A WALL INTERFERENCE ASSESSMENT/CORRECTION SYSTEM

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Title: A Wall Interference Assessment/Correction System

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Technical Objectives

A Wall Signature method, the Hackett method, has been selected to be adapted for the 12-ft Wind Tunnel WIAC system in the present phase. This method uses limited measurements of the static pressure at the wall, in conjunction with the solid wall boundary condition, to determine the strength and distribution of singularities representing the test article. The singularities are used in turn for estimating wall interference at the model location. The Wall Signature method will have to be formulated for application to the unique geometry of the 12-ft Tunnel. The development and implementation of a working prototype will be completed, delivered and documented with a software manual.

The WIAC code will be validated by conducting numerically simulated experiments rather actual wind tunnel experiments. It is an effective, but efficient way to validate the implemented code. The simulations will be used to generate both free-air and confined wind-tunnel flow fields for each of the test articles over a range of test configurations. Specifically, the pressure signature at the test section wall will be computed for the tunnel case to provide the simulated "measured" data. These data will serve as the input for the WIAC method--Wall Signature method. The performance of the WIAC method then may be evaluated by comparing the corrected parameters with those for the free-air simulation. Each set of wind tunnel/test article numerical simulations provides data to validate the WIAC method.

Status of Progress

A. Numerical Simulation of Tunnel Flow

A numerical wind tunnel test simulation is initiated to validate the WIAC methods developed in the project, specifically to the Wall Signature Method--Modified Hackett's method in the current phase. A low-order potential-flow panel method PMARC(Ref.1) with a aerodynamic plotting program PMAPP(Ref.2) has been selected to simulate the wind tunnel and test article geometries. This simulation should provide two sets of data: (i) a reference solution of the interference problem; and (ii) the surface pressure distribution on selected wall locations.

The flow field of a test article installed in the 12-ft Pressure Wind Tunnel has been simulated using the panel method code PMARC. Pressure coefficients on a given test article and wind tunnel wall panels were computed by this panel code. The geometry of the selected test article and the location of corresponding surface panel elements are depicted in Fig. A-1. The test article is installed in the NASA ARC 12ft Pressure Wind Tunnel as shown in Fig. A-2 which depicts the location of the wind tunnel wall panels relative to the location of the test article.

For the free air case, the pressure coefficient distribution is calculated on three selected cuts of the test article geometry. The location of the cuts is given in Fig. A-3. The pressure distribution for the wind tunnel case on the same three cuts is calculated as well. Corresponding free-air and wind tunnel solutions can be compared in Figs. A-4, A-5 and A-6. Surface velocities are slightly higher in the case of the wind tunnel solution as expected. The difference between free-air and wind tunnel solution of the pressure distribution on corresponding surface panel locations can be used as the reference solution of the interference problem.

The pressure coefficient distributions on five selected rows on the wind tunnel wall are also calculated. The location of the rows on the wind tunnel wall and corresponding pressure coefficient distributions are depicted in Figs. A-7a, b, c, d, e.
These calculated wall pressure coefficient distributions can be used as inputs into the Wall Signature method to obtain interference corrections.

All numerical computation were carried out on a research VAX computer at NASA/ARC Aerodynamics division.

B. Wall Signature Method Implementation

The Wall Signature method (Ref. 3) is considered to calculate a blockage and lifting(angle of attack) correction in the NASA/ARC 12-ft Pressure Wind Tunnel. In the present reported period, the blockage correction has been developed and implemented for a rectangular tunnel (Ref. 4) as well as 12-ft Pressure Tunnel (Ref. 5). Figure B-1 shows basic elements of a Wall Signature method. In the first part of the development, blockage corrections were investigated in detail. A modified form of the Wall Signature method was developed which describes an equivalent body geometry in terms of surface panel elements. It was shown that existing three-dimensional panel codes like PMARC can be combined effectively with the modified form of the Wall Signature method. The results of this study are reported in an AIAA paper No.92-3925 (Ref. 4) which was presented at the AIAA ground Testing Conference, July 1992. The preprint of this paper is enclosed in the appendix for reference.

In general, the modified Wall Signature method relates wall pressure measurements similar to the typical measurements depicted in Fig. B-2 to an equivalent body shown in Fig. B-3a,b,c. The equivalent body is then used instead of the actual test article to determine blockage corrections.

It was demonstrated that the modified Wall Signature method can successfully be applied to a three-dimensional wind tunnel with rectangular cross-section (Ref.4) and to the NASA/ARC 12ft Pressure Wind Tunnel (Ref.5). Figures B-4a, b and c show the geometry of a selected test article in the NASA/ARC 12-ft Pressure Wind Tunnel and the corresponding description in terms of surface panel elements.

The numerical example described in Fig.B-4a is used to demonstrate the practical application of the modified Wall Signature method. The signature analysis procedure was applied to a simulated wall pressure signature and the representation of the wall pressure measurement in terms of symmetric and antisymmetric part is given in Fig.B-5. The wall pressure measurement is related to the equivalent body description using precalculated influence functions depicted in Figs. B-6a, b, and c. Equivalent representations of test article and wake are shown in Figs. B-7a, b. These equivalent representations are superimposed to obtain the equivalent body geometry depicted in Fig. B-7c. The equivalent body is used to calculate the wall pressure signature. This wall pressure signature compares reasonably with the original signal as can be seen in Fig. B-8a. Figure B-8b shows excellent agreement between cross-section of test article and equivalent body .

Surface pressure coefficient corrections calculated on a selected test article surface location are compared favorably with the reference solution in Fig. B-9a. Finally, corrected surface pressures are compared with the free-air solution in Fig. B-9b. Corrected and free-air pressure distribution show reasonable agreement to verify the modified Wall Signature method.

An improvement of the signature analysis procedure has been developed as well. It is shown that the signature analysis of the symmetric signature can be based on a Gaussian. More details on the application of the wall signature method to the NASA/ARC 12-ft Pressure Wind Tunnel and on the improved signature analysis procedure can be found in Ref.5.

Future Plan:

A. The development of the lifting correction of Wall signature method will continue. The verification will be based on an solution obtained from the PMARC code.

B. The Wall Signature method with singularity representation of the equivalent body will be improved to include pre-computed "influence coefficients" of wall interferences for the implementation of on-line interference calculation.

C. The investigation of effects of the model support system in the 12-ft Pressure Tunnel on tunnel wall pressure signature measurements will be initiated.

References:

1. Ashby, D. L., Dudley, M. R., Iguchi, S. K., Browne, L., Katz, J., ''Potential Flow Theory and Operation Guide for the Panel Code PMARC,'' NASA TM 102851, NASA Ames Research Center, Moffett Field, California, January 1991.

2. Lovely, P.K., Wigren, L., PMAPP User's Guide Release 1.0, TN89-2000-205-100, Sterling Federal Systems, Inc., Palo Alto, California, December 1989.

3. Hackett, J. E. et al,"A Review of the Wall Pressure Signature and other Tunnel Constraint Correction Methods for High Angle-of-Attacks Tests", AGARD Report No. 692, May 1980

4. Ulbrich, N., Lo, C. F. and Steinle, F. W., ''Blockage Correction in Three-Dimensional Wind Tunnel Testing Based on the Wall Signature Method,'' AIAA 92-3925, presented at the 17th Aerospace Ground Testing Conference, Nashville, TN, July 6-8, 1992.

5. Ulbrich, N., ''Wall Interference Correction Based on Interface Measurements in Subsonic Wind Tunnel Testing,'' Ph. D. dissertation, The University of Tennessee, Knoxville, TN, August 1992.

FIGURES

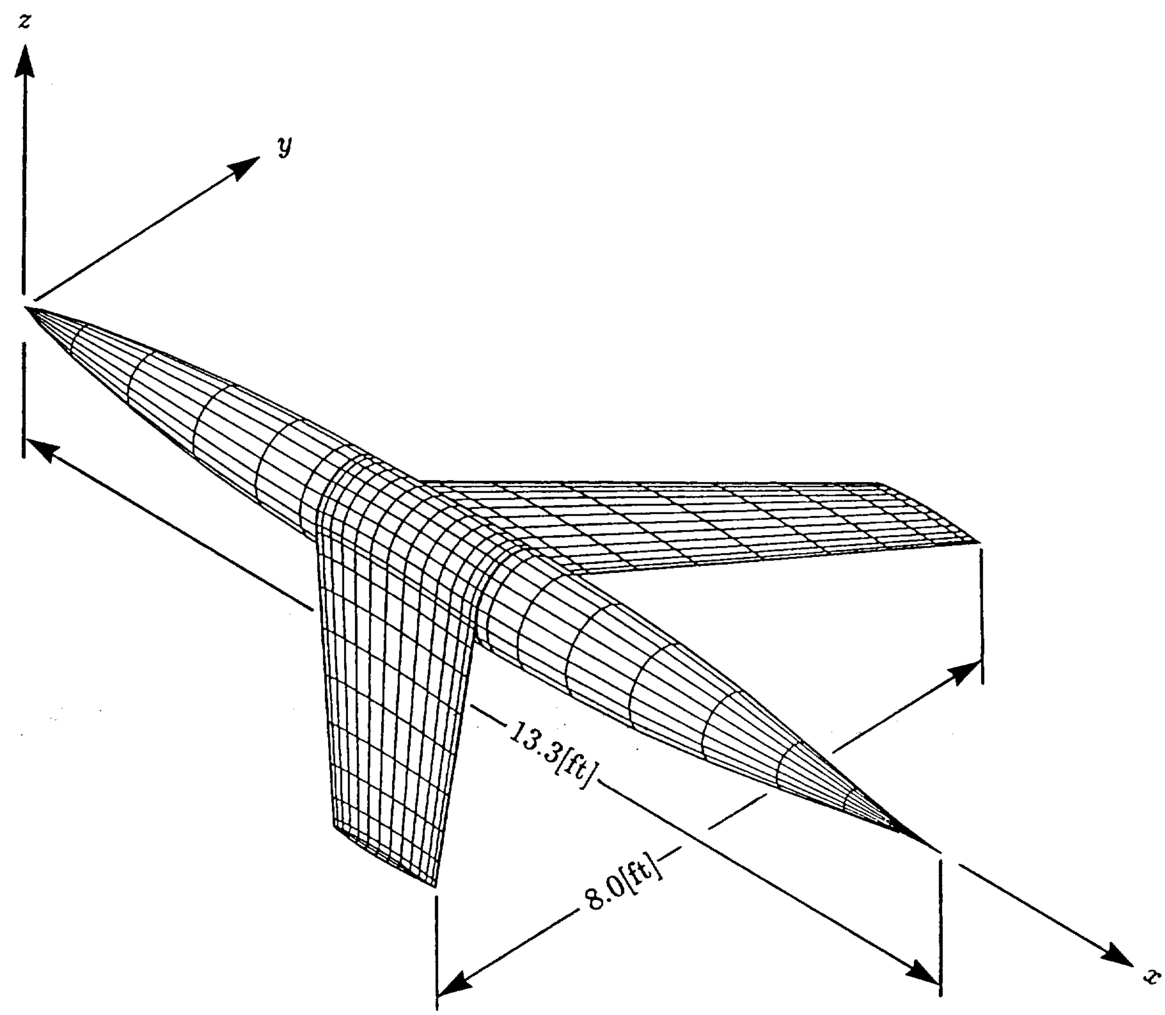


Fig. A-1 Description of test article in terms of surface panel elements; origin of coordinate system is located in fuselage tip.

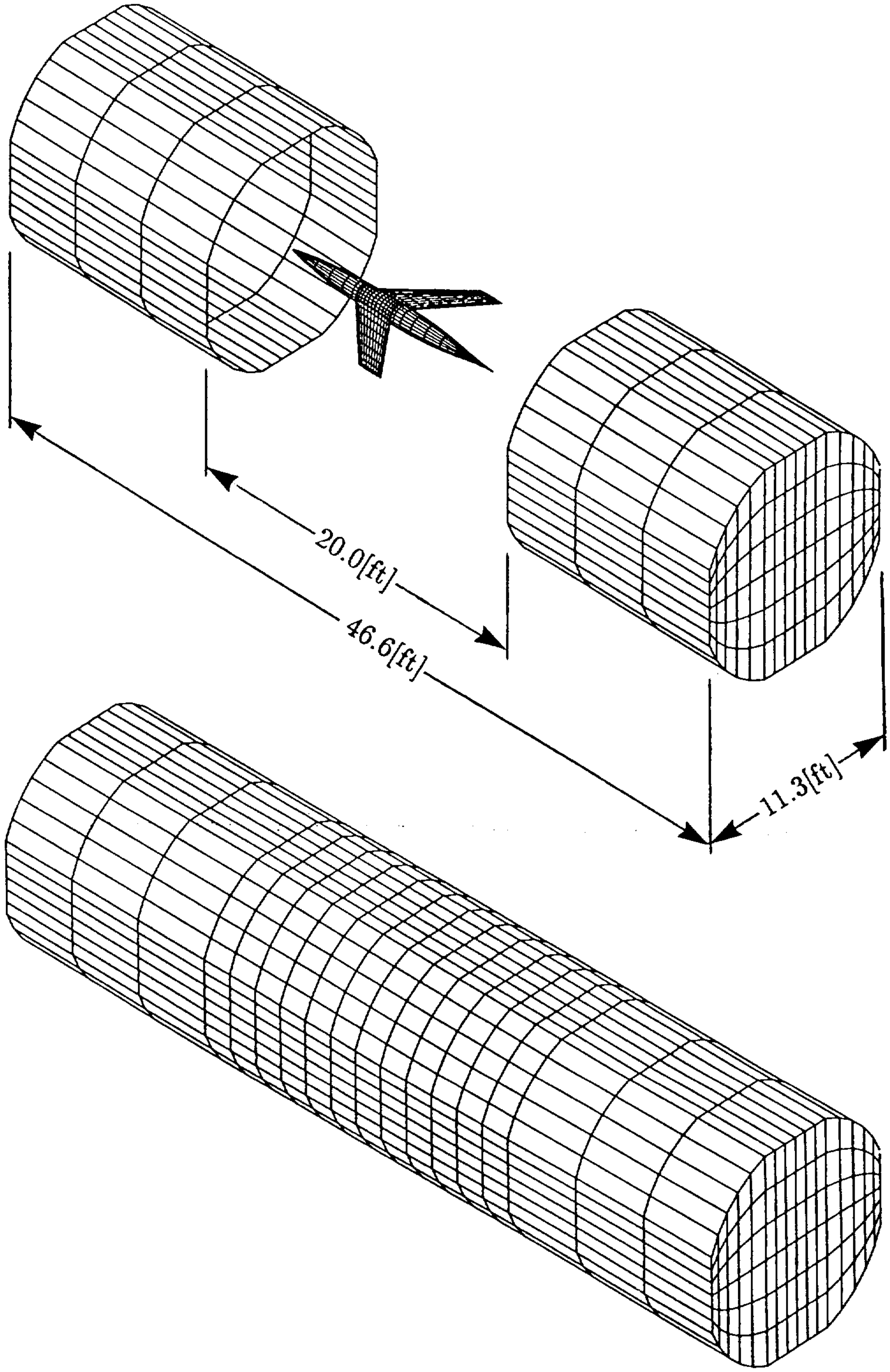


Fig. A-2 Description of test article and NASA ARC 12ft Pressure Wind Tunnel in terms of surface panel elements.

