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EXTRACTION OF MODEL PERFORMANCE FROM WALL DATA IN A TWO-DIMENSIONAL TRANSONIC FLEXIBLE WALLED TEST SECTION

M. J. Goodyer

KENTRON INTERNATIONAL, INC.
Hampton Technical Center
Hampton, Virginia 23666

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NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

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1. Introduction

In this work the phrase "wall data" refers to the data acquired from the flexible walls of the test section during the normal process of streamlining them around a two-dimensional model[1]. This data comprises the shapes of the two flexible walls and their streamwise pressure distributions, together with the tunnel reference flow conditions.

In principle it is possible to derive much steady-state information on the model including force components, moment and shape. The information on shape is the aerodynamic shape of the model, that is, its thickness combined with the displacement effect of its boundary layer and wake. Experience gained in the earliest days of this research (unpublished work in 1974) indicated that there was little likelihood of deriving an accurate shape of the model itself using wall data when the data carries the usual levels of experimental error. Much higher precision was required. More recent experience in airfoil testing suggested that data on wake displacement thickness was available from the walls, with the result that effort was put into deriving this data, and any other which might be available.

In the event, it has proved possible to derive lift force and pitching moment, in addition to wake thickness. The extraction of lift and pitching moment relies on a balance between pressure forces and momentum changes, while after the streamlining of the walls their movement apart from their straight positions is simply the displacement effect of the wake.

It will be seen that although at its present stage of development the data which the method provides is not all of good quality, its value lies in the fact that it provides an alternate source of information on model behaviour, and in some testing (for example, the testing of uninstrumented flow visualization models) may provide the only source of information.

2. Principles

A two-dimensional flowfield is sketched on figure 1 which shows a pair of streamlines, one above and one below the airfoil, which will be followed by the flexible walls when they are streamlined. Marked in broken lines are the upstream and downstream bounds of the test section, arbitrarily defined by geometry but assumed far enough from the disturbances created by the model for the static pressure to be constant at the reference value. The walls must be streamlined for this to be true at the exit. These bounds are chosen to be vertical. The streamlines with these end boundaries constitute a convenient control volume. Pressure forces act all over, but there are momentum fluxes across only the entry and exit planes. The force/momentum flux equation for the test gas is

$$\oint_{cv} P(s)\cos\theta(s)ds + \dot{m}(U_1\sin\alpha_1 + U_2\sin\alpha_2) - F_a = 0 \qquad (1)$$

where P(s) is the static pressure acting over the boundary, $\dot{m}$ is the air mass flow rate (equal at entry and exit in the absence of any suction or blowing in the test section) and U_1, U_2 and α_1, α_2 are mean velocities and flow angles at entry to and exit from the control volume. F_a is the force, positive downward, exerted by the airfoil.

As the test section is long, it is reasonable to assume flow perturbations at the entry plane to be small, and the velocity U_1 to be close in magnitude to U_∞, the reference velocity for the test section. In contrast, no similar assumption is valid in respect of U_2. A determination of U_2 would require a wake traverse, information not available in routine testing. Therefore in this analysis it is simply assumed that U_2 equals U_1: under most test conditions, and after wall streamlining, the bulk of the flow crossing the exit plane has a velocity close to this. The exceptions are the wake, and regions affected strongly by shocks.

Following these assumptions, (1) becomes

$$\oint_{cv} P(s)\cos\theta(s)ds + \dot{m}U_\infty(\sin\alpha_1 - \sin\alpha_2) - F_a = 0 \qquad (2)$$

The integral is evaluated as the sum of the pressure forces on finite intervals of wall length Δs in the form

$$\sum Cp.\Delta s.\cos\theta \qquad (3)$$

where Cp is a local pressure coefficient, and Δs the wall interval, here taken as one inch. Cp and θ are wall data. The summation is converted into a component of lift coefficient by

$$C_{L1} = \frac{\sum Cp.\Delta s.\cos\theta}{c} \qquad (4)$$

where c is the airfoil chord.

The momentum contributions are similarly reduced to the second component lift coefficient by

$$C_{L2} = \frac{\dot{m}\, U_\infty(\sin\alpha_1 - \sin\alpha_2)}{q_\infty\, c} \qquad (5)$$

where $C_L = C_{L1} + C_{L2}$, and q_∞ is the reference dynamic pressure.

The pitching moment about the reference point, which is the leading edge having a position relative to the test section shown on figure 1, is extracted in much the same way. The inlet momentum vector is assumed to lie mid-way between the walls and to have a slope equal to the mean wall slope at jack 1. Similarly at the outlet. The wall pressure components identified in equation 3, coupled with appropriate moment arms, contribute also to pitching moment, as do the additional force components $Cp.\Delta s.\sin\theta$.

When the walls have been streamlined, they are observed to asymtote to fixed distances apart, taken to equal the displacement effect of the model's wake. The choice of the streamwise station at which this is to be measured is rather arbitrary: in the program given later in this report, the average wake thickness is derived from jacks 16-18.

3. The FORTRAN IV Programme

The listings with identification of variables are given in Appendices 1 and 2. The code itself contains many comments.

There are two parts: data input, and data reduction. The data input section, generally 1SF, contains streamlined-walls data. The examples included may be used as program test cases. 1SF passes wall shapes and pressure coefficients for analysis to the data reduction subroutine 1SSL. This subroutine can optionally receive wall Mach number distributions as input for conversion to pressure coefficients, simply by deleting line number 0009.

1SSL carries out a curve fitting sequence up to line 0165, for pressure coefficients and wall displacements. Interpolations are carried out to give information on pressure coefficients, wall slopes and displacements at one-inch intervals. From figure 1 it can be seen that the first interpolated data is required at stations 7 and 8 inches. For this purpose the program curve-fits through the data for jacks 1 to 4, giving incidentally the values of the wall slopes in line 0004 of subroutine RINTER. The same curve-fit is then carried out for jacks 2-5 but the interpolation is then required only for the central portion, at stations 13 and 14. The latter pattern is continued throughout the test section, except at the downstream end where the curve-fit is used not only at its centre (stations 39, 40) but also towards the end, at stations 42 and 43. Many comments are included in the FORTRAN listing.

The accumulated data is then used in lines 0166-on to derive lift coefficient (real variable RL), pitching moment (PM) and wake thickness (WTH).

Descriptions of arrays and variables are given in Appendix 3.

4. Program Test Cases

The first test case is the potential flow data contained in 1SFLBW, see Appendix 4(a). For this, streamline shapes and pressure distributions have been calculated for the streamlines which pass through the wall anchor points. The streamlines are formed by combining a free stream and doublet with a free vortex centred on the doublet. In order to create the displacement effect of a wake, a source is embedded in what would otherwise have been the trailing edge of the cylinder formed by the doublet.

