NASA Technical Memorandum 81820

(NASA-TM-81820) SOME AERODYNAMIC CONSIDERATIONS RELATED TO WIND TUNNEL MODEL SURFACE DEFINITION (NASA) 13 p HC A02/MF A01 CSCL 01C

N80-32376

Unclas
G3/05 28865

SOME AERODYNAMIC CONSIDERATIONS RELATED TO WIND-TUNNEL MODEL SURFACE DEFINITION

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SEPTEMBER 1980

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NOTICE

1. Report No. NASA TM-81820	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SOME AERODYNAMIC CONSIDERATIONS RELATED TO WIND-TUNNEL MODEL SURFACE DEFINITION		5. Report Date September 1980
		6. Performing Organization Code
7. Author(s) Blair B. Gloss		8. Performing Organization Report No.
		10. Work Unit No. 505-43-23-06
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

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Better techniques for defining transonic model tolerances are needed even though model tolerance requirements should not be significantly dependent on Reynolds number.

Current specified model surface finishes appear to be compatible with a significant part of the NTF Reynolds number range. It is planned for the National Bureau of Standards to validate the accuracy of the stylus profilometer for surfaces typical of NTF models and develop a light scattering system to measure surface finishes on curved surfaces (wing leading edge regions). NASA tests are planned to determine the acceptability of using existing data on sand roughened surfaces to predicting NTF model surface requirements.

Available data on orifice induced pressure errors cover a part of the NTF Reynolds number range and cover only a small part of the range of the ratio of orifice diameter to boundary layer thickness needed. A research program has been initiated by NASA to extend this data base to higher Reynolds number conditions. Techniques for avoiding orifice edge distortions must be strictly adhered to.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Surface roughness Fabrication tolerance Pressure error	Star Category - 05 Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	11	A02

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SUMMARY

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INTRODUCTION

Because of the high Reynolds number capability of the NTF (see reference 1) with the attendant thin boundary layers and the requirement for high quality test data, NASA is re-examining the aerodynamic considerations related to model surface definition, particularly in the areas of fabrication tolerances, model surface finish and orifice induced pressure errors. Model fabrication tolerance requirements are very difficult to determine because of the accuracies needed in experimental and analytical studies for defining these tolerances at transonic speeds;

for practical purposes, there are no published results on this topic. Currently, transonic model tolerances are determined by past experience and the accuracy of the machines used to fabricate the model. Since the model tolerances do affect data accuracy and model costs, it is desirable to develop improved techniques for their definition. The same care should be exercised in defining model fabrication tolerances for any transonic model regardless of its projected test Reynolds number range, since model tolerances should not be significantly dependent on Reynolds number. There will be no further discussion of model fabrication tolerances in this paper.

The drag estimates of full-scale aircraft are made by adding the aircraft manufacturing roughness drag to the wind-tunnel model drag measured on a smooth wind-tunnel model; therefore, skin friction penalties associated with the wind-tunnel model surface roughness are undesirable. As the Reynolds number at which a model is being tested increases, the model boundary layer becomes thinner and the admissible surface roughness height (the maximum roughness height which results in no skin friction penalty) decreases, as shown in references 2 through 4. In addition, increased skin friction can result in early boundary layer separation or erroneous shock location; either of these conditions can potentially produce large errors in lift, drag, and pitching moment.

For some years, it has been realized that there is an orifice induced pressure error associated with static pressure measurements as discussed in references 5 through 9. However, since, for the most part, the boundary layer thickness (displacement thickness) is large compared to the orifice diameter for the Reynolds number range of conventional tunnels, the static pressure error is small and is usually neglected, reference 9. As Reynolds number increases, the boundary layer thickness decreases and the boundary layer thickness can become very small compared to the orifice diameter; thus, the orifice induced pressure error may not be negligible at the higher Reynolds numbers.

This paper will review the published data that is applicable to model surface finish and orifice induced pressure error. In addition, planned and on-going programs will be described which are needed to extend the available data into areas that are applicable for the high Reynolds number testing range of the NTF.

