Bauhaus-Universität Weimar

Experimental Structural Dynamics

Modal Analysis of an AluminiumPlate System
with Free-Free boundary conditions

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Introduction

I. Modal analysis is a method for understanding the vibration characteristics of structures . Modal Analysis extracts and process information such as natural frequency, damping and mode shapes from force-response measurement data.

II. There are several techniques that have been developed for determining modal characteristics of a structure experimentally . The most commonly used methods are :

   a) Experimental Modal Analysis(EMA)

   b) Operational Modal Analysis(OMA)

III. Experimental Modal Analysis(EMA) applies methods where both input and output signals are used to derive modal parameters.

IV. Operational Modal Analysis(OMA) often described as output-only modal analysis uses algorithms where only output signals are used to derive modal parameters.

Project Outline

I. Project Objective
II. Numerical Modal Analysis using ANSYS
III. Experimental Test
   a) Grid Development
   b) Setups
   c) Test details
- Modal Analysis using MACEC (A MATLAB toolbox for experimental
- And operational modal analysis)
I. Results
   a) Frequency and Damping
   b) Visual Comparison of the mode shapes
   c) Modal Assurance Criterion (MAC)
II. Conclusion

Project Objective

➢Objectives:

a) Perform Operational Modal Analysis (OMA) to determine the dynamic properties of the plate

b) Comparison with the analytical model.

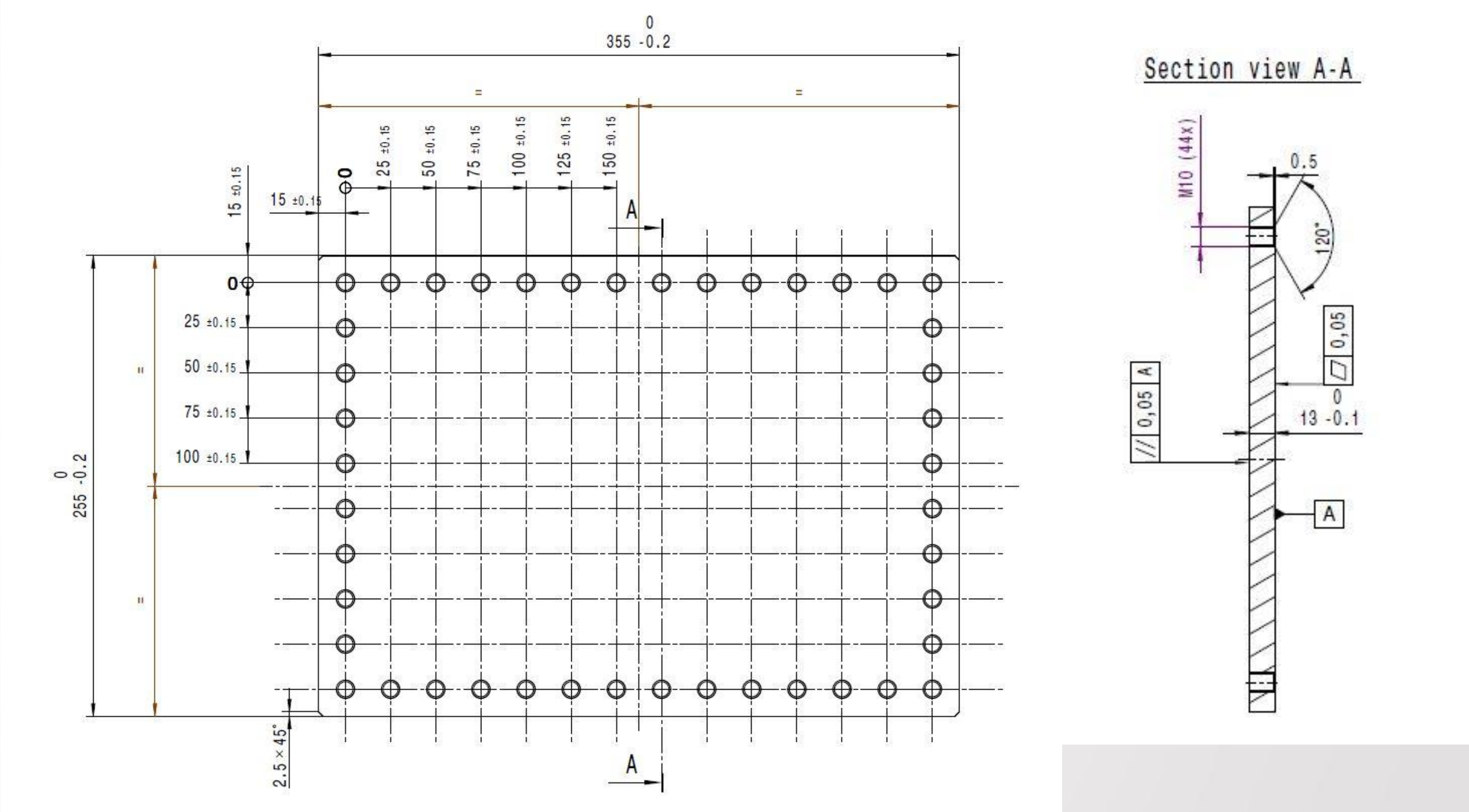


Fig. 1 Cross sectional properties of the Test Specimen

Modal Analysis (ANSYS)

- Boundary Condition: Free-Free
- Material Properties :

a) Aluminum

b) Density:2.66g/cm^3

c) Elastic Modulus: 71GPa

- Mesh Size = 10mm*

**Metall Service Menziken AG*

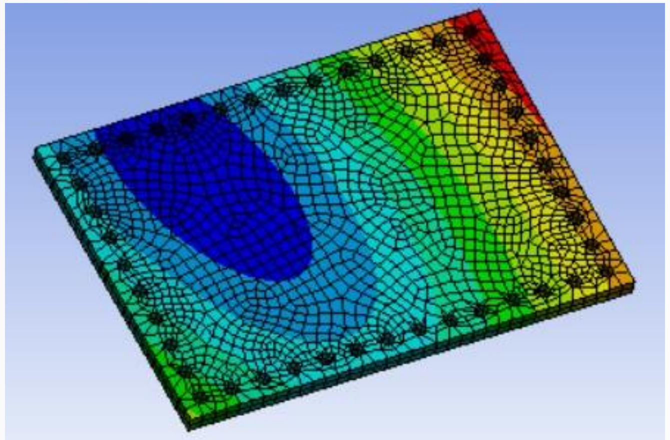


Fig 2. Rigid Body Mode (1) at 0 Hz

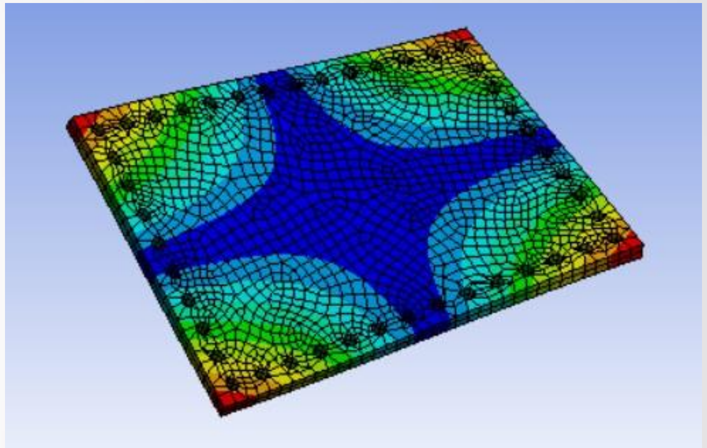


Fig 3. Flexible Body Mode (7) at 468.94 Hz

Rigid Body Modes → *Characterized by low frequency and are of no relevance to our study*

Flexible Modes

Mode	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Freq(Hz)	0	0	0	0.002	0.003	0.004	468.94	548.24	1081.8	1116.2	1351.7	1602	2013.3	2208.7

Table 1. Observed frequencies for the numerical model

Experimental Test-1 Setup 1

- Grid Details:
- Marking : Top
- No of grid lines in x : 21
- No of grid lines in y : 15
- Nodes : 315
- Setups = 5
- Reference Sensors(R) : 2
- (DOF in one direction only i.e. Z-axis.)
- Excitation Source =Hammer
- Sampling Rate (f_s) = 10kHz

Fig 4. Grid Marking

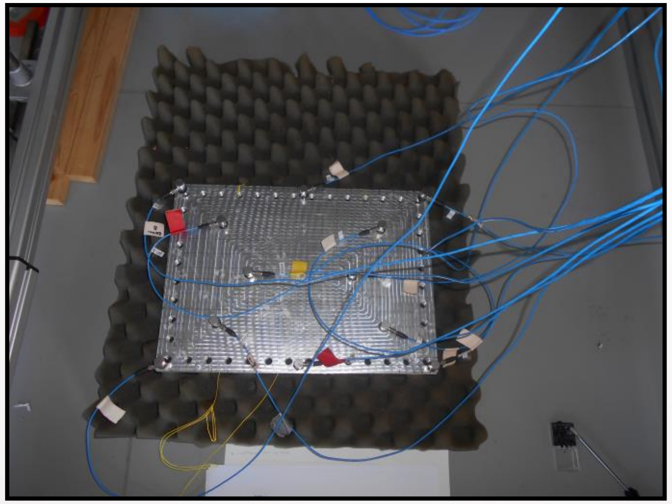
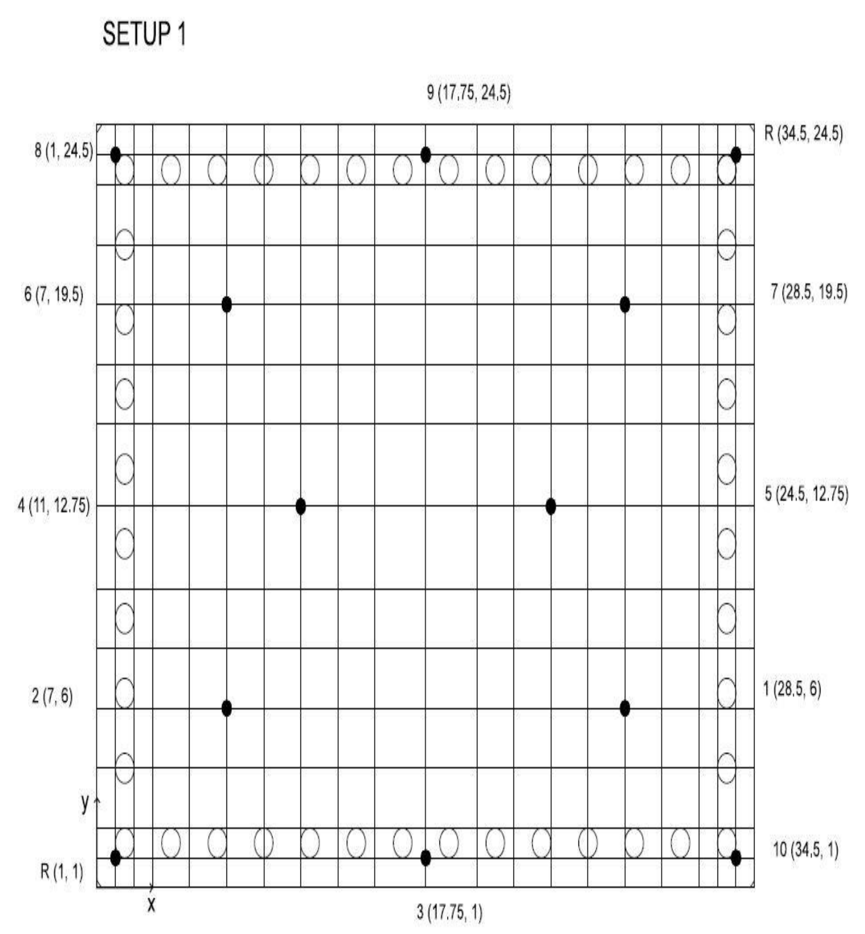


