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NASA TM X-72013

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NASA TM X-72013

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LOW BOOM EQUIVALENT BODY
AT MACH 4

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(NASA-TM-X-72013) WIND TUNNEL TEST OF
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(NASA) 16 p HC $3.00 CSCL 01A

N74-33438

Unclas
G3/01 50418

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TM X-72013		
4. Title and Subtitle WIND TUNNEL TEST OF LOW BOOM EQUIVALENT BODY AT MACH 4		5. Report Date September 1974 6. Performing Organization Code 37.710
7. Author(s) Floyd G. Howard and Odell A. Morris		8. Performing Organization Report No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		13. Type of Report and Period Covered NASA Technical Memorandum 14. Sponsoring Agency Code

15. Supplementary Notes
Special technical information release, not planned for formal NASA publication.

16. Abstract

A body of revolution, representing the equivalent area distribution of a low boom aircraft design cruising at 24,384 meters at a Mach number of 4, has been tested to determine whether its theoretical sonic boom characteristics could be experimentally verified. Results indicate that the essential features of the ground signature are well predicted.

17. Key Words (Suggested by Author(s)) (STAR category underlined)	18. Distribution Statement
Aircraft Sonic Boom Measured Wind-Tunnel Pressure Signatures Equivalent Body of Revolution Ground Signatures	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	14	$3.00

*Available from { The National Technical Information Service, Springfield, Virginia 22151
STIF/NASA Scientific and Technical Information Facility, P.O. Box 33, College Park, MD 20740

WIND TUNNEL TEST OF LOW BOOM EQUIVALENT BODY AT MACH 4

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SUMMARY

A wind tunnel investigation of a body of revolution has been conducted to determine whether the midfield low sonic boom characteristics at ground level, designed into the body through its equivalent area distribution by sonic boom theory (Whitham, Hayes, refs. 1 and 2), could be experimentally verified at Mach number 4. The results indicate that the essential features (signature shape, shock strength, and impulse) of the measured signature extrapolated to ground level are well predicted. Although not conclusive, a secondary finding suggests that the use of normal cross-sectional areas, rather than the more complex projection of Mach plane-body area intercepts, for inversely designing a fuselage to meet equivalent area due to volume requirements may be sufficiently accurate for preliminary design of low boom aircraft.

INTRODUCTION

The sonic boom theory developed by Whitham (ref. 1) and modified by the supersonic area rule concepts of Hayes (ref. 2) and Lomax (ref. 3) relates the aircraft to its sonic boom signature through the aircraft's equivalent area distribution. In this context the aircraft is replaced by an equivalent body of revolution that represents the aircraft's distribution of volume and lift along its length. During the design of aircraft to produce low sonic boom characteristics, then, the equivalent area distribution that produces these characteristics becomes a fundamental design requirement that the aircraft must satisfy.

Studies of these low boom aircraft have resulted in the definition of a number of equivalent area distributions that theoretically produce, at ground level, midfield signature shapes and shock strengths less than 48 N/m^2 (approximately 1 psf) for Mach numbers up to 4. At lower Mach numbers the theory gives reasonably good predictions of the experimental sonic boom signatures from equivalent bodies of revolution (ref. 4). At higher Mach numbers, however, the validity of the theory is questionable, especially for low boom area distributions, because higher order terms than those considered in the theory may become important. Wind tunnel tests, reported herein, were therefore made on a low boom equivalent body of revolution to allow a comparison of its theoretical and measured sonic boom characteristics at a Mach number of 4.

SYMBOLS

ALT	altitude
h	distance from body centerline
L	equivalent body length
M	free stream Mach number
P_{∞}	free stream static pressure
ΔP	pressure differential due to flow field of model
R	body radius
R_{MAX}	maximum body radius
RF	reflection factor
S	equivalent area
S_{MAX}	maximum equivalent area
X	longitudinal distance
μ	arcsin $\frac{1}{M}$

BACKGROUND

The area distribution that provided the basis for this study is shown by the dashed line in figure 1. This low sonic boom equivalent area distribution determined by Dr. A. Ferri under NASA Grant NGL 33-016-191 is representative of a Mach 4 transport weighing 211,812.5 kilograms (466,967 pounds) at a cruise altitude of 24,384 meters (80,000 feet). For sonic boom calculations, according to theory, this area distribution can be represented by a body of revolution having a corresponding distribution of equivalent areas composed of frontal projections of the body areas intercepted by Mach cutting planes. As a first approximation to this body, the contour shown in figure 2 was defined by simply using the normal cross sectional area distribution, $R(X) = \sqrt{S(X)/\pi}$, as the equivalent area. The correct equivalent area distribution (from Mach plane cuts) for this shape was then determined by the method described in reference 5. The resulting area distribution (solid line, figure 1) agreed very well with the desired distribution except near the maximum area where the area slope discontinuity was eliminated.

The sonic boom signatures for both of these area distributions were determined by applying the numerical method of Carlson (ref. 6) to obtain, at two body lengths from the body axis, pressure signatures which were then extrapolated through a standard atmosphere to ground level by the method of Thomas (ref. 7). A ground reflection factor of 1.9 was used. The resulting signatures (fig. 3) differed somewhat in detail, but gave about the same value of $\Delta P \approx 43$ N/m^2 for the maximum positive overpressure with the Mach cut area distribution giving the lower ΔP for the rear shock because of the area smoothing already noted. Since the body shape of figure 2 gave a sufficiently accurate approximation to the desired pressure signature, no further iterations on body shape were made and this contour formed the basis for the test model.

