# SCOUT DRONE: A DRONE-HELICOPTER COLLABORATION TO SUPPORT HEMS MISSIONS

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**Abstract**
The paper presents the idea to exploit the collaboration between unmanned VTOL drones and helicopters to increase the situational awareness of helicopter employed in emergency, medical or search and rescue missions. The need for this collaboration is initially presented in the introduction. Then, after performing a review of the current state of the art that indicates that no system of this type is currently under development, the principles of operation of such a system are expressed together with a first brief description of possible concepts of operation. Finally, some preliminary thought on two of the most relevant elements of this system, the drone and the control station are presented.
**Keywords:** Drones, HEMS

## 1. INTRODUCTION

Helicopter Emergency Medical Services (HEMS) and Search and Rescue (SaR) helicopter operations are types of mission where often, if not always, time is the most critical parameter. SaR operations completed within the first hours after the call are those that have the highest possibility for survival [1, 2]. A similar result could be inferred for HEMS operation from this recent study developed in Poland []rzonca2019helicopter, where the analysis a retrospective analysis based on the medical records of HEMS mission patients, showed an average criticality of NACA 4 (see [3] for a reference to the NACA severity scale), that means that the patient has "injuries or illnesses that may lead to a deterioration in vital signs". Additionally, "an improved odds of survival [for patients transported through HEMS] has been repeatedly demonstrated" [4].

Nowadays, most of the low-altitude flight operations by helicopters take place according to the Visual Flight Rules (VFR), which require the presence of appropriate VMC (Visual Meteorological Conditions) [5, 6]. These conditions rule in particular the visibility and height of the cloud base, which therefore constitute essential information for the planning of a mission by the pilots. In consideration of the fact that for HEMS flights are mission aimed at saving people who may be in danger of their lives, the regulations prescribe slightly different minimums, that seek a compromise between the additional risk that one decides to run and the risks for the health of one or more individuals involved in the rescue mission [7]. In any case, the need to carry out missions in VMC conditions severely limits the operation of helicopters dedicated to missions like HEMS and SaR. A particularly critical risk for VMC missions, considered as such by the pilots too, is Unintended flight in IMC conditions (UIMC), often caused by the rapid deterioration of weather conditions during the mission. The evaluation of the feasibility of the mission is made by the pilot-in-command (PIC) for the mission on the basis of the weather reports available, the analysis of the weather situation at the departure base combined with the experience and knowledge of the characteristics of the mission area, which can be used to correlate the weather conditions in the departure station with those of the site of operations. This incomplete knowledge may be a major cause, that leads to UIMC. In turn, UIMC together with the Low ALTitude operations (LALT), and the Loss Of Control In flight (LOC-I), often correlated with the first two, are considered by US Federal Aviation Administration FAA the three major causes of rotorcraft accidents [8]. Furthermore, the European Union Aviation Safety Agency (EASA), in the Annual safety review of 2019 [9], reported that for the “Helicopter Commercial Operations - Other than offshore” class collisions (with the ground, in flight, with obstacles, etc.) is an important cause of accidents, and identified among the elements that significantly contribute to this type of accident, factors such as lack of situation awareness, failure to identify the obstacles, flight in an environment with degraded visibility (that includes UIMC), or inadequate mission planning. Sometimes, incorrect information may give a false sense of security. On 29 January 2019 a Bell 407 operated by Survival Flight, a US air ambulance, suffered a serious accident . The analysis of the National Transportation Safety Board (NTSB) identified as the main cause an inadequate safety management, which led the pilot to fly in UIMC conditions [10]. The incorrect information provided by the weather map service used by the helicopter ambulance service operator, which did not provide low-altitude weather radar measurements, was identified as important factor. However, the installation of more weather radar in the remote sites that could be the site of HEMS or SaR operations is not feasible. So a different approach should be sought to provide better HEMS and SaR services.

