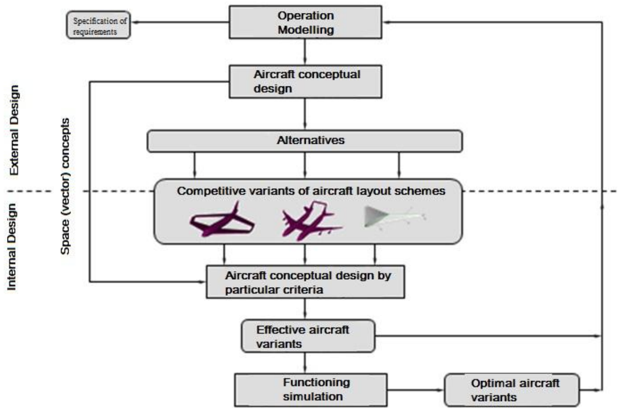


Figure 2: Long-haul aircraft conceptual design

Table 1: Infrastructural requirements

No.	Sign	1	2	3
U_1	Basing (landing field)	Runway length	Runway width	Runway strength
U_2	Service processing area	Dimensions of the terminal	Dimensions of parking spaces	Dimensions of transport areas
U_3	Maintenance and operational technological effectiveness	Loading and unloading of the target load	Inspection and refueling	Repairability
U_4	Ecology	Noise	Temperature	Toxicity
U_5	Regional and demographic factor	MCA	Biosphere	Radioactivity and magnetic fields

Many infrastructure constraints either directly or indirectly influence on the choice of the main parameter values and the dimension of the aircraft. The influence of infrastructure requirements on the dimension of the aircraft will be considered through the example of factors for which it is critical.

The demographic factor of infrastructure requirements developed historically and is the objective background that determines the location of aviation infrastructure in each individual region and on the globe as a whole. Due to the requirements specified in the specification of requirements, that the aircraft must meet, the demographic factor for some types of aircrafts becomes decisive. Typical representatives of such airports are Tegel (West Berlin), Hong Kong, Singapore, etc. This circumstance does not allow increasing the length of the runway and it requires an improvement in the take-off and landing characteristics. The urgency of this problem is confirmed by the tragic events in Irkutsk during the An-124 "Ruslan" air crash. One way to improve the take-off and landing characteristics is to either reduce the specific load on the wing, or increase the thrust-to-weight ratio of the aircraft. The number of parameters characterizing the influence of noise reduction and emission requirements on the terrain during the operation of the aircraft is generally large, but they can be reduced to the relative parameters of the aircraft, which enter into the equations characterizing the flight, technical, aerodynamic, and other characteristics. As parameters for deterministic search for rational values, it is necessary to use general aircraft parameters and functionals. So, almost unequivocally, it can be argued that, other things being equal, it is necessary to reduce the take-off mass, the area of the washable surface, the thrust and the number of engines, etc. Consequently, as the parameters for minimizing the take-off mass, one can consider the specific load on the wing and the thrust-to-weight ratio of the aircraft.

3. THE INFLUENCE OF INFRASTRUCTURE CONSTRAINTS ON THE DIMENSION OF A LONG-HAUL AIRCRAFT

Let's consider the influence of infrastructure constraints on the dimension of a long-haul aircraft. Under the conditions of increased competition between manufacturers, much attention is paid to the study of promising construction and layout schemes and the search for new design and construction solutions, since it is a question of designing new types of aircraft that have no analogues or prototypes. As alternative circuit solutions, along with the traditional normal aerodynamic balancing scheme of the aircraft, others are considered that have two distinct trends: to an increase in the number of bearing surfaces - "triplane" or to their decrease – "flying wing" [6-9, 15].

The main distinguishing feature of the long-haul aircraft with large passenger capacity is a very significant geometric and mass dimension of the aircraft. This feature is in conflict with a number of factors of the infrastructure already existing today. The operation of aircrafts must be carried out on the existing network of airports, which imposes on them a number of infrastructure constraints, such as: the length and width of the runway, the width and steering radius of the taxi ways, the distance from the wing console to the buildings, the distance between the consoles of aircraft wings on parallel taxi ways and runways, the strength of the runway cover, etc.

