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Design Considerations and Requirements for In-flight Refueling of Unmanned Vehicles

Ian R McAndrew[1]* **and Kenneth Witcher**[2]

[1]*Embry Riddle Aeronautical University, Brandon England, UK*
[2]*Embry Riddle Aeronautical University, Las Vegas Nevada USA*

Abstract

The need to refuel in-flight has become a significant part of military strategy for air forces to work at further distances from safe shores. The use of Unmanned Vehicles is increasing and expected to be the principal part of military deployment. This paper will address the concepts and requirements for applying refueling unmanned vehicles in a military context for supporting fixed and rotor aircraft. Design aspects of human factors in the process are considered, reviewed and solutions proposed to allow for the first generation of designs to be developed. Furthermore, the practical and operational limitations will be addressed as part of the human factors implications. Finally, the design parameters are proposed for the first stage developments to achieve Unmanned Vehicle refueling.

Keywords: Inflight refueling; Design considerations; Unmanned vehicles; Human factors

Introduction to the Problem

Inflight refueling has been a main aspect of supporting superiority in the skies and has evolved greatly since its conception. It relies on pilot skill and systems to deliver fuel to military aircraft in extreme conditions in hostile environments. As the role of manned aircraft decreases and unmanned increases the need to refuel inflight is becoming more important for unmanned vehicles. There are instances where very long operations have been required and in 1982 the initial bombing of the Falklands airport involved 11 refueling tankers to support the lead aircraft. Such requirements are extreme and current unmanned aircraft will operate in different environments. Their significantly lower costs to design, develop and operate make them viable for higher risk sorties. To maximize their roles they need to be operational for extended periods. Against this backdrop there is the problem that when no local airfield is available these increased distances will take significantly longer times to arrive and deploy.

There have been instances where unmanned aircraft have flown in excess of 24 hours, albeit with a limited or zero cargo [1]. As their roles expand with more advanced sensors, systems and weapons the take-off weight will increase and the endurance levels will reduce. Each new generation of unmanned vehicles will possibly have greater payloads and advanced weapons systems. Those that are now being designed to operate at altitudes above 60,000 ft will offer on ground commander's flexibility and instant information of terrain and activities without risking unnecessary loss of piloted aircraft. Currently, a 24 hour cycle is the norm, allowing for changes in ground operating personnel on a 3 shift basis. This may seem a long flight, but with limited top speed and the need for continuous monitoring of the ground their range is limited and need to be used locally. Given an advanced flight speed of 90–120 mph a 24 hour deployment will only have travelled under 3,000 miles. Or practically, it could take a whole day to travel to its needed deployment region. Thus, re-fueling is needed to just arrive and added to that more refueling to operate in-situ. As usage depends on proximity the only alternative to local bases and risks involved are sea launches, which prevents immediate and surprise usage. It may be necessary for these unmanned aircraft to fly extended periods before arriving at their destination.

To deploy unmanned aircraft at further distances and for extended periods of time they need more fuel, which will limit payload, or to be refueled in-flight as other military aircraft [2]. This paper will address the current problems, potential changes and aerodynamics of solutions for the next generation of usage. In addition, the practical human factors of operation are included to offer a practical description of the first generation of unmanned refuelers. These aspects are needed to set design parameters to develop prototypes for development.

Refueling Concerns

Cruising speeds of the majority of unmanned vehicles are within the range of 80–100 mph with top speeds around 120 mph [3]. New unmanned aircraft designs are not focusing on increasing these speeds as they will affect the effective usage and operation, there are some that are designed to have increased altitude ceilings of 60,000 ft to give a wider view of the ground with improved visual sensors and cameras. Slow speeds are good for flight stability and the sensors used onboard will produce results with higher resolutions at these speeds; it can be argued that there are justifiable reasons to increase these speeds [4]. If these unmanned cruising speeds are doubled to the region of 200 mph they are significantly below the stall speeds of current military refueling aircraft (KC-135 and A 330). Indeed, C-130 aircraft are refueled flying near maximum speeds and their refuelers flight paths are in descent to assist in maintain aerodynamics stability.

The possibility of using smaller designated manned aircraft to refuel inflight may be possible. An existing aircraft could be modified for carrying fuel, a delivery system and procedures to refuel unmanned aircraft [5]. There are human factors that need addressing, not least the need for potentially very long flights to remote regions and returning, which will exceed flight time capabilities and endurance limits unless numerous pilots. A manned aircraft being docked with an unmanned aircraft raises the concerns of safety incidents that cannot be ignored or

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***Corresponding author:** Ian R McAndrew, Embry Riddle Aeronautical University, Brandon England, UK, E-mail: McAnd4f1@erau.edu

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re-engineered [6]. Docking could be done automatically or remotely; either way an unmanned aircraft approaching a fuel source is a safety risk. Likewise, if they are intending to operate in hostile areas for as long as practical then refueling with manned aircraft is a high risk factor. Two lost unmanned aircraft is both financially and ethically more justifiable.

