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# OPERATIONAL MODAL ANALYSIS IN HELICOPTER STRUCTURES CONTAINING HARMONIC EXCITATIONS

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**ABSTRACT**

*Operational modal analysis is a method that is useful to find dynamic characteristics of a structure without measuring the force signal. In this paper, operational modal analysis method is applied to helicopter structure that contains harmonic excitations due to main and tail rotor. In the operational flight tests, a certain number of accelerometer data were collected from the military helicopter tail structure. Operational modal analysis steps were applied using the collected vibration data using the LMS Testlab® program. As a result of this analysis, harmonic filtering processes have been carried out in order to determine natural frequency and mode shapes. The results obtained were compared with ground vibration tests (GVT) results.*

## INTRODUCTION

Operational modal analysis (OMA) is an analysis method that does not require force measurement and only needs to measure responses. This method is especially used for bridges, buildings, etc. for a long time with successful results. In recent years, the method has started to be used in mechanical engineering applications in road conditions, flight tests etc [Peeters, Manzato and Auweraer, 2013].

The main reason for OMA being preferred is ease of application. Particularly in buildings, it is not possible to give the controlled amount of enough force to the structure. Another possibility is that it may not be appropriate for the building to be reserved for time-consuming classic modal test. In addition, the actual operating conditions (rigidity due to load, preloads on fasteners and structures, aero-elastic interactions etc.) may vary from laboratory test conditions. The results obtained with the measurements taken in the working conditions are more realistic, as they contain non-linear effects.

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Operational modal analysis procedure illustrated schematically in Figure 1. Since the force data is not measured in the operational modal analysis, preliminary assumption is made as equal input force in all frequencies (White noise) is applied as input [Brincker and Ventura, 2016]. However, since harmonic excitations such as helicopter rotor frequency, car motor

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rotation frequency etc. are not suitable for this preliminary assumption, the inputs at these frequencies must be filtered.

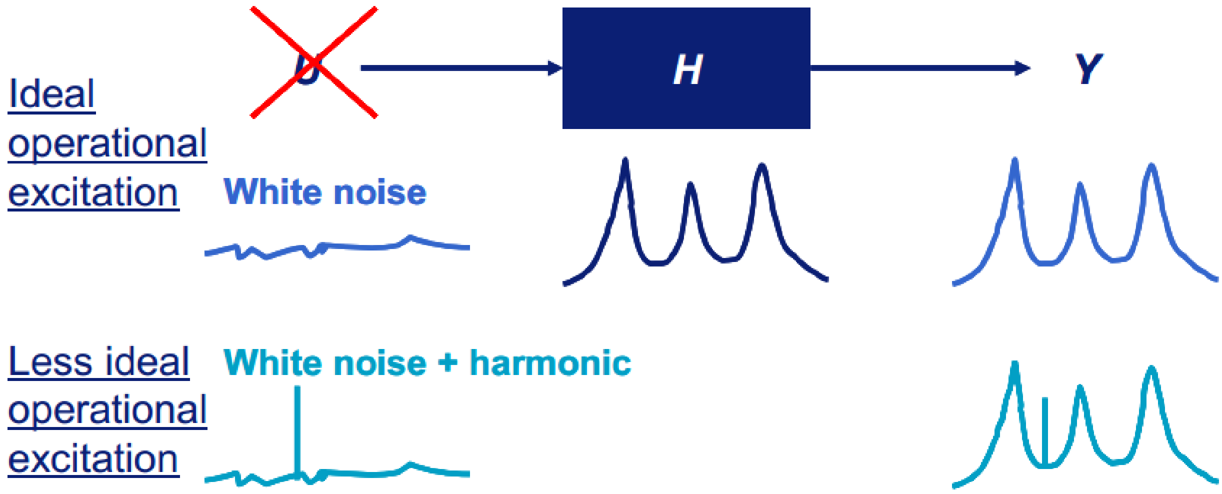



Figure 1: Operational Modal Analysis Schematic Presentation

**Harmonic Filtering**

In order to apply the harmonic filtering method, excitation rpm information is required. This information needs to be measured instantaneously with a tachometer, especially for structures such as vehicle engines. It is also possible that the rpm data can be obtained from the response data for constant rpm vehicles like helicopters. The harmonic filtering method applied in this study consists of the steps of estimating fundemantel frequencies of the helicopter, re-sampling the data in the angle domain, time synchronous averaging to remove orders and restoring original signal in time domain [Peeters, Cornelis, Janssens and Auweraer, 2007].

