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Military Technical College, Kobry Elkobbah, Cairo, Egypt,
Tel: +(202) 24025292 –24036138, Fax: +(202) 22621908

Design and Fabrication of Low Cost Parachute Recovery System for SUAVs

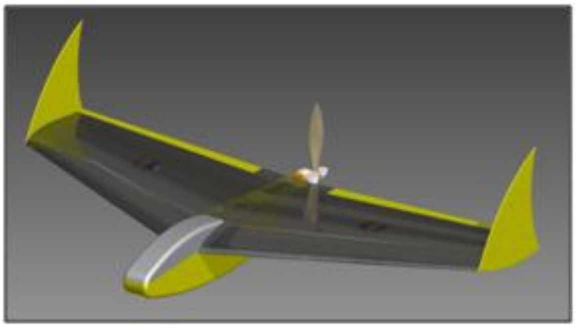
M. Y. Zakaria*

Abstract: The military has shown the most recent interest in small UAVs (SUAVs) for many reasons. A SUAV is much more portable than its large counterparts and requires only one operator. A smaller reconnaissance plane can assess ground targets at a closer range without being detected. We developed a recovery method for a designed SUAV short range reconnaissance in order to decrease fuselage failure probability during landing and also to save the SUAV for crashing due to flight testing while integration with the autopilot. Our Recovery parachute system Prototype was fabricated and tested under several flight conditions with remote control to examine inflation flight performance and tested with a designed SUAV case study (SAKR 2). The reliable feasibility of such a system will also be briefly considered. The findings of this work indicate that a PRS is capable of recovering these SUAV within an appropriate altitude. The low cost of implementation for a PRS also make it financially cost effective. The PRS can save SUAV when deployed at altitude more than 30 meter and with maximum forward speed 70 km/hr.

1. Introduction

The aim of this paper is to design and implement a Parachute Recovery System and to be a reliable method of safely recovering the SUAV from flight failure during flight testing, also to be a safe method for landing rather than skidding on ground. An aircraft parachute recovery system (PRS) is a procedure that relies on the deployment of a parachute to aerodynamically decelerate an aircraft allowing for a safer touchdown [1]. The test case used for testing the designed PRS is a small UAV (SAKR 2) designed and fabricated by the research group [2]. The scope of this paper work begins with the examination of existing PRSs, and a review of the principles involved with PRS design. The development of initial concepts will follow, then a focus on design requirement and selection of low cost accessories. More detailed design of the chosen concept will be pursued with the aid of experimental results, gathered through testing. The ability to safely recover UAVs in the event of flight failure and during autopilot integration is of significant importance. The ultimate goal of this work is to determine if a PRS can safely recover this small constructed UAV within an appropriate altitude. Because radio controlled aircraft operate at low altitudes it is unknown if a parachute can open quickly enough to save the aircraft. The design and construction of the SUAV was completed in early march 2011, after several months of work. As demonstrated in Figure 1 the SUAV consisted of a Tailless design, powered by a single electric engine, with Pusher arrangement.

* Egyptian Armed Forces, Egypt.



SAKR 2 Specification
Span:120 cm Length: 75 cm Height: 32 cm MTOW: 2.6 kg Range:10 km Endurance:25 min

Figure 1 Case Study Platform Specifications (SAKR 2 SUAV)

After the construction of the SUAV, there was reluctance for the flight testing to begin for fear of damage to the SUAV as a result of flight failure. It was suggested that a PRS could be used to reduce the risk of total aircraft damage in flight testing if flight failure were to occur during autopilot integration and adjusting PID control gains. Damage caused to the SUAV was considerably costly, and the inability to continue testing caused delays in research. The concept of the modern parachute is one that has been evolving steadily as the need arises. Initial concepts for parachute devices have been recorded as early as the twelfth century with designs by Leonardo DaVinci recorded in 1514 with deliberate use of drag as a medium for decreasing velocity. [3]

The development of modern parachutes deployed at high speeds and high altitudes started in the 1930's. Knacke and Madelung developed the ribbon parachute in Germany for decelerating heavy high speed payloads. After World War1 Knacke invented the ring slot parachute which is used for moderate subsonic speeds. This parachute is used primarily for cargo delivery and aircraft deceleration. PRSs are not a new concept, and there has been significant research undertaken into several of the more complex problems associated with their design. Most UAV's nowadays uses PRS at landing phase and to overcome any communication problems during its mission to be a safe way for survival. The following sections introduce some basic design features for selecting the main PRS parameters.

1.1 Canopy Shape

Principally, UAV PRSs use three different canopy shapes; cruciform or cross-type canopies, hemispherical canopies and parafoils [4]. Parafoils are gliding parachutes, designed to be steerable, allowing for a small level of navigation after deployment. Hemispherical Canopies are have high drag and opening force coefficients affording them the advantage of better reliability on opening. Hemispherical non-steerable parachutes are used for aircraft recovery because their simplicity enhances their reliability. Cruciform canopies are the simplest of the three canopy shapes consisting of two pieces of rectangular cloth overlaid and sewn together as shown in Figure 2. A quick comparison between those three shapes are tabulated form point of view of parachute design constraints shown in Table 1, concludes the selection of the canopy shape used in our PRS design.