SYMBOLS

$\bar{c}$	mean aerodynamic chord
c_f	local skin friction coefficient, $\frac{\text{local skin friction}}{q_\infty}$
Δc_p	orifice induced pressure error, $\frac{\text{measured pressure - correct pressure}}{q_\infty}$
d	orifice diameter

h	burr height
k_a	admissible roughness height
M_∞	free stream Mach number
q_∞	free stream dynamic pressure
$R_{\bar{c}}$	Reynolds number based on mean aerodynamic chord $\frac{V_\infty \bar{c}}{\nu_\infty}$
R_d	Reynolds number based on orifice diameter $\frac{V_\infty d}{\nu_\infty}$
V_∞	free stream velocity
δ^*	boundary layer displacement thickness
μ	micro, one millionth
ν_∞	free stream kinematic viscosity

DISCUSSION

Model surface roughness.- In most high Reynolds number transonic tests it is desirable to choose a model surface roughness that will not produce a measurable aerodynamic effect. As noted earlier, some of the potential areas of surface roughness influence are skin friction, shock wave location and boundary layer separation. Of these three areas, this paper will focus on the effect of model surface texture on skin friction. The admissible roughness height is the maximum surface roughness height that will not affect skin friction. The data in figure 1 show the variation of admissible roughness height, k_a, in a zero pressure gradient turbulent boundary layer, with Reynolds number, $R_{\bar{c}}$, where the mean chord, $\bar{c}$, is taken as 0.20m (0.65 ft). This mean chord is representative of a transport model sized for the NTF. Shown on figure 1 for reference are the maximum NTF Reynolds number, the Boeing 747 cruise Reynolds number and the maximum Reynolds number for current tunnels. At a given Reynolds number, any roughness height falling below the admissible roughness curve in figure 1 will produce no skin friction penalty. The shaded band on figure 1 is the range of typically specified and achievable surface finishes for current transonic models. Since the NTF Reynolds number range, based on a chord of 0.20m (0.65 ft), is approximately 0.5×10^5 to 95 to 10^6, the current specified model surface finishes appear to be compatible with a significant part of the NTF Reynolds number range. However, as is noted on figure 1, the admissible roughness curve is for a surfaced with uniformly distributed three-dimensional particles affixed to it, and as the photographs in figure 2 show, the surface of a typical model does not resemble a distributed particle roughness. Thus, an experimental program is planned to determine the equivalent distributed particle roughness for typical NTF model surfaces. In order to carry out this experimental program, a good definition of the topography of a typical NTF model surface is needed.

The instrumentation which is almost universally used to measure model surface roughness in model shops is the stylus profilometer type equipment. However, there are at least two potential problems associated with the stylus profilometer. Figure 3 depicts these two potential problem areas, roughness slope too steep and roughness frequency too high; it should be noted that the stylus radius is typically 2.5 microns (100 μin.). Since there are no published data which verifies that the stylus profilometer accurately determines surface topography data on surfaces typical of NTF models, it is planned that the National Bureau of Standards (NBS) will compare the topography of a surface typical of NTF models as measured by a stylus profilometer and stereo scanning electron microscope. In addition, the stylus profilometer has great difficulty measuring surface finishes on curved surfaces similar to the leading edge region of wings. The leading edge region of the wing is the region, of course, where the boundary layer is thinnest and thus is the region where the local skin friction is most sensitive to surface roughness. Thus, it is highly desirable to have the capability of measuring surface finish over the leading edge. Towards this end the NBS will develop a light scattering system to measure the surface finish accurately on surfaces with high curvature.

Orifice induced pressure error.- When the static pressure in a flow field is measured by a pressure orifice, the streamline curvature can change in the vicinity of the orifice and eddies can be set up inside the orifice resulting in the static pressure measurement being higher than the true value, references 5 through 9. If the boundary layer thickness is large compared to the orifice diameter, the orifice induced pressure error is small and usually neglected. However, as the Reynolds number increases and the boundary layer becomes thinner, the boundary layer thickness can become small compared to the orifice diameter. Under these conditions the orifice induced pressure error may not be negligible. An additional orifice error, that may be sizable in magnitude, can result from orifice imperfections. Although there are several types of orifice imperfection, experimental data (reference 6) exists only for a burr around the orifice. A burr can produce flow separation in the orifice causing additional streamline deflection. Some other types of hole imperfection which can produce pressure error are out-of-round orifices, particles in the orifice and the longitudinal axis of the orifice not normal to the model surface to mention a few.