The circulation is chosen such that with a chord of 4 inches the lift coefficient is unity. The run of this program gives C_L = ·9964, an error of 0.36%. The vortex is located at the quarter-chord point and therefore the exact pitching movement coefficient $C_{M_{\ell.e.}}$ is -0.25. 1SF gives 0·2441, an under-estimate of 2·4%. The wake thickness figure represents the displacement effect of the source.

Two other typical test cases are given, Appendices 4(b) and 4(c). These are runs from the transonic self-streamlining wind tunnel, (TSWT) on a 4-inch chord NACA 0012-64 section[2]. Both cases are at transonic speeds but case (c) has a supercritical top wall and a substantial separation on the airfoil upper surface.

5. Comparisons Between Airfoil-Derived and Wall-Derived Data in TSWT

Many streamlined-walls cases have been analysed, in addition to the above two. Comparisons of lift coefficient C_L are given on Fig.2 indicating good agreement. In contrast, the pitching moment coefficient data on figure 3 shows a high level of scatter coupled with a general over-estimate of magnitude, leading to the conclusion that at the present state of development, this method can only be used as a rough guide. The potential-flow test case (Appendix 4(a)) also shows poor agreement between the exact and 1SF values of pitching moment.

Wake displacement thickness is also shown on figure 3, with just one check point from a wake traverse 9 inches downstream of the airfoil trailing edge, roughly inline with jack 16. Only fair agreement is indicated, but methods are available and will be incorporated in due course for improving the precision of these measurements.

6. Conclusions

1. Wall data from a flexible-walled self streamlining test section can give good estimates of the lift coefficient of a two-dimensional model.

2. Estimates of pitching moment and wake thickness need improvement.

7. Acknowledgement

The test section and its control system were constructed and developed under NASA Grant NSG-7172.

8. References

1. Goodyer, M.J. and Wolf, S.W.D. "Development of a Self-Streamlining Flexible Walled Transonic Test Section", AIAA Journal, Feb.1982, p.227.

2. Wolf, S.W.D. "Selected Data from a Transonic Flexible Walled Test Section", NASA CR-159360, Sept. 1980.

APPENDIX 1

LISTING OF 1SFLBW

```
.FORT/LIST:TT: 1SFLBW
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      C     TWO DIMENSIONAL MODEL: CL & WAKE DISPLACEMENT THICKNESS
      C     FROM WALL DATA.
      C    ....... WALLS ARE STREAMLINED.......
      C      TEST CASE LBW. T,B ARE TOP,BOTTOM WALL CP'S AT JACK POSITIONS.
0001        DIMENSION D1(39),D2(39),U1(39),U2(39),S(39),S1(39),S2(39)
0002        DIMENSION X(19),T(19),B(19),U(39),RM1(19),RM2(19)
      C     CH IS AN ASSUMED CHORD. HT THE TEST SECTION HEIGHT AT ENTRY.
0003        CH=4.
0004        CHD=3.
0005        HT=6.
      C     A IS ANGLE OF ATTACK,DEGREES, RMO THE REFERENCE MACH NR.
0006        A=0.
0007        RMO=0.0001
0008        F1=(1+.2*RMO*RMO)
0009        F2=2/(1.4*RMO*RMO)
0010        WRITE(5,10)
0011  10    FORMAT(//'   TEST CASE: LIFTING BODY WITH WAKE. INCOMPRESSIBLE.')
      C     RM1,RM2 ARE TOP,BOTTOM WALL DISPLACEMENTS FROM AERODYNAMICALLY
      C     STRAIGHT,POSITIVE WHEN WALL ABOVE STRAIGHT. ALL INCHES.
      C     X ARE JACK STREAMWISE STATIONS. T,B TOP,BOTTOM CP'S AT JACKS.
      C     LINK WITH 1SSL,FORLIB
      C
      C     THE MOST UPSTREAM JACK (NR.1) IS AT STATION X=6 INCHES.
      C
0012        DATA X/6.,9.,12.,15.,18.,20.,21.,22.,23.,24.,25.,26.,27.,
           C29.,32.,35.,38.,41.,44./
      C     OUR JACK 20 IS NOT INCLUDED BECAUSE IT HAS NO
      C        STATIC PRESSURE TAPPING.
      C
0013        DATA T/.01678,.01907,.02091,.01778,-.01988,-.12316,-.20562,
           C-.27383,-.28947,-.25216,-.19506,-.14482,-.10861,-.06746,-.04127,
           C-.02955,-.02303,-.01887,-.01599/
0014        DATA B/.03041,.03939,.05436,.08215,.13626,.16214,.11957,.03852,
           C.01282,.0434,.05786,.05068,.03789,.0175,.0027,-.0031,-.00545,
           C-.00637,-.00666/
0015        DATA RM1/.05887,.13121,.22474,.35545,.55777,.74894,.84624,
           C.92101,.95695,.9531,.9222,.87928,.8341,.75155,.65331,.57751,
           C.51623,.46486,.42064/
0016        DATA RM2/.04545,.09748,.15734,.22416,.28063,.26101,.20584,
           C.13301,.08153,.05533,.02942,-.0052,-.04466,-.1236,-.22558,-.30757,
           C-.37469,-.43108,-.47948/
0017        CALL SSL(RMO,A,F1,F2,X,T,B,RM1,RM2,CH,CHD,HT)
```

