- 3:02 SEC, SURVIVE CALCULATE + LANDING (1 QTR) 12:45 – 12:52 GOOD QUESTIONS
- 2:09 SEC, PARA. DEPLOYMENT OF CHUTE ✓ 3.99 SEC, – 1 QTR.

AE 421
Aerospace Computer Aided Design
Spring, 2004
R.D. Hale
Team Design Project I,

NUTS AEROSPACE
(Students)

Introduction: 2 /2
- statement of problem

INTRODUCTION OF PEOPLE, GOOD (W/TIME!)
✓ EXPLOR. APPEARANCE; BRIEF!

Body: 4.5 /5
- design concepts
- documentation of concepts
- design decisions
- final concept

- GOOD ECHO OF REQMTS.
- BS PLAN INTERFERENCE FIT (2SEC IS TAKE MISTAKE)
→ WHAT IS LIFE OF IMPAC. FIT?
- EQUIS: DECELERATION, TIME ALOFT, INITIAL VELOCITY
→ BUT WHAT TIME ALOFT EXPECTED? (3SEC)
⇒ MANY CALCULATIONS: HOW MUCH PAYLOAD?
→ GOOD ANALYSIS OF COST & MODS. (TO INCLUDE COST AS # VEHICLES)

Conclusions: 3 /3
- merits of design concept

Organization: 5 /5

Presentation: 9 /10
- Clarity
- Uniformity
- Quality of Graphics
- Quality of Oration
- Response to Customer

→ WEAR OF IMPAC. FIT, NOT CONCERNED, BUT EXPER. WITH 6-7 TIMES.
→ WHAT EFFECT IN FOLD OF PARACHUTE?
- ACKNOWLEDGED WORST CASE OF NO PARACHUTE DEPLOYMENT (OK ~ ½ SEC. TO DEPLOY)
- WHAT KEEPS PARACHUTE FROM DEPLOYING PRIOR TO REACHING APEX. (NO RESPONSE)
- QUESTION ON 200 CERTAINTY - VERY WELL RECEIVED W/REFERENCE TO "200 MTJ". GOOD RESPONSE.
→ TOLERANCE ON HOLES? CAN INEXPERIENCED MANUF. DO WORK?
→ QUESTIONS ON MATERIALS?

References: /

Overall: 23.5 /25

NUTS Aerospace™

FLYING SQUIRREL

MICRO AIR VEHICLE

Marketing and Design Presentation

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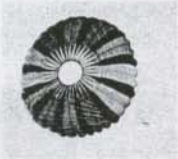
Presentation Overview

- Project Objectives
- Design Overview
- Performance Predictions
- Cost Summary
- Why NUTS?



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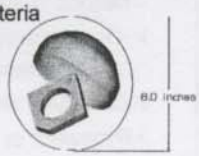
Project Objectives

- Develop flight vehicle that:
  - Satisfies configuration criteria
  - Maximizes endurance

And is:
- Cost effective
- Simple
- Versatile



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Design Overview

- 0.5 ounce Take-off Weight
- Balsa Wood Carrier
- Cloth parachute
- Vertical Launch (6 feet)
- String Attachment

Dimensions (Carrier)	Parachute Dimensions	String (x2) Length	Parts Count
0.25" x 1.5" x 1.5"	4.5" x 4.5"	8"	4

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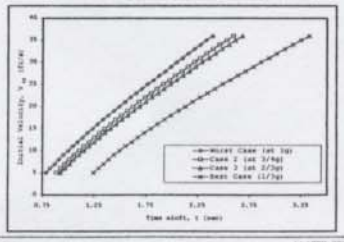
Performance Predictions

	Parachute Deceleration			
Case	1g	3/4g	2/3g	1/3g
Time Aloft (sec)	2.392	2.589	2.678	3.324



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Structural Analysis

	Parachute Deceleration			
	1g	3/4g	2/3g	1/3g
Tensile Force (lbs) in strings' sections	0.000	0.002	0.003	0.005
MS	N/A	507.82	380.61	189.81
Tensile Shock Force (lbs) in strings' sections	0.189			
MS	4.300			

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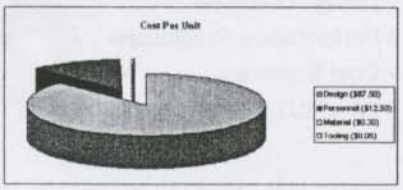
Cost Summary

- Estimated Sales: 20 units
- Cost/ Unit: $100.35



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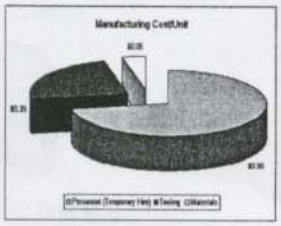
Cutting Costs: Manufacturing

- Total Manufacturing Cost/Unit: $1.25
  - Less skilled labor
  - Commonality of parts



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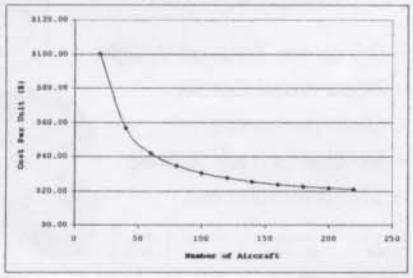
Cutting Costs: Production



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Why NUTS?

