and rotors was made but quickly discarded. With *Bees* design it is clear that a requirement for the propulsion system was an even number of motors. With four motors as a minimum, only eight motors would have been another option to increase redundancy (or even higher numbers of motors 16, 32 etc.). If a drone is powered by eight motors (two at each wingtip), the aircraft can compensate a motor failure. The remaining single engine at the wingtip would then have to spin much faster.
The problem with double mounted motors is a decrease of efficiency and also the overall structural weight of the power train would have been increased enormously. Another huge

deficit is, if the rear motor at one wingtip fails, the remaining motor is blasting against the failed rotor. This would increase windmill drag. A further aspect that has to be considered is the higher energy consumption while using even more motors.

It also needs to be considered, that today's electric motors are highly developed and without unusual loads, the motors are long-lasting. In the case of collisions (bird strikes, hail etc.) it is highly likely that not just one motor would fail but the whole motor pair. In this situation a double mounted engine won‘t have any advantages.

In conclusion, the higher weight, greater number of components, higher costs and increase of manufacturing steps do not compensate for the small amount of increased redundancy. A four-engine aircraft is the easiest, cheapest and lightest version to build a small sized delivery drone.

3.6.3 Choice of Propulsion System

Table 1: Choice of Propulsion System

Source of energy	Li-ion	Hydrogen	Fossil fuels
Energy-density [Wh/kg]	120-200	33000	1000
Advantages	faster charging capabilities than Li-po; automatable refueling; electricity available everywhere in urban areas, small motors;	highest available energy density; no CO2 emissions	availability secured; high energy density
Disadvantages	low energy density results in higher weights; even due fast charging capabilities, higher charging times	availability not secured, refueling difficult to automate, costly production of fuel cells, high structural weight of the tanks	hard to handle, corrosive, complicated automated refuelling, many more parts in combustion engines, higher wear, huge CO2 and noise emission

Lithium-ion batteries are still having a much smaller energy density than conventional fuels, but therefore they are more easily recharged than conventional fuels or hydrogen [11], while recharging times are much higher, batteries are swapped easily and the recharging scenario is easier to automate. Recharging is using "plug and play" techniques and does not require pumps, tanks or pipes. The whole recharging system can be easily installed and can use the local grid for power connection.

Moreover, during the last decade the development of Li-ion batteries has taken serious steps to become a good alternative to fossil fuels. The energy density has been raised in the last 15 years by more than 40% [12] and this growth is being expanded even more.

Also, the handling is easier, as fossil fuels can be corrosive and hydrogen has to be stored in high-pressure tanks, which are again not easy to handle or easy to automate [13].

Another reason to use an electric power train is a low noise profile, a much higher level of ef-

ficiency, relatively low costs compared to hydrogen fuel cells. An electric power train is fairly easy to maintain, and parts can be replaced fast and easy. Moreover an electric propulsion system has less moving parts than conventional combustion engines.
The non-emission of carbon dioxide is probably one of the biggest future-proof advantages of an electric power train, the reduction of carbon dioxide emission should be one of the main goals of all engineers and involved laborers. Transport is responsible for nearly 30% of the EU's total CO2 emissions, of which 72% comes from road transportation [14, 15, 16]. By using an electric propulsion system *Bee* can reduce the local CO2 emissions in every operating area.

3.6.4 System Architecture

The power train consists of four brushless motors, four ESCs, four propellers, and 24 3.7 V 4000 mAh Li-Ion cells. For a detailed view, how the components are connected, see Figure 23. Besides the propeller and motor, all components are sitting inside a sensor bay (see Figure 19, Appendix A.2). Thereby it is ensured that all components can be reviewed, maintained and changed easily.

- **Motor:** Every single motor provides a F_{max} of 5000 gram at sea level which means in total the aircraft has the ability to be flown with a maximum thrust of 20000 gram. This value seems too high for a conventional aircraft but a VTOL drone in this size should be using a thrust to weight ratio from 1.6-2 to guarantee a safe and maneuverable liftoff and touchdown [17], especially in higher leveled cities. During the horizontal flight, the required thrust to weight ratio is far less than mentioned before. This results in less energy usage during the horizontal flight, compared to lift-off and landing.

- **ESC:** The electronic speed controllers regulate the rotation speeds of the motors and thereby the thrust and energy consumption. Each ESC also provides a separate 5V/5A circuit to power various sensors, actuators, and communication devices. By having heat sinks mounted on the ESCs the waste heat will be transferred away from the components. Heat peaks will occur during take-off and landing. These periods will be minimized by quickly transitioning from vertical flight to horizontal flight (less than a minute).
- **Propellers:** The diameter is designed and calculated to be 22 inches while having a pitch of 6.6 inches. The propellers are designed to minimize the acoustics and the general noise level of the drone (see 4.8 Noise Reduction).
- **Battery:** The energy storage system consists of 24 Li-Ion cells which are grouped into four packs with six cells each, every single pack is able to power the aircraft. Four packs are used to reach the required amount of battery capacity. If one of these fails, the aircraft is still able to fly and land at a safe spot.

3.6.5 Battery

The energy system consists of 24 3.7 V 4000 mAh Li-Ion cells. Six cells are connected in serial to provide a 6s 22.2 V pack. Thereby 6s means the number of cells connected in serial to reach a specific voltage (here six cells, each 3.7 V, resulting in a 22.2 V system). Four packs are connected in parallel and are integrated in the payload cartridge. The decision to use separate, individual battery packs was made to reduce the risk of a battery failure. If one pack fails, the aircraft is still able to use the remaining packs to search for a safe landing

spot.
The separation of the energy storage is a perfect example of the aircraft redundancy.
Bees propulsion system is running on a 6s System, which equals to 22.2 V. The decision between a 6s setup and a setup running on a higher voltage was discussed in detail.
Positive aspects of a 6s circuit are the lower costs of components, lighter batteries, lighter motors, a lower voltage number as well as a lower risk of sparks while connecting the batteries to the circuit. This is a common issue in the RC aircraft industry. Due to the reason that the aircraft is made out of foam, which is not conductive, there won‘t be any problems with that.
Therefore higher voltage systems are decreasing the electric currents and reducing the waste heat. In this case the aircraft is lightweight and is only running on higher thrust levels during take off and landing, this means the problems of waste heat and higher currents are again minimized.
The batteries are charged inside the logistic platform. This process is well described in the logistic paragraph.
The decision to store the batteries inside the payload cartridge was made to ensure an easy way of charging the energy unit. While the payload cartridge is swapped for a fully charged one, the used batteries can be recharged right inside *Hive*. The whole cartridge will be taken out by *Hive* platform and the batteries will be recharged while still being inside the cartridge. Inside *Hives* bay, underneath the landing area, there will be a cartridge depot. This ensures all time availability of fully charged batteries.

3.7 Mass Estimation and Center of Gravity

The mass was calculated and estimated based on currently available components, that are used in small scale aircraft , such as RC planes etc.

