RDTE of Parachute Recovery System for ADFA UAV

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The aim of this thesis project is to design, manufacture, and test a Parachute Recovery System for a 25kg ADFA UAV, and was implemented in order to mitigate the costs of UAV system failure during flight testing. The first part of this project included the definition of the scope, timeline, and tasks. This was followed by a critical analysis of existing literature, with a particular emphasis on minimising parachute weight, activation and deployment subsystem design, and the development of experimental schedules. Successful project outcomes at this time include a critical literature review, project planning documentation and an initial thesis report; finalised design and costing of the parachute assembly; preliminary design of the deployment subsystem; finalised design and acquisition of the activation subsystem; finalised design of the experimental schedule, and preliminary design of individual testing procedures.

Nomenclature

List Of Symbols

W_P = Weight of parachute [kg]
D_o = Nominal diameter of canopy [m]
N_G = Number of gores (radials) in canopy
L_S = Length of suspension lines [m]
F_{SL} = Strength of suspension line [N]
w_c = Specific canopy weight [kg/m^2]
N_{SL} = Number of suspension lines
w_{SL} = Suspension line specific weight [kg/m]
v_{stall} = UAV stall speed
v_{max} = UAV maximum speed
v_{cruise} = UAV cruise speed
m_{prs} = PRS mass
m_{uav} = UAV mass

List Of Abbreviations

ADFA Australian Defence Force Academy
PRS Parachute Recovery System
RCFS Radio Control Fail Safe
SAE Society of Automotive Engineers
UAV Unmanned Aerial Vehicle

I.Introduction

A. Aim

The aim of this project is to design, manufacture and test a Parachute Recovery System for a 25kg UAV. The essential outcome for this project is the repeated successful deployment of a fully integrated PRS in rolling ground tests. The desired outcome for this project is the repeated successful recovery of a UAV in a flight test.

B. Scope

The scope of this project began with a review of existing literature on the subject of parachute recovery systems, parachute design and experimental testing methods. This was followed by the selection of criteria for the individual components of the Parachute Recovery System (main parachute/pilot parachute assembly, deployment subsystem and activation subsystem). After a suitable set of requirements was formulated, design

work was commenced in each of these components. An experimental schedule was then designed to verify the design and manufacture of each component. Manufacture of the activation subsystem and purchase of the parachute assembly has been commenced.

Future work to be completed in this project includes the finalised design and construction of the deployment subsystem, completion of the experimental schedule for individual components, integration and assembly of individual components into a Parachute Recovery System, and experimental testing of the integrated PRS. The final outcome of this project is to achieve repeated and successful deployments with the assembled Parachute Recovery System. This is a systems-based outcome intended to confirm the results of the feasibility study previously conducted and demonstrate a proof-of-concept deployment sequence.

C. Background

A Parachute Recovery System is an assembly that 'uses aerodynamic drag to decelerate people and equipment moving in air from a higher velocity to a lower velocity and to a safe landing'[1].

The first documented use of a parachute recovery system on a full scale aircraft in an in-flight emergency occurred in October 2002[2], and resulted in minimal damage to the airframe and no injuries. The system, developed by Ballistic Recovery Systems Inc. of Minnesota, in conjunction with the National Aeronautics and Space Administration (NASA), successfully demonstrated that a system capable of recovering a single-engine GA aircraft can be implemented at low cost and with a total weight less than 30kg.

Tasks directly preceding this project began in 2008 with the design and construction of a UAV, to be entered into the 2008 SAE Aero West competition. Consisting of a canard design and powered by a single piston engine, the ADFA entry was required to meet strict requirements on weight, size, payload, and performance. Following completion of design and construction in March 2008, it was suggested that a recovery parachute system should be implemented on the UAV to mitigate vehicle damage in the event of component or system failure during flight testing.