As an example for high-class airports, the considered characteristics of the basing of the long-haul aircraft with large passenger capacity are analyzed. The structural and parametric analysis of high-class airports allows us to identify the infrastructure requirements for long-haul aircraft and form a vector of constraints U = U (u_i), which characterizes the conceptual design problem of the long-haul aircraft with large passenger capacity:

$$u11 = u\,(L_{runway} < 3000\ \text{m}); \quad (1)$$

$$u12 = u\,(B_{runway} < 60\ \text{m}); \quad (2)$$

$$u13 = u\,(ACN < 65). \quad (3)$$

Analysis of infrastructure factors shows their impact on the dimension of the aircraft. The main indicator of the dimension of the aircraft is its take-off mass. At the stage of determining the dimension of the aircraft, it is determined by the weight balance equation: where m_{af} – air frame mass; m_{eu} – engine unit mass; m_{ec} – mass of equipment and control; m_f – mass of fuel; m_{tl} – mass of given target load; m_{sl} – mass of service load and equipment.

Solving the weight balance equation with respect to the take-off mass, we can determine its value in the first approximation. Data on the relative masses of the structure and engine unit are taken from the statistics, and the target load, inventory and equipment are given in the specification of requirements in absolute value. An example of the influence of infrastructure restrictions on the dimension of an aircraft through the masses of elements is the dependence of the relative mass of fuel $\overline{m}_T$ from the range of flight (demographic factor), which is determined by the Breguet formula.

At the layout stage, the triunique problem of aerodynamic, volume-weight and structural-force layouts is solved. The stage of synthesis of the layout scheme is aimed at resolving the contradictions of the internal layout and the formation of the external contours of the aircraft. When considering the impact of "hard" infrastructure requirements on the the aircraft layout, it can be seen that they form a conceptual description of the object. However, its meaningful content depends on the purpose of the aircraft and, as a consequence, the criticality of certain constraint.

In order to minimize the number of iterations of the layout, it is necessary to identify a critical factor and to build the layout procedures into a single algorithm with respect to it. In this case, the implementation of the "reverse" layout task begins with the identification of the layout space and its decomposition according to the characteristic features. As the latter, there are signs that are uniquely determined by infrastructural requirements (dimensions) and more multivalued signs (alignment, moments of inertia, specific density, etc.). Characteristic features carry a conceptual component both for individual units and for the aircraft in general. Implementation of the layout procedures with respect to the critical factor leads to the decomposition of layout procedures and the identification of the order of their execution.

4. FEATURES OF THE LAYOUT SPACE

Let's consider the identification of the layout space, its decomposition according to the characteristic features and the identification of a critical factor for the long-haul aircraft [10]. If we consider the whole issue, from the point of view of the volume-weight configuration, the optimal solution will be an aircraft for which the external contour was obtained as a result of positioning of individual aggregates taking into account the criticality of the layout both with respect to the three axes of coordinates and in three planes, and for any arbitrary radius-vector, starting from the center of mass of the aircraft.

A characteristic feature of the layout with "hard" dimensional constraints is the possibility of carrying out spatial coupling of many units in the first iteration, which allows us to build layout from a certain virtual center. It is convenient to choose the origin of the associated coordinate system, which coincides with the real center of mass of the aircraft. Therefore, the layout problem is reduced to the location and interconnection of units in the layout space due to infrastructure constraints from the condition of bringing the real center of mass to the virtual mass center (VMC) and providing characteristic features that satisfy both infrastructure requirements and others, for example, aerodynamic [5,13,14].

In Figure 3, the third level shows a three-dimensional image of the layout space for the long-haul aircraft, obtained from the results of the structural-parametric analysis of terminal configurations, the method of aircraft parking and taking into account the aircraft height limitations from the condition of pass ability to the parking shelter gate (23 m). Of course, in this case, the issues of antennas and equipment layout at the top of the fin surface are taken into account. Figure 3 at the second level shows conditionally the range of permissible placement of passenger decks of the long-haul aircraft. Their layout is determined by the dimensioning height (3.8 m), the length (20-25 m, and in prospect – 40-50 m) and the limiting deviation angles in the vertical plane (10%) of the terminal bridges. At the third level, the geometric shape of the layout space is revealed as a result of the structural-parametric analysis of the long-haul aircraft infrastructure constraints.

Further, there are many ways again, but we must take one of the hypotheses:

Circumferential fuselage;
Twin-fuselage scheme;
Flying wing;
Drop-shaped fuselage, etc.
Some alternatives are graphically represented at the fourth level of Figure 3. But let's analyze it. At the first stage, we determine the required volume for placing one passenger (see Figure 4).

