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"FLEXIWALL 3 SO": A SECOND ORDER PREDICTIVE STRATEGY FOR RAPID WALL ADJUSTMENT IN TWO-DIMENSIONAL COMPRESSIBLE FLOW

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Michael Judd

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This report was prepared under contract to The University of Southampton in support of NASA Grant NSG-7172 entitled "The Self-Streamlining of the Test Section of a Transonic Wind Tunnel". The Principal Investigator is Dr. M. J. Goodyer.

"FLEXIWALL 3 SO": A Second Order Predictive Strategy for Rapid Wall Adjustment in Two Dimensional Compressible Flow.

1. Basic Exact First Order Strategy.

The method is based on the exact first order strategy previously presented. Two functions $g_u(x)$ and $g_l(x)$, derived closely from the previous work, are used as the first order solutions. They are in fact the first order incremental changes in upper and lower wall positions.

$$
\begin{aligned}
g_u(x) = \; & -\frac{1}{2} f_u(x) \\
& - \frac{\beta}{2\pi} \int_0^L \frac{u_{ui}(x')}{U} \ln \left| \frac{x'-x}{x'} \right| dx' \\
& + \frac{\beta}{4\pi} \int_0^L \frac{u_{li}(x')}{U} \ln \left[\frac{(\beta h)^2 + (x'-x)^2}{(\beta h)^2 + x'^2} \right] dx' \\
& - \frac{\beta h}{2\pi} \int_0^L f_l(x') \frac{dx'}{[(\beta h)^2 + (x'-x)^2]}
\end{aligned}
\qquad (1.1)
$$

where x and x' are measured from the start of the working section. The symbols are defined by :-

h = tunnel height

$\beta = \sqrt{1-(\text{Mach no})^2}$

U = freestream velocity

$u_{ui}(x), u_{li}(x)$ = upper and lower internal velocity increments respectively, measured from wall static pressures

$f_u(x), f_l(x)$ = initial upper and lower wall displacements from straight, both positive upwards.

L = tunnel flexible section length

The second function is given by :-

$$
\begin{aligned}
g_l(x) \quad = \quad & -\frac{1}{2} f_l(x) \\
& + \frac{\beta}{2\pi} \int_0^L \frac{u_{li}(x')}{U} \ln\left|\frac{x'-x}{x'}\right| dx' \\
& - \frac{\beta}{4\pi} \int_0^L \frac{u_{ui}(x')}{U} \ln\left[\frac{(\beta h)^2 + (x'-x)^2}{(\beta h)^2 + x'^2}\right] dx' \\
& - \frac{\beta h}{4\pi} \int_0^L f_u(x') \frac{dx'}{\left[(\beta h)^2 + (x'-x)^2\right]} \qquad \text{--- (1.2)}
\end{aligned}
$$

To the first order the new wall positions $F_u(x)$ and $F_l(x)$ are given by :-

$$F_u(x) = f_u(x) + g_u(x) \quad \text{and} \quad F_l(x) = f_l(x) + g_l(x)$$

2. Second Order Effect in Determining the Wall Streamline.

Not all the second order effects are considered here rigorously but the single most important one is included. The basis for the second order effect in determining the streamline wall shape is shown in figure 2.1. In this figure, $v_u(x)$ is the velocity induced normal to the upper wall by the upper wall vorticity and lower wall shape. It is related directly to $g_u(x)$ through the mass flow equation :-

$$\int_0^x \rho_0 v_u(x') \, dx' = \rho_0 U g_u(x) \qquad — \quad (2.1)$$

The function $g_u(x)$ has already been obtained by the transformation method in the form of equation (1.1) Hence the first order equation reduces to

$$\frac{1}{U}\int_0^x v_u(x') \, dx' = g_u(x) \qquad — \quad (2.2)$$

The second order equation takes account of two effects:-

(a) the density $\rho(x)$ is a function of local Mach number

(b) the mean velocity across AB differs from the freestream velocity U.

The second order equivalent to equation (2.1) becomes :-

$$\int_0^x \rho(x')\, v_u(x')\, dx' = \rho(x)\left[U + \frac{1}{2}u_{ue}(x) + \frac{1}{2}u_{ui}(x)\right]\Delta f_u(x) \qquad \text{— (2.3)}$$

Using the isentropic flow relationship between ρ and the local Mach number and using equation (2.2), equation (2.3) can be put in the approximate form :-

$$\Delta f_u(x) = \left[g_u(x) - M_0^2\, h_u(x)\right] \Big/ \left[1 + \beta^2 \Delta u_u(x)\right] \qquad \text{— (2.4)}$$

where M_0 is the freestream Mach number corresponding to the velocity U and

$$\Delta u_u(x) = \frac{1}{2}\left[\frac{u_{ue}(x)}{U} + \frac{u_{ui}(x)}{U}\right] \qquad \text{— (2.5)}$$

and $$h_u(x) = \int_0^x \Delta u_u(x')\, \frac{dg_u(x')}{dx'}\, dx' \qquad \text{— (2.6)}$$

Here the incremental external wall velocity distribution $u_{ue}(x)$ must be computed from the initial wall shape $f_u(x)$ using the relationship :-

$$\frac{u_{ue}(x)}{U} = \frac{1}{\beta\pi} \int_0^L \frac{1}{(x'-x)} \frac{df_u(x')}{dx'} \, dx' \qquad \text{— (2.7)}$$

To the second order the new wall positions are given by:—

$$F_u(x) = f_u(x) + \Delta f_u(x) \qquad \text{— (2.8).}$$

and its lower wall equivalent.

The lower wall equations may be summarized as:-

$$\frac{u_{le}(x)}{U} = -\frac{1}{\beta\pi} \int_0^L \frac{1}{(x'-x)} \frac{df_l(x')}{dx'} \, dx' \qquad \text{— (2.9)}$$

$$\Delta u_l(x) = \frac{1}{2}\left[\frac{u_{le}(x)}{U} + \frac{u_{li}(x)}{U}\right] \qquad \text{— (2.10)}$$

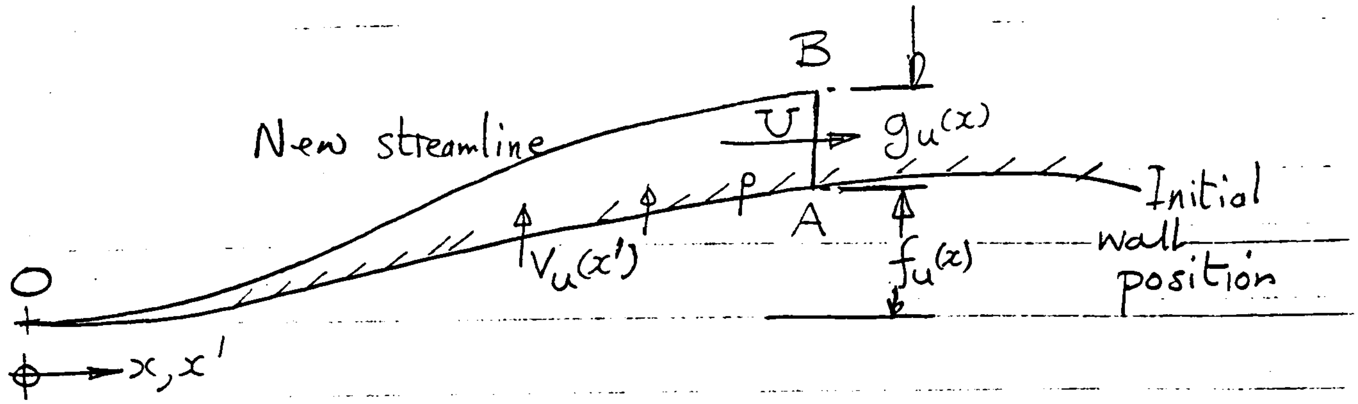
$g_l(x)$ from equation (1.2)

$$h_l(x) = \int_0^x \Delta u_l(x) \frac{dg_l(x')}{dx'} \, dx' \qquad \text{— (2.11)}$$

$$\Delta f_l(x) = \left[g_l(x) - M_0^2 h_l(x)\right] \Big/ \left[1 + \beta^2 \Delta u_l(x)\right] \qquad \text{— (2.12)}$$

$$F_l(x) = f_l(x) + \Delta f_l(x) \qquad \text{— (2.13)}$$

Figure 2.1. Comparison of First and Second Order Free Streamlines.

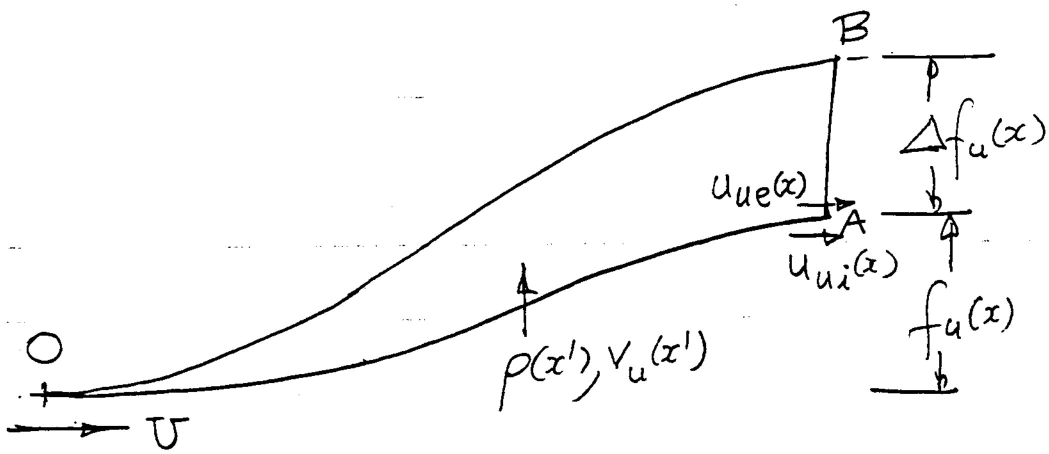


ρ_0 is flow density at velocity U.

Equating mass flow across OA to that across AB gives:-

$$\int_0^x \rho_0 V_u(x')\,dx' = \rho_0 U g_u(x)$$

Figure 2.1.a. First Order Prediction.



Equating mass flows gives:-

$$\int_0^x \rho(x')\,V_u(x')\,dx' = \rho(x)\left[U + \frac{1}{2}u_{ue}(x) + \frac{1}{2}u_{ui}(x)\right]\Delta f_u(x)$$

Figure 2.1.b Second Order Prediction.

3. Program Structure.

The sequence of operations in the program are shown diagrammatically in figure 3.1 for the upper wall. The operations are related to the equations developed in Sections 1 and 2. The measured quantities and input data are f_u, u_{ui}, f_ℓ and $u_{\ell i}$. The incremental velocity components u_{ui} and $u_{\ell i}$ are fed as data in the form of actual local Mach number $M(x)$ and then converted using:—

$$\frac{u}{U} = \left[M(x) - M_o\right] \Big/ \left[1 + \frac{(\gamma-1)}{2}M_o^2\right] M_o \qquad - \quad (3.1)$$

with γ taken as 1·4 and M_o as the undisturbed flow Mach number.

