# ENVIRONMENTAL REQUIREMENT ASSESSMENT OF AN UNMANNED AERIAL SYSTEM FOR SUPPORTING LIFE-GUARDS AT LAKE CONSTANCE

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**Abstract**

With the proliferation of unmanned aerial systems, the demand for systems supporting voluntary rescue services arises. In order to develop deployment scenarios and derive technical requirements for unmanned aerial systems for life-guarding services, logbooks documenting operations on Lake Constance between the years 1987 and 2010 of the life-guarding group of Nonnenhorn are analyzed. In this timespan, 212 operations are identified in which an unmanned aerial vehicle could have provided support. Technical requirements are derived by researching the character of the operations as well as environmental conditions during the missions. Besides the independent search, a deployment scenario to support the search in the proximity of the rescue vessel is identified. The latter scenario distinguishes itself by rather simple integration as well as little technical and training requirements.

**Keywords**

Unmanned Aerial System; UAS; Unmanned Aerial Vehicle; UAV; Life-Guarding; Life-Guard; Rescue; Search-and-Mark; SAM

## 1. MOTIVATION

With increasing numbers of Unmanned Aerial Systems (UAS) the range of applications is expanded. This holds also true in the field of safety and rescue services. In 2018, the Australian life-guarding group of Surf Live Saving New South Wales, that operates on Australia's Eastern shore, announced the world's first rescue using a UAS by dropping an inflatable floating device near two men struggling in strong surf [1].

In the examined case, the life-guarding group is stationed in the town Nonnenhorn at Lake Constance and incorporates 80 voluntary members. Being part of a network of voluntary and professional rescue services, the life-guards of Wasserwacht-Ortsgruppe Nonnenhorn secure the Bavarian shore of Lake Constance. For waterborne operation, the rescue vessel "Christopherus" with a minimum crew of four is available. The life-guarding group is typically deployed in joint operations with neighboring rescue services and can therefore serve as a representative example of a voluntary rescue service that secures a major water body which poses increased requirements upon material and training.

For the support of search-, escort- and patrol-missions, the idea to use an UAS was expressed. Hence, this work aims at the identification of tailored operational concepts, the conditions of operation as well as basic performance values for an UAS, based upon actual operations of the past. In order to facilitate implementation, the UAS should be operable by the life-guards of Nonnenhorn independently.

## 2. SITUATION ANALYSIS

Covering an area of 536 $km^2$ Lake Constance is the third largest lake in Central Europe. Neighbouring countries are Austria, Switzerland and Germany. As an oddity, the countries' borders on the lake have never been fixed, therefore it is considered international waters wherever the depth exceeds 25 m. In the international accident statistics for Lake Constance of 2018 [2] 183 accidents are stated. 437 people were rescued, yet 42 people were injured and 13 lost their lives.

The main area of operations of the life-guarding group in Nonnenhorn stretches over the Bavarian shore of Lake Constance between the towns of Langenargen and Lindau. Further operations are conducted in the Bay of Bregenz and the Swiss shore, in the area near the town of Rorschach (Fig. 1).

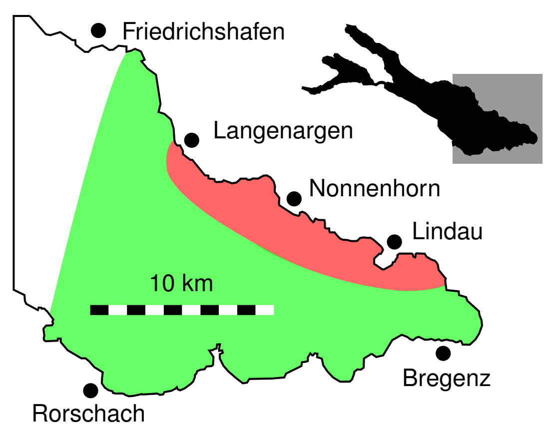


FIG. 1. Main (red) and extended (green) area of operation at the Eastern end of Lake Constance.

The typical distance of operations is ca. 10 km. In this area lie several shallow waters and nature reserves that are difficult to access from water- and land-side. These areas have to be searched with high effort in terms of time and personnel.



