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May 18, 2010

Senior Design Class
Russ Engineering 148
Wright State University
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Dear Dr. Roberts,

The attached is the final report for the design and testing of a sub-sonic ballute. The purpose of this design was to test the stability of a ballute traveling at sub-sonic speeds. This report contains important information regarding the manner in which this design was done, the cost including labor, relevance and potential applications, a brief explanation of the results obtained, and a time log for the project.

Sincerely,

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High Altitude Balloon – Ballute

May 18, 2010

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ABSTRACT

The team designed and constructed a re-entry vehicle for Earth's upper atmosphere. The design of the re-entry vehicle was a ballute. A ballute is a mix between a parachute and a balloon. The idea behind a ballute is to reduce the velocity of the vehicle by increasing the drag. There are many ways to construct a ballute. Most designs are a cone that has a toroid balloon attached to the top, or a toroid balloon tethered behind the vehicle re-entering the atmosphere. A ballute has been shown to be stable at supersonic speeds, but has yet to be proven at subsonic speeds. The data collected during this project will be used to determine whether or not the ballute is stable at these lower velocities. This data will be published and may be used by DARPA (Defense Advanced Research Projects Agency) to put a UAV (Unmanned Aerial Vehicle) anywhere on the planet. This can be done by placing a UAV on an intercontinental ballistic missile. Once the missile is ready to drop its payload, the ballute will be released into the upper atmosphere. At this point, the ballute will essentially be free falling. The design of the ballute will allow for the drag forces to slow the vehicle down from supersonic speeds to subsonic speeds. At subsonic speeds, the vehicle can safely deploy a parachute and/or release its cargo. This data could also be used by NASA (National Aeronautics and Space Administration) to put a UAV into the Martian atmosphere. This is possible because the atmosphere of Mars is similar to the atmosphere of Earth. This data will also be compared to the data gathered by previous design teams. The previous team's design was a teardrop and has been proven to be stable. After comparing the two, the goal is to prove that the ballute is the superior design.

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1 INTRODUCTION

The ballute was created in 1958 as a means of slowing a payload, especially at high altitudes and speeds. The original design consisted of a cone-shaped balloon fitted with a toroidal burble fence around its median, the widest part of the balloon. This burble fence creates a distortion of air flow around the balloon, slowing and stabilizing during its fall. However, since this design is meant for high speed use, careful testing has not been done at subsonic speeds. Figure 1 below shows an example of data collected at supersonic speeds (Mach 1+). Notice the grey area on the graph corresponding to the lower Mach numbers.

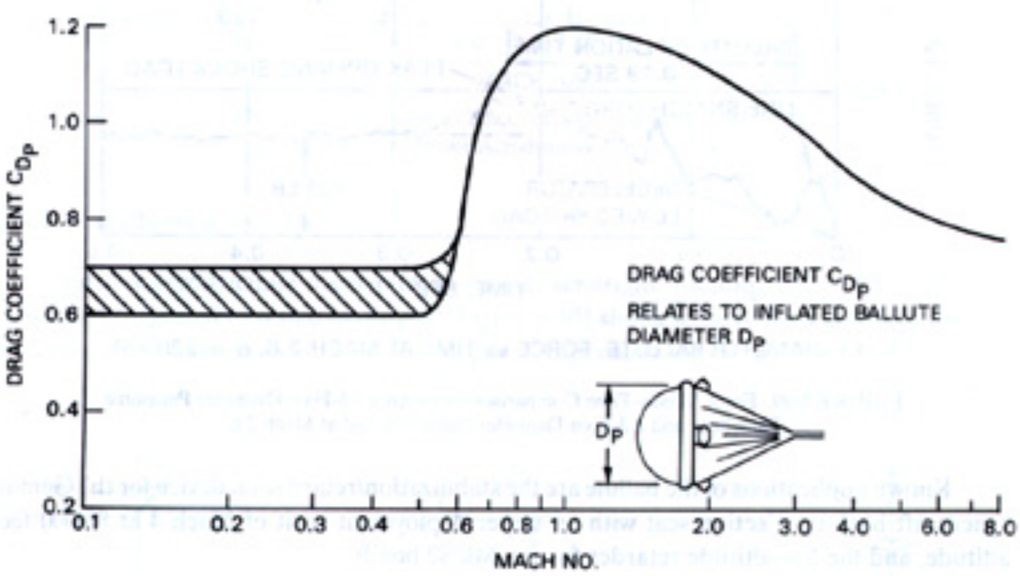

Figure 1 – Drag Coefficient vs. Mach Number (Jon Pyle, 1973)

