ADDED MASSES DETERMINATION OF PLATES IN INFINITE LIQUID ENVIRONMENT IN THE CASE OF VARIOUS TYPES OF MOVEMENTS

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I. INTRODUCTION

The knowledge of the added masses of bodies contacting with liquid is necessary for solving of various research and applied problems of hydromechanics, such as steady and transient movements of rigid bodies, general vibration of bodies in liquid, local vibration of the constructions in the fluid environment.

Nowadays software based on numerical approaches are widely used for calculate the added masses of various constructions. At the same time, for shipbuilding structures there is extremely important problem when structural elements make finite displacements and have elastically deformation together.

The method of temperature analogy, which is used in this work, is widely known in scientific community. This method is very convenient for solving the Laplace equation, which is used for searching the added masses of liquid. The movements of any structures as solid, immersed in liquid, are widely represented in the articles and books, but there are not a lot of publications describing the movements with vibrations and deformations in its own modes.

The purpose of this work is determine the added masses of the plate in the case of its movements as rigid and vibrations in liquid by numerical method; influence on result the dimensions of structure and liquid environment.

II. THE ADDED MASSES OF BODIES

Part one. The case of the body's movements as rigid

In first part we determine the added masses in the case of translational motions of the circular disk of radius r, immersed in an infinite liquid.

There is analytical solution of this problem. We suppose that there is volume V of rigid body has an external surface S. This body starts to move from initial position in infinite ideal homogeneous liquid without vortexes. Then, in the process of motion, the flow caused by body motions will be potential. We need to introduce some hypotheses to solve this problem:

We consider only small oscillations of the plate in liquid, which are described by linearized equations. There are small displacements of the plate and liquid is moving along with 2-D shaping in perfect contact;

We consider that the liquid is incompressible;

We consider that shape modes of the plate in liquid environment and empty space are identical.

Thus, the liquid influence will be inertial and the mass of the plate is increasing, therefore its own frequencies are decreasing.

There are no vortexes, so we consider that there is a potential function $\Phi(x, y, z, t)$, which is characterizing velocities of flow, which is arising in the case of structure vibrations in liquid. Potential Φ can be represented in the following form

$$\Phi = u_{0x}\varphi_1 + u_{0y}\varphi_2 + u_{0z}\varphi_3 + \omega_x\varphi_4 + \omega_y\varphi_5 + \omega_z\varphi_6$$

The added masses of liquid adjoining to the surface of a moving body can be determined by the following formulas

$$\lambda_i = \rho \iiint_v \ [(\frac{\partial\varphi_i}{\partial x})^2 + (\frac{\partial\varphi_i}{\partial y})^2 + (\frac{\partial\varphi_i}{\partial z})^2] dxdydz, \quad (1)$$

$$\lambda_{ik} = -\rho \iint_S \ \varphi_k \cdot \frac{\partial\varphi_i}{\partial n} dS, \quad (2)$$

where ρ is density of liquid.

For the numerical computation in the ANSYS software in the case of translational motion along $z-$ axis we can use the temperature analogy.

There is Table №1, which shows the results of added masses. These results have calculated by two different ways such as integration over the outer surface (S), which is bounding the volume of considered domain, and volume integration (V). The convergence of added masses on the size of liquid environment is presented in Figure 1.

Table 1 – The added masses in the case of translational motion along $z-$ axis

Formulation	Added mass, kg		
Analytical estimation			
Korotkin, Alexandr I., 1986	21 333,33		
Numerical results ($r = 2\ m$)			
$q\mid_S = 1$ $q\mid_{r\to\infty} = 0$ $T = 0$ on the cut surface	R, m	S	V
	10	20 626,16	20 311,90
	20	20 566,76	20 250,92
	30	20 560,40	20 239,33

