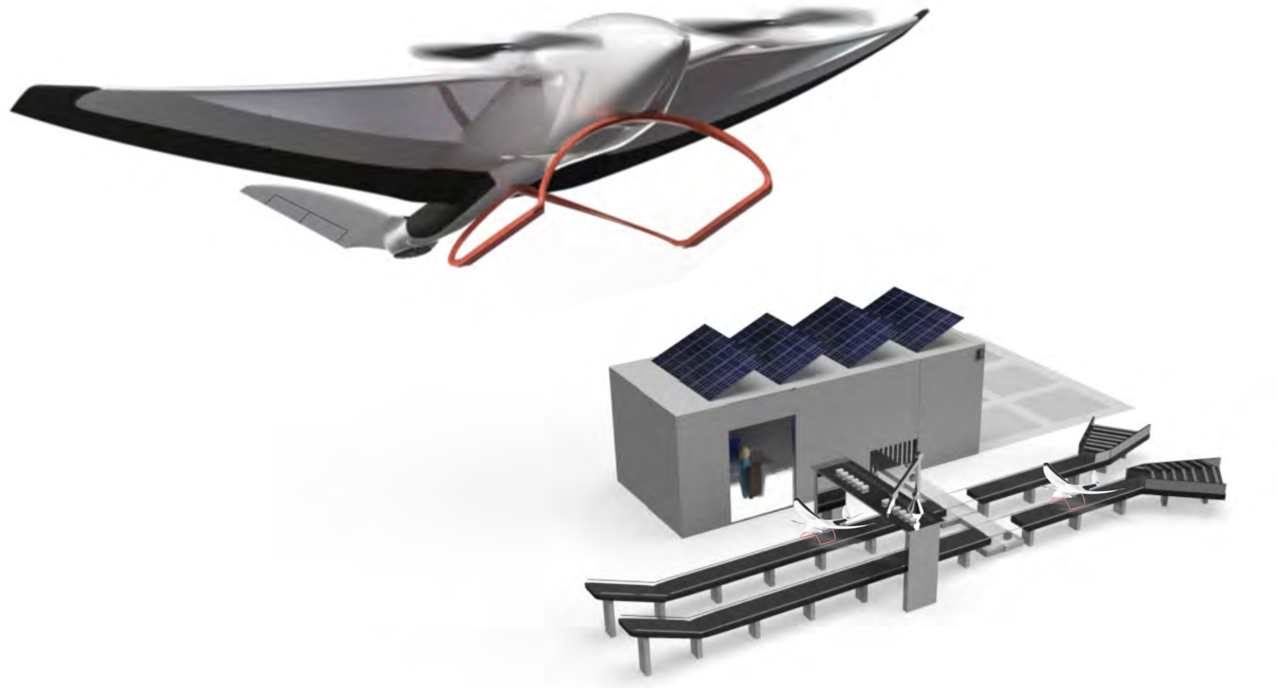
Universität der Bundeswehr München

NASA/DLR Design Challenge 2020

Urban Air Mobility

eCICONIA – Study of an autonomous last-mile Cargo Delivery UAS in an UAM Scenario

electrically-Charged Inner-City-Operating Noise-reduced Independent Aircraft



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Abstract

Worldwide, the population density in conurbations is constantly increasing. At the same time, the number of people making use of web-based delivery services is also increasing, currently additionally driven by the Corona Pandemic. The necessary increase in delivery traffic to meet the growing demand for ordered goods is in controversy with the currently declared goals of reducing pollutant and noise emissions, which must be achieved unconditionally. Particularly in inner-city areas, where bans on vehicles with combustion engines are currently being discussed because pollutant limits are being exceeded and high levels of noise pollution are a constant feature of everyday life, an unconventional, progressive approach is required to revolutionize the inner-city last mile of a supply chain.

From the current situation, the necessary requirements for a new concept for inner-city parcel delivery to the end user can be derived directly: A new propulsion concept to reduce pollutant emissions, a configuration and operation that reduces the overall noise level and a high performance operation to meet the great demand. In the context of these requirements, the Urban Air Mobility (UAM) sector is currently experiencing an enormous upswing, as new propulsion concepts promise low pollutant and noise emissions and the increasing degree of automation and the technological advancement in general promise high performance and reliability. The key aspect of this development is the use of the third dimension to relieve the high urban traffic volume while increasing delivery capacity. Thereby the top priority is to guarantee the safety of primary persons and secondary goods, which is ensured by strict licensing requirements and regulations for Unmanned Aerial Systems (UAS).

eCICONIA (electrically-Charged Inner-City-Operating Noise-reduced Independent Aircraft) meets these requirements with an efficient electric propulsion system designed for noise reduction. Its Vertical Take-off and Landing (VTOL) capability combined with fuel-efficient conventional aerodynamic horizontal flight allows a precise take-off and landing procedure at minimum space. A central base station with assembly line processing for parcel loading and battery change and integrated control center enables efficient and reliable operation with minimum space and time consumption. The use of existing infrastructure for parcel storage in the form of modified parcel stations offers a cost-effective option for reliable parcel delivery without endangering people by drones landing on the ground. Due to the installed positioning accuracy, there are minimum requirements for the size of the landing site. Safe flight operations are ensured by redundant instrumentation and the use of Unmanned Aircraft System Traffic Management (UTM). A combined safety system consisting of a parachute and airbags reliably prevents damage to people and goods in the event of a system failure. A sustainable and profitable business case guarantees the feasibility of this concept in the competitive delivery market.

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1 Introduction

1.1 Urban Air Mobility

Urban Air Mobility (UAM) is a rapidly emerging market segment, enabled by technological progress and driven by socio-economic trends. Modern societies create high demands for individual transportation and real time delivery logistics, fueled by accelerating trends like urbanization, digitization and individualism. Scientific research and technical developments, in energy-storage, digital-automatization and miniaturization increase adaptability for the mass market. These advancements will enable supply of high consumer demand. The modern Urban Air Mobility market differs from its predecessor, the rotary wing based inter-urban commute-service, which is more of a specialized niche of general-aviation. Expensive intercity helicopter transportation, available for a small range of selected customers only, is a comparatively small market and based on principles of classic civilian aviation. Urban Air Mobility however aims at the general population and universal application of a given urban area with high expectations regarding environmental impact, safety, noise emission, accessibility and sustainability. A key role in this field are Unmanned Aerial Systems (UAS), alternative engines and general automation. In context of this challenge, this report focuses on the unmanned last-mile delivery segment of urban air mobility. As the "last-mile" of any courier and delivery service is notoriously the most complicated, cost intensive and unpredictable part of a logistic chain, UAM has the potential to revolutionize this market.

1.2 Our Solution

Web-based distribution, shipping volume and demand for realtime-delivery are evermore increasing. Where population densities peak and traffic networks reached saturation, additional growth is limited. Using most recent technologies, detailed engineering and functional design we lifted those limitations, by shifting to the third dimension.

Our solution is an autonomously operating UAS fleet, monitored via a central processing and control station, providing a commercial parcel delivery service. With *electrically-Charged Inner-City-Operating Noise-reduced Independent Aircraft (eCICONIA)* (ciconia, lat. = "stork") at the center of our design we invented a reliable, efficient and innovative distribution vehicle while combining it in a sustainable and profitable business proposition. Resembling the dynamic and natural elegance of the stork, our approach combines the aerodynamic advantages of our biomimetic inspiration with practicality and branding. With its significance as a migratory bird, analogous for newly aroused life, it heralds a new era of service for urban inhabitants.

2 Businesscase

2.1 Market Analysis

The UAM-Market can be divided into three specific use cases: Air taxi and air metro as means of public transportation and unmanned last-mile delivery application. Where the latter is understood as transportation of small and lightweight packages via UAS with short turnover times directly to the customer.

Market studies conducted on behalf of the National Aeronautics and Space Administration (NASA) evaluate the market for UAS based last mile delivery to over 2 billion USD in the year 2030 in major US cities, based on projected demand as well as technological and regulatory restrictions. Depending on various variables in the underlying modeling, this service will be a profitable business from the year 2030. The largest barriers of entry are regulatory uncertainties and consumer acceptance. Very detailed parameters could already be estimated and quantified, for example expected vehicle cost, customer willingness to pay, infrastructural dependencies and other. [1]

The current courier- and delivery sector is already a constantly expanding market, especially due to wide range adoption of e-commerce. In 2019 the average German citizen alone received 24 packages, resulting in over 3.5 billion deliveries in total, including businesses. In 2018 the industry turned over 21 billion EUR, a 4.8 % growth to the previous year, with no indication of a stagnation in the upwards trend since then. In 2020 the Covid-19 pandemic caused an additional short-term increase of shipments comparable to the seasonal highs of the winter holiday business, pushing the local delivery services to their capacity limits. Issues like wage cost, working conditions and high traffic volume are allready considerable limiting factors of this sector. [2]

Sales in the delivery market are segmented into three categories: Business to Business (B2B), Business to Consumer (B2C) and Consumer to Consumer (C2C), whereas the proportion of the B2C deliveries is rising fast, and the C2C is negligible in this context. Almost two-thirds (62 % in 2018) are already taken up by the B2C segment. Considering, that around 80 % of B2C and 40 % of B2B deliveries are potentially suitable to be carried by an UAS the potential market is at least worth around 16.2 billion EUR, depending on the average shipment price. [3]

Besides the described type of commercial product delivery, other applications can be thought of in the context of UAM. Intracompany logistics, medical drug transports and humanitarian crisis supply are important possible use cases. Unfortunately, little to no representative market data is available, although there are several examples of promising trials. Medical transplants and samples delivered during ongoing operations and spare parts shipped for rapid prototyping were successfully performed. Their share on the total number of deliveries are however insignificant and do not require fully automated cargo loading procedures due to their low volume.