Figure 4 presents a compilation of experimental results for orifice induced pressure error of "perfect" (absence of imperfection) orifices from references 5 through 7 (only the subsonic data from reference 5 is included in figure 4). It is shown in reference 6 from local dynamical similarity considerations, that

$$\frac{\Delta c_p}{c_f} = f\left(R_d\sqrt{\frac{c_f}{2}}\right);$$

therefore, orifice induced pressure error is generally presented as $\Delta c_p/c_f$ versus $R_d\sqrt{\frac{c_f}{2}}$. The largest values of d/δ^* (orifice diameter/boundary layer thickness) for which test results are shown in figure 4 is 4.0. Using the data of reference 7, shown in figure 4, the variation of pressure error, Δc_p, with Reynolds number, $R_{\bar{c}}$, for three orifice diameters, 0.51 mm (0.02 in), 0.25 mm (0.01 in) and 0.13 mm (0.005 in) are shown in figure 5 where the local skin friction coefficient is taken as 0.0022 and the mean chord, $\bar{c}$, is taken as 0.20 m (0.65 ft). For reference the maximum NTF Reynolds number, Boeing 747 cruise Reynolds number and the maximum Reynolds number available in current tunnels are shown on figure 5. From the data in figure 5, it may appear that a 0.13 mm (0.005 in) diameter orifice is satisfactory for the complete range of NTF Reynolds numbers since the maximum error is only 0.008; however, all the data in figure 5 are for $d/\delta^* < 4.0$, and since d/δ^* for the high Reynolds number conditions can be of the order of 100, erroneous conclusions may be drawn regarding the level of the orifice induced pressure error if only this data is applied. Further, just extrapolating the curves for the 0.51 mm (0.02 in) and 0.25 mm (0.01 in) diameter orifices to the high Reynolds number region can lead to erroneous conclusions. Therefore, a test program is underway to extend the data shown in figure 5 to higher d/δ^* values and higher Reynolds numbers. Figure 6 shows a picture of the flat plate model to be used in this test program; the interchangeable orifices have diameters of 3.30 mm (0.13 in), 6.60 mm (0.26 in) and 13.21 mm (0.52 in). The reference orifice diameter is 0.51 mm (0.02 in). Only one of the interchangeable orifices will be in the plate at a time and the untested orifices will be replaced with plugs. Since this plate will be tested in the Langley 7- x 10-foot wind tunnel at low Reynolds numbers, the orifices were scaled up in size so that the proper d/δ^* could be attained; the complete orifice including plumbing was scaled up for these tests. Local skin friction and boundary layer thickness (δ^*) will be obtained from a boundary layer survey. Figure 7 shows the envelope of d/δ^* variation with Reynolds number, $R_{\bar{c}}$, for a 0.51 mm (0.02 in) diameter orifice attainable with the present hardware. Although the maximum d/δ^* encountered in the leading edge region of an NTF wing may be in excess of 100, these data will extend the data base far enough to allow judgement on whether the data may be extrapolated safely to the desired d/δ^* values. The d/δ^* range covered in this test will be adequate to directly assess the orifice induced pressure error for a large majority of the orifices on NTF models.

The hole imperfection data of reference 6 only extend to values of $R_d\sqrt{\frac{c_f}{2}}$ of 300. Burr heights of 1/42 the orifice diameter can increase the hole error by a factor of approximately five, figure 8, thus, it is desirable to fabricate orifices that have the hole imperfections minimized. Reference 9 outlines a routine for fabricating orifices with the final step calling for close visual and stylus profilometer inspection of each orifice.

CONCLUDING REMARKS

The requirement for high quality NTF test data and the high Reynolds number capability of the NTF have caused NASA to re-examine the areas of model fabrication tolerances, model surface finish and orifice induced pressure error. The results of this re-examination and planned research programs to extend the data base are summarized below.