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The biggest nature reserve in the main area of operations has a size of 0.27 $km^2$, in the extended area of operation, the biggest nature reserve stretches over an area of 3.19 $km^2$.
The logbook of the rescue vessel records the trips undertaken. For analysis entries of the categories "Recovery", "Rescue", "Patrol" and "Escort" are considered, leaving aside entries documenting maintenance or training trips a.o. During a recovery operation, lost goods are collected. In most cases the goods are already localized before the alarming and only need to be fine-tracked for collection. People are typically not in immediate danger. If people are in immediate danger, an operation is categorized as "Rescue". A search is often necessary beforehand. The category "Patrol" is used to describe operations to inspect a specified area, e.g. for assessing the situation due to drift wood after heavy rains in the adjacent alps. Lastly, the category "Escort" is used when the rescue vessel secures an event such as a regatta or long distance swim, often moving with the field of participants. Operations of the latter two categories are typically planned ahead and conducted during the daytime, with exceptions like a yearly nightly regatta.

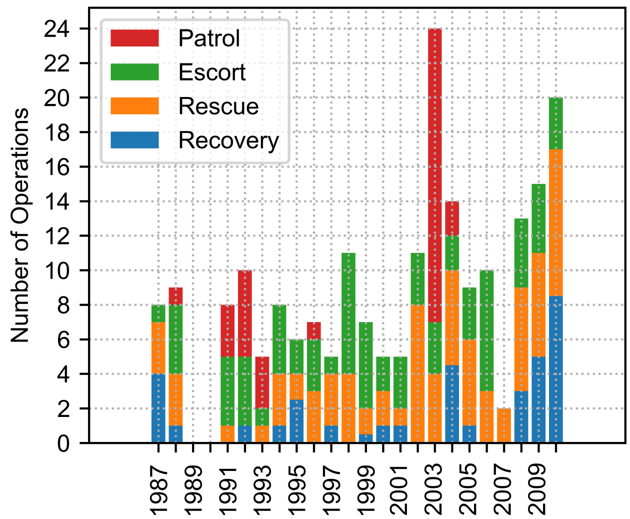


FIG. 2. Number of operations in the years between 1987 and 2010.

## 3. DATA AVAILABILITY

For the analysis, the logbooks of the years between 1987 and 2010, excluding the years 1989 and 1990, are available. In total 212 operations in the considered categories are documented. Since the logbooks contain sensitive content, the entries were anonymized before analysis and numbered.
The distribution over the years is depicted in Fig. 2, the distribution to categories is depicted in Fig. 3. Ten operations are assorted into two categories and considered with half value for each category. For later analysis, the entries are prioritized "Rescue", "Recovery", "Escort" and "Patrol" from highest to lowest. The entries record the following details: date, starttime, endtime, number of crew members, mission category and necessary searches. In some cases the area of operation, modus of alarm and measures taken are specified further. The recorded times describe the time of leaving the harbor and the time of return. The times are typically recorded in multiples of 5 minutes.
In order to assess the operational conditions, data provided by the German weather service DWD (Deutscher Wetterdienst) was analyzed respective to ambient temperature, precipitation and wind conditions. Data of weather stations in Langenargen, Lindau, Zeisertsweiler, Friedrichshafen and Constance are selected for their resemblance to the main area of operations and data availability. Each weather station of the DWD has an unique station-ID for identification. In each paragraph, the station-ID of the scrutinized data's origin is stated.

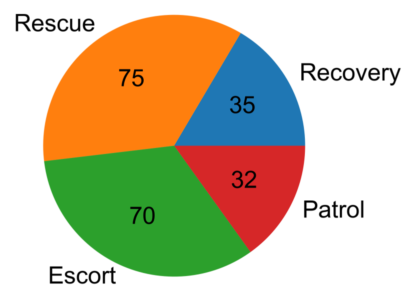


FIG. 3. Number and distribution of operations in the considered years according to categories.

## 4. DATA ANALYSIS

In this chapter, the data will be evaluated according to the operations during day- and nighttime as well as the conditions according to precipitation, wind and temperature. In the categories "Rescue" and "Recovery" a distinction between operations with search and operations without search is being made. During 59 % of rescue operations a search was necessary, but only during 14 % of recovery operations.

