



DESIGN AND SIMULATION OF AUTONOMOUS PARACHUTE SYSTEM FOR UNMANNED AERIAL VEHICLE

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INTRODUCTION

The project aims at Slybird which is a mini- unmanned aerial vehicle developed by National Aerospace laboratories. NAL Slybird is hand launched and with a soft landing recovery capability. It has an endurance of one hour with a range of 10 km. Its operational altitude is 300 meters and a service ceiling altitude of 15000 feet.

During belly landing, there is normally extensive damage to the UAV's. Belly landings carry the risk that the aircraft may flip over, disintegrate also it can catch fire if it lands too fast or too hard. Extra care should be taken while the UAV lands that is straight and level as possible also it should be having enough airspeed to maintain control over the UAV. The danger of performing belly landing increases with the involvement of strong crosswinds, damage to the airplane, or unresponsive instruments or controls. Thus here we are designing a suitable parachute for safe recovery of the UAV so as to reduce the kinetic energy of the UAV when it descends and performs landing.

The purpose of a parachute has always been to decelerate and provide stability to a payload in flight. The aerodynamic and stability characteristics of the parachute system are governed by the geometry of the parachute where extreme care is paid to this in the design process. The effects of deployment and also opening forces are critical in the safe operation of the parachute. The opening characteristics play a major role in the selection of geometry and other parameters in the design process. Parachutes for aerospace applications are generally symmetric about the canopy axis. This axis passes through the centre of the canopy and the confluence point of the suspension lines. The canopy is the cloth surface that inflates to provide the desired lift, drag, and stability. The suspension lines are used to transmit the retarding force from the canopy to the payload either directly or by a riser attached below the confluence point of the suspension lines.

Till now various kinds of parachutes have been designed for various applications like pilot, drogue, deceleration, descent, extraction etc. The modelling of the dynamics of parachute is too complex and difficult to be modelled accurately. At the Inflation and the terminal descent stage the dynamics of the parachute are governed by the coupling between the structural dynamics of the chute system and the surrounding air flow.

When the parachute dives in air in steady state the air flowing around the chute will separate at some location on the canopy. The shedding of the vortices from the canopy surface can affect the stability of the system and cause a periodic motion of both parachute and payload. The wake from a porous parachute consists of air that flowed around and through the canopy. The payload body in speed range of the parachute usage sheds a very turbulent wake. The flow entering the parachute is of a disturbed nature and that should also be considered regarding the aerodynamic performance of the parachute. Also for many types of parachutes, this change in airflow can be quite significant to be considered in the time taken by the parachute to inflate. In summary the calculations of different phenomenon involved in parachute like deployment, inflation and also deceleration requires a numerical solution to the equations of motion to the highly unpredictable airflow around which is viscous and turbulent. The parachute is also a flexible body which has a dynamic behaviour coupled with the behaviour of the flow, which passes through and around it. Thus from the above description it is obvious that a full-time solution of this unpredictable system is far from being easily feasible. To make a mathematical model that is feasible, simplifications have to be made, as long as the model can be validated satisfactorily by experiment or by comparison with reference data.

1.1 OBJECTIVES

The main objective of this work is to develop a suitable automatic deploying parachute for the Slybird so that the descent of the UAV can be in a controlled manner without any damage or disintegration of the structure. The project reviews existing circular parachute models and addresses the development of six degree-of-freedom model of a guided circular parachute. The project involves step-by-step development of the mathematical model of circular parachute that includes the basic equations of motion, analysis and computation of the aerodynamic forces and moments. Further it also includes the design for autonomous deployment of the parachute.

The project was completed in two phases where the first phase included a 2 Degree-of-Freedom model. Here the mathematical equations involved in the designing of the model were determined as well as a Simulink model based on the equations was developed.

The second phase comprises of the development of a six degree-of-freedom model of a guided circular parachute, it also involves the autonomous deployment system for the parachute when the UAV is in flight. The autonomous system developed in the second phase helps the parachute deployment when the free fall of the UAV occurs the system recognizes it and deploys the parachute helping in safe landing of the UAV.

1.2 SPECIFICATIONS

Design requirements and mission specifications of the UAV as well as parachute are:

Table 1.1 Details of Slybird

• Payload	Approx. 4.5 kg (UAV+ Chute)
• Range	Around 10 km
• Endurance	45-60 minutes
• Speed	10-30 m/s , 36-108 kmph
• Operating Altitude	30-300m
• Wingspan	1.6m (5.2ft)
• Length	1.3m (4.2ft)

The design of the parachute is based on the design considerations of the UAV, its material properties and others. Following is the required analysis of the strength of the UAV structure.

