Parachute Recovery System for Small Research UAV's

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Damage to UAV research aircraft, whether it is structural or systems damage can be costly. To combat this problem this project focuses on the development of a parachute recovery system for small experimental UAV research aircraft. The work will mainly involve designing the system with a secondary goal of testing the final design on the SAE Aero UAV, currently under construction. The project will also look at using the completed parachute recovery system on different UAV aircraft of similar scale. This project extends from the initial task of designing and constructing a model aircraft for competition in the SAE Aero Design Competition. The design criteria for this competition were to develop a remote control aircraft with set engine and geometric limitations to lift maximum payload up to a takeoff weight of 55 lb.

Nomenclature

m	=	*mass of descending body [kg]*
g	=	*gravity [ms^{-2}]*
C_d	=	*drag coefficient*
S	=	*surface area [m^2]*
D_o	=	*nominal parachute diameter [m]*
D_p	=	*inflated parachute diameter [m]*
a	=	*semi-major axis length [m]*
b	=	*semi-minor axis length [m]*
V	=	*descent velocity [ms^{-1}]*
ρ	=	*density [kg/m^3]*
F_d	=	*drag force [N]*
x	=	*parachute filling distance [m]*
t_f	=	*parachute filling time [s]*
n	=	*canopy fill constant*
PRS	=	*Parachute Recovery System*
UAV	=	*Unmanned Aero Vehicle*
SAE	=	*Society of Automotive Engineers*
ADFA	=	*Australian Defense Force Academy*

I. Introduction

The University of New South Wales at the Australian Defense Force Academy owns and operates several small UAV research aircraft. The justification for this project is a direct result of damage to one of these aircraft, during a flight test. The damaged aircraft was a small research UAV with a gross weight of no more than 25kg, which crashed due to radio controlled interference. Damage caused to the aircraft was considerably costly, and the inability to continue testing caused delays in research. One solution to this problem is to fit these small UAV research aircraft with a parachute recovery system.

An aircraft parachute recovery system (PRS) is a procedure that relies on the deployment of a parachute to aerodynamically decelerate the aircraft allowing for a safe touchdown (Knacke, 1992). The objective of this project is to research, design, test, and evaluate a PRS for the ADFA SAE Aero UAV (currently under construction).

This initial thesis report begins by outlining some of the elements of PRS's in the form of a literature review. This document then goes on to describe the particular UAV that this PRS will be designed for, and culminates with some initial design work unique to this PRS. Other elements of this report include a detailed project management plan, which sets out the guidelines for work to be completed throughout the lifespan of the project.

II. Literature Review

PRS's are not a new concept, and there has been significant research undertaken into several of the more complex problems associated with their design. While keeping the aims of the project in mind, this literature review summarizes some of the research that has occurred in this area.

Parachute terminology is used quite extensively throughout this review, so to aid understanding; a diagram of parachute parts is attached in ANNEX A.

A. Canopy Shape

Principally, UAV PRS's use three different canopy shapes; cruciform or cross-type canopies, hemispherical canopies, and parafoils (Wyllie, 2001). Parafoils are gliding parachutes, designed to be steerable, allowing for a small level of navigation after deployment. Their internal cell structure is ram-air inflated which forces the parafoil into a classic airfoil shape. To operate as intended parafoils need to stay inflated and are therefore constructed out of a low porosity fabric (Wyllie, 2001). This causes an increase in the opening shock forces experienced during inflation and a complex reefing mechanism is generally required to reduce these loads. Deployment is further complicated by the need to protect the control line servos from these opening loads (Wyllie, 2001). A follow on effect of inputting systems to reduce parachute opening loads causes a much slower deployment speed and therefore greater height loss during deployment.

Cruciform canopies are the simplest of the three canopy shapes consisting of two pieces of rectangular cloth overlaid and sewn together as shown in Fig. 1. These canopies have the smallest drag coefficients, and lower opening forces. The small opening forces, attributed to gentler parachute inflation, means that the falling body losses more height before full inflation is attained. Cruciform canopies produce lower oscillation than hemispherical canopies, which is one of the reasons they have been researched for use in precision airdrop systems are used as drogue stabilizing parachute (Keith Stein, 2001).