We continue with the description of a possible implementation of such a commercial B2B and B2C business around the location of the German city Munich. Using the laid down data it is not only possible to demonstrate, that even under pessimistic assumptions the required turnovers and capacities are reachable with a reasonable market share. Even more, with our approach and technological solutions, we developed a business model which is also highly lucrative.

2.2 Competitors

Several companies have already developed functional UAM solutions in the recent years, received considerable government funding and secured capital from investors. Both small start-ups and established global players are operating prototypes and have implemented concepts.

In the package delivery segment, we analy the most advanced available systems, which can differ noticeably in terms of performance and operational conditions. In particular, all compared systems are electrical Vertical Take Of and Landing (eVTOL) capable and utilize heavier-than-air flight principles.

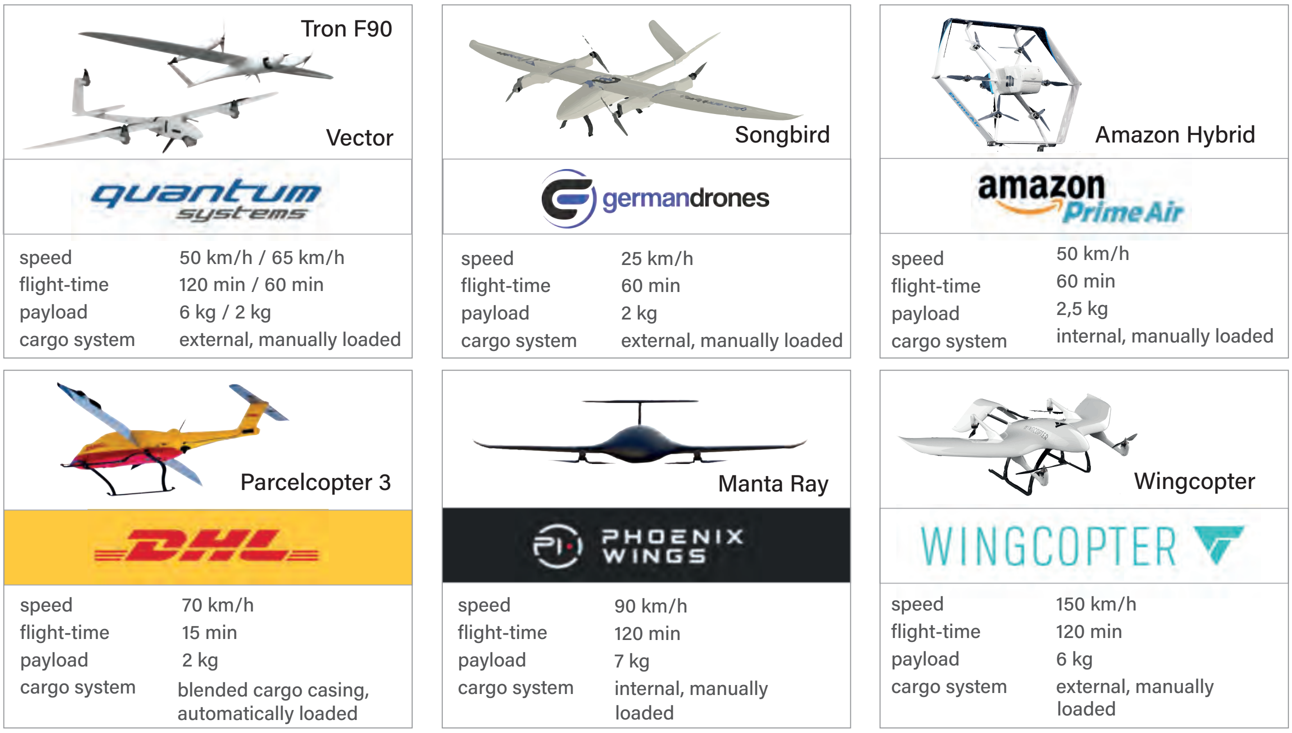

Figure 1: An overview of the current possible competitors in the UAS market with specifications and performance data [4], [5], [6], [7], [8], [9].

The "Parcelcopter 3" tested by DHL is the design solution to align closest to the underlying performance criteria in this challenge. It is the only current solution incorporating an fully automated loading procedure. This way, the UAS is capable of not only one-way delivery of cargo, but also picking up goods at the destination. A detachable cargo bay with integrated rechargeable batteries is swapped during each loading sequence and housed inside the station.

The second most promising systems, “Manta-Ray” by Phoenix-Wings Cooperation, and Wingcopter by its eponymous manufacturer are both copter-plane hybrids. With a blended-body airframe design and a quadcopter-style vertical lift-off configuration they provide the advantages of both approaches. In case of the Wingcopter, the cargo is stored in an aerodynamic shell under the airframe, whereas the Manta-Ray provides an internal cargo bay.

Very similar configurations are used by Zipline, the “Songbird” by German drones and the “Tron F90+” and “Vector” by Quantum-Systems. Different Cargo deployment procedures, like parachute dropping or manual unloading, flight performance and operation requirements highlight the various applications of these UAS.

One unusual configuration is the Amazon Prime Air Hybrid drone with a closed wing lift surface and six electrical driven propellers. Specifically designed for autonomous and safe delivery of commercial packages, it matches most of the requirements for a last-mile delivery UAS. The closed loop wing acts as a shroud around the high-speed propellers, and several cameras and sensors ensure save navigation in complicated terrain and shared airspace.

All currently operated systems have special advantages in their own regard but lack important components to make them suitable for an economically viable package delivery service in an UAM setup. As consumer acceptance studies imply and aviation regulators generally demand, certain technical barriers are strict. Safety and reliability are out of question, not only during general operation but even more importantly in unpredictable failure situations. Noise and exhaust emission are intolerable over strict thresholds. To run a profitable delivery business, wage and maintenance costs need to be minimal by simultaneous maximal service capacity. With our design solution we not only found a safe UAS with good aeronautical performance but especially an implementable business, exceeding our competitor’s profitability.

2.3 Business proposition

Different business models are possible and largely depend on which branch of industry the imaginary company wants to enter. One option is to maximize and optimize the production of UAS and selling the procedures, base station and software as a comprehensive system solution. Maintenance of the hard- and software as well as system integration would be provided as additional services.

2.3.1 Value proposition

The more sustainable approach is to provide the delivery service and operate the UAS and base station directly. Since in context of the challenge it is not intended to become an online retailer, warehouse operator or international logistics company, integration into the existing infrastructure is key. The primary value provided by the proposed business is a solution for the stagnating capacity of the conventional means of last-mile delivery. By partnering with an existing provider of express and delivery services at a large distribution hub, not only the end customer can benefit. The individual demand of businesses and consumers for feasible real time product delivery can be supplied. Furthermore the partnering shipping company will reduce their required operational expenses on the inefficient last-mile by non-automated parcel cars, while also still receiving their share on the overall shipping cost. Online-retailers and businesses can furthermore improve their turnovers by eliminating one of the last disadvantages they have against the traditional inner-city stores and shops: namely, the product access time. In the end it will be more time and cost

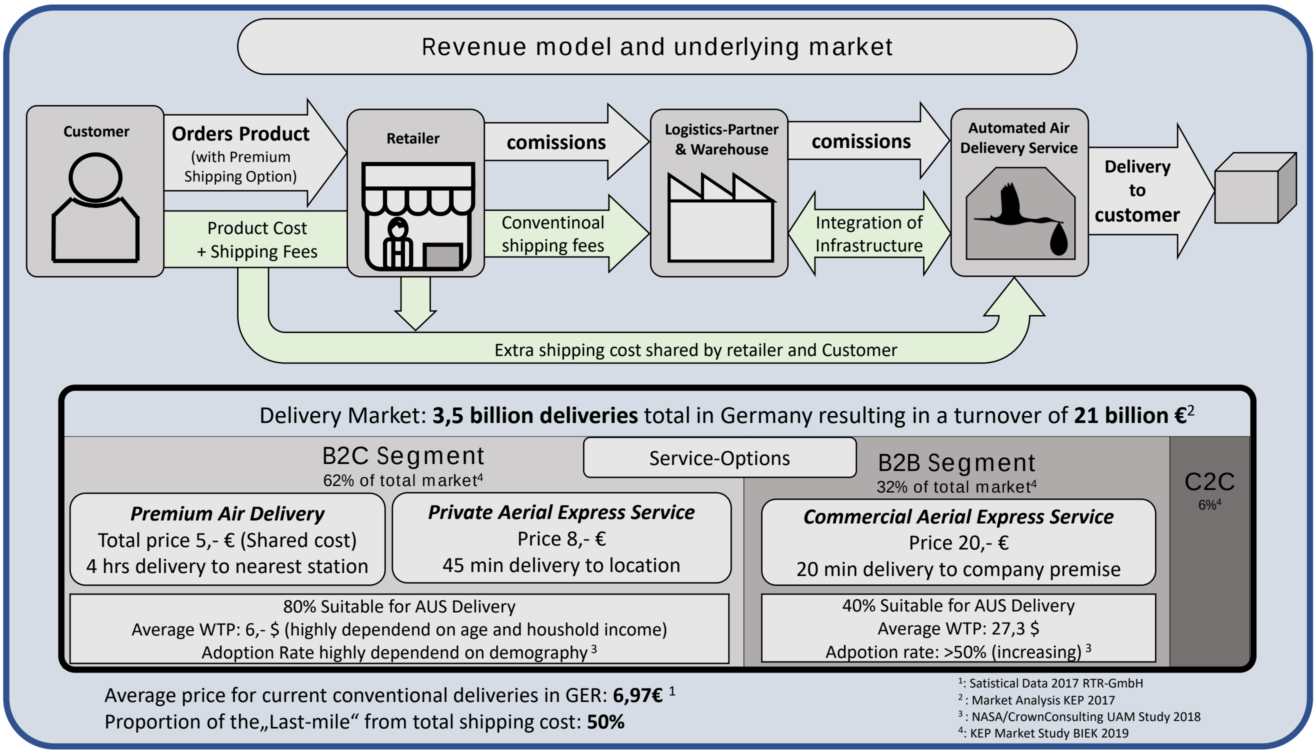

Figure 2: Flowchart of the proposed value chain and the revenue model required for a profitable business case of a last mile delivery UAS service.

effective for the consumer to order a product via express air delivery (with shipping time less than half an hour) instead of the necessary commute and waiting times for physical stores. And finally, the general public will benefit from the reduced traffic, carbon emissions and noise associated with the replaced deliveries by UAS.