Table 1 Canopy shapes Design constraint comparison

Design constraint	Parafoil	Cruciform	Hemisphere
Inflation time	Small	Gentle inflation	Large
Oscillation	Medium	Low	Large
Fabrication & bagging simplicity	Hard	Easy	Medium
Reliability for UAV Recovery	Low	Medium	High
Steerable	High	Medium	Low
Drag and opening Force	Medium	Very Small	Large

Figure 2 Different parachute canopies,
A- Cruciform, B- Hemisphere, C- Parafoil

1.2 Parachute Activation Concept

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. There are four main deployment systems used in releasing a PRS. Uncontrolled Deployment, this method of deployment essentially releases the parachute into the free-stream and the forward moving airflow does the work in opening the parachute to full inflation.

Due to the uncontrolled nature of this concept, there has been research that has shown it is only effective for parachutes less than 5 feet in diameter. Spring Release, This concept uses a high powered spring internally mounted to eject the main parachute into the free stream airflow. Pilot Chute Deployment, the final concept to discuss is the method of pilot chute deployment. During this method of deployment a small parachute called a pilot chute is used to drag out the main parachute as demonstrated in Figure 3. Ballistic deployment refers to the deployment of a parachute by the use of some kind of pyrotechnics Rocket deployment uses an angled nozzle rocket to pull out the main parachute. This is a very high speed deployment, and has been used successfully for larger aircraft PRS.

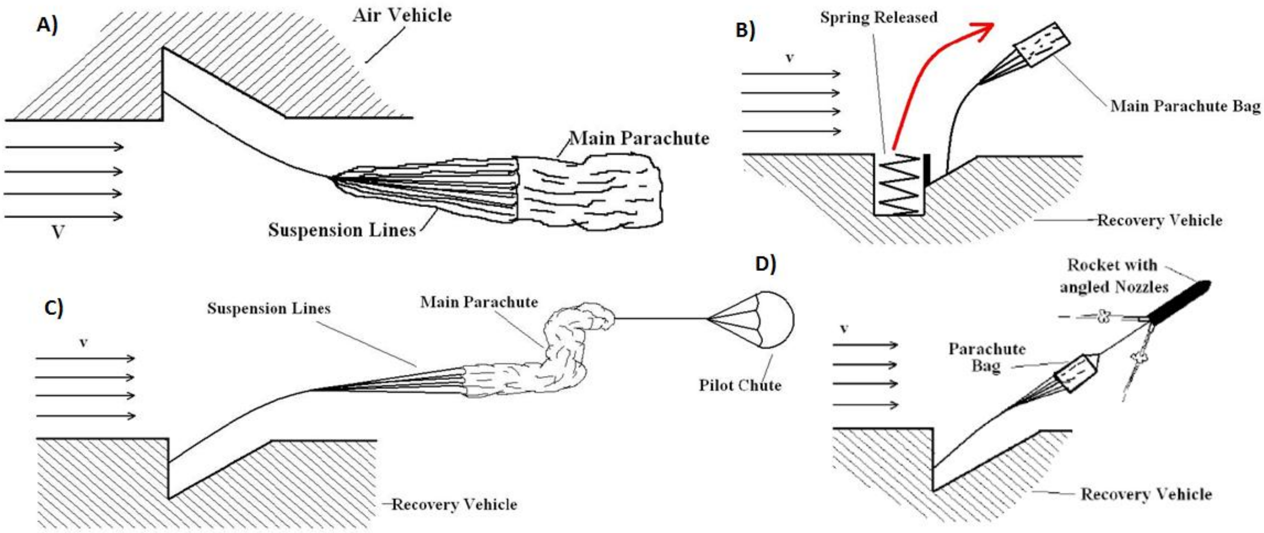


Figure 3 Types of Deployment Systems A) Uncontrolled, B) Spring loaded, C) Pilot chute, D) Ballistic

A quick Merit analysis comparison between deployment systems was done taking into consideration the design constraint shown in Table 2.

Table 2 Deployment systems for Parachutes table of merit

Design Constraint	Uncontrolled	Ballistic	Spring Release	Pilot chute
Development cost	Low	High	Moderate	Moderate
Deployment time	Medium	Very small	Small	Medium
Simplicity	Simple	Very Hard	Hard	Medium
Space occupied	Small	Medium	High	Medium
Weight	Low	large	Large	Moderate
Reaction Force	Small	Large	Moderate	Small
Reliability	Low	High	Moderate	Moderate

1.3 Parachute Filling Distance requirements

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 as seen in Figure 4.

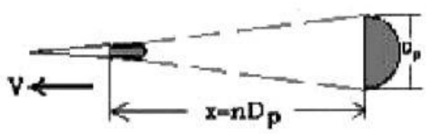


Figure 4 Canopy filling distance diagram

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. 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 canopy opens is a short distance.

1.4 Attachment Considerations

The attachment of the parachute to the UAV directly affects the operation of the system. The attachment points determine the behavior 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. In general, however, PRSs are attached at several points with the centre of gravity of the aircraft roughly in the middle to keep the system balanced. Figure 5 presents a nomenclature of parachute parts.

