

DLR Design Challenge 2022

## GLAROS Aircraft Concept



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

To whom it may concern,

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Best regards



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## **Zusammenfassung**

Im Zuge der DLR Design Challenge 2022 soll ein Konzept zur Bekämpfung von Waldbränden entwickelt werden. Gesucht wird dabei nach einer Flottenlösung von Luftfahrzeugen, die zusammen in einem Löschangriff 11.000 Liter Wasser abwerfen können. Das Luftfahrzeug, darf 5670 kg nicht übersteigen, muss von kleinen Flughäfen operieren können, nicht viel Lärm verursachen, eine Mindestdienstgipfelhöhe von 8.000 ft erreichen können und bis spätestens 2030 in Dienst gestellt werden können. In diesem Bericht wird *GLAROS*, ein ferngesteuertes Hochdeckerflugzeug mit Bootsrumpf und Hybrid-Elektroantrieb beschrieben. Durch die Fernsteuerung sollen weitere Unfälle mit tödlichem Ausgang vermieden werden und Europa von mindestens einer Basis abgedeckt werden. Mit der Nutzung des Hybrid-elektrischen Antriebs, wird einerseits eine effektive Nutzung der Energie und damit eine Erhöhung des Auftriebs bei wichtigen Flugabschnitten sowie eine Absicherung bei Triebwerksausfall, bei dem die gespeicherte Energie der Batterie genutzt wird. Der CO<sub>2</sub> Ausstoß kann durch die Anwendung von Sustainable Aviation Fuel reduziert werden. Zusätzlich ist durch den modularen Aufbau des Systems, der Transport von LD3 Containern möglich, welche weltweit in der Luftfahrt für den Transport genutzt werden. Das System wird von einer Hauptbasis betrieben und wird von dort nach der Alarmierung in das jeweilige Gebiet geflogen. Dort wird es über die Dauer der Brandbekämpfungsmission stationiert sein.

## **Abstract**

A concept for fighting forest fires is to be developed for the DLR Design Challenge. The search is for a fleet solution of aircraft that together can drop 11,000 liters of water in one firefighting attack. The maximum weight of the aircraft, must not exceed 5670 kg, must be able to operate from small airports, must not cause much noise, must be able to reach a minimum service ceiling of 8,000 ft and must be able to enter service by 2030. This report describes *GLAROS*, a remotely piloted high-wing aircraft with a boat hull and hybrid electric propulsion. Remote control is expected to prevent further fatal accidents and cover Europe from at least one base. With the use of the hybrid-electric propulsion, on the one hand an effective use of the energy and thus an increase of the lift during important flight sections as well as a protection in case of engine failure, in which on the stored energy of the battery is used. CO<sub>2</sub> emissions can be reduced through the use of Sustainable Aviation Fuel. In addition, the modular design of the system allows the transport of LD3 containers, which are used in aviation worldwide for transportation. The system is operated from a main base and is flown from there to the respective area after the alarm has been raised. There it will be stationed for the duration of the firefighting mission.

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## Table of Abbreviations

<b>DEP</b>	Distributed Electric Propulsion
<b>eVTOL</b>	electric Vertical Take-Off and Landing
<b>FOB</b>	Forward Operation Base
<b>ICAO</b>	International Civil Aviation Organization
<b>ICAS</b>	Congress of the International Council of the Aeronautical Sciences
<b>RLOS, BRLOS</b>	(beyond) radio line of sight
<b>RPAS</b>	Remotely Piloted Aircraft System
<b>STOL</b>	Short Take-Off and Landing
<b>UAS</b>	unmanned aircraft system
<b>UAV</b>	Unmanned Aerial Vehicle
<b>VTOL</b>	Vertical Take-Off and Landing
<b>VLOS, BVLOS</b>	(beyond) visual line of sight

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## 1 Introduction

In the 21st century, tackling the climate crisis has become the crucial challenge for humanity. Ever increasing temperatures and prolonged droughts are encouraging the spread of forest fires. They are an indispensable part of many ecosystems as they contribute to forest regeneration, however, they in turn also threaten the mitigation of the climate crisis because in addition to causing massive property and economic damage and loss of life, they also release large amounts of greenhouse gases, a vicious cycle is created. According to Greenpeace, wildfires cause global CO<sub>2</sub> emissions of 7.3 billion tons annually. This is more than global transport generates and is equivalent to half the global emissions from coal burning [1]. About 90% of wildfires are caused by humans [2]. The fires also lead to high levels of air pollution, which in turn leads to respiratory illnesses. They destroy the habitat of many animal and plant species and threaten human lives and settlements. They continue to encroach on landscapes and ecosystems that are not adapted to fires [3]. Experts estimate that it often takes decades or even centuries for forests to fully regenerate.

Since the mid-1980s, extreme heat waves and new record temperatures have sharply increased the intensity of fires in the western U.S., and as the main affected state, California experienced 8 of the 20 largest wildfires ever in the two years 2020/21 alone [4], with a total area as large as Ireland in the whole US [5]. Total annual losses are now in the multi-billion-dollar range and economic losses are orders of magnitude higher still (about \$400 billion in 2018) [6].

During Black Summer 2019/20 in Australia, it was mainly the heavily populated east coast that was affected instead of uninhabited bushland as normal, so rainforests that are not adapted to fire also burned. After a preceding drought lasting several years, about one-fifth of Australia's forest area was in flames [4]. This is roughly the size of Greece. It is estimated that about 1 billion higher animals died (including about 40% of the entire koala population) [5].

In the "green lungs of the earth," the Amazon rainforest, slash-and-burn practices are a popular means of deforesting large areas for cattle ranching, farming and logging, and with the ongoing drought, flames are spreading uncontrollably through the forest [6]. Already 17 percent of the original forest cover in the Amazon has been destroyed, and another 17 percent of the forest has already been damaged [7]. If tree death continues at the current rate for another 10 to 15 years, the southern Amazon could turn into savanna (desertification), a dangerous climate tipping point. The gigantic water cycle generated by the rainforest itself, the so-called "flying rivers", will be massively disrupted, and by 2050, half of the rainforest could already have irreversibly vanished [8].

The vast taiga forests of Siberia are also now experiencing long periods of drought and huge intense fires as the region warms faster than the rest of the world due to polar amplification [9]. Wildfires are steadily moving further north, as close as the 73rd parallel (Laptev Sea) in 2020 [10], and some of the smoke from the fires, which damages the ozone layer, is already drifting across the north polar region and down into Canada [11]. The area burned reached the size of half the national territory of Germany for the first time in 2021 (more than all other forest fires in the world during that time combined) [12], and nearly 1 billion tons of CO<sub>2</sub> were released between June and August alone [13]. As a result of the heat waves and forest fires, there has also been a thawing of the permafrost, which could become another climate tipping point. About twice as much CO<sub>2</sub> is stored here as in the entire atmosphere, and 10 to 20 percent of it could probably be released [14]. It also leads to subsidence of huge areas, thousands of kilometers of pipelines and roads lose their grip, and entire cities could become uninhabitable [15]. The climate crisis is increasing the risk of wildfires in the Mediterranean region as well, and there is an ongoing "Mediterraneization" of Europe. Large forest fires are no longer the exception but the norm [16], even in temperate climates such as Sweden, which even needed international firefighting assistance in 2018 [17]. The main cause of fires is again human activity, often due to real estate speculation and land reclamation for construction, but also hunting and grazing [18]. According to the projections, meteorological fire risk will continue to increase in most regions, and modeling studies suggest that the area burned could double with 3°C global warming [19], but measures such as increased fire suppression could significantly limit this increase.

The TU Dresden/Braunschweig team is aware of the special importance of forest firefighting and would like to present a concept in this report that represents an important contribution to the solution.

## 2 Market Analysis

As mentioned in the introduction the lack of firefighting resources is a serious problem with a steady increasing importance. Currently the stock of firefighting air-vehicles is rather small. A lot of which rely on outdated technology and are cost expensive in maintenance and operation. In the area of airplanes, there are some that have prevailed more. The most popular probably being the Canadair CL-415, coming with a heavy price tag [20], but also, a big number of planes sold and flown and thus, offering a lot of experience and data. There have even been supertankers like a B-747 that could carry up to 66 t of water but failed in the market [21]. Looking at helicopters, almost none of the ones used are specifically built for the fight of fires. It makes sense, to give an air vehicle multiple capabilities, so that once built, its usage is not limited to the wildfire-season. On the other hand, as said in the introduction, there is a big financial encouragement in the long run, to invest in more firefighting equipment. This is an aspect where politics could have been more active and will have to be to tackle the challenges in the future. We, as engineers, don't want to set the political direction, but the technical solution. Having said that, it is important to design the airplane of the future, we must look at the previous solutions. The water intake-process is one of the most critical phases. VTOL vehicles of course can collect the water in the smallest water sources. Airplanes have the big advantages of efficiency and speed. Most helicopters used for firefighting have a similar design, by mounting a bucket hanging with a rope from the helicopter. Possible Improvement there pales compared to firefighting airplanes. Furthermore, having more speed and efficiency and thus time in the air, can lead to a better overall result as our calculations later on show. The water intake-process is one of the most critical phases. VTOL vehicles of course can collect the water in the smallest water sources. Airplanes have the big advantages of efficiency and speed. Most helicopters used for firefighting have a similar design, by mounting a bucket hanging with a rope from the helicopter. Possible Improvement there, pales compared to firefighting airplanes. Furthermore, having more speed and efficiency and thus time in the air, can lead to a better overall result as the calculations later show.

At this time there is not a single aircraft used in the fight of wildfires that can be controlled fully from the ground. There are a few drones used in domestic fires [22], but nothing in the scale of 5 tons. For us, that and looking at the number of pilots that die every year in accidents really gives us an incentive to make the vehicle unmanned.

For the concept phase it is often a good first way to compare the requirements with existing vehicles of similar sizes. The Dornier Seastar with a MTOM of 5100 kg comes quite close to the given MTOM of 5670 kg. It has the prop mounted at the top, which protects it from water and has sponsons. These increase even more the distance to the water, which in general is something good, but it makes scooping with high waves difficult.

It is important to use everything learned from the existing approaches. This aircraft bears the name *GLAROS*, which means gull in Greek, country where every year big wildfires take place. The gull is one of the smartest sea birds. It is very agile but at the same time very fast. That lead to inspiration of the name.