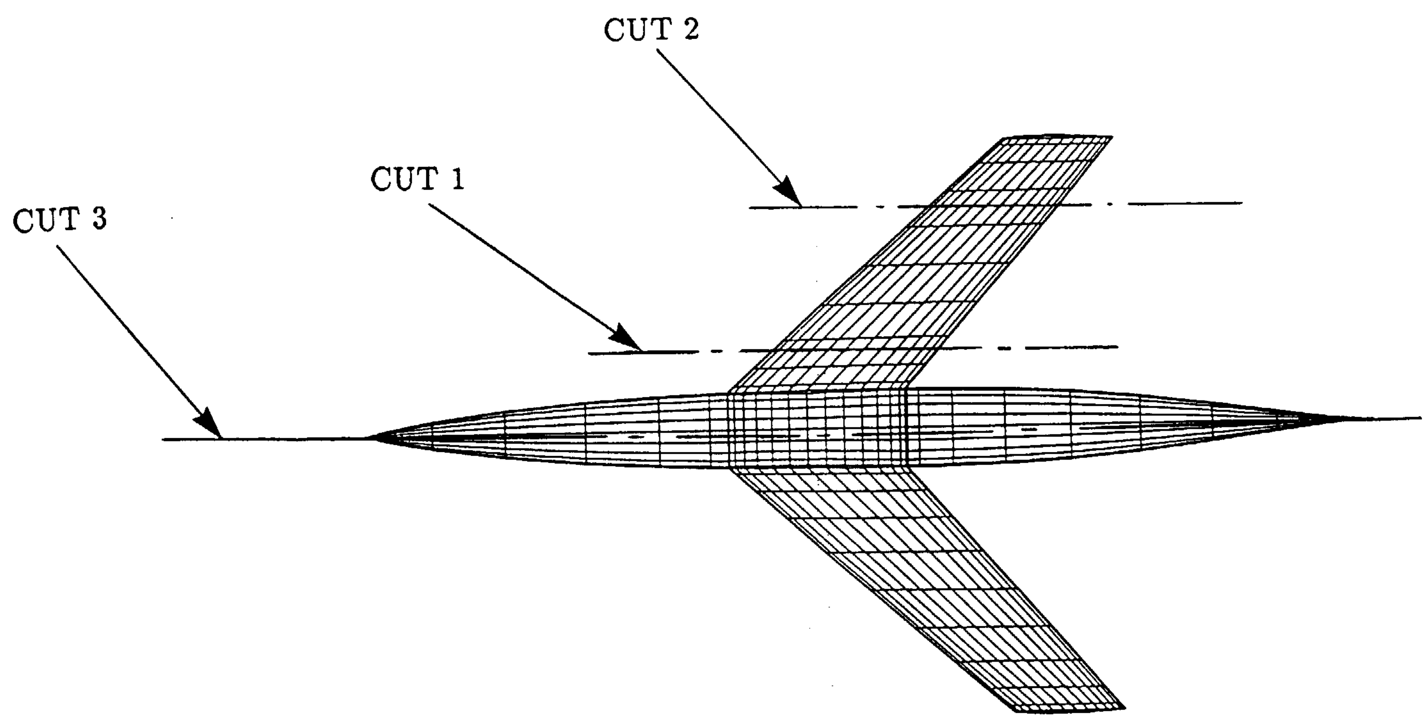


Fig. A-3 Location of selected cuts of test article geometry.

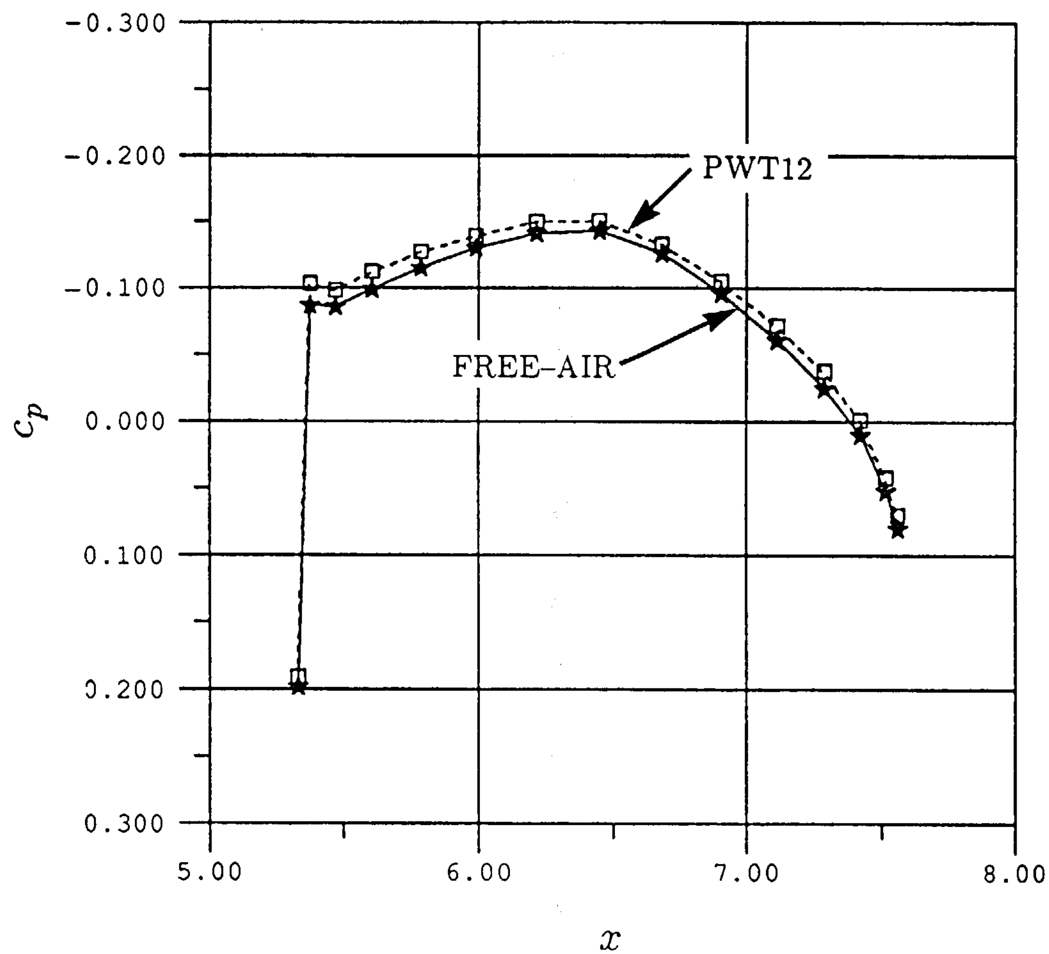


Fig. A-4 Surface pressure distribution ; CUT 1 ;
distance in [ft] from fuselage tip.

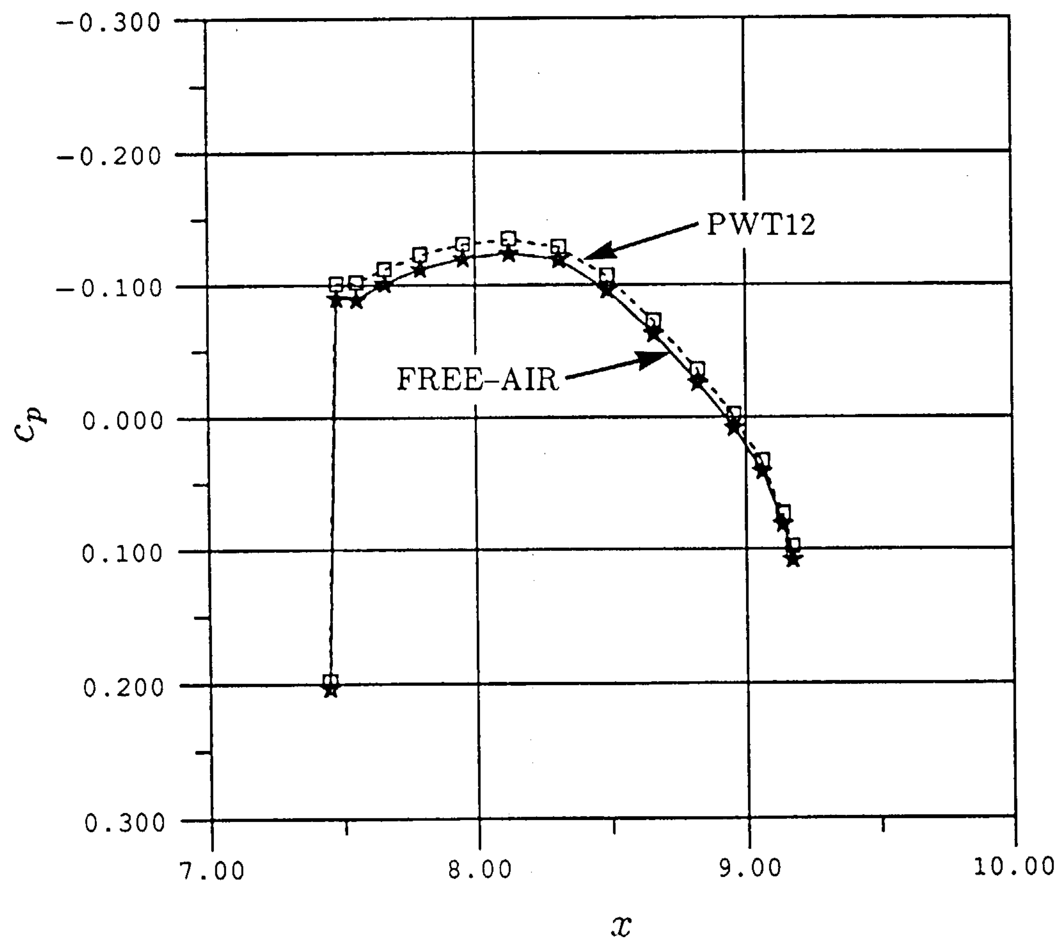


Fig. A-5 Surface pressure distribution ; CUT 2 ; distance in [ft] from fuselage tip.

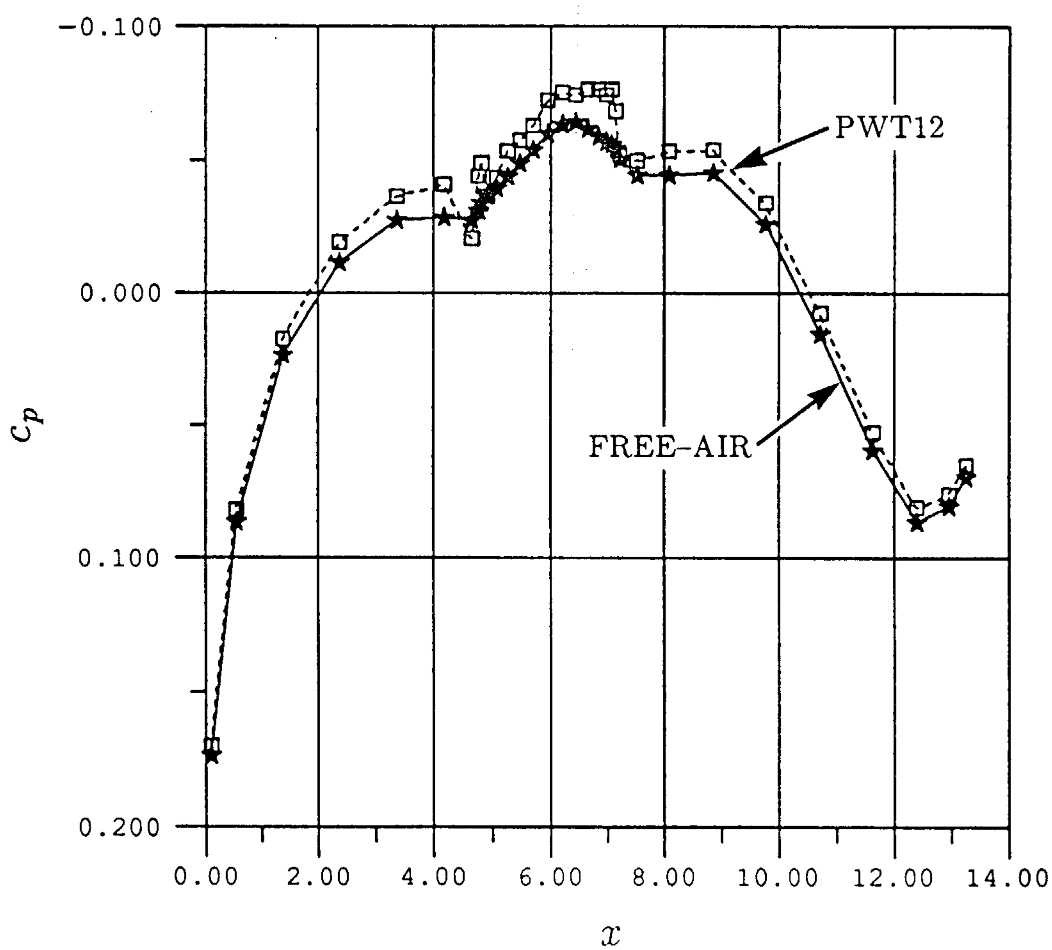


Fig. A-6 Surface pressure distribution ; CUT 3 ; distance in [ft] from fuselage tip.

