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MODAL ANALYSIS OF THE SMALL SPACECRAFT DYNAMIC MODEL

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ABSTRACT

Precise spacecraft FEM (finite elements models) are needed in order to obtain relevant forces acting on the spacecraft elements. Modal analysis of the space-rocket hardware being part of ground test campaign of any promising technology in this domain allows to obtain elements' frequency responses for further models' correlation. The goal of the present research is "Aist-2D" spacecraft FEM verification and confirmation by means of dynamic behavior of the spacecraft experimental data and calculus results comparison. In the frame of this research continuous-scan laser Doppler vibrometry (CSLDV) was used to recover the elements' modes' shapes and frequencies and modal analysis by calculation was performed using finite elements analysis by means of MSC.Patran/Nastran software. An experimental method of the dynamic behavior determination of the space-rocket hardware has been developed on the basis of "Aist-2D" example. A comparison of the elements' modal characteristics obtained by test and by calculation has been performed. During tests resonance frequencies were determined in 5-70 Hz band (this frequency band being considered as the most relevant because of the structural first modes). spacecraft elements' dynamic characteristics obtained in this research will allow for more accurate spacecraft dynamic models at preliminary design phase which itself will ensure more accurate results of the forces calculation acting on a spacecraft therefore improving their reliability.

Keywords: Modal analysis, spacecraft, dynamic model.
I-INCE Classification of Subject Number: 42

1. INTRODUCTION

The small spacecraft (SSC) "AIST-2D" (Figure 1) is designed for Earth remote sensing and scientific experiments, as well as for testing and certification of target,

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scientific equipment, support systems and their software for further use in advanced developments and improving the training of highly qualified specialists in the space industry.

The satellite platform has a mass of about 250 kg, and together with the target and scientific equipment, the total mass of the SSC is 531.4 kg. According to the international classification, it is included in the niche of small spacecrafts.

The “AIST-2D” space platform allows the use of various types of target equipment, in particular, a hyperspectrometer. The chosen platform construction provides an opportunity to significantly increase the area of solar cell batteries and ensure the use of electric jet engines to keep the orbit. A low-cost upgrade of communications and controls of the device is possible, which significantly increases its reliability and active operation life.

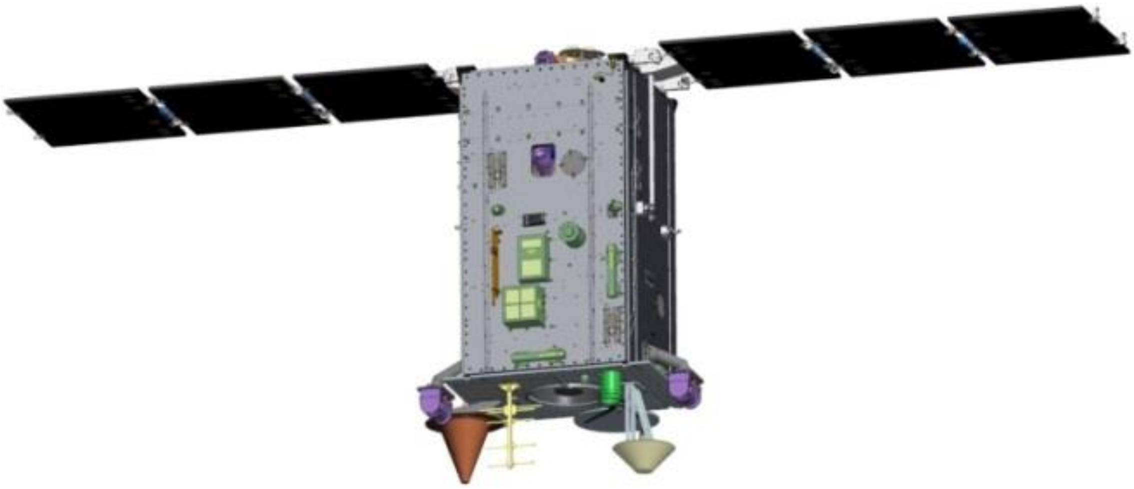


Figure 1 : Small spacecraft “AIST-2D”.

