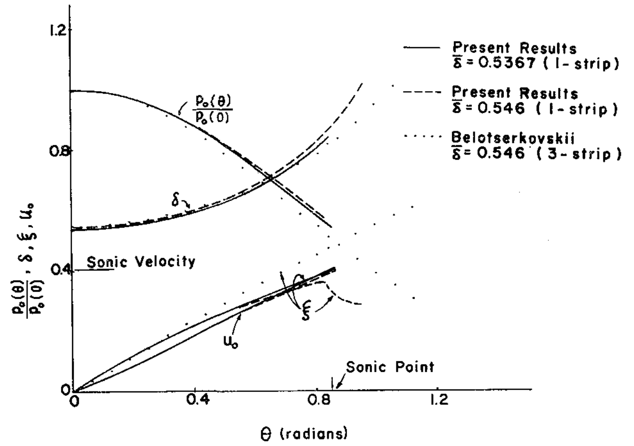

Fig. 3 Numerical results of one-strip approximation for a circular cylinder at $M\infty = 4$, $\gamma = 1.4$ and their comparison with Belotserkovskii's results of two-strip approximation under the same conditions.

schematic plotting of this $u_0 - t_0$ curve is shown in Fig. 2. Thus, for a body with a smooth surface, the sonic point is located where t_0 reaches maximum, or dt_0/ds equals zero. This is in accord with the sonic condition that the acceleration does not become infinite, which is explicitly applied when δ, ξ, and u_0 are used as dependent variables. For a certain class of bodies having sonic shoulders (an example of such a shoulder is shown in Fig. 2), the sonic point is fixed where $u_{0*} = (\gamma - 1)^{1/2}(\gamma + 1)^{1/2}$. After the sonic line the flow undergoes an expansion; u_0 changes from u_{0*} to some higher value within an infinitesimally small distance. Thus, u_0 in the $u_0 - t_0$ diagram jumps abruptly from u_{0*} to $u_0 > u_{0*}$.

To demonstrate the preceding method let us choose a simple example, i.e., a circular cylinder in a supersonic stream with $M_\infty = 4$ and $\gamma = 1.4$ and using a one-strip approximation. The numerical integration is carried out from the stagnation point through the sonic point into the supersonic region. The flow conditions used here are the same as those in Ref. 2, and therefore we can compare the results directly. It should be noted that the results of Ref. 2 are obtained by using a two-strip approximation, whereas ours are the one-strip approximations; hence some discrepancies are to be expected. It is interesting to notice that for an inaccurate guess of the initial condition we can still extend the integration beyond the sonic point without encountering numerical instabilities, though the sonic condition is not satisfied (the dashed-line curves in Fig. 3). With the usual computational scheme, it has been shown in Ref. 4 that, unless the initial condition for one-strip approximation can be guessed to at least six significant figures, the integration diverges before the sonic point is reached. Thus, the advantage of the present scheme is that it is stable near the sonic point.

Although we have only carried out a simple example with one-strip approximations, it is believed that the situation is the same for higher approximations and for more complex geometrical configurations. Work along this line is continuing.

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Measurements of Errors Caused by Misalignment of Floating-Element Skin-Friction Balances

F. B. O'Donnell* and J. C. Westkaemper†
University of Texas, Austin, Texas

The floating-element skin-friction balance has been used extensively in boundary-layer research. It is probably the most accurate means of measuring skin friction, since it has the advantage of direct measurement, whereas other methods usually involve the deduction of friction forces from temperature or pressure measurements. Experience has shown, however, that special care must be used in testing with the balance in order to realize its theoretical advantages. In particular, the installation requirements include the obvious necessity of aligning the floating element so that it is flush with the test surface. Coles[1] and Dhawan,[2] for instance, both used optical methods to insure the flushness of the element and permitted only a few microinches of misalignment. Other investigators (Smith and Walker[3] and Shutts et al.[4]) concluded that larger misalignments could be tolerated without serious error. It did not appear from these investigations that any systematic study of misalignment effects had been made. Instead, most investigators realized the potential error involved and attempted to minimize the error as much as practicable. Because of the importance of this factor in skin-friction work, an experimental investigation was made to systematically measure the error resulting from misalignment.

Experimental Equipment and Methods

The tests were conducted in a 2- × 2-in. continuous flow wind tunnel. The surface in which the balance was mounted was the flat test-section floor. It was possible to vary the test Mach number by means of an adjustable nozzle, and a Mach Number range of 1.7 to 3.6 was utilized. The flow was adiabatic for all tests.

