DESIGN OF UNMANNED AIR SYSTEMS FOR USE IN SEARCH AND RESCUE IN THE NORTH ATLANTIC

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Abstract

A comparison of aircraft performance and program costs involved with unmanned air vehicle (UAV) projects has been performed. The assessment has been taken from a systems engineering point of view when designing a new unmanned air system for a search and rescue case study. Two different design strategies were investigated, one being a traditional aircraft system with servicing and maintenance intervals and the other being a single use aircraft system. The design paradigm is design-to-objective, whilst optimizing for cost.
The primary objective is to assess the size of a search and rescue scenario to determine when a single use expendable system becomes more cost effective than a traditional reusable design. To be able to holistically assess the operational effectiveness of the search and rescue system, aircraft subsystems and the system level need to be modeled.

1 Background

In maritime rescue, response time is critical. The longer a person is in the water, the lower his chances are for survival. Typically, survival time for a man overboard scenario with minimal thermal insulation in frigid water is under two hours, figure 1.

For this paper, the case study selected was a design of a search-and-rescue system based on unmanned air vehicles in the north Atlantic, centered on the Faroe Islands. The current search and rescue capacity of the Faroe Islands is very capable, though not great enough to effectively respond to the crisis that a cruise vessel accident would create. Also, since much of the Faroe Island's economy is based off of fishing, it is important to be able to offer quick response to aid fishermen in distress. The current SAR organization is organized through the Torhavn Maritime Rescue Coordination Centre (MRCC), which through a SAR mission Coordinator (SMC) has direct access to three rotorcraft[1]. These rotorcraft include two SAR Bell 412; one is fully SAR equipped, and one is a commercial helicopter fitted with necessary SAR equipment. Additionally the MRCC has access to one of the Danish navy's Lynx helicopters. In the event of large accidents additional resources be acquired through an agreement with adjoining countries, the UK and Iceland; NATO forces; or through requisition from local aviators.

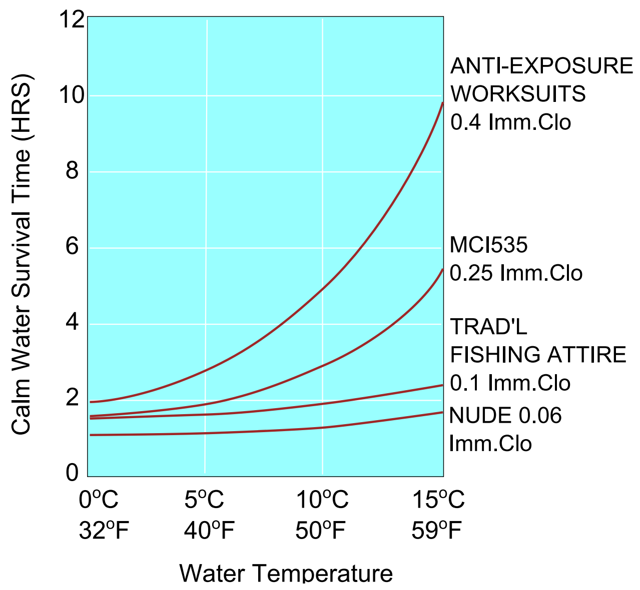

Fig. 1. Prediction of survival time based on different levels of protective clothing Immersed Clothing (Imm. Clo) [5]

Overall, the Faroe Islands utilize a very competent search and rescue organization. It follows the same type of makeup as many other SAR organizations around the world, especially in utilizing helicopters for SAR missions.

Historically, fixed wing amphibious aircraft were used for SAR missions before helicopters became available. Some nations still use amphibious aircraft, but now in a secondary role of maritime patrol with rescue capability. Land based fixed wing aircraft are used in different parts of the world as patrol aircraft satisfying the search role, leaving the actual rescue mission to helicopters.

This paper aims at investigating the use of fixed wing aircraft in SAR operations around the Faroe Islands as a complement to the current organization, with the particular goal of investigating the viability of a single use aircraft – designed and constructed with the intention for it to be used only once, although significant recycling would be permitted.

Because the life cycle cost of an aircraft design project is often locked in during the conceptual design phase of the project, careful study must be performed to determine aircraft requirements [6].

2 Method

The design mission is to deliver a 150 kg motorized life raft to a person in distress somewhere in a designated search area. Mission rules state that the MRCC has been alerted of the emergency, and that a rough position is available to establish a search area.

