

34th Annual AHS International Student Design Competition
sponsored by Sikorsky, a Lockheed Martin Company

24 Hour Hovering Machine



Ephemeron Executive Summary

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PFH | PRIVATE UNIVERSITY
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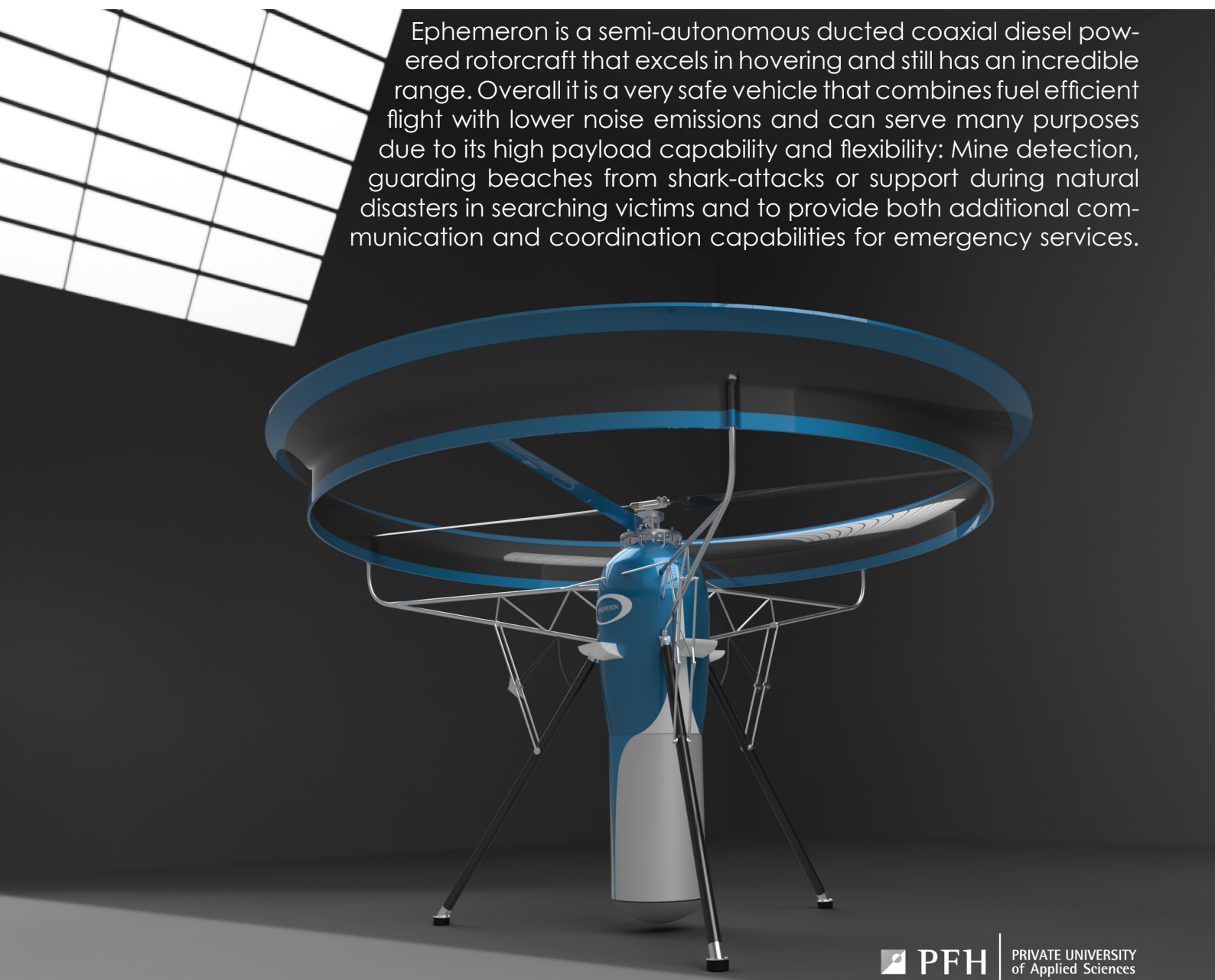


About Ephemeron



A mayfly is an insect that typically only lives a very short time. The German translation for mayfly „Eintagsfliege“ indicates that it lives a single day. This shows that nature can still be an inspiration as Ephemeron, greek for mayfly, proposes a design for a revolutionary type of aircraft: One that can stand still in the air for more than 24 hours.

Designing a VTOL with 24 hour hovering capability involves a complete overhaul of the traditional helicopter design as it is beyond the limit of what is possible with available technology. Nevertheless, Ephemeron is happy to present a solution that surpasses the original goal: This was only possible thanks to choosing the optimal aircraft configuration, combinations of both cutting-edge and proven rotorcraft technology and developing ingenious innovations.



Ephemeron is a semi-autonomous ducted coaxial diesel powered rotorcraft that excels in hovering and still has an incredible range. Overall it is a very safe vehicle that combines fuel efficient flight with lower noise emissions and can serve many purposes due to its high payload capability and flexibility: Mine detection, guarding beaches from shark-attacks or support during natural disasters in searching victims and to provide both additional communication and coordination capabilities for emergency services.

Coaxial Rotor

- specialised for hovering
- slow rotation for decreased noise
- simple mechanism, no tailrotor required



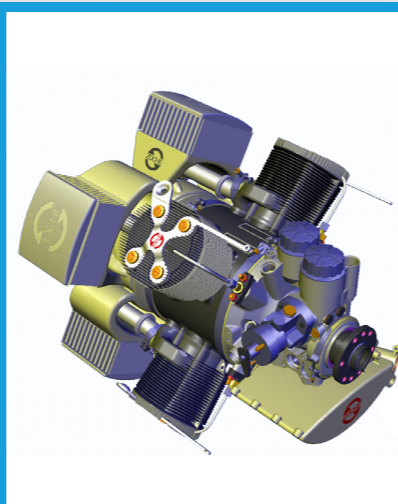
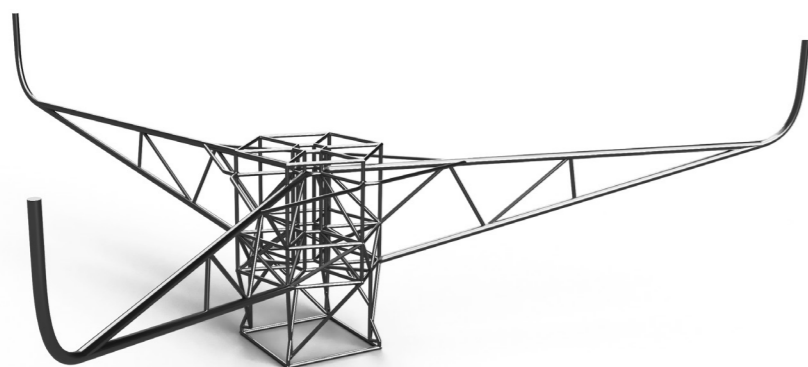
Landing Gear

- fail-safe mechanism
- optimized for low aerodynamic drag
- „out-of-the-way“ for increased visibility



Lightweight

- cost-effective
- lightweight by design
- the right material for the appropriate task



Propulsion

- incredible fuel economy
- easy integration and service
- excellent power to weight ratio

Duct

- lowers noise
- increased efficiency
- improved safety, no open rotors



Requirements

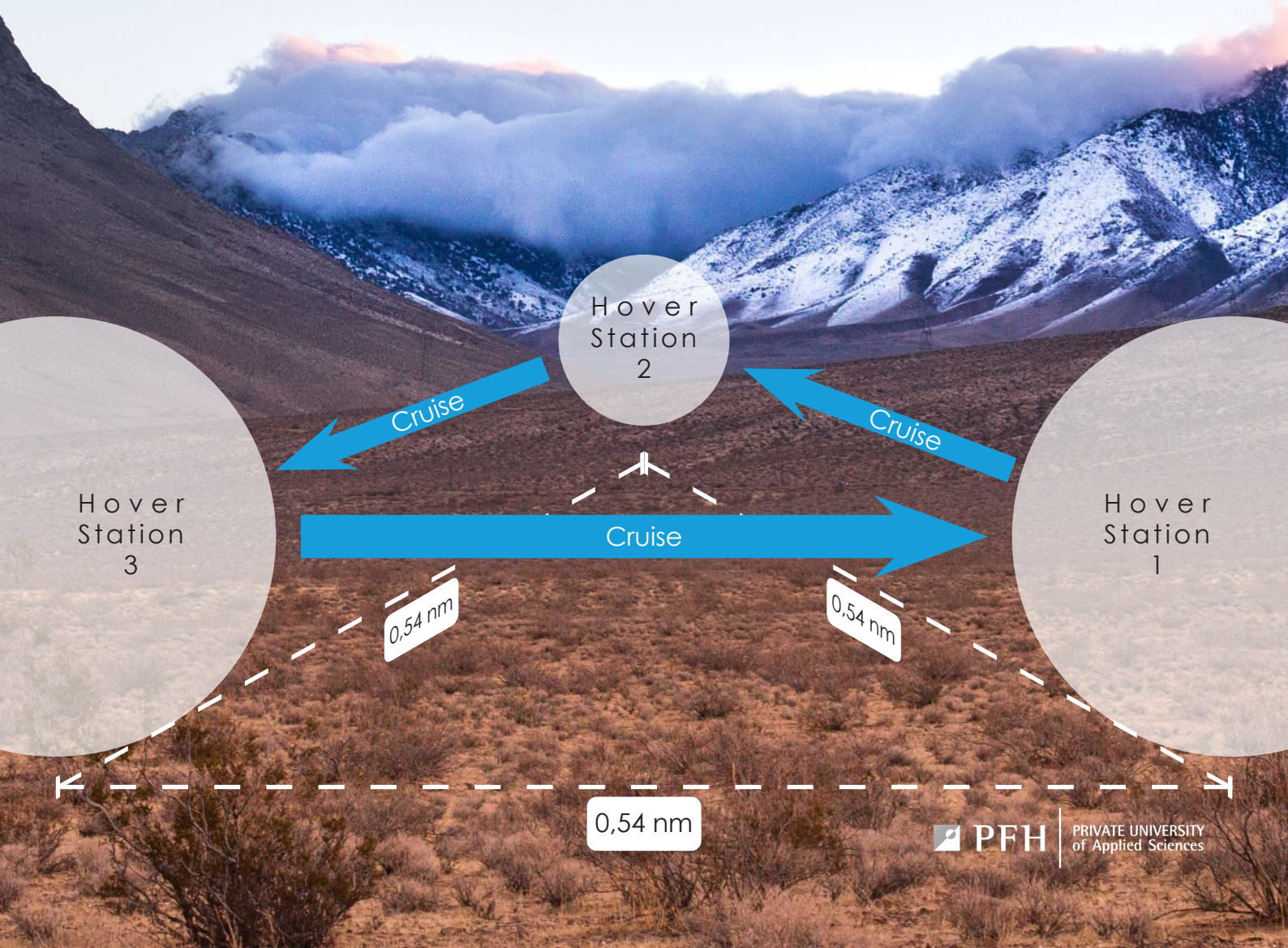


The 2017 AHS Student Design Competition requests a proposal for an aircraft that can hover for a cumulative duration of 24 hours. More details are presented here:

Hover Station 3	Hover Station 1	Hover Station 2	Hover Station 3
vehicle startup vehicle warmup takeoff			
hovering (out of ground effect)	hovering (out of ground effect)	hovering (out of ground effect)	hovering (out of ground effect)
			landing vehicle shutdown

Total time spent hovering inside the three hover stations, which are spheres of 20 m diameter, must add up to 24 hours. These hover stations are at least 0.54 nm (1 km) apart from each other and this distance must be covered on-top of hovering 24 hours.