The operating principles of the balance may be deduced from Fig. 1. The disk-shaped floating element was mounted on a pair of leaf springs which allowed the element to be displaced by the skin-friction forces. The displacement was indicated by a linear variable differential transformer whose output was converted to drag force by means of dead weight calibrations made after each run. The disk diameter was 1 in., and the opening in the tunnel floor was 0.01 in. larger, resulting in an annular gap of 0.005 in. in which the element "floated."

The balance was mounted on a fixed-end support beam (Fig. 2) that restricted the balance motion to translation in a direction perpendicular to the wind-tunnel floor. This beam also served as a restoring spring to return the balance to the recessed position when the displacing force was removed. A drive mechanism was constructed which permitted suitably small increments of balance translation. This mechanism consisted of a differentially threaded lead screw and a cantilever beam. Displacement changes were made by means of a hand wheel attached to the lead screw. As seen in Fig. 2, the lead screw and beam permitted a relatively large rotation of the wheel for small balance translations, thus providing the necessary precision in setting balance misalignments. A correlation between hand-wheel rotation and balance trans-

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* Research Engineer, Defense Research Laboratory; now with Norair Division, Northrop Corporation.

† Research Engineer, Defense Research Laboratory, and Assistant Professor of Aerospace Engineering. Member AIAA.

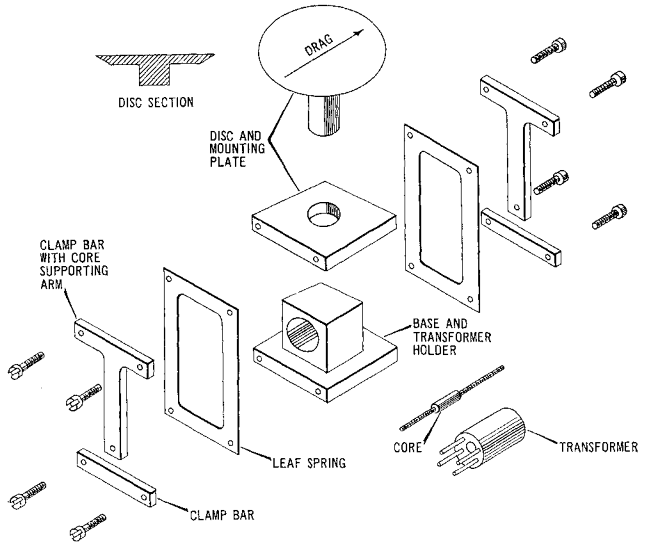

Fig. 1 Exploded view of skin-friction balance.

lation was obtained from measurements of element position with respect to the tunnel floor.

The displacement used ranged from a recess of 0.003 in. to a protrusion of an equal amount. In general, the test procedure involved making a traverse of the balance in increments of approximately 0.0006 in. at one Mach number. The tunnel was then shut down and the necessary calibrations made, followed by the next run at another Mach number. In order to keep the test program within reasonable limits, the misalignment was limited to the case of floating-element translation; inclination with respect to the tunnel floor was eliminated by installing the balance and lapping the element to insure that it was flat and parallel to the floor.

Results and Discussion

The general performance of the balance was checked by comparing with theory the friction measurements obtained when the misalignment was zero. The agreement was within the estimated accuracy of the balance. To show the effects of misalignment, the results were normalized by dividing each measurement by the corresponding value measured when the element was flush. The magnitude and direction of any error is thus immediately evident. Figures 3 and 4 present results that are representative of tests made at 23 combinations of Reynolds and Mach numbers. The variation of normalized output with misalignment is shown, where a positive misalignment indicates a protruding element, and a negative value indicates a recessed element.

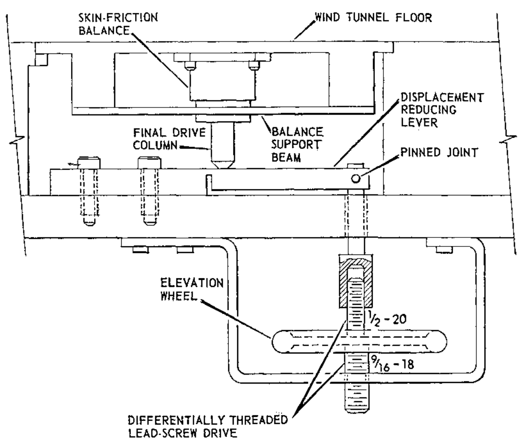

Fig. 2 Skin-friction balance elevation mechanism.

