GLOBAL FEM MODEL OF COMBAT HELICOPTER

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Abstract

Air structures like Mi-24 were designed in last decades of the XX century, when computer aided design was not available. Philosophy of the exploitation so-called „safe life" postulate exploitation is defined by the manufacturer time. Such attitude turned out very uneconomical because of the various profiles of the use of aircrafts. Extending the initial period of exploitation is a quite common way to extend an aircrafts' life. Such solutions are accepted in the majority of countries, even the richest. In order to obtain detailed geometry of the real structure reversed engineering techniques were used. The geometry was obtained using two methods: digital photogrammetry and optical scanning using ATOS scanner from GOM Company. Geometric model, which was used for numerical Finite Element Method model, was developed based on the data from measurements, available technical documentation and detailed inspection of the structure. Global FEM model is being used for finding critical elements of aircraft's structure. Structure elements such as stringers, ribs or frames were modelled using bar and beam elements with specially defined properties and cross sections. Structure elements which didn't take part in transferring the loads, but with significant mass were made in a simplified manner so that their weight in the model correspond to actual or were modeled as concentrated masses.

Keywords: *Mi-24 global FEM model, photogrammetry, 3D scanning, reverse engineering, FEM*

1. Introduction

Mil Mi-24 are heavy combat helicopters designed in the OKB-Mil and produced in factory called „Rostwiertol". Mi-24's tasks are support from air and transportation up to eight soldiers in the loading space. Those helicopters started service for ZSRR in 1976 and are being used nowadays by over 30 countries.

Mi-24 design is based on an earlier transport helicopter Mi-8. It is one rotor aircraft with tail propeller. The front of the fuselage was built to carry a double cabin crew in tandem covered with cover of the armoured glass. The rear, pilot' seat has been placed over the head of the co-pilot acting as the operator of arms. From the sides of the fuselage are mounted wings serving as a suspension of arms, but also generating about 25% lift in horizontal flight. Aeronautical structures, which are being exploited, have been designed in the last decades of the twentieth century, when the computer aided design process was very archaic, or did not exist. Many of the technical solutions has been developed on the basis of designers' experience. The philosophy of operation of these aircraft structures so "safe life" involved the exploitation of the time specified by the manufacturer. In account of different profiles of aircrafts' usage, such an approach has proved to be very uneconomical. Extending the initial period of exploitation is a quite common way to extend an aircrafts' life. Such solutions are accepted in the majority of countries, even the richest.

To ensure the safety of aircraft operations with prolonged overhaul life must be developed a system of additional surveys and inspections. Priceless knowledge is acquaintance of critical structure elements. Constructor's Experience used in the design must be complemented by appropriate computer analysis of the stress distribution. Complexity of aircraft structures causes serious complications. Best solution is creating hierarchical FEM models.

Global FEM model of structure in this case is designed to identify critical places and to calculate forces acting on it. Detailed analysis of the stress distribution is possible after the execution of specific, local models.

Creating MES model took following phases:

- measurement of the shape of the helicopter,
- building of the geometrical model,
- building of the MES model.

2. Construction of the helicopter's geometrical model
Measurement of helicopter's shape and construction of coating model

2.1.1. Photogrammetric Measurement

Due to the lack of available technical documentation on the airframe structure, it was decided to use optical measuring instruments. Measurement of the fuselage is made using the technique of digital photogrammetric system, called TRITOP, which ensures the coordinates of points with 0.2 mm accuracy. TRITOP is an industrial, non-contact optical measuring system for exact 3D coordinate acquisition of discrete object points. This mobile technology supports time-optimized measurements for on-site quality control and deformation analysis. Each point of computer model corresponds to the point marker on the surface of the fuselage (Fig. 1). Points were placed on the helicopter's fuselage in such as way as to reflect, where possible, frames and stringers. Tail boom and vertical stabilizer were mapped numerically with 3D scanner - ATOS.

