Final Design Report

EK301 Section C1

Professor Schimidt

Group Name: ***Bear***

4/25/13

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Table of content

Abstract

In this report, there is one final truss design, designed under certain limitations of span and cost. This design, along with other three different designs, will be well evaluated and analyzed. By using MATLAB, the force that acting on each member of the truss can be determined. Together with the results from the Straw Test, it can be determined that which member will buckle first when the whole truss fails in loading.

Introduction

A truss will be considered as a good one if it is economic but efficient. The purpose of this report is to evaluate a truss design before it has been built. By using MATLAB, the force acting on each member will be determined; in addition, it will tell the possible maximum load of the truss. To determine which design will be built eventually, load-to-cost ratio and expense are taken as priority.

Considering the fact that triangle appears to be the most stable geometry shape, the motivation for the design is to put different triangles together to form a strong truss. Meanwhile, a few standards have to be met, such as the span will be 55 ± 1cm, length of each member will between 8cm and 15cm, and the cost will be less than \$335 where cost would be determined by

$$\text{Cost} = \$10 \cdot \text{Joints} + \$1 \cdot \text{Length}.$$

To improve the loading ability of a truss, the following facts are taken into account. Firstly, the maximum force that a straw can experience is inversely proportional to its length, which means the shorter the length is, the more force that a straw can hold. Thus, the motivation of making progress on preliminary designs will be to reduce the length of the critical members. Secondly, the load should be distributed into different members as equally as possible. Thus, the design should contain fewer right triangles as those used in preliminary design No.1. Instead, more triangles with shorter sides should be considered.

The rationale for using MATLAB is to write down the static analysis while assuming every member experiences a tension force, and convert all the equations into several matrixes so that the computer can help solving.

Procedure

For Design No.1 from Preliminary Design (page 14), considering the span should be between 54cm and 56cm, and each straw should be between 8cm and 15cm, 6*9=54 first came to mind. For simplicity, symmetry is considered, and the general shape of the truss can be flat. Thus, a decision was made that there will be 6 pieces and 9cm each for the bottom line. After the first sketched was made, the cost calculation turned to be less than $335 (page 14). From Preliminary Design Report, this design works well. Thus, the decision is made to improve this truss. Since the maximum force that a straw can experience is inversely proportional to its length, which means the shorter the length is the more force that a straw can hold, reduce the length of the critical members will increase the loading ability of a truss. In addition, the load should be distributed into different members as equally as possible. Therefore, the design should have fewer right triangles as those used in preliminary design No.1 but to have triangles with shorter sides and suitable angles. As a result, see Design No.3 (page 10).

For Design No.2 from Preliminary Design (page 14), difference became the priority, because different types of truss can bring more analysis, which can benefit the final project in the future. Since Design No.1 is a flat shaped, Design No.2 then is decided to be non-flat shape. By thinking of the roof of houses, a sketch of a roof-like truss was made. Due to the cost limitation, the sides of triangles are carefully selected. Since the span should be 55±1cm, one side of the triangle then is determined to be 13.5cm. For the rest of two sides, one of these has to be greater than 8cm, so the other one has to be 15.9cm (It doesn't violate the limitation because 15.69cm indicates joint-to-joint distance). And the cost turned to be valid. Therefore, a final sketched is made (page 10). However, from the result from Preliminary Design Report, this design should be eliminated since its limited maximum load disqualifies itself.

For Design No.4 (page 15), the basic idea of design is inspired by suspension bridges. The base, with 9cm by 6 pieces, shares the same idea with Design No.1 and No.3. Due to the cost and span limitation, it is to design with 5 vertical beams symmetrically, and tallest of those should be 10cm because of ease to measure and the relation between the length and loading ability of straws. Like a suspension bridge, there will be few members diagonally connecting two joints to form a more stable geometry of triangles.

