Some features of supersonic drag

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Abstract

A numerical simulation of supersonic gas flows is performed. Qualitative features of supersonic flow associated with the characteristics of drag are studied. A capability of significant enhancement of the value of the maximum lift-to-drag ratio of a supersonic flying vehicle by means of the incidence angle of a fuselage nose section is shown. Features of occurrence of the minimum in the drag coefficient are revealed for the class of aerodynamic configurations with a conical stabilizer. New fundamental and applied results have been obtained on shaping optimal aerodynamic geometries.

1. Introduction

Results of a numerical investigation associated with the aerodynamic drag of a fuselage of a supersonic flying vehicle and a configuration with a truncated cone-shaped stabilizing device are obtained.

In the first part of the present work, simulation results on the choice of efficient parameters of different fuselage configurations of flying vehicles are presented. The effect of the droop angle of the fuselage nose section on the aerodynamic characteristics of a supersonic flying vehicle is studied. The investigations were carried out for the cone-cylinder configuration which was considered as the initial one and the three versions of the modified fuselage configurations with different shapes of cross sections. It is shown that for the modified aerodynamic configuration the maximum lift-to-drag ratio increased by about 0.5. Parametric investigations on the effect of the incidence angle of the fuselage nose section on the value of the maximum lift-to-drag ratio are performed. A quantitative estimate of enhancement of the value of the maximum lift-to-drag ratio of a supersonic flying vehicle by means of the incidence angle of a fuselage nose section is presented.

In the second part, a mechanism of occurrence of a minimum in the drag of bodies of revolution with a stabilizing device in the form of a truncated cone is studied. The determinant influence of the pressure distributions along the surface of the tail stabilizer on the total value of the wave drag coefficient of the considered configurations is demonstrated. Fundamentally new approaches on the choice of optimal parameters of aerodynamic configurations with a conical stabilizer have been obtained.

2. The effect of the droop angle of the fuselage nose section on the aerodynamic characteristics of a supersonic flying vehicle

2.1 Statement of the problem

In supersonic flight, when the free-stream Mach number is equal or greater than 3 ($M_\infty \geq 3$), a flying vehicle cannot be considered as a configuration producing small disturbances. At these Mach numbers, a flying vehicle generates strong disturbances accompanied by the shock waves appearance. Also, to perform a flight at high supersonic speeds, the use of fuels with large volume requirements is needed. Thus, the principles of the traditional classical layout of a flying vehicle and Cayley's design concept based on the fact that the means for providing volume, lift, propulsion, and controls which are separate and largely independent of one another do not allow researchers to develop a flying vehicle meeting the specified requirements. Consequently, when designing a flying vehicle for high supersonic speeds it is advisable to follow the requirement of providing volume and lift based on the same shock waves in the flow. Such an approach results in a necessity of the use of the integrated method of design of flying vehicles when the total drag constituents are combined in an optimal way to provide the lowest total drag value. Only such a method of designing a flying vehicle for high supersonic speeds when the means for providing volume and lift will be more and more integrated will make it possible to obtain the required aerodynamic characteristics. As an example of such a method a capability of enhancement of the value of the maximum lift-to-drag ratio of a supersonic flying vehicle depending on the droop angle of a fuselage nose section is considered in the present work. Because of a significant influence of the nose part on the main characteristics of a flying vehicle, the choice of the nose shape and geometrical parameters must be based on the results of the investigations covering not only the required aerodynamic characteristics, but also the necessary volumes.

2.2 Calculation method

Numerical computations of the aerodynamic drag of the fuselage of a supersonic flying vehicle were done using the Euler equations according to Kovalenko's computer program [1]. The surface of the head shock wave was emphasized explicitly. Integration of the Euler equations was performed using the explicit finite-difference MacCormack scheme. The friction forces of the fuselage were taken into account using the engineering method. The values of the friction drag coefficient were calculated taking into account the local Mach number values and the dynamic pressure on the external boundary of the boundary layer. It was supposed that the laminar-turbulent transition for the boundary layer was achieved at the local Reynolds number ($Re = 10^6$). The Reynolds numbers in the calculations of flow over the considered configurations were determined using the parameters of the incoming flow and the characteristic length, equal to the diameter of the midsection of the fuselage. As characteristic parameters in the computation of the drag coefficient of the fuselage of a supersonic flying vehicle the dynamic pressure values of the incoming flow and the area of the midsection of the considered configuration were used. In the processing of the numerical computation results the bottom pressure was supposed to be equal to the pressure of the undisturbed flow.

