On Application of the Ground Effect For Highspeed Surface Vehicles

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ABSTRACT. The paper describes a new approach for driving efficiency estimation. Authors proposed a new approach to assess the energy consumption for vehicle, which are able to rich high speed. Also, there is proposed a new concept of vehicle, which technology based on the ground effect. The concept compounds the automotive and aircraft's solutions in order to reach high driving speed, driving efficiency and low energy consumption per cargo unit. As a result, the defined performance indicators for the transport systems opens up the possibility to formulate and solve optimization problems of structural and parametric synthesis of new types of transport, provide the analytical tools to make informed decisions in the process of design and construction, provide an overall controlled evolution of transport systems.

It is well-known, that the speed range 150-600 km/h for the vehicles of air and ground transport is not developed to its maximum. Therefore, this a gap, which can be filled with a new kind vehicle. Some countries are still working under the idea of such vehicles and are going to develop a new kind, which technical-economic performance and exploitation characteristics will satisfy the market demands.

One of the most perspective kinds of ground transport is well-known in aviation ground-effect craft (Ekranoplane), which technology is based on the ground effect.

Through the years, specialized military institutions were involved in the projects in order to solve sophisticated issues in aerodynamics, strength, safety and exploitation reliability of ground-effect craft. As a result, several ground-effect crafts (GEC) have been designed and produced (Strizh, Volga-2, Lun) (fig. 1).

Fig. 1. Ground-effect craft Lun

Such companies as Vehicle Research Corp., General Dynamic, Kawasaki, Lockheed etc, have developed several projects of GEC. There are well-known projects «Columbia», «Aerofoilboat» X-112, X-113, X-114.

To the date, many SMEs worldwide make an effort to develop multifunctional vehicle, which will satisfy the market needs in the niche of such transport. However, those vehicles, the implementation of which has reached the current sample piece or small batch production, pronounced structural features of aircraft and have no specific layout solutions for the automotive structure. This significantly decrease the market prospects of these models. In fact – they are aircrafts, adapted for the auto roads of general purpose, with the performance inherited from the automotive industry, as you can see from the photos, below (Figure 2).

Fig. 2. GEC prototypes

For a theoretical study [1-5] for a multifunctional vehicle (MFV) it seems appropriate to start from the classical measures of mechanical motion – the amount of motion, proposed by Descartes and kinetic energy (Leibniz introduced as a "living force") and Helmholtz. It is also known that the increase in speed is the objective tendency for existing terrestrial means of transportation of cargoes and passengers. An integral, averaged vehicle performance indicator can be the amount of energy and its cost value spent per moving mass and speed along the route in the real external disturbances and influence:

$$E_Q = \frac{P\,\tau}{M\,L}, \tag{1}$$

where P – energy (fuel) consumption;

M – avarage mass of the vehicle;

L – the traversed path;

τ – the travelling time.

It is obvious, that $\frac{L}{\tau} = V$ – is the speed of the vehicle. Than:

$$E_Q = \frac{P}{M\,V}, \tag{2}$$

where $MV = Q$ − the average amount of motion for the vehicle:

$$E_Q = \frac{P}{Q}. \tag{3}$$

It is known, that widely used easy performance indicator of the vehicle is determined by the formula:

$$E_L = \frac{P}{L} \tag{4}$$

Moreover, it characterizes the power consumption (or fuel) per the travelling distance unit. Then, the connection between input efficiency index and known one will be described as:

$$E_Q = \frac{\tau}{M} E_L. \tag{5}$$

Note, that the performance indicators of the vehicle are dimensional quantities.

It seems reasonable, to provide invariative factor, which links the average kinetic energy $T = \frac{M\,V^2}{2}$ and the energy consumption P_E, that have the same unit:

$$E_T = \frac{P_E}{T}. \tag{6}$$

Thus, it is not difficult to establish a link with the indicators considered earlier E_Q и E_L:

$$E_T = 2\frac{\tau}{L} E_Q,\; E_T = 2\frac{\tau^2}{M\,L} E_L. \tag{7}$$

Thus, a comparative evaluation of the vehicle efficiency is reduced to finding the minimum value of the imposed indicators E_L, E_Q, E_T. Note, that a well-known performance indicator E_L is easy to define, and E_T − provide an appropriate value. The most important part of the theoretical study to develop a feasible multifunctional vehicle allows combination the characteristics of the aircraft and the car is a factor of driving performance:

$$K = \frac{G}{X}, \tag{8}$$

where $G = g\,M$ − the vehicle mass;

g − gravity constant;

$X = c_x\; qS$ − resistance force;

c_x − resistance coefficient;

$q = \dfrac{\rho V^2}{2}$ − dynamic pressure;

ρ − atmospheric density;

S − midsection area.

