*Л.Н. Гумилев атындағы Еуразия ұлттық университетінің ХАБАРШЫСЫ.*
*ISSN: 2616-7263. eISSN: 2663-1261*
**ТЕХНИКАЛЫҚ ҒЫЛЫМДАР ЖӘНЕ ТЕХНОЛОГИЯЛАР СЕРИЯСЫ /**
**TECHNICAL SCIENCES AND TECHNOLOGY SERIES/**
**СЕРИЯ ТЕХНИЧЕСКИЕ НАУКИ И ТЕХНОЛОГИИ**

IRSTI 55.49.05;
Scientific article

*DOI: https://doi.org/10.32523/2616-7263-2024-146-1-21-33*

# On the possibility of changing the trajectory of a projectile or a rocket based on aerodynamic impact in the shock wave zone

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**Abstract.** A physical hypothesis is proposed that it is possible to change the design trajectory of the projectile on the basis of mechanical action on the entire volume of shockwave zones with a unilateral, asymmetric presence of the second projectile. Deviating from the original trajectory results in a positive result when it comes to a defensive task.

A new semi-empirical model has been developed and compiled, which allows you to calculate the trajectory of the projectile taking into account the air resistance to movement.

In the new model, it is recommended that only four easily detectable values be used in upcoming experiments:

the initial departure speed v_0, the maximum altitude y_max, the maximum flight range x_2 and the full time. The calculation scheme uses iterative calculations. On the basis of which the values  of numerical coefficients in the semi-empirical model are specified. The physical idea that external powerful laser radiation can heat the side surface of the projectile and the entire zone of wave jumps of the seal is justified. On one side of the semi-plant, that is, it is one-way heating. The asymmetrical thermal state on both sides of the missile may cause the missile or projectile to deviate from the previously assigned heading. This circumstance is also in favor of the proposed idea.

**Keywords:** wavefront, projectile, rocket, aerodynamic resistance, calculations, trajectory, iteration.

**Received 05.06.2023. Revised 11.08.2023. Accepted 21.08.2023. Available online 29.03.2024**

## 1. Introduction

In modern combat and military technologies, rocket attacks from long distances play a leading role. The way when numerous troops are fighting figuratively speaking "head-on" with machine guns in hand is a thing of the past. This method of warfare is apparently outdated, as it leads to great human losses on both sides. This "old" method of warfare will be effective only when conducting some very local special operations, that are characterized by short-term, fast operations, and very small human losses.

The utilization of various missiles (small, medium, and long-range) and long-range artillery shells is very effective for the targeted large-scale destruction of various enemy objects. In this article, we are talking about distances from several dozen at a minimum and up to several thousand kilometers at a maximum.

In our article, we focus on new protective measures from various missile attacks. More precisely, this paper describes a method to forcefully change the trajectory of a flying combat projectile. Protective actions are designed to prevent a missile or a projectile from hitting exactly the assigned target according to the preliminary combat calculation. Instead, the projectile deviates from its trajectory and hits a different, non-intended place, which nullifies the effect of its use. The proposed method can be used as the last option for defense against enemy projectiles when traditional interception methods such as direct kinematic hits or a proximity explosion have failed.

The general theory of gas-dynamic currents is presented in works [1-11]. Theoretical foundations of probabilistic models are presented in [12]. The same sources provide basic formulas that describe the ratios of physical quantities and parameters of shock waves. The theory of projectile flight in an ideal environment that does not exert resistance to movement is detailed in the works [13-15].