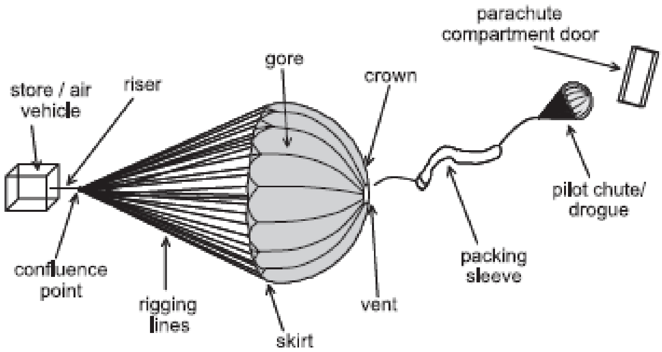


Figure 6 Nomenclature of parachute parts [5]

Canopy: the major drag producing member of the parachute, Vent: very upper region of the canopy, open to airflow to decrease oscillation, Suspension Lines: load bearing members extending from the canopy to the payload, Radials: load bearing member running from the suspension lines at the skirt to the vent lines, Gore: section of a parachute canopy between two radials. Riser: a line connecting a parachute to its payload. PRS may utilize a single or multi-point attachment scheme. To understand attachment requirements a diagram of parachute parts and gliding forces during descent is shown in Figure 7.

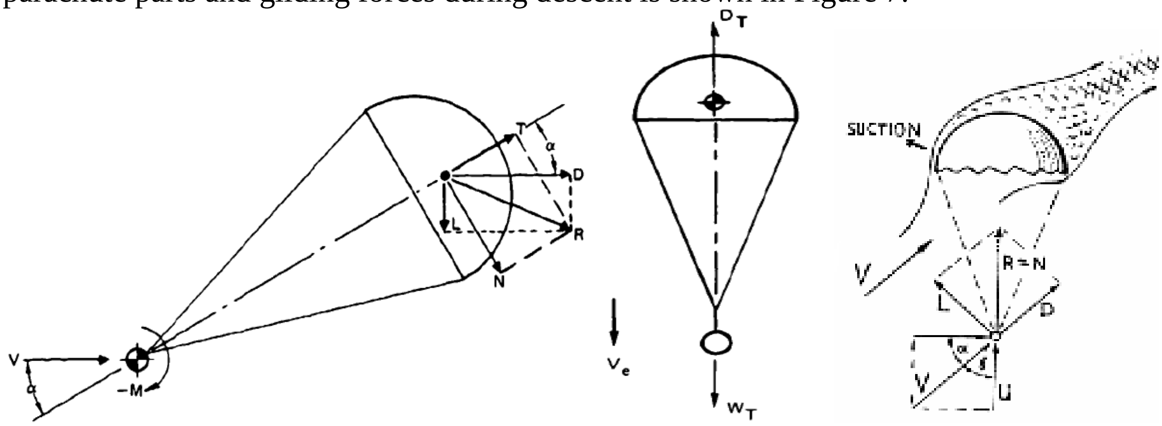


Figure 7 Parachute gilding forces during descend

2. Parachute System Design

A Parachute Recovery System assembly for a lightweight vehicle comprises approximately 5% of the total vehicle weight [6]. For a UAV of 2.6 kg, this equates to a PRS mass of 130 gm. In order to start to design a parachute, the vertical descent rate provided by a parachute in a stable descent is given by:

$$V_e = \frac{\sqrt{2W_t}}{S_o C_d \rho} \tag{1}$$

During the conceptual design phase, it was decided that the PRS would use a pilot chute deployment method assisted with low cost rubber band for ejection force. Canopy Shape was selected for this PRS to be 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. Parachutes rely on the aerodynamic drag force, represented by Eq.(2), to slow the descent of a body. Assuming that the parachute is in a steady state descent means that the drag forces 'Fd' can be equated to the weight of the descending body, as represented by Eq.(3). Rearranging Eq.(1) for surface area yields Eq. (4).

$$F_D = \frac{1}{2}\rho V^2 S C_D \tag{2}$$

$$m_g = \frac{1}{2}\rho V^2 S C_D \tag{3}$$

$$S = \frac{2mg}{\rho V^2 C_D} \tag{4}$$

All variables in equation (4) are already known quantities and tabulated in Table 3.

Table 3 Deign variables for calculating canopy Area

Parameter	mass	gravity	density	Descend Velocity (Historical trend for Hemispherical parachutes) [7]	Drag coefficient (standard for hemispherical parachutes)
Value	2.6 kg	9.81m/s^2	1.225 kg/m^3	5 m/s	0.7

The required area for the selected canopy shape is calculated to be:

$$S = \frac{2mg}{\rho V^2 C_D} = 2.379 \text{ m}^2 \tag{5}$$

The nominal diameter of a parachute can be calculated by using Eq. (6) as follows:

$$D_o = \sqrt{\frac{4S}{\pi}} = 1.74 \ m \tag{6}$$

The ratio between inflated diameter 'Dp' and nominal diameter 'Do' for a hemispherical parachute is given in Eq.(7). [1]

$$D_p = 0.66 D_o = 0.66 \times 1.74 = 1.15 \ m \tag{7}$$

2.1 Pilot Chute Design

The pilot chute, which is generally about a quarter of the size of the main parachute, is small enough that it can be released at high speeds without producing large shock forces. The issue of containment space is less of a problem using this method. Because the pilot chute is made of the same material as the main canopy it can be folded to take up very little space within the fuselage of the recovery vehicle. The first method estimated that a pilot chute with an inflated diameter of 0.35 m was required, based on historical trend. The second method is a mathematical method similar to that of the calculation of the main parachute size. Given that the main canopy of the designed parachute including bridle has a total weight of 150 gram. Knowing the weight of the main parachute and assuming the worst case scenario that the pilot chute must have the ability to pull out the main parachute at the stall condition of the aircraft (approx. 5 m /s), the mathematical calculation gives the inflated diameter of the pilot parachute to be equal 0.3 m.