Considering continuous fibre composite for higher strength and stiffness we have a list of reinforcing fibres commonly used in aerospace applications.

Table 1.2 Reinforcing fibres commonly used in aerospace applications

Fibre	Density (gm/cc)	Modulus (GPa)	Strength (Gpa)	Application Areas
Glass				
E-glass	2.55	65-75	2.2-2.6	Small passenger a/c parts, air-craft interiors, rocket motor casings
S-glass	2.47	85-95	4.4-4.8	Highly loaded parts in small passenger a/c
Aramid				
Low modulus	1.44	80-85	2.7-2.8	Fairings , non load bearing parts
Intermediate modulus	1.44	120-128	2.7-2.8	Radomes, some structural parts
High modulus	1.48	160-170	2.3-2.4	Highly loaded parts
Carbon				
Standard modulus	1.77-1.80	220-240	3.0-3.5	Widely used for almost all types of parts in a/c satellites, missiles.
(high strength)	1.77-1.81	270-300	5.4-5.7	
	1.77-1.80	390-450	2.8-3.0	
Intermediate modulus	1.80-1.82	290-310	4.0-4.5	Primary structural parts in high performance fighters
			7.0-7.5	Space structures, control surfaces in a/c
High modulus				Primary structural parts in high performance fighters, spacecraft
Ultra-high strength				

Given:

$$\begin{aligned}
 \text{Diameter of UAV} &= 6 \text{ inch (approx), } 0.1524 \text{ meters} \\
 \text{Length} &= 1.3 \text{ m} \\
 \text{Surface area} &= 2*\pi*r*h \\
 &= 2*\pi*0.0762*1.3 \\
 &= 0.6225 \text{ meter}^2
 \end{aligned}$$

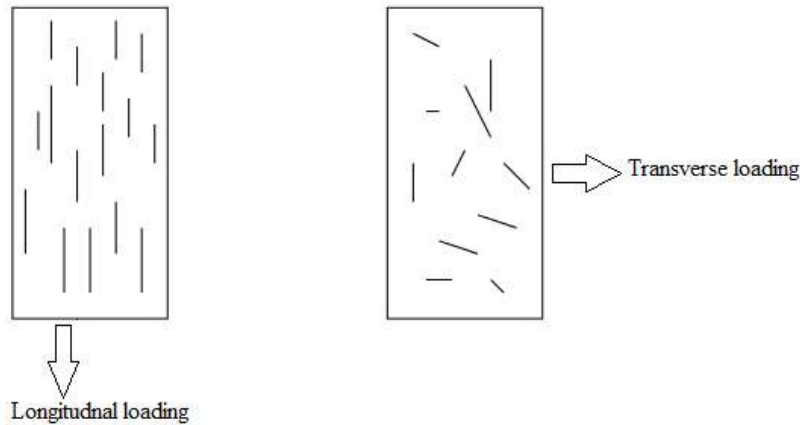


Figure 1.1 Loading in composites

- Longitudinally aligned fibrous composites are anisotropic, maximum strength is achieved in that direction fibre alignment.
- Transverse direction fracture usually occurs at low tensile stress.

As shown in table 1.1 the glass reinforced fibres have a strength of 4.4 – 4.8 GPa i.e. it can withstand 4400 – 4800 N/mm². But this strength is when the loading is in longitudinal direction. The strength reduces considerably when loaded in transverse direction and it is as low as 10% of the longitudinal loading. Thus the UAV structure can sustain only 440N/mm² in transverse direction.

By the momentum principle, it gives the relationship between the net force on an object and that object's change in momentum

$$F_{net} = \frac{\Delta P}{\Delta t}, \quad \text{where } \Delta P = m\Delta v \quad \begin{array}{l} m = \text{mass of UAV} \\ \Delta v = \text{Descending velocity} \end{array}$$

$$F_{net} = F - mg = \frac{\Delta P}{\Delta t}$$

$$F - mg = \frac{0 - mv}{\Delta t}, \quad \text{as final velocity is zero and the initial velocity is in the } -y \text{ direction as shown in figure 1.2}$$

$$= \frac{0 - (-4.5 * 4)}{0.1}, \quad \text{considering that the time of impact is 0.1 seconds}$$