2.3.2 Value chain

First, we establish a base station with packaging lane and maintenance area at the partnering Amazon Large Warehouse and Logistic Centre DMU2 in the outer eastern part of Munich. From here a large percentage of the approximately 30 million total annual deliveries are processed. [2] A customer, that is a business in B2B or consumer in B2C case, orders a premium shipping service upgrade in addition to the normally provided classical shipment for a suitable product. The already automated warehouse provides the package to our processing area. Depending on the chosen delivery product, the retailer will carry a small part of the costs, as a price for the higher turnover rates. The logistic partner receives its normal share of the total shipping costs plus an extra margin for providing access to the distribution center and return of the cargo-casings. Since there are almost no additional external costs and dependencies, the own profits can be easily optimized by internal efficiency improvements. Other aspects, like UAS production, maintenance, certification, UAS operation and quality control are managed by the company itself.

Table 2: Turnover projection for 100 % delivery capacity per UAS Unit.

Delivery option distribution	50 %	30 %	20 %	1 delivery in 20 min
Delivery option price	5.-	8.-	20.-	16 h daily -> 48 deliveries
# Deliveries p.a.	7,296	4,377	2,919	304 days p.a.
Turnover p.a. per UAS:	129,864.-			at 100 % capacity

2.3.3 Revenue model

The primary revenue is created by providing the described service in cooperation with an established shipping partner at a distribution center. When the customer is ordering at an online retailer there are different shipping options possible if the product is UAS suitable, as laid out in fig. 2. At a theoretical maximal delivery capacity, every UAS can deliver 3 packages per hour, assuming an average mission duration of 20 min, as outlined in the requirements. This is a reasonable estimation since the UAS has some excess power reserve beyond the initial requirements and can compensate delays by faster return airspeed. Additionally, most target locations would be located around the city center reducing the average flight distance. The prices are based around representative market studies indicating a Willingness To Pay (WTP) well inside the proposed price range. The adoption rate and market acceptance found in these studies suggest a sufficient demand for this service, with less than 25 % strictly opposing such possibilities.

A second possible revenue stream would be the direct distribution of the UAS and base stations as ready to use integrated system solutions. Companies with large premises or multiple locations can benefit from this additional fast independent intercompany logistics. Samples from research-labs, prototypes and spear parts for maintenance could be transported in real-time directly to the location of use with little cost. A proper turnover projection in these cases is especially complex and can only be done for concrete projects. A reasonable margin however would increase the total turnover and gross profit tremendously each year, after the concept is established and has proven its reliability.

2.4 Costs and Projections

To evaluate a possible realization of such an enterprise every possible income and cost source needs to be considered in their respective expected time frame.

The studied time frame of the first seven years is divided into different phases of operation, with the most capital-intensive one being the development. During an expected duration of two years, the founding team members would research and develop the *eCICONIA*-UAS, operation and controls system, design the base station layout and find solutions for an optimized processing lane. The aim is to build two functional prototypes, always considering upcoming certification and airworthiness as well as technological advancements. By presenting proof of concept and partnering with a current delivery provider, the project enters the implementation phase. Through integration into the existing delivery infrastructure and investments into the required hardware, commercial operation is started.

Table 3: Business projection for the first 5 years after the development phase. Previous total Research and Development (R&D) cost of 0.5 Mio. with 1.92 % interest rate and plausible infrastructural reinvestments are included.

		Year 1	Year 2	Year 3	Year 4	Year 5
Investment	Base Station	109,267	0	5,000	50,000	10,000
	Workshop	81,050	0	30,000	50,000	50,000
Operation	Base Station	190,080	190,080	290,080	290,080	290,080
	UAS	11,360	22,720	51,120	90,880	136,320
Production	UAS	36,560	91,400	127,690	146,240	146,240
	Cargo Casings	10,000	100	500	1,500	3,000
Finance	Interest Rate	105,816	105,816	105,816	105,816	105,816
Sum of Expenses		544,133	410,116	610,476	734,516	741,456
# Operated UAS	0	2	4	9	16	24
# Produced UAS	2	2	5	7	8	8
Turnover		129,864	363,619	993,459	2,077,824	3,116,736
	Capacity	50 %	70 %	85 %	100 %	90 %
Gross Profit		-414,269	-46,497	382,983	1,343,308	2,375,280
Balance		-414,269	-460,766	-77,783	1,265,525	3,640,805

First, deliveries would be performed to trial customers under temporal regulatory clearances. With increasing successful deliveries and proven reliability, all processes and hardware become fully certified and are cleared for independent operation. In this phase the first UAS are produced in series while constantly integrating iterative performance improvements into the design. At the beginning of year four of operation, the company would break even turnovers and past costs.

2.4.1 UAS Unit costs

Table 4: Estimation of production costs of each *eCICONIA* UAS unit.

Materials		**Wage**		**Quality Control**		**UAS Unit Cost**
Components	6,780	Yearly	48,000	Electrical/SW	500	Σ 18,280
Hardware	2,000	per UAS	6,000	Flighttests	500	
Consumables	1,500			Certification	1000	

The total unit costs of each UAS is composed of the hardware components, wage costs for the producing worker, use of consumables and individual certification. Each produced UAS undergoes an intense quality control and rigorous flight tests, adding additional costs before cleared for operation. The price for prototypes is calculated differently and is therefore included in the initial development costs. The production time is estimated to around 1.5 months per unit after all processes and external hardware suppliers are coordinated. UAS unit production costs would come up to around 18,300 €.

2.4.2 Setup costs

The setup costs and initial investments include the expenses for development, estimated legal and regulatory costs for initializing the business and external partnerships, investments regarding production facilities, realization costs of the base station including processing lane, control room and their maintenance.

The development costs includes the wage for the founding team members, hardware components, software licenses, outsourced development work, estimated travel and miscellaneous expenses due to collaborations with research institutes and authorities. A large scope for failure, rebuilds and upgrades is included in the estimation for flight hardware during the development. The costs for the production facilities include the initial workshop, required tooling, Occupational Safety and Health (OSH) equipment, machinery and so on. Estimates for production process and facility certification are also considered in this position. Since the production processes and manufacturing methods are depending on the general design, not all required machines and tooling are assessable. Costs can be reduced by employing manufacturing methods which minimize the need for special certification and qualification for employees, e.g. welding or soldering licenses. The total production facility setup costs are estimated to around 81,000 € capable of producing eight UAS per year with two employed aerospace mechanics.

The base station, consisting of the control room and two processing lanes for maximal efficiency is the last part of the overall setup costs. Computer and office hardware as well as the work space take up the largest position of the expenses for the control room. The processing lane consisting of a series of conveyor belts, sensors, actuators and the robotic arm is meant to operate fully automated. It also houses the stock of replaceable batteries and charging stations. As listed in the estimations for setup costs in table 5, the sum for the base station including certification and tooling for maintenance is around 190,317 €. Upgrades, expansions and additional investments into the production facilities, the processing lane and control room are added during the overall projection. Maintenance costs for the ground hardware are posted under operating costs.

2.4.3 Operating costs

The operating costs are composed of the general operating costs of the base station and the yearly operating costs per UAS unit. Each UAS is operated 304 days a year, leaving enough maintenance time to replace worn-down hardware before malfunctions occur. Early replacement of critical components is therefore a key component of safety and reliability. Therefore, the most stressed components e.g. batteries, motors, mechanical hinges etc., are replaced long before their previously determined failure cycles and operating hours. Highly qualified and certified personnel perform those works, adding to the overall costs. Legal fees, most importantly insurance for commercially operated UAS and authority permits are comparatively small expenses.

Regarding the base station, operating costs are independent of the operated number of drones. The largest contributor is the wage of the at least four employees needed to ensure efficient operation. For packaging, handling and managing cargo, at least two workers are required, working

Table 5: Setup costs estimations.