### 3 GLAROS- Technical Specifications

specification	amount	unit
<b>Length</b>	15	m
<b>Wingspan</b>	19,8	m
<b>Wing area</b>	28	m <sup>2</sup>
<b>Tail height</b>	4,2	m
<b>Hull width</b>	1,9	m
<b>MTOM</b>	5670	kg
<b>MZFW</b>	5220	kg
<b>OEM</b>	3020	kg
<b>Payload</b>	2200	kg
<b>Fuel capacity</b>	560	L
<b>cargo volume</b>	8,8	m <sup>3</sup>
<b>Propulsion</b>	1000	kW
<b>Maximum cruise speed</b>	155	kn
<b>Range at max cruise speed</b>	465	NM
<b>Maximum Range</b>	660	NM
<b>T/O distance at MTOM</b>	323	m
<b>Landing distance at MTOM</b>	304	m
<b>Max rate of climb at MTOM</b>	770	ft/min

Table 1 - Technical Specifications

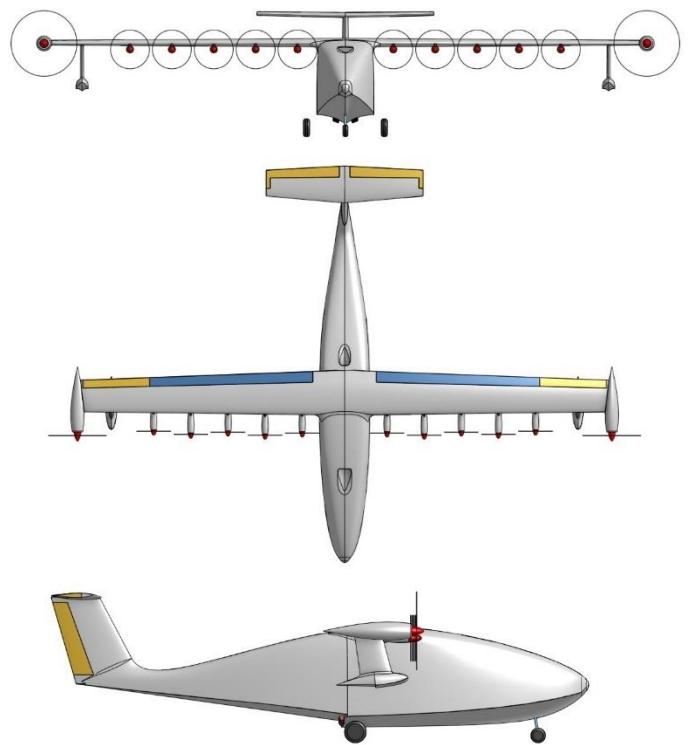


Figure 1 - Three view drawing

### 3.1 Overview with weight & balance

part	mass fraction [%]	mass [kg]
<b>fuselage</b>	10,5%	595
<b>tail</b>	2,3%	130
<b>wing</b>	12,2%	692
<b>payload</b>	38,8%	2200
<b>turbogenerator</b>	5,3%	301
<b>landing gear</b>	3,0%	170
<b>avionics</b>	1,5%	85
<b>systems</b>	5,0%	284
<b>battery</b>	3,0%	170
<b>cruise motors</b>	1,4%	79
<b>high-lift motors</b>	1,5%	85
<b>electrical system</b>	1,0%	57
<b>nacelles</b>	2,0%	113
<b>margin</b>	1,0%	57
<b>fuel</b>	7,9%	448
<b>cruise props</b>	1,3%	74
<b>high-lift props</b>	0,7%	40
<b>water tank</b>	1,6%	91

Table 2 - Weight Overview

### 3.2 Configuration

During the development of GLAROS, we decided on a more future oriented solution without neglecting well established methods in aerial firefighting. GLAROS is a remote-controlled high-wing aircraft with a boat hull and powered by a hybrid electric propulsion system.

In the following section our decision-making process will be described extensively.

When we were confronted with the subject of aerial firefighting the most striking fact was how dangerous it is due to the low flight altitude and high-risk flight maneuvers.

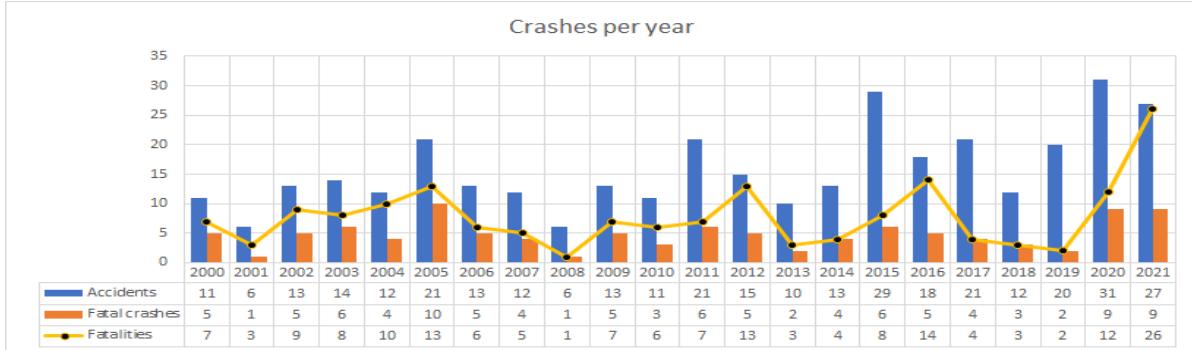


Figure 2 - Crashes per year

As shown in figure 1 there have been 89 fatalities within the last 10 years, 26 of them last year. Overall, there have been many accidents in the last few years.

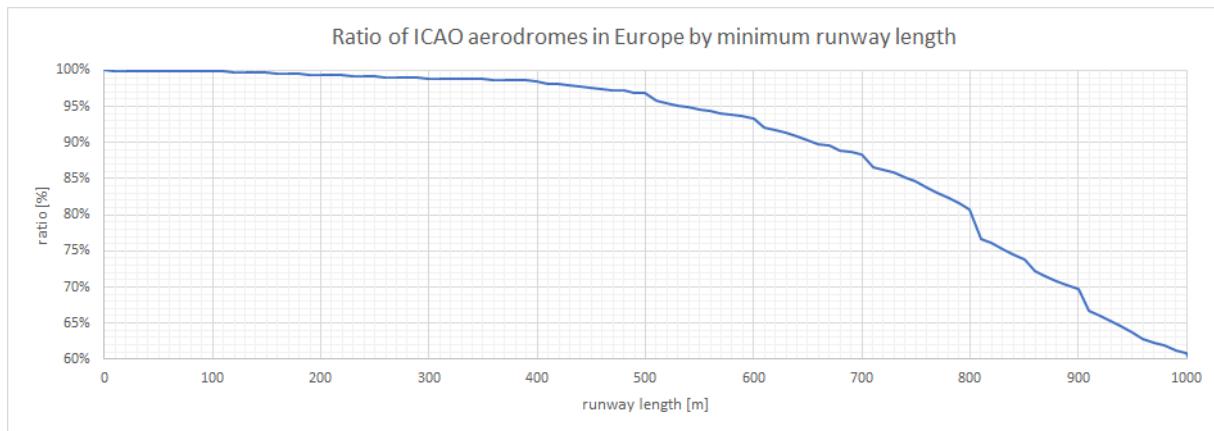
In order to avoid these life-threatening risks, we decided to use a remote-controlled aircraft.

Furthermore, this brings additional advantages. Thanks to system support and automatically flown flight sections, the pilot's workload decreases a lot. In the example of a CL-415, 3 People are needed for operating the aircraft. With *GLAROS* remote controlled system this could be reduced to up to one. Additional sensor technology allows the remote-control configuration to be flown at night or in poor visibility conditions such as smoke or fog. Areas contaminated by ammunition, such as Treuenbrietzen in Brandenburg, can currently only be approached by up to 1km. These and other risk margins can be reduced due to the remote-control system of *GLAROS*.

The disadvantages of remote-controlled flying are difficult approval, an all over lack of experience with fire-fighting drones, big latency, through which it could become difficult to control, and the necessary sensors to fly the plane safely. Our decision was made because the advantages of remote-controlled flying clearly outweigh the disadvantages.

We opted for a STOL fixed-wing aircraft instead of an eVTOL aircraft or helicopter. Whilst the hovering has benefits related to the water intake such as a shorter way, a greater variety, and the reduced influence of swell, which is also why the VTOL aircrafts don't need a boat hull.

Also, they have nearly no take-off distance and a light landing gear. However, hovering consumes a lot of energy, which gives these aircraft less cruising speed and range and high operation costs in comparison to planes. Also, the hovering produces a lot of noise and the so-called downwash which can swirl up water that could be harmful for the engines or blow on the fire. Consequently, the STOL aircraft has a much higher economical and time related efficiency over longer distances and time periods. As shown in table 2, even with a take-off distance of 650m, the aircraft would still be able to land on 90% of the runways in Europe. Because of these arguments we decided on a STOL plane.



*Figure 3 - Minimum runway length of Europe's aerodromes  
(only runways with available data considered, ~70% of Europe's runways)*

This commitment led to the next decision on the MTOM. Because of the plane configuration it is easier to carry more mass with less energy than a VTOL system. The larger the aircraft, the better the surface-to-volume ratio to carry more water. With more water fire can be fought much more efficiently without flying very low so that the water doesn't evaporate or spray too much. A heavier airplane is not so prone to waves, disturbances, or gust loads, which makes it easier to scoop and maneuver through the thermally affected areas above the fire. Finally, we decided on the maximum allowed MTOM of 5670 kg with a water mass of around 39%, at least 2200 l, to enable the specified 11000 l in one attack with a fleet of 5 aircraft.

The water intake is one of the main decisions too. We had 4 possibilities which are a water boom [23], the classic touchdown, a “Bambi bucket” or a tank that gets dropped and retrieved afterwards. Our first idea was the water boom with a blended wing configuration, but due to the poor flight stability, the low climb and descent rate and the great leverage from the boom, we decided against this solution. The fly by slurp was also not used, because of the necessary pumping, the high angle to redirect the water and that it has not been tried yet. The “Bambi bucket” has too much drag and is not suitable for a plane. Both these possibilities and the third one of dropping and retrieving a tank have the advantage of no contact with the water and thereby less wear, but because of the salty mist over the sea there is also wear of the engines and the whole plane. With the drop and retrieve option we have seen some issues with picking up the tank in flight as it needs to be accelerated to flight speed which couldn't be done directly but with buffering through a cable. This makes it a lot harder to catch the tank and needs some distance before it is over the treetops. Due to these issues with the other water intake options, we decided for the classic and well proven method of touchdown scooping.

After deciding that the plane needs to touchdown in the water, we knew it needed a boat hull and high wings for the propulsion system to be as far away from the water as possible. We orientated ourselves on the Canadair CL-415, the Dornier Seastar and the Shinmaywa US-2. The boat hull is very robust and requires very little maintenance, but also increases drag during flight. This is a necessary trade off, because the plane needs to be able to land and start from the water due to an emergency or cargo transportation on water. We also brought up the topic of hydrofoils in the initial design phase, but rejected it due to added weight, inexperience, added drag and a complex and thus heavy folding mechanism and obscurity if it even benefits the purpose.

Perhaps the most important point is the propulsion system. To be able to transport this much weight a full electric system needs very large and heavy battery systems, which are only sufficient for a short range, since they don't lose their fuel mass during flight. But we wanted to be innovative hence we decided on the Distributed Electric Propulsion system, which is being researched by various renowned research institutes like the DLR [24] and NASA [25].

Above all, we were convinced by a significantly increased  $c_{L,\max}$  during takeoff and landing, which allows the wings to be optimized for cruising flight while at the same time enabling a short takeoff distance. Furthermore, due to counter-rotating wing tip propellers the induced drag can be reduced or lead to an increase in the efficiency

of the propeller. All in all, the distributed electric propellers have many advantages, including a relief of punctual thrust load on the wing because of the distributed engines, a lower volume due to the turbo generator integrated in the fuselage, high safety due to many different propulsions and a rudder control by the wingtip propellers, which means that vertical tail surfaces can be reduced. Due to a battery that absorbs peak loads, the turbo generator can be designed smaller and always operate at the optimum speed. Because of the high failsafe the entire drive unit requires very little maintenance and thanks to the electric motors and the turbo generator, the operation costs are kept low.

