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Project Aerial Navigation, Air Transport, and Airports

UAV application in Search & Rescue at sea: monitoring of a determined area with the aim of seeking distressed vessels and alert of their position

Gemma Aguado Cuadrado, Álvaro Melgosa Pascual, Alberto De Miguel Izquierdo, Álvaro Ordax Machín
Jesús Perales Díaz, Jorge Luis Sáez de Teresa, Lara Cristina Sánchez Hernández

Universidad Carlos III de Madrid (UC3M)
Leganés (Madrid), Spain

Hundreds of lives are lost at sea every year despite the Search and Rescue operations carried by the Coast Guard organisations all over the world. This figure could be significantly reduced by augmenting the surveillance and monitoring tasks performed by these teams. However, the S&R equipment and technology currently in use seems to be ineffective and very costly to operate on a continuous basis. Thus, there exist a gap in S&R operations that can be filled with UAV technology as it will be exposed in the present document.

The main goal of this project is to analyse the current technology in order to, using an iterative methodology, design an innovative UAV system that could accomplish surveillance and monitoring tasks in a predefined maritime area. In this case the selected mission will be focused in the Mediterranean Sea due to the current migrant crisis that affects Europe, studying several ways of solving this problem and selecting the most appropriate one.

***Index Terms*— Unmanned Aerial Vehicle, Search and Rescue, Monitorisation, Swarm**

1. Introduction

A. Background

The first remotely radio controlled models appeared in the early twentieth century as small prototypes for potential manned aircraft. Afterwards, and during most of the century, the investigation and development lines were directed towards the military scope, in which the main objective of UAVs, which is still applied today, was to substitute manned aircraft in three types of military operations, commonly known as “the three D’s”:

- Dirty: operations performed in a contaminated environment.
- Dangerous: operations entailing some risk for the pilot.
- Dull: long and monotone operations, such as monitoring operations.

In the 70’s and the 80’s, efforts were directed to improve the technical characteristics of these vehicles. But it was not until the late 80’s when a revolution in the industry took place with the introduction of the GPS navigation system, whose accuracy in geolocation opened a whole new spectrum of possibilities.

Regarding the civil sector, the potential applications of UAVs in the non-military field are much more diverse. Nowadays these vehicles are in the process of finding new niche positions in the civilian market, having been introduced up to now in different industry sectors such as agriculture, forest fire fighting, search and rescue, aerial photography, cartography, or security and surveillance, among others. Despite the latter, the use of UAVs for civil purposes is relatively recent in comparison with the military sector. This late implementation in the civilian field was caused mainly by two limitations which are of minor relevance in the fighting industry: legislation and economy.

With respect to the economic factors, i.e. cost of ownership and operation, there is an important difference in economic investment between the civil and the military sectors. Nevertheless, the statistics of 2015 are expected to show a breakout in UAV investment, as these vehicles have already raised $172 million in equity financing in 2014, more than the previous three years combined [1].

In relation to the legislative factors, given the dynamism of this incipient industry, it is necessary to create a flexible and updated regulation which allows the industry to evolve and grow within some limits of safety and order rather than imposing technological barriers that lessen the possibilities of development. However, the technical characteristics and operations of UAVs are very disparate, making the creation of a regulatory framework an extremely complex process. This fact has led to a preliminary incomplete and already outdated legislation which is damaging the economy of the most pioneer countries in this sector. Just to pose an example on this fact, U.S. losses are estimated in $10 billion in potential economic impact for every year the FAA does not regulate this aspect [2].

Apart from the economic and regulatory difficulties, the main technical obstacle of UAVs nowadays relies in the limitation of the ”see and avoid” capabilities, which makes the coordination between manned and unmanned vehicles extremely difficult. Therefore, efforts are being concentrated in increasing the automation of the UAVs to reduce the human factor, and ultimately improve the reliability of these vehicles.

Hence, these three previous factors, technical, economic and legislative, restrain the evolution of the UAVs in the civil market. This appears contrary to the interests of many industry sectors towards the implementation of these vehicles with the purpose of improving the efficiency of their operations or developing new ways of exploitation. Thus, for this implementation to become a reality the industry needs to evolve in the following sequence: first it is necessary to improve the reliability of the vehicles, then create an appropriate regulation, and finally improve the affordability and availability of these devices [3].

B. Social concerns

Among those previous interests of the industry to implement these vehicles, they are not only economic but also social interests. This is the case of the Search and Rescue sector, which may be the only application in which the use of drones is directly related to helping people in life or death situations. Therefore, if properly implemented this new technology could be saving hundreds of lives per year. This goal is what should emphasize the priority of the Search and Rescue sector in terms of UAVs development and implementation.

Nowadays, one of the best examples of the importance of this field is the worrisome situation of the refugees in the Southern Europe. According to the United Nations Refugee Agency [4] in 2015, 1,015,078 refugees arrived to Europe through the Mediterranean sea and 3,771, which accounts for the 0.37%, died or went missing in their attempt. So far this year, 184,801 people have reach the European coasts, whereas the number of lost lives reaches 1,361 people, which implies a 0.74%, twice the last year's percentage. This increment in the rate of human losses clearly states the need of improving the insufficient capabilities of the Search and Rescue sector.