2. DINAMYC MODEL EVALUATION

Preliminary, before the experimental analysis, it is necessary to evaluate the basic frequency of the finite element model of the test unit.

A preliminary evaluation of the dynamic model was performed in the MSC Nastran. Analysis of the basic frequency and vibration modes of the structure, excluding damping, is performed in the framework of SOL_103. This is the Normal Modes Analysis in MSC/NASTRAN terminology. In this case, the amplitude-frequency response was obtained by the Lanczos method, since this method is recommended for eigenvalues extracting [1].

3. EXPERIMENTAL DATA OBTAINING

The modal analysis of aerospace equipment elements constitutes a part of a complex program for ground-based experimental development of advanced samples of rocket and space equipment.

To increase the reliability and resource of spacecraft, rocket vehicles and their elements, and to reduce the cost of their experimental development, the development of modal analysis technology is necessary.

The analysis of vibration modes based on the data obtained as a result of tests provides a definite description of the construction response, which can be evaluated in comparison with the design specification. It also makes it possible to obtain a modal model that allows to determine the effect of structural modifications or to predict the behavior of the structure under changing operating conditions.

The purpose of this work was to obtain experimental parameters of the dynamic behavior of the test object for subsequent verification (specification) of the evaluated finite-element dynamic model of the spacecraft “AIST-2D”. In the present work, the finite-element model (FEM) and the calculations of its own forms and frequencies (modal analysis) are performed using the MCS Patran/Nastran software package.

Dynamic mock-up of spacecraft “AIST-2D” (Figure 2) was subjected to modal tests, the composition, construction and layout of which correspond to the flight article of the experimental technological SSC in the configuration corresponding to the operational flight cases. Instead of standard devices and units, technological or dimensional mass-centering layouts are installed, made with standard elements and attachment points, as well as standard cable connection nodes. As the optical-electronic equipment and the node of the optical-electronic equipment cover, their dimensional mass-centering layouts were used.

