University of Colorado - Boulder

ASEN 3112: Structures

ASEN 3112 Lab 3 : Plane Shaker

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Lab 3 for ASEN 3112 focuses on the analysis a replica airplane subject to harmonic vibration from a shaker table. Data is collected by both an Accelerometer, and a laser Vibrometer. Using the data recorded from theses instruments, the goal is to locate natural frequencies of the plane. A frequency sweep technique is implemented in which the frequency of the shaker table increases slowly exciting all modes of the airplane. In order to then locate the natural frequencies using the recorded data, a fast Fourier transform is implemented to convert the acceleration versus time data into an acceleration versus frequency plot. The natural frequencies of the first three modes are located at the first three peaks on the acceleration versus frequency plot. Lastly, the natural frequencies observed through experimental data will be compared to predictions created using finite-element analysis and error will be discussed and quantified. More specifically, frequencies of the first three modes will be found using a two-element and four-element model. The mode shapes provided by FEM will be compared to the experimental results.

Contents

Nomenclature

L	=	End-shaker-to-start-tail span [in]
f	=	Frequency [Hz]
E	=	Young's Modulus [psi]
ρ	=	Material's density [lb-sec$^2/in^4$]
w	=	Width [in]
L_E	=	Elevator span [in]
L_R	=	Rudder span [in]
h	=	Thickness (fuselage and wing) [in]
h_E	=	Thickness (elevator) [in]
h_R	=	Thickness (rudder) [in]
I_{zz}	=	Moment of Inertia [in^4]