In response to this suggestion, an ADFA undergraduate student commenced a thesis project, the aim of which was 'to determine if a Parachute Recovery System is a mechanically and economically feasible method of safely recovering the ADFA SAE Aero UAV from flight failure[3]'. By analysing various canopy shapes and deployment methods, a preliminary design was generated and a main parachute/pilot parachute assembly was manufactured for testing. The thesis concluded that, based on initial ground test data and mathematical analysis, 'a PRS is mechanically feasible for use on small UAV research aircraft', and recommended that further research be conducted towards the full integration and testing of a Parachute Recovery System on the UAV.

D. Justification

Research in the field of Parachute Recovery Systems for a small UAV is justified for several reasons; primarily, on grounds of costs resulting from airframe damage, in addition to effects such as lost research time. Without a system installed, in-flight failures will lead to extensive airframe damage due to ground impact forces; an operational system would significantly decrease the risk of such an occurrence. This has the effect of decreasing the cost of crashes, both in terms of monetary value and equipment downtime.

In a cost-benefit analysis conducted as part of a previous thesis, it was estimated that a $500 parachute recovery system has the potential to recover a research UAV that can cost as much as $6000, and that even if only the internal systems survive (total airframe destruction) a saving of $4000 can be achieved[3]. This does not take into account the significant amount of time lost in suspending research until a new UAV can be manufactured or purchased.

This project has the added benefit of adaptability to other UAVs of similar mass; although the background for this project is based on the ADFA SAE Aero UAV, the parachute recovery system consists of components that can be readily transferred between airframes.

E. Methodology

The methodology designed to achieve the stated of this project is broken down into several stages. These are:

1. Design and manufacture of the main parachute/pilot parachute assembly
2. Design and manufacture of the parachute deployment subsystem
3. Design and manufacture of the parachute activation subsystem
4. Testing of individual system components
5. Integration of individual system components into assembled parachute recovery system
6. Testing of assembled parachute recovery system

II.Parachute Assembly Subsystem

The parachute assembly of a PRS consists of the parachutes used to aerodynamically decelerate the aircraft prior to ground impact. In this project, the parachute assembly consists of a pilot parachute (to extract the main parachute deployment bag from the aircraft) and a main parachute (to decrease the descent rate of the aircraft). The geometry of the parachute assembly tested in the feasibility study was retained, in order to simplify testing and comparative analysis. Design work performed in this project has focused on decreasing the weight of the parachute assembly, and preventing suspension line tearout.

A Parachute Recovery System assembly for a lightweight vehicle comprises approximately 5% of the total vehicle weight[1]. For a UAV of 25kg, as stated in the client brief, this equates to a mass m_{prs} of 1.25kg. The PRS assembly tested during the feasibility study weighed 1.4kg[3], indicating that a weight decrease could be achieved. In order to identify and assess the weight decrease possible, research was conducted in the areas of suspension line materials.

A. Suspension Line Material Selection

The design of the main parachute used in the feasibility study incorporates 18 suspension lines constructed of Type III paracord. Paracord is a nylon kernmantle rope (an inner core covered by an outer sheath); Type III paracord consists of 7 inner core strands covered by a nylon sheath, with a minimum breaking strength of 2440N[4].

Using the designed geometry of the parachute, this means that the 18 lines can support a load of 39.5 kN. However, the designed maximum load is 1471 N (*25kg x 9.81m/s^2 x 4g x 1.5 SF*); this value is calculated using the nominal mass of the ADFA SAE UAV (m_{uav} = 25kg), the maximum opening shock value of 4g encountered during feasibility testing[3], and a safety factor of 1.5. This indicates that the suspension lines can be constructed of a significantly weaker (and therefore lighter and less bulky) material, without compromising the function of the PRS.

Paracord is commonly available with tensile strengths of 1774N (Type II) and 2440N (Type III)[5]. Type III paracord has a specific weight of 6.59g/m; Type II paracord has a specific weight of 4.96g/m. By selecting Type II paracord for 18 suspension lines of 4.2m length, a weight saving of 125g can be achieved. This option of altering the suspension line construction material was implemented, because such an alteration would not increase the cost of the parachute assembly.