At all times a non-productive payload weighing at least 80 kg is carried.



Capabilities



Beyond its ability to hover for 24 hours, Ephemeron shows many new applications for rotorcraft. One of them would be to show support when disaster strikes.

Earthquake in Italy - case example

Italy is known for suffering from earthquakes frequently. Often they occur in mountainous areas that are incredibly difficult to reach by emergency services. Although Ephemeron is much slower

Ephemeron could be placed near metropolises like Rome.

than conventional rotorcraft it still probably is at the site much earlier than personnel by foot. This allows scouting out of possible hazards or quick and safe pathways in advance of arrival of rescue teams. As often communication and internet are broken down as well, Ephemeron provides wireless communications for coordination of rescue personnel as well. Through cooperation with mobile network providers, victims could use Ephemeron to call for help through their mobile phones.



An earthquake killed nearly 300 people in Amatrice near Rome in early 2017

In the case of an earthquake in Amatrice Ephemeron would show a short response time of at least 2 hours and 12 Minutes. It would then provide support for up to 24 hours in the air and 22 hours if standstill hovering is required. It would then land and could be refueled with conventional diesel. The equivalent of only four car fillings is enough to refuel Ephemeron.

Two Ephemérons allow for 24/7 support, even if return to base in Rome would be required.



1 kW LED on an electric UAV

By loading cameras that work in the visible and infrared spectrum Ephemeron can support search and rescue day and night. Thanks to the 10 kW onboard generator Ephemeron could easily drive high power LED and thereby makes it easier to continue search during night.

It can be summed up that through Ephemeron's flexibility in terms of its payload and its novel hovering endurance many possible use cases arise for this aircraft.

Configuration

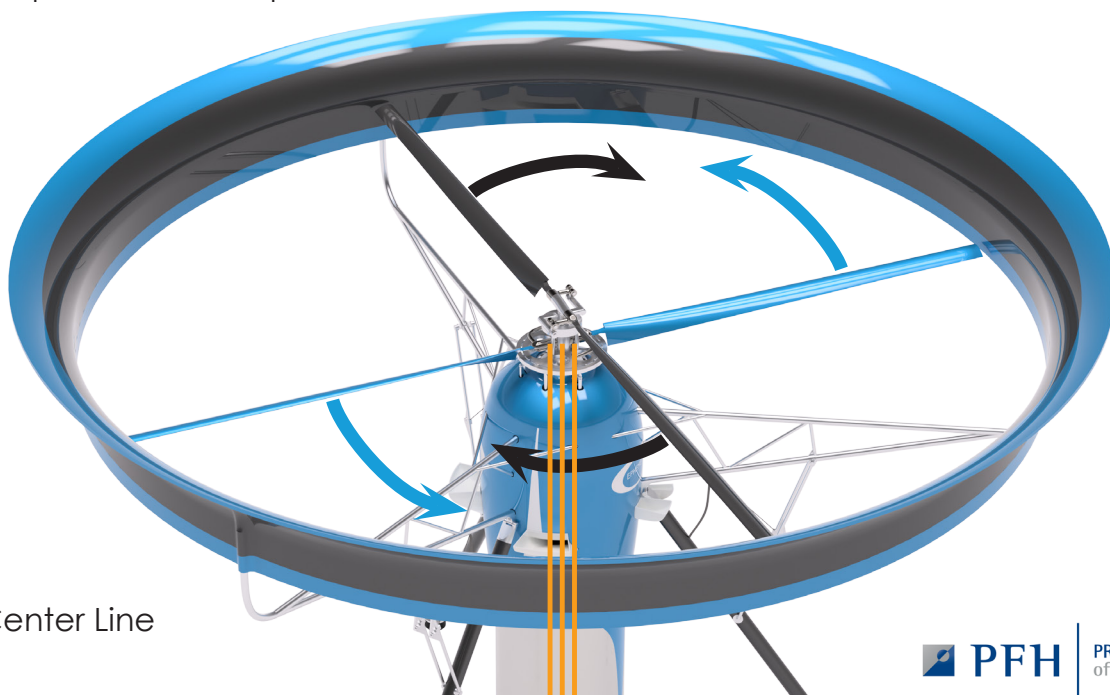


The Ephemeron has an unusual design, compared to common helicopters currently available. Because there is no cabin for crew or passengers, the engine could be placed right beneath the main rotors, so there are as few gearboxes as possible, which is a great benefit for the efficiency of the whole engine and drive train. The coaxial setup has promises highest performance for an endurance hover vehicle. This has been analysed through the use of a weighted decision matrix.



Measures (Weight)	conventional helicopter	coaxial helicopter	quadcopter	"Shredder"	Tandem	Intermeshed
Weight Empty Fraction (10)	9	6	3	6	6	6
Figure of Merit (8)	9	6	3	9	6	6
Torque Balance (8)	3	9	9	6	9	6
Risk of Design (7)	9	9	6	3	6	6
Cost of Manufacture (2)	9	6	6	3	6	6
Cost of Operation (5)	6	6	6	3	6	6
Transportability (3)	6	9	3	3	3	9
Safety (4)	6	9	9	3	6	9
Result	339	348	243	243	297	303

The duct itself brings a lot of advantages for the lift and the efficiency of the main rotors. Also, the duct harmonizes greatly with the configuration of Ephemeron's lift system, the coaxial main rotors. The coaxial configuration brings the great benefit of losing no power to a tail rotor, while keeping the simple shape of our duct, which would not be possible, with e.g. an intermeshing or a tandem configuration. Also coaxial rotors are quite simple to control and do not require as much space as tandems do, which would add a lot of extra weight.

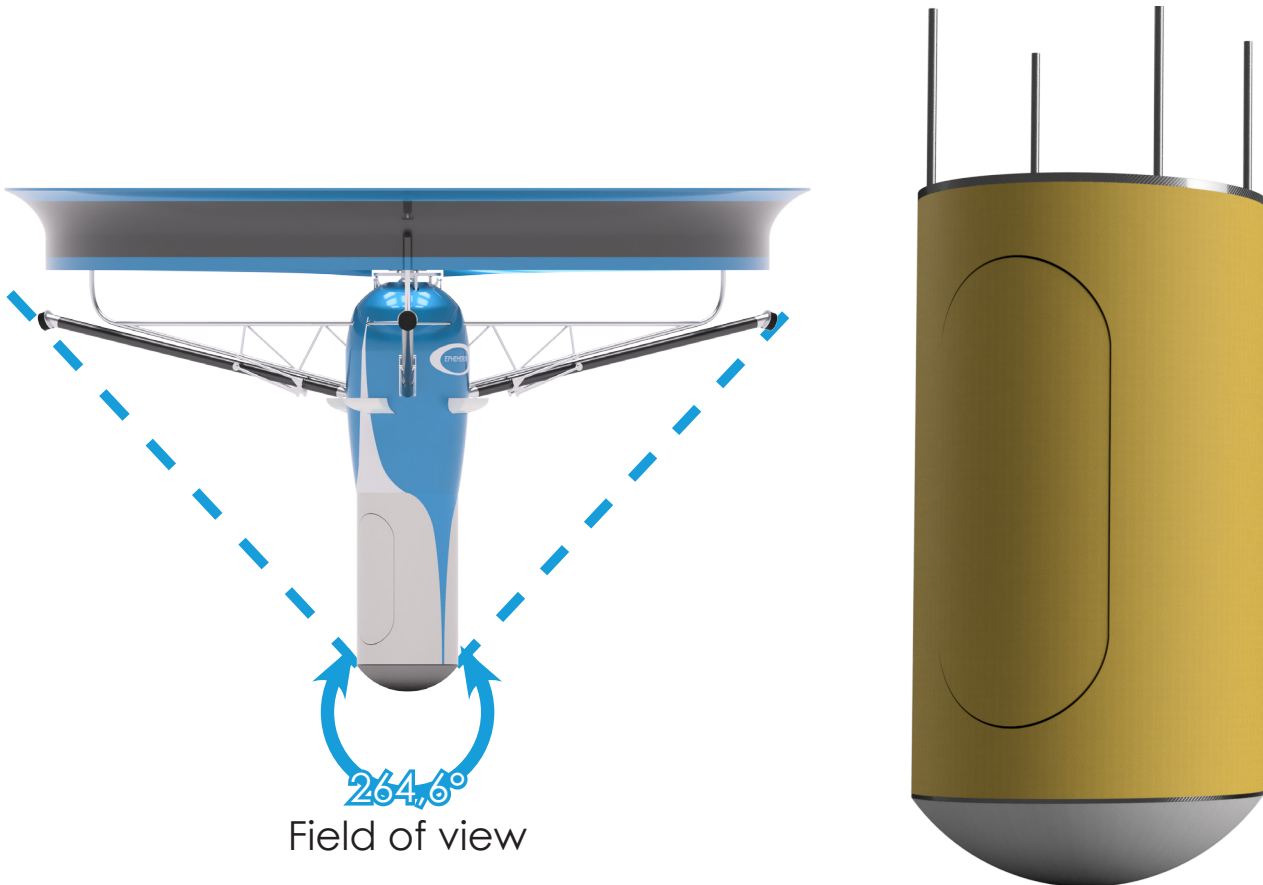


Center Line

Payload overview

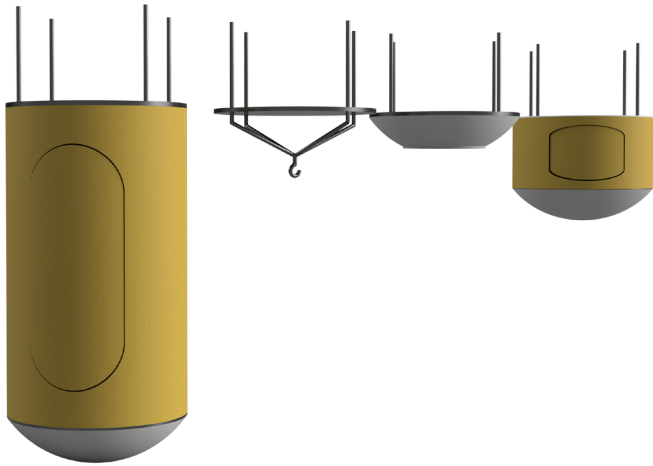


Ephemeron's payload system for the mission of the competition is a cylindrical box. The box is not made to carry a human, but it is possible because of the height of the box. Enter Ephemeron's box is very easy because of the big door which makes the assemble of new measuring equipment very easy. In a mission, a big box is not needed, only 4 bolts must be removed and the box is separated from the Ephemeron.