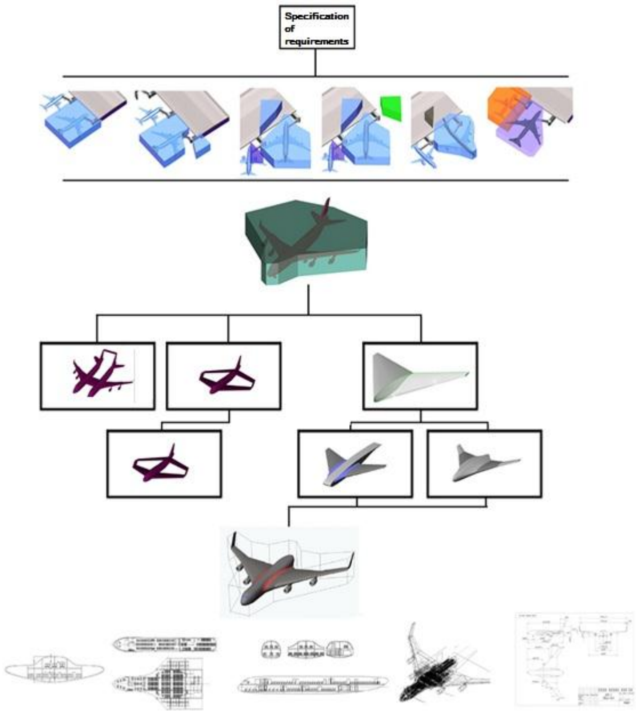


Figure 3: Influence of infrastructure restrictions on the geometric shape of the long-haul aircraft

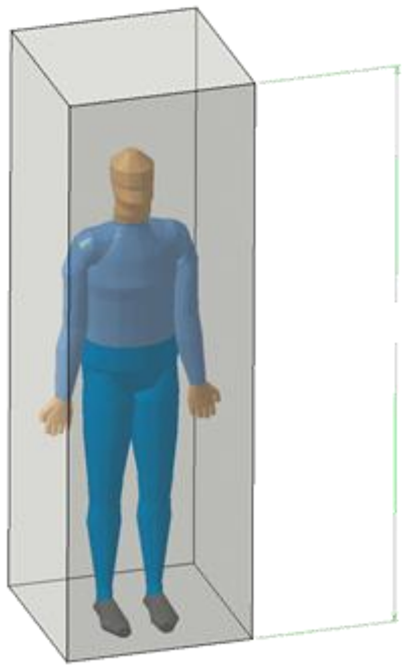


Figure 4: Geometrical model of the passenger

Traditionally, the layout of the passenger compartment of the long-haul aircraft is realized from the cross section, which is replicated in length as a model, taking into account the nuances of kitchens, wardrobes, toilets, etc. However, the excess pressure causes a circular cross section. The fuselage, made in a cylindrical shape and having a circular cross-section, has a minimal mass. In Figure 5. a change in the geometric shapes of the cross section of the cylindrical-shaped fuselage from the influence of excess pressure is given. In order for the section to keep the shape in the beam fuselage structure in the frame, in addition to the longitudinal force elements, the formers are installed, as transverse power elements.

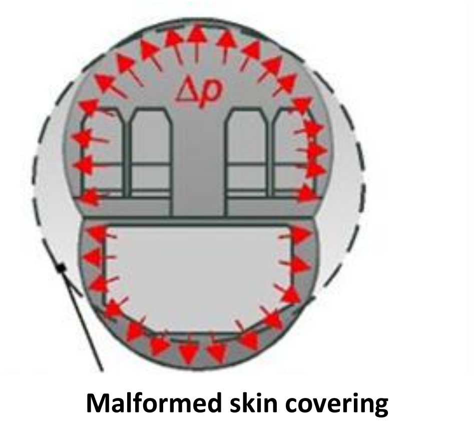


Figure 5: Change of geometric shapes of the cross-section of the cylindrical-shaped fuselage from excess pressure

At the second stage, the number of passengers is taken from the specification of requirements, which multiplied by the volume of one passenger allows us to determine the minimum required volume of the aircraft. If the volume is known, then the minimum area of the washable surface has a body equivalent to the sphere (see Figure 6).