A significant eduction of risks may be obtained through a more extensive introduction of Point-in-Space routes [11]. However, the cost of definition and certification of these routes represents an hurdle to the extensive application. An idea of the of development and certification effort of PinS routes could be inferred from [12]. Additionally, given the intrinsic nature of emergency mission, not all approach routes necessary for a safe mission could be covered by a PinS route.

So, to improve safety it is necessary to provide more accurate information about the status on the theatre of operations, keeping always in mind that this information has to be provided in a timely but flexible manner. The solution proposed here in this paper is based on the development of a drone, the Scout Drone, which, when properly instrumented, can provide essential information for carrying out missions. The drone brought in the operative area by support vehicles, or in some cases launched directly from the rotorcraft, can collect information to be provided to the HEMS mission crew to increase the situation awareness, and so achieve a potential reduction of mission time, together with an important increase of flight safety. Once released, the drone constitutes a real additional "eye" and/or "arm" that can be used by the crew to complete the mission. The scout drone however can be also see as a facilitator to reduce the effort and cost of development and certification of PinS routes [12].

The operative mission proposed for the Scout Drone are the following:

1. Detection of weather or environmental conditions on the area subject to helicopter rescue operations, or on any other area on which the crew needs to know in advance of the helicopter’s arrival relevant information for the completion of the mission.

2. Detection and verification of all the elements that may constitute a danger to flight safety along a route designed to become a PinS route, to allow a more rapid and economical verification and certification of the route itself. The data that will be acquired will relate to the presence and reliability (accuracy, integrity, availability and continuity) of the GNSS signals, and those relating to the presence of obstacles along the path.

The rest of the paper will be dedicated to a description of the the proposed system, detailing the concepts of operations (CONOPS) that have been envisaged together with the main elements of the system.

## 2. REVIEW OF THE EMPLOYMENT OF DRONES IN EMERGENCY MISSIONS

The idea of using remote and automated technologies to increase the capabilities of individual operations and enabling new capacity of system is not new. However, drones seems to have a great technological and economical potential given the relative low cost at which they can provide new data to make decision and manage operations more effectively, included the easy implementation of on-demand operations [13].

The usage of drones ranges from hobbies and recreation, to logistics (Amazon Air Prime [14]), agriculture, surveillance and construction. However it is the sector of emergency, search and rescue where the potential of drones promises to revolutionize critical applications. Of course, the potential disruption brings with it issues and problems that have to be managed like security, privacy and acceptance. However, it can be expected that the usage for public emergency missions can help the acceptance by the general public. Consequently, it is quite frequent to find publications that discuss ideas and experimentations related to emergencies support, e. g. usage in SaR missions during forest fires [15], possible employment for migration flow monitoring and SaR [16], disaster relief [17], or medical product transport [18].

Reading many of these papers it results clear that often the maximum potential in SaR missions can be reached when the Manned-UnManned-Teaming (MUM-T) is exploited, i.e. the capacity to manage in coordinated manner a team of heterogeneous vehicles though a coordinating station. In [19] a set of UAVs talk together to search missing people, sharing information and taking decisions in a distributed way. In [20] it is presented a similar teaming trial for post-disaster relief situations. [15] focus on trials in situations like forest fires, searching of missing people, transportation of first aid equipment or check air quality and gases, where several unmanned vehicles were teaming "to communicate and share recorded information and data, such as images, videos, chemical data, among different interested parties or organizations, and at different command levels (strategic, tactical, operational)". Ref. [21] present the concept for a heterogeneous unmanned team designed for autonomous persistent inspection of offshore wind turbines. Other applications related to the future smart cities and the necessity to enhance radio communications, internet of things and public safety are reported in [22], while [23] reports the on-site experience of using UAVs gained during 2013 Lushan earthquake.