Current designs for re-entry vehicles are heavy, and therefore, the cost of these vehicles is rather significant. The ballute has been considered as a possible alternative to current designs. Current technologies for re-entry vehicles feature heat shields to provide the deceleration and also to protect the vehicle from high heating rates associated with re-entry. The ballute, however, is considerably lighter which effectively lowers the heating rates during re-entry. Additionally, they offer space saving storage because they can be stored in a fairly small amount of space (Masciarelli and Miller, 2006).

Currently, there are two designs for trailing ballutes. One design features a large ring shaped ballute that is tethered to the spacecraft using some sort of rope or wire. For this design, it could be possible to gain steering capabilities by shortening or extending the wires. The second design features the ballute clamped to the spacecraft (Masciarelli and Miller, 2006). The ballutes are constructed from various light weight films and fibers. Figure 2 below shows the two ballute designs.

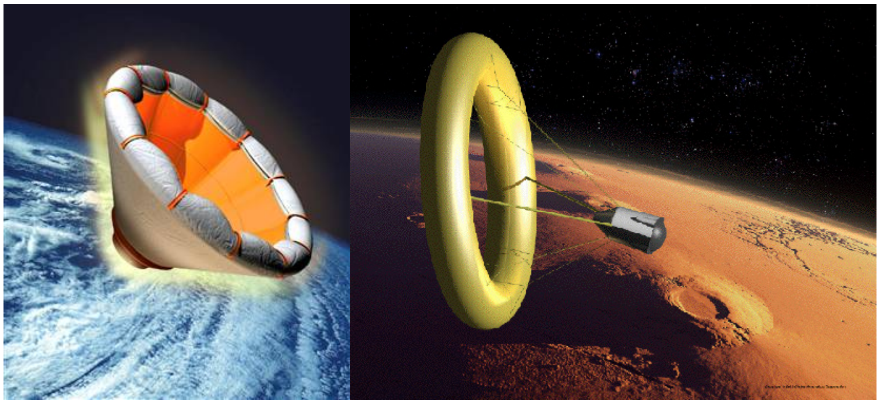

Figure 2 – Left is a Clamped Ballute (NASA MSFC, 2005) and right is a Tethered Ballute (Page, 2009)

Ballutes can be used for a wide range of applications. NASA could use a ballute to put a UAV into Mars' atmosphere. This could be a very useful means of gathering more information about Mars. Ballutes also have some possible military applications. Ballutes could be put onto the ends of munitions to allow for better control and increased accuracy during bombing runs. Another possible application would be to transport a UAV using an intercontinental missile and deploying the UAV once it gets closer to the target area.

The design chosen and constructed most closely resembles the clamped ballute mentioned above. However, this ballute is not trailing a spacecraft and is not made of the light weight films and fibers that the other ballutes were constructed from. In order to reduce the cost, the cone shape of the ballute was constructed using Styrofoam and the toroidal burble fence was constructed from pool noodles which are another type of foam material. The parachute for the vehicle is stored within the ballute and is deployed during freefall. The mouse trap design effectively catapults the drogue chute out of the top of the vehicle and into the air flowing around its sides. Various electronics are also stored within the ballute. These devices include nichrome wire circuits for cutting, one GPS unit for tracking the packages, payload release mechanisms to separate the packages from each other and from the balloon, IMU and data loggers to collect and record data, and a 900 MHz Spread Spectrum Command, Control, and Communications Demonstration device to send commands to the packages during flight.

To test the stability, the ballute was lifted to between 90,000 and 100,000 ft using a weather balloon. Once the desired altitude had been reached, the package was separated from the balloon. At this point, the vehicle began to free fall. The IMU, which essentially is an accelerometer, and data logger collected and recorded the data during the fight. Due to Federal Aviation Administration (FAA) regulations, a parachute should be deployed by 60,000 ft. With this in mind, once the package reached around 65,000 ft., commands were sent to deploy the parachute. Using the GPS tracking, the package was tracked and chased throughout the flight and recovered once it landed.

