Formula SAE Chassis Modal Test and Analysis

ME4701
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The goal of this project is to understand chassis dynamics at different frequencies that can help FSAE performance.

- Rotating components that could excited chassis resonance
  - Wheels: 25-70 mph -> 9Hz - 25Hz (16" tire diameter)
  - Engine: 1800-10000 rpm -> 30Hz - 170Hz
- Excessive chassis resonance could lead to accelerated fatigue failure.

Figure 1- Consequence of resonance during Toyota Tundra operation.

The test plan was structured around the operating frequencies of rotating components.

Table 1- FSAE Modal Test Plan

Acquisition Parameters	Value	Reasoning
Bandwidth	256 Hz	The Engine operating frequency converts to 168 Hz, the complexity of the frame likely will yield many modes in this bandwidth
Spectral Lines	512	Resolution of 1 Hz
Averages	5	Because the accelerometers don't need to be moved the team can take many strikes at each point and get an average across many points.
Hammer Tip	Steel	Impart the most energy based on size of hammer, most likely to excite all modes. Validated with preliminary strikes.
Modes		The team is interested in all modes within bandwidth, specifically idle and top speed
Derived Nodes	None	Using tri-axial accelerometers at each node location means that derived nodes are not required.
Boundary Condition	Free-Free	Car is suspended on relatively low stiffness bunjies. A low frequency highpass filter will be used to eliminate the translational modes.
# of Nodes	43	Node Selection is sufficient to represent the geometry with the number of accelerometers
Test Type	Roving Hammer	The team is using 43 tri-axial accelerometers to accelerate the data gathering process. The team has selected the top of the roll cage and the front bumper corners as strike points for this testing. The team can use the drive points from the front bumper strikes to validate the data.

The chassis was simplified from tube geometry to nodes.

- Tube chassis was modeled in Inspire
- Nodes were extracted at welded joints

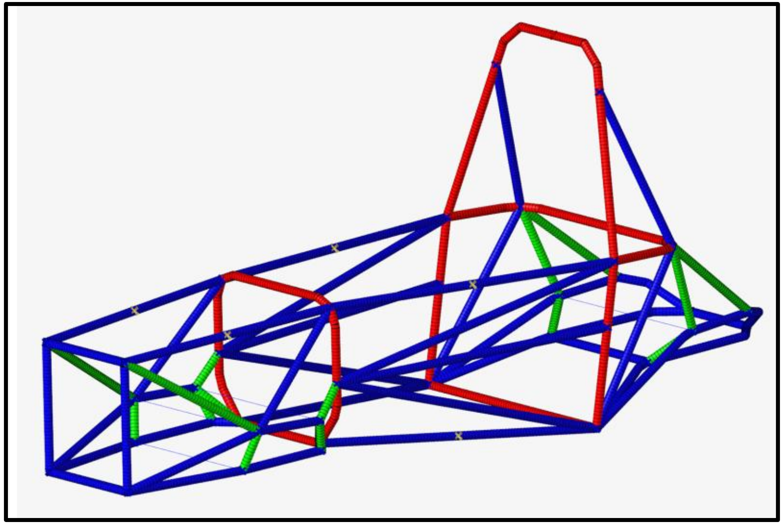


Figure 2- Tube chassis in Hypermesh.