- Demonstrated capability to dramatically reduce manufacturing cost
- Design simplicity (ease of fabrication, no expensive tooling)
- Attractive design
- Prospect of global market

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"Solving the world's problems....
on the back of an envelope."™

AE 421
Aerospace Computer Aided Design
Spring, 2004
R.D. Hale
Team Design Project I

NUTS
(Students)

Introduction: 5 /5
- statement of problem

GOOD.

Body: 28 /30
- design concepts
- documentation of concepts
- design decisions
- final concept

• SO FAR, YOU ARE THE ONLY CO. WITH A MARKETING REVIEW!
• GOOD COST ANALYSIS, AND RECOMMENDATIONS
• ACCURATE PREDICTION OF PERFORMANCE, THOUGH 3 SIG. FIG. IS OF QUESTIONABLE VALUE.
⇒ A NICE REPORT, BUT I DON'T SEE ANY OTHER CONCEPTS – WHAT ELSE DID YOU CONSIDER?

Conclusions: 4 /5
- merits of design concept

• LACKING A SUMMARY, THOUGH GOOD OTHERWISE – YOU SHOULD HAVE CLOSED THE ANALYSIS & DOCUMENTATION.

Organization: 5 /5

Grammar: 5 /5

References: /

Overall: 49 /50

VERY NICE DOCUMENTATION.

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on the back of an envelope."™

FLYING SQUIRREL

MICRO AIR VEHICLE

Marketing and Design Report

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EXECUTIVE SUMMARY

The NUTS Aerospace™ Flying Squirrel MAV is at the cutting edge of low cost, high performance micro air vehicles. Designed to meet the needs of an emerging demand for high endurance transports of U.S. currency, the Flying Squirrel merges high frugality technology and innovative ideas into a highly effective aircraft system. This MAV epitomizes the design philosophy of NUTS Aerospace™, to "solve the world's problems . . . on the back of an envelope" ™.

The primary marketing point of the Flying Squirrel is its ability to accomplish the high-end design objectives ~~of the design~~. The Flying Squirrel has a payload capacity of three standard U.S. quarters, with an option of reducing the payload as needed for the utility of the customer. With its parachute fully deployed, this micro air vehicle also has an average endurance of over three seconds. This easily meets the payload demands of the aircraft contract and provides a highly competitive endurance performance. At the same time, the stability of the aircraft has also been verified through both theoretical analysis and general flight-testing.

This MAV also has the advantage of being low cost and of simple design. The tools needed to construct the Flying Squirrel can be found at any local hardware store, and anyone with basic woodworking skills can create a Flying Squirrel from the build-to package due to the high tolerances given to each design feature. The materials needed to construct each vehicle are also easy to acquire and of very low cost, making it possible for the Flying Squirrel to be produced in facilities worldwide. The lack of computer aided milling and machining tools in the build-to package also greatly reduce the personnel and machine wear costs associated with this vehicle.

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Since there is no need for general re-tooling of assembly facilities nor a need for personnel re-training, every aerospace company, regardless of size and prestige, would have the capability to mass produce this air vehicle to met any projected demand for the aircraft. This, combined with the low personnel and material costs and the low cost of transporting such a small and robust vehicle, makes the Flying Squirrel a highly cost effective vehicle and a profitable enterprise so long as a strong demand exists for the aircraft. It is the goal of all NUTS Aerospace™ employees to contribute high utility, robust, and low cost micro air vehicles to the general aviation world. The Flying Squirrel MAV embodies all of these goals.

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VERIFICATION OF DESIGN

This Flying Squirrel design prototype has been tested and verified for meeting the standards set forth by the Micro Air Vehicles Directorate. The configuration of the Flying Squirrel prototype is subject to alteration as authorized by NUTS Aerospace to accommodate changes in performance criteria. All inquiries regarding this design should be directed to NUTS Aerospace.