$$= 180 \text{ N}$$

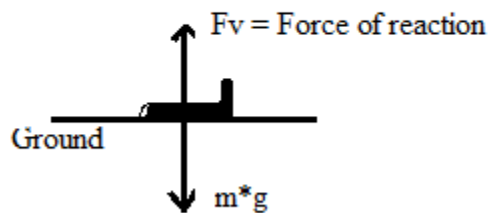


Figure 1.2 Forces on UAV

Thus this is the maximum Impact force which acts on the structure of UAV which is less than the above calculated strength of the UAV structure. From the above it can also be stated as the time of impact increases, further the force induced reduces and thus the landing terrain has an impact on the induced force as grassy land will have more impact time and thus reduces the force acting on the structure of UAV. The force acting on the UAV can be calculated by putting an accelerometer on UAV and by calculating the acceleration just before it hits the ground and from that the force can be calculated. Thus from the above it is clear that the force during impact is very less and the air vehicle is safe while landing if the descending velocity is below 4m/sec. The parachute has to be selected and designed based on this velocity. The further chapters give a detailed knowledge about the designing details of the selected parachute.

Autonomous Recovery System

Here in this chapter we are designing an autonomous recovery system for the SLYBIRD. The problem for any UAV arises when the battery potential falls below a threshold and the UAV cannot land before it falls so a suitable recovery system is needed which keeps on checking the battery level and switches off the motor and other equipments which drain the battery and opens the parachute for safe landing.

The recovery system designed here is based on the Arduino Nano. The microcontroller also uses the accelerometer and the GPS module coupled with it on a breadboard. The GPS module classifies the GPS coordinates, the accelerometer mounted is used so as to keep a check over the forces produced in the flight system and the main battery voltage is also being checked so that when the battery diminishes because of any reason during the flight of the Slybird we can have the privilege to open the parachute system. The system designed here has been programmed in a manner that if it senses any problem as described below it will automatically instruct the servo motor to open the door of the spring loaded box of the parachute and lets the parachute to get out and hold the Slybird and help in landing it down safely. The problems discussed above are given below

- When the Slybird gets away from the sight of the operator the parachute system will automatically open and help in landing it down safely.
- When any type of freefall is being detected for 1 to 2 meters may be due to any reason and the operator loses control the parachute system will open.
- Also it will be operator controlled that is when it will come down in a normal manner to the prescribed landing height the system can be opened.

The Recovery system is very much required for the unmanned systems because the control over them is done by a remote operator and due to any circumstance if the connection is lost or the drone gets out of sight or any other problem occurs then atleast we can have it land on the ground safely without any disintegration of its parts. Further the design and other considerations are explained.

8.1 Parts of the Recovery system

The recovery system should be controlled independently of the UAVs flight controller, to ensure proper operation of the recovery system when the main battery has depleted. Thus for this condition a separate Arduino Nano microcontroller is used which is powered separately by a 7.4V Li-Po battery.

This microcontroller provides 14 Digital Input/output pins, 8 Analog pins, regulated 5V power source with a 16MHZ clock and 2Kb of SRAM. With this unit, all decision making process are completed. Each hardware component is connected to the microcontroller with the digital or analog pins.

8.1.1 Accelerometer

The accelerometer is connected to the microcontroller with the analog input pins. With the help of this the acceleration components in x, y and z direction are read according to voltage values generated. Since this module does not requires much current, analog output pins were sufficient to power the accelerometer.

A 3-axis accelerometer attached to the system constantly monitors the forces exerted on the UAV. The main reason of this to be used is to monitor the UAV for detecting free fall. The accelerometer here is used to monitor the force acting on UAV continuously so as to get a check when UAV falls due to unnecessary forces. In the case when the operator loses control over the UAV, where many UAVs cannot recover from free fall accelerations, the recovery system deploys the parachute and cuts power to the main control with a relay. The accelerometer detects free fall when the UAV experiences zero acceleration in x, y and z directions.

8.1.2 GPS

The GPS unit constantly checks position information (latitude, longitude, altitude and time) in National Marine Electronics Association (NMEA) (ASCII) format. The GPS module communicates with a RS232 serial connection to the Arduino Nano.

The operator has a complete view of the aircraft while in flight, If the UAV exceeds the predetermined range from its takeoff point, the recovery system will take over and cut power from the main system. Once the power is cut, the recovery system will deploy the parachute and land safely.

8.1.3 Voltage Sensor

The voltage sensor is connected to an analog pin on the microcontroller. The voltage sensor unit acts as a 4:1 voltage divider circuit, providing a voltage range within the limits of the analog-to-digital conversion circuitry on the Arduino's analog input pins.