Analysis

Computational approach:

1. Set up parameters for joint locations, member-joint connections, reaction forces locations, and the load.
2. Assume all members are under tension. Using FDB to analyze the static equilibrium and construct a system of equations.
3. Since there is a linear relation between the load and the force that acting on each member, the maximum load can be calculated through finding the buckling strength of the critical member(s).

```
%The demonstration here is analysis on Design No.
%The definition of the connection marix C
C=[1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0;1,0,1,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,1;0,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
;0,0,0,1,0,1,1,0,1,0,0,0,0,0,0,0,0,0,0,0,1;0,0,0,0,1,1,0,1,0,0,0
,0,0,0,0,0,0,0,0,0,0;0,0,0,0,0,0,0,0,1,1,0,1,0,0,0,0,0,0,0,0,0;0
,0,0,0,0,0,1,1,0,1,1,0,1,0,0,0,0,0,0,0,0;0,0,0,0,0,0,0,0,0,0,1,1
,0,1,1,0,1,0,0,0,0;0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,1,0,0,0,0,0;0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,1,0,0;0,0,0,0,0,0,0,0,0,0,0,0,0
,0,1,1,0,1,0,1,0;0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0];

%The definition of the reaction forces in the x-dirextion
Sx=[1,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0];

%The definition of the reaction forces in the y-dirextion
Sy=[0,1,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
```

```
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,0;
    0,0,1];

% The definition of the vectors X and Y joint locations
X=[0,9,9,19.5,18,27,27,34.5,36,45,45,54];
Y=[0,8,0,5.20000000000000,-
2.80000000000000,8,0,5.20000000000000,-2.80000000000000,8,0,0];


% The definiton of the vector of applied external loads L
L=zeros(24,1);
L(19)=4.9;

%This following script is used to find matrix A
[r,cl]=size(C);
A_x=zeros(r,cl);
length=zeros(1,cl);
for j=1:cl
    p=C(:,j)';
    l=find(p==1);
    a=l(1);
    b=l(2);
    R=norm([X(a),Y(a)]-[X(b),Y(b)]);

    A_x(a,j)=(X(b)-X(a))/R;
    A_x(b,j)=(X(a)-X(b))/R;


    length(j)=R;
end

A_y=zeros(r,cl);
for j=1:cl
    p=C(:,j)';
    l=find(p==1);
    a=l(1);
    b=l(2);
    A_y(a,j)=(Y(b)-Y(a))/norm([X(a),Y(a)]-[X(b),Y(b)]);
    A_y(b,j)=(Y(a)-Y(b))/norm([X(a),Y(a)]-[X(b),Y(b)]);
end
A=[A_x,Sx;A_y,Sy];

T=A\L;
```

```
disp('EK301, Section C1, Group Bear, 4/7/2013')
disp('Cong Liu, ID 75856171')
disp('Zeming Wu, ID 61003163')
fprintf('DATE: %s\n',date)
Load=L(L~=0);
fprintf('Load: %.2f N\n',Load)

disp('Member forces in Newtons')
[r,c]=size(A);
for i=1:(c-3)
    if T(i)>0
        fprintf('m%d: %.3f (T)\n',i,T(i))
    elseif T(i)<0
        fprintf('m%d: %.3f (C)\n',i,-T(i))
    else
        fprintf('m%d: %.3f \n',i,T(i))
    end
end

disp('Reaction forces in Newtons:')
fprintf('Sx1: %.2f\nSy1: %.2f\nSy2: %.2f\n',T(end-2),T(end-
1),T(end))

totallen=sum(length);
fee=10*r/2+totallen;
fprintf('Cost of truss: $%.0f\n',fee)

%This following script is to determine the maximum load for the
entire
%truss
%ignore the members that are in tension, for easier calcutaion
of maximum load
T1=T(1:end-3);
V=T1<0;
CT=abs(T1(V));
CT=CT';
%to find maximum load for all the members that are under
compression
maxload=1215.75./(length(V).^2);
%find the ratio of the mamximum load and the experiencing force
ratiovec=maxload./CT;
%the member that has the minimum ratio is the critical member
ratio=min(ratiovec);
%since they are linear, calculate the maximum load
Newload=(L(L~=0))'*ratio;
fprintf('The theoretical maximum load is %.2f \n',Newload)
%to find the maximum load for every member
```

```
maxloadall=1215.75./(length.^2);
%to find which member is the critical member
T2 = maxloadall'./abs(T1);
%use the relation between theoretical maximum load, joint-to-
joint length, and
%actual length to find actual maximum load
Ta = (length(T2==ratio)/(length(T2==ratio)-0.6))*Newload;
fprintf('The actual failure load F_actual is %.2f \n',Ta)
fprintf('Theoretical max load/cost ratio in
N/$: %.4f\n',Newload/fee)
```