2.3 Results of an investigation

Figure 1 shows the investigated fuselage configurations of a supersonic flying vehicle. All of the investigated fuselage configurations had the same aspect ratio λ which was equal to 8.8. The classical cone-cylinder configuration with a cone semiapex angle of $\theta = 10°$ was considered as the initial one (Fig. 1a). The modification of the fuselage shape of a supersonic flying vehicle was implemented at the fixed maximum dimensions of cross-sections; the height and the width remained equal to the diameter d of the cylindrical part of the cone-cylinder configuration. All of the modified fuselage configurations have a flat lower surface and different shapes of upper surfaces. The cross sections of all the modified fuselage configurations have the following shapes: a semicircle and a rectangle (Fig. 1b), a triangle and a rectangle (Fig. 1c), and the shape of an ellipse (Fig. 1d).

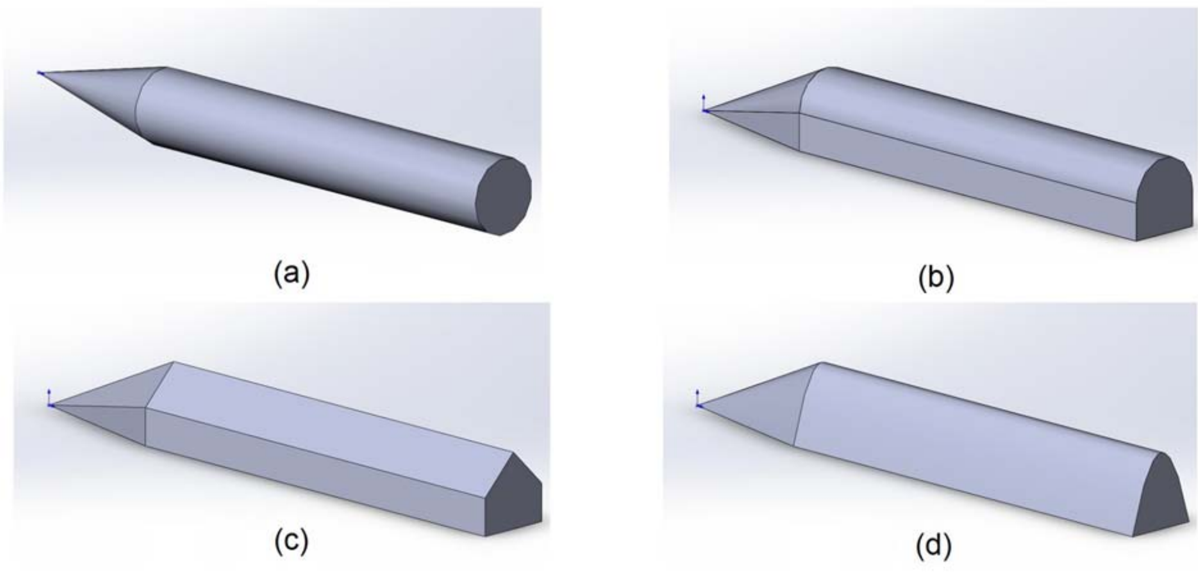

Fig. 1. Investigated configurations

a) Cone-cylinder
b) Modified configuration with the deflected downward nose part and cross section in the form of a semicircle and a rectangle
c) Modified configuration with the deflected downward nose part and cross section in the form of triangle and a rectangle
d) Modified configuration with the deflected downward nose part and cross section in the form of an ellipse

The volume coefficient τ for the cone-cylinder configuration was τ = 0.27. It was calculated by the formula $\tau = V/S^{3/2}$, where V is the overall volume of the aerodynamic configuration and S is the projected plan area. The values of the volume coefficient τ for the modified fuselage configurations with «semicircular», «triangular», and «elliptic» cross sections were 0.31, 0.26, and 0.27, respectively. Thus, the volume coefficient τ for the modified fuselage configuration with an «elliptic» cross section completely coincided with that for the cone-cylinder configuration.