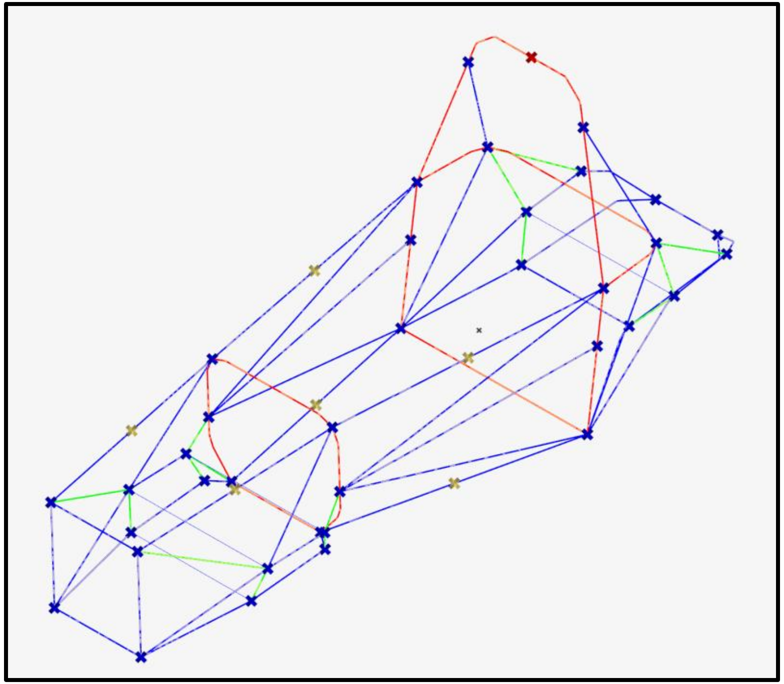


Figure 3- Extracted nodes at welded joints with midpoints on bars of interest.

Our Testplan organized the nodes and channels.

Point Name	x position (m)	y position (m)	z position (m)	x channel	y channel	z channel	calibration
Hammer				12			2.25 mv/N
Point1	-1.3208	0.1651	-0.2233	13	14	15	100 mv/g
Point2	-1.3208	-0.1651	-0.2233	16	17	18	100 mv/g
Point3	-1.3208	-0.1651	0.1577	19	20	21	100 mv/g
Point4	-1.3208	0.1651	0.1577	22	23	24	100 mv/g
Point5	-0.9541	0.1971	0.1726	25	26	27	100 mv/g
Point6	-0.9541	-0.1971	0.1726	28	29	30	100 mv/g
Point7	-0.9362	-0.2292	-0.2233	31	32	33	100 mv/g
Point8	-0.9362	0.2292	-0.2233	34	35	36	100 mv/g
Point9	-0.9028	0.2645	-0.1083	37	38	39	100 mv/g
Point10	-0.9028	-0.2645	-0.1083	40	41	42	100 mv/g
Point11	-0.6687	-0.2643	-0.1229	43	44	45	100 mv/g
Point12	-0.6687	0.2643	-0.1229	46	47	48	100 mv/g
Point13	-0.6337	-0.2299	-0.2233	49	50	51	100 mv/g
Point14	-0.6337	0.2299	-0.2233	52	53	54	100 mv/g
Point16	-0.5874	0.1700	-0.2233	58	59	60	100 mv/g
Point17	-0.5874	0.2290	0.1875	61	62	63	100 mv/g
Point18	-0.5874	0.2500	-0.0330	64	65	66	100 mv/g
Point19	-0.5874	-0.2290	0.1875	67	68	69	100 mv/g