## 2. The theoretical solution to the problem

**Figure 1 shows a photograph of a flying projectile at supersonic speed, which is taken from [1]**

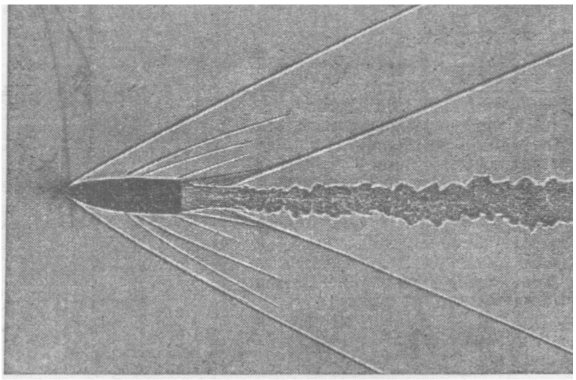


**Figure 1 – Photo of a projectile flying with a supersonic speed [1]**

Figure 2 shows the supersonic flow pattern and the pressure distribution along the surface of the curved body from the work [1].

These two figures show that along the surface of the streamlined body: 1) Not one, but several shock wave fronts occur; 2) Along the transverse Y coordinate, shock waves have dimensions several times larger than the diameters of the transverse size of the projectile or rocket itself. The primary loss of initial rocket or projectile momentum occurs at these shock waves.

The new idea that we propose is the following. A flying projectile (or rocket) can be approached by another projectile from behind and it will be in the inner zone of this shock wave. That is, they fly almost parallel in the same direction. This situation is shown in Figure 3. We will call it projectile number 2. The initial, flying combat projectile (or missile) is designated with the number 1. Let's say that projectile 2 is inside the shock wave zone above projectile 1, Figure 3. We will analyze the situation by evaluating the change in the wave resistance of the flying projectile 1. Figure 3 shows the situation where projectile 2 is close to the main projectile 1 inside the zone of its supersonic wavefront. That is, they fly almost parallel in the same direction, close to each other.

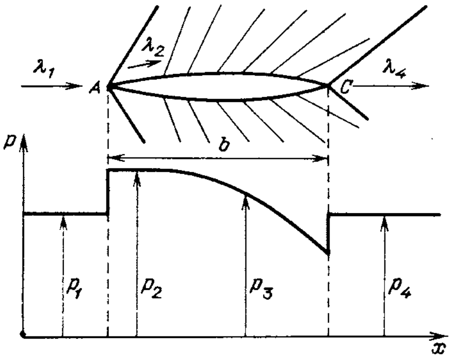


**Figure 2 – Diagram of supersonic flow around curved arc bodies and wave jumps (shock waves) [1]**

Explanations to Figure 3: 1-first main projectile; 2-second projectile that shoots down the main projectile 1; 3, 4-shock wavefronts from the first projectile; 3', 4'- shock wavefronts displaced in space from the second projectile; 5, 6-tail guide vanes.

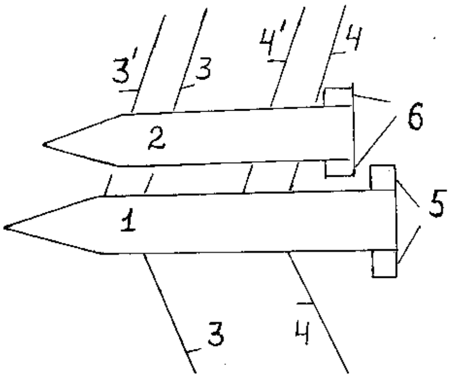


**Figure 3 – Aerodynamic interaction diagram two shells or two missiles**

As a result of projectile 2 being inside the wave zone of projectile 1, the position of the shock wave front of the first main projectile or missile is displaced. The main shock wave 3 in Figure 3 will shift either downstream or upstream to the frontal front of the projectile, 3'. Other shock waves will also be altered. The angles of their inclination will also be changed. Perhaps even the shock wave front will have a slightly curved shape. As a result of these processes, projectile 1 will for some time experience asymmetrical and unequal levels of pressure distribution, and the general aerodynamic drag on the upper and lower sides of the surface will be different. In other words, the resistance of the shock wave branches in the space below projectile 1 will be different from the resistance of the shock wave branches in the space above it.