I. Experimental Results

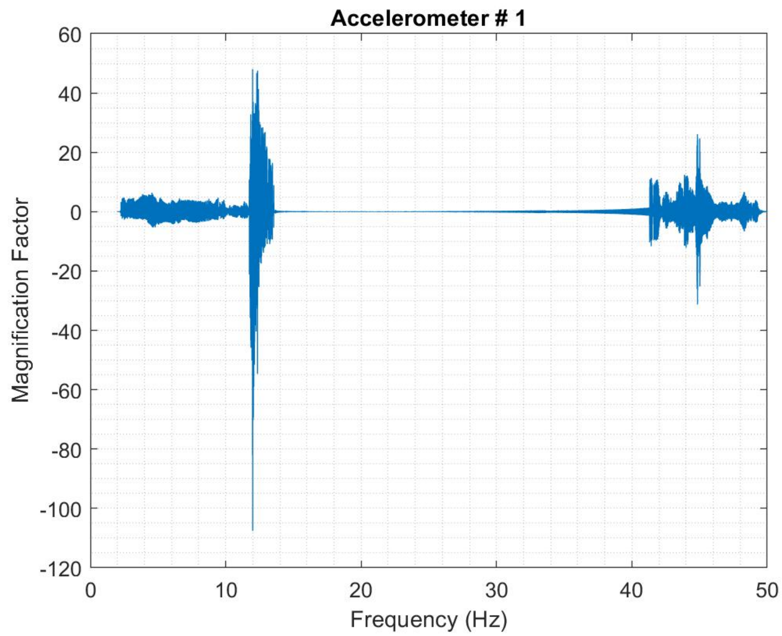

Fig. 1 Magnification Factor for Accelerometer # 1

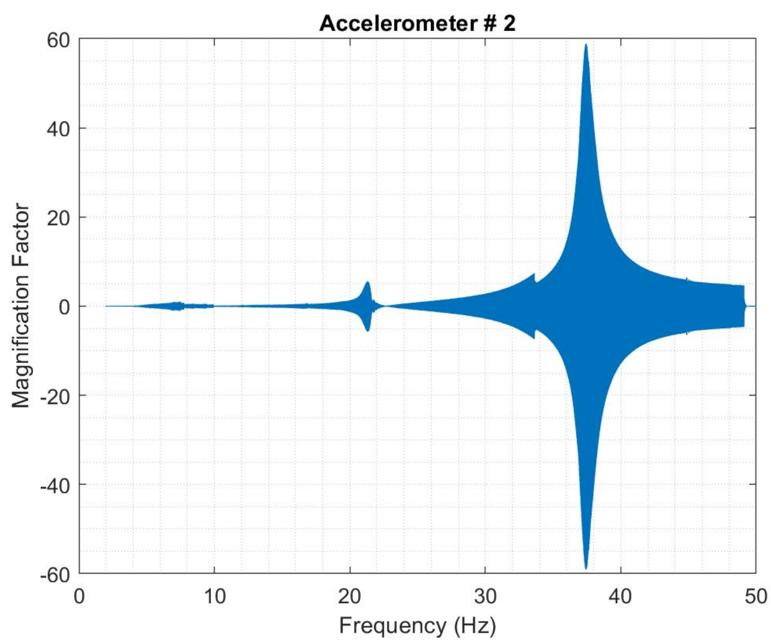

Fig. 2 Magnification Factor for Accelerometer # 2

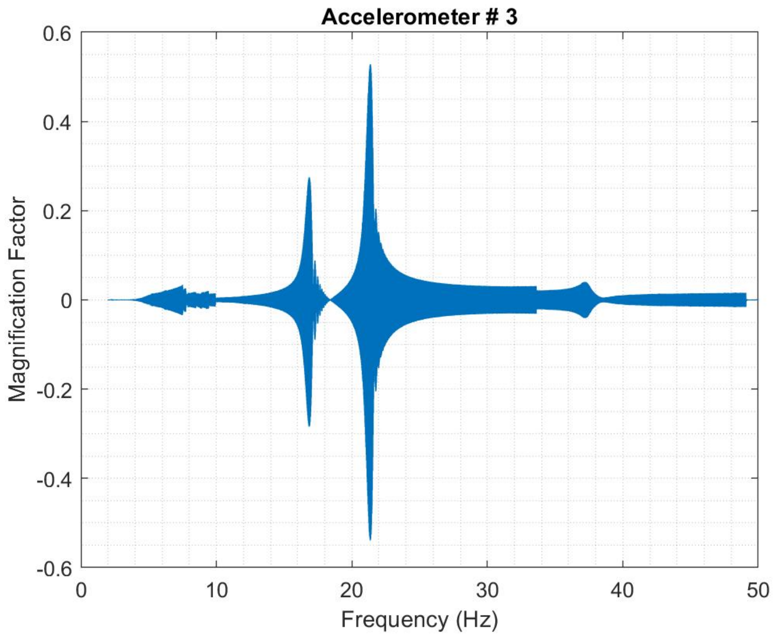

Fig. 3 Magnification Factor for Accelerometer # 3

The raw data for displacement was not used in analysis since there was an unusual growth with time. Therefore, the acceleration data was used instead and the raw data was converted to magnification factor. To facilitate this, first, we find the maximum value of acceleration at the center, channel 0, and then for each accelerometer. The acceleration was scaled by the maximum acceleration. Meaning, the acceleration for each accelerometer (tail, nose, and wingtip) is divided by that maximum acceleration.

From figure (1)-(3), the resonant frequencies are approximately: 12 Hz, 17.5 Hz, 21.8 Hz, 37.8 Hz, and 45 Hz. These values are obtained from where the peaks occur. Note that the scale for figure (3) is different than the ones for figure (1) and (2).

Accelerometers 1,2 and 3 are located on the tail, nose and wingtip respectively. The first mode, 12 Hz, is dominated by tail vibration as you can see in figure (1). The second mode, 17.5 Hz, is dominated by nose vibration from figure (2) and figure (3) seems like it is dominated by the wingtip but the scale for wingtip accelerometer is much lower than nose accelerometer. The third mode, 21.8 Hz, is characterized by the high nose shake and some wingtip shake. The fourth mode, 37.8 Hz, is dominated by, again, nose vibration. Lastly, the fifth mode, 45 Hz, is another tail vibration dominant.

II. FEM Results - Resonant Frequencies

To simulate vibrations on the aft-fuselage span of the model airplane, the lab team began with a simple two element model consisting of two Bernoulli-Euler plane beam elements with six total degrees of freedom. Then, for a more precise simulation, a four element four element model was considered in a similar fashion, with the resulting positional vector containing 10 degrees of freedom. The eigenvalue problem used to solve for frequencies was given in the following form.

$$\hat{K}U = \omega^2 \hat{M}U \tag{1}$$

In this eigenvalue problem, $\hat{K}$, and $\hat{M}$ represent the reduced stiffness and mass matrices respectively and U represents the position vector. The reduced mass and stiffness matrices are 4x4 in the two element method and 8x8 in the four element method after applying the boundary conditions, since it was assumed that the displacement and slope of the first node located at the shaker were zero. The following equation solves the eigenvalue problem for the squared frequencies in $(\frac{rad}{s})^2$ since we assume non trivial solutions ($\omega^2 \neq 0$).

