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LIFECYCLE COSTS AND FEASIBILITY ANALYSIS OF THE DESIGNS OF UAV'S FOR HUMANITARIAN RELIEF MISSIONS

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Abstract

A simulation study has been done estimating the possibility of using Unmanned Areal Vehicle (UAV), also called drones. By testing cost and sizing of a UAV for relevant missions expected for a humanitarian relief mission a dataset is built upon which conclusions may be drawn. The largest factors are the size of the fleet and how many missions an aircraft are expected to survive.
The development of regulations of autonomous UAVs may make or break the possibility of using UAVs to deliver humanitarian aid. However, it is already now technically possible & economically plausible for such a solution.

1 General Introduction

1.1 Background

United Nations (*UN*) estimate that there will be 135 million persons in need of humanitarian aid during 2018 [1], with the needed humanitarian aid operations budget of 22.5 billion USD. The United Nations Office for the Coordination of Humanitarian Affairs acknowledges that the humanitarian air service has insufficient funds to cover its operations. The scale of the endeavor means that even a slight increase in transport system performance will have a great financial impact. For perspective, according to [2], the United Nations World Food Program (UN-WFP) deployed 70 aircraft, delivered more than 60 thousand metric tons of cargo and carried close to 300 thousand passengers during 2015. While the aerospace scientific community has limited possibility to affect funding for humanitarian aid, it can provide the knowledge needed to establish an even more effective air transport system for humanitarian aid and disaster relief.

1.2 Introduction

The European Union is the single largest contributor to intentional humanitarian aid [3] with around 7 billion euro contributed by the member states in 2017. Article 61 of the European consensus on humanitarian aid [3] allows for the use of military assets for humanitarian aid, especially for infrastructure and in support roles. However in order to avoid "confusion of roles", military assets should only be used as a last resort. This means that new systems being developed should primarily be regulated under the civilian regulatory frameworks. In the last decade, huge strides forward has been made on the development of autonomous systems for a variety of transport implementations, some of them air born. This paper presents a conceptual study of the use of unmanned aerial systems (UAS) for humanitarian aid and disaster relief and the financial ramifications of their use.
The development of UAV Systems with better performance than previously has enabled potential new use cases. Their use as solutions to ”Dull, Dirty, and Dangerous Jobs” have been proposed by several authors. [4] [5] Such a system may also provide an affordable solution for gathering areal information about disaster as-

sessment [6] which would be a valuable input in the disaster response management.A comparison of different modes of transport for humanitarian aid missions in dangerous conditions have been done by [7], where the conclusion is that the major drawbacks with utilizing UAV's are: capacity, technological maturity and a difficult prediction of the cost per tonne. However, this conclusion is drawn on exiting systems and the development of cargo-scale UAVs was encouraged for future scenarios.

The field humanitarian logistics have developed by an ever-increasing demand on the special kind of logistics required for a humanitarian relief mission [8] [9]. That kind of logistical characteristics are high levels of asymmetric information and damaged or unreliable infrastructure. In that situation an airborne solution may overcome these complications with an (compared to a road vehicle) fast and agile solution. The humanitarian logistics is also characterized by a time limited venture. An operation has a main mission to temporary interlink supply chains which has been damaged by the crisis causing the need for a humanitarian venture.[8][9][10][11]

The disaster relief management which is the

Source: Patrick Safran. 2003. A strategic approach for disaster and emergency assistance. Contribution to the 5th Asian Disaster Reduction Center International Meeting and the 2nd UN-ISDR Asian Meeting, 15-17 January 2003, Kobe, Japan.

Fig. 1 The Disaster Management Cycle as proposed by Safran[12].

core of humanitarian logistics heavily depends on the cycle concertized by Safran [12]. It means that the key to a successful humanitarian relief mission is good preparations. Therefore, both UNHCR, UNICEF and WFP have large storages of supplies around the world [11]. When the governing UN organization i.e. *WFP - World Food Program* conclude that there is a risk or a situation of Food insecurity [10] they start the giant task of transporting the supplies from the storages to airfields where the supplies are needed. The supplies are mostly packed in manageable units. i.e. the sacks one may see from humanitarian aid bags with 50kg of rice. One way of transporting the goods are by a drone.