2 DESIGN OF EXPERIMENTAL PROCEDURE

The specifications for this experiment were to prove that a ballute is stable at subsonic speeds. This drove the design of the ballute to make it as stable as possible. One of the major factors that drove the stability of the ballute was the half cone angle. From our research on the topic, it was found that this angle varies from 70° to 45°. If the angle is too small, the drag force will not decelerate the ballute to an acceptable speed, but if the angle was too large the wake will increase and cause the ballute to be less stable. The angle controls the drag coefficient. The drag coefficient is based largely on the area perpendicular to the wind. With a large angle the drag coefficient is higher because the air is hitting a larger area of the cone at once. If was found that if the flow around the ballute is tripped turbulent early, the wake will decrease and this will increase stability. (Dong, 2010) This was incorporated into the final design.

The FAA has regulations on what can be launched on an unmanned balloon. Title 14 section 101.1 subsection 4 item (ii) states the payload package must weigh less than six pounds, and item (iii) declares that the combined weight of the payloads must be less than twelve pounds. (Federal Aviation Administration, 2010) Both of these regulations limited the size of the ballute. The FAA also requires that any payload below 60,000 feet have the ability to deploy a parachute. To overcome this regulation a parachute deployment system was also designed.

The parachute deployment design works off of the same principles as a catapult. The torsion spring in a mouse trap is used to "throw" a drogue parachute into the flow around the ballute. Once the drogue parachute enters the air flow around the ballute it will inflate be caught up in the free stream. As the drogue parachute gets pulled behind the ballute, it will then pullout the main parachute and decelerate the ballute to an acceptable speed.

It was decided that the ballute would be made of polystyrene. Polystyrene was chosen because of its lightweight nature, strength, ease of use, and the fact that it is easily accessible and relatively inexpensive. The below table shows a few materials considered and there densities,

Material	Density
Polystyrene	2 lb/ft^3 (McLaughlin, 2010)
Carbon Fiber	111.13 lb/ft^3 (Composite Resources, 2010)
Plexiglas/Acrylic Glass	74.3 lb/ft^3 (hydrosight)

Table 1, density of considered materials

When these materials were considered, one of the major factors was the thickness of the ballute. With the polystyrene, the thickness is one inch. If the carbon fiber or plexiglass/acrylic glass were to be used the thickness of the sides would be substantially less because of the increase strength of the material. The ballute was constructed out of two pound density polystyrene by Scenic Solutions Inc of West Carrollton, OH. A Computer Aided Drafting (CAD) drawing of the ballute can be seen in Figure 3,

