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Modal testing methodology of a missile fin structure

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Abstract
Modal testing is a form of vibration testing of an object whereby the natural frequencies, modal masses, modal damping ratios and mode shapes of the object under test are determined. A modal test consists of an acquisition phase and an analysis phase. The complete process is often referred to as a Modal Analysis or Experimental Modal Analysis. There are several ways to do modal testing but impact hammer testing and shaker (vibration tester) testing are commonplace. Impact hammer testing is ideal for small light weight structures; however as the size of the structure increases issues can occur due to a poor signal to noise ratio. In this project, we are testing a fin of a missile with impact hammer testing.

Keywords: Modal testing, mode shape, modal damping ratio, natural frequency.

1. Introduction
Modal testing is a form of vibration testing of an object whereby the natural frequencies, modal masses, modal damping ratios and mode shapes of the object under test are determined. Vibration is a phenomenon whereby oscillations occur about an equilibrium point. There are many types of vibrations. Free vibration occurs when a mechanical system is set off with an initial input and then allowed to vibrate freely. Examples of this type of vibration are pulling a child back on a swing and then letting go or hitting a tuning fork and letting it ring. The mechanical system will then vibrate at one or more of its "natural frequency" and damp down to zero. Forced vibration is when a time-varying disturbance (load, displacement or velocity) is applied to a mechanical system. The disturbance can be a periodic, steady-state input, a transient input, or a random input. The periodic input can be a harmonic or a non-harmonic disturbance. Examples of these types of vibration include a shaking washing machine due to an imbalance, transportation vibration (caused by truck engine, springs, road, etc.), or the vibration of a building during an earthquake. For linear systems, the frequency of the steady-state vibration response resulting from the application of a periodic, harmonic input is equal to the frequency of the applied force or motion, with the response magnitude being dependent on the actual mechanical system.

2. Problem Definition
In this study fin structure of a missile is considered to do modal testing for finding modal parameters like Structural Frequency Response Functions, Natural frequencies of the structure, Mode shape at each natural frequency, Modal damping ratio.

3. Design Specifications
3.1 Properties of Fin
Type of fin: clipped delta fin
Material used: Alloy Steel (mithani steel)
Young’s modulus 200 GPa
Density 7800 kg/m3
Poisson’s ratio 0.3
Allowable stress 1200 MPa

3.2 Specifications of Apparatus Used
3.2.1 Miniature ceramic shear ICO accelerometer specifications
Make – PCB
Model No – 352C41

3.2.2 Impact hammer specifications

- Impact hammer type: 8202 includes force transducer type 8200
- Sensitivity at output of hammer 101 pc/N (includes the built-in attenuation of approx. 12dB)
- The additional mass decreases frequency range approx. 30%
- Weight of plastic tip is 3,0g.

Table 1.1: Specifications of hammer

Type of tip	Force Range (N)	Duration-Range (ms)	Approx. Frequency Range (-10 dB) (Hz)
Rubber tip	100 – 700	5 – 1.5	0 - 500

Table 1.2: Accelerometer specifications and performance parameters

Performance	English	SI
Sensitivity	10 mV/g	1.02 mV/(m/s^2)
Measurement range	±500 g pk	±4900 m/s^2 pk
Frequency range (±5%)	0.5 to 10k Hz	0.5 to 10k Hz
Environmental Temperature-Range (operating)	-65 to +250 °F	-54 to +250 °F
Electrical Excitation Voltage	20 to 30 VDC	20 to 30 VDC
Constant Current Excitation	2 to 20 mA	2 to 20 mA
Physical Sensing Element	Ceramic	Ceramic
Sensing Geometry	Shear	Shear
Housing Material	Titanium	Titanium
Weight	0.10 oz	2.8 gm

4. Test Setup

The test setup for modal testing of fin is shown in Figure 4.1.