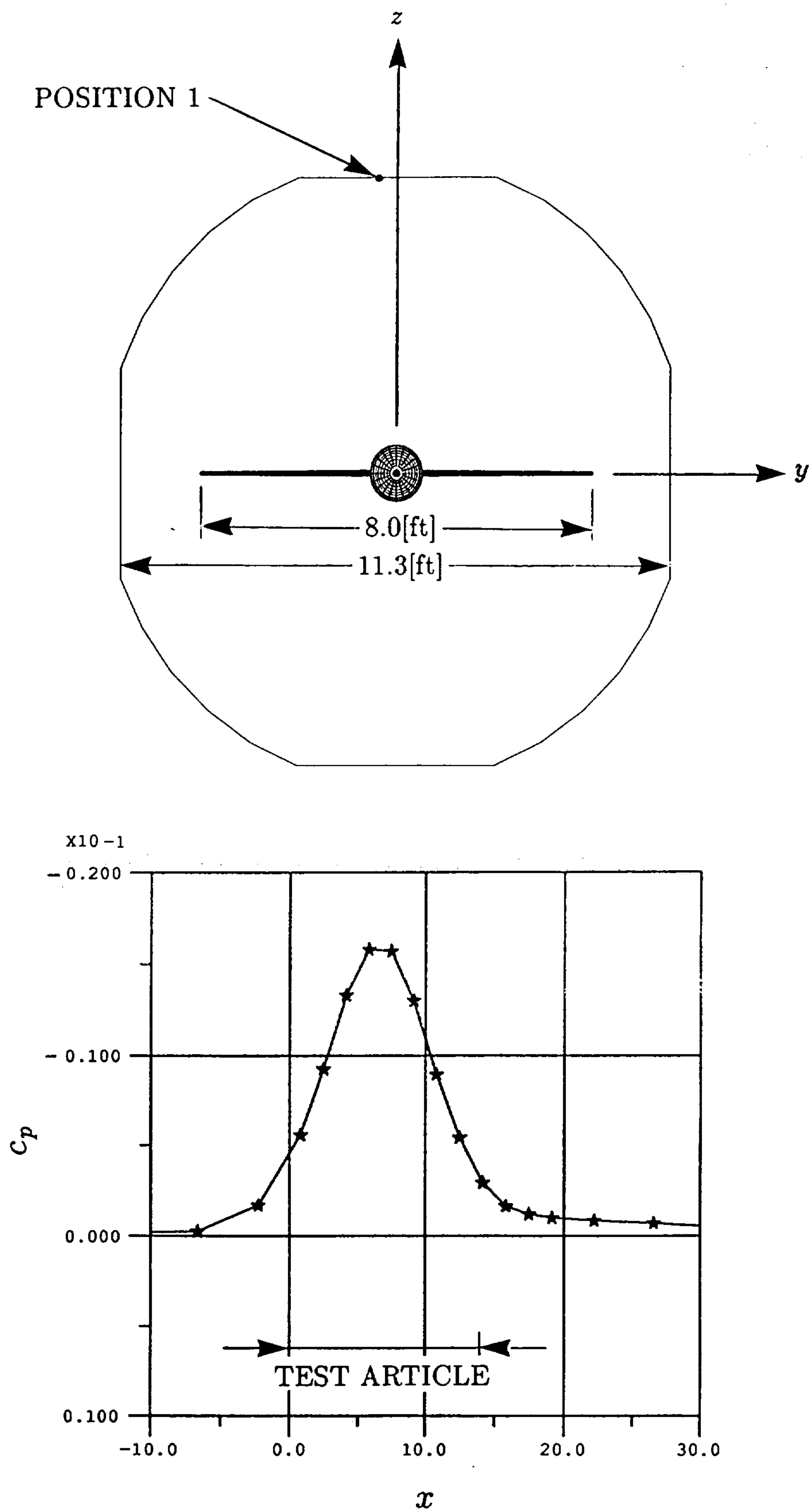


Fig. A-7a Wall pressure coefficient distribution ; POSITION 1 ; distance in [ft] from fuselage tip.

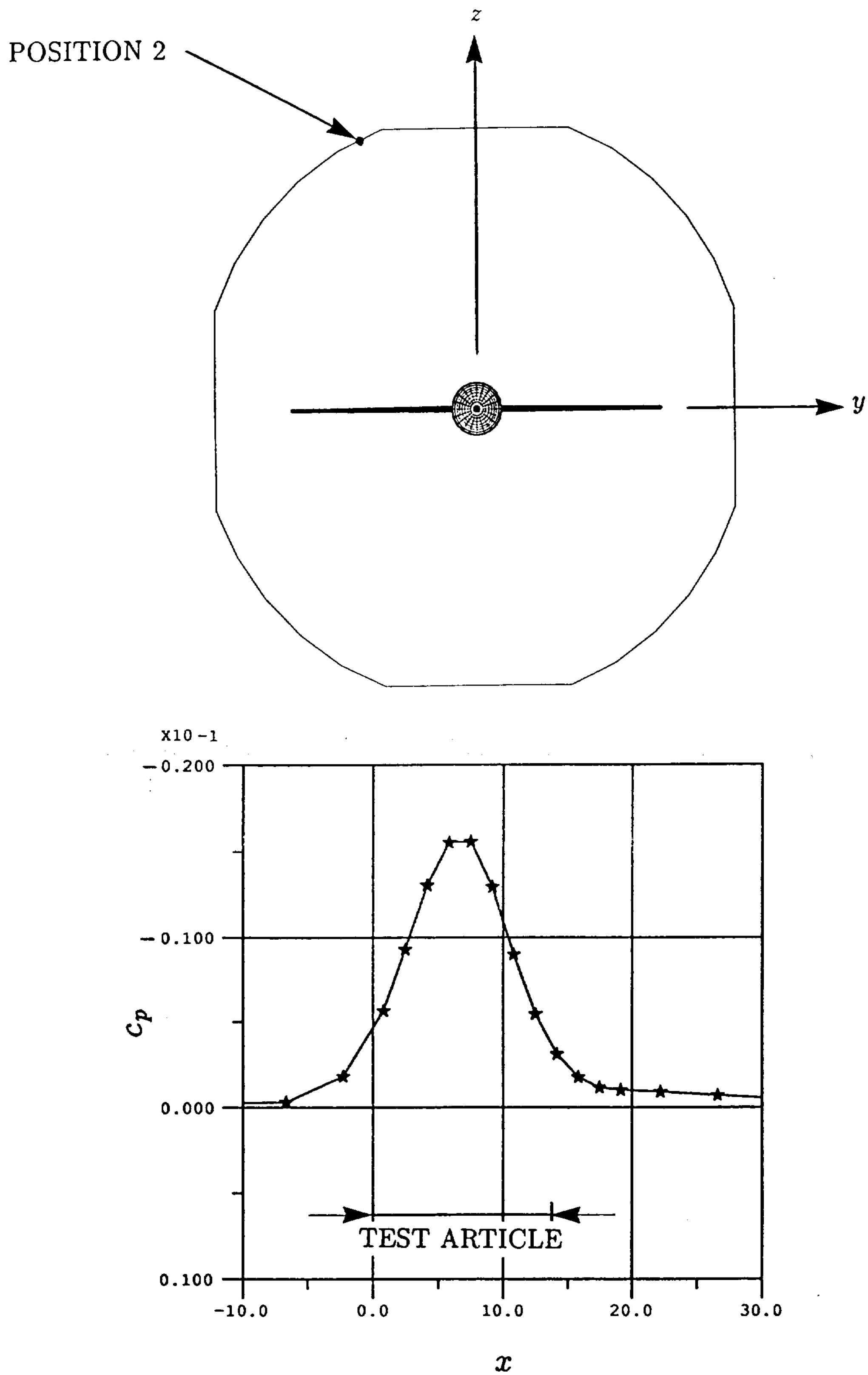


Fig. A-7b Wall pressure coefficient distribution ; POSITION 2 ; distance in [ft] from fuselage tip.

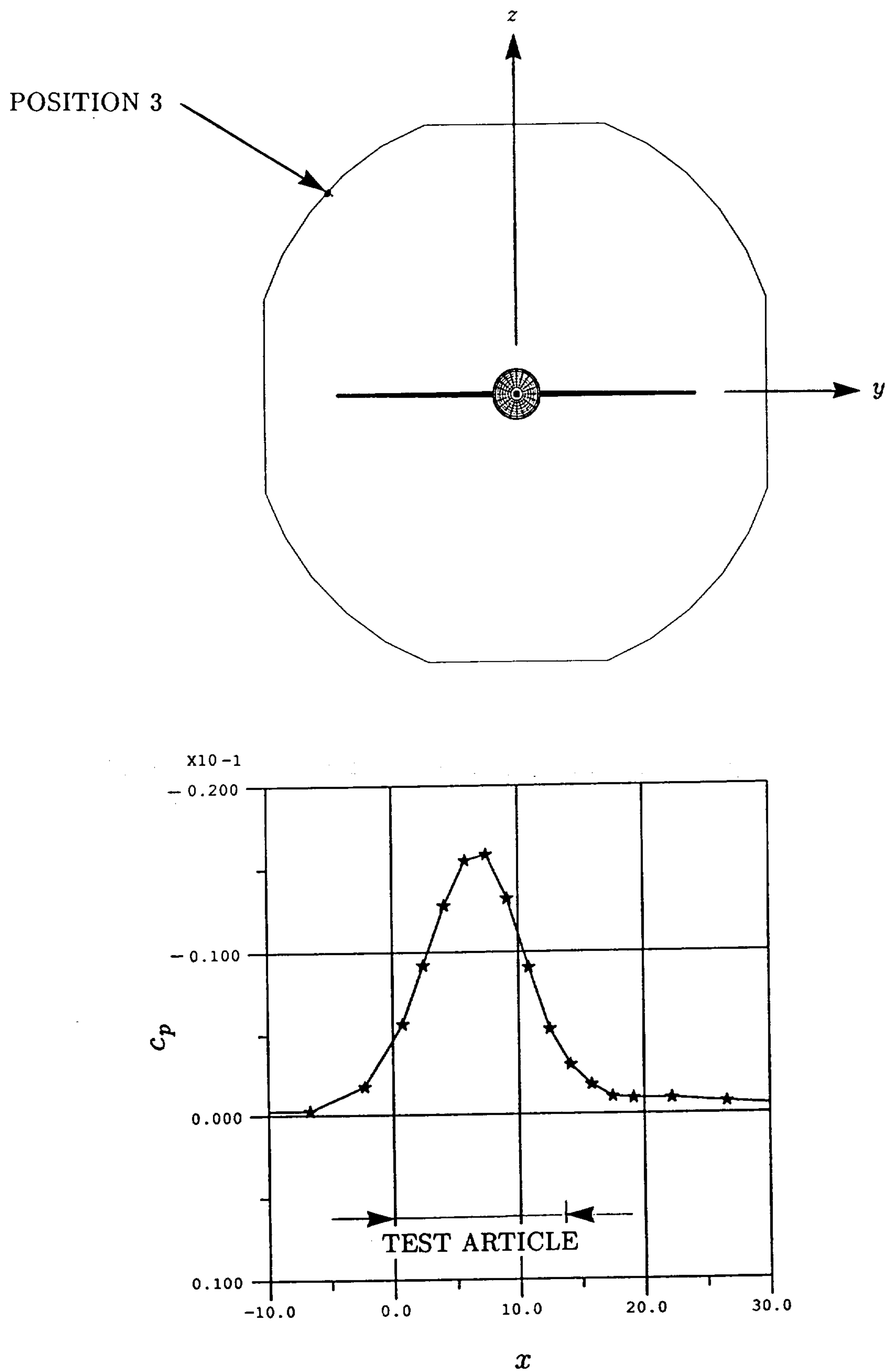


Fig. A-7c Wall pressure coefficient distribution ; POSITION 3 ; distance in [ft] from fuselage tip.