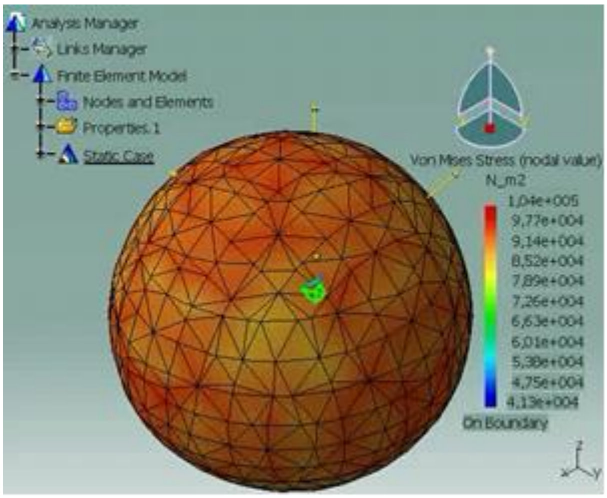


Figure 6: A sphere equivalent to the fuselage volume of the long-haul aircraft

Excess pressure, which suppresses the shell from the inside, gives a uniform distribution of the stress-strain state. However, for a flight in the atmosphere, the spherical shape is not suitable. The geometric shape for subsonic flight should be stretched and be more like an aerodynamic profile.

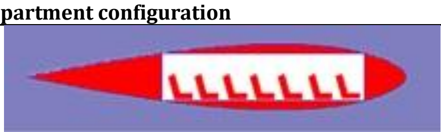
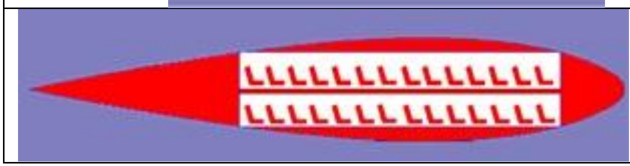
Comparison of interior layouts by S_{vol}			
Parameters / Passenger compartment configuration	Number of passengers	S_{vol}	S_{vol} per one passenger
	100	330 m^2	3.3 m^2
	800	1315 m^2	1.644 m^2

Figure 7: The fuselage in the form of an aerodynamic profile equivalent to the fuselage volume of the long-haul aircraft

Performing the geometric operations of affine extension-compression with an equivalent sphere in volume, we obtain the disk (see Figure 7). The structural-parametric analysis of the stress-strain state shows a pronounced anomalous zone. For its compensation, a power element connecting the two poles is needed.

The aerodynamics of discs has not been estimated yet, but several dozen of projects are known. The long-haul aircrafts are oriented to a long flight, so a high priority in the formation of the washable surface is a high aerodynamic quality. And it is the higher, the lower the resistance and the greater the bearing capacity is. Figure 8 shows the drop shape of the bearing fuselage and the washable surface of the aircraft made according to the integral form.