APPENDIX 2

LISTING OF SUBROUTINE 1SSL

```
.FORT/LIST:TT: 1SSL
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0001          SUBROUTINE SSL(RM0,A,F1,F2,X,T,B,RM1,RM2,CH,CHD,HT)
0002          DIMENSION X(19),T(19),B(19),RM1(19),RM2(19)
0003          DIMENSION D1(39),D2(39),U(39),U1(39),U2(39),S(39),S1(39),S2(39)
      C       CHD IS DISTANCE FROM MODEL AXIS OF ROTATION (WHICH IS ON
      C          THE TEST SECTION CENTERLINE) TO THE LEADING EDGE.
0004          AU1=0.
0005          AU2=0.
0006          RL=0.
0007          ARM1=0.
0008          ARM2=0.
0009          GO TO 45
      C       BECAUSE FOR THIS TEST CASE THE INPUT WALL DATA IS ALREADY
      C         IN CP FORM.
0010          DO 20 N=1,19
      C       CONVERT WALL CENTERLINE MACH'S INTO CP :
0011          F3=1.+.2*T(N)*T(N)
0012          T(N)=(((F1/F3)**3.5)-1.)*F2
0013          F3=1.+.2*B(N)*B(N)
0014          B(N)=(((F1/F3)**3.5)-1.)*F2
0015   20     CONTINUE
0016   40     FORMAT(I3,4F9.5)
      C       Y8,X8 ARE DISTANCES OF L.E. ABOVE,AHEAD OF AXIS OF
      C            ROTATION OF MODEL.
0017   45     Y8=CHD*SIN(A/57.2958)
0018          X8=CHD*COS(A/57.2958)
      C       FOUR INTERPOLATIONS FOLLOW :
0019          DO 250 N4=1,4
      C       N4=1,2 FOR TOP,BOTTOM CP INTERPOLATIONS.
      C       N4=3,4 FOR TOP,BOTTOM WALL DISPLACEMENT INTERPOLATIONS.
0020          IF(N4.EQ.1) GO TO 270
0022          IF(N4.EQ.3) GO TO 200
0024          IF(N4.EQ.4) GO TO 240
0026          DO 50 N1=1,19
0027          T(N1)=B(N1)
0028   50     CONTINUE
0029          GO TO 270
0030  200     DO 60 N1=1,19
0031          T(N1)=RM1(N1)
0032   60     CONTINUE
0033          GO TO 270
0034  240     DO 70 N1=1,19
0035          T(N1)=RM2(N1)
0036   70     CONTINUE
0037  270     DO 560 N3=1,4
0038          X1=X(N3)
0039          X2=X(N3+1)
0040          X3=X(N3+2)
0041          X4=X(N3+3)
0042          Y1=T(N3)
0043          Y2=T(N3+1)
0044          Y3=T(N3+2)
0045          Y4=T(N3+3)
0046          CALL COEFF(X1,X2,X3,X4,Y1,Y2,Y3,Y4,A2,B2,C2)
0047          IF(N3.EQ.1) GO TO 410
```

```
      IF(N3.EQ.2) GO TO 450
      IF(N3.EQ.3) GO TO 490
      IF(N3.EQ.4) GO TO 530
410   DO 100 IX=6,12
      CALL RINTER(IX,X4,Y4,A2,B2,C2,SA,UA)
      S(IX-5)=SA
      U(IX-5)=UA
100   CONTINUE
      GO TO 560
450   DO 110 IX=13,15
      CALL RINTER(IX,X4,Y4,A2,B2,C2,SA,UA)
      S(IX-5)=SA
      U(IX-5)=UA
110   CONTINUE
      GO TO 560
490   DO 120 IX=16,18
      CALL RINTER(IX,X4,Y4,A2,B2,C2,SA,UA)
      S(IX-5)=SA
      U(IX-5)=UA
120   CONTINUE
      GO TO 560
530   DO 130 IX=19,20
      CALL RINTER(IX,X4,Y4,A2,B2,C2,SA,UA)
      S(IX-5)=SA
      U(IX-5)=UA
130   CONTINUE
560   CONTINUE
      DO 700 N3=5,10
      X1=X(N3)
      X2=X(N3+1)
      X3=X(N3+2)
      X4=X(N3+3)
      Y1=T(N3)
      Y2=T(N3+1)
      Y3=T(N3+2)
      Y4=T(N3+3)
      CALL COEFF(X1,X2,X3,X4,Y1,Y2,Y3,Y4,A2,B2,C2)
      X5=N3+16.-X4
      S(N3+11)=3.*A2*(X5*X5)+2.*B2*X5+C2
      U(N3+11)=T(N3+2)
700   CONTINUE
      DO 1050 N3=12,16
      X1=X(N3)
      X2=X(N3+1)
      X3=X(N3+2)
      X4=X(N3+3)
      Y1=T(N3)
      Y2=T(N3+1)
      Y3=T(N3+2)
      Y4=T(N3+3)
      CALL COEFF(X1,X2,X3,X4,Y1,Y2,Y3,Y4,A2,B2,C2)
      IF(N3.EQ.12) GO TO 860
      IF(N3.EQ.13) GO TO 900
      IF(N3.EQ.14) GO TO 940
```

```
0109          IF(N3.EQ.15) GO TO 980
0111          IF(N3.EQ.16) GO TO 1000
0113   860    DO 880 IX=27,29
0114          CALL RINTER(IX,X4,Y4,A2,B2,C2,SA,UA)
0115          S(IX-5)=SA
0116          U(IX-5)=UA
0117   880    CONTINUE
0118          GO TO 1050
0119   900    DO 920 IX=30,32
0120          CALL RINTER(IX,X4,Y4,A2,B2,C2,SA,UA)
0121          S(IX-5)=SA
0122          U(IX-5)=UA
0123   920    CONTINUE
0124          GO TO 1050
0125   940    DO 960 IX=33,35
0126          CALL RINTER(IX,X4,Y4,A2,B2,C2,SA,UA)
0127          S(IX-5)=SA
0128          U(IX-5)=UA
0129   960    CONTINUE
0130          GO TO 1050
0131   980    DO 990 IX=36,38
0132          CALL RINTER(IX,X4,Y4,A2,B2,C2,SA,UA)
0133          S(IX-5)=SA
0134          U(IX-5)=UA
0135   990    CONTINUE
0136          GO TO 1050
0137   1000   DO 1020 IX=39,44
0138          CALL RINTER(IX,X4,Y4,A2,B2,C2,SA,UA)
0139          S(IX-5)=SA
0140          U(IX-5)=UA
0141   1020   CONTINUE
0142   1050   CONTINUE
       C      LOAD APPROPRIATE ARRAYS :
0143          IF(N4.EQ.2) GO TO 1320
0145          IF(N4.EQ.3) GO TO 1360
0147          IF(N4.EQ.4) GO TO 1410
0149          DO 1300 IP=1,39
0150          U1(IP)=U(IP)
0151   1300   CONTINUE
0152   250    CONTINUE
0153   1320   DO 1340 IP1=1,39
0154          U2(IP1)=U(IP1)
0155   1340   CONTINUE
0156          GO TO 250
0157   1360   DO 1390 K=1,39
0158          S1(K)=S(K)
0159          D1(K)=U(K)
0160   1390   CONTINUE
0161          GO TO 250
0162   1410   DO 1440 K=1,39
0163          S2(K)=S(K)
0164          D2(K)=U(K)
0165   1440   CONTINUE
       C      INTERPOLATIONS COMPLETE.
```

```
C     INTEGRATION OF THE CONTRIBUTIONS OF WALL PRESSURE TO LIFT &
C        PITCHING MOMENT:
      DO 1600 N=1,39
      A1=ATAN(S1(N))
      AU1=AU1+U1(N)*COS(A1)
      A2=ATAN(S2(N))
      AU2=AU2+U2(N)*COS(A2)
      ARM1=ARM1+U1(N)*COS(A1)*(24.56-N-5.-X8)
      ARM1=ARM1-U1(N)*SIN(A1)*((HT/2.)+D1(N)-Y8)
      ARM2=ARM2+U2(N)*COS(A2)*(24.56-N-5.-X8)
      ARM2=ARM2+U2(N)*SIN(A2)*((HT/2.)-D2(N)+Y8)
1600  CONTINUE
C     SUM THE COMPONENTS OF LIFT:
      RL=(AU2-AU1)/CH
      SL1=(S1(1)+S2(1))/2.
      AS1=ATAN(SL1)
      RL=RL+2.*HT*SL1/CH
      SL2=(S1(39)+S2(39))/2.
      AS2=ATAN(SL2)
      RL=RL-2.*HT*SL2/CH
C     SUM THE COMPONENTS OF PITCHING MOMENT:
      Y9=(D2(1)+HT+D1(1))/2.
      Y1=(18.56-X8)*SL1
      Y2=(Y8+(HT/2.))-Y9
      B1=(Y2-Y1)*COS(AS1)
      Y9=(D2(39)+HT+D1(39))/2.
      Y1=SL2*(19.44+X8)
      Y2=(Y8+(HT/2.))-Y9
      B2=(Y2+Y1)*COS(AS2)
      BM1=2.*HT*B1/(CH*CH)
      BM2=2.*HT*B2/(CH*CH)
      PM=BM2-BM1+(ARM2-ARM1)/(CH*CH)
C
C     THE WAKE DISPLACEMENT THICKNESS WTH IS TAKEN AS THE AVERAGE
C        MOVEMENT APART OF JACKS 16-18:
1680  WTH=(RM1(16)+RM1(17)+RM1(18)-RM2(16)-RM2(17)-RM2(18))/3
      CALL IDATE(ID1,ID2,ID3)
      WRITE(5,1700)RL,PM,WTH
      WRITE(5,1705)ID2,ID1,ID3
1705  FORMAT(4X,'ANALYSIS DATE ',3I3,23X,,'INCHES')
      TYPE 1710
1710  FORMAT(' WANT INTERPOLATIONS ?  INPUT 1 FOR NO:')
      READ(5,*)PP
      IF(PP.EQ.1) GO TO 1800
      WRITE(5,1708)
1708  FORMAT(' STAT-_  DISPLACEMENTS           CP               SLOPES')
      WRITE(5,1709)
1709  FORMAT(' ION    UPPER    LOWER    UPPER    LOWER    UPPER    LOWER
     C')
      DO 1699,L=1,39
      WRITE(5,1698)L+5,D1(L),D2(L),U1(L),U2(L),S1(L),S2(L)
1698  FORMAT(I3,6F9.4)
1699  CONTINUE
1700  FORMAT(3X,' CL=',F7.4,'  CM=',F7.4,'  WAKE DISP. THICKNESS=',F6.4)
```