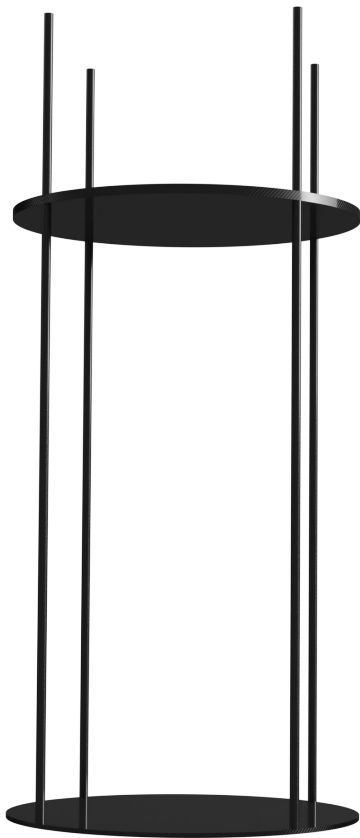


The box is a lightweight framework construction with a sandwich jacket surface. Load is carried by four CFRP tubes and a sandwich plate on the bottom. To protect the sensitive payload from rockfall and rain the sandwich panels are made from Aramid fibers and foam core. If the fiber reinforced plastic gets disrupted by little stones the impact resistant foam core absorbs the stone. After the mission, a part of the foam can be removed and a new foam piece gets placed. The box is fully repaired and ready for the next mission after laminating a new layer of Aramid fibers on the outside of the box.

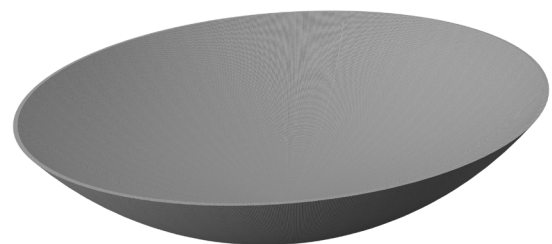
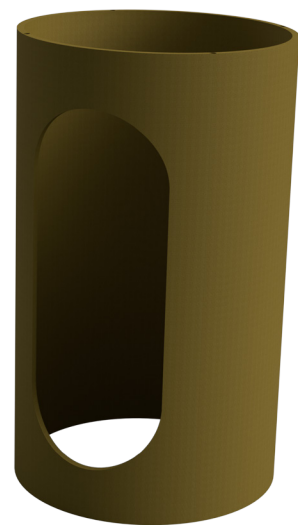
Payload features



A payload of 80 kg could be placed on a hook on the aircraft's bottom. To carry complex measuring equipment a simple hook is not the ideal solution and thus Ephemeron's payload system is designed as a cylindrical box with good aerodynamic features. It is a lightweight design with a weight of only 7 kg.



The payload box has a door which is large enough for a human to enter the Ephemeron aircraft. Sitting in the „cabin” is possible, but a human payload is not the typical use case for the Ephemeron. A large door is comfortable to install new measuring equipment.



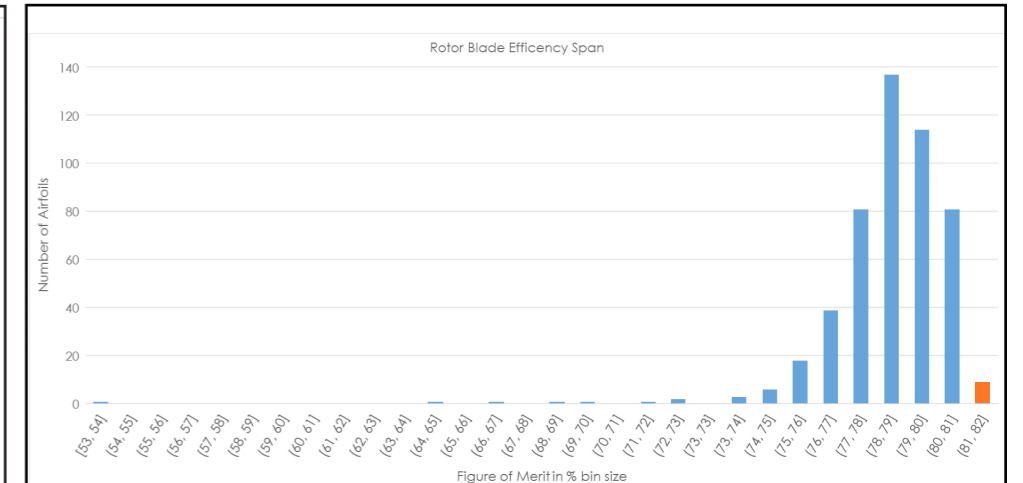
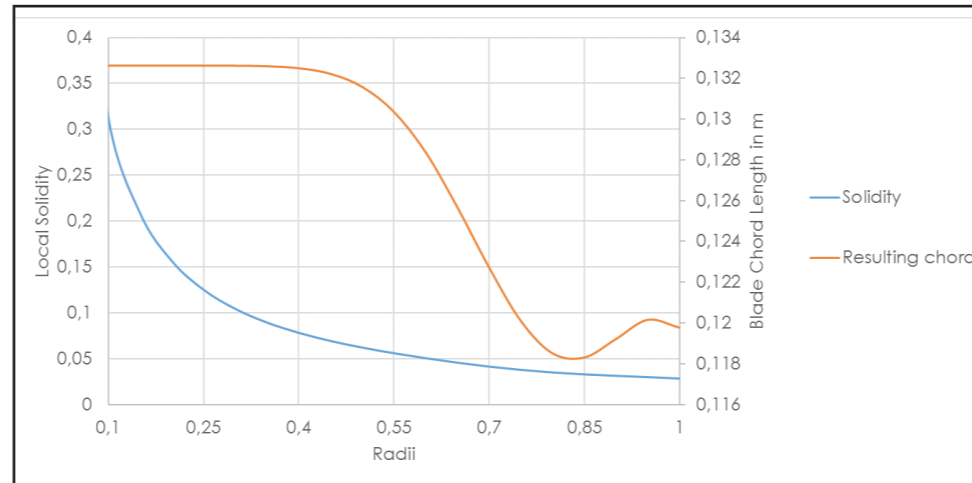
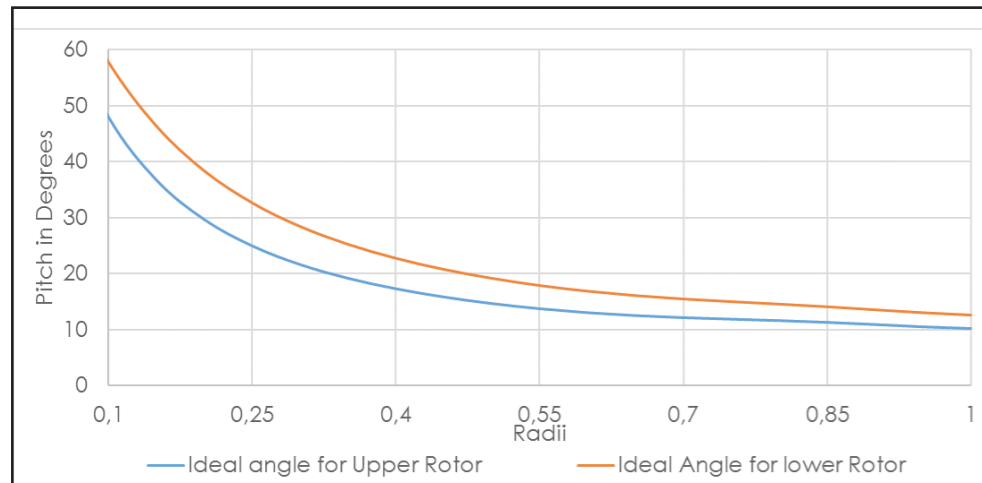
Tubes that are connected to a sandwich sheet are the main structure of the payload box. Each of the four tubes is able to carry 100 kg of weight. It is the lightest option to use a framework which carries the main load and big surfaces around the frame are made from lightweight aramid / foam sandwich panels. These panels are impact resistant and protect the payload from atmospheric conditions and flying debris like small rocks.

The radome on the bottom of the payload box is made of quartz fiber because radar waves, which might be used to scan the ground by a scientific payload, have to pass through the radome. CFRP would absorb the waves and a precise measurement is not possible. To install the measurement system radome is easily removed. Flying without radome is possible too, for example

Rotor Blade Design and Optimisation



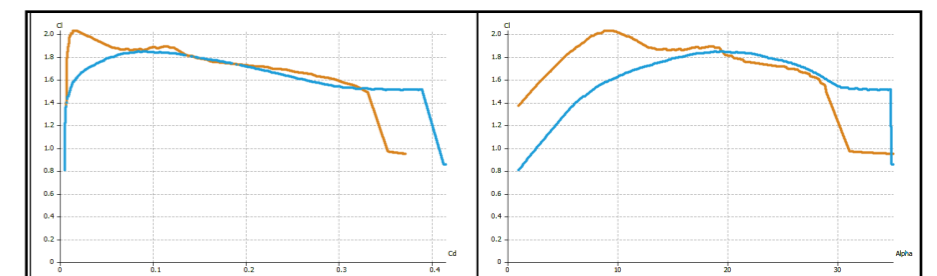
A conventional rotor has to excel in both hover and high-speed regimes. Ephemerons rotor is highly specialised in hover and slow speed flight and achieves better efficiency than any other rotor design. Theory for an optimum hover rotor has been adapted and applied to 500 airfoils. Furthermore each rotor has been optimised for use in a coaxial setup.