Comparison of the results of the computational investigations of the lift coefficient C_{ya}, drag coefficient C_{xa}, and lift-to-drag ratio K of the cone-cylinder configuration and the modified configuration which has a «semicircular» cross section with the experimental data [2] is shown in Fig. 2. The computational dependences of the lift coefficient C_{ya}, drag coefficient C_{xa}, and lift-to-drag ratio K depending on the angle of attack for the considered configurations correspond well to the experimental data.

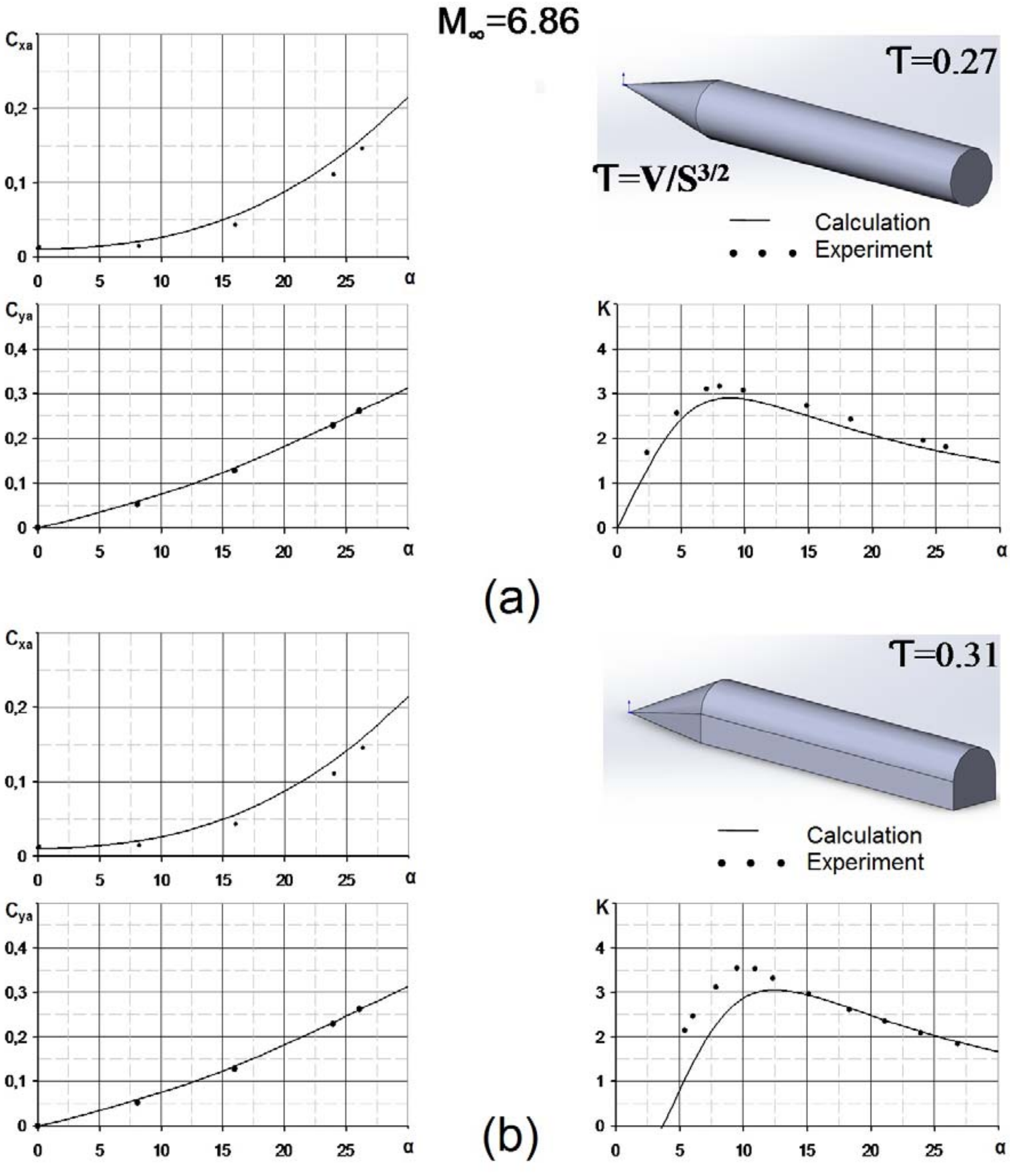

Fig. 2. Comparison of the results of the computational investigations of the cone-cylinder configuration (a) and the modified version of the fuselage with a «semicircular» cross-section (b) with the experimental data [2]

The results of calculations of the lift coefficient C_{ya}, drag coefficient C_{xa}, and lift-to-drag ratio K of the cone-cylinder configuration and of all the considered fuselage modifications of a supersonic flying vehicle are presented in Fig. 3. The modified fuselage configurations with a flat lower surface make it possible to improve significantly the values of the maximum lift-to-drag ratio K of a flying vehicle. For example, for