B. Removal of Suspension Lines

The option of decreasing the number of suspension lines was investigated as a method of further decreasing weight. Although the potential weight savings are significant (27.7g per suspension line), this option was rejected for financial reasons; a standard parachute with nominal diameter D_o of 3.65m from the selected manufacturer consists of 18 suspension lines and costs $400. A nonstandard parachute of similar size with a reduced number of suspension lines would increase these costs, due to changes necessary in the manufacturing process[6].

C. Canopy Material Selection

The original design for the parachute assembly consisted of main and pilot parachute canopies manufactured from ripstop nylon with a specific canopy weight w_c of 1.1oz/yd^2 (0.0373kg/m^2). Although preliminary research was conducted into alternative construction materials for the main canopy, it was decided that these materials possessed sufficiently similar characteristics as to make design changes unnecessary. Additionally, selecting alternative construction materials would increase the cost of the parachute assembly, without gaining significant benefit.

D. Suspension Line Tearout

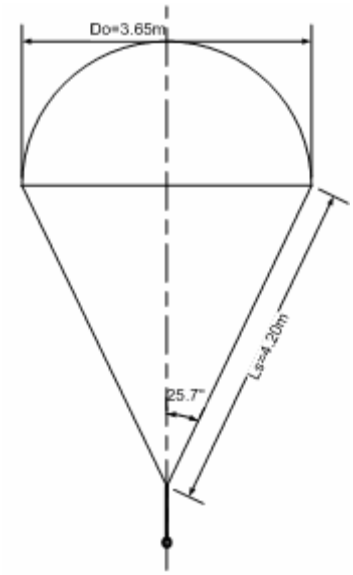
Suspension line tearout occurs when the canopy/suspension line attachment points are unable to support the inflation loads and the lines separate from the canopy. Tearout occurred during the feasibility study preceding this project, which halted further testing and highlighted the need to reinforce the attachment points (Pearn, 2009). As a result of this, the main parachute design has been altered to include webbing tape reinforcement along the attachment point seams; this will better distribute the inflation loads and provide a stronger mounting area for the suspension lines.

E. Additional Considerations

When the order for a new parachute assembly was placed, it was discovered that due to low demand for recovery parachutes in the sizes required, a total of six weeks would be required for the main parachute to be constructed, delaying the expected completion date for the parachute assembly to late May, delaying the project by a month. It was decided to continue with acquisition of this parachute assembly, as it is an integral component of the PRS.

F. Main Parachute Design Data

Design data for the main parachute is shown below in Figure 1.



Canopy Data

W_{Pmain}	= 0.9 kg	(Weight of main parachute)
D_o	= 3.65 m	(Nominal diameter of main parachute)
N_G	= 18	(Number of gores)
w_c	= 0.0373 kg/m^2	(Specific weight of suspension lines)

Canopy material is 1.1oz nylon ripstop.

Suspension Line Data

N_{SL}	= 18	(Number of suspension lines)
L_S	= 4.20 m (1.15 x D_o)	(Length of suspension lines)
F_{SL}	= 1774 N	(Minimum strength of suspension lines)
w_{SL}	= 4.96g/m	(Specific weight of suspension lines)

Suspension line material is Type II (440lb) paracord.

Note that imperial units are used here as suppliers commonly refer to their products with units used in the MILSPEC documents that cover their respective areas.

Figure 1. Design Data For Main Parachute (Foon, 2009)

III.Activation Subsystem Design

The activation subsystem of a PRS is a control system that initializes the deployment sequence of the parachute assembly in a variety of scenarios. In order to design an activation subsystem for this project, research was conducted into existing methods of deployment sequence initiation. This was followed by a needs analysis, to determine the required functions of the system, and a set of qualitative requirements identified. After a number of options were identified, they were assessed on the basis of cost, ease of implementation, and functionality.

A. Existing Methods of Deployment Sequence Activation

Research into existing radio control fail safe (RCFS) designs indicated that autonomous control of a remotely controlled aircraft or UAV can be maintained through the use of an electronic microcontroller, placed between the aircraft radio signal receiver and the actuator (normally a servo motor)[7], which is shown below in Figure 1. The purpose of the RCFS microcontroller is to override the control input from the receiver and command the actuator to default to a preset condition if the control signal fails to satisfy a preselected range of values for signal strength and signal-to-noise ratio.

