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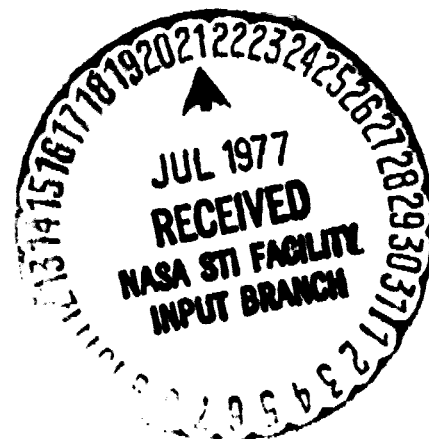
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**FORTTRAN PROGRAM FOR CALCULATING LEADING- AND
TRAILING-EDGE GEOMETRY OF TURBOMACHINE BLADES**

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SUMMARY

A FORTRAN IV program has been written which calculates leading- and trailing- edge circle radii, tangency angles on the leading- and trailing- edge circles, and stagger angle of turbomachinery blade sections using only spline points defining the blade surfaces. The program also shifts the origin of the blade coordinates to the leading edge of the blade. Required input includes (m, θ) coordinates of a sufficient number of spline points to adequately define the two surfaces of the blade. Other required input are the radii from the axis of rotation of the leading- and trailing- edges. The output from this program may be used directly as the geometrical input for a NASA developed program for calculating transonic velocities on a blade-to-blade stream surface of a turbomachine (TSONIC). The program may be used for axial, radial, and mixed flow turbomachine blades.

INTRODUCTION

In recent years, several computer programs have been written which calculate the velocities on a blade-to-blade surface of a turbomachine (ref. 1, 2, 3). These programs require an accurate geometrical description of the blade since spline fit curves (ref. 4) are used to define the blade surfaces. The inputs required include blade chord, blade stagger, leading- and trailing-edge circle radii, angles of tangency on the leading- and trailing-edge circles, and intermediate spline points. These inputs are usually obtained from measurements made on a physical layout of the blade or from a meridional flow analysis program such as MERIDL (ref. 5, 6). In either case, it is difficult to specify these inputs with the degree of accuracy necessary to insure a smooth blade shape without using a costly and time consuming trial-and-error procedure with the computer. Small errors in any of the input can result in a spline fit through the given input spline points in which the first and second derivatives of the curve do not vary smoothly. Since the computation of surface velocities is highly dependent on the blade surface curvatures which in turn are determined from the values of $d\theta/dm$ and $d^2\theta/dm^2$ obtained from the spline fit curve, it is important that the geometry input be specified accurately. If the first and second derivatives are not smooth unrealistic peaks and valleys in the surface velocity distribution will occur.

This report presents a Fortran IV computer program which analytically calculates the leading- and trailing-edge circle radii, tangency angles, and stagger angle of a turbomachine blade section using an iterative procedure. The required input includes enough blade surface (m, θ) coordinates to adequately define the general shape of the blade surfaces and the radius from the axis of rotation of the leading- and trailing-edges. This input is much easier to specify than the input for TSONIC. It will also yield smoother blade shapes. The output from this program may be used directly as the geometrical input for TSONIC (ref. 1) and TANDEM (ref. 3). A complete description of the input required and output obtained are given. Also given are two example cases and the program listing.

SYMBOLS

- c meridional chord length, meters, see fig. 1(b)
- m meridional distance, meters, see fig. 1
- r_L radius of leading edge circle, meters, see fig. 1(b)
- r_T radius of trailing edge circle, meters, see fig. 1(b)
- R radius from axis of rotation to the blade surface, meters, see fig. 1
- β angle between the blade surface and the meridional direction, degrees, see fig. 1(b)
- δ angular distance between the origin of the input blade coordinates and the center of the leading edge circle, radians, see fig. 1(b)
- θ angular coordinate about the axis of rotation, radians, see fig. 1
- σ blade stagger angle from the center of the leading edge circle to the center of the trailing edge circle, radians, see fig. 1(b)

Subscripts:

- L leading edge
- LT leading edge tangency point
- T trailing edge
- TT trailing edge tangency point
- 1 surface 1
- 2 surface 2

DESCRIPTION OF INPUT AND OUTPUT

The program computes leading- and trailing- edge circle radii, tangency angles, blade stagger and blade chord from input blade surface coordinates. The blade surface coordinates are defined by meridional distance, m , and the angle about the axis of rotation, θ . Also required as input are the radii from the axis of rotation of the leading- and trailing-edges. The input blade geometry is shown in figure 1(a). Since spline fit curves are used to define the two blade surfaces, the input spline points should not reflect the leading- and trailing- edge circle curvatures but should define a smooth blade with the surfaces extrapolated to the leading and trailing edges as shown in figure 1(a). This is the type of blade definition obtained from a known mean camber line and tangential thickness distribution.

