CONTROL OF THE TRANSONIC STREAMLINE OF THE AIRFOILS BY EXTERNAL ENERGY SUPPLY

S.M. Aulchenko, V.P. Zamuraev, and A.P. Kalinina

Khristianovich Institute of Theoretical and Applied Mechanics SB RAS,
Novosibirsk State University
630090 Novosibirsk, Russia

Introduction

The progress of modern space aircraft technologies is often based on successful control of gas flow. Traditional aerodynamic techniques do not meet the increasing requirements concerning aircraft operating performances. Only comprehensive approaches and use of new technologies can solve this problem. Energy supply to a gas flow is a promising method of control of aerodynamic characteristics of aircrafts and their components (in particular, wings). There are different means of energy supply: laser radiance, SHF, electric discharge etc.

The authors’ researches [1-4] concerning pulsed-periodic energy supply in compact zones have shown that the airfoil wave drag coefficient weakly depends on the form and locations of the energy supply zones downstream of the airfoil midsection. This is a consequence of linear dependence of airfoil wave drag coefficient on energy supply.

In the papers [5-9] we present the results which testify to the existence of nonlinear effects that arise at energy supply in a pulsed-periodic regime in the thin zones lying along the profile. The present work continues the investigations of the shock-wave structure of transonic flow around a airfoil.

In the model under consideration, the pulsed energy supply is carried out instantaneously, and this implies no change in the gas density and velocity. The gas energy density $e$ in the zones of its supply increases by the amount $\Delta e = \Delta E/\Delta S$, where $\Delta E$ is the total energy supplied to a single zone, $\Delta S$ is the zone area. In the present work, the energy was supplied in thin zone with one (lower) side from profile that allowed us to obtain the lift force and pitching moment.

Computational results

The numerical results were obtained for a NACA-0012 wing profile streamlined by an ideal gas with an ratio of specific heats $\gamma = 1.4$. The incident flow had a Mach number of $M_\infty = 0.85$. The angle of attack $\alpha$ varied within the limits from 0 up to 3º. The energy $\Delta E$ supplied with one (lower) side from profile. The magnitude of energy $\Delta E$ changed from 0.0001 up to 0.0085. The period of a supply of energy $\Delta t = 0.05$ (here and below, all variables are dimensionless).

The values of $C_x$, $C_y$, $C_m$ and $K$ are summarized in Table 1 as functions of the supplied energy $\Delta E$ for different angles of attack $\alpha$. ($C_x$ – drag coefficient, $C_y$– lift coefficient, $K$ – aerodynamic quality, $C_m$ – pitching moment coefficient). As can be seen, the energy supply initially leads to an increase in both lift and drag coefficients. However, as the energy is increased above certain level (in these calculations at $\alpha = 0^\circ$, $\Delta E > 0.001$), the drag coefficient $C_x$ ceases to grow further while the lift continues to increase.

For the comparison, Table 2 gives the values of $C_x$ and $C_y$ for various attack angles $\alpha$ without energy supply. As can be seen, an increase in $\alpha$ (within indicated limits) leads to an increase in both lift and drag of the airfoil.

Table 1. The aerodynamic characteristics for various supplied energies

<table>
<thead>
<tr>
<th>α, degree</th>
<th>ΔE \cdot 10^4</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_x</td>
<td>0.459</td>
<td>0.467</td>
<td>0.479</td>
<td>0.492</td>
<td>0.593</td>
<td>0.635</td>
<td>0.637</td>
<td>0.635</td>
<td>0.634</td>
<td></td>
</tr>
<tr>
<td>C_y</td>
<td>0</td>
<td>0.147</td>
<td>0.223</td>
<td>0.289</td>
<td>0.524</td>
<td>0.590</td>
<td>0.600</td>
<td>0.639</td>
<td>0.670</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>3.15</td>
<td>4.65</td>
<td>5.87</td>
<td>8.83</td>
<td>9.30</td>
<td>9.43</td>
<td>10.1</td>
<td>10.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_m</td>
<td>-0.55</td>
<td>-0.83</td>
<td>-1.07</td>
<td>-1.95</td>
<td>-2.19</td>
<td>-2.22</td>
<td>-2.35</td>
<td>-2.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C_x</td>
<td>0.533</td>
<td>0.555</td>
<td>0.581</td>
<td>0.655</td>
<td>0.767</td>
<td>0.789</td>
<td>0.794</td>
<td>0.804</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C_y</td>
<td>0.279</td>
<td>0.337</td>
<td>0.398</td>
<td>0.530</td>
<td>0.682</td>
<td>0.704</td>
<td>0.715</td>
<td>0.753</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>5.24</td>
<td>6.08</td>
<td>6.85</td>
<td>8.09</td>
<td>8.88</td>
<td>8.93</td>
<td>9.00</td>
<td>9.37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C_m</td>
<td>-1.00</td>
<td>-1.22</td>
<td>-1.44</td>
<td>-1.93</td>
<td>-2.50</td>
<td>-2.58</td>
<td>-2.61</td>
<td>-2.74</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. The aerodynamic characteristics for various attack angles α