Data

From the result of Straw Test, a relationship between the buckling strength and length of the straw was found:

$$F(L) = \frac{A}{L^2} \qquad \qquad Where\ A = 1215.75\ N \cdot cm^2$$

And the uncertainty of this result is:

$$U_{F_{(L)}} = \frac{600}{L^3}\ N$$

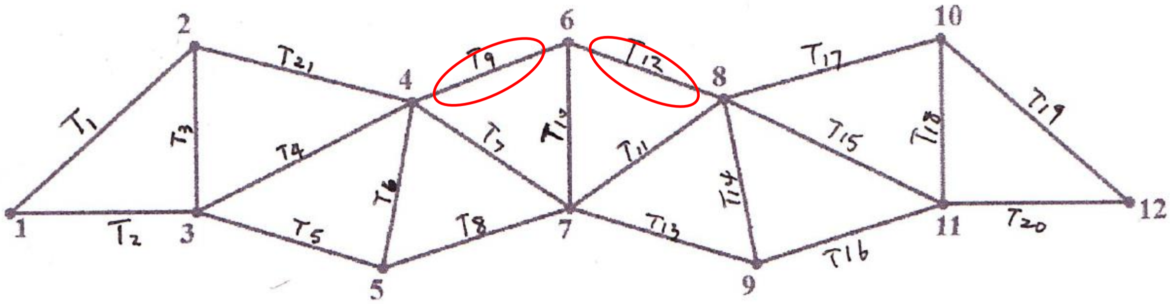
Thus, the theoretical maximum load and uncertainty of buckling strength can be calculated from the equations above. As for the uncertainty for the maximum load, the following equation can be applied:

$$\frac{test\ load}{compression} = \frac{maximum\ load}{buckling\ strength \pm uncertainty}$$

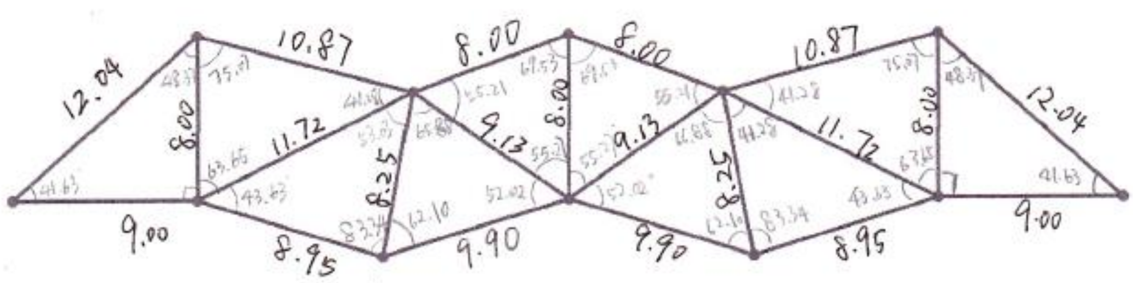
Where the test load is some random load plugged into MATLAB, so that tension or compression analysis for every member can be obtained. The difference got from this equation is the uncertainty of the maximum load.

Note: Members with red circles in the diagrams or highlighted in the chart will buckle first.

2: (9.00, 8.00)
3: (9.00, 0.00)
4: (19.50, 5.20)
5: (18.00, −2.80)
6: (27.00, 8.00)
7: (27.00, 0.00)
8: (34.50, 5.20)
9: (36.00, −2.80)
10: (45.00, 8.00)
11: (45.00, 0.00)



Design No.3



Output of MATLAB code:

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Cong Liu, ID 75856171

Zeming Wu, ID 61003163

DATE: 26-Apr-2013

Load: 4.90 N

Member forces in Newtons

m1: 3.688 (C)

m2: 2.756 (T)

m3: 3.185 (T)

m4: 3.221 (C)

m5: 5.909 (T)

m6: 3.793 (C)

m7: 2.345 (T)

m8: 6.642 (T)

m9: 8.826 (C)

m10: 6.174 (T)

m11: 2.345 (T)

m12: 8.826 (C)

m13: 6.642 (T)

m14: 3.793 (C)

m15: 3.221 (C)

m16: 5.909 (T)

m17: 2.853 (C)

m18: 3.185 (T)

m19: 3.688 (C)

m20: 2.756 (T)

m21: 2.853 (C)