Fig 5. Sensor Placement for Setup 1



Experimental Test-2 Setup

- Grid Details:
  - Marking : Top
  - No of grid lines in x : 21
  - No of grid lines in y : 15
  - Nodes : 315
  - Setups = 5

- Reference Sensors(R) : 2
- (DOF in one direction only i.e. Z-axis.)
- Excitation Source =Loudspeaker
- Sampling Rate (f_s) 10kHz

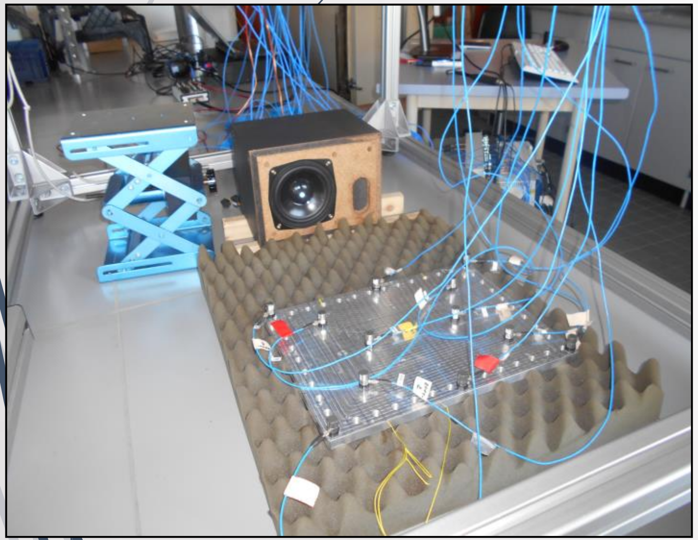


Fig 6. Sensor Placement for Setup 1

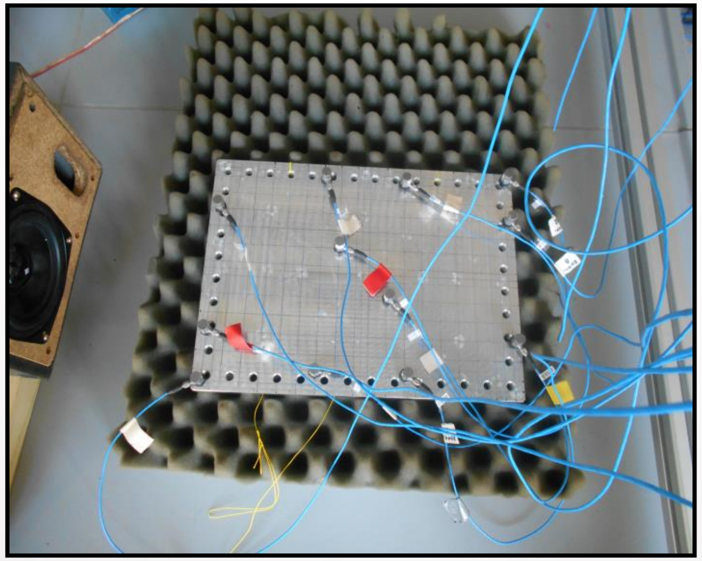
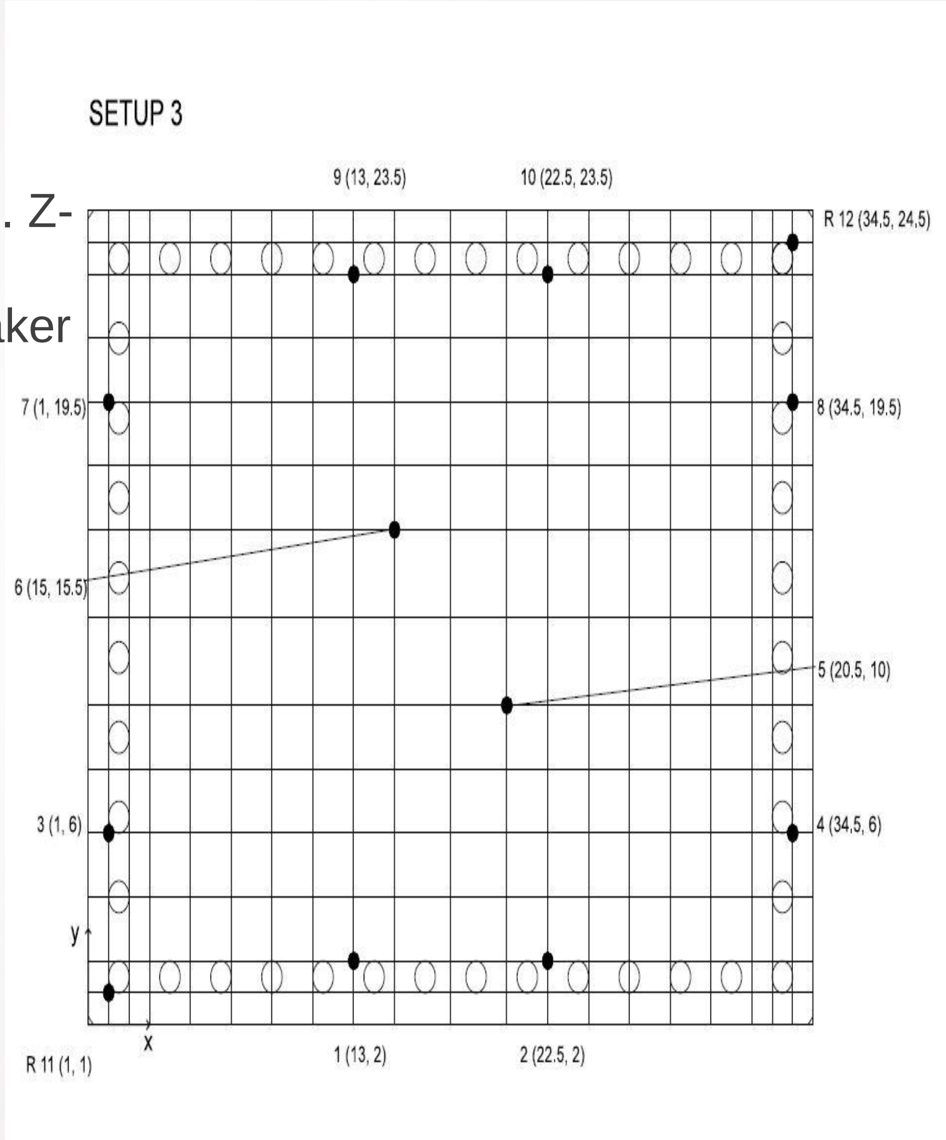


Fig 7. Sensor Placement for Setup 3



Modal Analysis using (MACEC)

- Nodal Representation in MACEC : Surface
- Sampling Frequency : 10kHz
- Signal Processing:
  a. Offset Removal
  b. Removal of the force channel
  c. Decimating the frequency range by 2

  Measured DOF's : Positive and Negative "Z"
- Criteria for choosing points on Stabilization Diagram:
  a) Stable Modes Only
  b) Modal Phase Collinearity (MPC) close to 1.
  c) Experiment Source 1: Both Frequency, damping and MPC were considered.
  d) Experiment Source 2: Frequency and damping was considered.

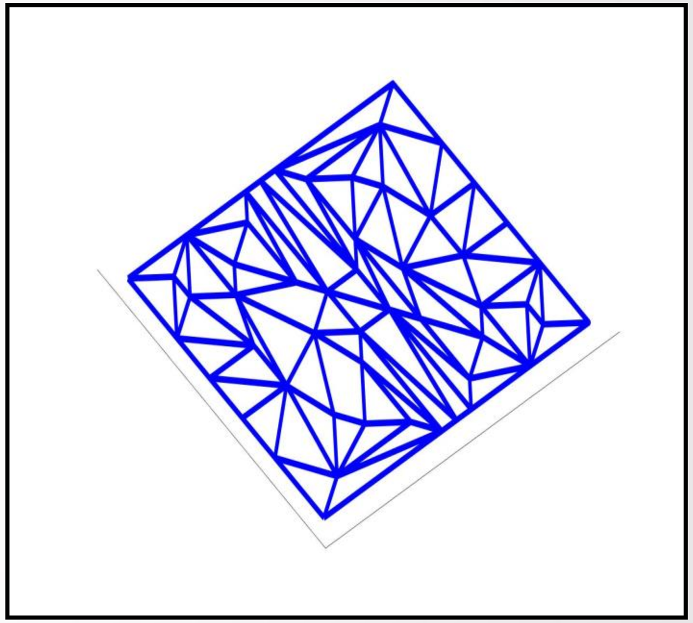


Fig 8. Surface Nodes Mesh

Comparison of Observed Dynamic Properties

Mode	Ansys	Hammer	Difference %	Loudspeaker	Difference %
1	468.94	447.66189	4.54%	447.99154	4.47%
2	548.24	531.06626	3.13%	530.499	3.24%
3	1081.8	1025.4782	5.21%	1026.4734	5.11%
4	1116.2	1075.4417	3.65%	1083.651	2.92%
5	1351.7	1306.4785	3.35%	1306.3025	3.36%
6	1602	1514.4185	5.47%	1517.3058	5.29%
7	2013.3	1920.8484	4.59%	1908.7148	5.19%
8	2208.7	2109.8657	4.47%	2117.0157	4.15%