Several articles examines the topic of humanitarian drones. There is however an inconsistency in the definition of humanitarian drone: Sandvik & Lohne [13] performs more of a holistic analysis approach but emphasizes the moral injustice of having armed Humanitarian drones, thus Sandvik & Lohne have interpreted "humanitarian" as in that its humanitarian to carry out targeted attacks with a few civilian damages. That its humane to kill a target fast and effectively. McNab & Matthews [14] on the other hand describes on the legal ramifications of UAV operations for military operations according to International law.

To co-op with a new level of automation in the sky describes Sáez Nieto [15] both perspective on how ATM (Air Traffic Management) works at the present as a socio-technical multi agent system and how it may develop.

Civilian International law governing UAV operations is still in the bud. The future framework has a possibility to further allow more or less autonomous UAV's [16][17], but until a new regulation is implemented the current regulation will apply. For UAV operation it will mean that one have a pilot directly in control of the vehicle and also in verbal radio contact with Air Traffic Control.

2 Method

A point model of a propeller-propulsed fix-winged aircraft was created.[18][19] The choice to abandon ideas with a helicopteric design since its efficiency on transporting payload a long distance is far less than a fix wing model, which is clearly illustrated by Torenbeek's [18]. The model was built up around an of-the-shelf engine (Hirth F 23 LW, *50hp*). The engine M-ω properties were estimated from the provided product specifications [20]. The propeller properties are derived from a well known NACA 0012 profile with an arbitrary chord length and twist along the propeller length [21]. A desired speed and flight path angle was continuously controlled through a linear throttle setting and attitude control. The speed desired are the climb phase for the Carson-speed. The fuel consumption was monitored throughout each mission with varying total cruising altitude, payload, delivery distance, mission distance, delivery altitude and wing surface area. The cost of the fuel consumption is then factored by the market price of aviation fuel on the African continent 2^{nd} march 2018.[22] To estimate the development and manufacturing cost Heiss' & Romanoff's model is used. [23] The production cost is then broken up depending on assumptions different orders of survivability for the drone (T), i.e. survives 1, 10, 100, 1 000 & 10 000 missions. The produced quantity (Q) is also varied as 1, 10, 100, 1 000 & 10 000 aircrafts.

To estimate the cost of Airport Tariffs and Air Navigation Services the cost is estimated for each mission.[24] The different countries examined are the countries where *UNHAS - UN Humanitarian Air Service* performed special operations in 2015 [25] except Afghanistan. All flights by the humanitarian drone is considered to be domestic, since the humanitarian Relief still has to be cleared through customs, which is easiest done in the proximity to a port or airport. [26].

Each of the cost of this system is then added after taking into account inflation. The reference year for US dollar is defined in is the year 2011.[27] Then conclusions can be drawn.

3 Results

The model did in the end produce 316 data points. Certain conclusions may be drawn from both the implementation of the flight model and the data from them. Analyzing the data lead to the conclusion that the average time for a mission will enable an aircraft to make 3 missions per day.

To be able to draw conclusions about the plausibility of the drone, have some economical figures been estimated. By the average cost of a delivery mission it is then possible co compare that to the value of the cargo. In Figure 3 one can see how the cost for each mission changes depending on how dangerous the flying is i.e. for how how many missions will it fly until it is expected to get shot down. In the figures is this factor noted as T. The quantity of the produced aircrafts will also be a factor, which is denoted as Q.

The data provided in Figure 3 is suitable for showing the economic plausibility of a human-

The Baseline Aircraft

Wing Surface Area	5 m^2
Wing Span	5 m
Piston Engine Power	50 hp
Maximum Take-off weight	318 kg
Maximum Payload Weight	160 kg
Ceiling	>5 100 m

Fig. 2 The table describes the attributed factors of the baseline aircraft. The ceiling is defined for the International Standard Atmosphere.

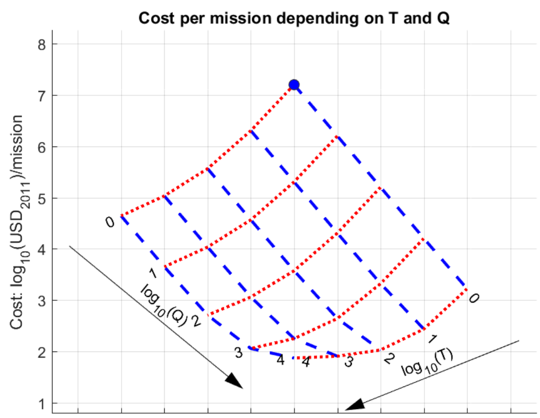


Fig. 3 Carpet plot describing the average cost for a mission.