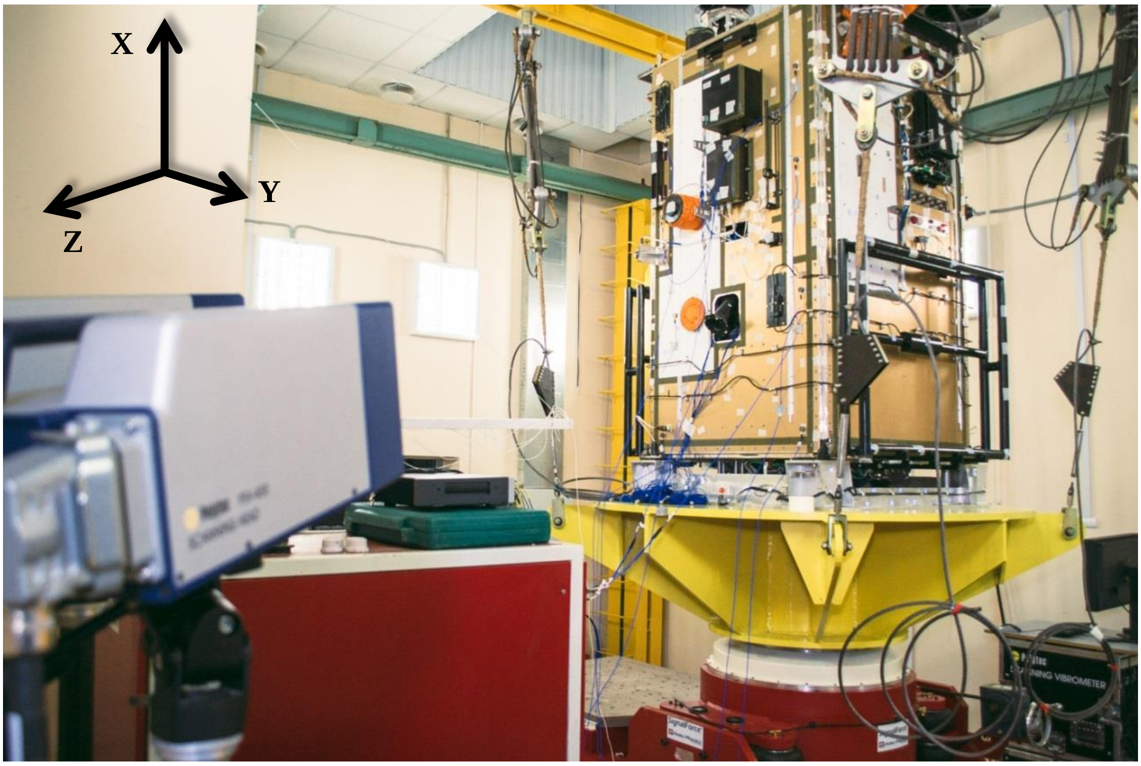


Figure 2 : Physical form of the dynamic mock-up “AIST-2D” in the testing process.

Before the standard mode tests, the amplitude-frequency characteristic of the test unit (AFC of TO) was determined. Test equipment should not affect the dynamic characteristics of the TO under study in the frequency range up to 70 Hz.

The test unit was attached to the weight relief system and installed on the vibration bench. A reference signal sensor measuring vibration acceleration was mounted on the moving part of the vibration bench coil.

3 series of measurements with the signal “Whitenoise” were performed consistently in the frequency range of 5-70 Hz.:

1) measurements when SSC is forced along the horizontal Z axis;

2) measurements when SSC is forced along the vertical X axis;

3) measurements when SSC is forced horizontally along the Y axis.

In the process of testing, we identified target resonant frequencies of oscillations of the test object in the frequency range from 5 to 70 Hz, since the construction first tones of interest to us are in the considered frequency range.

We also estimated the nonlinearity of the dynamic responses of the test object construction under the influence of excitation forces of various levels. The data were obtained using a three-component laser vibrometer Polytec PSV-400-3D [2].

The diagram of the transfer function dependence upon frequency and of the peak amplitude point phase dependence upon frequency when SSC is forced horizontally along the Z axis is shown in Figure 3.