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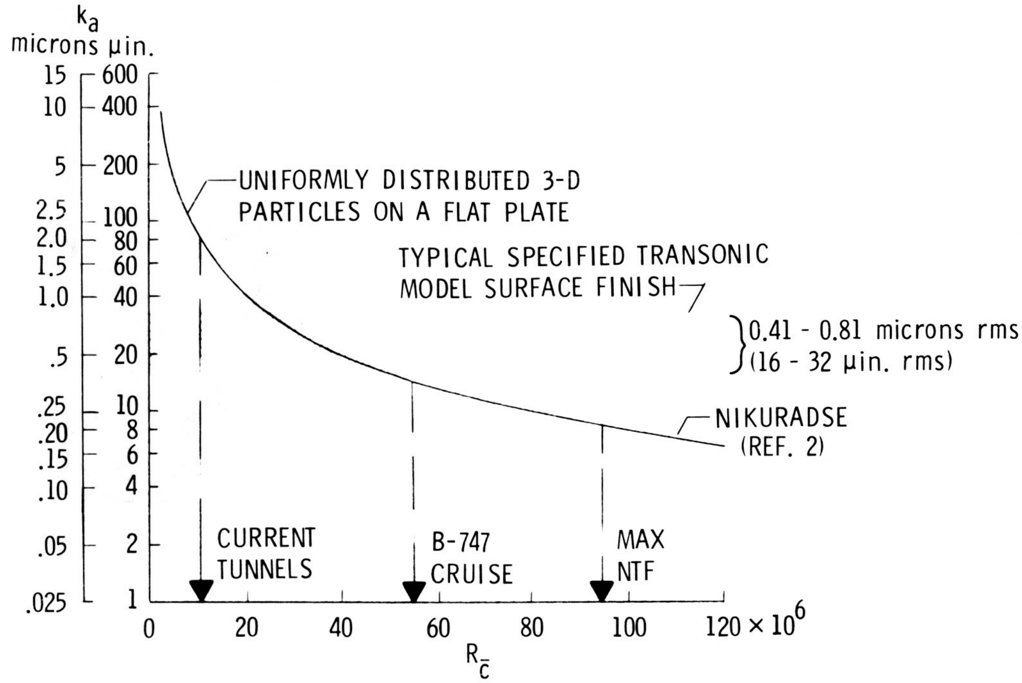

Figure 1.- Admissible roughness (k_a) for typical NTF sized models, $\bar{c}$ = 0.20 m (0.65 ft).