2.2 Material Used in Parachute Fabrication

The canopy will be constructed from the synthesized fiber, nylon. Nylon cloth rectangular weaves 60 inch G.11.A, Strip Nylon 3/8 Force 200 lb for vent and periphery, this Nylon fabric has a porosity of 960 Ltr/m^2/s [8]. This is as it is strong, durable, elastic and abrasion resistant. It is also used as it is only slightly absorbent to water thus can be used successfully in inclement weather conditions. Suspension lines were selected from commercial market known as cord Spectra with strength 300 lb as shown in Figure 8.

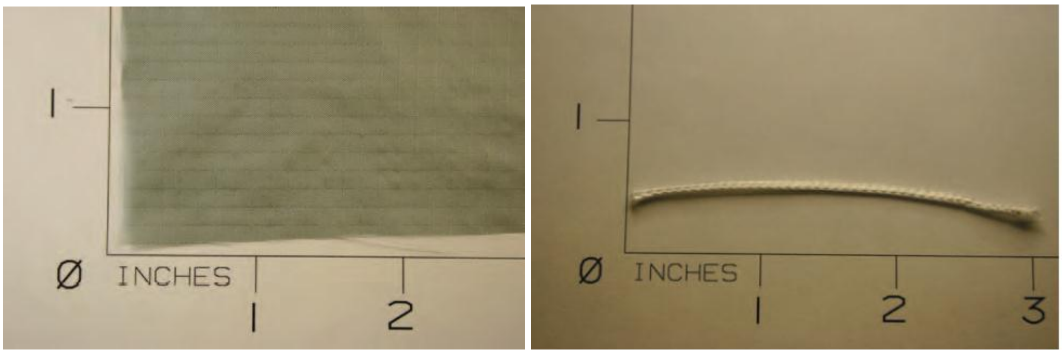


Figure 8 Material used in fabrication of PRS

Using those materials, a main and pilot parachute was fabricated with different diameters as shown in Table 4.

Table 4 Designed parachute specifications

Parachute	Mass (gm)	Inflated Diameter	Nominal Diameter	Vent Diameter	No. of suspension lines	Length of Suspension lines
Main	150	1.15	1.74	9 cm	16	95 (1.15 x Do)
Pilot chute	20	0.23	0.35	3 cm	10	30

Using the designed geometry of the parachute, this means that the 16 lines can support a load of 2157 N. However, the designed maximum load is 153 N (2.6 kg x 9.81m/s2 x 4g x 1.5 SF); this value is calculated using the nominal mass of the Sakr2 SUAV, the maximum opening shock value of 4g encountered during feasibility testing [9], 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. Taking into consideration the risers fixation with the contact points on the SUAV to be rigid enough.

2.3 Parachute Initiation Procedures

Figure 9 shows the parachute system compartment designed box, the wooden ballet pre-stressed by low cost rubber bands at the corners and the small electronic servo for releasing the pinned cover. The entire PRS is initiated by the pulling of the servo arm which consequently sprung the cover into the free airflow and the deployment process begins.

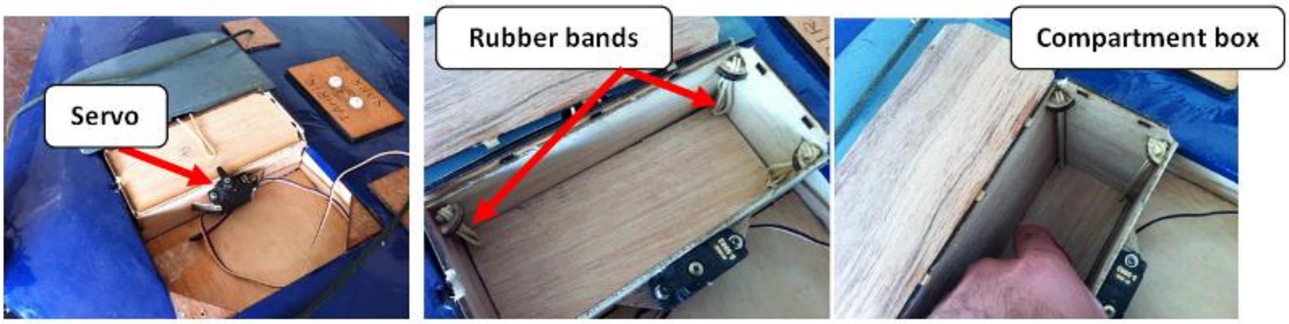


Figure 9 Parachute Deployment Compartment

The pilot chute is ejected by using a very lightweight rubber band mechanism. The bridle is sewn into the pilot chute crown area and collapses for easy storage at the mid of the SUAV fuselage just behind the aft bulkhead as shown in Figure 10. The pilot chute rubber band is compressed and held in place by a two position switch servo motor.

Figure 10 The main Parachute and pilot chute during inflation

2.4. Attachment Considerations

From a structural perspective it is important to make sure that the attachments are connected to structurally strong fixtures, able to handle the large forces that can be experienced due to the rapid deceleration of the SUAV during canopy inflation. The attachment risers of length 40 cm consists of 3 main points on the wing platform fixed on the perimeter of a virtual drawn circle of radius 17 cm, where the center of this circle is the SUAV C.G as shown in Figure 11. This is done to keep SUAV leveled during ascending.