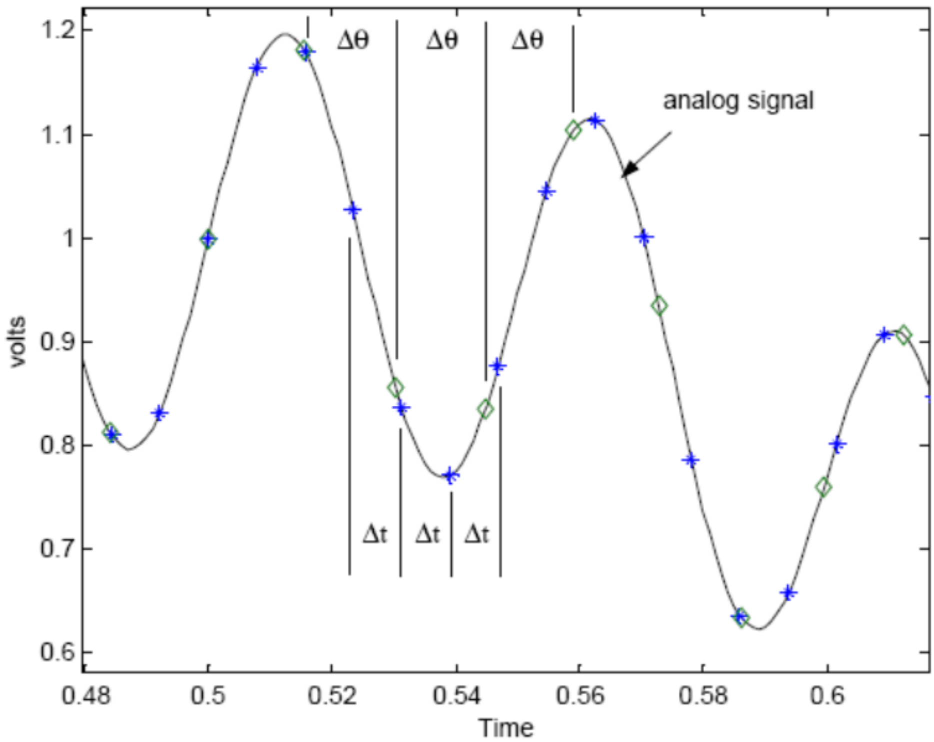



Figure 2: Harmonic Filtering Re-Sampling Demonstration

For example, as shown in Figure 3, the helicopter vibration data includes high amplitudes in excitation frequencies originating from the main rotor and tail rotor actuators.