The meaning of the running quality factor is to assess the value of the total weight, carried by the vehicle to the value of the losses associated with energy dissipation in the process of high-speed traffic, i.e., this ratio is analogue of the coefficient of aerodynamic quality for aircraft:

$$K_Y = \frac{Y}{X}, \qquad (9)$$

where Y − lift force.

It is known, that increasing the speed of wheeled vehicles more, then 150 km/h arise a complex of physical processes, affecting the comfort and safety of movement. These processes lead to a number of environmental, economic and technical problems, which include:

− Significant investments to alienate territories, construction and operation of a special road surface;

− Overcoming the resistance forces, mainly aerodynamic;

− Smoothness the support surface, the local irregularities in the curvature of the path plan and profile, a small clearance;

– "Vibrating barrier", arising from vibrations caused by irregularities of the supporting surface;

– "Traction barrier" due to decrease of the grip between wheel and supporting surface etc.

It should also take into account, that driver and passengers affected by many disturbing factors be taken into account, registration, assessment and certification of the relevant criteria and indicators. The most important of these factors are dynamic loads (overload), vibration, acoustic vibrations, micro-climatic conditions, etc. Each of them covers a wide range of problems. In particular, the dynamic loads on the power structure or overload affecting a person due to inertial forces at high-speed-controlled movement along a spatial path defined by the support surface and characterized by the curvature in plan and profile, local irregularities, as well as other random factors.

As an illustration, below follows a graphical analysis of a wide range of speeds on the basis of performance indicator *K*.The results of these studies are shown in Figure 3, in the form of dependence of the driving characteristics of the operational speed of the vehicle:

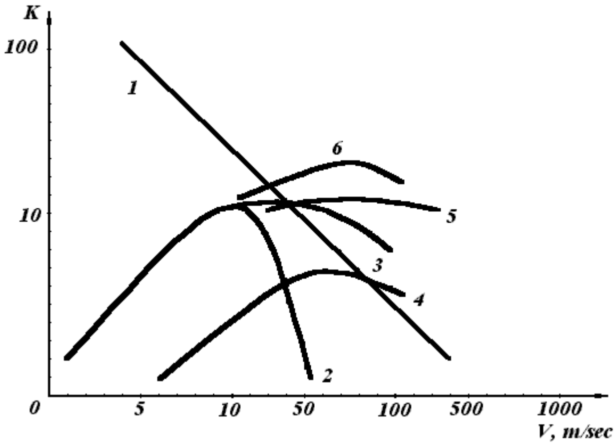

Fig. 3. Graphic curves of the driving performance

As shown on the Fig. 3, factor of driving performance of wheeled vehicles (road, rail) with the increase in speed and decreases monotonically at a speed of 50 m/s does not exceed 10 (curve 1). For example, the maximum driving performance of the helicopter is 7 at a speed 70 m / s (line 4); hydrofoils – 10 at a speed 12 m/s (curve 2); hovercraft – 12 at a rate of 40 to 60 m / s (curve 3), the jet – 15 at a rate of 50 to 500 m/s (curve 5) GEC craft – 40 at a speed of 80 m / s (350 km / h, curve 6).