The general procedure for the solution of the problem is described in the appendix. An iterative procedure is used which fits a circle in the region bounded by the two blade surfaces and the leading or trailing edge (fig. 1). The requirement that the circle be tangent to all three boundaries leads to a unique solution. Once the radius of this circle is determined, the remaining geometry is easily calculated. The variables calculated by the program are shown in figure 1(b).

INPUT

The input data sheet along with the values used in an example case are shown in figure 2. NP1 and NP2 are integer variables and must be right adjusted on 5-column format fields. The remaining input are real variables and are specified in 10-column fields. Either English or SI units may be used. The input variables are as follows:

NP1, NP2	Number of spline points on surfaces 1 and 2 respectively (maximum 50).
M1, M2	Arrays of m -coordinates of spline points on the two blade surfaces, meters, see fig. 1(a). The origin of the m coordinates may be anywhere but must be the same for both surfaces.
THETA1, THETA2	Arrays of θ -coordinates of spline points corresponding to M1 and M2, radians, see fig. 1(a). The origin of the θ -coordinates may be anywhere but must be the same for both surfaces.
ML, MT	Meridional distance, m , of the leading and trailing edges respectively, meters, see fig. 1(a). The origin for ML and MT must be the same as for M1 and M2.

RL, RT Radius of blade section from the axis of rotation at the leading and trailing edges corresponding to ML and MT, meters.

Surface 1 must always be the upper surface, i.e., the surface with the larger numerical values of θ as shown in figure 1(a). If this is not the case, an error message will be printed and no further computation will be done. Also, the leading- and trailing edge thicknesses must not equal zero for this technique.

It is advisable, if possible, to specify spline points beyond the leading and trailing edges of the blade as shown in figure 1(a) since this reduces the effect of the end conditions used in the splint subroutine (i.e. that the second derivative at the end points is one-half of that at the adjacent point). However, this is not an absolute requirement since the splint subroutine has the capability of linear extrapolation and therefore the specified spline points do not have to extend up to or beyond the leading- and trailing-edges.

OUTPUT

Two examples of the output obtained from the program are shown in figure 3. The output is divided into three points. The first part is a listing of the input data. The second part is a listing of the variables computed by the program. They are:

RLE	r_L , meters, see figure 1(b)
BETAL1	β_{LT1} , degrees, see figure 1(b)
BETAL2	β_{LT2} , degrees, see figure 1(b)
RTE	r_T , meters, see figure 1(b)
BETAT1	β_{TT1} , degrees, see figure 1(b)
BETAT2	β_{TT2} , degrees, see figure 1(b)
CHORD	c , meters, see figure 1(b)
STGR	σ , radians, see figure 1(b)
DELTA	δ , radians, see figure 1(b)

The third part of the output is a list of the input blade coordinates with the origin shifted to the leading edge of the blade as shown in figure 1(b). Also shown are the calculated tangency points. The values of the first and

second derivatives ($d\theta/dm$, $d^2\theta/dm^2$) obtained from the spline fit are also listed. A check on the smoothness of the blade can be made by examining the values of the second derivatives. They should vary smoothly from inlet to exit and have no wild oscillations. Any input coordinates whose m value is less than m_{LT} or greater than m_{TT} are not listed since these values should not be used as input to TSONIC. The values of the tangency points also should not be used as input coordinates to TSONIC (except as dummy variables) since these values will be calculated by TSONIC. The remaining coordinates may be used directly as input to TSONIC with no further modification.