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```
      1800 AU2=AU2/CH
           AU1=AU1/CH
           AS1=AS1*2.*HT/CH
           AS2=AS2*2.*HT/CH
           ARM1=-ARM1/(CH*CH)
           ARM2=ARM2/(CH*CH)
           WRITE(5,1804)
      1804 FORMAT(' BREAKDOWN:'14X'     FLEX. WALL                    MOMENTUM')
           WRITE(5,1805)
      1805 FORMAT(18X'            PRESSURES                 FLUXES')
           WRITE(5,1806)
      1806 FORMAT(18X'          TOP       BOTTOM      INLET       OUTLET')
           WRITE(5,1802)-AU1,AU2,AS1,-AS2
           WRITE(5,1810)ARM1,ARM2,-BM1,BM2
      1810 FORMAT(' MOMENT COMPONENTS: ',4F12.4)
      1802 FORMAT(/'  LIFT COMPONENTS:  ',4F12.4)
           END
```

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```
           SUBROUTINE COEFF(X1,X2,X3,X4,Y1,Y2,Y3,Y4,A2,B2,C2)
      C    COEFFICIENTS A2-C2 FOR CUBIC THRO' THE 4 POINTS (0,0),(X5,Y5),
      C      ..(X7,Y7) :
           X5=X3-X4
           X6=X2-X4
           X7=X1-X4
           Y5=Y3-Y4
           Y6=Y2-Y4
           Y7=Y1-Y4
           B1=(X5*X5)-(X5*X5*X5)/X6
           B3=X7*X7-(X7*X7*X7)/X6
           C1=X5-(X5*X5*X5)/(X6*X6)
           C3=X7-(X7*X7*X7)/(X6*X6)
           Z1=Y5-(Y6*(X5*X5*X5)/(X6*X6*X6))
           Z3=Y7-Y6*(X7*X7*X7)/(X6*X6*X6)
           C2=((Z1*B3)/B1)-Z3
           C2=C2/(((C1*B3)/B1)-C3)
           B2=(Z1-(C2*C1))/B1
           A2=((Y5-(B2*X5*X5)-C2*X5))/(X5*X5*X5)
           RETURN
           END
```

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```
           SUBROUTINE RINTER(IX,X4,Y4,A2,B2,C2,SA,UA)
      C    VALUES BETWEEN JACKS BY INTERPOLATION WITH CUBIC:
           X5=IX-X4
           UA=Y4+A2*X5*X5*X5+B2*X5*X5+C2*X5
           SA=(3.*A2*X5*X5)+2.*B2*X5+C2
           RETURN
           END
```

APPENDIX 3

ARRAYS AND VARIABLES USED IN 1SF AND 1SSL

```
PROGRAM 1SFLBW.FOR

ARRAYS:
          X         JACK STREAMWISE STATIONS.
          T         TOP    WALL PRESSURE COEFFICIENTS (OR MACHS).
          B         DITTO,BOTTOM.
          RM1       TOP WALL MOVEMENTS UP FROM AERODYNAMICALLY STRAIGHT.
          RM2       DITTO,BOTTOM.
          D1        TOP WALL INTERPOLATED DISPLACEMENTS UP.
          D2        DITTO,BOTTOM.
          U1        TOP WALL INTERPOLATED PRESSURE COEFFICIENTS.
          U2        DITTO,BOTTOM.
          S1        TOP      WALL SLOPES AT ONE-INCH INTERVALS.
          S2        DITTO,BOTTOM.
          S,U       DUMMY ARRAYS.
VARIABLES:
          A         ANGLE OF ATTACK OF AIRFOIL, DEGREES
          CH        CHORD
          CHD       DISTANCE FORWARD OF LEADING EDGE(WHICH IS
                            MOMENT REFERENCE POINT) FROM AXIS
                            OF ROTATION(WHICH IS ON THE CENTERLINE).
          F1,F2     COMPRESSIBLE FLOW PARAMETERS.
          HT        HEIGHT OF TEST SECTION AT ENTRY.
          RMO       REFERENCE MACH NUMBER.