MODEL, APPARATUS, TESTS

The test model (figure 4) consists of a forebody, which corresponds to 1/645-scale reduction of the contour of figure 2 and a cylindrical afterbody having a diameter equal to the maximum forebody diameter. Model dimensions were within 0.0076 cm of those specified.

A sketch of the wind tunnel apparatus is shown in figure 5. Both the model and the pressure measuring probes were mounted on support systems which provided for remote control adjustments of their longitudinal positions. The pressure measuring probes were slender cones (4° total angle) with two 0.0889 cm diameter static-pressure orifices leading to a common chamber. Orifices were circumferentially located 180° apart in a horizontal plane. Two gages having load limits of 7.182 N/m^2 (0.15 psi) and 2.394 N/m^2 (0.05 psi) were used to measure the pressures simultaneously. The agreement between the data from both gages was excellent throughout the tests.

Tests were made in the Langley Unitary Plan wind tunnel at a Mach number of 4 with a stagnation temperature of 353° K, and a stagnation pressure of 281.5×10^3 N/m^2. Pressure signatures were measured at 15.24 and 30.48 cm (h/L values of .645 and 1.29) from the body axis in the vertical plane containing the probe and model axis.

RESULTS AND DISCUSSION

The experimental pressure signatures obtained at both h/L values are compared with theoretical signatures in figure 6. The signatures are located with respect to each other by equating X values for $\Delta P = 0$ on the expansion portion of the signature. The experimental signatures do not show a step rise in pressure across shocks. Instead, a gradual pressure rise occurs followed by a rounding at the peaks. This behavior is primarily due to vibration of the model and measuring probe and is discussed in more detail in reference 6.

The theoretical signature (based on Mach cutting plane equivalent areas using method of reference 6) shows many low magnitude internal shocks. Many of these are not real but result from unavoidable inaccuracies in equivalent area developments. (For example, in figure 7 the pressure signature calculated from an analytically defined area distribution $S(X) = S_{MAX} (X/L)^{5/6}$ does not contain the many internal shocks displayed by the signature calculated from a corresponding area distribution read from the hand-faired area curve.) Taking this into account, the agreement between experiment and theory is reasonably good. By converting to full-scale dimensions and applying the method of reference 7, the ground signatures represented by these experimental data were obtained. These signatures are shown in figure 8 along with the theoretical predictions. The data points extrapolated from h/L values of 0.645 and 1.29 are in excellent agreement and the theory gives a very good prediction of the positive portion of the signature (indicating a good impulse prediction) and both front and rear shock strengths.

It seems reasonable to conclude then, that an equivalent area distribution composed only of volume terms and designed by the theory of references 1 and 2, to give midfield low sonic boom characteristics at ground level, will in fact produce an excellent approximation to these characteristics for Mach numbers as high as 4. Until additional investigations of lifting configurations are made, this conclusion should not be extended to an equivalent area distribution that is composed of both volume and lift terms.

As an additional point of interest, the ground signature given by theory using normal plane equivalent area is also included in figure 8; and although agreement with the experimental signatures is not as close as that using Mach cutting planes, a reasonable prediction is still provided especially with regard to the front shock strength. Because of its simplicity of application, therefore, the use of normal plane equivalent areas, rather than Mach plane areas, may be sufficiently accurate for preliminary design of the fuselage for low boom aircraft. This approximation should improve at lower design Mach numbers.

CONCLUDING REMARKS

A wind tunnel investigation of a body of revolution has been conducted to determine whether the midfield low sonic boom characteristics at ground level, designed into the body through its equivalent area distribution by sonic boom theory (Whitham, Hayes), could be experimentally verified at Mach number 4. The results indicate that the essential features (signature shape, shock strength, and impulse) of the measured signature extrapolated to ground level are well predicted. Although not conclusive, a secondary finding suggests that the use of normal cross-sectional areas, rather than the more complex projection of Mach plane-body area intercepts, for inversely designing a fuselage to meet equivalent area due to volume requirements may be sufficiently accurate for preliminary design of low boom aircraft.