APPLICATION OF THE PROGRAM

The primary purpose of this program is to easily obtain the input for TSONIC or TANDEM when only the blade surface coordinates are known or can easily be obtained (e.g. from a known mean camber line and tangential thickness distribution - fig. 4(a)). This is the type of output obtained from a meridional flow analysis program such as MERIDL. The current version of MERIDL (ref. 5 and 6) employs the technique presented in this report for the calculation of TSONIC input data. This program can also be used in conjunction with a physical layout since it is often difficult to measure angles and leading and trailing edge radii with any degree of accuracy while it is a relatively easy task to obtain 5 or 6 spline points on the blade surfaces which will yield a smooth blade shape (fig. 4(b)). It is also easy to obtain splitter blade geometry using this program by simply changing the value of m_L and R_L as is shown in example 2 (figs. 3(b) and 4(c)).

PROGRAM LISTING

```

0000100      DIMENSION M1(50),M2(50),THETA1(50),THETA2(50),DTDM1(50),DTDM2(50),-
0000200      1D2TDM1(50),D2TDM2(50)
0000300      REAL M1,M2,ML,MT,MTL1,MTL2,MTT1,MTT2
0000400 C
0000500 C      READ AND WRITE INPUT DATA
0000600 C
0000700      10 READ(5,1000,END=999)
0000800          WRITE(6,1001)
0000900          WRITE(6,1000)
0001000          WRITE(6,1100)
0001100          READ(5,1010) NP1,NP2
0001200          WRITE(6,1010) NP1,NP2
0001300          WRITE(6,1110)
0001400          READ(5,1020) (M1(I),I=1,NP1)
0001500          WRITE(6,1030) (M1(I),I=1,NP1)
0001600          WRITE(6,1120)
0001700          READ(5,1020) (THETA1(I),I=1,NP1)
0001800          WRITE(6,1030) (THETA1(I),I=1,NP1)
0001900          WRITE(6,1130)
0002000          READ(5,1020) (M2(I),I=1,NP2)
0002100          WRITE(6,1030) (M2(I),I=1,NP2)
0002200          WRITE(6,1140)
0002300          READ(5,1020) (THETA2(I),I=1,NP2)
0002400          WRITE(6,1030) (THETA2(I),I=1,NP2)
0002500          WRITE(6,1150)
0002600          READ(5,1020) ML,MT,RL,RT
0002700          WRITE(6,1030) ML,MT,RL,RT
0002800 C
0002900 C      COMPUTE LEADING EDGE RADIUS AND TANGENCY ANGLES
0003000 C
0003100          CALL SPLINT(M1,THETA1,NP1,ML,1,THL1,DL1,D2L1)
0003200          CALL SPLENT(M1,NP1,THETA1,DTDM1,D2TDM1)
0003300          CALL SPLINT(M2,THETA2,NP2,ML,1,THL2,DL2,D2L2)
0003400          CALL SPLENT(M2,NP2,THETA2,DTDM2,D2TDM2)
0003500          DAMP=1.
0003600          ITER=0
0003700      20 BETAL1=ATAN(RL*DL1)
0003800          BETAL2=ATAN(RL*DL2)
0003900          RLE1=(THL1-THL2)*RL*COS((BETAL1+BETAL2)/2.)/2.
0004000          IF(RLE1.LE.0.) GO TO 120
0004100      30 MTL1=ML+RLE1*(1.-SIN(BETAL1))
0004200          MTL2=ML+RLE1*(1.+SIN(BETAL2))
0004300          CALL SPLINT(M1,THETA1,NP1,MTL1,1,TTL1,DTL1,D2TL1)
0004400          CALL SPLINT(M2,THETA2,NP2,MTL2,1,TTL2,DTL2,D2TL2)
0004500          BETAL1=ATAN(RL*DTL1)