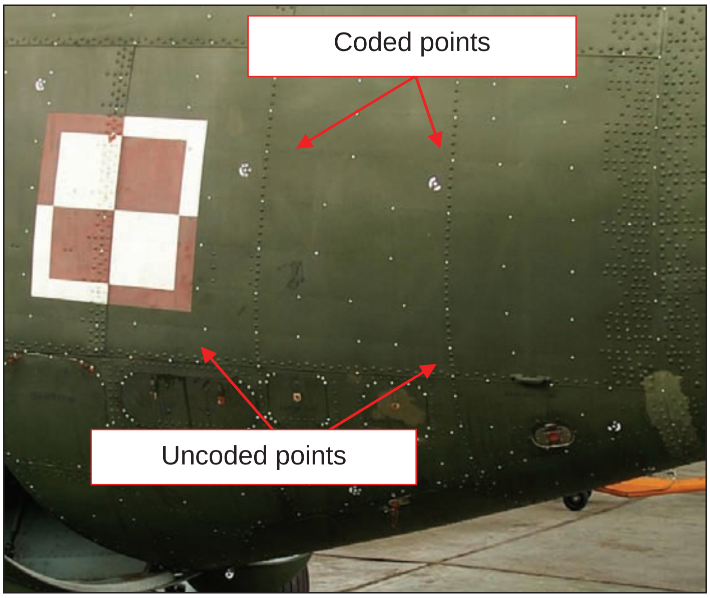

Fig. 1. Example of distribution of markers on the Mi-24 helicopter's fuselage

The photogrammetric method consists in photographing reference points from different positions. Software that uses the principle of photogrammetry is able to calculate the location of reference points in space. To calculate the position from which the photographic image was taken, software uses coded points. They are characterized by the fact that each of them has a unique, 15-bit code, which is automatically recognized. Digitization of maps of the reference points also requires verification of a model's scale. For this purpose, the certified scale bars are required. The system uses a pair of TRITOP scale bars, which sets the measurement error, as the differences in their length. Camera, which is used to perform measurements, represents a professional digital SLR camera Nikon. The camera body is equipped with a 12 million pixel CMOS sensor. Fixed focus lens has a focal length of 24 [mm]. The camera is equipped with a wireless modem, through which images are sent directly to computer. The software automatically detects and orients reference points in space.

In preparation for the measurement on helicopter uncoded markers were placed in places that have been chosen. In addition, to the fuselage surface coded markers were stuck, which measuring system uses for the orientation of two-dimensional images in the process of determining the 3D model. Scale bars were placed as well.

Photogrammetric measurement of helicopter consisted of three levels shooting and over a dozen matches. On each image measurement should be at least five points coded, and each scale bar should be included in its entirety at least on one photographic image. The method of measurement using the TRITOP system is illustrated in Fig. 2.

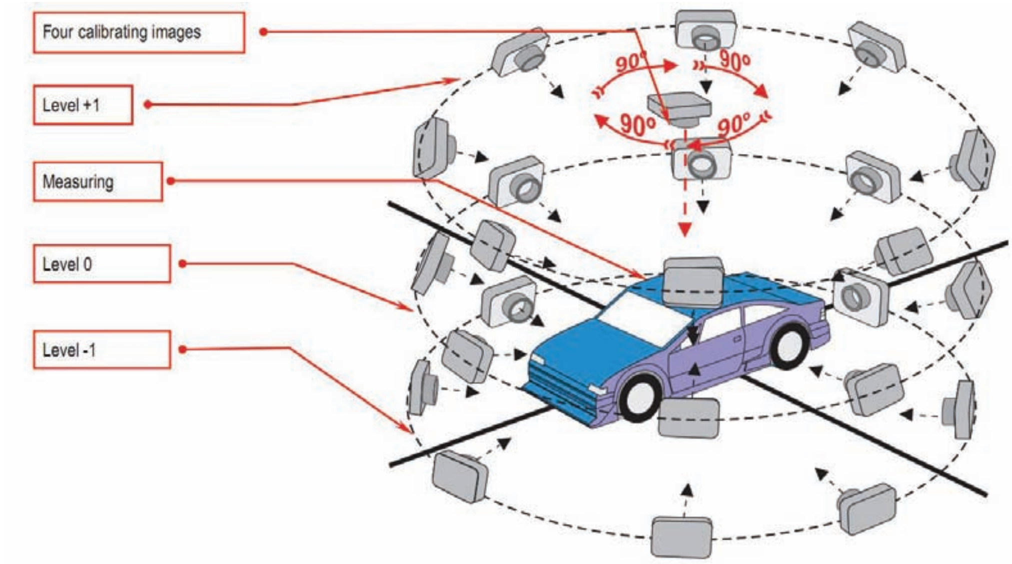

Fig. 2. Performance chart of TRITOP measurement

As a result of photogrammetric measurement of the fuselage 3,920 points were received (Fig. 3). During the measurement two scale bars were used with a nominal length of 2.5 m. The average error of scale bars length was 0.0336 mm and the mean error of measurement expressed in pixels was 0.0993 pixels.