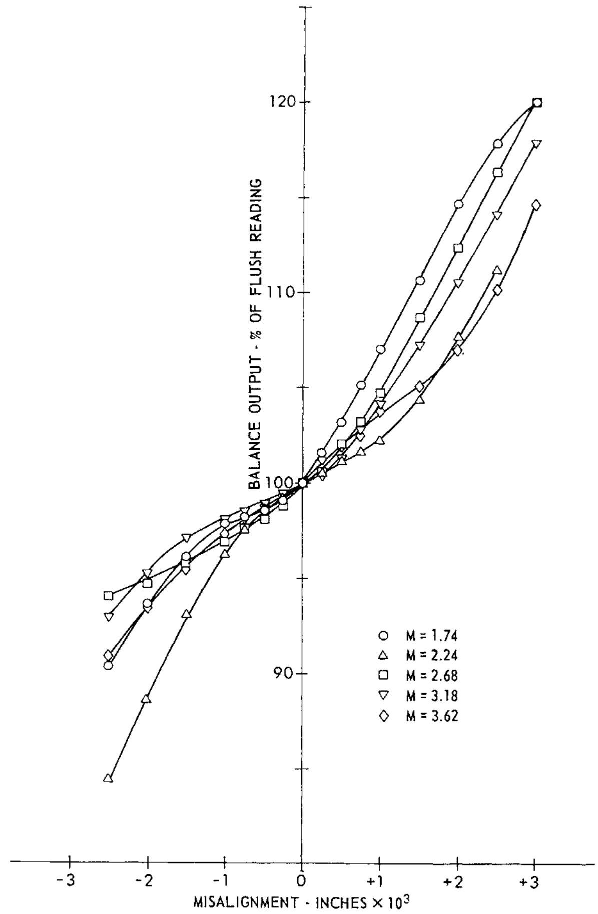

Fig. 3 Effect of misalignment for several Mach numbers at R_θ = 9830.

Although the test data show some scatter, the over-all trend is clear. Based on comments made by earlier investigators, it was expected that there would be a small range of recessed positions that would not produce appreciable errors in balance performance. The data show that this is not true, but rather that any misalignment, however small, will result in a corresponding error in balance output. In general, the magnitude of the error produced by a recessed disk is not as large as that resulting from an equal projection. The error curve is continuous through the flush position, however, and it is obvious that precise alignment is necessary to preclude error. The scatter and minor inconsistencies in the plotted data are probably the result of efforts to traverse the balance in very small steps, which required that the traversing mechanism be operated very near its limit of accuracy. The region of main interest is that where the displacements are small such that the corresponding errors are also small. In this region the results are satisfactory and may be approximated by a linear relation between error and displacement. The linear relation indicates an error of 3 to 3.5% per 0.001-in. misalignment.

Consideration of Fig. 3 indicates no obvious effect of Mach number. The variation among the several runs is believed to be primarily a result of variation in tunnel operation and equipment performance. If a Mach number effect is in fact present, it is unquestionably small. Similarly, a consideration of Fig. 4 indicates that any effect of Reynolds number is also small. Although the results vary somewhat with Reynolds and Mach numbers, there does not appear to be a consistent pattern in the variation.

Some observations concerning the displacement and measurement errors may be pertinent at this point. On a smooth surface, a misalignment of 0.0002 in. can be felt by hand; an error of 0.0005 in. can be readily seen. Thus, unintentional installation errors greater than 0.0005 in. seem unlikely, and the average error in measured force noted for this misalignment was less than 2%. The accuracy of the test equipment is thought to be of secondary importance, since the linear approximation of the results is dependent upon relative changes rather than absolute measurements. Since the test data are referenced to the flush position and the corresponding balance output, a minor error in either of these reference values would result only in a shifting of the linear relation, without modifying the slope appreciably. The good repeatability of the data is indicative of the quality of the relative measurements and thus of the over-all conclusions.

A comparison of the data obtained in this investigation with previous misalignment studies indicates general agreement. The tests of Shutts, Hartwig, and Weiler[4] were conducted in a continuous-flow supersonic tunnel with flow conditions similar to those of the present investigation. They found that lowering the floating element 0.001 in. reduced the balance output by 3.1%, a result that compares favorably with data obtained herein. They were not, however, able to make measurements with a projecting disk. Smith and Walker[3] made studies under subsonic flow conditions using a null-type balance. They found that: "the surface of the floating element could be depressed as much as 0.005 in. without any change in the surface shear. However, when the element protruded above the surface of the wall, there were noticeable deviations in the measured shear force." They also stated that the accuracy of the skin-friction balance used was believed to be ±2%. Since the present study indicates that the average error for a depression of 0.0005 in. is 2%, it is reasonable to suppose that Smith and Walker would not attempt to distinguish between measurements that fell within the expected accuracy of their instrumentation.