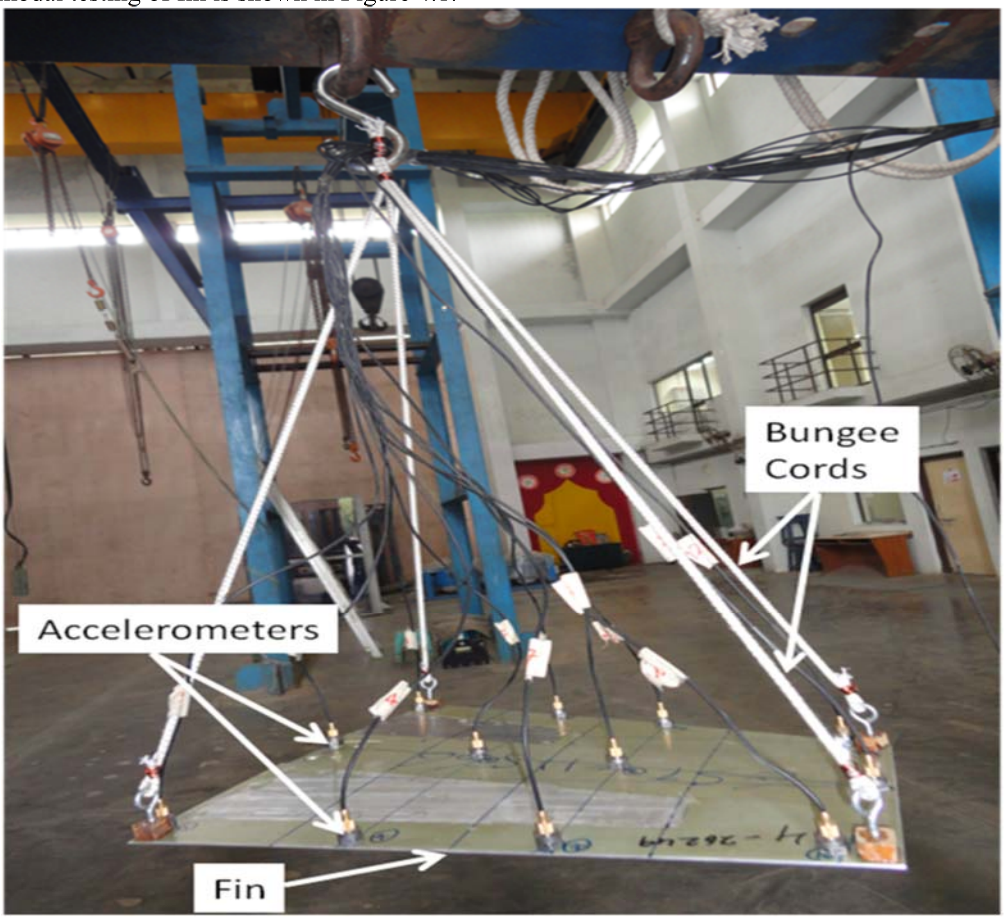

Fig 4.1: Photograph of the test setup

4.1 Suspension

The fin is suspended using bungee cords such that the suspension frequency is 1/10th of the first bending frequency of the fin. This ensures that the rigid body suspension frequencies are well separated from the first bending frequency and there is no interaction between the suspension and the bending modes.

4.2 Excitation

The fin is excited using an impact hammer at the center of the fin. The instrumented hammer consists of a force transducer. The output of the force transducer is connected to the input of the signal conditioner and the output of the signal conditioner is connected to the data acquisition system. The force levels are the excitation signals used as the reference inputs.

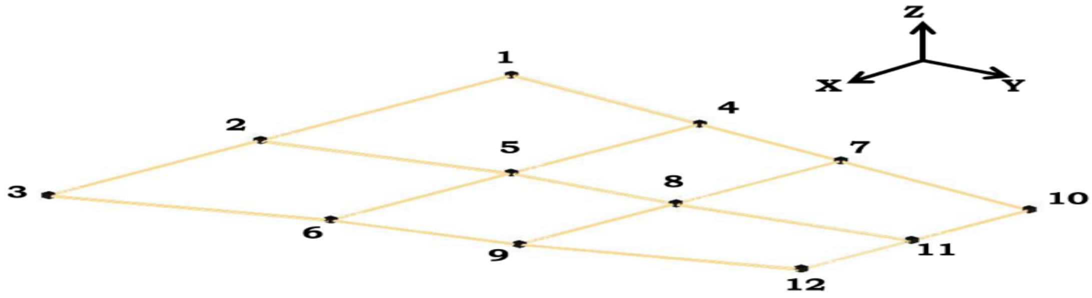

Fig 4.2: Locations of accelerometers on the fin

4.3 Response

Twelve accelerometers are mounted on the fin to measure the acceleration responses as shown in Figure 4.2. The output of each accelerometer is connected to the data acquisition system (SCADAS-III). The locations of accelerometers on the fin are given in Table 4.1.