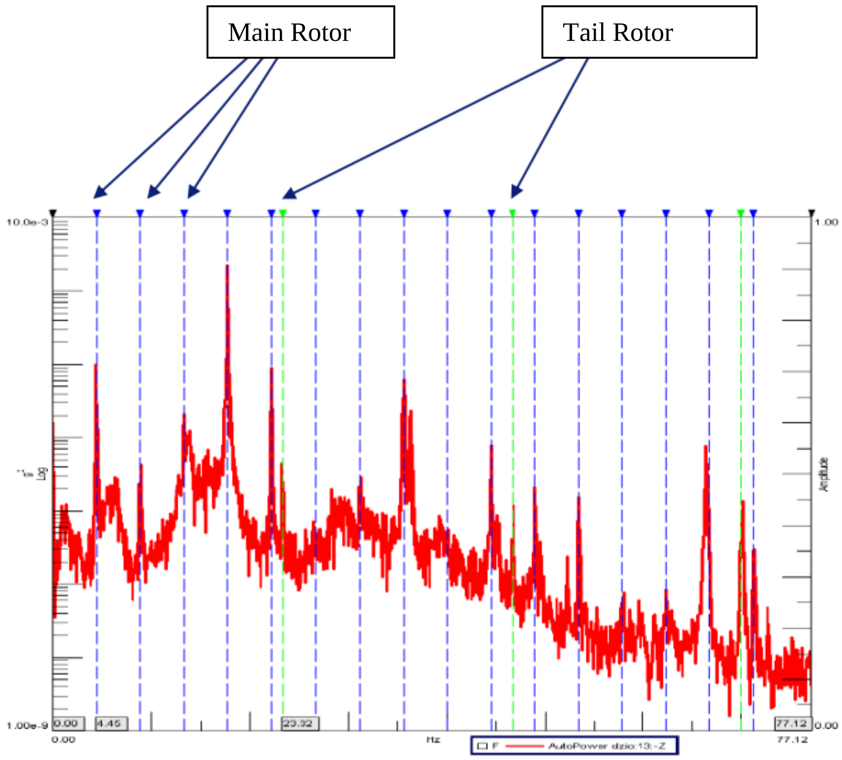



Figure 3: Harmonic Filtering Re-Sampling Demonstration

In the harmonic filtering process, as shown in Figure 4, the high amplitude in the filtering frequency disappears and an anti-resonance-like low amplitude region is formed according to the degree of filter. When the filter grade is low, the filtering performance increases, but the low amplitude region becomes more pronounced. This increases the useless frequency range. When the filter level is raised, the low amplitude region is reduced the most, but filtering at some harmonics may fail.

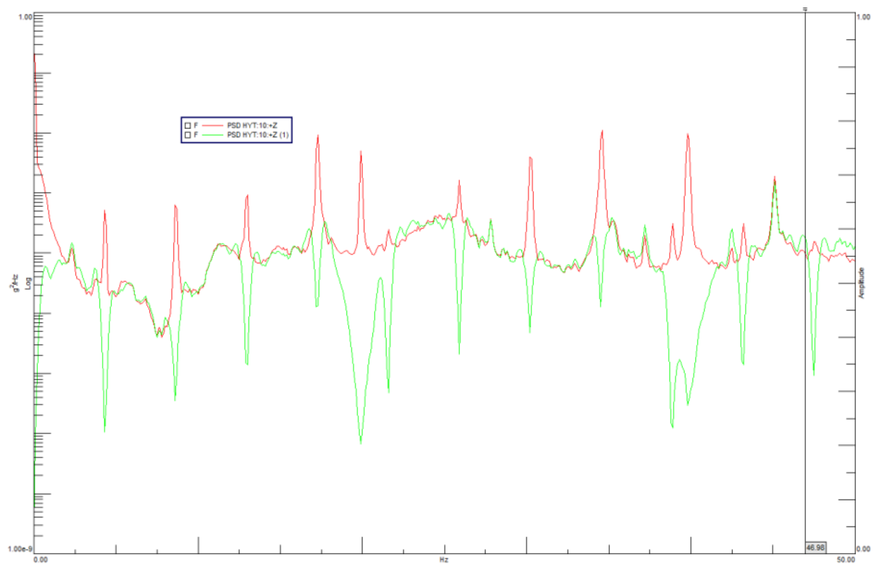


Figure 4: Sample Filtered Helicopter Vibration Data (Red: Unfiltered Data, Green: Filtered Data)

**Test Procedures**

OMA Test: In operational flight tests, accelerometer data were collected by using DEWE-501® data acquisition system at different speeds and altitudes in the vertical (Z) and horizontal (Y) directions from the points shown in Figure 5 to use in OMA.


Figure 5: Operational Flight Tests Accelerometer Locations

Ground Vibration Test: GVT is conducted by using 2 shakers which are used to excite the tail structure in both vertical and lateral directions and 45 accelerometers which collect the data in the vertical (Z) and horizontal (Y) directions. The number of accelerometers are more than operational flight tests since the GVT results are also used in finite element model updating of the tail structure [Ersoy, Genç and Atasoy, 2016].

General test setup including the shakers in vertical position and accelerometers is given in Figure 6.