As an example of the limited resources of S&R, in Spain all the manned rescue operations are performed with a lacking aerial equipment consisting of 11 helicopters and 3 planes [5]. Unfortunately, the current technology of UAVs is far from being applicable to rescue operations. Nevertheless, the tracing power of these unmanned vehicles greatly exceeds the visual tracking skills of any trained human. For this reason, increasing the automation of the sector by implementing unmanned vehicles will lead to a rise in the efficiency of S&R services.

C. Project focus

With this social motivation, the main goal of this project is the design of a prototype of UAV capable of fulfilling the specified requirements of a given Search and Rescue mission, which will consist in the surveillance of a given maritime area for the detection of small vessels, assumed to be carrying refugees. For this ultimate end, several secondary objectives will be addressed:

- To obtain a deeper knowledge of the State of the Art of both the Search and Rescue sector and UAVs sector separately,
- Identify the applications and level of development of the UAVs inside the S&R field in order to identify a niche position in the market [1], and ultimately,
- To design a vehicle able to perform a monitoring operation in a specified area with the objective of locating vessels, and to study its viability within the current economic and regulatory scenario.

2. State of the Art

This section will consist of a preliminary overview of the social concerns raised by the European migrant crisis, followed by the State of the Art of the S&R and the UAVs sectors (treated separately), as well as the current implementation of UAVs to the S&R services.

A. Socieconomic aspects

The Coast Guard of each country is responsible for an array of maritime duties, from ensuring safe and lawful commerce to performing rescue missions in severe conditions. Search and rescue (S&R) is one of the Coast Guard's oldest missions. Warding off the loss of life, personal injury, and property damage by helping boaters in distress has always been a top priority. Coast Guard S&R response involves multi-mission stations, cutters, aircraft, and boats linked by communications networks.

In 2014 the budget of the United States Coast Guard amounted for $10,321,874,000 [6], while the budget of the Spanish "Salvamento Marítimo" barely reached 168.37 million euros [7], from which 3.38 were dedicated to investigation.

From a humanitarian perspective, the main goal of the Coast Guard of each country is always the prevention of the loss of human lives at sea. However, it must be acknowledged that the inherent danger involved in the maritime environment makes this goal difficult to achieve.

Nowadays the Mediterranean Sea is a hotspot scenario for maritime immigration that concerns the S&R institutions of different European countries from this mentioned humanitarian perspective. For this reason, this will be the scenario considered for the case of study.

According to the statistics of "Salvamento Marítimo" [7],,in 2014, 423 boats were detected crossing the Mediterranean Sea trying to arrive to the Spanish coast. 3,421 people were rescued, 1,853 assisted, 13 were dead, and 43 lost. However, this data differs from the one obtained from other organisms such as the UNHCR (Office of the United Nations High Commissioner for Refugees) [4] that assures that 3,805 people came to Spain from the sea in 2014. From all these people, 25 died in the sea. The difference in the figures from these two institutions is due to the fact that, although the Spanish "Salvamento Marítimo" is one of the few European organisms that publishes the numbers of migrants who died in their attempt to the Member country, it only identifies such corpses collected inside Spanish territory and not those found in international waters.

[1] As it will be argued subsequently, this niche position will be restricted to surveillance S&R operations.

As previously introduced, nowadays Europe is suffering a migrant crisis: so far this year, the ratio between lost lives and arrivals to the continent has doubled the proportion of last year

Maritime safety missions measure the effectiveness of the collective prevention and response efforts using a ma. Simply stated, this measure accounts for the number of lives saved versus the number of ”lives in distress”. In here, ”lives in distress”, refers to persons in peril caused by some extraordinary event (e.g. injury, material failure of the vessel, environmental conditions, etc.) beyond the inherent danger of the maritime environment. When a life is in distress, there are three possible outcomes; the life is saved, the life is lost or a person remains missing at the conclusion of search efforts. The ”lives lost” portion of the measure further acknowledges that some of those lives will be lost before the Coast Guard is notified or has any chance to affect the outcome. Therefore, ”lives lost” is further divided into ”lives lost before notification” and ”lives lost after notification”. Nevertheless, the missing persons are not divided into “before” and “after”, but they are all accounted together for the purposes of the primary lives saved performance measurement: Percent of lives saved from imminent danger in the maritime environment. To calculate this measure, equation (1) is used [8]:

$$\frac{LS}{LS + LLB + LLA + LUF} \tag{1}$$

Where:

- LS means ”lives saved”.
- LLB means “lives lost before notification”.
- LLA means “lives lost after notification”.
- LUF means “lives unaccounted for” or missing.

In the following table it can be observed the percentage of people saved by the United States Coast Guard after notification in waters over which it has S&R responsibility. As improvements are expected to be done in the S&R operations, they are expected to be reflected in the response performance as shown below with planned periodic adjustments to the benchmark.