Currently, refueling is carried out using one of two principal types of systems. The *Boom* operated version that requires the aircraft to be refueled effectively parking at the rear of the refueler and a boom operators positions the refueling arm in place to transfer fuel. A *Drogue* system is one that will trail a funnel cone behind the aircraft from a feeder pipe for the incoming vehicle to dock and received fuel. This latter system has the advantage of being suitable for both fixed wing and rotary aircraft. It could be argued that this has many advantages with rotor unmanned vehicles will play significant roles and to remove its capability before use would be counter-productive.

All the human factors for each of the above mentioned systems vary considerably. Boom arms are controlled by within the refueler by an independent operator at the rear of the aircraft for visible recognition, or by electronic screen, who positions the boom into the receiver aircraft. Skill and dexterity are required to accurately position in various types of weather and atmospheric conditions. The pilots of the refueler and receiver have a separate task to keep flying level and identical speeds with little room for error. The boom arm is designed for lateral and vertical displacements to overcome slight movements and aerodynamic effects, for example *dutch roll*. To work effectively both pilots and a boom operator are required to work in unison and need instant vocal links.

All drogue refueling systems work with the refueler flying straight and level at a pre-arranged altitude and flight pattern. The drogue is deployed into position by the refueler and docking would not be attempted until the feed system is in-situ and not being adversely affected by air conditions. The human factors are directed to the receiver pilot positioning their aircraft to dock, whether remotely of a pilot if manned. One person is responsible to control the system, no second party [7]. As with all refueling the speeds need to be maintained within tolerances of altitude, speed and cross winds. Fast reduction in gross weight and gain as fuel is transferred will require power adjustment to maintain joint constant speed between each aircraft. The drogue system has more flexibility both laterally and vertically and is considered more forgiving by pilots. This system has been automated and can easily be added to an unmanned aircraft for auto docking without major weight additions.

Drogue refueling

Applying *Drogue* refueling for unmanned aircraft has several advantages. First, the refueler can fly straight and level whist the unmanned aircraft positions itself accordingly. Secondly, the drogue can be positioned at a distance to minimize flying in the wake of the air turbulence. Thirdly, the docking can be achieved for control of one aircraft with the possibility of this being achieved automatically. Positional movement of either aircraft is accommodated by the free movement of the fuel line between the refueler and receiver. The disadvantages are that this method supplies fuel at a lower flow rate; nevertheless unmanned aircraft do not require the large volumes for piloted aircraft. To transfer 500 kg of fuel could be achieved within less than 3 minutes. Figure 1 shown the height drop below the aircraft that the drogue operates, which a parameter is to be determined according to aerodynamic requirements of the aircraft. The drogue is collapsible and the storage pod under the wing clearly visible.

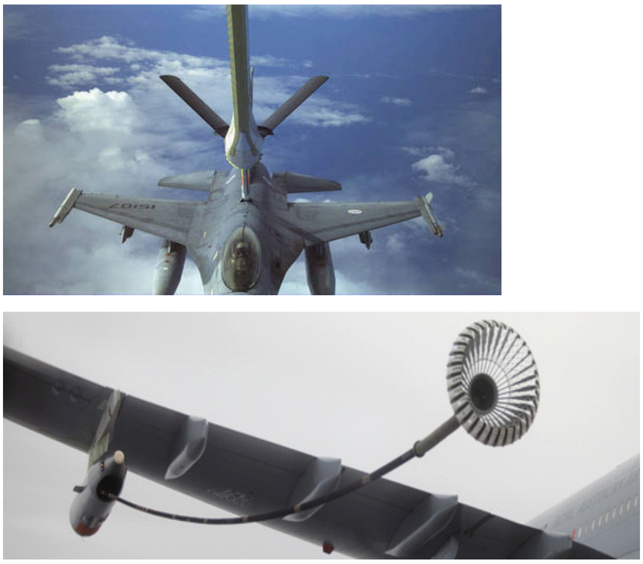

Figure 1: Drogue (below) and Boom (above) refueling.

Boom refueling

A *Boom* system works in an opposite process to drogue ones. The aircraft to be refueled positions itself behind the refueler and a boom arm is positioned manually to attach the nozzle and supply fuel. Its fast flow rate reduces the refueling time and positional movements are compensated by lateral movement allowances in the boom arm. When large volumes of fuel are transferred the supply aircraft has to incrementally reduce the power to the engines whilst the receiver aircraft has to increase the power to allow for both to maintain the same airspeed. The principal disadvantage is that accurate positional reliability is needed by both aircraft, possible with unmanned aircraft but advanced control systems needed. For the purpose of unmanned refueling this system has to be superseded by the drogue one for practical and design reasons.