Reaction forces in Newton:

Sx1: 0.00

Sy1: 2.45

Sy2: 2.45

Cost of truss: $319

The theoretical maximum load is 10.53

The actual failure load F_actual is 11.38

Theoretical max load/cost ratio in N/$: 0.0330

member #	tension or compression	theoretical length (cm)	Actual length (cm)	Theoretical buckling strength with uncertainty (N)	Actual buckling strength with uncertainty (N)	maximum load and uncertainty with theoretical length(N)	maximum load and uncertainty with actual length (N)	force of each member @ predicted actual maximum load (N)	Engineering intuition adjustment on buckling strength (N)
T1	C	12.04	11.54	8.38±0.34	9.13±0.39	11.13±0.46	12.13±0.52	9.61	9.10
T2	T	9.00	8.50	15.01±0.82	16.83±0.98	N/A	N/A	7.18	N/A
T3	T	8.00	7.50	19.00±1.17	21.61±1.42	N/A	N/A	8.30	N/A
T4	C	11.72	11.22	8.86±0.37	9.66±0.43	13.48±0.56	14.70±0.65	8.39	9.60
T5	T	9.43	8.93	13.68±0.72	15.26±0.84	N/A	N/A	15.40	N/A
T6	C	8.14	7.64	18.35±1.11	20.83±1.35	23.70±1.43	26.91±0.56	9.89	20.80
T7	T	9.13	8.63	14.60±0.79	16.34±0.93	N/A	N/A	6.11	N/A
T8	T	9.43	8.93	13.68±0.72	15.26±0.72	N/A	N/A	17.31	N/A
T9	C	8.01	7.51	18.97±1.17	21.58±1.42	10.53±0.65	12.77±0.79	23.00	21.50
T10	T	8.00	7.50	19.00±1.17	21.61±1.42	N/A	N/A	16.09	N/A
T11	T	9.13	8.63	14.60±0.79	16.34±0.93	N/A	N/A	6.11	N/A
T12	C	8.01	7.51	18.97±1.17	21.58±1.42	10.53±0.65	12.77±0.79	23.00	21.50
T13	T	9.43	8.93	13.68±0.72	15.26±0.84	N/A	N/A	17.31	N/A
T14	C	8.14	7.64	18.35±1.11	20.83±1.35	23.70±1.43	26.91±0.56	9.89	20.80
T15	C	11.72	11.22	8.86±0.37	9.66±0.43	13.48±0.56	14.70±0.65	8.39	9.60
T16	T	9.43	8.93	13.68±0.72	15.26±0.84	N/A	N/A	15.40	N/A
T17	C	10.87	10.37	10.3±0.47	11.31±0.54	17.69±0.81	20.35±0.93	7.43	11.30
T18	T	8.00	7.50	19.00±1.17	21.61±1.42	N/A	N/A	8.30	N/A
T19	C	12.04	11.54	8.38±0.34	9.13±0.39	11.13±0.46	12.13±0.52	9.61	9.10
T20	T	9.00	8.50	15.01±0.82	16.83±0.98	N/A	N/A	7.18	N/A
T21	C	10.87	10.37	10.30±0.47	11.31±0.54	17.69±0.81	20.35±0.93	7.43	11.30

*The highlighted members are predicted to buckle first.

*The value used in the last column above is 12.77N

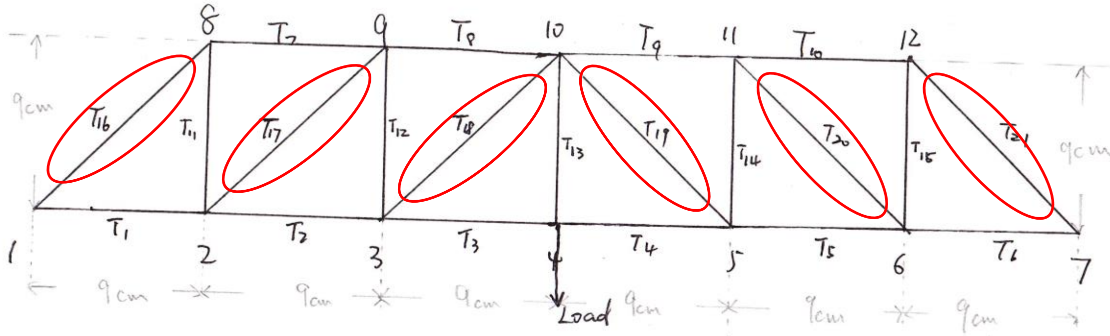
Results:

The critical member on this Design No.3 is T9 and T12. In theory, they should have length of 8.01cm, and buckling strength of 18.97 ± 1.17 N. While in prediction, the truss should actually have length of 7.51cm and buckling strength of 21.58 ± 1.42N.

Theoretically, the truss should have maximum load of 10.53 ± 0.65 N, truss cost of $319, and load-to-cost ratio of 0.0330 N/$. However, in prediction, the truss should actually have maximum load of 12.79 ± 0.79N, truss cost of, and load-to-cost ratio of 0.0388 N/$. And the adjusted maximum load could be 12.70N.

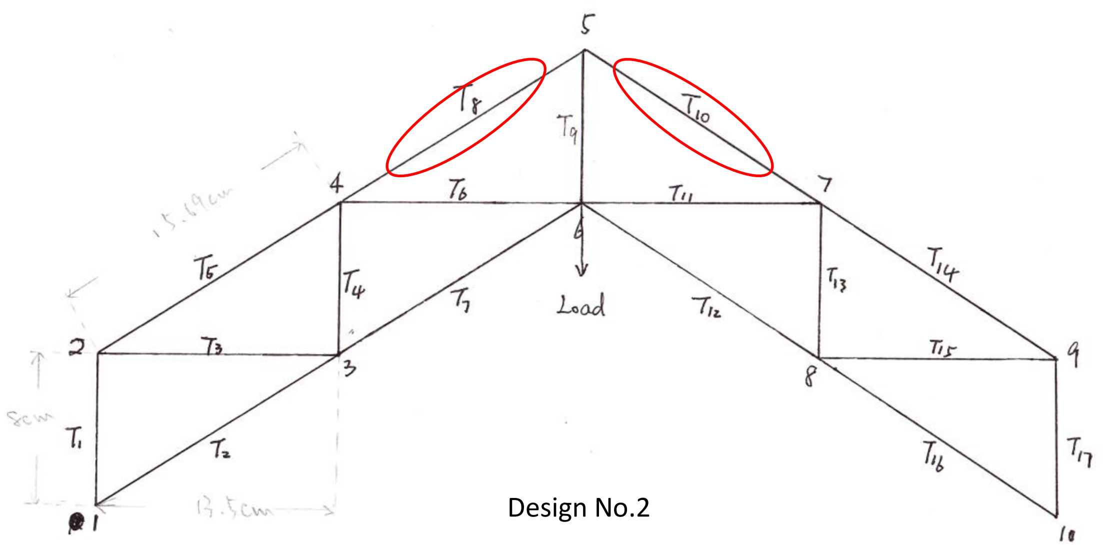
Discussion and Conclusion

From the result of Preliminary Design Report, Design No.1 works well. Thus, the decision is made to improve this truss. Since the maximum force that a straw can experience is inversely proportional to its length, which means the shorter the length is the more force that a straw can hold, reduce the length of the critical members will increase the loading ability of a truss. In addition, the load should be distributed into different members as equally as possible. Therefore, the design should have fewer right triangles as those used in preliminary design No.1 but to have triangles with shorter sides and suitable angles. As matter of a fact, the initial design consists of 5 vertical straws. However, due to the relationship between length and loading ability, the idea is to shrink the truss, especially the critical members, even more. Thus, joint 4 and 8 are shifted towards the center, making T9 and T12 shorter. By calculating the difference of movement, it is decided to let those joints shift 1.5 cm towards the center, creating optima on load-to-cost ratio and ease of building.