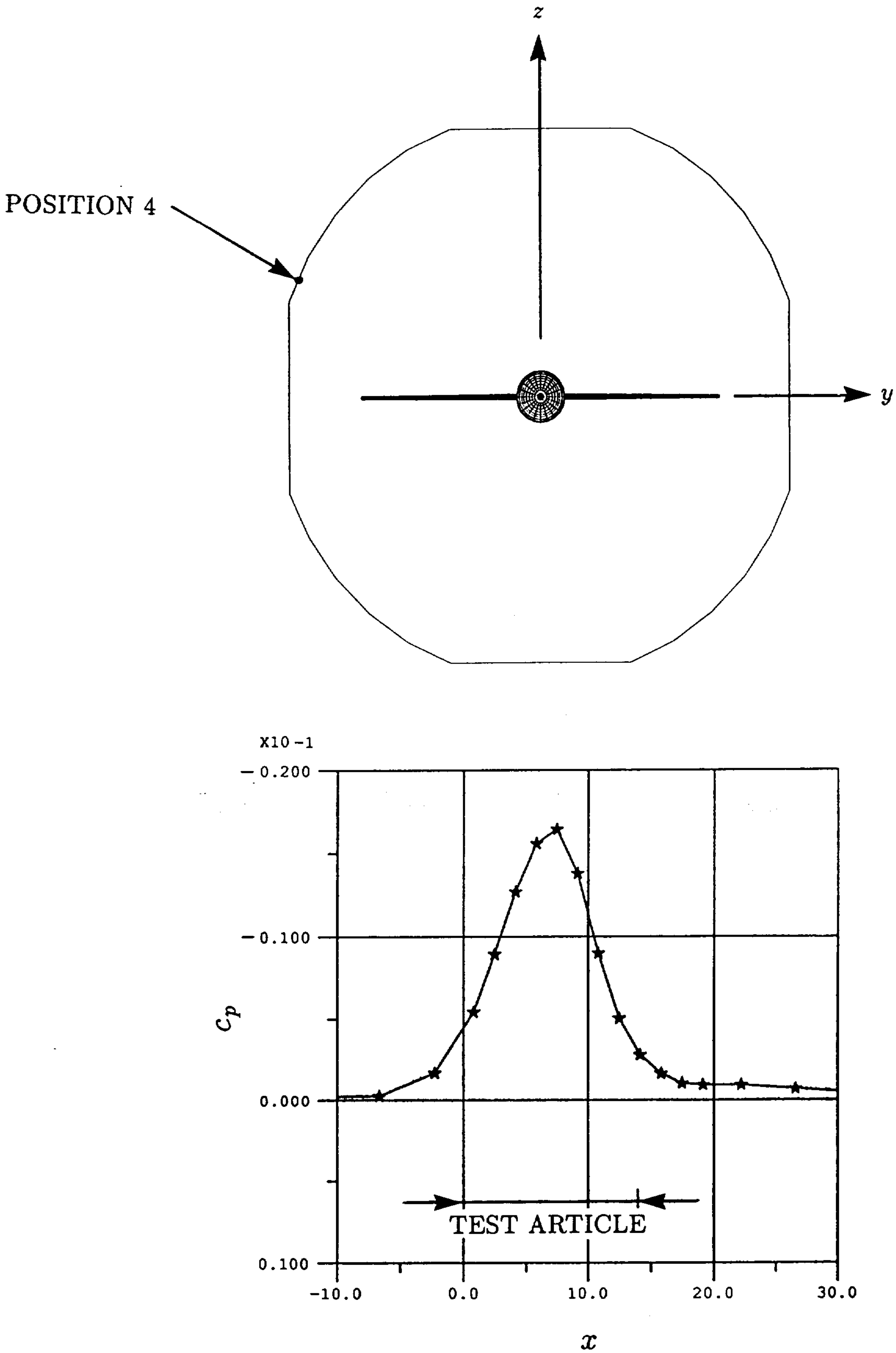
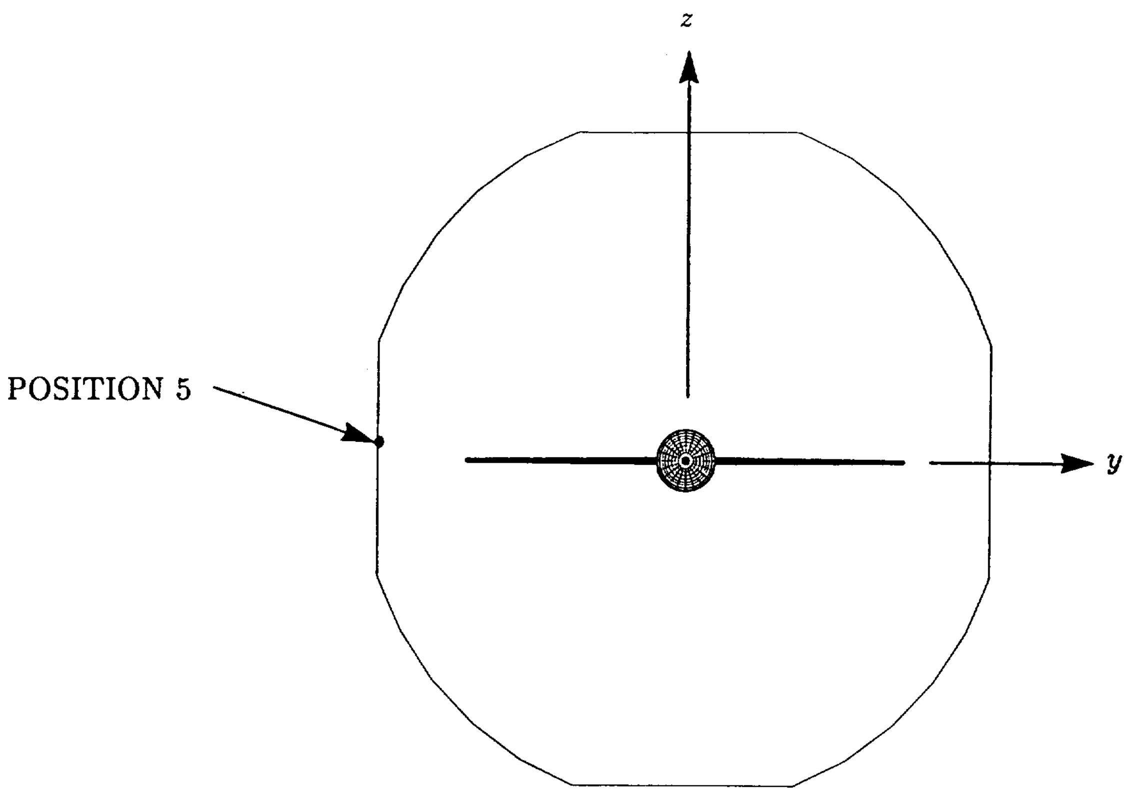


Fig. A-7d Wall pressure coefficient distribution ; POSITION 4 ; distance in [ft] from fuselage tip.



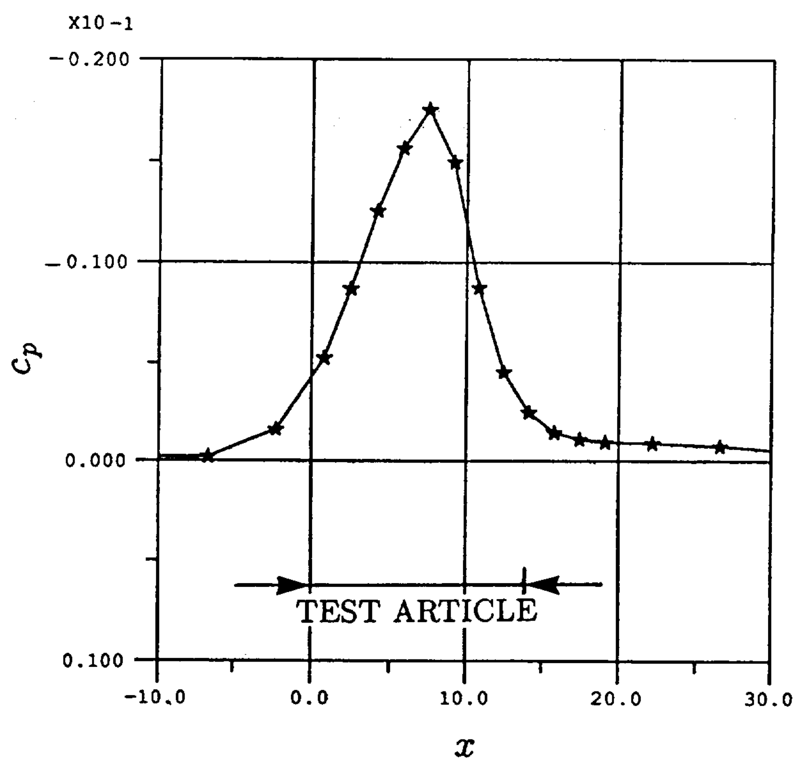


Fig. A-7e Wall pressure coefficient distribution ; POSITION 5 ; distance in [ft] from fuselage tip.

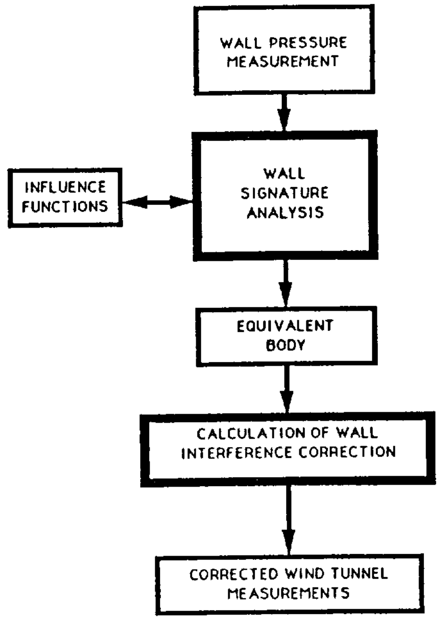


Fig. B-1 Basic elements of a Wall Signature method .

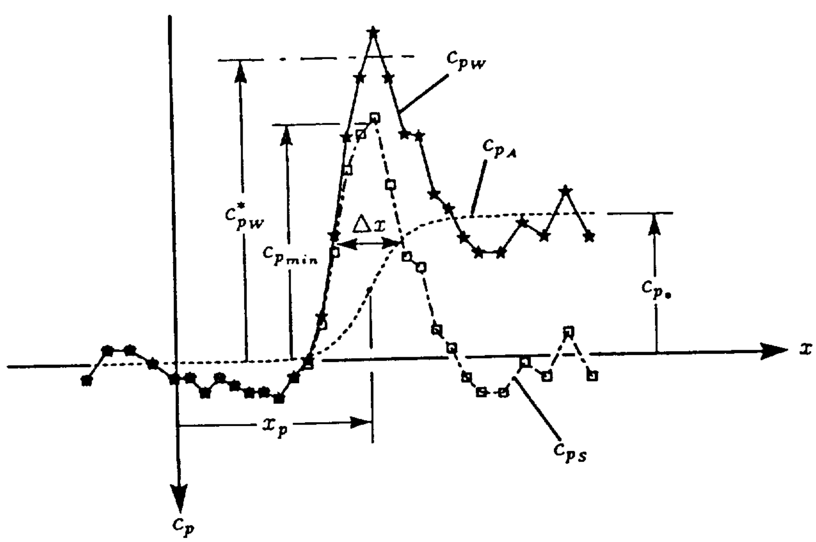


Fig. B-2 Wall pressure signature c_{pw} represented as sum of symmetric part c_{ps} and antisymmetric part c_{pA} .

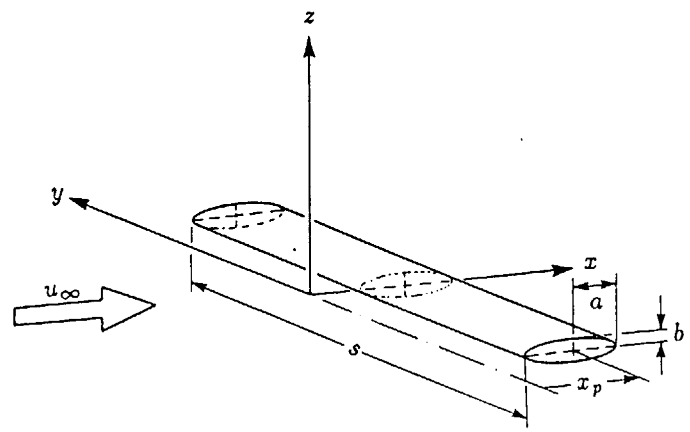


Fig. B-3a Idealized test article representation .

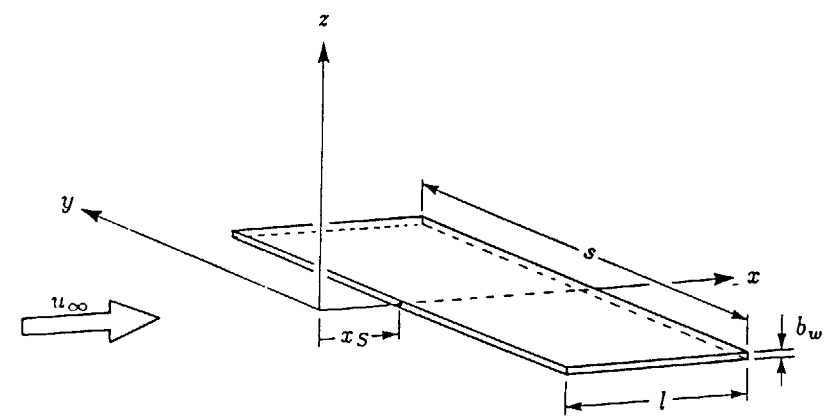


Fig. B-3b Idealized wake representation .

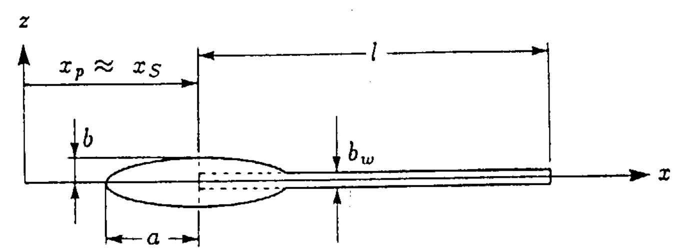


Fig. B-3c Equivalent body geometry .

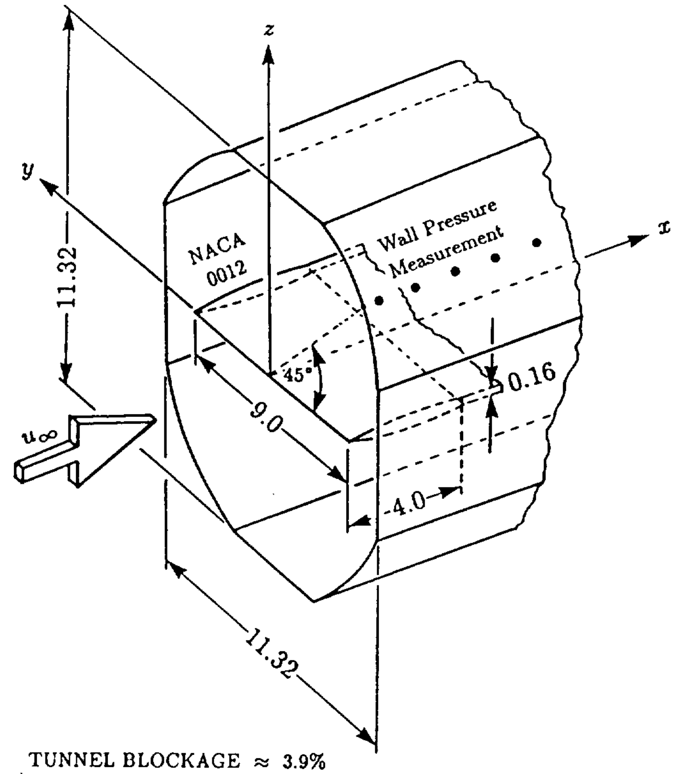


Fig. B-4a Geometry of numerical example .

