Journal of Applied Mechanics and Technical Physics, Vol. 37, No. 2, 1996

INFLUENCE OF PRESSURE DISTRIBUTION OVER A WING ON SONIC BOOM PARAMETERS

V. F. Volkov

UDC 533.69.011.72

Estimation of the parameters of the sonic boom (SB) produced by supersonic passenger aircraft (SPA) and development of methods for its reduction along the flight path remain important tasks. Existing asymptotic methods [1–3] allow one to estimate the SB at large distances from a disturbance source with satisfactory accuracy. Application of these methods for simple bodies (bodies of revolution) is not difficult. For a real SPA the problem is complicated due to the necessity of allowing for the mutual effect of the wing, fuselage, and engine nacelles. Therefore, the methods of determining the intensity of SB in a far field based on conversion of flow parameters from the reference surface taken in the SPA near field are widely used [4–7]. The flow parameters are determined by numerical solution of the problem of flow past a real configuration or by testing a model in wind tunnels [6, 7]. According to the assessments in [8], the SB intensity produced by SPA depends mainly on the load distribution on a wing, which can be obtained in numerical calculations or experiments [9, 10]. In the present work the relation between the pressure distribution on the surface of the TU-144 wing and the SB intensity is analyzed on the basis of the theory of propagation of weak shock waves [1, 2, 4].

The effect of lift of the wing is taken into account by the velocity potential, which has the form [3, 11]

$$\varphi = \frac{1}{4\pi q}\iint \frac{z(x-x')\Delta P(x',y')\,dx'\,dy'}{[(y-y')^2+z^2]\{(x-x')^2-\beta^2[(y-y')^2+z^2]\}^{1/2}}.$$

Here $q = 0.5\rho_\infty W_\infty^2$ is the velocity thrust; $\beta = (\mathrm{M}_\infty^2 - 1)^{1/2}$; $\Delta P = (P_\mathrm{w} - P_l$ (P_w and P_l are the pressures on the windward and leeward wing sides, respectively); M_∞ is the Mach number of free flow.

For long distances r from the wing, the disturbed velocity component in the x-direction has the form [3]

$$u = \frac{\partial\varphi}{\partial x} = -\frac{F(t,\theta)}{(2\beta r)^{1/2}}, \tag{1}$$

where

$$F(t,\theta) = \frac{1}{2\pi}\,\frac{\beta\cos\theta}{2q}\int_0^t \frac{Y''(\tau,\theta)d\tau}{(t-\tau)^{1/2}}.$$

Here $Y''(\tau,\theta) = \partial Y'(\tau,\theta)/\partial\tau$; $Y'(\tau,\theta) = \int_{\gamma_1}^{\gamma_2} \Delta P(\alpha,\gamma)\,d\gamma$ is the change of the lifting force in the direction

$$\tau = \alpha - \beta\sin(\theta)\gamma \quad (\alpha = x' - \Psi(\eta), \quad \gamma = y' - \eta, \quad \theta = \arctan(y/z)). \tag{2}$$

The functions $x = \Psi(\eta)$ and $y = \eta$ describe the leading edge of the wing; the coordinate y denotes the lateral recession from the flight path. The characteristic coordinate $t = x - \Psi(\eta) - \beta r$ [$r = (y^2+z^2)^{1/2}$] is limited by the inequality $t \geqslant \alpha - \beta\sin(\theta)\gamma$. The integration limits γ_1 and γ_2 are found as the points of intersection of the straight line (2) with the wing edge.

The following variants of data with fixed lifting force were used to determine the effect of the character of pressure distribution on the surface of a wing of prescribed geometry in plan on the SB parameters: 1) the

Institute of Theoretical and Applied Mechanics, Siberian Division, Russian Academy of Sciences, Novosibirsk 630090. Translated from Prikladnaya Mekhanika i Tekhnicheskaya Fizika, Vol. 37, No. 2, pp. 99–102, March–April, 1996. Original article submitted November 11, 1994; revision submitted December 5, 1994.

