Engineering Notes

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Aerodynamic Configurations Yielding Lift without Sonic Boom

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THIS Note deals with the utilization of special configurations for the reduction of the sonic boom of supersonic flight. Various schemes have been proposed for control of supersonic flow. Theory has suggested alteration of conventional designs based on minimal overpressure[1] and more desirable signature profiles.[2] The use of nonslender and exotic shapes may produce favorable reflection or redistribution of waves.[3–5] Electrostatics suggests force at a distance for flow control.[6] At hypersonic speeds, the presence of aerodynamic plasma suggests similar possibilities for MHD control.[7] Finally, alteration of the mass and energy of the flow opens up new possibilities. Of all the techniques, only the latter appears capable of eliminating the boom with lift altogether, at least ideally, neglecting the open wake. Thus, consideration and choice of engine cycle and its integration into the aircraft merits investigation for boom reduction. Ferri[8] has suggested this for boom because of volume. In the present Note, lifting configurations are considered. The necessary features of the devices are described. As the simplest example, the performance of a mass sink device is analyzed.

For the present purposes, we restrict discussion to two-dimensional, frictionless flow. It is noted that the effects of wakes and ends contribute adversely. The basic requirement of boom-free flight is that the aircraft not disturb the flow over its lower side. The Busemann bi-plane accomplishes this at zero angle of attack but then has no lift. For boom-free lift, one must rely on suction on the upper surface.

In Fig. 1, a device is shown which develops lift by low pressure on its upper surface. The internal flow is "processed" in such a way that it exhausts at the freestream pressure p_∞ and through an exit with area less than the inlet area. The matching of pressure is necessary in order to prevent interaction with the freestream. Whether or not thrust is produced depends on the internal process. In order to obtain the desired result, the critical area A^* and/or the total pressure p_0 must be reduced from the inlet valves. Functionally, for one-dimensional perfect gas flow

$$p = p_0(p/p_0) = p_0 f(A/A^*) \tag{1}$$

where f is a monotonically decreasing function of the area ratio.[10] The amount of lift produced depends on the difference in inlet and exit areas. In order to evaluate the performance of such a device, we consider a special case where this difference is maximized with zero exit area, all internal flow being absorbed.

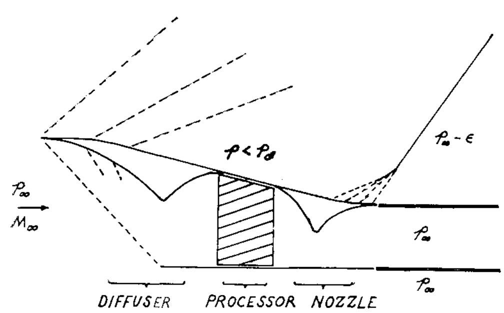

Fig. 1 Schematic of ideal, lifting, boom-free configuration.

In Fig. 2, a schematic of the sink device is illustrated. At this point, it is noted that a slight nonuniform wave pattern is induced by the trailing shock in the configurations of both Fig. 1 and Fig. 2. This is due to the loss in pressure because of expansion and subsequent compression through a shock. Thus, there is a tendency for a slight upwash and, eventually, a slight interaction with the freestream. The effect is so small that it cannot be illustrated on the figures without exaggeration and for all practical purposes can be neglected.

The lift coefficient based on the length of the lifting surface l and a unit span is

$$C_L = \frac{(p_\infty - p)l\cos\theta}{\rho_\infty V_\infty{}^2/2l} = \frac{2(1 - p/p_\infty)\cos\theta}{\gamma M_\infty{}^2} \tag{2}$$

where θ is the turning angle of the lifting surface subjected to pressure p, γ is specific heat ratio, M is Mach number, and ∞ denotes the freestream. The effect of θ at $M_\infty = 3$ is illustrated in Fig. 3. Optimum lift occurs at $\theta = 30°$. The calculations were based on nonlinear Prandtl-Meyer expansion theory. The linear approximation is discussed below.

Drag is due to lift and to mass absorption

$$\begin{aligned} C_D &= [(p_\infty - p)l\sin\theta + \rho_\infty V_\infty{}^2 l\sin\theta]/(\rho_\infty V_\infty{}^2/2l) \\ &= C_L\tan\theta + 2\sin\theta \end{aligned} \tag{3}$$

The mass-absorption rate per pound of lift is

$$\frac{\dot m}{L} = \frac{\rho_\infty V_\infty l\sin\theta}{C_L\rho_\infty V_\infty{}^2/2l} = \frac{0.0644\sin\theta}{M_\infty C_L}\text{lbm/(sec lbf)} \tag{4}$$

with the speed of sound $a_\infty = (\gamma p_\infty/\rho_\infty)^{1/2}$ taken as 1000 fps. The results are also shown in Fig. 3 for $M_\infty = 3$, and indi-