Loral O'Hara, President — Date: 4.15.04

Eric Stewart, Sr. Vice President and CFO — Date: 04/15/04

Bradley Torgler, Chief Engineer — Date: 04/15/2004

NUTS Aerospace
University of Kansas
Learned Hall, Room 3101
Lawrence, KS 66045

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MARKET REVIEW

The RAND Corporation initiated the first feasibility studies on micro air vehicles (MAVs) in 1993. The Lincoln Laboratory soon joined the research, which resulted in a Defense Advanced Research Projects Agency (DARPA) workshop in 1995. In 1996, DARPA initiated a program for the research and development of MAVs. Since then, the industry has grown swiftly, and is the vanguard of current technological advances. Technological feasibility has been enabled by the development of various micro-electromechanical systems (MEMS), which combines micro electronic technology with mechanical components of similar size. Despite the technical challenges of small-scale construction, MAVs offer major advantages of terms of relatively short design and fabrication times. This aspect will allow MAV development to progress at a greater rate, and facilitate the rapid increase in MAV capabilities.

Research in MAVs takes place at various levels. DARPA is a key organization, whose WASP MAV set an endurance record for one hour and 47 minutes in 2002.[1] Commercial organizations include AeroVironment, Inc. and BAE Systems. The Black Widow, a vehicle developed by AeroVironment, features a color video camera that downlinks live footage to the pilot. AeroVironment also headed the design, fabrication, and flight tests of DARPA's WASP. The largest amount of research, however, takes place at the university level, with a variety of research grants and sponsored competitions held at the University of Florida and Arizona State University.[2] It is these universities that will prove to be the greatest competition for the NUTS Aerospace Flying Squirrel due to their similar operating circumstances.

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The potential customer base for MAVs is vast. Since the September 11 terrorist attacks, the utility of MAVs has increased immensely. In the future, micro air vehicles will be indispensable in reconnaissance activities and other military applications. Because military operations have become dependent on small, autonomous teams operating in urban environments, micro air vehicles have become essential to both personnel safety and mission success. [1] In addition, the technology developed to facilitate vehicle autonomy will also have applications in situations where human involvement would prove dangerous, such as search and rescue, border patrol, police surveillance, and scientific field research.[2] Due to the dual military and civilian applications, the development of a successful micro air vehicle will be crucial to staying abreast of emerging technologies and remaining competitive in the industry.

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COST ANALYSIS AND BENEFITS

COST ANALYSIS

Numerous factors drive the total cost of each Flying Squirrel produced, and it is therefore necessary to determine the contribution to the total unit cost of each MAV incurred from personnel, tool wear and maintenance, materials, and the cost of designing the aircraft itself. Each expense grouping will contribute varying costs to the overall cost of the MAV depending on factors such as expected aircraft sales, expected machine lifetime, and the amount of time required for manufacturing both in terms of time on the machine and the cost of the operating personnel. Simplicity of design, tolerance levels, and the skill sets required will be the primary driving factors for pricing the final deliverable product.

Several assumptions were also made in the formulation of the per-unit cost estimate of the micro air vehicle. First, it was assumed that the overall machine lifetime would be the total number of years the machine is under warranty multiplied by the number of weeks in a year, which in turn was multiplied by an assumed ten hours of machine running time per week. Once this lifetime was determined, the total acquisition cost was divided among this lifetime to find the per-hour operating cost. In addition to this assumption, the amount of personnel time was assumed to be the average time needed at each machine to create a prototype. Salaries were based on current company payroll figures, and the overall design cost was divided among the estimated vehicle sales. Once this was accomplished, the per-unit cost of the Flying Squirrel was found by calculating the contributions of each expense category per MAV.

→ HIGH USAGE, IF EACH FLIGHT IS 3 SEC. (12000 MILLION / WEEK). IS THIS, INSTEAD, YOUR MANUF. COST?

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Table 1. Tool Costs

Tool Name	Total Cost ($)	Warranty (yrs)	Expected Tool Life Expectancy (hrs)	Tool Cost (per Hour Tool Life)	Estimated Tool Time (hrs/unit)	Cost/MAV
Dremel	$97.90	5	2600	$0.038	0.16666667	$0.006
Drill Press	$221.87	2	1040	$0.213	0.03333333	$0.007
Band Saw	$299.99	2	1040	$0.288	0.06666667	$0.019
Misc.						$0.015
					Total/MAV:	**$0.048**

Table 2. Material Costs

Material	Total Cost (per unit material)	Units Needed	Cost/MAV
Balsa Wood (0.25"x2"x36")	$3.520	0.0472222	$0.166
Cloth (sq. inch)	$0.031	4	$0.125
String (inch)	$0.001	12	$0.010
		Total/MAV:	**$0.301**

Table 3. Personnel Costs

Position	Salary/hr (w/ Overhead)	Time/MAV (hr)	Total Cost/MAV
Machinist	$90.000	0.0833333	$7.500
Misc.	$75.000	0.0666667	$5.000
		Total/MAV	**$12.500**

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Table 4. Design Costs			
Position	**Salary/hr (w/ Overhead)**	**Design Time**	**Design Cost**
CEO	$150.00	5	$750.00
Design Engineers	$200.00	5	$1,000.00
		Total	**$1,750.00**

← DOES THIS INCLUDE REPORTING TIME, BRAINSTORMING, CAD, FLIGHT TEST...?