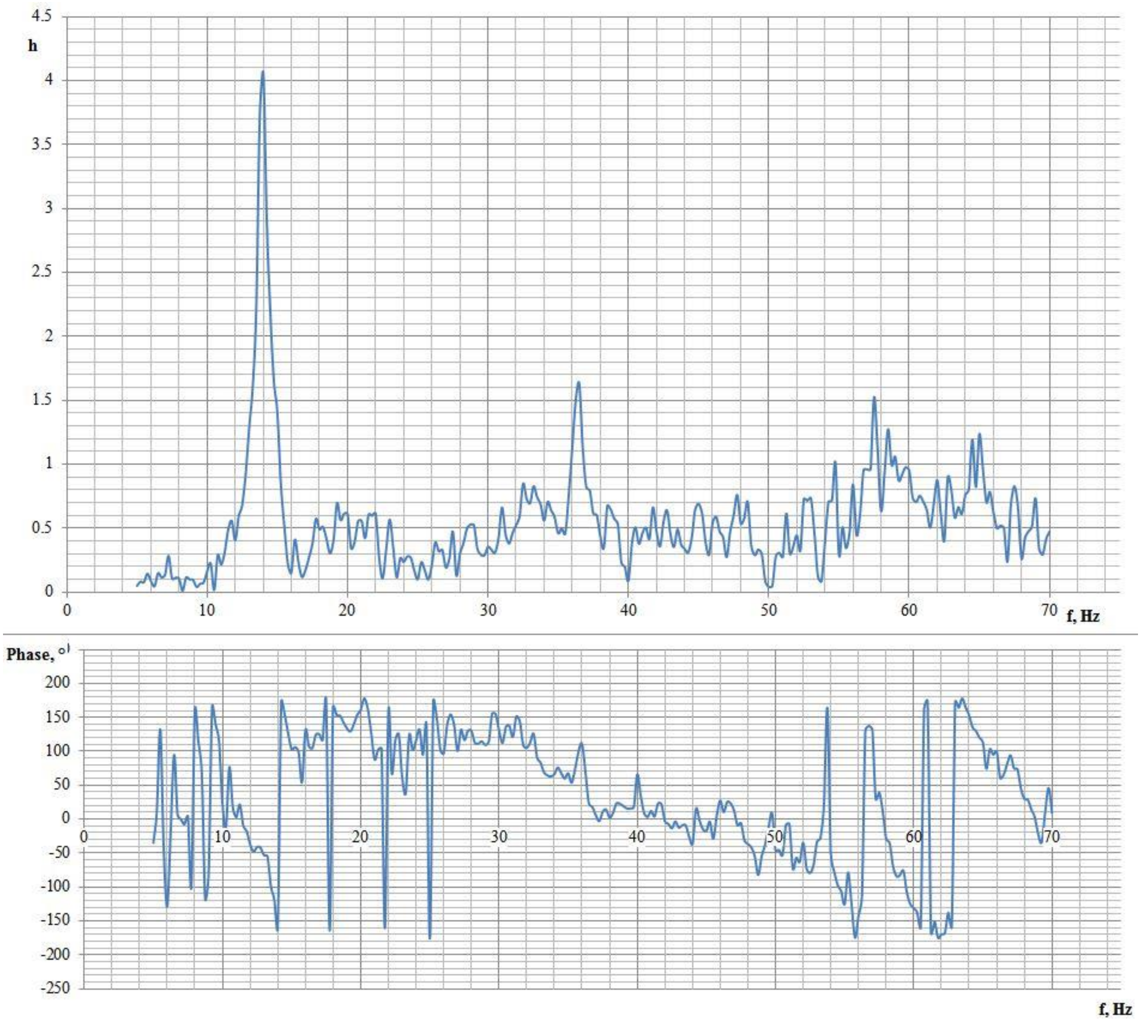


Figure 3 : The transfer function of the test object and the diagram of the phase dependence upon frequency when SSC is forced horizontally along the Z axis.

Based on the obtained spectrum and the diagram of the phase dependence upon frequency (Figure 3), it can be concluded that SSC is excited normally when the it is forced horizontally along the Z axis, and the equipment installed in the mock-up does not create a large number of subharmonics. As a result, it can be said that this measurement method is well suited for performing one of the set tasks - determining of the SSC modes.

Using the results of three series of measurements (measurements when the SSC is forced along the horizontal Y axis; measurements when the SSC is forced along the vertical X axis; measurements when the SSC is forced horizontally along the Z axis), it is possible to determine that the SSC horizontal forcing along the Z axis is the most suitable for obtaining basic frequency and vibration modes. Since the measurement object is normally forced particularly with this type of forcing, and the equipment installed in the SSC does not add strong subharmonics to the measurement result.

After calculating the modal parameters using the Polymax method in the LMS Test.Lab software environment, we obtained data cleared of parasitic oscillations modes. In Figure 4 and Table 1 the results of the calculation of modal parameters by the Polymax method are presented.

Table 1 : Target modes after processing the measurement results with the Polymax method.

	Property Reference	Frequency	MPC(%)	MPD(°)	Scatter
1	Mode1	13.795 Hz	82.496	36.716	high
2	Mode2	22.509 Hz	93.279	15.829	?
3	Mode3	32.435 Hz	84.125	23.217	high
4	Mode4	36.287 Hz	88.570	18.662	high
5	Mode5	57.621 Hz	93.777	15.417	?
6	Mode6	59.238 Hz	96.790	19.859	?