As a result, the trajectory of projectile 1 will bend downward or upward toward the ground. That is, this projectile will deviate from the original and planned trajectory. This result is what we need. Therefore, a brief presence of the second projectile in any area of the shock waves will result in a deflection of the trajectory of the first projectile. That is, it will fall to another, not planned, not calculated point. Thus, the task of defense will be achieved based on the fact that the projectile will hit (or fall into) a different location.

We considered the case of the smallest effect of the second projectile, when it flies along a parallel trajectory or along a tangent trajectory, without a direct collision with projectile 1. If projectile 2 has a direct actual physical collision (impact) with projectile 1, then the expected effect will be greater. In the case when projectile 2 experiences a collision, the change in the trajectory of projectiles 1 and 2 is easily explained on the basis of the law of maintaining the total momentum of the system.

Let's take a closer look at this situation. With such an almost parallel flight of these two projectiles, the likelihood of the influence of the second projectile on the first increases sharply. We didn't specifically use the word "hit" here. Since the expected result can be achieved not only as a result of a clean hit (a precise mechanical collision) but also as a result of their parallel and close flight close to each other for some short period of time. This can be proved by calculating and estimating the probability of their mutual "interaction". The term "interactions" that we use means the result of their mutual mechanical influence on each other during the time when they are nearby in the zone of effective mutual influence. This is achieved by the fact that during a certain duration of time, their trajectories are almost or close to parallel. So, the result of their "interaction" is estimated by determining the probability that the volumes of their shock waves' effective zones (or wave fronts) turn out to be merged. That is when the shock waves penetrate each other.

Figure 3 shows a scheme of aerodynamic interaction in the following combination: two missiles, two shells, or a rocket and a shell. Due to the fact that the second projectile is located in the zone of shock waves of the main shell, the front of shock wave 3 moves away and is located at the new position as shock wave 3'. In the same way, the primary wave 4 changes its position and becomes the shock wave 4'. That is, the shock wave fronts are displaced along the longitudinal coordinate x. For this reason, the total drag force at the top of projectile 1 will be smaller than at its bottom. Such asymmetry of the drag force will result in the deflection of the trajectory of projectile 1. This completes the proof.

Consider the theoretical solution in two versions: 1) the air resistance force is constant $F_a = const$; 2) the air resistance force is variable and is a function of the velocity of the projectile $F_a = F(v)$ missile.

Solving Problem 1.

Dynamic equations in Cartesian coordinates are

$$\begin{cases} m\frac{dv_x}{dt} = -F_{a,x}, \\ m\frac{dv_y}{dt} = -F_{a,y} - mg. \end{cases} \tag{1}$$

The equation for $v_y$ is solved separately in two parts: 1) until the point of maximum elevation $0 \le t \le t_1$; 2) from $t_1$ moment until the end of flight (falling to the ground) $t_2$, $t_1 \le t \le t_2$. Thus, the time of the full flight is $t_s=t_1+t_2$. At the end of the flight, the projectile falls to the ground.

Solving these equations we get

$$F_{a,y} = \frac{mv_{0,y}}{t_1} - mg, \tag{2}$$

$$v_{y,2} = \left(g - \frac{F_{a,y}}{m}\right) t_2, \tag{3}$$

where $v_{y,2}$ – the y-axis velocity projection at the end of the flight.

From the first equation of the system (1) we get

$$F_{a,x} = \frac{(v_{0,x}-v_{x,2})m}{t_s}, \tag{4}$$

where $v_{x,2}$ is the velocity of the projectile at the end of the flight, that is, before it hits the target, which is located on the ground.

Equation (4) allows you to use it in reverse order, that is, you can calculate the $v_{x2}$. Assuming that $F_{ax} \approx F_{ay}$. Next, the total drag force $F_s = \sqrt{F_{a,x}^2 + F_{a,y}^2}$.

Solving Problem 2.

In this case, the resistance force is variable and is a function of the velocity

$F_a=F(v)$.

Equation for y projection is written as

$$m\frac{dv_y}{dt} = -F_{a,y}(v) - mg. \tag{5}$$

The air resistance force can be represented as the following nonlinear function of velocity

$$F_{a,y}(v) = av_{0,y} + bv_y + cv_y^2 \tag{6}$$

In turn, in the first approximation $v_y=kt$ – some linear function with time t. It is due to the presence of wave aerodynamic drag that $k \neq g$.