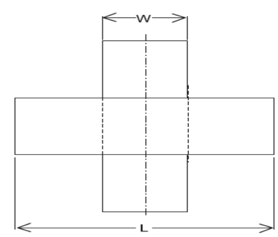

Figure 1. Cruciform Canopy Configuration (Wyllie, 2001**).** Cruciform parachute are also called cross chute for obvious reasons.

Hemispherical canopies have high drag and opening force coefficients (Wyllie, 2001), affording them the advantage of better reliability on opening. Hemispherical non-steerable parachutes are used for aircraft recovery because their simplicity enhances their reliability. Simplicity pertains not only to the parachutes reliability but also to ease of construction and packing, an imperative requirement for this project.

B. Parachute Activation

Parachute activation refers to the method of deployment prior to inflation. It can be assumed that a key factor of parachute deployment systems is reliability. Three principal deployment methods are forced ejection systems, drogue or pilot parachute systems, and rocket extraction systems (Huckins, 1970).

Forced ejections systems are common extraction methods due to their simplicity. The mortar, catapult, and pressure bellows are examples of mechanisms designed to produce a forced ejection of the packed parachute (Huckins, 1970). These systems tend to be heavy and they also produce high reaction loads, which is important when considering the platform in which the system will fire.

Parachute deployment using a drogue or pilot parachute has numerous advantages. The system is quite flexible since the parachute extraction force is applied continuously over the entire deployment sequence, and the system is also lighter. This system relies on aerodynamic force to extract the main parachute, thus problems may arise due to pilot chute interference with the wake turbulence of the descending body (known in skydiving as ‘hesitation’). Used in tandem, individual extraction systems increase their effectiveness as demonstrated by the Gemini Spacecraft, which used a drogue gun to launch a drogue parachute to stabilize the re-entry vehicle, until a height at which the pilot chute was extracted, pulling out the main chute (Vincze, 1966).

A rocket extraction system for parachute deployment has all the advantages of a drogue parachute system, but does have a slight weight penalty. Furthermore, the rocket extraction system produces very light reaction loads, and is only slightly dependent on the characteristics of the vehicle wake (Huckins, 1970). The rocket extraction does however increase the risk of damaging the parachute fabric on extraction, and has the added complexities of dealing with pyrotechnics.

C. Inflation Characteristics

In view of the fact that parachute inflation is a very complex and unsteady process, it is well known that parachute theory is a difficult problem in the aerodynamic field (Calvin, 1984). PRS’s in UAV’s require parachute inflation to be reliable and quick, to ensure minimum loss of height during opening. In manned PRS’s, such as the Ballistic Recovery System (BRS) used in the Cirrus SR20 (Ballistic Recovery Systems Inc.), complex dis-reefing mechanisms are put it place to slow the inflation process and reduce shock forces caused by the opening canopy. The process of dis-reefing shown below in Fig. 2 is done to reduce the forces felt by the manned occupants, and is important for unmanned PRS design from s structural integral aspect.