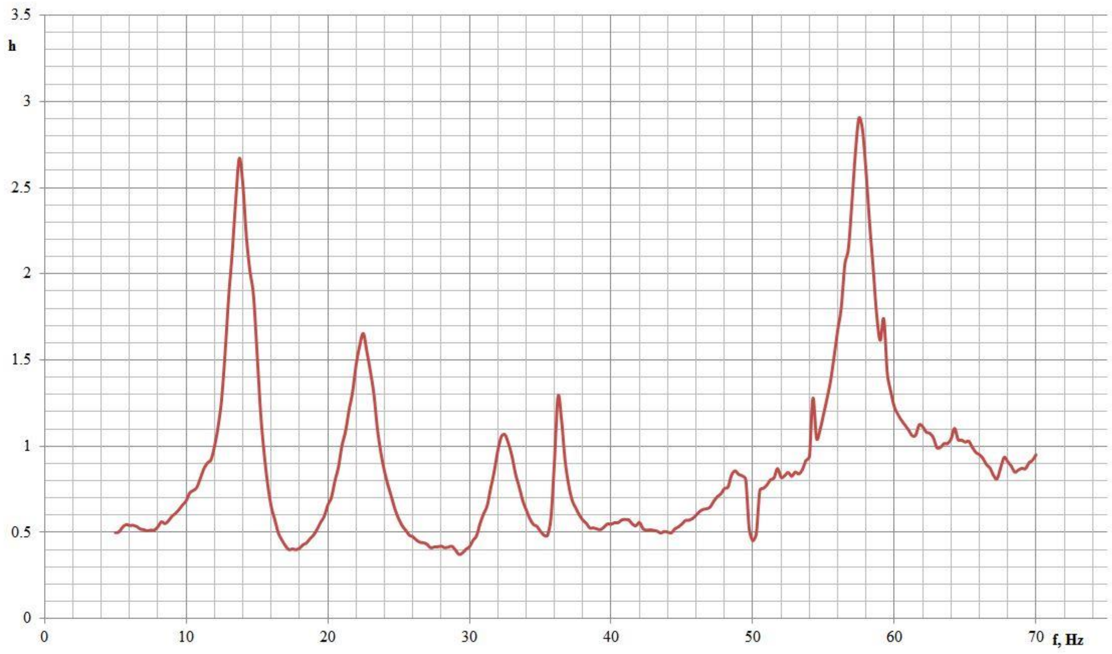


Figure 4 : The diagram of the range dependence upon frequency when SSC is forced horizontally along the Z axis after processing with the Polymax method.

4. COMPARISON OF EXPERIMENTAL AND CALCULATED DATA AND CORRECTION OF THE END-ELEMENT MODEL BASED ON THE RESULTS OF COMPARISON

After receiving and processing the experimental data, it is necessary to compare them with the results of the calculation. Here we will compare the tones and explore the effect of design parameters on the frequency response of the test object. In Figure 5 and Table 2 of the modes comparison, it can be seen that the main modes (the first and the second modes) have a discrepancy that is far from acceptable values.

