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RECENT TESTS AT LANGLEY WITH A UNIVERSITY OF TENNESSEE SPACE INSTITUTE (UTSI) SKIN FRICTION BALANCE

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UTSI SKIN FRICTION BALANCE CONCEPT

Figure 1 serves to illustrate the principle of operation of the UTSI (University of Tennessee Space Institute) moving belt skin friction balances. The balance is mounted such that the belt part is flush with the surface to be investigated. The two drums that support the belt are in turn supported by flexures. When the belt experiences force due to the shear of a passing fluid, it rotates the drums against the restoring force of the flexures. The stiffness of the flexures is selected to allow a maximum of 3 degrees of rotation for the expected forces. Strain gages are attached to the flexures to produce a voltage proportional to, and linear with, the torque produced by the belt rotating the drums. Since the small gaps that are open to the flow do not change with this rotation, there is no need for a closed-loop nulling device to center the measuring element, as there is in the floating element type balances. Further details are available in reference 16.

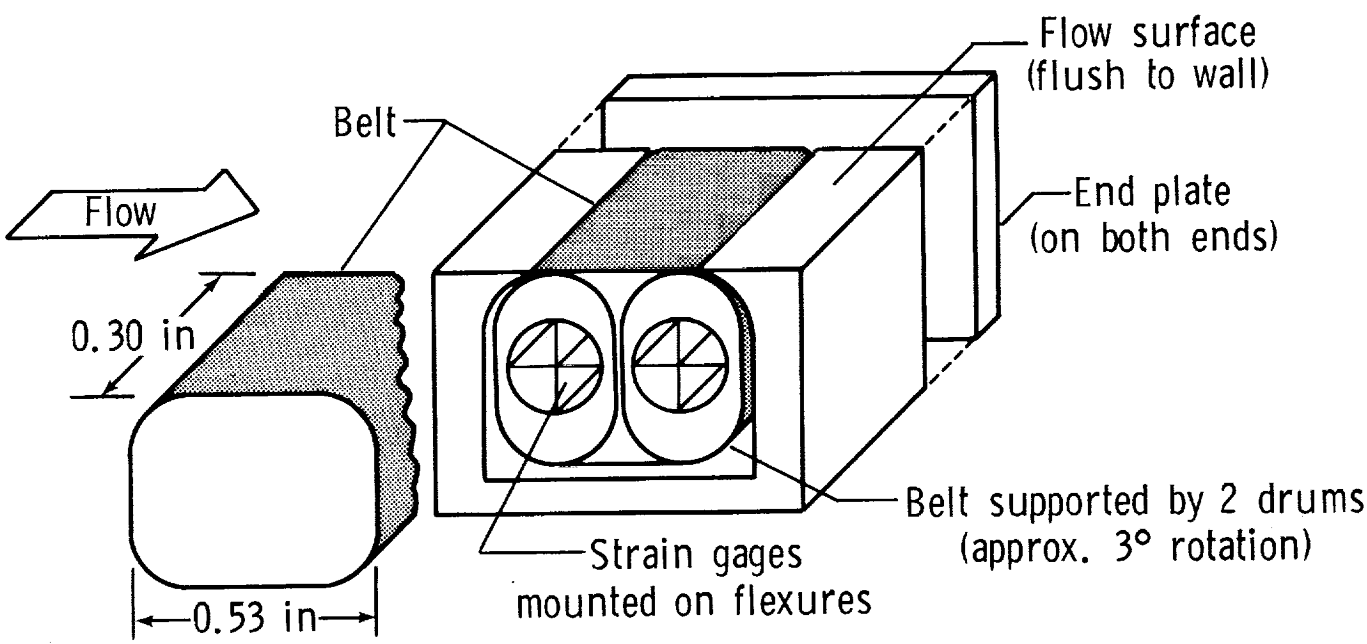

Figure 1

SUMMARY OF TEST EXPERIENCE ON TEST SECTION SIDEWALLS

Figure 2 summarizes the experience at LaRC with UTSI (University of Tennessee Space Institute) skin friction balances. The results shown were measured on the test section sidewalls of the 0.3-meter Transonic Cryogenic Tunnel, or 0.3-m TCT, and the Unitary Plan Wind Tunnel. The comparison is presented in the incompressible plane since the Mach number ranges from low subsonic to transonic in the 0.3-m TCT, and through the supersonic range in the Unitary tunnel. The Karman-Schoenherr flat plate skin friction formula is included for comparison. The shaded area represents data taken over the history of the Unitary tunnel with floating element skin friction balances (references 37, 38, and 39.)

The present results of testing on tunnel sidewalls should not be used to judge the accuracy of the skin friction balances. Rather, the data shown here should simply be taken as evidence of operational experience. Unless extraordinary precautions are taken, tunnel sidewall boundary layers are not classical flat-plate turbulent boundary layers. At a minimum, they are non-adiabatic and affected by wall roughness. Figure 3 shows that the 0.3-m TCT data level shown here can be represented by an equivalent wall roughness of only .02 mm. Since the ratio of boundary layer length to roughness height is the scaling parameter, and the boundary layer length increases with tunnel size, the large Unitary Plan Wind Tunnel would be only one-fourth as sensitive for the same absolute roughness height.