### 4.1. Daytime of Operations

The logbooks record 44 operations that were conducted partly during night times, i.e. before sunrise or after sunset. 17 more were entirely during the nighttime. This results in a percentage of ca. 29 % and 8 % respectively of operations that were conducted during the nighttime. Between categories, however, rather big differences arise: while ca. 37 % of rescue operations are conducted partly or entirely at night, only ca. 6% (n=2) of patrols last until less than an hour past sunset. This matches the intuitive assumption that patrols are planned for daylight hours. The biggest percentage of nightly operations can be found among rescue operations which entries mention a search: in this subgroup the majority (ca. 57 %) of operations were conducted partly or entirely at night. An obvious explanation is that people and things get lost out of sight easier in darkness and necessary searches progress slower than during daylight hours. The numbers are compiled in Table 1.

TAB. 1. Percentages of operations conducted partly or entirely at night.

| Category | Partly at night | Entirely at night |
|---|---|---|
| All Operations | 21 % | 8 % |
| Rescue (all) | 21 % | 16 % |
| Rescue with search | 34 % | 23 % |
| Recovery (all) | 17 % | 11 % |
| Recovery with search | 20 % | 20 % |
| Escort | 29 % | 1 % |
| Patrol | 6 % | 0 % |

### 4.2. Durations of Operations

The durations of the operations range between 5 minutes and 14 hours, with an average duration of 2:54 hours and a rather large standard deviation of 2:38 hours. A histogram of the operations in different categories according to their duration is depicted in Fig. 4.

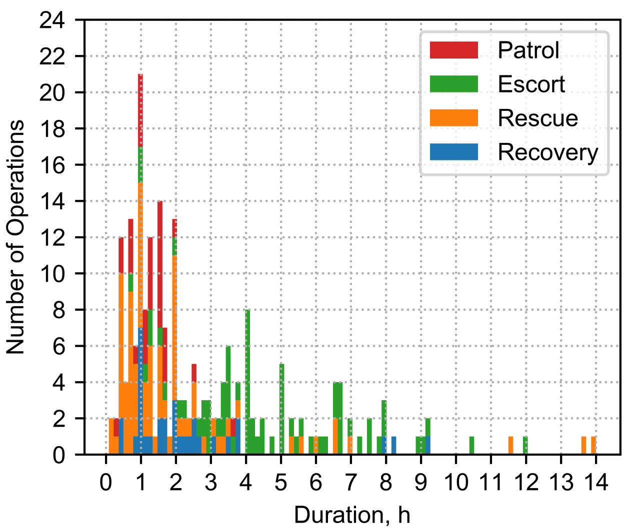


FIG. 4. Distribution of operations in different categories according to their duration.

The maximum value lies at 14 hours, while the 80th, 90th and 95th percentile lie at 4.5 hours, 6.7 hours and 8 hours, respectively. The durations differ between the different categories. While the majority of "Patrol" operations lasted less than two hours, which seems to be a reasonable time to inspect the area around Nonnenhorn, the operations of category "Escort" lasted between two and twelve hours. The entries of categories "Recovery" and "Rescue" scatter more: The majority of operations lasted up to four hours. However, Fig. 4 shows five operations that lasted more than eight hours, with a maximum of 14 hours in the category "Rescue". On the other side, also one of the shortest recorded operations is an operation of the category "Rescue". The reason for this distribution may lie in the rather high number of stopped searches, because a lost person/item was found by bystanders already, was able to save itself or a search was deemed futile, before the rescue vessel reached the area of interest, which result in very short operations on the one hand. On the other hand, extensive searches are conducted if it is assured that someone or something is lost, resulting in long durations of operation. In Fig. 5 the operations are depicted with a distinction being made between operations with and without search. It is evident, that the majority of operations with search last 4 hours or less. The logbooks mention stopped of searches in several cases, yet it is to be doubted that every occurrence was recorded.