          ALL DIMENSIONS ARE INCHES.
```

SUBROUTINE 1SSL.FOR

ARRAYS:

```
        T,B       THESE CAN INITIALLY CONTAIN WALL MACH NUMBER
                          DISTRIBUTIONS,LATER CONVERTED TO PRESSURE
                          COEFFICIENT FORM. ARRAY T IS LOADED
                          SEQUENTIALLY WITH DATA FOR INTERPOLATION.
```

REAL VARIABLES:

```
        ARM1      SUMMATION OF TOP WALL PRESSURE COEFFICIENT
                          CONTRIBUTIONS TO PITCHING MOMENT.
        ARM2      DITTO,BOTTOM. LATER IN COEFFICIENT FORM (LINES
                          217,218).
        AS1       FLOW ANGLE AT INLET TO C.V.(RADIANS). ALPHA 1.
        AS2       DITTO, AT OUTLET. ALPHA 2 ON FIG.1.
        AU1       SUM OF CP*S*COS(WALL ANGLE). LIFT COMPONENT DUE
                          TO PRESSURE ON TOP WALL. S=1 INCH. FORCE
                          DOWN IS POSITIVE.
        AU2       DITTO, BOTTOM WALL. FORCE UP IS POSITIVE.
        A1        LOCAL TOP WALL SLOPE AS AN ANGLE (RADIANS).
        A2        DITTO, BOTTOM WALL.
                  > THEN A COEFFICIENT IN THE CUBIC EQUATION USED
                          IN INTERPOLATION. THE EQUATION HAS THE
                          FORM Y=A2*(X)^3+B2*(X)^2+C2*X
        BM1       CONTRIBUTION TO PITCHING MOMENT COEFFICIENT CM
                          OF INLET MOMENTUM FLUX. NOSE UP POSITIVE.
        BM2       DITTO AT OUTLET. NOSE DOWN POSITIVE.
        B1        MOMENT ARM OF INLET MOMENTUM VECTOR ABOUT MOMENT
                          REFERENCE POINT (SEE FIG.1). WHEN
                          POSITIVE THE VECTOR PASSES ABOVE THE
                          REFERENCE POINT.
        B2        DITTO,BOTTOM. ALSO A COEFFICIENT IN THE CUBIC.
        C2        COEFFICIENT IN CUBIC.
        F3        ISENTROPIC COMPRESSIBLE FLOW FUNCTION.
        PM        PITCHING MOMENT COEFFICIENT ABOUT LEADING EDGE.
        RL        LIFT COEFFICIENT CONTRIBUTION FROM WALL PRESSURES.
        SA        SLOPE DERIVED BY CURVE FITTING AND INTERPLOATION.
        SL1       MEAN SLOPE OF FLOW AT ENTRY TO C.V.
        SL2       DITTO AT EXIT.
        UA        PRESSURE COEFFICIENT OR WALL DISPLACEMENT DERIVED
                          BY CURVE FITTING AND INTERPOLATION.
        X1-X4)    DATA TO WHICH THE CUBIC IS TO BE FITTED.
        Y1-Y4)     "
        X8        DISTANCE OF MOMENT REFERENCE POINT AHEAD OF AXIS
                          OF ROTATION. SEE FIG.1.
        Y1        RISE IN THE INLET FLOW VECTOR LINE BETWEEN THE
                          INLET & THE MOMENT REFERENCE POINT. LATER
                          THE SAME FOR THE OUTLET VECTOR.
        Y8        DISTANCE OF REFERENCE POINT ABOVE THE CENTERLINE.
        Y9        HEIGHT OF INLET (OR OUTLET) VECTOR ABOVE THE LOWER
                          WALL (WHEN WALL STRAIGHT) WHERE VECTOR
                          CROSSES THE INLET (OR OUTLET) BOUNDARY
                          OF THE C.V.
```

SUBROUTINE COEFF:

```
        X5,Y5)
        X6,Y6)    INPUT DATA REFERENCED TO X4 & Y4.
        X7,Y7)
```

APPENDIX 4(a)

TEST CASE LBW

```
.RUN 1SFLBW

  TEST CASE: LIFTING BODY WITH WAKE. INCOMPRESSIBLE.
   CL= 0.9964  CM=-0.2441  WAKE DISP. THICKNESS=0.8906
   ANALYSIS DATE   9  7 82                          INCHES
WANT INTERPOLATIONS ?  INPUT 1 FOR NO:
0
```

STAT-ION	DISPLACEMENTS UPPER	DISPLACEMENTS LOWER	CP UPPER	CP LOWER	SLOPES UPPER	SLOPES LOWER
6	0.0589	0.0455	0.0168	0.0304	0.0224	0.0159
7	0.0816	0.0619	0.0173	0.0332	0.0232	0.0169
8	0.1055	0.0792	0.0181	0.0361	0.0247	0.0178
9	0.1312	0.0975	0.0191	0.0394	0.0268	0.0187
10	0.1592	0.1166	0.0200	0.0434	0.0294	0.0196
11	0.1902	0.1366	0.0206	0.0483	0.0327	0.0204
12	0.2247	0.1573	0.0209	0.0544	0.0365	0.0212
13	0.2625	0.1797	0.0219	0.0615	0.0402	0.0225
14	0.3056	0.2022	0.0212	0.0706	0.0463	0.0223
15	0.3555	0.2242	0.0178	0.0821	0.0536	0.0215
16	0.4133	0.2493	0.0150	0.0997	0.0622	0.0233
17	0.4803	0.2694	0.0039	0.1184	0.0720	0.0163
18	0.5578	0.2806	-0.0199	0.1363	0.0831	0.0055
19	0.6511	0.2828	-0.0621	0.1619	0.0964	-0.0082
20	0.7489	0.2610	-0.1232	0.1621	0.0984	-0.0369
21	0.8462	0.2058	-0.2056	0.1196	0.0890	-0.0656
22	0.9210	0.1330	-0.2738	0.0385	0.0581	-0.0687
23	0.9570	0.0815	-0.2895	0.0128	0.0162	-0.0395
24	0.9531	0.0553	-0.2522	0.0434	-0.0195	-0.0219
25	0.9222	0.0294	-0.1951	0.0579	-0.0394	-0.0288
26	0.8793	-0.0052	-0.1448	0.0507	-0.0457	-0.0377
27	0.8341	-0.0447	-0.1086	0.0379	-0.0440	-0.0398
28	0.7914	-0.0845	-0.0838	0.0268	-0.0413	-0.0397
29	0.7516	-0.1236	-0.0675	0.0175	-0.0383	-0.0384
30	0.7157	-0.1598	-0.0552	0.0109	-0.0342	-0.0351
31	0.6831	-0.1938	-0.0468	0.0061	-0.0312	-0.0329
32	0.6533	-0.2256	-0.0413	0.0027	-0.0285	-0.0307
33	0.6259	-0.2549	-0.0362	0.0000	-0.0262	-0.0283
34	0.6008	-0.2821	-0.0324	-0.0018	-0.0242	-0.0263
35	0.5775	-0.3076	-0.0295	-0.0031	-0.0224	-0.0246
36	0.5557	-0.3314	-0.0269	-0.0042	-0.0211	-0.0230
37	0.5353	-0.3537	-0.0248	-0.0049	-0.0197	-0.0216
38	0.5162	-0.3747	-0.0230	-0.0055	-0.0185	-0.0204
39	0.4981	-0.3945	-0.0214	-0.0059	-0.0176	-0.0193
40	0.4811	-0.4133	-0.0201	-0.0062	-0.0166	-0.0183
41	0.4649	-0.4311	-0.0189	-0.0064	-0.0158	-0.0173
42	0.4495	-0.4480	-0.0178	-0.0065	-0.0150	-0.0165
43	0.4348	-0.4641	-0.0169	-0.0066	-0.0144	-0.0157
44	0.4206	-0.4795	-0.0160	-0.0067	-0.0139	-0.0151

BREAKDOWN:	FLEX. WALL PRESSURES TOP	FLEX. WALL PRESSURES BOTTOM	MOMENTUM FLUXES INLET	MOMENTUM FLUXES OUTLET
LIFT COMPONENTS:	0.5095	0.3860	0.0574	0.0434
MOMENT COMPONENTS:	-0.7322	0.4472	0.2626	-0.2216

APPENDIX 4(b)

TEST CASE 72