$$det(\hat{K} - \omega^2 \hat{M}) = 0 \tag{2}$$

The following tables contain results from FEM simulations for two and four element method, where the lowest three frequencies are observed. Equation 3 was used to convert from $\frac{rad}{s}$ to Hz. Here, the lowest two resonant frequencies correspond to modes two and five from the experimental data. The third resonant frequency in the table below is simply an additional predicted frequency for completeness.

$$f_i = \frac{\omega}{2\pi} \tag{3}$$

Table 1 FEM Frequencies

	$\omega(rad/s)$	2 Element (Hz)	4 Element (Hz)
1st Frequency	75.6	12.0	12.0
2nd Frequency	320.6	51.0	51.1
3rd Frequency	1272.4	202.5	203.4

Table 2 Frequency Errors

	2 Element FEM	4 Element FEM
2nd Mode Experimental	45.8%	45.8%
5th Mode Experimental	11.7%	11.9%

The percent differences in Table 2 are comparing only the first two frequencies from the FEM simulation to the second and fifth frequencies of the experimental data, which 2nd mode and 5th mode are identified as "Horizontal tail vertical + T section sideway and horizontal tail vertical second mode vibrations, respectively". Table 2 shows that at lower resonant frequency, the error is larger than at larger resonant frequency. These errors could be due to the fact that the simulations assume that motion of the plane is strictly 2 dimensional and cuts out motion about the nose of the plane and any roll that the entire plane experiences.