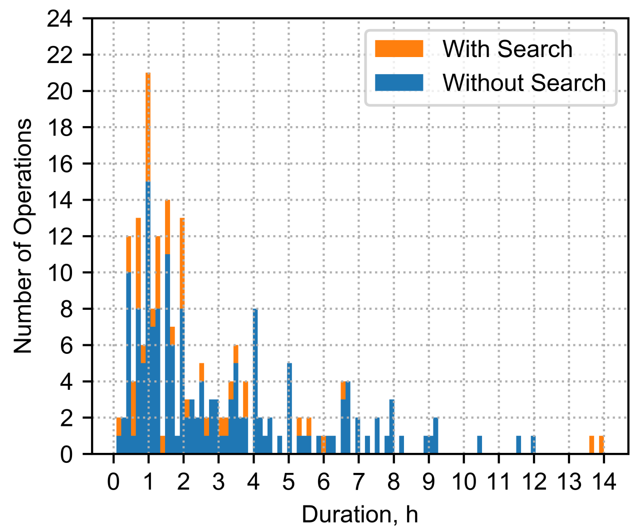


FIG. 5. Distribution of operations with and without search.

Figure 6 shows the distribution of operations when distinguished by daytime. None of the night operations lasted longer than six hours, the majority ended within 4 hours. Also, the rescue operations longer than eleven hours were conducted primarily during daylight hours, typically starting during daylight hours and continuing past sunset. However, it cannot be reconstructed, how many searches during night time were stopped because they were deemed futile due to bad visibility. Finally, after scrutinizing the rescue operations lasting longer than 11 hours, it can be stated that the events leading up to such long operations are highly unlikely, further relativizing the occurrence of night operations longer than 8 hours.

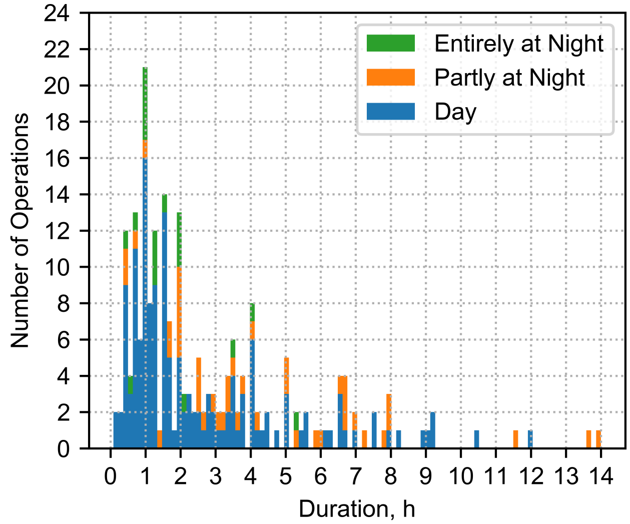


FIG. 6. Distribution of operations of different daytimes according to their duration.

### 4.3. Temperature

For evaluation of temperature, the hourly data of Constance (station-ID 2712) is chosen, due to unavailability of data from Lindau (station-ID 6102) or Friedrichshafen (station-ID 1490) [3]. The values obtained are plotted in Fig. 7.

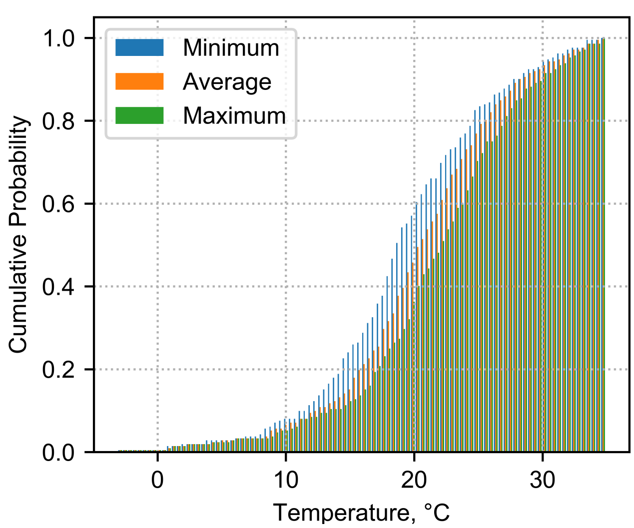


FIG. 7. Distribution of average, minimum and maximum temperatures during operations.

Even though the distance from Constance to the main area of operation is long, the data is deemed more suitable than geographically closer stations due to the Constance's proximity next to Lake Constance, which poses a high influence on temperature.