Two design solutions are proposed to be evaluated against each other. The baseline solution was formulated using conventional technology, and where possible off the shelf products. The other design solution is a UAV system intended to be comprised up of a fleet of single use aircraft.

The baseline design features a solution utilizing a general aviation aircraft, in this case a Piper PA28 equipped to carry a 150 kg lifeboat stationed at an ordinary airfield. The baseline aircraft was modeled in Tornado to evaluate is aerodynamic properties, and further analyzed in a search and rescue mission using an agent based model developed in Netlogo.

2.1 Tornado

The performance model used is based on first principles vortex lattice method (VLM) called Tornado for the computation of the aerodynamic forces acting on the design. Tornado has a strip theory implementation of the viscous forces. The code has been developed for linear aerodynamic wing design applications

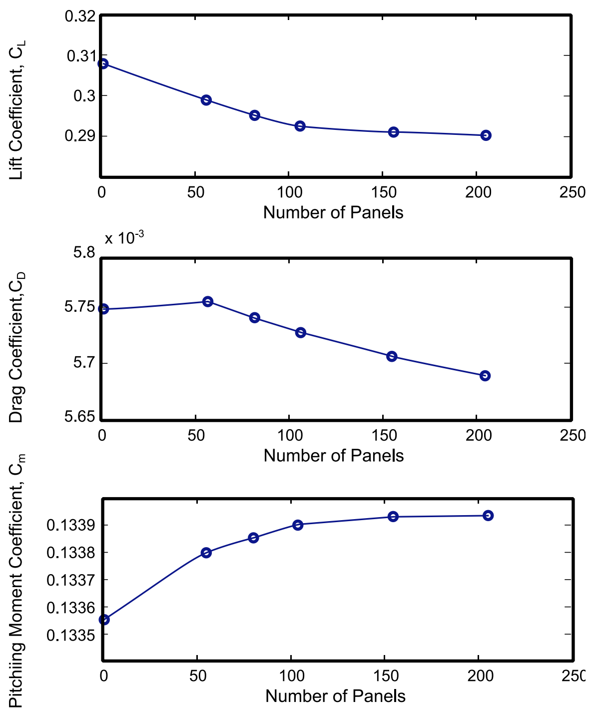

Fig. 2. Grid convergence study for the baseline aircraft. The cutoff criterion was a difference in coefficients between iterations less than 0.005, which was reached at 150 wing panels in total.

in conceptual aircraft design. By modeling all lifting surfaces as thin plates and modeling the flow as a potential flow, Tornado can solve for most aerodynamic derivatives for a wide range of aircraft geometries. With a very high computational speed, Tornado gives the user immediate feedback on design changes, making quantitative knowledge available earlier in the design process.

The aircraft geometry in Tornado is fully three dimensional with a flexible, free-stream following wake. Tornado allows a user to define most types of contemporary aircraft designs with multiple wings, both cranked and twisted with multiple control surfaces. Each wing may have taper of both camber and chord.

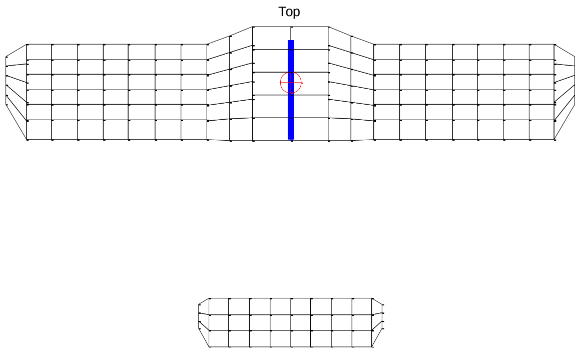

Fig. 3. Lattice distribution of the reference aircraft, Piper PA28. Main wing and horizontal tail modeled.

By running the VLM in batch mode, aerodynamic data can be assessed at runtime within the optimization. Inline grid convergence studies ensure that the aerodynamic data maintain good quality. Figure 2, shows a typical grid convergence example, with the final grid distribution shown in figure 3