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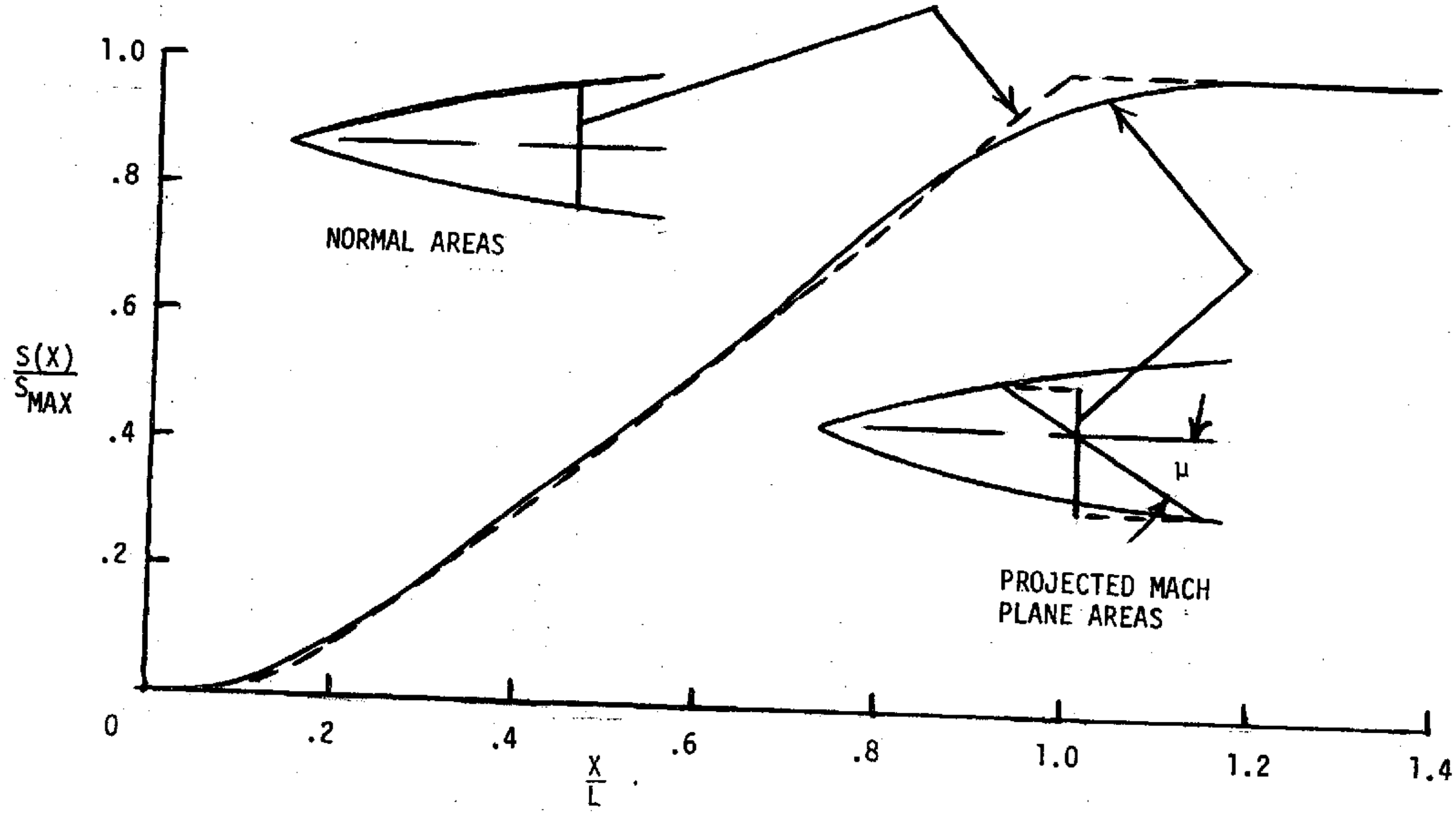


FIGURE 1.- COMPARISON OF EQUIVALENT AREAS.
$M = 4$; $S_{MAX} = 128.58\ m^2$; $L = 152.4$ m.