	Component Mass [kg]	Amount	Total Mass [kg]
Max. Payload			2.5
Empty Weight			6.71
Structure			1.98
Main Wing	1.22	1	1.22
Canard	0.37	1	0.37
Fuselage	0.39	1	0.39
Power Plant			3.38
Engines	0.18	4	0.72
Propellers	0.08	4	0.30
Batteries	1.05	2	2.11
Regulators	0.06	4	0.25
Fixed Equipment			1.32
Flight Controls	0.13	1	0.13
Electrical System	0.16	1	0.16
Avionics	0.27	1	0.27
Payload Cartridge	0.31	1	0.31
Parachute System	0.45	1	0.45
DTGW			**9.18**

Table 2: Component Mass Breakdown

Center of Gravity Case	CG in x-direction [mm]	CG in z-direction [mm]
with **Max. Payload** [2.5kg]	461	98
without Payload	462	112

Table 3: CG Cases: in the coordinate system, with its origin located centered at the front edge of the canard wing

3.8 Ground Systems

3.8.1 *Hive* - Landing Pad

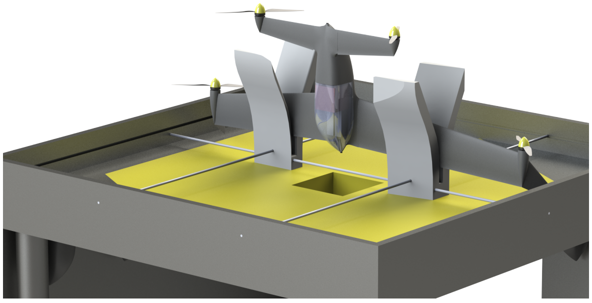

Figure 6: Perspective view of a landed *Bee*

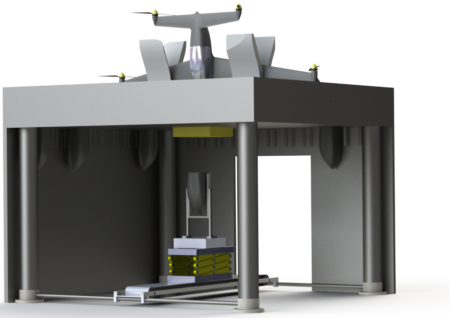

Figure 7: *Hive* during loading process

Each *Hive* ground station consists of the landing pad and the logistic support below. To keep the drone upright with minimal technical effort, the decision was made to let the drone land within two Y-shaped landing pods. This form was chosen as the upper opening of the Y would allow deviations in the position of the drone to the landing block without impacting the landing process. Moreover the y- shaped landing pods increase the stability during high winds on the ground enormously.

The landing pods will be covered in soft foam to avoid any damage to the wings of the aircraft. The position of the landing pods will be directed by gear rods. Two for the X- and one for the Y-direction. Thereby larger deviations can be compensated.

These gear rods will be movable mounted on the side walls.This system was chosen for its technical simplicity and ease of installation.

Once *Bee* begins its landing approach it will transmit the data of both the rear camera and GPS sensors to *Hive*, which will process it and determine the exact position of the drone, based on this data. The landing pods will then adjust their position as dictated by the data transferred from the drone to ensure that the drone will land exactly within them. Once the drone has landed it will be moved by the landing pods to the center of the landing pad where the processing of its cargo and battery will happen.

Approximately 9 m^2 of solar panels could be used per landing pad. Today, solar panels can reach a maximum peak of up to 1 kW per 8-10 m^2 [18]. Thereby, eight *Hives* could produce up to 7500 kWh [19]which could be used to supplement the local power grid in charging the cartridges. Thereby the carbon footprint of *BeeHive* is further reduced.

A *Hive* module consists of ground computers (used for creating a virtual map of all nearby aircraft), storage space for the cartridges, a cartridge removal lift and the landing pad itself. A single module will be sized 3.75 m x 3.75 m and is able to process one *Bee* at a time. Several modules can be connected and will then work as one larger landing array. Two rows

of four modules will correspond in a total size of 7.5 m x 15 m.
Each side wall of *Hive* can hold and charge up to 11 cartridges which sums up to 44 cartridges that can be stored and charged. Theoretically there is no limitation of how many modules can be added.

3.8.2 Ground Handling

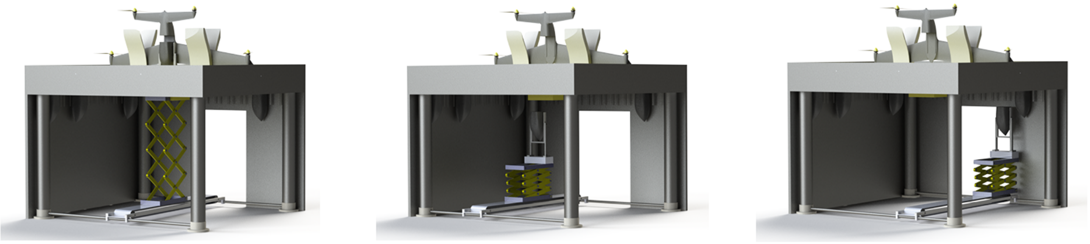

Figure 8: Cartridge exchange - for better visibility only two side walls are shown

After a drone has landed the lift section will move on its rails below the payload opening and move upwards. The arms then will be on each side of the cartridge and with four electromagnets the cartridge will be held. *Hive* will tell the drone to release the cartridge, while being held by the lift arms, the cartridge moves downwards. On its rails the whole removal lift will then move to the side to place the cartridges in their charging spots. The whole unloading process is shown in Figure 8. At the same time the charging spot is the place where the payload can be unloaded from the outside doors.
One side of each main logistic module consists, besides of the charging spots for the cartridges, of a load and unload facility. The cartridges are hanging downwards from the ceiling, from the outside customers can open a door with a digital code and can unload their parcel, similar to the already used Packstations (used by DHL Germany) [20].
Loading a parcel into a cartridge works very similar. A customer opens the lock and puts the parcel into the cartridge. *Hive* automatically detects which door was opened and thereby which cartridge has been loaded. *Hive* will automatically load the cartridge into the next aircraft and the parcel will then be delivered. Each cartridge is identified via a RFID chip. This chip is read and written during the unload and load process by the lift arm. Thereby each package has its own parcel number and is easily identified. Also the target location is stored on the chip.

4 Performance Analysis

4.1 Takeoff

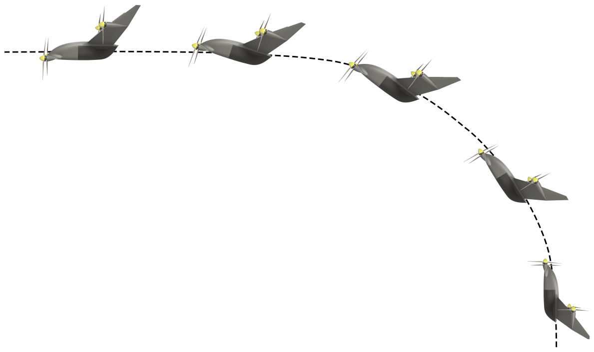

Figure 9: Take Off Flight Path

For the best use of the available space in urban areas *Bee* starts vertically from *Hive*. Therefore, no certain landing and starting path is needed. In fact locating a landing platform in the slipstream of a nearby building might lower wind speeds and simplify a safe start and landing. The vertical takeoff is divided into two stages, the vertical climb and the parabola maneuver.

4.1.1 Vertical Climb

The vertical climb, to a height of 50ft marks the first critical stage of each flight. A maximum vertical acceleration $\mathrm{a}_{\mathrm{max}_\mathrm{v}} = 4.8\mathrm{m/s}^2$, that is needed to start in strong winds, is achieved by using each of the canard mounted motors at full Thrust $\mathrm{F_c} = \mathrm{F_{max}} = 49\mathrm{N}$ and both wing mounted motors at a thrust of $\mathrm{F_w} = 18,2$ N.

4.1.2 Parabola Maneuver and Climb

During the second takeoff stage *Bee* further increases its vertical velocity while the wings start to create lift. To follow a parabolic flight path the nose is pitched down until the final minimum climb angle of $\gamma_{\mathrm{climb}} = 4°$ is reached. At that angle, the aircraft will climb at a true airspeed (TAS) of 22,8 m/s and a thrust of 16 N until reaching the initial cruise altitude (ICA) of 120 meters. After 1.26 min with a climbing speed of 1.59 m/s *Bee* will have traveled 1.5 km over ground before it reaches its final height.