The temperatures during the hours of operations were extracted and the minimum, maximum and average temperature of the collections determined. The values range from a minimum temperature of -3.1 °C to a maximum temperature of 34.9 °C. During 80% of operations, the minimum and maximum of temperatures measured stay the range between 11 °C and 30 °C. In 90% of operations, the temperature values stay in the range from 8 °C to 33 °C. In 95% of operations the range between 4 °C and 34 °C was not left. It needs to be mentioned, however, that winter operations were only possible starting from 2007 on due to a change of vessel and infrastructure. Yet, out of 50 operations in the year 2007 and later, only during six operations temperatures of less than 5 °C were recorded.

### 4.4. Wind

For the evaluation of wind conditions, the DWD stations in Friedrichshafen (station-ID: 1490) and Lindau (station-ID: 6102) are considered [4]. For every hour, one 10-minute average value for the wind speed is given. Hourly peak values that are to be expected due to gusts are not available. The available recordings of the DWD station Lindau start on the 31.03.1999. Operations of earlier dates therefore utilize data of the DWD station Friedrichshafen, as well as operation 94, for which no data from Lindau is available. Due to gaps in the recordings, no wind data is available for the first 17 operations, as well as operation 78. Therefore, a total of 194 operations is taken into consideration.

The distribution of average, minimum and maximum wind speed is depicted in Fig. 8.

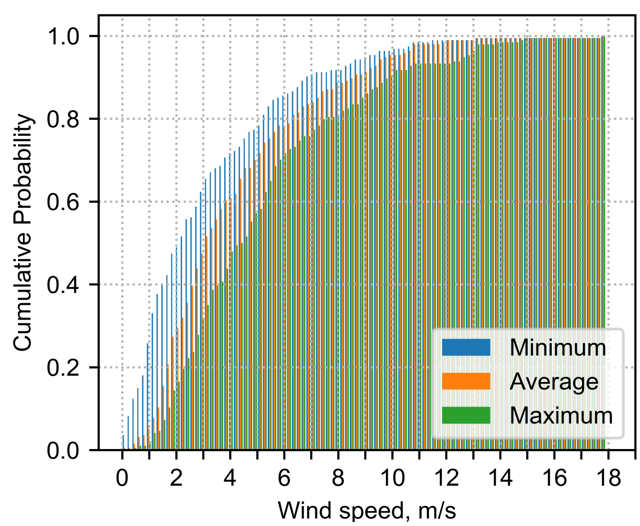


FIG. 8. Distribution of average, minimum and maximum wind speeds during operations.

For each operation, the values of every hour begun are evaluated in order to find the minimum, maximum and average wind speed during a operation. The highest value observed is a wind speed of 17.9 m/s, which corresponds to number 8 on the Beaufort scale. The vast majority of operations, however, is conducted at slower wind speeds: the 80th percentile of maximum values lies at 7.5 m/s, the 90th percentile at 10 m/s and the 95th percentile at 12.7 m/s, corresponding to numbers 4, 5 and 6 on the Beaufort scale.

### 4.5. Precipitation

The data to evaluate the conditions in terms of precipitation originate from weather stations in Lindau (station-ID 3010), Langenargen-Oberdorf (station-ID: 2846) and Zeisertsweiler (station-ID: 4704) [5]. The recordings of the station in Lindau have a gap in the timespan from 31.12.2005 to 01.02.2011, so values are taken from whichever of the other stations has recorded the higher value for precipitation. The data is provided daily, the value represent the amount of precipitation during the timespan from 7 o'clock to 7 o'clock the following day. Therefore, the date of the start of a operation is chosen to collect the precipitation data.

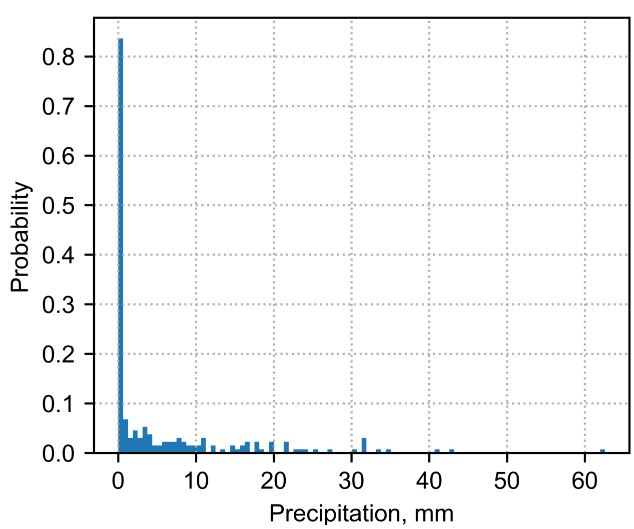


FIG. 9. Distribution of precipitation on the days the operations started.