<table>
<thead>
<tr>
<th>α, degree</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_x</td>
<td>0.533</td>
<td>0.715</td>
<td>0.956</td>
<td>1.229</td>
</tr>
<tr>
<td>C_y</td>
<td>0.279</td>
<td>0.503</td>
<td>0.697</td>
<td>0.790</td>
</tr>
<tr>
<td>K</td>
<td>5.24</td>
<td>7.03</td>
<td>7.64</td>
<td>8.03</td>
</tr>
<tr>
<td>C_m</td>
<td>-1.00</td>
<td>-1.97</td>
<td>-2.17</td>
<td>-2.52</td>
</tr>
</tbody>
</table>

In the fig. 1 the curves represent dependence of the airfoil quality from the energy supplied. Every curve is obtained for the fixed value of the attack angle. The dash line corresponds to the maximal airfoil quality without energy supply. The energy supply provides a considerable increase of airfoil quality. We can notice that control of aerodynamic quality can be done as by attack angle, as by energy supply, or by using of them together. In the last case the choice of the attack angle and energy supplied values depends on used technical solutions concerning the possibility to supply only small amount of energy. It is correspond to the selection of one or another curve in the Fig. 1 for energy up to 0.0006.

An important characteristic of an airfoil is pitch moment. As it follows from the tables 1 and 2 pitch moment at the fixed value of the lift force for the both control method is practically the same. The Fig. 2 shows the influence of energy supply to the moment coefficient $C_m$. The Fig. 3 gives the change of the moment coefficient $C_m$ in dependence of attack angle while supplied energy is fixed. The curves $C_m(\alpha)$ corresponds to the following values of the energy supplied: $1 – ΔE = 0$, $2 – ΔE = 0.0004$, $3 – ΔE = 0.001$ and $4 – ΔE = 0.003$. The curve incline is negative and sufficiently large. It ensures the aircraft stability margin for the considered energy values range, when significant re-organization of the shock wave structure near the profile take place (shift of closing shock wave on the upper surface downstream to the back edge and significant weakening of the analogous shock-wave at the lower surface). This can be confirmed as by comparison of the data in the Fig. 2 with the curve $I$ in the Fig. 3, as by comparison of the curves $I – 4$ in the fig. 3 between them.
Fig. 1. Dependence of the airfoil quality $K$ on the energy supplied $\Delta E$ for the attack angles:
1 $\alpha = 0^\circ$; 2 $\alpha = 1^\circ$; 3 $\alpha = 2^\circ$; $\square$ $\alpha = 3^\circ$. Dashed line $K_{\text{max}}$ when $\Delta E = 0$.

Fig. 2. Dependence of the pitch moment coefficient $C_m$ on the energy supplied $\Delta E$ for the attack angles:
$\triangle$ $\alpha = 1^\circ$; $\square$ $\alpha = 3^\circ$.

Fig. 3. Dependence of the pitch moment coefficient $C_m$ on the attack angle for the energy supplied $\Delta E$: 1 $\Delta E = 0$; 2 $\Delta E = 0.0004$; 3 $\Delta E = 0.001$; 4 $\Delta E = 0.003$.

The calculations were done for high-lift airfoil as well (optimal according to the quality for $M_\infty = 0.85$). Some results are represented in the Fig. 4 and 5. The energy supply for it causes quality improvement as well.
Conclusion

It was established that the supply of energy allows effective control of airfoils aerodynamic characteristics in transonic flight mode.

This research is supported by the Russian Foundation for Basic Research (Grant № 08-08-90003-Bel_a).

REFERENCE