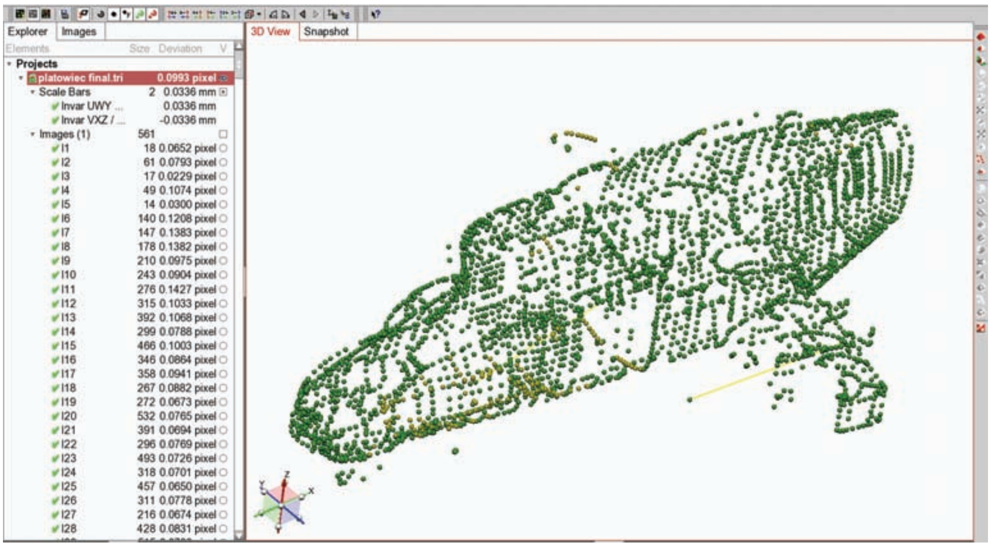

Fig. 3. The spatial distribution of reference points on the fuselage of the helicopter

Based on the spatial distribution of reference points located on the beam and the tail fin reference grid for ATOS III measurement was performed. Optical scanner requires the deployment of non-coded points on the test object in a random set. After that stereographic surface shape measurement was made. This system uses a network of non-coded points, measured initially by TRITOP system as a basis for spatial orientation. As a result of the measurement we obtained a model composed of many triangles on the basis of which it is possible to image the shape characteristics of the test object. Based on the triangle mesh parallel to the No. 1 cross frame sections was set which are underling the construction of a CAD model (Fig. 4).

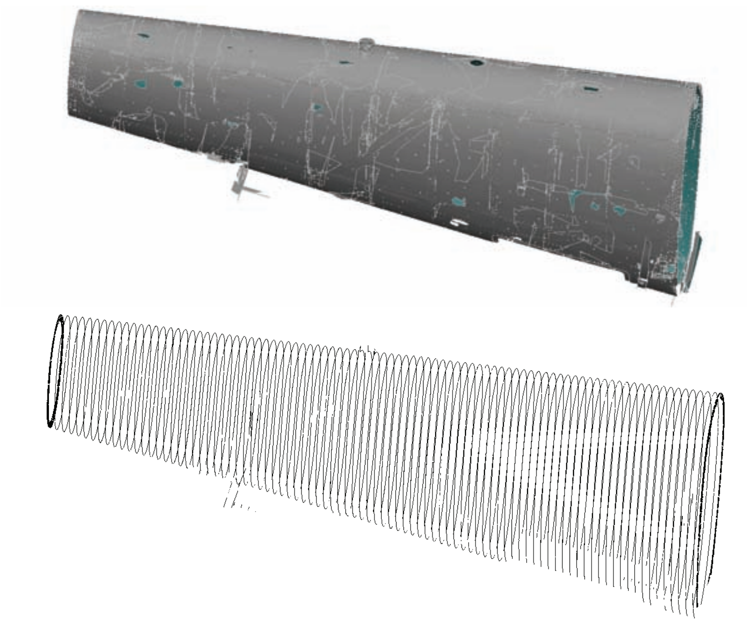

Fig. 4. Result of the optical scanner measurement of tail beam in a triangle mesh from which sections were performed

