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IDENTIFICATION OF MODAL PARAMETER ON THE PAYLOAD STRUCTURE DURING THE VIBRATION TEST USING OPERATIONAL MODAL ANALYSIS

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Abstract. *Rockets' payload is subjected to an intense environmental vibration during the launch that excites its natural frequencies that could cause interferences on the embayed systems. Operational Modal Analysis was performed on the Payload during vibration test in order to identify natural frequencies and the modal shapes. All measurement were performed with 34 channel equipment that monitored dynamical signal collected in equidistant points of the structure of the Payload, where we have used 30 uni-axial sensors on the X and Y axes and one tri-axial sensor on the top of the structure. The structure was excited by an electrodynamics' shaker. The results obtained showed that the payload structure has a spin behavior coupled with the modal shapes which could be due to unbalancing forces acting inside the structure. The identification of the modal shapes acting with spinning was an important issue that could help to prevent the instability of the payload during the free-flight phase.*

Keywords: *Modal Analysis, vibration modes, Payload, identification in the frequency domain, OMA®.*

1. INTRODUCTION

1.1 Modal Analysis

The vibrations environments to which the rocket payloads are exposed during launch can generate damage to equipment on board or even jeopardize the entire mission (Harris, 1996). To reduce unwanted vibrations in a large structure is necessary, at first; know the natural oscillations of the system (Doyle, 1997). In this context, it is necessary to monitor the structure under different operating conditions and also the identification of its main parameters of vibration. Methods for identifying such as Modal Analysis are widely used for the determination of natural frequencies and damping factors of the system (McConnel, 1997).

The Modal Analysis is a procedure used to investigate the dynamic behavior of mechanical systems. This behavior is described by its dynamic properties: natural frequency, damping and vibration modes (Ewins, 2000). The Modal Analysis can be divided into three major areas: Theoretical, Operational and Experimental Modal Analysis. In Theoretical Modal Analysis, systems can be represented by mathematical models; Experimental Modal Analysis in classic, the dynamic characteristics of the model are derived from the transfer function that defines a direct relationship between input and output of the system (Maia et al, 1997);

Operational Modal Analysis, the technique employed in this work, the input forces are not measured, an analysis is performed based on the measured responses of the structure during the test conditions (Camargo et al, 2011). However, as the input forces are not measured, it is not possible to obtain and Frequency Response Functions (FRFs) of the system. The identification of modal parameters is based on Singular Value Decomposition (SVD) and the entry is regarded as white noise.

This article reports the tests conducted in the payload in order to simulate the environmental conditions encountered during the rocket launch. The tests were done using an electrodynamics' vibrator where the payload was attached. The Modal Analysis used to identify the operating modes of the payload and damping, were made with 34 channels measuring system and the responses were measured at equidistant points. In order to compare the results, the Enhanced Frequency Domain Decomposition Method (EFDD) in the frequency domain method and the Stochastic Subspace

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Identification (SSI) in the time domain were used to identify the modal parameters, as it will be explained in the following sections.

1.2 Enhanced Frequency Domain Decomposition (EFDD)

Enhanced Frequency Domain Decomposition (EFDD) is the frequency domain analysis technique (Gade et al, 2005) where each measured signals are associated, on the power spectral density matrix, as a singular value decomposition (SVD), creating values and singular vectors. Through these values and singular vectors, the dynamic parameters of the analyzed structure, such as natural frequencies, damping ratio and mode shapes, can be estimated.

1.3 Stochastic Subspace Identification (SSI)

Stochastic Subspace Identification (SSI) is the time domain technique where the system response is represented by the Hankel matrix and the size of the matrix represent the maximum number of the model order. Results are taken by a singular value decomposition of the matrix and the modes in the model are extracted of the subspace thus dynamic parameters of the structure are estimate (Brincker and Andersen, 2006). The SSI technique use three different algorithmics to stimate the modal parameters: Unweighted Principal Component (UPC), the Principal Component (PC) and the Canonical Variated Analysis (CVA). This paper use the SSI - PC algorithmic to estimate the parameters of the Payload structure.

2. MATERIAL AND METHODS

The proposed experimental setup was carried out with 34 channels, divided into two frames with 17 channels each, which monitor the dynamics of the signal collected. Measurements were performed using 30 unidirectional accelerometers (15 in X axis and 15 in Y axis) and one tri-axial accelerometer was placed on the top of the structure as shown in Figure 1, in order to measure the X, Y and Z axes. The payload was placed on the table of electrodynamics' vibrator, shaker, and excited by a white noise. The data acquisition was performed using the software called LabShop® and Operational Modal Analysis was performed with the software called OMA® both from Brüel & Kjer (B & K).