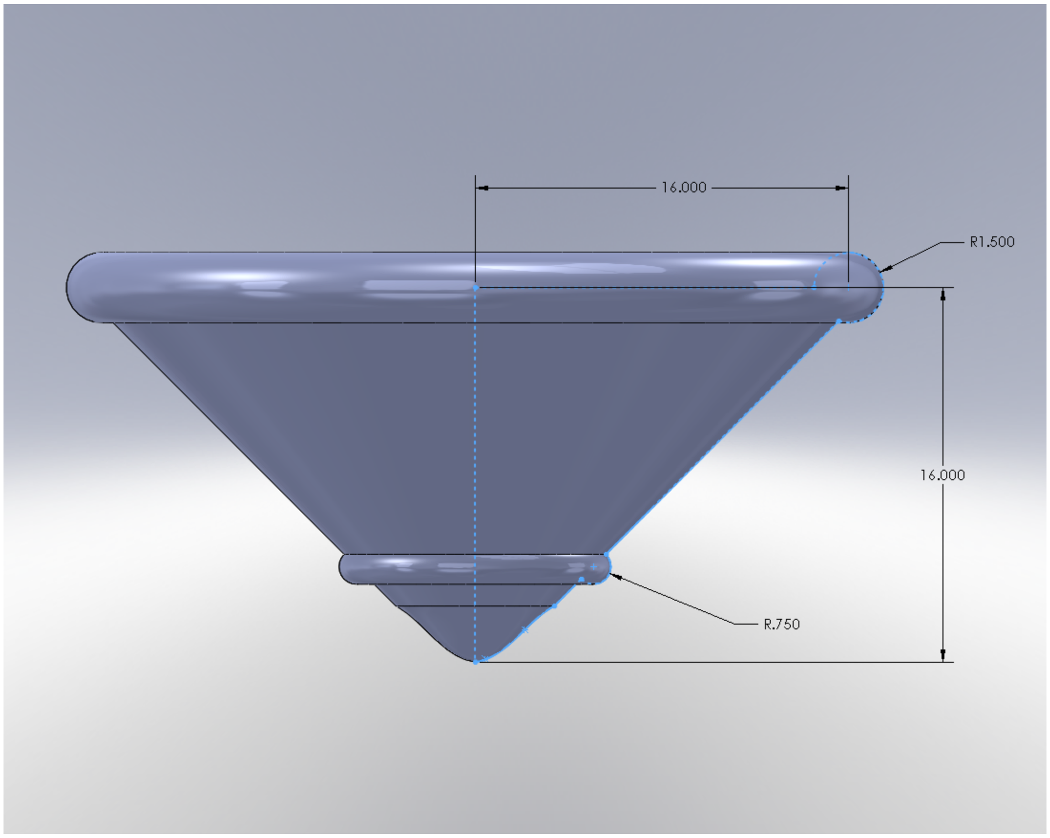

Figure 3, final dimensions for the ballute

Computational Fluid Dynamics (CFD) simulations were ran on the ballute using Cradle software. The properties used can be seen in table 2,

	Air	Polystyrene
Density, ρ	1.534 kg/m^3	32 kg/m^3
Specific heat, Cp	1005 J/kg*K	1300 J/Kg*K
Thermal conductivity, K	.0204 W/m*k	.08 W/m*K
Dynamic Viscosity, μ	6.2255 E^{-6} N-s/m^2	-

Table 2, properties used in CFD simulation (The Engineering ToolBox , 2005), (Wikipedia, 2010)

Due to computer problems, convergence of the 'CFD' simulation was not possible. This was due to the fact that the computer crashed when trying to run a fine mesh.

3 RESULTS

The objective of the experiment was to determine whether the ballute is stable during sub-sonic flight. This was tested by lifting the ballute into the upper atmosphere using a weather balloon and allowing it to free fall. Accelerometers collected the data during the flight, and this data was analyzed to determine whether it was stable or not. This data was also compared to data gathered from the teardrop design provided by previous design teams.

Before the dimensions of the ballute were chosen, a number of computer numerical simulations were run using CFD software. The purpose of this was to see how the fluid flow around the vehicle was changed as the half cone angle of the ballute changed. In addition to this, the software was used to determine the size of the low pressure region above the ballute for possible parachute deployment mechanisms. The mouse trap mechanism side steps this problem because it throws the drogue chute into the air flow around the sides of the vehicle.

After running the CFD software, the dimensions of the ballute were chosen. The half cone angle was selected to be 45°, the wall thickness was selected to be 1 inch, and the top diameter was selected to be 32 inches. To reduce the wake during flight, a line of silicone was added around the bottom to induce turbulent flow.

As of yet, no flight testing has been done, and therefore, there are no results to report on the experiment yet. It is expected that the ballute will be stable during its subsonic flight. The results expected from this experiment will be measured using accelerometers and Inertial Measurement Units (IMUs). The accelerometers and IMUs will measure the aerodynamic forces exerted on the ballute during freefall. After this data is analyzed one will be able to deduce if the ballute was stable during freefall. Figure 4 shows the terminal velocity of the ballute versus altitude,