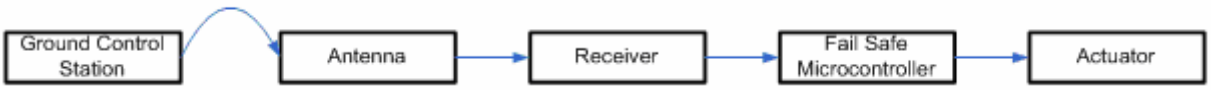


Figure 2. Block Diagram of Radio Control Fail Safe Signal Path (Foon, 2009)

The majority of commercially available RCFS microcontrollers use a program burned onto a PIC chip to select the preset conditions. These are designed to be used in conjunction with a programmable receiver on the aircraft, and typically rely on the receiver to interrupt noisy signals (simulating a signal loss condition). More sophisticated RCFS microcontrollers have the ability to analyse control signals independently, in addition to greater functionality.

B. Functional Requirements

In order to design a suitable activation subsystem, the possible failure modes of a UAV in flight were considered. The modes identified as the most likely (with the potential for recovery) were:

1) Engine failure
2) Loss of radio control (due to interference or component failure)

In response to this, a number of criteria were examined and, through consultation with the project client, a set of core requirements selected. These were that the activation subsystem must be able to:

1) Be activated and deployed under manual control
2) Activate autonomously in the event of radio control signal loss/interference
3) Be resistant to transient interference

Additional requirements were also selected as contributing to the effectiveness of the activation subsystem. These were that the activation subsystem should be able to:
1) Be controlled using a radio control frequency separated from the main control frequencies
2) Be controlled using an independent secondary control circuit
3) Be operated independently of the UAV electrical source

C. Microcontroller Acquisition

Two options were identified to acquire the radio control fail safe microcontroller for the activation subsystem; purchase a commercially available microcontroller, or assemble one from individual components according to available designs. Although the option of purchasing the components separately was investigated and a preliminary costing performed, it was decided that despite the financial benefits (as the individual components collectively cost $4.50 per microcontroller), the equipment, time, and skill necessary to assemble them negates any advantages gained.

Various commercial microcontrollers were investigated and a single supplier selected, on the grounds of activation criteria, weight and cost. The results of this investigation are presented below in Figure 2. The selected RCFS microcontroller will be supplied by A1 Hobby Group, and will be delivered earlier than required by the project plan.

Supplier	Fail Safe Activation Criteria			Voltage	Weight	Cost
	Out-Of-Range	Interference	Low Voltage	[V]	[g]	[AUD]
Gadget Galaxy	Yes	Yes	Yes	4.8-6	6	$40
RC Hobbies	Yes	No	Yes	4.8-6	6	$19
A1 Hobby Group	Yes	Yes	Yes	4.8-6	5	$20

Figure 3. Product Information of Commercially Available Fail Safe Microcontrollers (Foon, 2009)

IV.Deployment Subsystem Design

The deployment subsystem of a PRS is the mechanism that ejects and regulates the release and inflation of the parachute assembly. A well-designed deployment subsystem minimizes opening time and opening force, ensures a uniform deployment and inflation, and keeps tension on all parts of the pilot parachute.

The feasibility study preceding this project identified four concepts: uncontrolled, ballistic, spring, and pilot chute[3]. Each of these was analysed according to a set of criteria, covering complexity, reaction forces, adaptability, weight, and cost, with a particular emphasis on reliability, speed of deployment, and ability to provide a lines first deployment. A concept design for a spring-launched pilot chute deployment subsystem was included in the feasibility study.

A. Consideration of Opening Shock Attenuation Methods

For a parachute recovery system, the greatest deceleration and shock force is generated during deployment at the point of canopy inflation. In order to maintain the structural integrity of the UAV and protect its payload and internal equipment, it is desirable to decrease the opening shock the UAV is subjected to[8].

In almost all of the attenuation systems described below, the opening shock is decreased by slowing down the deployment time. This has the effect of increasing the time it takes for the PRS to recover the platform. Therefore, the designer must consider the optimal balance between opening shock and deployment time in the design phase.