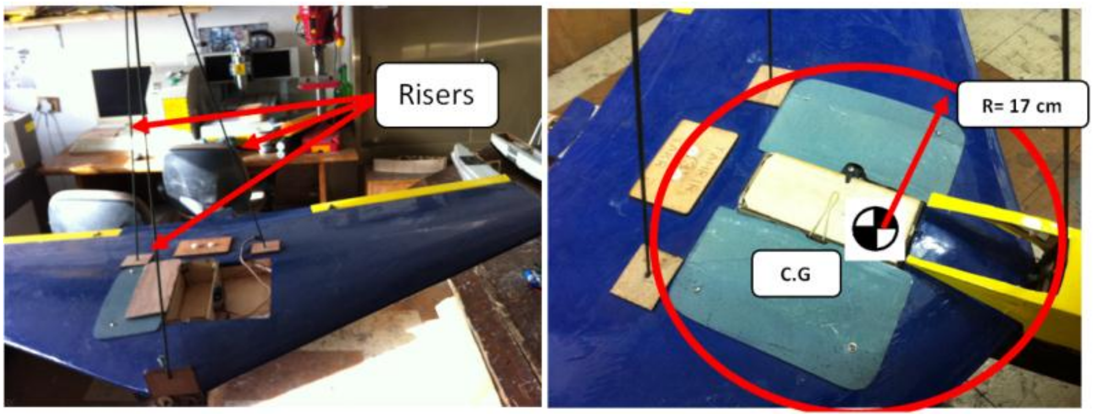


Figure 11 Parachute attachment locations

2.5. Parachute Folding

In order to fit the PRS into the compartment box, there is several ways to fold the parachute to start the inflation after deployment, Figure 11.

- Open and lay out your parachute.
- Grab all the shroud lines and organize the gores (panels) of the chute parachute.
- Fold over the gores on both sides towards the center.
- Organize the chute until it is about 15% of the diameter of the chute size.
- "Z" fold the chute into thirds.
- Pull the fabric on the underside of the chute around the edge and onto the top.
- Start to wrap the shroud lines around the chute.

Note that the back of the chute is smooth with the material all pulled around into the crease. Stop when you reach the end of the chute.

Figure 12 Parachute folding steps

3. Testing and Analysis

3.1 Experimental Parachute Drop Test

The testing occurred on a calm day to ensure that the results would be as reliable as possible. Figure 13 illustrates the fully inflated canopy during parachute drop from building rooftop.

Figure 13 Drop, forward drop in the parachute drop test.

Tests were conducted, at height 15 m and with different drop ways and different concentrated mass. Each deployment speed was repeated several times so that an average of the results could be attained. The average of the results is displayed in Figure 14. It is clear that increasing payload leads to increase in descend speed.

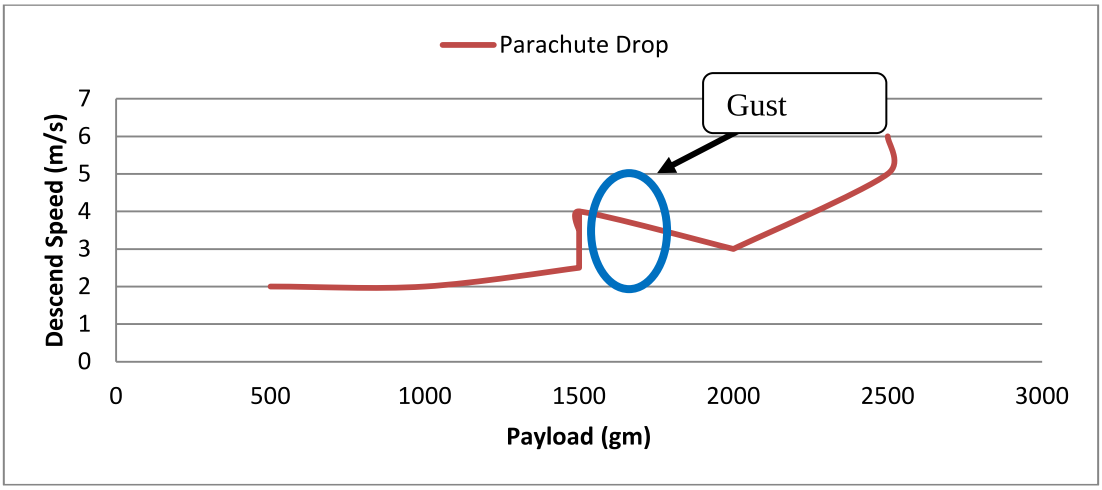


Figure 14 Descend speed vs. payload

The figure shows the gust effect for the same mass taking into consideration the effect of concentrated mass falling differs from the mass of SUAV due to its planform shape exerts a drag force during landing as the three point fixation sustained the SUAV to be leveled during landing.

3.2 Drag Force Testing

The most common method of testing parachutes is in the wind tunnel. Due to the limited resources, a simple method designed to reproduce the effects of a wind tunnel test. The basic test approach will involve dynamic parachute testing. The method will make use of a motor vehicle to induce different parachute opening speeds, once the parachute allowed to inflate the data being recorded for analysis. This will be repeated several times at different deployment velocities.