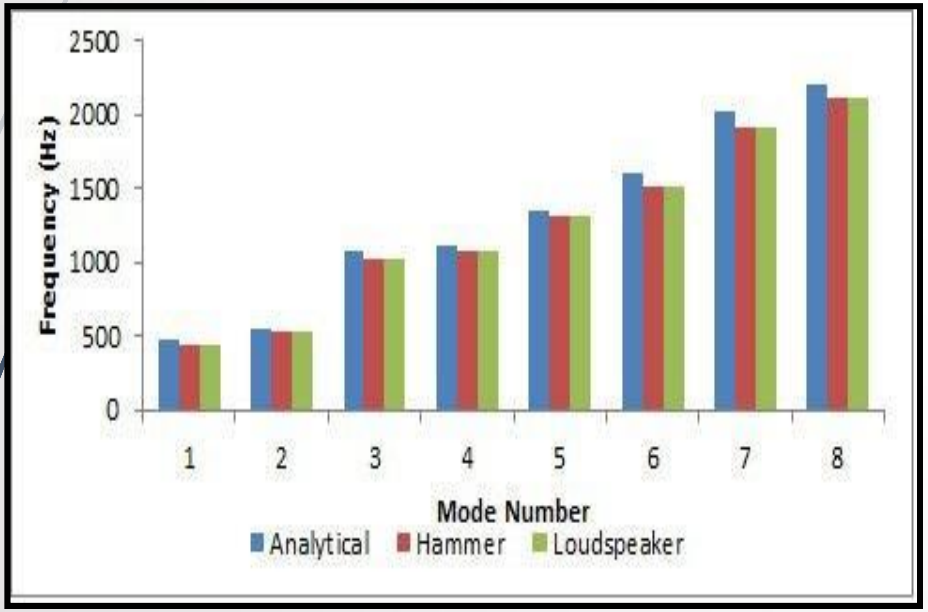
Table 1. Natural frequency (Hz) comparison between Analytical Model and Experimental Setup

Mode	Hammer	Loudspeaker	Difference
1	0.54082	0.33751	0.20331
2	0.22501	0.20995	0.01506
3	0.4085	0.46583	0.05733
4	0.31074	0.35594	0.0452
5	1.1341	0.35714	0.77696
6	1.3875	0.78647	0.60103
7	1.9624	0.40374	1.55866
8	1.0901	0.56601	0.52409

Table 2. Damping(%) comparison between Analytical Model and Experimental Setup

Comparison of Dynamic Properties (Exp.1 & Exp.2)

- The modal frequency obtained by Modal Analysis through MACEC for the combined setups is similar for both source of Excitation.
- The modal damping for the combined setups from the two Experimental Setup has some difference.



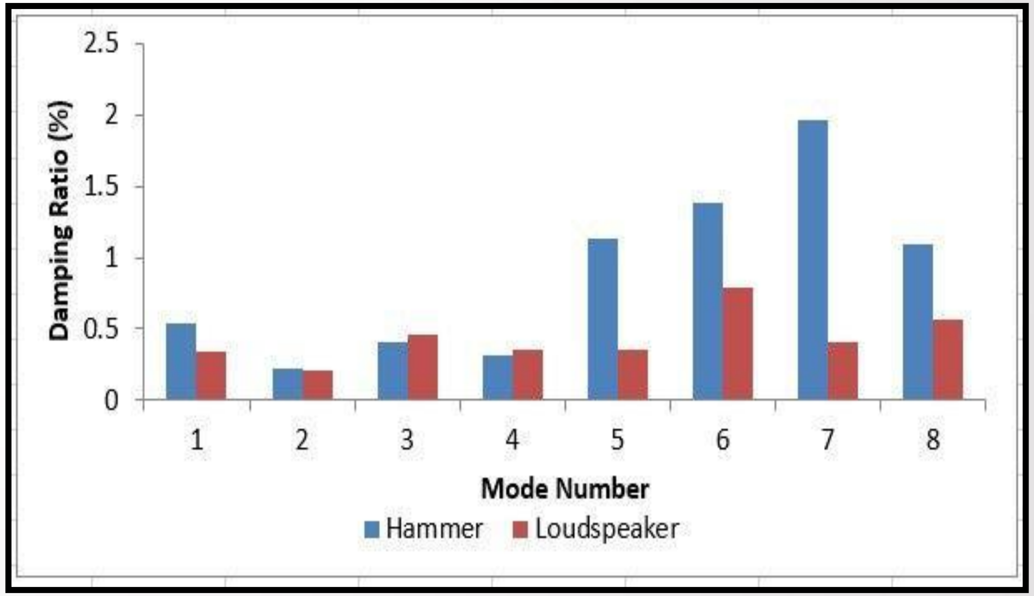


Fig 11. Frequency and Damping values resulting from the two laboratory tests

Damping calculation with Logarithmic Decrement (Exp.1 Setup 1)

- Signal Used = Reference Sensor 2 (Channel 12)
- Filter Used= Band-pass filter

MODE NO	Damping (%) through MACEC	Damping(%) through Logarithmic Decrement
1	0.184	0.195
2	0.234	0.288
8	1.009	0.840

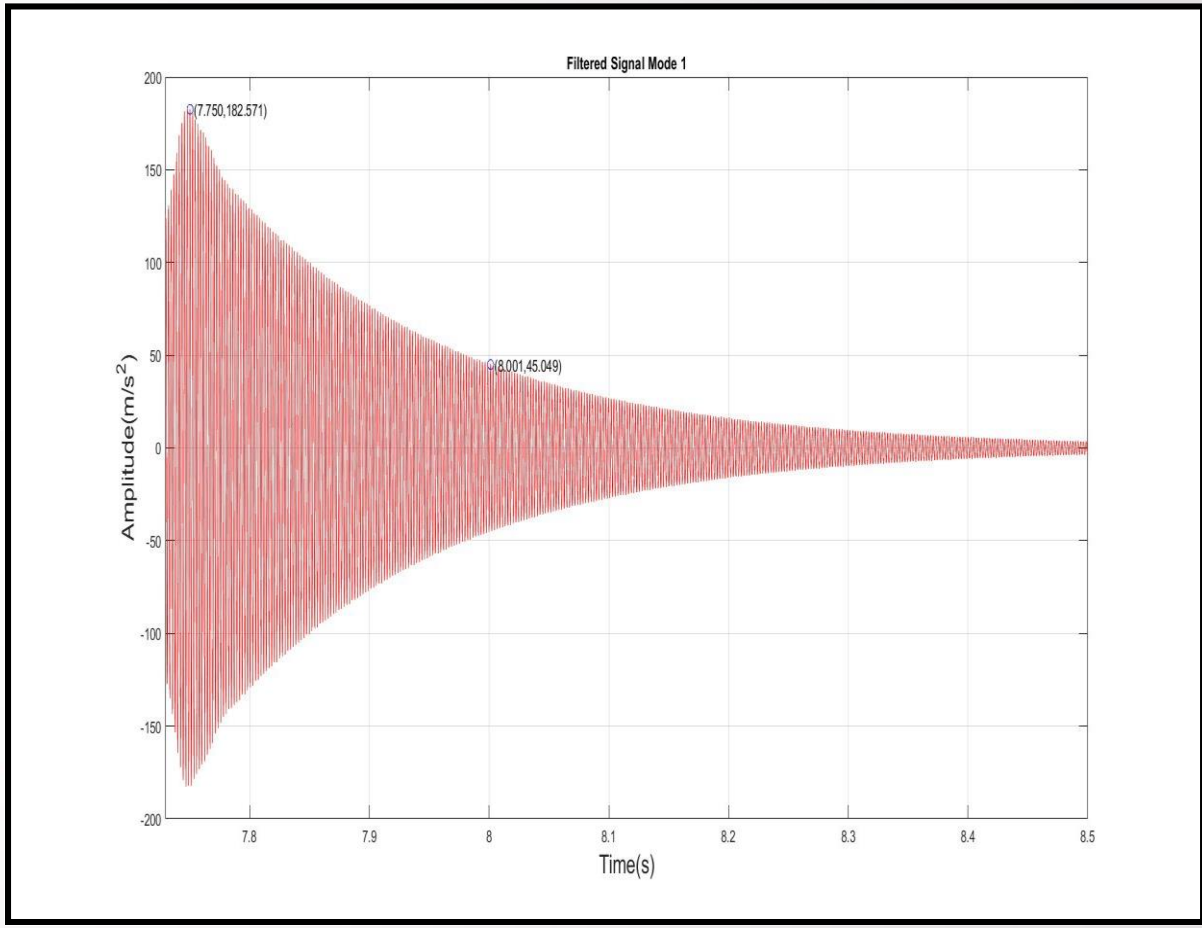


Fig 12. Filtered Signal for vibration of plate at first mode

Modal Analysis stabilization plots through (MACEC)