2.1 The payload

The VSB-30 is two stages sounding rocket without active control and belongs as result of partnership between the Institute of Aeronautics and Space (IAE) and Deutschland fur Luft-und Raumfahrt (DLR). The first stage consists of a propellant booster called S31 and the second stage consists of a propellant booster called S30, both stages provide a high accelerating the rocket.

This article refers to the payload dynamic acceptance test (DAT) where the payload is exposed to intense vibration, in all three, axes regarding environmental conditions of flight vehicle VSB-30. The structure of the payload was fabricated in carbon steel 1020 and has 3300mm in length, 430 mm in diameter and the geometry used to perform the analysis, in the OMA software, was discretized into fifteen sections in the radius and twelve rows along the length as can be seen in the Fig. 1.

2.2 Experimental setup

Along the structure of the payload, accelerometers, type 4508B, were placed in the X and Y axes and one tri-axial accelerometer, type 4520, was placed at the top of the structure. A schematic drawing of the experimental setup is shown in Fig. 1. A single axis vibration test system and a closed-loop vibration control system were employed to generate the vibration corresponding to the excitation spectra defined.

The LDS V964LS shaker has a maximum output force of 89kN and it can excite within a 5-3000Hz range. The LDS V964LS power amplifier magnifies the drive signal from the Spectral Dynamics Jaguar shaker controller and sends it to the shaker to excite the structure. The acceleration was measured on the slip table along the direction of primary vibration excitation and it was used as the feedback control signal; while the control system generates the acceleration PSD derived from the excitation spectra.

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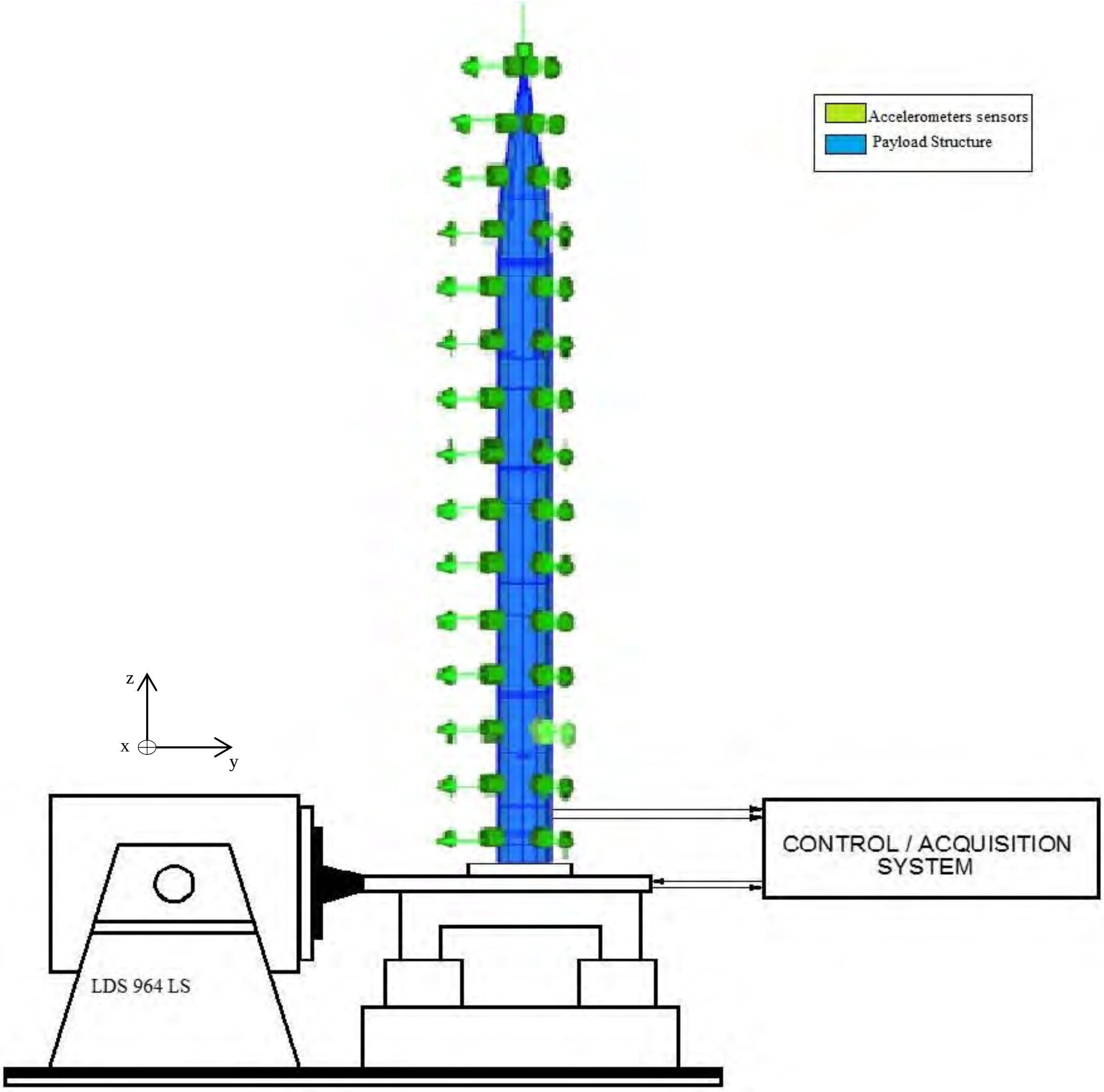