the modified fuselage configuration with a «triangular» cross-section the maximum lift-to-drag ratio K increased by about 0.5 (see Fig. 3) in comparison with the cone-cylinder configuration.

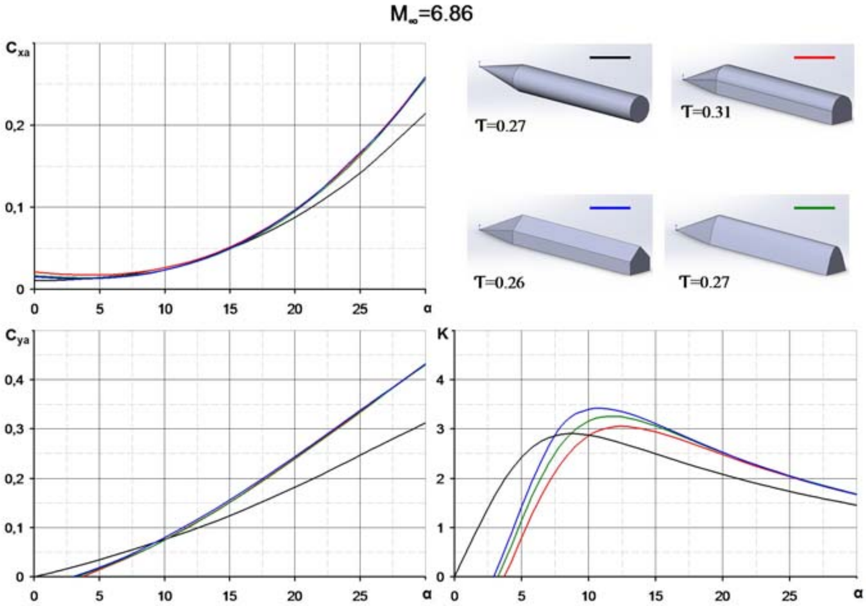

Fig. 3. Aerodynamic characteristics of the investigated configurations

The effect of the droop angle of the nose part on the aerodynamic characteristics of the fuselage of a supersonic flying vehicle was examined for the modified aerodynamic configuration with a «triangular» cross-section (Fig. 4) for the droop angles δ ranging from - 2° to 6°. The downward deflection (δ = - 2°) of the fuselage nose part leads to a decrease in the lift and drag coefficients and, therefore, the maximum lift-to-drag ratio K decreases by about 0.2. The 2° and 6° upward deflection of the fuselage nose section results in an increase in C_{ya}, and the maximum lift-to-drag ratio K increases by about 0.1. It should be noted that the maximum in the dependence of the lift-to-drag ratio on the angle of attack K(α) is shifted by about 2° to smaller angles of attack. The increase in the upward deflection of the fuselage nose section from 2° to 6° practically does not influence the maximum lift-to-drag ratio.