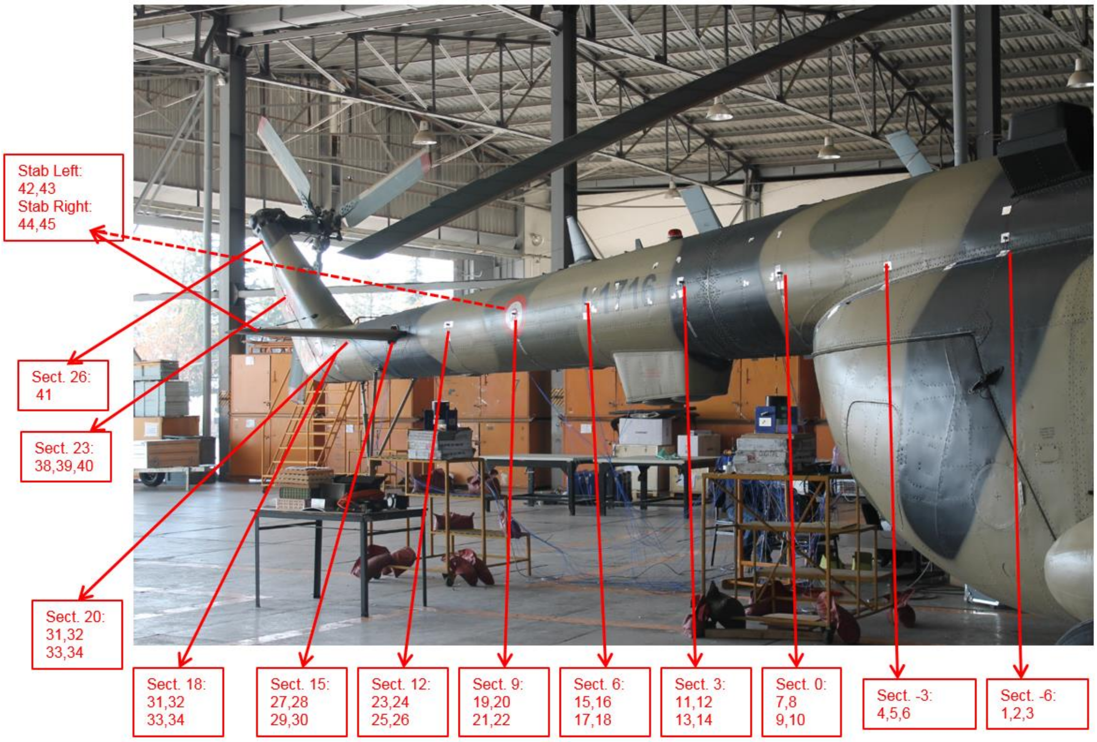



Figure 6: Ground Vibration Test Accelerometer and Shaker Locations

To make separate the rigid body modes and the flexible modes of the helicopter, tyre pressures are decreased as in Figure 7.


Figure 7: Tyre Pressure Degradation of the Helicopter

**OMA and GVT Results**

OMA and GVT results are calculated by using LMS Testlab Software® and similar modes are compared in Figure 8-Figure 11.

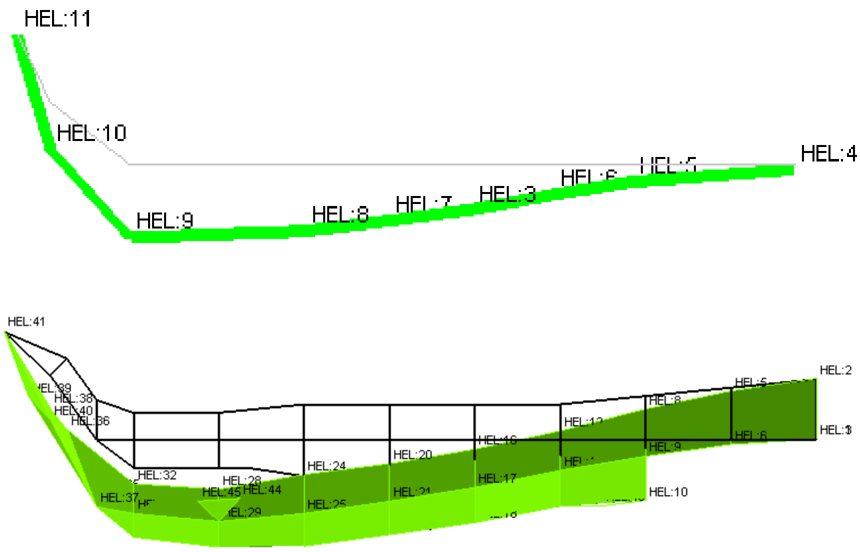
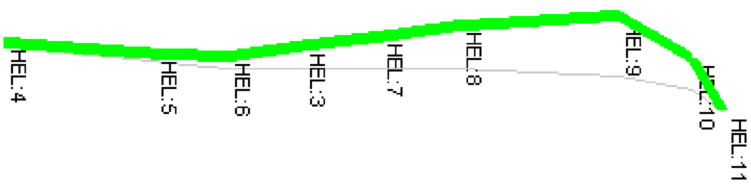



