A detailed description and justification of finite-difference methods for the solution of multidimensional gasdynamic problems were presented in [1, 2]. This article presents results of calculations and an analysis of three-dimensional supersonic ideal gas flows made using these methods. Computations of flow past circular and elliptical paraboloids and cones with spherical blunting are included. Primary attention is devoted to new effects in three-dimensional gas flows that were discovered in the numerical analysis.

1. A detailed study of three-dimensional supersonic ideal gas flow past blunt bodies must be based on the basis of the complete gasdynamic equations, without any simplifying assumptions. In spite of inherent difficulties, the necessity of a detailed study of the flowfield is evident.

Because of the absence of exact analytic solutions, numerical methods, particularly the method of finite differences, dominate the study of three-dimensional flows. Often, numerical methods make possible detailed study of these flows. We emphasize that the numerical solution must be obtained with known and high precision; otherwise, many significant differences of the flow will remain unnoticed and incorrect conclusions concerning the flow may occur.

The finite-difference solution consists of the values of the unknown functions at several tens of thousands of grid nodes. Analysis of such a tremendous amount of information (up to several billion decimal digits) and presentation of the results in clear and convenient form require special methods of automatic information processing; therefore, special processing programs must be written.

We present some results obtained in a study of perfect gas flowfields about cones with spherical blunting and, also, about circular and elliptic paraboloids. We also discuss briefly the numerical methods used for the calculations.

A special processing program was compiled to analyze the three-dimensional flowfields obtained by numerical methods. The following basic operations are used output to the printer of the required quantities and functions in the specified planes: \( z = \text{const} \); computation of the various integral flow characteristics, i.e., the aerodynamic coefficients; determination of the precision of the numerical solution by calculating the values of the Bernoulli integral; determination of the values of the entropy function; calculation and monitoring of the differences; monitoring satisfaction of the conservation laws, etc.; determination of the external values of the functions; construction of the streamlines and function isolines.

We omit a more detailed analysis of the structure and description of the processing program blocks; however, we note that analysis of the isolines is, apparently, important for the detailed study of three-dimensional flow. The isolines make possible both a qualitative and quantitative study and a clear representation of the three-dimensional flowfield. The analysis of three-dimensional flow with the aid of the isolines is effective only if the numerical solution is highly precise.

The results are given in the cylindrical coordinate system \((z, r, \theta)\). The following notations are used: \( M \) is the Mach number, \( \alpha_k \) is the cone half-angle, \( \alpha \) is the angle of attack, and \( S = \rho_k/\rho \) is the entropy function. The subscript \( \text{unperturbed} \) denotes values of the unperturbed gas stream.

The pressure \( p \) and density \( \rho \) are referred to \( p_{\infty} \) and \( \rho_{\infty} \). The linear dimension units are as follows: for calculations of flow past a circular paraboloid the radius of curvature at the apex is 1, in studying flow about cones with spherical blunting, the sphere radius equals 1.

The flow calculations were made for a constant ratio \( k = 1.4 \) of the specific heats. The results were obtained by the author and V. V. Rusanov.

2. The slope of the shock wave to the \( z \)-axis in each meridional plane is determined by the derivative \( F_z = (\partial F/\partial z)_{\theta=\text{const}} \), where \( F \) is the distance from the \( z \)-axis to the shock surface.

In Fig. 1 the solid curves show the function for flow past a circular paraboloid with \( M_{\infty} = 4 \). The derivative \( F_z \) decreases monotonically with increase of \( z \), and up to \( z = 45 \), it approaches its asymptotic value monotonically. However, these examples do not imply that the establishment of asymptotic values will always be monotonic.

Figure 2 shows curves of the function \( F_z \) for three values of \( \theta \) for flow past a cone with a half-angle \( \alpha_k = 10^\circ \) and spherical blunting for \( M_{\infty} = 10 \) and \( \alpha = 5^\circ \). Here, \( F_z \) has a much more complex form because of the variation of the body surface curvature, in particular, discontinuity of the curvature at the line where the sphere joins the cone. The interaction of the resulting compression wave, its multiple reflections from the body surface, and the shock wave determine the nonmonotonic nature of \( F_z(z) \).

The interaction is strongest in the \( \theta = 0 \) plane. In the region of spherical influence \( F_z \) first decreases monotonically, reaching a minimum of 0.157 for \( z = 12 \). Then the effect of the cone on the form of \( F_z \) is manifested. A "plateau," also noted in [2] for flow past a body of
Fig. 3, a, b

Fig. 4