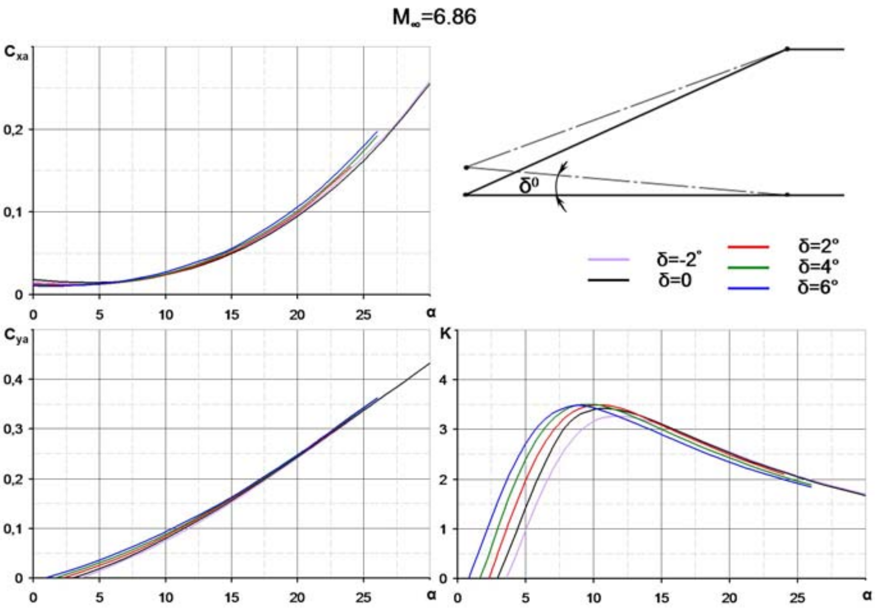

Fig. 4. The effect of the droop angle of the nose part on the aerodynamic characteristics of the fuselage of a supersonic flying vehicle with a «triangular» cross-section

3. Minimum in the drag of aerodynamic configurations with a conical stabilizer

Interest in revolution bodies appeared in aerodynamics mainly due to supersonic and hypersonic speeds. Initial data in the field of aerodynamics of revolution bodies were obtained from artillery problems solving. Since the advent of rockets and aircraft, whose airframe components are mostly bodies of revolution or have similar shapes, aerodynamics of revolution bodies has become significantly advanced. The choice of optimal shapes for given flight conditions has been the main problem since the early days of aerodynamics. Investigation of flow around the most needed shape of a flying vehicle, namely, a revolution body, still draws researchers' attention.

The revolution bodies which consist of three clearly defined parts, namely, the forward (nose) section, the middle (central), and the rear (tail) section, are widely distributed in practical aerodynamics. In general case the area of the base is larger or smaller than the area of the midsection. In special case the tail section can be cylindrical. In general case the central section of a revolution body can have an arbitrary shape. In some cases the central section has the form of a conical surface with the small generating-line angle, but in the majority of cases it is made in the form of a cylinder. The nose and the tail parts of a revolution body play the main role in the generation of the pressure drag. The cylindrical part has an indirect influence on the value of the pressure drag and generates, as a rule, the main fraction of the friction drag. At supersonic speeds the wave drag of the blunted-nose revolution body exceeds the friction drag. In order to reduce the wave drag of the configuration, its nose shape is made sharp, but with slight bluntness—which is the optimal or close to optimal form by the wave drag.

Aerodynamic configurations with a conical stabilizer are widely distributed in the class of bodies of revolution.

A common feature of existence of a minimum in the dependence of the drag on the ratio of the diameter of the cylindrical part to the diameter of the maximum cross section (d/D) of configurations with a conical stabilizer was revealed in [3, 4], Fig. 5. A mechanism of occurrence of a minimum in the drag of aerodynamic configurations with a stabilizing device in the form of a truncated cone is studied.