This data is particularly useful, as the descent velocity of a SUAV may be determined, knowing the SUAV mass. To conduct this testing, a ground vehicle was temporarily converted into a "flying test bed", by helping of the front passenger seat and installing the test rig, as shown in Figure 14. The parachute was tethered to the end of an aluminum arm, which protruded about 1.5 meters outside of the car. This arm was equipped with a pivot located 1/3 way from the inside end. In this manner, the drag force is effectively amplified by a factor of 2:1. The inside end of the arm was fitted with a hook to which a digital scale (40 kg capacity) would be attached. To limit the movement of the arm, a "stop" was bolted to the base plate, against which the arm could bear under loading. To conduct a test, the car was driven at a certain constant speed. The scale was then used to pull the arm away from the stop. A force measurement was then taken and recorded. The test was then repeated, moving in the opposite direction, to allow for correction due to wind. Such testing was conducted at various velocities, and the results were plotted for the 1.15 m prototype parachute.

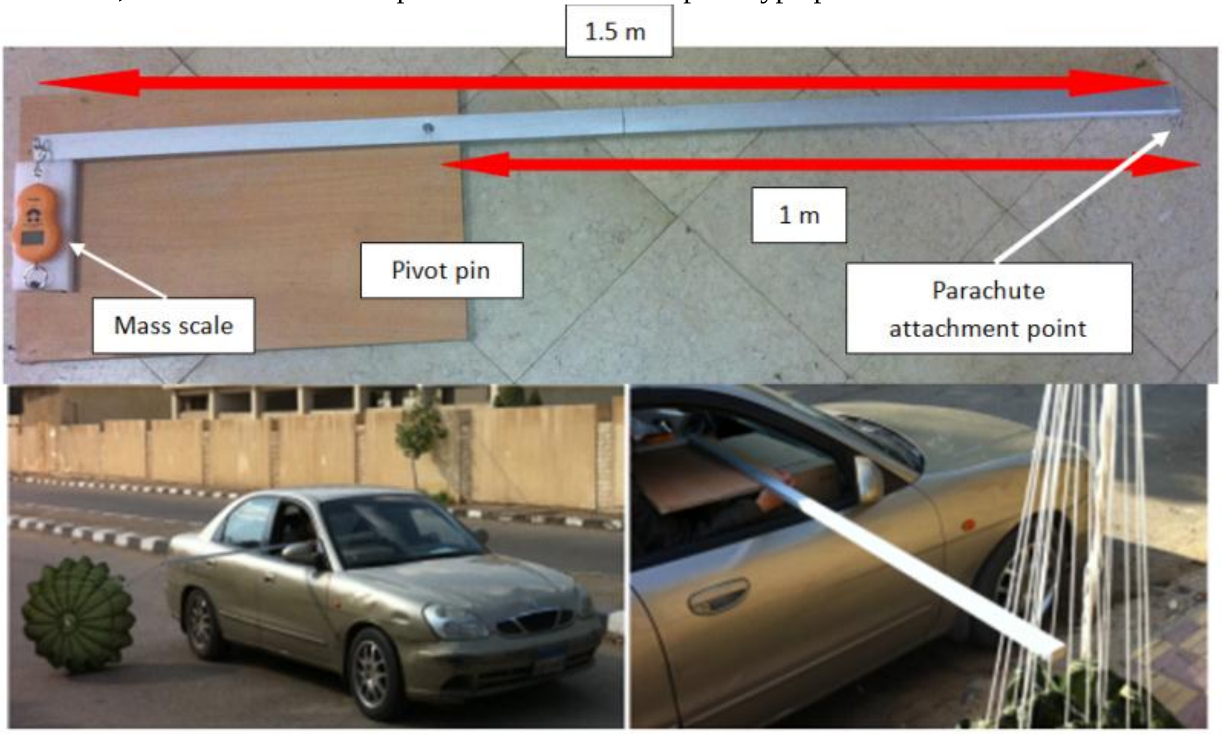


Figure 15 Car test rig for measuring drag force

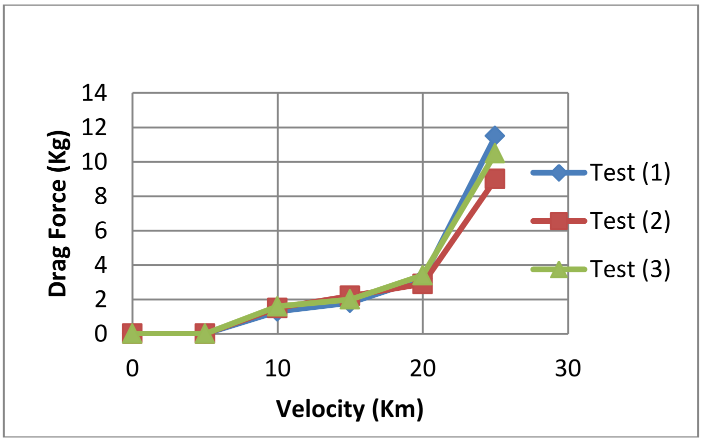


Figure 16 Drag force vs. velocity

From the above graph (Figure 15), it can be seen that this parachute would be suitable for UAV having a weight in the range between 1.5 to 3 kg, giving descent velocities of 10 km/hr to 25 km/hr, respectively. The average of these would probably be most suitable (10 km/hr -> 25 km/hr), as a descent rate of 20 km/hr may result in excessive drifting due to wind, and 30 km/hr may be considered a hard touchdown.

3.3 Parachute Flight Testing

A EAGLETREE data flight recorder with a seagull wireless data transmitter which used static pressure / pitot tube/ transducer combination for flight speed and pressure altitude, Figure 16. The recorder also recorded the servo positions and control inputs from the radio. Data was recorded at 10 hz and saved on an onboard computer. Velocity, altitude and signal strength were continuously transmitted to a ground station.