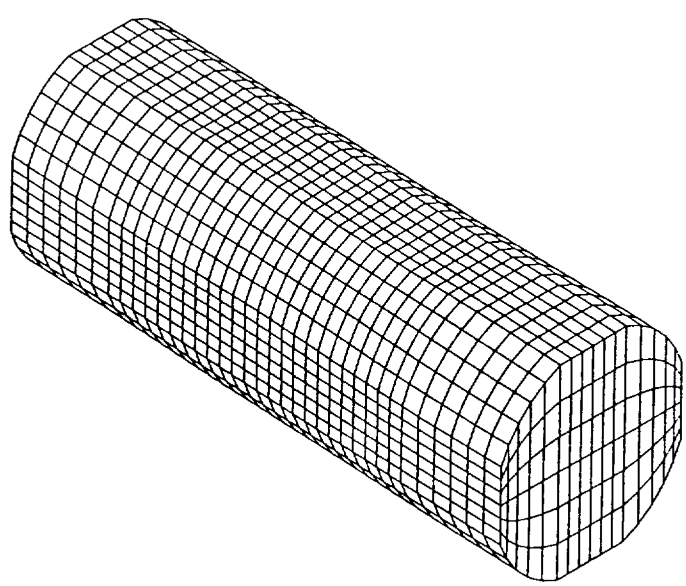


Fig. B-4b Location of wind tunnel wall panels .

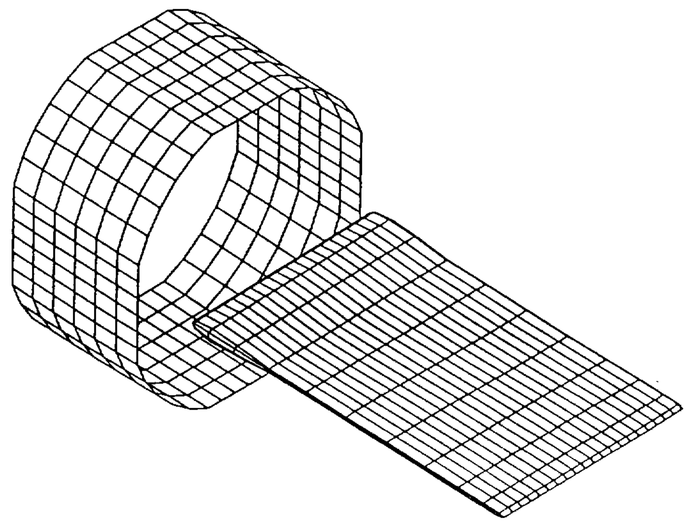


Fig. B-4c Location of test article and wake panels .

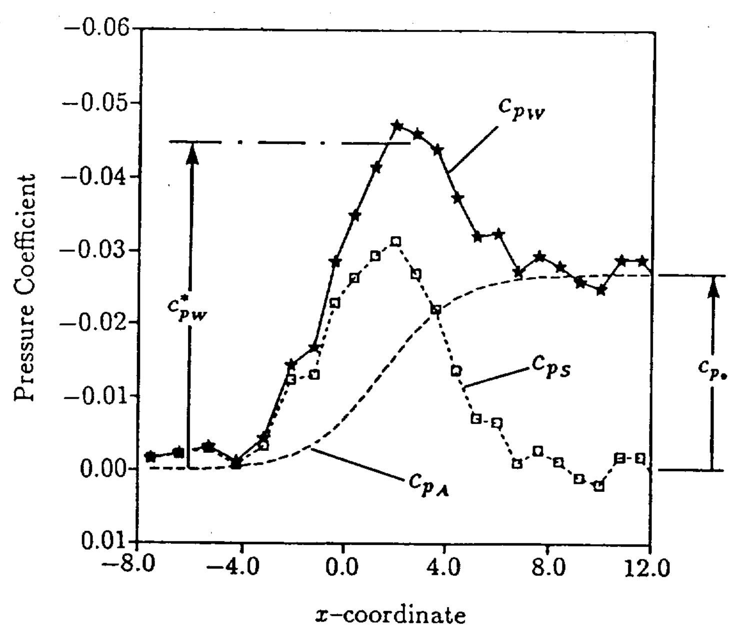


Fig. B-5 Representation of simulated wall pressure measurement in terms of symmetric and antisymmetric part .

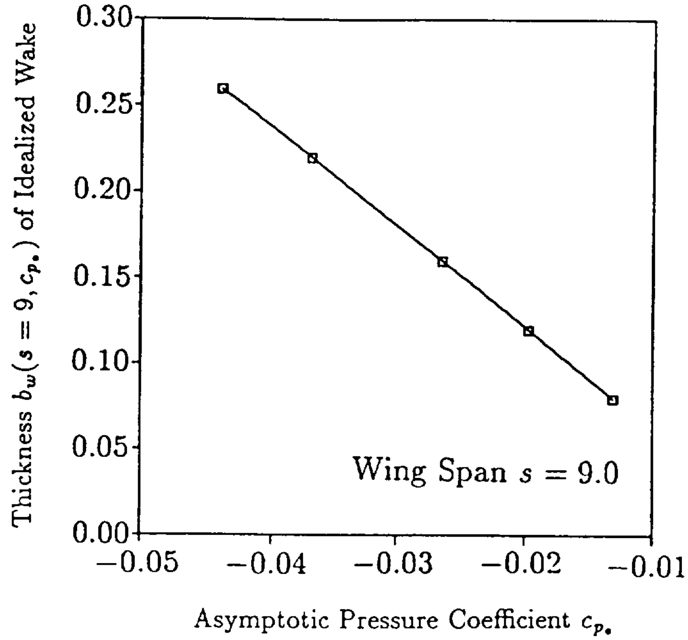


Fig. B-6a Influence function $b_w(s = 9, c_{p_\infty})$.

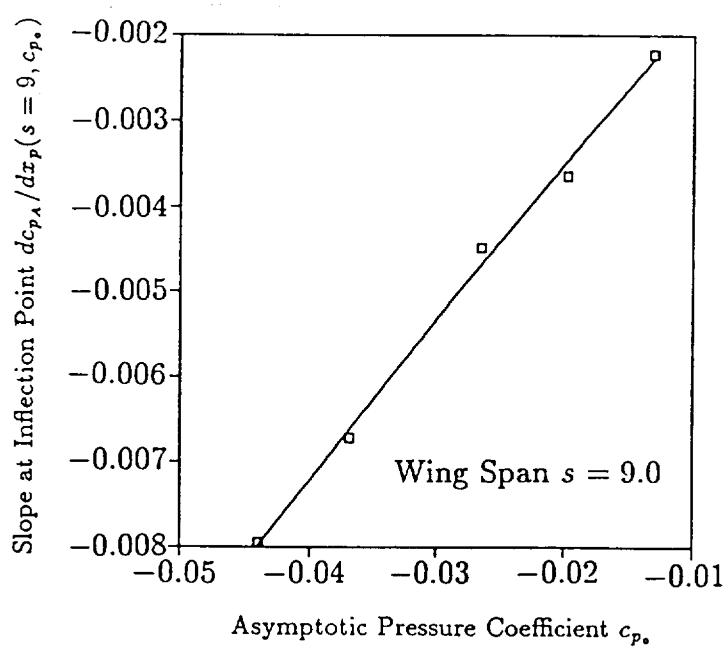


Fig. B-6b Influence function $dc_{p_A}/dx_p(s = 9, c_{p_\infty})$.

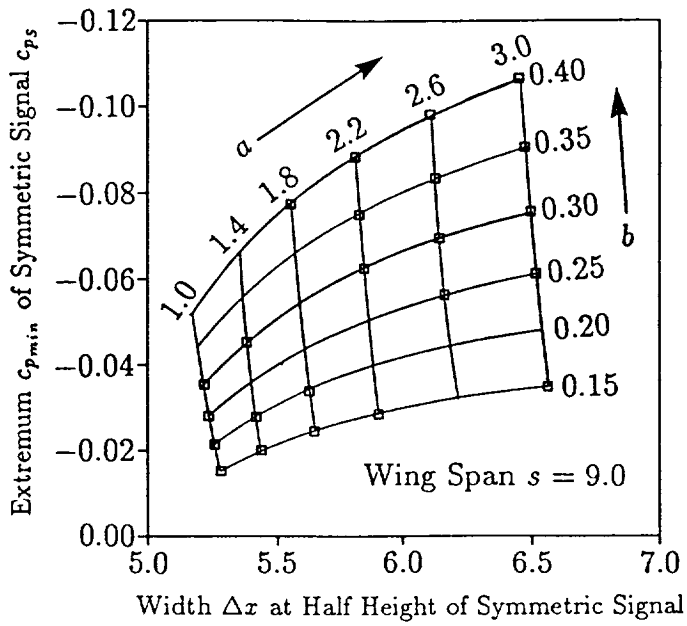


Fig. B-6c Influence functions $a(s = 9, \Delta x, c_{p_{min}})$, $b(s = 9, \Delta x, c_{p_{min}})$.

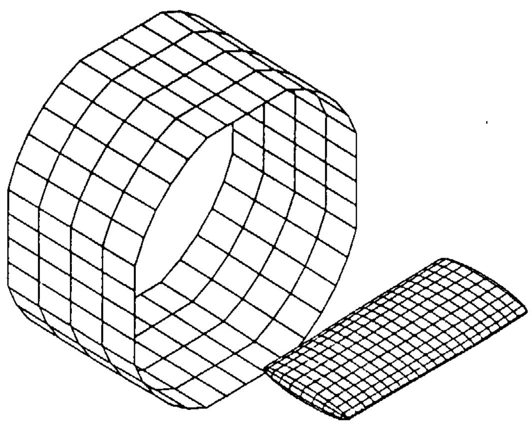


Fig. B-7a Location of idealized test article panels ($a = 2.2, b = 0.3$) .

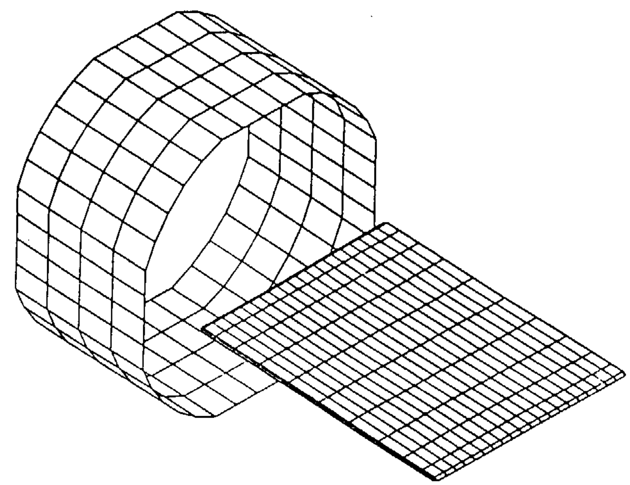


Fig. B-7b Location of idealized wake panels ($b_w = 0.16$) .

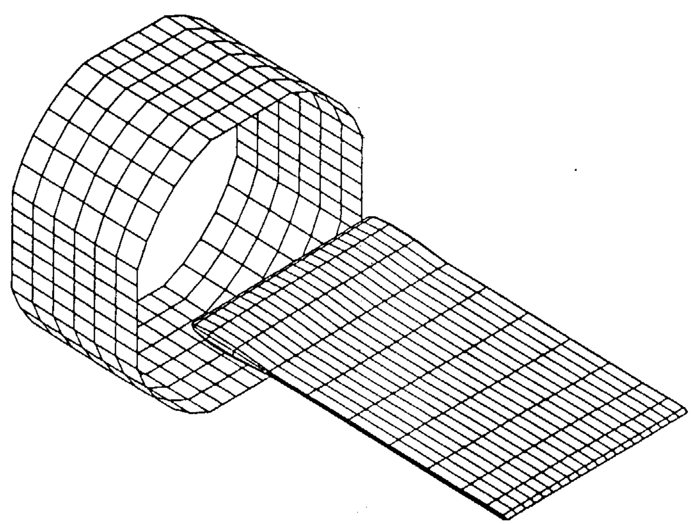


Fig. B-7c Location of equivalent body surface panel elements .

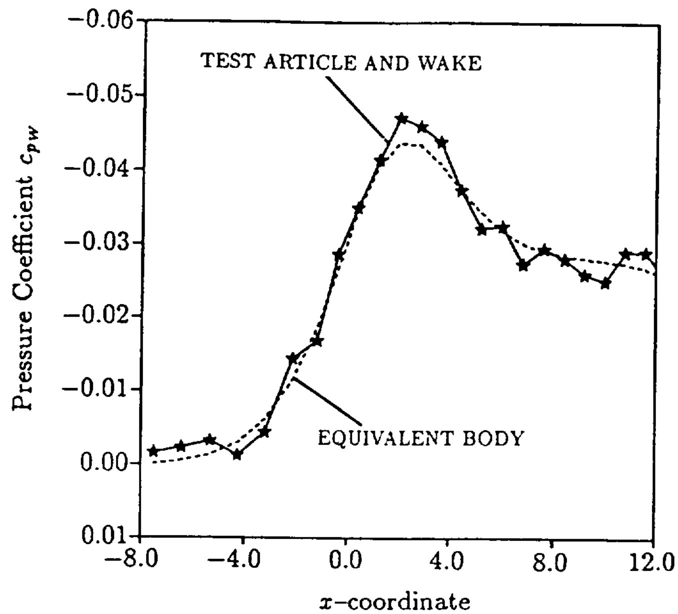


Fig. B-8a Comparison of simulated wall pressure measurement and wall signature derived from corrected equivalent body geometry .

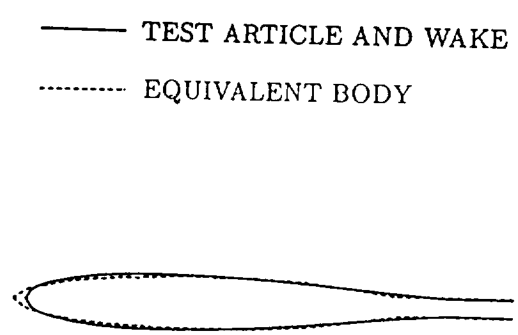


Fig. B-8b Comparison of test article and equivalent body geometry .