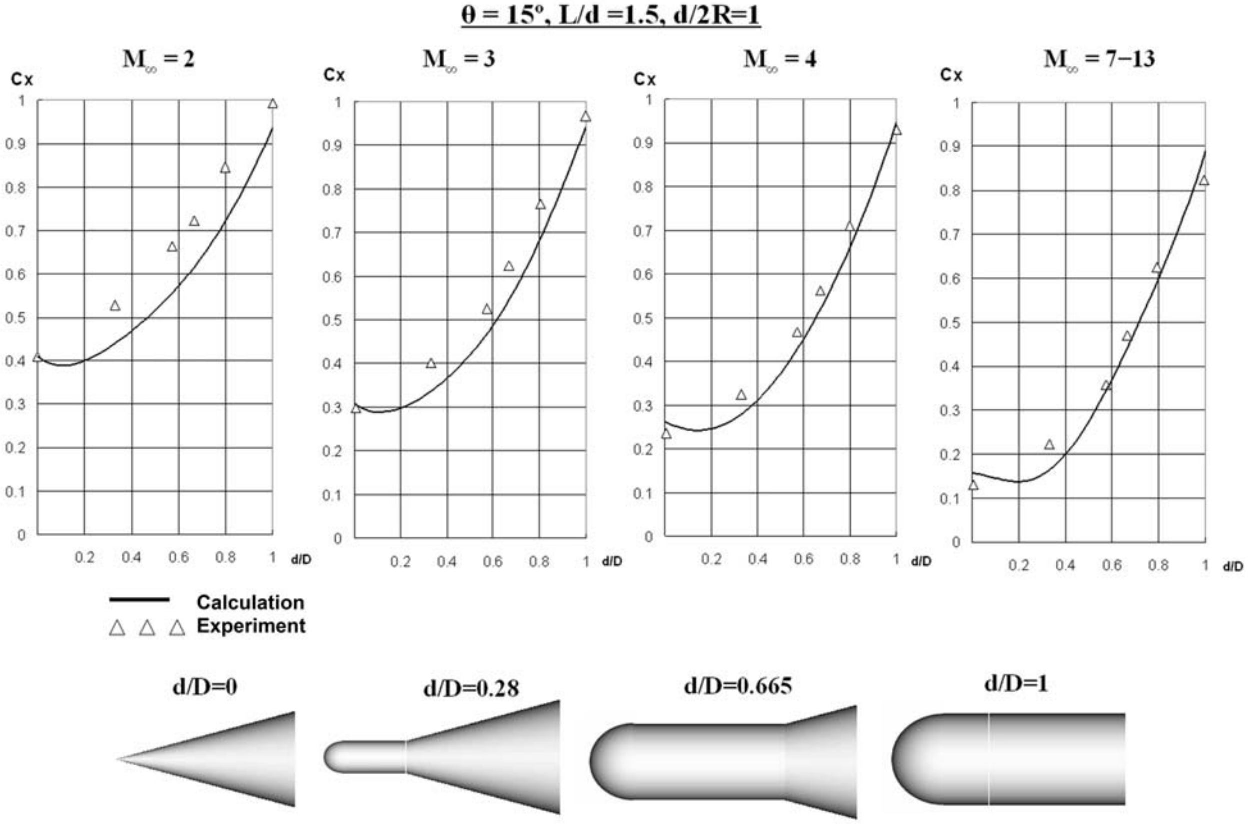

Fig. 5. Minimum in the dependence of the drag of a flying vehicle with a conical stabilizer on the ratio of the diameter of the cylindrical part to the diameter of the maximum cross section

In this work, the effect of nose shape on the aerodynamic drag of a revolution body at supersonic speeds is considered. Computational studies of bodies of revolution having a tail part in the form of a truncated cone with different nose parts (hollow cylinder, cone, and spherical bluntness), and the same central cylindrical parts are performed (Fig. 6). The generating-line angles of the tail part θ_2 ranged from -20 to 35º. Qualitative features of the drag of the revolution bodies with a tail part in the form of a truncated cone in a supersonic flow are considered. It is shown that for such bodies from the standpoint of minimization of the drag coefficient the flared tail part is preferable ($\theta_2 > 0$). Particular attention is paid to the physical aspects of the flow around the considered configurations and to elucidating the mechanisms responsible for a minimum in the drag coefficient of a revolution body with a tail part in the form of a truncated cone.