Methods of decreasing opening shock include:
1. Securing lines and risers with break cord
2. Reefing system
3. Line packing/line bundling
4. Increasing porosity of main canopy
5. Adding textile dampers, such as elastic line segments
6. Adding spring segments
7. Stepped main chute deployment
8. Restricting airflow into the bottom of the canopy
9. Apex retraction[9]

B. Consideration of Parachute Packing Methods

In order to minimize the amount of time, equipment and skill required for packing the PRS, it was decided that the parachute assembly will be packed by hand. Although this will result in a lower packing density, and therefore a larger packed volume, the use of a properly designed deployment bag will ensure that the packed geometry will conform to the space set aside within the UAV fuselage for the PRS.

After consulting a professional parachute rigger[10] and the packing instructions provided by the manufacturer of the main chute used for testing in the feasibility study[11], two methods of parachute packing were identified.

The 'air channel' method layers the gores whilst maintaining a clear channel through the middle of the parachute. When the parachute is deployed, this channel allows air to enter the apex of the parachute first and inflate downwards. This decreases the amount of time required for full inflation to occur. The suspension lines are looped and packed in woven loops on the exterior of the deployment bag.

The 'Fruity Chutes' method sequentially folds the parachute in on itself and wraps the suspension lines around the parachute before stowing in a deployment bag. This method is designed for ease of packing, which decreases the amount of time and experience required to pack the parachute.

C. Detailed Design of Deployment Subsystem

With the basic design concepts of a spring-ejected pilot chute extracting the main parachute in a deployment bag, a detailed design was developed for the deployment subsystem. This design is intended in a modular arrangement that simplifies installation, maintenance, packing, and adaptability to other airframes. A non-scale design is shown below in Figure 3.

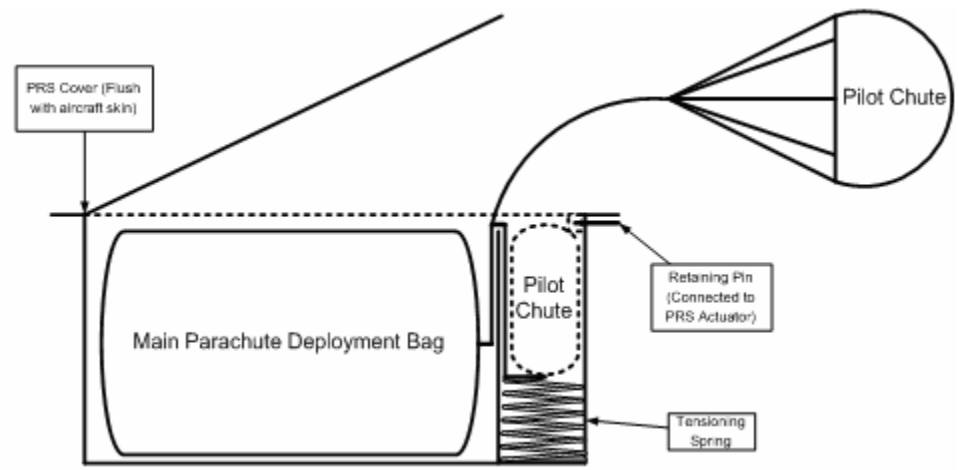


Figure 4. Diagram of Deployment Subsystem Detailed Design (Foon, 2009)

The outer cover of the PRS acts as part of the aircraft skin, and is held in place under tension by a retaining pin. The retaining pin is attached to the activation subsystem, and is retracted when the actuator is moved. The tensioning spring and pilot chute are packed into a tube within the compartment. The tensioning spring pushes on the pilot chute, which pushes on the outer cover. When actuated, the pilot chute is ejected clear of the aircraft into the freestream, where it will inflate and extract the main parachute deployment bag. This sequence is shown below in Figure 4.