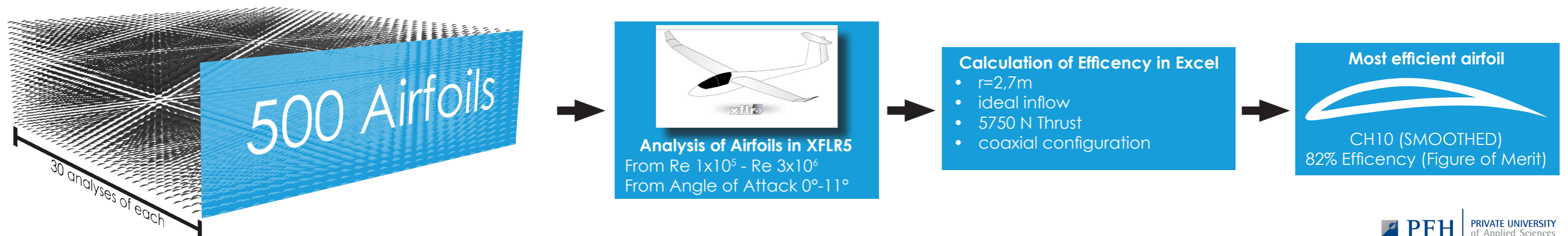
Rotor efficiency in hover primarily depends on drag from rotation and secondly is dominated by how uniformly it accelerates air downwards. In Blade Element Momentum Theory these quantities can be determined and used to define a rotor blade geometry. Ephemeron turned the table and assumed uniform inflow and adjusted the blade geometry accordingly.

Using Xfoil-based XFLR5, Ephemeron analysed 500 airfoils at various Angles of Attack to find out the Angle of Attack for highest Lift to Drag ratio. It was then repeated at varying Reynolds numbers to consider lower airspeed from the rotor tip on inwards.

Using Blade Element Momentum Theory and splitting up one rotor blade into 100 segments, twist and planform was then calculated analytically for each segment in a way to achieve uniform, most efficient, inflow while in a hover state. Also, each blade segment operates at its ideal Angle of Attack. An Excel Macro automatically read and processed the CFD Analysis from XFLR5 and generated the ideal rotor blade for each airfoil. The efficiency of that blade, basically losses from coaxial rotor interactions and airfoil drag, was assessed by the Macro at the same time. Airfoil „CH10(Smoothed)“ was chosen for its highest Efficiency but also offers a high C_L value of over 1.7 at its ideal Angle of Attack (see orange Graph to the right for CH10 vs the second most efficient airfoil). This allowed Ephemeron to reduce rotor blade cord and thus weight.



Workflow of Airfoil Analysis



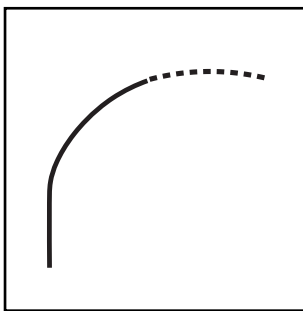
Duct



A striking feature of Ephemeron, that can also be found in our logo, is a shroud or duct around the main rotor. This unconventional approach has been researched for decades but was rarely realised in actual VTOL.

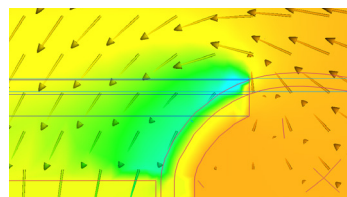


A hover- or low-speed-dominated mission is well suited for the use of a duct: No high drag or up-pitching moment from cruise flight occur .

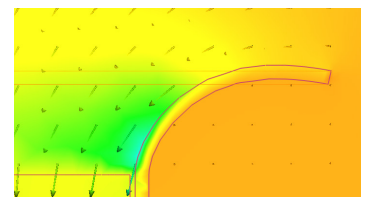


Computational Fluid Dynamics Analysis has shown that reducing the duct profile, as shown schematically to the left, only slightly lowers lift while reducing weight

Pressure variations from Autodesk CFD 2016



smaller duct
739 Newtons lift



larger duct
806 Newtons Lift

The pressure-drop of accelerated air around the inlet results in additional lift that occurs at the duct and makes more than up for the initial weight penalty.

Ephemeron only uses the inlet part of a conventional duct and dismisses the diffuser, which further reduces its weight while retaining most of its positive properties.

Tip-loss effects are reduced which not only improves rotor efficiency but also allowed Ephemeron to redesign the rotor blade to achieve uniform inflow at the main rotor and thus further increase the rotor efficiency.

Ply Stack

symmetrical
around foam

20mm Rohacell 31A
Foam

1. 0° C-UD 400g/m² ST 400
2. +45/-45 46g/m² C-fibre weave Samurai SY-12k
3. 0°/90° 110g/m² Aramid Twaron 1055 420

Through the use of carbon-foam sandwich and a smaller rotor diameter due to additional lift provided by the duct, the weight penalty can be further reduced.

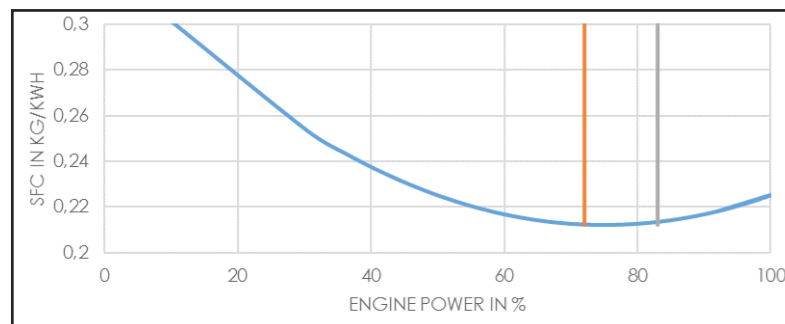
Propulsion



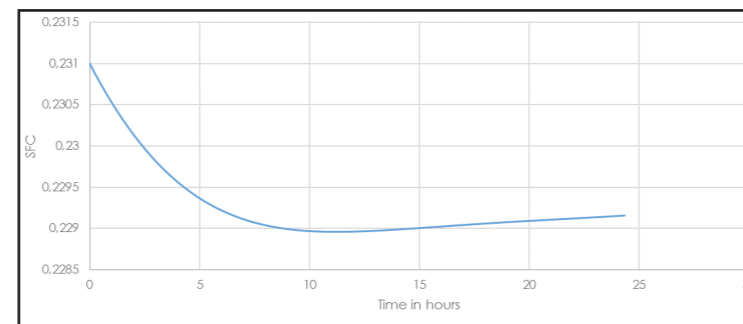
Still today, fossil fuels offer some of the highest energy densities among all fuels. For this reason a conventional combustion engine has been chosen. Nevertheless Ephemeron's Zoche ZO 01A engine offers latest cylinder technology and other refinements and most importantly runs on conventional diesel.

Zoche ZO 01A has been chosen because of its low weight/power ratio, as shown by the dotted line below. The only alternatives are either much heavier, resulting in an overall larger, heavier and more expensive vehicle, or are less efficient.

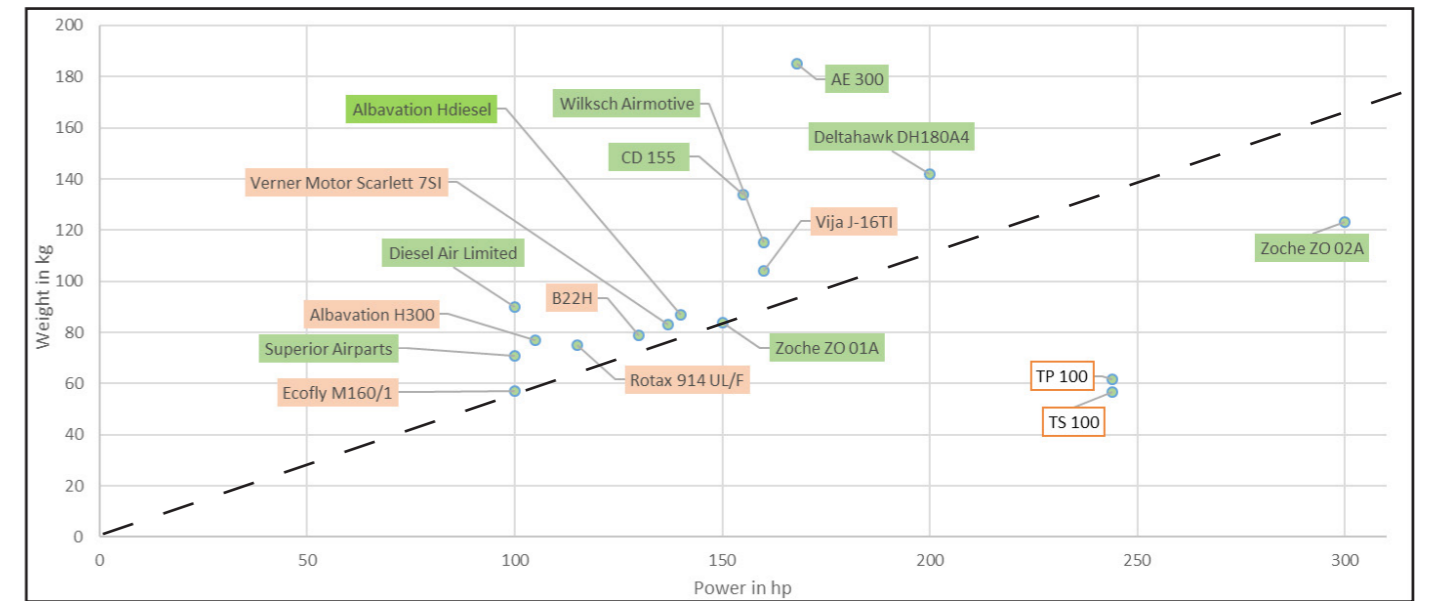
With a brake specific fuel consumption of just 0.346 lb/hp/hr or 212 g/kWh it is much more efficient than comparable petrol engines or gas turbines which are lighter but at least 30% less efficient.