The appropriate conclusion to be drawn here is that the balance is capable of operation in environments as diverse as the cryogenic, transonic, high-shear rate of the 0.3-m TCT, and the high-temperature supersonic environment of the Unitary Plan Wind Tunnel.

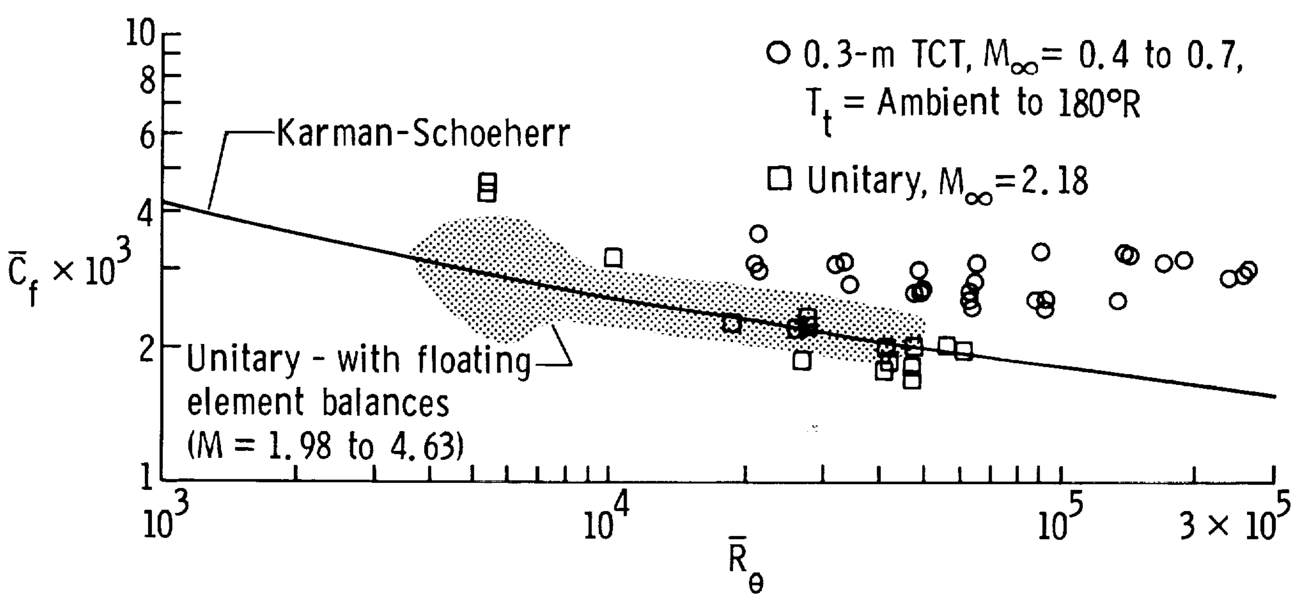

Figure 2

COMPARISON OF 0.3-M TCT DATA AND WALL ROUGHNESS EFFECTS

The data shown here (fig. 3) for the 0.3-m TCT are the same as shown on the previous plot, but have not been transformed to incompressible coordinates. Curves are shown for constant values of distributed roughness. The actual roughness was not measured. The approximate formula for rough flat plate flow used to generate the curves was

$$C_f = (2.87 + 1.58\log(x/\epsilon))^{-2.5}$$

where ϵ is the roughness height and x is distance form the leading edge, reference 40. References 17 and 18 discuss the details of applying this formula to a test section wall boundary layer, by calculating an equivalent flat plate length. The curve labeled smooth in figure 3 was calculated from the relation,

$$C_f = 0.027 / (Re_x)^{1/7}$$

also from reference 40.

The intent of this figure is not to promote a rough wall prediction method or fully explain the data trends. It does serve to demonstrate the severe effects of small roughness heights in a turbulent boundary layer, and that an equivalent roughness height of only .02mm is sufficient to match the data. Further discussion may be found in references 17 and 18.

Current plans call for further testing of UTSI balances on a large flat plate in the NTF. Floating element balances as well as other types of skin friction measuring devices will also be tested for comparison. The surface finish will be carefully controlled and extensive boundary-layer profile surveys will be conducted. The result will be a boundary layer much better understood than the test section sidewall cases.

The basic feasibility of the UTSI balance to operate in cryogenic conditions has been demonstrated. Carefully controlled testing will be required to establish limits on accuracy.