III. FEM Results - Mode Shapes

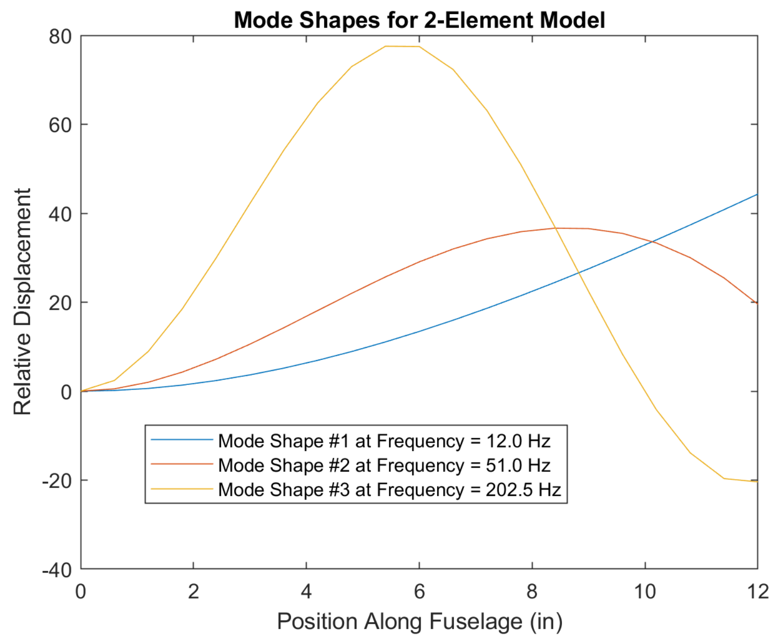

Fig. 4 Mode Shape for 2 Element System

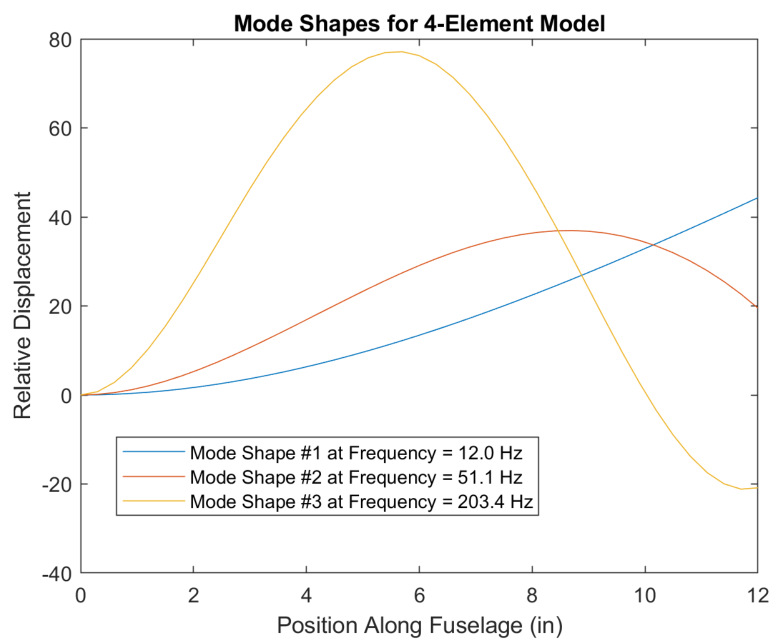

Fig. 5 Mode Shape for 4 Element System

In order to compare the experimental results to the corresponding mode shapes generated with the FEM results a Matlab script was written. This script identifies the index where the frequency of the first mode occurs for the nose, center and tail channels. With these indices, the corresponding y-positions provide a snapshot in time. Using the polyfit function in Matlab and these three points, and estimation of the distribution of displacement across the entire length of the fuselage is created. This is then superimposed on the 4 element FEM which has been normalized so that it can be compared to Mode shape 1. It is clear in figure 6, that even with a crude estimation of the mode shape from the data that a similar shape is achieved by the FEM modal analysis. A similar process could be done to find compare against mode shape 2 and 3 by simply finding the time stamp associated with those frequencies.

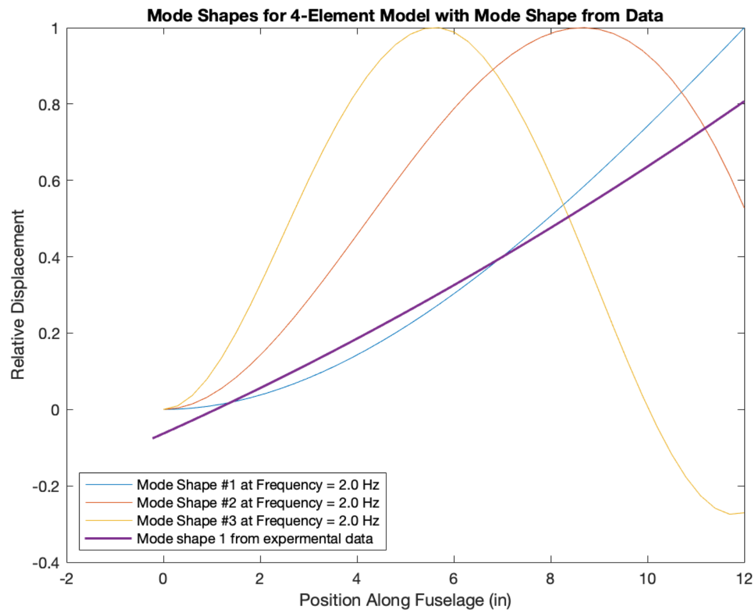

Fig. 6 First Mode shape from Experimental Data

IV. Conclusion

In this lab, an exploration into the mechanics of vibration by analyzing the frequency resonances of a model airplane undergoing harmonic base excitation from a shaker table. These resonant frequencies were identified through a frequency sweep, which the frequency of the shaker table is increased slowly to identify natural frequencies of the plane. Data from the frequency sweep was collected from an accelerometers and a laser vibrometer. However, another method to identify resonant frequencies was FEM. Utilizing MATLAB, the resonant frequencies and mode shapes were determined and compared to the frequency sweep data.

The experimental results clearly identified the resonant frequencies from conducting FFT on the data, which shows the magnification factor for varying frequencies. From the accelerometer data, there are approximately 5 resonant frequencies.

Analysis utilizing FEM depended on two different models: a two-element model and a four-element model. Each model represented the aft-fuselage as a number of Bernoulli-Euler plane beam elements with varying degrees of freedom. Solving the eigenvalue problem set up from these models yielded interesting values for the 2nd and 5th modes. Compared to the experimental values, the 2nd mode differed greatly with an error of 45.8% and the 5th mode having an error of about 11.8%. Curiously, the 4 Element FEM has a greater error compared to the 2 Element. This could be due to the assumption that the motion is in two dimensions, which eliminates motion about the nose and any roll the plane experiences.

Acknowledgements

The team would like to thank Dr. Mahmoud Hussein for helping them understand the material directly pertaining to this lab. The team would also like the Teaching Assistants to help them clear all questions and doubts one had during the analysis.