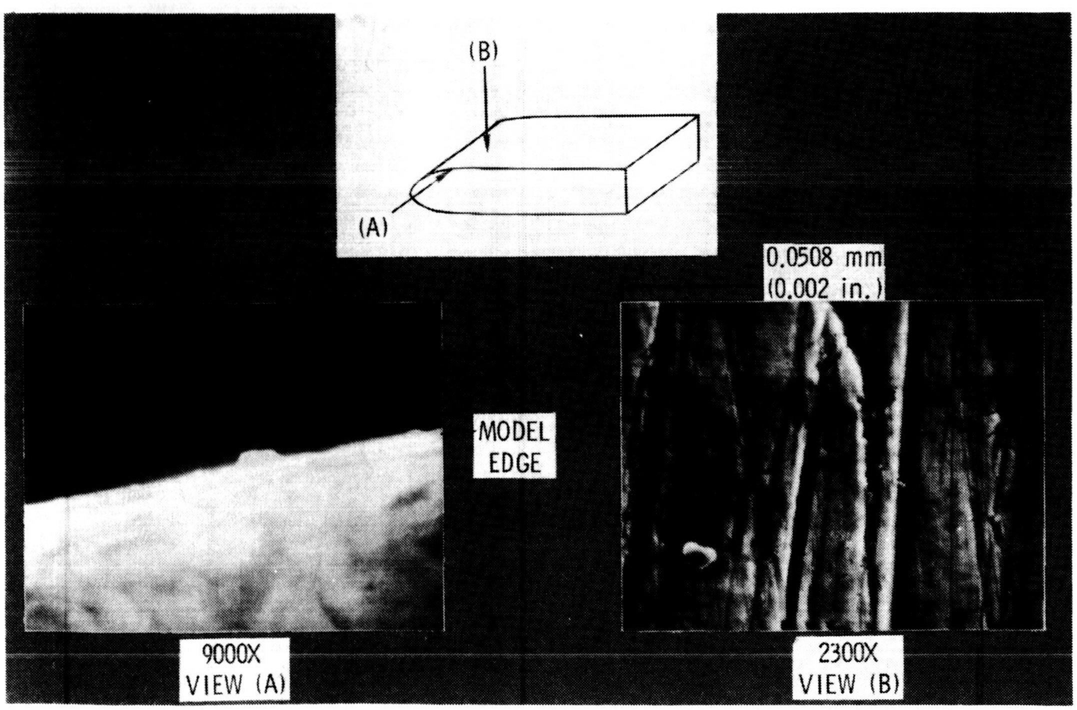

Figure 2.- Electron micrographs of typical NTF model surface. Model surface finish, 0.2-0.3 microns (8-12 μ in.) rms (stylus measured).

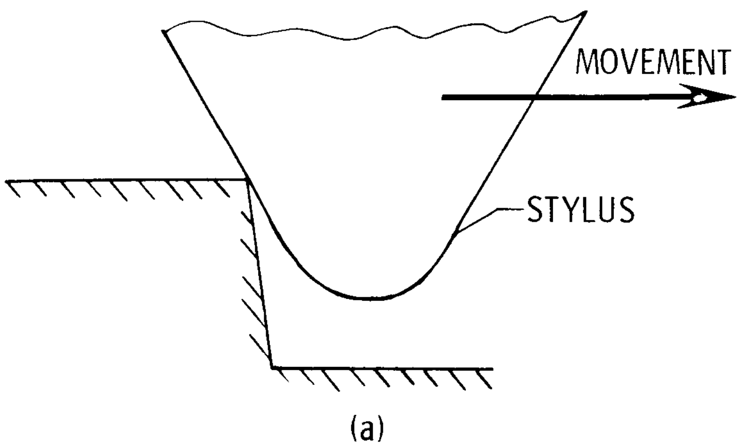

Figure 3.- Potential stylus profilometer problem areas.

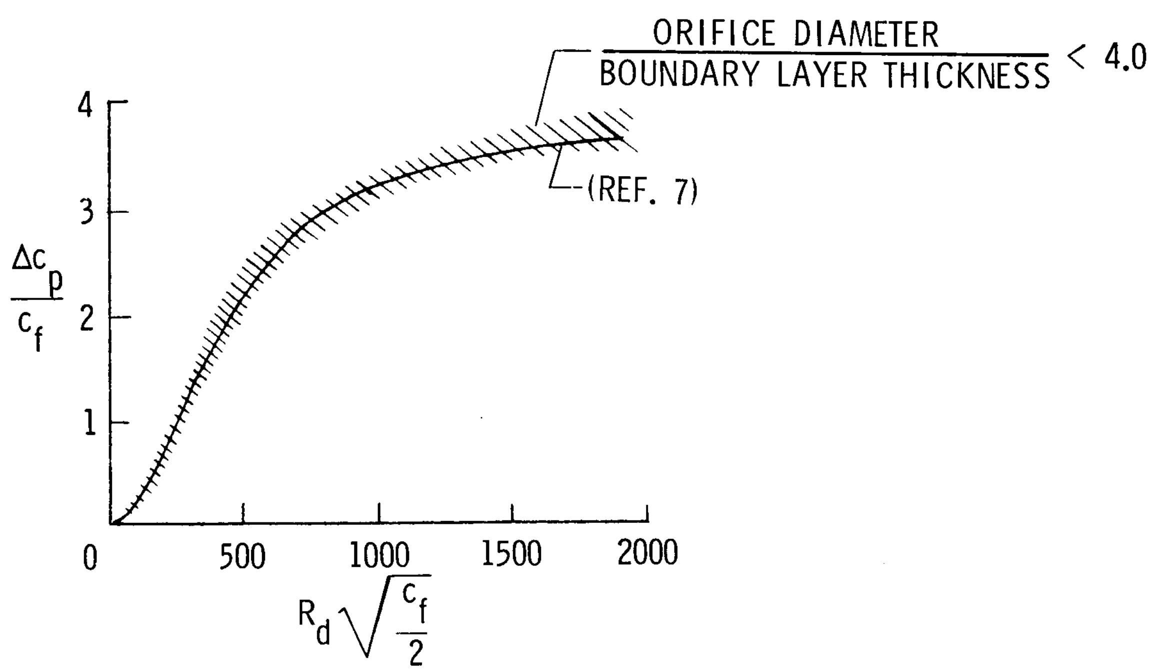

Figure 4.- Compilation of test results for orifice induced pressure error.