Table I: Percentage of lives saved [9]

Fiscal Year	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Before improvements	76%	76%	76%	77%	77%	77%
After improvements	83%	83%	83%	84%	84%	84%

Coast Guard S&R response involves multi-mission stations, cutters, aircraft, and boats linked by communications networks. However, this technology is not able to cover the needs of monitoring and surveillance due to the fact that the costs of developing these operations with manned vehicles is extremely elevated as it will be explained in the next section. So there exists a vacuum in this field that has to be filled.

B. Search and Rescue surveillance operations

It should be pointed out at this point that in spite of the fact that the current technological state of the UAVs nascent industry still does not permit the application of unmanned vehicles for Rescue operations, UAVs are irreplaceable in surveillance tasks, since their available technology is much more accurate than the visual search procedures performed by manned S&R teams.

Therefore, this section will be devoted to the analysis of S&R monitoring operations currently performed with the use of boats, helicopters, and satellites:

- Boats: The main advantage in the usage of boats is that at the same time someone is localized on the water, it is possible to provide help to him. However, the capacity of a boat to monitor a certain region in the sea is very limited due to the short visual range (the boat is located in the surface of the see), and also to the speed at which the vehicle can move, which will be smaller as the size of the boat (this is, the capacity to carry the survivors) increases. Therefore, even if boats are needed to perform rescue operations, they do not seem to be a good option for the task of surveillance.

- Helicopter: Concerning the helicopters, as it occurs with boats, it exists the advantage of providing immediate rescue operations once the survivors have been found due to the capacity of the helicopters to perform a hover flight. Nevertheless, the operational cost of helicopters is very high: in Spain, for each hour a helicopter is airborne, Civil Protection spends 1639 € [10].
  The main source of this cost is the fuel consumption and the expenses associated to the salary of the workers in the helicopter (the staff of a helicopter for search and rescues operations is composed of 4 people: a pilot, a copilot, a worker on the crane, and a rescuer to go down and attach the survivor to the crane). Regarding fuel consumption, the fact that helicopters are less efficient than airplanes reduces their endurance, which constitutes a major drawback for surveillance: the time employed in returning to the base and refuelling cannot be harnessed for monitoring purposes. As a matter of fact, national Search and Rescue agencies use helicopters so as to give a fast response to an alert warning, not as a surveillance vehicle [11].

- Airplanes: Airplanes can be thought as a good option, not for the very rescue operation, but for surveillance due to its good endurance (which is indeed maximized with turboprop engines). In Spain, there are currently 3 airplanes working in surveillance operations. It seems not a sufficient fleet to cover the whole Spanish coast, but again, the high acquisition, maintenance and operation costs of a larger fleet is a substantial problem [12]. In spite of this, the Spanish fleet has been enhanced with a new model of airplane and new technology, since as the very government admits: ”Airborne surveillance has been demonstrated as the most useful and efficient tool to enhance maritime safety” [13].

- Satellites: Satellites can perform photo surveillance, a

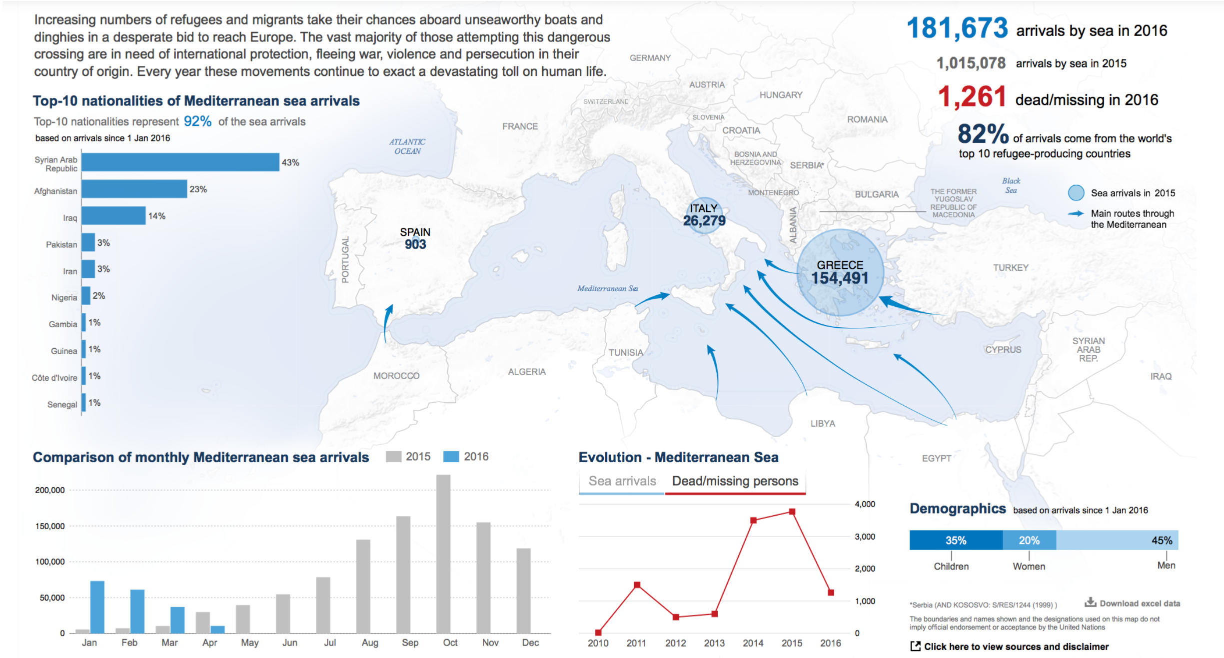


Figure 1: Migration patterns in the Mediterranean sea [4]

technique that may seem to solve the problem of monitoring a given area on the sea. However, these services can only be provided when the satellites are above the region of the Earth's surface which they are aiming at capturing. Obviously, this creates a strong dependency on the periodical translation of the satellite, and therefore, specific points could not be observed when required.