← WHAT ABOUT SOFTWARE, HARDWARE, FACILITIES...?

Expected Sales	20
Total MAV Cost (per Unit)	**$100.35**

COST SAVING IDEAS

After determining the overall cost of each MAV to be $100.35, it was determined to be necessary to find ways to reduce costs. Below are suggested cost saving measures that would help reduce the per unit cost of each vehicle:

1. *Less skilled machinists.* Due to the high tolerances and simple design of the Flying Squirrel, it is not necessary to use highly skilled, computer-aided machinists or machining tools. Someone with basic woodworking skills could be employed, at a much lower cost, to build this MAV. It is therefore recommended that the company's less-specialized skilled workers be tasked with production.
2. *Greater Sales.* Though difficult to achieve, increasing the production fleet of the Flying Squirrel from the estimated 20 aircraft would dilute the cost of design over a larger fleet of aircraft. Aggressive marketing is therefore recommended.

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3. *Improved Overall Efficiency*. Once the design enters mass production (market depending), the overall amount of time needed to produce each Flying Squirrel vehicle will decrease, therefore further reducing the costs associated with time on machine and personnel costs.

Thought the overall cost per unit will decrease assuming greater sales and a less skilled workforce, the price of the Flying Squirrel may prove to be cost ineffective over the long term. It is therefore also recommended that the company executive board determine what price is sustainable and whether or not the company can sustain a production line at that per unit cost. Further market research is therefore needed and highly recommended.

Note: Reference for cost analysis is shown in Appendix A.

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DESIGN CONFIGURATION

FINAL DESIGN

Table 5. Parts List

PART NO.	DESCRIPTION	VENDOR
24-001	Balsa Wood	University of Kansas Aerospace Engineering Department
25-001	String	Hobby Lobby (Lawrence, KS)
25-002	Cloth	Hobby Lobby (Lawrence, KS)

good

Table 6. General Design Characteristics

Vehicle Weight with Maximum Payload	Dimensions (Carrier)	Parachute Dimensions	String (x2) Length	Parts Count
0.5 oz	0.25" x 1.5" x 1.5"	4.5" x 4.5"	6"	4

*Dimensions listed above are subject to tolerance guidelines as specified by the Build-To Documentation

WHAT IS PAYLOAD? HOW MANY QUALITY, WHAT WEIGHT?

HOW MANY STRINGS?

Figure 1. Final Design Configuration

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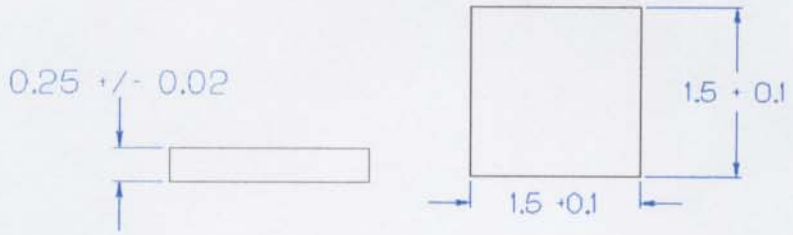
BUILD TO DOCUMENTATION

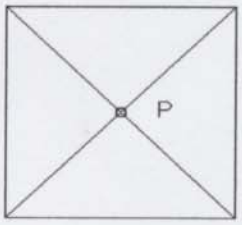
The following process describes the manufacture of the Flying Squirrel Micro Air Vehicle. The dimensions and construction techniques shown within are subject to alteration as authorized by NUTS Aerospace.

PLATE CONSTRUCTION

1. Obtain a plate of balsa wood 0.25 inches thick and 1.5 inches in length and width. For larger pieces, use a band saw to cut to the specifications, as shown below.



2. Determine the approximate center, or point "P," of the plate using the intersection points of the diagonals connecting the four corners. Using a straight edge, draw the guidelines on the part.



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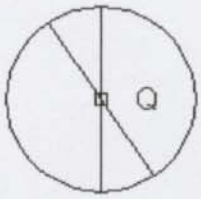
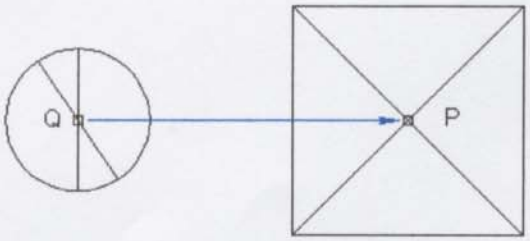
3. Note the approximate center point on a US quarter, shown at point "Q," by using two diameter lines and marking the intersection. Using a straight edge, draw the guidelines on the plate.



4. Place the center of the quarter (point Q) on the center of the plate (point P) by using estimation. The objective is to have equal edge spacing from every side of the plate within a 0.10-inch tolerance.

