Growth of Turbulent Boundary Layers over Nonstationary Boundaries

ALAN T. ROPER*
Rose-Hulman Institute of Technology, Terre Haute, Ind.

AND

GARL L. GENTRY†
NASA Langley Research Center, Hampton, Va.

Nomenclature

H = shape factor
R = ratio of ground plane to freestream velocity = V_B/U
R_x = Reynolds number (based upon x) = Ux/ν
u = longitudinal velocity component within boundary layer
U = freestream longitudinal velocity component
V_B = ground plane longitudinal velocity
x = longitudinal coordinate measured from leading edge of belt
y = coordinate measured normal to belt
δ = boundary-layer thickness
δ^* = displacement thickness
θ = momentum thickness

Special Notation

$\tilde{}$ = quantity based upon velocity measured relative to ground plane
(0) = stationary ground plane quantity

Introduction

THIS Note presents experimental verification of a power law representation for turbulent boundary layers above moving plane boundaries. Such flows are of interest in such diverse studies as the Ludweig tube, moving shock waves near solid boundaries, and the near field drag of tube vehicles.

The empirical data presented were obtained in two wind-tunnel facilities equipped with moving ground belts. Both facilities employ porous suction plates to remove the normal tunnel boundary layer; therefore layers presented in this study are assumed to originate at the leading edge of the belt. Data taken from Ref. 1 were measured above a belt of rough woven texture ($2.7 \times 10^6 < R_x < 5.2 \times 10^6$), while those of Ref. 2 were obtained over a smooth belt ($0.65 \times 10^6 < R_x < 2.0 \times 10^6$).

Velocity Distribution

The power law depicts the velocity within the boundary layer as

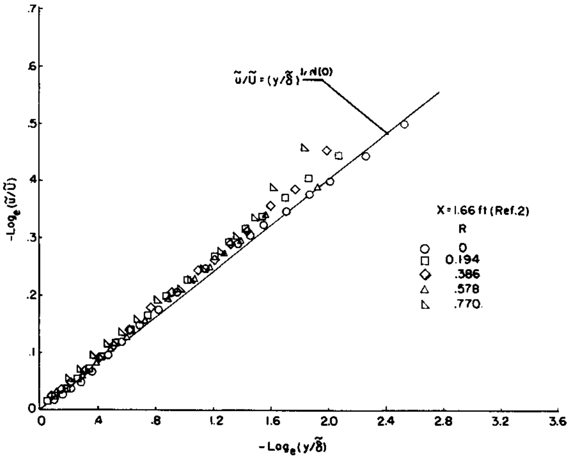
$$u/U = (y/\delta)^{1/n} \tag{1}$$

where n is somewhat dependent upon Reynolds number. Empirical data[1,2] indicate that velocity distributions measured relative to a moving boundary admit to a similar formulation

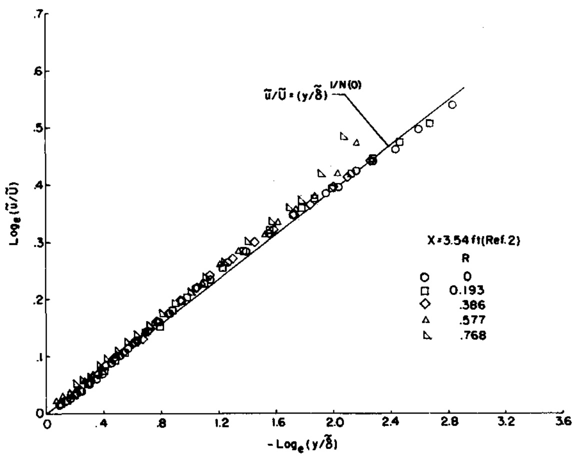
$$\tilde{u}/\tilde{U} = (u - V_B)/(U - V_B) = (y/\tilde{\delta})^{1/N} \tag{2}$$

where N is nearly independent of R. Representative profiles in the format suggested by Eq. (2) are presented in Fig. 1.

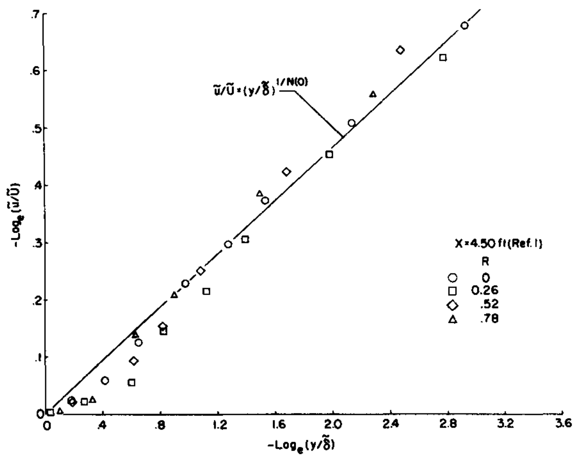
Slopes of all measured profiles are summarized in Fig. 2 for the forms suggested by both Eqs. (1) and (2). It is important to note that while n is strongly dependent upon R, N is nearly



a) $x = 1.66$ ft (Ref. 2).



b) $x = 3.54$ ft (Ref. 2).



c) $x = 4.50$ ft (Ref. 1).

Fig. 1 Distribution of velocity relative to the ground plane.

constant. The primary motivation for the power law formulation is simplicity. To maintain this simplicity, it appears desirable to set $N = N(0)$ and accept the inaccuracy implied by the slight R dependence apparent in Fig. 2.

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* Professor and Chairman, Division of Civil and Mechanical Engineering.