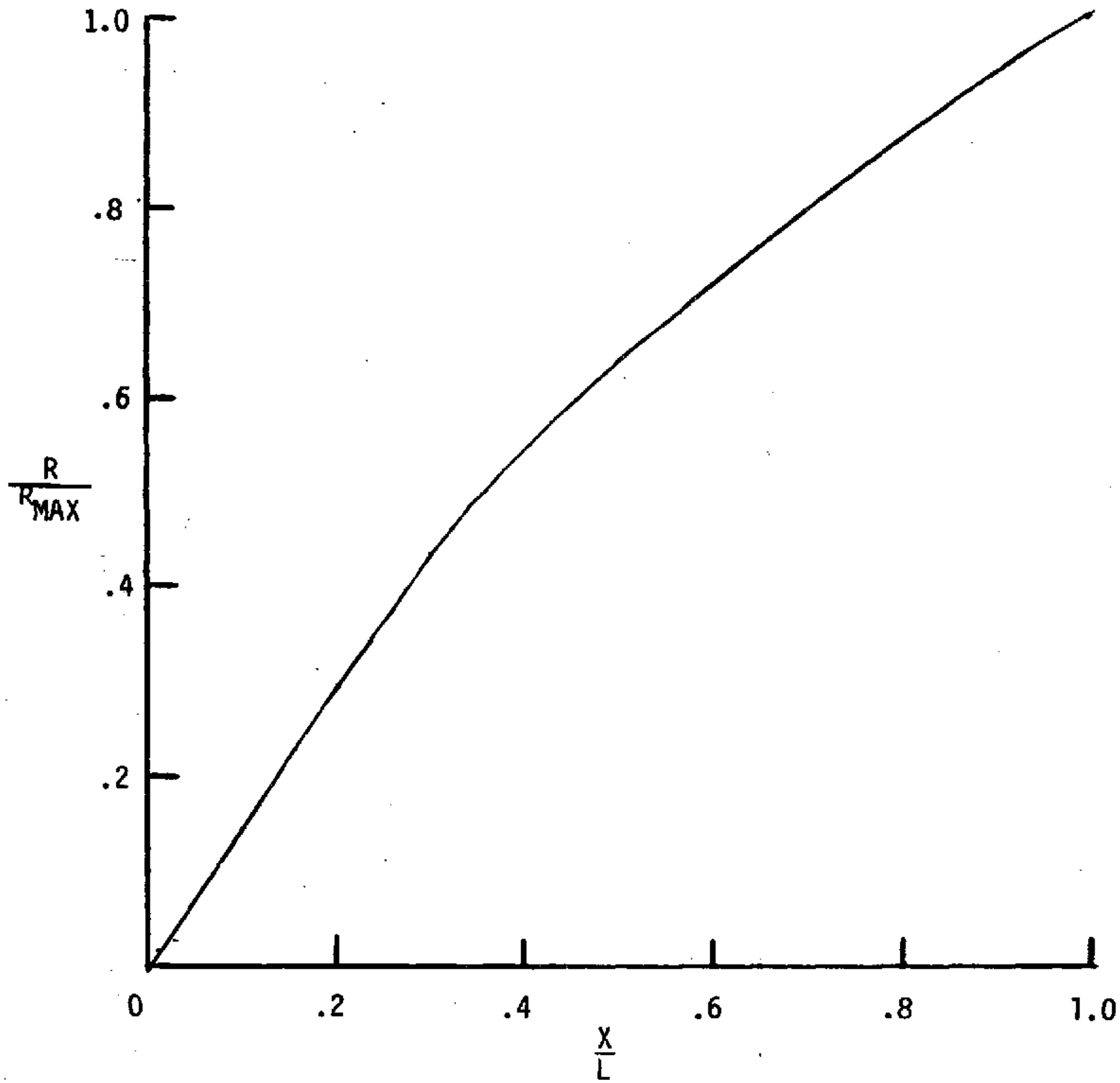


FIGURE 2.- EQUIVALENT BODY CONTOUR.
$L = 152.4$ m; $R_{MAX} = 