Position	Estimate	Details
General Infrastructure	10,849	Workspace, Exterior-Roofing, Utilities, PC-Interfaces
Control Room	11,950	PC-Hardware, Software Licenses, Furniture, Office supplies
Maintenance Workshop	7,700	Tooling, Machine, Consumables, Storage Space, etc.
Dual Processing Lane	47,568	Conveyors, Sensor, Actuator, Robotic Arm, Charging Station, etc.
Legal and Regulatory	16,200	Technical Safety (TÜV), EASA Part 145 and Part 21-J, OSH Equipment, EN9001, Consulting, etc.
Production Workshop	81,050	Work Space, Tooling, Machines, EASA Part 21-G, QM-certification, etc.
2 year R&D Phase	500,000	Founding Team Members Salary (5), Prototyping Components, PC Soft- and Hardware, Tooling, etc., Regulatory Expenses
Total Setup Costs	675,317	

Table 6: Estimation of annual operational costs for the base station and maintenance per UAS unit.

Personnel	(2) Controlling	100,000	**UAS**	Insurance	180
(wage cost)	(2) Packaging	40,000	(Cost per Unit)	Maintenance	3,500
	Administration	12,000		Components	2,000
Regulatory	Qualification	10,000	**Energy**	Machinery	89 kWh
	Insurance fees	1,460	Daily electricity	Office hardware	105 kWh
	Recertification	4,500		UAS Batteries	210 kWh
	Accounting	590		Annual costs:	21,530
Total annual operating costs:		190,080	Annual operating costs per UAS:		5,680

in shifts. In the control room, specialized and certified operators monitor the autonomously conducted flights, also working in shifts. When the number of operated drones is more than five, the monitoring workload is too high for a continuous shift, which means that additional personnel will be required. Mission monitoring would then be performed similarly to civilian Air Traffic Control (ATC), when parallel working colleagues replace each other after set time intervals, to consider the human factor in performance and safety. Company related insurances, book and tax-keeping expenses, recertification according to both European Union Aviation Safety Agency (EASA) and industry regulations (e.g. EN9001, EN9100), as well as employer qualifications are also included in the operating costs. The large electrical consumption due to the batteries, cooling system and industrial machines add up to approximately 96 MWh/year, with additional costs for water, heating and waste disposal on the company premises. For the first years (requiring only 2 controllers) the total running costs of the base station add up to approximately 190,000 € a year, rising to 290,000 € (with four controllers) once the number of operating UAS exceed five units.

2.5 Regulatory Considerations

In relation to commission implementing regulation (European Union) 2019/947 of 24 May 2019, *eCICONIA* must be categorized to know under which circumstances *eCICONIA* can be authorized and operated. The ordinance distinguishes three categories of establishments: Open, special and subject to approval.
As *eCICONIA* may be operating in densely populated urban areas, it is possible that crowds of people will be overflown. The flying over crowds of people ensures that *eCICONIA* falls into the category requiring approval. To be able to operate a UAS in the category subject to approval, a comprehensive risk assessment is necessary, which must be submitted to a national authority for approval. Based on this risk assessment and other possible national requirements, an operating licence can be granted [10].
In Germany, for example, the *Luftverkehrs-Ordnung* is binding. This regulation states that flying Beyond Visual Line Of Sight (BVLOS) with UAS over 5 kg is not permitted, unless the operator is an authority [11, §21b]. Similar regulations exist in other European countries, so operations would only be possible with special permits.
Commercial drones are already operated in African countries BVLOS. Therefore it is a realistic assumption that in the near future regulations will be adapted to support commercial UAM.

3 Landing sites

3.1 The base station

The pivotal point of the largely autonomous *eCICONIA* parcel delivery network is the base station, visualized in fig. 3, where the central aspects of parcel bundling, processing (drone loading and battery change) and controlling of the entire network are handled.

The main idea for the realization of the processes from drone returning until heading towards the next destination is a fully autonomous assembly line processing. This concept guarantees high efficiency in the form of minimum space, material and personnel requirements for the realization of a defined dispatch frequency through standardized procedures and associated minimum time expenditure. The specified take-off frequency of one drone every 2 min is accomplished by two parallel lanes with asynchronous process control, each with a time consumption of 4 min from landing to take-off, while a controlled holding pattern guarantees the optimal timing of the returning drones to prevent standstill on the two lanes. The number of two processing lanes increases the dispatch reliability by compensating for the failure of one conveyor belt.

For a precise landing, the drones' on-board Global Navigation Satellite System (GNSS) is supported by a laser altimeter for higher resolution in the vertical positioning. The landing platforms of the two lanes (1) are equipped with rollers, which reliably transfer the drones via a funnel-shaped inlet to the conveyor belts for autonomous processing. The drones are fixated on the conveyor belts by a hooking mechanism on the skids guaranteeing centering and an accurate alignment.

The first handling step is the loading of the drones with the package to be delivered (2). For this purpose, the parcels are transported by a conveyor belt from the warehouse (6) to the two processing lanes. At ground clearance sections of the conveyor belts, where the drones are precisely stopped by a light barrier, the parcels are lifted to normal ground level by a lifting cylinder so that the standardized parcel packages can be gripped by the integrated gripping mechanism of the drones and picked up in the fuselage as described in section 5.1. After transmitting a signal that the parcel has been picked up correctly, the drones are taken to the next processing step – the battery change (3). From the moment the new parcel is picked up, the on-board computer plans the new route based on the delivery address, which is read out by a Near Field Communication (NFC) chip integrated in the parcel packages.

Stopping at another light barrier the fully autonomous battery change is performed by a gripper arm that covers both processing lanes. The batteries are removed after pressing and subsequently opening a flap mechanism as visualized in fig. 4 and are placed in a charging station. In a cyclical sequence at least twelve pairs of batteries in total are used successively. After a successful status check of the newly inserted batteries by the on board Battery Management System (BMS), the drones, hooked on the skids, are accelerated on a ramp (4) with 4 g to approximately reach a lift-off velocity of 15 m/s after a length of 3 m. This starting procedure avoids a vertical take-off and consequently saves battery. For maintenance and downtime the drones autonomously position on the parking areas (8).

The base station is operated by a minimum of two persons at the same time. One of them is responsible for packaging, handling and managing cargo. Furthermore a specialized operator

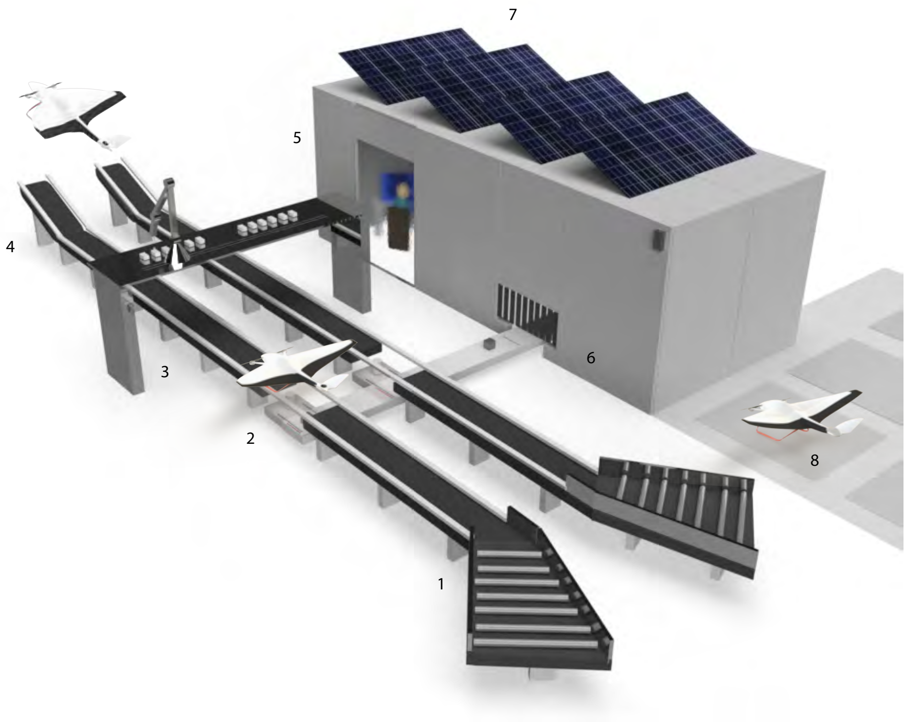

Figure 3: Visualization of the base station with its two processing lanes and warehouse with integrated control center.

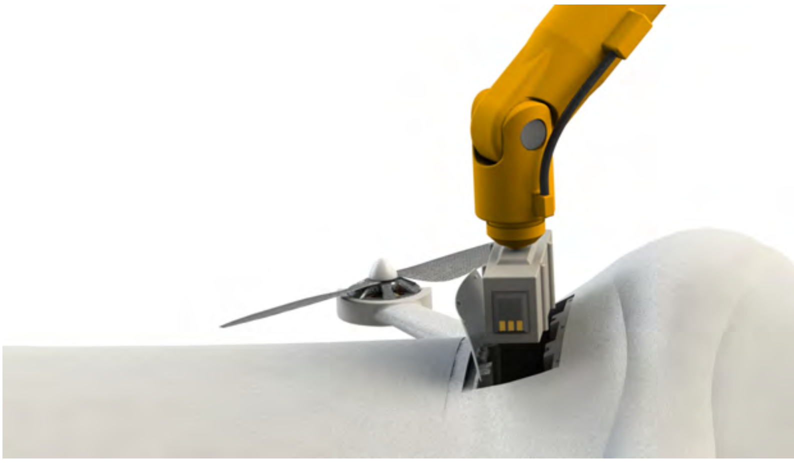

Figure 4: Battery change by the autonomous gripper arm [12].

monitors the base station processes on the one hand and the status of the active drones on the other hand in the control room (5). These working positions are staffed with two persons each, alternating in shifts. In the case at least more than five UAS are operated from one base station the operator personnel is increased to guarantee safety and reliability of the whole network.