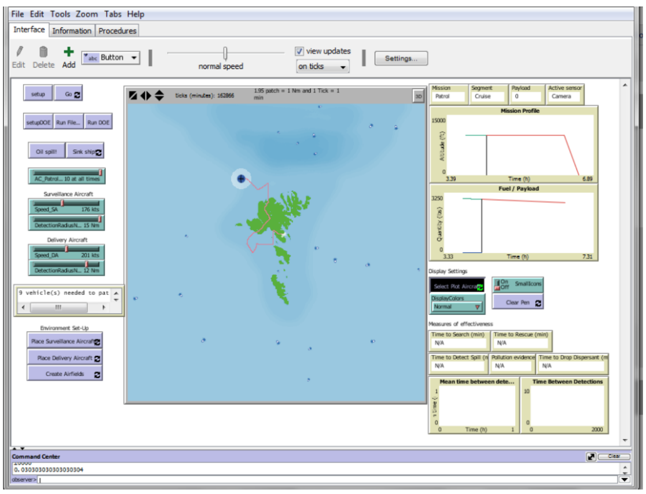

Fig. 4. Search and Rescue System of Systems Environment

2.2 Engine

The engine model used for the baseline aircraft is the Lycoming O-360-A4M, that is used on the

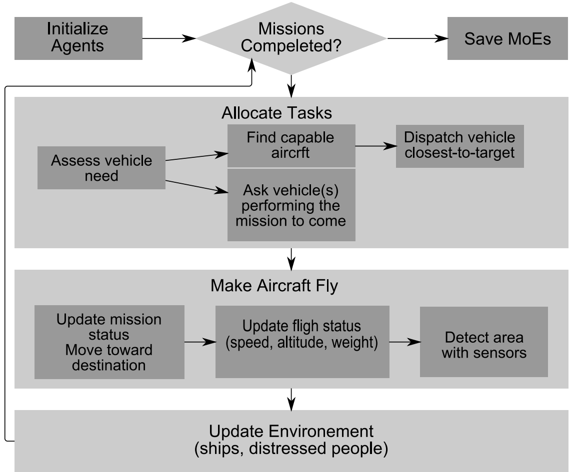

Fig. 5. Flow of agent based model

Piper Archer LX today. On the Proposed UAV design it's a rubber scaled engine [4], based on the Ecofly M160 engine, a derivative of the Mercedes Benz Smart car engine.

2.3 Search and Rescue Model

The search and rescue model was created using agent based modeling with the performance of the agents determined by the system models. Agents are independent objects with sets of rules that govern their behavior. UAV agents are defined by several characteristics: payload, sensor capabilities, fuel, position, and speed. UAV agents were also implemented with a mission profile calculator which is useful for assigning UAVs to certain tasks along with ensuring that sufficient fuel remains onboard for the completion of the assigned task. Persons-in-the-water were also implemented as agents possessing a certain lifetime and detection characteristics, see figure 1. A graphical user interface, shown in figure 4, allows for examination of the simulation at runtime for verifying the agents' behavior is correct.

The flow of the simulation can be seen in figure 5. At each time step in the simulation, the task manager determines which tasks are needed to be performed and then gets a list of which aircraft are capable. The task manager then assigns the most capable aircraft to perform the task based on the rule set and the current state of the simulation. The task manager makes the simulation more robust by not having preprogrammed flight paths and adapting to the environment.

For the search portion of the simulation, an aircraft is assigned to search for the distressed person given a last known location. This last know location is based off of the ship that lost the person. Once the assigned aircraft arrives at the last known location, and the person is not found, it then enters a specified search pattern. Currently, three different search patterns are implemented for the aircraft: parallel search, sector search, and expanding square. The parallel search pattern is illustrated in figure 6. This pattern also adapts to the number of aircraft searching, dividing the total search area among all of the available aircraft.

Once the person is found, the task manager identifies aircraft capable of rescue (not necessarily the same aircraft that found the person). This rescue aircraft then proceeds to deliver aid to the person. At the end of the simulation the amount of time people were stranded in the water is recorded.

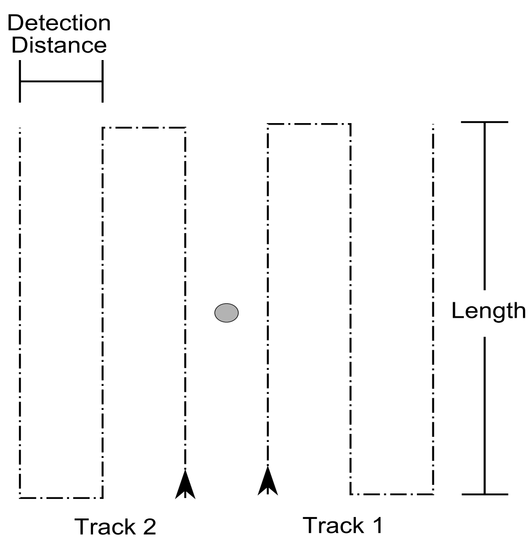

Fig 6. Parallel Search Pattern

2.4 Economics

The case study was employed by comparing the cost for the two different design strategies with each other: The first approach is a reusable one, in which one airframe is reused for several types of mission, with scheduled service intervals to replace required subsystems. This would typically be done by a standard aircraft, such as the Piper PA28, used here as the baseline aircraft, or any similar general aviation aircraft. The second approach is a single use design, were each airframe is only used once but have no servicing at all. Some amount of part recycling is taken into account to ameliorate the cost of losing an airframe. Components such as engine and avionics are recycled an in the cost model written off with a residual price.

