Selecting Materials for Drone

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Introduction 简介

Having a passion for aerodynamics, I attended a summer program at the Rose-Hulman Institute of technology (1) during summer vacation in 10th grade. There, I learned basic knowledge on designing a glider and built one with a partner. We then made test flights and fine-tuned it to achieve the gliding performance. I had a great time there.

After returning home, I wanted not only to make a glider, but also to design my own powered drone. My plan was to assemble a pre-designed drone and then optimize the build until it becomes a completely new drone. I purchased the drone (2), as shown in Figure 1, from a web dealer.

Figure 1 Drone.

Figure 2 Balsa Wood

The drone material was a kind of foam that boasted low density. I wanted to find out whether there were better materials available to make the drone, and I was curious why the pre-designed drone was made from foam instead of balsa wood, which we used for the gliders at Rose-Hulman. Therefore, I found some Balsa wood on the internet (3) as shown in Figure 2.

The purpose of this paper is to document how I had compared the mechanical properties of these materials. I searched for relevant information on material mechanics on Wikipedia as a start. After some reading, I concluded that the three most important properties of structural materials are:

- Density is obviously related with the weight the load capacity of the drone. It is a very important property and should be measured.
- Stiffness (5) is the extent to which an object resists deformation in response to an applied force.
- Strength (4) typically refers to various methods of calculating the stresses and strains in structural members, such as beams, columns, and shafts. In the mechanics of materials, the strength of a material is its ability to withstand an applied load without failure or plastic deformation.

Below is the procedure I had used to measure the density and stiffness of the foam and balsa wood. Based on this kind of method, it is quite easy for any reader to make the measurement of the Strength of materials.

Density Measurement 密度测量

Density is the mass per unit of volume of any object. Its equation is:

$$\rho = \frac{m}{V}$$

Where m is the mass, V is the volume and ρ is the density of the material. I used a digital scale in mom's kitchen to measure the mass of the materials (6). Its precision is one decimal place.

Figure 3 digital scale

	Foam						
Length(cm)	51.8	49.8	49.9	51	49.8	49.9	48.7
Width(cm)	20.7	24.4	24.3	23.8	21.8	21.8	23.9
Height(cm)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Volume	536.13	607.56	606.285	606.9	542.82	543.91	581.965
L*W	1072.26	1215.12	1212.57	1213.8	1085.64	1087.82	1163.93

Table 1: Foam's dimension

	Balsa wood						
Length(cm)	50.6	50.7	50.1	50.1	50	50.2	50.1
Width(cm)	10.1	10.1	10	10	10	10	10
Height(cm)	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Volume	204.424	204.828	200.4	200.4	200	200.8	200.4
L*W	511.06	512.07	501	501	500	502	501

Table 2: Balsa wood's dimension

	Volume	Mass(g)	Density
3D Plastic	4025.57	242.5	0.06024
3D B-wood	1411.252	174.8	0.123862
2D Plastic	8051.14	242.5	0.03012
2D B-wood	3528.13	174.8	0.049545

Table 3: Density of foam and Balsa wood

The density of balsa wood (0.123862 g/ cm^3) is about twice of the density of foam (0.06024 g/cm^3) and the wood's planar density is near 1.64 times that of foam.

Stiffness Measurement 刚度测量

The stiffness (5) of a body, *k*, is a measure of the resistance offered by an elastic body to deformation. For an elastic body with a single degree of freedom (DOF) (for example, stretching or compression of a rod), the stiffness is defined as

$$k = \frac{F}{\delta}$$

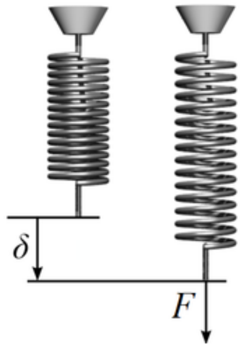


Figure 4 Stiffness

where,

- F is the force on the body
- δ is the displacement produced by the force along the degree of freedom (for instance, the change in length of a stretched spring)

The main wing of the aircraft is a cantilever beam structure. According to Wikipedia (5), the stiffness of cantilever beam structures can be divided into 3 types (shown in figure 5):

- Tensile stiffness and compression stiffness: Acts in the x+ and x- directions.
- Bending stiffness: Acts in the y+, y-, z+, and z- directions.
- Rotational stiffness: Acts clockwise or counterclockwise around the x-axis, y-axis and z-axis.