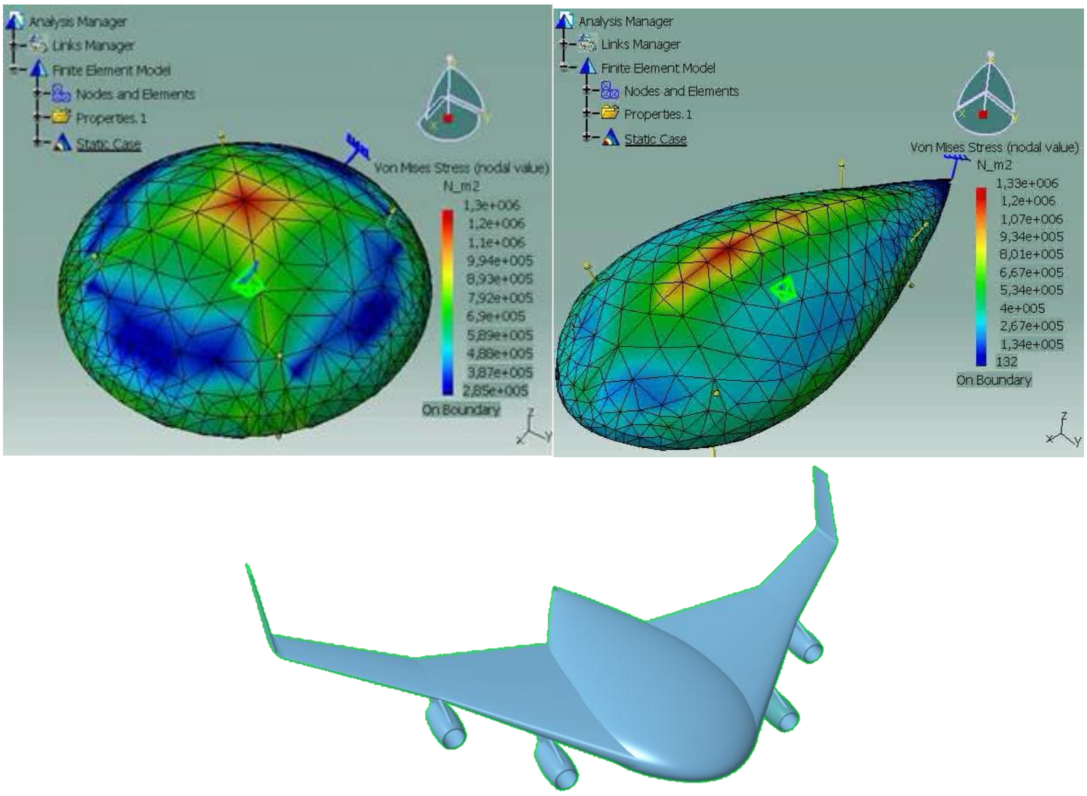


Figure 8: The drop shape of the bearing fuselage and the washable surface of the aircraft made according to the integral form

The structural-parametric analysis of the stress-strain state shows a pronounced anomalous zone. To compensate it, a power longitudinal element separating the drop-shaped fuselage into two symmetrical segments is needed. Let's make a comparative analysis of the aircraft made on the basis of the Flying Wing scheme and the Normal Scheme. The data are given in Table 2 (calculations were made by the MAI student A.G. Patrakov) [7].

Table 2: Comparative analysis of the aircraft made on the basis of the "Flying Wing" scheme and the Usual (Normal or Classical) scheme

Aircraft iteration	Usual scheme		"Wing" scheme		Absolute difference		Percentage difference	
	S_{vol} (m²)	V (m³)	S_{vol} (m²)	V (m³)	S_{vol} (m²)	V (m³)	dS_{vol} %	dV %
1	1412.71	2515	1315.86	2515	97.71	0	-7	0
2	2493.88	2895.23	2576.34	3290.28	82.46	395.04	3	14
3	2916.54	2994.31	2704.68	3307.23	-211.8	312.92	-7	12
4	**3181.94**	**3084.06**	**3147.74**	**3426.84**	**-34.19**	**342.78**	**-1**	**11**

As a base, the passenger compartment of the long-haul aircraft (iteration No. 1) was adopted. The second iteration is the wing and fuselage. Third iteration is the wing, fuselage and tail. And the fourth iteration is the whole composition of the aircraft aggregates, which corresponds to the complete washable surface (taking into account the engine nacelles). So, the specific volume per passenger (average in all cabins) was 2.485m³, which is 1.17 times worse than for the base aircraft (normal aerodynamic scheme), but 1.30 times better than for the aircraft in the "lifting fuselage" scheme, and 2% better than for the aircraft with a triplane scheme with an articulated wing.

The developed method of the aircraft layout from the layout space made it possible to obtain the aircraft layout that meets all infrastructure requirements, with take-off mass of 30-40 tons less than that of the prototypes. Within the framework of the research work at the MAI, a structural-parametric analysis of alternative layouts of the long-haul aircraft with large passenger capacity was carried out. The analysis shows the advantages of the layout carried out according to the above method (LHA-5 "flying wing" scheme) in relation to other non-traditional schemes and a minor loss to the base aircraft.