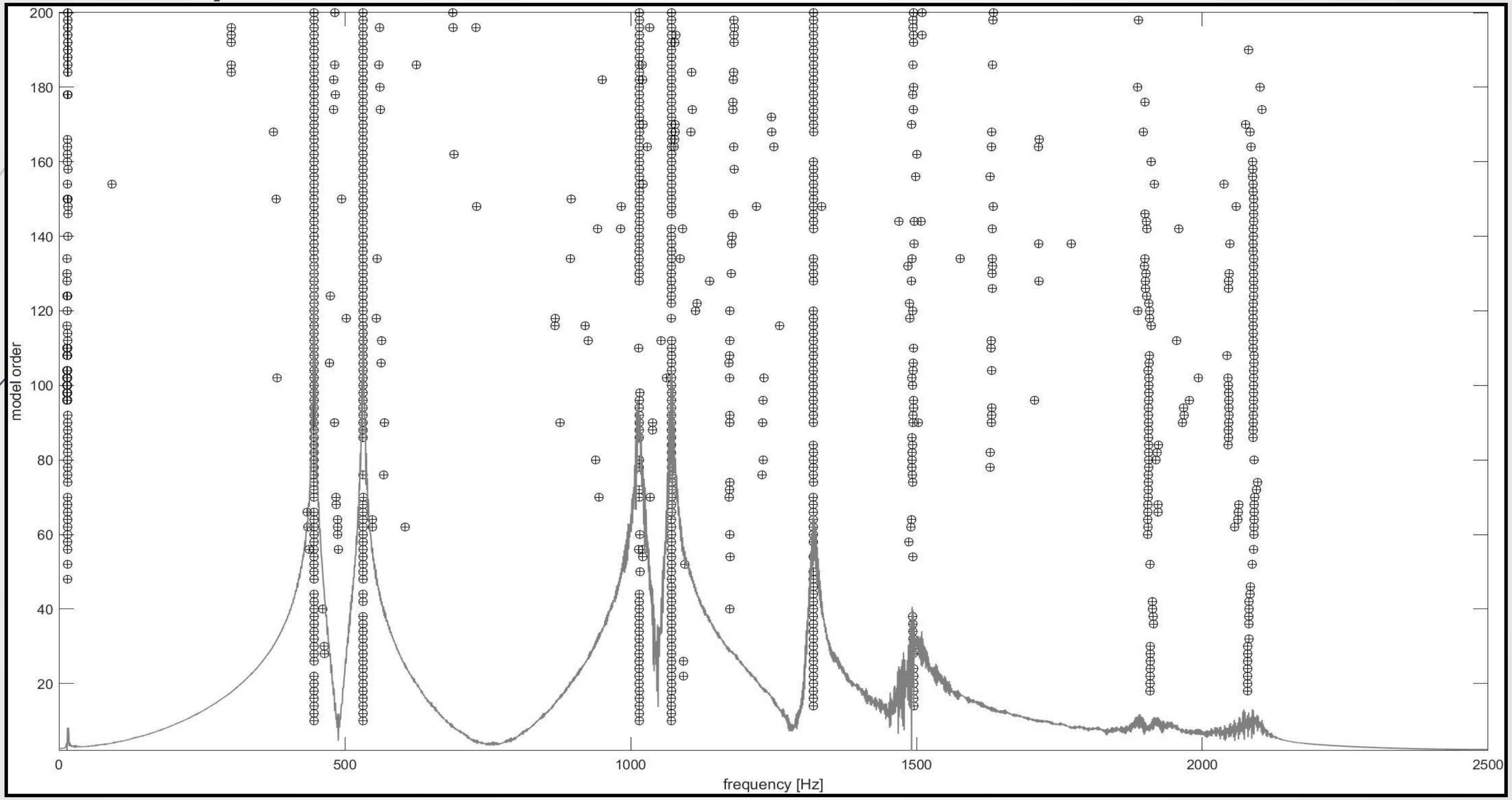
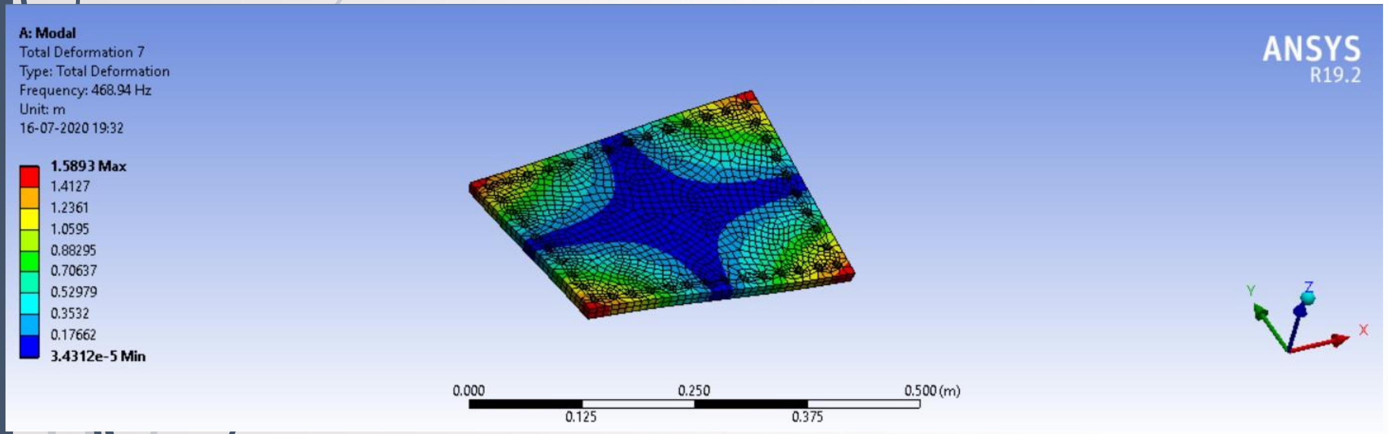
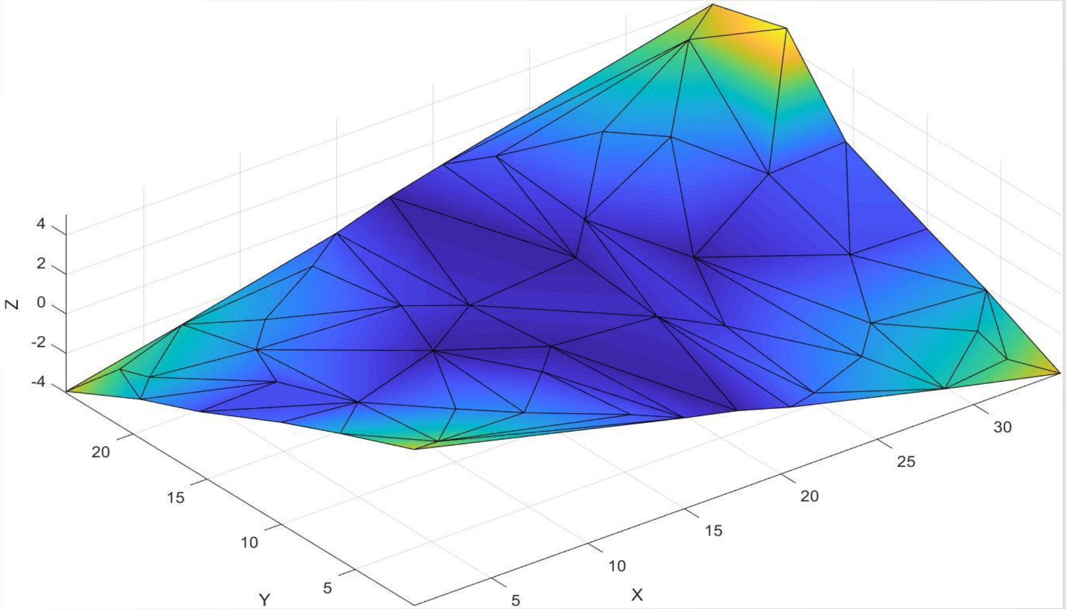


Fig 13. Stabilization Plot Setup 1 Exp. 1

Visual Comparison of Modes (Analytical and Experiment - I)