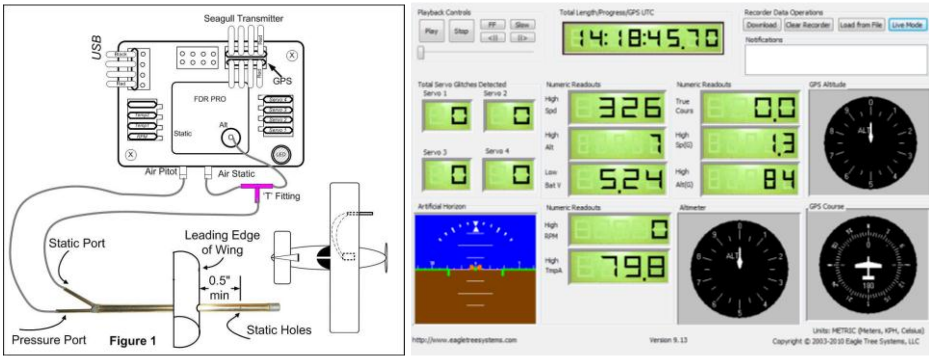


Figure 17 Eagle tree FDR and its customized GCS for SUAV

The FDR records altitude data as well as velocity pattern and SUAV orientations during flight. The parachute tests on SUAV were conducted several times to ensure reliability. The PRS on the SUV was deployed at 100 meter and at velocity 60 km/hr. A problem occur during the first flight testing due high snatch force, which results in damage the risers fixation and lead to unsuccessful recovery, as shown in Figure 18.

Figure 18 Parachute inflation with high peak snatch force

The snatch force can be attributed to the sudden reacceleration of the decelerator mass (Ewing et al, 1978) and a typical such example of the snatch force versus time is shown in Figure 19.

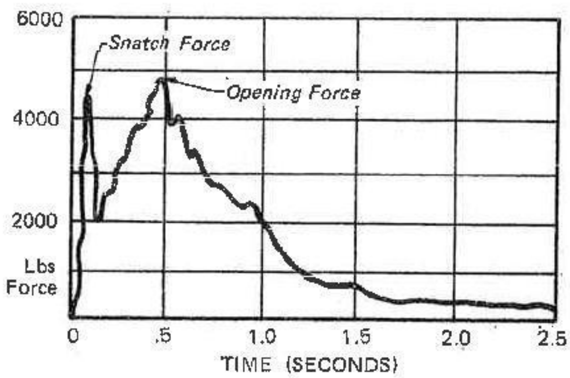


Figure 19 Force versus time during Deployment and Inflation sequences (Courtesy of Recovery Systems Design Guide [5])

Some trials was done to solve this problem such as using a deployment bag as shown in Figure 20, but due to small size of our parachute and the weight design constraints the team solved this problem by making a time delay between the signal which kills the engine and at the same time opens the compartment cover of the parachute to be deployed, this delay was done to be 2 seconds after engine was killed.

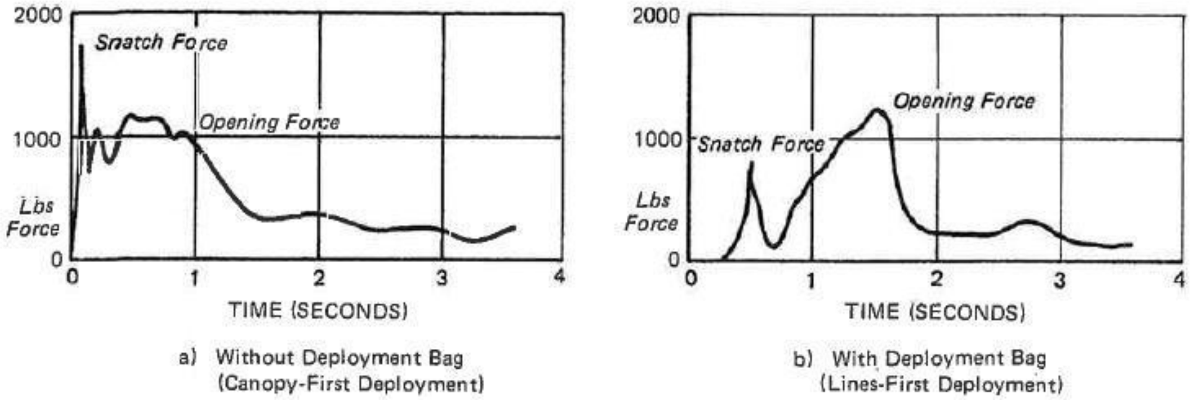


Figure 20 Snatch force peak with and without deployment bag

It can be seen that while the snatch force has a peak almost as high as the opening force, it is of a much shorter duration, so much so that it can be considered an „impulse" type force. From this it is apparent that the snatch force, while still important in terms of accounting for it in the design of a parachute

The second flight, the PRS must be initiated by the observer on the ground, Figure 20. A signal will be sent from the ground control station to the SUAV that will kill the engine and after 2 seconds release the pilot chute. The engine will be killed to prevent line tangling in case the suspension lines come in the vicinity of the propeller.

Figure 21 PRS deployment for SUAV (Sakr 2)

The path plot in Figure 22, shows that a height loss of 5 meters will occur for a deployment at 16 m/s. It is important to understand that the analysis is point analysis and does not take into consideration the length of the complete system after deployment. The parachute, UAV and suspension lines are approximately 2 meters in length. The implication of this is that although an altitude loss of 5 meters was predicted, the PRS will require a minimum of 9 meters in vertical height to deploy at its full line stretch. Furthermore, to allow the pendulum effect of the canopy to wear off, it is my recommendation that the PRS not be deployed below 30 meters of altitude.