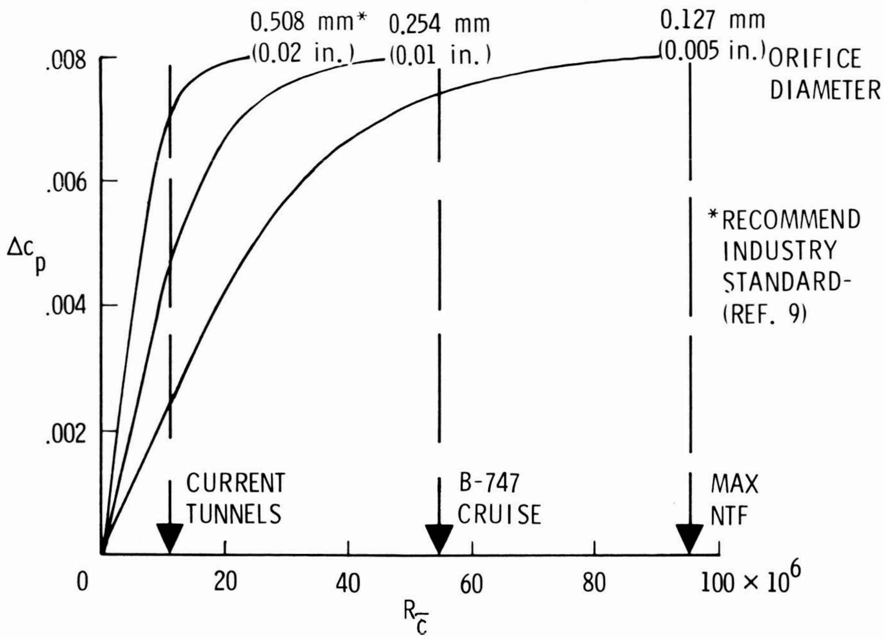

Figure 5.- Orifice induced pressure error. $c_f = 0.0022$; $\bar{c} = 0.20$ m (0.65 ft).