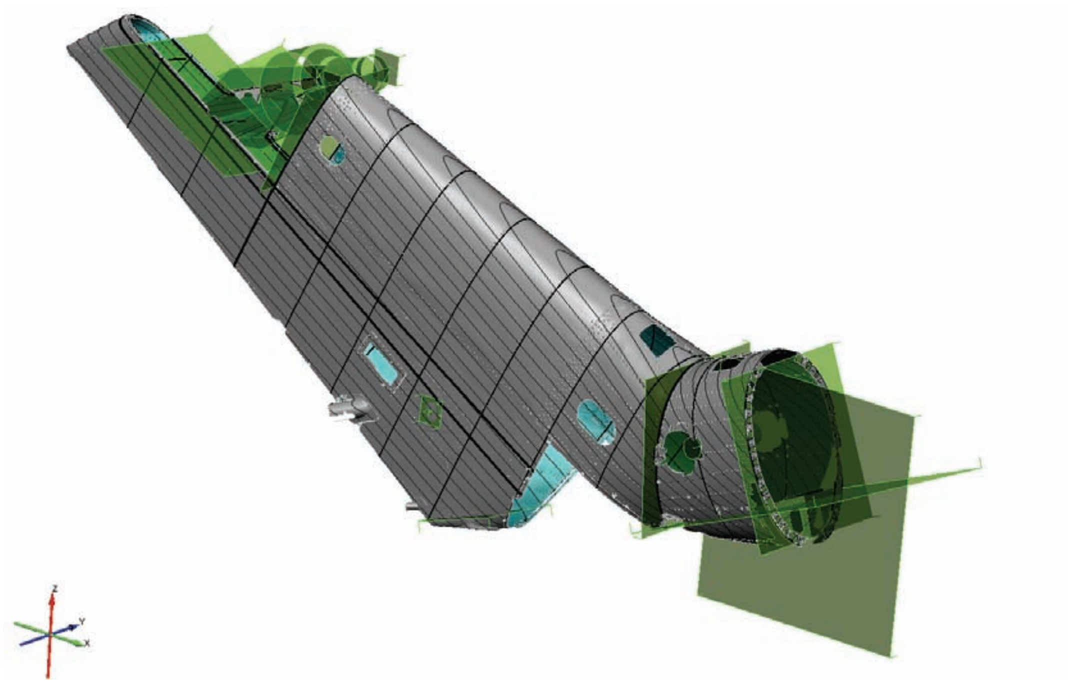

Fig. 5. Result of optical scanner measurement of fin with marked cross-sections

After measurement and pre-treatment the measured points have been transferred to the CAD system, where were the basis for the implementation of a numerical model of the fuselage of Mi-24 helicopter.

2.1.2. Helicopters preliminary shell model

The geometric model, consisting of curves and surfaces, was created basing on the points obtained with the above described method. Both the geometric and finite element models were created in the MSC.Patran environment which enables both to use advanced modelling tools as well as meshing.

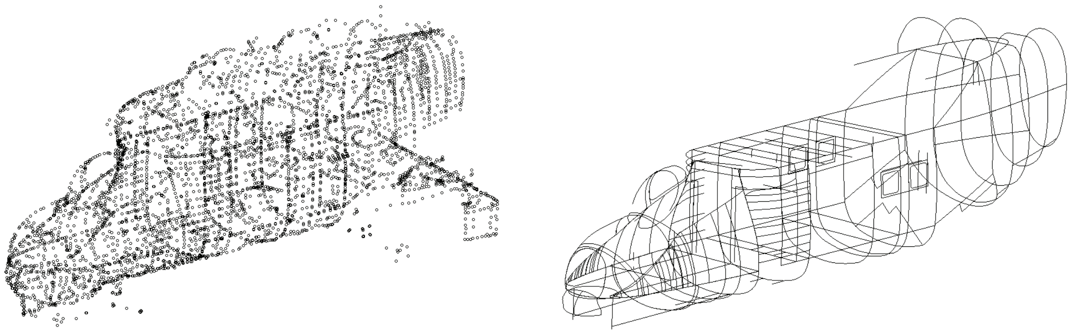

Fig. 6. Geometric model – Points obtained from photogrammetric measurement and subsequent curves