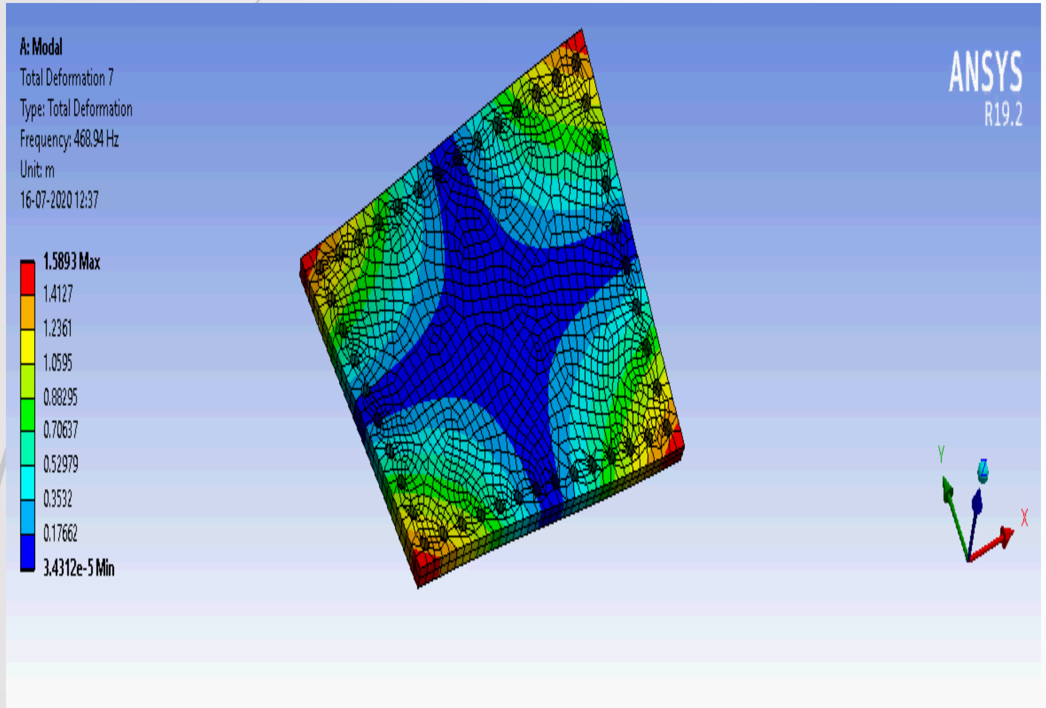




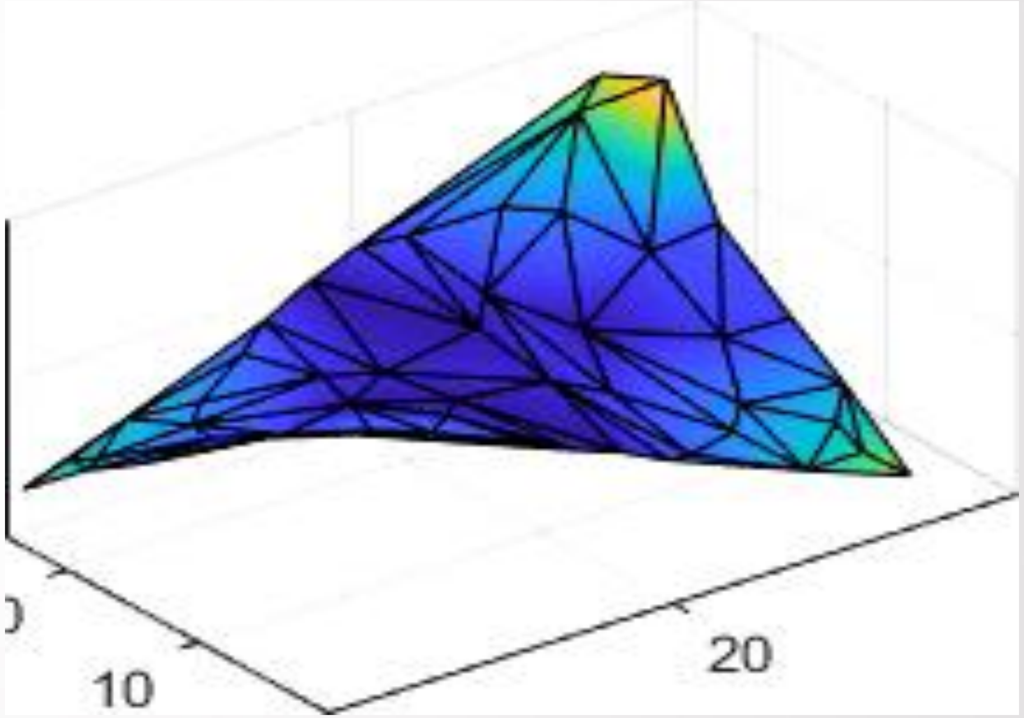
Mode 7: f = 468.94 Hz

Mode 1: f = 446.61Hz

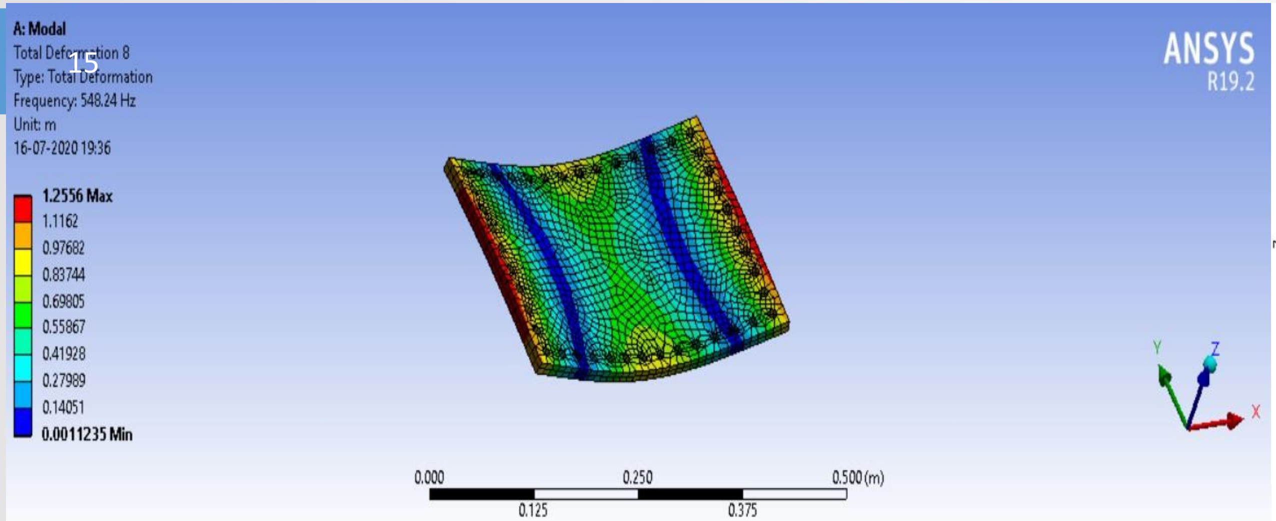
Visual Comparison of Modes (Analytical and Experimental Setup)