```
 RUN 1SF72

      RUN 65  A-O-A=2.00 DEG.    MACH  0.7030

   CL= 0.1799  CM=-0.0093  WAKE DISP. THICKNESS=0.0300
   ANALYSIS DATE   0  0  0                        INCHES
WANT INTERPOLATIONS ?  INPUT 1 FOR NO:
1
BREAKDOWN:
```

	FLEX. WALL PRESSURES		MOMENTUM FLUXES	
	TOP	BOTTOM	INLET	OUTLET
LIFT COMPONENTS:	0.1843	-0.0156	0.0069	0.0042
MOMENT COMPONENTS:	-0.1803	0.1633	-0.0454	0.0531

```
.FORT/LIST:TT: 1SF72.FOR
FORTRAN IV      V02.5      Mon 12-Jul-82 00:01:23              PAGE 001

      C     TWO DIMENSIONAL MODEL: CL & WAKE DISPLACEMENT THICKNESS
      C     FROM WALL DATA.
      C     ....... WALLS ARE STREAMLINED.......
0001        DIMENSION D1(39),D2(39),U1(39),U2(39),S(39),S1(39),S2(39)
0002        DIMENSION X(19),T(19),B(19),U(39),RM1(19),RM2(19)
0003        CH=4.
0004        CHD=3.
0005        HT=6.
0006        RUN=65.
0007        RMO=.703
0008        A=2.0
      C     RMO IS REF. MACH NR.  A IS A-O-A., DEGREES.
0009        F1=1.+.2*RMO*RMO
0010        F2=2/(1.4*RMO*RMO)
0011        WRITE(5,10)A,RMO
0012  10    FORMAT(/'        RUN 65  A-O-A=',F4.2,' DEG.   MACH',F8.4,/)?
***** I
      C     RM1,RM2 ARE TOP,BOTTOM WALL DISPLACEMENTS FROM AERODYNAMICALLY
      C     STRAIGHT,POSITIVE WHEN WALL ABOVE STRAIGHT. ALL INCHES.
      C     X ARE JACK STREAMWISE STATIONS. T,B TOP,BOTTOM MACHS AT JACKS.
0013        DATA X/6.,9.,12.,15.,18.,20.,21.,22.,23.,24.,25.,26.,27.,
           C29.,32.,35.,38.,41.,44./
0014        DATA T/.7054,.7051,.7071,.7022,.7017,.708,.7215,.7484,.7614,
           C.748,.7248,.7157,.7096,.7033,.705,.7044,.707,.7096,.7082/
0015        DATA B/.7008,.6988,.7085,.6982,.694,.6908,.6951,.7085,.7178,
           C.73,.713,.7101,.6993,.7039,.705,.7067,.705,.7053,.7044/
0016        DATA RM1/.006,.0147,.0237,.0356,.0596,.0942,.1269,.1622,.175,
           C.1639,.1398,.1151,.0928,.0648,.0385,.0268,.0245,.0181,.0108/
0017        DATA RM2/.0106,.0149,.0202,.0284,.0321,.0181,-.0023,-.0285,
           C-.0445,-.0487,-.0372,-.0262,-.0142,-.0071,-.0043,-.0043,-.0091,
           C-.0071,-.0059/
0018        CALL SSM(RMO,A,F1,F2,X,T,B,RM1,RM2,CH,CHD,HT)
```

APPENDIX 4(c)

TEST CASE 82

```
RUN 1SF82

   RUN 172.  A-O-A=2.00 DEG.   MACH  0.8480

   CL= 0.0577  CM= 0.0795  WAKE DISP. THICKNESS=0.0569
   ANALYSIS DATE   9  7 82                        INCHES
 WANT INTERPOLATIONS ?  INPUT 1 FOR NO:
1
BREAKDOWN:                       FLEX. WALL                MOMENTUM
                                 PRESSURES                  FLUXES
                             TOP         BOTTOM        INLET       OUTLET

 LIFT COMPONENTS:           0.0785      -0.0231       0.0037      -0.0014
MOMENT COMPONENTS:         -0.1094       0.1582      -0.0575       0.0883
```