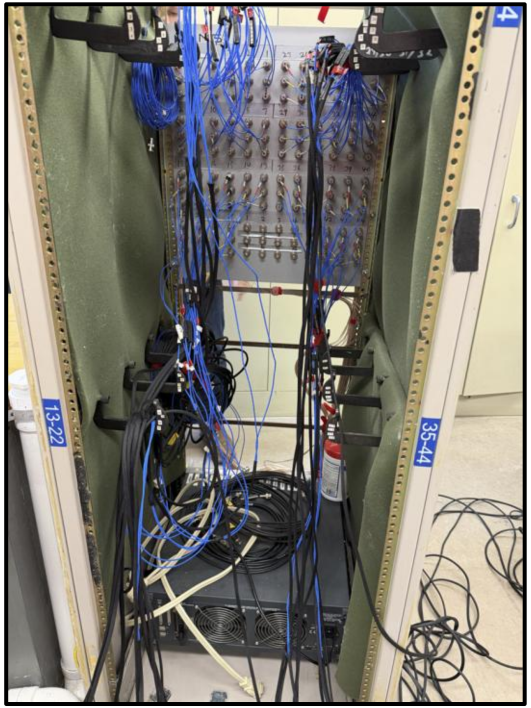
Point Name	x position (m)	y position (m)	z position (m)	x channel	y channel	z channel	calibration
Point20	-0.5874	-0.2500	-0.0330	70	71	72	100 mv/g
Point21	-0.1416	0.2628	-0.2720	73	74	75	100 mv/g
Point22	-0.1416	-0.2628	-0.2720	76	77	78	100 mv/g
Point23	-0.0996	0.2923	0.1414	79	80	81	100 mv/g
Point24	-0.0996	-0.2923	0.1714	82	83	84	100 mv/g
Point25	0.3042	0.3556	-0.3207	85	86	87	100 mv/g
Point26	0.3042	-0.3556	-0.3207	88	89	90	100 mv/g
Point27	0.3550	0.3556	-0.0330	91	92	93	100 mv/g
Point28	0.3550	-0.3556	-0.0330	94	95	96	100 mv/g
Point29	0.3882	0.3556	0.1553	97	98	99	100 mv/g
Point30	0.3882	-0.3556	0.1553	100	101	102	100 mv/g
Point31	0.4688	-0.2194	0.6128	103	104	105	100 mv/g
Point32	0.4689	0.2194	0.6130	106	107	108	100 mv/g
Point33	0.6415	0.3217	0.1432	109	110	111	100 mv/g
Point34	0.6415	-0.3217	0.1432	112	113	114	100 mv/g
Point35	0.6416	-0.2056	-0.2190	115	116	117	100 mv/g
Point36	0.6418	0.2056	-0.2190	118	119	120	100 mv/g
Point37	0.7476	-0.2822	-0.1341	121	122	123	100 mv/g
Point38	0.7478	0.2822	-0.1341	124	125	126	100 mv/g
Point39	0.9683	0.2777	-0.1216	127	128	129	100 mv/g
Point40	0.9685	-0.2776	-0.1217	130	131	132	100 mv/g
Point41	1.0989	-0.1192	-0.2188	133	134	135	100 mv/g
Point42	1.0989	0.1174	-0.2188	136	137	138	100 mv/g
Point43	0.4908	-0.0006	0.7372	139	140	141	100 mv/g