The voltage sensor pulls a value continuously from the main battery source. Brushless DC motors often used on UAVs are voltage dependent that is the voltage of the power source primarily determines that the motors are able to be kept running. Lithium Polymer battery is used as these batteries have steady voltage until the battery reaches the end of charge. If the voltage of the main battery is inadequate, the system cut off power to the UAV via relay, and deploys the parachute for safe landing.

8.1.4 Servo Motor

The Servo motor is utilised to deploy the parachute which is contained in a spring loaded container. The servo motor is controlled via a Pulse Width Modulation (PWM) signal from the microcontroller's digital pins. The servo used, opens the spring loaded box and the chute deploys, this happens due to the input from Arduino which processes any problem.

8.1.5 Relay Module 5 volts

The relay module is activated by a 5V digital signal from the microcontroller and cuts the power to the UAV's motors when activated. The relay used here was 'Active High', providing a 5V signal to the module which activates the internal switch.

8.1.6 Parachute

The parachute is being deployed from the spring loaded box using a servo motor at the door of the box. The parachute fabric is launched outward because of the spring force of the compressed spring placed in the box. The box can be 3D printed keeping in mind the size constraints as provided by the manufacturer of the UAV. For simplicity it can be constructed of a PVC tube, large spring, base plate and a servo motor holder.

The Figure below represents the schematic design of the recovery system.

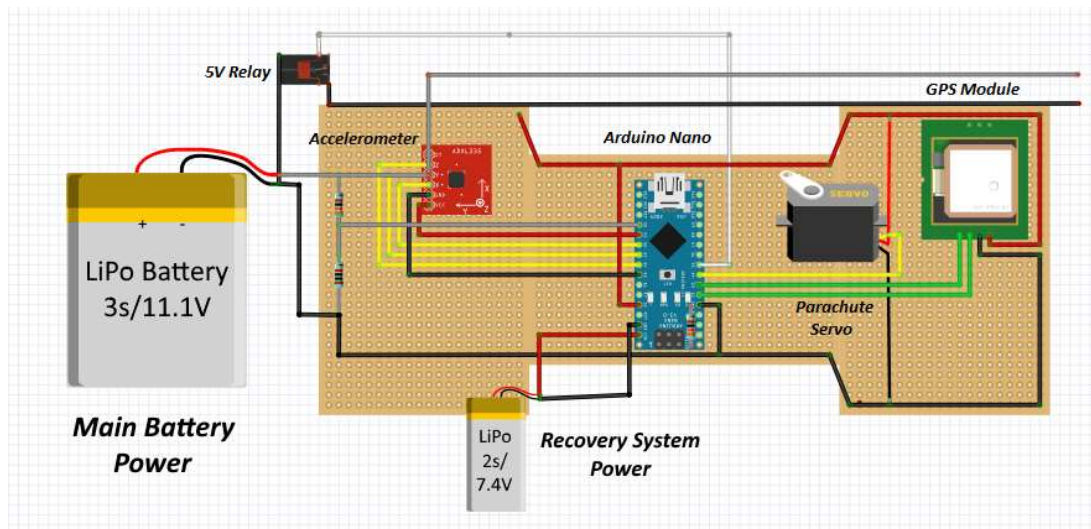


Figure 8.1 Design schematic of recovery system

8.2 Program Flowchart

The program continuously monitors three conditions to determine if UAV failure has occurred:

- Depletion of main battery voltage below a certain level.
- Free fall of UAV.
- UAV going beyond the line of sight from the operator according to GPS.

When the different values are being monitored, specific calibration is needed for proper use. The accelerometer values need to be set to detect free fall. The voltage sensor must also be calibrated to proper cut-off voltage of motors. The GPS should work efficiently and obtain the current position from satellites and compare the expected values stored in the microcontroller. The Flowchart of the process is given as below:

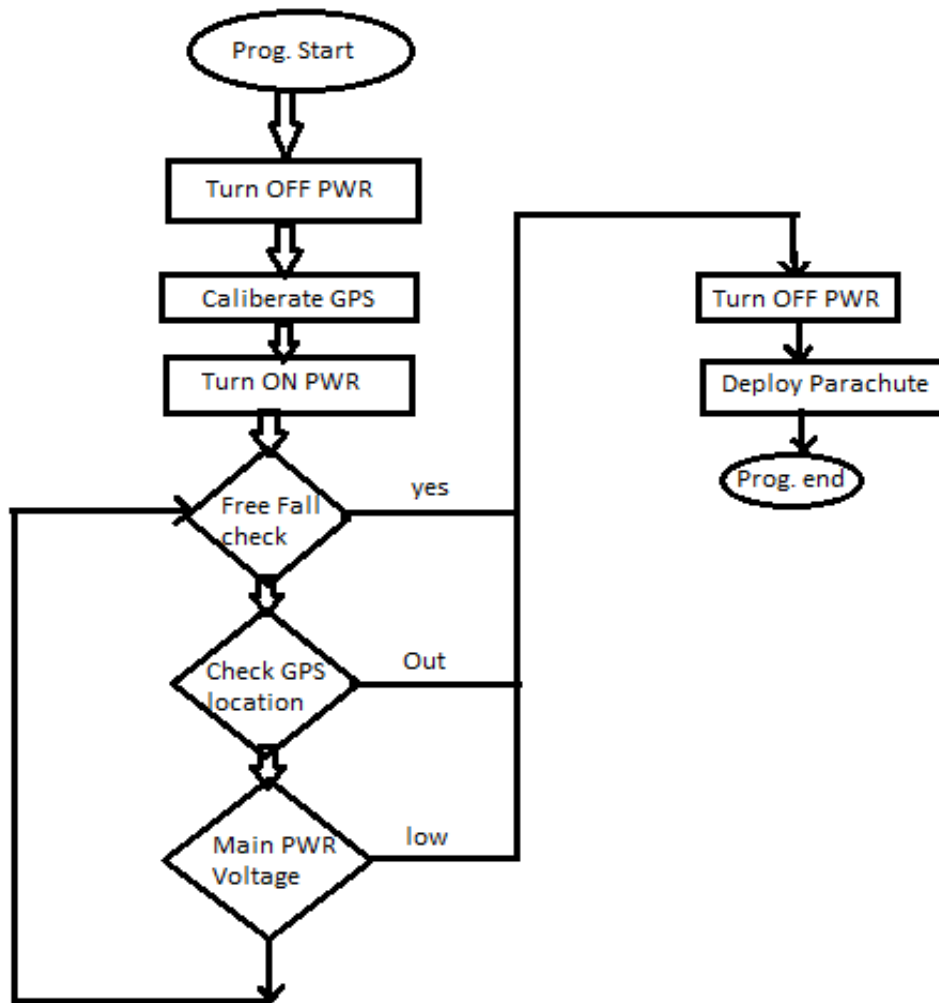


Figure 8.2 Flowchart of the recovery system program

The above described recovery system can be utilised to make the parachute deployment autonomous and thus the requirement of the project is completed. Further we go to the results generated by the six degree-of-freedom model.

Results and Discussions

The following results are generated from the Simulink model explained in chapter 7. The trajectory graph is as shown in the figure 9.1, is plotted in 3D which shows the wavy nature of the parachute falling to the ground with the UAV.