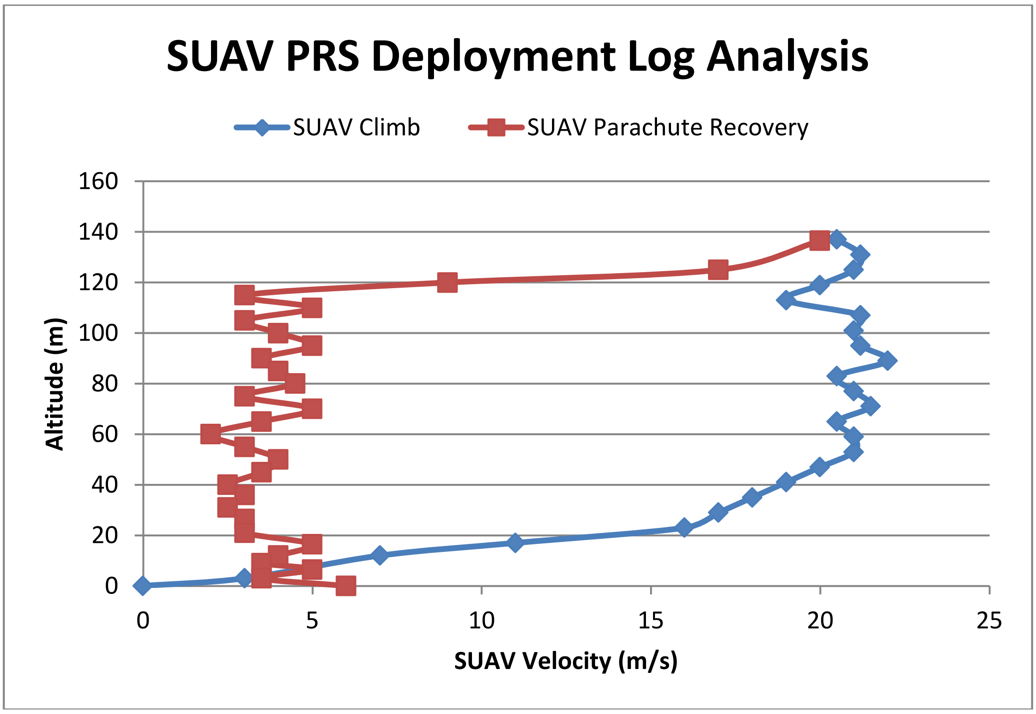


Figure 22 SAKR 2 PRS deployment

4. Conclusion

The task was to design a system suitable for the SUAV. Once this system was designed, dynamic testing was carried out to determine the time taken for a deployment to reach full canopy inflation. The data that was gathered from the tests was analyzed and used to predict the vertical altitude lost during a system deployment. The experimental data was also used to predict the forces experienced by the SUAV during a recovery. The experimentation and analysis have indicated that the designed PRS can fully deploy within an altitude of 15 m. Given that these SUAV research aircraft generally operate above this altitude. The force data shows that the SUAV may experience a deceleration as high as 2g. This is within the aircrafts capability to withstand and it also possible that a force attenuation system could reduce this force if required. In terms of altitude lost and force experienced during a deployment, the findings of this paper indicate that a PRS is mechanically feasible for use on small UAV research aircraft. Considering future work, further testing should be pursued. Parachute drop tests should be done to show the steady state behavior of the inflated canopy with a fore body. Similar testing to that done in this project should be carried out but with a load cell in the loop to further validate the predictions of the force experienced by the recovery vehicle during canopy inflation. Detailed design of the PRS should continue with a focus on weight reduction. Using lighter suspension line would be the first place that weight reduction can occur. A more realistic determination of the PRSs reliability should be made. This may require the development of more advanced testing procedures that will allow the system to go through its whole cycle from initiation to steady state descent. A catapult system may be required to simulate a flying body.

5. References

[1] Parachute Recovery Systems Design Manual, Theo W. Knacke, Naval Weapons Center China Lake, Ca 93555-6001, March 1991.
[2] "Design and Production of small Tailless Unmanned Aerial Vehicle", M. Y. Zakaria, Moatassem M. Abdallah, M Adnan Elshafie, 15th International Conference On Applied Mechanics and Mechanical Engineering, May, 29 - 31, 2012.
[3] Potvin, J, 2007, „Parachute‟, McGraw-Hill Encyclopedia of Science & Technology, 10th edn, vol. 13, p. 2-6
[4] Wyllie, T., 2001, "Parachute Recovery for UAV Systems", Aircraft Engineering and Aerospace Technology, vol. 73, no. 6, pp.542-551.
[5] Behr, V. and Potvin, J., "Parachute Definitions, Nomenclature and Types," H.G. Heinrich Parachute Systems Short Course, 15-19 May 2006.
[6] Knacke, T. W. (1992). Parachute Recovery Systems: Design Manual. Santa Barbara: Para Publishing.
[7] Fluid structure interactions on a Cross Parachute. Computer Methods in Applied Mechanics and Engineering , 673-687. Knacke, T. W. (1992).
[8] The Porosity, Translucency And Deformability Of Nylon Parachute Fabrics
[9] Cartwright, K. (2008). Feasibility of Parachute Recovery Systems for Small UAVs.