Reference channel

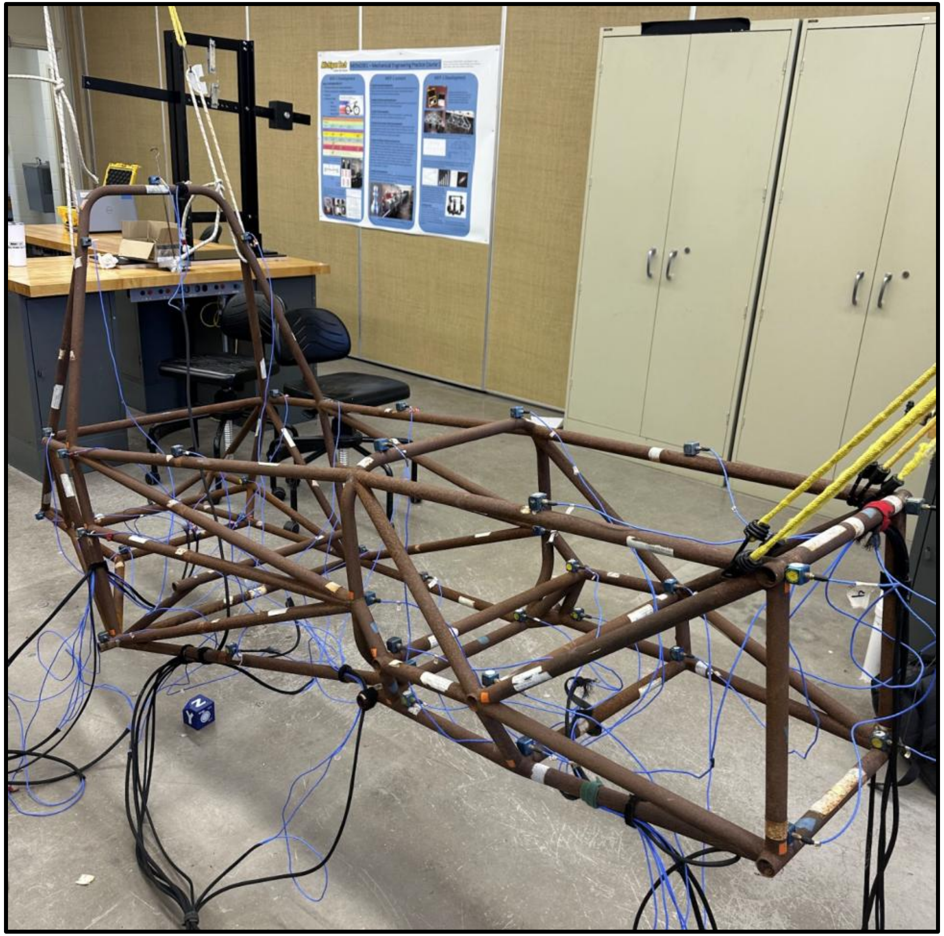
No response from channel

Strike Points

The hardest part of modal testing is staying organized.



<u>Figure 4-</u> Modal cabinet with prelabeled and connected accelerometers.



<u>Figure 5-</u> Accelerometers installed on suspended chassis.

