# VORTEX PROPULSION UNITS OF SEA VESSELS AND AIRCRAFTS

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### ABSTRACT

Basic diagrams and estimates of the main parameters of sea vessels and aircrafts with propulsion units in the form of generators of vortex pairs, including toroidal vortices (thermals) are proposed. It is shown that the efficiency of such propulsion units increases with the increase in their dimensions, so that in case of surface vessels propulsion units provide the buoyancy of the vehicle, the ability to locate a useful volume in the abovewater part, and in case of air and submarine vessels – inside the propulsion unit. Since the vortex pair moves in the environment, without experiencing frontal resistance, vessels, manufactured according to the proposed schemes, also do not have frontal resistance. This factor gives the design a considerable advantage in the cost of power to move through water and air.

Keywords: aircraft, sea vessels, vortex pair, drag, dissipation of vortex energy, structural features.

**Background.** Almost all modern water and air vehicles (vessels) are made in a separate scheme «propulsion unit – vessel's hull», in which the propulsive device, as a result of interaction with the surrounding environment, creates a necessary traction effort. With such an arrangement, to move the vessel, it is required to overcome the force of the medium's resistance, caused by a counter- impact pressure, acting on the body, and more often on the body and on the propulsion unit.

With the increase in the dimensions of vehicles and the speeds of their movement, these resistance forces increase, and the power required for movement increases in proportion to their product, which in this case is proportional to the product of the velocity cube over the cross-sectional area of the vessel.

A possible option is not to overcome, but «bypass» the problem of water or air resistance (the cases of a ship and airship, respectively) is the use of a specific flow known in hydrodynamics as a vortex pair [1–3] and its particular case is a toroidal vortex or thermal.

A vortex pair is two relatively closely spaced vortices with mutually opposite directions of rotation [4, 5]. The arrangement can be considered close if each of the vortices comparatively efficiently interacts with the current created by the other. In such a flow there is such a limited region (volume) with closed trajectories of fluid motion, which moves in the environment, and there is no jump in the velocity of the fluid at the boundary of the moving region, that is, this region moves in the environment without frontal resistance.

Located in the closed flow area, the vessel's hull, combined with the vortex generator, also moves in the medium, without experiencing frontal resistance. The constructive scheme of such a hypothetical vessel, both water and air, is radically different from all used up to the present time.

The purpose of this work is to analyze the possible layout schemes for vessels «hull – generator of a vortex pair that is a propulsor» with an assessment of the main parameters of such vehicles and their comparison with traditional schemes.

**Objective.** The objective of the authors is to consider vortex propulsion units of sea vessels and aircrafts.

Methods. The authors use general scientific and engineering methods, mathematical calculations, evaluation approach, comparative analysis. Results.

#### 1. Vortex pair hydromechanics

Two vortices with opposite in sign but equal in modulus circulation (Pic. 1a) move translationally along a straight line perpendicular to the segment joining the centers of the vortices with the velocity [5, 6]:

$$V = \frac{G}{4\pi r};\tag{1}$$

$$G = 2\pi a v_0 = 2\pi \omega a^2 , \qquad (2)$$

where G is circulation of the vortices, r is the distance from the line of symmetry to the center of the vortex.

Pic. 1b shows a diagram of the current lines of a vortex pair in a reference frame moving with vortex filaments. Part of the fluid, marked with dashes, remains constantly in the vicinity of the vortex filaments.

Such a pair of vortices is a plane element of a vortex ring, which can be another version of the organization of the vortex propulsor. For example, a vehicle in the form of a torus is possible, the outer



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Pic. 2. The toroidal vortex.

shell of which will generate a toroidal vortex (Pic. 2) and act as a propulsor.

An estimate of the translational velocity of a vortex ring is obtained from the Kelvin formula [7, 8]:

$$V = \frac{G}{4\pi r} \left[ \ln \frac{8r}{a} - \frac{1}{4} \right]. \tag{3}$$

At a sufficient depth of the reservoir, a pair of rectilinear vortices closes in the underwater part, forming a half of the toroidal vortex (Pic. 3).