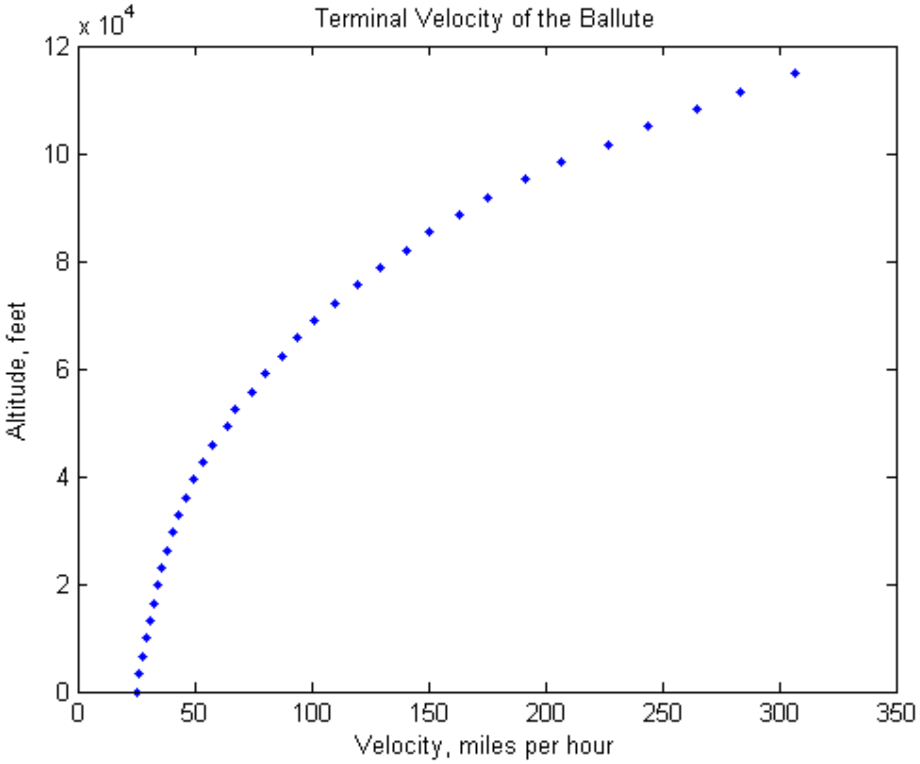

Figure 4, Terminal Velocity of the ballute

It can be seen that the terminal velocity at sea level is 25.376 miles per hour. The terminal velocity is behaving as expected, it decrease as the density of the air increase. Since the density is the only thing that changes throughout the fall, the rest of the variables can be treated as constant. The MatLab code can be found in the appendix.

4 DISCUSSION

After running the numerical simulations using the CFD software, the half cone angle of 45° was selected. The diameter of the top of the ballute was selected to be 32 inches. The thickness of the walls of the ballute was selected to be 1 inch. The 1 inch thickness was chosen because previous teams, for their design, used this thickness and it worked for them.

Up to this point, we have not been able to flight test the ballute, therefore, we do not yet have flight results to present here as far as our determination of the overall stability.

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6 APPENDICES

```
%This m file will calculte the termainal velocity of the ballute as it

%falls from 120,000 feet, or 35000 meters

clear all

clc

v=ones(1,35);

u=input('what unit system are you using, 1=metric 2=english')

if(u==1) %--------METRIC UNITS---------------------------

alpha=input('what is the half cone angle in radian?')

%alpha=pi/4 rad

alpha=alpha*(180/pi) % This converts radian to degrees

Cd=.0112*alpha + .162; % Unitless

D=input('what is the diameter in meters?')
```

```
%D=.8128 m

A=(pi*D^2)/4; %square meters

Fd=input('Frag Force in Newtons?') %Newtons

%Fd=26.888 N

elseif(u==2) %-------ENGLISH UNITS---------------------

alpha=input('what is the half cone angle in degrees?')

%alpha=45 degrees

Cd=.0112*alpha + .162; % no conversion needed.

D=input('what is the diameter in inches?')

%D=32 inches

A=(pi*(D/12)^2)/4; %square feet

A=A*.0929; %This converts square feet to square meters

Fd=input('Frag Force in pounds?')

%Fd=6 lb

Fd=Fd*4.4482 %this converts pounds to Newtons

end

Den=[  1.2

1.1,

1.0,

0.91,

0.82,

0.74,

0.66,

0.59,

0.53,
```

0.47,

0.41,

0.36,

0.31,

0.27,

0.23,

0.19,

0.17,

0.14,

0.12,

0.10,

0.088,

0.075,

0.064,

0.054,

0.046,

0.039,

0.034,

0.029,

0.025,

0.021,

0.018,

0.015,

0.013,

0.011,

```
0.0096,
0.0082]; %This are in Kg/m3

for i=1:36
v(i)=sqrt(Fd/(.5*Den(i)*Cd*A));%meters/sec
end
h=[0:1000:35000];%meters
h=transpose(h);%meters
figure(1)
v, 'meters per second'
plot(v,h,'.')
xlabel('Velocity, meters per second')
ylabel('Altitude, meters')
title('Terminal Velocity of the Ballute')
figure(2)
v=v*3.28, 'feet per second'
h=h*3.28084 %feet
plot(v,h,'.')
xlabel('Velocity, feet per second')
ylabel('Altitude, feet')
title('Terminal Velocity of the Ballute')
figure(3)
v=v*.6818, 'miles per hour'
plot(v,h,'.')
xlabel('Velocity, miles per hour')
```

```
ylabel('Altitude, feet')

title('Terminal Velocity of the Ballute')
```