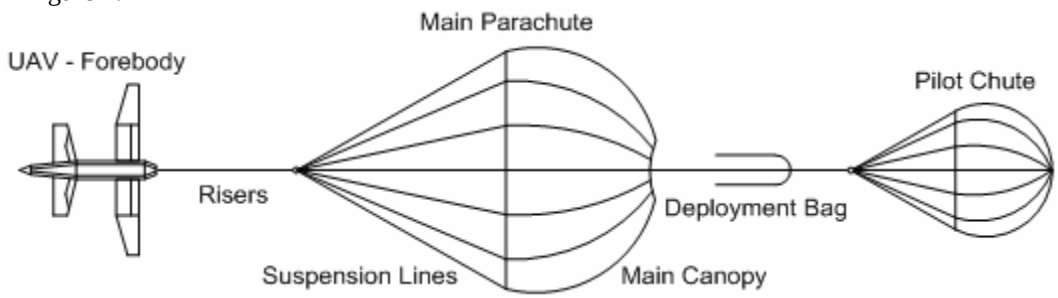


Figure 5. Diagram of Parachute Recovery System Deployment Sequence (Foon, 2009)

Future design work on the deployment subsystem will include sizing of each of these components, as well as alterations to the deployment bag geometry to conform to the aircraft fuselage geometry.

V.Experiment Design

The experiment schedule for this project was designed for two reasons; primarily, to ensure the correct operation of each subsystem (individually and collectively) and secondarily, to assess and quantify its opening behaviour and steady state characteristics. All testing falls into two main categories: performance testing and functional testing. Performance testing obtains data on a specific range of characteristics over a wide range of test conditions, and is generally more complex than functional testing, which simply demonstrates whether the system works or not.

Parachutes and parachute recovery systems can be tested with a variety of methods, which can be categorised into three main groups; free flight testing, captive (or tow) testing, and wind tunnel testing. In order to design a suitable experimental schedule, it was necessary to explore each of the different testing methods available.

A. Free Flight Testing Considerations

Free flight testing is characterised by the unrestrained motion of a test article through stationary air. Methods of free flight testing include: aircraft drop testing, boosted vehicle launch from aircraft, test vehicle launch from high-altitude balloon, test vehicle launch from ground, gun/mortar-launched ballistic vehicles, and ejected vehicle sled launch.

Free flight testing has the following advantages:
1. No physical restraints on the parachute-forebody system (no interference)
2. Testing occurs with a finite mass, rather than the infinite mass of other testing methods
3. Interaction between the forebody and the parachute can be observed
3. Test conditions are identical to real-world operating conditions
4. The complete system can be tested for functionality
5. Other performance characteristics can be assessed, such as system stability, flight trajectory, rate of descent, and drift.

Free flight testing has the following disadvantages:
1. It is extremely difficult to control the test conditions
2. It is difficult to obtain precise data on test article performance
3. Highly complex equipment and significant resources are required
4. Highly expensive

B. Captive Testing Considerations

Captive testing is characterised by the restrained (towed) motion of a test vehicle through stationary air. Methods of captive testing include: aircraft tow, rocket sled tow, truck tow, and water tow.

Captive testing has the following advantages:
1. Relatively easy to control test conditions
2. Accurate and precise performance measuring can be conducted
3. Test vehicles can be recovered and reused
4. Testing can be repeated easily and quickly
5. Testing can occur without expensive test equipment
6. Relatively inexpensive compared to free flight test methods

Captive testing has the following disadvantages:
1. Test article restraint means that motion during testing is severely limited
2. Infinite mass testing creates inaccurate rates of velocity decay; which means that reliable data can only be obtained for steady state behaviour
3. Other factors are introduced that further decrease the accuracy of the results obtained, such as ground effects, vehicle forebody effects and wall effects.[5]

C. Wind Tunnel Testing Considerations

Wind tunnel testing is a specialised form of captive testing in which the test article is held stationary in a moving airstream. Although there are a large variety of wind tunnels available, they all possess similar advantages and disadvantages. With appropriate facilities available, wind tunnel testing is the most of the captive test methods.