Therefore it can be concluded that, although their task in Rescue operations cannot be replaced, the costs and other functional drawbacks make manned vehicles be very limited to perform surveillance operations.

C. Current development of UAVs sector

Nowadays, due to the high needs of investment in the sector, almost all the UAVs development is been performed by private companies or by the army. Some representative examples of these models can are exhibited in Table II.

This table shows a wide range of sizes and capabilities. Concerning those of larger dimensions: Hermes 450, Predator, Reaper, Herti and Hunter, all of them were developed by the military sector due to the highly advanced technological equipments on-board needed in the operations of the defense field. On the contrary, the UAVs of civil application, such as Manta B, ScanEagle or Fulmar, have a lower weight capacity since their requirements are not so demanding.

Regarding the military sector, it must be considered that the endurance of the UAV depends mainly on its size, and, since most of them are used for aerial operations related with espionage and defense issues, they require high level of autonomy and resistance. These are the reasons for such improvement of these characteristics.

These vehicles use engines with different power levels, from 39 Kw for the case of the engine Wankel used in the Hermes 450, to 712 kW in the engine AlliedSignal Garrett AiResearch TPE-331-10T used in the Reaper. Nonetheless, all of them are provided with exterior blades for a more efficient configuration.

With respect to the smaller vehicles, as mentioned beforeall the UAVs for civil use are included in this group, although there are also some of them dedicated to the army, as in the case of Gull 24, Raven B and Shadow 200. The first and the second are very small with the purpose of being carried by a soldier to the area of use. The last one, is used for specific operations with higher requirements, such as advanced surveillance and reconnaissance missions.

The rest of the designs in the table, are produced by private companies, and destined to different purposes: Manta B and Silver Fox are both used for tracking small vessels and entangled whales, and also for identifying and documenting the activities and locations of individual vessels; Fulmar is used for the identification of shoals of tuna; Integrator for any intelligence, surveillance and reconnaissance task on land or at sea; ScanEagle is intended for fish-spotting; Phoenix is an all-weather, day or night, real-time surveillance UAV; and finally, eBees is destined to aerial photography.

Prominent among these designs are the ScanEagle and the Fulmar, which will be treated more deeply in the next lines. The first one has an endurance of more than 24 hours with only 18 kg of MTOW and a payload capacity of 6 kg. It is currently being used for a handful of different operations, from monitoring the distribution and population of seals in the Bering sea to seizing over 1000 lb of cocaine from a fast boat in the Eastern Pacific in an operation led by the US Coast Guard. The second model, has an endurance of 12 hours with a similar MTOW and payload capacity of 19 kg and 8 kg, respectively. This vehicle is currently being used for helping

Table II: Representative UAV models

Manufacturer	Model	Payload(kg)	MTOW(kg)	Wingspan(m)
Warrior	Gull 24	2.0	18.0	2.7
Aerovironment	Raven B	0.2	1.9	1.4
Adv. Ceramics Research	Manta B	6.8	23.5	2.7
Elbit	Hermes 450	150.0	450.0	10.5
InSitu	Integrator	23.0	59.0	4.8
InSitu / Boeing	ScanEagle	6.0	18.0	3.1
Adv. Ceramics Research	Silver Fox	2.3	12.2	2.4
General Atomics	Predator	336.0	1020.0	14.8
BAE Systems	Phoenix	50.0	177.0	5.5
General Atomics	Reaper	1700.0	4760.0	20.0
AAI	Shadow 200	36.0	209.0	6.2
BAE Systems	Herti	150.0	780.0	12.6
Northrop Grumman	Hunter	226.0	890.0	10.4
SenseFly	eBee	0.0	0.73	0.96
Aerovision	Fulmar	8.0	19.0	3.0

the local fishermen to detect tuna shoals making use of its ability to perform sea-landing.

Therefore, the relative high endurance of these vehicles compared to their dimensions, make them suitable for a wide variety of applications as it has been stated above. In particular, the two previous models could represent an important advance in the inefficient S&R surveillance operations as it will be discussed later on.

In the following section, a few models that have been directed to the S&R sector will be addressed in more detail.

D. Implementation of Unmanned Aerial Vehicles to the Search and Rescue sector

On the basis of the above, on one hand, from the State of the Art of S&R it was concluded that the monitoring operations carried out by manned vehicles, such as helicopters, boats or airplanes, are extremely expensive and, consequently a larger fleet is unaffordable.