6.388$ m.

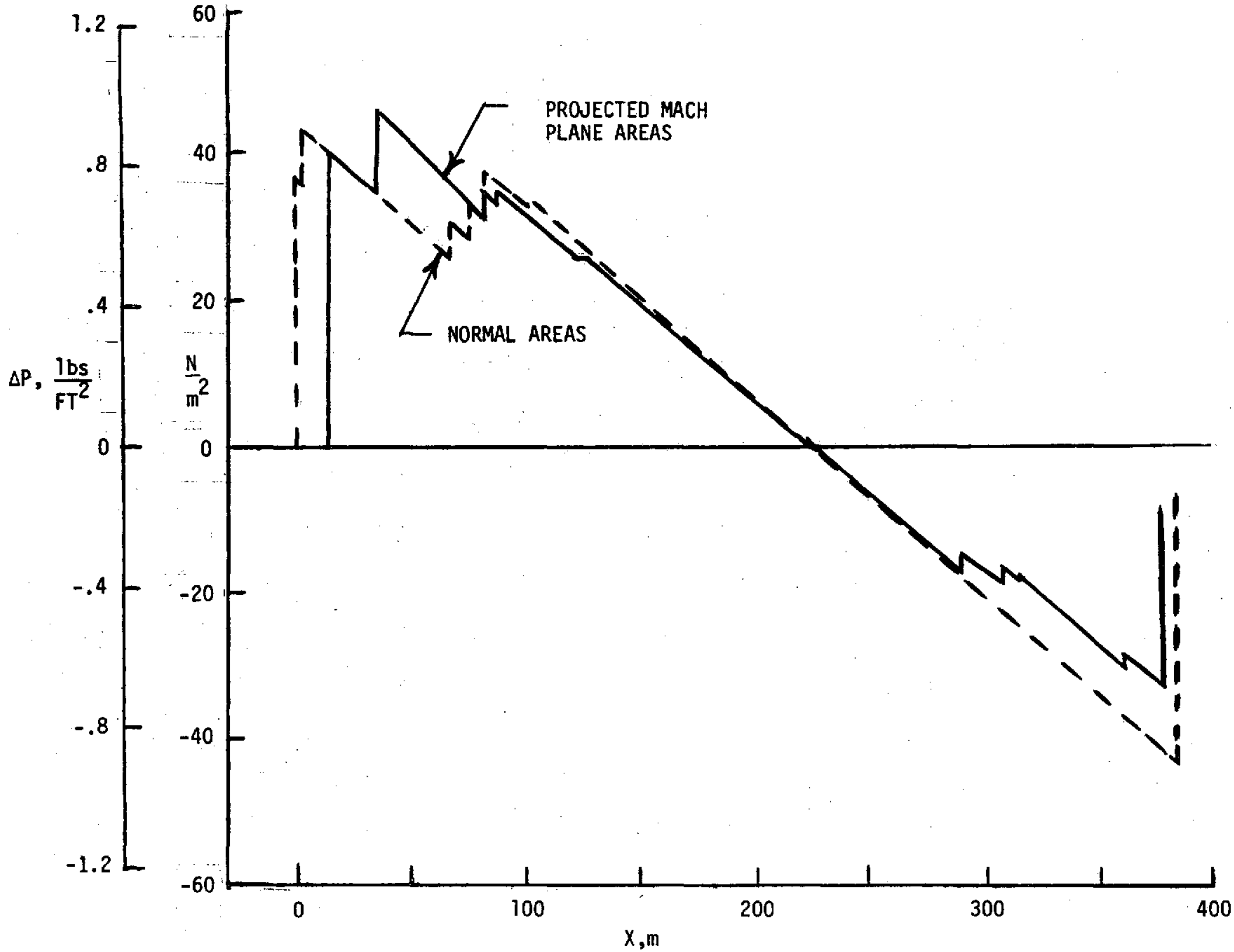
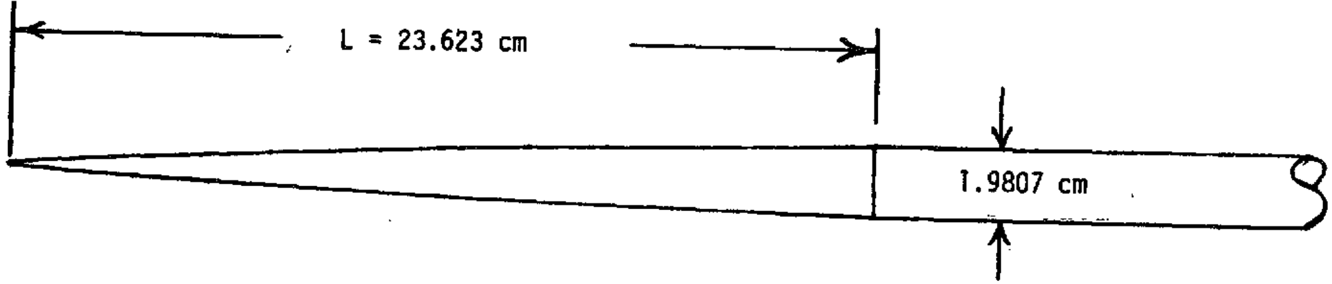