The base station may be equipped with photovoltaic panels (7) and an energy storage system to ensure an independent energy supply via renewable energy sources under appropriate environmental conditions.

3.2 Delivery locations

For B2B deliveries, a landing area marked as such on already demarcated company premises is inspected, measured with GNSS and digitally assigned.

Under the premise of reducing infrastructure expenditure and minimizing the already very limited space available inner-city, a cost-efficient upgrade of existing parcel stations for B2C deliveries as visualized in fig. 5 is pursued. The requirements for a modified parcel station are an increased roof area for landing and additional compartments for drone delivered freight. The packages are distributed from the roof via a slide to the compartments, where they are ready for collection. A further advantage of this concept is the high level of safety by reducing the risk of unauthorized human interaction with drones landing on the ground.
As long as such modified parcel stations are not available comprehensively, any inspected, measured and assigned landing platform with the minimum size of $4 \times 4\,\text{m}$ based on the positioning accuracy provided by the on-board GNSS, as specified in section 5.4, can be used for delivery instead. Thus the required maximum size of the landing site of $15 \times 7.5\,\text{m}$ is fulfilled.

Figure 5: Modified parcel station with landing site for drone deliveries.

4 UAS performance

At *eCICONIA* a rapid prototyping approach is followed, the aerodynamic data are from basic analytic estimations and others from basic CFD simulations. The design is visualized with 3D-CAD tools, whereas structural simulations where conducted with FEM-simulations and analytic calculations.

4.1 Airfoil and Aerodynamics

The behavior of the airflow is essential for the choice of the profile, which is characterized by the Reynolds number. Since the Reynolds number depends on the velocity of the airflow and its density, which changes with altitude, the aerodynamic considerations for different Reynolds numbers are necessary.
Furthermore, different flight phases are planned: The VTOL and the range flight, these phases will be flown with varying weight because either a package is in the cargo hold or not.

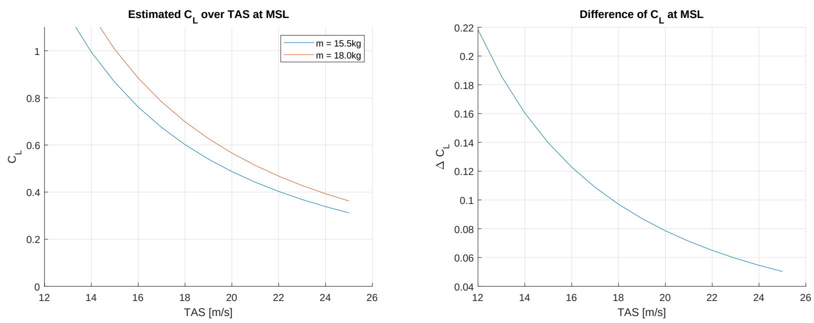

Figure 6: Estimated coefficients of lift and the deviation for different masses.

Figure 6 shows the estimated lift coefficients for the two different masses (l.) and its difference (r.) at sea level. The two graphs are derived from the stationary consideration of weight and buoyancy.
The difference in weight in the area of interest also makes a difference in the coefficient of lift. Therefore a profile was chosen which shows a relatively constant polar curve in this area at different Reynolds numbers and different lift coefficients.

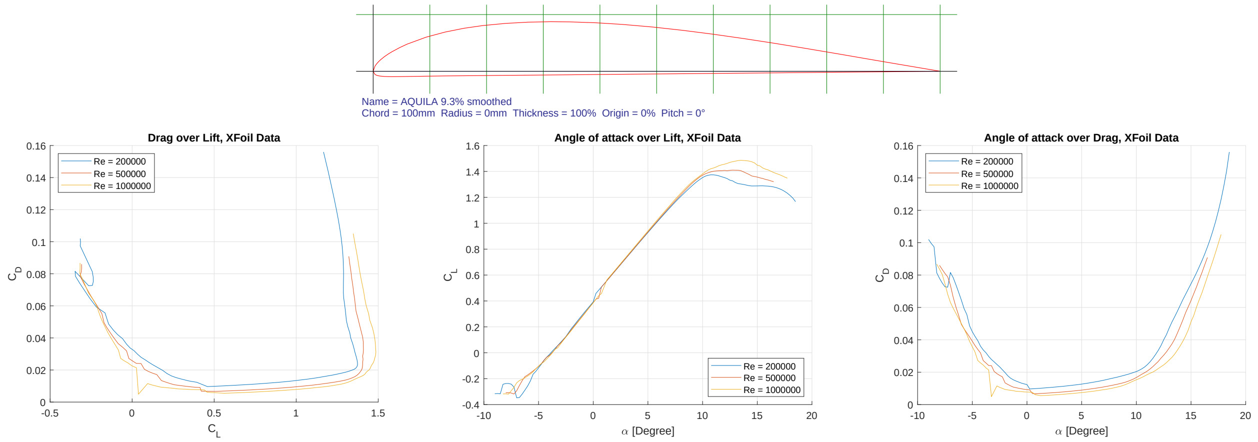

Figure 7: The profile (top) and aerodynamics of the profile (bottom), data from XFoil [13].

The AQUILA 9.3% smoothed profile was chosen because it meets the required polar properties at different Reynolds numbers. Furthermore, figure 7 shows that it has an almost linear lift increase with the angle of attack and only a moderate drag increase at different angles of attack.
We assume that the profile is flown at the lowest possible angle of attack when the package is delivered and on its return. In addition, the optimum speed is flown if possible, which reduces the drag and therefore increases the flight time.

4.2 Power supply and Engines

Our design in cooperates a three-engine-configuration, utilizing propeller drives powered by brushless direct current electrical motors. The two forward counter rotating 18,5 inch (= 470 mm) propellers have a pitch of 6.3 inch (= 160 mm), made out of carbon fiber 3K matrix and are commercially available. Many manufacturers in the recreational drone market have established highly optimized and efficient propellers, which have proven their reliability. In the standard configuration *eCICONIA*'s front propellers are each driven by a KDE®815XF Heavy-Lift motor with a Motor Velocity Constant of 205 RPM/V. The maximum performance data measured by the manufacturer is listed in table 7 and sets the baseline for the UAS design. In VTOL mode, the propeller plane is oriented horizontally, so that the thrust completely acts as vertical lift. The motor is mounted in a frame with a hinge, and is able to rotate 87° forward to point the propeller plane vertically to produce forward thrust during cruising. To optimize the Center of Gravity (COG)-situation and drag, the driving servo-motor is integrated into the blended main air frame. Thereby, the orientation of the propellers is actuated indirectly by a drive rod, reducing the load on the engine boom. All sensible electrical connections are watertight, whereas the motor itself is unaffected by rainy flight conditions.

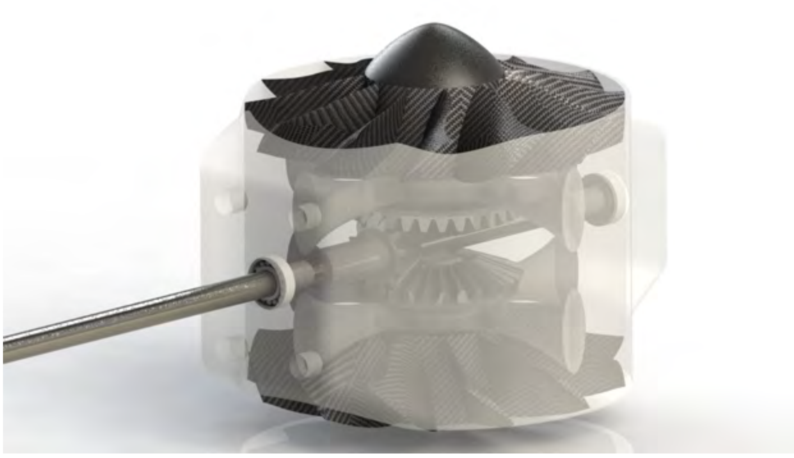

Figure 8: Assembly of the two counter rotating impellers.

In VTOL mode, the 3.66 inch (= 93 mm) aft impeller assembly visualized in fig. 8 provides additional lift and counteracts the transverse torque of the main propeller. Two twelve-bladed counter rotating carbon fiber impellers DS-51-DIA HST® are powered by a DSM 4335-950 motor placed upstream via a bevel gear to reduce the installation space at the tail unit. The counter rotating impeller blades, with optimized geometry for this configuration, increase the available thrust density compared to open propellers.

Table 7: Performance data for propeller and impeller engine assemblies.

Propeller Specifications		**Impeller Data**	
110.32 N	at 9,000 RPM	81.5 N	at 40,000 RPM
57 A at 52.2 V	∅ 18.5 inch	130 A at 44.0 V	∅ 3.66 inch
3,226 W	Efficiency: 0.0342 g/W	5,720 W	Efficiency: 0.0142 g/W

The power supply is provided by two 12S lithium-polymer batteries, each with a capacity of 10000 mAh. Both batteries have a self locking casing with a mechanical connection point for the robotic manipulator arm (section 3.1) and electrical contacts. For simultaneous supply of propellers and impeller at peak performance in VTOL mode a C-rate of minimum 25C is required for the desired discharging currents.