How does this affect mass balance?



5. Trace the outside of the quarter with a pencil or other marking device. Ensure the marking device creates a line no wider than a standard #2 pencil.

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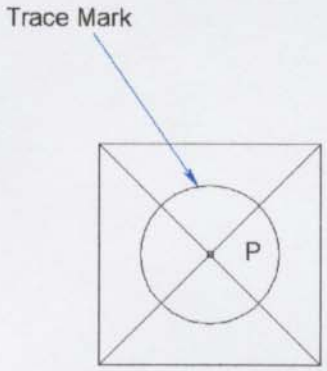
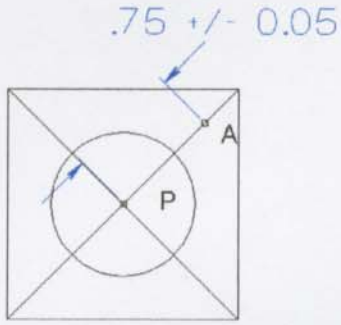


6. Mark a point "A" along one of the diagonal lines on the part 0.75 inches from the approximate center point of the plate. This will serve as the connection point for the parachute ties.



7. Using a Dremel® tool, place a sand bit (sized smaller than a US quarter), as seen from a top view. Beginning in the center, drill through the quarter inch thickness of the plate.

8. Once the hole is made, sand the inner walls until they match the traced pattern of the quarter as seen from a top view. It should be noted that the diameter of the circle cutout is subjective to tolerances of +0.00 inches and –0.05 inches.

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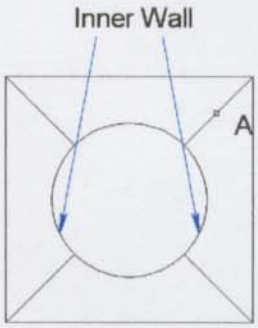
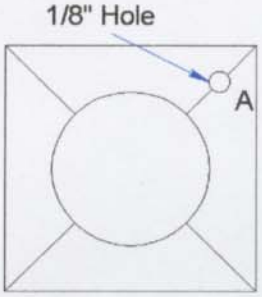


TOP VIEW

9. Using a 1/8 inch sized drill bit, drill through point A. The center of the drill bit should be no more than a 0.5" radial distance from point A. Ensure hole uniformity to the "best machine tolerances".



10. Make a 1/16-inch chamfer at the corner where the 1/8-inch drill bit is located. See the diagram below. Also create a 0.25-inch chamfer at the corner opposite of the hole located at A (corner C). Both chamfers are governed by +/- 1/32-inch tolerance.

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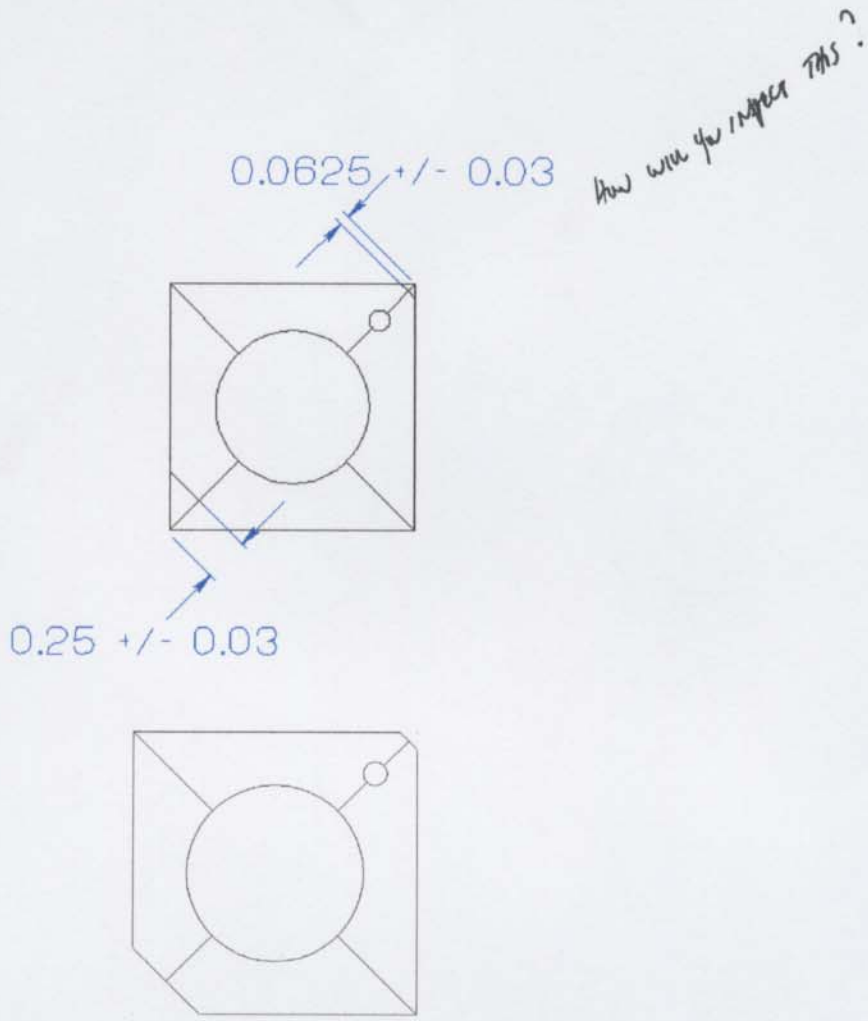