To prevent the wing and the wing tip propeller from dipping into the water we attached wing tip floats, which guarantee very good lateral stability. We ruled out possible “sponsons” due to less safety for the wing tip propellers and greater aerodynamic drag.

Tail unit and landing gear configuration are yet to be decided. A canard configuration was out of the question due to the low speeds and difficult construction as a flying boat, and a box wing could also be ruled out due to the water contact and insufficient experience. Based on classic experience we have chosen a high wing kite configuration with T-tail in order to place the wings and tail as far away from the water as possible and the elevator experiences no disturbance from the wing and the electric propellers that much. In terms of landing gear, we opted for a tricycle. The advantages lie in the even loading and easier control during take-off and landing without risking the aircraft to nose over.

### 3.3 Aerodynamics

The main focus in the aerodynamic design of the wing is on the combination of a short take-off and landing distance, i.e. a high lift performance, and a fast cruise flight. These two design points are basically in conflict, since a short takeoff and landing distance is initially related to a low stall speed in addition to a high propulsive power, which in turn is firmly linked to a high maximum lift coefficient and a large wing area. However, this large wing area is a hindrance to good cruise performance, which is why STOL aircraft generally have a rather low maximum cruise speed. In order to resolve this contradiction, a configuration must be found which, on the one hand, has a high wing loading and thus a small wing area. On the other hand, the lift coefficient in low-speed flight must be high enough that a low stall speed can still be achieved.

Part of the solution lies initially in the use of single slotted fowler flaps, which increase the wing area and provide a good compromise between high lift performance, weight and relatively low complexity. This alone allows maximum lift coefficients of 2.5 to 2.9 [26]. Slats are not used because, in contrast to flaps, they do not fundamentally increase the lift coefficient, but rather cause an energy input into the boundary layer on the upper side of the wing through the gap and increase the maximum angle of attack through the associated delayed stall, which in turn allows a higher  $C_L_{max}$  to be achieved. However, a high angle of attack is undesirable for the flying boat concept, since a rather small angle of attack range is available for an optimallanding on the water and the tail must not hit the water surface first in any case. In addition, slats generate a very high technical complexity and a low shape tolerance, which increases the manufacturing effort and thus the costs.

One of the most important aspects of increasing  $C_L_{max}$  lies in the use of a distributed electric propulsion system. This involves the use of relatively small electric motors with propellers optimized for low-speed flight, distributed along the span to accelerate the flow over the wing during takeoff and landing. This results in both active control of lift and circulation and re-energization of the boundary layer, as well as control of flow separation at higher angles of attack. In combination with the Fowler flaps, this results in so-called blown flaps, which are also used, among others, in the Japanese state-of-the-art amphibious aircraft ShinMaywa US-2 and which, together with an active boundary layer control system, ensure a unique VSTOL performance (280 m takeoff distance at water at 43000 kg loaded weight:  $v_{stall} = 49 \text{ kn}$ ). A boundary layer control system is also not used for *GLAROS*, as it would lead to significantly increased complexity, maintenance, costs, weight and additional energy consumption, while at the same time the benefits are difficult to estimate in a relatively small design volume.

Due to the small diameter of the high lift propellers, an increased disc loading and thus a reduced propeller efficiency can be assumed. However, this is partially compensated by the lift effect alre ady described, a higher energy density of small electric motors caused by a lower cooling requirement, and the relief of the wing by the distributed

nacelles and thus a reduced structural weight. Investigations could show that the diameter should optimally correspond approximately to the chord [27]. The propellers are not adjustable to keep weight and complexity low. Instead, the propeller blades are folded for cruise flight, creating the lowest possible drag.

The use of DEP is currently the subject of intensive research and estimates have already been made for maximum lift coefficients that can be achieved. These range from about 3 (in launch configuration) [28] to 4 and 5 [29], [30] to 5.6 [31]. Final values will ultimately have to be shown by CFD simulations and real tests. At this point, a  $Ca_{max}$  of 4 is estimated to find a balance between conservative and progressive.

Due to the high lift coefficient in slow flight, an increased induced drag can be expected. To partially compensate for this, a high aspect ratio is initially chosen. It is limited by the increasing structural weight, since the shallow wing depth also reduces the overall height for the spar and the torsional area, the root bending moment is increased, and yet high stiffness must be ensured for high g-loads during the mission and a flutter speed that is as far as possible above the maximum cruise speed.

A further reduction in induced drag is provided using wingtip-mounted propellers. They rotate in the opposite direction to the wingtip vortex and counteract it. Here, propeller blade pitch is provided in order to be able to optimally adapt the thrust to the respective mission phase and to keep the propeller drag low in the event of failure. Precise information on the reduction effect of wingtip-mounted propellers on the induced drag cannot be provided within the scope of this report, as complex CFD analyses would be required for this. Therefore, the effect must be estimated. NASA expects a 5% drag reduction for the X-57 Maxwell in cruise flight [27] and other publications also predict 3-6% [28]. More important for the *GLAROS* concept, however, is not only the drag reduction in cruise flight, but a good take-off and landing performance, to which the wingtip-mounted propellers could make an important contribution. A disadvantage, on the other hand, could be a reduced roll rate due to the greater inertial forces acting on a larger lever arm than with classically inner-mounted turboprops. High maneuverability is important for the *GLAROS* mission, though, which is why the ailerons will be dimensioned larger. The additional weight, on the other hand, has a relieving effect on the wing structure, which presumably must be designed more torsional stiff to compensate for aeroelastic effects and vibrations.

Another advantage of the wingtip-mounted propeller is the improved yaw control, which allows the rudder to be designed smaller and thus results in a drag reduction. In addition, the T-tail reduces the lever arm to the horizontal stabilizer, resulting in a reduction in structural mass. In the event of a wing tip propeller failure, the advantage of the large lever arm becomes a disadvantage, but the momentum generated can be compensated by the propeller blade pitch, the shutdown of the opposite propeller and the thrust of the high lift propellers. In contrast to a pilot-controlled airplane with a relatively long reaction time, remote control makes it possible to react very quickly to the failure.

The wing is unswept. The cruise speed remains below 30% of the speed of sound, so compressible air effects are not to be expected. A wing sweep would be rather disadvantageous for *GLAROS* because it supports cross-flow in the spanwise direction, makes laminar retention more difficult, and decreases maximum lift. It also increases the wing structural weight.

An optimum dihedral of the wing cannot be determined within the scope of this work, since stability analyses about the longitudinal and vertical axes would have to be performed for this purpose. However, many unswept high-wing aircraft, such as the CL-415, do not have a dihedral, presumably to ensure good maneuverability. Therefore, the concept design of the *GLAROS* does not include a dihedral either. In addition, it should be mentioned that the wingtip-mounted propellers require sufficient prop clearance for takeoff and landing and thus have a major influence on the dihedral in addition to flight stability.

The wing is tied to the fuselage in a normal configuration, as in classic high-wing aircraft. Struts between the fuselage and wing, as on the Dornier Seastar, are not used, since this increases aerodynamic drag and the decision to use a narrow but high hull allows a direct and thus lighter structural connection.

The same value of 0.7 as on the Nasa X-57 Maxwell is used for the taper ratio of the wing. This allows the pressure point to be shifted inward, reducing root bending moment and wing mass. However, there is an increase in the local lift coefficient in the wing outer area, which results in an increased risk of stall. Therefore, the wing is additionally provided with a washout of 2 degrees to ensure that the first stall does not occur at the outer wing but optimally at about 40% of the half span and subsequently moves inward. In this way, disadvantageous stall behavior can be prevented.

In order to find a suitable wing profile, the profiles of comparable seaplanes are first analyzed (Air Tractor = NACA 4415; PZL Dromedar = NACA 4416/4412; CL 415 = NACA 4417 mod; Dornier Seastar = NACA 23015) [32]. For novel DEP concepts, GAW-1, GAW-2, and NACA 5415 in particular are used as the basis for further optimization. Therefore, a GAW-1 is provided for *GLAROS*.

In the following, an example of how the drag is distributed over the individual components is given for the cruise flight under design mission restrictions. The resistance diagram of the Nasa X-57 Maxwell was taken as a model, since it is similar to the *GLAROS* system and the estimation is better than classical formulas [33].

Drag in cruise flight (5500 ft, 155 kn, MTOM, ISA + 20°C)

	C_w	ratio	N
<b>interference</b>	0,00061	1,11%	52
<b>induced</b>	0,00795	14,51%	680
<b>wing friction</b>	0,0037	6,75%	316
<b>wing profile</b>	0,00159	2,9%	136
<b>tail friction</b>	0,00190	3,46%	162
<b>tail profile</b>	0,00032	0,58%	27
<b>high-lift nacelles</b>	0,00468	8,54%	400
<b>cruise nacelles</b>	0,00189	3,45%	162
<b>fuselage</b>	0,02917	53,22%	2493
<b>Wing floats</b>	0,00300	5,47%	256

Table 3 Drag Coefficients

### 3.4 Propulsion/power plant

To ensure a short takeoff and scooping distance and a high cruising speed, a correspondingly high power must be used. In order to be able to plausibly estimate a propulsion power first, a comparison of various already existing flying boats and amphibious aircraft is made, as shown in Figure 4 Power output of water-aircrafts.

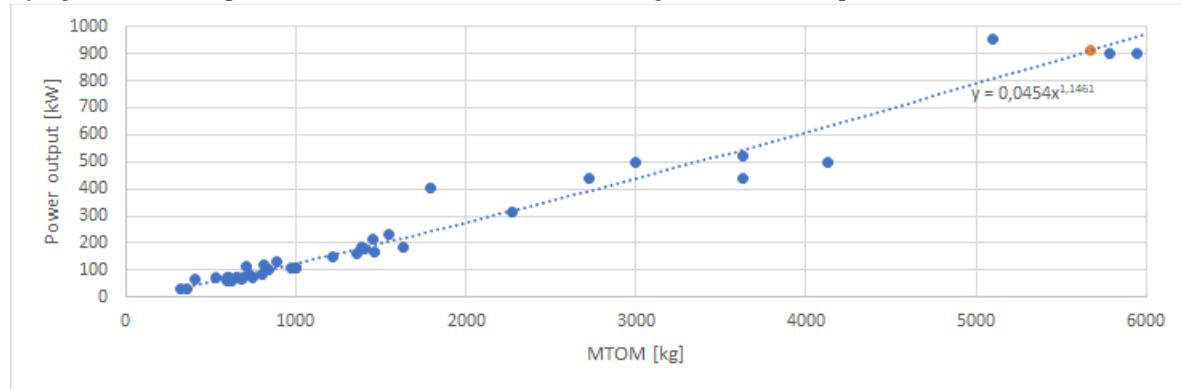


Figure 4 Power output of water-aircrafts

The result of this analysis suggests a propulsion power of about 900 kW at 5670 kg MTOM as a first estimate. The most commonly used propulsion method in this weight class is the turboprop, which is a long-established combustion technology. However, new types of propulsion are now being researched that are based on electric motors with propellers attached to generate propulsion. The advantage here is that the motors, with their high-power density, can be placed at points on the aircraft where they can specifically influence the aerodynamics and thus achieve the best effect. This is called distributed electric propulsion (DEP). Here, many (smaller) electric motors are placed on the wing so that, in addition to propulsion, they improve lift performance in low-speed flight (as already described in the chapter on aerodynamics).