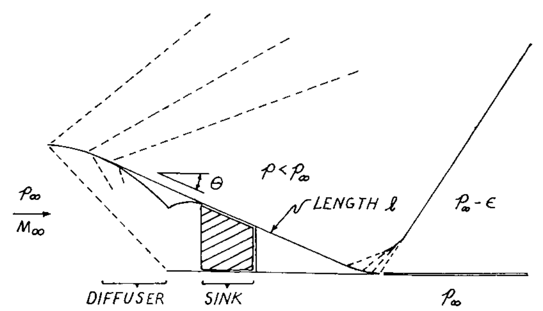

Fig. 2 Schematic of lifting device with internal flow sink.

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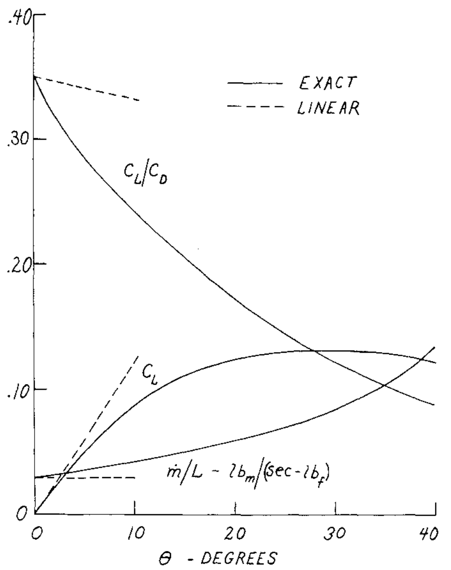

Fig. 3 Performance of lifting device with internal flow sink, $M_\infty = 3$.

cate optimal performance at small θ. This suggests the usefulness of linear theory, also illustrated, where

$$\frac{p - p_\infty}{\rho_\infty V_\infty^2/2} = \frac{2\theta}{(M_\infty^2 - 1)^{1/2}} \tag{5}$$

θ is in radians. The resulting performance parameters are

$$C_L = 2\theta/(M_\infty^2 - 1)^{1/2} \tag{6}$$

$$C_L/C_D = 1/[\theta + (M_\infty^2 - 1)^{1/2}] \tag{7}$$

$$\dot{m}L = (1 - 1/M_\infty^2)^{1/2}/a_\infty \tag{8}$$

The lift coefficients are lower than those of conventional airfoils, because of the reliance on suction alone. At a small angle of attack, a flat plate would generate twice the lift. The lift-drag ratio is about one order of magnitude smaller, at angle θ of optimal lift of the present device, than for the flat plate at the same angle of attack. This is due to the absorption of mass and the reaction to its momentum. Further, the absorption of such large flow rates obviously makes the configuration impractical with known technology.

In the case of the more general device of Fig. 1, alteration of energy could be substituted for the mass sink of the present example. It is noted that the lift coefficient is unchanged. The amount of drag would depend on the internal process. One possibility appears to be a compression process.

Although it does not seem possible to eliminate the sonic boom entirely because of the wake and end effects, a contribution due to lift is nonessential. Perhaps the integration of wings and engines, which normally contribute adversely themselves, can reduce the boom.

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The Spadoryc—A Method of Determining Damping

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Introduction

Because existing methods of obtaining the value of damping from experimentally acquired decay traces are cumbersome, a slide rule has been devised which will enable the engineer to accomplish this with a high degree of speed and with acceptable accuracy.

Background

If A_0 and A_n represent the amplitudes of a freely oscillating decaying vibration at times n cycles apart, the damping of

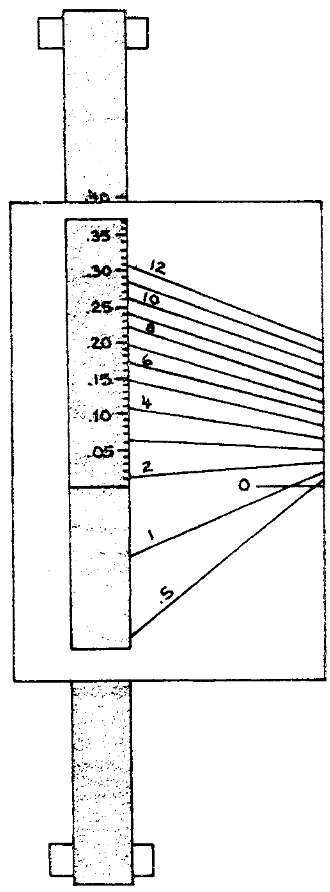

Fig. 1 The spadoryc.

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