Figure 1. A schematic drawing of the experimental setup.

2.3 Vibration Excitation Spectra

In the random vibration, the most common approach to analyze the recorded signal is to decompose it into its component frequencies, represented by the power spectral density (PSD) (Harris, 1996). The acceleration PSD proposed represent the vibration characteristics in the Y direction as it is shown in Fig. 2. A tolerance of ±6 dB was defined in the 20 Hz to 2000 Hz frequency range. The RMS acceleration value due the vibration excitation spectra was 12.77 g rms, applied along of each vibration axis during 2 minutes.

Table 1 shows the values used to set-up the shaker control systems and to generate the vibration spectra

Table 1. Profile Table

Frequency Hz	Acceleration $(gn)^2$/Hz	Slope dB/Oct
20.0	0.004	1.62
400.0	0.02	0
2000.0	0.02	-

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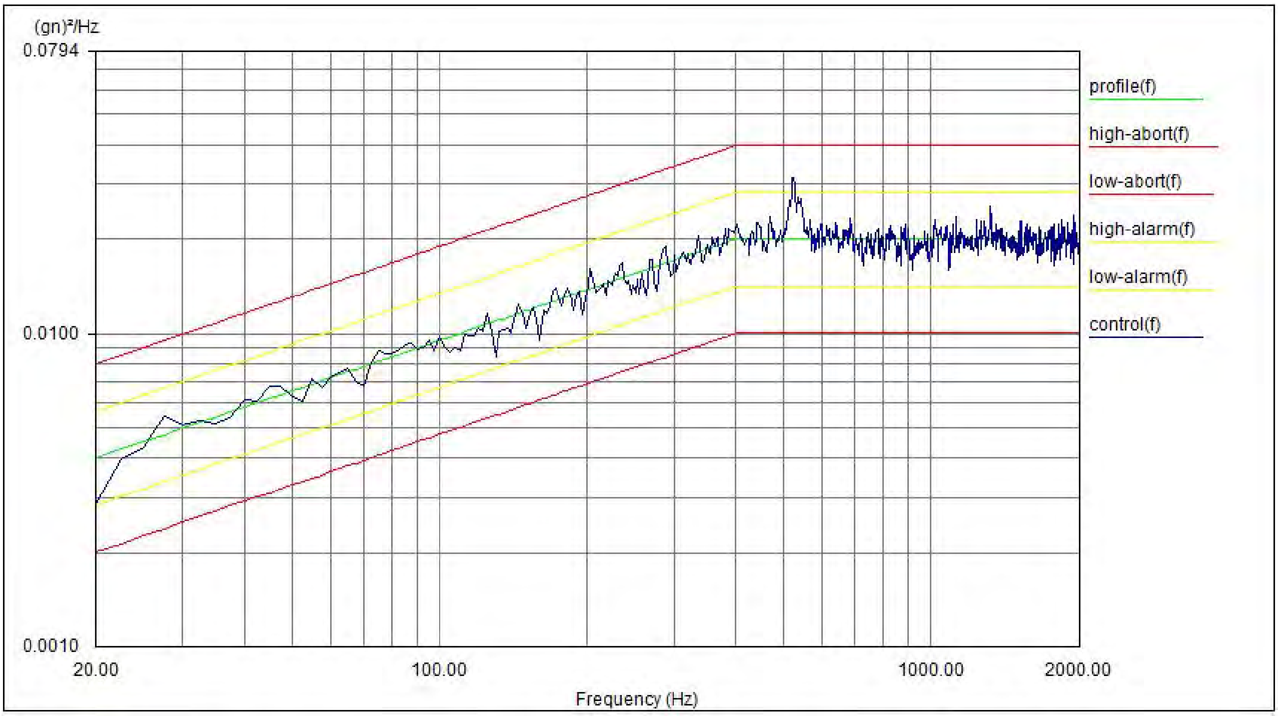