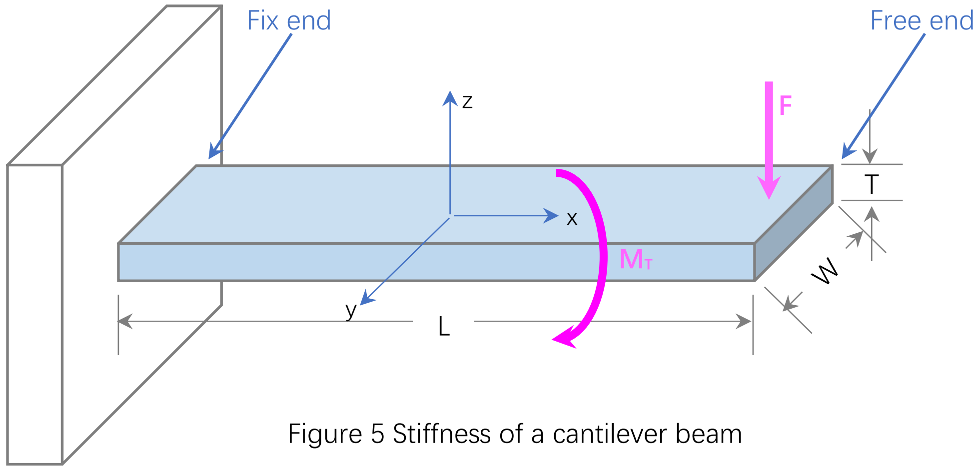


Figure 5 Stiffness of a cantilever beam

In order to balance these forces and moments, as the thickness of the beam (T in figure 5) is the smallest one of the three dimensions (T, W, L in figure 5), it must be multiplied by the maximum force at the fixed end of the beam to balance the force (F in figure 5) and moment (M_T in figure 5) in this direction. In other words, the bending stiffness and strength in this direction are the most critical ones for this material so that in this paper we only measure them.

Procedure:

Step 1: make 2 beams with wood and foam respectively. The widths of both beams are 2.5 cm and the length are 45 cm.

Step 2: fix one of the beams to the table as in figure 6.

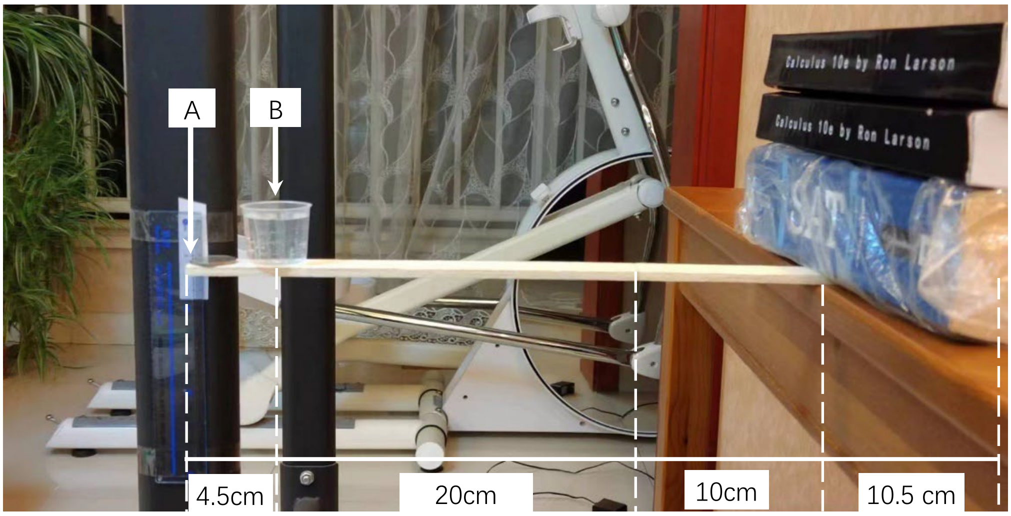


Figure 6 Test bench for stiffness

The length of the fixed part is 10.5cm and it stretched out of the edge of the table by 34.5 cm.

Step 3: At point A, place a coin to cancel the virtual displacement and record the initial position x_1.

Step 4. At point B, place a plastic container with water as the load for the beam. The load must meet the following requirements:

4.1 When the moment arm is 30 cm (as shown in figure 6), the beam bends downward. The load cannot be so massive that it compromises its stability.

4.2 When the moment arm is 20 cm, the load must massive enough so that the displacement at point A is large enough to reduce measurement error.

4.3 The load meets the above requirements for both plastic and wood beams.

Record the new position x_2.