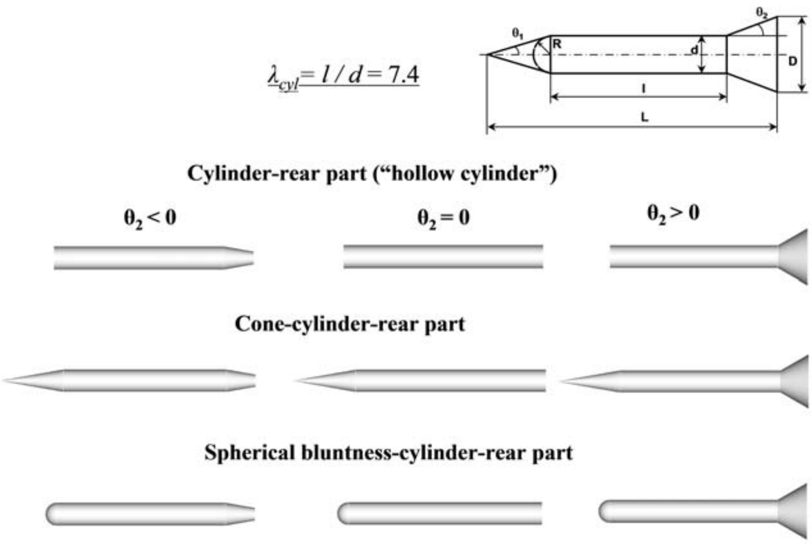

Fig.6. Investigated configurations

Numerical computations of the aerodynamic drag of bodies of revolution were done using the Euler equations [1]. Computational dependences of the total drag of the considered bodies of revolution on the generating-line angles θ_2 of the tail part are shown in Fig. 7. The ranges of the generating-line angles θ_2, at which the total drag coefficient of the considered configurations has an advantage, are obtained. At a free stream Mach number of M_∞=9.22 and the generating-line angles $\theta_2 \leq 17.5°$ the minimum total drag has the hollow cylinder configuration. At the generating-line angles from 17.5º to 23.5º the best result from the drag standpoint has a configuration with a conical nose part. Finally, at θ_2>23.5º an aerodynamic configuration with spherical bluntness of the nose has the minimum total drag.
A mechanism of occurrence of a minimum in the drag coefficient of revolution bodies with a tail part in the form of a truncated cone is of a special interest.

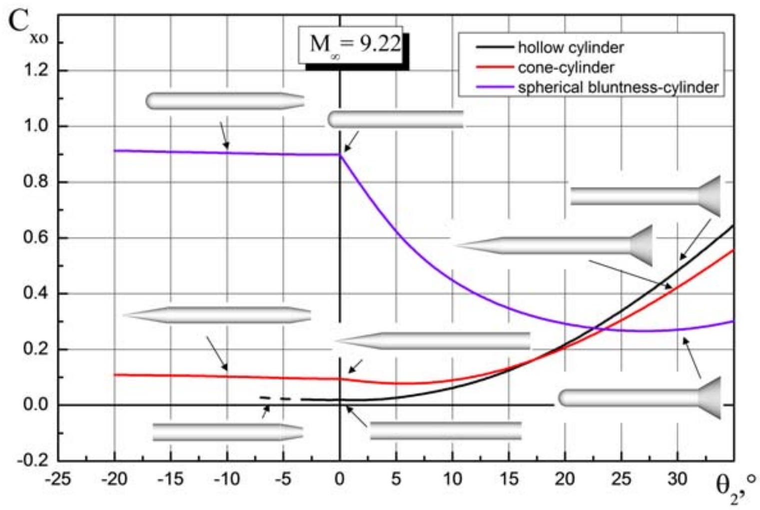

Fig.7. Dependence of the drag coefficient C_{xo} of the considered bodies of revolution on the generating-line angle of the rear part