On the other hand, from the State of the Art of UAVs it was extracted that there are vehicles, such as the ScanEagle and the Fulmar, which are currently being used in other industry sectors for different purposes, that can signify the resolution to the exposed problem about manned S&R monitoring operations.

Therefore, as mentioned before, in this section the current applications of UAVs in the Search and Rescue sector will be exposed.

Nowadays, one of the most relevant projects concerning the implementation of UAVs in S&R operations is the ICARUS project [14], developed by the European Commission's Directorate-General for Enterprise and Industry. The general aim of this project is the development of robotic technology which can provide assistance in critical situations that call for search and rescue services. In particular, one of the main lines of action is the use of UAVs in the S&R operations at sea.

As previously mentioned, it is worth mentioning that the current technological state of the UAVs nascent industry is far from being applicable to Rescue procedures. Nevertheless, UAVs are irreplaceable in surveillance tasks: on one hand, their technology is much more accurate than the visual search procedures performed by manned S&R teams and they imply a relevant reduction of costs (since no on-board crew is necessary, there is no budget devoted to pay their salaries, and in addition the dimensions of the vehicle are smaller, with all that this implies). On the other hand, they can provide the information about the position independently on the availability of use of a satellite, contrary to the GPS-based surveillance technique. For this reason, the efforts regarding the application of UAVs to the Search and Rescue sector are mainly focused on the monitoring operations.

One of the vehicles which is currently being used in the ICARUS project for the Search operations at sea is the Lightweight and Integrated platform for Flight Technologies (LIFT) developed by Eurecat [15]:

Figure 2: LIFT UAV, by Project ICARUS

The main characteristics of this vehicle are:

- Coaxial-quadrotor platform
- Empty weight of 4.3 kg
- Maximum take-off weight (MTOW) of 11.6 kg
- Flight endurance (with recommended payload): 35 min

The relatively high weight capacity of this quadrotor is due to the fact that it has been equipped with a specialised payload for S&R operations. This payload includes visual and thermal cameras for the location, detection and tracking of human beings. Additionally, the vehicle is also able to carry a 1-kg-survival kit and it is provided with an automatic collision detector. All these features make the LIFT a useful tool for a wide variety of S&R operations.

Actually, the majority of the vehicles in the sector have a multirotor configuration since it allows the UAV to be stationary for a more accurate obtaining of images to obtain a rapid overview of the situation. Nevertheless, their short endurance is a major drawback. Therefore, these vehicles might be a good approach when different types of S&R operations are trying to be addressed with one single vehicle, although they may not be the most efficient solution for any of them in particular.

Moreover, the protocol of these vehicles is quite restrictive: they are deployed only once the S&R team has received an alert message, since their short endurance is a major constraint to perform monitoring operations.

In this line of action a fixed-wing solar UAV, called Atlantik-Solar, is currently being used for 3D low altitude mapping in the ICARUS project [16]:

Figure 3: AtlantinkSolar UAV, by Project ICARUS

This UAV has a lightweight carbon fibre and kevlar structure with a winspan of 5.6 meters and a mass of 6.3kg. It is powered by 1.4 m^2 of solar panels with Li-Ion batteries and its payload includes a digital HD-camera with real-time image transmission. Although it is capable of reach an endurance of 10 days with this solar system, the payload carrying capabilities are limited and its performance in bad weather conditions are poor compared to the multirotor configuration.

Therefore, for the specific surveillance mission to be addressed in this project the characteristics of both fixed-wing and multirotor configurations are necessary.

The approach of the mission is to locate distressed vessels which are not capable of sending an alert signal (as it is the case of the boats carrying refugees in the Mediterranean Sea), and alert of their position to the nearest S&R station. To accomplish that, first it is necessary to constantly monitor a specific area, an operation for which the endurance of the vehicle is a key parameter. And then, in order to locate and trace the vessel, the subsystems of the vehicle, and consequently, the payload capacity, are other relevant characteristics.

Thus, the goal of this project is to design a unique optimum vehicle to comply with this specific mission as efficiently as possible.

3. Case study: UAS design

After identifying the niche position, the requirements needed for the UAV system shall be considered. Since the solution is intended to be groundbreaking in the field, the usual Systems Engineering design process [17] will not be used, because it needs that all the requirements, including those specified by the potential customers, are established in the very early stages of the design process. In this case it is not possible due to the fact that the ultimate goal of this project is to provide an innovative system on which to base future work in the area, but without setting specific requirements that would make the solution too specific to a bound problem. Instead an iterative development of ideas and prototypes shall be employed.

A. Design process

Ditching the conventional design workflow, a new design process will be developed. It consists on considering all the possible high-level options in terms of aircraft configuration quantitatively, evaluating some performance parameters that are considered important according to the State Of The Art study made before.

After selecting the most suitable configuration for the posed problem, additional alternatives will be set in terms of operative model, considering again the relevant parameters for Search & Rescue labours, evaluating them quantitatively and deciding on the best solution.