Equations (5), as well as (1), are solved in two parts separately: 1) to a point of the maximum elevation $0 \le t \le t_1$; 2) from the moment of the beginning of descent t_1, until the end of falling $t_1 \le t \le t_2$.

Part 1.

For the moment of $t_1$ we have a solution

$$v_{0,y} = gt_1 + \alpha a + \beta b + \gamma c, \tag{7}$$

where

$$\alpha = \frac{v_{0,y}t_1}{m}, \beta = \frac{kt_1^2}{2m}, \gamma = \frac{k^2t_1^3}{3m}. \tag{8}$$

For the purposes of our tasks, equation (7) is interesting. As yet unknown coefficients *a, b, c* are determined by solving matrix equation (7) which is obtained at the given values $(v_{0,y})_i$ and $(t_1)_i$ – (for example, measured from the experiment).

Since there are only 3 unknown coefficients, then in our case three equations and three values *at i = 1, 2, 3* are enough. However, if in equation (6) we would add an additional term to the power of 3, then accordingly *i = 1, 2, 3, 4*. For example, it can be $F_{a,y}(v)=av_{0,y}+bv_y+cv_y^2+dv_y^3$. However, it is most likely that a quadratic function (6) is sufficient. Since in this case, with respect to time t, we have a cubic equation. As you know, third-degree splines accurately describe a variety of highly curved profiles.

Part 2.

Down, descent. For it, in equation (5), the gravity term will be written with a plus sign

$$m\frac{dv_y}{dt} = -F_{a,y}(v) + mg. \tag{9}$$

Solving equation (9), we get

$$v_{y,2} = gt_2 - \sigma_1 t_2^2 - \sigma_2 t_2^3, \tag{10}$$

where

$$\sigma_1 = \frac{bk}{2m}, \sigma_2 = \frac{ck^2}{3m}, \tag{11}$$

$v_{y,2}$ –the speed component before hitting the target, its final value.

Part 3.

We solve the first equation of (1) for $v_x$. In this case

$$F_{a,x} = av_{0,x} + bv_x + cv_x^2 . \tag{12}$$

Solving (1) and taking into account (12) we will get

$$v_{x,2} = v_{0,x} - \frac{v_{0,x}}{m}\, at_s - \sigma_3 t_s^2 - \sigma_4 t_s^3, \qquad (13)$$

where $v_{x,2}$ – is the value of the velocity projection before falling, hitting the target, this is the final velocity, and

$$\sigma_3 = \frac{bk_1}{2m},\ \sigma_4 = \frac{ck_1^2}{3m},\ \ k = k_1 \pm g.$$

From the formula tg α'= $\dfrac{v_{y,2}}{v_{x,2}}$ , the angle of incidence of $\alpha'$ can be determined. And $\alpha' > \alpha$. In case of medium resistance the flight range decreases. In an environment that has no resistance, the range will be longer. Knowing $\alpha'$ and $x_s$ we can estimate the strength or the drag resistance level of air.

Equations (6) to (13) allow iterative solutions and refinement of coefficients. The fact is that in the first approximation and at the first, initial iteration, we can take the $k \approx g$ – acceleration of free fall. $k_1$ is determined by experimental data using formula (13) and $x_2$. And equation (7) must be used twice within the iteration cycle. When iterated, the values of $k_1$ either decrease or increase with a certain fine $h_k = (0.01 \div 0.05)k_1$ step size. This is determined from the analysis of the obtained numerical results. So to speak, visual control of values with different variations.

Alternately: first as (7) and then as (10).

$$v_{y,1} = 0 = v_{y,0} - gt_1 - \frac{v_{0,y}}{m}\, at_1 - \sigma_1 t_1^2 - \sigma_2 t_1^3. \qquad (14)$$

(14) are equations (5), (7) written for a time $t_1$. This is the time of maximum elevation.