Striking the chassis with more energy reduced noise.

- Preliminary testing revealed noise at lower frequencies, shown by the red curve in Figure 6

- Higher amplitude impacts reduced noise at lower frequencies while maintaining measurement at high frequencies.

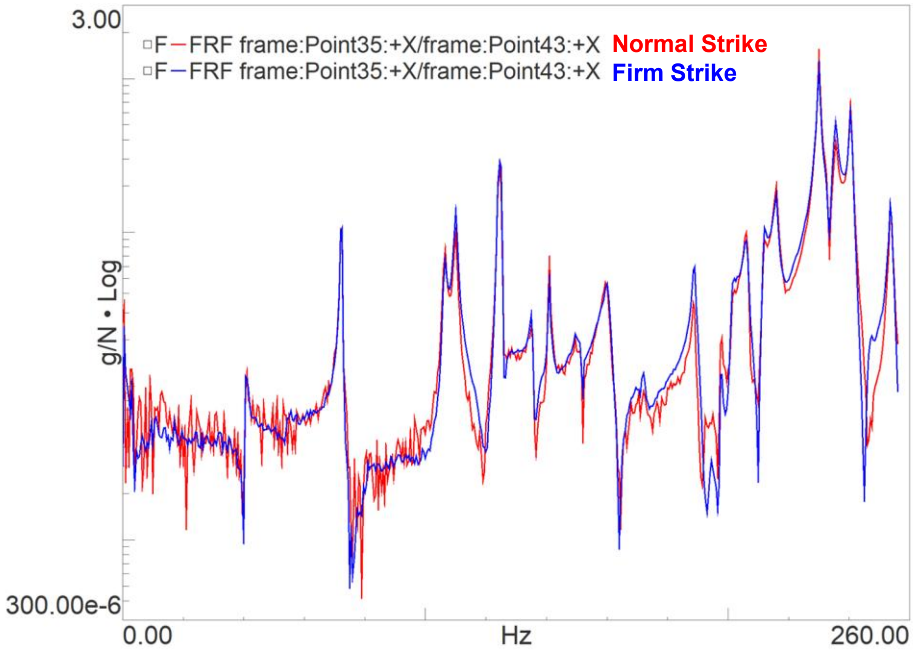
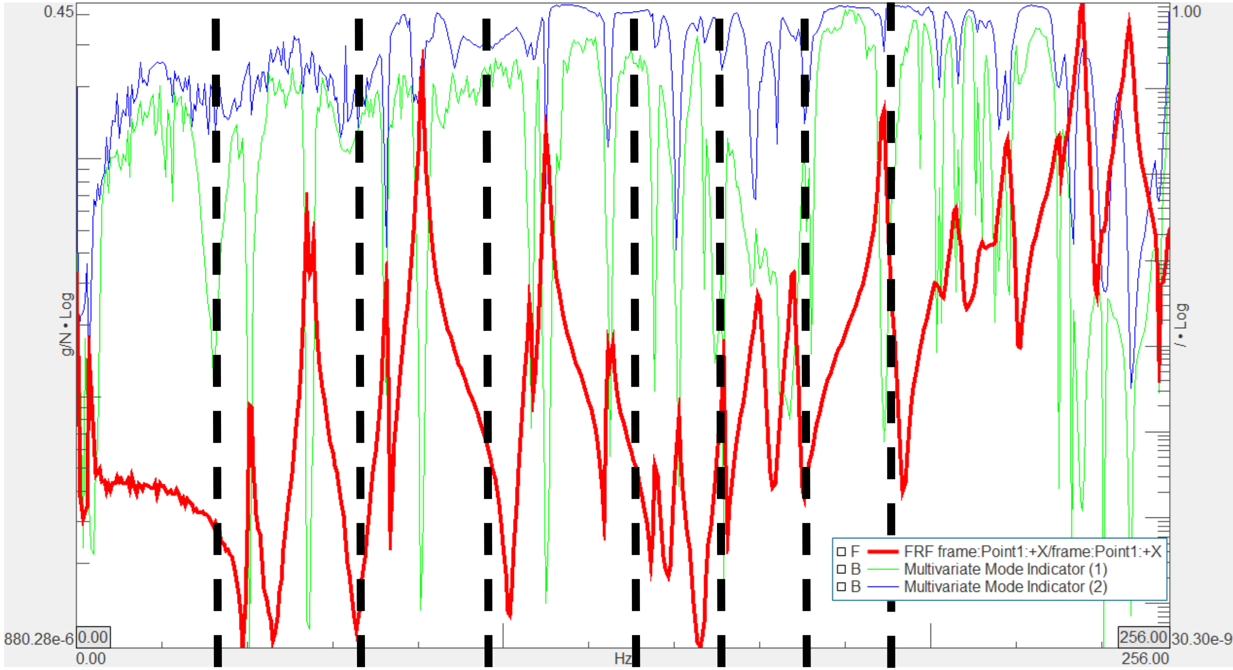