0004600          BETAL2=ATAN(RL*DTL2)
0004700          RLE2=RL*(TTL1-TTL2)/(COS(BETAL1)+COS(BETAL2))
0004800          IF(ABS((RLE2-RLE1)/RLE1).LT..0001) GO TO 50
0004900          ITER=ITER+1
0005000          IF(ITER.LE.100) GO TO 40
0005100          WRITE(6,1200)
0005200          GO TO 50
0005300      40 RLE1=(DAMP*RLE1+RLE2)/(DAMP+1.)
0005400          IF(RLE1.GT.0.) GO TO 30

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0005500      DAMP=DAMP+20.
0005600      GO TO 20
0005700 C
0005800 C      COMPUTE TRAILING EDGE RADIIUS AND TANGENCY ANGLES
0005900 C
0006000      50 CALL SPLINT(M1,THETA1,NP1,MT,1,THT1,DT1,D2T1)
0006100      CALL SPLINT(M2,THETA2,NP2,MT,1,THT2,DT2,D2T2)
0006200      DAMP=1.
0006300      ITER=0
0006400      60 BETAT1=ATAN(RT*DT1)
0006500      BETAT2=ATAN(RT*DT2)
0006600      RTE1=(THT1-THT2)*RT*COS((BETAT1+BETAT2)/2.)/2.
0006700      IF(RTE1.LE.0.)GO TO 120
0006800      70 MTT1=MT-RTE1*(1.+SIN(BETAT1))
0006900      MTT2=MT-RTE1*(1.-SIN(BETAT2))
0007000      CALL SPLINT(M1,THETA1,NP1,MTT1,1,TTT1,DTT1,D2TT1)
0007100      CALL SPLINT(M2,THETA2,NP2,MTT2,1,TTT2,DTT2,D2TT2)
0007200      BETAT1=ATAN(RT*DTT1)
0007300      BETAT2=ATAN(RT*DTT2)
0007400      RTE2=RT*(TTT1-TTT2)/(COS(BETAT1)+COS(BETAT2))
0007500      IF(ABS((RTE2-RTE1)/RTE1).LT..0001)GO TO 90
0007600      ITER=ITER+1
0007700      IF(ITER.LE.100)GO TO 80
0007800      WRITE(6,1210)
0007900      GO TO 90
0008000      80 RTE1=(DAMP*RTE1+RTE2)/(DAMP+1.)
0008100      IF(RTE1.GT.0.)GO TO 70
0008200      DAMP=DAMP+20.
0008300      GO TO 60
0008400 C
0008500 C      CALCULATE AND PRINT OUTPUT DATA
0008600 C
0008700      90 DELTA=(TTL1*COS(BETAL2)+TTL2*COS(BETAL1))/(COS(BETAL1)+COS(BETAL2))-
0008800      1)
0008900      STGR=(TTT1*COS(BETAT2)+TTT2*COS(BETAT1))/(COS(BETAT1)+COS(BETAT2))-
0009000      1-DELTA
0009100      CHORD=MT-ML
0009200      BETAL1=BETAL1*57.29578
0009300      BETAL2=BETAL2*57.29578
0009400      BETAT1=BETAT1*57.29578
0009500      BETAT2=BETAT2*57.29578
0009600      MTL1=MTL1-ML
0009700      MTL2=MTL2-ML
0009800      MTT1=MTT1-ML
0009900      MTT2=MTT2-ML
0010000      TTL1=TTL1-DELTA
0010100      TTL2=TTL2-DELTA
0010200      TTT1=TTT1-DELTA
0010300      TTT2=TTT2-DELTA
0010400      WRITE(6,1160)
0010500      WRITE(6,1030)RLE1,BETAL1,BETAL2,RTE1,BETAT1,BETAT2
0010600      WRITE(6,1170)
0010700      WRITE(6,1030)CHORD,STGR,DELTA
0010800      WRITE(6,1180)

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0010900      J=1
0011000      WRITE(6,1040) J,MTL1,TTL1,DTL1,D2TL1
0011100      DO 100 I=1,NP1
0011200      M1(I)=M1(I)-ML
0011300      THETA1(I)=THETA1(I)-DELTA
0011400      IF (M1(I).LE.MTL1.OR.M1(I).GE.MTT1) GO TO 100
0011500      J=J+1
0011600      WRITE(6,1050) J,M1(I),THETA1(I),DTDM1(I),D2TDM1(I)
0011700 100 CONTINUE
0011800      J=J+1
0011900      WRITE(6,1040) J,MTT1,TTT1,DTT1,D2TT1
0012000      WRITE(6,1190)
0012100      J=1