Table 4.1: Location of accelerometers on the fin

Accelerometer	Location from tip of missile (m)		Accelerometer	Location from tip of missile (m)	
	X	Y		X	Y
1	0	0	7	0	0.21
2	0.16	0	8	0.105	0.21
3	0.295	0	9	0.205	0.21
4	0	0.12	10	0	0.33
5	0.12	0.12	11	0.075	0.33
6	0.235	0.12	12	0.145	0.33

4.4 Data acquisition

All the accelerometer outputs are connected to the SCADAS-III data acquisition system. The frequency response functions (FRF's) are obtained using in built DSP in SCADAS-III. The system can automatically adjust gains to get a better signal to noise ratio.

5. Test Procedure

The following test procedure is used to obtain the modal parameters.

a) The fin is suspended using bungee cords.
b) Twelve accelerometers are mounted on the fin in the plane of excitation.
c) The impact hammer is used to excite the fin in the range (0 - 500 Hz) such that the bending frequencies of the fin are covered. The amplitude of the force excitation is adjusted till a good signal to noise ratio is obtained.
d) The responses of all the accelerometers are obtained using LMS data acquisition system. Test. Lab software is used to obtain the FRFs.
e) The frequency response functions (FRFs) at station 'i' are obtained as below.

$$FRF_{ij} = \frac{\ddot{x}_i}{F_j}$$

where, $\ddot{x}_i$ is the acceleration output at station 'i' for i=1 to no. of accelerometers. F_j is the excitation force from the hammer

f) From these FRFs, structural frequencies are identified as peaks in magnitude plot and corresponding 180^0 phase change.
g) From these responses, the normalized amplitudes for a particular bending frequency are obtained and the experimental mode shape is constructed.
h) Half power method is used to obtain the modal damping ratios.

6. Results and Discussions

6.1 Frequency Response Functions:

A typical frequency response function at accelerometer location 5 is shown in Figure 4.2. From FRF's obtained, peaks are identified at 5.80 Hz, 250.59 Hz and 339.69 Hz. At these natural frequencies, experimental mode shapes are obtained and are shown in Figure 6.1, Figure 6.2, Figure 6.3 and Figure 6.4.