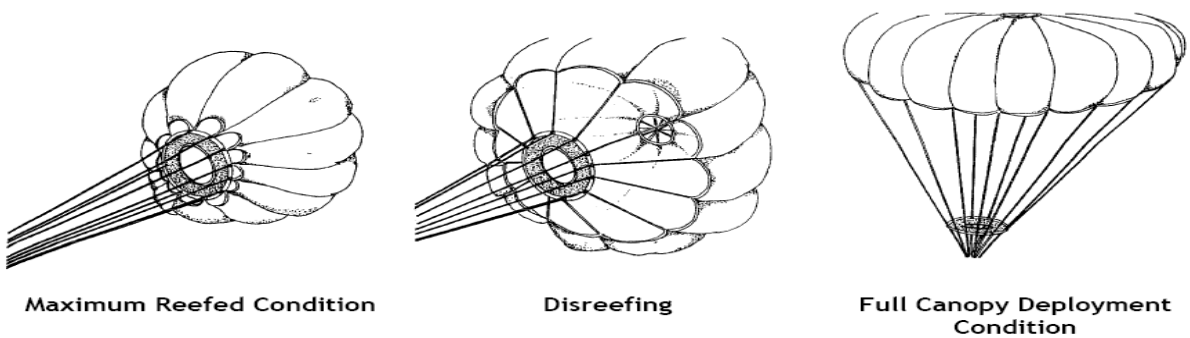

Figure 2. Dis-Reefing of a Hemispherical Canopy.

Reefing a parachute slows the inflation, meaning more height loss, however there is another reason for reefing a parachute aside from reducing shock forces. There is a phenomenon called wake recontact, sometimes called “canopy collapse.” This phenomenon occurs when the parachute decelerates the payload so rapidly that the air behind the parachute catches up to the canopy: causing it to deform (“collapse”) and lose drag (Peterson, Strickland, & Higuchi, 1996).

An important characteristic of inflation is the variation of drag throughout the opening process. A mathematical simulation carried out using momentum theory produces the drag characteristic plot shown in Fig. 3. The plot predicts that for small values of displacement the drag characteristic is also small. This can disrupt the unfurling of a parachute just after the deployment, because there is little drag available to ‘pull out’ the rest of the parachute from the deployment bag, which decreases inflation speed. The brake parachute system that was used by the Jaguar had a canopy

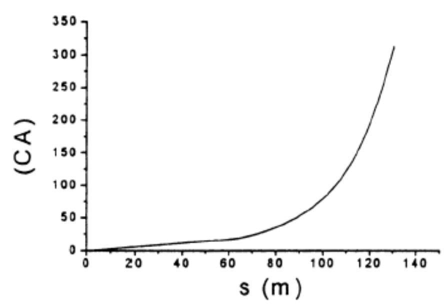

Figure 3. Characteristic Drag Plot During Parachute Inflation (Cao & Xu, 2004)**.** (CA) is the Characteristic Drag and (s) is the displacement in meters.

that was designed with special fabric scoops in the vent area, which would increase the drag at the apex during the early stages of deployment, helping to increase inflation speed (Aircraft Engineering, 1968).

D. Parachute Filling Distance

Parachute filling distance is defined as the distance required for the parachute canopy to open, taken from the point of initial line stretch to full inflation. Fig. 4 demonstrates this definition (Mohaghegh & Jahannama, 2008). Mueller and Scheubel reasoned that, based on the continuity law, parachutes should open within a fixed distance, because a given conical volume of air in front of the canopy is required to inflate the canopy (Knacke, 1992). With the confirmation of drop tests the parachute filling distance was found to be proportional to the inflated parachute diameter D_p, multiplied by the canopy fill constant *n,* as shown in Eq. 1 below (Mohaghegh & Jahannama, 2008).

Figure 4. Canopy Filling Distance (Mohaghegh & Jahannama, 2008)**.**

$$x = nD_p \qquad (1)$$

The canopy fill constant, typical for each parachute type, is an indicator of the filling distance as a multiple of nominal parachute diameter. Having found the canopy filling distance only one further step is required to determine the canopy filling time. Given speed is distance over time, the canopy filling time is simple given as Eq. 2 (Mohaghegh & Jahannama, 2008).

$$t_f = \frac{nD_o}{V} \qquad (2)$$

Canopy filling distance and canopy filling time are very important in PRS because they are a direct reflection of how much height loss may occur during the inflation process. Small UAV research aircraft have to operate at low altitudes and it is therefore imperative that the campy opens is a short distance.

E. Attachment Considerations

The attachment of the parachute to the UAV directly affects the operation of the system. The attachment points determine the behaviour of the aircraft during canopy inflation, and also the attitude at which the UAV will fall once inflation is complete and the PRS is in the steady state condition.