This completes the balsa portion of the Flying Squirrel.

PARACHUTE CONSTRUCTION

1. Obtain silk or meshed nylon cloth and string. From the cloth, cut a square of size 4.5" long and 4.5" wide. It should be noted that the square is subjected to tolerances of +0.00 inches and –0.50 inches.

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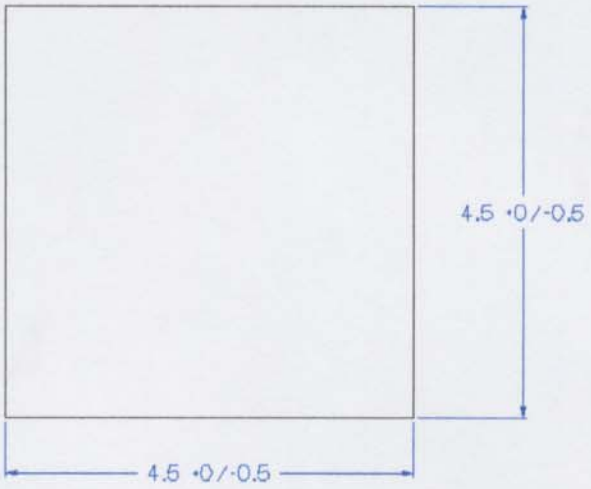
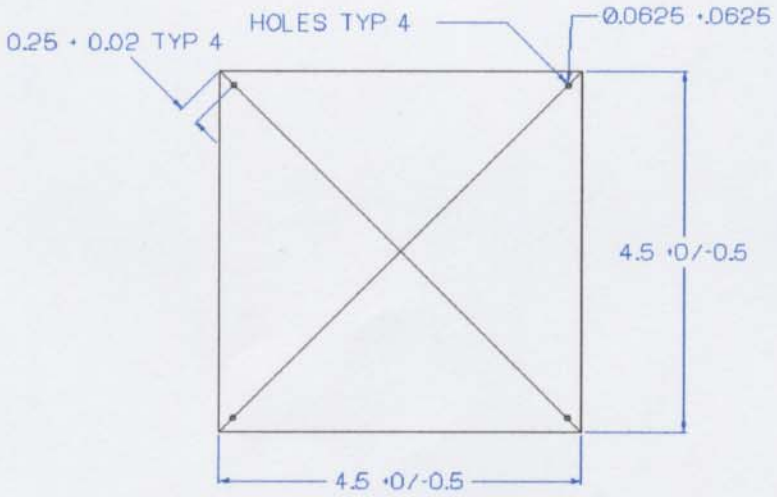


2. Make diagonal lines from corner to corner on the cloth. Along the diagonals, mark points ¼" from the corners. Poke a hole through the points no smaller than 1/16" in diameter, but no larger than 1/8" in diameter.



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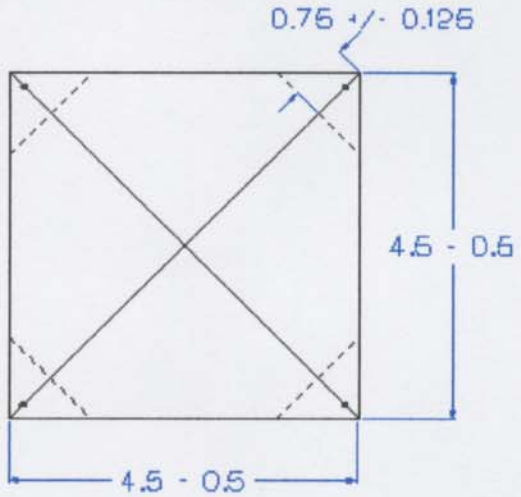
3. Cut two pieces of string of length 6 inches, within a tolerance of +/- 0.25 inches. Lay the cloth on a flat surface, and fold the corners inwards 0.75 inches (shown as dotted lines) such that the corner tips are aligned with the diagonals drawn in Step 2.