4.3 Design and Layout

*eCICONIA*s airframe is a modular assembly of six main structural components, each designed for lightweight, streamlined efficiency and unique appearance. With manufacturing and operational endurance in mind, we developed the main structure to be feasible in the overall context of the business model and UAM-restrictions. The wings act as primary lift surfaces and are connected to the main body. Bending and torsional moments are transferred into the stiff main carbon fiber structure of the body. A carbon-fiber honeycomb sandwich structure makes the wing extremely lightweight and still ensures stability to the high aerodynamic forces. Structural limits are well outside the anticipated flight envelope and thereby contribute to the overall safety of the UAS, which justify their high manufacturing costs. Small caps containing the position lights smooth the wingtips. As for the central body, the structure is made of carbon fiber reinforced plastic, with stabilizing frames, stringers and a 1 mm thin wall. They prevent warping and bending along the major axes and also houses connection points for the internal components. The central body frame is the biggest contributor to total vehicle mass and carries most of the subsystems and components, as well as the cargo bay. Most noticeable is the smooth transition of the fuselage to the airfoil resembling a blended wing body. Referring to figure 9, the center of mass (1)

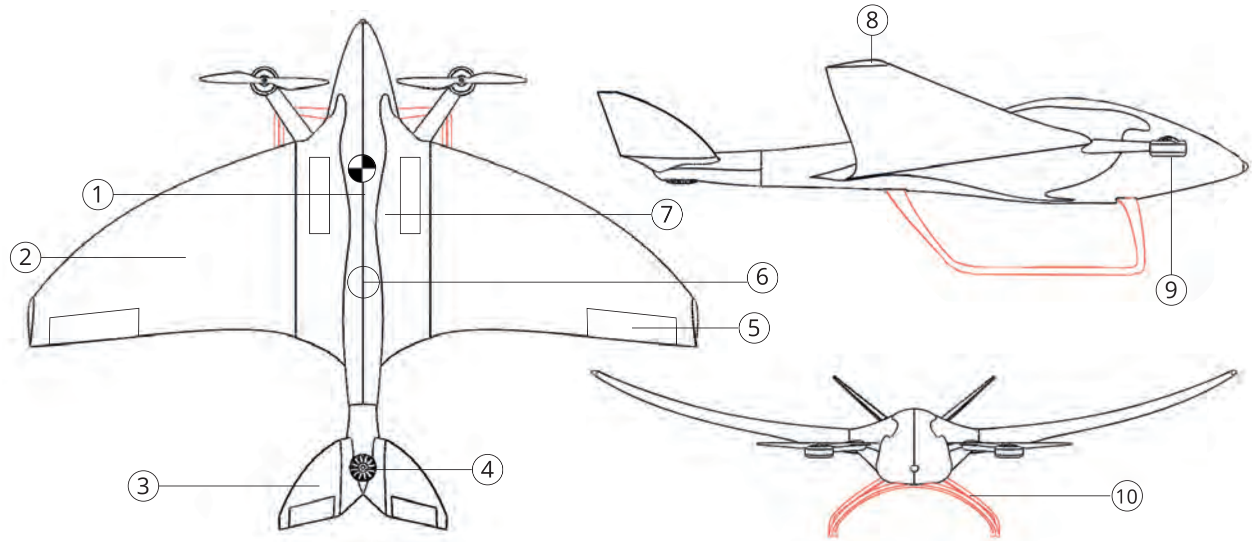

Figure 9: Schematic views of *eCICONIA* airframe.

Table 8: The technical data of *eCICONIA*.

Emptymass	15.7 kg	Wingspan	2.355 m	Length	1.83 m
MTOW	18.2 kg	Wingarea	1.274 m^2	Height	0.5 m
Wing tip length	0.17 m	Wing root length	0.7 m	Angle of incidence	6.5°

is at 0.9 m from the nose and was estimated with the CAD model. The transition element (7) houses the heavy batteries and holds the propeller extension beam. Additionally it stabilizes the frame against transversal bending. The wings (2) are designed with geometric washout and have a slight V-position which is realized over a radius and stabilizes the aircraft around the roll axis. The tail unit (3) is a V-tail. To generate as much torque as possible with a given control surface, the ailerons (5) are mounted far out. The main emergency system (6) is a parachute and is described in detail in section 6. The transition element (7) houses the heavy batteries and holds the propeller extension beams, as well as stabilizes the frame against transversal bending. The engine and power system (4,9) consists of two main engines and an impeller, described in chapter 4.2. The wingtips (8) have sharp edges to increase lift and reduce drag [14]. The flexible skids (10) serve as landing system and also contain two inflatable airbags as part of the emergency system, one per skid. Made from one uniform carbon fiber laminated part, they absorb the landing shock load in case of a rough emergency landing by flexibly dissipating impact energy. All latches and hatches have inserted sealing rings to make them watertight in rainy flight conditions.

4.4 Specifications and Performance

It is given that *eCICONIA* has a Maximum Take-Off Weight (MTOW) of about 18.2 kg. Together the installed engines with the front propellers generate a maximum of about 220 N of thrust.
To estimate the Specific Excess Power (SEP), models for thrust and drag are necessary: As a simple model a decrease over the flight altitude is assumed for the thrust, the drag is estimated in a basic Computational Fluid Dynamics (CFD) simulation. Since the drag is composed of the drag coefficient, the dynamic pressure and the wing area, a mean drag coefficient is calculated after the simulation. Therewith different resistances for different speeds and flight altitudes are calculated.

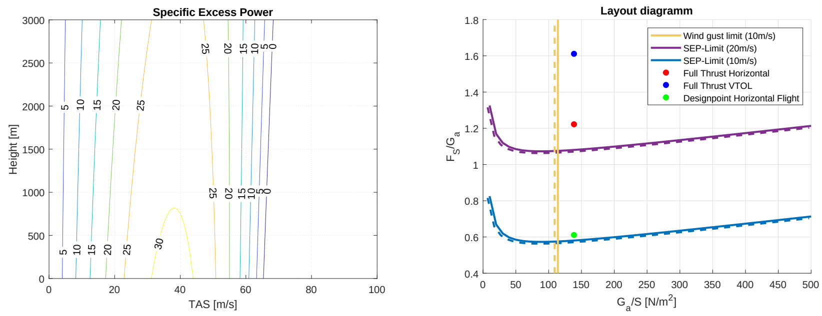

Figure 10: SEP and layout diagramm.

With the SEP the maximum speeds for different flight altitudes and the theoretical maximum achievable flight altitude can be determined.
The requirements are that the landing platform is at maximum 2500 m above Mean Sea Level (MSL) and the flight altitude is about 120 m above ground. Therefore the SEP is shown here up to 3000 m above MSL. Figure 10 shows a maximum speed of about 65 m/s at MSL. The maximum flight altitude cannot be read, so it is definitely above 3000 m above MSL, which meets the requirements.
The design diagram usually consists of many performance limits: The take-off and landing limit, the Mach number limit, the turn rates and several others. Since *eCICONIA* can take off and land vertically, and turn rates are not so important here, we will limit ourselves here to the SEP limit and the gust limit.
In the VTOL configuration, the main engines and the impeller are used, so the thrust-to-weight ratio at maximum thrust is higher (blue, 1.6), which is also necessary to have a certain maneuverability to perform the take-off and landing safely. In horizontal flight only the main engines are used, therefore the thrust-to-weight ratio at maximum thrust is lower (red, 1.2).
The design point is shown in green, this is in horizontal flight when half the thrust is assumed. This shows that a climb rate of 10 m/s can be achieved with half the thrust, while *eCICONIA* can achieve a climb rate of 20 m/s at full thrust. Furthermore, a flight in gusts with the required

20 kts is permanently possible. *eCICONIA* must be able to climb within a radius of 1500 m to 120 m above ground. Since the take-off phase begins with a vertical flight phase and *eCICONIA* only starts to change to horizontal flight after 20 m height at the earliest, only 100 m have to be overcome in the climb. This results in a climb angle of about 3.81°.
With a stationary climb rate of 10 m/s and a speed of 17 m/s, which results in a climb angle of more than 30°, *eCICONIA* can easily meet this requirement.

5 Components and Subsystems

5.1 Cargo System

The cargo system needs to be able to safely carry and reliably unload the casing on destination. We developed a system that is storing the casing fully inside the air frame of the UAS. It works partly through a Compliant Mechanism that is meeting all criteria and additionally adds several perks. Our design is light, cheap and easy to produce as it is 3D-printed. Furthermore, the compliance ensures great reliability. By avoiding classical mechanical hinches and using parts printed as one component, functional reliability is increased while reducing weight. We aim for our compliant mechanism to be examined after 30,000 cycles uses and get replaced after 60,000 uses, which is equivalent to every other year at 100 % delivery capacity.

Figure 11: *eCICONIA* cargo system during unloading procedure.

Two independent servo motors, which are installed inside the inner hull, drive a pulley and thereby winding a pair of string moving a rigid frame. The movement is guided by the super light compliant joint mechanism, as displayed in fig.11. Flexible joints at the bottom connect to the rigid frame, which carries the universal casing. Spring loaded latches attache to grooves in the bottom of the casing, ensuring a tight and secure grip.

After landing, the cargo doors drop open and the servo motors start unwinding the pulley. By its own weight, stabilized and guided by the joint compliant zig-zag mechanism, the parcel is gently lowered out of the cargo bay. Approximately 2 cm above the ground, the position of the compliant joint mechanism indirectly actuates the spring latches, thereby releasing the package. The servo motors, then rewind and retract the mechanism to its locking position. To avoid conflict between the cargo doors and the parcel, *eCICONIA* first starts its lift-off sequence. Just then, a smaller separate servo motor in the lower part of the hull starts rotating a excenter mechanism pulling the hanging cargo doors close.