Conventional PRS's deploy in such a way that the aircraft falls undercarriage first in order to protect the airframe; however this is not always the case. The Phoenix UAV, for example, has a PRS that allows the aircraft to roll over and land upside down (Wyllie, 2001). This is done to protect some of the sensor equipment underneath the aircraft. Manipulation of the aircraft attitude during steady state descent is generally achieved by changing the position of the PRS's attachments in relation to the aircrafts centre of gravity. This allows the designer the freedom to choose how the aircraft touches down; main undercarriage, or nose wheel first for example. In general however, PRS's are attached at several points with the centre of gravity of the aircraft roughly in the middle to keep the system balanced. From a structural perspective it is important to make sure that the attachments are connected to structurally sound aircraft fixtures, able to handle the large forces that can be experienced due to the rapid deceleration of the aircraft during canopy inflation.

The attachments to the aircraft are also vitally important during the inflation stage, where careful placement of the attachment points can protect the parachute canopy from entering the wake of the aircraft. If the parachute is attached forward of the centre of gravity, deployment will cause a strong pitch up moment forcing the canopy into the wake of the aircraft. This situation may even cause the to aircraft fall backwards through the suspension lines, tangling the parachute. When attached behind the centre of gravity it causes a pitching down moment allowing the canopy to inflate in the free stream air and also stopping the aircraft from stalling. If used carefully the attachment method can be instrumental in controlling the pitch dynamics of the aircraft during the deployment cycle.

F. Parachute Release Mechanism

There may be instance where the PRS causes more harm than good and needs to be released or discarded. After touchdown on a windy day, for example, the parachute may remain inflated and cause damage to the UAV by dragging it along the ground. An In flight parachute release may be required as the parachute may become tangled after a failed activation and cause the aircraft to become even more uncontrollable.

Parachute release mechanisms are common devices and are used regularly is sports parachutes to release the main chute in preparation to deploy the reserve. A very similar parachute release mechanism is used by the BRS system on manned aircraft recovery. Both of these release systems use a three ring release design similar to that shown in Fig. 5. By looping one ring through another, a significant reduction in forces is felt by the final ring allowing for a simple release pin to hold the system together.

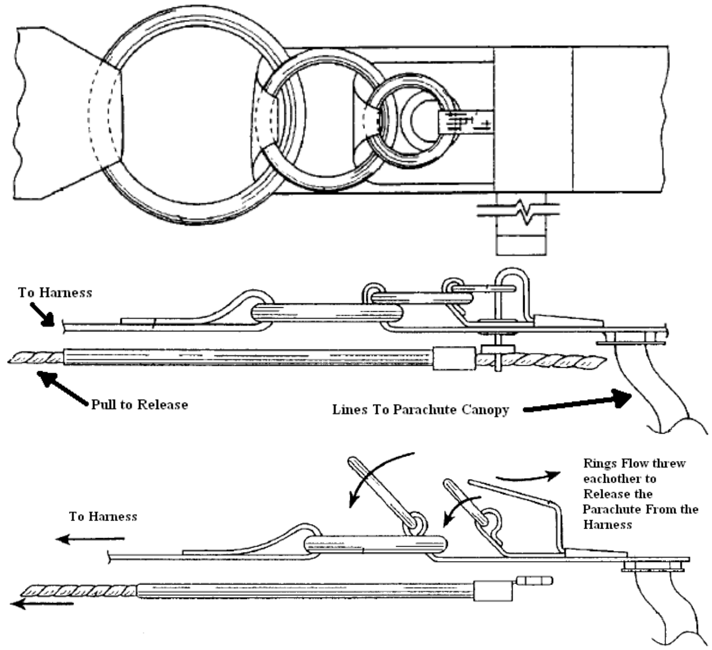

Figure 5. Three Ring Parachute Release Mechanism (Collins, 1998)**.**

III. ADFA SAE Aero UAV

The PRS is to be initially designed for the ADFA SAE Aero UAV. In order to get an understanding of the type of PRS it is important to have a brief description of the aircraft it is intended for. This UAV was designed under the strict customer requirements outlined below.