Figure 2. Vibration excitation spectra

3. RESULTS

Measurements were done in two axes (X and Y axes) in order to compare the symmetry of the structure and to obtain the modal parameters.

3.1 X axis

In the X axis, the analysis was done using EFDD method and the modal parameters found are shown in Tab. 2. It was observed a slight circular motion around the axis in a counterclockwise direction with reference to the observation from the top of the payload. This circular motion is present in the high frequency modes (4th Mode and 5th Mode). The modal shapes of the structure, obtained when the excitation was applied to the X axis, can be seen in the Fig.3 and show clear and well defined modes, the damping ratio obtained also show good agreement with the experimental results obtained using experimental modal analysis.

Table 2. X axis results

Mode	Frequency (Hz)	Damping (%)	Mode description
1st Mode:	52	4.05	First bend mode
2nd Mode:	140	4.1	Second bend mode
3rd Mode:	224	9.04	Third bend mode
4th Mode:	432	3.71	Fourth bend mode

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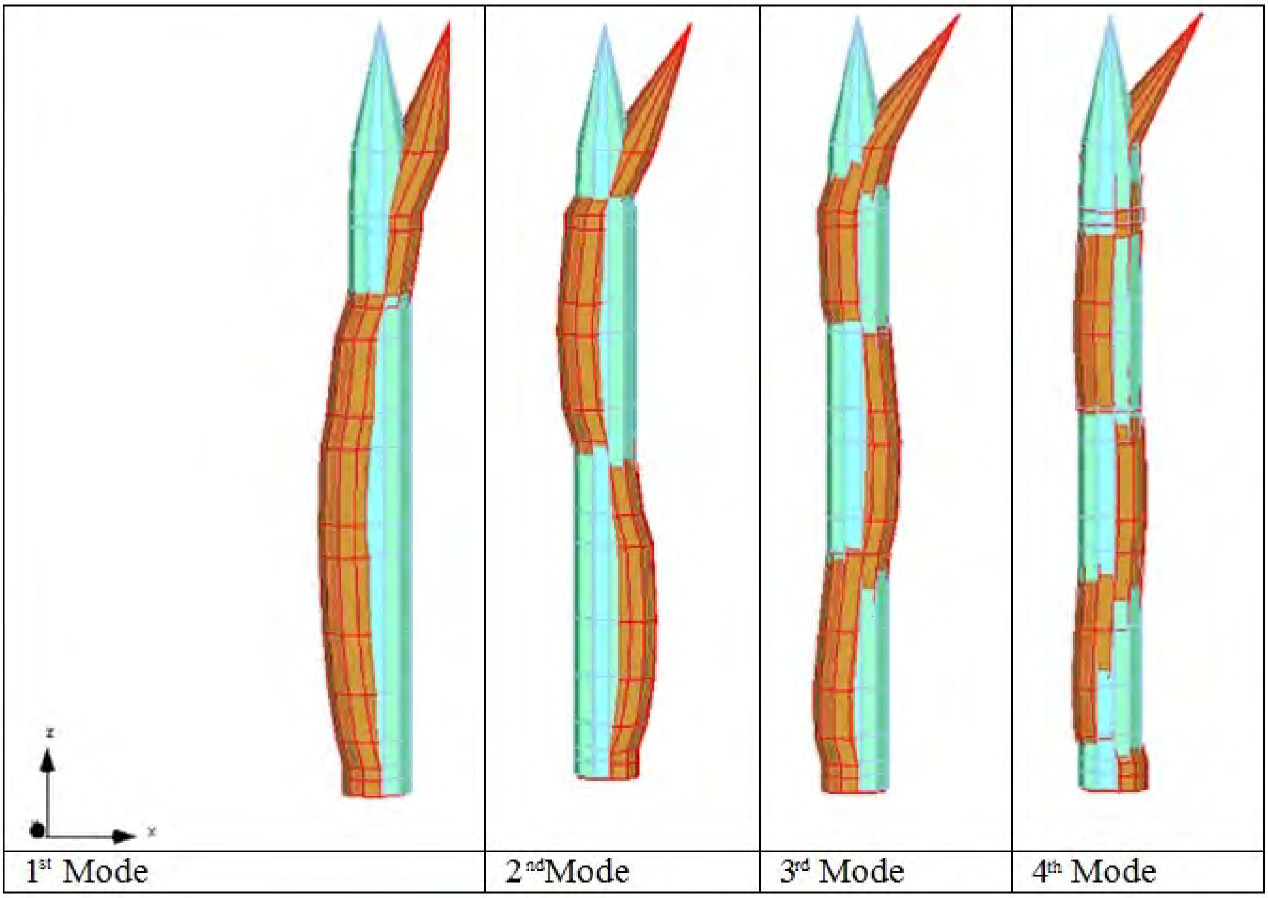