V. Appendix

A. Participation Report

Team Member	Experiment	FEM Modeling	2.1	2.2	2.3	Report	Total Score
Matt Bridges:	1	1	2	1	1	1	100
Ricky Carlson:	1	1	1	1	2	1	100
Aidan Sesnic:	2	1	1	1	1	1	100
Kunal Sinha:	1	1	1	1	1	2	100
Chris Nylund:	1	2	1	1	1	1	100
Panitnan Yuvanondha:	1	1	1	2	1	1	100
John Hugo:	1	1	1	1	1	2	100
Marin Grgas:	1	1	1	1	1	1	100

Table 3 Participation table is scored as follows: 2 - Led Section, 1 - Worked On, 0 - Not Responsible For. Total Score is a numerical reflection of team members' contributions out of 100.

B. Matlab Code

Listing 1 4 FEM code

```
% Housekeeping
clc;clear;close all;

% 4 FEM code

%% Constants
L=12; %Cantilever span (in)
LE=4.5; %Elevator span (in)
LR=5; %Rudder span (in)
w=1;
h=1/8;
he=1/4;
hr=0.04;
E=10175000;
p=0.0002505;
Mt=p*1.131;
St=0.5655*p;
It=23.124*p;
A=w*h;
Izz=w*h^3/12;
cm4=p*A*L/806400;
ck4=8*E*Izz/L^3;

K4r=[0 12*L -96 12*L 0 0 0 0 0 0; 0 0 -12*L L^2 0 0 0 0 0 0; 0 0 0 0 -96 12*L 0 0 0 0; 0 0 ...
    0 0 -12*L L^2 0 0 0 0; 0 0 0 0 0 0 -96 12*L 0 0; 0 0 0 0 0 0 -12*L L^2 0 0; 0 0 0 0 0 ...
    0 0 0 -96 12*L; 0 0 0 0 0 0 0 0 -12*L L^2; 0 0 0 0 0 0 0 0 0 -12*L; 0 0 0 0 0 0 0 0 0 0];
K4l=K4r';
K4diag=diag([96;2*L^2;192;4*L^2;192;4*L^2;192;4*L^2;96;2*L^2]);
K4=K4r+K4l+K4diag;
K4=K4*ck4;

M4=zeros(10);
M4(1,2:4)=[2916*L, 23712, -1284*L];
M4(2,3:4)=[1284*L -73*L^2];
M4(3,5:6)=[23712 -1284*L];
M4(4,5:6)=[1284*L -73*L^2];
M4(5,7:8)=[23712 -1284*L];
```

```
M4(6,7:8)=[1284*L -73*L^2];
M4(7,9:10)=[23712 -1284*L];
M4(8,9:10)=[1284*L -73*L^2];
M4(9,10)=-2916*L;
M4=M4+M4'+diag([77088; 172*L^2; 154176; 344*L^2; 154176; 344*L^2; 154176; 344*L^2; 77088; ...
    172*L^2]);
Mtemp=zeros(10);
Mtemp(9,9)=Mt;
Mtemp(9,10)=St;
Mtemp(10,9)=St;
Mtemp(10,10)=It;
M4=cm4*M4+Mtemp;

K4hat=K4(3:10,3:10);
M4hat=M4(3:10,3:10);

[ev_red, eval]=eig(K4hat,M4hat);
omega=real(sqrt(diag(eval)));
freq=1/(2*pi)*omega(1:3);
ev=0*K4;
ev(3:end,3:end)=ev_red;

nsub=10;
scale=1.0;
nel=4;
nv=nel*nsub+1;
Le=L/nel;
dx=Le/nsub;

for t=3:5 %size(ev,2)

    k=0;
    x=zeros(nv,1);
    v=zeros(nv,1);

    for e=1:nel

        xxi=Le*(e-1);
        vi=ev(2*e-1,t);
        teti=ev(2*e,t);
        vj=ev(2*e+1,t);
        tetj=ev(2*e+2,t);

        if (e==1); ni=0;else; ni=1;end

        for n=ni:nsub

            xk=xxi+dx*n;
            xi=(2*n-nsub)/nsub;
            vk=scale*(0.125*(4*(vi+vj)+2*(vi-vj)*(xi^2-3)*xi+Le*(xi^2-1)*(tetj-teti+(teti+tetj)*xi)));

            k=k+1;
            x(k)=xk;
            v(k)=vk;
        end
    end
    title('Mode Shapes for 4-Element Model');
    xlabel('Time (seconds)');
    ylabel('Displacement (inches)');
    plot(x,-v); hold on;
    str1=sprintf('Mode Shape #1 is %.1f rad/s at Frequency = %.1f Hz',omega(1),freq(1));
    str2=sprintf('Mode Shape #2 is %.1f rad/s at Frequency = %.1f Hz',omega(2),freq(2));
    str3=sprintf('Mode Shape #3 is %.1f rad/s at Frequency = %.1f Hz',omega(3),freq(3));
    legend(str1,str2,str3,'Location','SouthWest');
    grid minor
end
```