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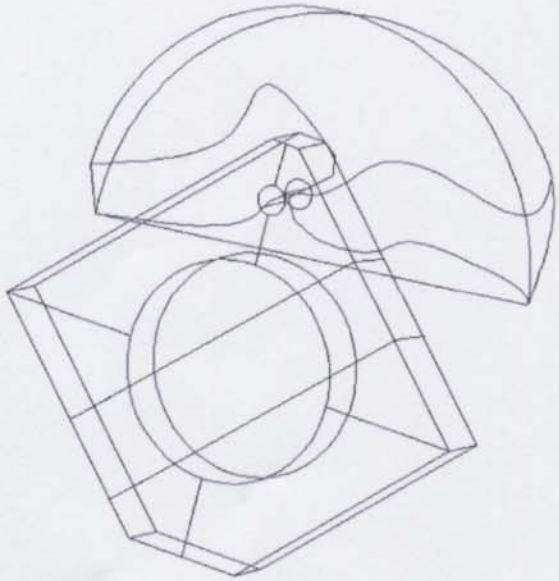
FINAL ASSEMBLY

To complete the assembly, place one end of each string through the 1/8" diameter hole in the balsa wood piece and secure each end of each string to the holes located diagonally each other on the cloth. Make the string taut and double knot in securing to the cloth parachute. Cut off the excess ends of the strings. Note: If the vehicle is larger than 6" in length in the case of an un-deployed parachute, then place a hole at the top of the chute by cutting across the top. The resulting hole may be filled with additional material, or left open. Place three U.S. quarters in the 15/16" diameter hole (by tolerance fitting). Ensure payload (quarters) security by placing a piece of scotch or duct tape of thickness 0.25" to 1" wide one revolution around the approximate center of the balsa wood piece as shown below in the "see through" final assembly.



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PERFORMANCE AND STRUCTURE ANALYSIS

PERFORMANCE

The Flying Squirrel's performance for maximizing endurance is greatly dependent on the manner in which it is launched and atmospheric conditions such as wind when launched outdoors. The analysis ~~done~~ performed for the flight dynamics and structural compliance of the Flying Squirrel assumes no wind conditions and defines "launch" as projecting the vehicle by hand at a height of 6 feet above level ground orthogonally away from the ground plane in a manner such that the lateral velocity is essentially zero (negligible). Figure 2 below shows a generic sketch of the vehicle flight path. There is lateral displacement shown in the schematic solely for the purpose of visual enhancement.

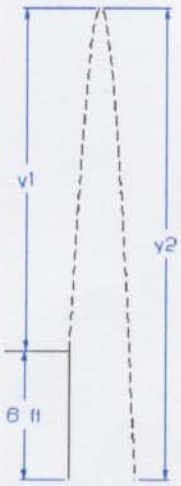

Figure 2. Projection Flight Path Schematic of the Flying Squirrel

Performance analysis for endurance time is based on four different case scenarios*, which depends on the amount of deceleration the Flying Squirrel will

* Case scenarios were selected arbitrarily to cover an expansive range of deceleration values, which were assumed based on previous observations.

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experience from the flight path apex on its return to the ground. These case scenarios consist of:

1) Worst Case – the parachute is ineffective (no deployment) and deceleration is therefore at 1g (note that g = -32.2 ft/s^2).
2) Case 2 – the parachute's effectiveness provides for a deceleration of 3/4g
3) Case 3 – the parachute's effectiveness provides for a deceleration of 2/3g
4) Best Case – the parachute's effectiveness provides for a deceleration of 1/3g

SENSITIVITY ANALYSIS. VERY GOOD.

Note that it is possible that the parachute could actually have an effectiveness of deceleration less than 1/3g, yet a conservative estimate was made at this value for the Best Case.

Using the kinematic equation defined in Equation 1, the total endurance time for the Flying Squirrel was determined for each case scenario assuming an initial velocity of 36 ft/s (just under 25 mph). For other initial velocity conditions, refer to Table B.1 located on page B.1 in Appendix B.

$$y = y_o + V_o t + \tfrac{1}{2} a t^2 \qquad \text{Equation 1}$$

Where: y_o is the initial height at launch (6 ft)

V_o is the initial velocity at launch (ft/s)

a is the acceleration felt during flight (ft/s^2)

t is the time aloft (sec)

The table below shows the results for time aloft for each case scenario.

Table 7. Maximized Endurance Time Assuming Initial Velocity of 36 ft/s for Case Scenarios

	Parachute Deceleration			
Case	**1g**	**3/4g**	**2/3g**	**1/3g**
Time Aloft (sec)	2.392	2.589	2.678	3.324

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The figure below depicts the results for time aloft for each case scenario for initial velocities ranging from 5 ft/s to 36 ft/s.