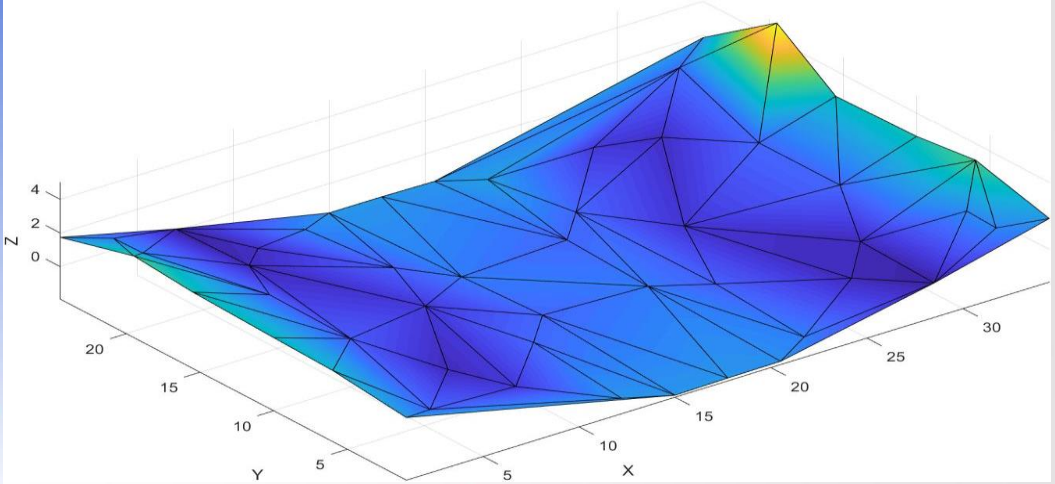
Mode 7: f = 468.94 Hz



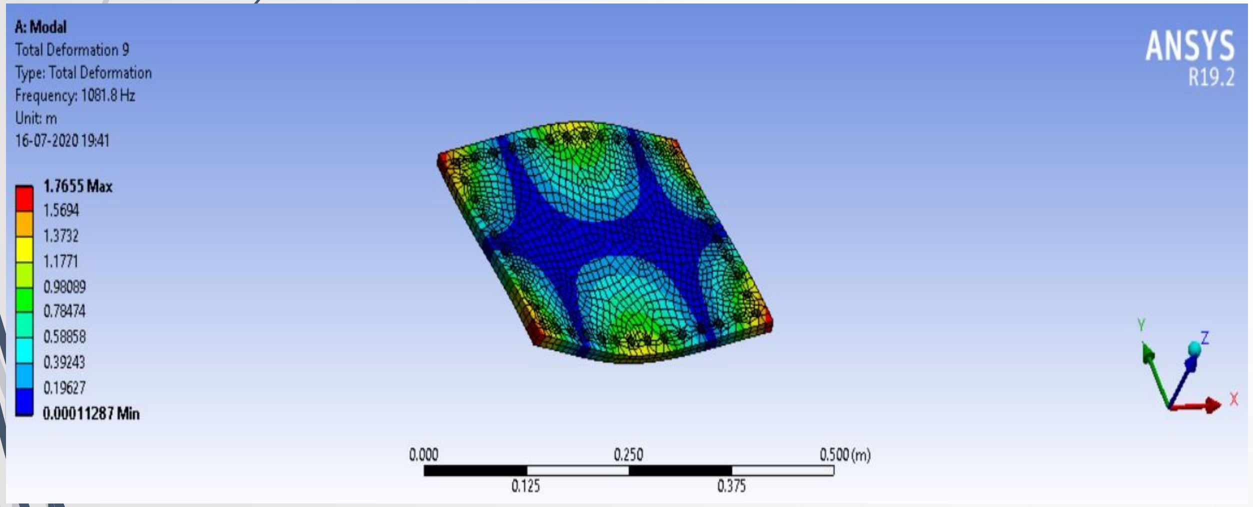
Mode 1: f = 446.61Hz



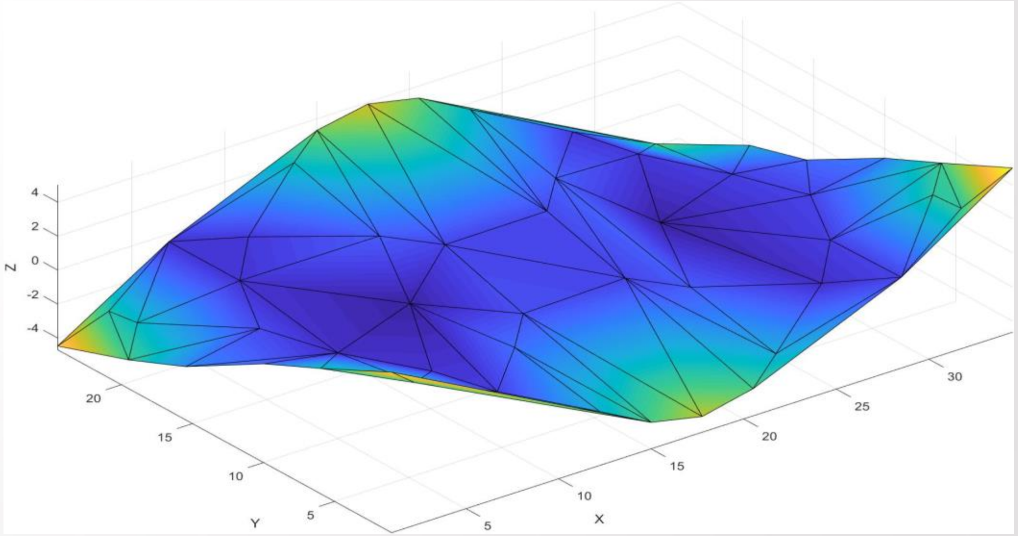
Mode 8: f=548.24 Hz



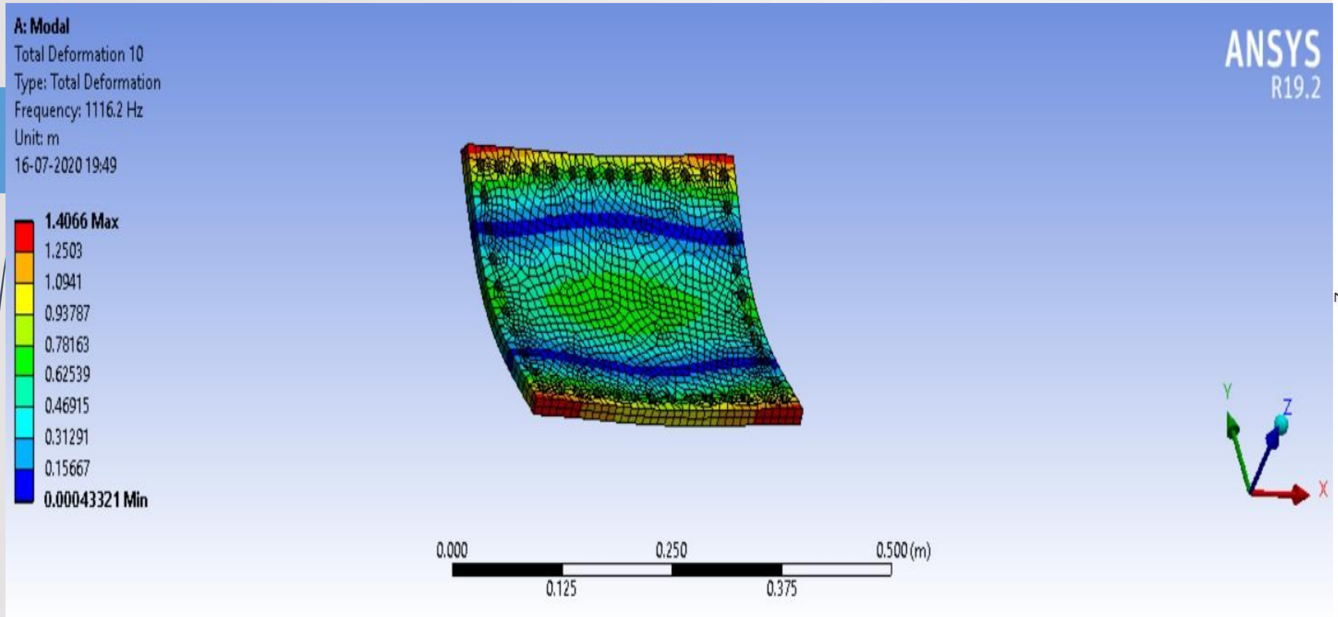
Mode 2: f=531.06 Hz



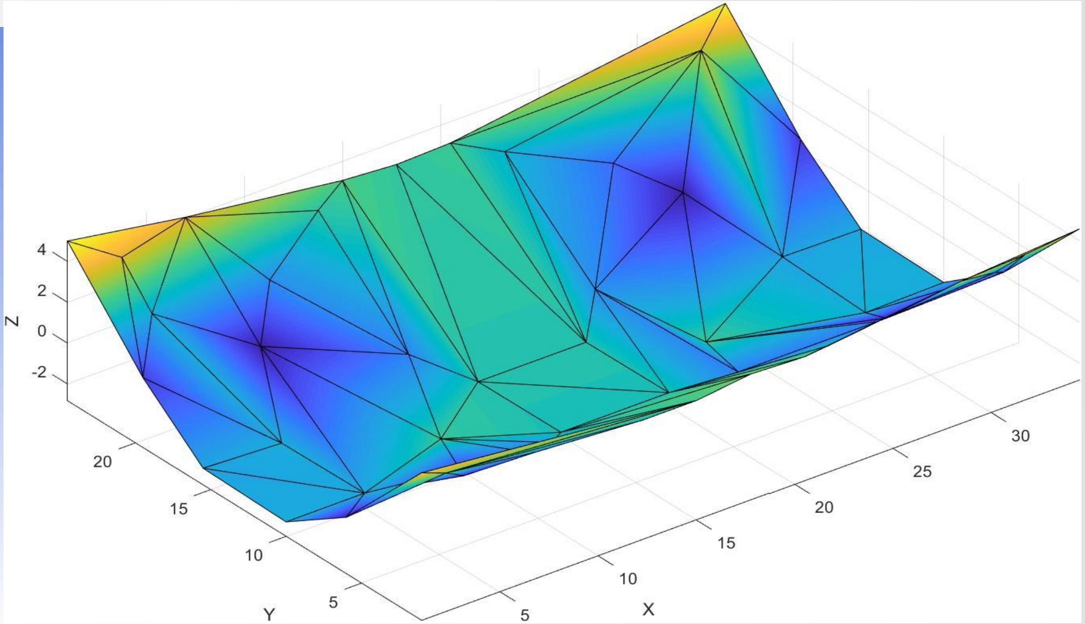
Mode 9: f=1081.8 Hz



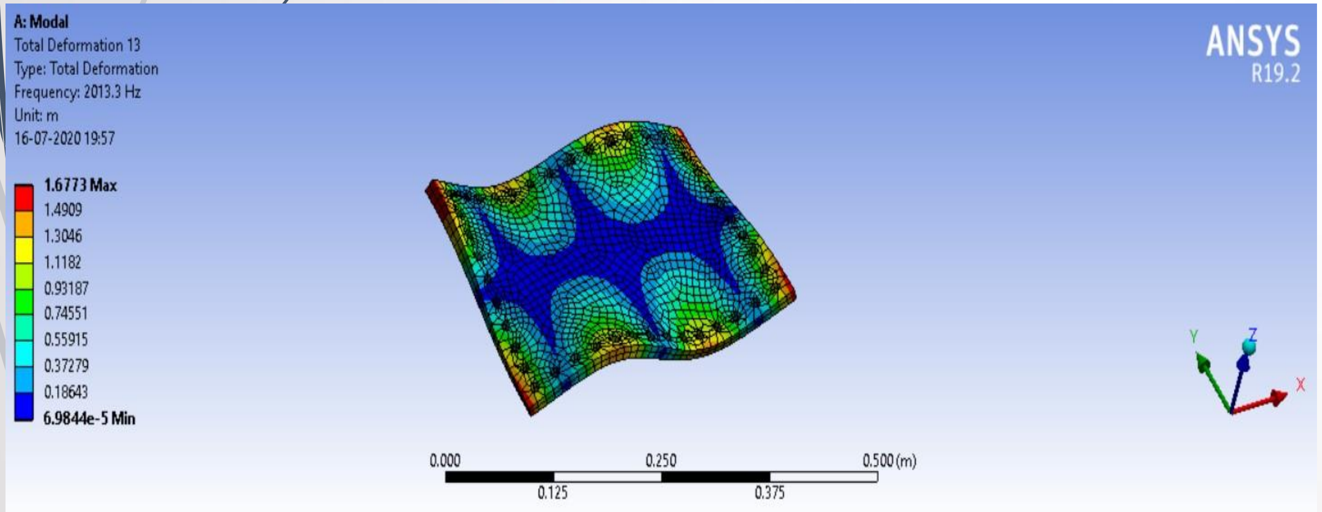
Mode 3: f=1025.47 Hz



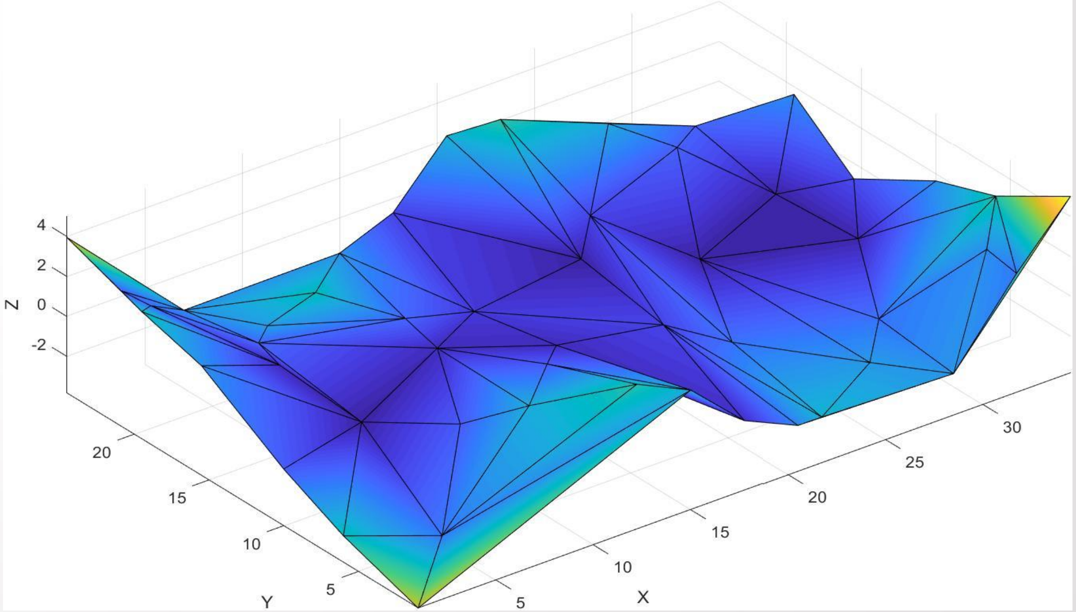
Mode 10: f=1116.2 Hz



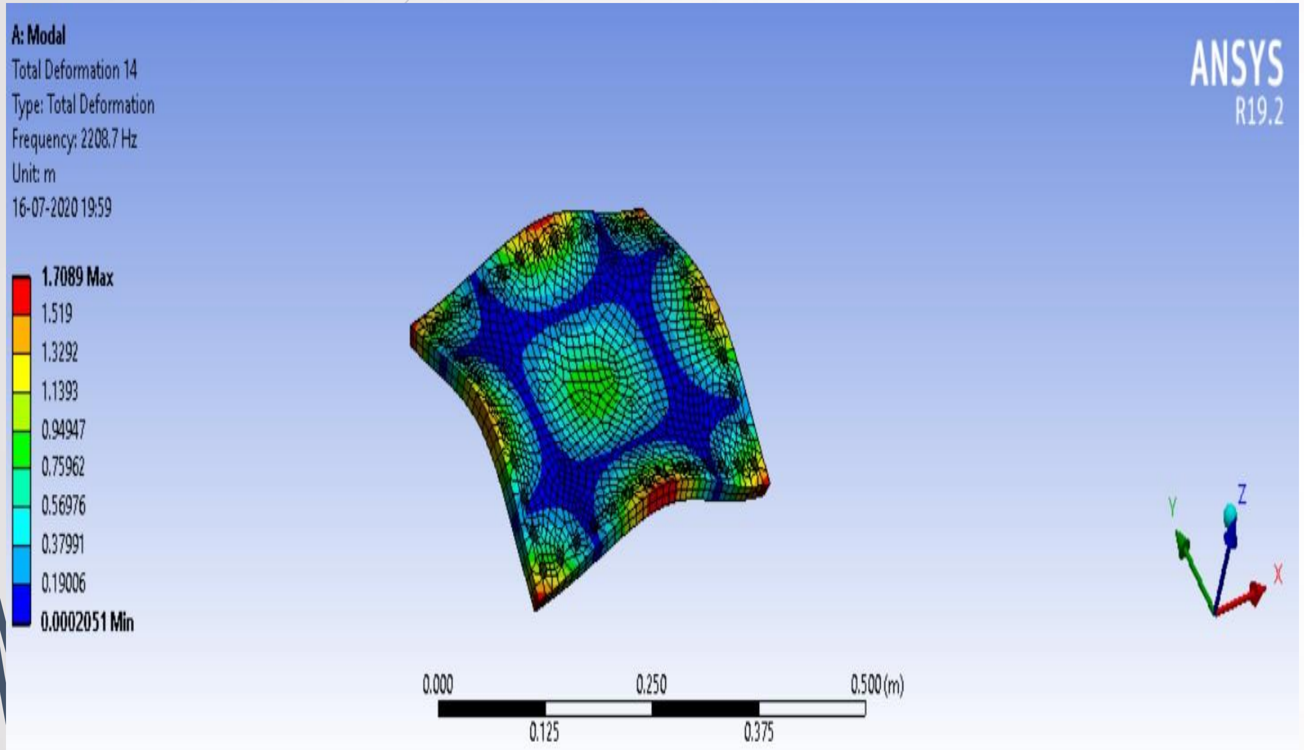
Mode 4: f=1075.44 Hz



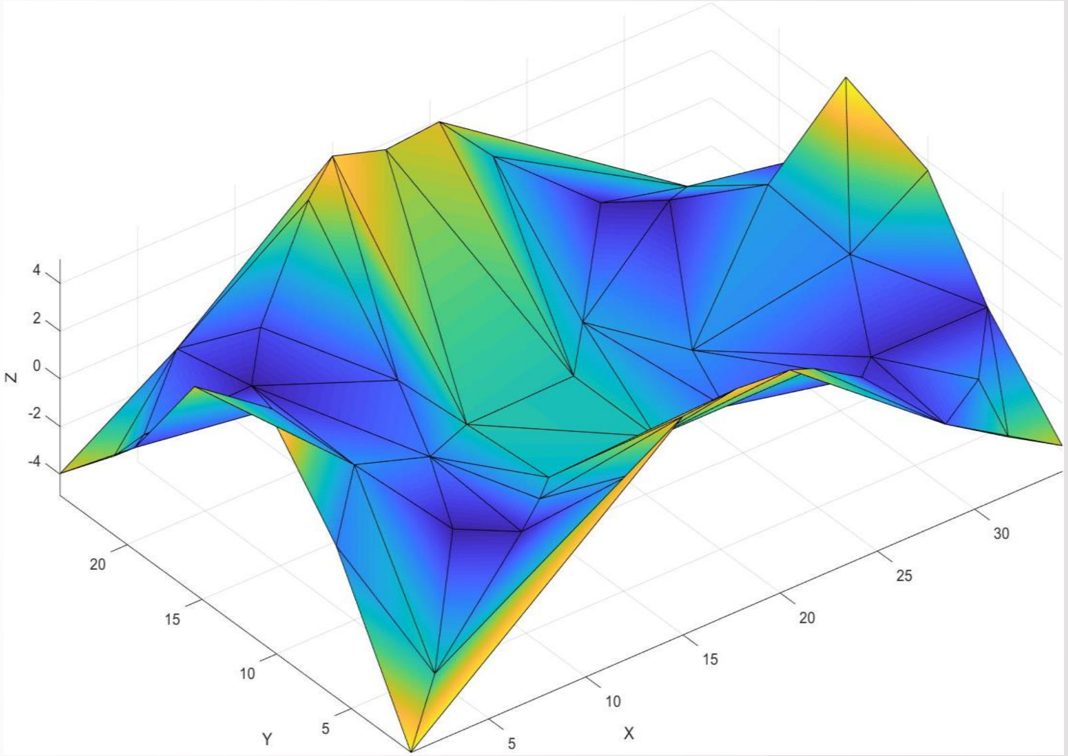
Mode 13: f=2013.3 Hz



Mode 7: f=1920.84 Hz



Mode 14: f=2208.7 Hz



Mode 8: f=2109 Hz

Modal Assurance Criterion (MAC)

- MAC Analysis is used to determine the similarity of mode shapes .