However, the literature review revealed that the MUM-T in SaR applications is mainly related to interaction with ground vehicles or control stations, while very little literature is available on MUM-T between manned and unmanned aerial vehicles. A notable exception is the paper [24], where a classification is proposed depending on the Level of Interoperability (LoI), composed by 6 levels:

- Level 1 – Receipt of information from the unmanned platform via its ground control element;
- Level 2 – Direct receipt of information from a UAV to a manned helicopter (via remote terminal);
- Level 3 – Manned platform directly controls the payload of the UAV directly;
- Level 4 – Manned platform controls the airborne platform & payload, except recovery;
- Level 5 – All functions supported in Level 4 plus the ability to take off and recovery of the UAV;
- Level-X – Refers to the evolving capability of a single manned platform to control multiple UAVs.

Ref. [24] presents several CONOPS that include classical SaR and emergency missions and several military application of MUM-T. However, non of them is related to support to HEMS missions. So, in conclusion the proposal of a Scout Drone system, while being part of the well assessed field of usage of drones to support SaR and monitoring missions, introduces an innovative way to exploit the MUM-T to increase the effectiveness of HEMS mission. Consequently, it comes the necessity to define specific CONOPS that can support the development of the concept.

## 3. REQUISITES IF THE SCOUT DRONE MANNED-UNMANNED TEAMING SOLUTION

To increment the situation awareness of the crew employed in a HEMS mission it is here proposed to develop a solution that is based on a drone exploiting the MUM-T approach. The Scout Drone (SD) is a drone equipped with sensors that can allow the crew to evaluate in advance the practicability of portions of the planned route. The help of the SD could be particularly useful during the final portions of the mission, composed by the approach and landing to the intervention location. However, there could be other portion of mission where the crew may be in need of acquiring further information about the environment that cannot be inferred using the systems available on the aircraft. When unexpected obstacles or meteorological conditions are met the SD could be deployed to identify the existence of possible alternative paths to achieve the mission objective. For this reasons the SD should be designed so that it can be deployed from the helicopter, similarly to what has been proposed and realized by AIRBUS in [24]. The Scout Drone will be equipped with instrumentation capable of verifying, along the portion of the route on which it will be used:

- visibility
- the weather conditions in the final stages of the approach,
- the presence of obstacles along the expected trajectory.

Thanks to the transmission of video and infrared images of the site to be reached, the SD can significantly increase the situational awareness of the crew of the site to be reached, with the particular advantage of having the ability to provide information and measurements on the site taken only few minutes before the passage of the helicopter. Of course, in the most simple solution the SD could be deployed from ground support vehicles or stations (see 1) can fly taking care of sending information on the approach route to the intervention site planned while operated by a trained member of the ground crew vehicle or by the mission crew

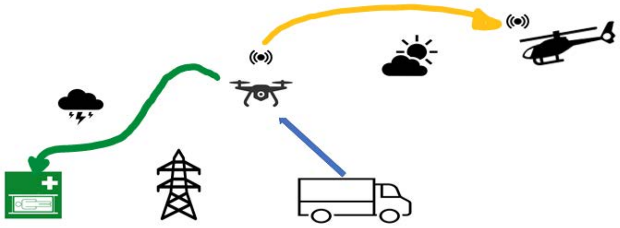

Figure 1: Mission strategy 1 of a MUM-T composed by the helicopter, the SD and a deploying ground vehicle.

on the helicopter, realizing a MUM-T with a LoI of level 2 or 3 in some cases. This solution, however, could limit the applicability of what is proposed to cases in which the intervention area is easily accessible by a vehicle equipped with the SD and the staff trained to release it. This, in turn, would require the creation of a widely distributed network of vehicles and crews trained in the use of the drone, with logistical complications and high management costs. Alternatively, it is proposed to transport the drone on board the helicopter and, if necessary, to release it near the intervention area to help plan the final approach and landing phase. The drone, cold be released by means of the winch at a distance sufficient not to constitute a problem to the drone flight performance and or a danger for the helicopter itself. This type of release of a quad-rotor VTOL drone has been already proposed and tested in Ref. [24]. In this case the drone would travel an ad hoc preplanned approach and landing route, under the supervision of an operator on board of the helicopter. During the flight the drone will send the following information, by means of a dedicated datalink that connects a control interface brought on board the helicopter with the drone:

- identification of unexpected obstacle or other traffic along the route;
- any reduction of visibility that can endanger the flight of the helicopter;
- any presence of weather conditions that could be endanger flight;
- a video of the identified landing spot to identify any possible risk;
- a verification of the reliability of the GNSS and EGNOS signals.