The integers, variables and arrays used in the program are defined in Appendix A together with a program listing. The FLEXIWALL 3 SO program is general for lines 20 to 6310. Data is input beginning at line 7000. Some description is included with the program listing.

A sample program print out is given in Appendix B. This comprises the data listing and the results for the case of flow normal to a flat plate, the test case described in Section 4.

In the input data (lines 100 and 7000), M is the number of jacks (and wall pressure taps) ie M = 20 for the Southampton tunnel. For the analytical case in Section 4

M was taken as 26. The x-coordinates corresponding to these locations is given by X(N) (lines 210 and 7020)

The run time for the full program is 25 to 30 minutes on the Apple II computer with a Trendcom printer. This can be considerably reduced by eliminating the print out of all parameters except the new wall positions. Initial results suggest that the second order quantities $h_u(x)$ and $h_l(x)$ are extremely small and it is unnecessary to compute them.

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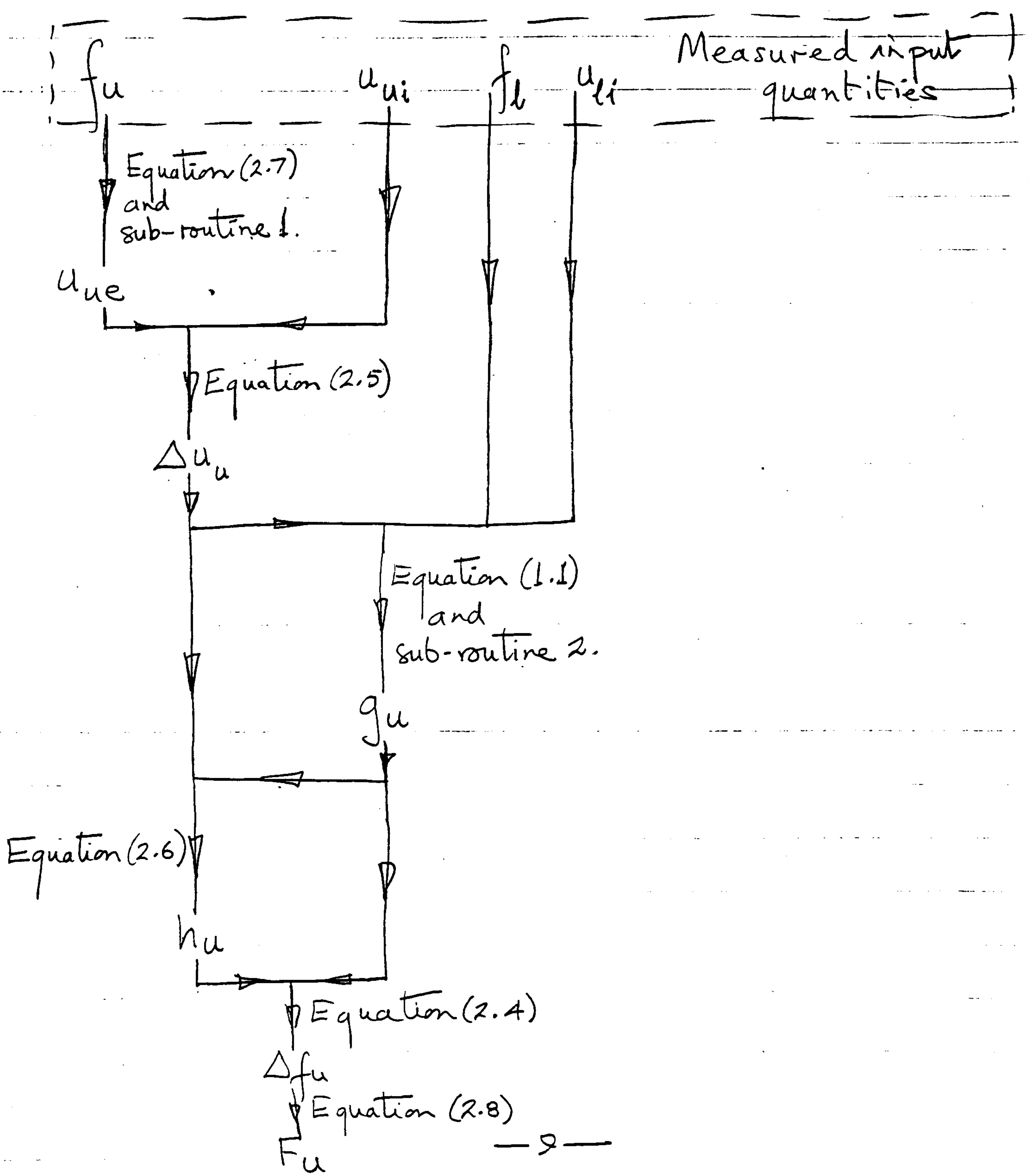
Figure 3.1. Program Flow Diagram for the Upper Wall Adjustment.



4. An Exact Analytic Test Case for the Wall Adjustment Strategy.

In order to test the validity of the strategy it is useful to have an exact analytic test case. In this way, the viscous flows around the real model will not be present and produce adjustments to the model flow field. The case used here is shown in figure 4.1. In figure 4.1.a, the potential flow around a flat plate wing of chord $2c$ is constrained between straight walls distance h apart and equidistant from the wing. The wing is normal to the flow, which is incompressible. The velocity distribution along both top and bottom walls is given by:-

$$u(x) = \frac{U\left(1 + \exp\frac{\pi x}{2h}\right)}{\sqrt{1 + \exp\frac{\pi x}{h} + 2\exp\frac{\pi x}{2h}\cos\frac{\pi c}{2h}}} \qquad — (4.1)$$

where x is measured downstream from the wing position.

The equation for the streamline which asymptotes to $y = h/2$ in the unconstrained flow is given by:-

$$y = \frac{h}{2}\sqrt{\frac{x^2 + c^2 + (h/2)^2}{x^2 + (h/2)^2}} \qquad — (4.2)$$

The velocity distribution in equation (4.1) was used with the program listed in Appendix A to generate the wall movements as "NEW UPPER POSN" and "NEW LOWER POSN" in the results of Appendix B. The agreement is good, particularly when it is appreciated that the blockage is extremely high. The total chord (2c) of the wing is equal to the tunnel semi-height (h/2) and, for the straight walls, the wall velocity at the plate location is more than 40% higher than the freestream velocity. Since the flow is inviscid, there is no viscous flow adjustment at the model with and without the wall presence i.e. there is no transition or separation point movement or boundary layer growth change.

Figure 4.1. Notation for Potential Flow Normal to a Flat Plate With and Without Straight Wall Constraints.

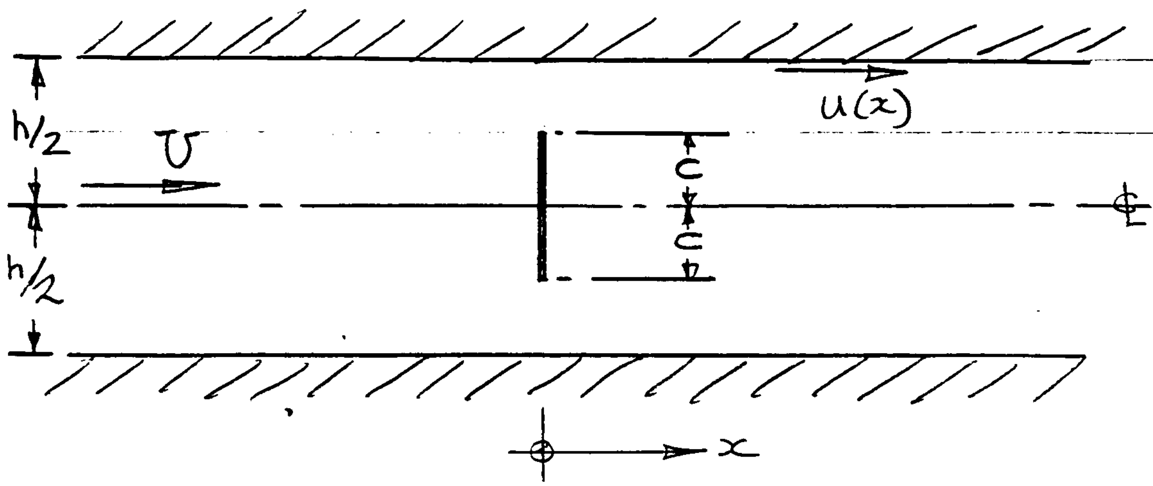


Figure 4.1.a. Flow over Normal Flat Plate and Constrained between Straight Walls.

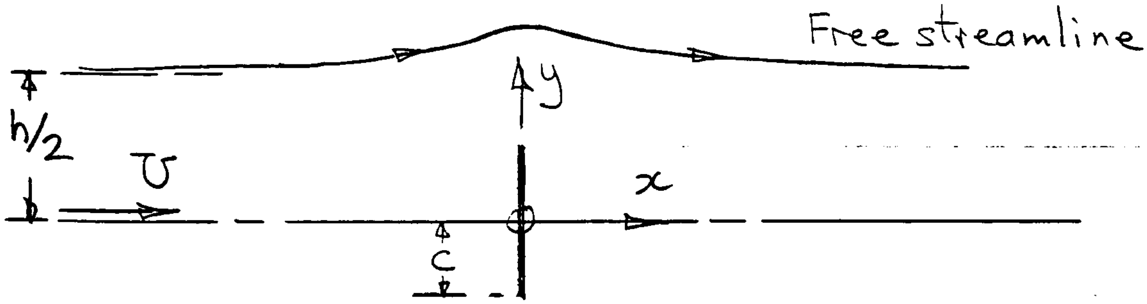
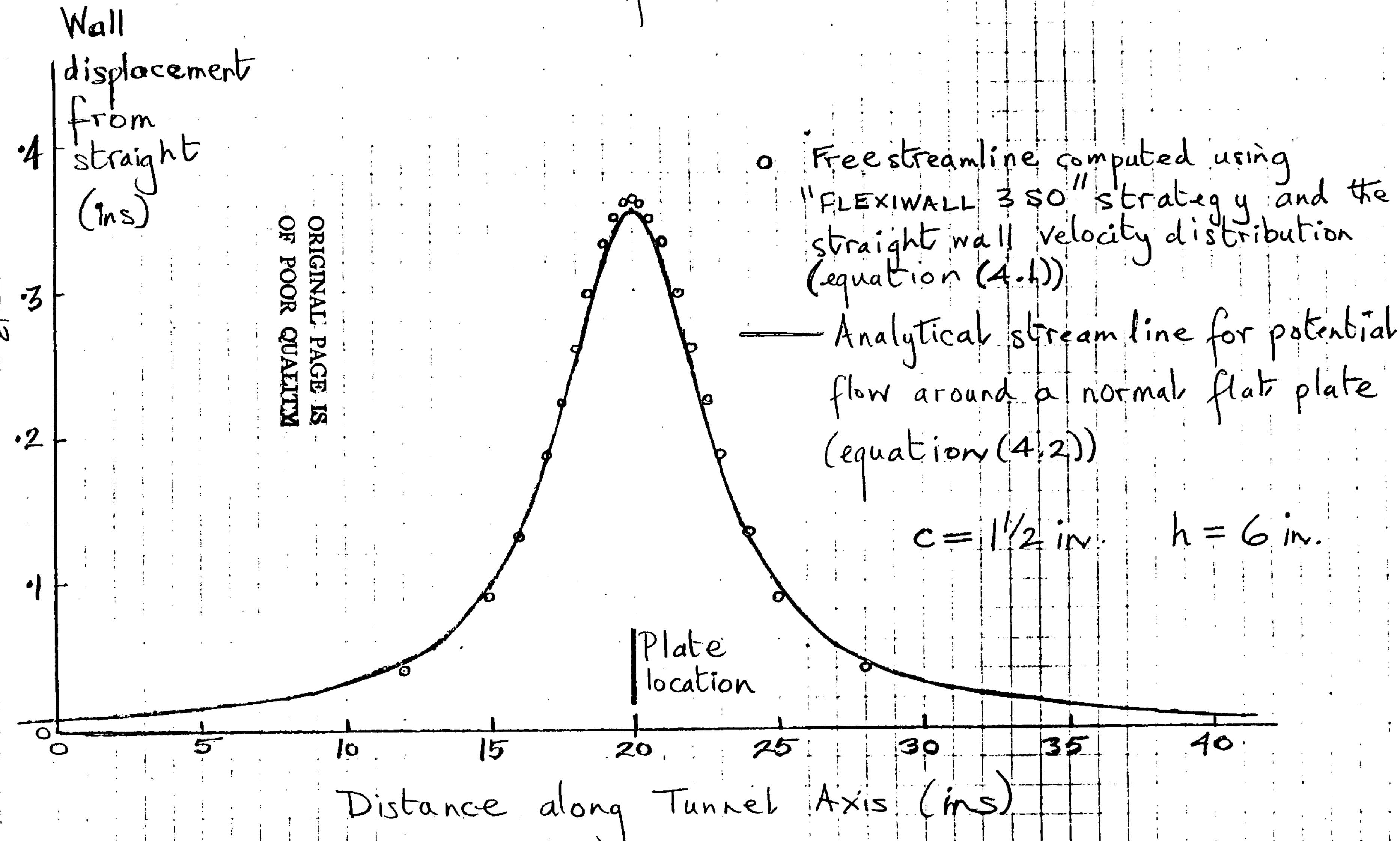