The value of the global criterion of comparative characteristics of emergency evacuation of aircraft passengers and crews, obtained by the methodology of professor M.G. Akopov by convolving seventeen particular criteria through weighting coefficients for LHA-5 was V = 0.634, which is much better than the values of the global criterion for all other layouts. So, in comparison with the base aircraft of a normal aerodynamic scheme, the global criterion is better by 1.78 times, and in comparison, with the triplane scheme with an articulated wing – 2.39 times. In comparison with the base aircraft of a normal aerodynamic scheme, the cost of a flight hour is 84%, and in comparison, with a triplane scheme with an articulated wing - 94%. The advantages of aircrafts designed according to the "flying wing" scheme in relation to other schemes rise with the increase in the dimension of the aircraft. So, the greater value of the target load and the flight range is, the better application of this scheme is. The variants of the internal layout of passenger cabins, presented in Figure 3, are obtained for the case of transportation of 616 passengers in a three-class layout of cabins for a distance of 13 700 km. At the same time, the degeneration of the "flying wing" scheme is clearly visible. In this dimension a developed fuselage part already appears. This fact is connected with the peculiarities of the layout of passenger cabins. The need to provide the specified volumes, height and width of passenger compartments requires an increase in the internal volumes of the flying wing. For example, the increase in overall heights in the central part of the wing is due to the provision of a minimum height of the passages. Therefore, in the central part of the wing the chords are enlarged to provide the necessary overall heights.

5. CONCLUSIONS

The structural-parametric analysis of the influence of infrastructural requirements on the long-haul airplane with large passenger capacity confirms the fundamental possibility of creating an aircraft of this type for economically efficient operation in an already existing infrastructure complex and demonstrates possible directions for the development of this type of main aviation.

In comparison with the base aircraft of a normal aerodynamic scheme, the cost of a flight hour is 84%, and in comparison, with a triplane scheme with an articulated wing - 94%. The advantages of aircrafts designed according to the "flying wing" scheme in relation to other schemes rise with the increase in the dimension of the aircraft. So, the greater value of the target load and the flight range is, the better application of this scheme is.

REFERENCES

[1] Eger, S.M., Lisejtsev, N.K., Samoilovich, O.S. 1986. Fundamentals of automated design of aircraft. Mashinostroyeniye, Moscow.

[2] Dolgov, O.S., Kuprikov, M., Yu. 2008. Momento-inertial factor in the formation of the shape of the aircraft. MAI-PRINT Publishing House, Moscow.

[3] Dolgov, O.S., Kuprikov, M., Yu., Kuprikov, N.M. 2010. Features of detecting the moment-inertial appearance of perspective aircraft, in the early stages of design. Bulletin of the Moscow Aviation Institute, 2(17), 5-15.

[4] Dolgov, O.S., Kuprikov, M., Yu., Ripetsky, A.V. 2010. Features of geometric synthesis at different stages in the formation of the shape of a large passenger capacity aircraft. Bulletin of the Moscow Aviation Institute, 5(17), 43-48.

[5] Avedian, A.B., Kuprikov, M., Yu., Markin, L.V. 2012. The layout of aircraft. MAI Press, Moscow.

[6] Kuprikov, M.Yu., Maksimov, S.V. 1999. Influence of infrastructure restrictions on the appearance of a long-range long-range aircraft. News of universities "Aviation equipment", 1, 52-55.

[7] Kuprikov, M., Yu., Patrakov, A.G. 2004. Use of CAD. In: CAE systems in detecting the appearance of the main aircraft. Proceedings of the IX International Symposium "Dynamic and Technological Problems in Mechanics of Constructions and Continuous Media" (pp. 58-59). MAI, Moscow.

[8] Kuprikov, M., Maximov, S. 1997. Selecting rational parameters for the lift system of a subsonic transport plane, AC TCH – 96-24, Russian Sci-tech, 1, 17-20.

[9] Kuprikov, M., Maximov, S. 1997. Using Engine Thrust Excess to Control Aircraft Flight and Trimming, AC TCH –96-23, Russian Sci-tech, 1, 22-27.

[10] Malchevsky, V.V. 1987. Automation of the airplane layout process. MAI, Moscow.

[11] Egorov, E.V., Tuzov, A.D. 1988. Modeling surfaces of airborne units. MAI, Moscow.

[12] Egorov, E.V., Nartova, L.G. 2012. Constructive geometry. MAI, Moscow.

[13] Kuprikov, M., Yu. 2003. Structural-parametric synthesis of the geometric shape of the aircraft under severe constraints. MAI, Moscow.

[14] Formalev, V.F., Kolesnik, S.A., Selin, I.A., Kuznetsova, E.L. 2017. Optimal way for choosing parameters of spacecraft's screen-vacuum heat insulation. High Temperature, 55(1), 101-106.

[15] Kuznetsova, E.L., Leonenko, D.V., Starovoitov, E.I. 2015. Natural vibrations of three-layer circular cylindrical shells in an elastic medium. Mechanics of Solids, 50(3), A012, 359-366.