There are various ways to provide the electrical energy for this powertrain. On the one hand, electricity is stored in rechargeable batteries so that the complete powertrain is fully electric and thus climate-neutral and low-maintenance. However, this often requires a battery mass-to-MTOM ratio of around 30% to achieve an acceptable range. Also, unlike a fuel tank, the battery does not become lighter during cruise, which further reduces range.

The second option is to use a hybrid propulsion system, in which a range extender generates power through classic combustion of fuel and with the use of a generator and passes it on to the electric motors. Initially, this necessarily generates a higher propulsion mass, but the benefits of the DEP can save mass elsewhere, reducing the additional weight overall. In *GLAROS*, a hybrid drive with turbogenerator is provided as a range extender. These are already offered, for example, by the well-known engine manufacturers Honeywell [34] or Rolls-Royce [35] with a power range of up to 1000 kW or are currently under development. These engines can run on conventional kerosene as well as on SAF (sustainable aviation fuel) or even hydrogen, which ensures a high degree of operational flexibility and thus makes it possible to react quickly and easily to the fuels available at the airports. In addition, a rechargeable battery is used to temporarily store the generated energy and thus cushion load peaks during flight operations. For example, during power-intensive takeoff or scooping, more power can be made available for a short time than the turbogenerator can provide at maximum. This allows the propulsion weight to be reduced. In addition, in the event of a generator failure, all-electric flight can continue, and an emergency landing can be performed. Current batteries have an energy density of about 200 Wh/kg, but in the next few years, densities can be expected to double as many different industries work together to increase them. However, at about 1000 W [36], power densities are too low to provide a significant portion of propulsion power under full load. Supercapacitors ("supercaps") have high power densities with a long lifetime, but only low energy densities and therefore cannot store energy for a long period of time. Research is already underway to combine the two storage technologies [37] and it is expected that batteries with simultaneously high power and energy densities will be available and ready for use by 2030. If this is not the case, the battery mass will be reduced, and the power of the turbogenerator will be increased accordingly.

*GLAROS* uses a turbogenerator with 600 kW power (mass 300 kg) and a battery with a mass of 170 kg, which stores 68 kWh and generates 400 kW in the short term. Overall, the total power of the propulsion system is 1000 kW, which is higher than the original estimate to respond to the particular challenges from the task. The battery is sufficient to bring the aircraft either back to the base airport or to the lake where it can make an emergency landing in the event of a turbogenerator failure.

A flow diagram of the propulsion system is shown in Figure 5 - Powertrain, which is a modification of the propulsion system of the aircraft concept "aDEPt" of RWTH Aachen University for a transport aircraft with DEP and hybrid propulsion in a similar weight class as *GLAROS* [38].

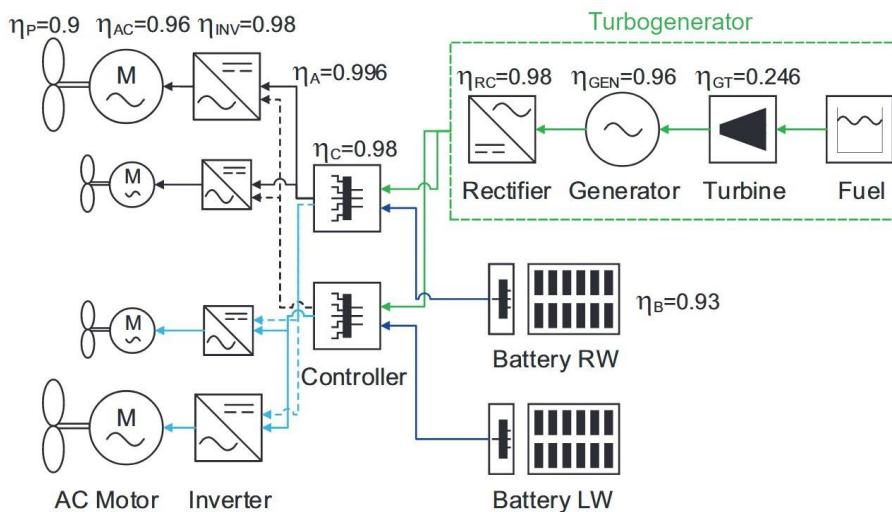


Figure 5 - Powertrain

By chaining the efficiencies along the path between fuel and propeller, a specific fuel consumption can be determined [0.3954 kg/kWh], which is important for calculating the range.

The turbogenerator is located centrally in the wing root area above the payload, allowing the air intake to be placed on the upper side of the fuselage and thus sufficiently protected from splash water. In addition, the drive unit is thus close to the center of gravity, which minimizes the center of gravity shift when loading and unloading the payload. The distance between the fuel tank and turbogenerator is thus also short, which reduces mass. The tanks and accumulators are located in the wing to lighten the wing, which also reduces structural mass. In addition, the installation of the turbogenerator in the fuselage has a positive effect on reducing the noise level of the overall system.

For the design of the DEP system of *GLAROS*, the model of the NASA X-57 Maxwell was closely followed. Ten smaller high lift propellers are provided, attached to nacelles along the wing ahead of the wing. They are optimized for low-speed flight and fold up at higher speeds to reduce drag. The choice of diameter (1.30 m), which is based on the mean aerodynamic chord (MAC), can optimize efficiency [39]. Three of the nacelles on each side are also used to support the suspension of the fowler flaps.

A diameter of 2.2 m is provided for the larger wingtip propellers. They accomplish the entire propulsion during cruise flight and additionally reduce the induced drag. To protect them in particular from contact with the water surface, wing floats are used in the area of the wingtips. The electric drive generally ensures quiet travel.

### 3.5 Hull-Design

The design and the requirements for the flotation system are based on the script for the lecture “Grundlagen des Seeflugwesens” by Prof. Dr.-Ing Wilczek.

The step width is to be considered in relation to the weight and in the, which reduces the spray. This is in addition to the spray rails, similar to Shin Maywa US-2 diverted and reduced. Likewise, the LD-3 container had to be accommodated, which affected the size of the hull. The large surface area of the hull distributes the impact forces, which increase as the sea state grows during takeoff and landing. Likewise, the size increased the stability of the system as it floats in the water. Shock loads that occur when the aircraft touches the water, e.g. scooping, are absorbed by reinforcing the bottom using CFRP sandwich construction. *GLAROS* is made of CFRP, which offers enormous stiffness and weight savings. It is possible to land with the system in fresh and salt water, whereby the launch distance is shortened in salt water due to the density of the water. The corrosion resistance of the CFRP is useful here. A forward bow should run for a long time without curvature to be ideally designed. Hydrodynamic pressure is reduced by the plaining tails. Rudder size is orientated on the Dornier Seastar. T-tail proven configuration and use the advantages of the relatively small rudder area and that no downwind loading by the wing must be made in cruise flight

**Slenderness ratio:** Float length/step width

$$14,3 \text{ m} / 1,89 \text{ m} = 7,5$$

**Sternpost Angle:**  $8^\circ$  [40]

**Step height** should be  $0.05 - 0.08 * \text{step width}$ , maximum 18 cm, average **12 cm** (0,06)

### 3.6 Container modularity

One of the biggest financial challenges of operating firefighting air vehicles is keeping maintenance costs at a minimum while usage is reduced drastically within warm weather seasons. *GLAROS* solves this problem to a point by making use of its highly modular design. The Aircraft is able to be adapted to more than one use case. In order to operate the main purpose of the Aircraft, a modular Water Tank is placed inside the planes storage unit and is connected to the Tubing System.

In seasons in which firefighting airplanes are less needed due to weather conditions, *GLAROS* can be modified to serve cargo purposes. There will be a cargo-exclusive version available.

In Cargo-configuration the main water tank will be exchanged by two conventional LD3 Containers. Due to its high usage and compatibility with other cargo- and passenger aircrafts a standardized Container, like a LD3 standard, has many advantages over a customized build.

Offering space for two containers enables *GLAROS* to take advantage of its maximum takeoff weight. One LD3 Container allows a maximum gross weight of 1,588 kg. With only one full container (by weight), the maximum cargo weight is only used up by 69% (1588/2300). It consequently makes sense, adding a second one, but with

the restriction that each container can have a maximum gross weight of 1150 kg. Most cargo containers are fully filled by volume, but not by weight. Thus, reducing the maximum payload weight of the containers doesn't necessarily reduce the volume of cargo delivered. Both containers are placed in a way that the plane's center of gravity is trimmed to an optimum, regardless of the containers load level.

The *Cessna SkyCourier* is a real-life example of this multi-purpose utilization [41]. Designed to switch between use cases whenever required. A lightweight plane that is able to transport either up to 19 Passengers or 3 LD-3 containers. Thus, the *SkyCourier* has a maximum Payload of 2720 kg.

That limits the weight per container down to 907 kg. The approach made by designing *GLAROS* was to reduce the maximum weight and increase the Cargo transported by Container.

The water tank takes the outer dimensions of an LD-3 container (Figure 6). It is a special designed construction with flanges, openings and inside stability supports. By having about 4,4 m<sup>3</sup> of inner storage it offers more than enough room for the 2,3t of water plus the anti-splash units as well as tubing and vents. However, the all over tank volume is limited to exactly 2,3t so there is no possibility of "overscooping" and so having an overload on the aircraft.

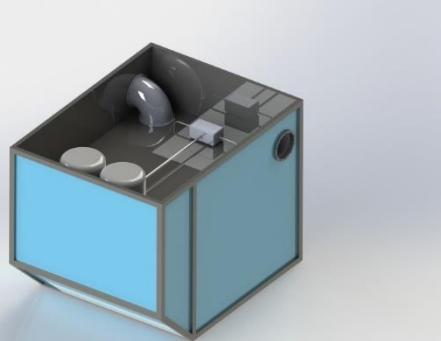


Figure 6 - Water Tank

### 3.7 Scooping mechanism, water tank and release

The intake of water must take place as effectively as possible. To design the system, a big guide for *GLAROS* was the CL-415. The *GLAROS*-Mechanism has two extensible vents located at the lowest part of the airplane. They

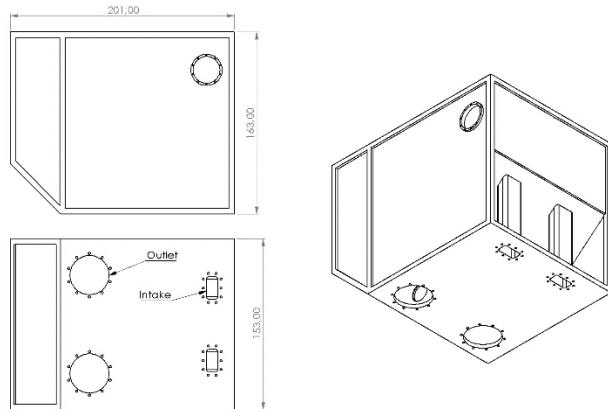


Figure 7 - Side Views of Container

unfold shortly before contact with water. Due to the dynamic pressure the water will be transported via a rectangular shaped tube to the outlet inside the water tank. The tank fills up until the maximum water level is reached. A very important aspect is the limitation of the water volume. If the amount is too little, the airplane will not reach its maximum efficiency. If it is too much, the airplane is at risk of having an overload and therefore being too heavy for the start.