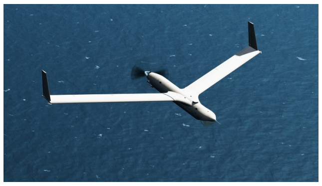
B. Vehicle configuration

Due to the unexplored nature of the UAV usage for Search and Rescue operations, no limitations will be initially imposed to the configuration of the aircraft. Hence the alternatives considered include:

- **Fixed wing** This is the conventional aircraft configuration. It is remarkable for its reliability and speed, although it is not very versatile.
- **Rotorcraft** Very versatile in flight, but endurance is an issue.
- **Blimper** The buoyancy principle on which it operates allows it to have almost unlimited endurance. However, it is the slowest alternative and has less than ideal controllability.
- **Tilt-rotor** Tries to combine the advantages of both the rotorcraft and the fixed-wing aircraft, at the expense of greater complexity.

On the other hand, the parameters chosen for being relevant for S&R applications are those involving general performance of the aircraft as well as payload carrying capabilities and overall reliability of the vehicle.

In Table III a rating over 5 points (being 1 not relevant and 5 extremely relevant) will be given to each of the parameters considered according to their importance for the S&R operations. Additionally each of the configurations will be assigned with a similar value representing their capability in each of the parameters (being 1 poor and 5 excellent). Finally the value assigned to the parameter importance and the value obtained for the aircraft capability in said parameter will be combined (multiplied) in a single figure, which summed across all the performance parameters will give a final rating of the aircraft configuration. The highest rating will determine the most capable alternative according to the predefined ratings.



(a) Fixed-wing [18]

(b) Rotorcraft [19]

(c) Blimper [20]

(d) Tilt-rotor [21]

Figure 4: Examples of possible vehicle configurations

Table III: Vehicle configuration selection

Parameter	Rating	Helicopter		Fixed wing		Blimper		Tilt-rotor	
Efficiency	2	2	4	4	8	5	10	3	6
Speed	2	3	6	5	10	1	2	4	8
Range	5	3	15	4	20	5	25	4	20
Endurance	5	2	10	3	15	5	25	3	15
Stability	3	3	9	4	12	1	3	4	12
Payload	4	2	8	4	16	3	12	4	16
Reliability	3	2	6	4	12	3	9	2	6
Operative flexibility	2	5	10	3	6	1	2	4	8
TOTAL			**68**		**99**		**88**		**91**

The Decision Table yields a tight result in the leading positions, with the conventional fixed wing configuration being objectively better than the tilt rotor due mainly to its simpler design and improved efficiency. Nevertheless, the tilt-rotor might still be a suitable alternative for its higher versatility, specially when operating in difficult-to-reach environments. It is also remarkable the good result of the blimper, with its good range and endurance that are ideal for monitoring, although being very sensible to adverse weather conditions prevent it from being in the top positions. As expected, the rotorcraft's poor range, endurance and payload-carrying capabilities restrict it to the last position, albeit being the most versatile of all the choices.

Hence, after the objective evaluation of the alternatives, it can be stated that the fixed-wing configuration is the most suitable for the Search mission that is intended to be covered by the UAS[2]. From hereon, all the other options shall be ditched, applying the next design iteration to the selected one only.

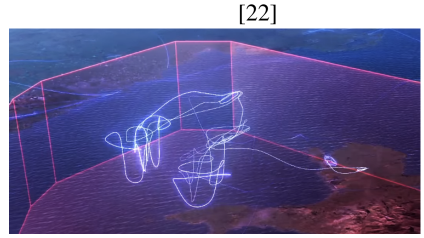
C. Operative model

Once the vehicle has been selected to have the conventional fixed-wing configuration for being the best platform to develop S&R activities in the conditions described above, there is still a substantial amount of room for improvement. Thus, some operative models, all of them based on fixed-wing aircraft, are proposed for study:

- **Glider-like aircraft** The proposed vehicle is not a glider by itself, since it needs to have some kind of propulsion system for its correct operation. Nevertheless, it presents the high aerodynamic efficiency characteristics of gliders with the aim of achieving high range and endurance values.
- **Swarm of small aircraft** This model is considered because it allows the attainment of unlimited surveillance time and high revisit rate while keeping small and relatively simple vehicles. This is done by counteracting the inherent deficiencies of these inexpensive platforms with the ability of having a swarm of several vehicles operating at the same time, while additional ones are being maintained or refuelled at the Ground Station.
- **High performance aircraft** This concept lies on the idea that, even if the platform used is not remarkable in terms of parameters that were considered in Table III, those limitations can be balanced by a vehicle that is able to return to the Ground Station for maintenance and be back on the Region of Interest in a short period of time, with high return rates.

(a) Glider-like aircraft [20]

(b) High performance aircraft [22]



(c) Swarm concept [23]

Figure 5: Examples of possible operative models

As for the parameters consider for the Decision Table, they now focus on operating characteristics of each alternative, rather than performance capabilities. This is the case because performance is expected to be similar for each of the alternative, since the configuration of all of them is identical. Instead, it is now of interest to assess the parameters that most affect the S&R operations, such as detection time and coverage area.

The same approach as in Table III for the Vehicle Configuration selection will be followed in Table IV for the Operative Model selection, which in addition will loosely define a high-level Concept of Operations (ConOps) of the system.