Figure 4.1.b. Unconstrained Flow over Normal Flat Plate.

Figure 4.2. Comparison of Actual Free Streamline with Computed Wall Position for Potential Flow Normal to a Flat Plate.



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5. Application to Model Test Data in the Southampton Tunnel.

The method of Flexiwall 3 SO was applied to existing data obtained from test runs in the Southampton Tunnel. The results are presented in figure 5.1. There are three curves each for the upper and lower walls. These were derived as follows :-

Curve A, upper and lower wall, solid circles

Results obtained by applying "FLEXIWALL 3 SO" to straight wall data from Run No. 40. The data and results are tabulated in APPENDIX C.

Curve B, upper and lower wall, open circles

Results obtained by applying "FLEXIWALL 3 SO" to the wall position and velocity data from Run No. 112 i.e. to the data for the wall streamlined by the present Southampton method. The data and results are tabulated in APPENDIX D.

Curve C, upper and lower wall, diagonal crosses.

Streamlined wall shapes predicted by the present Southampton method and used as the basis for the velocity distributions obtained in Run No. 112.

7.

If the "FLEXIWALL 3 SO" strategy is "exact" then curves A and B should coincide. They are close for the upper wall but there is some discrepancy for the lower wall. There is also a significant difference between these curves and the presently accepted shape in Curve C. During computation it was noted that the magnitude of the wall change was sensitive to incremental changes in wall Mach number. It is also possible that there would be some adjustment in flow around the model. No account has been made in Curves A and B for wall boundary layer growth. It is not easy to relate the errors in wall position to quantitative errors in the model pressure distributions or forces. However, the velocity potential inside the tunnel is available from an extension of the analysis previously submitted. This takes the form:-

$$\phi(x,y) = \frac{U}{2\beta^2 h}\int_0^L \left\{ f_u(\xi)\frac{\sinh \chi}{(\cosh\chi + \cos\frac{\pi y}{h})} - f_l(\xi)\frac{\sinh\chi}{(\cosh\chi - \cos\frac{\pi y}{h})}\right\} d\xi \qquad -(5.1)$$

where $\chi = \dfrac{\pi(\xi - x)}{h}$

The centreline velocity components can be obtained by differentiation. The results are :-

$$u\left(x,\frac{h}{2}\right) = -\frac{\pi U}{2\beta^3 h^2}\int_0^L \frac{\{-f_u(\xi) - f_l(\xi)\}}{\cosh^2 \frac{\pi(\xi - x)}{\beta h}}\, d\xi \qquad \text{— (5.2)}$$

and $$v\left(x,\frac{h}{2}\right) = \frac{\pi U}{2\beta^3 h^2}\int_0^L \{f_u(\xi) + f_l(\xi)\} \frac{\sinh \frac{\pi(\xi - x)}{\beta h}}{\cosh^2 \frac{\pi(\xi - x)}{\beta h}}\, d\xi . \qquad \text{— (5.3)}$$

The differences in upper and lower wall positions between curves A and B in figure 5.1 were used in equations 5.2) and (5.3) to compute the corresponding increments in u and v at the centreline opposite jack station 11 (22 ins. from the tunnel origin). The results were:-

$$u = 0{\cdot}0043\, U \qquad \text{— (5.4)}$$

$$v = -0{\cdot}000904\, U \qquad \text{— (5.5)}$$

The error in u is equivalent to an error in C_p or C_L of -0.0086.

The error in v is equivalent to an error in incidence of $-0{\cdot}0518°$.

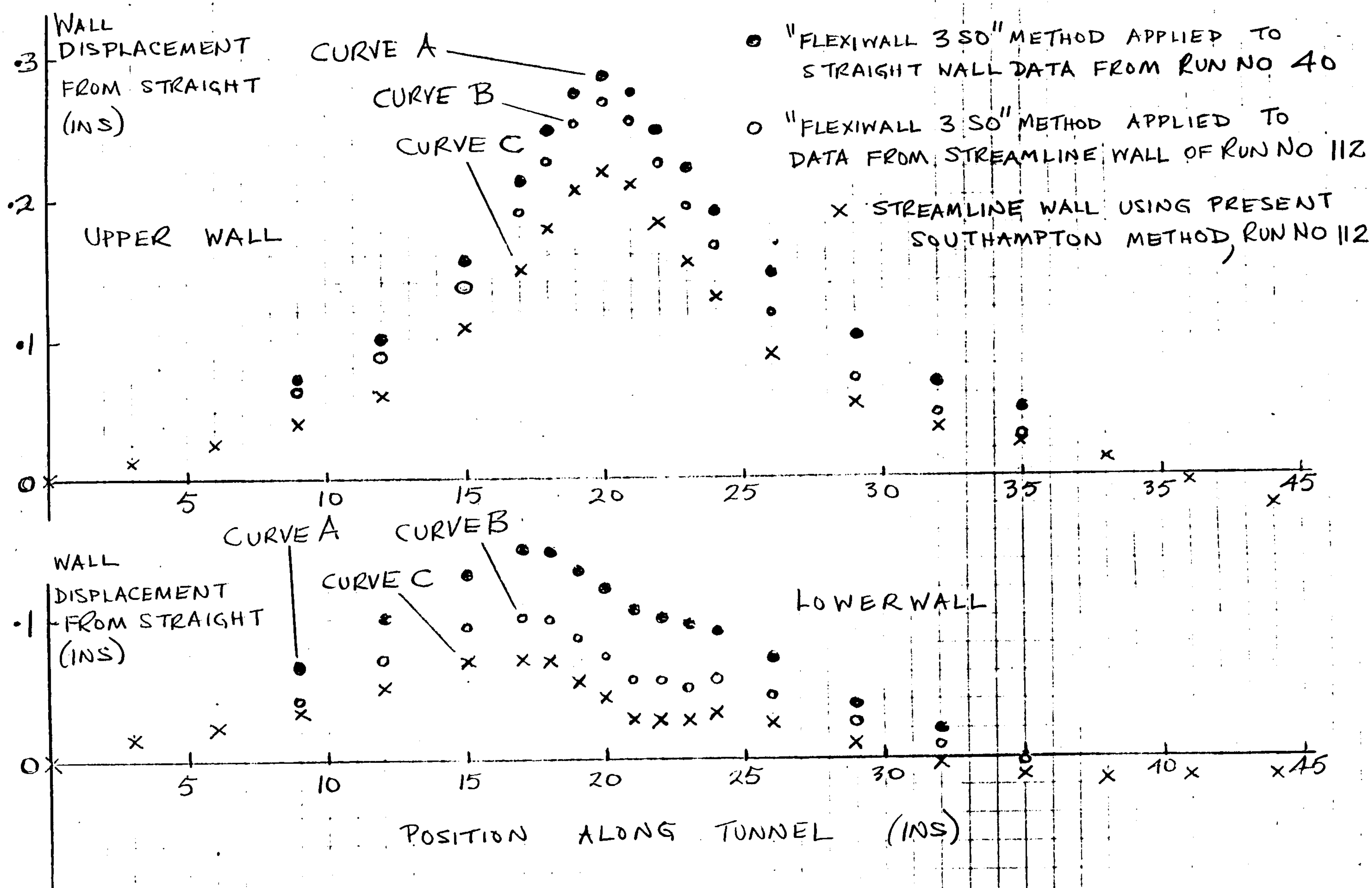

FIGURE 5.1. TSWT WALL CONTOURS: $\alpha = 4^\circ$, MACH NO = 0·5

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6. Conclusions.

An "exact" second order strategy for wall adjustments in compressible flow has been developed. This allows a one-step wall movement provided there are no significant viscous flow adjustments at the model itself and provided transonic flow effects are not large.

The method has been applied to a computer experiment based on the potential flow normal to a flat plate with and without straight wall constraint. The method gives an exact prediction of the free streamlines for the flat plate.

When applied to data from the University of Southampton transonic self-streamlining wind tunnel, some discrepancy in results occurs. Further study is required and other cases should be analysed.

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APPENDIX A. PROGRAM LISTING.

This Appendix first relates the program integers, variables and arrays to the equivalent symbols in equations (1.1) to (2.13), and to the physical quantities that these symbols represent. The program listing for the flat plate case in Section 4 is then presented.

Numerical variables

MØ	Mach no. of mean flow	
B	$\beta = \sqrt{1-(\text{Mach no})^2}$	
H	h = tunnel height	(h = 6 in.)
PI	π	
M	no. of stations	(M = 20)
EO	sub-routine 1	
E1	" " 1	
E2	" " 1	
B1	" " 1	
C1	" " 1	

7.

I1	sub-routine		1
I2	"	"	1
I3	"	"	1
F0	sub-routine		2
F1	"	"	2
F2	"	"	2
A2	"	"	2
B2	"	"	2
C2	"	"	2.
I4	"	"	2
I5	"	"	2
I6	"	"	2.
I7	"	"	2
I8	"	"	2.