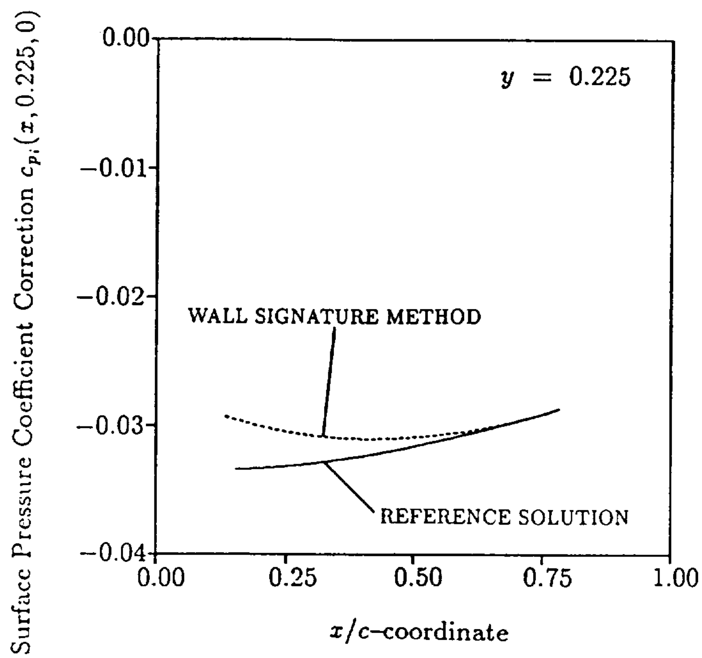


Fig. B-9a Pressure coefficient correction $c_{p_i}(x, 0.225, 0)$ on test article surface .

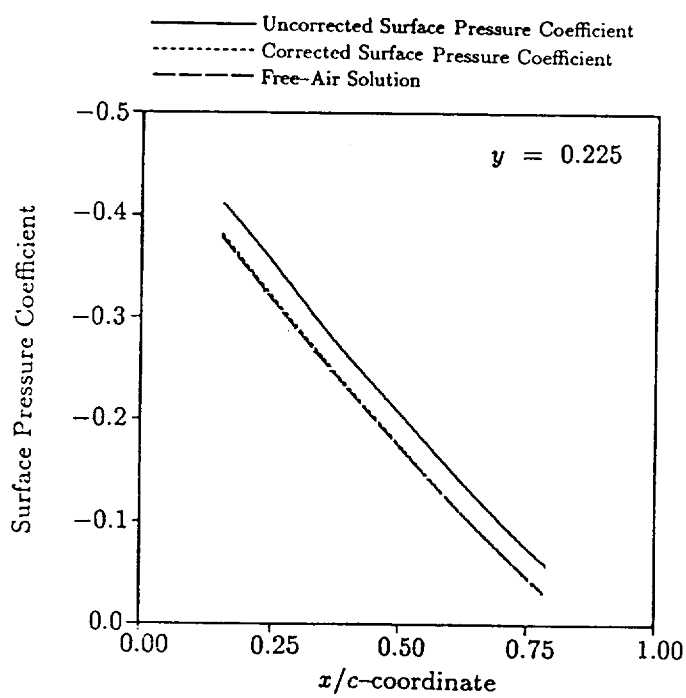


Fig. B-9b Comparison of uncorrected and corrected surface pressure coefficient with free–air solution ; $y = 0.225$.

APPENDIX

AIAA 92-3925

BLOCKAGE CORRECTION IN THREE-DIMENSIONAL WIND TUNNEL TESTING BASED ON THE WALL SIGNATURE METHOD

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BLOCKAGE CORRECTION IN THREE–DIMENSIONAL WIND TUNNEL TESTING BASED ON THE WALL SIGNATURE METHOD

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Abstract

An improved wall interference assessment and correction method for three–dimensional wind tunnel testing is presented. Blockage corrections on the surface of a test article are calculated based on a limited number of wall pressure measurements. These measurements are combined with a signature analysis procedure and influence functions to determine an equivalent test article and wake representation. Pressure coefficient corrections are calculated based on this equivalent body. The signature analysis procedure is modified to improve the on–line operation of the wall signature method. A new geometry of the equivalent body is introduced which can be combined with existing panel codes more effectively. The calculation of influence functions and the determination of pressure coefficient corrections are based on a panel code. Therefore it is possible to apply the present method to any closed tunnel cross section. A numerical simulation of the idealized flow field of a wing and its wake in a rectangular wind tunnel is used to verify the improved wall signature method. The present method is considered to calculate blockage corrections in the NASA/ARC 12ft Pressure Wind Tunnel.

Nomenclature

a	=semi major axis of ellipse
a_1, a_2, a_3	=coefficients of exponential function
$a_1^{(0)}, a_2^{(0)}, a_3^{(0)}$	=initial guess of a_1, a_2, a_3
b	=semi minor axis of ellipse
b_w	=thickness of the wake
c_{p_A}	=antisymmetric part of the wall pressure measurement
c_{p_F}	=pressure coefficient in free–air flow
c_{p_i}	=pressure coefficient correction
$c_{p_{min}}$	=pressure coefficient minimum of symmetric signature
c_{p_S}	=symmetric part of the wall pressure measurement
c_{p_T}	=pressure coefficient in wind tunnel flow field
c_{p_W}	=pressure coefficient measurement on the wind tunnel wall
c_{p_∞}	=asymptotic value of c_{p_W}
$\lvert\Delta c_p\rvert$	=pressure coefficient error
dc_{p_A}/dx_p	=slope of antisymmetric signal at inflection point location
l	=length of flat plate
s	=wing span
x	=x–coordinate (streamwise direction)
x_p	=inflection point location; peak location
x_s	=stagnation point location (flat plate)
Δx	=width at half height of the symmetric wall signature
y	=y–coordinate (spanwise direction)
z	=z–coordinate

1. Introduction

Wall interference prediction in three–dimensional wind tunnel testing based on the wall signature method was investigated in the past. Basic assumptions and elements of this method are described by *Hackett et al.*[1] and *Allmaras*[2]. *Lo and Ulbrich*[3] calculated blockage corrections in a two-dimensional subsonic flow field using the wall signature method and available experimental data[4]. Results of this calculation compared favorably to results obtained by applying an analytic two–interface method[5].

An improved version of the wall signature method is presented in this paper. This version is considered to calculate blockage corrections due to wall interference in the NASA/ARC 12ft Pressure Wind Tunnel which has a quasi–octagonal cross–section. Only a limited number of wall pressure measurements is used to determine blockage corrections.

At first, basic elements of the wall signature method are presented. Wall pressure measurements are combined with a signature analysis procedure and precalculated influence functions to determine an equivalent representation of the test article and its idealized wake. The equivalent representation is used to

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calculate pressure coefficient corrections due to model blockage.

The calculation of influence functions and blockage corrections is based on a three–dimensional panel code. It is demonstrated how the improved wall signature method can be combined more effectively with existing panel codes like PMARC[6].

A numerical verification of the improved wall signature method is given. The flow field of a wing and its idealized wake inside a closed rectangular wind tunnel is simulated using panel code PMARC. Wall pressure coefficients on a limited number of wall locations are calculated and combined with a set of randomly generated disturbances. The perturbed wall pressure coefficients are considered as simulated wall pressure measurements c_{pw}. These simulated wall pressure measurements are used in combination with the wall signature method to calculate blockage corrections. A reference solution of the blockage problem is calculated as well. The reference solution is compared to blockage corrections obtained from the wall signature method to verify results.

Finally, necessary changes are described if the improved wall signature method is to be applied to the NASA/ARC 12ft Pressure Wind Tunnel.

2. Wall Signature Method

2.1 General Remarks

The wall signature method described by *Hackett et al.*[1] consists of two major parts: the signature analysis procedure which calculates an equivalent representation of the test article and its wake; the determination of blockage corrections based on this equivalent body. *Hackett et al.*[1] used line sources and sinks to describe an equivalent body. However, it is difficult to use the idea of line sources and sinks in combination with panel codes. A different approach is selected in this paper: an equivalent body is described in terms of surface panel elements instead of line sources/sinks.

The signature analysis procedure uses wall pressure measurements in combination with precalculated influence functions to determine an equivalent body.

Influence functions relate geometric parameter of the equivalent model representation to parameter derived from the wall signature analysis. They depend on the type of tunnel cross–section, the location of the wall pressure measurements and on the class of equivalent body representing the test article and its wake. The present method uses panel code PMARC to obtain these influence functions.

Blockage corrections are calculated using the equivalent test article and wake geometry derived from the signature analysis procedure. Panel code PMARC calculates surface pressures on the equivalent body in the free–air flow field and in the wind tunnel flow field. A blockage correction is found by taking the difference of pressure coefficients on corresponding surface locations.

It was demonstrated by *Hackett et al.*[1] that blockage corrections can be calculated with sufficient accuracy if the equivalent body is used instead of the actual test article and wake geometry.

The pressure coefficients on the selected wall locations can be calculated as well. A comparison of calculated and measured pressure coefficients on the tunnel wall can be used to check the quality of the equivalent body.

Figure 1 gives details on the improved wall signature method.

2.2 Signature Analysis

The signature analysis procedure presented in this paper is developed to correct for test article and wake blockage of a rectangular wing in three–dimensional incompressible wind tunnel testing. Basic elements of the signature analysis remain the same if a different class of test article (e.g. body of revolution, swept wing, etc.) or a different wind tunnel cross–section is considered.

The signature analysis procedure works as follows: During a wind tunnel experiment of a rectangular wing of wing span 's' wall pressure coefficients 'c_{pw}' on a single row of pressure orifices are recorded. The asymptotic value 'c_{p_∞}' of the wall pressure measurements is determined numerically.

The signature analysis procedure uses the measured wall pressure signature 'c_{pw}' and its asymptotic value 'c_{p_∞}' to determine an equivalent representation of the test article and its idealized wake. The total wall signature 'c_{pw}' is split into a symmetric and antisymmetric part:

$$c_{pw} = c_{p_A} + c_{p_S} \tag{1}$$

The signature splitting requires an iteration procedure which is terminated as soon as the x–location 'x_p' of the minimum of the symmetric signature 'c_{p_S}' agrees with the location of the inflection point 'x_p' of the antisymmetric signature 'c_{p_A}'.

The equivalent geometric representation of the test article is derived from the symmetric signature; the representation of the wake is derived from the antisymmetric signature. The wall pressure signature caused by this representation of test article and wake will reproduce the original wall signature if the signature analysis procedure is successful.

In their original approach *Hackett et. al*[1] used a rankine oval and a half body represented by line sources/sinks to find an equivalent representation. However, it is difficult to combine this idea with existing panel codes. Therefore a different approach is used in this paper. The test article is represented using a wing type body of span 's' with elliptical cross section described by semi axes 'a' and 'b'. The idealized trailing edge wake is represented by a flat plate of span 's', thickness 'b_w' and length 'l'. A description of the geometry of the bodies selected for the test article and wake simulation is given in Figs. 2a and 2b. Equivalent test article and wake representation are combined as shown in Fig. 3 to obtain the cross section of the equivalent body. The equivalent body is discretized using surface panel elements and combined with panel code PMARC to determine blockage corrections.

It is assumed that the span 's' of the test article is known. An equivalent representation of the test article and its wake is found, if the location and axes of the ellipse and the length, thickness and location of the flat plate are found. The length 'l' of the flat plate should be chosen such that $l \gg b_w$. The remaining five unknows, i.e. semi axes 'a' and 'b' of the ellipse, location 'x_p' of the center of the ellipse (identical with the inflection point location of the wall signature caused by the flat plate), thickness 'b_w' and stagnation point location 'x_S' of the flat plate, are a function of the wing span 's', the wall pressure measurement 'c_{pW}' and influence functions calculated for the given wind tunnel geometry and orifice location.

The five unkowns are found as follows: (1) get the asymptotic value of the pressure coefficient 'c_{p_∞}' from the wall pressure signature; (2) use the precalculated influence function $b_w(s, c_{p_\infty})$ to get the thickness of the plate 'b_w'; (3) use the precalculated influence function $dc_{p_A}/dx_p(s, c_{p_\infty})$ to get the slope at the inflection point 'dc_{p_A}/dx_p' ; (4) guess the value of 'x_p' and make the following approximation of the antisymmetric signal:

$$c_{p_A} = \alpha_1 \cdot \left[\, 1 + \tanh[\alpha_2 \cdot (x - x_p)]\, \right] \qquad (2a)$$

where

$$\alpha_1 = \frac{c_{p\infty}}{2} \qquad (2b)$$

$$\alpha_2 = \frac{2}{c_{p\infty}} \cdot \frac{dc_{p_A}}{dx_p} \qquad (2c)$$

(5) subtract the approximated antisymmetric signal 'c_{p_A}' from the wall pressure signature 'c_{pW}' to get the symmetric signature 'c_{pS}'; (6) repeat steps (4) and (5) in an iteration procedure until the location of the minimum '$c_{p_{min}}$' of 'c_{pS}' agrees with the inflection point location 'x_p' of the approximated antisymmetric signature 'c_{p_A}'.

A numerical investigation has shown that the difference between the x–location of the inflection point 'x_p' of the antisymmetric signature and the stagnation point location 'x_s' of the flat plate is significantly smaller than the semi–major axis 'a' of the ellipse. Therefore the following approximation is possible: $x_s \approx x_p$.

The geometry of the flat plate described by 'b_w', 'x_s' and 's' is now determined. The calculation of the test article representation requires further steps.

The location of the center of the elliptical cross–section 'x_p' is related to the symmetric signature. It is found as a result of the iteration procedure. The semi axes 'a' and 'b' of the ellipse are then obtained as follows: apply an exponential least squares fit (see section 2.5) to the symmetric signature 'c_{pS}' and calculate the width of the signature at half height 'Δx' and the minimum value of the pressure coefficient '$c_{p_{min}}$'; use influence functions $a(s, \Delta x, c_{p_{min}})$ and $b(s, \Delta x, c_{p_{min}})$ to obtain 'a' and 'b'. On–line operation of this procedure is improved if the distance weighted least squares interpolation described by *McLain*[8] is used to calculate 'a' and 'b' from corresponding influence functions.

2.3 Blockage Correction

After the successful completion of the signature analysis procedure the equivalent representation of the test article and its trailing edge wake is found. The surface pressure distribution for the free–air case and the wind tunnel case is calculated using the equivalent geometry and panel code PMARC. Blockage corrections are obtained by taking the difference of pressure coefficients on corresponding panel locations:

$$c_{p_i} = c_{pT} - c_{pF} \qquad (3)$$

It is suggested to used the same surface panel distribution in the free–air and wind tunnel calculation which simplifies the application of Eq. (3).