Signs for $k_1$ are determined after correction, re-clarification of $t_1$, $t_2$, $t_s$, $v_{0,y}$, $y_{max}$, $x_2$, $v_f$ from the experiment. That is, after iterative calculations. Formula (7) is written in such a way as to find unknown coefficients *a, b, c*. And formula (10) is written as such in order to calculate the velocity value for any given time value t.

We have some experience in developing algorithms and compiling our computing programs in C++ and Visual Fortran. Which make it possible to make detailed calculations at different variations of angles of attack, flight path and initial conditions of departure from the launcher. Taking into account the iteration. Our calculation scheme can include algorithms for fast, emergency determination of the flight path of projectile 1 from experimental data of the induced laser beam and computer analytical calculation of its flight path.

All the above is supplemented and explained by Figure 4: 1-trajectory in the presence of air resistance; 2 – trajectory in the absence of air resistance; $v_0$ – initial speed; $v_f = v_2$ – finishing speed; $\alpha'$ – drop angle in case of air resistance accounting; $x_2$ – maximum flight range.

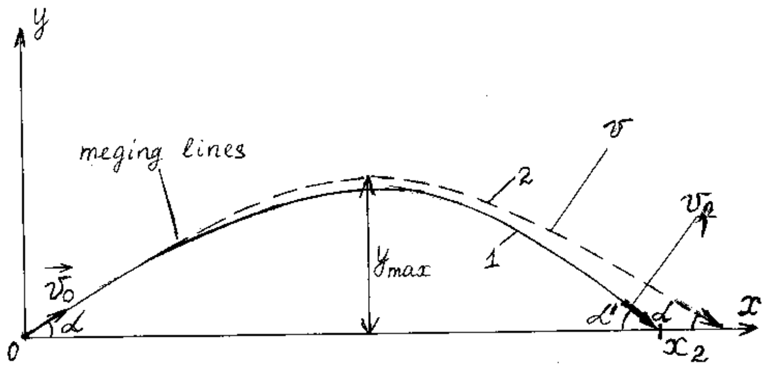
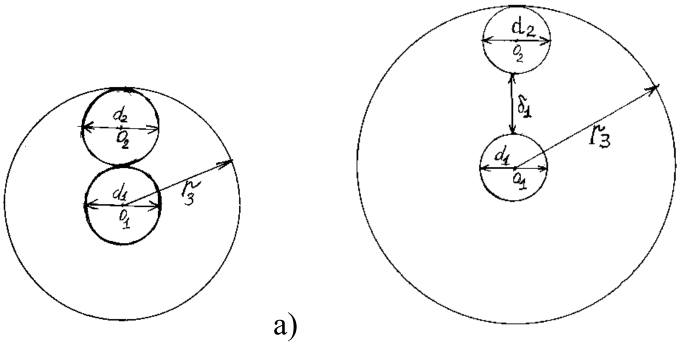


**Figure 4 – Diagram of projectile flight**

Figures 5 show a diagram from which the effective areas of aerodynamic interaction of two shells or two missiles can be calculated. *If* $\delta_1 \approx 0$, the probability of success can be taken approximately as 1. Next, we assumed that the spread of $\delta_1$ values obeys the function of the normal distribution of random variables. Based on this approach, it is possible to estimate the approximate number of shells launched so that, with a probability of, for example, 95%, be sure that an enemy missile or projectile will be shot down.



a) b)

**Figure 5 – Diagram of mutual location**

The two-dimensional probability density function for this representation is [12]

$$p(r,\varphi) = \frac{1}{2\pi} e^{-\frac{r^2}{2}}.$$

Hence, the probability itself for an arbitrary $r_3$ radius will appear as the next double integral

$$P(r,\varphi) = \frac{1}{2\pi} \int_0^{r_3} \int_0^{2\pi} e^{-\frac{r^2}{2}} r dr d\varphi. \qquad (15)$$

(15) is the frequency of projectiles flying through the circle area with a radius of $r_3$.