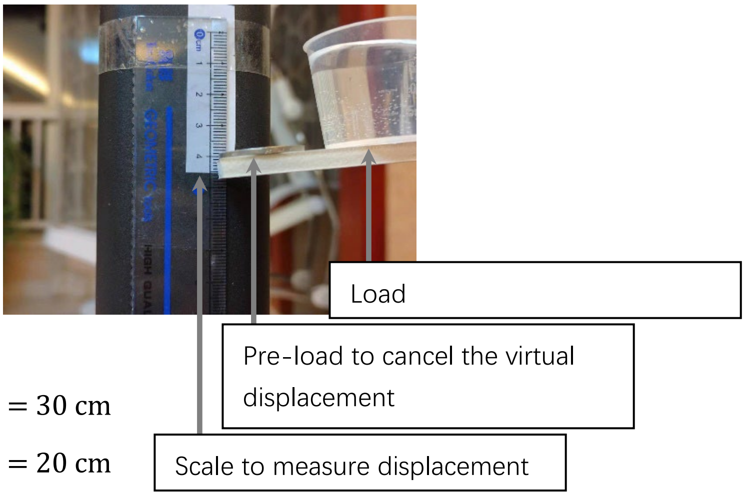


Figure 7 load

Repeat step 3 and 4 for

Wood beam, moment arm = 30 cm

Wood beam, moment arm = 20 cm

Plastic beam, moment arm = 30 cm

Plastic beam, moment arm = 20 cm

Test results

material dimensions	
width	2.5 cm
Distance AB	4.75 cm
load	22.3 g

Table 4: dimensions for foam and balsa wood

Balsa wood			
arm	x_1	x_2	δ
20cm	1.70	1.80	0.10
30cm	1.80	2.11	0.31

Table 5: Stiffness test for balsa wood

Foam			
arm	x_1	x_2	δ
20cm	1.89	2.50	0.61
30cm	2.30	4.16	1.86

Table 6: Stiffness test for foam

Here is an introduction of the virtual displacement of which we often experienced in measuring force-displacement characters of materials. We often find that the displacement for the initial load is abnormal (usually a little larger). Figure 8 shows the compression test on a book. A force F is applied on a book to test the compression stiffness of it. When we start squeezing the book with some force, there are some air gaps between the paper pages. The displacement caused by our squeezing is partly due to squeezing out the air gap, and partly due to compression of the paper. When all the gaps are squeezed out, we can only compress the paper. At this moment, the same amount of force can only produce a relatively small displacement. That is to say, the displacement at the beginning of squeezing the book is mostly not caused by the deformation of the paper, but by air gaps. These displacements (V-d in figure 8) are called virtual displacements. The purpose of loading coins before adding actual loads in this test is to eliminate the influence of these virtual displacements.

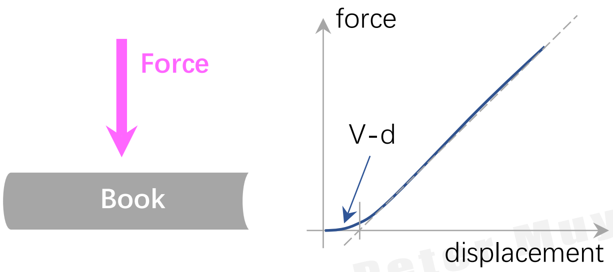


Figure 8 Virtual Displacement

Strength Measurement 强度测量

In material mechanics, the strength of a material is its ability to withstand an applied load without failure or plastic deformation (4). Strength is characterized by stress and strain. The method to measure tensile strength (stress) is also introduced in (4).

Before the experiment, it is unknown whether the material is an elastic material or plastic material, so we have to test it. We place a load on the different materials and increase the load until it fractures. The maximum load recorded before the fracture is the tensile strength of the material.

Figure 9 test bench for strength

Figure 9 shows the test bench for strength measurement, and it is very similar to that of the stiffness measurements. The difference for this test bench is that the load is hanged in a bag, since the bending of the material caused by large loads will cause objects on top to tip over.

material dimension	
width	1.85 cm
leading for coin	4.75 cm
moment arm	30 cm

Table 7: dimensions for both foam and arm:

load (g)	Position (mm)
0	2.09
6	2.80
12	3.50
18	4.31
24	5.12
30	5.99
36	6.89
42	7.80
48	fracture

Table 8: Test result for foam

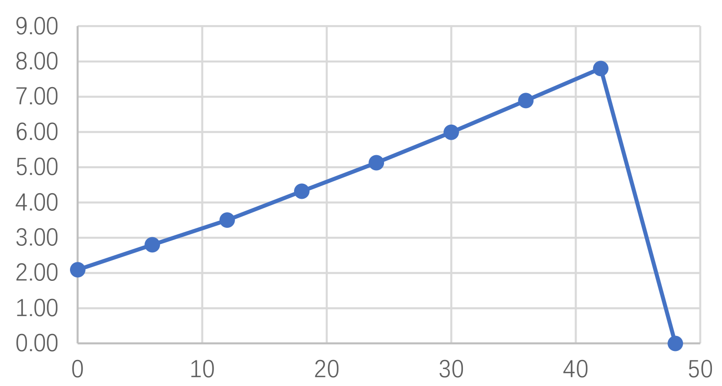


Figure 10 Strength test for Foam

load (g)	Position (mm)
0	1.88
6	2.00
12	2.10
18	2.25
118	4.00
218	5.78
318	7.53
418	9.40
468	10.34
498	11.20
503	fracture