Listing 2 2 FEM code

```
% Housekeeping
clc;clear;close all;
% 2 FEM code

%% Constants
L=12; %Cantilever span (in)
LE=4.5; %Elevator span (in)
LR=5; %Rudder span (in)
w=1;
h=1/8;
he=1/4;
hr=0.04;
E=10175000;
p=0.0002505;
Mt=p*1.131;
St=0.5655*p;
It=23.124*p;
A=w*h;
Izz=w*h^3/12;
cm2=p*A*L/100800;
ck2=4*E*Izz/L^3;

M2=zeros(6);
M2(1,:)=[19272 1458*L 5928 -642*L 0 0];
M2(2,:)=[1458*L 172*L^2 642*L -73*L^2 0 0];
M2(3,:)=[5928 642*L 38544 0 5928 -642*L];
M2(4,:)=[-642*L -73*L^2 0 344*L^2 642*L -73*L^2];
M2(5,:)=[0 0 5928 642*L 19272 -1458*L];
M2(6,:)=[0 0 -642*L -73*L^2 -1458*L 172*L^2];
Mtemp=zeros(6);
Mtemp(5,5)=Mt;
Mtemp(5,6)=St;
Mtemp(6,5)=St;
Mtemp(6,6)=It;
M2=cm2*M2+Mtemp;
K2=[0 6*L -24 6*L 0 0; 0 0 -6*L L^2 0 0; 0 0 0 0 -24 6*L; 0 0 0 0 -6*L L^2; 0 0 0 0 0 ...
    -6*L; 0 0 0 0 0 0];
K2=K2+K2';
K2=K2+diag([24;2*L^2;48;4*L^2;24;2*L^2]);
K2=ck2*K2;
M2hat=M2(3:6,3:6);
K2hat=K2(3:6,3:6);
[ev_red, eval]=eig(K2hat,M2hat);
omega=real(sqrt(diag(eval)));
freq=1/(2*pi)*omega(1:3);
ev=0*K2;
ev(3:end,3:end)=ev_red;

nsub=10;
scale=1.0;
nel=2;
nv=nel*nsub+1;
Le=L/nel;
dx=Le/nsub;

for t=3:5 %size(ev,2)

    k=0;
    x=zeros(nv,1);
    v=zeros(nv,1);

    for e=1:nel

        xxi=Le*(e-1);
        vi=ev(2*e-1,t);
        teti=ev(2*e,t);
```

```
        vj=ev(2*e+1,t);
        tetj=ev(2*e+2,t);

        if (e==1); ni=0;else; ni=1;end

        for n=ni:nsub

            xk=xxi+dx*n;
            xi=(2*n-nsub)/nsub;
            vk=scale*(0.125*(4*(vi+vj)+2*(vi-vj)*(xi^2-3)*xi+Le*(xi^2-1)*(tetj-teti+(teti+tetj)*xi)));

            k=k+1;
            x(k)=xk;
            v(k)=vk;
        end
    end

    title('Mode Shapes for 2-Element Model');
    xlabel('Time (seconds)');
    ylabel('Displacement (inches)'); hold on;
    plot(x,v);
    str1=sprintf('Mode Shape #1 is %.1f rad/s at Frequency = %.1f Hz',omega(1),freq(1));
    str2=sprintf('Mode Shape #2 is %.1f rad/s at Frequency = %.1f Hz',omega(2),freq(2));
    str3=sprintf('Mode Shape #3 is %.1f rad/s at Frequency = %.1f Hz',omega(3),freq(3));
    legend(str1,str2,str3,'Location','SouthWest');
    grid minor

end
```