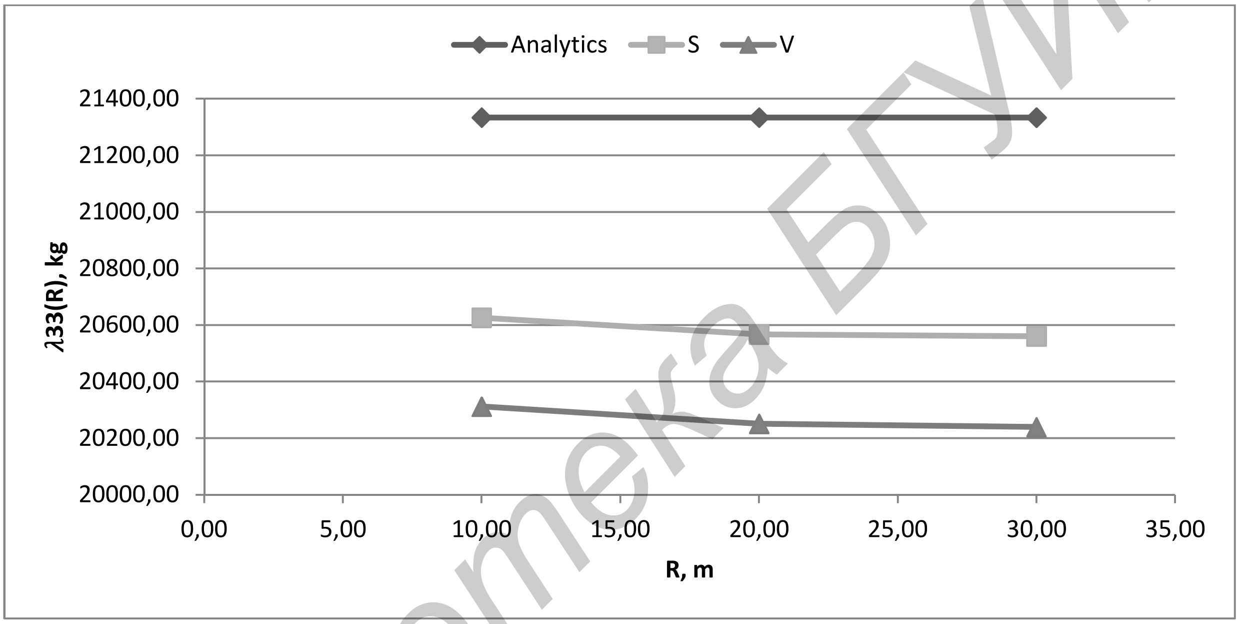

Figure 1 – The convergence of the added masses on the size of liquid environment, which have calculated by integration over the outer surface and volume integration

Part two. Vibrations of a fixed rectangular plate

In the second part of the work we are solving more difficult problem of the rectangular plate movements in an infinite liquid. The plate dimensions are $a\ x\ b$. Here, as the motion of the plate, we will consider its vibrations with the following deformations. In the first part of the work we introduced the hypothesis that the liquid is incompressible. The influence of the liquid compressibility on vibrations is determined by dimensionless parameter. This parameter is called the Strouhal number:

$$St = \omega l / c_0, \quad (3)$$

where c_0 is speed of sound in the water; l is the characteristic size, which is the distance between the nodes of the mode of vibrations; ω is vibrations frequency.

We need to use previous formulas (1) and (2) for determination of added masses in the case of the plate vibrations in an infinite liquid. We are solving the problem in the case when the part of the boundary of the volume V adjoining to the plate is represented by rigid screens.

There is Table 2, which shows the comparison of the analytical and numerical results, which are obtained for different sizes of liquid environment R. The convergence of the added masses for freely-supported plate on the size of liquid environment is presented in Figure 2.

Table 2 – The added masses for freely-supported plate

Formulation	Added mass, kg		
Analytical estimation			
Davydov, Vadim V., Mattes, Natalia V., 1974	6 560		
Shimanskiy, Julian A., 1963	6 720		
Postnov, Valeriy A., 1983	6 880		
Numerical results ($a = 4\ m, b = 4\ m$)			
$q \mid_S = \sin\left(\pi \frac{(x - a/2)}{a}\right) \cdot \sin\left(\pi \frac{(y - b/2)}{b}\right)$ $T \mid_{r \to \infty} = 0$ $q = 0$ on the cut surface	R, m	S	V
	10	5 867,96	6 477,48
	40	6 020,83	6 082,67
	100	6 109,81	6 037,70
	200	6 141,15	6 011,49
	250	6 147,41	6 008,96