Design No.1

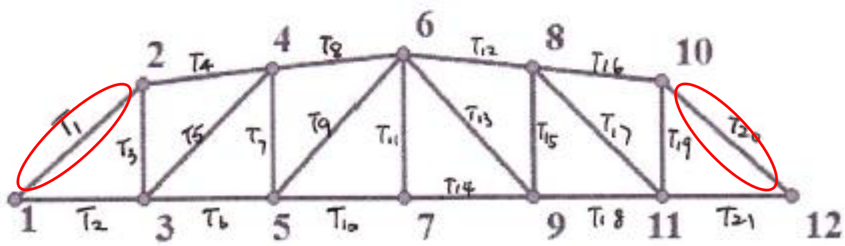
Critical members are in the red circles. Theoretical maximum load is 10.61±0.44N, and load-to-cost ratio is 0.0320N/$.



Design No.2

Critical members are in the red circles. Theoretical maximum load is 2.523±0.08N, and load-to-cost ratio is 0.0079N/$.

1: (0.00, 0.00) 8: (36.00, 9.00)
2: (9.00, 8.00) 9: (36.00, 0.00)
3: (9.00, 0.00) 10: (45.00, 8.00)
4: (18.00, 9.00) 11: (45.00, 0.00)
5: (18.00, 0.00) 12: (54.00, 0.00)
6: (27.00, 10.00)
7: (27.00, 0.00)



Design No.4

Critical members are in the red circles. Theoretical maximum load 11.41±0.45N, and load-to-cost ratio is 0.330N/$.

From Preliminary Design Report, this design works well. Thus, the decision is made to improve this truss. Since the maximum force that a straw can experience is inversely proportional to its length, which means the shorter the length is the more force that a straw can hold, reduce the length of the critical members will increase the loading ability of a truss. In addition, the load should be distributed into different members as equally as possible. Therefore, the design should have fewer right triangles as those used in preliminary design No.1 but to have triangles with shorter sides and suitable angles. As a result, see Design No.3 (page 10). When comparing Design No.1 with Design No.2 and No.3, there’s only little difference on maximum loading and even load-to-cost ratio. The main reason for Design No.3 to be the final winner is that its cost is the lowest. In addition, artistic factors shouldn't be ignored even for engineers. Since the shape of Design No.3 is quite different from others, Design No.3 becomes outstanding among all the designs.

It may require the following techniques to build the truss. First, the length of each straw should be measured as accurate as possible because the length of each straw for this truss are not all integers. Second, each trimmed member should be labeled consisting to the design to avoid mistaking any members. Third, the most important of all, the angles between each member must be accurate, which may be accomplished by drawing accurate angles lines on the connecting gusset plate and aligning the center of each straw with the lines.

As for the adjusted estimate, it is mainly concerned by the accuracy the assembly and the weights. Moreover, as said in Fundamental Canon No.1 from the Code of Ethics of Engineers, National Society of Professional Engineers, “engineers shall hold paramount the safety, health, and welfare of the public in performance of their professional duties,” it is more appropriate to round the predicted value down in order to avoid possible physical damage it will cause if the truss collapse.

Appendix

Meeting Minutes of the Hartford Roof Collapse Discussion			
Date:	4/22/2013		
Time:	6:00-6:30 PM		
Place:	Ingalls		
Participants:	Zeming Wu (recorder)	Cong Liu(chair)	
Agenda:	23-Apr - 24-Apr	25-Apr	26-Apr
	Discuss and make more possible structures for the truss. Analyze and improve the truss design through MATLAB.	Go to the tutoring room to cut the materials and start assembling	Finish assembling
Important Points:	Zeming Wu: the truss should be built as accurate as drawn, avoiding any constructing errors that may ruin the truss	Cong Liu: select the material as careful as possible, discard any straws with defects	
	Zeming Wu: calculate the uncertainty every time for every truss, getting known how stable the truss can be	Cong Liu: ideal truss design should have fair cost-to-load ratio and outstanding look	
	Zeming Wu: When considering the practical problem like the roof case in Hartford, more factors should be taken into account, like natural causes	Cong Liu: a truss should be test with more sets of load on computer before starting building	
Conclusion:	The designed truss would be test with different loads on MATLAB (Cong Liu)	Calculate the uncertainty of each designed truss (Zeming Wu)	Accurately calculate and measure the straw length and angles between each two (Zeming Wu)
Next meeting:	Decided not to have another meeting due to limited time		