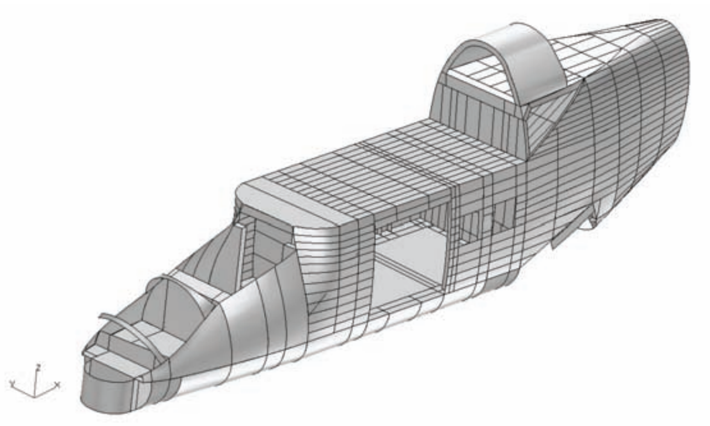

Fig. 7. The geometric model of the fuselage coating Mi-24

The geometry shown above was used to crate the finite element model. The other parts of the helicopter, such as tail boom, vertical stabilizer, and wing were created as separate independent models. Since this is a global model there were some simplifications introduced. Insignificant shape details, riveted joints in sheeting, stringers lower shelves were neglected. One must be aware that such simplifications shorten time needed to create the model as well as computing time but influence the overall reliability of the computations.

2.2. Shell-beam FEM model

2.2.1. FEM model construction

The FEM model was created on the basis of geometric model. The meshing was done so that regular mesh is used whenever possible. The majority of elements are quad shell elements with six degrees of freedom in each node. Some trial elements were used to fill the gaps and to enable smooth transition between structural parts. Solid elements were introduced for parts such like strengthened ribs or mass elements like transmission boxes. Bar and beam elements were used for such parts for which one dimension was dominant.

Structure elements such as stringers, ribs or frames were modelled using bar and beam elements with specially defined properties and cross sections.

The laminar sandwich panels were modelled with eight node elements as a filling between two layers of shell quad elements.

The helicopter's fuselage consisted of around 14 300 elements. Since the structure is thin walled the majority was quad shell elements but also beam and solid elements were introduced. The elements were divided into groups to enable further modifications and easier management of the model. All the elements were also placed in 20_MES_wszystko group. The groups generally represent the technical division of the structure so that separate modifications of stringers, sheeting or ribs will be possible.

Tail boom and vertical stabilizer were created with higher complexity level since more sophisticated calculations, like residual strength or fatigue life estimations, were planned. Their FEM models were created from about 30 000 elements. As in case of the fuselage the majority of elements were shell elements but also brick and bar elements were introduced whenever necessary or profitable.

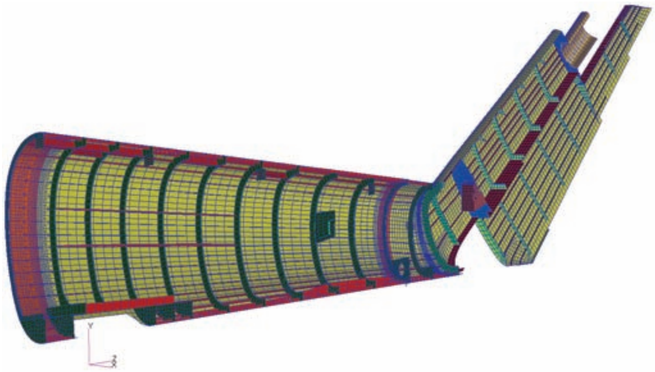

Fig. 8. Section through the entire tail of the helicopter model

2.3. FEM model constrution – solutions

2.3.1. Fuselage

The numerical model presented within this article is a global model. Hence some simplifications and unifications had to be done, which influence the models overall reliability and accuracy of the obtained results. The introduced simplifications were:
- stringers cross sections simplification,
- neglecting the sandwich construction of some elements (stringers lower shelves),
- neglecting the riveted joints in sheeting,
- simplifying shape of some structural elements like horizontal stabilizer.
- some structural element of the fuselage like strengthened ribs were modelled with bar elements

The structural elements which geometry was simplified will be analyzed thoroughly with separate detailed models.