Figure 8: OMA (Top) and GVT (Bottom) 1. Mode Comparison (Vertical 1. Body Bending Mode)



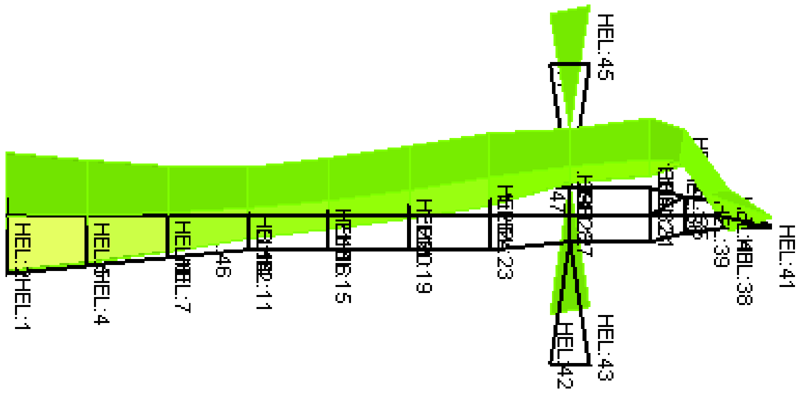


Figure 9: OMA (Top) and GVT (Bottom) 2. Mode Comparison (Lateral 1. Body Bending Mode)

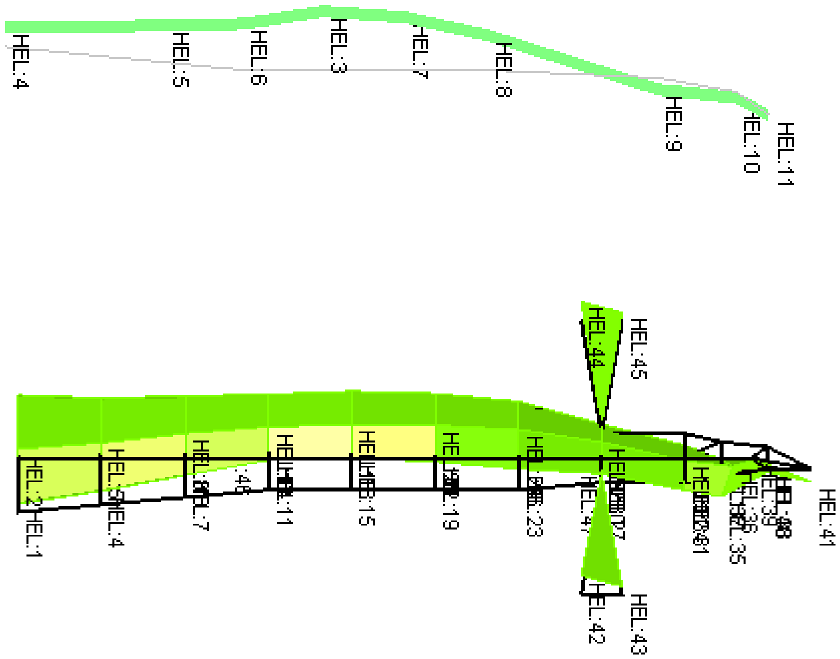
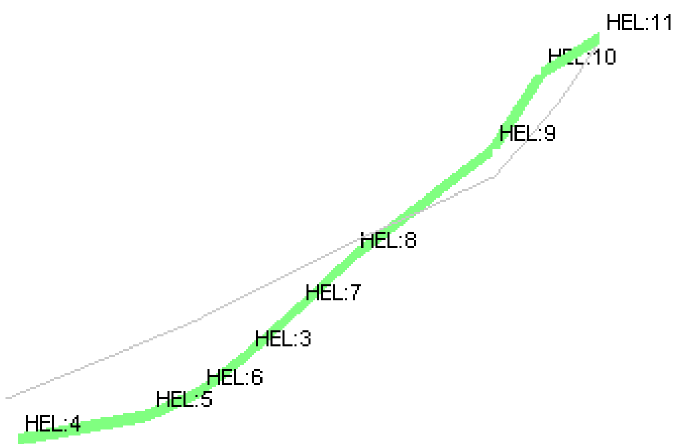