It turns out that in order to successfully hit a missile (or projectile) with an attacking missile (or projectile), it is best to fly, catch up, and hit it from behind. First, track it from behind, and only then catch up and hit it while flying along its own trajectory. In other cases of approach (attacks from the front or side), the likelihood of missing or not hitting the target (slipping past) will be greater.

And finally, the last. In sufficiently low earth orbits, it is possible to arrange a device that will emit very powerful narrowly directed laser beams, Figure 6. In this case, very strong one-way heating of the entire side surface of the rocket or projectile can be carried out. The entire adjacent wave zone will also be heated. The highly heated air in the wave zone will significantly change the physical characteristics and physical condition of this section of the shock wave front. That is, in one half-space, shock waves will overheat greatly, and in another half-space, there will be no changes. As a result, the asymmetrical aerodynamic drag of these wave portions will cause the projectile path to deviate from the original intended course. Thus, our goal will be achieved, the trajectory will change and the projectile will hit another unnecessary point.

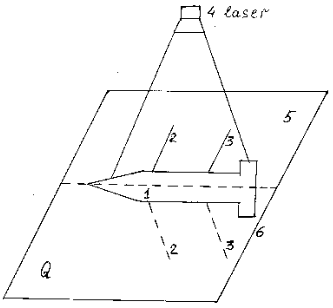


**Figure 6 – Shock Thermal Impact Diagram wave zone and half side projectile surface**

Explanations to Figure 6:1 – projectile; 2, 3 lines of shock wave fronts; 4-laser unit; Q is a plane that divides the entire space into two half-spaces 5 and 6.

Such influence or impact on the projectile is much better, easier, and more effective than the traditional way when they try to completely burn, melt, destroy, or detonate this shell or rocket with a laser beam. With this method, an excessively large, almost impossible, very costly overspending of thermal energy will be required. This is far from reality.

## 3. Discussion

The semi-empirical theory developed by us, however, is suitable only for the flight and fall of bodies in a field of constant gravitational attraction. If there were no gravity, it would be impossible to close the system of equations to calculate unknown semi-empirical coefficients, which simply allow you to take into account the resistance of the medium to the flight of the projectile as a nonlinear function of time.

As a development of this approach, we plan to further consider the following possibilities. To develop a semi-empirical theory, when the flight of a rocket or a projectile occurs with a variable mass. For example, this is the real situation when gradual consumption of fuel takes place.

In work [15], it is noted that in previous research the function of medium resistance in the following different types: $F(v)=av$, $F(v)=bv^2$, $F(v)=av+bv^2$ were used. However, the further use of this formula differs from our method. Namely, these equations for F(v) used previously known works to solve the following differential equation [15]

$$\frac{d(v\cos\vartheta)}{d\vartheta} = \frac{vF(v)}{g}, \tag{16}$$

where $v=\psi(\theta)$. As indicated in the same source [15], the integration of equation (16) with an unknown function $v=\psi(\theta)$ and with unknown coefficients a, b has insurmountable difficulties. That is, further calculation techniques and methods for obtaining final results differ from ours. This is easy to see from [15].

You can shoot down a rocket or a projectile with a direct hit. It is also possible to change its trajectory based on the explosion of another projectile in close proximity to it. These are common techniques. However, our method is designed as a backup for the worst-case scenario, in the event of an invasion into the shock wave zone, it is also possible to change the flight path. As a result, even this so-called "weak impact" can achieve the desired goal. Then the projectile or rocket will not hit the intended point, at which the projectile was originally aimed at.

Laser correction of the heading is possible only if there is no rotation of the projectile. Consideration of the question of the rotation of the rocket itself and the effect of this rotation on the gas boundary layer is a large separate and deep topic for self-study. So far, we do not touch on this issue.

## 4. Conclusions

4.1. A physical hypothesis is proposed that it is possible to change the design trajectory of the projectile on the basis of mechanical action on the entire volume of shockwave zones with a unilateral, asymmetric presence of the second projectile. Deviating from the original trajectory results in a positive result when it comes to a defensive task.