Figure 6- Hit Strength Response Comparison

Data was processed using PolyMax Plus Curvefitting incrementally through the bandwidth.

- Data fitted in increments to ensure accurate mode selection

- Data presented relatively little "stable" points compared to previous tests



<u>Figure 7-</u> Hit Strength Response Comparison

Results: Mode Shapes

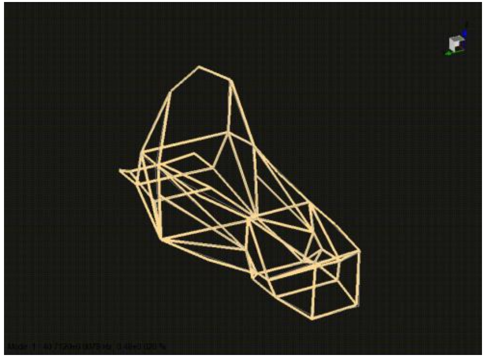


Figure 8- Mode 1 at 40.7 Hz

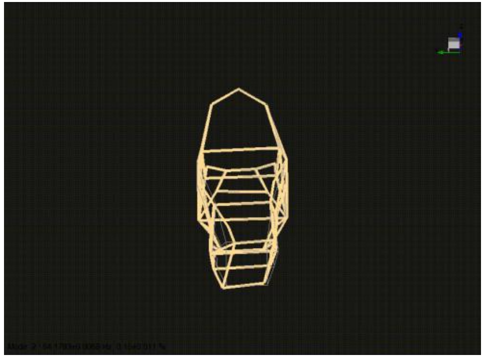


Figure 9- Mode 2 at 54.2 Hz

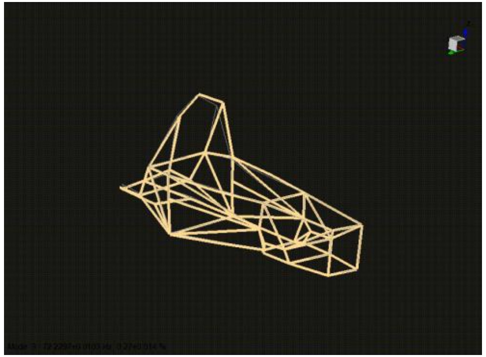


Figure 10- Mode 3 at 72.2 Hz

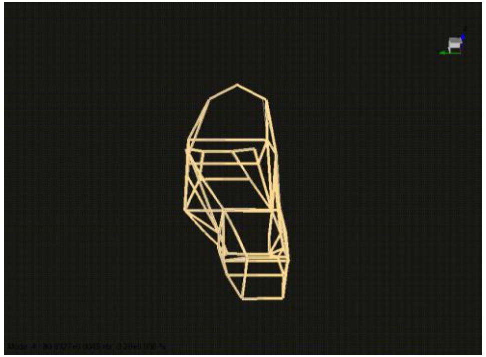


Figure 11- Mode 4 at 80.9 Hz

Figure 12- Mode 5 at 106.3 Hz

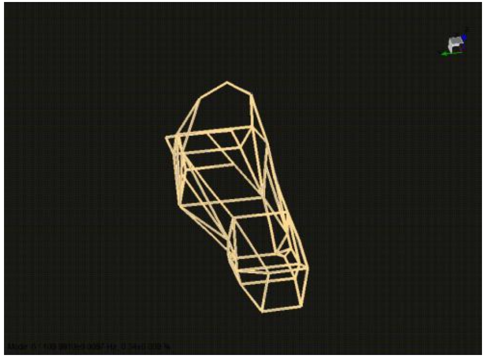


Figure 13- Mode 6 at 110.0 Hz

Results: Mode Shapes

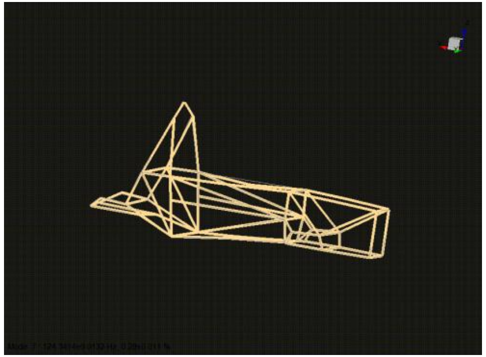


Figure 14- Mode 7 at 124.3 Hz