- For identical mode shapes the MAC will have a value of one. On the other hand for completely unrelated mode MAC has a value of Zero.
- For modes with different shapes the MAC value will lie between zero and one .

$$MAC(\{\varphi_r\},\{\varphi_s\}) = \frac{|\{\varphi_r\}^{*t}\{\varphi_s\}|^2}{(\{\varphi_r\}^{*t}\{\varphi_r\})(\{\varphi_s\}^{*t}\{\varphi_s\})}$$

$\{\emptyset_i\}$ = Mode Shape/Eigenvectors of the i^{th} Mode

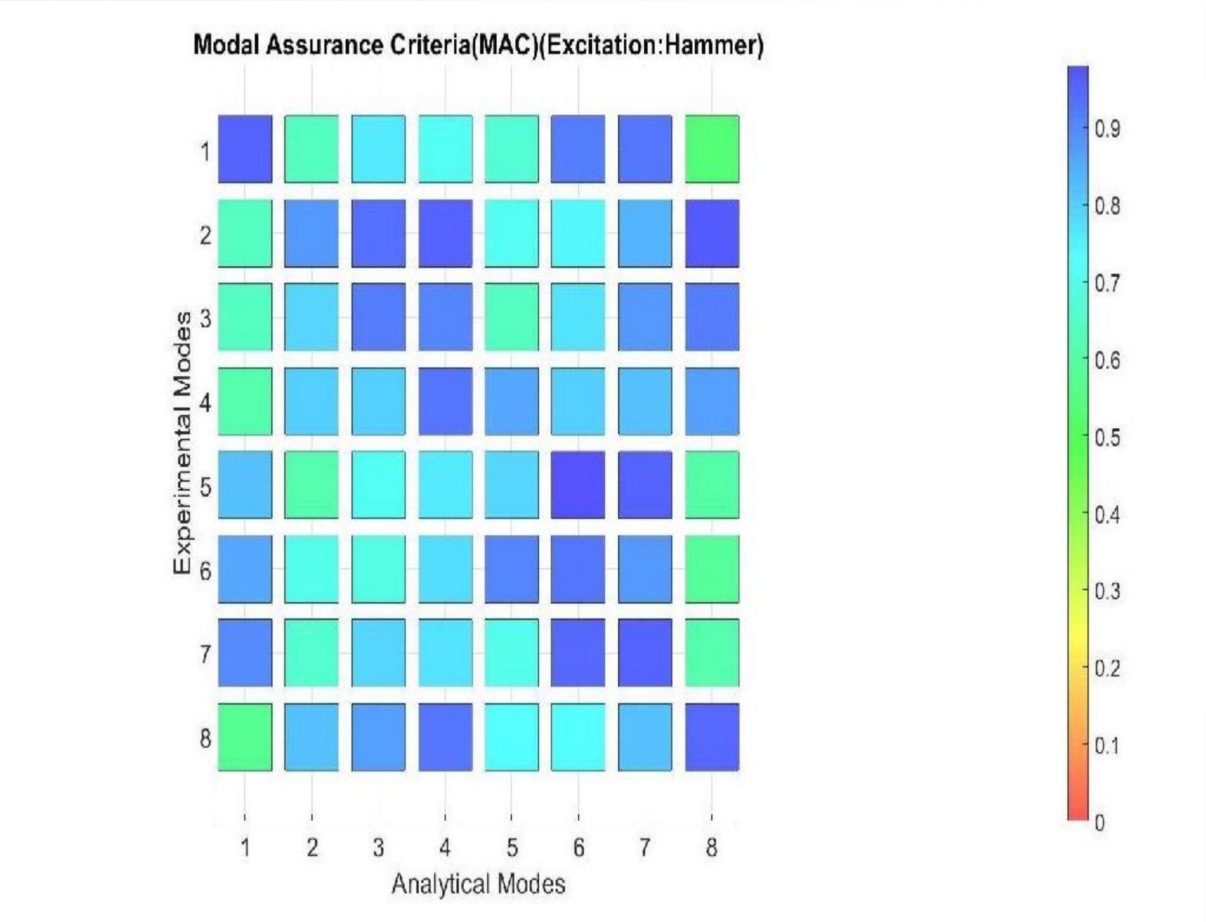
Modal Assurance Criterion (MAC) Experiment - 1

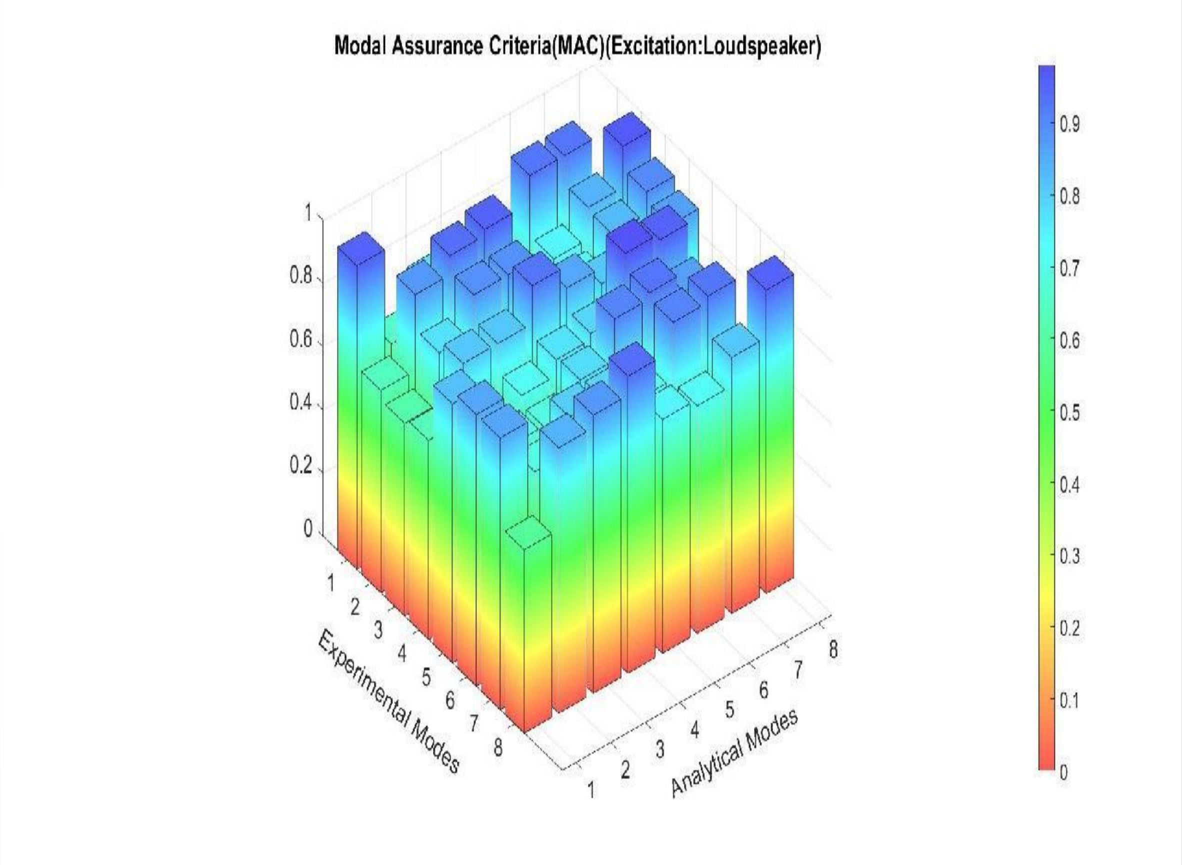
- The MAC Matrix shows that the Modes from both Analytical model and Experimental Setup 1 with Hammer Excitation are very well correlated.