4.2. A new semi-empirical model has been developed and compiled, which allows you to calculate the trajectory of the projectile taking into account the air resistance to movement. From the initial experiment, only four easily detectable quantities are used: the initial departure speed $v_0$, the maximum elevation $y_{max}$, the maximum range $x_2$, and the total flight time. The design scheme can be used in the design and operation of shells and missiles both guided, homing and unguided. The air resistance force is modeled as a nonlinear function of velocity. It is represented in the form of a polynomial of the third degree from time to time.

4.3. The physical idea that external powerful laser radiation can heat the side surface of the projectile and half-space of the entire zone of shockwaves is proposed. The asymmetrical thermal state on both sides of the missile may cause the missile or projectile to deviate from the previously assigned flight path. This circumstance is also in favor of the proposed idea.

## 5. contribution of the authors

1 author: general guidance, problem setting, solving theoretical issues, calculations, conclusion.

2 author: formula checking, calculation checking, article design, typing.

### References

Abramovich, G. N. Prikladnaya gazodinamika. Part 2. [Applied gas dynamics] (Moscow, Nauka, 1991, 305 p.) [in Russian].

Abramovich, G.N. Prikladnaya gazodinamika. Part 1. [Applied gas dynamics] (Moscow, Nauka, 1991, 601 p.) [in Russian].

Krasnov N. F. (editor), Koshevoy V. N., Danilov A. N., Zakharchenko V. F. Rocket Aerodynamics (Moscow, Vysshaya shkola, Press, 1968, 1047 p.) [Translation in English National aeronautics and space administration, Washington, june 1971].

Hemsha M, Neilsen J (editors). Aerodinamika raket. Book 1. Introduction to aerodynamics [Aerodynamics of rockets] (Moscow, Mir, 1989, 433 p.) [in Russian].

Hemsha M, Neilsen J (editors). Aerodinamika raket. Book 2. Aerodynamic calculation methods [Aerodynamics of rockets] (Moscow, Mir, 1989, 512 p.) [in Russian].

Krasnov N. F. (editor). Prikladnaya aerodinamika [Applied aerodynamics] (Moscow, Vysshaya shkola, 1974, 731 p.) [in Russian].

Rakhmatulin H. A., Sagomonyan A. Ya., Bunomovich A. I., Zverev I. N. Gazodinamika [Gas dynamics] (Moscow, Vysshaya shkola, 1965, 722 p.) [in Russian].

Loytsyansky, L. G. Mechanika zhidkosti i gaza [Fluid and gas mechanics] (Moscow, Drofa, 2003, 840 p.) [in Russian].

Houghton, E.L., Carpenter, P.W. Aerodynamics for Engineering Students. (Fifth edition published by Butterworth-Heinemann 2003, 614 p.) [in English].

John D. Anderson. Fundamentals of Aerodynamics (New York, McGraw-Hill Companies, 2001, 912 p.) [in English].

Bai Shi I. Vvedenie v teoriu techeniy szhimaemoi zhidkosti [Introduction to the theory of compressible fluid flow] (Moscow, Foreign Publishing House literature, 1961, 413 p.) [in Russian].

Hald A. Matematicheskaya statistika s technicheskimi prilogeniami [Mathematical Statics with Technical Applications] (Moscow, Foreign Publishing House, 1956, 664 p.) [in Russian].

Zeldovich Y.B., Jaglom, I. M. Vysshaya matematika dlya nachinayushich fizikov [Higher Mathematics for Beginner Physicists] (Moscow, Nauka, 1982, 510 p.) [in Russian].

Loitsyansky L. G., Lurie A. I. Kurs teoreticheskoi mehaniki. T.1 [Course of Theoretical Mechanics. Book 1] (Moscow, Drofa, 2006, 449 p.) [in Russian].