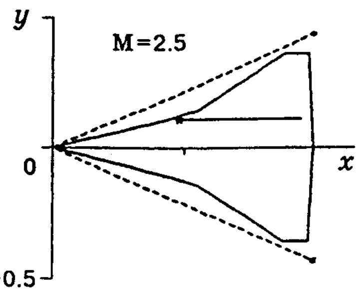

Fig. 1

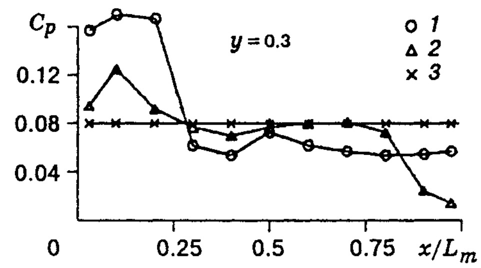

Fig. 2

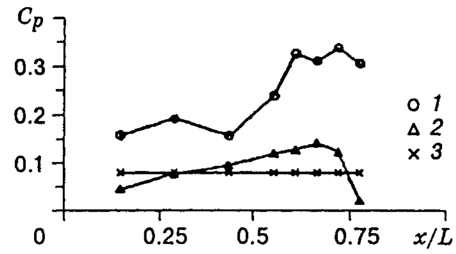

Fig. 3

results of experimental study of local aerodynamic characteristics of the SPA wing in the wind tunnel T-313 (Institute of Theoretical and Applied Mechanics, Siberian Division, Russian Academy of Sciences) [9]; 2) the results of numerical investigation of the same wing in [10]; 3) data for a uniformly loaded wing.

The wing configuration in plan is shown in Fig. 1. The wing consists of a leading-edge wing extension and a basic wing. Dashed line shows the trace of the Mach cone in the Oxy coordinate plane.

Figure 2 shows three variants of the load profiles $\Delta C_p(\bar{x}) = C_{p_w} - C_{p_l}$ along the local wing chord in the section $\bar{y} = 0.3$. Here $\bar{x} = x/L_m$, $\bar{y} = y/L_r$, L_m, and L_r are the local chord length and the wing half-span; C_{p_w} and C_{p_l} are the pressure coefficients on the bottom and upper surfaces. The origin of the coordinate $\bar{x}$ is shifted to the leading wing edge and the first points on the curves $\Delta C_p(\bar{x})$ in Fig. 2 correspond to the values of ΔC_p in the neighborhood of the leading edge. In Fig. 1 this neighborhood on the line $\bar{y} = 0.3$ is shown by an asterisk. The points 1–3 in Figs. 2–5 correspond to the numbers of variants.

For the profiles $\Delta C_p(\bar{x})$ (Fig. 2), the basic distinction of curves 1–3 falls in the interval $\bar{x} < 0.2$. It should be noted that a similar behavior of the curves $\Delta C_p(\bar{x})$ is observed in other cross sections ($\bar{y}$ = const). The load distribution along the neighborhood of the leading edge is presented in Fig. 3, where L is the length of the root chord of the wing.

The functions $F(t)$ for all three variants of distribution of local loads on the wing are presented in Fig. 4. The characteristic features of curve 3 for ΔC_p = const in the entire wing area are determined by the wing geometry in plan. These features are also observed for curves 1 and 2. A comparison of the results in Figs. 2–4 shows that the discrepancies between the values of the function $F(t)$ on curves 1–3 corresponds to the difference between the values of local loads in the neighborhood of the leading wing edges.

Following the linear theory [11], the pressure coefficient is determined by the relation $C_p = -2u$, which jointly with (1) and the second-approximation equation of the Mach line

$$x = \beta r - k_1 F(t,\theta) r^{1/2} + t \qquad \left(k_1 = \frac{(\gamma + 1)\mathrm{M}_\infty^2}{2^{1/2}\beta^{3/2}}\right)$$

gives the solution as a deformed wave profile at distance r from the body.