With our reusable casing we not only aim to reduce the amount of waste caused by delivering services, we are also ensuring a safe and reliable transfer of goods. Our casing is designed for carrying a 15 × 15 × 15 package, according to the underlying design criteria. However in a commercial delivery scenario, this volume is insufficient for many potential delivery goods. Our proposed solution is fully scalable and would adapt to parcel-sizes according to actual customer demand in a realistic implementation scenario.

Firstly, a passive read-on-memory NFC chip acts as a Unique Identifier (UID) and identifies the casing, so it can be tracked by the central data management system. It is scanned by the employee at the station before clearing the package for the autonomous loading process, as well as in the cargo bay of the UAS. Thereby it is ensured that cargo assignments, casing-IDs and delivery orders match correctly. Secondly, two metal contacts, which have their counterparts in the fuselage, indicate to the on board control system, that the casing is placed accordingly in the cargo bay before the drone takes off. Inside the casing is a variable foam padding on all side walls, dampening the cargo and warranting a safe, damage-free transport. The elastic foam makes a tight fit preventing movement of the contents and thereby avoids any change in the COG. Since our business model foresees that the casings are regularly picked up by parcel trucks from customers who have been supplied, the casings are foldable and stackable.

5.2 Automated Control System

The software and electronics design is based on segmented subcomponents, programs and sensors and is outlined in fig. 12. In this approach the system has a central Operating System (OS) to which most systems are connected via two-way data transfer. Only the safety critical BMS and the emergency system therefore have a limited one-way connection to the central system to minimize negative impact on their functionality.

Between all other subsystems, the OS has the function to ensure necessary communication and delegate inputs to the appropriate subprogram. For example, it will utilize the telemetry with the connection to the UTM service as well as the Detect and Avoidance (DAA) system to generate a situation picture. The Navigation (NAV) calculates course corrections if necessary and adjusts the flight path for the next way point. In the end the OS instructs the Attitude Control (AC) and Engine Control (ENG CON) to perform the required control surface inputs and throttle adjustments. The OS is run on a PCB processor, like a Raspberry Pi 4®, which is sufficient for the demanded calculations, and can be independently powered by a small 9 V battery in case of the two main batteries failing or disconnecting. To decrease probability of complete system failure, the AC, ENG CON and NAV programs are run on a secondary processing board. For communication with the base station via the Communication (COM) subroutine, a Multi-Band

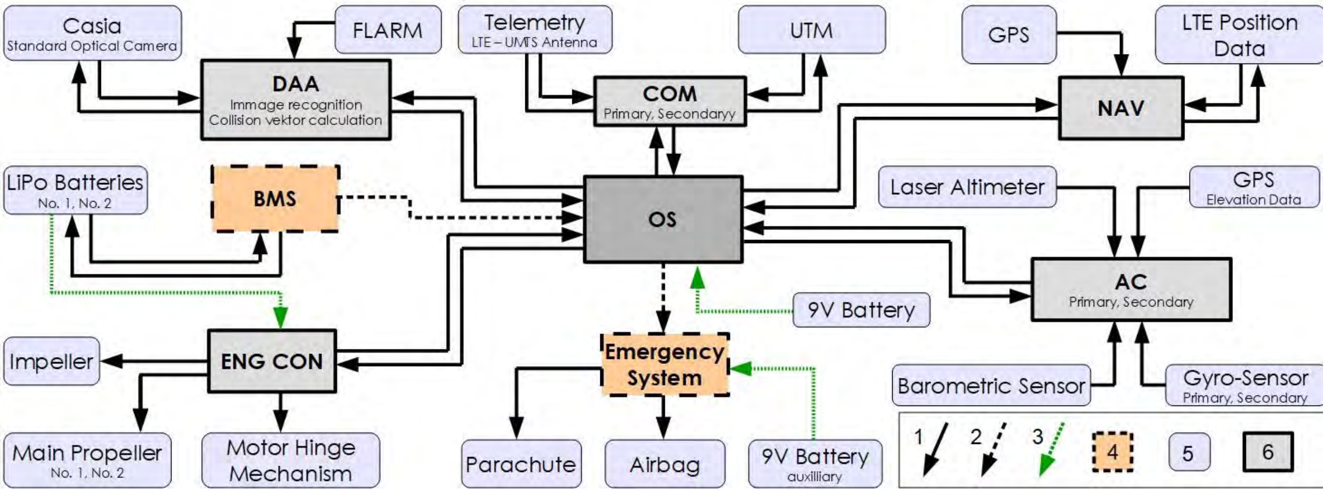

Figure 12: Schematic overview of the automated control system architecture. Legend: **1.** Data Transfer, **2.** Periodic Status Signal, **3.** Electrical Energy Transfer, **4.** Independent Printed Circuit Board (PCB), **5.** Subcomponent or Sensor, **6.** Control Program

Long Term Evolution (LTE) Module is used. This will also utilize UTM, regarding the current definition of the standard, by just integrating into the established telecommunications network. The control system is designed to fly *eCICONIA* fully automatically by making deterministic navigation decisions while incorporating external sensor information. A human operator can always remotely trigger the emergency system via the redundant COM systems.

5.3 UTM

The UTM system defines an environment in which UAS are allowed to take part in the controlled and uncontrolled airspace. Therefore it defines procedures and operation principles as well as capabilities those systems have to fulfill, for example mandatory authentication of each participating UAS. It is conceived on the principle of cooperation between operators and regulators to organize and harmonize the future airspace utilization by UAS. Once active it will ensure a safe coexistence of manned aviation, residential inhabitants and UAS. A service is therefore implemented which enables standardized exchange of relevant information, like UAS identification, intend, Notice To Airmen (NOTAM), etc. In the future it will also provide general aviation data like weather, traffic and terrain information. [15] To utilize UTM for our application a active internet connection to *eCICONIA* (in our case via LTE) and integration into the Service Supplier Network is required, including all control systems in the base station. Operators, or their UAS respectively, request real-time aviation information and send registration, mission-intend, etc. while receiving public safety restrictions, operation constrains and other NOTAM-like information. With the additional use of the DAA and NAV system, collision avoidance requirements as well as other conditions are fulfilled. We further highlight the subsequent implications for other subsystems and operational procedures.

5.4 Navigation

Navigation and positioning is based on GNSS, with two separate antennas receiving satellite information. We utilize the free of charge Galileo system with one antenna for a higher resolution in the horizontal positioning below 0.2 m required for the landing approach in addition to the increased accuracy in the vertical positioning guaranteed by the laser altimeter. [16] During processing in the base station, the central mission management system in the control room calculates the optimal course to the designated target location. It thereby incorporates real-time weather and airspace data, compensating for possible UAS traffic or ground based restrictions. After take-off, the scheduled trajectory and destination are unchangeable to make fraudulent use impossible. This approach makes it imperative, that the system has the ability to navigate on its own with the usage of GNSS and also has a stable telemetry system to tell the operator and UTM-network the current location and system status for monitoring reasons. During flight the on-board navigation system updates the flight path, dependent on a changing situation picture it receives from its on board sensors. It therefore utilizes a stored virtual map of the area of operation, including coordinates of "No-Fly-Zones", obstacles, possible landing sites and the home base location. After parcel delivery the UAS performs the preplanned Return To Base (RTB) course before precision landing on the processing lane in the base station. In an event of COM failure, malfunctions requiring a RTB, or direct activation by UAS controller, the homing function navigates *eCICONIA* home as soon as possible considering the available virtual map restrictions. This backup homing function running on the primary Raspberry Pi® is independent and functional without the primary NAV program.

5.5 Sensors

Our *eCICONIA* design incorporates a multitude of interconnected sensors from which the current flight situation is continuously and reliably derived. Miniaturized digital derivatives of standard aviation instruments are used for primary flight control, whereas additional sensors ensure the compatibility to UTM and provide traffic information.

Digital gyroscopes resolve attitude, barometer PCB's track altitude and a miniature pitot-tube provides true airspeed data. In addition with the redundant GNSS information, the OS of *eCICONIA*achieves controlled flight. For precise landing, the GNSS vertical inaccuracy is compensated by a laser altimeter, once flying under a certain altitude threshold.

Where UTM cannot provide traffic information (e.g. unauthorized uncooperative UAS) via telecommunication, additional sensors are installed. The FLARM system broadcasts and detects digital UID radio signals independent of network connectivity from compatible systems. A UAS FLARM module is independently equipped with barometric and gyroscopic sensors, which a accessible for the main OS. Originally designed for private gliders, it calculates relative position and velocity from received signals to enable early collision avoidance measures and increase situation awareness [17]. To further detect unequipped and UTM uncooperative (potentially hazardous) drones, a long range optical camera system is equipped, called CASIA® by *IRIS Automation*.

In principle, these redundant and reliable sensors allow remote operation in BVLOS conditions. Additionally, when returning to the crowed airspace of the base station, UAS separation is kept small during holding and landing which in turn increases the processing lane efficiency.

5.6 Detect and Avoid

The DAA System is utilizes sensor data from the previously described FLARM and CASIA® components. Those systems are capable of detecting other aerial vehicles around them as well as obstructions which are not directly known to the navigation system. If an obstacle or airborne object (e.g. birds, ballons, UTM incompatible aviation devices) is within the direction of fight, the CASIA® camera can detect and track its position and velocity. For distances up to 500 m and within a 60° field of view, potential risks of collision can be identified. [18] As described in chapter 5.2 regarding the control system work flow, a detection triggers a series of counter measures. The DAA program evaluates all sensor inputs and assesses the potential risk of collision and reports the data to the OS. A course deviation is plotted and evasion maneuver executed, which differs in severity depending on distance and collision probability. If the OS redeems a evasion impossible even with maximal thrust and control surface input, or in case of major DAA failure, the emergency System is triggered according to section 6. The control operator can monitor all proximity alerts as well as planned and executed diversions via telemetry in the control room.