Once the reconnaissance of the route is completed, the scout drone would land in a planned landing area, to be then recovered by the crew, if possible, or by another vehicle at a later time, in case the mission is aborted. De facto, the drone could be able to validate a sort of real time tracking of a PinS based on the performance of the specific aircraft that is conducting the mission, verifying in real time that the identified route can be travelled by the helicopter following current regulations, avoiding entering in UIMC conditions and increasing the crew's situational awareness especially with regard the presence of disturbance and the presence of unexpected obstacles. A real time tracking of a PinS route it is not something that is in any form allowed by the current rules [11], however we think a research in this direction may be useful to understand the feasibility of an approach of this type.

In case of identification of elements that preclude the possibility of navigating the route safely, the drone could either return to the ground, while the crew aborts the mission, or try to follow alternative routes re-planned in real time by the crew, until resources are exhausted. At this stage the possibility to recover the drone from helicopter (as done in [24]), has not been considered, since it may introduce an unnecessary complexity. Before take-off, the drone could then be launched again, possibly after replacing the batteries, to support the tracking and verification of the take-off course, should the change of weather conditions require it.

The information acquired by the drone would be displayed in the cabin through an interface that would integrate: the planned route, including the approach path to the intervention site, and available both as a horizontal profile and as an elevation profile, the information acquired from external databases in relation to maps territorial, meteorological maps, and the information acquired by the SD.

To perform the described missions the SD should be developed according to the following requirements:

- ability to carry out missions from an altitude of 450 m (1500 ft) above the ground and 3000 m (10000 ft) above sea level;
- ability to reach cruising speeds at least of the order of 13-18 m/s (25-35 knots);
- possibility of detecting the presence of obstacles at a distance of 500 m (0.3 nm) around its position, while travelling a trajectory at cruising speed;
- ability to travel, in automatic guided configuration, a flight path of 5 nm in length (which would therefore be flown in an average time of 10 minutes);
- endurance of at least 20 minutes;

- small dimensions and weights of less than 10 kg, such as to be easily stowed and launched from the helicopter;
- ability to fly in windy conditions up to a maximum speed of 15 m/s.

Given the type of task described there seems to be no need to have fully autonomous drone. In fact, while autonomous drones are in principle conceivable, the analysis of the data collected during the missions still require a human intervention to be transformed in pieces of information useful for the helicopter. These requirements represent a compromise that allows the SD to be built using a multi-rotor configuration, given its simplicity and robustness. Wider requirements, in terms of maximum achievable flight speed, endurance and range, would be achievable, only by increasing significantly the complexity and consequently the costs. Future expansions towards more performing drones are possible if the concept is proved successful. It would even be conceivable in the future a system in which to select the drone from a family, according to the mission it will have to support. The aforementioned drone and the related operation should fall within the scope of current EASA legislation [25]. The data detected by the drone and transmitted to the helicopter, once recorded and archived by the control station, should be available for the debriefing of the mission, and allow to acquire a database of information and experience that can be collected, catalogued, and used in followed for the continuous training of the crews.

Using the requisites defined in the previous section it has been possible to define three Concepts of Operations (CONOPS). The CONOPS are the description of how a set of capabilities can be used to achieve a goal.

**CONOP1: SD launched and guided by a support ground vehicle**. A ground vehicle reaches the area of intervention. The drone is released from the ground vehicle and perform a reconnaissance mission collecting data. the data are transferred to the control station and from there to the HEMS mission crew that can then analyze the data and take informed decision on the mission to be performed. A geofencing is implemented to define an airspace where the drone employed in a HEMS or SaR mission is free to move without creating a danger for other flying vehicles.