Table 9: Test result for Balsa wood

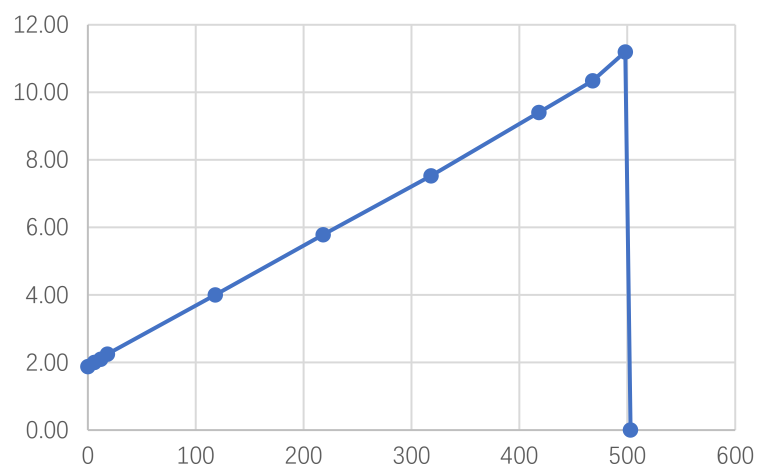


Figure 11 Strength test for Balsa Wood

Figure 12 shows the fracture of the wood.

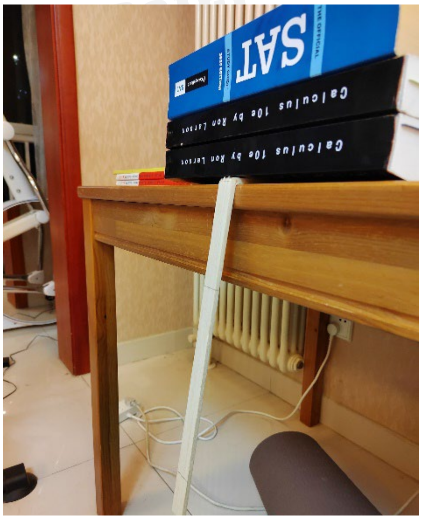


Figure 12 Fracture of the wood

Analysis and Conclusion 分析和结论

Density measurement

1. The density of balsa wood (0.123862 g/ cm^3) is about twice that of foam (0.06024 g/cm^3)
2. The planar density of wood is around 1.64 times that of plastic.

Stiffness test

1. Bending stiffness is not linear with respect to the moment arm length. When the arm length increases 1.5 times from 20 cm to 30 cm, the bending stiffness increases to 3 times for both beams.
2. The stiffness of Balsa wood is 6 times that of foam.

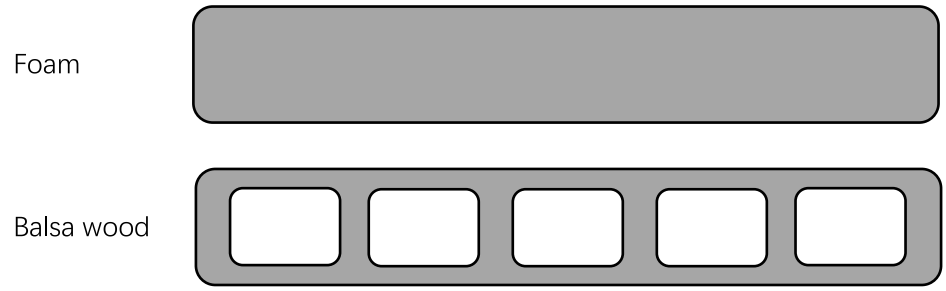
Strength test

1. Bending strength is almost linear with respect to the load for both foam and wood.
2. The strength of Balsa wood is 498/42=11.9 times that of foam.

Comparison of the two materials

Although the density of foam provided by the drone maker is 1/2 of that of balsa wood, the stiffness of foam is only 1/6 that of wood, and the strength is 1/11.9 that of wood. Thus, the overall performance of the balsa wood is much better.

Further Research and Discussion 延申研究及讨论



Since balsa wood provides more stiffness and strength per unit density, it is speculated that the balsa wood can be cut into the shape shown above to decrease its mass while maintaining better stiffness if I use it to make a new fuselage for the drone.

This paper also demonstrates the conduction of a fundamental material test with public information (Wikipedia) and facilitation of it at home.

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