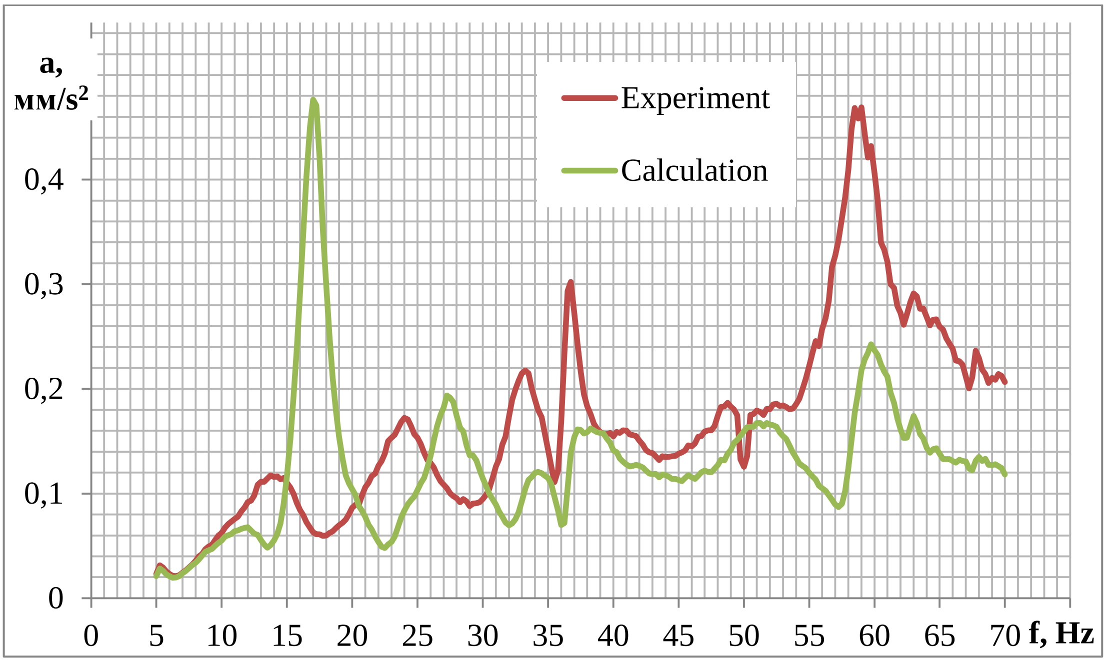


Figure 5 : Comparison of the calculated and experimental modes of the test object before the correction.

Table 2 : Comparison of the calculated and experimental modes of the test object before the correction.

Number of modes	Calculated frequencies, Hz	Experimentally certain frequencies, Hz	Error, %
1	17	13.8	23.2
2	27.3	22.5	21.3
3	34.3	32.4	5.9
4	37.3	36.3	2.8
5	59.8	57.6	3.8
6	59.7	59.2	0.9

Further, the calculation forms and their comparison with experimental forms on the same tones were considered. Here it was determined that at frequencies up to 35 Hz, forms without warping effect of the structure itself are observed. Shell deformations are observed above 35 Hz.

When analyzing the vibration forms, we determined the connections stiffness of the structural elements that make the greatest contribution to the tone formation. By correction of these stiffnesses, we changed the frequencies of the first two modes. So, reducing the connection stiffness of the adapter with the SSC (see Figure 6) by factor k = 0.8, we managed to achieve the convergence of the first tone.