F0 variables used in
F1 lines 800
F2 through 1060
F3
F4
F5

7.

F6 variables used in
F7 lines 1100
F8 through 1400
F9
G0
G1

E3 variables used in
E4 lines 1450
E5 through
B3 1720
C3
G2

E6 variables used in
E7 lines 1750
E8 through
B4 2020
C4
G3

A5 variables used in both
B5 subroutines

7.

Arrays.

X(N) x or x_n coordinate of station n.

UU(N) $\frac{u_{ue}(x)}{U}$ upper external vel.

UL(N) $\frac{u_{le}(x)}{U}$ lower external vel.

VU(N) $\frac{u_{ui}(x)}{U}$ upper internal vel

VL(N) $\frac{u_{li}(x)}{U}$ lower internal vel.

DU(N) $\Delta u_u(x) = \frac{1}{2}\left[\frac{u_{ue}}{U} + \frac{u_{ui}}{U}\right]$

DL(N) $\Delta u_l(x) = \frac{1}{2}\left[\frac{u_{le}}{U} + \frac{u_{li}}{U}\right]$

FU(N) $f_u(x)$ upper wall coordinates.

FL(N) $f_l(x)$ lower wall coordinates.

GU(N) $g_u(x)$ derived function

GL(N) $g_l(x)$ " "

HU(N) $h_u(x)$ derived function

HL(N) $h_l(x)$ " "

EU(N) $\Delta f_u(x)$ change in upper wall position

EL(N) $\Delta f_l(x)$ change in lower wall position.

FW(J) sub-routine 1

SL(N) sub-routine 1.

VW(J) sub-routine 2.

S2(N) " " 2.

PØ(N) parking array for intermediate value of GL(x) prior to printout

SU(N) $\frac{dg_u}{dx}$

SL(N) $\frac{dg_l}{dx}$

NU(N) $f_u(x) + \Delta f_u(x) \equiv F_u(x)$, new upper wall position

NL(N) $f_l(x) + \Delta f_l(x) \equiv F_l(x)$, new lower wall position

APPENDIX A(CONTD). PROGRAM LISTING.

FLEXIWALL 3SO. FOR FLAT PLATE NORMAL TO POTENTIAL FLOW.

```
]PR#0
]LIST

20  PRINT "FLEXIWALL 3 SO"
50  PRINT "SECOND ORDER FLEXIWALL
     PREDICTIVE STRATEGY"
100  READ M
```

H is tunnel height

```
110  READ H
120 PI = 3.142
130  READ M0
```

Free stream Mach no.

```
135  PRINT "M=";M,"H=";H;"INS","M
     ACH NO=";M0
140 B =  SQR (1 - M0 ^ 2)
```

$B = \beta$.

```
150  DIM X(M)
155  DIM UU(M),UL(M),VU(M),VL(M)
160  DIM DU(M),DL(M),FU(M),FL(M)
165  DIM GU(M),GL(M),HU(M),HL(M)
170  DIM EU(M),EL(M)
175  DIM FW(M),S1(M),VW(M),S2(M)
180  DIM P0(M),SU(M),SL(M)
185  DIM NU(M),NL(M)
200  FOR N = 0 TO M
210  READ X(N)
215  NEXT N
```

x-coords. of jack and pressure tap locations

```
220  FOR N = 0 TO M
225  READ FU(N)
230  NEXT N
240  FOR N = 0 TO M
245  READ FL(N)
250  NEXT N
260  FOR N = 0 TO M
265  READ VU(N)
270 VU(N) = (VU(N) - M0) / ((1 +
     (M0 ^ 2) / 5) * M0)
275  NEXT N
280  FOR N = 0 TO M
285  READ VL(N)
290 VL(N) = (VL(N) - M0) / ((1 +
     (M0 ^ 2) / 5) * M0)
295  NEXT N
400  REM  CALCULATION OF UPPER WA
     LL EXTERNAL VELOCITY
420  FOR N = 0 TO M
425 FW(N) = FU(N)
430  NEXT N
440 UU(0) = 0
445  FOR N = 2 TO M - 2
450  GOSUB 5000
455 UU(N) = S1(N)
460  NEXT N
462 UU(M - 1) = UU(M - 2)
465 UU(M) = UU(M - 1)
468 UU(1) = UU(2) / 2
```

Calculation of external upper wall velocity increment $u_{ue}(x)$ using equation (2.7)

```
470  PRINT "X COORD","UPPER VEL"
475  FOR N = 0 TO M
480  PRINT X(N),UU(N)
482 DU(N) = (UU(N) + VU(N)) / 2
485  NEXT N
```

Calculation of $\Delta u_u(x)$, equation (2.5)

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```
500  REM  CALCULATION OF LOWER WA
     LL EXTERNAL VELOCITY
520  FOR N = 0 TO M
525 FW(N) = FL(N)
530  NEXT N
540 UL(0) = 0
545  FOR N = 2 TO M - 2
550  GOSUB 5000
555 UL(N) =  - S1(N)
560  NEXT N
562 UL(M - 1) = UL(M - 2)
565 UL(M) = UL(M - 1)
568 UL(1) = UL(2) / 2
```

Calculation of external lower wall velocity increment $u_{le}^{(x)}$ using equation (2.9)

```
570  PRINT "X COORD","LOWER VEL"
575  FOR N = 0 TO M
580  PRINT X(N),UL(N)
582 DL(N) = (UL(N) + VL(N)) / 2
```

— Calculation of $\Delta u_l(x)$, equation (2.10)

```
585  NEXT N
600  REM  CALCULATION OF PRINCIPA
     L VALUE INTEGRAL IN·GU(X)
620  FOR N = 0 TO M
625 UW(N) = UU(N)
630  NEXT N
640 GU(0) = 0
645  FOR N = 3 TO M - 2
650  GOSUB 6000
655 GU(N) =  - FU(N) / 2 - S2(N)
660  NEXT N
662 GU(M - 1) = GU(M - 2)
665 GU(M) = GU(M - 1)
668 GU(2) = GU(3) / 2
669 GU(1) = GU(2) / 2
```

FU(N)/2 in 655 is $f_u(x)/2$ in equation (1.1)

S2(N) in 655 is the principal value integral in equation (1.1)

```
670  PRINT "X COORD","TERM 1+2 IN
      GU(X)"
675  FOR N = 0 TO M
680  PRINT X(N),GU(N)
685  NEXT N
700  REM  CALCULATION OF PRINCIPA
     L VALUE INTEGRAL IN GL(X)
720  FOR N = 0 TO M
725 UW(N) = UL(N)
730  NEXT N
740 GL(0) = 0
745  FOR N = 3 TO M - 2
750  GOSUB 6000
755 GL(N) =  - FL(N) / 2 + S2(N)
760  NEXT N
762 GL(M - 1) = GL(M - 2)
765 GL(M) = GL(M - 1)
768 GL(2) = GL(3) / 2
769 GL(1) = GL(2) / 2
770  FOR N = 0 TO M
775 P0(N) = GL(N)
780  NEXT N
```

FL(N)/2 in 755 is $f_l(x)/2$ in equation (1.2)

S2(N) in 755 is the principal value integral in equation (1.2)

```
800' REM  CALCULATION OF REMAINDE
     R OF GU (X) AND OF FINAL GU(
     X)
850 GU(0) = 0
860  FOR N = 1 TO M
870 J = 0
880 F0 = 0
890 J = J + 1
900 F1 = VL(J) *  LOG (((B * H) ^
     2 + (X(J) - X(N)) ^ 2) / ((B
      * H) ^ 2 + X(J) ^ 2))
910 F2 = VL(J - 1) *  LOG (((B *
     H) ^ 2 + (X(J - 1) - X(N)) ^
     2) / ((B * H) ^ 2 + X(J - 1)
      ^ 2))
920 F0 = F0 + B * (F1 + F2) * (X(
     J) - X(J - 1)) / (8 * PI)
930  IF J < M THEN  GOTO 890
950 J = 0
960 F3 = 0
970 J = J + 1
980 F4 = FL(J) / ((B * H) ^ 2 + (
     X(J) - X(N)) ^ 2)
990 F5 = FL(J - 1) / ((B * H) ^ 2
      + (X(J - 1) - X(N)) ^ 2)
1000 F3 = F3 + (B * H * (X(J) - X
     (J - 1)) * (F4 + F5)) / (4 *
     PI)
1010  IF J < M THEN  GOTO 970
```

Calculation of third and fourth terms in equation (1.1)

```
1020 GU(N) = GU(N) + F0 - F3
1030  NEXT N
1040  PRINT "X COORD","FULL TERM
     GU(X)"
1050  FOR N = 0 TO M
1060  PRINT X(N),GU(N)
1070  NEXT N
1100  REM  CALCULATION OF REMAIND
     ER OF GL(X) AND OF FINAL GL(
     X)
1150 GL(0) = 0
1160  FOR N = 1 TO M
1170 J = 0
1180 F6 = 0
1190 J = J + 1
1200 F7 = VU(J) *  LOG (((B * H) ^
     2 + (X(J) - X(N)) ^ 2) / ((B
      * H) ^ 2 + X(J) ^ 2))
1210 F8 = VU(J - 1) *  LOG (((B *
     H) ^ 2 + (X(J - 1) - X(N)) ^
     2) / ((B * H) ^ 2 + X(J - 1)
      ^ 2))
1220 F6 = F6 + B * (F7 + F8) * (X
     (J) - X(J - 1)) / (8 * PI)
1230  IF J < M THEN  GOTO 1190
1240 J = 0
1250 F9 = 0
1260 J = J + 1
1270 G0 = FU(J) / ((B * H) ^ 2 +
     (X(J) - X(N)) ^ 2)
1280 G1 = FU(J - 1) / ((B * H) ^
     2 + (X(J - 1) - X(N)) ^ 2)
1290 F9 = F9 + (B * H * (X(J) - X
     (J - 1)) * (G0 + G1)) / (4 *
     PI)
1300  IF J < M THEN  GOTO 1260
1310 GL(N) = GL(N) - F6 - F9
1320  NEXT N
```

Calculation of third and fourth terms in equation (1.2)

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```
1330  PRINT "X COORD","TERM 1+2 I
      N GL(X)"
1340  FOR N = 0 TO M
1350  PRINT X(N),P0(N)
1360  NEXT N
1370  PRINT "X COORD","FULL TERM
      GL(X)"
1380  FOR N = 0 TO M
1390  PRINT X(N),GL(N)
1400  NEXT N
1450  REM  CALCULATION OF HU(X)
1500 SU(0) = 0
1510  FOR N = 1 TO M - 1
1520 E3 = GU(N - 1) / ((X(N) - X(
     N - 1)) * (X(N + 1) - X(N -
     1)))
1530 E4 = GU(N) / ((X(N - 1) - X(
     N)) * (X(N + 1) - X(N)))
1540 E5 = GU(N + 1) / ((X(N - 1) -
     X(N + 1)) * (X(N) - X(N + 1)
     ))
1550 B3 =  - (X(N) + X(N + 1)) *
     E3 - (X(N - 1) + X(N + 1)) *
     E4 - (X(N - 1) + X(N)) * E5
1560 C3 = E3 + E4 + E5
1570 SU(N) = B3 + 2 * C3 * X(N)
1580  NEXT N
1590 SU(M) = SU(M - 1)
1600 HU(0) = 0
1610  FOR N = 1 TO M
1620 J = 0
1630 G2 = 0
1640 J = J + 1
1650 G2 = G2 + ((DU(J) * SU(J) +
     DU(J - 1) * SU(J - 1)) * (X(
     J) - X(J - 1))) / 2
1660  IF J < N THEN  GOTO 1640
1670 HU(N) = G2
1680  NEXT N
1690  PRINT "X COORD","HU(X)"
1700  FOR N = 0 TO M
1710  PRINT X(N),HU(N)
1720  NEXT N
```