2.4 Influence Functions

Influence functions relate parameter derived from the signature analysis to the geometry of the equivalent model and wake representation. The calculation of these influence functions $b_w(s, c_{p_\infty})$, $dc_{p_A}/dx_p(s, c_{p_\infty})$, $a(s, \Delta x, c_{p_{min}})$ and $b(s, \Delta x, c_{p_{min}})$ has to be done using panel code PMARC.

The functions $b_w(s, c_{p_\infty})$ and $dc_{p_A}/dx_p(c_{p_\infty})$ are obtained as follows: (1) select a set of reasonable values of 'b_w' for the selected wing span 's'; (2) use PMARC to calculate the discrete wall signature on the selected wall location where pressure measurements will be taken; (3) use the formula for the difference approximation of the second derivative to determine the inflection point location (it is suggested to use the formula derived for unequal grid spacing given by *Smith*[7] as the distance between chosen wall panels is not necessarily constant); (4) find the x–location of the inflection point by linear interpolation (second derivative has to be equal to zero); (5) find the inflection point slope 'dc_{p_A}/dx_p' using linear interpolation of the two closest points; (6) find the minimum of the calculated pressure coefficient and consider it as the asymptotic pressure coefficient 'c_{p_∞}'.

The calculation of the functions $a(s, \Delta x, c_{p_{min}})$ and $b(s, \Delta x, c_{p_{min}})$ is done in a similar fasion: (1) select a set of reasonable semi major and semi minor axes 'a' and 'b'; (2) calculate the wall pressure distibution on the selected wall panel locations using panel code PMARC; (3) derive the values of width at half height 'Δx' and minimum value of these precalculated wall signatures '$c_{p_{min}}$' numerically.

2.5 Exponential Least Squares Fit

The values of width at half height 'Δx' and the minimum value of the symmetric signature '$c_{p_{min}}$' have to be calculated using a least squares approach. In their original publication *Hackett et al.*[1] suggested to fit a parabola in the vicinity of the minimum of the symmetric signature. This, however, requires some additional qualitative check of the user to make sure that the least squares fit is reasonable. The calculated parabolic least squares fit is not unique.

A different least squares fit is suggested in this paper to avoid the problem of non–uniqueness and to improve the on–line operation of the signature analysis procedure. The symmetric signature is fitted as follows:

$$c_{p_S} = a_1 \cdot \exp\left[-a_2 \cdot (x - a_3)^2\right] \tag{4}$$

The function will fit the symmetric signature in the neighborhood of the minimum '$c_{p_{min}}$'.

The least squares problem leads to a set of three nonlinear equations which can be solved numerically if Newton's Method is applied. A concise description of this method can be found in *Burden and Faires*[9]. Several different checks have shown that Newton's Method can only successfully be applied to this set of nonlinear equations if a reasonable initial guess is made. Therefore the following initial guess of values '$a_1^{(0)}$', '$a_2^{(0)}$' and '$a_3^{(0)}$' is suggested: consider the smallest value of the symmetric signature 'c_{p_S}' as initial guess of '$a_1^{(0)}$'; consider the x–location of the smallest value of the symmetric signature 'c_{p_S}' as initial guess of '$a_3^{(0)}$'; find an initial guess of '$a_2^{(0)}$' based on the related logarithmic least squares problem[9].

After the successful completion of the iteration the peak location 'x_p', the minimum value of the the symmetric signature 'c_{pmin}' and the width of the symmetric signature at half height 'Δx' are calculated as follows:

$$x_p = a_3 \tag{5a}$$

$$c_{p_{min}} = a_1 \tag{5b}$$

$$\Delta x = 2 \cdot \sqrt{\ln 2 / a_2} \tag{5c}$$

Different checks were applied to show that the exponential least squares fit can be used as a part of the signature analysis procedure. It could be shown that the calculation of 'x_p', '$c_{p_{min}}$' and 'Δx' hardly depends on the selected interval where discrete measurements are considered. Therefore the exponential least squares fit is better than the parabolic least squares fit.

3. Numerical Verification

The verification of the improved version of the wall signature method requires a numerical simulation of a three–dimensional wind tunnel flow field as no experimental data were available for the present study. The flow field of a wing with NACA 0012 airfoil section and a trailing edge wake in a rectangular wind tunnel is simulated. The selected geometry is given in Fig. 4. Tunnel blockage is 4.5% for the selected test article and wind tunnel geometry.

In a first step panel code PMARC was used to determine surface pressures in the free–air and wind tunnel flow field using the original test article and trailing edge wake geometry. The reference solution of the blockage problem was obtained by taking the difference of the surface pressure coefficients on corresponding panels (see Eq. (3)). This reference solution will be used to check the result of the improved wall signature method. The reference solution of the pressure coefficient correction on the surface of the test article at a distance of $y = 0.075$ from the tunnel centerline is given as the solid line in Fig. 7a .

In a second step wall pressure coefficients on chosen wall locations are calculated using panel code

PMARC. The wall locations are shown in Fig. 4 . The ideal wall pressure signature is perturbed by adding random disturbances of amplitude $|\Delta c_p| = 0.005$. This assumption is based on an experimental investigation[4]. Figure 6a shows the perturbed simulated wall pressure measurement 'c_{pw}'. This perturbed wall pressure signature will be used in combination with the wall pressure signature method to determine blockage corrections.

In the next step the wall pressure signature method is applied to the simulated wall pressure measurement given in Fig. 6a. The signal is split into a symmetric and antisymmetric part and the equivalent model representation is calculated based on procedures described in the previous sections. Figure 6a gives the result of the signature analysis procedure after the successful completion of the iteration. Figure 6b compares the exponential least squares fit of the symmetric signature to the measured signature.

Required influence functions were calculated for the specific wall pressure orifice location and wind tunnel cross-section. These charts are given in Figs. 5a, 5b and 5c . Figure 6c compares the test article with its equivalent geometric representation after completion of the signature analysis procedure. Test article and calculated equivalent representation show reasonable agreement.

In the last step blockage corrections 'c_{p_i}' are calculated as desribed in section 2.3. Figure 7a shows results of this calculation and compares them to the reference solution of the blockage problem. The agreement between reference solution (solid line) and the solution derived from the wall signature method (dashed line) is excellent which verifies the improvements.

The wall pressure signature based on the equivalent body are calculated as well. A comparison of this signature (dashed line) with the original simulated wall pressure measurement (solid line) is given in Fig. 7b. Both signals are in excellent agreement.

Panel code PMARC calculates velocities on panels using a numerical iteration technique. Therefore it is necessary to select the panel location on the test article, wake model and tunnel wall such that the panel code will converge for a variety of geometries. All calculations of the numerical example were done with a total number of panels in the order of 1000 .

4. Conclusion and Remarks

An improved version of a wall signature method to determine surface pressure corrections on the surface of a test article is presented. The method can be used in three-dimensional wind tunnel testing. It requires the measurement of wall pressure coefficients on a limited number of wall locations. These wall pressure measurements are combined with a signature analysis procedure to determine an equivalent representation of the test article and its wake. Blockage corrections are calculated based on the equivalent body.

Significant improvements of the signature analysis procedure are introduced to make the present method more efficient in on-line operation. It is also demonstrated that the present method can be combined with existing three-dimensional panel codes more effectively if an equivalent body is described in terms of surface panel elements.

The improved wall signature method is verified by using a numerical simulation of a wing and its trailing edge wake in a rectangular wind tunnel. Calculated blockage corrections show excellent agreement with the reference solution.

A few modifications will be required to apply the present method to the NASA/ARC 12ft Pressure Wind Tunnel. Influence functions will have to be calculated based on the quasi-octagonal cross-section of the tunnel and selected pressure orifice locations. This will require only a change in the panel code input file which describes the internal flow geometry.

In the future it will be necessary to apply the present method to existing experimental data to gain confidence in the method.

Acknowledgement

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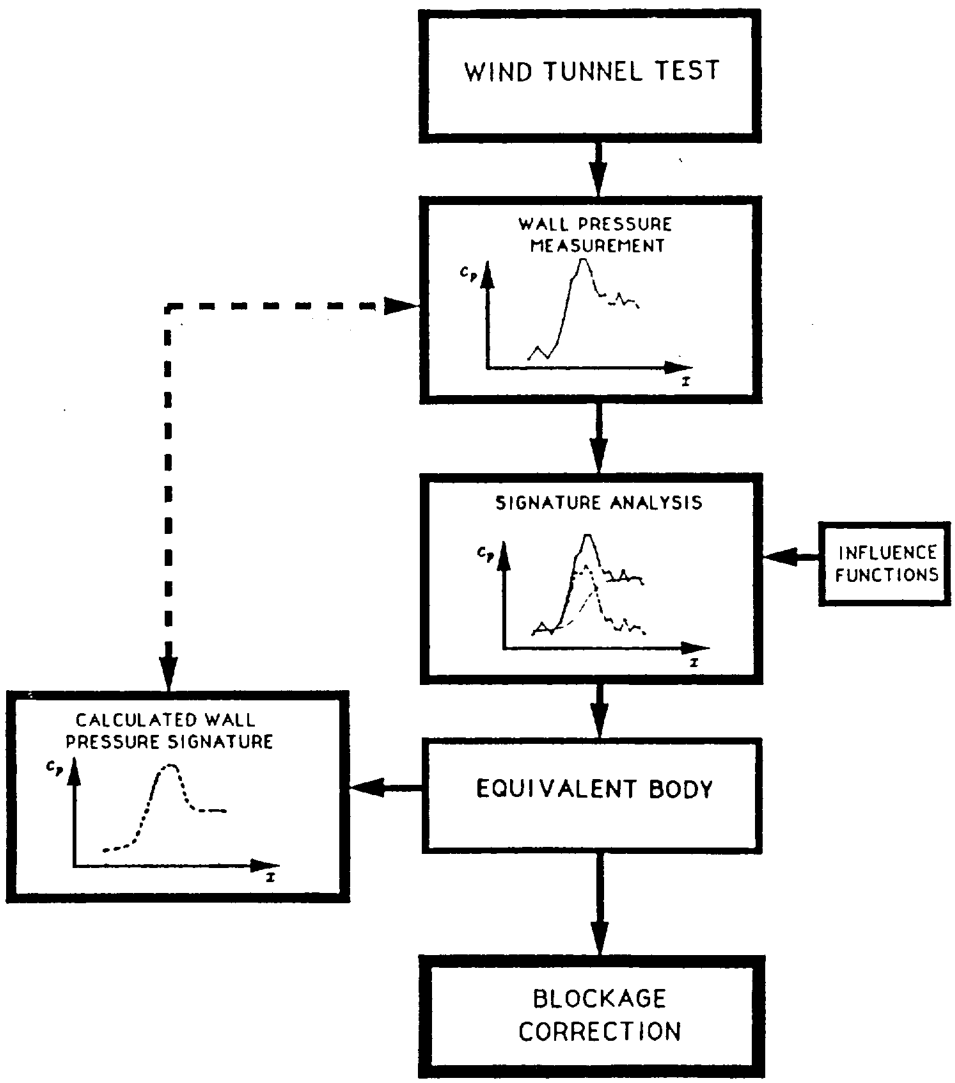