Engine specific fuel consumption
 ■ lowest power setting
 ■ highest power setting

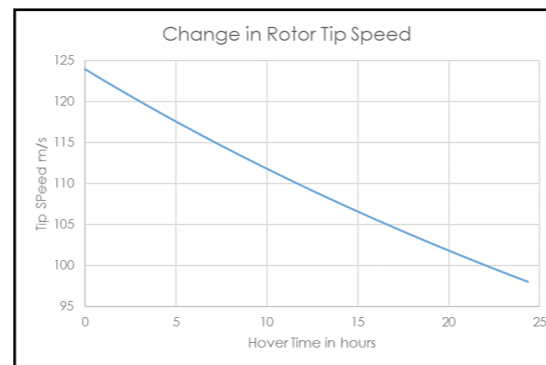


Ephemeron specific fuel consumption

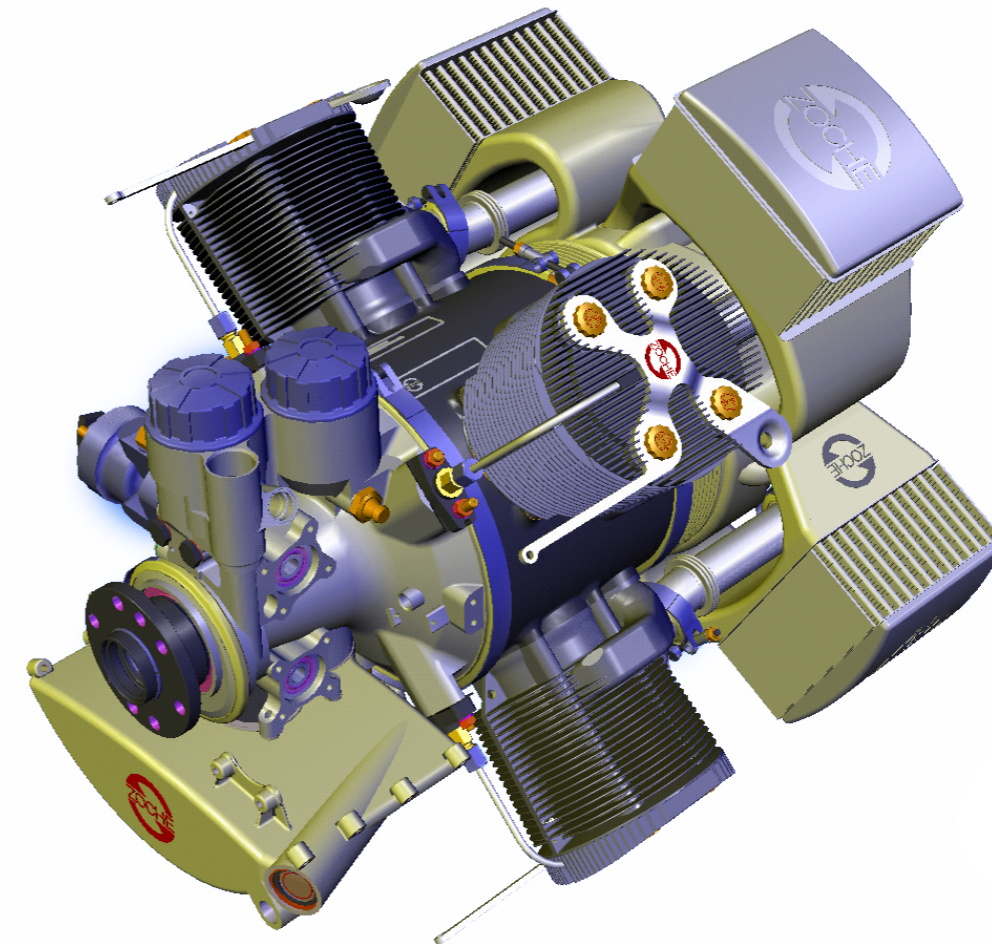
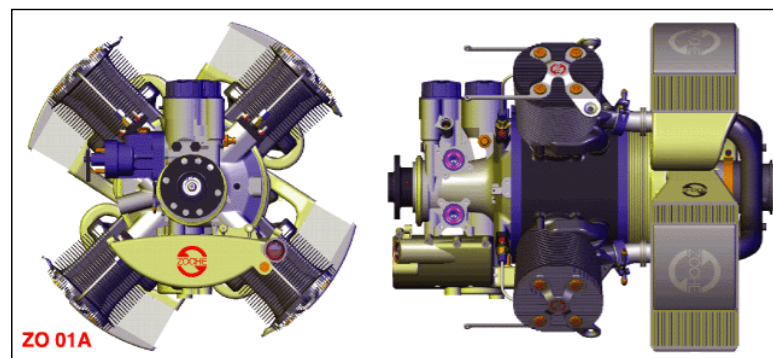


From the engine specific fuel consumption and the Ephemeron's specific fuel consumption it is apparent that most time is spent at a lower power setting as fuel is burned much more quickly in the beginning than in the end. By accounting for the change in specific fuel consumption for the entire mission envelope and using the Excel solver function, Ephemeron optimised the gear ratio in order to maximise fuel economy and thus hover endurance.

It should be noted that the engine and thus rotor speed is varied and in the end is 70,7% compared to the rotor speed at takeoff. This is due to changing thrust requirements and guarantees ideal aerodynamic conditions at the rotor blades nevertheless. This approach is far simpler and lighter than using a complicated and heavy multi-speed gearbox system.



The engine already includes all important components at a low weight of 84 kg, including a 10 kW starter generator that could be used for power generation for the payload. Also, its center of gravity lies in the centerline of its cylindrical outline and in the plane of its four cylinders.



- 110 kW (150 HP)
- Displacement 2.66 liters
- Diameter including cooling ducts 648 mm
- Weight 84 kg
- Cruise (75%) BSFC 212 g/kWh (0.346 lb/hp/hr)

Performance



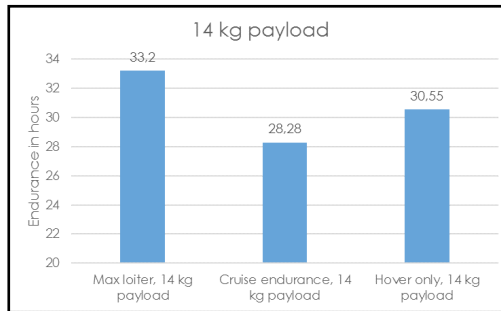
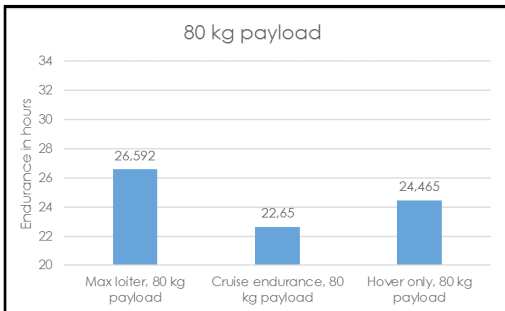
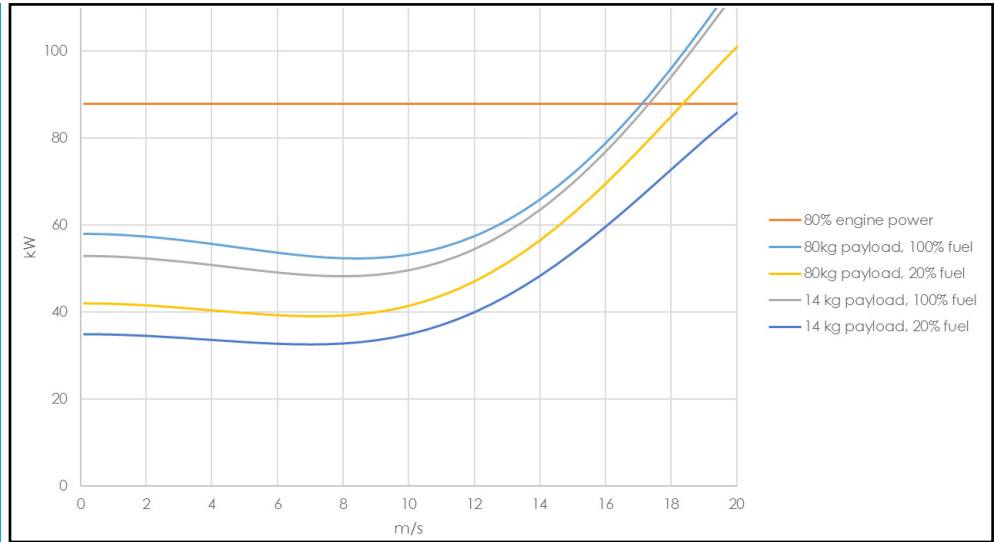
Ephemeron is able to cover a wide variety of tasks. Details on Ephemerons performance are presented below.

Cruise at 29 mph
(13m/s)

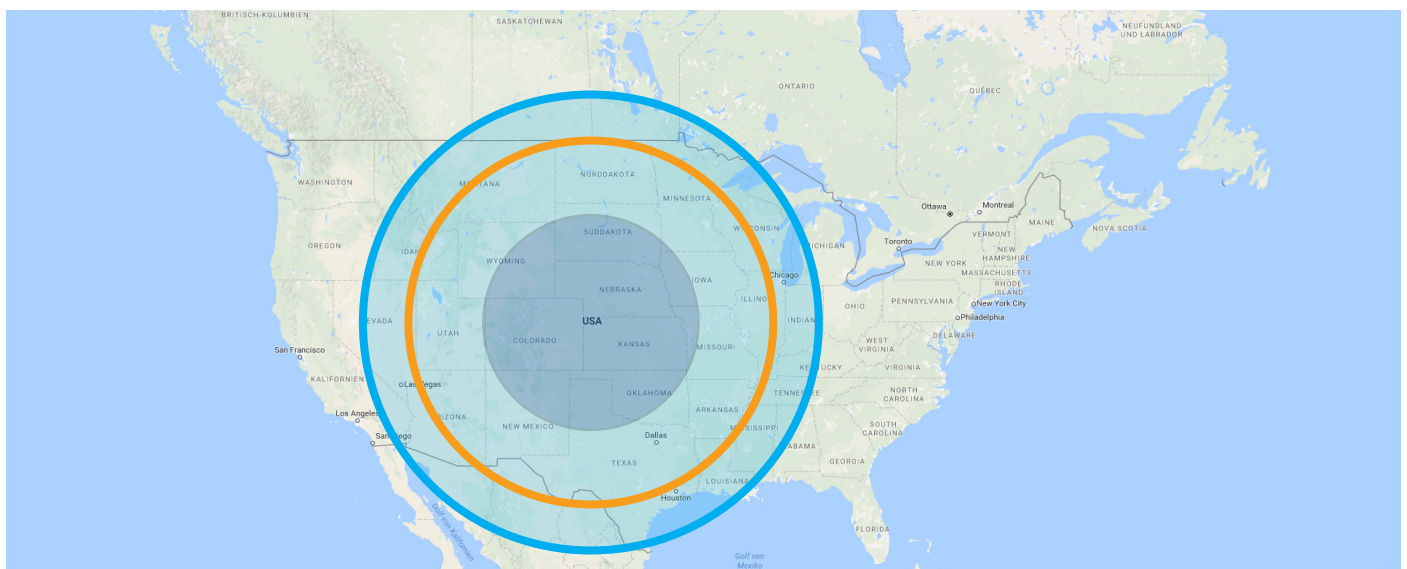
Max Speed 38 mph
(17m/s)

Conveyance flight
range up to 932 miles
(1500km)

Speed for best en-
durance 18 mph
(8m/s)



Ephemeron is suitable for a variety of tasks. Its mission-performance can be optimized by tailoring payload and speed to the specific mission requirements.