† Aerospace Technologist, Low-Speed Aircraft Division.

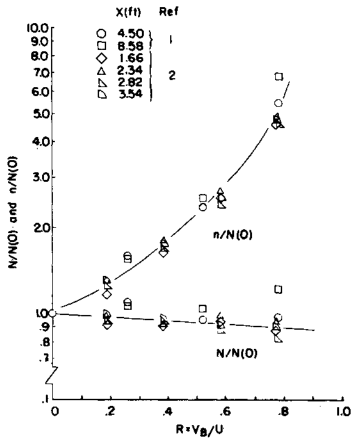

Fig. 2 Slopes of relative and absolute velocity profiles.

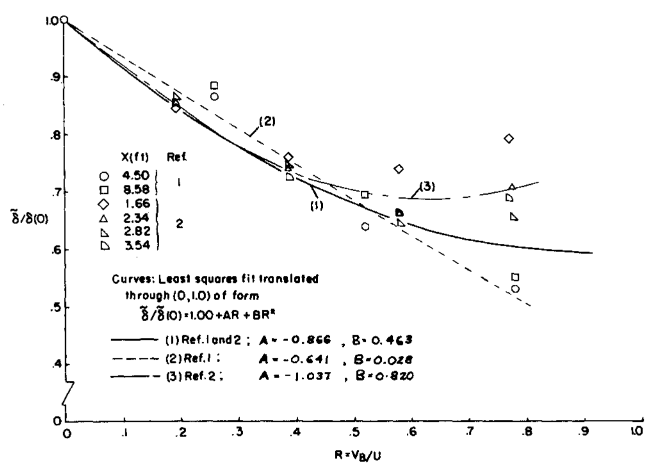

Fig. 3 Variation of boundary-layer thickness with ground plane speed.

Integral Parameters

The usual integral parameters can be developed using their respective definitions and Eq. (2).

$$\delta^*/\delta^*(0) = (1-R)\bar{\delta}/\delta(0) \tag{3}$$

$$\theta/\theta(0) = (1-R)\left(\frac{N+2R}{N}\right)\bar{\delta}/\delta(0) \tag{4}$$

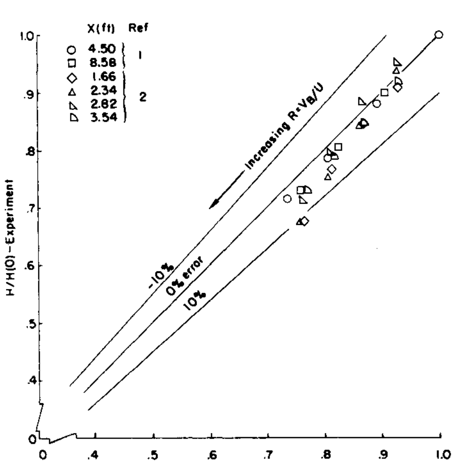

Fig. 4 Comparison of experimental and predicted values of shape parameter.

$$H/H(0) = N/(N+2R) \tag{5}$$

Once stationary ground plane parameters are computed, these equations can be used to predict the moving ground plane values, provided a suitable expression for $\bar{\delta}/\delta(0)$ can be developed. A rather large amount of scatter is however apparent in empirical values of $\bar{\delta}/\delta(0)$ beyond $R = 0.5$ (Fig. 3). Therefore only values of $H/H(0)$ are presented for comparison in this Note (Fig. 4).

Conclusions

Empirical information indicates that the velocity distribution in a turbulent boundary layer over a moving ground plane can be adequately represented by Eq. (2).

References

[1] Turner, T., "Wind Tunnel Investigation of a 3/8-Scale Automobile Model Over a Moving-Belt Ground Plane," TND-4229, 1967, NASA.

[2] Roper, A. and Gentry, G., Jr., "Analysis of a Turbulent Boundary Layer Over a Moving Ground Plane," TND-6788, July 1972, NASA.

Response of a Hot Wire Oscillating in a Shear Flow

R. H. Kirchhoff* and R. A. Burbank†
University of Massachusetts Amherst, Mass.

Introduction

A HOT wire is known to have a d.c. response proportional to the normal component of the mean flow velocity vector and an a.c. response proportional to the normal component of the instantaneous velocity fluctuation. In this paper the response of a hot wire oscillating in a shear flow is examined.

The theory is developed for a linearized constant temperature wire oscillating in a two-dimensional shear flow. By performing a Taylor series expansion in the direction of oscillation the wire response can be ordered in terms of the increasing harmonics and powers of the dimensionless amplitude of oscillation. Analysis of the harmonic components of the wire response in the one-dimensional case yields the first and second mean flow spatial derivatives in the direction of the wire oscillation. In the two-dimensional case the same analysis serves to separate the two components of the mean flow and also yields their first spatial derivatives in the direction of the wire oscillation. Separation of the harmonic components of the wire response which are coherent with the forced oscillation is achieved with a two phase lock-in amplifier.

This paper gives an account of the development of the theory and a discussion of the measurement technique. Recent experimental work[1,2] has established the validity of the technique in the one-dimensional case.

Theory

A shear flow is assumed to have three-dimensional mean velocity components U_1 (x_1, x_2, x_3), U_2 (x_1, x_2, x_3) and U_3

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* Associate Professor, Department of Mechanical and Aerospace Engineering. Member AIAA.

† Postdoctoral Associate; presently Research Engineer with E. I. Dupont de Nemours & Company, Waynesboro, Va. Member AIAA.