Loitsyansky L. G., Lurie A. I. Kurs teoreticheskoi mehaniki T.2 [Course of Theoretical Mechanics. Book 2] (Moscow, Drofa, 2006, 721 p.) [in Russian].

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## О возможности изменения траектории снаряда или ракеты на основе аэродинамического воздействия в зоне ударных волн

**Аннотация.** Обоснована физическая гипотеза о том, что можно изменить расчетную траекторию снаряда на основе механического воздействия на весь объем волновых зон сопротивления при одностороннем, несимметричном вторжении второго снаряда. Отклонение от первоначальной траектории приводит к положительному результату, когда речь идет об оборонительной задаче.

Разработана и составлена новая полуэмпирическая модель, которая позволяет рассчитать траекторию снаряда с учетом сопротивления воздуха движению. В новой модели рекомендовано, чтобы в предстоящих экспериментах использовать только четыре легко определяемые величины: начальная скорость вылета $v_0$, максимальная высота подъема $y_{max}$, максимальная дальность полета $x_2$ и полное время. Расчетная схема использует итерационные вычисления, на основе которых уточняются значения численных коэффициентов в полуэмпирической модели. Обоснована физическая идея о том, что внешнее мощное лазерное излучение может нагревать боковую поверхность снаряда и всю зону волновых скачков уплотнения с одной стороны полупространства, то есть это односторонний нагрев. Несимметричное тепловое состояние с двух сторон ракеты может привести к отклонению ракеты или снаряда от прежде назначенного курса. Данное обстоятельство также в пользу предлагаемой идеи. Расчетная схема может найти применение при проектировании и эксплуатации снарядов и ракет как управляемых, самонаводящихся, так и неуправляемых.

**Ключевые слова:** волновой фронт, снаряд, ракета, аэродинамическое, сопротивление, расчеты, траектория, итерация.

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## Соққы толқындары аймағындағы аэродинамикалық әсер ету негізінде снаряд немесе зымыран траекториясын өзгерту мүмкіндігі

**Аңдатпа.** Мақалада екінші снарядтың біржақты, симметриялы емес, кіруі кезінде кедергінің толқын аймақтарының барлық көлеміне механикалық әсер ету негізінде снарядтың есептік траекториясын өзгертуге болатындығы туралы физикалық гипотеза негізделген. Бастапқы траекториядан ауытқудың қорғаныс міндеті туралы сөз болғанда бұл оң нәтижеге әкеледі.

Қозғалысқа ауа кедергісін ескере отырып, снарядтың траекториясын есептеуге мүмкіндік беретін жаңа жартылай эмпирикалық модель әзірленді және жасалды. Жаңа модельде алдағы эксперименттерде оңай анықталатын төрт шаманы ғана пайдалану ұсынылады: $v_0$ – ұшып шығуының бастапқы жылдамдығы, $y_{max}$ көтерудің ең жоғары биіктігі, ұшудың ең жоғары қашықтығы $x_2$ және толық уақыт. Есептеу схемасы итерациялық есептеулерді пайдаланады. Олардың негізінде жартылай эмпирикалық үлгідегі сандық коэффициенттердің мәні нақтыланады. Сыртқы қуатты лазерлік сәулелену снарядтың бүйір бетін және тығыздаудың толқын секірістерінің барлық аймағын қыздыра алады деген физикалық идея негізделген. Кеңістіктің бір жарты жағынан әсер ету, яғни бұл біржақты жылыту. Зымыранның екі жағынан симметриялық емес жылу жағдайы зымыранның немесе снарядтың бұрын белгіленген бағыттан ауытқуына әкелуі мүмкін. Бұл жағдай да ұсынылып отырған тұжырымды айқындауға көмектеседі. Есептеу схемасы снарядтар мен зымырандарды жобалау және пайдалану кезінде басқарылатын, өздігінен басқарылатын және басқарылмайтын түрде де қолданылуы мүмкін.

**Түйін сөздер:** толқын аймағы, снаряд, ракета, аэродинамика, кедергі, есептеулер, траектория, итерация.

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