**CONOP2: SD launched from the ground vehicle but guided from the helicopter crew**. A ground vehicle reaches the area of intervention. In case uncertainties on the status of the area of intervention arise, the HEMS mission crew launches and guides the drone to explore the are of intervention and to clear the approach path to be followed by the helicopter. The availability of the all information in real time by the helicopter can increase significantly the situational awareness. in this case too the geofencing is implemented too. Additionally, the drone is grounded when the helicopter is entering in the area of intervention.

**CONOP3: SD launched and controlled by the helicopter crew**. In this case the drone is transported on board the helicopter and is deployed whenever the crew thinks additional information are necessary to complete safely the mission. The drone is released using the winch, bringing it to a distance where is not significantly affected by the downwash of the helicopter main rotor and then detached. To allow to safely operate the helicopter and the drone in the same airspace, as suggested by Ref. [24], an additional movable fencing system is enforced to protect the helicopter from the risk of collision with the drone. This sytem will define areas around the helicopter position in which the trajecotry of the drone is not allowed to penetrate.

## 4. PRELIMINARY DESIGN OF THE DRONE

To be able to carry out the mission for which it is designed, the drone must carry on board a set of sensors that collect information from different sources and domains: e.g., weather data, images in the visible and infrared domain, distance from surrounding obstacles. This in turn allow the drone operator on board the helicopter to acquire awareness of the surrounding, to support the helicopter pilot in making decisions about how (and whether) to continue the mission. The sensors should have a reduced weight and footprint, so that they can be easily integrated on board the drone and in turn keep the ability to carry payloads and ultimately the footprint and weight of the drone reduced.

To keep costs low, sensors available on the market (COTS components) were chosen. Specifically, the following suite of sensors was chosen:

- a LIDAR with a range of 120m to detect the presence of obstacles around the drone.
- one or more cameras that record the view of the drone in the front and side directions.
- an infrared camera mounted on board to support the flight in poor or night vision conditions.
- an anemometer to measure wind speed and direction

- weather sensors (barometer, thermometer, hygrometer) to complete the suite of sensors that provide measurements of meteorological and environmental quantities.
- GNSS instrumentation capable of providing all information regarding the number of satellites in sight, minimum number of satellites, average PDOP, maximum observed HDOP. In case of presence of EGNOS signal the VPL and HPL and the observed maximum VDOP should be recorded.
- an antenna to transmit data from the drone to the operator.

While the cameras in the visible domain represent the classic payload traditionally carried on board drones, LIDARs and IR cameras represent more sophisticated tools, which can be integrated on board the drone to increase the ability to perceive the surrounding environment. and collect data in different domains.

Similarly, the components that make up the drone will be chosen from COTS components available on the market. The variety of components available on the market allows the development of an ad hoc solution tailored and optimized for the requirements of the specific mission scenario taken into consideration, while at the same time keeping component costs low. The drone footprint requirement is crucial to make SD depoyable from the helicopter. This in turn, imposes the use of a multi-rotor configuration, possibly with foldable arms and / or propellers, in order to minimize the footprint. The use of different drone configurations (for example, the fixed-wing configuration) would involve much larger dimensions that are not compatible with the application scenario taken into consideration.

As for the software, open source solutions are currently being considered. In particular, the use of open source software represents a winning approach in the development of drone solutions, as on the one hand it allows you to reuse a code and knowledge base shared and widely tested by the community, and on the other it allows you to easily integrate third party components in the drone system; this last aspect is particularly important in the context of this project, given the variety of sensors taken into consideration.