```
 FORT/LIST:TT: 1SF82
FORTRAN IV      V02.5       Fri 09-Jul-82 03:22:57                    PAGE 001

      C      TWO DIMENSIONAL MODEL: CL & WAKE DISPLACEMENT THICKNESS
      C      FROM WALL DATA.
      C     ....... WALLS ARE STREAMLINED.......
0001         DIMENSION D1(39),D2(39),U1(39),U2(39),S(39),S1(39),S2(39)
0002         DIMENSION X(19),T(19),B(19),U(39),RM1(19),RM2(19)
0003         RMO=.848
0004         A=2.
0005         CH=4.
0006         CHD=3.
0007         HT=6.
0008         RUN=172.
      C      RMO IS REF. MACH NR.  A IS A-O-A.
0009         F1=1.+.2*RMO*RMO
0010         F2=2/(1.4*RMO*RMO)
0011         WRITE(5,10)RUN,A,RMO
0012  10     FORMAT(//'     RUN ',F4.0,'  A-O-A=',F4.2,' DEG.   MACH',F8.4,/)?
*****  I
      C      RM1,RM2 ARE TOP,BOTTOM WALL DISPLACEMENTS FROM AERODYNAMICALLY
      C      STRAIGHT,POSITIVE WHEN WALL ABOVE STRAIGHT. ALL INCHES.
      C
      C      LINK WITH 1SSM,FORLIB.
      C
      C      X ARE JACK STREAMWISE STATIONS. T,B TOP,BOTTOM MACHS AT JACKS.
0013         DATA X/6.,9.,12.,15.,18.,20.,21.,22.,23.,24.,25.,26.,27.,
            C29.,32.,35.,38.,41.,44./
0014         DATA T/.8498,.8431,.844,.8382,.8311,.8253,.8431,.899,.9901,
            C.9602,.8779,.8625,.8496,.8401,.8475,.8374,.846,.8489,.8515/
0015         DATA B/.8512,.8406,.8361,.8347,.8247,.8253,.8352,.8786,.9331,
            C.963,.8957,.8619,.8479,.8413,.8486,.846,.8452,.8449,.8489/
0016         DATA RM1/.006,.0068,.0111,.0147,.0353,.0733,.1121,.1624,.1948,
            C.188,.152,.1203,.0929,.0613,.0374,.0316,.0305,.0238,.0169/