Unmanned Requirements and Human Factors

For unmanned aircraft to refuel in-flight the same practical concerns exist with safety, docking and undocking control. The human factors influence current processes and will if unmanned refueling is used. For example, remote control will require totally on sensors and relayed video links. No true situational awareness can be achieved. In bad weather conditions visibility may be poor and as many unmanned aircraft have lower ceiling limits this can remove flying over bad weather that are available for conventional aircraft. Alternatively, refueling in cloud cover may be desirable.

Ground based control of unmanned aircraft may be flown by trained pilots, but increasingly they are specifically trained unmanned aircraft operators. These people are not fully aware or experienced to the same situational awareness of pilots; although this can be addressed long-term it does leave a shortcoming within the usage. An alternative would be to have the receiver aircraft hand over control to the refueler for this particular operation if the refueler is manned. It cannot be emphasized that even without manning any accident in flight will result is potentially dangerous situations that may have serious consequences for areas on the ground under any safety concern incident [8].

Ideally, remote computer control from the refueler is probably the safest procedure and sensors will overcome visibility and weather constraints. Here, when in close proximity to each other, the flight control will be released from the ground operators and resumed by them when refueling complete and undocked. The control could even be operated with infrared so as not to be detectable from afar.

Aerodynamic Considerations

An unmanned aircraft flying in the wake of a larger refueler will have stability control issues that may significantly inhibit docking or maintaining level flight for safe fuel transfer regardless of method used. Boom methods will increase the likelihood of stability in level flight and lower speed further compound the concerns. The concerns of human comfort for the receiver aircraft are not relevant and can be ignored in this scenario and remove some design considerations. Likewise, unmanned aircraft are not generally designed to operate at high or supersonic speeds; thus, aerodynamic changes to produce stability, extra lift or reducing the effect of turbulence can be incorporated that will not have adverse influences on use or range. Low flight requires its own unique design parameters especially at low altitudes where inclement weather is likely to be influential [9]. Consequently, low speed flight requires high lift and this is easily achieved by large wing area without additional lift devices, *e.g.*, flaps or slot.

Dutch roll

A problem that occurs in all aircraft, regardless of design, operational use or weather and a result of a weaker positive stability compared to positive lateral stability. It is more obvious when flying behind another aircraft with a focus point. In effect, the aircraft oscillates in an elliptical manner–a major concern when marrying the flight path of two aircraft. This is a major concern for the aerodynamics of aircraft at low speeds and increasing altitude. Traditionally this has been engineered out as a concern by using yaw damping sensors–albeit that this would add extra complexity to the aircraft system and weight. The influence of *Dutch Roll* from the wake of a smaller aircraft could significantly reduce the effect and possibly removed the need for an added yaw system to be used. Even if the *Dutch Roll* cannot be removed the damping systems could be designed to eliminate its need as without human occupants the certification process would be different. Alternatively a wing structure with a very high wing aspect ratio would reduce the effects; which is a typical design parameter currently used.

Design consideration for unmanned refuelers

Currently most unmanned aircraft cannot operate at speeds approaching those needed by the principal refuelers currently employed. Thus any refueling tanker that could be used to work at lower speeds would need to be aerodynamically capable for low speeds, high lift and a significant fuel carrying capacity. Basing a full fuel system for a typical unmanned aircraft at 500 kg, and the capability to re-fuel 4 craft in one sortie the fuel requirements would be at least 3,000 kg if you include the fuel needed for the tanker. An initial design specification would use the assumption of 4,000 kg as a probable total weight at take-off. This could be increased if more than 4 refuels were required; however, this paper's focus is on the principles of unmanned refuelers are a concept. Thus, the fundamental lift needed is based upon:

$$L = \frac{1}{2}\rho v^2 A C_L \tag{1}$$

Where L is the Lift of 4,000 kg, ρ=1.225 kg m^{-2}, take off speed of 35 m s^{-1}, C_L=0.3 (estimate) at take-off speed with a low angle of attack. A≈ 15m^2 wing area. As mentioned above, this would be ideally used with a high wing aspect ratio to assist in stable flight control. The maximum width would be limited to the runway width, and a balance needed to ensure it would not be limited to use depending on the available runways [10]. However, if the wing cord length was only 0. 5m the wing tip length would still only be 30 m, still smaller than a B 737 and suitable for most commercial and military airfields. This would not necessarily limit its use from small remove fields or clearings if needed.