FIGURE 3.- GROUND SIGNATURE.
ALT. = 24384 m; RF = 1.9



X/L	R/L	X/L	R/L	X/L	R/L
0.0	.000	.40	.02245	.80	.03635
.02	.001596	.42	.02323	.82	.03694
.04	.002764	.44	.02404	.84	.03756
.06	.003909	.46	.02493	.86	.03818
.08	.005046	.48	.02578	.88	.03883
.10	.006180	.50	.02665	.90	.03944
.12	.007399	.52	.02743	.92	.04005
.14	.008740	.54	.02814	.94	.04065
.16	.009707	.56	.02883	.96	.04118
.18	.01117	.58	.02949	.98	.04163
.20	.01226	.60	.03015	1.00	.04192
.22	.01340	.62	.03086	1.2	
.24	.01449	.64	.03151	1.4	
.26	.01568	.66	.03215	1.60	
.28	.01693	.68	.03276	1.80	
.30	.01809	.70	.03334	1.93	
.32	.01915	.72	.03368		
.34	.02012	.74	.03458		
.36	.02099	.76	.03514		
.38	.02176	.78	.03574		

FIGURE 4.- TEST MODEL.

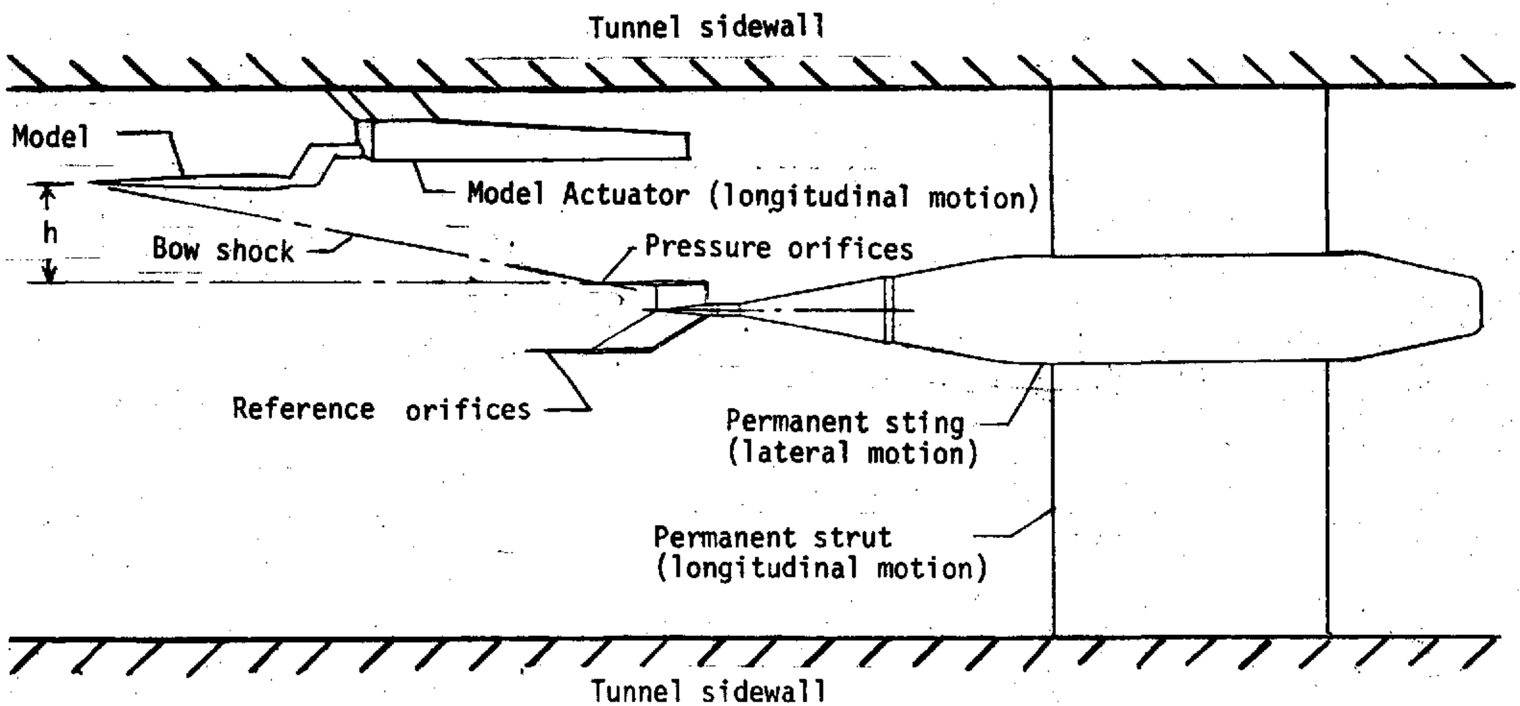
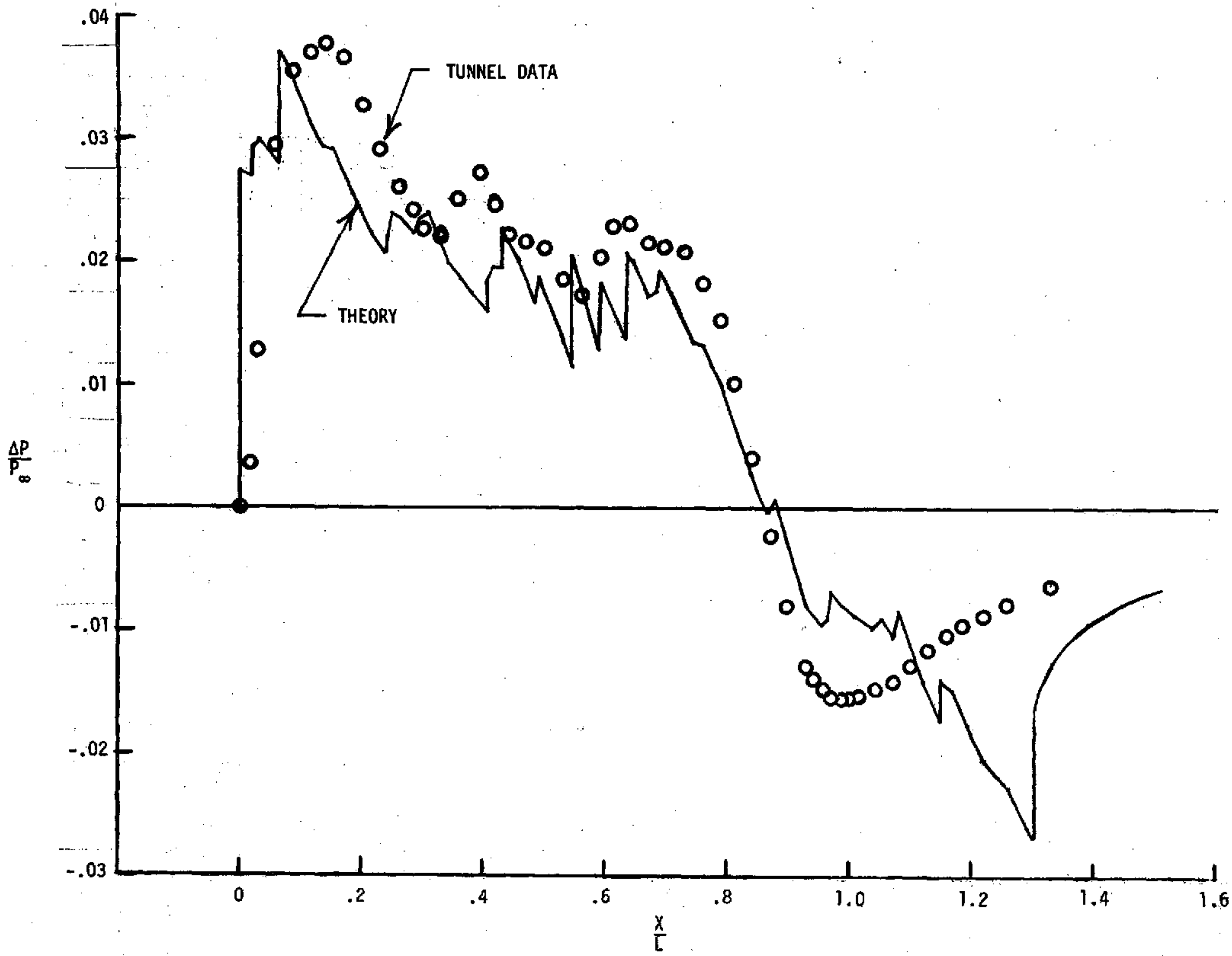
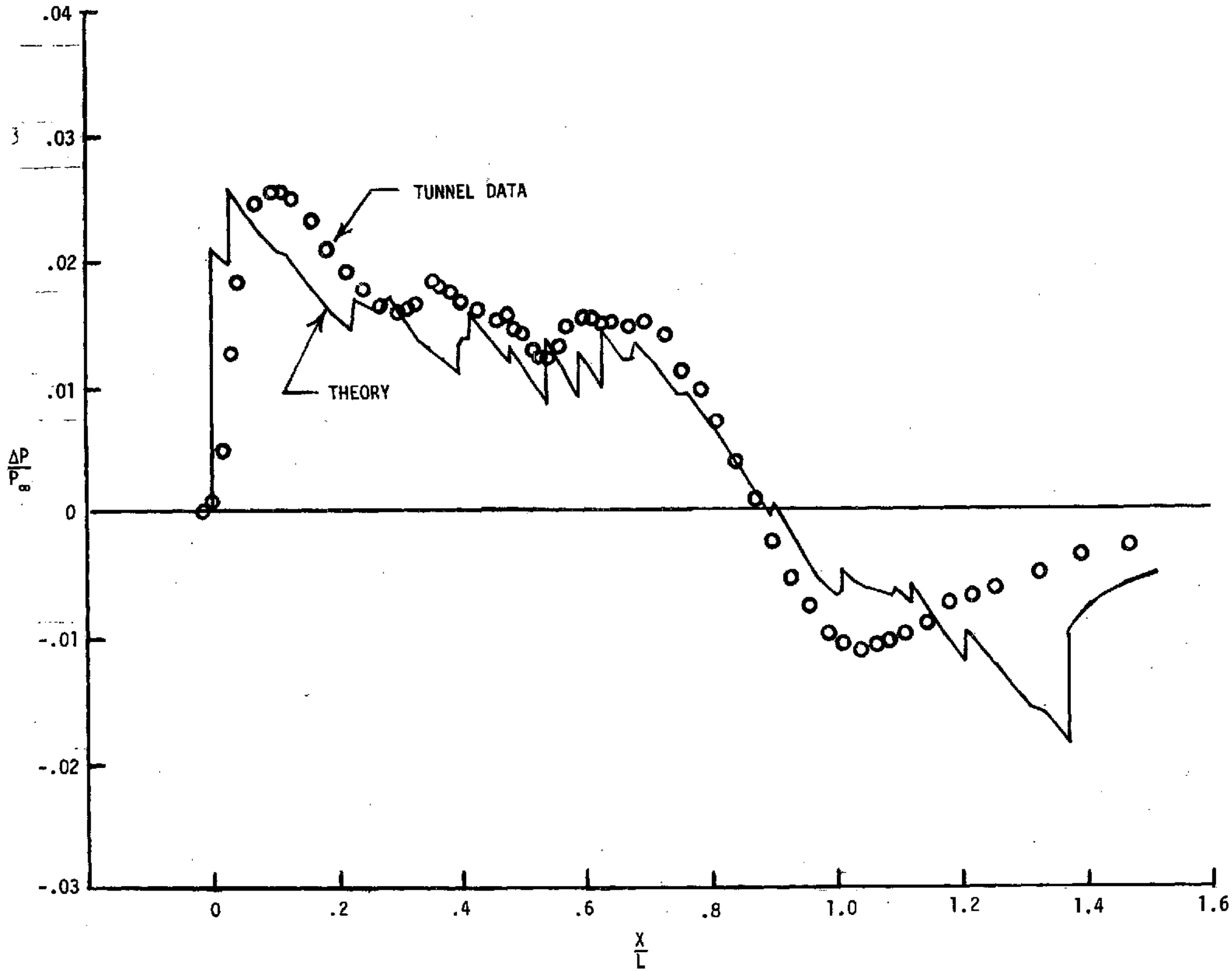