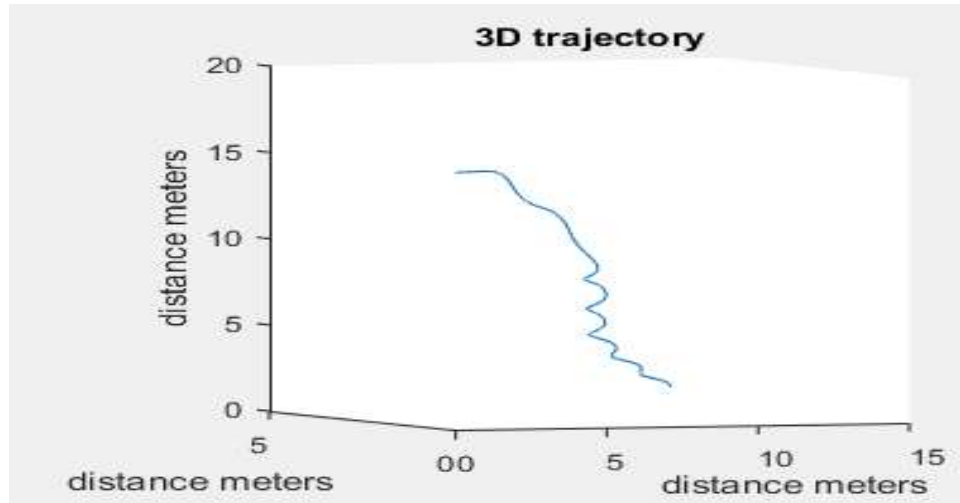


Figure 9.1 3D trajectory of the parachute with UAV

The vertical velocity graph is as shown in figure 9.2, where the velocity at the start is zero and it reaches to 3 m/sec also in the meantime because of the sudden opening of the parachute it fluctuates and as the wind is trying to pass through the parachute from bottom the velocity reduces also and it appears as if the chute is going upwards, but in the end after the required time of 10 seconds the velocity again reduces till 1m/sec or approximately zero and thus explains that the parachute with the payload lands very safely with very low vertical velocity and thus the Slybird remains safe, as the safe landing velocity calculated in the previous chapters was nearly equal to 4m/sec. But here it is being reduced to 1m/sec, thus the parachute designed is in compliance with the desired problem.

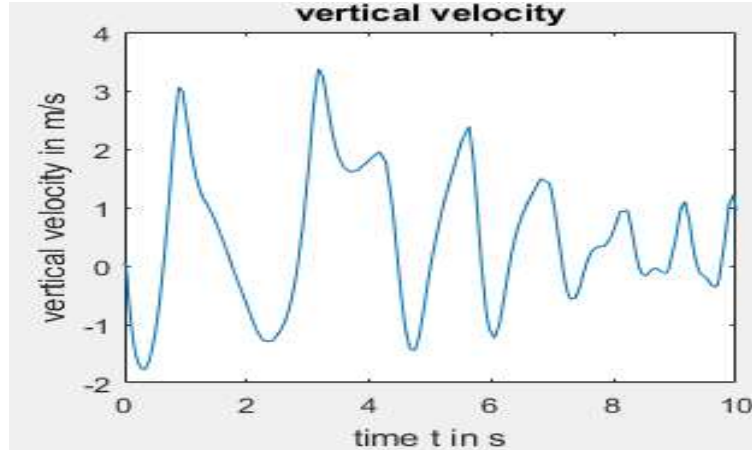


Figure 9.2 Vertical velocity of the falling parachute

The altitude at which the parachute is opening is assumed to be 15 meters, and thus the altitude reduction graph is shown in figure 9.3 which reduces to zero in approximately 10 seconds. The Model generated also generates the different angle graphs and the forces which act in particular x, y and z directions.

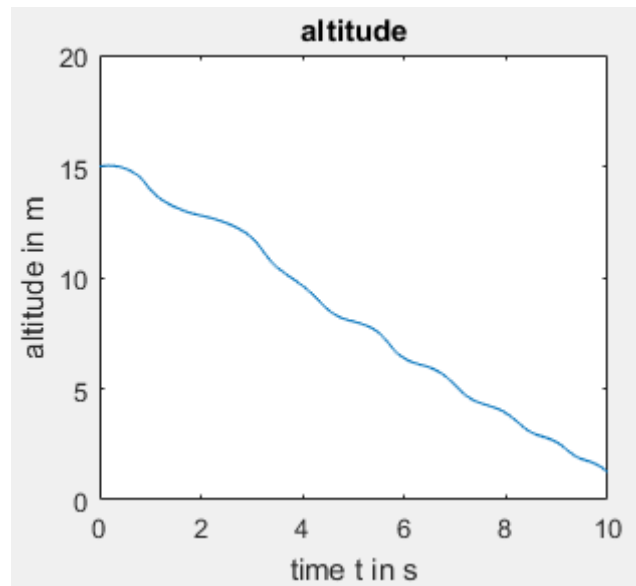


Figure 9.3 Altitude reductions with respect to time

By changing the various parameters like the suspension line lengths and the canopy area the values recorded change and various different graphs can be generated.

Conclusion

The project represents the results of the development of six degree-of-freedom model of the circular parachute canopy. Key contributions of the project include the following:

- Development of a six degree-of-freedom model for a circular parachute with elaborated study over the different aspects of opening forces and other parameters.
- Providing an autonomous mechanism so as to build a recovery system for UAVs. The codes over Arduino are simple and so not provided here.

The model developed gives the permissible results, however further improvement is possible. It includes involving more optimized parameters into the model development equations. The parachute can also be controlled using actuators which control the riser or suspension line lengths and hence control the manoeuvrability of the parachute.

As the parachute was opening at very low altitude so the concept of added mass is not considered. Due to less height the control of the parachute was also not possible. Further study may involve these parameters so as to get a controlled autonomous parachute.