0012200      WRITE(6,1040) J,MTL2,TTL2,DTL2,D2TL2
0012300      DO 110 I=1,NP2
0012400      M2(I)=M2(I)-ML
0012500      THETA2(I)=THETA2(I)-DELTA
0012600      IF (M2(I).LE.MTL2.OR.M2(I).GE.MTT2) GO TO 110
0012700      J=J+1
0012800      WRITE(6,1050) J,M2(I),THETA2(I),DTDM2(I),D2TDM2(I)
0012900 110 CONTINUE
0013000      J=J+1
0013100      WRITE(6,1040) J,MTT2,TTT2,DTT2,D2TT2
0013200      GO TO 10
0013300 120 WRITE(6,1220)
0013400      GO TO 10
0013500 C
0013600 C   FORMAT STATEMENTS
0013700 C
0013800 1000 FORMAT(80H
0013900      1
0014000 1001 FORMAT(1H1)
0014100 1010 FORMAT(16I5)
0014200 1020 FORMAT(8F10.6)
0014300 1030 FORMAT(8G15.6)
0014400 1040 FORMAT(6X,14HTANGENCY POINT,3X,I2,4G15.6)
0014500 1050 FORMAT(23X,I2,4G15.6)
0014600 1100 FORMAT(/10H NP1 NP2)
0014700 1110 FORMAT(8X,8HM1 ARRAY)
0014800 1120 FORMAT(8X,12HTHETA1 ARRAY)
0014900 1130 FORMAT(8X,8HM2 ARRAY)
0015000 1140 FORMAT(8X,12HTHETA2 ARRAY)
0015100 1150 FORMAT(6X,2HML,13X,2HMT,13X,2HRL,13X,2HRT)
0015200 1160 FORMAT(///32X,25H** COMPUTED BLADE DATA **///6X,3HRL,12X,
0015300      16HBETAL1,9X,6HBETAL2,9X,3HRT,12X,6HBETAT1,9X,6HBETAT2)
0015400 1170 FORMAT(6X,5HCHORD,10X,4HSTGR,11X,5HDELTA)
0015500 1180 FORMAT(///34X,21H* BLADE COORDINATES */30X,30H(ORIGIN AT BLADE LEA-
0015600      1DING ED' E) //40X,9HSURFACE 1//24X,1HI,6X,1HM,14X,5HTHETA,10X,4HDTDM-
0015700      1,11X,6HD2TDM2)
0015800 1190 FORMAT(///40X,9HSURFACE 2//24X,1HI,6X,1HM,14X,5HTHETA,10X,4HDTDM,
0015900      111X,6HD2TDM2)
0016000 1200 FORMAT(///5X,61HSOLUTION FOR LEADING EDGE HAS NOT CONVERGED IN 100 -
0016100      1ITERATIONS)
0016200 1210 FORMAT(///5X,62HSOLUTION FOR TRAILING EDGE HAS NOT CONVERGED IN 100-

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0016300      1 ITERATIONS)
0016400 1220 FORMAT(///10X,43HINPUT ERROR -- ONE OF THREE POSSIBLE CAUSES/ -
0016500      117X,32H1. SURFACES 1 AND 2 ARE INVERTED/ -
0016600      217X,54H2. BLADE THICKNESS IS ZERO AT LEADING OR TRAILING EDGE/ -
0016700      317X,68H3. SURFACES 1 AND 2 CROSS OVER AT SOME POINT DUE TO A BAD S-
0016800      4PLINE FIT)
0016900 999 STOP
0017000      END

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0000100      SUBROUTINE SPLINT (X,Y,N,Z,MAX,YINT,DYDX,D2YDX2)
0000200 C
0000300 C--SPLINT CALCULATES INTERPOLATED POINTS AND DERIVATIVES
0000400 C--FOR A SPLINE CURVE
0000500 C--END CONDITION - SECOND DERIVATIVES AT END POINTS ARE
0000600 C--SDR1 AND SDRN TIMES SECOND DERIVATIVES AT ADJACENT POINTS
0000700 C
0000900      DIMENSION X(N),Y(N),Z(MAX),YINT(MAX),DYDX(MAX),D2YDX2(MAX)
0001000      DIMENSION G(101),SB(101),EM(101)
0001100      IERR = 0
0001200      SDR1 = .5
0001300      SDRN = .5
0001400      TOLER= ABS(X(N)-X(1))/FLOAT(N)*1.E-5
0001500      C = X(2)-X(1)
0001600      IF (C.EQ.0.) GO TO 130
0001700      SB(1) = -SDR1
0001800      G(1) = 0.
0001900      NO = N-1
0002000      IF (NO.LE.0) GO TO 140
0002100      IF (NO.EQ.1) GO TO 20
0002200      DO 10 I=2,NO