4.2 Cruise

Following the climb, the cruise takes up the majority of the distance flown by the drone which can be up to 15 km. It takes place at a height of about 150m over the ground. During the cruise the drone will fly at its fastest to reach the destinations in time.

- **Velocity:** *Bee* is designed for the worst case scenario. According to that the cruise flight must be calculated for the maximum range of 15 km which must be reached in 20 min, handicapped by a permanent headwind of 20 knots. The final minimum TAS of *Bee* is 22.8 m/s.

- **Maximum distance:** The used battery pack adds up to a total capacity of 16 Ah of which 20% are reserve, 40% are assigned for the take-off and the landing and 10% are assigned for supplying the sensors. That leaves a rest of 30% for the cruise flight. With a calculated drag of 5 N the maximum cruise flight distance is 76 km.
  Due to the high maximum range in comparison to the general operational range *Bee* will arrive at a *Hive* without having drained all of its available battery capacity. This ensures the drone still has enough charge left to reach an alternative landing spot or return to its starting point in the case of not being able to land. Moreover, a delivery to a *Hive* without the infrastructure for recharging is possible, allowing return flights. Therewith the expansion of the operable network is offered.
  Generally only a portion of the batteries capacity will need to be recharged. In case of a high take-off frequency, completely recharging batteries is not required and not viable. A drone can take of with a partially charged battery while still being able to reach its operational objectives with a safe margin for error. This mitigates the threat of no sufficiently charged batteries being present within *Hive*. Therefore the 2 min starting target is guaranteed.
  In case of a low take-off frequency batteries need to only be partially recharged increasing battery lifespan while decreasing charging times. However, in special circumstances it also allows *Bee* to fly longer routes at the expense of battery lifespan and charging times. Finally, the big disadvantage of Li-ion batteries in charging times, compared to other fuels, is bypassed.

Finally the aerodynamic characteristics of the cruise flight are stated in Table 4. They are comfortably fulfilled by the geometry and the propulsion system of *Bee*.

C_D	0.0206
C_L	0.3715
L/D	18.0340

Table 4: Aerodynamic characteristics

4.3 Stability

In order to reduce the effort of stabilizing the vehicle through motors and flaps, the CoG has to fit into certain limits which are given by the following conditions for static longitudinal stability [21]:

$$\frac{\partial C_M}{\partial \alpha} < 0 \ and \ \frac{\partial C_M}{\partial C_L} < 0 \tag{1}$$

To calculate the first condition the Equation (C2-3) of the document "Appendix C2: Design of Canard Aircraft" was used [5]. The second Condition was solved much simpler by a formula from the lectures of Professor Wolf [21].

$$\frac{\partial C_M}{\partial C_L} = \frac{h - h_{AC}}{\bar{C}} < 0 \tag{2}$$

Derived from these conditions the final limits of the CoG were estimated:

$$\frac{S_C C_{L\alpha C}(l_{CW} - h_{AC})}{S C_{L\alpha W}(1 + \frac{S_C C_{L\alpha C}}{S C_{L\alpha C}})} - \frac{h_{AC}}{1 + \frac{S_C C_{L\alpha C}}{S C_{L\alpha C}}} < h < h_{AC} \tag{3}$$

The required values as shown in Table 5 are given by the geometry of the vehicle and by the lift coefficient curve slopes of the canard [22, 23] and the main wing with the coordinate origin being placed at the front tip of the canard wing root.

canard wing area	S_C	0.11904 m^2
main wing area	S	0.61840 m^2
lever arm from AC of the canard to the AC of the main wing	l_{CW}	0.49 m
coordinate of the AC of the main wing	h_{AC}	0.565 m
canard lift coefficient curve slope	$C_{L\alpha C}$	9.1669
main wing lift coefficient curve slope	$C_{L\alpha W}$	5.7307

Table 5: Required Values

After inserting the values, the final limits are:

$$0.450m < h < 0.565m \tag{4}$$

With the CoG being placed in between those limits, with and without the payload (compare with Table 3), a self stabilizing flight condition is assured.

4.4 Maneuvering

The drone is able to rotate around the roll-, yaw- and pitch-axis by individually control the ailerons and separately adjusting the thrust of each engine. It can rotate around the roll- and yaw-axis by using the ailerons on one side. Pure rolling can be performed by compensating the yaw-moment with additional thrust on the opposite motors. On the other hand pure yawing can be performed by keeping the ailerons in a neutral position and giving additional thrust on the two motors on the right or the left of the drone depending on the wanted direction. Pitching is performed by using the ailerons simultaneously. The canard wing can be rotated by servo motors to allow the drone to get into VTOL configuration and vice versa.

4.5 Landing/ Hovering

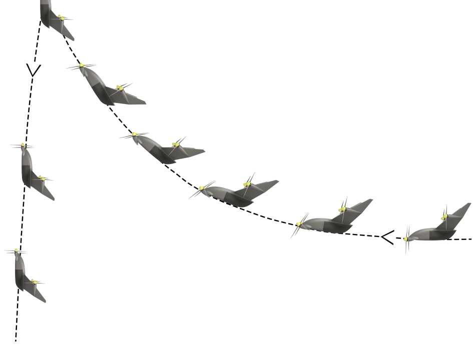

Figure 10: Landing Maneuver

Approaching its destination, *Bee* will descend with an angle of 4° until reaching a height of 50 ft. To switch into the upright position the aircraft will perform a climbing curve supported by the rotors. Slowing down and reaching a steep pitch angle, the wings will not provide lift, so the rotors take over. By creating lift they stabilize the aircraft and prevent it from tumbling. Once *Bee* has stopped climbing the transition is finished and the aircraft will head for the landing platform hovering using all engines. Getting closer to *Hive* the two systems will communicate, transmitting the drones data of the GPS sensor and rear camera for a precise touchdown in the Y-shaped landing pods, as described in 5.2.1 *Hive* - Landing Pad.

4.6 Noise Reduction

There are several options to reduce the noise generated by an aircraft. For example, the usage of electric motors instead of combustion engines makes a significant difference. Propellers with a larger diameter and smaller blade angle along with a streamlined shape of the aircraft are lowering noise emissions as well. Therefore *Bee* consists of a low body profile with a body height of less than 30cm reducing drag and wind noises.

Because the noise level increases by the 6th potency of the rotational speeds of the blade tip, larger propellers with lower rotation speeds are used to reduce wind noise and to increase effectiveness. By decreasing the blade angle from 22° to 19° the noise level is reduced by 1.5dB [24].

Therefore the optimal propeller consists of a large diameter, a small blade angle, a small aspect ratio, and a thin profile. It is not always possible to implement all of these options. The rotors must have a certain thickness to withstand all encountered aerodynamic loads and also the size of the diameter is limited by the dimensions of the aircraft, the landing pad, and the used motors. Using larger propellers increases the power drain and motor temperatures and thereby reduces the flight time.

Using a push-pull configuration was discussed, but would have increased the noise level. A push motor sits right behind the aircraft or next to its trailing edge and thereby pushes the swirled air from the airfoil which decreases the effectiveness and increases noise [25, 26].

Another option could have been the usage of a multi-bladed rotor. Propellers with more than two blades can reduce noise levels in. Therefore, the effectiveness can be decreased. A two-bladed propeller produces two larger pressure pulses per revolution instead of a three-bladed propeller which produces three smaller pressure pulses and thereby produces less noise. Moreover, vibrations can be decreased by using a three-bladed propeller [27]. The decision towards a two-bladed propeller was made because of its perfect balance between noise, cost and effectiveness.