Calculation of $h_u(x)$ in equation (2.6)

```
1750  REM  CALCULATION OF HL(X)
1800 SL(0) = 0
1810  FOR N = 1 TO M - 1
1820 E6 = GL(N - 1) / ((X(N) - X(
     N - 1)) * (X(N + 1) - X(N -
     1)))
1830 E7 = GL(N) / ((X(N - 1) - X(
     N)) * (X(N + 1) - X(N)))
1840 E8 = GL(N + 1) / ((X(N - 1) -
     X(N + 1)) * (X(N) - X(N + 1)
     ))
1850 B4 =  - (X(N) + X(N + 1)) *
     E6 - (X(N - 1) + X(N + 1)) *
     E7 - (X(N - 1) + X(N)) * E8
1860 C4 = E6 + E7 + E8
1870 SL(N) = B4 + 2 * C4 * X(N)
1880  NEXT N
1890 SL(M) = SL(M - 1)
1900 HL(0) = 0
1910  FOR N = 1 TO M
1920 J = 0
1930 G3 = 0
1940 J = J + 1
1950 G3 = G3 + (DL(J) * SL(J) + D
     L(J - 1) * SL(J - 1)) * (X(J
     ) - X(J - 1)) / 2
1960  IF J < N THEN  GOTO 1940
1970 HL(N) = G3
```

Calculation of $h_l(x)$ in equation (2.11)

```
1980  NEXT N
1990  PRINT "X COORD","HL(X)"
2000  FOR N = 0 TO M
2010  PRINT X(N),HL(N)
2020  NEXT N
2100  REM  CALCULATION OF DELTA F
     U(X),NEW FU(X),DELTA FL(X) A
     ND NEW FL(X)
2150  FOR N = 0 TO M
2160 EU(N) = (GU(N) - M0 ^ 2 * HU
     (N)) / (1 + B ^ 2 * DU(N))
2170 NU(N) = EU(N) + FU(N)
2180 EL(N) = (GL(N) - M0 ^ 2 * HL
     (N)) / (1 + B ^ 2 * DL(N))
2190 NL(N) = EL(N) + FL(N)
2200  NEXT N
```

Calculation of changes in upper and lower wall positions and new upper and lower positions, equations (2.4), (2.8), (2.12) & (2.13)

```
2210  PRINT "X COORD","UPPER DELT
     A F","NEW UPPER POSN"
2220  FOR N = 0 TO M
2230  PRINT X(N),EU(N),NU(N)
2240  NEXT N
2250  PRINT "X COORD","LOWER DELT
     A F","NEW LOWER POSN"
2260  FOR N = 0 TO M
2270  PRINT X(N),EL(N),NL(N)
2280  NEXT N
2300  GOTO 10000
```

Sub-routine 1.

```
5000  REM  SUBROUTINE 1 FOR EXTER
     NAL VELOCITY
5010 J = 0
5020 I1 = 0
5030 J = J + 1
5040 A5 = (X(J) * FW(J - 1) - X(J
      - 1) * FW(J)) / (X(J) - X(J
      - 1))
5050 B5 = (FW(J) - FW(J - 1)) / (
     (X(J) - X(J - 1)) * 2)
5060 I1 = I1 + A5 * ( - 1 / (X(J)
      - X(N)) + 1 / (X(J - 1) - X
     (N))) + B5 * ( LOG (X(N) - X
     (J)) - X(N) / (X(J) - X(N)) -
      LOG (X(N) - X(J - 1)) + X(N
     ) / (X(J - 1) - X(N)))
5070  IF J < N - 1 THEN  GOTO 503
     0
5080 J = N + 1
5090 I2 = 0
5100 J = J + 1
5110 A5 = (X(J) * FW(J - 1) - X(J
      - 1) * FW(J)) / (X(J) - X(J
      - 1))
5120 B5 = (FW(J) - FW(J - 1)) / (
     (X(J) - X(J - 1)) * 2)
5130 I2 = I2 + A5 * ( - 1 / (X(J)
      - X(N)) + 1 / (X(J - 1) - X
     (N))) + B5 * ( LOG (X(J) - X
     (N)) - X(N) / (X(J) - X(N)) -
      LOG (X(J - 1) - X(N)) + X(N
     ) / (X(J - 1) - X(N)))
5140  IF J < M THEN  GOTO 5100
5200 I3 = FW(N - 1) / (X(N - 1) -
     X(N)) - FW(N + 1) / (X(N + 1
     ) - X(N))
5210 E0 = FW(N - 1) / ((X(N) - X(
     N - 1)) * (X(N + 1) - X(N -
     1)))
5220 E1 = FW(N) / ((X(N - 1) - X(
     N)) * (X(N + 1) - X(N)))
5230 E2 = FW(N + 1) / ((X(N - 1) -
     X(N + 1)) * (X(N) - X(N + 1)
     ))
5240 B1 =  - E0 * (X(N) + X(N + 1
     )) - E1 * (X(N - 1) + X(N +
     1)) - E2 * (X(N - 1) + X(N))

5250 C1 = E0 + E1 + E2
5260 I3 = I3 + (B1 + 2 * C1 * X(N
     )) *  LOG ((X(N + 1) - X(N))
      / (X(N) - X(N - 1))) + 2 *
     C1 * (X(N + 1) - X(N - 1))
5270 S1(N) = (I1 + I2 + I3) / (B *
     PI)
5280  RETURN
```

```
6000  REM  SUBROUTINE 2 FOR PRINC
     IPAL VALUE INTEGRAL IN GU(X)
      AND GL(X)
6010 J = 1
6020 I4 = 0
6030 J = J + 1
6040 A5 = (X(J) * UW(J - 1) - X(J
      - 1) * UW(J)) / (X(J) - X(J
      - 1))
6050 B5 = (UW(J) - UW(J - 1)) / (
     (X(J) - X(J - 1)) * 2)
6060 I4 = I4 + A5 * ( - (X(N) - X
     (J)) *  LOG (X(N) - X(J)) -
     X(J) *  LOG (X(J)))
6070 I4 = I4 + A5 * ((X(N) - X(J -
     1)) *  LOG (X(N) - X(J - 1))
      + X(J - 1) *  LOG (X(J - 1)
     ))
6080 I4 = I4 + B5 * ((X(J) ^ 2 -
     X(N) ^ 2) *  LOG (X(N) - X(J
     )) - X(N) * X(J) - X(J) ^ 2 *
      LOG (X(J)))
6090 I4 = I4 + B5 * ( - (X(J - 1)
      ^ 2 - X(N) ^ 2) *  LOG (X(N
     ) - X(J - 1)) + X(N) * X(J -
     1) + X(J - 1) ^ 2 *  LOG (X(
     J - 1)))
6100  IF J < N - 1 THEN  GOTO 603
     0
6110 J = N + 1
6120 I5 = 0
6130 J = J + 1
6140 A5 = (X(J) * UW(J - 1) - X(J
      - 1) * UW(J)) / (X(J) - X(J
      - 1))
6150 B5 = (UW(J) - UW(J - 1)) / (
     (X(J) - X(J - 1)) * 2)
6160 I5 = I5 + A5 * ((X(J) - X(N)
     ) *  LOG (X(J) - X(N)) - X(J
     ) *  LOG (X(J)))
6170 I5 = I5 + A5 * ( - (X(J - 1)
      - X(N)) *  LOG (X(J - 1) -
     X(N)) + X(J - 1) *  LOG (X(J
      - 1)))
6180 I5 = I5 + B5 * ((X(J) ^ 2 -
     X(N) ^ 2) *  LOG (X(J) - X(N
     )) - X(J) * X(N) - (X(J) ^ 2
     ) *  LOG (X(J)))
```

Sub-routine 2.

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```
6190 I5 = I5 + B5 * ( - (X(J - 1)
      ^ 2 - X(N) ^ 2) *  LOG (X(J
      - 1) - X(N)) + X(J - 1) * X
     (N) + (X(J - 1) ^ 2) *  LOG
     (X(J - 1)))
6195  IF J < M THEN  GOTO 6130
6200 F0 = UW(N - 1) / ((X(N) - X(
     N - 1)) * (X(N + 1) - X(N -
     1)))
6210 F1 = UW(N) / ((X(N - 1) - X(
     N)) * (X(N + 1) - X(N)))
6220 F2 = UW(N + 1) / ((X(N - 1) -
     X(N + 1)) * (X(N) - X(N + 1)
     ))
6230 A2 = X(N) * X(N + 1) * F0 +
     X(N - 1) * X(N + 1) * F1 + X
     (N - 1) * X(N) * F2
6240 B2 =  - (X(N) + X(N + 1)) *
     F0 - (X(N - 1) + X(N + 1)) *
     F1 - (X(N - 1) + X(N)) * F2
6250 C2 = F0 + F1 + F2
6260 I6 = (X(N) - X(N - 1)) *  LOG
     (X(N) - X(N - 1)) + (X(N + 1
     ) - X(N)) *  LOG (X(N + 1) -
     X(N)) + X(N - 1) *  LOG (X(N
      - 1)) - X(N + 1) *  LOG (X(
     N + 1))
6270 I7 = (X(N) * (X(N - 1) - X(N
      + 1)) + (X(N - 1) ^ 2) *  LOG
     (X(N - 1)) - (X(N + 1) ^ 2) *
      LOG (X(N + 1)) - (X(N - 1) ^
     2 - X(N) ^ 2) *  LOG (X(N) -
     X(N - 1))) / 2
6275 I7 = I7 + ((X(N + 1) ^ 2 - X
     (N) ^ 2) *  LOG (X(N + 1) -
     X(N))) / 2
6280 I8 = X(N) * (X(N - 1) ^ 2 -
     X(N + 1) ^ 2) / 2 + (X(N) ^
     2) * (X(N - 1) - X(N + 1)) +
     (X(N - 1) ^ 3) *  LOG (X(N -
     1)) - (X(N + 1) ^ 3) *  LOG
     (X(N + 1))
6290 I8 = (I8 - (X(N - 1) ^ 3 - X
     (N) ^ 3) *  LOG (X(N) - X(N -
     1)) + (X(N + 1) ^ 3 - X(N) ^
     3) *  LOG (X(N + 1) - X(N)))
      / 3
6300 S2(N) = ((I4 + I5 + A2 * I6 +
     B2 * I7 + C2 * I8) * B) / (2
      * PI)
6310  RETURN
```

```
7000  DATA  26,6
7010  DATA  .1
7020  DATA  0,4,8,12,15,16,17,17.
      5,18,18.5,19,19.4,19.7,20,20
      .3,20.6,21,21.5,22,22.5,23,2
      4,25,28,32,36,40
7030  DATA  0,0,0,0,0,0,0,0,0,0
7040  DATA  0,0,0,0,0,0,0,0,0,0,0

7045  DATA  0,0,0,0,0,0
7050  DATA  0,0,0,0,0,0,0,0,0,0
7060  DATA  0,0,0,0,0,0,0,0,0,0,0

7065  DATA  0,0,0,0,0,0
7070  DATA  .1,.1,.1,.1,.1001,.10
      15,.1042
7080  DATA  .1070,.1115,.1183,.12
      75,.1353,.1397;.1414
7090  DATA  .1397,.1353,.1275,.11
      83,.1115,.1070,.1042
7100  DATA  .1015,.1001,.1,.1,.1,
      .1
7110  DATA  .1,.1,.1,.1,.1001,.10
      15,.1042
7120  DATA  .1070,.1115,.1183,.12
      75,.1353,.1397,.1414
7130  DATA  .1397,.1353,.1275,.11
      83,.1115,.1070,.1042
7140  DATA  .1015,.1001,.1,.1,.1,
      .1
10000  END
```

Data for normal flat plate.

APPENDIX B. PROGRAM PRINTOUT.

FLEXIWALL 350 FOR FLAT PLATE NORMAL TO POTENTIAL FLOW.

PRINTOUT OF INPUT DATA AND RESULTS.