The results depicted in Fig. 9 show that in over 80% of operations no or little rain has fallen over the course of the day. It needs to be stated, however, that further conclusions are problematic, since the period of time, in which the precipitation occurs, is pivotal for its classification. The maximum precipitation per day in Fig. 9 above 60 mm could have been severe weather if it fell over the course of 12 hours or rather unproblematic if it fell over a timespan of 24 hours. On the other hand, any incidence of rain above a value of 10 mm could have been severe weather.

### 4.6. Summary of Environmental Conditions

The requirements posed on an UAS by the environmental conditions are summarized in Table 2. For each of the values scrutinized the minimum, maximum as well as the 80th, 90th and 95th percentile is given. Note that in the case of temperature, a span is given that comprises 80%, 90% and 95% of operations. In case of precipitation, it is only stated that in more than 80% of operations, no or little precipitation has fallen.

TAB. 2. Summary of environmental conditions during operations.

| | | Percentile | | | |
|---|---|---|---|---|---|
| | Min. | 80th | 90th | 95th | Max. |
| Duration [h] | 0.2 | 4.5 | 6.7 | 8 | 14 |
| Temperature [°C] | -3.1 | 11-30 | 8-33 | 4-34 | 34.9 |
| Wind speed [m/s] | 0 | 7.5 | 10 | 12.7 | 17.9 |
| Precipitation [mm] | 0 | 0 | - | - | - |

## 5. PROPOSED UAS CONCEPTS

Based upon the nature of operations two UAS concepts are considered: one UAS that is capable of replacing the vessel for search tasks during operations of categories "Rescue" and "Recovery" and one UAS that augments the searching and surveillance capabilities of the vessel during operations of all categories.

### 5.1. Independent Search-and-Mark UAS

In this scenario, the goal is the maximizing of the area searched: an UAS is operated by a life-guard from a Ground Control Station located in the town of Nonnenhorn controlling the air vehicle and assessing video data, searching for lost persons or goods in parallel or ahead of the rescue vessel. In case of a finding, necessary data is sent to the rescue vessel, guiding it into position for a rescue or recovery. A schematic overview of the concept is given in Fig. 10

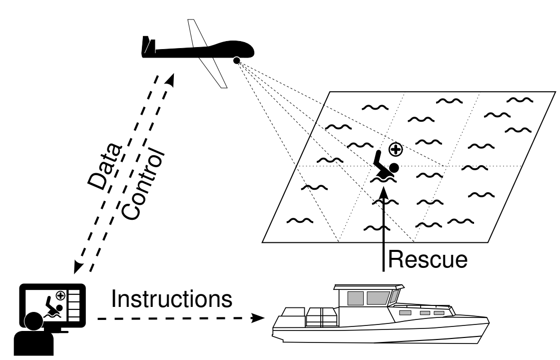


FIG. 10. Schematic concept for a search-and-mark UAS.

The required minimum altitude is 50 m AGL or ca. 345 m

MSL in order to avoid collisions with ships. The maximum altitude may vary according to the proximity of airports (e.g. Friedrichshafen EDNY or Altenrhein LSZR). In order to keep up with the rescue vessel, the minimum ground speed in cruise has to exceed vessel's maximum velocity of 40 km/h.
The necessary mission performance can be estimated by estimating the area covered by the vessel during a search. Assuming that the crew of the vessel can search the waters 50 m left and right of the search path and the vessel moves with a speed of ca. 6.2 m/s (12 knots) (according to statements of the life-guarding group both optimistic values), an area of ca. 2.2 km$^2$ is searched per hour. During an operation involving search of 6.7 h (90th percentile of operations) therefore an area of ca. 14.7 km$^2$ could have been covered. The flight speed during search and the sensors' capabilities need to be picked accordingly.
Examples of commercially available UAS are the Quantum systems TRINITY F90$^+$ [6] or TRON F90$^+$ [7] which can search areas of 7 km$^2$ and 15 km$^2$ respectively, cope with wind speeds of up to 12 m/s in cruise flight state as well as operate in all temperatures experienced. However, the ranges of datalinks stated are stated with 5-7.5 km and >5 km, while the typical distance of operations is 10 km. Nevertheless, such UAS could support or replace the vessel in patrol operations as well as search operations in the proximity of Nonnenhorn, given the availability of suitable sensors.