0002300      A = C
0002400      C = X(I+1)-X(I)
0002500      IF (A*C.EQ.0.) GO TO 130
0002600      IF (A*C.LT.0.) IERR = 1
0002700      W = 2.*(A+C)-A*SB(I-1)
0002800      SB(I) = C/W
0002900      F = (Y(I+1)-Y(I))/C-(Y(I)-Y(I-1))/A
0003000      10 G(I) = (6.*F-A*G(I-1))/W
0003100      20 EM(N) = SDRN*G(N-1)/(1.+SDRN*SB(N-1))
0003200      DO 30 I=2,N
0003300      K = N+1-I
0003400      30 EM(K) = G(K)-SB(K)*EM(K+1)
0003500      IF (MAX.LE.0) RETURN
0003600 C
0003700      ENTRY SPLENT (Z,MAX,YINT,DYDX,D2YDX2)
0003800      DO 120 I=1,MAX
0003900      K=2
0004000      IF (ABS(Z(I)-X(1)).LT.TOLER) GO TO 40
0004100      IF (Z(I).GT.2.0*X(1)-X(2)) GO TO 50
0004200      GO TO 80
0004300      40 YINT(I) = Y(1)
0004400      SK = X(K)-X(K-1)
0004500      GO TO 110
0004600      50 IF (ABS(Z(I)-X(K)).LT.TOLER) GO TO 60
0004700      IF (Z(I).GT.X(K)) GO TO 70
0004800      GO TO 100
0004900      60 YINT(I) = Y(X)
0005000      SK = X(K)-X(K-1)
0005100      GO TO 110
0005200      70 IF (K.GE.N) GO TO 90
0005300      K = K+1
0005400      GO TO 50
0005500      80 S2 = X(2)-X(1)

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0005600      Y0 = EM(1)*S2**2+2.*Y(1)-Y(2)
0005700      DYDX(I) = (Y(2)-Y(1))/S2-7.*EM(1)/6.*S2
0005800      YINT(I) = Y0+DYDX(I)*(Z(I)-X(1)+S2)
0005900      D2YDX2(I) = 0.
0006000      GO TO 120
0006100  90  IF (Z(I).LT.2.*X(N)-X(N-1)) GO TO 100
0006200      SN = X(N)-X(N-1)
0006300      YNP1 = EM(N)*SN**2+2.*Y(N)-Y(N-1)
0006400      DYDX(I) = (Y(N)-Y(N-1))/SN+7.*EM(N)/6.*SN
0006500      YINT(I) = YNP1+DYDX(I)*(Z(I)-X(N)-SN)
0006600      D2YDX2(I) = 0.
0006700      GO TO 120
0006800  100 SK = X(K)-X(K-1)
0006900      YINT(I) = EM(K-1)*(X(K)-Z(I))**3/6./SK +EM(K)*(Z(I)-X(K-1))**3/6.-
0007000      1 /SK+(Y(K)/SK -EM(K)*SK /6.)*(Z(I)-X(K-1))+(Y(K-1)/SK -EM(K-1)-
0007100      2 *SK/6.)*(X(K)-Z(I))
0007200  110 DYDX(I)=-EM(K-1)*(X(K)-Z(I))**2/2.0/SK +EM(K)*(X(K-1)-Z(I))**2/2.-
0007300      1 /SK+(Y(K)-Y(K-1))/SK -(EM(K)-EM(K-1))*SK/6.
0007400      D2YDX2(I) = EM(K)-(X(K)-Z(I))/SK*(EM(K)-EM(K-1))
0007500  120 CONTINUE
0007600      IF (IERR.EQ.0) RETURN
0007700  130 WRITE(6,1000)
0007800      WRITE(6,1020) N,(X(I),Y(I),I=1,N)
0007900      IF (IERR.EQ.0) STOP
0008000      WRITE(6,1030)
0008100      RETURN
0008200  140 WRITE(6,1010)
0008300      WRITE(6,1020) N,(X(I),Y(I),I=1,N)
0008400      STOP
0008500  1000 FORMAT (1H1,10X,44HSPLINT ERROR -- ONE OF THREE POSSIBLE CAUSES/ -
0008600      117X,51H1. ADJACENT X POINTS ARE DUPLICATES OF EACH OTHER./ -
0008700      217X,38H2. SOME X POINTS ARE OUT OF SEQUENCE./ -
0008800      317X,32H3. SOME X POINTS ARE UNDEFINED.)
0008900  1010 FORMAT (1H1,10X,62HSPLINT ERROR -- NUMBER OF SPLINE POINTS GIVEN I-
0009000      1S LESS THAN TWO)
0009100  1020 FORMAT (//17X,18HNUMBER OF POINTS =,I4//17X,8HX ARRAY,6X,8HY ARR-
0009200      1AY/(17X,2G13.5))
0009300  1030 FORMAT (1H1)
0009400      END