Listing 3 Experimental Modal Analysis Code

```
clear; clc; close all;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% ASEN 3112 Lab 3 Experimental Mode Shape analysis
%
%Authors: Ricky Carlson
%
%Date Created: 04/20/20
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
expData = load('expData.mat');
rawData = expData.rawData;


L=12; %Cantilever span (in)
LE=4.5; %Elevator span (in)
LR=5; %Rudder span (in)
w=1;
h=1/8;
he=1/4;
hr=0.04;
E=10175000;
p=0.0002505;
Mt=p*1.131;
St=0.5655*p;
It=23.124*p;
A=w*h;
Izz=w*h^3/12;
cm4=p*A*L/806400;
ck4=8*E*Izz/L^3;

K4r=[0 12*L -96 12*L 0 0 0 0 0 0; 0 0 -12*L L^2 0 0 0 0 0 0; 0 0 0 0 -96 12*L 0 0 0 0; 0 0 ...
    0 0 -12*L L^2 0 0 0 0; 0 0 0 0 0 0 -96 12*L 0 0; 0 0 0 0 0 0 -12*L L^2 0 0; 0 0 0 0 0 ...
    0 0 0 -96 12*L; 0 0 0 0 0 0 0 0 -12*L L^2; 0 0 0 0 0 0 0 0 0 -12*L; 0 0 0 0 0 0 0 0 0 0];
K4l=K4r';
K4diag=diag([96;2*L^2;192;4*L^2;192;4*L^2;192;4*L^2;96;2*L^2]);
K4=K4r+K4l+K4diag;
```

```
K4=K4*ck4;

M4=zeros(10);
M4(1,2:4)=[2916*L, 23712, -1284*L];
M4(2,3:4)=[1284*L -73*L^2];
M4(3,5:6)=[23712 -1284*L];
M4(4,5:6)=[1284*L -73*L^2];
M4(5,7:8)=[23712 -1284*L];
M4(6,7:8)=[1284*L -73*L^2];
M4(7,9:10)=[23712 -1284*L];
M4(8,9:10)=[1284*L -73*L^2];
M4(9,10)=-2916*L;
M4=M4+M4'+diag([77088; 172*L^2; 154176; 344*L^2; 154176; 344*L^2; 154176; 344*L^2; 77088; ...
    172*L^2]);
Mtemp=zeros(10);
Mtemp(9,9)=Mt;
Mtemp(9,10)=St;
Mtemp(10,9)=St;
Mtemp(10,10)=It;
M4=cm4*M4+Mtemp;

K4hat=K4(3:10,3:10);
M4hat=M4(3:10,3:10);

[ev_red, eval]=eig(K4hat,M4hat);
omega=real(sqrt(diag(eval)));
freq=1/(2*pi)*omega(1:3);
ev=0*K4;
ev(3:end,3:end)=ev_red;

nsub=10;
scale=1.0;
nel=4;
nv=nel*nsub+1;
Le=L/nel;
dx=Le/nsub;

for t=3:5 %size(ev,2)

    k=0;
    x=zeros(nv,1);
    v=zeros(nv,1);

    for e=1:nel

        xxi=Le*(e-1);
        vi=ev(2*e-1,t);
        teti=ev(2*e,t);
        vj=ev(2*e+1,t);
        tetj=ev(2*e+2,t);

        if (e==1); ni=0;else; ni=1;end

        for n=ni:nsub

            xk=xxi+dx*n;
            xi=(2*n-nsub)/nsub;
            vk=scale*(0.125*(4*(vi+vj)+2*(vi-vj)*(xi^2-3)*xi+Le*(xi^2-1)*(tetj-teti+(teti+tetj)*xi)));

            k=k+1;
            x(k)=xk;
            v(k)=vk;
        end
    end
    title('Mode Shapes for 4-Element Model with Mode Shape from Data');
    xlabel('Position Along Fuselage (in)');
    ylabel('Relative Displacement');
    plot(x,-v/max(abs(v))); hold on;
```

```
end


%%
%Extract data for each parameter
t = rawData(:, 1); %Time
a_center = rawData(:, 2); %Center acceleration
a_tail_raw = rawData(:, 3); %Tail acceleration
a_nose_raw = rawData(:, 4); %Nose acceleration
a_wingtip_raw = rawData(:, 5); %Wingtip acceleration
u_tail_raw = rawData(:, 7); %Tail displacement, mm
u_nose_raw = rawData(:, 8); %Nose displacement, mm
u_wingtip_raw = rawData(:, 9); %Wingtip displacement, mm
u_vib_raw = rawData(:, 10); %Virbometer displacement, mm

% Normalize accelerations
a_tail = a_tail_raw ./ a_center;
a_nose = a_tail_raw ./ a_center;

a_wingtip = a_wingtip_raw ./ a_center;
    freq = linspace(2,50,length(t));
    freq = freq';



%%
index_freq_tail_mode1 = find(a_tail_raw == max(a_tail_raw));
index_freq_nose_mode1 = find(a_nose_raw == max(a_nose_raw));


t_1 = rawData(:, 1) - rawData(1, 1); %Time
u_tail_mode = rawData(:, 7)*0.0393701; %Tail displacement, in
u_center_mode = rawData(:, 6)*0.0393701; %Center displacement, in
u_nose_mode = rawData(:, 8)*0.0393701; %Nose displacement, in

u_tail = detrend(u_tail_mode);
y_pos_tail_mode1 = u_tail(index_freq_tail_mode1);

u_nose = detrend(u_nose_mode);
y_pos_nose_mode1 = u_nose(index_freq_nose_mode1);

a_center_1 = detrend(a_center);


index_freq_center_mode1 = find(a_center_1 == max(a_center_1));

u_center = detrend(u_center_mode);

y_pos_center_mode1 = u_center(index_freq_center_mode1);

y_plot_mode1 = [y_pos_nose_mode1,y_pos_center_mode1,y_pos_tail_mode1];

x_plot_mode1 = [0,11,22];

p = polyfit(x_plot_mode1,y_plot_mode1,2);

x_mode1 = linspace(0,22,100);
y_mode1 = zeros(1,100);

for i = 1:100


    y_mode1 = +p(1)*(x_mode1.^2) + p(2)*x_mode1 + p(3);

end

plot(x_mode1(45:100)-10,y_mode1(45:100),'LineWidth',1.5);
```

```
str1=sprintf('Mode Shape #1 at Frequency = %.1f Hz',freq(1));
    str2=sprintf('Mode Shape #2 at Frequency = %.1f Hz',freq(2));
    str3=sprintf('Mode Shape #3 at Frequency = %.1f Hz',freq(3));
    str4=sprintf('Mode shape 1 from expermental data');
    legend(str1,str2,str3,str4,'Location','SouthWest');
```