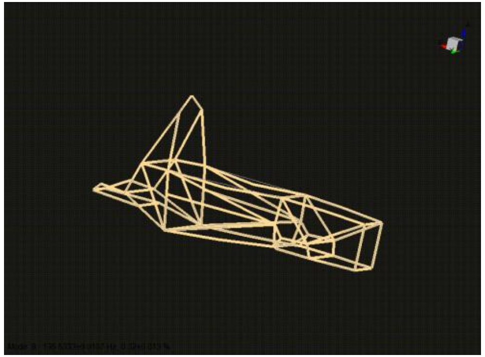


Figure 15- Mode 8 at 135.5 Hz

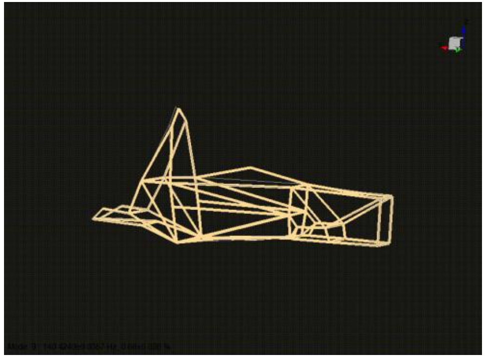


Figure 16- Mode 9 at 140.4 Hz

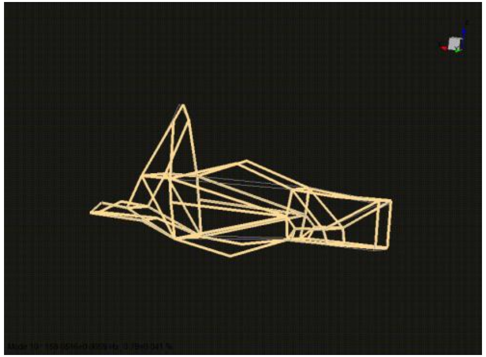


Figure 17- Mode 10 at 158.7 Hz

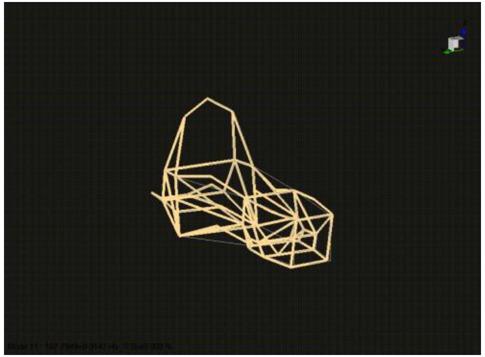


Figure 18- Mode 11 at 167.8 Hz

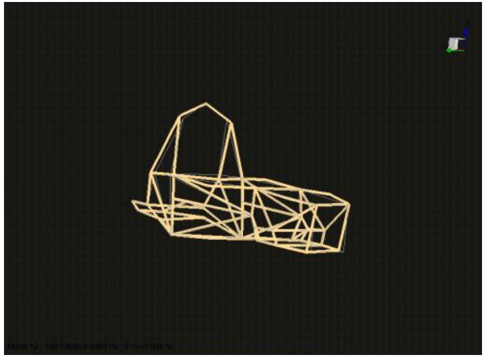


Figure 19- Mode 12 at 188.5 Hz

Reciprocity analysis validates the test setup.

- Y and Z directions showed high quality reciprocity
- X had slight variance in peak amplitudes

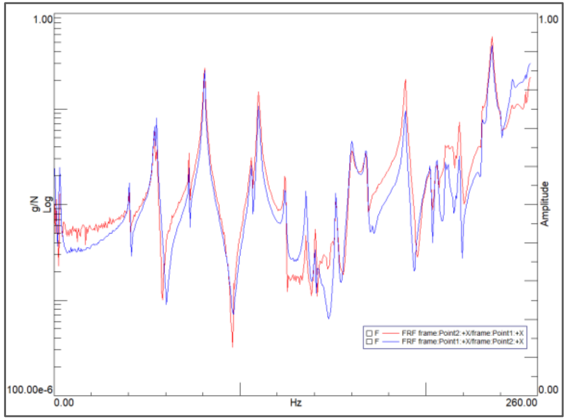


Figure 20- X Reciprocity of points 1 and 2.

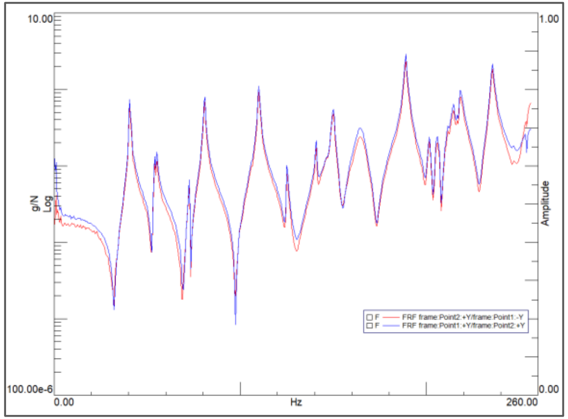


Figure 21- Y Reciprocity of points 1 and 2

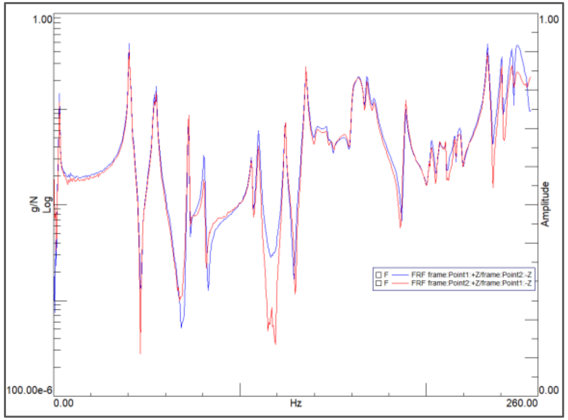


Figure 22- Z Reciprocity of points 1 and 2

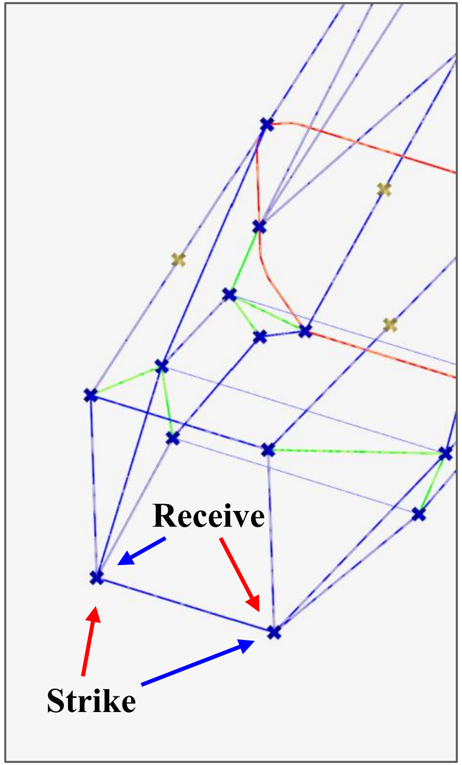


Figure 23- Strike and receive points for reciprocity test.