Figure 3. Modal shapes related to the X axis excitation.

3.2 Y axis

In the Y axis, the analyses were done using EFDD and SSI methods and the modal parameters found were show in the Tab. 3.

Table 3. Y axis results

	Frequency (Hz)		Damping (%)		
Modes	EFDD	SSI	EFDD	SSI	Mode description
1st Mode:	51.42	51.07	3.5	3.65	First bend mode
2nd Mode:	141.8	140.6	4.65	2.51	Second bend mode
3rd Mode:	223.1	223.7	7.35	3.29	Third bend mode
4th Mode:	403.6	416.4	3.71	1.44	Fourth bend mode

As can be seen in the Fig. 4, the modal shapes of the structure, obtained when the excitation was applied to the Y axis, show clear and well defined modes and the results of both methods has a good agreements in terms of frequency, also compared with the X axis results. The damping ratio, considering the EFDD method agrees with the X axis results with slightly difference for the 2nd, 3rd and 4th modes. The analysis done with SSI methods shows results closer to the experimental results compared to the EFDD method and its can be due to the better algorithmic used for the damping estimation used in this method and also can be due to the reduction in the frequency range during the analysis.

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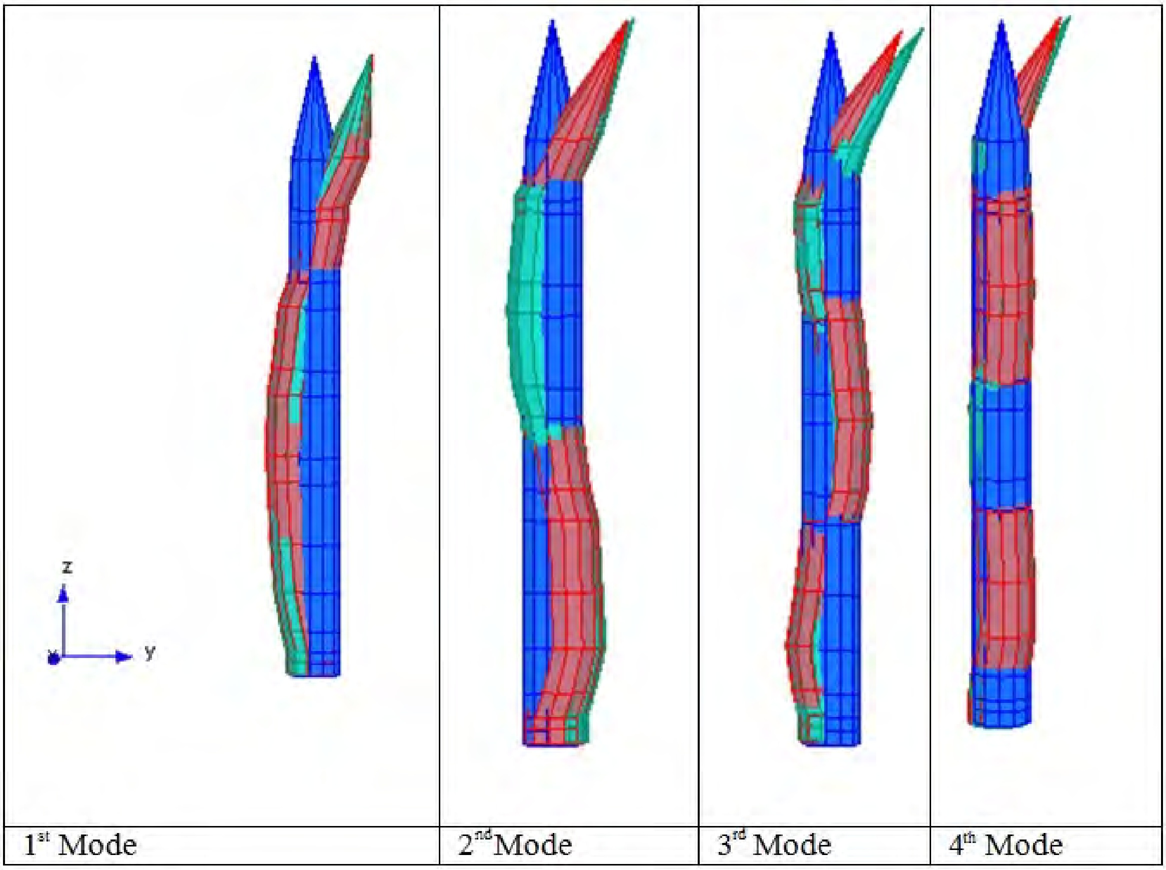
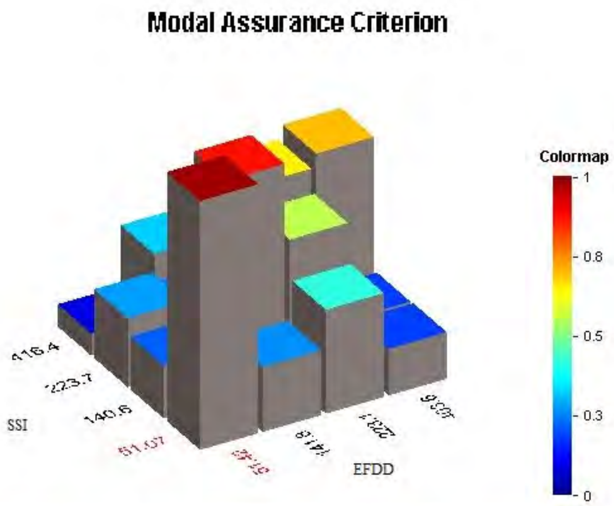


Figure 4. Comparison methods of SSI (in light blue) e EFDD (in red). Dark Blue is related to the static body.

In order to verify the orthogonallity between modes and validate the modal analysis performed at different methods presented above, we used the MAC®, that calculates the model assurance criterion and the results of the comparison can be seen in Fig. 5.



EFDD / SSI	51.07 Hz	140.6 Hz	223.7 Hz	416.4 Hz
51.42 Hz	0.9895	0.2111	0.274	0.08913
141.8 Hz	0.2586	0.8734	0.2332	0.3314
223.1 Hz	0.4128	0.5664	0.6568	0.3281
403.6 Hz	0.1654	0.1822	0.7112	0.0239

Figure 5. MAC comparison