The cost assessment was made in two steps, the first approach utilizes Roskam's price as a function of weight [7] method and the second more detailed approach was based on using the DACPA IV [8] combined with Raymer [4] method. A production series of 200 aircraft was assumed ad hoc, and the cost breakdown per engineering discipline and aircraft was computed. In a real aircraft program, the actual number of aircraft produced would have to subject to customer demand. The cost categories considered were: Engineering, Tooling, Manufacturing, Quality Control, Development Support, Flight Testing, Materials, and Engine.

In Roskam's method, the aircraft price for a single engine propeller aircraft with a normally aspirated engine can be described according to equation 1:

$$P = 10^{(-1.2435+1.8459(log_{10}(TOW)))} \quad (1)$$

Where P is the aircraft purchase price in 1989 USD and TOW is the aircraft takeoff weight. As this equation is exponential, the sensitivity to error will increase with increasing error. However, at small errors, the sensitivity is roughly a factor of two. At 10% weight error, price will be 20% off.

The MTOW of the Piper Archer LX is 1156 kg, and the projected UAV MTOW is 500 kg. This gives with equation 1, which is based on MTOW alone, the cost of the UAV design should be 21% of the manned aircraft.

Using the DACPA model, a production series of 200 aircraft was assumed ad hoc, and the cost breakdown per engineering discipline and aircraft was computed. In a real aircraft program, the actual number of aircraft produced would have to subject to customer demand. The cost categories considered were: Engineering, Tooling, Manufacturing, Quality Control, Development Support, Flight Testing, Materials, and Engine. Engine cost was taken from list prices of the Lycoming engine, featured in the piper, and the Smart roadster engine planned for the UAV. The DACPA model is more linear than Roskam's method, and gives that the cost UAV design should be about 40% of the manned aircraft.

In the Life cycle assessment, the two different approaches are compared with each other. The program costs for the UAV system is sensitive to how many missions there are per year, and how many aircraft are used per mission. The manned system is fairly inelastic to the number of missions due to the larger overhead of higher procurement costs, maintenance and crew training. Even with a 50% cost recovery trough recycling, the UAV program is only cost effective if no missions are performed. In order to have a break even between the two programs at say 50 aircraft missions per year, the flyaway cost of the UAV's needs to be reduced by two orders of magnitude – which would put it the price lower than the fixed cost for the engine alone.

If however, the UAV system is redesigned to be reusable, adding maintenance cost and training missions, the cost of the UAV system will be approximately 2/3 of the manned system.

Once the aircraft design module, the cost estimation module, and the system of systems models are integrated, a capability to quantitatively evaluated both operational effectiveness and cost of alternative approaches to the search and rescue problem will exist. This paper will exercise the capability presenting results for the two cases suggested a traditional lifetime vs. a single use UAV.

3 Explore design space

The search and rescue performance of the baseline aircraft was analyzed with the created agent based simulation. Only one aircraft was utilized for the search and rescue operations to conform with the current methods of operation.

The simulation was for a single man overboard operation requiring aerial assistance. Once the task manager received the overboard signal the baseline aircraft was dispatched.

In this analysis the detection range was varied from one nautical mile to 10 nautical miles to determine the operational sensitivity to different sensors.

Figure 7 shows the probability of finding a person as a function of time for varying detection ranges. The analysis confirms that the probability of finding the distressed person will increase with the detection range.

There is still not a great chance because transit time to the location of the man overboard can be high.