If a rotary cylinder is used as an artificial vortex generator, the maximum linear velocity on the lateral surface of the cylinder should not exceed the value at which the velocity head of the liquid is equal to the

# total pressure in the liquid [8], i.e. $v_{max} = \sqrt{\frac{2p_0}{\rho}}$ , where

 $p_o$  is the pressure in the liquid. At higher speed cavitation of the liquid occurs and its acceleration by rotation of the rotor is impossible. In the case of a surface vessel  $p_o = 1 \text{ atm} \approx 10^5 \text{ N}/m^2$ ,  $\rho = 10^3 \text{ kg}/m^3$  and the maximum permissible linear velocity on the surface of the rotors is  $v_{max} \approx 15 \text{ m}/\text{ s}$ ; at  $p_o = 10 \text{ atm}$ ,  $v_{max} \approx 45 \text{ m}/\text{ s}$ ;

Since, on the one hand, with other things being equal, the speed of the vessel increases, the smaller is the interaxial distance I = 2r, and on the other, this distance must be large enough that a closed flow forms in the vicinity of each rotor, the optimization question I acquires an independent value. The initial condition for optimization can be the distribution of fluid velocity in the vicinity of a rotating cylinder – a vortex generator. In the absence of dissipative losses, the circulation of the liquid is constant  $G_0 = \text{const}$ , and the ratio of the velocity of translational motion to the linear velocity of the vortex depends on the distance between the centers of the vortices, which is shown in Pic. 4.



Pic. 3. Closure of two near-surface linear vortices with the formation of a half-toroidal vortex.









Pic. 5. Dependence of the dimensionless speed of the vessel from the radius of the rotor for different values of the inter-rotor distance.



Pic. 7. Dependence of the power consumption on the speed of movement.



Pic. 5 shows a family of curves 
$$rac{V_{
m ves.}}{v_{
m o}}(a)$$
 for several

I - values of the inter-rotor distance.

In a viscous fluid, to maintain such motion, it is necessary to impose energy from outside the source of vorticity, for example, from a cylinder rotating in a liquid. The force required to overcome the forces of internal friction  $F_{fr}$ .

$$F_{fr} = S\eta \frac{dv}{dr} = -\frac{h\eta aG}{2r^2},$$
(4)



Pic. 6. Dependence of power consumption on the speed required to maintain vortices.



Pic. 8. Dependence of the energy consumed for rotation of vortices on the velocity of the vortex pair.

where S is the area of the cylinder,  $\eta$  is the dynamic viscosity of the fluid; and the power is:

$$P = F_{fr}v(r) = -\frac{h\eta a G^2}{4\pi r^3}.$$
 (5)

Pic. 6 shows the dependence of the power consumption on maintaining the vortex motion on the speed of the vessel with displacement of 4000 tons.

For vessels with traditional propulsors, the dependence on the speed of power consumed to overcome the drag for a drop-shaped body with displacement of  $\cong$  4000 tons, in the underwater position, is determined in accordance with:

$$P(v) = F_{fr}v = C_x S \frac{\rho v^3}{2}, \quad C_x = 0,045.$$
 (6)

Pic. 7 is a graph of this dependence.

As can be seen from the graphs, the power consumption of vessels with propellers of the proposed type is 10<sup>7</sup> times less than for vessels with traditional propulsors.

However, for rotation of vortices it is necessary to expend a considerable amount of energy, exceeding the figures for traditional engines. The energy consumed for rotation of vortices has a dependence

$$E = \frac{G^2 \rho h}{16\pi} \ln(10) \tag{7}$$

and is shown in Pic. 8.

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Pic. 10. Scheme of ship realization on two vortex pairs obtained by vertically rotating cylinders: 1 – rotor, 2 – support, 3 – platform, 4 – medium (water).



Pic. 11. Symmetrical arrangement of the vortex generators and current flow diagrams.

When starting the drive of the vortex generators, they are initially surrounded by a stationary medium. This stage corresponds to the maximum velocity gradients. They can be estimated from above by assuming that at the initial moment the velocity drop from the linear velocity of motion on the surface to zero is realized on the thickness of the boundary layer of the medium (liquid).

The thickness of the boundary layer  $\delta$  is estimated from the relation:

$$\delta = \frac{L}{\sqrt{\text{Re}}} \,. \tag{8}$$

where L is the length of an accelerating section, Re is the Reynolds number.