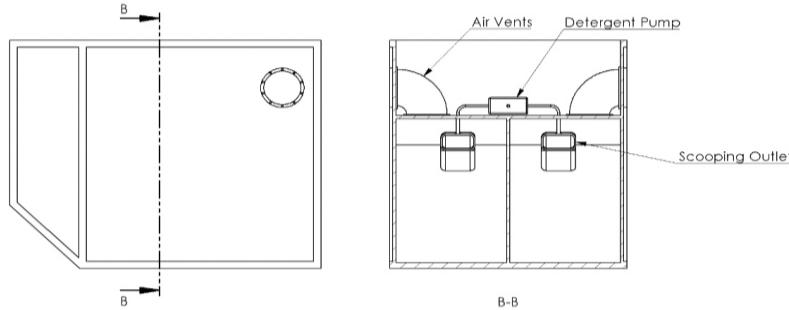
To ensure that the tank does not get overfilled the Air Vents act also as an overflow channel.

Each of these scooping vents are 10cm x 20cm in size. At an average scooping velocity of  $135 \frac{km}{h}$  this results in a flow rate of  $0,75 \frac{m^3}{s}$  cubic meters per second. This value must be corrected by a factor to consider pressure losses at the entrance and exit as well as the inside of the tubing (curvature and resistance). *GLAROS* will be able to collect 2,2t of water in about only 5-6s.

The openings for the airflow are substantial during the scooping process as well as the water release. The high flow rates of water leaving and entering the tank result in drastic pressure changes. These must be equalized as

fast as possible to guarantee optimal waterflow. On the upper part of the tank the opening connects directly to an opening to the outside of the airplane.

Another feature of *GLAROS* is the usage of a biodegradable extinguishing agent. A foam/detergent that was developed by Furukawa Techno Material together with Shabondamaekken K.K. and the Kita-Kyushu City Fire Department in 2001 to 2003 [42]. The technology increases the waters “extinguishing performance”. According to the developers According to the developers the detergent-mix is 17 times more ef-



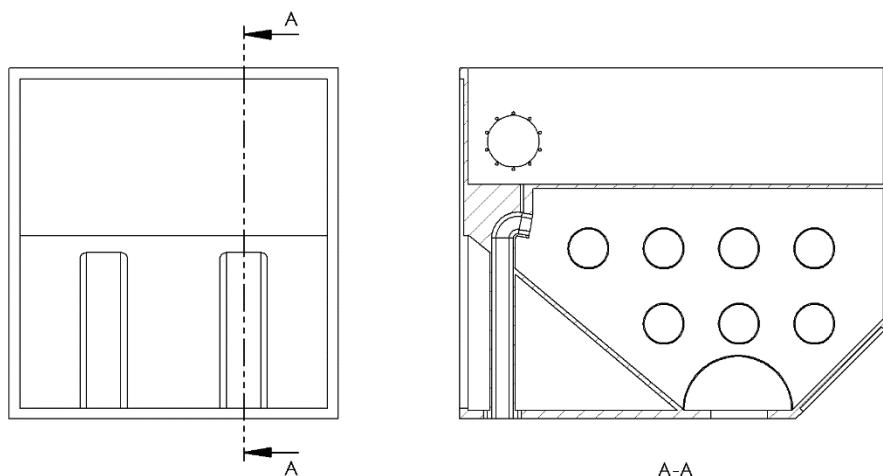
*Figure 8 - Sectional View of Vent and Detergent Tubing*

fective than only using water.



*Figure 9 - Sectional View of extinguishing agent*

sections, there are 8 cutouts within the separation-wall (Figure 10)



*Figure 10 - Anti Sloshing Unit*

### 3.8 Control

As we previously learned, the pilot's job of flying the airplane is linked with a lot of stress and actual risk of life. To drastically scale up the amount of air vehicles fighting wildfires, we can't rely on more people risking their lives. The solution is an unmanned air vehicle (UAV). The implementation of a 5,6t heavy drone with the capability of scooping and delivering 2,2 t of water is not trivial. Thus, team *GLAROS* has put a lot of thought into this and therefore the following large section will be dedicated to it.

To secure the primary goal of delivering the water, we must guarantee total control of the vehicle at all times and minimize the risk of losing the vehicle. *GLAROS* has a series of protocols of procedures and multiple redundancies.

*GLAROS* needs a secure and uninterrupted connection to the main base. As well as receiving instructions from the ground base, the UAV will be autonomous to a high degree. The communication works with the following two technologies:

#### 1. Mobile Network: 4G/5G

Latency:	1 - 100 ms (4G: 15- 80ms and 5G: 1-10 ms [43])
Data rate:	5 Mbps - 10 Gbps [44] (depends highly on location)

#### 2. Satellite connection: Ku, Ka, L-Band

Latency:	250-500 ms
Data rate:	up to 88kbps download and 22kbps upload

The mobile network is much faster and allows theoretically due to the low latency the direct control of the control from the ground station. Even though we are rapidly developing into the 5G era, it is for sure that a lot of remote places will still be unconnected to mobile network in 2030. In the worst case relying only on a mobile network would imply the loss of the vehicle when the connection is lost. There are satellite providers like Starlink, that promise a latency to down to 20 ms [45], combined with a download speed of up to 10 Gbps [45]. This may sound promising at first, but currently there are too many data interruptions, and it is not sure that we fully can rely on this service until 2030. The current satcom providers, which are for the most part Inmarsat and Iridium, still offer 250 ms latency at its best from end to end. As our priority is a permanent connection without interruptions, we lower the requirements for latency and data transfer rate. Therefore, there will be no direct joystick-control for the pilots at the home base. Instead, the pilots give the drone instructions to follow.

The main sensors regarding the detection of the surroundings are optical camera, IR-camera, Lidar and Radar.

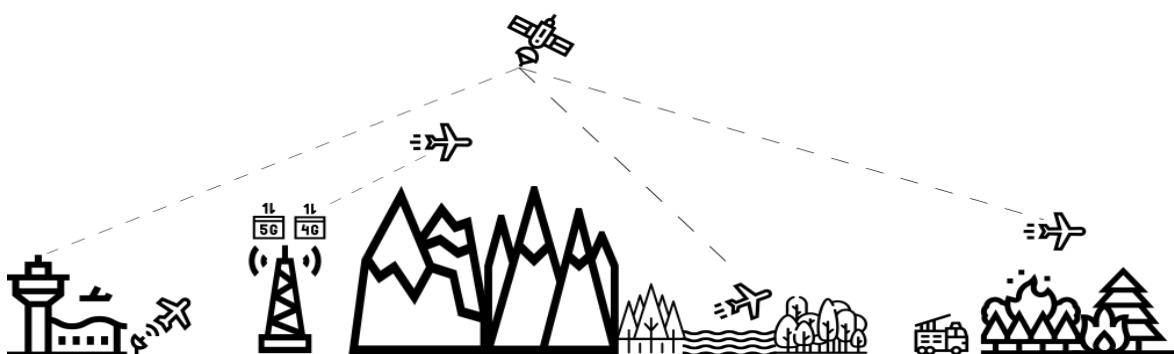


Figure 11-Communication Diagramm

The data rate allows for a live video transmission for the pilots. They can decide if a scooping maneuver can be executed or needs to be aborted because of people swimming near the plane's scooping-trajectory. The pilots give the UAVs commands, where to pick up the water and where to drop it. The IR-camera can accurately locate the flames and the onboard computer calculates the best moment for the water drop. The ImageIR® 6300 Z which is developed by Infratech [46] is a good camera for that purpose. At day and with a clear view, the pilots will have a view of the camera installed on the airplane. The resolution will be as good as the data rate allows it. At night they can switch to the IR-camera. For the measuring of depths, the drone is equipped with a Lidar, together with

a Radar. The Leica Chiroptera-5 can measure distances of up to 1600m [47]. This LiDAR is also bathymetric, which means that it is perfectly suited for our purposes. For bathymetric measurements the maximum flight height is 600m. A radar, although being less precise than Lidar, can achieve even greater distances and is less susceptible to fog or smoke. Thus, every *GLAROS* will also be equipped with one.

At the start of the mission all drones have the same information about the location of the home-base, the fire and the water source. Both the fire and the water source are selected by the operations management. When the UAVs fly to the water source, the LiDAR measures the depth of the water and checks for obstacles before starting the scooping maneuver,. The decision of whether the scooping maneuver is executed or aborted is left to the pilots at the main base. In a real scenario there could be people swimming in the scooping trajectory. To leave this decision up to an AI would be negligently. Such an important decision, which could decide over the life of a human, shouldn't be left to a computer. As a matter of fact, no decision will be left to an AI. A possible application however is the collection of data from *GLAROS* to train an AI, so that after several missions it will be capable of giving advice to the pilots on certain settings of the missions

During all operation time *GLAROS* will be collecting more data that it can send due to the low data rate of satcom. Nevertheless, it is important to give the pilots as much information as possible. For that purpose, the UAVs can communicate and send information between them when they are flying in an area close to each other. Every UAV that lands for a refueling at the base will send all collected information to the base and from there to the pilots at the home base. At the base we can expect the mobile network to be good enough for that.

With the collected data from the sensors an augmented reality map with the active fires is created. The development of the new CL-515 shows that this is possible [48]. The small data transfer rate doesn't allow for a simultaneous transmission but once the data has arrived at the home base the pilots can assess the position of the fires and develop a strategy.

Another discussed idea was an additional small drone flying at high altitude over the operation area. This light-weight drone would provide a constant connection between all UAVs and the base, offering very small latency. One single drone responsible for the communication however constitutes a single point of failure. That idea goes against the *GLAROS* philosophy of having a system as reliable as possible.

### 3.9 Certification

To accomplish the missions, the system must operate in night flight under visual and instrument flight conditions. The system will be in lower airspace during forest fire missions and cargo transport. It is not envisioned that the system will use higher than FL 100. Pilots must be proficient in all procedures for international commercial airports as well as small airfields. To ensure this, pilots must hold an ATPL license and then receive special training on *GLAROS*. The German Air Force pursues the concept of letting pilots for RPAS with an ATPL license control them and then letting them fly business jets with flight experience and proof of hours in order to obtain the license [49].

“SkyGuardian is the base model of ‘Protector’ – the next-generation, medium-altitude long-endurance RPAS (remotely piloted aircraft system) currently being procured by the MoD. The aircraft has an impressive 6000+ mile range; can fly for over 40 hours on a single sortie; can be fully automated including for take-off and landing; can carry a detect & avoid radar system; and can be equipped with a wide array of different capabilities. [...] On 12th September 2021 the aircraft flew from RAF Waddington, in Lincolnshire, to RAF Lossiemouth, in north-east Scotland, flying through controlled airspace and receiving an air traffic control service from NATS, just like any ordinary aircraft. [...]