In addition to the advantages of captive testing, wind tunnel testing has the following advantages:
1. Test conditions can be precisely controlled and rapidly altered
2. Extremely precise measurements can be made

3. Airflow can be easily visualised
4. Tests can be rapidly repeated

In addition to the disadvantages of captive testing, wind tunnel testing has the following disadvantages:
1. Limitations are placed on the size and scale of the models
2. Tunnel introduces blocking and wall effects
3. Difficulty in obtaining similarity between test articles and full scale designs
4. Difficulty in mounting models to minimise flow separation effects

To ensure the accuracy and reliability of data obtained from wind tunnel testing, past parachute wind tunnel testing has limited the test size of the test article to 5%-6% of the area of the test section, to avoid the appearance of tunnel blocking effects[12].

D. Scale Model Testing Considerations

When considering the use of scale models in testing (in free flight, captive testing or wind tunnels) it must be understood that significant differences exist between their uses in aircraft and parachute design. In the aircraft field, models are used to directly obtain aerodynamic data. In the parachute field, models are used to obtain comparative relationships between various designs.

If a design modification is applied to a scale model parachute and tested, it will generate the same percentage of performance change on a full scale parachute. Using this rule, it is possible to investigate the effects of design changes. This rule can be applied to drag, stability and opening force characteristics.

Parachutes with an inflated diameter $D_i \leq 50$cm exhibit inflation behaviour and steady state characteristics that do not replicate those of larger parachutes[1]. This lack of similarity occurs due to dissimilarities in material properties and parachute geometry. When manufacturing a model parachute, it is necessary to choose a material that is both sufficiently lightweight and sufficiently porous to accurately represent the full scale parachute. Such materials are usually extremely difficult to manufacture or cannot be obtained. Additionally, it can be difficult to manufacture a model parachute to the correct scale; models will shrink 5% to 10% because of takeup during sewing, which creates a noticeable difference between the theoretical canopy geometry and the actual geometry.

For the purposes of obtaining qualitative data, it is often easier to perform a theoretical comparison and manufacture full scale prototypes. For quantitative or comparative data, small scale model parachutes can be used effectively.

E. Experiment Schedule

The experiment schedule was designed to be conservative, in order to limit the possibility of damaging the test article or any individual components. It was also designed with a ‘bottom-up’ focus, to verify the correct operation of each of the subsystems prior to integration and more complex testing. After functional testing of the integrated PRS components is completed and its correct operation verified, further investigation of performance will be conducted.

The chronological sequence of experiments to be conducted is:
1) Functional bench testing of activation subsystem
2) Functional bench testing of deployment subsystem
3) Functional rolling test of parachute assembly
4) Functional rolling test of integrated parachute recovery system
5) Rolling performance test to investigate and verify inflation behaviour and steady state characteristics
6) Rolling performance test to investigate the effects of various opening shock attenuation methods

F. Experiment Equipment and Setup

Rolling tests will be conducted using the captive testing method, with the test article mounted on a stand secured to the bed of a utility vehicle. The stand is intended to raise the test article clear of the vehicle’s wake and maintain its position in the freestream. The experimental setup is shown below in Figure 5.

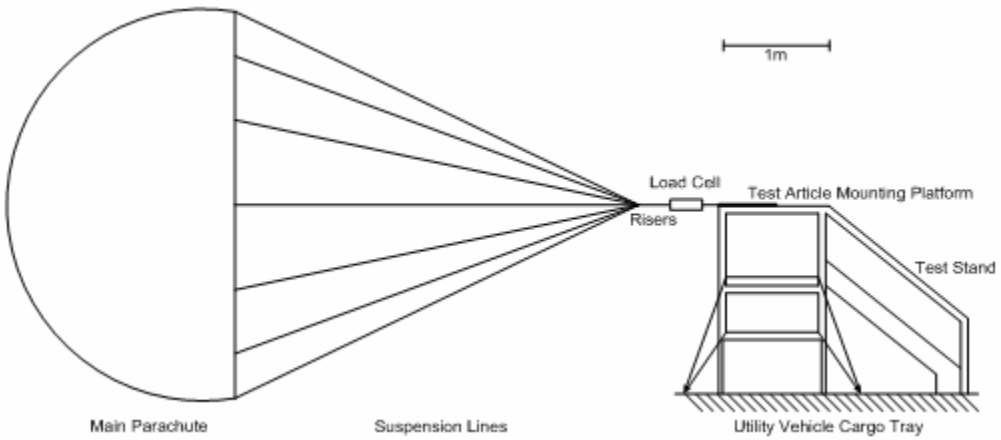


Figure 6. Scale Diagram of Rolling Test Equipment Setup (Foon, 2009)