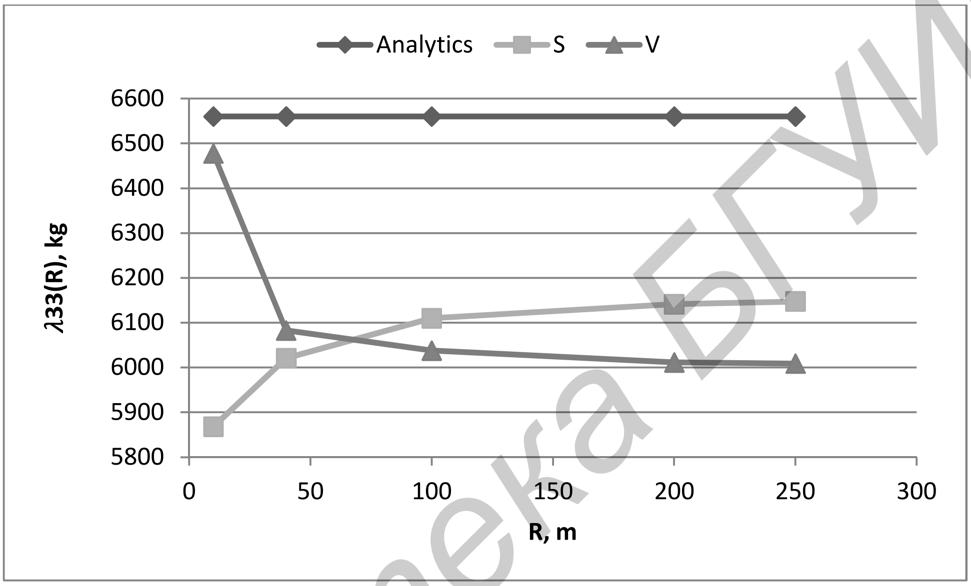

Figure 2 – The convergence of the added masses on the size of liquid environment, which have calculated by integration over the outer surface and integration through volume

III. CONCLUSIONS

Part one.

The differences between the results of numerical solution and analytical result are less than 5 percent.

Increasing the size of liquid environment leads to computational complicating. We can see that there is the convergence of the added masses for the circular plate movements in the case of increasing the liquid environment size R. We have found that there is the ultimate size of liquid environment $R = 10a$, where is a – radius of the plate.

At added masses determination for translational movements of the plate we used two methods of integration: integration over the outer surface of the plate and integration through liquid volume. These methods are acceptable for solving the problem. We can use any of them. But finite element model for volume integration requires a regular finite element mesh overall volume.

Part two.

We can see that there is the convergence of the added masses for vibrations of the rectangular plate in the case of increasing the liquid size environment R.

The analysis of the size of liquid environment influence showed that we can select reasonable limit for the size of liquid environment above which value there is no need to increase the one. The difference of added masses for size of liquid environment $R = 200\ m$ and $R = 250\ m$ is in range 0.05 – 0.1%. Therefore, a suitable size of liquid environment is $R = 50a$, where a is the biggest side of the plate . Further increasing the size of liquid environment leads to computational complicating.

The differences between the results of numerical solution of the problem of vibrations of the rectangular plate in an infinite liquid and analytical result are no more than 6 %.

In this problem as in the previous for finding the added masses for vibrations of the plate we used two methods of integration: integration over the outer surface of the plate and volume integration of liquid. These methods are acceptable for solving the problem. We can use any of them. But finite element model for volume integration as was noted earlier requires a regular finite element mesh overall volume.

TOPOLOGY OPTIMIZATION AND CASTING PROCESS SIMULATION FOR LIGHTWEIGHT DESIGN AND MANUFACTURING FEASIBILITY OF AN AIRCRAFT BRACKET

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There is a large amount of cases, when it is required to reduce the mass of a casted part, while the structural performance shall remain unchanged. The most efficient way of doing this is based on the topology optimization procedure, which allows reaching the required goals, but makes the manufacturing much more difficult in case of using the traditional casting process design. The workaround is to use the optimization software in combination with the special tools for direct simulation of the casting processes. This approach allows designing such components, which fulfill both the structural and mass requirements and the technological requirements, while making the process of development of complex casts shorter. Current article shows the complementary effect of the topology optimization and casing simulation software on the design and manufacturing workflow for an aircraft bracket.

The methodology is based on the iterative process, which involves two software tools – Inspire and Click2Cast by solidThinking, Inc., the company owned by Altair Engineering, Inc. The tools are used for preparing the design of the bracket, which is lightweight, durable and technologically feasible.

Topology optimization is carried out in solidThinking Inspire, which allows designing lightweight parts without compromising their strength. The system analyzes the structural loads and constraints as well as the technological constraints and generates the distribution of the solid material inside the fixed volume – design space.

The part, which is considered in the article, is the bracket that is installed on the casing of a jet engine and carries the weight of the engine during service operations that are performed on the ground. Each of the engines is equipped with four brackets, which fly with the aircraft during the whole life of the machine. The mass of the original bracket is 1.046 kg.

The original geometry of the bracket and all the loads and supports are shown in Fig. 1.

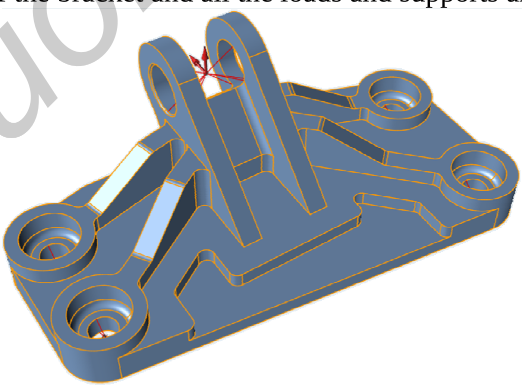

Figure 1 – Original geometry of the bracket

The design space with all the loads and supports for the considered bracket is shown in Fig. 2. The regions, where the solid material is distributed during the topology optimization run, are shown dark brown. Grey color represents the unchangeable regions.