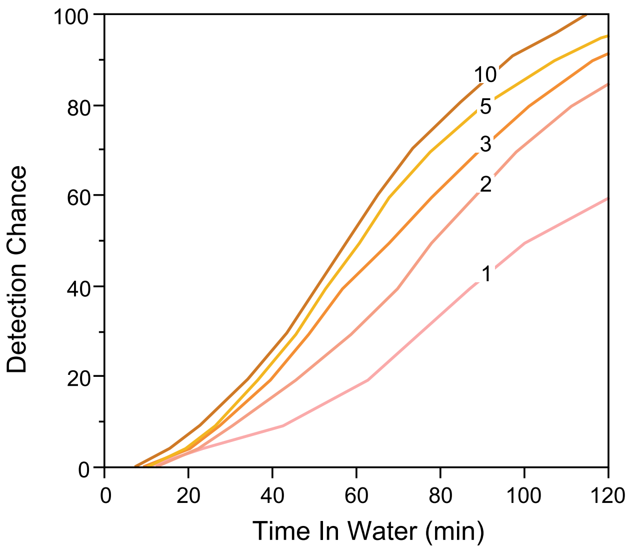

Fig. 7. Probability of detection versus time in the water for varying detection ranges for the baseline aircraft

The search and rescue performance of the UAV was executed in a similar manner, however, the ideal number of aircraft working cooperatively is not known. This parametric study was performed by varying the number of aircraft as well as the detection range.

The probability of detection contours are plotted in figure 8. As expected, the best chances of finding the man overboard occur with using the maximum number of search aircraft with the highest detection radius. This figure also illustrates the tradeoff that occurs between the number of aircraft and their detection range.

Determining the best detection range and number of aircraft requires additional economic calculations. It is expected that higher detection ranges come with increased costs due to requiring better quality sensors. Additionally, more aircraft will also increase the costs of the program, and considering that these aircraft are designed to be single use, minimizing their numbers is important.

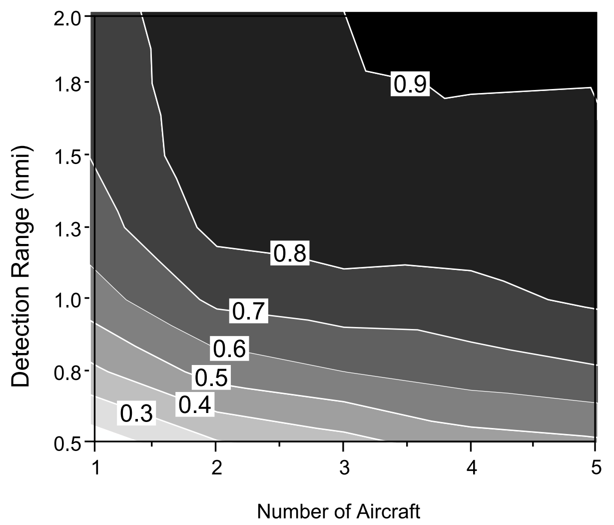

Figure 8. Detection probability at two hours for varying detection ranges and number of UAV

4 Discussion of results

The Roskam cost model is based on aircraft manufactured prior to 1990. This means that aircraft with a substantial avionics suite will not fit well in the historical trend. Indeed, when verifying the equation set with current piper sales material for the Piper Archer LX [2], the Aircraft price and adjusting for inflation using US consumer price index, the 2012 price for a Piper Archer LX is 320 kUSD, while Roskams prediction according to equation one is 205kUSD - A difference of 56%. Similarly, when verifying the Cessna Skylane, the list price [3], comes out 35% over Roskam's prediction. This indicates that equation 1 should not be used for absolute pricing, but rather only for investigating price differences.

Additionally, the MTOW weight of the UAV is below the lower bounds of equation 1, so using those results are questionable, likewise the DACPA model was not intended for general Aviation airplanes, and requires a substantial fudge factoring to calibrate against known aircraft.

5 Conclusions

The objective of this study was to investigate the viability of using a single use UAV in a search and rescue mission. Because of the frigid waters in the scenario, quickly detecting any distressed person in the water is paramount to their survival. To determine the mission effectiveness of the proposed UAV system, models were developed and used at the subsystem and system levels. An economic analysis was performed to determine the feasibility of the UAV system.

Results show that there may by some benefit of a UAV system due to the potential of higher numbers of search aircraft but more economic analysis is necessary. The traditional cost models as Roskams, and DACPA IV are not entirely suitable for estimating the cost of Ultralight or UAV systems. Even with significant noise in predicting the flyaway costs, it has been proven impossible to do good economics out of a single use aircraft program. This is most likely why the single use systems in use today are designed more towards reaching objective goals than to keep the cost down.

Without actually building and testing a system such as the proposed UAV solution, it is difficult to motivate a claim of better economic, safety or performance. There seems to be some validity in stating: -If you think aircraft maintenance is expensive, consider the alternative cost of not performing it.

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