Fig.1 Basic Elements of a Wall Signature Method

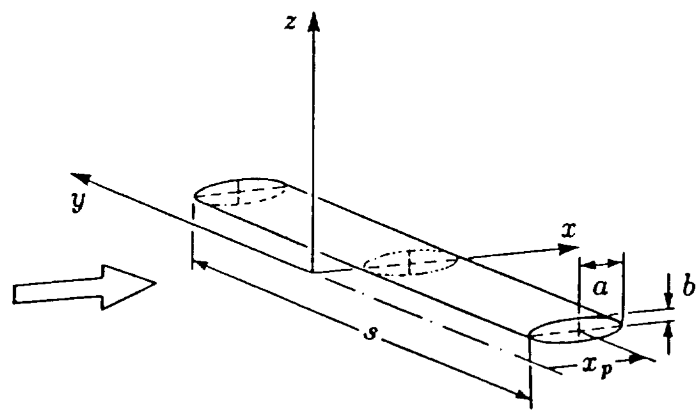

Fig.2a Test Article Model

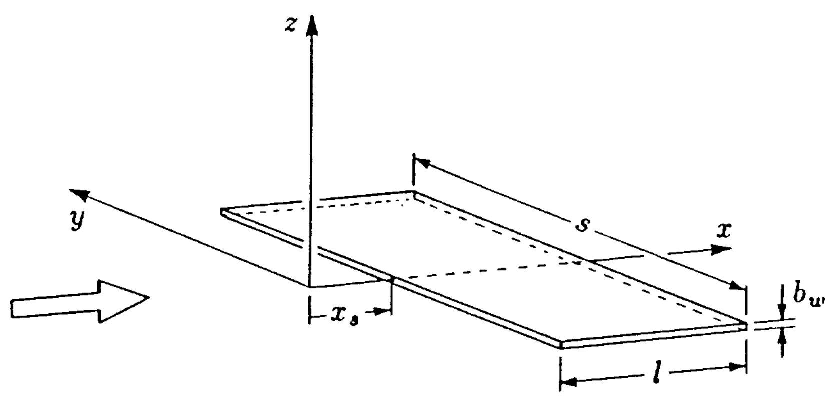

Fig.2b Wake Model

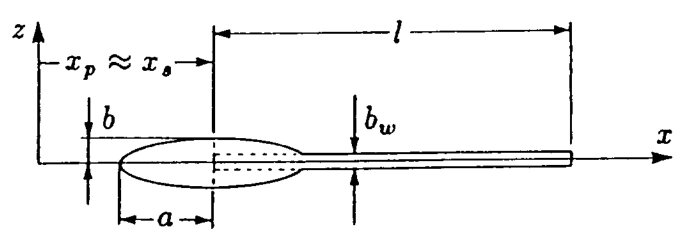

Fig.3 Equivalent Body

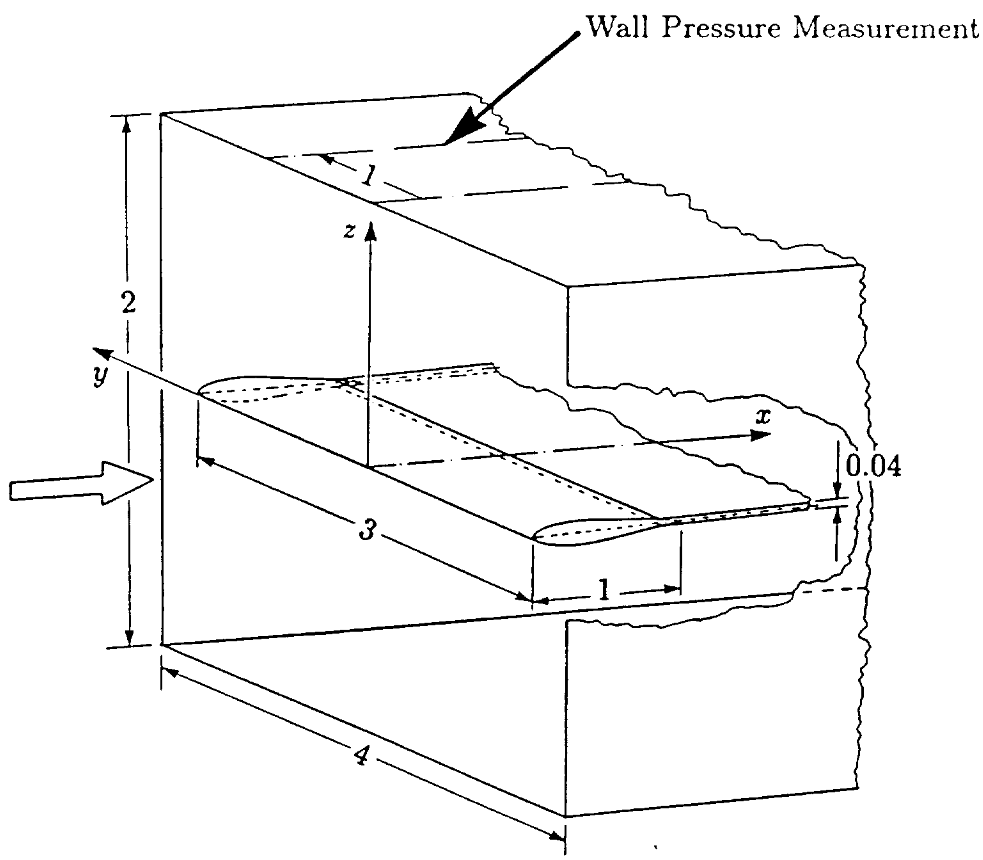

Fig.4 Geometry of Numerical Example

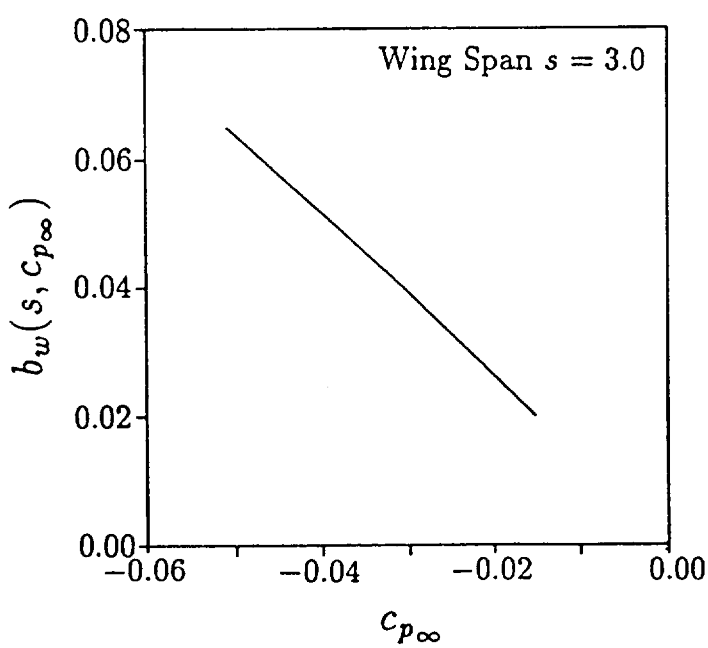

Fig.5a Influence Function $b_w(s, c_{p_\infty})$

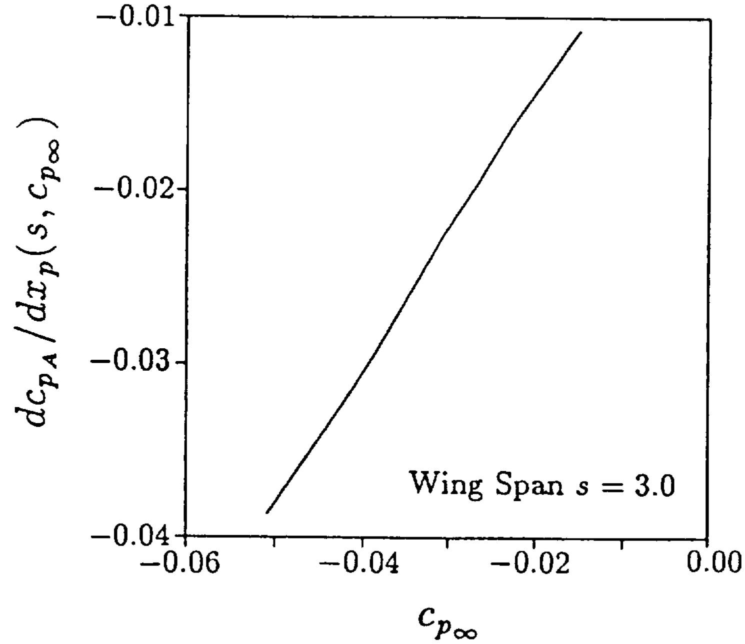

Fig.5b Influence Function $dc_{p_A}/dx_p(s, c_{p_\infty})$

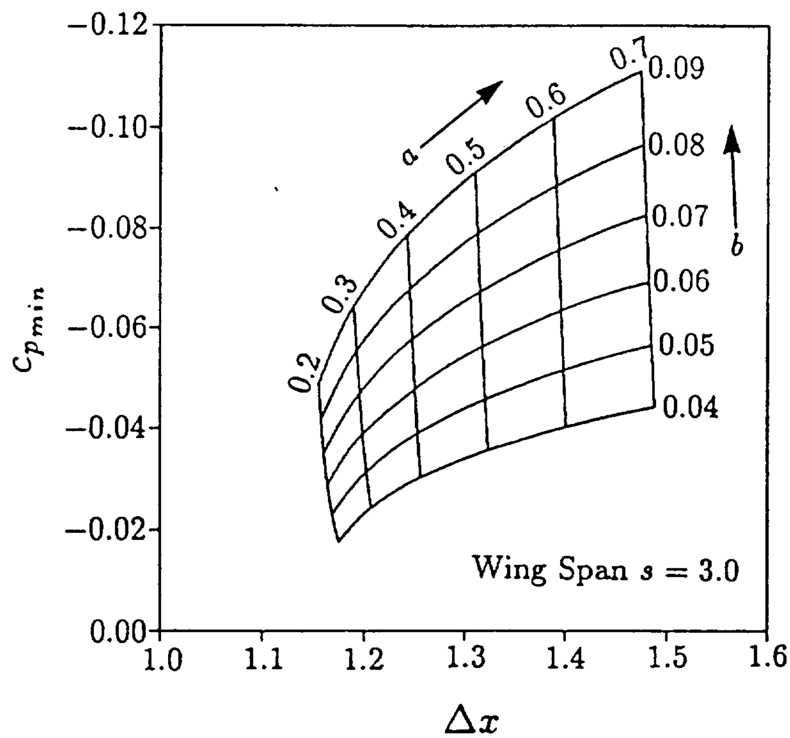

Fig.5c Influence Functions $a(s, \Delta x, c_{p_{min}})$, $b(s, \Delta x, c_{p_{min}})$

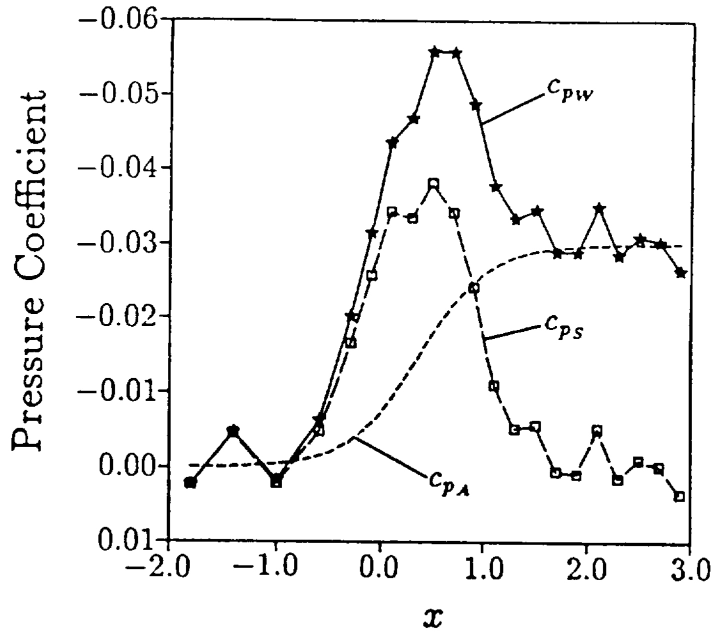

Fig.6a Signature Analysis

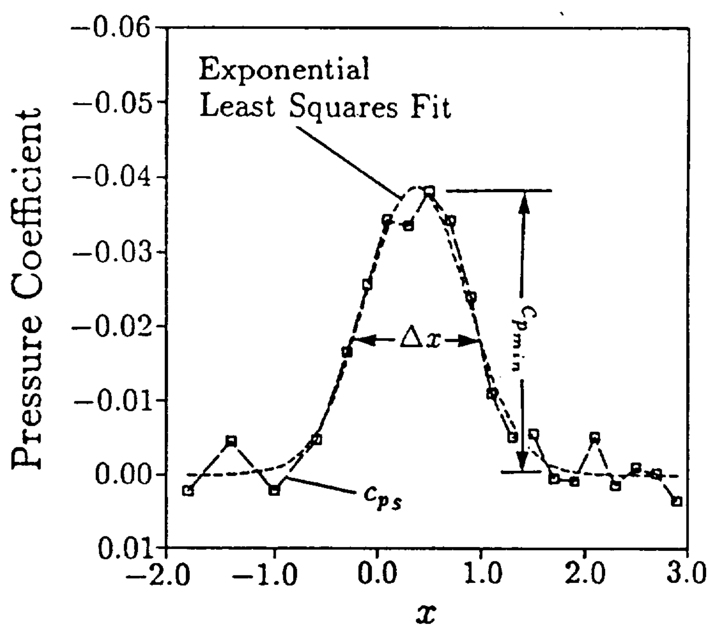

Fig.6b Exponential Least Squares Fit

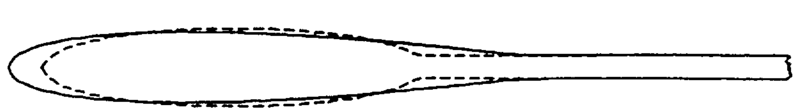

Fig.6c Comparison Test Article / Equivalent Body

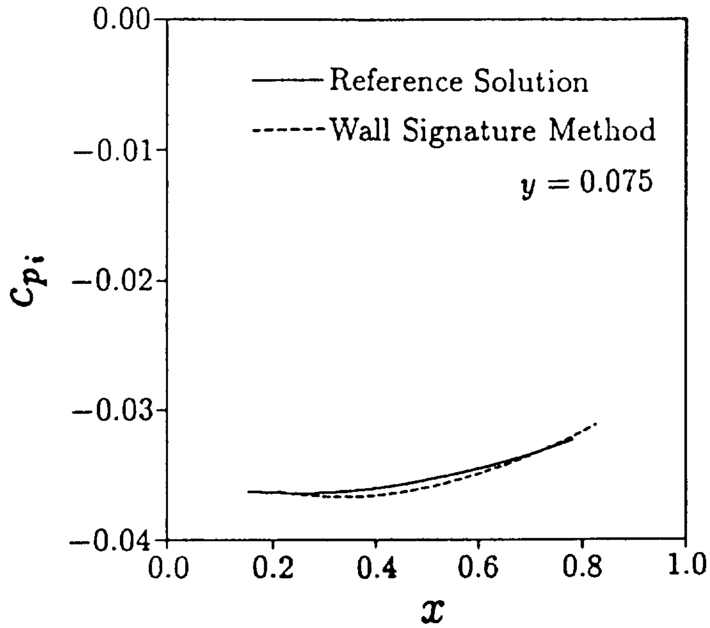

Fig.7a Pressure Coefficient Correction c_{p_i}

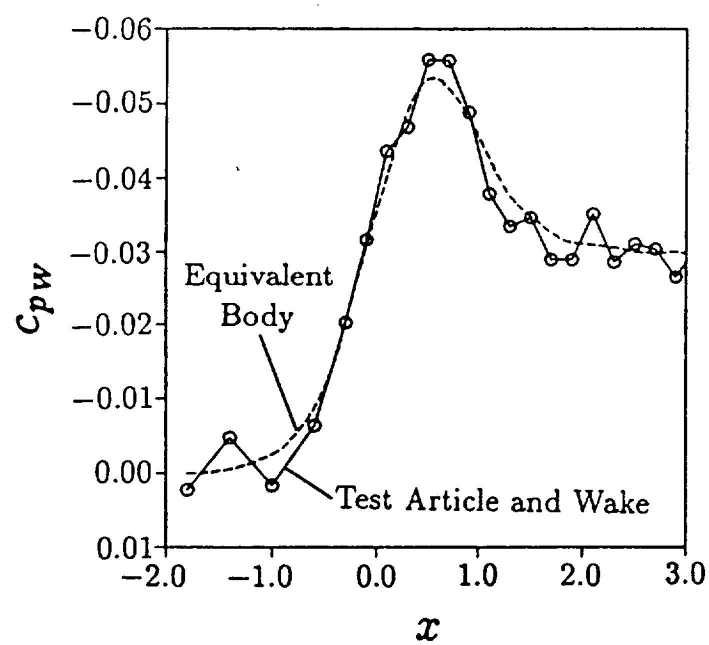

Fig.7b Wall Pressure Coefficient Comparison