The flight was controlled through more complex airspace than any previous UAS flights in the UK, requiring NATS ATCOs to transfer control between multiple civil sectors as it skirted the busy Manchester TMA and passed through the Scottish TMA to reach its destination. [...] The procedures for the flight were close to what we do with conventional crewed aircraft, which helped validate those existing methods are equally applicable to controlling remotely crewed aircraft, when they can be detected and perform like SkyGuardian” [50].

This shows that integration into civil airspace is possible. Crucial is the ability to operate under VFR and IFR conditions equivalent to manned aircraft by detecting possible hazards and aircraft and being recognized as such.

It must be possible at any time for the necessary inputs to the system to be carried out and safety measures to be implemented.

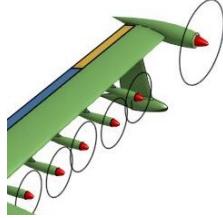
At the moment there is no certification standard for *GLAROS*, equivalent to the dimensions and the mission area is the EASA Certification Specification 25. In the military area the regulation STANAG 4671 is used which covers fixed-wing Unmanned Vehicles between 150 - 20,000 kg. This is used as an orientation. In addition, requirements for automatic landing systems are described in CS25.1329

### 3.10 Risk Management

In order to obtain approval for the aircraft, it is important to prove that it also reacts safely in foreseeable risk situations and has enough redundant systems. Due to the high reliability of the electric motors, the turbo generator and the batteries, a general high level of safety is already ensured.

- I. The worst failure would be that of the turbogenerator, as it would no longer provide power for the drive and control unit. This deficit must be compensated by the batteries. The respective flight phase is decisive for the executed safety-maneuver. In addition, the water tanks are emptied every time to reduce weight and increase range.
  - A. During the take-off phase over the base airport, a traffic circuit is made in order to land safely at the airport again. Due to the automatic control, no Go-Around must be considered.
  - B. During the cruising phase, the distance from the airport or water point is crucial. Here we designed the aircraft with its glide ratio for the given design mission.
    1. Within closer distance to the water source, the plane glides to the water source to ditch.
    2. Within closer distance to the base airport, it glides to the base airport.
    3. In the extinguishing phase/flight phase from and to extinguishing, it slides back to the water point for emergency watering there. It is important to know the exact position of the aircraft and the ground forces so that the water is not drained directly over them but at a safe distance.
- II. A wing tip prop failure would affect the controllability of the aircraft. In such an event, the high-lift props would have to be extended immediately and the pitchable wing tip prop would have to do in-flight feathering. To prevent strong counter steering of the vertical tail the props opposite the failure side throttle down. After such an incident, the drone must go back to the base airport for repairs. The number of propellers ensures that if one fails, the aircraft is still fully able to fly.
- III. Connection loss  
Even with the reliability of satcom, the event of a total connection loss must be discussed. Depending on the respective scenario, *GLAROS* will execute the following command:
  - A. While starting from the base: *GLAROS* finishes the starting maneuver and flies to the next indicated position. On position it begins to circle and scans its surroundings until the connection is reestablished
  - B. While scooping: Immediate cancellation of the scooping-process. Scoops are retracted and airplane proceeds to start and begins to circle on a predetermined spot until the connection is reestablished
- IV. Obstacles before/during scooping maneuver  
If any disruption to the scooping process is detected, it is immediately aborted and the aircraft climbs at full power to a safe height of 1000ft above the ground.

### 3.11 Key Features



#### Distributed electric propulsion

DLR [24] and NASA [25] are conducting studies about it. There are already other concepts with this technology [51].



#### LD3-Water container

This container is already widely used by different aircrafts [52]. The Cessna *SkyCourier* with a similar take-off weight [41] is equipped with three LD3-containers.



#### UAV

The industry of unmanned air vehicles is booming. The needed regulations are firmly believed to be established until EIS [53]. The required technologies are chosen conservatively, taking only yet existing or close to be finished technologies.

## 4 Operational Concept

### 4.1 Main operating Base and transfer

*GLAROS* should have the main operating base in a big international airport or at least close to one. This airport should be ideally located in the middle of Europe, to guarantee a central position. This base is equipped with maintenance hangars to perform on site repairs on the *GLAROS* fleet by its own.

hangars for the *GLAROS* fleet and replacement parts with experts on site. For the cargo missions it makes sense to be located at an airport with high cargo volume. Sufficient space and trained personnel should be available for loading and unloading LD3 containers. There, the containers can be easily loaded and delivered. The existing covered route network can be used to deliver the rapidly needed supplies or firefighting equipment to the mission regions. Outside of the wildland fire season, the location is important for cargo shipments during this time. The pilots and the entire Team in charge of the control of *GLAROS* work from there.

For a bigger Europewide concept, multiple bases are beneficial. For the construction of additional bases, the conversion of a modified military base on Lanzarote can be used as a model.

This base was converted for the use of RPAS at a cost of 500,000 €. One focus was the construction of the control rooms and the renewal of electrical and antenna systems [54].

The manufacturing of the *GLAROS* system goes to the manufacturer, so the operators do not have to be manufacturing or development companies. Major repairs and overhauls can be done by specialists who do not have to be at each base.

For the secondary mission of cargo transport, an airport with a lot of cargo traffic is a good choice. There, loading can take place, personnel can be deployed in a targeted manner and the distribution of cargo can be used in a versatile manner. The covered route network of the airport used can be helpful for transporting support material or replacements or firefighting parts to the mission regions. Outside of the wildland fire season, the location is important for cargo shipments during this time.

Each base should have maintenance hangars on site to perform repairs on its own. Sufficient space and trained personnel should be available for loading and unloading LD3 containers. On Lanzarote, Spain, a military base

was modified for the use of RPAS at a cost of 500,000 €. One focus was the construction of the control rooms and the renewal of electrical and antenna systems [55]. The manufacturing of the *GLAROS* system goes to the manufacturer, so the operators do not have to be manufacturing or development companies. Major repairs and overhauls can be done by specialists who do not have to be at each base.

## Transfer

Being fast is a top priority when it comes to fire. *GLAROS* can be at any point of Europe in less. It is important however to note that wildfires are relatively predictable in terms of season and location. The recommendation therefore is, that the operational times of cargo and firefighting are strictly separated from each other, leaving for example half year for each purpose. When starting the wildfire-season, it can be begun to transfer some *GLAROS* to the more affected regions. For the transfer from the main base to the forward operating base it is possible that additional equipment or supplies are required there. A second tank can be used to carry extra fuel and spare parts to the scene. These containers can be prepared and pre-packed to either be packed in the *GLAROS* when it is transferred or to be moved via airline transport to the vicinity of the mission. Maintenance personnel may need to be planned or brought to the mission site during the mission. This can also happen by air. For that case there can be respectively one *GLAROS* travelling with two LD3-cargo containers and one *GLAROS* travelling with two empty LD3-water containers. Traveling with one container for water and the other container with cargo would lead to a shift of the center of gravity and is thus not intended.

## 4.2 Forward Operating Base

The forward operating base has other requirements as the main base. However, a few should be mentioned. An asphalted runway with at least 332 meters is needed. Due to the short distance, almost every airport in Europe is suitable based on the runway distance. The asphalted runway is important, although for other missions than the main mission, it can be possible, that this base is a water airport.

The second major requirement is a gas station capable of supplying permanently at least one fleet of *GLAROS*. The priority of fuel is a biofuel, but in the case of doubt always the shorter airport available will be selected, as it results in less CO<sub>2</sub> emissions.

What can't be forgotten, is that *GLAROS* as a drone brings no people with it when arriving to a new location. For small fixes, mechanics need to arrive there independently from *GLAROS*, as it is not designed to carry people. Along with them, there must be a person that communicates with the operations management of the firefighters at the fire scene. This person has an important role, as it coordinates the strategy of *GLAROS* with the firefighters and gives orders to the team at the main operating base. For mission command during wildland fire suppression, the *GLAROS* team can provide specialists. Initially on-site, and perhaps virtually after *GLAROS* is implemented in European safety mechanisms, these specialists can be available to mission command to act as an interface to ensure communication between firefighters and pilots. *GLAROS* is capable of collecting and forwarding information that can be of enormous benefit in the fight on the ground as well.

## 4.3 Missions

### 4.3.1 Design Challenge Mission

In order to fulfill the given design mission as best as possible, the distances should be covered as quickly as possible. The mission begins at the Forward Operating Base (FOB) without an empty water tank. *GLAROS* has a range of 465 NM. This allows 8 firefighting cycles before having to return to the FOB. A mission from FOB to FOB takes 203min and 30s. With an additional 12-minute stay at the airport (approx. 10-minute refueling), a *GLAROS* drone can fly 7 missions within 24 hours. This calculation applies to the optimal case without required maintenance, which can be kept very low due to the low-maintenance electric motors and gas turbine. This means that 56 extinguishing water drops with a total water volume of 123,200 liters can be carried out over 24 hours by one drone. To enable the required 11,000 liters in one firefighting attack, only 5 *GLAROS* drones are required.

However, we recommend a fleet size of at least 7 to compensate for possible non-departure due to maintenance and to achieve a higher extinguishing-water-drop-density.

With the minimum fleet size of 5, an average extinguishing water attack of 2,200 liters can be carried out every 5 minutes. A total of 616,000 per 24 hours can be dropped by the 5-drone fleet.