itarian drone. It is suitable for comparison between different means of transportation. The Figure 4 enables such an analysis. It shows the average cost of transporting a (metric-)tonne of payload one kilometer. Just as earlier is T estimation how many missions an aircraft is expected to survive. The quantity of the produced aircrafts is denoted as Q.
The baseline design which is used for this study

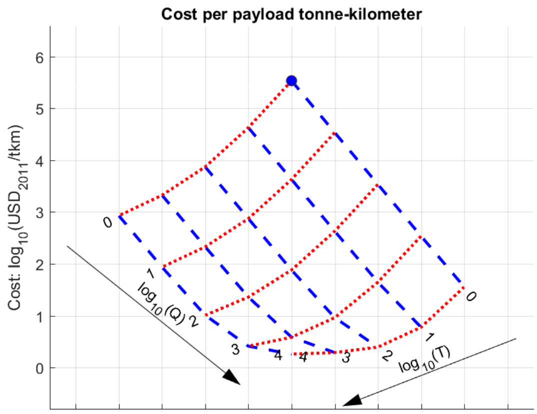


Fig. 4 Carpet plot describing the average cost per ton payload per kilometer.

is an fix-winged aircraft with wing surface area of 5m^2 and a wingspan of 5m. Figure 5 show the relative effect, compared to the baseline design, on the cost of changing the parameter wing area (S) and wingspan (b). The bullet (●) shows the origo of log_{10} of Q & T.

One major part of this study has focused on how fees apply to the suggested solution. The average cost for the fees covers all tested missions, but is calculated for each country. Mostly it has a minimum charge, but in other cases the fees are based on distance, MTOW and time of day. The charges has been identified according to the categories ”landing fees”, ”fuel fees”, ”navigation fees” and ”security & cargo fees”. As one may see in figure 6 the major part of the navigation and landing fees are built on the average Air Navigation charge.

Assessing the relative share of the cost shows the costs structure that one may see in Figure 7 an increase in the number of produced aircraft will

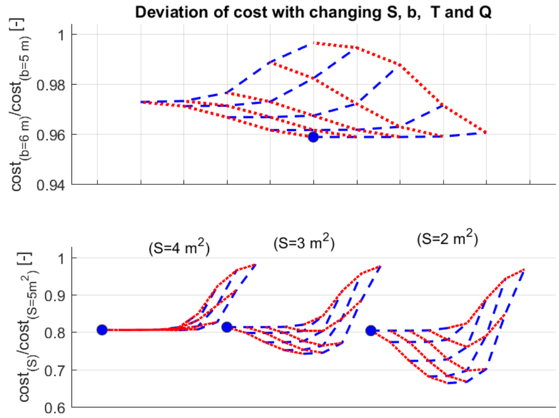
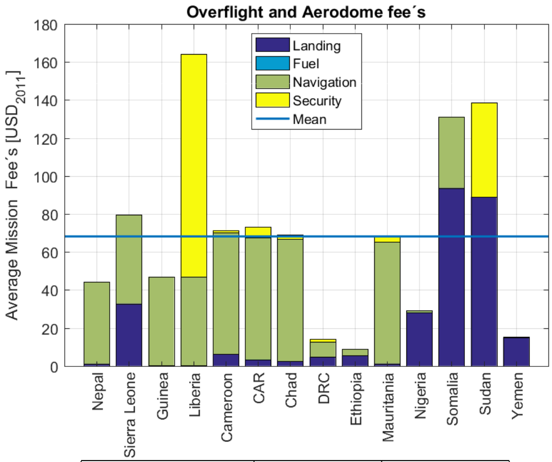


Fig. 5 Carpet plot describing the relative change in cost per mission depending on wing area (S) and Wing span (b).

also increase the share of operating fees of the total cost. By using formation flight may only one of the planes be in contact with Air Traffic Control. In case only one of the aircraft would need to pay for Navigation-service would determine how much cost one then could save. The Figure 8 shows the potential relative savings that could be made if formation flight is allowed and that it would decrease cost assuming that only the lead aircraft needs to pay for its navigation charges.
To enable comparison with other means of transportation and its environmental impact the CO_2 has been estimated from the fuel consumption and its variation with mission length, which is given by Figure 9.