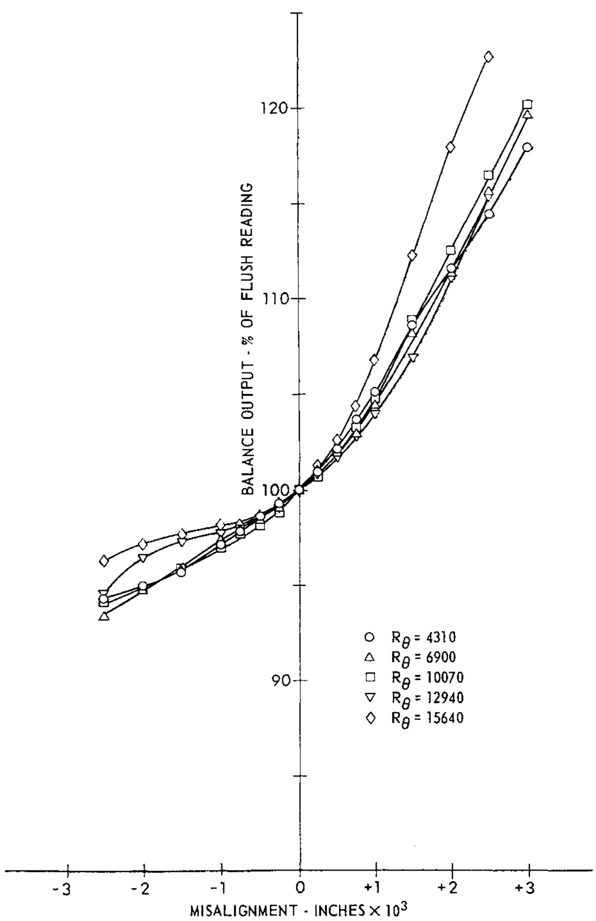

Fig. 4 Effect of misalignment for several Reynolds numbers at $M = 2.67$.

It should also be noted that both of the previous investigations discussed in this study were of the nature of minor digressions from other studies. Neither one utilized a traversing mechanism for the skin-friction balance, and it would seem likely that the data suffered from the scatter expected when an attempt is made to exactly repeat operating conditions from run to run.

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Some Recent Data on Stagnation-Point Convective Heat Transfer in Partially Ionized Air

Dale L. Compton* and David M. Cooper†
NASA Ames Research Center, Moffett Field, Calif.

Nomenclature

$\dot{q}$ = stagnation-point heating rate, Btu/ft²-sec
r = nose radius, ft
p_{st} = stagnation pressure, atm
h_{st} = stagnation enthalpy, Btu/lb
h_w = wall enthalpy, Btu/lb
V_∞ = freestream velocity, fps

SEVERAL investigators[1–4] have presented data on convective heating in partially ionized air, and it is now generally agreed that, for conditions studied experimentally to date, ionization does not have a gross effect on convective heating. However, at least one experimental discrepancy still exists. Shock-tube measurements of heat transfer to nickel gages have been reported to be as much as a factor of 2 greater than similar measurements to platinum gages, both for air and for N_2-CO_2-A mixtures.[5] Other measurements (in N_2-CO_2-A) do not show this difference.[5] It is the purpose of the present work to use an independent experimental technique[6] to investigate the heat transfer from air to nickel-surfaced gages.

The experimental technique uses the time of onset of melting on small 7075-T6 aluminum models as a measure of the stagnation-point heating rate. A sabot-held $\frac{1}{4}$-in.-diam. aluminum hemisphere is gun-launched at high velocity into either still air or an oncoming airstream in the Ames Prototype Hypervelocity Free-Flight Facility. In this facility there are 11 spark shadowgraph stations, 4 ft apart on center, beginning 15 ft from the gun muzzle. Aerodynamic heating raises the temperature of the model, and, if heating is sustained, the surface of the model will at some time begin to melt. Melting occurs first in the model's stagnation region, where the heating rate is highest. Since the viscosity of molten aluminum is low, aluminum flows off the model surface and

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* Research Scientist, Vehicle Environment Division. Member AIAA.

† Research Scientist, Vehicle Environment Division.