- 637 km Range (+10 hours hovering at target, 80 payload, one way)
- 1141 km Range (80 kg payload, one way)
- 1429 km Range (14 kg payload, one way)

Lightweight Design

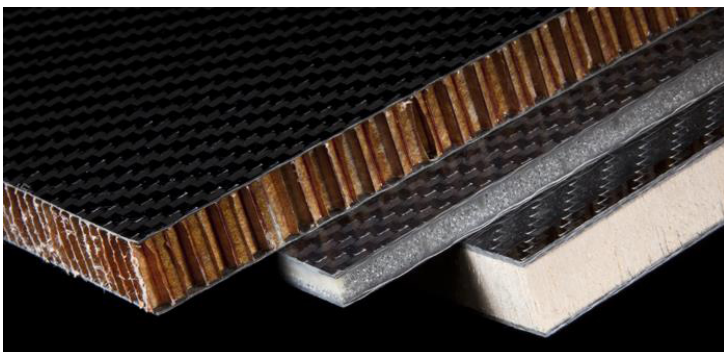


A conventional functional design of the aircraft components is not the way to achieve Ephemeron's flight duration of 24 hours. Lightweight parts are unavoidable. Using lightweight materials is only one part of lightweight components. To design these components, two ways are mainly used: Framework constructions and the use of sandwich materials offer the best weight to strength ratio.

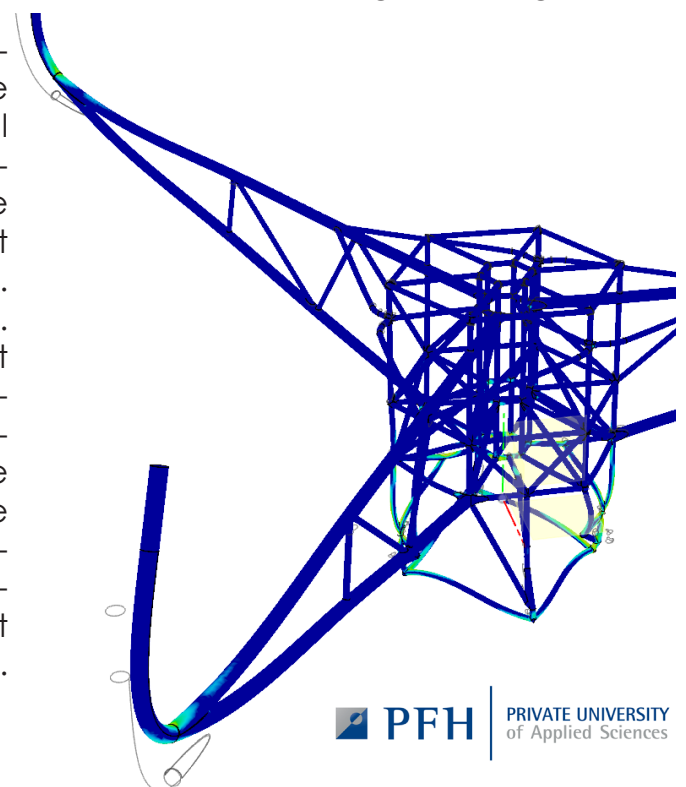
Ephemeron's duct must be lightweight because it only has a positive effect for the aircraft if the thrust it achieves is higher than the weight of the component.

The aerodynamic construction of the duct determines the thrust of the part. But the best lifting profile is futile if the duct is too heavy. A framework construction is not possible in this case because an aerodynamically smooth surface is needed. Thin CFRP panels could load the tensile forces but between the framework on which the duct is fixed to the aircraft, bending stiffness is more important. To

achieve bending stiffness the wall thickness should be increased. But bigger wall thicknesses from CFRP are too heavy. In this case sandwich materials are the lightest option. Two thin layers of CFRP on a sandwich core combine a greater wall thickness with a reduced weight of the component. Sandwich materials are the best option for lightweight components with a high bending stiffness.



In framework design, tubes are loaded with tension or compression forces and can be made from nearly any material. Lightweight material could be used too, but the connection technology is the limiting factor. CFRP tubes have a very low density and a high strength, but the connection between the tubes is difficult. Most metals are easy to connect by welding. Low cost material like steel could be used but the density is too high for a lightweight construction. More expensive, yet lower density, materials like aluminum are a very good choice for framework construction because they are easily welded and cheaper than CFRP. Ephemeron's main structure is an aluminium framework construction because it is the most lightweight way to achieve a tough airframe.



Landing Gear



One of Ephemeron's eye-catching features are its retractable landing struts that house a simple and yet ingenious fail-safe locking mechanism.

While deployed for landing and on the ground, the tripod-style landing struts are held in place through a spring-loaded self-locking joint. To retract the struts, the safety is disengaged and the struts are elevated through the use of winch-driven cables.

How does the fail-safe emergency deployment work? In case of a power outage, the electrically braked winches can no longer exert pulling force on the cables, and thus the spring-loaded joints force the landing gear down into the deployed and locked position. The aircraft can then safely land on it without harming the payload.



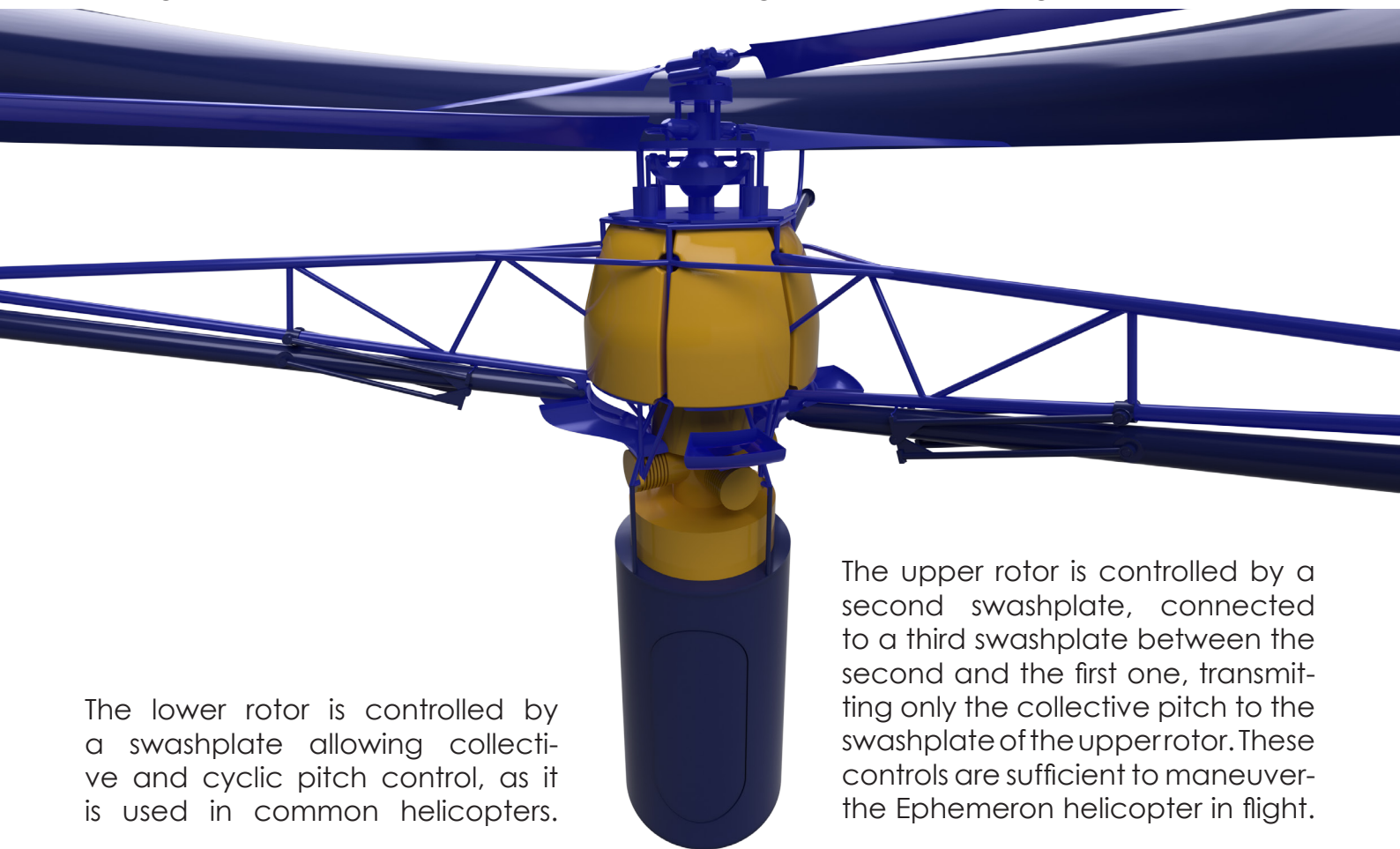
How does the landing gear complement the payload? It does so in two ways: While deployed, it keeps the payload well clear of the ground. The payload is easily accessed by personnel. While in the air, the struts are lifted out of the surrounding of the payload compartment, making space for a wide variety of possible applications that require an unobstructed view to the sides, like optical instruments or antenna installations.