1. Maximum take-off weight of 55 lb
2. All cargo carried in cargo bay
3. Combined length, width and height of 175 in
4. Carry a minimum of a fully enclosed rectangular block measuring 5 x 5 x 10 inches
5. Must be controlled in flight
6. Take off distance 200ft (61m) (unassisted)
7. Landing in distance 400ft (122m)
8. Fly without payload.
9. O.S. .61 FX engine with E-4010 Muffler (no alterations apart from piping exhaust)
10. Engine must have spinner or rounded safety nut.
11. Propeller must rotate at engine RPM.
12. Fuel common grade 10% nitro methane.
13. Payload consists of support assembly and payload plates.
14. Radio pack minimum of 500-mAh capacity.
15. All radio transmission meet FCC 1991 standard.

Fig. 6 below is an aircraft plan of the ADFA SAE Aero UAV design. The plan indicates the aircraft layout, size and configuration; factors that have a direct effect on the design of the PRS.

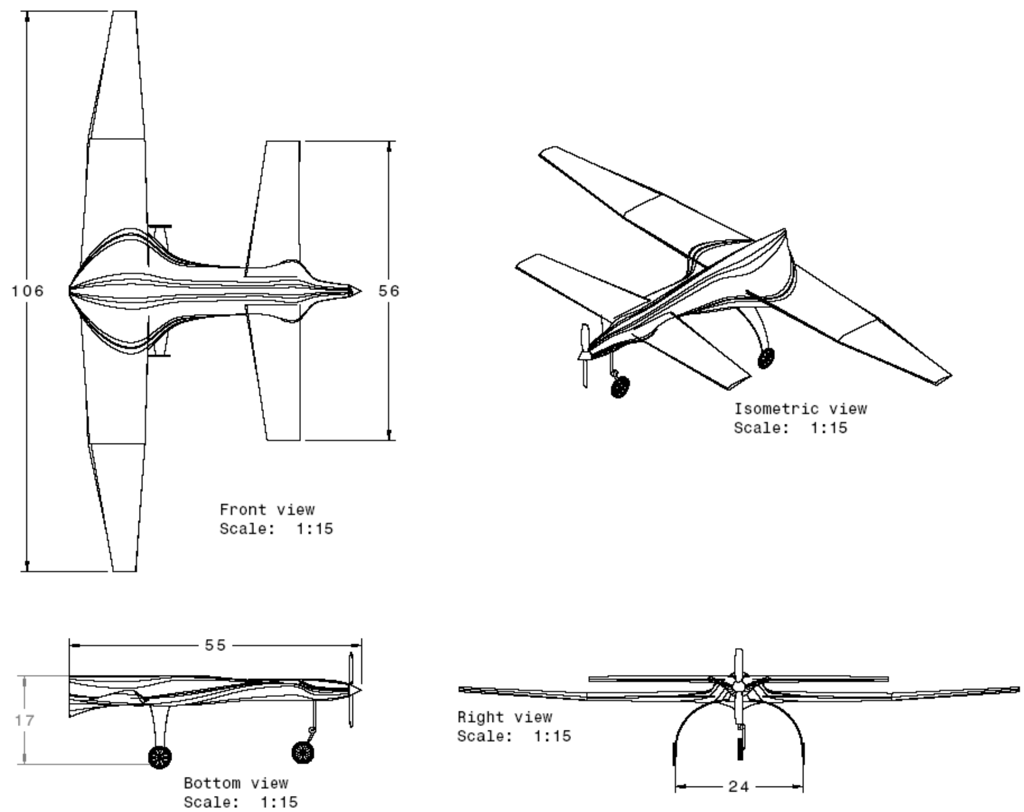

Figure 6. ADFA SAE Aero UAV Plan. The UAV is a high canard low wing design with no vertical stabilizer. It uses a tractor propeller piston engine for propulsion and has a tri-fixed undercarriage arrangement.