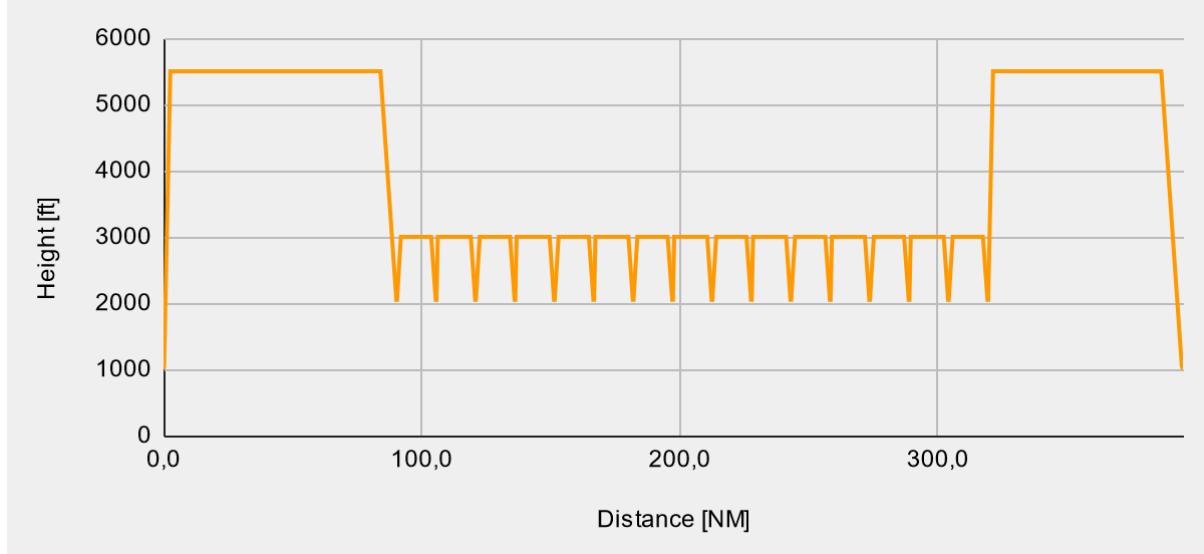


Figure 12 - Distance curve of a mission

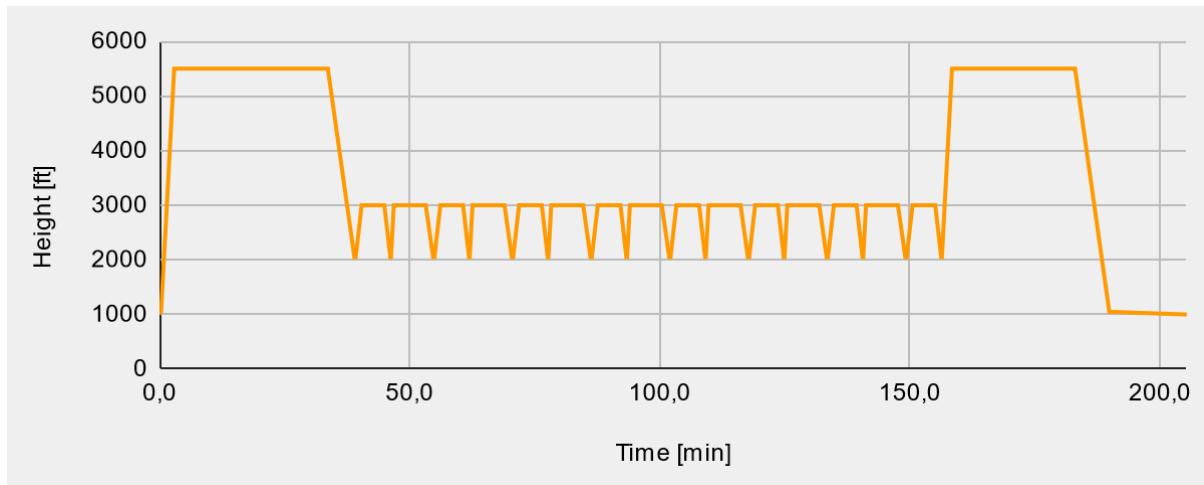


Figure 13 - Timeline of a mission

*GLAROS* is able to fly most of the routes independently using saved waypoints so that the pilot is only required for monitoring. Only the scooping maneuver requires special control by a pilot. These must be carried out one after the other, which makes it possible to monitor several drones at the same time with one pilot. Thus, *GLAROS* results in cost efficiency in comparison to today's aerial firefighting operations. Regular communication between the emergency services on-site and the pilots is crucial for the success of the mission. Thus, a fairly accurate position of the fire can be located, which is then specified with the help of the infrared sensors of *GLAROS*. Air firefighting always acts as additional support for the ground forces, so the coordination and assignment of tasks is carried out by a superior operations center to which the pilots report.

## Flight segments:

- Ascent from Main Operating Base 1,000 ft to 5,500 ft at a rate of climb of 1700 ft/min
- Acceleration to  $v_{cruise}=155\text{kn}$
- Flight direction water source
- Descent from 5500 ft to 2050 ft at a sink rate of 650 ft/min
- Scooping maneuver with  $v_{scoop}=61\text{kn}$
- Ascend to 3000 ft at a climb rate of 800 ft/min
- Accelerate on the  $v_{cruise}$  in the direction of Brand
- Descend to 2100 ft at a sink rate of 800 ft/min
- Water shedding with  $v_{drop}=115\text{ kn}$
- Ascending to 3000 ft
- Acceleration on  $v_{cruise}$  towards the water source  
*(Repeat for 8 runs)*
- Climb to 5,500 ft at a rate of climb of 1700 ft/min
- Acceleration on  $v_{cruise}$
- Flight towards main operations base
- Descend from 5,500 ft to 1050 ft with sink rate 650 ft
- Landing

### 4.3.2 Inland mission

For the Inland mission, a real scenario is chosen as reference. This way the conclusions derived are as close to reality as possible. In the middle of Spain there are not a lot of water sources and every year there are active fires. For a fire occurring at the national park of the Cabañeros the closest water source is a lake located 40 km away. There are some small aerodromes nearby, but the nearest airport, that meets the requirements established for the forward operating base is in Madrid. The distance is to there is about 120 km. Increasing the amount of *GLAROS* used is a strategy to augment the water delivered, but to have a better comparison with the main mission, we will be calculating again with five. The total water delivered in 24 hours is 92400 Liters per airplane and one *GLAROS* can execute a total of 6 water drops before having to return to the base. Because of the high distances, it is much more recommended to use the soap at its highest capability. The regions where the fires occur are usually very dry regions with water problems. It thereby makes sense to bring extra water from the surroundings instead of using a small range aircraft and filling it on site with water that is already barely enough for the local fire-fighters.

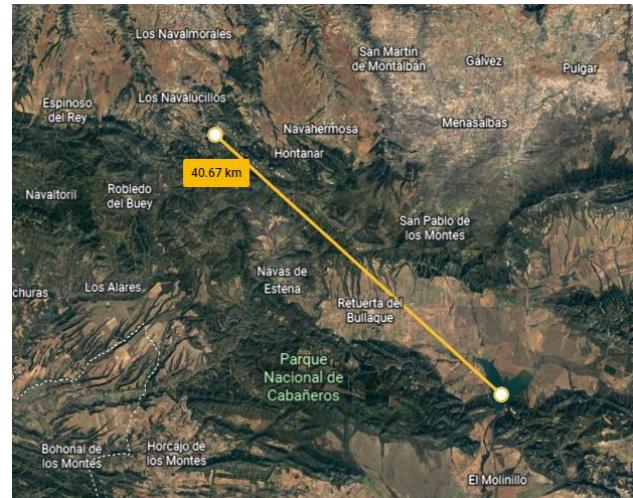


Figure 14 Inland Mission

### 4.3.3 Coastline Mission

For this mission, the 2021 fire of the island Euboea [56] in Greece is taken as a reference. The important point to note of the coastline-scenario is that the overall distances are much shorter. Even though Euboea is the second largest island of Greece [57], almost the entire island can be accessed in less than 10 km from the surrounding water.

This means, that the full speed of *GLAROS* will never be reached. On the other hand, *GLAROS* still offers the big advantage of needing less fuel recharging cycles, than VTOLs. On Euboea there are no airports, however the closest one is the Skiathos airport, located only 37 km from the fire. This airport serves the refueling purposes.

Another important aspect when looking at this scenario is the sea water. Saltwater augments significantly the corrosion. The boat hull is made from CFRP. And the tank is made from aluminum. After the season, a closer eye must be put on the rubber sealings as they are the most susceptible component. What is also important to keep in mind are the sea waves: The boat hull of *GLAROS* allows for waves up to 1 meter. The LiDAR can detect their height very precisely, but it is recommended, that for this scenario, added communication with the coast guard is established to inspect the water turbulence. As the water source is so close to the flames, with this mission, the soap or fire-retardant feature will play a less important role. Although the next big airport is only 33 km away from the fire, *GLAROS* will be starting empty and scooping

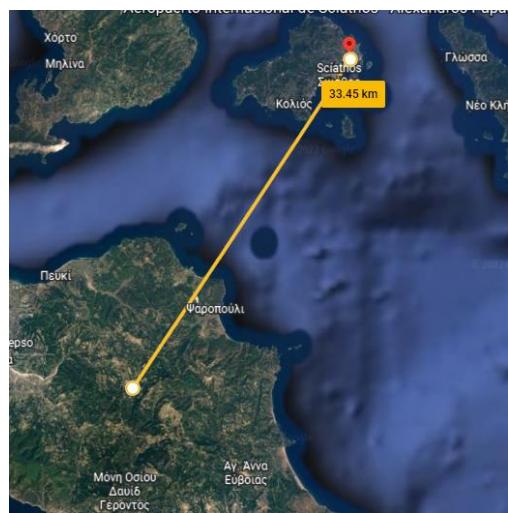


Figure 15 Coastline Mission

ant feature will play a less important role. Although the next big airport is only 33 km away from the fire, *GLAROS* will be starting empty and scooping

### 4.3.4 Cargo transportation

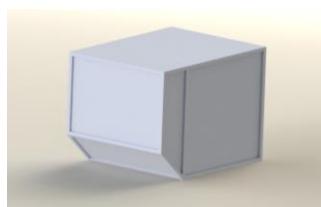


Figure 16 - LD3-Container

As described earlier *GLAROS*'s modular Water Tank will be replaced by 2 LD-3 Containers if needed. The LD3 is a commonly used Standard in Aero-Logistics. Due to its high usage and familiar handling, operating staff would be able to work effectively and safely. Figure 16 - LD3-Container.

The Containers will be loaded from the side, through the Cargo door beneath the left Wing of the Airplane. As mentioned in 3.4 the two Containers have a maximum cargo load of 3,176t.

This Ability makes *GLAROS* a flawless transportation tool for minor and light-weight Shipments, such as Packaging, Medicine, etc. . Owing to compact and remote design it's also perfect for reaching smaller and isolated airports.

In case there is a need for increased transportation quantity there will be an “*GLAROS-Cargo*” option available as well. This model differs from the normal *GLAROS* version by only having a storage unit without scooping mechanism and tubing system.

## 5 Costs

In addition to the direct impact of the fires, such as vegetation that must be extensively renatured, people who lose their homes, insurance money, destruction of human habitats, there are also many other cost points and causes of further destruction and associated costs. These are such as the warming of the climate due to the enormous CO<sub>2</sub> emissions or loosing farm production and absent tourism. In addition, fires directly and indirectly cost not only money but also human lives, on the run or in connection with fighting the fires. This problem requires a rapidly deployable system that is safe for the operators. In the beginning, it can be offered as a European system, which provides rapid and versatile deployment of co-users. The core of the system and all other attachments is the purposeful use of modern possibilities to use the technical progress and not to remain on old systems. Opportunities in the field of drone deliveries have already been lost, hampered by hurdles in the integration into the airspace, the development of Wingcopter or Zipline shows that the innovation carriers have migrated and thus opportunities

were lost, which are now belatedly reopened. No more time should be lost, every meter burned is a great danger to people and costs a lot of money. 2018 were 8500 separate fires in California, direct and indirect losses were 148 billion Dollar [58]. In the whole United States have been 58,985 wildfires in 2021 and these affected 7,1 billion acres. „2020 wildfires in the U.S. caused 16,5 billion in damages“ [59] [60] Greece is investing 2.5 billion euros in the area of forest fire fighting and aftercare. 1.76 billion euros will be spent on the procurement of 36 Air Tractor firefighting aircraft, eight new CL-515s and the modernization of seven CL-415s [60]. The sales manager of the manufacturer of the CL-415 firefighting aircraft estimates the demand in the next 20 years at 160 firefighting aircraft, which can carry 6100l per aircraft and cost 30 million euros each [61]. Scaled up, this would be a need of approximately 445 GLAROS firefighting drones.