Rotor Control



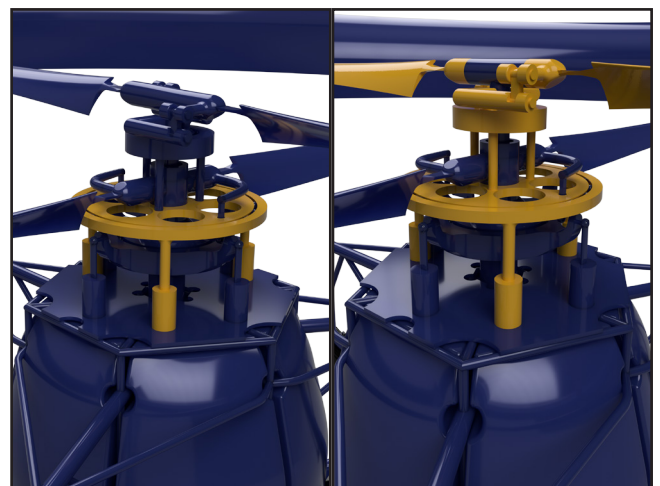
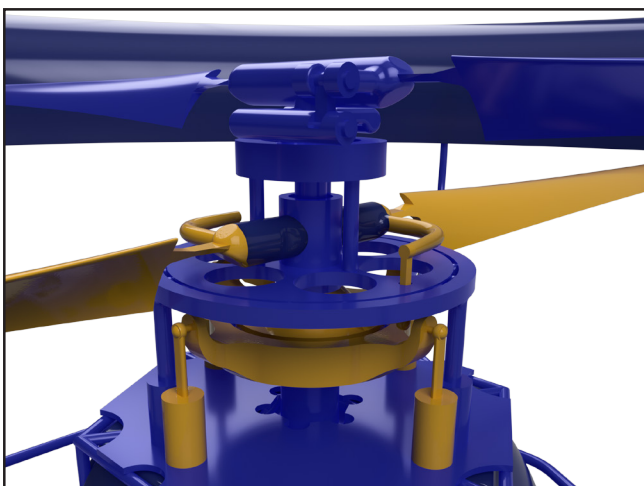
The Ephemeron is designed to hover for most of its flight time. A very calm and smooth flight is appreciated for almost every use case and for some operations is indispensable, e.g. the use as a mine detector. Therefore, the Ephemeron has two design elements to guarantee a smooth and controlled flight.

The first is its low center of gravity, due to the position of the engine and the tanks, the heaviest components of the aircraft, as low as possible and in axis with the rotor shaft, so any changes of the fuel on board do not result in changes of the center of gravity.

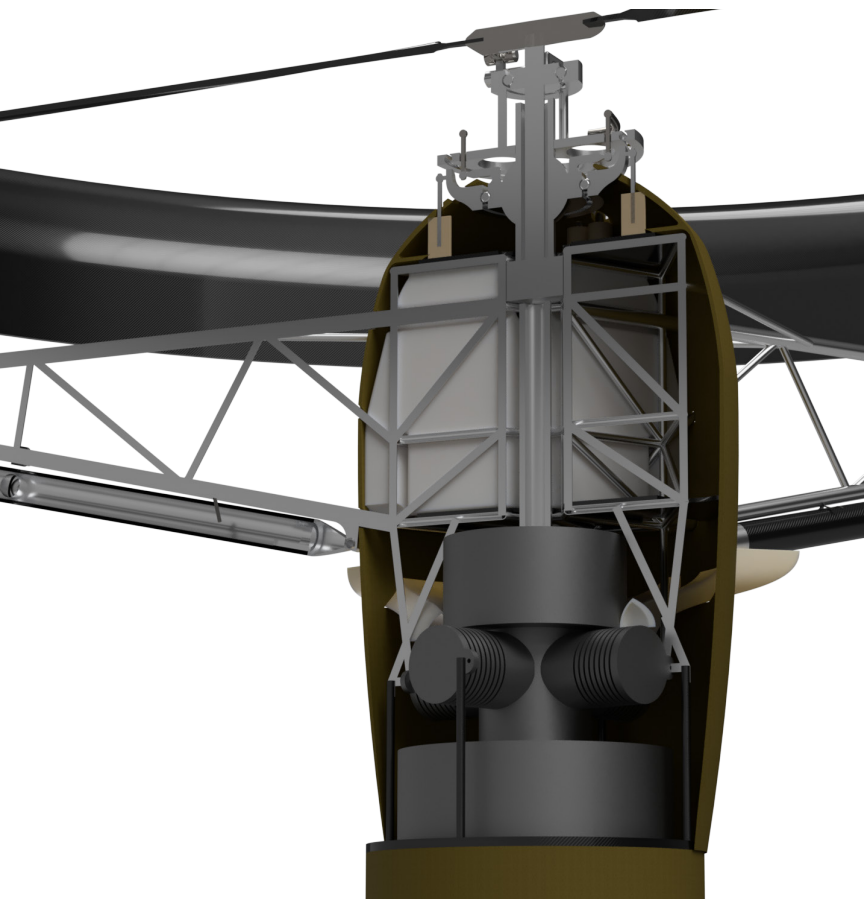


The lower rotor is controlled by a swashplate allowing collective and cyclic pitch control, as it is used in common helicopters.

The upper rotor is controlled by a second swashplate, connected to a third swashplate between the second and the first one, transmitting only the collective pitch to the swashplate of the upper rotor. These controls are sufficient to maneuver the Ephemeron helicopter in flight.



The Ephemeron was designed to perform hovering flights for up to 24 hours of total flight time without the need for refueling or any other discontinuity. The Ephemeron itself is an unmanned vehicle, but for its operation a crew is indispensable nevertheless. The ground operation of the Ephemeron is quite simple, due to the easy access to all important components of the aircraft, by simply removing the covering skin.



The refueling of the aircraft is possible for all six tanks by one fuel filler neck on the top one of the tanks: Due to the permanent connection of all six tanks, they will fill up equally. Maintenance and operation of the payload is possible via the service door in the payload compartment.

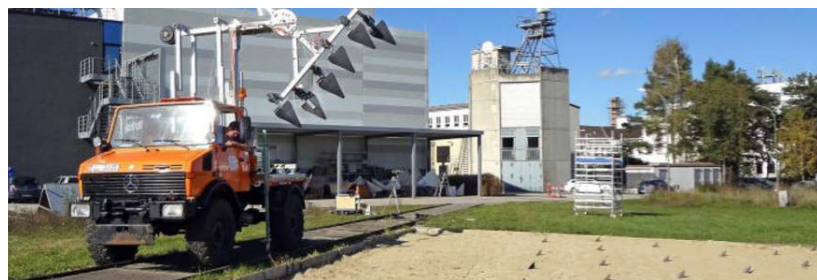
In flight Ephemeron can be operated in three different modi. The first modus is by an operator for in time controls. For that reason remote control equipment comparable to any other UAV is necessary. The connection between Ephemeron and its control center will be by radio, due to the poor availability of satellite connections for operations with little preparation time.

The second modus is the operation by flying a predefined profile, which will be uploaded to the aircraft before takeoff, and performed by it autonomously. A permanent connection to the aircraft is not absolutely necessary, but would allow to switch to predefined emergency modi if any problems occur during the mission.

The third modus is the semi autonomous flight. The ephemeron only needs its mission profile and the GPS coordinates and performs its flight without any further inputs from the control center. To autonomously perform its mission there needs to be at least one data link from the scientific payload to the aircraft. Such a connection could be implemented in later versions of the aircraft, but is currently (with respect to the rules) not provided.

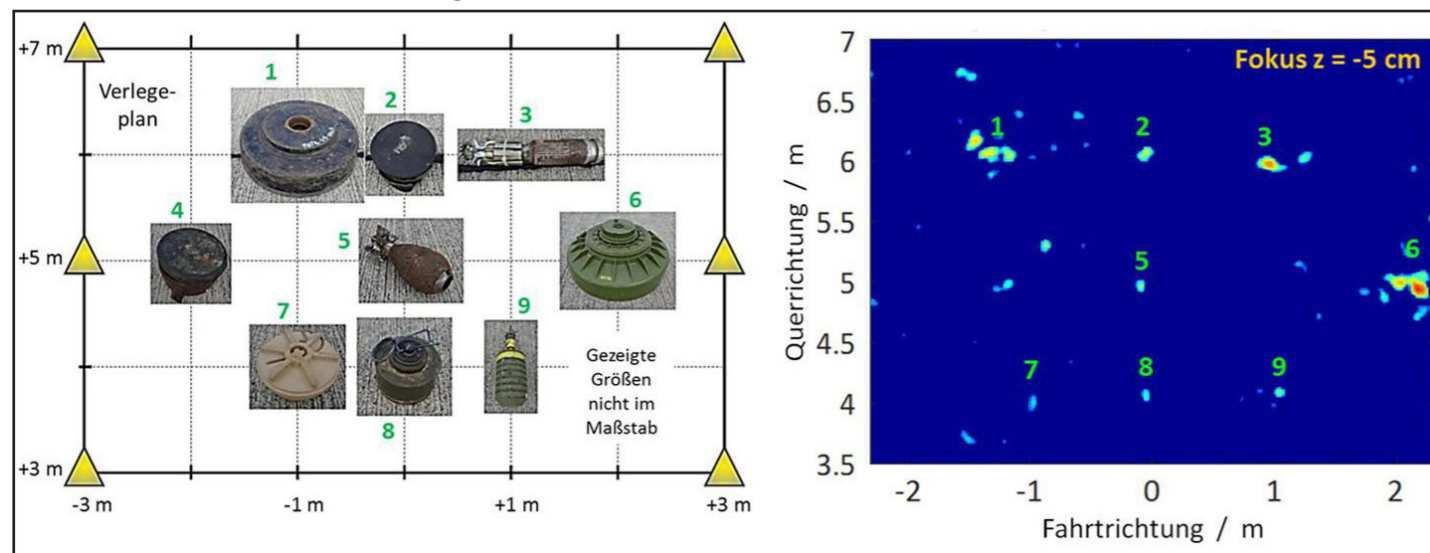
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Operation as mine detector



Every day up to 10 people are injured or killed by landmines. Former battle zones were prepared with mines, but after the end of the conflict mine mapping and mine clearing activities are usually minimal. Today, mine detection is difficult because the areas are often not accessible. In their project "TIRAMI-SAR",

the German Aerospace Center DLR in Oberpfaffenhofen (Germany) developed a radar based mine detection system to be carried on a truck. Mine detection is much simpler and cheaper with this system. Installing a smaller version on an aircraft could be an option in the future.