From Table IV it can be seen how the most appropriate solution for the S&R problem is to set up a swarm of vehicles that complement each other's deficiencies by creating a group

[2]The concept of UAS (Unmanned Aerial System) is different from UAV in that the UAS refers to the whole system, including one or more UAVs, the control station, the communications subsystem, etc.

Table IV: Operative Model selection

Parameter	Rating	Glider		Swarm		High performance	
Deployment time	5	2	10	5	25	4	20
Trajectory flexibility	3	3	9	5	15	4	12
Coverage area	5	2	10	5	25	3	15
Production cost	1	3	3	3	3	1	1
Operative cost	3	4	12	3	9	1	3
Payload	4	4	16	1	4	5	20
Endurance	2	5	10	5	10	3	6
Range	4	5	20	2	8	3	12
Upgradability	3	3	9	5	15	3	9
TOTAL			**99**		**114**		**98**

synergy. Furthermore, the system is very easily upgradable by introducing extra vehicles to cover more area or specialise themselves in some specific payload system intended to fulfil different needs as a group. One thing is clear: the high modularity offered by a group of vehicles allows for almost unlimited possibilities in terms of innovation and future enhancement of the UAS. Some of these possibilities will be explored in section 4.

4. Additional improvements for the UAS

As it was mentioned above, an Unmanned Aerial System consisting on a set of cooperating vehicles allows the heterogeneous distribution of specific tasks and payload systems to different UAVs. However, the actual layout would highly depend on the mission that is to be carried out by the system, and will not be explored here.

Instead, even though the swarm concept quantitatively proved to be the most suitable operational model for the Search & Rescue problem, it is clear that it also has some deficiencies that limit its potential operational scenarios; some solutions will be proposed in this section to alleviate them.

A. Range enhancement

From Table IV it is clear that the main weaknesses of the swarm-of-small-vehicles concept are their payload carrying capabilities and the range of each of the vehicles. Furthermore, if the aircraft is overloaded with a heavier sensor system, the range would be further reduced. This trade-off between payload and range could be slightly mitigated, as it was mentioned before, by segregating all the sensors of interest into different vehicles with different tasks each, but the range is a parameter that depends on the aerodynamic and propulsive efficiencies, as well as the fuel mass ratio, and is given by the Breguet equation (for propeller-powered aircraft in particular):

$$R = \frac{-\eta_p L/D}{C_{pow}} \log\left(1 - \frac{m_F}{m_{TO}}\right) \tag{2}$$

Where

- η_P is the propeller efficiency
- L/D is the aerodynamic efficiency
- C_{pow} is the specific fuel consumption
- m_F and m_{TO} are the fuel mass and the mass at take-off, respectively

From the previous equation it is clear that the limiting factor for small aircraft is the fuel-to-weight ratio, which can be seen also by extrapolating from the manned counterparts in Figure 6

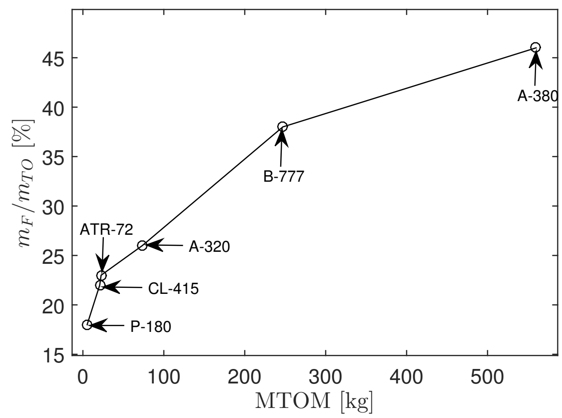


Figure 6: Mass ratio for several aircraft

Hence, in terms of the vehicles themselves, there is not much that can be done to boost their fuel-to-weight ratio while maintaining their payload-carrying capabilities. Instead, an innovative solution is proposed:

If the system is to be operated from a Control Station located on land, the potential maritime area, which is limited by the range of each of the vehicles, would have the shape of a semicircle. However, if a way is found to refuel the vehicles and operate the system from a Station located itself off-shore, the covered area grows to sweep the whole circle, duplicating the area of influence.

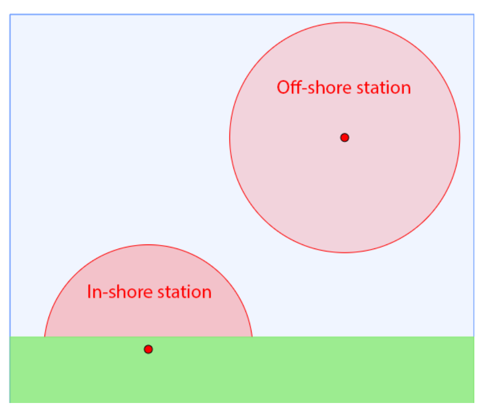


Figure 7: Advantages of an off-shore Station

Furthermore, being the final purpose of the system to automate the monitorisation and search procedures as much as possible, it would not be useful if the barge station needs to be operated by humans. Fortunately, there is already some research and advancements in that area too, being SpaceX the most notable leader in the usage of autonomous ”Droneships” to recover their Falcon9’s first stage after launch [24]