G. Experiment to Investigate Inflation Behaviour and Steady State Characteristics

The aim of this experiment is to gather data on the performance of the PRS during inflation (opening) and the steady state (descent) phase. This data is required to investigate the:

1) Opening time of the PRS
2) Opening/shock forces
3) Opening geometry
4) Steady state oscillation behaviour
5) Steady state load state
6) Variation of these characteristics with forward speed

In order to obtain this data, repeated captive ground tests will be conducted at a range of forward speeds (the range to be investigated will extend from v_{stall} to v_{max}. This range is intended to simulate the entire flight envelope of the UAV. A load cell will be connected to the main parachute risers and the test article mounting platform, in order to measure the load state of the main parachute. Cameras and timers will be mounted at various locations on the utility vehicle and the test stand, in order to record the opening time and geometry of the PRS, as well as observe how the main parachute oscillates once full inflation has been achieved.

H. Experiment to Investigate The Effects of Various Shock Attenuation Methods

The aim of this experiment is to gather data on how implementation of some of the opening shock attenuation methods detailed previously will affect the opening time and opening shock experienced by the PRS. The methods to be tested are:

1) Securing of lines and risers with break cord
2) Line packing/line bundling
3) Reefing system
4) Adding textile dampers, such as elastic line segments

These methods were selected as the simplest to implement without major alterations to the parachute assembly or the deployment subsystem. Each of these methods can be applied individually or collectively in order to modify the opening behaviour of the parachute assembly, and can be removed and repacked with minimal down time between test runs.

In order to obtain this data, repeated captive ground tests will be conducted at a fixed forward speed (v_{cruise}) to obtain comparative performance data. As with the previous experiment, a load cell, cameras, and timers will be used to measure the opening forces and record the opening behaviour of the PRS. These experiments have been designed with maximum commonality, so that they can be run during a single testing session without the need to reconfigure the test vehicle or test equipment setup.

I. Further Experiments

In the event that the essential outcome for this project is achieved with sufficient time for further development and testing, flight testing will occur. The design and construction of equipment for flight tests will occur in the event that this stage occurs.

VI.Summary

Work on this project has commenced and the majority of the design work has been completed. Outcomes that have already been achieved at this time include:

1) An introduction, critical literature review, project planning documentation and an initial thesis report.
2) Finalised design and costing of parachute assembly
3) Preliminary design of the deployment subsystem
4) Finalised design and acquisition of the activation subsystem
5) Finalised design of experimental schedule
6) Preliminary design of individual experiment procedures

A. Future Outcomes

Outcomes that will be achieved with additional work include the completion and verification of each of the subsystems, integration of those subsystems into a complete PRS, and functional and performance testing of the integrated PRS. These tasks are outlined in the milestone chart presented below in Figure 6.

Milestone	Responsibility	Target Date
1. Initial Thesis Report	Project Manager	29/04/09
2. Activation Subsystem Completed	Project Manager	20/05/09
3. Deployment Subsystem Completed	Project Manager	20/05/09
4. Parachute Assembly Completed	Project Manager	31/05/09
5. Thesis Viva Session	Project Manager	TBA
6. PRS Integrated and Tested	Project Manager	30/06/09
7. Performance Testing Completed	Project Manager	31/08/09
8. Thesis Seminar	Project Manager	15/09/09
9. Final Thesis Document	Project Manager	19/10/09

Figure 7. Milestone Chart for Parachute Recovery System Design Project (Foon, 2009)

B. Project Management Documentation

Project management documentation appended to this thesis report include a project plan with task breakdown, Gantt chart, work breakdown structure, and risk assessment covering all tasks included in this project.

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