4 Discussion

The study has put in a large effort in the estimation of fuel consumption and required fuel. The reason is that the initial conceptual calculation predicted a low fuel consumption. Since it was lower than initially expected was it difficult to assess the plausibility in that information. Afterwards, it is easy to conclude that the fuel cost is almost negligible.
One may argue that the choice of using Hess’ & Romanoff’s model of estimating the cost of developing and manufacturing an aircraft since



Fees	Mean	St.dev
Total	\$68.18	\$46.38
Landing	\$20.24	\$30.67
Fuel	\$ 0.018	\$ 0.133
Navigation	\$35.03	\$25.64
Security	\$12.89	\$ 31.51

Fig. 6 Overflight and other Fees.

the study don't even have statistically significant data. But the study is well-cited and it gives the possibility to make this study comparable to those other studies which also have used the same method.

Since the purpose is foremost to estimate the plausibility of using UAV's for humanitarian relief missions is the choices of dimensionless drag coefficient and propeller-design are based on something that is not theoretically optimal, but rather would be easy to manufacture and have a simple design.

4.1 Air Traffic Control and airspace

A hot topic in the aerospace industry is automation. At the same time regulatory agencies are developing their regulations, which may allow the further development of autonomous drones. The opinion of the authors are that one may never separate the accountability of a commander of a vehicle, which has centuries of history. The authors assess through the route of development how one may command several vehicles simultaneously though simple and accessible software. The major issue is then how Air Traffic Control

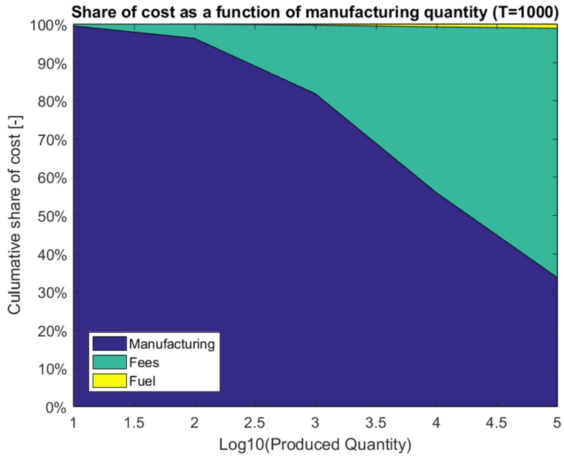


Fig. 7 The share of the tree costs for an expected lifetime of 1000 missions.

still may control its aerospace safely, but which decision hierarchy should be applied becomes a hard nut to crack. The communication between autonomous systems should require a higher degree of automation in Air Traffic Control.

One may see that a major part of the Air Traffic Control cost of such an system as proposed by this paper is rather high. The size of this aircraft is so small they reaches the floor of the size of the fee's for flying in the airspace of the controller. This cost is by the authors expected primarily to finance the cost of providing the services used by the airlines and their passengers. For some countries the fees are also designed to bring a little profit for the service provider, for others it is a way of financially control its airspace.

4.2 Type of Certification

There's a foundation for a major discussion to what type of certification the proposed aircraft should get. There's three different kinds one may choose among. It is most suitable to register the aircraft according to a civilian protocol. Foremost it is according to humanitarian international law a war crime to attack civilian targets during wartime. If then humanitarian aid may be delivered to civilians with civilly registered aircraft would one who would have fired at such an aircraft be punishable by law. The largest con for a civilian registration is the cost and effort it means

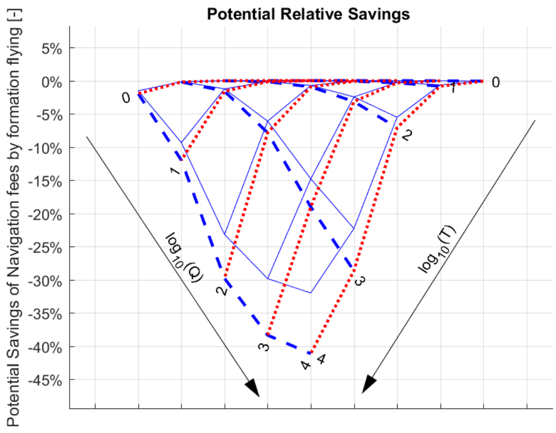


Fig. 8 The potential savings by formation flight for navigation fees compared to if a full price is paid for the Navigation Service Charge for formation groups of 3 & 7 aircraft, where 7 aircrafts gives the largest savings