FIGURE 5.- PLAN VIEW SKETCH OF WIND TUNNEL APPARATUS.



(a) h/L = 0.645.

FIGURE 6.- MEASURED AND THEORETICAL SIGNATURE.
L = 23.623 cm.



(b) h/L = 1.29.

FIGURE 6.- CONCLUDED.

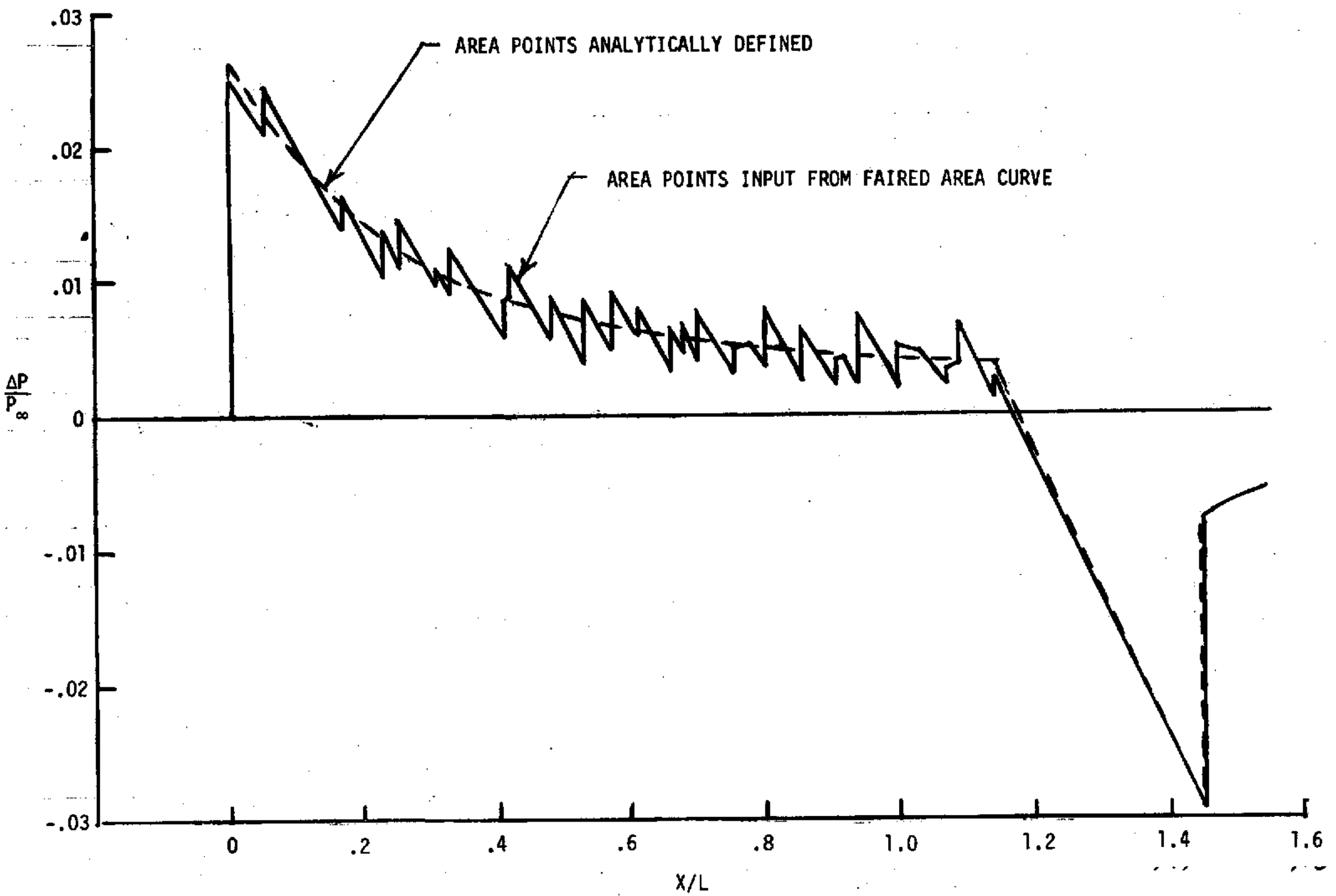


FIGURE 7.- EFFECT OF EQUIVALENT AREA ACCURACY OF PRESSURE SIGNATURE.
M = 4; h/L = 1.29.

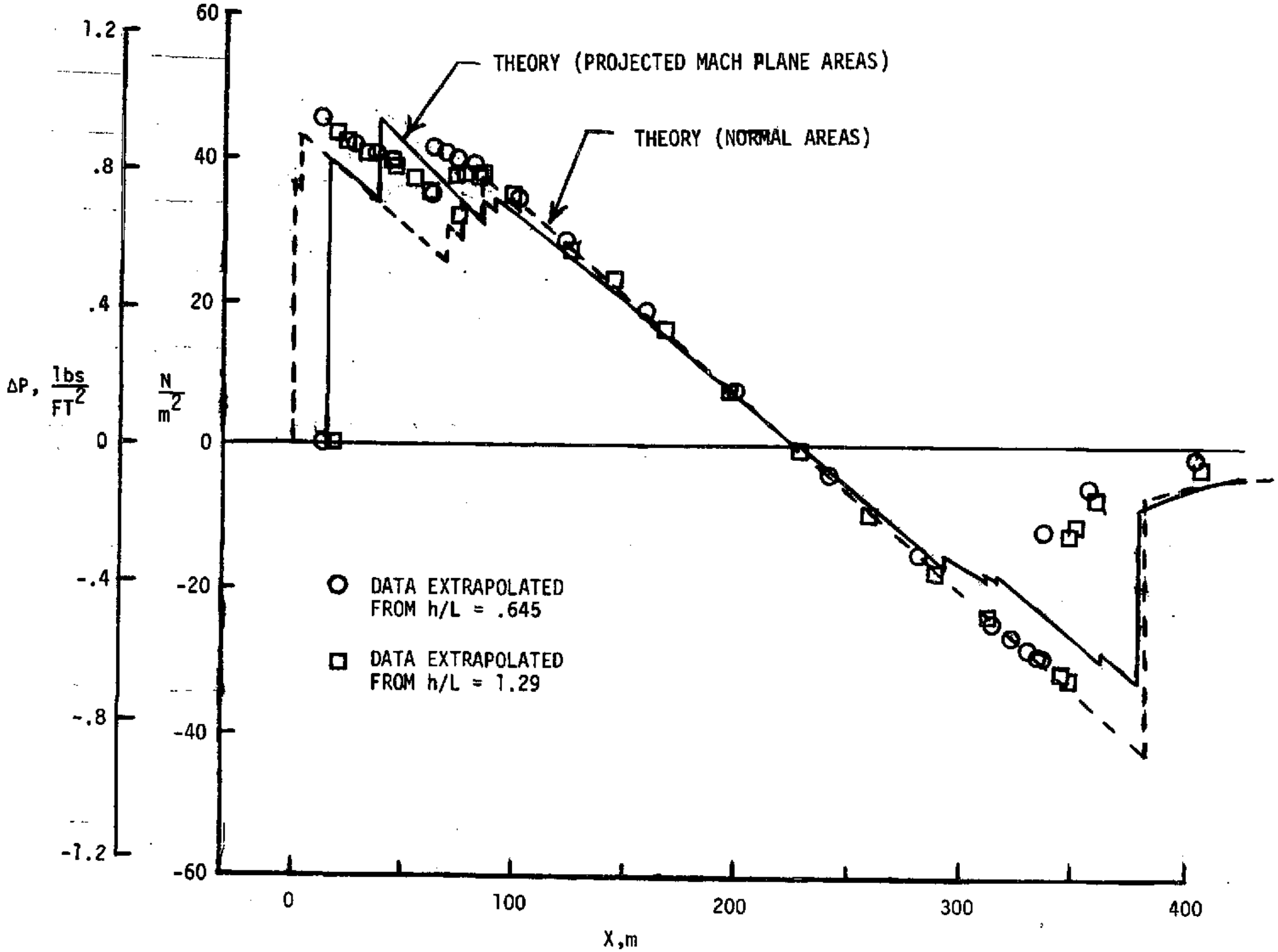


FIGURE 8.- COMPARISON OF GROUND SIGNATURES.
ALT. = 24383 m; RF = 1.9.