Propeller layout

Unmanned aircraft are usually of a push design, rear mounted propeller (Figure 2). A refueler would require a front mounted propeller, tractor, in order not to interfere with the refueling system and reduce any wash created from the propeller and in the wake if only one used. Alternatively, a twin rear mounted engine combination with a centrally deployed drogue would allow for an operational layout with advantages. For example, if *canards* were incorporated this would assist in reducing *dutch roll* and allow potentially for more stability in straight and level flight (Figure 3).

Fuel delivery type

Boom systems may deliver fuel faster (less than 1 minute is possible after docking) but require accurate flight control of both aircraft. There are no recorded examples of automatic boom control on any aircraft. To automate a joint remote design on small unmanned aircraft would likely take the design to a level without any guarantee of success. A boom arm would add significantly more weight, extra control and complexity. A drogue system would be less complex and could be deployed independently, leaving the receiver to be adjusted in-flight for docking. A drogue will need to be centre mounted, unlike typical refuelers that have them mounted on both wings. There are applications

Figure 2: Unmanned Vehicle with a push propeller system.

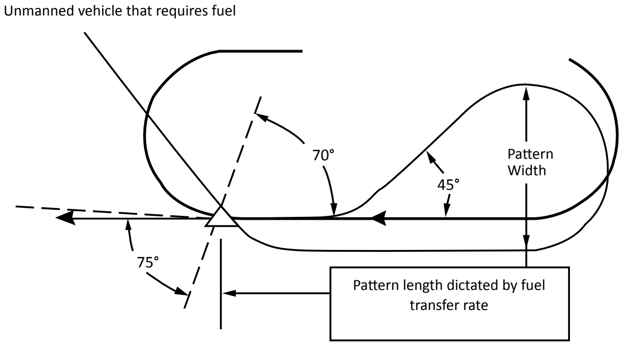

Figure 3: Holding pattern for unmanned refueling.

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of centrally mounted drogues on large scale refuelers; however, it does not allow for twin refueling that is required for certain applications. For a small unmanned aircraft the weight and aerodynamic loads would require wing structures heavier than needed otherwise if twin refueling was an aim.

Operational use

Refueling would have to occur at straight and level flight; all air-to-air requires this procedure for optimum easy and safety. A holding pattern similar to those waiting to land at airports would be needed and expected to be a parallel pattern with minimum turning radius between turns [11]. Taking a drogue design as the slowest refueling time a transfer status of 4 minute would need to be linked to a docking pattern. If this allows for 4 minutes then an 8 minute combined time, at 100 mph, needs a minimum of 14 miles. The approaching aircraft needs to accelerate to a position behind the refueler then slow to align.

Unmanned Refueler Specifications

This paper has addressed the principal aspects and operational requirements of unmanned refuelers and how conventional design aspects can be conflated to produce a specification for prototype design.

The key assumptions are that the unmanned vehicle does not need to be redesigned from its current layout. A tube mounted centrally at the front to receive fuel is the only specification recommended. It may be necessary to add canard wings to assist in flight stability when transferring fuel; and this could dictate the fuel transfer rates.

The refueling unmanned vehicle will for the reasons stated above be of a central drogue fuel delivery system. A high wing stricture with probably twin wing mounted engines and a lower central refueling tank to allow stability. The fundament parameters of designing an unmanned vehicle are not complex [12]. The additional supplementary procedures are where detail, agreement and application will dictate. For example, the protocol of holding patterns to enable receiving aircraft to dock efficiently and safely must be finalized [13]. More so, if you think NATO might need to share operational use of deployed refuelers. Likewise, dis-engagement procedures for emergencies, i.e., if attacked, when transferring fuel. Nevertheless these are not leading edge considerations but aspects to verify.

Finally, the significant aspect to develop and refine now is the extension of the drogue and the drop from the refueler to the receiver. Space will be limited for storage of the drogue. Figure 2 does highlight that its collapsible design does allow for safe storage within a small device. Currently, this aspect is being researched to allow for more data, subsequently to allow for further detail design.

Summary

Requirements to allow unmanned refueling have been addressed in this paper. All the principal practical difficulties of using current aircraft has be reviewed and shown that is it not feasible or possible to reconfigure current refueling aircraft. Thus, smaller unmanned aircraft are possible but not a practical solution unless key aspects are considered and accommodated. An unmanned refueler is both practical and possible given these constraints are addressed. A front mounted engine or twin high wing engine mounting is required for the refueling envelope. Drogue systems are the most suitable method for fuel transfer and designs can accommodate the low speed and conditions. Whether the docking is achieved remotely or automatically is unimportant, either way the human factor risks remove risk to life in an operational environment.

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