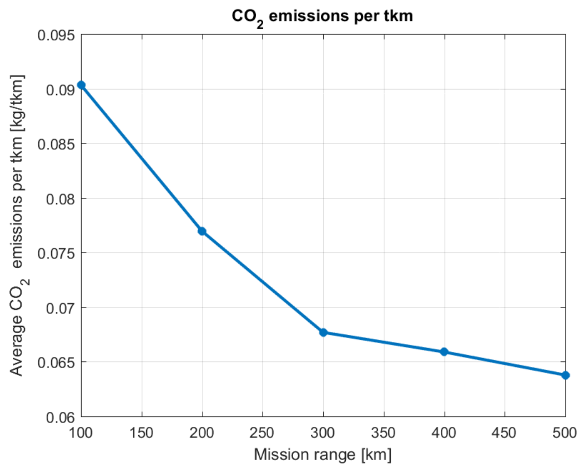


Fig. 9 The average CO_2 emissions for varying mission range

to certify such an aircraft.
One option is to certify the aircraft according to military protocols. It would be a little cheaper and require less effort, but then it would be more difficult to argue how humanitarian law could protect those aircrafts.
The cheapest way would be to build the aircrafts as *Remotely Controlled Aircrafts* (RC) which then would not have the same requirement for certification, but it would arguably be reasonable difficult for such an aircraft to utilize aeronautical infrastructure such as ATC and airports.

4.3 Factors which has not been quantified in this study

The cost of the organization which would be needed for operating such an humanitarian venture which could utilize such an solution as proposed by this paper. In logistics but especially humanitarian logistics it is important that the right package gets to the right recipient. To certify that it is very important how goods changes possession between agents and thereby who is responsible. Therefore at least one representative from the aiding organization who may distribute the goods according to recipient needs. That person may suggestible be airlifted to the site of delivery to civilians by i.e. helicopter. Depending on the rate of security in the area where the humanitarian venture is required that transportation may vary.
The cost of storing the aircraft has not been estimated. The cost of transporting the aircraft to a center of response location has not been estimated, but an idea is that many the dissembled aircraft could be loaded in the cargo hold of an Boeing 767 aircraft. Neither, is estimated the cost of reassembling of the aircraft at the venture or maintenance cost. The logistical planning, ”Pilot” or cost of loading the aircraft is not included in the study.
How airport operations should be performed with the aircraft and how it relates to its suggested design has not been quantified.
Since an humanitarian relief venture is special in such way one may not presume that all infrastructure is fully functional. That may e.g. be expressed as power failures or shortage of fuel. Since it is relatively easy to transport fluid fuels this study has only investigated a solution based on a combustion engine. The potential cost of transporting fuel to the relief mission is thus neglected. Neither is estimated the recycling or scrapping cost of the the aircraft. As a first step has it been assumed that an aircraft mostly will be written off by an armed attack than the actual need for scrapping the vehicle. It is clear that if

the UAV would be used in a safer environment eventually the operator would need to deal with increasing maintenance cost and in the end scrapping cost.

5 Conclusion

The concept of introducing other sciences to the humanitarian venture is not uncommon, it is a way to use science to efficiently in fulfilling their purposes e.g. how humanitarian organizations uses Economics, Law, logistics, nutrition etc. Therefore it is relevant to look into the humanitarian venture with an aeronautical perspective.

It is presently technically possible to make a humanitarian drone. Economically it is plausible, i.e. if there's enough demand it would be possible. When looking at the transported goods in the humanitarian logistics 16 million tonnes may be delivered by 10 000 aircrafts in one year. Presently the humanitarian UAV are not legally feasible to do use yet. The part which needs development is both the feeing system, but also the operational procedures for integrating autonomous vehicles with present type of air traffic. Depending on how the ruling will evolve will make or break the potential for drones to provide affordable and safe logistical options.

It might be that mission drivers for using UAVs in dangerous conditions, primarily crew safety, is not strong enough to allow a widespread use in the humanitarian aid air transport system. Instead the paradigm shift of UAV's as a viable solution for civilian logistical operators should drive for this development.

The proposed design is a wing area about 2 m^2, Wing span around 5-6 meters, Structural weight 78kg, dead weight 98kg, maximum payload weight 160kg, Maximum take-off weight 258kg. Fuel is not a real problem for the range. A small change in fuel-tank size gives a large change in range.

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