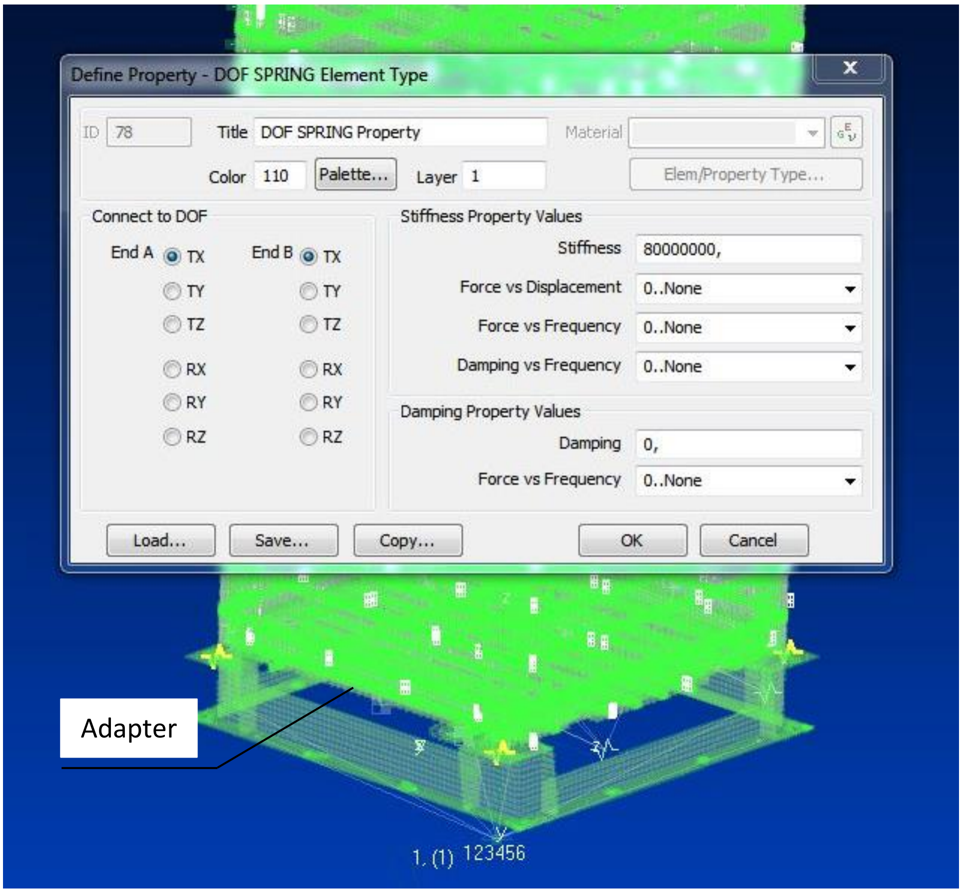


Figure 6 : Changing the stiffness value of the adapter and SSC connection.

In Figure 7 and Table 2 it can be seen that the discrepancies of the first modes were significantly reduced. In Figure 8, for clarity, experimental and calculated forms at a frequency of 13.8 Hz are presented.

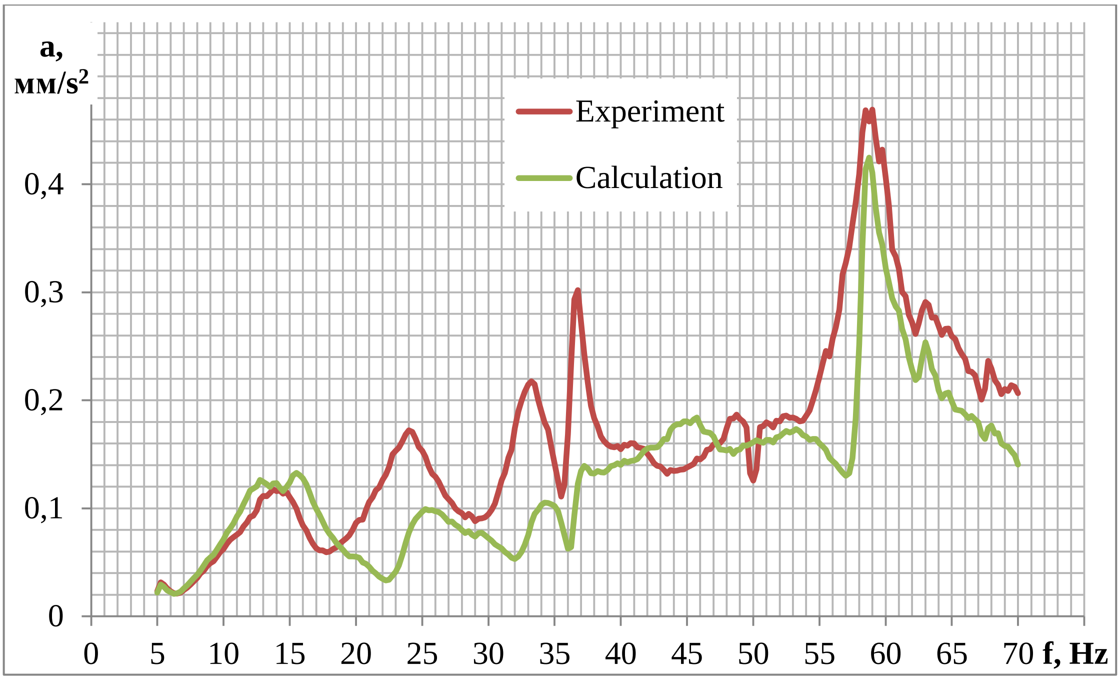
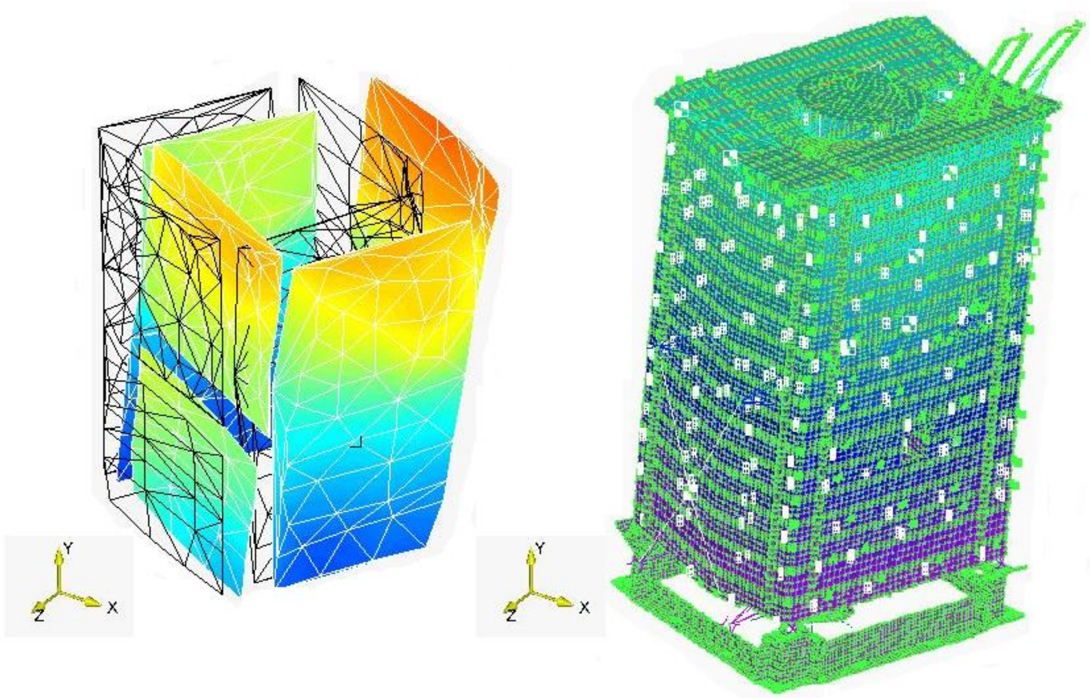