6 Safety and Emergency System

6.1 Saftey and Reliabilty

The most critical aspect of any UAM concept is obviously operational safety and reliability. Requirements regarding design, materials and processes are based on the strict standards of classical aviation. Every aspect is subject to rigorous quality control, certification and inspection processes. In the context of UAM, safety is a particularly difficult problem to solve. Currently, in almost every technological application, the final decision or control input is made by a human. With increasing autonomy, the human influence is marginal, but is ultimately kept in the loop as a final safety feature. With regard to UAS however, the reaction time and possibilities of action are extremely limited for the controlling operator. In the high-risk airspace of highly populated urban areas and low flight levels, every possible system malfunction or conflict has to be managed by the UAS itself. Therefore every component described in this report has been designed with redundancy and automated failure response in mind. Even though a control operator has always the possibility to override a decision made by the UAS, as described in 5.2, the deployment of safety measures cannot be depending on a human input.

6.2 Emergency System

The OS of the UAS is developed to handle multiple component failures or system malfunctions. However if stable attitude cannot be maintained, or an emergency landing is impossible, damage to ground property or even personal harm must be avoided under any circumstances. A possible emergency system preventing uncontrolled descent must function under complete system failure and loss of all on-board and external control options. Our solution for this scenario is an independent emergency subsystem, consisting of a parachute, two self-inflating airbags, two emergency system PCB's and an independent 9 V battery. There is also a built-in acoustic beeper that emits a loud warning noise when the emergency system is activated. It is either triggered by the OS actively via controller command or by the subsystem itself. The OS continuously sends a 3 Hz status signal to confirm its proper operation. If the checkup-signal between the OS is interrupted for subsequent three transmissions, the emergency system is immediately activated. A central parachute is placed behind the cargo bay and connected with 3 tethers to the airframe. When the parachute is deployed, the attachment points and COG of the UAS are balanced to keep the air frame in horizontal attitude during decent. With an area of 8.61 m^2 the parachute slows down the UAS to 4.43 m/s vertical decent speed. The parachute is folded inside a spring-loaded casing, which is kept under tension by a thermoplastic cocking pin. When triggered, the pin is melted due to short circuit currents and the package is spring ejected directly into the air stream, enabling a rapid reliable deployment in every attitude and airspeed. Airbags are used to further dampen the impact and reducing the risk of damaging anything on the ground. The ultralight airbag fabric is stowed inside the landing skids and connected via tubing to CO_2 cartridges. A single use burst valve releases the CO_2 pressure and inflating the airbags which absorb the impact shock and immensely reduce the risk of damage or personal harm.

This emergency situation is visualized in fig. 13.

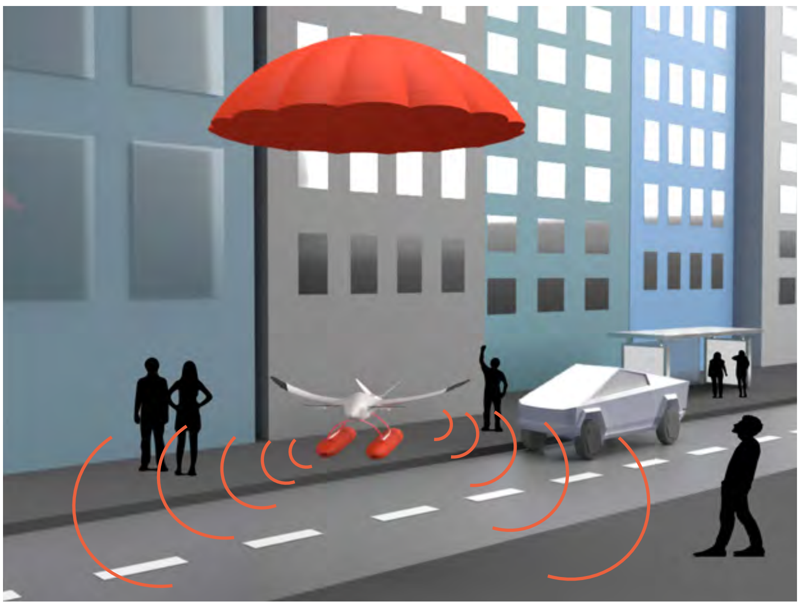

Figure 13: Enabled emergency system of *eCICONIA* [19], [20].

7 Noise Pollution

„Noise has become a central problem in recent years, as our society is still often limited to consuming the benefits of modern technology while accepting the adverse side effects such as noise. The increasing traffic volumes and the rapid development of urban and industrial conurbations have led to the fact that in the Federal Republic of Germany today, one in two citizens feels disturbed by noise, one in four is disturbed during the night.“ [21]
Considering these problems of urban noise pollution, the goal is to minimize the noise power which people receive when delivery drones fly through cities.

7.1 Theory

First, in volume estimation, a distinction is made between the power at the point of emission and the received volume power. Secondly, the volume is measured in the unit dB (decibel). Decibel is a logarithmic scale, which means that a 3 dB reduction in power means a reduction of half.
The human hearing has the threshold of hearing at about 0 dB, which means that a healthy ear can sense sound starting at a power of 0 dB. The pain tolerance of human hearing is around 130 dB. In this range of power, the human ear can hear frequencies from 20 Hz to 20000 Hz, where 1000 Hz is the frequency at which the human ear is the most sensitive. To put this into perspective, a normal conversation has a noise power of about 55 dB.
However, the experience of sound and tones is very subjective and it is possible that one experiences noise differently. [22]

7.2 Emission of the propeller blades

The equation, that describes the Noise Power emission from a point source:

$$L_{pointsource} = 10 \cdot \log(v_{tip}^5) + 10 \cdot \log(D) - 4 \tag{1}$$

v_{tip} is the speed of the propeller blade tips in meters per second, which is a function of the angular velocity of the propeller and their size. D is the size of the propeller in meters.
The equation that describes the power loss over a specified radius, modeled, as if the noise travels in all directions equally:

$$L_{noisereceiver} = L_{pointsource} - 10 \cdot \log(4\pi R^2) + K \tag{2}$$

K is a correction factor, which is used to model effects like noise reflecitons. [22]
Using those equations a solution for the noise power near the ground as a function of the angular velocity of the propellers is found. The solution is plotted for different propeller sizes:
With this estimation, it is possible to analyze the propeller and engine market to choose a suitable combination. The selection has to produce enough thrust that all maneuvers (VTOL and horizontal flight with a varying mass) are possible while the noise power level near the ground is

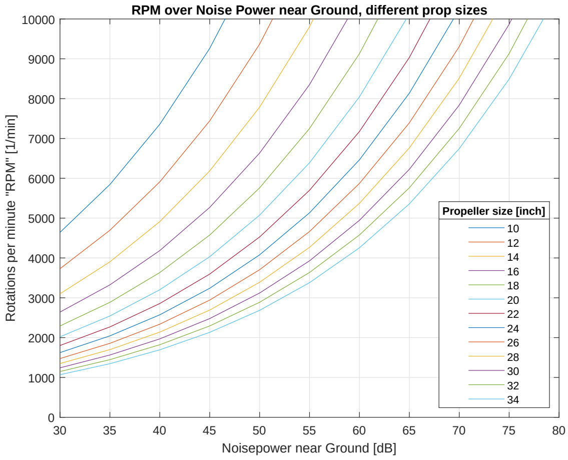

Figure 14: RPM over noise power near Ground, with different propeller sizes.

in an acceptable range. In order to achieve a certain thrust, the propeller diameter is chosen large enough to be operated at low speed resulting in an lower noise level.
With the correlations given so far and a propeller size of 18.5 in, according to the engine manufacturer a speed of about 5800 RPM at half thrust results. At a flight altitude of 120 m 51 dB are estimated on the ground in the city with sound reflections from buildings. At full thrust, for example during take-off in vertical flight, *eCICONIA* is louder, but this phase is over after a very short time. For this reason, a volume estimation of the take-off phase is not made. *eCICONIA* thus meets the requirement for a reasonable noise exposure, since the estimated volume output is within the range of a normal conversation.

8 Abbreviations

ATC	Air Traffic Control
AC	Attitude Control
B2B	Business to Business
B2C	Business to Consumer
BMS	Battery Management System
BVLOS	Beyond Visual Line Of Sight
C2C	Consumer to Consumer
CAD	Computer Aided Design
COG	Center of Gravity
CFD	Computational Fluid Dynamics
COM	Communication
DAA	Detect and Avoidance
EASA	European Union Aviation Safety Agency
eCICONIA	electrically-Charged Inner-City-Operating Noise-reduced Independent Aircraft
eVTOL	electrical Vertical Take Of and Landing
ENG CON	Engine Control
FEM	Finite Element Method
GNSS	Global Navigation Satellite System
LTE	Long Term Evolution
MSL	Mean Sea Level
MTOW	Maximum Take-Off Weight
NASA	National Aeronautics and Space Administration
NAV	Navigation
NFC	Near Field Communication
NOTAM	Notice To Airmen
OS	Operating System
OSH	Occupational Safety and Health
PCB	Printed Circuit Board
RTB	Return To Base

SEP Specific Excess Power

UAM Urban Air Mobility

UAS Unmanned Aerial Systems

UID Unique Identifier

UTM Unmanned Aircraft System Traffic Management

VTOL Vertical Take-off and Landing

WTP Willingness To Pay

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