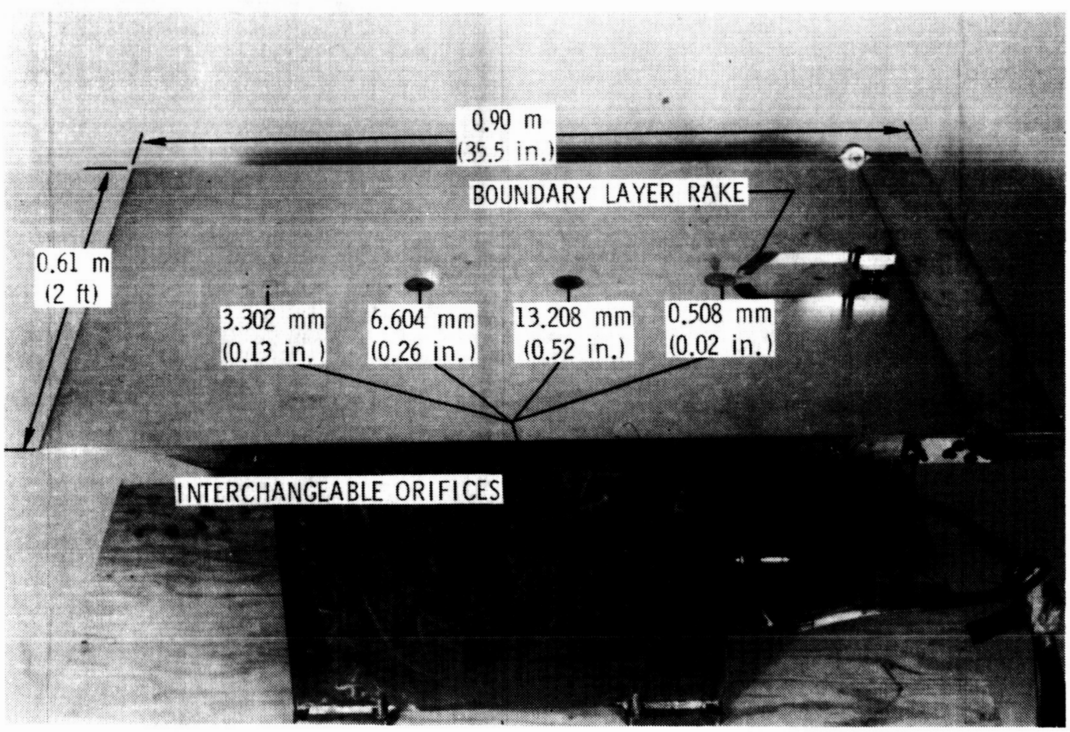

Figure 6.- Model setup for orifice induced pressure error studies.

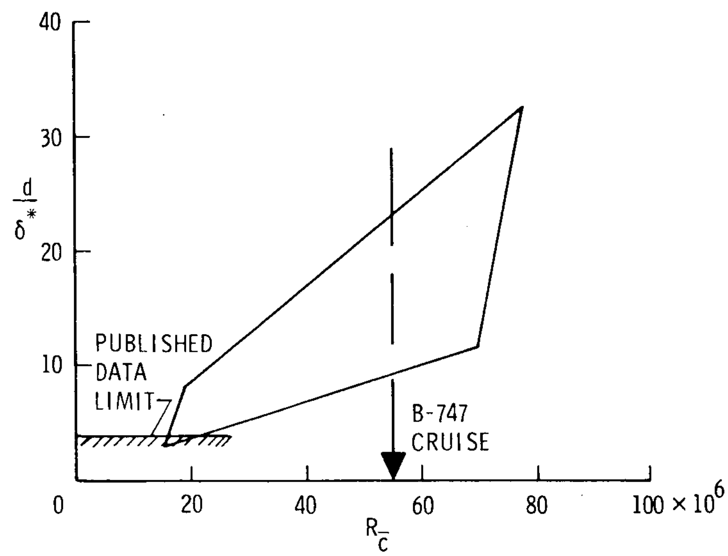

Figure 7.- Envelope of current pressure error experiment, c_f = 0.0022, M_∞ = 0.85, $\bar{c}$ = 0.20 m (0.65 ft), d = 0.508 mm (0.020 in.).

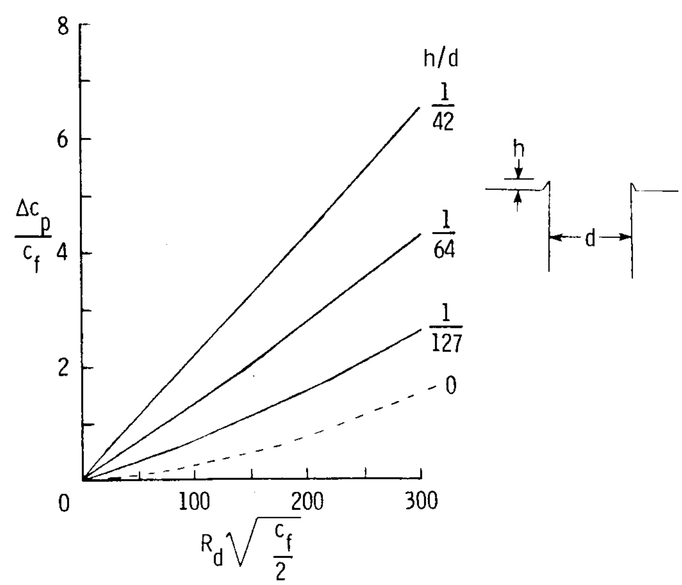

Figure 8.- Effect of hole imperfection on orifice induced pressure error (ref. 6).