0017         DATA RM2/.0113,.0141,.0119,.0182,.0118,-.0091,-.0378,-.0767,
            C-.1069,-.1208,-.0992,-.0828,-.058,-.0411,-.0303,-.0295,-.0285,
            C-.0268,-.0215/
0018         CALL SSM(RMO,A,F1,F2,X,T,B,RM1,RM2,CH,CHD,HT)
```

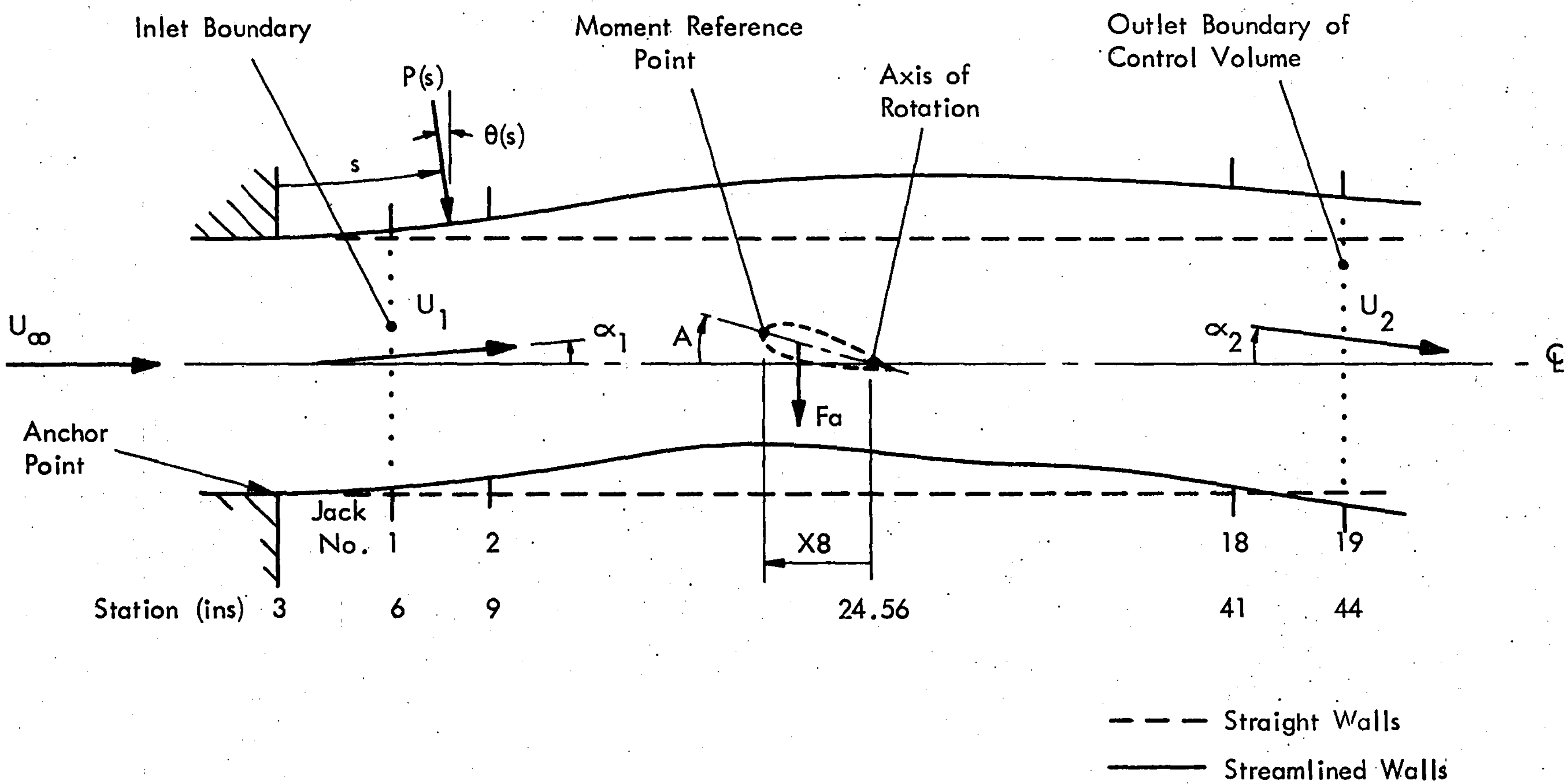
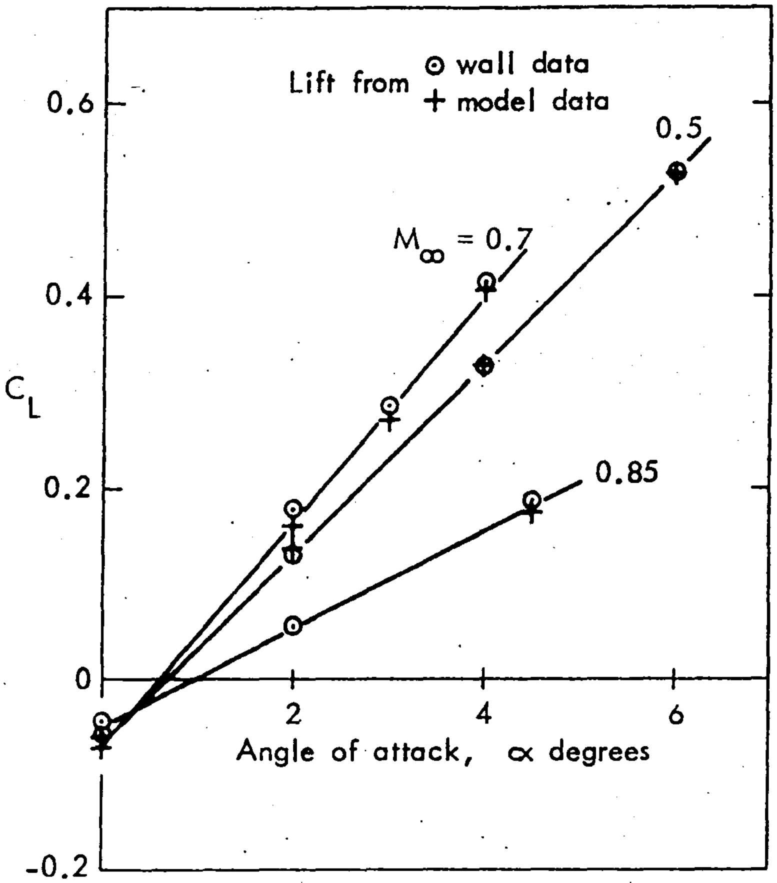


FIG. 1 GEOMETRY OF MODEL AND TEST SECTION



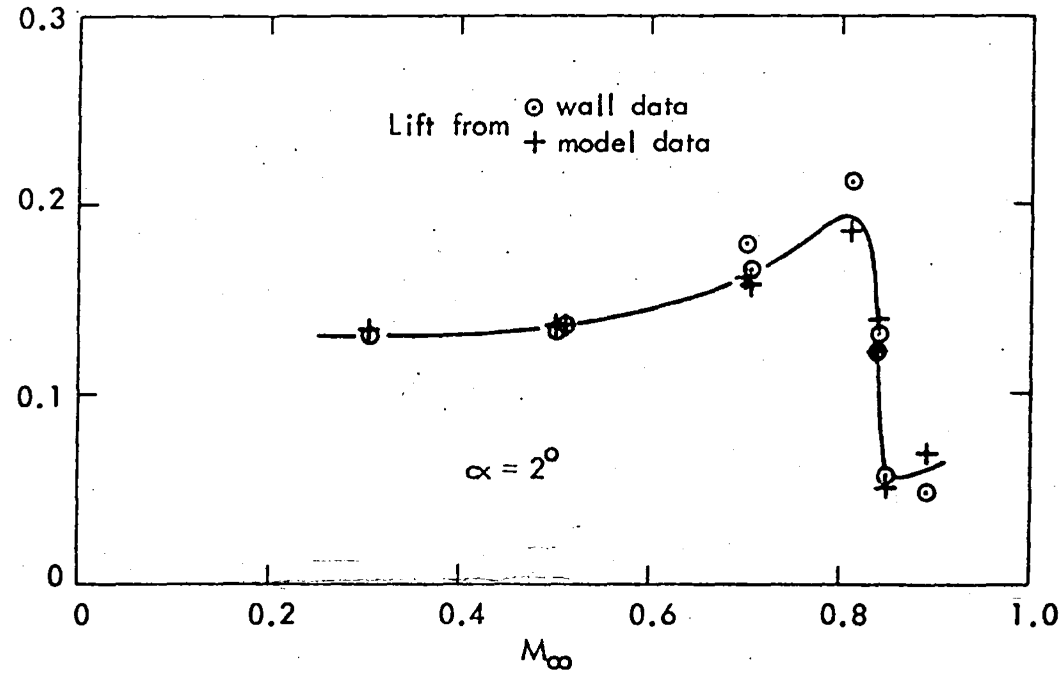


FIG 2 TWO-DIMENSIONAL TESTING OF NACA 0012-64: COMPARISONS OF LIFT COEFFICIENTS DETERMINED FROM WALL AND MODEL DATA.

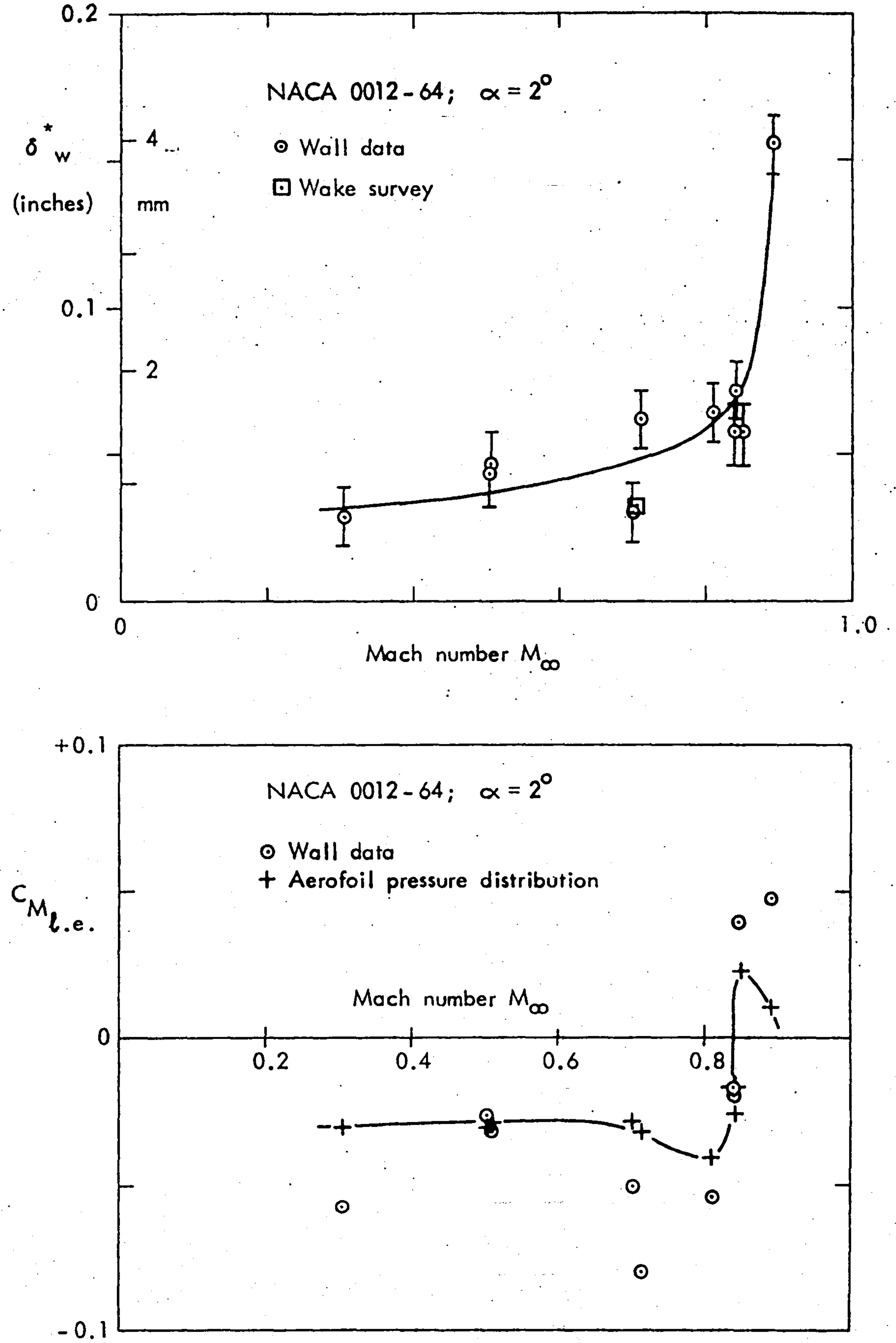


FIG. 3 AEROFOIL WAKE THICKNESS AND PITCHING MOMENT

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NASA CR-165994		

4. Title and Subtitle	5. Report Date
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M. J. Goodyer	T03-TZ20
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	13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546	14. Sponsoring Agency Code 505-31-53-06

15. Supplementary Notes

Langley Technical Monitor: Charles L. Ladson
Final Report

16. Abstract

Data obtained from the boundary of a test section provides information on the model contained within it. This report describes a method for extracting some of this data in two-dimensional testing. Examples of model data are included on lift, pitching moment and wake displacement thickness. A FORTRAN listing is also described, having a form suitable for incorporation into the software package used in the running of such a test section.

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End of Document