MAC (Analytical vs Experimental)(Excitation: Hammer)									
Analytical	Mode	7	8	9	10	11	12	13	14
Experimental	1	0.96	0.64	0.76	0.71	0.67	0.92	0.93	0.53
	2	0.64	0.88	0.94	0.96	0.71	0.74	0.84	0.97
	3	0.64	0.79	0.92	0.91	0.64	0.77	0.88	0.92
	4	0.61	0.80	0.80	0.93	0.86	0.80	0.82	0.87
	5	0.82	0.61	0.71	0.76	0.79	0.98	0.96	0.60
	6	0.86	0.70	0.69	0.78	0.91	0.93	0.88	0.58
	7	0.90	0.66	0.79	0.77	0.70	0.95	0.96	0.61
	8	0.57	0.82	0.87	0.93	0.73	0.73	0.82	0.95

Table 3. MAC matrix for the comparison between Analytical model and Experiment I

Modal Assurance Criterion (MAC) Experiment - 1





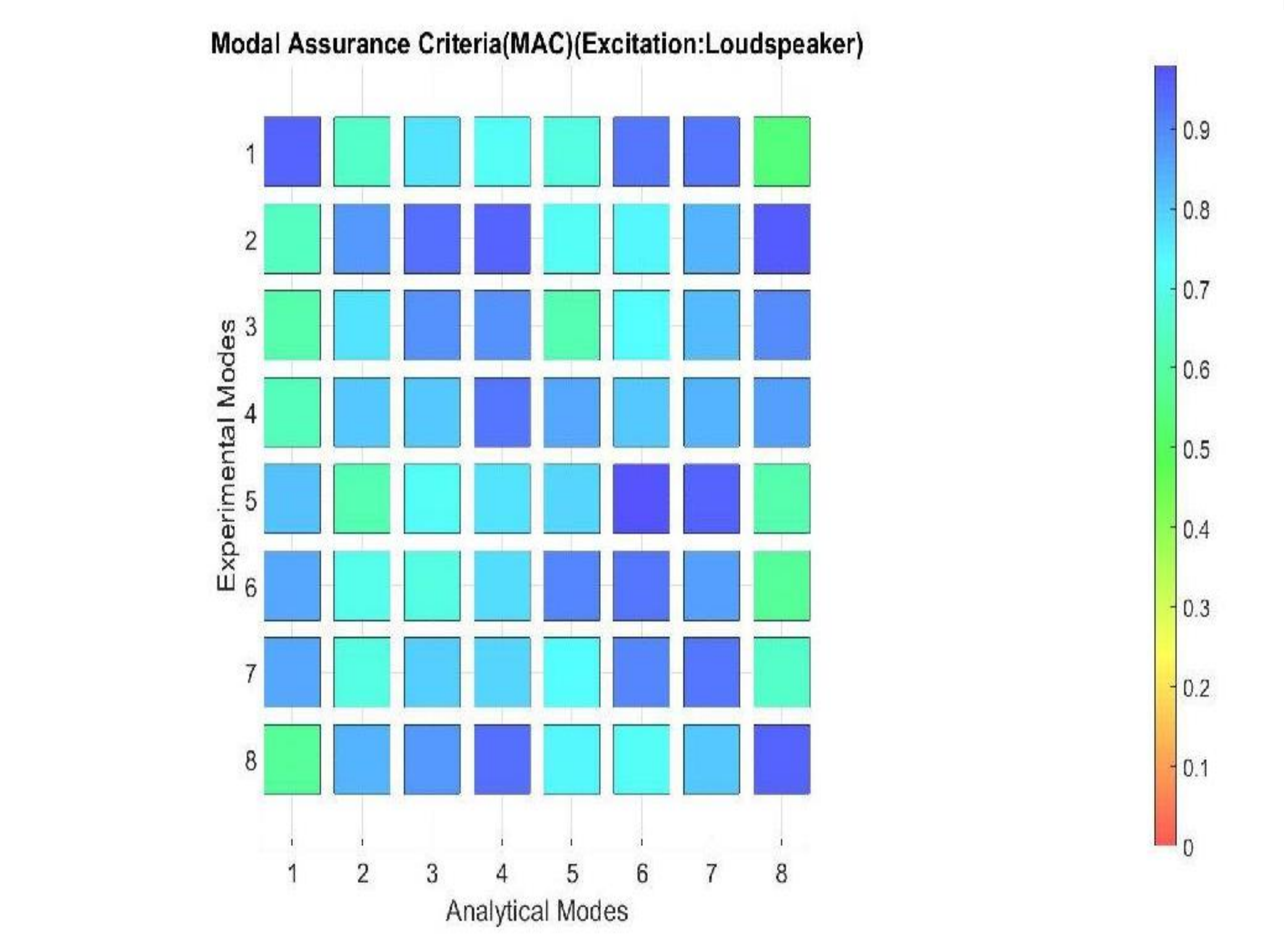
Modal Assurance Criterion (MAC) Experiment - 2

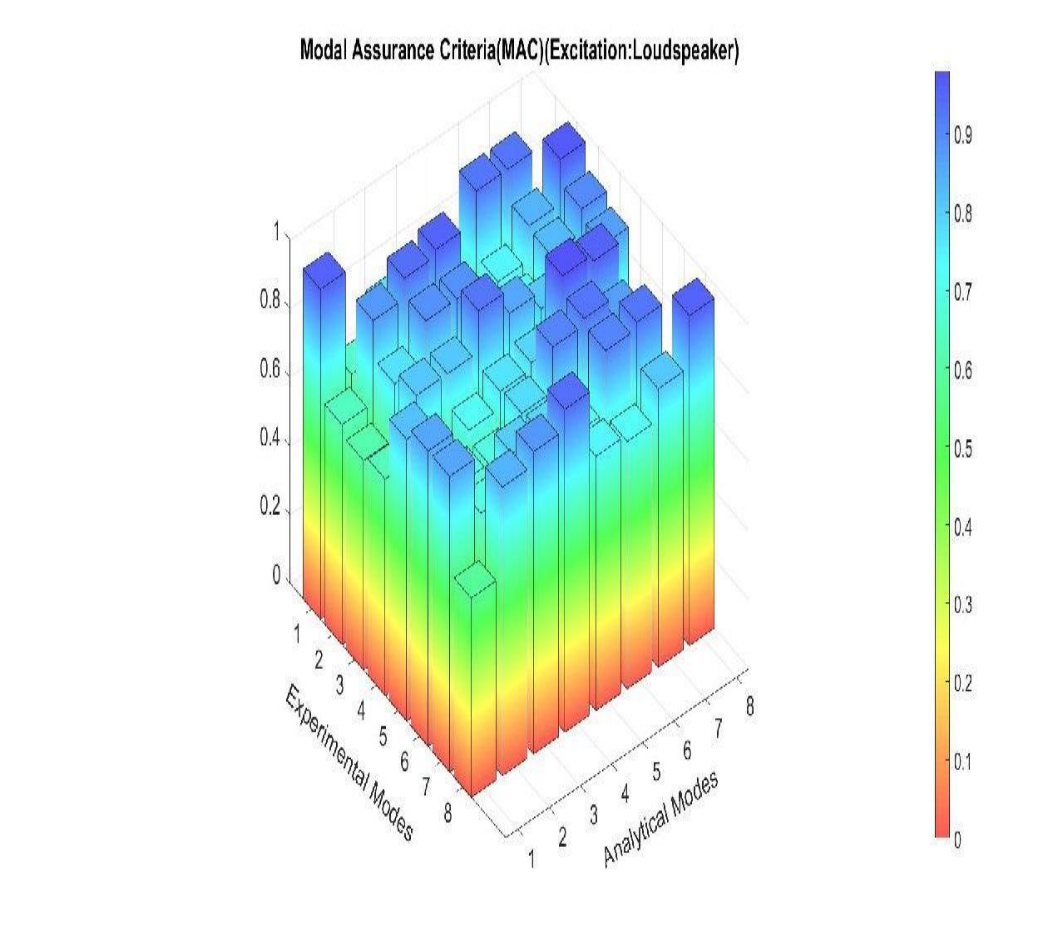
- The MAC Matrix shows that the Modes from both Analytical model and Experimental Setup 2 with Loudspeaker Excitation are well correlated.

MAC (Analytical vs Experimental)(Excitation: Loudspeaker)									
Anlytical	Mode	7	8	9	10	11	12	13	14
Experimental	1	0.96	0.65	0.77	0.72	0.69	0.93	0.93	0.54
	2	0.64	0.88	0.94	0.96	0.72	0.74	0.84	0.97
	3	0.61	0.77	0.89	0.89	0.62	0.73	0.83	0.90
	4	0.63	0.81	0.81	0.93	0.86	0.81	0.84	0.87
	5	0.82	0.62	0.72	0.77	0.79	0.98	0.96	0.61
	6	0.86	0.70	0.69	0.78	0.91	0.93	0.87	0.58
	7	0.86	0.69	0.80	0.79	0.73	0.91	0.93	0.65
	8	0.58	0.84	0.88	0.94	0.74	0.72	0.81	0.96

Table 4. MAC matrix for the comparison between Analytical model and Experiment II

Modal Assurance Criterion (MAC) Experiment - 2





Conclusion

1. The natural frequency from analytical model and experimental setup shows good concurrence at lower modes but differs at higher modes.
2. The damping is less for first few modes and then increases at higher modes.
3. The material homogeneity and defects affects the modal parameters.
4. For extracting modal properties with more accuracy sensors should be placed at locations where there is zero displacement for particular nodes .
5. Similar modal frequency does not represent similar modal properties . MAC values can be used to compare modal similarities.
6. Damping values differ for loudspeaker and hammer.
7. It is not necessary that any two modes which look similar visually will have a high correlation as shown in MAC. (as seen in Experiment 1).
8. Six closely correlated modes were captured during this project.

References

1. Dr. -Ing Volkmar Zabel ,“Manuscript Experimental Structural Dynamics
2. Júlio M. Montalvão e Silva, Nuno Manuel Mendes Maia, “Modal Analysis and Testing”.
3. Workbench User’s guide, ANSYS.
4. A Matlab Toolbox For Experimental and Operational Modal Analysis(MACEC 3.3), KU LEUVEN.