IV. Parachute Recovery System Design

A. Project Plan

The requirement for a parachute recovery system (PRS) for use on small UAV research aircraft has been identified. This project seeks to fulfill this requirement by completing the following clearly defined tasks.

1. Review existing PRS's.
2. Design a system suitable for small UAV aircraft.
3. Develop a prototype.
4. Fit to a test aircraft.
5. Commence final testing.

There is a clearly defined time constraint in place for this project, culminating in the submission of a final thesis document on the 20th October 2008. A project planning document outlining a logical process to meet the above tasks by the completion date is attached in ANNEX B.

B. Parachute Recovery System Requirements

Determining the requirements of the PRS will give the design process a direction. Listed here are the essential and desirable requirements.

Essential Requirements

1. Minimise Damage to airframe on ground impact
2. Deploy Reliably
3. Internal power source for activating the deployment system
4. Stand alone remote controlled deployment switch
5. Minimal impact on aircraft aerodynamic stability when attached
6. Capable of carrying a 25kg payload

Desirable Requirements

7. Deploy Reliably at any flight Condition (i.e. Spin, Stall)
8. Parachute Release Mechanism
9. Interchangeable for different aircraft
10. Aircraft touches down on its undercarriage
11. Light weight
12. Minimal Height loss during parachute inflation

C. Canopy Shape

Understanding that this PRS is to be used as a lower atmosphere, subsonic aerodynamic decelerator steers the choice of parachute canopy shape to three different options. These options are Para foil, Cruciform, and hemispherical parachutes. As discussed in the literature review parafoil shaped designs, common in sports parachutes, are steerable systems, unnecessary for this application. The parafoil design also adds unnecessary complexity to the construction of the intended PRS.

Cruciform or hemispherical parachutes are more commonly used in aircraft recovery systems. This PRS will use a hemispherical parachute design due to the larger drag coefficient than the cruciform parachute allowing for the use of a smaller parachute for the same descent speed. The cruciform parachute has a smaller opening force coefficient which means less shock force occurs during parachute inflation; however this is outweighed by the reliability of the hemispherical parachute.

Hemispherical parachutes also have a lower canopy filling constant which reduces filling distance. Therefore less height is lost during inflation. Further reasons for choosing a hemispherical parachute shape are listed below.

1. Ease of construction.
2. Ease of packing.
3. Better consistency on opening.
4. Large inflation shock forces acceptable due to unmanned aircraft.
5. Large Drag coefficient.

One negative aspect of using hemispherical parachutes is their tendency to oscillate. Oscillation is a result of an unstable parachute where the vortex shedding initiates a rocking motion back and forth. Hemispherical parachutes often have a tendency to have large oscillations, up to ± 30°. Research has shown however that these oscillations only occur at the higher descent velocities (≥ 9m/s), which is as much as 4 m/s faster than the descent velocity this PRS is designed to achieve.

D. Determination of Initial Canopy Data

Having decided that the canopy shape will be hemispherical, the initial canopy sizing can be evaluated with the objective of calculating inflated parachute diameter. Parachutes rely on the aerodynamic drag force, represented by Eq. (3), to slow the descent of a body. Assuming that the parachute is in a steady state descent means that the drag force F_d can be equated to the weight of the descending body, as represented by Eq. (4). Rearranging Eq. (4) for surface area yields Eq. (5).

$$F_d = \frac{1}{2}\rho V^2 S C_D \qquad (3)$$

$$mg = \frac{1}{2}\rho V^2 S C_D \qquad (4)$$

$$S = \frac{2mg}{\rho V^2 C_D} \qquad (5)$$

The unknowns in Eq. (3) to determine surface area are, payload mass 'm', and descent velocity 'V'. All other variables in the equation are already known quantities, ρ=1.225kg/m^3, C_D=0.7(standard for hemispherical parachutes) (Knacke, 1992), and g=9.81m/s.