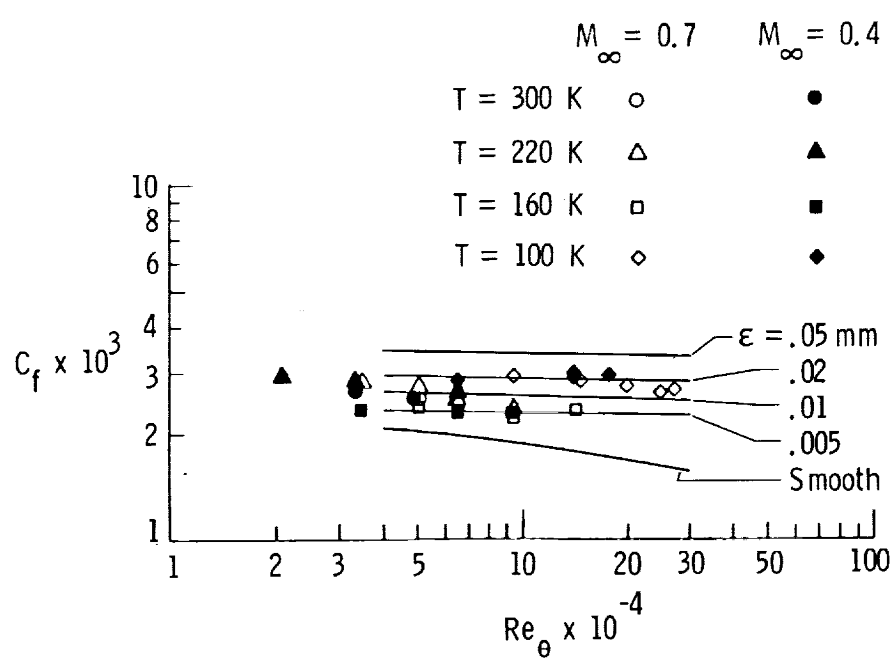

Figure 3

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PROPOSED NEW RESEARCH

Work to be done under a new grant from LaRC to UTSI will include the use of fiber optics to read the movement of the belt rather than strain gages. This technique is expected to be less sensitive to temperature changes, thus simplifying balance calibration and use at cryogenic temperatures. Also electrical noise and error due to gage heat will be eliminated. Finally, eliminating the strain gage removes the primary barrier to miniaturization.

A concurrent effort is also under way to fabricate these balances using the relatively new wire-cut method (electron discharge machining using a wire for an electrode). The use of the wire-cut technique has the potential to lower the cost of the balances by reducing the part count and simplifying the assembly procedure. The combination of the wire-cut technique and the use of fiber optics may reduce the cost per balance sufficiently to allow them to be tailored to a specific test. It is conceivable that as many as 10 balances could be dedicated to a single airfoil configuration. A typical layout is shown in figure 4 on a 14 percent thick, 10-inch chord airfoil. Each balance would be contoured to match the airfoil surface. This would simplify measurement of the location of transition, separation and transonic shocks.

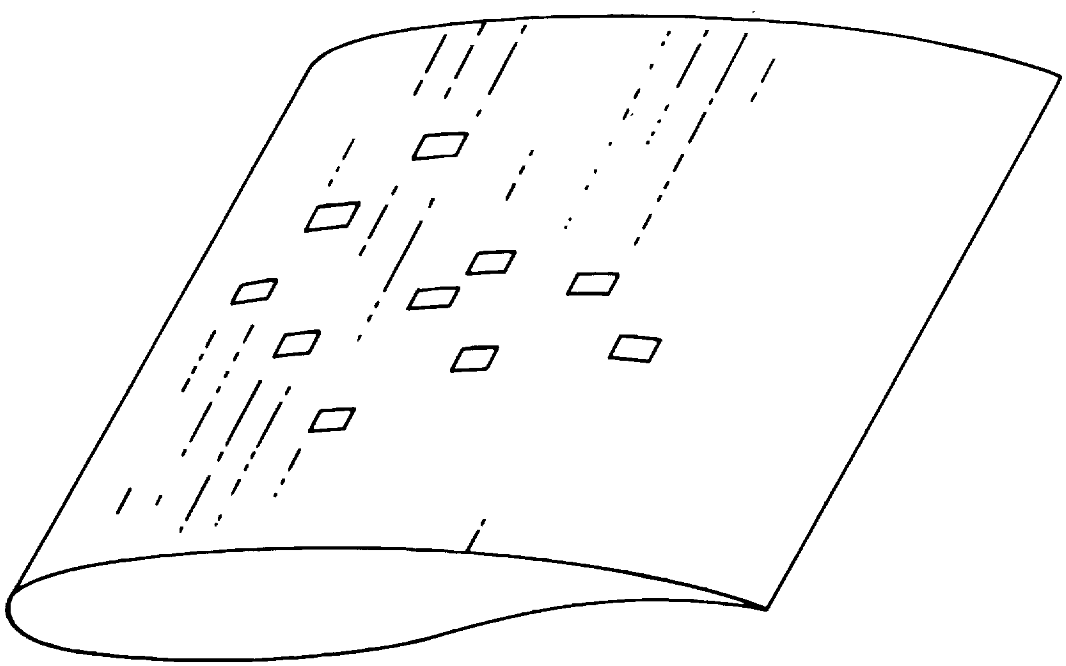

Figure 4