Besides being lightweight, EPP has another advantage. The foam like material has brilliant shock absorbing properties. Through that, noise generating vibrations are minimized. Vibration dampers between the motor and the mounting can be used to lead to another optimization of motor noise reduction [28].

Intelligent flight path planning is indispensable for a minimal noise pollution, by lifting off vertically, the noise generating aircraft is brought to higher levels within seconds and thereby is reducing the constant noise pollution in urban areas. Additionally, a Propeller/Rotor Phase Control for reduction of community noise (noise) is implemented [29].

The most significant reduction of noise is achieved during cruise flight. Due to the wide wingspan of *Bee* the engines can be throttled to about 90% of the average takeoff thrust.

As a consequence, a low-noise flyover of the city is achieved resulting in minimal interference with its inhabitants.

5 Operational Concept

5.1 Safety and Reliability

Safety and reliability are key features to ensure a safe and user-friendly system. Targets that must be achieved are minimization of harm to people as well as a minimization of damage to the ground unit and surroundings in the case of a total failure. Loss of life is unacceptable. To achieve a highly secure drone several ways of redundancy are implemented in the *BeeHive* system.

The following enumeration shows what kind of sensors are used inside *Bees* sensor bay. Flight controller, barometer, magnetometer, two GPS modules (used for GPS blending), two cameras (flight path controlling and airspace sensing, DAA), 4G/5G GSM module, RFID chips (cartridge identifying) and a parachute. These modules are easily exchangeable as seen in Figure 19 in Appendix A.2.

5.1.1 Flight path

A huge advantage of aerial transport is a faster, easier, and safer way to transport items. Therefore, a smart path planning is a key feature to ensure safe operations (see Figure 22, Appendix)). To minimize the calculations that are done by the drone itself, the whole process is outsourced to ground computers located inside *Hive*. Those are planning the flight path which is then flown by the aircraft. The drone is equipped with a barometer and two GPS modules to ensure a correct height calculation and the GPS modules are also used for global positioning, velocity controls, and route adjustments. Moreover the GPS modules (also working with GLONASS l& Galileo), can be used for GPS blending [30] or precise point positioning [31]. Additionally, using two GPS units is another part of *Bees* redundancy system.

The processing unit located inside the landing platform generates a virtual map of all *Bees* and all other known airspace participants. If two aircraft are getting to close to each other on *Hives* virtual map, it will automatically detect those aircraft and will send signals to both aircraft on how they have to react. Therefore each aircraft on *Hives* virtual map is surrounded by a fictional bubble. If an aircraft enters another one's bubble, the flight controllers (ground computers) will then guide the aircraft apart from each other.

During take off this system will work in a slightly different way, the bubbles are getting smaller when the aircraft is slowing down and enters the airspace around one Hive. Then the bubbles are getting even closer until the landing pad is reached by the drone. Thereby, it is secured that each drone will always be in its one safe zone, but at the same time drones are allowed to get closer to each other while being close to a landing platform.

In each operating area are several emergency landing zones advised. These could be recreation parks, sports grounds or other wide and open areas. In case of on an unlikely emergency, drones can land at those spots. Even in the case of a non powered flight *Bee* is still able to glide to a safe spot. While gliding to an emergency landing zone the cameras will automatically detect if there is a safe spot to do an emergency landing. *Bee* will open its parachute, when having reached an empty space. The parachute is located right behind the sensor bay (See Appendix A.2, Figure 19) and is again easily exchanged. It is held by electromagnets, thereby it will be assured that during a total loss of power the parachute will open automatically due to the magnets loosing power. A small battery is powering the electromagnets while the payload cartridge is being swapped, thereby it won't open during the unloading process. The parachute has a spring loaded mechanism to ensure a fast ejection.

5.1.2 DELS - Drone Emergency Landing System

DELS consists of three main features. First, the flight computers inside the base, both cameras and a parachute.

In the case of a "soft failure", which means, the drone is still flying above 80 m but all motors have stopped working (birdstrike, hail which damaged the propellers or motors), *BeeHive* will work as one unit, *Hive* is calculating the fastest route to an emergency zone and *Bee* is using its cameras to detect an alternate landing spot. If a landing spot is find, *Bee* will lower itself to 15 m (safe height for parachute opening) and will then activate its parachute. If the parachute would open earlier the drone could be pushed aside by winds. At the same time all motors will be stopped immediately, thereby it is secured that no one will be harmed. A GPS signal is still being transferred to *Hive*. Due to the materials that are used, for example foam, *Bee* is fairly soft to its emergency landing site and won't produce any further damage or harm.

The parachute has a surface of 4m^2 and is able to reduce the vertical velocity to less than 20km/h (a skydiver lands with 18km/h) [32].

5.1.3 DAA - Detect and Avoid

Bee is using two cameras to detect its surroundings. Located in the front and the back, they are securing that the drone is able to detect and sense other airspace participants if they do not use any kind of identification like a standardized transponder. Aircraft that are equipped with a transponder are detected by *Hives* ground computers.

The cameras are using high refresh rates to be able to detect the smallest movements like birds and smaller aircraft. If an unknown flight object is detected by a drone, cross-correlation is used to calculate the flight path of the unknown object. If there is a chance of a crash the drone is using its 4g/5g link to the next *Hive* station to signal all other airspace participants that there are intersections of two flight paths. *Hive* will calculate how the affected drones need to react. If they have to change their position or even have to land, the drones will do so.

Hive is also communicating with FAA's UTM (unmanned traffic management), the system, which is still being developed, allows the usage of flight levels which are relatively close to the ground (up to 400 ft) [33]. UTM combines various sources of airspace restrictions such as government buildings, airports, hospitals but also temporally limited restrictions such as city festivals or visits from heads of state. By using the UTM system, the drones and all other UTM users will be notified about airspace restrictions but also about emergencies like rescue helicopters. The UTM will send information of other aircraft about their flight path, velocity, current position, and height to *Hive*. Thereby it will automatically detect if aircraft are getting to close to each other. If so, *Hive* will send instructions to all the affected aircraft and how they have to react.

If the flight path of a rescue helicopter, or anything similar, is intersecting with the path of a drone, *Hive* will be warned by the UTM system and will then control all drones out of that certain flight path. Therefore it is necessary that the flight path of a rescue helicopter, or any other airspace user, is shared with the UTM system. Due to standardized transponders codes this is already available. Transponder codes are showing which heights, velocities and flight paths are used by the airspace user [34, 35].

5.2 Legal

Regulations regarding the commercial drone sector are improvable. Current FAA 107 regulations do not allow a flight beyond the pilots visual line of sight, prohibits operation during nighttime and does not regulate the autonomous piloting of those small aircraft [36].
On this point a big governmental investment is necessary to set clear and state of the art regulations.
Nevertheless, it is possible to get certified by the FAA Part 135 standard to overcome those barriers for an operable urban drone delivery network [37, 38].

6 Marketing Plan

The *BeeHive* delivery concept is designed to satisfy the needs of a mixed customer base to improve the productivity of as many customers as possible. That is why the following specific customer group will be described to clarify the conformity of the concept.

6.1 Customer

Possible customers are all businesses in urban areas that need to shorten their delivery time of small goods to a minimum. Especially in the health care sector those small dimensions and low weight of very time-sensitive freight are fulfilled.
As such *BeeHive* will initially focus on pathology laboratories and the hospitals in their immediate area. This market is a highly specialized niche market where a high transport volume is expected. The need for a fast and reliable transport system results from the missing integration of pathology laboratories and hospitals. In the city of Dresden, out of ten hospitals only two are equipped with an in-house pathology department [39]. Similar situations can be found in other major cities like Frankfurt [40], Munich [41], and Cologne [42]. The other 80 % of the hospitals in the city are depending on ground transportation links between the hospital and the pathology to analyze tissue samples. In most cases, those are sampled during an ongoing operation, for example, to verify if the whole tissue affected by cancer cells was removed. The probe needs to be analyzed as fast as possible to lower the period of narcosis of the patient to an absolute minimum. Thereby medical risks for the patient, the cost of the medical staff involved and the utilization of surgery are reduced. Therefore, tissue samples need to be delivered on the quickest way possible to a pathology laboratory [43]. At present this is achieved by the use of an ambulance or special transport vehicles with emergency lights to mitigate delays caused by red lights and congestion. As seen in Figure 11 those options of transportation result in high costs compared with a low reduction in travel time.