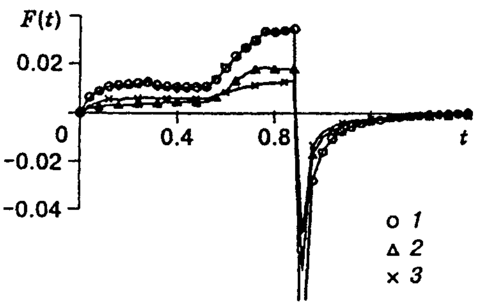

Fig. 4

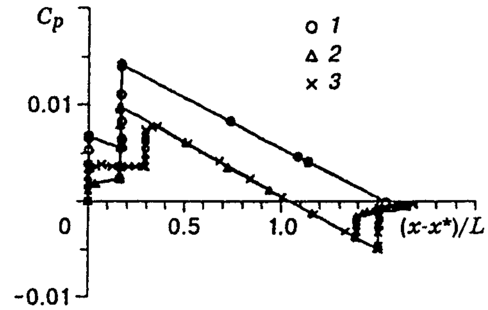

Fig. 5

The ambiguity of the solution for the shape of the wave profile is eliminated by introducing discontinuities whose position and intensity are determined using the methods of [1, 2].

From the calculation results in Fig. 5 one can judge the influence of the pressure distribution on the wing on the wave profile parameters. Figure 5 presents three pressure wave profiles in a plane separated by distance $\bar{r} = z/L = 10$ from the wing plane (x^* denotes the coordinate of the leading shock wave). The influence of the character of loads in the neighborhood of the leading wing edge is clearly noticeable for the variants of the pressure fields on the wing. This is clearly seen from a comparison of Figs. 3 and 5. The first profile is generated by the wing, which strongly disturbs the flow by the leading edges. The second profile is due to the weak perturbation of the flow from the leading extension edges and strong disturbance at the edges of the basic wing, which reduces the momentum of the positive phase of the profile by 48% and the intensity of the leading pressure jump by 28%. The leading edges of the wing disturb slightly the flow for the third profile, which reduces the momentum and in the shock wave intensity by 50% and 30%, respectively, compared with the first profile.

The calculation results show that the shape of the wave profile in the near zone is appreciably determined by the shape of the wing in plan, while the wave profile and SB parameters far from the body depend on the character of the load distribution on the wing surface.

REFERENCES

1. G. B. Whitham, "The flow pattern of a supersonic projectile," *Comp. Pure Appl. Math.*, **5**, No. 3, 301–338 (1952).
2. G. B. Whitham, *Linear and Nonlinear Waves* [Russian translation], Mir, Moscow (1977).
3. F. Walker, "The shock pattern of a wing-body combination far from the flight path," *Aeron. Quart.*, **9**, No. 2, 164–194 (1958).
4. O. S. Ryzhov, "Attenuation of shock waves in steady flows," *Prikl. Mekh. Tekh. Fiz.*, No. 6, 36–43 (1961).
5. V. G. Dulov and A. I. Rudakov, "Spatial supersonic flows at large distances from a finite-volume body," *Prikl. Mekh. Tekh. Fiz.*, No. 3, 77–83 (1972).
6. E. N. Zatoloka, V. F. Chirkashenko, and Yu. N. Yudintsev, "A system for measuring the parameters of a sonic boom in wind tunnels with the use of a computer," Preprint No. 21, Institute of Theoretical and Applied Mechanics, Sib. Div., Academy of Sciences USSR, Novosibirsk (1983).
7. M. D. Brodetskii, V. F. Volkov, E. K. Derunov, and A. B. Koshcheyev, "Study of far field sonic boom parameters based on experimental data in the vicinity of a supersonic aircraft model," Int. Conf. on Aerophysical Research Methods, Novosibirsk (1992), pp. 19–22.
8. J. Morris, "An investigation of lifting effects on the intensity of sonic booms," *J. Roy. Aeron. Soc.*, **64**, No. 598, 610–616 (1960).

9. M. D. Brodetskii, A. B. Koshcheyev, and G. A. Cheremukhin, "Experimental study of distributed aerodynamic characteristics of nonplanar wings at supersonic velocities," in: *Studies on Aerodynamics of Nonplanar Wings* [in Russian], Institute of Theoretical and Applied Mechanics, Siberian Division, USSR Academy of Sciences, Novosibirsk (1977), pp. 144–159.
10. M. D. Brodetskii, Yu. G. Bokovikov, A. B. Kashcheyev, and A. M. Makhnin, "Investigation of aerodynamic characteristics of nonplanar wings at supersonic velocities," in: *Gas Dynamics Issues* [in Russian], Novosibirsk (1975), pp. 183–186.
11. W. R. Sears, *General Theory of High-Speed Aerodynamics* [Russian translation], Izd. Akad. Nauk SSSR, Moscow (1962).