### 5.2. Surveillance UAS

This concept seeks to increase the progress of searches by increasing the field of view of the crew during vessel-bound searches. An schematic overview is given in Fig. 11.

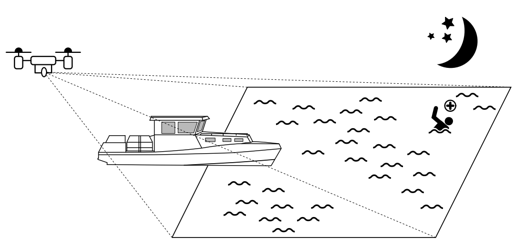

FIG. 11. Schematic concept for a surveillance UAS supporting vessel-bound search.

A UAS follows the vessel, increasing the progress of searches by extending the field of view due to the perspective from above and by carrying optical sensors of different spectra, such as night or thermal vision. A second application of the UAS would be the inspection of special areas of interest such as flats or nature reserves, which the UAS reach the area quickly to give a comprehensive overview of the situation.
In both applications the minimum ground speed of the UAS has to exceed the vessel's maximum speed of 40 km/h. For the support of vessel-bound search, the necessary flight times exceed several hours. For inspecting special areas of interest, the required minimum mission performance is the inspection of an area of 0,27 km$^2$ which resembles the area of the biggest nature reserve in the main operation area. Flight speeds, endurance and sensors need to be picked respectively.
As an example the consumer grade multicopter DJI PHANTOM 4 PRO V2.0 can be operated at wind speeds of up to 10 m/s and temperatures between -10° C and 40° C [8], which is sufficient for 90% or even 100% of recorded operations. Even though no precipitation was found in the vast majority of operations, from a practical perspective it would be advisable for a device to be able to land in the water in order to facilitate retrieval after deployment and withstand mishandling and accidents. Tethering the UAS would enable the power supply to be sustained over such long periods of time, when deployed in vessel-bound search.

## 6. DISCUSSION

In the present work the logbooks of the rescue vessel of the life-guarding group in Nonnenhorn at Lake Constance are analyzed and the environmental conditions during the operations investigated using meteorological data provided by the DWD. Even though the availability and significance of data is in some aspects limited in terms of its temporal resolution and location of measurement, a rather clear picture emerges: The requirements posed upon a UAS by the environment are rather undemanding and in the majority of operations can even be met by consumer grade UAS.
For the implementation of a search-and-mark UAS as described in subchapter 5.1 and the surveillance UAS described in subchapter 5.2, commercial products are available.
Advantages of the first scenario lie in the quick response after alarming, since only one operator needs to be present to operate the UAS. Therefore, the search can commence as soon as the first life-guard has reached the operating station unlike the rescue vessel, for which four crew members have to assemble before leaving. The area of interest is reached faster, which also reduces possible drift of lost persons or items. Disadvantages lie in the complexity of the system's operation in cooperation with other rescue services, both at sea and air. The aforementioned aspects require a high level of specialized training for both the scrutinized life-guarding group as well as neighboring services, therefore hindering rapid implementation.
Advantages of the second concept are the comparably simple implementation and little required training for operation. Its versatility allows the deployment not only for searches, but also for quick, closer inspections during operations of categories "Escort" and "Patrol". Disadvantages are the limited performance, e.g. in terms of achievable air speeds that can make a following of the vessel against the wind problematic.
In order to determine suitable ways for data gathering, processing, transmitting and display, tests should be conducted with different sensors in different conditions (e.g. surface of water in calm and excited conditions, driftwood, different shore vegetations, structures and at different temperatures) as well as data display.

## 7. ACKNOWLEDGEMENTS

The authors would like to thank the life-guards of Nonnenhorn for their service, voluntarily spending their leisure time in training and securing Lake Constance.

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