```
]PR#0
]LIST 7000,10000

7000  DATA  26,6
7010  DATA  .1
7020  DATA  0,4,8,12,15,16,17,17.
      5,18,18.5,19,19.4,19.7,20,20
      .3,20.6,21,21.5,22,22.5,23,2
      4,25,28,32,36,40
7030  DATA  0,0,0,0,0,0,0,0,0,0
7040  DATA  0,0,0,0,0,0,0,0,0,0,0

7045  DATA  0,0,0,0,0,0
7050  DATA  0,0,0,0,0,0,0,0,0,0
7060  DATA  0,0,0,0,0,0,0,0,0,0,0

7065  DATA  0,0,0,0,0,0
7070  DATA  .1,.1,.1,.1,.1001,.10
      15,.1042
7080  DATA  .1070,.1115,.1183,.12
      75,.1353,.1397,.1414
7090  DATA  .1397,.1353,.1275,.11
      83,.1115,.1070,.1042
7100  DATA  .1015,.1001,.1,.1,.1,
      .1
7110  DATA  .1,.1,.1,.1,.1001,.10
      15,.1042
7120  DATA  .1070,.1115,.1183,.12
      75,.1353,.1397,.1414
7130  DATA  .1397,.1353,.1275,.11
      83,.1115,.1070,.1042
7140  DATA  .1015,.1001,.1,.1,.1,
      .1
10000  END
```

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```
]RUN
FLEXIWALL 3 SO
SECOND ORDER FLEXIWALL PREDICTIVE STRATEGY
M=26               H=6INS             MACH NO=.1
X COORD            UPPER VEL
0                  0
4                  0
8                  0
12                 0
15                 0
16                 0
17                 0
17.5               0
18                 0
18.5               0
19                 0
19.4               0
19.7               0
20                 0
20.3               0
20.6               0
21                 0
21.5               0
22                 0
22.5               0
23                 0
24                 0
25                 0
28                 0
32                 0
36                 0
40                 0
X COORD            LOWER VEL
0                  0
4                  0
8                  0
12                 0
15                 0
16                 0
17                 0
17.5               0
18                 0
18.5               0
19                 0
19.4               0
19.7               0
20                 0
20.3               0
20.6               0
21                 0
21.5               0
22                 0
22.5               0
23                 0
24                 0
25                 0
28                 0
32                 0
36                 0
40                 0
```

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X COORD	TERM 1+2 IN GU(X)
0	0
4	.0486516005
8	.0973032009
12	.194606402
15	.294736715
16	.354822111
17	.4254887
17.5	.470694978
18	.52068881
18.5	.575736135
19	.631703107
19.4	.669361417
19.7	.687648952
20	.694362569
20.3	.687655763
20.6	.669372782
21	.631696377
21.5	.575688562
22	.520628019
22.5	.470638752
23	.425290968
24	.354683182
25	.293054642
28	.194495082
32	.107807524
36	.107807524
40	.107807524

X COORD	FULL TERM GU(X)
0	0
4	6.58690456E-03
8	4.46373623E-03
12	.040382392
15	.0900382214
16	.134321612
17	.190993321
17.5	.230206924
18	.275060678
18.5	.325950567
19	.378856844
19.4	.414917341
19.7	.432524384
20	.439010313
20.3	.432531195
20.6	.414928706
21	.378850115
21.5	.325902995
22	.274999887
22.5	.230150699
23	.19079559
24	.134182683
25	.0883561488
28	.0402710725
32	.0149680597
36	.0657428285
40	.107807524

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X COORD	TER 1+2 IN GL(X)
0	0
4	-.0486516005
8	-.0973032009
12	-.194606402
15	-.294736715
16	-.354822111
17	-.4254887
17.5	-.470694978
18	-.52068881
18.5	-.575736135
19	-.631703107
19.4	-.669361417
19.7	-.687648952
20	-.694362569
20.3	-.687655763
20.6	-.669372782
21	-.631696377
21.5	-.575688562
22	-.520628019
22.5	-.470638752
23	-.425290968
24	-.354683182
25	-.293054642
28	-.194495082
32	-.107807524
36	-.107807524
40	-.107807524

X COORD	FULL TERM GL(X)
0	0
4	-6.58690456E-03
8	-4.46373623E-03
12	-.040382392
15	-.0900382214
16	-.134321612
17	-.190993321
17.5	-.230206924
18	-.275060678
18.5	-.325950567
19	-.378856844
19.4	-.414917341
19.7	-.432524384
20	-.439010313
20.3	-.432531195
20.6	-.414928706
21	-.378850115
21.5	-.325902995
22	-.274999887
22.5	-.230150699
23	-.19079559
24	-.134182683
25	-.0883561488
28	-.0402710725
32	-.0149680597
36	-.0657428285
40	-.107807524

X COORD	HU(X)
0	0
4	0
8	0
12	0
15	2.7956976E-05
16	2.26188949E-04
17	1.16095167E-03
17.5	2.26799767E-03
18	4.37568651E-03
18.5	8.1188523E-03
19	.0138200064
19.4	.0190278886
19.7	.0221280946
20	.023321675
20.3	.0221293637
20.6	.0190294376
21	.013819491
21.5	8.11499583E-03
22	4.37047169E-03
22.5	2.26146284E-03
23	1.15233512E-03
24	2.1302309E-04
25	1.1757429E-05
28	-1.69678565E-05
32	-1.69678565E-05
36	-1.69678565E-05
40	-1.69678565E-05

X COORD	HL(X)
0	0
4	0
8	0
12	0
15	-2.7956976E-05
16	-2.26188949E-04
17	-1.16095167E-03
17.5	-2.26799767E-03
18	-4.37568651E-03
18.5	-8.1188523E-03
19	-.0138200064
19.4	-.0190278886
19.7	-.0221280946
20	-.023321675
20.3	-.0221293637
20.6	-.0190294376
21	-.013819491
21.5	-8.11499583E-03
22	-4.37047169E-03
22.5	-2.26146284E-03
23	-1.15233512E-03
24	-2.1302309E-04
25	-1.1757429E-05
28	1.69678565E-05
32	1.69678565E-05
36	1.69678565E-05
40	1.69678565E-05

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X COORD	UPPER DELTA F	NEW UPPER POSN
0	0	0
4	6.58690456E-03	6.58690456E-03
8	4.46373623E-03	4.46373623E-03
12	.040382392	.040382392
15	.089993484	.089993484
16	.133331341	.133331341
17	.187099674	.187099674
17.5	.222490342	.222490342
18	.260232741	.260232741
18.5	.298851913	.298851913
19	.333422147	.333422147
19.4	.35314367	.35314367
19.7	.361420348	.361420348
20	.364275186	.364275186
20.3	.361426032	.361426032
20.6	.353153334	.353153334
21	.333416227	.333416227
21.5	.29880832	.29880832
22	.260175267	.260175267
22.5	.222436059	.222436059
23	.186906045	.186906045
24	.133193565	.133193565
25	.0883124038	.0883124038
28	.0402712422	.0402712422
32	.0149682294	.0149682294
36	.0657429982	.0657429982
40	.107807694	.107807694

X COORD	LOWER DELTA F	NEW LOWER POSN
0	0	0
4	-6.58690456E-03	-6.58690456E-03
8	-4.46373623E-03	-4.46373623E-03
12	-.040382392	-.040382392
15	-.089993484	-.089993484
16	-.133331341	-.133331341
17	-.187099674	-.187099674
17.5	-.222490342	-.222490342
18	-.260232741	-.260232741
18.5	-.298851913	-.298851913
19	-.333422147	-.333422147
19.4	-.35314367	-.35314367
19.7	-.361420348	-.361420348
20	-.364275186	-.364275186
20.3	-.361426032	-.361426032
20.6	-.353153334	-.353153334
21	-.333416227	-.333416227
21.5	-.29880832	-.29880832
22	-.260175267	-.260175267
22.5	-.222436059	-.222436059
23	-.186906045	-.186906045
24	-.133193565	-.133193565
25	-.0883124038	-.0883124038
28	-.0402712422	-.0402712422
32	-.0149682294	-.0149682294
36	-.0657429982	-.0657429982
40	-.107807694	-.107807694

APPENDIX C.