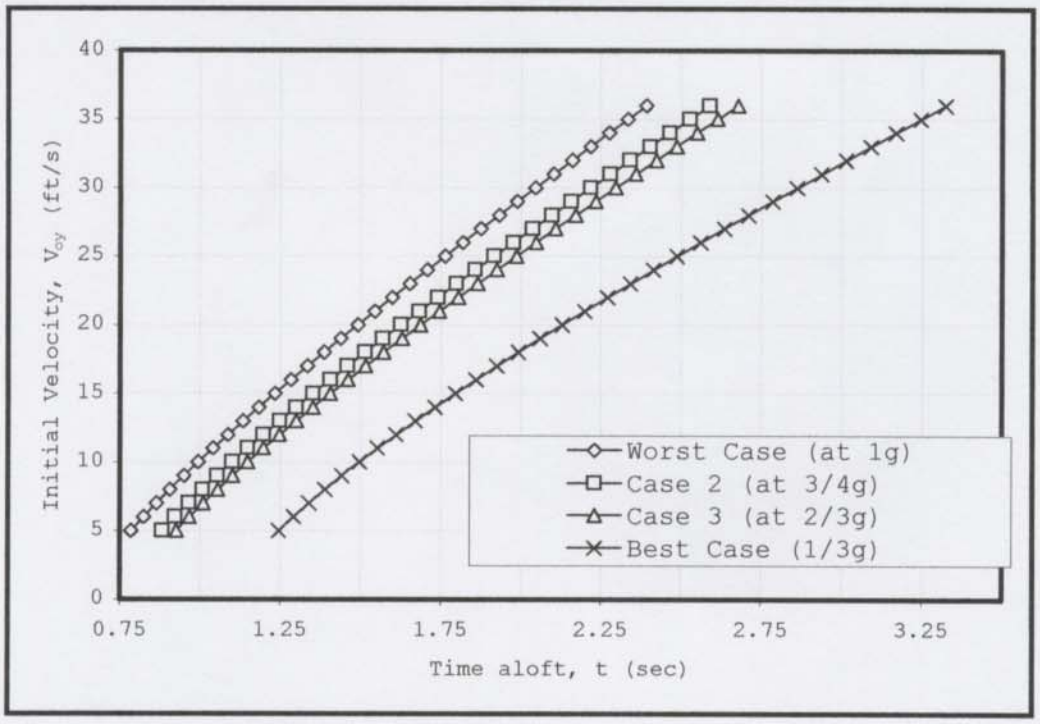

Figure 3. Potential Time Aloft for Given Initial Flight Velocities

One of the great benefits of the Flying Squirrel design is its ability to obtain flight stability. During its ascension after launch, it is subject to rotation in three-dimensions, yet assuming deployment of the parachute at or just after the flight apex, there will be mass-center balancing of the balsa piece holding the three U.S. quarters through tensile forces in the strings connecting the balsa piece to the parachute. This allows for stability of the vehicle while in dynamic flight.

Upon initial opening of the parachute, there will be a "shock" force caused by the parachute trying to accelerate the Flying Squirrel upwards while the force of gravity is pulling it towards the earth. According to a study done by Parks

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College Parachute Research Group, the largest shock expected to be felt by parachute deployment is somewhere around 6g's[3]. The effects of this on the structure and the tensile strength of the string are addressed in the next section.

STRUCTURAL ANALYSIS

The greatest concern in the survivability and success of the Flying Squirrel is in keeping the parachute attached to the balsa piece by the strings. Therefore, tensile analysis was done on the strings for the 6g shock described above as well as for when the vehicle settles after the shock for each case scenario. Because there are four juncture points connecting the parachute, it is assumed that the tensile load going through each string section connection is ¼ of the entire force pulling on them. The governing equation used for this analysis is Newton's 2nd Law, which is given in Equation 2 below.

$$F = ma \qquad \text{Equation 2}$$

Where: F is force (lbs)

m is the vehicle mass (0.5 oz)

a is the acceleration felt during flight (ft/s^2)

The following page shows the results for the string attachment tensile strength analysis along with margins of safety calculations. The maximum allowable force through each string section is assumed to be 1 lb, though the string used for the Flying Squirrel prototype has a higher tensile strength.

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Table 8. Tensile Resilience for Flying Squirrel String Attachment

	Parachute Deceleration			
	1g	3/4g	2/3g	1/3g
Tensile Force (lbs) in strings' sections	0.000	0.002	0.003	0.005
MS	N/A	507.82	380.61	189.81
Tensile Shock Force (lbs) in strings' sections	0.189			
MS	4.300			

IS THE STRING REALLY THE PROBLEM? WHAT ABOUT THE JOINT WHERE THE STRING ATTACHES TO THE PARACHUTE?

From the structural analysis, the Flying Squirrel is adequately constructed to withstand the conditions for launch and descent.

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2. AeroVironment Website: Black Widow. [http://www.aerovironment.com]

3. "Ram-Air Parachute Deployment Study." [http://www.pcprg.com/pcraps.htm].

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