Listing 4   Experimental Results code

```
 close all;clear all; clc

    % Load .mat file of data
expData = load('expData.mat');
rawData = expData.rawData;

%Extract data for each parameter
t = rawData(:, 1); %Time
a_center = rawData(:, 2); %Center acceleration
a_tail_raw = rawData(:, 3); %Tail acceleration
a_nose_raw = rawData(:, 4); %Nose acceleration
a_wingtip_raw = rawData(:, 5); %Wingtip acceleration
u_center = rawData(:, 6); %Center displacement, mm
u_tail_raw = rawData(:, 7); %Tail displacement, mm
u_nose_raw = rawData(:, 8); %Nose displacement, mm
u_wingtip_raw = rawData(:, 9); %Wingtip displacement, mm
u_vib_raw = rawData(:, 10); %Virbometer displacement, mm

% Normalize accelerations
a_tail = a_tail_raw ./ a_center;
a_nose = a_tail_raw ./ a_center;
a_wingtip = a_wingtip_raw ./ a_center;
    freq = linspace(2,50,length(t));
    freq = freq';

    % Remove secular drift from center displacement data
coeff_ctr = polyfit(t, u_center, 1); %Find line representing secular drift
u_0 = coeff_ctr(1).*t + coeff_ctr(2); %Find vector of the point about which the center is ...
    oscillating
u_center_norm = u_center - u_0;

% Normalize vibromter data
u_vib = u_vib_raw ./ u_center_norm;

    figure(1)
    plot(freq,u_center_norm)
    grid minor



    %% Magnification factor
    maxi= max(a_center);

    % Accelerometer 1 (tail)
    figure
    plot(freq,a_tail_raw./maxi)
    xlabel('Frequency (Hz)')
    ylabel('Magnification Factor')
    title('Accelerometer # 1')
    grid minor

    % Accelerometer 2 (nose)
    figure
    plot(freq,a_nose_raw./maxi)
     xlabel('Frequency (Hz)')
    ylabel('Magnification Factor')
    title('Accelerometer # 2')
```

```
    grid minor

    % Accelerometer 3 (Wingtip)
    figure
    plot(freq,a_wingtip_raw./maxi)
     xlabel('Frequency (Hz)')
    ylabel('Magnification Factor')
    title('Accelerometer # 3')
    grid minor

    % Combine all into one graph
    figure
    hold on
    plot(freq,a_tail_raw./maxi)
    plot(freq,a_nose_raw./maxi)
    plot(freq,a_wingtip_raw./maxi)
     xlabel('Frequency (Hz)')
    ylabel('Acceleration Factor')
    title('All 3 Accelerometers')
    grid minor
```

References

[1] Hussein, Mahmoud "ASEN 3112 Lab 3" published on Apr. 2, 2020, pp.1-11.