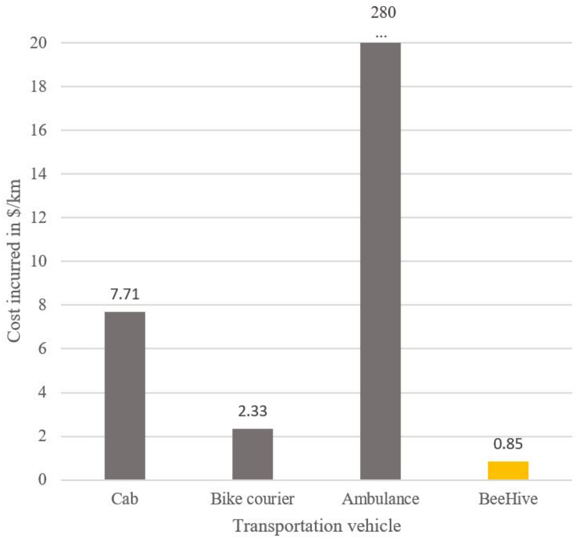

Figure 11: Cost of transport alternatives in urban areas [44, 45, 46, 47]

BeeHive offers the possibility of reducing transport costs by 279.09 $ per kilometer compared to the use of an ambulance and saving an extra 27 minutes of transport time as shown in Figure 1 (see the following subsection Fiscal Planning for the calculation of the operating cost of *Bee*). Moreover, the respective tissue can be transported from the surgery directly to *Hive* where it is loaded in *Bee* without any human interaction cutting preparation time even further. To guarantee the obligatory privacy policies and integrity of the probe the payload cartridge of *Bee* is designed to be opaque and impermeable to ultraviolet light. For the intended transport time there is no further need for cooling the tissue [48]. Nevertheless, chilled transportation is possible. Due to the payload cartridges EPP outer walls a probe on ice will be insulated for the duration of the flight.

6.2 Competition

The market for urban air delivery is vibrant. Many startups and entrenched logistic companies, first of all DHL and UPS, are investing in developing their own aircraft to transport goods over the last mile in a limited time [49]. UPS however, after earning its full FAA Part 135 certification in October 2019, probably became the biggest competitor in the whole air delivery market [50]. Nevertheless, this company is leading in the field of package delivery to private consumers - a market *BeeHive* does not focus on.

Another big competitor with a very similar performance as *Bee* is the German company Wingcopter [51]. Because the Wingcopter is not integrated into an autonomous ground station it is suitable for highly individual missions in rural areas but not for cities with a high transport frequency.

The Hamburg based concept Medifly targets a very similar market as *BeeHive* but also does not fly and load without human interaction. In the medical application, this results in a loss of valuable minutes and adds high personnel costs that make the concept unprofitable. Moreover, it is not equipped with a fixed-wing mode resulting in lower efficiency and range. Other companies are compared in Table 6.

As seen in the comparison in Table 6 *BeeHive* operates on the same level and surpasses even some of its competitors. To conclude, the challenges poised by the current regulatory

	UPS Quadcopter	DHL	Amazon	Wingcopter	*BeeHive*
Autonomous flight	no	yes	yes	partially	**yes**
Autonomous ground station	no	yes	-	no	**yes**
VTOL	yes	yes	yes	yes	**yes**
Fixed-wing-mode	no	yes	yes	yes	**yes**
Drive	electric	electric	electric	electric	electric
Payload [kg]	2.3	4	2.2	6	2.5
Range [km]	20	65	24	45	76
v_{cruise} [km/h]	-	130	-	100	82.08

Table 6: Comparison of selected delivery drone companies [50, 52, 53, 51]

framework, the DHL Packetcopter 4.0 and the Wingcopter are the biggest competitors to *BeeHive*. However their components are not as environmentally friendly as *Bee*, like the use of EPP and solar electric power.

6.3 Advertising and sales strategy

Right after market entry *BeeHive* will focus on the medical market as described above. Therefore the whole concept is adapted better than all its current opponents. Hence a collaboration with a well-known hospital will be assembled right after market entry to attract the attention of other medical institutions. Special attention will be employed towards gaining large scale hospital operators as initial customers. After the market position in this segment is assured other entries into markets such as the B2B area will be targeted.
To summarize the *BeeHive*-company is going to advertise its product with its innovation itself and its striking design. Moreover, the company needs to enter the global market as fast as possible to impress as many people as possible with an unfamiliar appearance. This is much more valuable than an expensive and well thought of marketing campaign.

7 Fiscal Planning

To show the viability of *BeeHive* a detailed cost calculation is mandatory. In the following the Production Costs (PC), Operating Costs (OC) and Design and Development Costs (DDC) of the system, altogether described as Life Cycle Costs, are elucidated to ascertain the break-even analysis of the business.

7.1 Life Cycle Costs

7.1.1 Production Costs

All the integrated components are common RC aircraft parts, with the exception of custom made parts such as wings, fuselage, and payload cartridge. All the used prices are gross prices for one item per order. When ordering multiple parts the cost of those will be reduced. All labor costs are set as described by Gudmundsson and adjusted for inflation: engineering 99 \$/h, tooling and assembly 66 \$/h, manufacturing 58 \$/h [5]. Only the wings, fuselage, safety system and payload cartridge are no standard components and therefore stand out by their manufacturing price as seen in Figure 12.

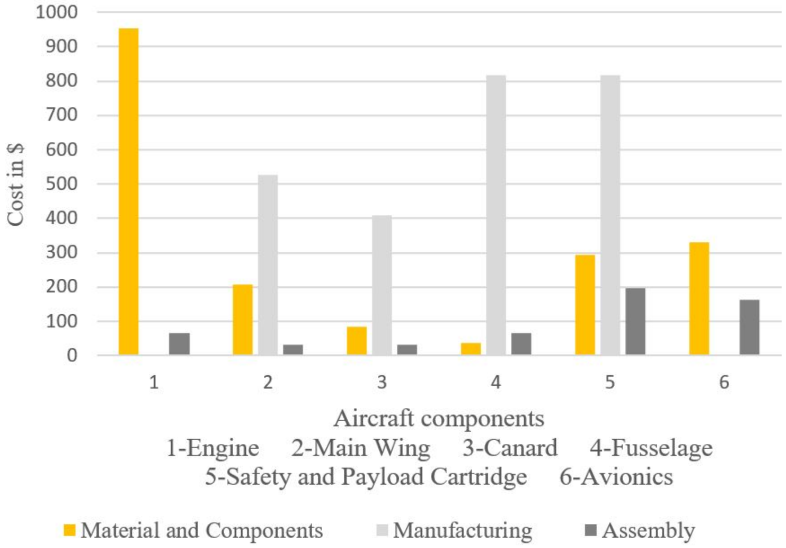

Figure 12: Costs of *Bee's* individual components

Altogether the gross production price for *Bee* is 5035$. By ordering higher quantities of parts this price can still be reduced due to possible order volume discounts.