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The results obtained with the MAC for the first two modes had values above 0.8 showing good correlation between the methods, but the following two modes (third and fourth), MAC values were below the limit of 0.8, showing that despite modes are similar in shape mode, matrix components by the estimates used did not correlate well. This results might be due to the time required for stabilization mode, longest data acquisition time probably cause an improvement in the correlation of modes.

4. CONCLUSIONS

This work presents an experimental investigation on the dynamic behavior of the payload of the VSB-30 sounding rocket. The measurements were conducted during DAT Test and showed good behavior when subjected to rigorous environmental conditions of the launching and flight of the rocket. The identification of the main modes of vibration of the payload was presented and analyzed using the software OMA. Two algorithms methods, EFDD and SSI, were used to compare the modes found when the excitation was applied to the Y axis of the payload. The results obtained by the methods EFDD and SSI showed a rapid stabilization of the poles for the whole frequency range analyzed, thus showing a quick and with very clear results. Regarding the result of the MAC ®, the first mode had an excellent orthogonally during the comparison; however the high frequencies modes did not have the same good orthogonally. The values of damping ratio were similar, for the two axes, when using the EFDD algorithm, but with different values for modes 2nd, 3rd and 4th compared with the SSI algorithm, however the results were inside the 10% expected for this kind of structure. The results obtained, also, show that the payload structure has a spin behavior coupled with the modal shapes which could be due to unbalancing forces acting inside the structure.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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