## 5. THE GROUND STATION

The acceptability of the system is largely based on the level of interaction of the SD operator through the system itself. The UX/UI plays a very important role in the success of the system and its usability. The control station has the main objective of allowing a quick and safe decision-making regarding the continuation of the mission by the helicopter. This requires the operator to view the information detected by the SD effectively with a detailed connection with the waypoints established on flight plan to be performed. The information that is mainly collected relates to weather conditions, GPS signal quality, obstacles that can compromise or make it dangerous to reach the target. The following ways of representing information can be defined:

- Contextualize information on the position/route of the elements in flight (helicopter, drone), by superimposing the information on a geo-referenced map. The visualization should focus on the flight area covered by the drone, possibly optimizing the scale factor to improve the visualization.
- Introduce warning/alert mechanisms to proactively indicate the presence of particularly critical situations, e.g. particularly critical weather conditions, no GPS signal, obstacle on the path, etc. The warning/alert indications should be commensurate with the severity of the situation, for example warning in case of poor GPS signal, alert in case of absence.
- Operator interaction should be guided by available information, e.g. if images detected by the SD are available, their presence is notified, the operator can decide to use them or not.
- A synthesis of the amount of information available on the map should be performed to avoid creating confusion in the representation of the scenario captured by the drone. e.g. define visualization layers to enrich the information on request: weather layer with visualization of meteorological data on the map, GPS layer with indication of the degree of coverage and signal quality on the route, altimetric layer with indication of the altitude profile of the route etc.

The control station bases the display of information on three different types of content depending on the operational phase:

- Planning: defines the route that the SD will have to follow, including the possible exit point in case of failure. It must be possible to define the route to follow starting from the launch point in terms of waypoints (position and height) that indicate how to reach the target (target zone). Based on the altitude profile, it will be possible to view the heights that the defined route intercepts. In the case of "search and rescue" missions, it will be possible to use predefined search paths above the identified area. Since the mission may vary over time, as the helicopter approaches the drone launch area, the previously defined plan may undergo changes. The planning phase can therefore be conducted both in advance, before the start of the flight, and during the flight by the operator in charge. The planning requires the availability of maps relating to the overflight zone. The control station must therefore be previously configured by loading the cartographic and elevation data necessary to carry out the planning.

- Monitoring: coincides with the flight phase of the drone. Near the launch, the monitoring phase is carried out in which: a) initially, the drone's operational status, connectivity and mission availability are checked; b) following the launch, during the flight, information is continuously transmitted to the control station, the operating status (autonomy, connectivity, ...), flight data (position, height, speed, ...), application data (GPS quality, weather conditions, obstacles ...), multimedia data (images, video streaming ...). The data received, being quite heterogeneous, will be represented according to the type with appropriate formalisms and symbols (mainly following the aeronautical rules).
- Decision support: to meet the primary purpose of using the drone, the information received from the drone will be analysed to calculate a risk index on the execution of the mission by the helicopter. The information detected by the drone will also be available to support decision making: images, reconstruction of obstacles, GPS coverage, weather data.

Despite the distinction in three different modes of representation, the display of the flight conditions of the drone will always be active, i.e. it will always be possible for the operator to switch from one display to another without losing supervision on how the drone is operating. The signals detected by the drone (e.g. obstacle) will always be active, allowing the operator to intervene quickly and effectively following any event that could compromise the mission.

## 6. CONCLUSIONS

The paper presented a solution to develop a system for manned-unmanned teaming system to improve the possibilities to accomplish the HEMS and SaR missions without compromising safety. The system is based on the development of a VTOL drone that could be deployed either by ground support vehicles or by directly by the helicopter through the usage of the winch. The drone works as a deployable set of sensors that can increase the situational awareness of the crew that is performing the mission, allowing to investigate several aspects of the area that will be interested by the helicopter in advance a with a reduced risk. The system has the potential to solve one of the most crucial issue that affect VTOL flight: the flight close to ground and obstacles that is the most dangerous flight phase but also the one where the value of VTOL transport vehicles is really at its maximum. The presented approach has the potential to allow rotorcraft flight safety to make a gigantic step forward, allowing to increase the situational awareness during the phases of the mission that are performed at low altitude close to the ground. The project presented, has been sponsored by the Regione Sardegna, and it is currently in the phase of developing and testing of the first prototypes of both the Scout Drone and the control station. If this prototypical phase will be successful, the project will proceed to the implementation and testing of the integrated system.


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