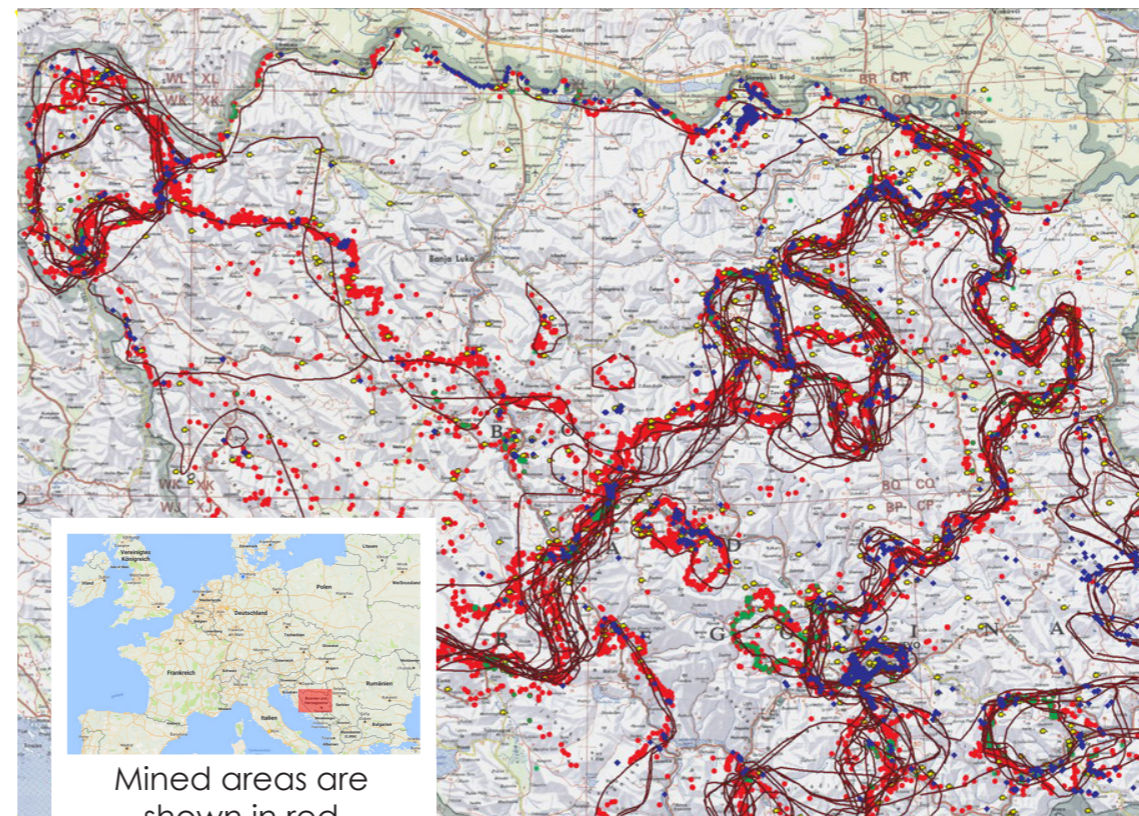
In Croatia, 500 km² of land are still spoilt with landmines and many of these areas are not mapped. The TIRAMI-SAR radar system is able to scan an area of 100 m² in a few minutes. When mounted on the back of a truck, a great disadvantage is the need of a safe corridor through the mine field. The truck requires a driver who is in constant danger because he is in the middle of the mine field and always prone to be affected by exploding mines.

The Ephemeron is unmanned and 6 times faster than the truck. The ground station could be placed safely outside the mine field and the Ephemeron automatically scans and maps vast areas. No safe corridor for a truck to drive on required and no human needs to enter the area. Inaccessible areas with big rocks or steep slopes are no problem for the Ephemeron because it can fly over the any obstacle.



A radar antenna array like the one used on the truck is too large for the Ephemeron. A smaller version is currently being developed and could be placed under the radome of Ephemeron's payload box. The measuring equipment is placed inside the box and can be powered from Ephemeron's generator.

Radar waves with a frequency between 500 MHz and 3 GHz penetrate the ground and are reflected by nearly any surface hidden in the ground. The reflected signals are evaluated and a mine map of the area is created.



A single Ephemeron is capable of mapping

● 11 km² in 24 hours

330 km² in 30 days

500 km² in 45 days

Manufacturing

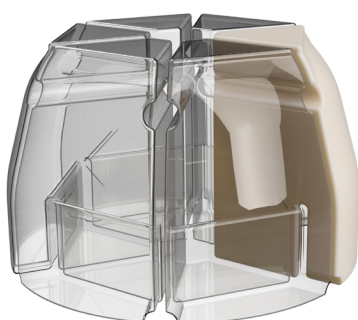
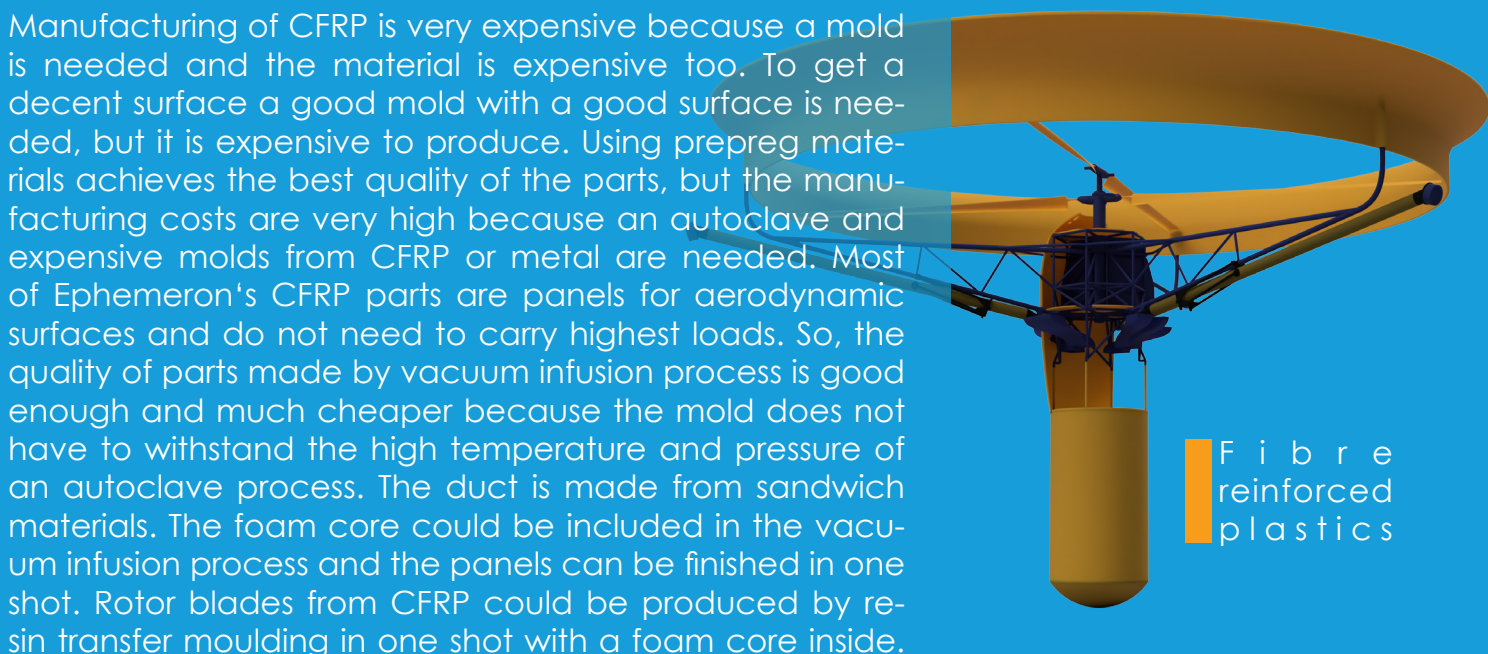


Construction and design of an aircraft is the first step of the process. The manufacturing is a very important part of the genesis of a new product. Designing complex geometries is simple but building them is not. So, the manufacturing process should begin with designing of the components to reduce development and manufacturing costs.



The airframe of Ephemeron is made from aluminium tubes. To connect them the best way is to weld the tubes. Welding aluminium is not as easy as welding steel but it is cheaper than connecting CFRP tubes. The problem of aluminum welding are oxides which form on the surface of the metal. They must be removed carefully to achieve a viable connection between the tubes, without gas or oxide inclusions.

Manufacturing of CFRP is very expensive because a mold is needed and the material is expensive too. To get a decent surface a good mold with a good surface is needed, but it is expensive to produce. Using prepreg materials achieves the best quality of the parts, but the manufacturing costs are very high because an autoclave and expensive molds from CFRP or metal are needed. Most of Ephemeron's CFRP parts are panels for aerodynamic surfaces and do not need to carry highest loads. So, the quality of parts made by vacuum infusion process is good enough and much cheaper because the mold does not have to withstand the high temperature and pressure of an autoclave process. The duct is made from sandwich materials. The foam core could be included in the vacuum infusion process and the panels can be finished in one shot. Rotor blades from CFRP could be produced by resin transfer moulding in one shot with a foam core inside.



To hover for 24 hours a lot of fuel is needed. A fuel tank made from CFRP is not easy to produce because it must be caulked. Ephemeron's fuel tanks are made from polyethylene because it is cheap to produce, impact resistant and close for the fuel. Also each tank only holds less than 50 liters of diesel, which allows Ephemeron to adapt automotive fuel tanks and reduce development effort.

Repair & Service



The Ephemeron is designed to be maintained easily: The covering skin panels are detachable, so each component can be reached without greater difficulties. To maintain the engine the payload compartment can be removed, which allows unobstructed access to or even the removal of the engine.



The repair of damaged covering panels is quite simple as well. If smaller objects impact the structure, even with an impact energy energy great enough to pierce the outer layups, it will usually be stopped by the foam core of the sandwich structure and won't be able to damage the inner layups or even the component behind. Such damages can occur during hovering flights at very low altitude. To repair such damages the area around the impact in the outer layups and the damaged part of the foam core are removed. Then, the hole is filled up with a new pieces of foam, shaped to fit exactly. The foam is fixed with glue and the removed areas of the outer layups can be replaced. For the repair or exchange of any components, the covering skin can be detached, which allow unobstructed access. If the tanks have to be inspected, they can easily be disconnected and removed.



Summary



As requested by Sikorsky and the American Helicopter Society, Ephemeron is an original and innovative proposal that explores the possibilities of vertical flight and shows the wide range of future applications.

By thinking of possible applications, assessing decades of rotorcraft engineering to choose the most suitable technology, conducting aerodynamic research, tailoring the use of material in order to decrease the aircraft weight and working out the design in much detail, Ephemeron promises to be a product that the world has never seen. But it also promises to be a product that, without a doubt, no-one would like to abstain from.

Beyond the competition and its discussed use cases, Ephemeron also could easily be scaled down. Doing so uniformly would most likely reduce hover time. Nevertheless, endurance would still be significantly higher compared to current UAV in the civil market. Many different market opportunities, especially as a competitor of electric multirotor system, could arise, should Ephemeron be developed further and eventually be produced as a scaled version.

The team behind Ephemeron is proud to have found and developed such an appealing solution. One that meets and exceeds the requested capabilities specified in the SDC 2017 Request for Proposal.