7.1.2 Operating Costs

To calculate the OC following assumptions were made:

- The total quantity of *Bees* produced is conservatively assumed to be 500 pieces. The average operation time is 5 years, with a conservative assumption of 8 operating hours a day and two flights per hour over a distance of 15 kilometers. The operating days are assumed to be 360 days a year to allow time for maintenance.
- *Hive*, as assumed to consist of one landing platform (gross manufacturing price: 8000 $) and one storing system (gross manufacturing price: 17000 $). For a bigger system, the operating price can be cheaper by scaling up with more landing platforms.
- **Interest:** The interest rate is assumed to 5 % over 10 years.
- **Insurance:** Insurance contribution is set to 500 $ per year [54]. Especially the liability coverage is needed because of the highly sensitive goods transported in the pathology sector.
- **Electricity:** Average commercial electricity costs in the USA in April 2020: 0.1041 $/kWh. 60% of the necessary electricity will be produced by the solar cells on *Hive* [55].
- **Personnel:** One flight operator is supervising the autonomous flight of 4 drones at a time for additional safety reasons (This already assumes further development of FAA Part 107, where one drone has to be operated by one pilot). Moreover, costs for management are included.
- **Maintenance:** Maintenance costs are fixed as 140 $/h and assumed for once every 20 flights for 15 minutes (due to the robust design). Due to the use of a carbon-fiber structure, the electric propulsion system and the clean design maintenance is reduced to a minimum [56].

- **Batteryswap:** The Li-ion batteries will be replaced after 1500 charging cycles [57].
- **Spare parts:** Due to the quick availability of the installed standard components, costs for spare parts are limited to a minimum. Most of them are delivered just-in-time.
- **Logistics and installation:** Because of the modular design of *Hive* the sections can be transported by standard trucks and stacked together.

Therewith the total DOC can be calculated as 0.60 $ per kilometer. Its components can be seen within Figure 13.
The highest impact on the Direct Operating Costs results from personnel costs of the flight operator. In the upcoming years, the autonomous flight will be improved even further, resulting in a decreasing personal cost per flight and increasing the profitability of *BeeHive* even further.

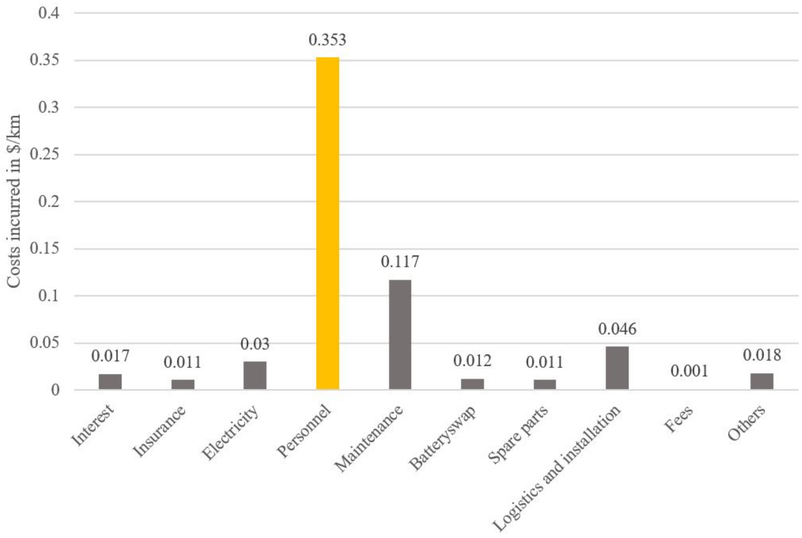

Figure 13: Direct Operating Costs of *BeeHive* for a 15km delivery.

7.1.3 Design and Development Costs

The DDC are calculated as proposed by Gudmundsson [5]. Therefore the total cost of Engineering, Development Support such as administration, overheads or facility maintenance, Flight Test Operations, Tooling, Quality Control, and Registration are taken into account. The assumptions made in the section above were still used. Moreover, Gudmundssons Eastlake business model was adapted for the use case of a drone. Hence the certification costs were adapted to FAA Part 107 [36], costs for Tooling and Quality Control are shortened due to the reduced amount of self-made parts and extra costs for the development of the Autonomous Flight Control (AFC) are added.
Therewith the total Design and Development costs for *Bee* are calculated with 332,000 $, including an amount of 180,000 $ for the development of AFC. Together with the DDC for *Hive*, that is calculated with 290,000 $, this adds up to a total Design and Development Costs of 622,000 $.

7.2 Break-even analysis

BeeHive targets to be a profitable concept within 5 years. Therefore the total income, including all income from the leasing of the drone and its logistic system, and the total expenses are compared over this period in intervals of 1 quarter. To calculate the latter, the DDC, all production costs and monthly costs such as rent, wages, interest, insurance, and others are added. Moreover, the assumptions from section 7.1.2 were used, added by the following:

- Five new customers are acquired per quarter, starting from Q3 in the first year.
- Each customer orders 3 *Bees* in average.
- Labor budget for administration, management, and sales personnel is rising 10,000$ per month each year due to the order position.

Therewith the following cost structure of the leasing system, not including tax, is developed to reach the Break-Even-Point just before the end of the fourth quarter in the fifth year as shown in Figure 14:

- Commitment fee per new customer: 3950 $
- Rental fee per month per *Bee*: 370 $
- Fee per flight within the 15 km radius: 11.21 $

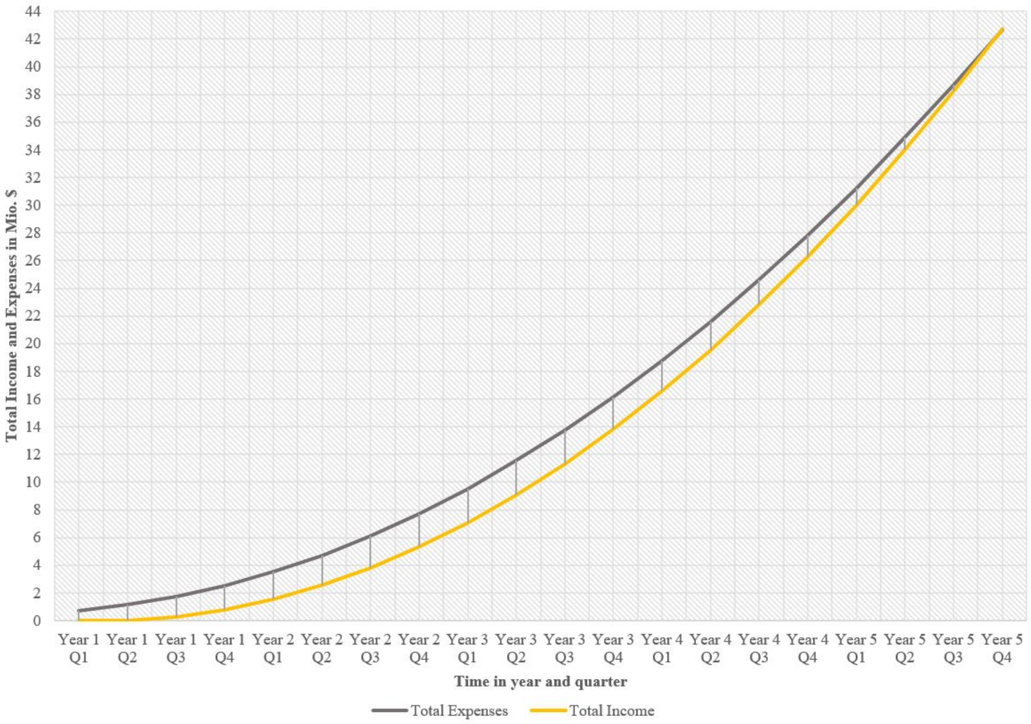

Figure 14: Break-even analysis for the *BeeHive*-Company

Besides the low capital commitment for its costumers and the full control over the technology by the company, the leasing structure offers another huge advantage that gets apparent from the break-even analysis. Over the whole time of operation of *BeeHive* the capital demand is not exceeding 2.48 million $. As result, the concept is fully operational with an investment of 1.73 million $ from the start with borrowing or auto financing by investors. After Q4 of the first year, another investment of 0.75 million $ is necessary. With this strategy, the interest can be set to a minimum and the value of the company will have increased at that time offering a higher amount of money per share in a second investment round if financed by equity.