FLEXIWALL 3 SO APPLIED TO DATA FROM TSWT RUN NO. 40.

```
]LIST7000,10000

7000  DATA  20,6
7010  DATA  .521
7020  DATA  0,3,6,9,12,15,17,18,1
      9,20,21,22,23,24,26,29,32,35
      ,38,41,44
7030  DATA  0,0,0,0,0,0,0,0,0,0
7040  DATA  0,0,0,0,0,0,0,0,0,0,0

7050  DATA  0,0,0,0,0,0,0,0,0,0
7060  DATA  0,0,0,0,0,0,0,0,0,0,0

7070  DATA  .521,.5222,.5216,.521
      9,.5190,.5251,.5425,.5668,.5
      931,.6061
7080  DATA  .5933,.5670,.5526,.53
      98,.5315,.5278,.5259,.5282,.
      5285,.5262,.5262
7090  DATA  .521,.5209,.5193,.519
      9,.5174,.5125,.5060,.5099,.5
      209,.5282
7100  DATA  .5378,.5324,.5330,.52
      76,.5279,.5297,.5274,.5274,.
      5262,.5239,.5239
10000  END
```

]RUN
FLEXIWALL 3 SO
SECOND ORDER FLEXIWALL PREDICTIVE STRATEGY
M=20 H=6INS MACH NO=.521

X COORD	UPPER VEL
0	0
3	0
6	0
9	0
12	0
15	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
26	0
29	0
32	0
35	0
38	0
41	0
44	0

X COORD	LOWER VEL
0	0
3	0
6	0
9	0
12	0
15	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
26	0
29	0
32	0
35	0
38	0
41	0
44	0

X COORD	TERM 1+2 IN GU(X)
0	0
3	.0186249803
6	.0372499605
9	.0744999211
12	.107518388
15	.167881907
17	.231940658
18	.277995155
19	.316229372
20	.335584198
21	.325135935
22	.294990303
23	.268225609
24	.237581747
26	.19660457
29	.15468802
32	.122295925
35	.102671597
38	.080687971
41	.080687971
44	.080687971

X COORD	FULL TERM GU(X)
0	0
3	.0177308821
6	.0352715497
9	.070806538
12	.100832915
15	.15545156
17	.2132493
18	.25543658
19	.289480079
20	.304531495
21	.2898916
22	.255850498
23	.225599408
24	.191919718
26	.146170644
29	.0999527155
32	.0663389091
35	.0480910854
38	.029607931
41	.0346017605
44	.0402283527

X COORD	TER 1+2 IN GL(X)
0	0
3	2.98765595E-04
6	5.97531191E-04
9	1.19506238E-03
12	3.57182387E-03
15	4.23475221E-03
17	2.01032496E-03
18	-.0108031615
19	-.0292542215
20	-.0449532293
21	-.0618565771
22	-.0647269689
23	-.0707369734
24	-.068548133
26	-.0750127875
29	-.0827507003
32	-.0788540246
35	-.0767845448
38	-.0695918921
41	-.0695918921
44	-.0695918921

X COORD	FULL TERM GL(X)
0	0
3	.0192031587
6	.0408584233
9	.0660547348
12	.0972772077
15	.130495514
17	.148887432
18	.14453828
19	.13251023
20	.120728128
21	.105034223
22	.100772947
23	.0911350749
24	.0879633585
26	.0676219441
29	.0366265091
32	.0182604643
35	-2.97308638E-04
38	-.013058766
41	-.0330290777
44	-.052725226

X COORD	HU(X)
0	0
3	9.63205052E-06
6	2.65111245E-05
9	4.71859055E-05
12	2.20885135E-05
15	1.21401049E-04
17	9.52248178E-04
18	2.11625303E-03
19	3.7163158E-03
20	4.52982101E-03
21	3.73683083E-03
22	2.26284938E-03
23	1.13009015E-03
24	4.12987635E-04
26	-2.91821126E-04
29	-7.00476628E-04
32	-8.81844001E-04
35	-9.99857837E-04
38	-1.08306454E-03
41	-1.09351991E-03
44	-1.06838436E-03

```
X COORD            HL(X)
0                  0
3                  -9.29809138E-07
6                  -1.99849535E-05
9                  -5.22333634E-05
12                 -1.19149424E-04
15                 -2.87383758E-04
17                 -3.66609665E-04
18                 -3.26373111E-04
19                 -2.8446221E-04
20                 -3.28939702E-04
21                 -4.50250845E-04
22                 -5.62601012E-04
23                 -6.33640141E-04
24                 -6.85156572E-04
26                 -7.82513867E-04
29                 -9.76671129E-04
32                 -1.1281768E-03
35                 -1.22756878E-03
38                 -1.31191681E-03
41                 -1.3768281E-03
44                 -1.42918385E-03
X COORD            UPPER DELTA F
NEW UPPER POSN
0                  0                0
3                  .0177141701
.0177141701
6                  .0352503268
.0352503268
9                  .0707515004
.0707515004
12                 .100960831
.100960831
15                 .154997158
.154997158
17                 .209996569
.209996569
18                 .24734914
.24734914
19                 .275307237
.275307237
20                 .287098798
.287098798
21                 .27565977
.27565977
22                 .247680354
.247680354
23                 .220668159
.220668159
24                 .189445615
.189445615
26                 .145238489
.145238489
29                 .099693268
.099693268
32                 .0663626238
.0663626238
35                 .0481326561
.0481326561
38                 .0297539255
.0297539255
41                 .0347786495
.0347786495
44                 .0403791053
.0403791053
```

```
X COORD            LOWER DELTA F
NEW LOWER POSN
0                  0                 0
3                  .0192046847
.0192046847
6                  .0409099709
.0409099709
9                  .0661171461
.0661171461
12                 .0975424305
.0975424305
15                 .131313752
.131313752
17                 .150483936
.150483936
18                 .145699423
.145699423
19                 .132596239
.132596239
20                 .120243258
.120243258
21                 .10399774
.10399774
22                 .100168351
.100168351
23                 .0905861613
.0905861613
24                 .0877651855
.0877651855
26                 .0675253539
.0675253539
29                 .0366799834
.0366799834
32                 .0184882261
.0184882261
35                 3.57521134E-05
3.57521134E-05
38                 -.0126590023
-.0126590023
41                 -.0325926663
-.0325926663
44                 -.0522368224
-.0522368224
?BAD SUBSCRIPT ERROR IN 5060
```

APPENDIX C.

UNIVERSITY OF SOUTHAMPTON
TRANSONIC SELF-STREAMLINING WIND TUNNEL
****

MANUAL MODE
0- 0- 0

RUN NO. = 40

Walls Straight

MODEL ALPHA (DEG) = 4.0

$M_\infty = 0.52$

TEST PARAMETERS

NO. OF WALL DATA POINTS = 24

NO. OF MODEL DATA POINTS ? 44

NO. OF REFERENCE CHECKS = 8

INPUT DATA FILE NAME - *PAD.DAT

NO. OF RECORDS = 10
SIZE = 512 WORDS

INPUT AMBIENT CONDITIONS
TEMP (DEG.C) - 22.

PRES. (CM HG) - 76.455

TURN ON WIND

TUNNEL REFERENCE VALUES

INCHES HG	MACH NO.
5.20	0.5206
5.20	0.5206
5.18	0.5198
5.17	0.5191
5.18	0.5198
5.22	0.5221
5.21	0.5213
5.17	0.5191

PRESSURE CHECKS (INCHES HG)

5.19	0.14	5.23	6.55	5.04	
		5.20	5.45	4.20	11.78

RUN NO. 40 $M_0 = 0.521$

DELTA STAR CALCS.

TOP WALL

TAP NO.	DU/DX		MACH NO. (0.521)	D*	DD*
1	0.1593		0.5222	0.0168	0.0168
2	-0.0530	DATA	0.5216	0.0235	0.0235
3	-0.4253	LINE	0.5219	0.0302	0.0302
4	0.5287	7070	0.5190	0.0361	0.0361
5	5.8568		0.5251	0.0399	0.0399
6	18.2842	→	0.5425	0.0382	0.0382
7	23.9370		0.5668	0.0361	0.0361
8	18.6679		0.5931	0.0340	0.0340
9	0.4269		0.6061	0.0344	0.0344
10	-18.2436		0.5933	0.0378	0.0378
11	-19.2038		0.5670	0.0441	0.0441
12	-12.9906	DATA	0.5526	0.0500	0.0500
13	-9.4957	LINE	0.5398	0.0550	0.0550
14	-2.8011	7080	0.5315	0.0626	0.0626
15	-0.7866		0.5278	0.0697	0.0697
16	0.0525		0.5259	0.0752	0.0752
17	0.4203		0.5282	0.0794	0.0794
18	-0.3153		0.5285	0.0844	0.0844
19	-0.3677		0.5262	0.0895	0.0895
20	0.0000		0.5262	0.0945	0.0945

UNIT REYNOLDS NO. = 259051.7 D* FPG = 0.0092

BOTTOM WALL

TAP NO.	DU/DX		MACH NO. (0.521)	D*	DD*
1	-0.2108		0.5209	0.0168	0.0168
2	-0.1579	DATA	0.5193	0.0239	0.0239
3	-0.3170		0.5199	0.0302	0.0302
4	-1.2197	LINE	0.5174	0.0370	0.0370
5	-2.5702	7090	0.5125	0.0441	0.0441
6	1.5089	→	0.5060	0.0479	0.0479
7	7.3537		0.5099	0.0487	0.0487
8	9.3356		0.5209	0.0483	0.0483
9	8.5634		0.5282	0.0475	0.0475
10	2.0195		0.5378	0.0479	0.0479
11	-2.3107	DATA	0.5324	0.0496	0.0496
12	-2.3315	LINE	0.5330	0.0521	0.0521
13	-3.4693		0.5276	0.0550	0.0550
14	0.4256	7100	0.5279	0.0592	0.0592
15	0.0520		0.5297	0.0643	0.0643
16	-0.3635	→	0.5274	0.0697	0.0697
17	-0.2083		0.5274	0.0752	0.0752
18	-0.5740		0.5262	0.0802	0.0802
19	-0.3657		0.5239	0.0861	0.0861
20	0.0000		0.5239	0.0911	0.0911

UNIT REYNOLDS NO. = 259051.7 D* FPG = 0.0092

WALL CP ERROR

TOP - 0.0751 BOTTOM - 0.0236

APPENDIX D.

FLEXIWALL 3 SO APPLIED TO TSWT RUN NO. 112.

```
]PR#0
]2300 GOTO 10000

]626 STOP

]656 STOP

]666 STOP

]671 STOP

]RUN
FLEXIWALL 3 SO
SECOND ORDER FLEXIWALL PREDICTIVE STRATEGY
M=20                H=6INS          MACH NO=.507
```

X COORD	UPPER VEL
0	0
3	-7.30348125E-04
6	-1.46069625E-03
9	-4.80160144E-03
12	-5.22274645E-03
15	-.0164190839
17	-.0567269977
18	-.0723234705
19	-.0570947716
20	-.0394865451
21	-.0102137779
22	.0529385571
23	.105865676
24	.0827943038
26	.0407531279
29	.0300120748
32	.0281079068
35	.0237068796
38	.0157391869
41	.0157391869
44	.0157391869

X COORD	LOWER VEL
0	0
3	8.02443586E-04
6	1.60488717E-03
9	1.61768895E-03
12	1.86649161E-03
15	3.42679366E-03
17	-.0180921949
18	-5.9462483E-03
19	-.0262007733
20	-.0295731203
21	-.040836922
22	-.0391109604
23	-.0366768989
24	-.0147300742
26	-3.43912249E-03
29	-6.84176018E-03
32	-8.85428156E-03
35	-.0102086495
38	-.0102537116
41	-.0102537116
44	-.0102537116

ORIGINAL PAGE IS
OF POOR QUALITY

X COORD	TERM 1+2 IN GU(X)

BREAK IN 671
]CONT

0	0
3	5.38985889E-03
6	.0107797178
9	.0215594356
12	.0250448211
15	.0323422338
17	.0363228344
18	.0407552843
19	.0412177704
20	.0438229273
21	.0398386781
22	.0358063262
23	.0350770188
24	.0317392601
26	.0262831207
29	.0112756076
32	6.24725328E-03
35	-1.38556752E-04
38	-3.02905997E-04
41	-3.02905997E-04
44	-3.02905997E-04