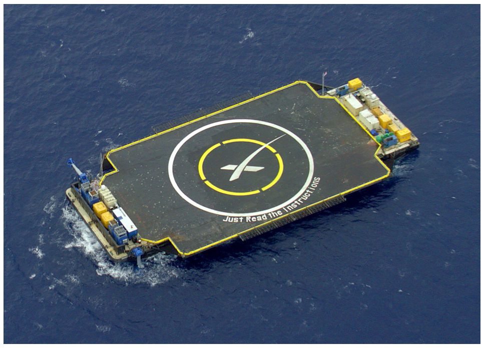


Figure 8: SpaceX’s droneship for rocket recovery

Adapting such technology for the take-off and landing of aircraft instead of rockets is not trivial nonetheless, since the droneship is designed for vehicle to land vertically, and the proposed fixed wing aircraft land horizontally, in what would be a carrier-like procedure. This fact poses an added problem, which shall be studied in the following section.

B. *Autonomy enhancement*

[Sidenote: In this section the word ”autonomy” does not refer to the endurance of the vehicles, but to the ability of the system to operate with minimum input from human operators]

With the final goal of designing a system that can monitor a predefined area autonomously, it is of utmost importance that the vehicles are able to perform the process of landing, refuelling and taking off without the help of human operators, be it on land or at an off-shore station. Yet, technology has not been developed to the point where carrier-like operations are feasible without human intervention, since the level of accuracy needed to guarantee safe operation cannot be achieved by current machine-guided vehicles.

Nevertheless, the slow speeds of hover-capable aircraft allow higher accuracy approach procedures that are already being investigated at university and hobbyist level [25]. These algorithms are usually based on target detection via computer vision or high precission Assisted-GPS.

Even though it was determined with Table III that a conventional fixed-wing aircraft would be better to perform the Search mission, it might be interesting to consider now that, if the augmented range given by off-shore barge Station is to be exploited, a hovering-capable vehicle better suited for the task. That is, Droneship operational model would lead to additional requirements in said Table, which could have altered the results towards the other configurations.

Furthermore, there are already some working prototypes that exhibit a hybrid configuration between the fixed-wing and the tilt-rotor aircraft. This low exploited configuration usually gets the name of ”tailsitter” aircraft. The working principle is similar to that of the tilt-rotors, but instead of tilting the propulsive units while keeping the vehicle horizontal, the tailsitter configuration tilts the whole vehicle to the vertical position, very much like SpaceX land their rockets. This approach keeps the mechanical complexity low since there are less moving parts.

This kind of aircraft started their development after WWII, but most of them did not abandon the prototype phase because they lacked the ability to transition the pilot to a comfortable position when in vertical flight. However, Unmanned Aerial Vehicles do not suffer that issue since by definition they are remotely piloted. Recently, some companies have been developing unmanned tailsitters, such as Martin UAV with their V-Bat [26].

Figure 9: V-Bat tailsitter, by Martin UAV

The V-Bat could be a great solution for the UAS if the autonomous barge concept was implemented, for the reasons mentioned above; but it also adds some difficulties to the operation. For instance, like for all aircraft capable of VTOL (Vertical Take Off and Landing), The thrust-to-weight ratio needs to be greater than one, while for conventional take off aircraft that figure is closer to 0.2. In addition, while in vertical position, the wings become large drag generators, which would make really challenging its operation with moderate winds, like it is usually the case in open sea. In Elon Musk’s words on the Falcon 9, ”it is like trying to balance a rubber broomstick on your hand in the middle of a wind storm” [27].

One thing is clear: while the autonomous droneship seems a good idea to greatly expand the range of existing vehicles, there are still some challenges that need to be solved before UAV become truly autonomous systems capable of landing, refuelling and taking off without the intervention of a human. More research and development are needed in the field of high precision global positioning.

5. Conclusion

From this design study it can be extracted that in recent years UAV platforms have been intensively improved to the point that they can provide acceptable payload carrying capabilities with significant range. However, the effort needs now to be directed towards the implementation of these vehicles into full-fledged Unmanned Aerial Systems, meaning that they should be able to accomplish a mission autonomously or with minimum human input. Obtaining such state of technological maturity would allow the operators to get from the UAS their desired final goal: to autonomously carry out Dirty, Dangerous and/or Dull activities while allowing humans to focus on higher level tasks.

In particular, in the field of Search & Rescue, the niche for UAVs is clearly surveillance and monitoring, crucial first stage towards the goal of saving lives; that is, the Rescue stage that inevitably has to be done by humans. Nevertheless, current technology is not sufficient to carry out this tasks as safely and efficiently as their manned counterparts. For unveiling the full potential of these autonomous systems, it is first necessary to improve the reliability of not only the vehicles but the whole systems (for instance, in this case it would be to achieve the high precision positioning for autonomous landing on the off-shore barge), which then could be used as a strong argument towards changing the prevailing and rather restrictive regulations, to finally encourage the development of the market to its full potential, leading to a society in which monotone and dangerous, although still of vital importance, tasks are executed by machines while humans put their complete effort into saving lives.

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