Figure 8a demonstrates the distribution of pressure coefficient P/P_∞ along the length of the hollow cylinder configuration with the generating-line angles of the tail conical part equal to ±1°. The geometry of the considered configuration is presented in this figure as well. At θ_2=+1° the dependence of the drag coefficient of the hollow cylinder has a minimum (Fig.7). The dependences of pressure coefficient P/P_∞ along the length of the configuration are practically symmetrical for the considered values of the parameter θ_2=±1° (Fig. 8a). The minimum in the dependence of the drag coefficient of the hollow cylinder configuration is achieved because of growth of the characteristic area, namely, the area of the midsection of the investigated body of revolution.

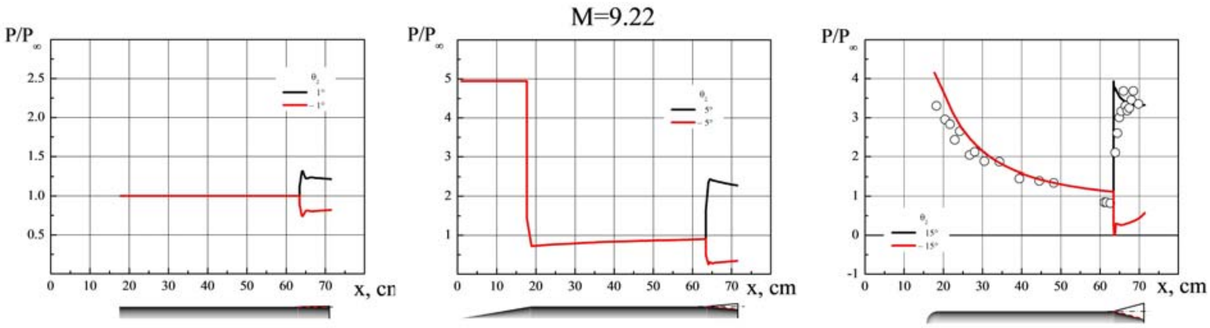

Fig.8. Distribution of pressure coefficient P/P_∞ along the length of the investigated bodies of revolution at M_∞=9.22:——, —— – calculation, ○ ○ ○ – experiment [5]

The dependence of the drag coefficient of the cone-cylinder-rear part configuration has a minimum at the value of θ_2 =+5° (Fig.7). Figure 8b shows the distribution of pressure coefficient P/P_∞ along the length of the cone-cylinder-rear part configuration with the generating-line angles of the tail part equal to θ_2=±5°. The geometry of the considered configuration is presented in this figure as well. At θ_2=+5°we have a greater pressure change than at θ_2=-5° (Fig. 8b). The minimum in the drag coefficient of the cone-cylinder-rear part is also achieved at a positive slope angle of the generating line because of growth of the characteristic area (the area of the midsection of the configuration).
The occurrence of a minimum in the drag coefficient of the configuration with spherical bluntness (Fig.7) at θ_2 =+27° is qualitatively similar to the above-considered cases. Note, however, that there is no completely symmetrical geometry with a negative slope angle of the generating line of the tail part for this configuration. Consequently, to analyze the drag of the considered configuration the distribution of pressure coefficient P/P_∞ along the length of the spherical bluntness-cylinder-rear part configuration (Fig. 8c) with the generating-line angles of the tail part equal to θ_2=±15° is shown. The results of the experimental data [5] are presented in this figure as well. Note that the results of calculations of pressure coefficient P/P_∞ along the length of the spherical bluntness-cylinder-rear part configuration are in good agreement with the experimental data [5].
The examined features of supersonic flow associated with the characteristics of the drag of bodies of revolution having a tail part in the form of a truncated cone made it possible to study the mechanism of occurrence of minimum in the drag coefficient for the given class of aerodynamic configurations, which is certainly of theoretical interest and practical importance in choosing rational parameters of wingless flying vehicles.

References

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