ORIGINAL PAGE IS
OF POOR QUALITY

X COORD	FULL TERM GU(X)
0	0
3	2.36582271E-03
6	9.19347994E-03
9	.0215916163
12	.0270979021
15	.0362291843
17	.041095772
18	.0458699627
19	.0465919605
20	.0493630618
21	.0454499691
22	.0414081558
23	.0406154067
24	.0371910753
26	.0315878869
29	.0165089719
32	.0114095729
35	4.49066888E-03
38	2.93994765E-03
41	4.92559893E-04
44	-3.07041464E-03

X COORD	TER 1+2 IN GL(X)
0	0
3	-2.29312976E-04
6	-4.58625953E-04
9	-9.17251906E-04
12	7.05658917E-03
15	9.07843717E-03
17	.0118643725
18	.0125936291
19	.0146253943
20	.0141346635
21	.0109120827
22	.0136316223
23	9.70089607E-03
24	.0113752656
26	8.23506493E-03
29	8.80486059E-03
32	.0122744705
35	.0133981251
38	.0106007336
41	.0106007336
44	.0106007336

X COORD	FULL TERM GL(X)
0	0
3	-2.4713409E-03
6	2.4613206E-03
9	6.81543115E-03
12	.019056494
15	.0242731793
17	.028290653
18	.0293347188
19	.0314421633
20	.030751123
21	.0270324299
22	.028972728
23	.0240192181
24	.02447217
26	.0184050217
29	.0136579087
32	.0117174738
35	8.00266108E-03
38	7.73461299E-04
41	-3.83144107E-03
44	-9.09911623E-03

X COORD	HU(X)
0	0
3	2.39440608E-06
6	5.33591606E-06
9	7.31232545E-06
12	1.2450382E-06
15	-2.30243412E-05
17	-1.02158408E-04
18	-1.56437387E-04
19	-1.74885157E-04
20	-1.78453078E-04
21	-2.36023274E-04
22	-3.43062455E-04
23	-4.67999792E-04
24	-6.1850654E-04
26	-8.67114056E-04
29	-1.06629634E-03
32	-1.17420505E-03
35	-1.24015284E-03
38	-1.2758694E-03
41	-1.29630697E-03
44	-1.31713775E-03

X COORD	HL(X)
0	0
3	-2.14846142E-07
6	-1.61542182E-06
9	4.4460303E-06
12	-1.83669611E-06
15	-3.16087071E-05
17	-6.82399541E-05
18	-9.19825861E-05
19	-1.10086371E-04
20	-9.66014935E-05
21	-6.84022335E-05
22	-4.53008423E-05
23	-1.00731278E-05
24	1.33139818E-05
26	2.97523834E-05
29	4.9799601E-05
32	6.42019154E-05
35	8.75490314E-05
38	1.1847882E-04
41	1.50930676E-04
44	1.85498521E-04

X COORD NEW UPPER POSN	UPPER DELTA F	
0	0	0
3 .012963378	2.36337799E-03	
6 .0341913311	9.19133106E-03	
9 .061884616	.021584616	
12 .0868388876	.0271388875	
15 .137047881	.0363478813	
17 .189148493	.0416484934	
18 .224619763	.0464197625	
19 .252663425	.0465634255	
20 .26802136	.0487213604	
21 .254040978	.0446409785	
22 .222541869	.0401418687	
23 .19361952	.0388195199	
24 .16521161	.0360116098	
26 .118459132	.0312591318	
29 .0696174844	.0166174844	
32 .0457959795	.0115959795	
35 .0295664764	4.76647635E-03	
38 .0164437443	3.24374427E-03	
41 -6.37845652E-03	8.21543475E-04	
44 -.0253178492	-2.71784917E-03	

X COORD	LOWER DELTA F	NEW LOWER POSN
0	0	0
3	-2.47192691E-03	.0105280731
6	2.46267027E-03	.0248626703
9	6.80545619E-03	.0402054562
12	.0191009589	.0694009589
15	.0243845064	.0933845064
17	.02871124	.09961124
18	.0296615892	.0979615892
19	.0319574346	.0850574347
20	.0312123726	.0734123726
21	.0273910901	.0557910901
22	.0294387505	.0557387505
23	.0243364214	.0499364214
24	.0246655935	.0545655935
26	.0184466501	.0424466502
29	.0136865692	.0238865692
32	.0117477977	8.5477977E-03
35	8.01445914E-03	-5.48554086E-03
38	7.45847372E-04	-.0165541526
41	-3.89047879E-03	-.0204904788
44	-9.19463571E-03	-.0257946357

APPENDIX D Walls S/lined

SIZE = 512 WORDS

INPUT AMBIENT CONDITIONS
TEMP (DEG.C) - 21.

PRES. (CM HG) - 76.5

TURN ON WIND

^C

.@FLEX

.RUN FLEX

DATA ATTACHED

$\alpha = 4^\circ$ $M_\infty = .5$
$\alpha = 4^\circ$ $M_\infty = .7$
$\alpha = 2^\circ$ $M_\infty = .7$

Straight & Streamlined Walls

GRIT OFF FOR ALL TESTS

UNIVERSITY OF SOUTHAMPTON
TRANSONIC SELF-STREAMLINING WIND TUNNEL
****

MANUAL MODE
24- 7-79

RUN NO. = 112

MODEL ALPHA (DEG) = ~~3.0~~ 4.0

M_∞ = .5067

TEST PARAMETERS

NO. OF WALL DATA POINTS = 24

NO. OF MODEL DATA POINTS ? 44

NO. OF REFERENCE CHECKS = 8

INPUT DATA FILE NAME - *PAD.DAT

NO. OF RECORDS = 50
SIZE = 512 WORDS

INPUT AMBIENT CONDITIONS
TEMP (DEG.C) - 21.

PRES. (CM HG) - 76.5

TURN ON WIND

DATA OUTPUT FILE = *ADC.DAT

WAS COMPUTING NOW !!

DELTA STAR CALCS.

TOP WALL

Wall

TAP NO.	DU/DX	MACH NO.	D*	DD*
1	0.1082	0.5085	0.0168	0.0000
2	0.1080	0.5079	0.0235	0.0000
3	-0.1622	0.5099	0.0302	0.0000
4	0.2153	0.5076	0.0361	-0.0004
5	2.7818	0.5113	0.0412	-0.0016
6	8.2205	0.5191	0.0420	-0.0046
7	10.0094	0.5298	0.0416	-0.0067
8	8.9278	0.5397	0.0416	-0.0084
9	0.3073	0.5483	0.0424	-0.0093
10	-10.1808	0.5404	0.0454	-0.0084
11	-9.2050	0.5272	0.0500	-0.0059
12	-5.3869	0.5214	0.0538	-0.0042
13	-4.3075	0.5162	0.0571	-0.0025
14	-2.0279	0.5106	0.0630	0.0000
15	-0.3248	0.5053	0.0693	0.0013
16	0.3254	0.5063	0.0743	0.0012
17	0.4868	0.5073	0.0790	0.0013
18	-0.2168	0.5093	0.0836	0.0013
19	-0.5411	0.5060	0.0890	0.0012
20	0.0000	0.5060	0.0941	0.0013

BOTTOM WALL

TAP NO.	DU/DX	MACH NO.	D*	DD*
1	-0.2686	0.5062	0.0168	0.0000
2	0.1611	0.5056	0.0239	0.0000
3	-0.5929	0.5080	0.0302	0.0000
4	-1.4579	0.5027	0.0370	0.0005
5	-1.2629	0.4991	0.0441	0.0013
6	-1.0932	0.4965	0.0483	0.0021
7	1.3092	0.4955	0.0500	0.0025
8	3.5920	0.4991	0.0512	0.0021
9	5.8165	0.5027	0.0517	0.0009
10	1.4562	0.5109	0.0521	-0.0008
11	-1.4428	0.5057	0.0542	-0.0008
12	-1.1319	0.5080	0.0563	-0.0004
13	-2.7426	0.5034	0.0588	0.0004
14	0.9578	0.5050	0.0630	0.0004
15	0.5392	0.5063	0.0672	-0.0004
16	0.0000	0.5060	0.0718	-0.0009
17	0.1611	0.5063	0.0769	-0.0004
18	-0.2152	0.5070	0.0819	-0.0008
19	-0.3226	0.5050	0.0869	-0.0013
20	0.0000	0.5050	0.0920	-0.0012

UNIT REYNOLDS NO. = 255610.3 D* FPG = 0.0092

WALL CP ERROR

TOP - 0.0046 BOTTOM - 0.0045

Jack Positions relative to wall anchor pt.

NEW JACK SETTINGS

TOP WALL

X Position	JACK	y^* Contour POS.	DELTA	OLD	SET (V)
		0.0000			
3	1	0.0106	0.0010	466	466
6	2	0.0250	0.0029	577	579
9	3	0.0403	0.0054	543	547
12	4	0.0597	0.0073	592	598
15	5	0.1007	0.0104	604	612
17	6	0.1475	0.0126	575	585
18	7	0.1782	0.0132	612	623
19	8	0.2061	0.0132	645	656
20	9	0.2193	0.0134	669	679
21	10	0.2094	0.0122	636	646
22	11	0.1824	0.0118	593	602
23	12	0.1548	0.0118	607	616
24	13	0.1292	0.0115	588	597
26	14	0.0872	0.0101	660	668
29	15	0.0530	0.0080	604	610
32	16	0.0342	0.0065	145	150
35	17	0.0248	0.0050	216	220
38	18	0.0132	0.0039	212	215
41	19	-0.0072	0.0036	185	187
44	20	-0.0226	0.0027	278	280

+ve up

Movement from straight

BOTTOM WALL

JACK	POS	DELTA	OLD	SET (V)
0	0.0000			
1	0.0130	0.0022	602	600
2	0.0224	0.0023	528	526
3	0.0334	0.0024	576	573
4	0.0503	0.0052	589	584
5	0.0690	0.0069	572	566
6	0.0709	0.0075	451	444
7	0.0683	0.0083	511	503
8	0.0531	0.0090	530	522
9	0.0422	0.0086	532	524
10	0.0284	0.0076	588	581
11	0.0263	0.0071	546	540
12	0.0256	0.0061	569	563
13	0.0299	0.0054	559	554
14	0.0240	0.0039	689	685
15	0.0102	0.0007	693	692
16	-0.0032	0.0012	330	328
17	-0.0135	0.0018	288	286
18	-0.0173	-0.0003	234	234
19	-0.0166	-0.0006	201	201
20	-0.0166	-0.0011	330	330

+ve up

OUTPUT RECORD NO. = 43

WING RECORD NO. (>2) = 32

STOP --

ORIGINAL PAGE IS OF POOR QUALITY

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Report Documentation Page

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16. Abstract

The author presents an improvement to his existing two-dimensional (2-D) strategies for adjustment of the flexible top and bottom walls of an Adaptive Wall Test Section (AWTS). This adjustment is part of the wall adaptation process to eliminate top and bottom wall interference at its source. The improvements to account for second order effects are described in mathematical detail. It is intended that these improvements should further minimize the necessary iterations in the wall adaptation process. An associated computer program written in BASIC is presented and several test cases run with this program are discussed. The strategy performs well for a theoretical test case but when applied to experimental AWTS data, some discrepancies in the adapted wall shapes are found. The author concludes that further study of the new strategy is required.

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