The power consumed at the stage of rotation of the rotors can be found with the aid of the relation

$$N^* = S_{vor} \mu (gradV)_{max} v_{max} .$$
<sup>(9)</sup>

where  $\mu$  is dynamic viscosity of the fluid, and the maximum velocity gradient is defined as follows:

$$(gradV)_{\max} = \frac{V_{\max}}{\delta}.$$
 (10)

Based on the performed calculations of the capacities, it is possible to estimate the time required for rotation of the rotors:

$$t = \frac{E}{N^*} = \frac{\rho a \delta}{8\mu} \ln(d) , \qquad (11)$$

where d is the ratio of the rotor-to-rotor distance to the rotor radius,  $\rho$  is the density of the medium (water),  $\mu$  is the dynamic viscosity of the medium.

Pic. 9 shows the dependence of the time of formation of motion on the radius of the rotor for different values of the inter-rotor distance.

## 2. Generator circuits and layout options

The toroidal vortex has the best characteristics as a propulsive device (Pic. 2), which has minimal

dissipative losses and maximum lifetime in the absence of an initiating source of rotation. However, a toroidal vortex can arise and exist only in a homogeneous medium, with reference to the conditions of our theme - in an atmosphere or an aqueous layer of thickness at least an order of magnitude larger than the torus. At the interface, for example, on the surface of water, a toroidal vortex is essentially impossible. The simplest generator of the toroidal vortex is a rotating toroidal shell. In this case, the hull of the vessel is placed (built in) inside such a shell. The structural and technological realization of such airships (dirigibles) and water vessels (in this case always underwater vessels) due to the originality of most structural elements is obviously connected with a number of technical (engineering) problems.

The simplest generator of a surface vortex pair are two vertical rotating (in mutually opposite directions) cylinders, which ultimately realize a semitoroidal vortex (Pic. 3). However, on such a separate pair of cylinders, it is not possible to mount a body of a surface vessel without additional supports in the water. Two or more pairs of cylinders allow the platform to be mounted in the above-water part (supported on the axis of the cylinders) as a bearing element of a surface vessel [10]. Essentially, there are no obvious limitations on the shape and carrying capacity (displacement) of the platform. As the diameter of the cylinders increases, the displacement and stability of the vessel increase and a greater efficiency of the motion of the vortex pair is realized.

Vortex generators can be, for example, cylinders arranged in the form of two parallel rows on which the supporting platform (housing) is placed. Such a design assumes the formation of two vortex chains, and the vortex generators (cylinders) can be arranged in two ways: each vortex generator of one row is placed opposite the cylinder of the other row (Pic. 11)



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Pic. 12. Displacement of vortex generators and current flow diagrams.

or placed opposite the middle of the interval between two neighboring cylinders of the other row (Pic. 12). Each of these systems will also move forward with

speeds:

For a symmetrical arrangement

$$V = \frac{G}{2b} cth \frac{\pi 2r}{b}, \qquad (12)$$

For shifted location

$$V = \frac{G}{2b}th\frac{\pi^2 r}{b},\qquad(13)$$

where *b* is the distance between neighboring vortex generators.

The stability of the systems of these different arrangements of vortices relative to each other was studied by Karman. It was proved that the symmetrical arrangement is unstable, that is, with the passage of time, the vortices shift from positions corresponding to the unperturbed state. The displaced location is stable, and therefore does not require additional energy costs to overcome the forces displacing the vortices. The stability condition obtained by Karman has the form [11]:

$$\frac{2r}{b} = 0,2806$$
 (14)

With the number of pairs of cylinders larger than two, the optimization of their number and mutual arrangement becomes a separate independent task.

### Conclusions.

1. A targeted survey analysis of the flows generated by the vortex pair was carried out. From the fact of the continuity of the distribution of the velocity of the medium in the neighborhood of the pair, a consequence is pointed out that the region of closed motion moves in an environment without frontal resistance.

2. Principal schemes of the layout of air and submarine vessels with the placement of vessel's hulls inside the generators of vortex pairs are proposed. For surface vessels, a scheme is proposed for the hull of the ship outside the water with support on the axis of the immersed cylinders – vortex pair generators. Vessels performed according to the proposed schemes do not experience drag when moving.

3. It is shown that the power required to move ships executed according to the proposed schemes is several (5–7) orders less than the power consumed by traditional vessels.

4. Estimates of the energy required for the formation of steady motion in the region of a closed flow in the vicinity of the vortex pair and the time of its formation are performed.

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