Engineering Notes

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Generalized Comparison between Optimized and Conventional Diffusers

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Introduction

RECENTLY, the author has derived a principle to specify how the two-dimensional compressible turbulent boundary layer can be decelerated in an optimum way.[1] As applied to diffusers, this optimization principle is a compromise between the following three requirements: high performance, short diffuser length, and wide operating range. Also, a straight wall channel diffuser (SWCD) tested in Ref. 2 and two conical diffusers (CD) tested in Ref. 3 were found to have boundary layers that developed in a manner close to the optimum. (SWCD and CD are the "conventional" diffusers which we will consider.) In order to determine whether SWCD and CD are really optimum, it is necessary to make a generalized comparison which covers a large range of Reynolds number, Mach number, and diffuser inlet blockage which is defined as (1 − actual mass flow rate/ideal mass flow rate).

Basis of Comparison

It is clear that we shall use the best diffusers tested in Refs. 2 and 3 for the comparison. For such diffusers, the static pressure recovery coefficient C_p (defined as static pressure rise/inlet dynamic pressure) is obviously the suitable criterion to judge the performance. Furthermore, we shall compare the values of C_p of different diffusers based on the same diffuser length L. A suitable scale to nondimensionalize L is the inlet boundary-layer displacement thickness δ_I^*, as suggested by Stratford, et al.[4] Using L/δ_I^* as the length scale will implicitly take into account the inlet blockage B_I, since δ_I^* is directly related to B_I. Based on the theory of Ref. 1, the optimized curve in the form of C_p vs L/δ_I^* corresponding to an optimum boundary-layer development can be calculated. Another advantage of using L/δ_I^* is that the optimization curve is independent of the inlet Reynolds number based on δ_I^*, i.e., (Re_I^*), if $Re_I^* > 2000$. Thus for high Re_I^*, the optimized curve depends on the inlet Mach number M_I only. If the performance of SWCD and CD matchs the corresponding optimized curves, the SWCD and CD are optimum. In Refs. 2 and 3, complete performance maps are established for these diffusers. The ranges considered for this comparison are Re_D (inlet Reynolds number based on inlet diameter) $\cong 10^6$, $B_I = 0.02$ to 0.12 and $M_I = 0.2$ to 1.0 for SWCD, $Re_D = 1.14 \cdot 10^5$ to $4.04 \cdot 10^5$, $B_I = 0.04$ to 0.12, and $M_I = 0.4$ to 1.0 for CD. For a given M_I, the data of C_p and L/δ_I^* are obtained from the best diffusers (which yield the shortest length for a given C_p, the so-called C_p^* line) and compared with the optimized curves.

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Index categories: Boundary Layers and Convective Heat Transfer—Turbulent; Nozzle and Channel Flow; Subsonic and Transonic Flow.

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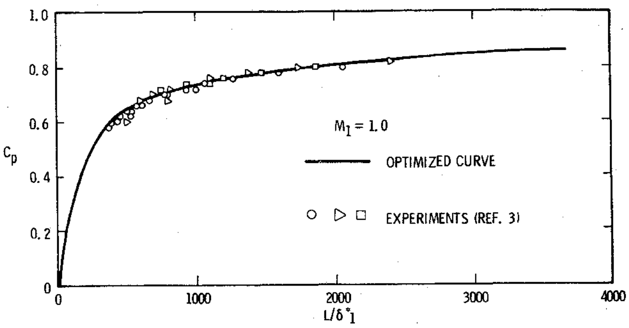

Fig. 1 Comparison between experimental and theoretical optimized C_p values at $M_I = 1.0$ for conical diffusers.

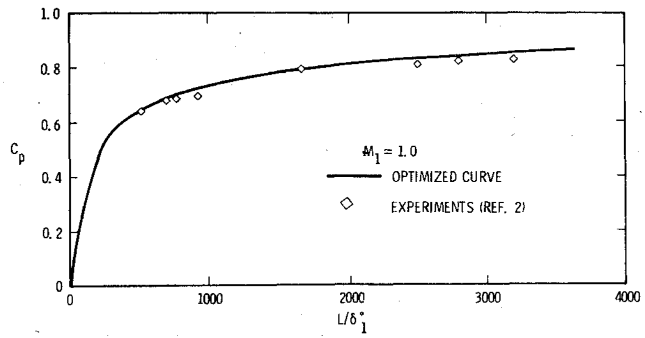

Fig. 2 Comparison between experimental and theoretical optimized C_p values at $M_I = 1.0$ for straight wall channel diffusers.

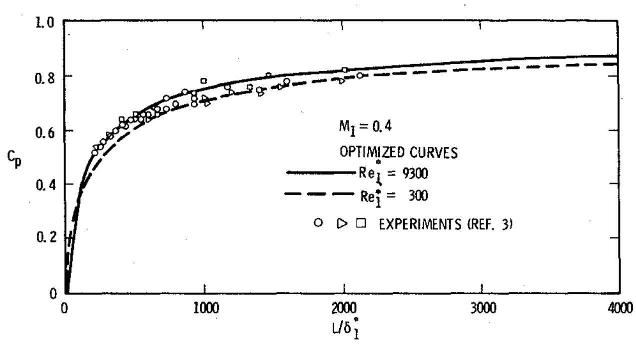

Fig. 3 Comparison between experimental and theoretical optimized C_p values at $M_I = 0.4$ for conical diffusers.

Results

The results are shown in Fig. 1 for CD at $M_I = 1.0$, in Fig. 2 for SWCD also at $M_I = 1.0$, in Fig. 3 for CD at $M_I = 0.4$ and in Fig. 4 for SWCD at $M_I = 0.2$. In Fig. 3, Re_I^* of the experiments is lower than 2000; hence the influence of Re_I^* cannot be neglected. Therefore, two optimized curves are calculated which correspond to the upper and lower limits of the values of Re_I^* in the experiments.

