REDUCING THE WAVE DRAG OF WING AIRFOILS IN TRANSONIC FLOW REGIMES BY THE FORCE ACTION OF AIRFOIL SURFACE ELEMENTS ON THE FLOW

S. M. Aul’chenko and V. P. Zamuraev

Mathematical modeling of the influence of forced oscillations of surface elements of a wing airfoil on the shock-wave structure of transonic flow past it has been carried out. The qualitative and quantitative influence of the oscillation parameters on the wave drag of the airfoil has been investigated.

Keywords: transonic flow past a wing airfoil, forced oscillations, wave drag.

Introduction. Previous investigations of the present authors into the control of transonic flow past wing airfoils have shown the possibility of reducing substantially (by more than 50%) the wave drag and increasing significantly the lift-drag ratio of transonic airfoils in pulsed-periodic energy supply [1–5]. We determined the shape and position of perturbation regions (narrow zones extended along the airfoil and located in the immediate vicinity of the surface) and the ranges of frequency and power at which nonlinear effects of flow restructuring (changes in the dimension and position of local supersonic zones and in the intensity of (compression) shocks) are observed. But, despite the great effect which can be produced by the use of external energy supply, high-temperature zones arising here in the immediate vicinity of the wing surface can become an obstacle in practical application of this method of control.

At the same time, studying the mechanism of shock-wave restructuring of transonic flow past wing airfoils in the case of pulsed-periodic energy supply [6] enables us to infer that it is possible to attain analogous effects using other means, in particular, by exciting oscillations of wing surface elements.

Formulation of the Problem. As a mathematical model of flow, we use the system of two-dimensional non-steady gasdynamic equations for an ideal gas

$$\frac{\partial U}{\partial t} + \frac{\partial F}{\partial x} + \frac{\partial G}{\partial y} = 0,$$

$$U = (\rho, pu, pv, e), \quad F = (pu, p + pu^2, \rho u + (p + e)), \quad G = (pv, \rho uv, p + pv^2, v (p + e)).$$

Here the axes of the coordinates $x$ and $y$ are guided along the airfoil’s chord and perpendicularly to it respectively and are referred to its length $b$ (the coordinate $x$ is reckoned from the nose of the airfoil); the time $t$ is referred to $b/a_{\infty}$, the velocity components, to $a_{\infty}$, and the density, to $\rho_{\infty}$; the pressure $p$ and the total energy of a unit volume of the gas $e$ are made dimensionless by the parameter $p_{\infty}a_{\infty}^2$ and $\rho_{\infty}$ is determined from the condition $p_{\infty} = \rho_{\infty}a_{\infty}^2$.

The system of equations is supplemented with boundary conditions on the boundaries of a doubly connected computational domain, which represents a rectangle with an internal boundary corresponding to the contour of the wing airfoil in question. Conditions of an unperturbed flow are set on the left-hand, upper, and lower boundaries of this domain, "soft" conditions are specified on the right boundary, and a nonflow condition is set on the contour of the airfoil outside the moving element. On a segment of the contour with boundaries $x_1$ and $x_2$, we prescribe a variation in its initial geometry $f_0(x)$ by the law

$$f(x, t) = f_0(x) + A \sin \left( \frac{2\pi t}{\Delta t} \right) \sin \left( \pi \frac{(x - x_1)}{(x_2 - x_1)} \right),$$

and the equality of the velocities of the flow and the boundary as the boundary condition. For numerical solution of the formulated problem, we use a finite-volume scheme diminishing the total variation.


Calculation Results. The results have been obtained for a NAS
A-0012 airfoil in the case of ideal-gas flow
(with an adiabatic exponent \( \gamma = 1.4 \)) past it at the Mach number of the incident flow \( M_\infty = 0.85 \) and a zero angle of
attack. The oscillation amplitude and the position of the moving element and its
dimension were varied. Table 1 gives
the values of the wave-drag coefficient \( C_x \) as a function of the oscillation amplitude for fixed boundaries of the mov-
ing element \( x_1 \) and \( x_2 \). In the first line, there is given its value for steady-state flow when the airfoil is located at
\( 3 \leq x \leq 4 \) (here and in what follows all quantities are dimensionless).

As the oscillation amplitude increases, flow topology has no time to be restored over a period, and the up-
stream shift of the breakdown shock attains its maximum. As a result the value of \( C_x \) is considerably reduced. Figure 1a
gives the distribution of the pressure coefficient \( C_p \) along the chord of the wing
airfoil at different values of the oscillation amplitude of the wing surface ele-
ment (a) and at different positions and lengths of the oscillating surface ele-
ment (b). Curve numbers correspond to the variant numbers in Table 1 (a) and
Table 2 (b).

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Fig. 1. Distribution of the pressure coefficient \( C_p \) along the chord of the wing
airfoil at different values of the oscillation amplitude of the wing surface ele-
ment (a) and at different positions and lengths of the oscillating surface ele-
ment (b). Curve numbers correspond to the variant numbers in Table 1 (a) and
Table 2 (b).

TABLE 1. Values of the Drag Coefficient of the Airfoil \( C_x \) as a Function of the Oscillation Amplitude of the Element of the Wing Airfoil

TABLE 2. Values of the Drag Coefficient of the Airfoil \( C_x \) as a Function of the Position and Dimension of the Oscillating Element of the Wing Airfoil