8 Conclusion

BeeHive manages to reach and surpass the design goals set for it, as can be seen in Table 7.

	Topic	Threshold	*BeeHive*	Design Feature
1	Take-off capabilities	STOL	**VTOL**	Tilting rotor layout
2	Climbing ability	120 m within 1500 m	Vertical climb ability	rotor layout
3	Sink capability	120 m within 1500 m	Vertical decline ability	rotor layout
4	Height landing site	up to 2500 m	up to 2500 m	Aerodynamics, propulsion system
5	Flight in winds	up to 20 kts	20 kts	Aerodynamics, propulsion system
6	Cruise height	120-150m	120-150m	Aerodynamics, propulsion system
7	Flight range	2 x 15 km	**76 km**	Aerodynamics, propulsion system, power train
8	Autonomy of logistics	autonomous	autonomous	*Hive*-System
9	Mission duration	below 20 min	**between 8.5 min and 20 min**	Aerodynamics, propulsion system
10	Flight in rain	possible	possible	GRP coating
11	Payload dimension	15 cm cubical	15 cm cubical	Payload cartridge
12	Payload weight	2.5 kg	**up to 4 kg**	Propulsion system
13	Autonomy	autonomous	autonomous	AFC

Table 7: Compliance with Requirements

Especially in the area of range, take-off and landing capabilities, and maximum payload weight *BeeHive* is able to outperform the set design goals.

Bee provides fast and reliable freight delivery over short ranges while *Hive* is capable of the complete autonomous recharging and handling of the aircraft. Due to the low operating cost, the modular design, and the use of mainly standard components, the system is available at a low price and scaleable for every size of operation. Together with the leasing system, this offers wide accessibility for its customers allowing a low financial barrier of entry and high flexibility.

*BeeHive*s abilities allow it a wide range of uses, from health care to last-mile cargo delivery. The advanced level of automated flight and additional safety concepts, like the return-to-*Hive* capability if a landing is not possible, the *Drone Emergency Landing System* (DELS), and the *Detect and Avoid* (DAA) system are highly compatible with the high significance of security in urban areas. Together with well-defined flight paths and the nearly silent cruise flight *BeeHive* is a desirable alternative to already existing competitors while matching and even surpassing their performance in key areas.

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A Appendix

A.1 Flow Simulation

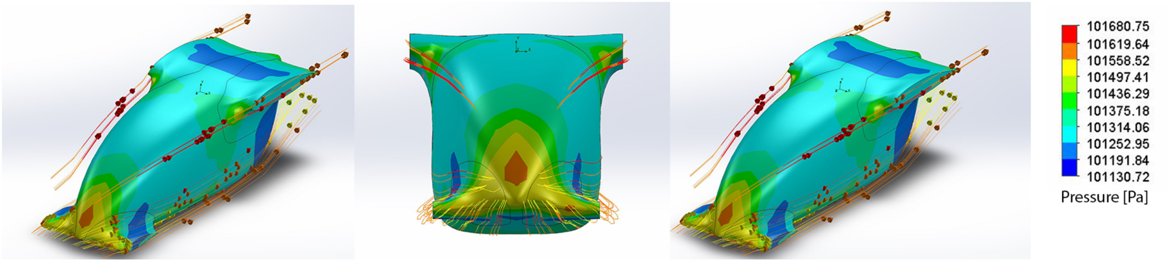

Figure 15: Flow simulation of the fuselage

A.2 Pictures of the *BeeHive* Concept

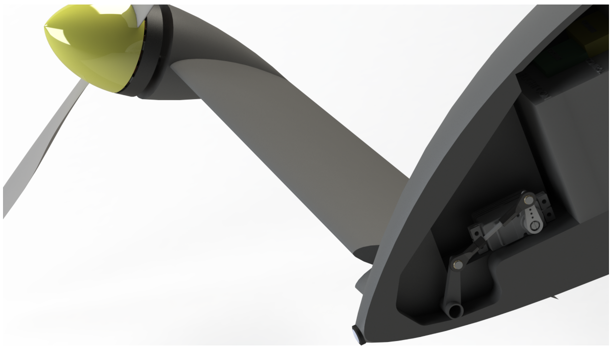

Figure 16: Swivel mechanism front wing

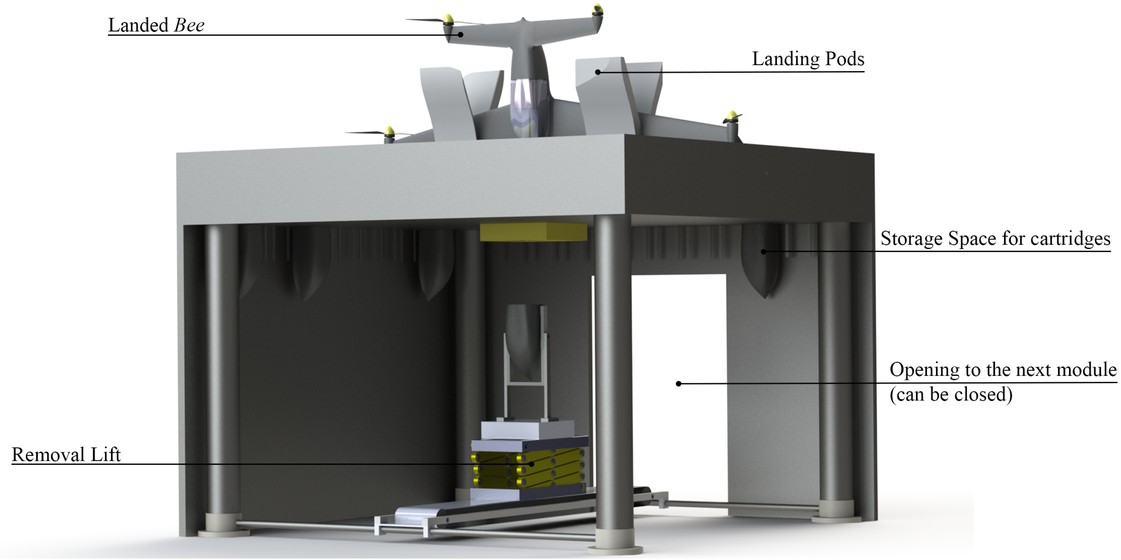

Figure 17: *BeeHive* Concept

Figure 18: Fiberglass frame

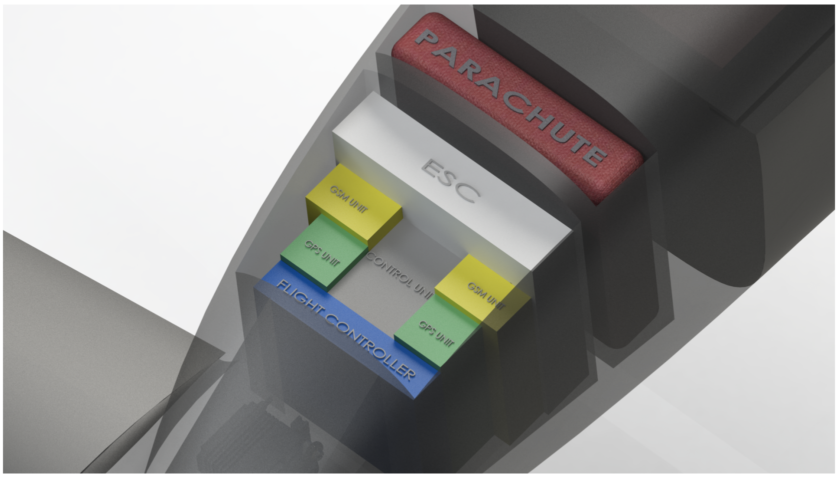

Figure 19: Sensor Bay

- Red = Parachute
- Yellow = GSM Units
- White = ESC Unit
- Blue = Flight Controller
- Green = GPS Units