Conclusions

From the comparisons it can be concluded that the best geometries of SWCD and CD do indeed have a performance close to the optimum. Their performance can only be improved by boundary-layer control methods such as inlet swirl, suction, enhanced turbulence, etc.

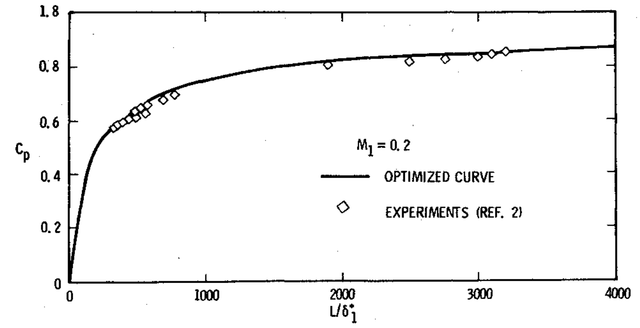

Fig. 4 Comparison between experimental and theoretical optimized C_p values at $M_l = 0.2$ for straight wall channel diffusers.

References

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[2] Runstadler, P. W. Jr. and Dean, R. C. Jr., "Straight Channel Diffuser Performance at High Inlet Mach Numbers," *Transactions of the ASME, Journal of Basic Engineering*, Vol. 91, Sept. 1969, pp. 397-422.

[3] Dolan, F. X. and Runstadler, P. W. Jr., "Pressure Recovery Performance of Conical Diffusers at High Subsonic Mach Numbers," NASA CR-2299, Aug. 1973.

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Passive Flutter Suppression

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Nomenclature

V_f = flutter velocity, fps
ΔV_f = change in flutter velocity, fps
α_0 = static angle of attack, deg
α_s = static stall angle of attack, deg

Introduction

LUGT[1] and Daniels[2,3] found that the auto-rotation of a flat plate and cruciform fins could be controlled or eliminated through the use of spanwise slots. Comparison of the flowfield about an airfoil in a bounded flutter oscillation, via smoke flow visualization,[4] revealed similarities in vortex shedding patterns between that of the auto-rotating flat plate and cruciform fins. Hence, it was felt that a spanwise slot could possibly increase the flutter velocity of an airfoil. This fact was proved in subsonic wind tunnel tests conducted on an NACA 0012 airfoil. The details of this experimental program are given in Ref. 5; only the major results are presented in the following section.

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Index categories: Nonsteady Aerodynamics; Aeroelasticity and Hydroelasticity.

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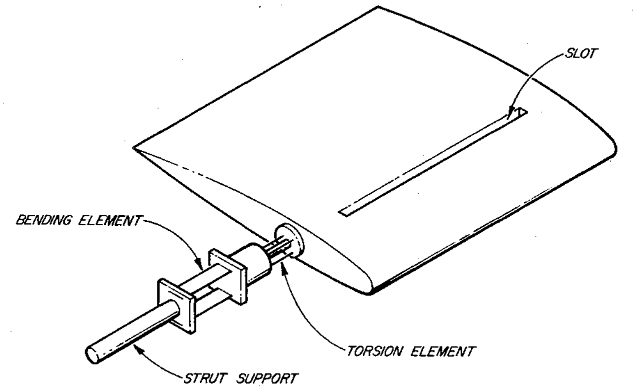

Fig. 1 Slotted airfoil and support system.

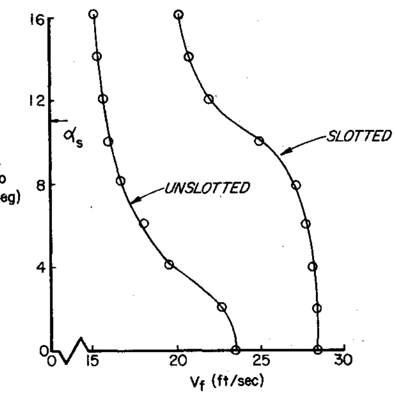

Fig. 2 Flutter velocity vs angle of attack.

Test Results

The NACA 0012 airfoil section used for the flutter tests, the type of spanwise slot considered, and the support system are shown in Fig. 1. The airfoil model is completely rigid; the two-degree-of-freedom flutter support system (details are given in Ref. 4) allows separation of the bending and torsional modes. This support system facilitates independent variations of either the torsional or bending structural characteristics. Bending and torsional elements were employed which possessed linear structural restoring and damping characteristics.

The slot is a spanwise cut completely through the airfoil section. The area of the slot is approximately 0.20 of the surface area of the airfoil. The flexural axis and the slot are located at the quarter chord position.

The flutter velocity, V_f, as a function of static angle of attack, α_0, i.e., the angle between the chord line and the wind tunnel velocity vector are presented in Table 1. These values were repeatable to within one percent. This data clearly shows that the slot does increase the flutter velocity. A plot of this data as a function of α_0 (Fig. 2) better defines the trends. A maximum increase in V_f, 57.8%, occurs at $\alpha_0 = 8°$, just prior

Table 1 Flutter velocity vs angle of attack

α_0 (deg)	V_f (fps) Unslotted	V_f (fps) Slotted	ΔV_f (fps)	% Increase
0	23.5	28.6	5.1	21.7
2	22.8	28.2	5.4	23.7
4	19.3	27.8	8.5	43.1
6	18.0	27.2	9.2	51.1
8	16.6	27.0	9.6	57.8
10	15.8	24.8	9.0	57.0
12	15.6	21.8	6.2	39.7
14	15.4	20.7	5.3	35.4
16	15.2	20.1	4.9	32.2