Designing, manufacturing, and certifying a new aviation system will cost more than buying an aircraft from a manufacturer. However, there is no system yet that can accomplish the tasks as *GLAROS* can. The uniqueness of remote flying in the field and the safety the system provides to the user and the environment must justify the cost. Any pilot who does not have to give his life in the mission against the forest fire will have to be taken into account. The other important pillar of the system, in this regard, is the system stability and therefore the protection of people. Based on current times for flight tests and the planning of projects of this magnitude, the certification framework can be taken from the Roadmap 2030 for an optimal process. The focus of the system is on the propulsion and control components. The propulsion, which is usually a quarter of the cost, would thus lead to a total system price of 3.2 - 4 million euros. Particularly with novel drone systems, there is a high degree of uncertainty in the cost required to get the system operational. This must take into account the uncertainty in certification that occurs during the process. Uniform European standards are not yet usable. However, the more systems that want to come to market, the greater the political pressure and the costs that arise can be spread in this way. The robustness of all safety systems is conducive to this. *GLAROS*, even in case of main engine failure, still fulfills the possibility to get to an alternative airport, which can be within 45 NM, by using the battery. Even water areas can be used for an emergency ditching. The use of Remoted Aircrafts represents a step forward in aviation, the development of new standards is necessary for the certification of this and other systems will be groundbreaking. *GLAROS* will use the technology sensibly and safely in all areas. The idea of using the system throughout Europe in the shortest possible time further strengthens international cooperation and safety. Maintenance can benefit from the modular design. Defective extinguishing water tanks or tanks requiring maintenance can be easily replaced. Financial saving to other comparable extinguishing system is given, because only one pilot is needed for each drone.

## Roadmap 2030:

The roadmap is calculated according to the schedule for the introduction of the Eurodrone. Airbus and the German Ministry of Defense assume that a newly developed Remoted Piloted Aircraft System can be delivered after seven years starting with the conclusion of the contract.

The Eurodrone is scheduled to make its first flight in 2026 and is also pursuing the approach of designing the system for integration into civil air traffic from the outset.

The advantages of this direct concept are that it will enable the Eurodrone to fly through international airspace without the need for lengthy certification processes. This possibility would be extremely important for a Europe-wide deployment of *GLAROS*.

Germany is to act as the lead nation in the project, which means that Airbus Germany will also be responsible for manufacturing the flight management system, integrating it into the airspace and the ground control station. A great deal of expertise in precisely this area is bundled in Germany, from which *GLAROS* could benefit [62].

2022 September 2022:

Presentation of *GLAROS* at the ICAS 2022.

End of 2022:

Presentation of *GLAROS* to interested European countries.

2023 Mid 2023:

Signature of the partnercountries.

Division of the individual components for manufacturing.

Establishment of different development teams: propulsion, fuselage with landing gear, wings with floats, ground station, certification and extinguishing tank.

	End of 2023
	Production and assembly of the first prototype
2024	Early 2024: General flight tests of the prototype with station prototype 1.
	Mid 2024: Second prototype for certification of scooping maneuver, integration into airspace. Testing with second ground station.
	Two prototypes ensure faster coverage of the required flight tests for certification. Flight testing can continue even in the event of a total loss of one aircraft.
	1) Propulsion testing, day/night operations, general flight tests, firefighting maneuvers 2) Flighttests in different extreme weather conditions, Certification for Cargo
2025	Commissioning of the first link test route for cargo (route proving) Test flights during fires Decision of the partners, at which locations, the system should be established
2026	Preparation of <i>GLAROS</i> sites Rewriting of approach maps, bureaucratic work Possible infrastructure work at airports
2027	Increasing of production of <i>GLAROS</i>
2028	Delivery of individual systems to all stations involved, start of implementation of procedures at airports, e.g. education/training for cargo staff
2029	Integration of operating bases into European <i>GLAROS</i> network, delivery of all systems
2030	Entry Into Service of <i>GLAROS</i>

## 6 Concept Summary

The DLR Design challenge 2022 looks for new airborne firefighting vehicles that solves the problems that the current firefighting air-vehicles have. A fast responding, robust and effective vehicle is needed. The current approach for firefighting aircraft leaves a lot of room for improvement. *GLAROS* is a very well thought out aircraft. The biggest advantages being its modularity, its flexibility and its control.

The lack of aircrafts designed specifically for the combat of wildfires has a lot to do with the uneconomical aspect for the lower season. *GLAROS* can be used all year for different cargo missions. A conversion to the fire-combat mode is a matter of unloading and loading between three containers.

*GLAROS* has a STOL capability that helps it reach even remote locations and deliver cargo to places that have no runway.

We make use of uninterrupted data connection combined with a high degree of autonomous flight. That allows us to have a UAV controlled completely remotely and with no restrictions regarding control distance.

When compared to helicopters even more advantages emerge. *GLAROS* travels faster than any helicopter and has a much higher range because its flight is much more effective. The important downside of *GLAROS* is its relatively large scooping distance in comparison to helicopters. A STOL-take-off-distance is simply not as short as a VTOL-take-off-distance. However, *GLAROS* delivers a much higher amount of water than any VTOL-configuration ever could. Additionally due to the distributed propulsion system the take-off distance is significantly shorter than other airplanes of the same weight class. The distributed propulsion system allows the wings to be much more optimized for the flight instead of mainly for the take-off.

Something we learned in the process is that the design of a aerial firefighting aircraft is very diverse. It is not possible to go into every small detail, as deep as one would want to. Also, it is important to always compare the concept with something existing. A technology jump in the right direction is good, but for this challenge a proven solution is needed. The given maximum takeoff-weight is fully used resulting in a total amount of water delivered per airplane of exactly 2200 liters.

The overall fleet concept is consistent and promises to mark a change in the way firefighting airplanes are designed.

## 7 Requirements checklist

<b>11.000l water in a single firefighting attack</b>	5 Aircraft, à 2200 liters
<b>VSTOL capabilities</b>	STOL capability; 323m take-off; 304m landing
<b>Aircraft should be able to reach small seas surrounded by trees</b>	500m scooping distance
<b>Single Pilot/Remote controlled</b>	Remote controlled
<b>Night Operations</b>	IR-visibility; LiDAR
<b>Poor visibility operations</b>	IR-visibility; LiDAR
<b>Accurate dropping of the water</b>	Tracking through IR; precise dropping controlled per computer
<b>Automatically correction of current wind conditions</b>	Correction by the onboard computer
<b>Scoop maneuver</b>	500
<b>MTOW 5670 kg</b>	MTOM of 5670 kg (designed 5613 with a margin of 5613kg) 500m scooping distance “The density altitude can also be considered to be the pressure altitude adjusted for a non-standard temperature. “ Air Density: $1000\text{ft} = 1,10768 \text{ kg/m}^3$ $2000\text{ft} = 1,07487 \text{ kg/m}^3$ $5500\text{ft} = 0,96586 \text{ kg/m}^3$ Decreasing the density degrades takeoff performance because $v_{stall}$ increases and the engine performs poorly (in hot and high conditions)
<b>ISA + 20°C</b>	turbogenerator integrated in fuselage; electric propulsion system; thereby quieter than a comparable turboprop
<b>Noise protection</b>	Returning before maximum range
<b>Return to refuel and replenish the additives</b>	Maximized through high cruise speed and optimal payload/distance use [Figure 17]; regarding to the Design Mission: 7 missions each with 8 firefighting attacks; 123.200 liters/24h
<b>Maximize the water quantity in 24h</b>	<i>Described in 3.10 Key Features</i>
<b>EIS 2030</b>	<i>Described in 4.3.1 Design Challenge Mission</i>
<b>Design Mission scenario</b>	<i>Described in 4.3.3 Coastline Mission</i>
<b>Coastline scenario</b>	<i>Described in 4.3.2 Inland Mission</i>
<b>Inland region scenario</b>	cargo configuration; distribution from large to small airports/seaports
<b>Consider commonality, modularity, or retrofit considerations to a cargo variant</b>	possibility of converting to cargo transporter; LD3 containers to maximize the generally usability
<b>Consideration of additional roles to maximize usage rate/minimize costs with it</b>	

Table 4 Requirements Checklist

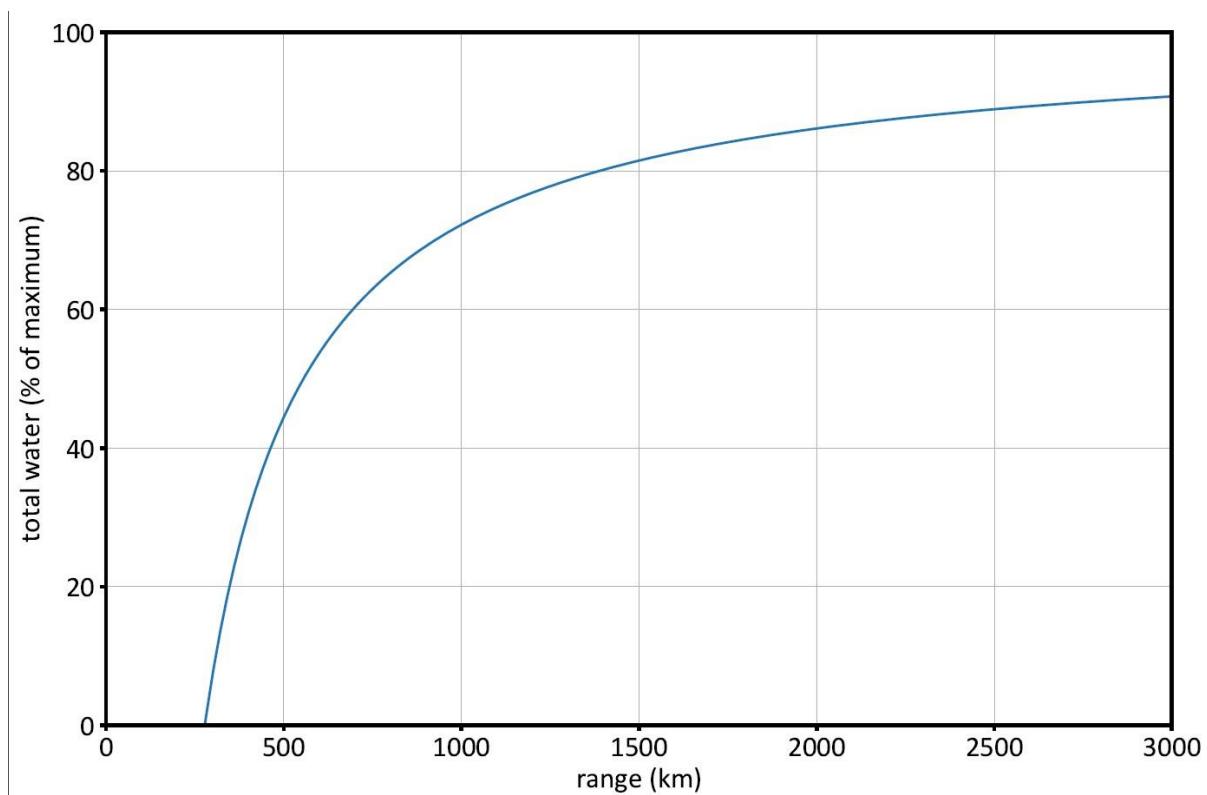


Figure 17 - Water mass to total aircraft mass [%] over range

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