Test Validation included Modal Synthesis and M.A.C. comparison.

- Modal synthesis was analyzed with all mode shapes at all directions.

- While relatively high coherence was observed in many locations, different directions yielded relatively low coherence comparatively.

Figure 24- Modal Synthesis Sample

The M.A.C. Matrix confirms linear independence of the mode shapes.

- MAC comparison was used to determine the independence of the modeshapes compared to themselves.
- Mode 3 and mode 7 yielded near 25 percent dependence, physical analysis allowed for inclusion of both modes.

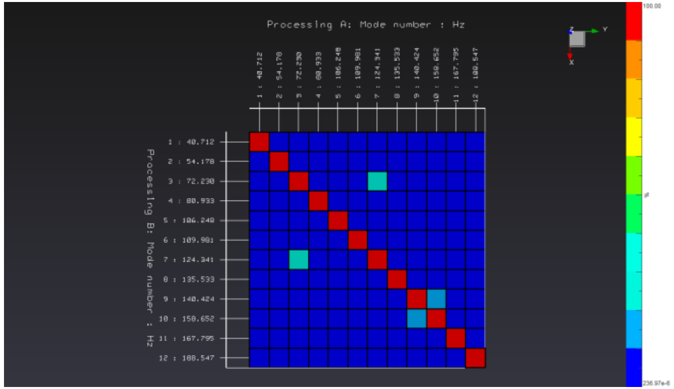


Figure 25- MAC Verification

Figure 26- Mode 7 compared to Mode 3

Our project was successful, but improvements to the test could be helpful to the MTU FSAE team.

- Goal of obtaining and analyzing mode shapes through expected operating frequencies of FSAE events was met.
- FSAE team can use information presented to refine chassis design within rulebook for desired performance characteristics.
- Further curve fitting analysis could potentially refine modal results even further.
- The team wishes to thank Dr. DeClerck and Dr. Taylor for aiding in supplying materials that made this analysis possible!

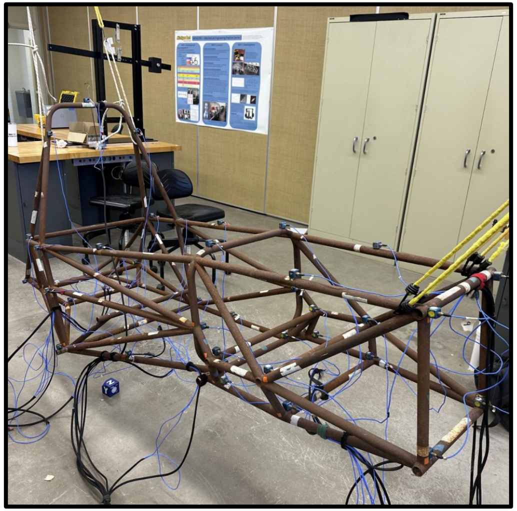


Figure 5- Accelerometers installed on suspended chassis.

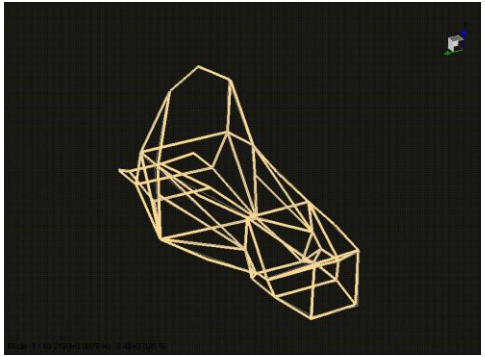


Figure 8- Mode 1 at 40.7 Hz