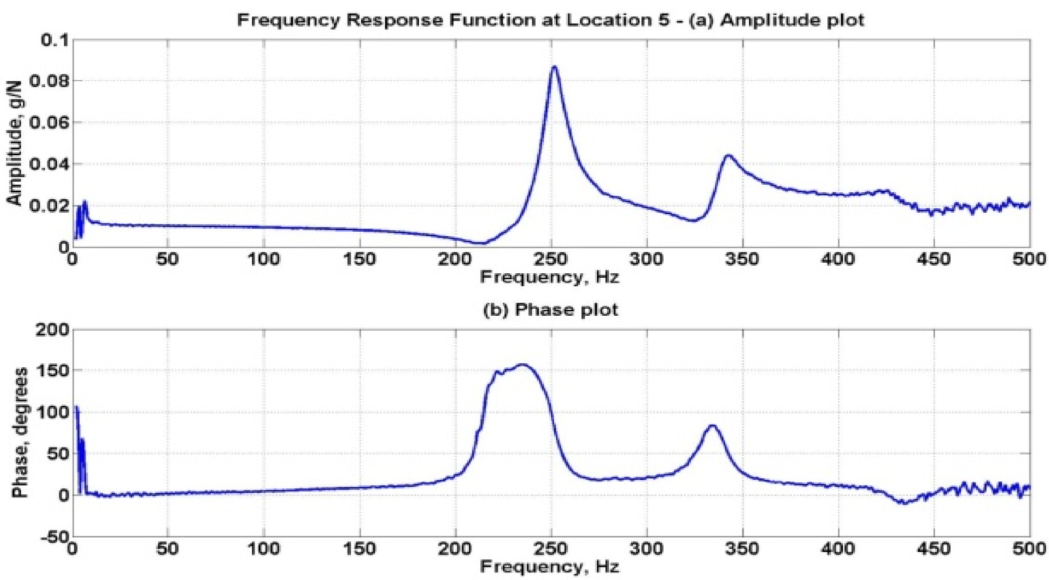

Fig 6.1 Typical frequency response functions at location 5 on the fin

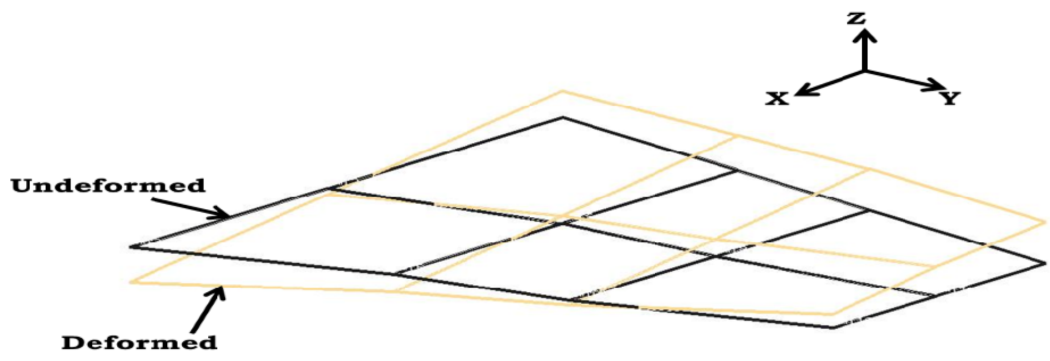

Fig 6.2: Mode shape of the fin at 5.80 Hz

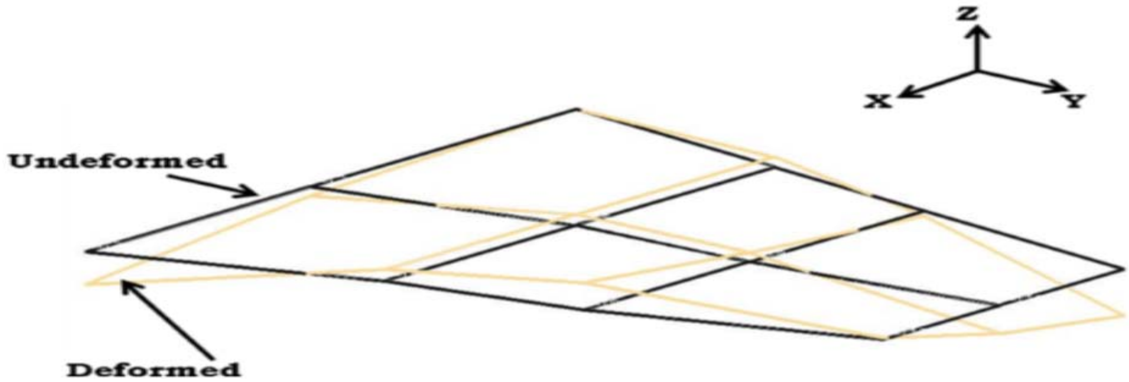

Fig 6.3: Mode shape of the fin at 250.59 Hz

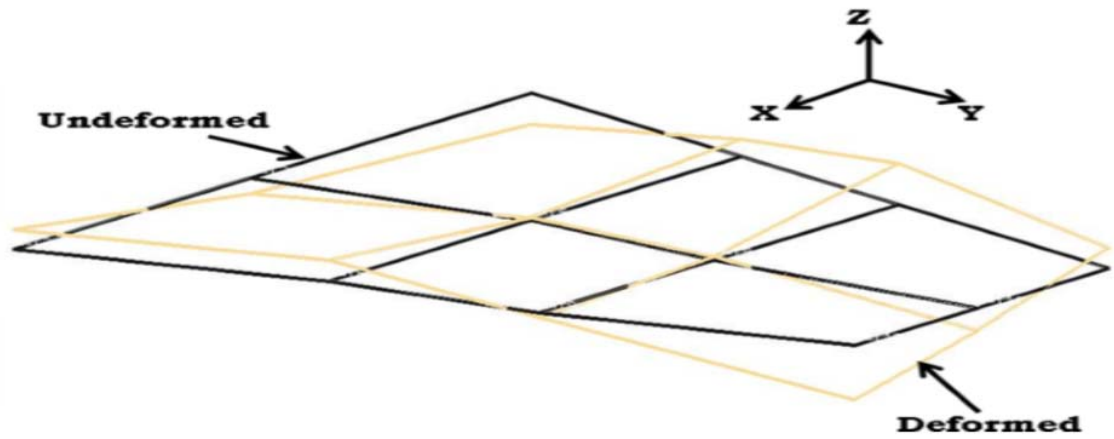

Fig 6.4: Mode shape of the fin at 339.69 Hz

Table 6.1: Natural Frequencies and modal damping ratios of the fin

Mode	Frequency, Hz	Modal damping ratio, %
I	5.80	8.74%
II	250.69	2.05%
III	339.59	2.06%

7. Conclusions
From the mode shape plots, it has been observed that: a mode shape at 5.80 Hz is a rigid body mode, mode shape at 250.59 Hz is a bending mode and mode shape at 339.69 Hz is a twisting mode of the fin.

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