Payload mass is known due to the ADFA SAE Aero UAV gross weight not exceeding 55lbs (≈25kg), therefore m=25kg. The descent velocity can be obtained from historical data, which shows that aircraft PRS's have descent velocities between 4-6 m/s (Wyllie, 2001). Taking the average and using 5 m/s for '*V*' means that surface area can be quantified.

Now that surface area can calculated the nominal parachute diameter can be found. The nominal diameter of a parachute is simple a reference diameter found by using Eq. (6), (Knacke, 1992) below.

$$D_o = \sqrt{\frac{4S}{\pi}} \qquad (6)$$

Using table 5-1 (Knacke, 1992), found in ANNEX C, the ratio between inflated diameter 'D_p' and nominal diameter 'D_o' is highlighted. This allows for the calculation of the inflated diameter using the Eq. (7) below.

$$D_p = 0.66 D_o \qquad (7)$$

Now that the canopy has been sized and relevant parameters determined, it is possible to give an estimation of the parachute filling distance. Parachute filling distance is calculated using Eq (1) outlined within the literature review.

The excel spreadsheet shown in Fig. 7 was used to calculate the parachute data, using the equations outlined previously.

Canopy Sizing			
	Parameter	**Value**	**Units**
	Mass	25.00	**kg**
	Gravity	9.81	**m/s^2**
	Density	1.23	**kg/m^3**
	Desent Velocity	5.00	**m/s**
	Drag Coefficient	0.70	
	Parachute Filling Parameter	8.00	
	Surface Area Required	22.88	**m^2**
	Nominal Parachute Diameter	5.40	**m**
	Infalted Parachute Diameter	3.56	**m**
	Parachute Filling Distance	28.50	**m**

Figure 7. Calculation of Canopy Data.

The excel spreadsheet shows that for a 5m/s rate of descent, a parachute with a 3.56m inflated diameter is required. This data now serves as the first iteration in the design process. From this point further preliminary design can occur. Using two smaller parachutes and clustering them together instead of one larger parachute may be better for example. Further design work is beyond the scope of this initial thesis report, however will be covered in the future.

The spreadsheet calculated a parachute filling distance of 28.5m. This is important as it shows that the parachute can open even at very low altitudes. More mathematically complex equations exist to more accurately determine canopy filling distance, and will be looked at in future design work.

V. Future Direction

The ultimate goal of this project is to deliver a reliable PRS to the ADFA SAE Aero UAV. In order to achieve this goal a large amount of work is still required. Detailed design of the PRS needs to be completed, so that testing of individual systems can begin. These systems include;

1. Parachute Extraction System
2. Parachute Reefing System
3. Parachute Initiation System
4. Parachute Release Mechanism
5. Parachute Container

The timeline for the completion of the PRS is within the project planning document attached in ANNEX B. The project has clearly defined milestones that are outlined below in Fig. 8.

Project Title: Parachute Recovery System
Project Manager: Kirk Cartwright

	Responsible	Target Date	Actual Date	Signature
1. Submission of Project Plan documents.	Project Manager	04/04/08		
2. Initial Thesis Report	Project Manager	30/04/08		
3. Mid year review of final designs	Project Manager	21/0708		
4. Testing Phase	Project Manager	25/08/08		
6. Thesis Seminar	Project Manager	16/09/08		
7. Final Thesis Document	Project Manager	02/10/08		

Figure 8. Project Milestones.

VI. Conclusion

The requirement for a PRS for small UAV aircraft has been justified. This project seeks to fulfill that requirement by designing a PRS to be tested on the ADFA SAE Aero UAV.

This initial thesis document has discussed the current research into PRS's relevant to this project. A small discussion of the ADFA SAE Aero UAV in provided within this report and also some initial design work is compiled pertaining to canopy shape and canopy sizing. A plan to complete the final project has been provided, with a milestone chart to track progress.

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