Within global model the solid elements representing three dimensional strength elements were modelled with simplified bar elements. These elements will be analyzed in separate detailed models which will assure sufficient accuracy. Since inertial loads are considered in the analysis some additional mass declarations had to be introduced. They will allow to use inertial loads which occur during flight manoeuvres and to monitor the structures response to such loads.

2.3.2. Mass elements

Structure elements which didn't take part in transferring the loads, but with significant mass, due to the use of inertial loads, were made in a simplified manner so that their weight in the model correspond to actual or were modeled as concentrated masses. This allowed achieving a proper weight of the whole structure without complicating the model. Examples of such elements are: gears, shafts and horizontal stabilizer.

2.3.3. Combining models

The independent models, depending on ongoing computing tasks, were combined with each other by means of tying nodes corresponding to location of mounting bolts in the adequate ribs. These nodes correspond to the position of bolts in bolt connections occurring in the actual construction of the helicopter. For example, in order to obtain the boundary conditions corresponding to the real state, the rear part of the fuselage was introduced to the tail boom and vertical stabilizer models.

3. Sample results

Below are presented some example results of numerical calculations carried out on the helicopters tail boom and vertical stabilizer models. The main purpose of the model was the mechanical calculations to determine the characteristic points of stress concentration during flight and landing. . Loads used in the calculations correspond to the actual loads in flight and were determined by means of stain gauge measurements during flight. The obtained model also allowed for additional modal analysis (Fig. 9) as well as estimating fatigue life.

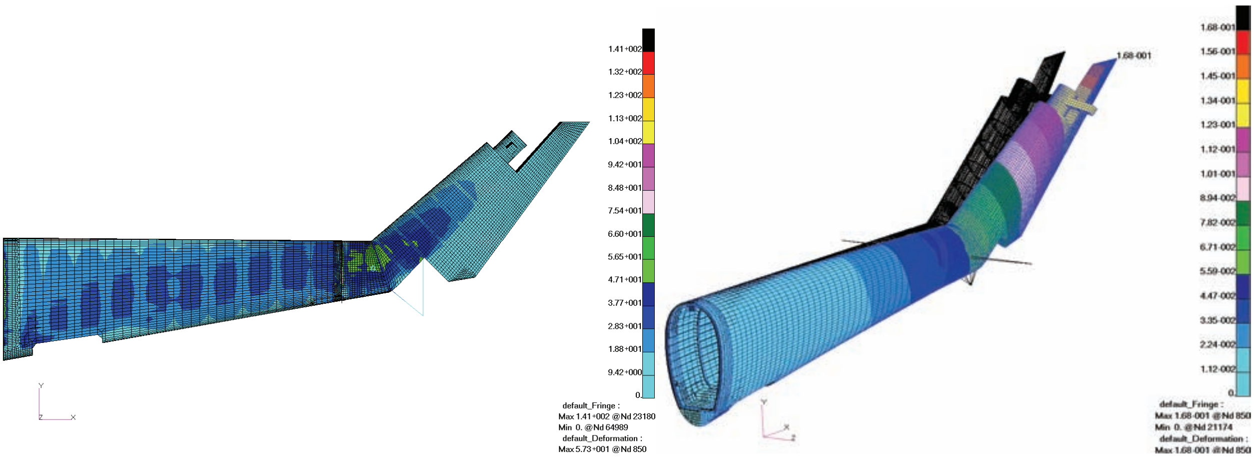

Fig. 9. Reduced stress according to Huber-Mises theory for the landing maneuver and results of modal analysis - first mode

4. Final conclusions

The presented model of combat helicopter Mi-24 was made using the available modern techniques of CAM / CAD. Application of photogrammetric measurement helped to reduce the measurement time and significantly improved its accuracy. It should be noted that the laser measurement techniques become more and more available today. Many complex reverse engineering systems appear on the market. They are characterized by excellent parameters and are integrated with computer software. The only barrier to their propagation is their price. It may be assumed that the continuing development of laser technology and digital imaging will significantly reduce the cost of these systems. Global FEM model of helicopter is mainly used to determine the critical elements of its structure. With simple modifications it is possible to carry out virtually any mechanical analysis. Important from the point of view, the selection of loads, boundary conditions and the reliability of the model are the results of strain gauge measurements of forces and stresses during flight.

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