Figure 7 : Comparison of the calculated and experimental modes of the test object after the correction.

Table 2 : Comparison of the calculated and experimental modes of the test object after the correction.

Number of modes	Calculated frequencies, Hz	Experimentally certain frequencies, Hz	Error, %
1	13.8	13.8	0
2	25.3	22.5	12.4
3	34.3	32.4	5.9
4	37.3	36.3	2.8
5	58.8	57.6	2.1
6	59.7	59.2	0.8



Experimental first form
at a frequency of 13.8 Hz

Calculated first form
at a frequency of 13.8 Hz

Figure 8 : Calculated and experimental forms of SSC oscillations at 13.8 Hz.

5. CONCLUSIONS

As can be seen from the diagrams (Figure 7) and Table 2, AFR of FEM slightly differs from the AFR of a real object. Since the SSC has a large number of uncertainties in the stiffness parameters of structural elements, the discrepancy in determining the basic frequencies at the first stage of the research reached 23.2% (Table 1), which once again confirmed the need for modal testing.

The performed preliminary correlation analysis and subsequent refinement of the stiffness parameters of some structural elements made it possible to reduce these frequency determination discrepancies, but the results at the initial stage of verification are not yet close enough to acceptable levels specified in operations [4, 5].

The dynamic characteristics of spacecraft structural elements obtained as a result of the operations conducted will later allow to create more reliable and accurate dynamic spacecraft models at the design stage, which in turn will increase the accuracy of spacecraft loading calculations and the reliability of the products as a whole.

Verified by the results of dynamic tests FEM will allow further reliable calculations with: changed operating conditions, product upgrades and the development of new products of this class. At the same time, the amount of required experimental testing can be reduced up to the replacement of qualification dynamic tests by calculated testing using FEM.

6. ACKNOWLEDGEMENTS

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