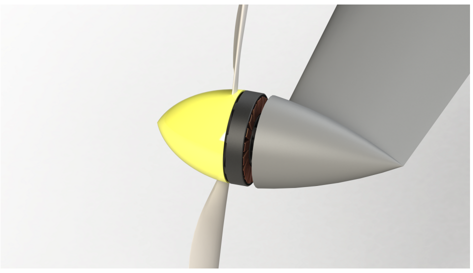

Figure 20: Front left motor

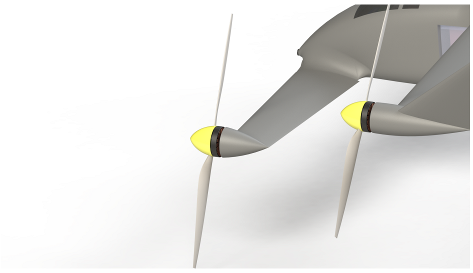

Figure 21: Front and rear left motor

A.3 The Canard Configuration

comparative values	box-wing BSW	box-wing FSW	Canard with winglets
C_L	0.4335	0.3889	0.3071
C_{Di}	0.0081	0.0075	0.0034
L/D	20.05	21.64	21.15
m=const.			
V=const.			
S=const.			

Table 8: Comparison of configurations

comparative values	NACA0015/NACA2415	NACA 2415/NACA 4415	MH200/MH201
C_{Di}	0.0069	0.0060	0.0065
L/D	19.86	20.15	22.60
C_L=const.			
m=const.			
V=const.			
S=const.			

Table 9: Comparison of airfoils

Values	Canard wing	Main wing
b	0.9523m	2.4066m
S	$0.1190m^2$	$0.6184m^2$
Λ	7.6208	9.3657
Γ	0	10°
φ	0	10°
λ	0.6667	0.6667
α	4°	2.3°
Profile	MH201	MH200

Table 10: Characteristics of the wings

A.4 Safety and Communication

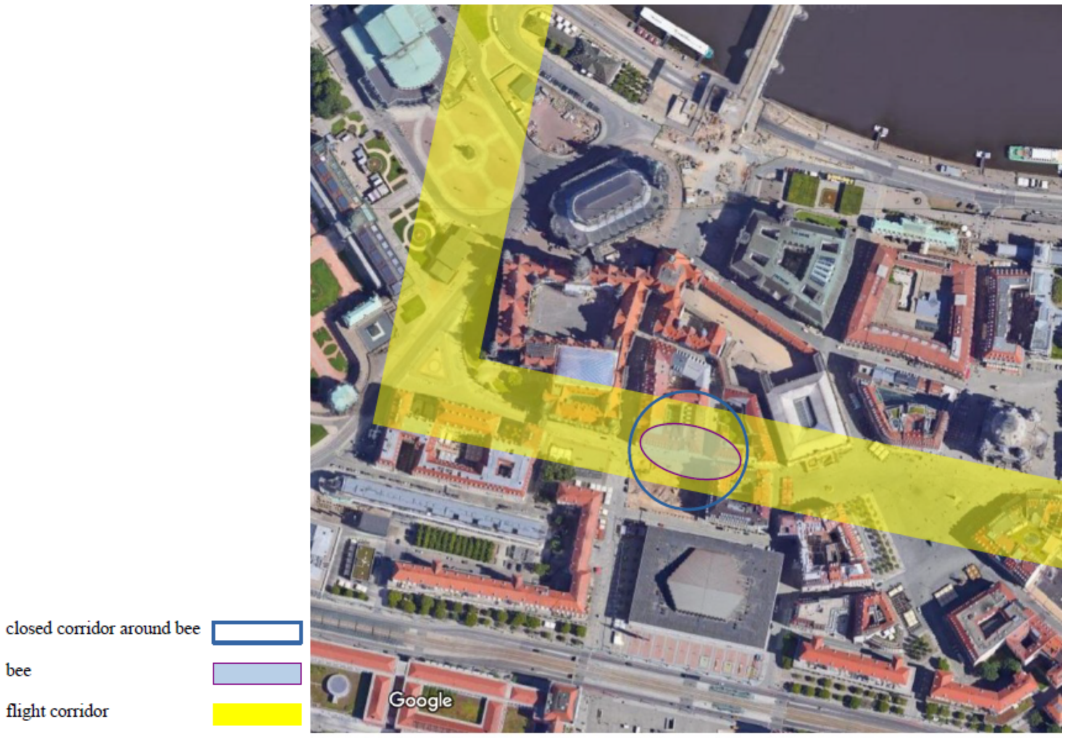

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Figure 22: Possible flight path over the City of Dresden

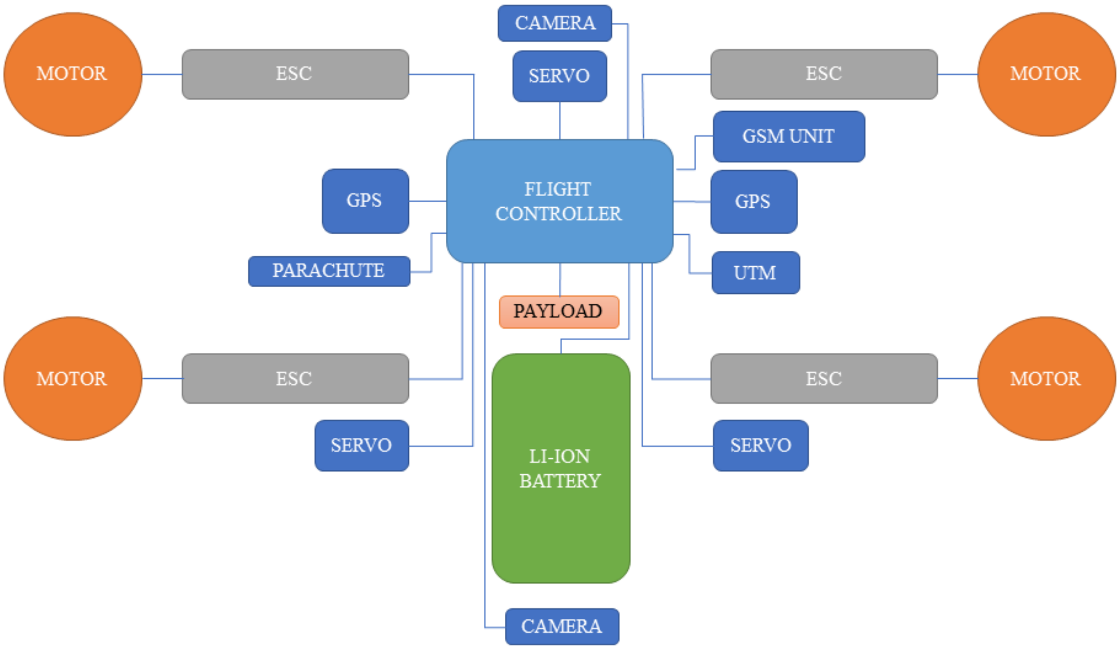

Figure 23: Inner layout of the electronic components