Figure 10: OMA (Top) and GVT (Bottom) 3. Mode Comparison (Lateral 2. Body Bending Mode)



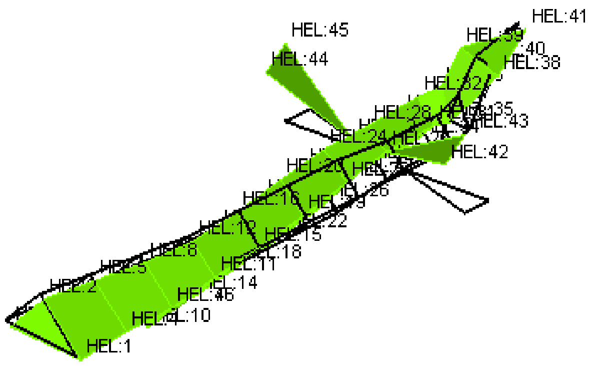



Figure 11: OMA (Top) and GVT (Bottom) 4. Mode Comparison (Vertical and Lateral Body Bending Mode)

MAC (Modal Assurance Criterion) function is a useful tool to compare the results of different kind of modal parameter extraction methods such as classical modal analysis with GVT results and to obtain correlations of mode shapes [Ersoy, 2014].

In this work, MAC method is used to compare mode shapes extracted from GVT and OMA. Equation 1 is used when MAC is calculated. In this equation, $\{\boldsymbol{\varphi}\}_r$ and $\{\boldsymbol{\varphi}\}_s$ are 2 related modes. MAC = 1 indicates perfect correlation and MAC = 0 indicates no correlation. For practical applications, for example for finite element model validation according to the modal test results for space projects, it is stated that for the basic bending mode MAC value shall be greater than 0.9 and the frequency deviation shall be smaller than % 3. For other modes, the MAC value shall be larger than 0.8 and the frequency deviation shall be smaller than 10% [ECSS Requirements & Standards Deviation, 2008].

$$\boldsymbol{MAC_{rs}} = \frac{\left|\{\varphi\}_r^T\{\varphi\}_s\right|^2}{\left[\{\varphi\}_r^T\{\varphi\}_r\right]\left[\{\varphi\}_s^T\{\varphi\}_s\right]} \tag{1}$$

MAC values for the first 4 modes are given in Table 1. The MAC values for the first 2 modes are high enough, while the MAC values are lower for 3rd and 4th modes. It is evaluated that different boundary conditions may be more effective for higher modes and that higher modes may not be excited in flight conditions for OMA.

Table 1: GVT-OMA MAC Values

| | |
|---|---|
| $MAC_{11}$ | 0.786 |
| $MAC_{22}$ | 0.877 |
| $MAC_{33}$ | 0.548 |
| $MAC_{44}$ | 0.340 |

## RESULTS AND DISCUSSION

According to the obtained results, it is evaluated that operational modal analysis method can be practically applied in helicopter structures by distinguishing excitation frequencies using harmonic filtering method. GVT is a costly and time consuming test method. OMA is evaluated to be an alternative practical method to demonstrate that the aircraft is dynamically secure in different flight configurations. Considering the test results obtained, it is evaluated that the method gives reliable results especially for the first modes which are effective in dynamic behaviour of the helicopter.

As future work, harmonic components can be automatically detected by using Kurtosis Function which checks probability density function in each frequency and determines the harmonic components since they do not have Gaussian distribution together with different methods like Curvefit Frequency Domain Decomposition [Gade, Schombls, Hundeck and Fenselau C, 2009].

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