It should be noted an important feature of the dependences: there is a critical point where the driving characteristics of a wheeled vehicle and GEC matches. This point corresponds to the velocity of 120 km / h and 150 km / h and driving performance coefficient is 20. As follows from this conclusion, there is a necessity to improve research of the GEC craft. A combined transport system can provide stable and high driving quality (20-40), that is not achieved by any known means of transport in the speed range of 150-600 km / h. Creating the proposed combined system of the ground transportation, wholly or partly eliminates the above mentioned technical problems, associated with high-speed movement ("vibrating barrier", "traction barrier" etc.). The support surface for this type of combined transport at high speeds is a combination of conventional pavement, grass or water. Note also the absence of the special road constrictions (bridges etc.) while the motion in the “screen” regime. However, other technical issues might arise at this new technological level. Among these problems are:

- Selection of the optimal aerodynamic shape of the supporting frame, ensuring the highest ground effect and the lowest aerodynamic drag;
- Routing security, stability and control the sub-screen movements;
- Selection of efficient energy sources and ways of its implementation in the operational speed range of 150-600 km / h;

To maintain such vehicle, a dynamical design approach have to used. The vehicle should have efficient aerodynamic shape of the supporting frame. Preliminary proposal of this multifunctional vehicle shown on Fig. 4.

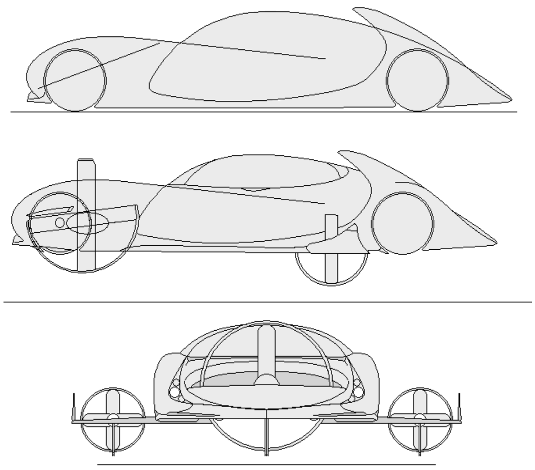

Fig. 4. The main lines of the frame and engines

Here, the wedge-shaped body with cross bending is performed to form on top of the discharge surface. Strengthening the screen effect is provided by extension from under the bottom of the unit, which allows increasing the area twice and creates underfloor duct tunnel, which situates a dynamic air cushion when the motion of the device. An additional lift force induces screw propulsion engine. To ensure the manageability and sustainability movement at “sub-screen” regime use airfoils with steering bodies. Resistance movement gives the horizontal wing airfoil, which creates an additional adjustable lift, stabilizing movement and is used to control the formation of forces and moments in the channels of pitch and yaw. Control forces and moments are provided with a front helical boosters, with oncoming traffic screws, placed in the front of the vehicle in a circular nozzle (a gimbal suspension) and two additional engines in the bottom of the body to put forward aerodynamic surfaces. It should be noted, that the screw propeller is most effective at speeds of 200 - 500 km / h, i.e. in the speed range corresponding to the operating mode of GEC craft. To reduce weight, impart improved aerodynamic shape, strength, processability, surface of the wing-shaped body is made of carbon fiber material, and the lower part and the main structural components are made from light alloys.

Taking into account the psycho-physiological abilities of the person, management and routing movement of the vehicle on the movement speeds of over 200 km/h orientation and stabilization systems might be used.

Summary. Thus, the search for universal performance indicators (objective functions) transport systems opens up the possibility of formulating and solving optimization problems of structural and parametric synthesis of new types of transport, provides the analytical tools to make substantiated decisions in the process of design and construction, providing an overall controlled evolution of transport systems.

References

[1] Kravets V.V., Kravets T.V., *On estimation of the centrifugal, Coriolis and gyroscopic forces in high-speed movement of the train crew,* Applied Mechanics, 2008, Vol.44, pp. 123-132.

[2] Jian-lin Qian, Chin Dai, *Unsteady flow structure of an airfoil in ground effect,* Journal of Shanghai University, June 2010, Volume 14, Issue 3, pp 228-234.

[3] Yang Zhigang, Yang Wei, *Complex Flow for Wing-in-ground Effect Craft with Power Augmented Ram Engine in Cruise*, Chinese Journal of Aeronautics 23（2010）pp.1-8

[4] Rozhdestvensky K. V. *Wing-in-ground effect vehicles*. Progress in Aerospace Sciences 2006；42 (3): pp. 211-283.

[5] Yun, Liang, Alan Bliault, and Johnny Doo. *GEC Craft and Ekranoplan: Ground Effect Craft Technology*. New York: Springer, 2010. Internet resource.