```

APPENDIX

CALCULATION PROCEDURE OF THE PROGRAM

The program computes the leading- and trailing-edge circle radii and tangency angles by an iterative procedure. Figure 1 shows the basic blade geometry. The input coordinates are given as (m, θ) coordinates where m is the length in the meridional direction and θ is the angle in radians about the axis of rotation. The origin for both the m and θ coordinates may be anywhere since it will be shifted by the program to the leading edge of the blade.

From figure 1(b) (with the assumption that $r_L \ll R_L$), the following equations can be written for the leading edge circle:

$$m_{LT1} = m_L + r_L (1 - \sin \beta_{LT1}) \quad (1)$$

$$m_{LT2} = m_L + r_L (1 + \sin \beta_{LT2}) \quad (2)$$

$$\theta_{LT1} = \delta + \frac{r_L \cos \beta_{LT1}}{R_L} \quad (3)$$

$$\theta_{LT2} = \delta - \frac{r_L \cos \beta_{LT2}}{R_L} \quad (4)$$

Equations (3) and (4) can be solved for r_L which gives

$$r_L = \frac{R_L (\theta_{LT1} - \theta_{LT2})}{\cos \beta_{LT1} + \cos \beta_{LT2}} \quad (5)$$

The tangency angles are determined from the equations

$$\tan \beta_{LT1} = R_L \left(\frac{d\theta}{dm} \right)_{LT1} \quad (6)$$

$$\tan \beta_{LT2} = R_L \left(\frac{d\theta}{dm} \right)_{LT2} \quad (7)$$

The angle θ and $d\theta/dm$ for a given value of m are obtained from a spline fit curve (subroutine SPLINT, ref. 4) on the input surface coordinates. Equations (1), (2), (5), (6) and (7) along with the spline fit curves on the surfaces are sufficient to solve the problem. Similar equations can be written for the trailing edge.

The program procedure is as follows:

- (1) A first estimate of the leading edge radius is obtained from the equation

$$r_L \approx R_2 (\theta_{L1} - \theta_{L2}) \cos \left(\frac{\beta_{L1} + \beta_{L2}}{2} \right) \quad (8)$$

where θ_L and β_L are values obtained from a spline fit curve at the leading edge (see fig. 1(a)).

- (2) Values of m_{LT1} and m_{LT2} are obtained from equation (1) and (2) using the estimated value of r_L , the leading edge values of β_L , and the input value of m_L .

- (3) Splint calls are done on both surfaces using the computed values m_{LT1} and m_{LT2} which will yield values of θ_{LT} and β_{LT} .

- (4) A new value of leading edge radius is obtained from equation (5).

- (5) An average value of r_L is used to start the next iteration. The average value will be weighted toward the previous value if r_L becomes negative. The values of β_{LT} from the previous iteration are used.

- (6) When the values of r_L for two successive iterations are within 0.01% of each other, the solution is converged.

- (7) The solution for the trailing edge is obtained.

- (8) Values of δ , stagger (σ), and chord (c) are obtained from the equations

$$\delta = \frac{\theta_{LT1} \cos \beta_{LT2} + \theta_{LT2} \cos \beta_{LT1}}{\cos \beta_{LT1} + \cos \beta_{LT2}} \quad (9)$$

$$\sigma = \frac{\theta_{TT1} \cos \beta_{TT2} + \theta_{TT2} \cos \beta_{TT1}}{\cos \beta_{TT1} + \cos \beta_{TT2}} - \delta \quad (10)$$

$$c = m_T - m_L \quad (11)$$

(9) The input blade coordinates are shifted so that the origin is at the blade leading edge by the following transformation

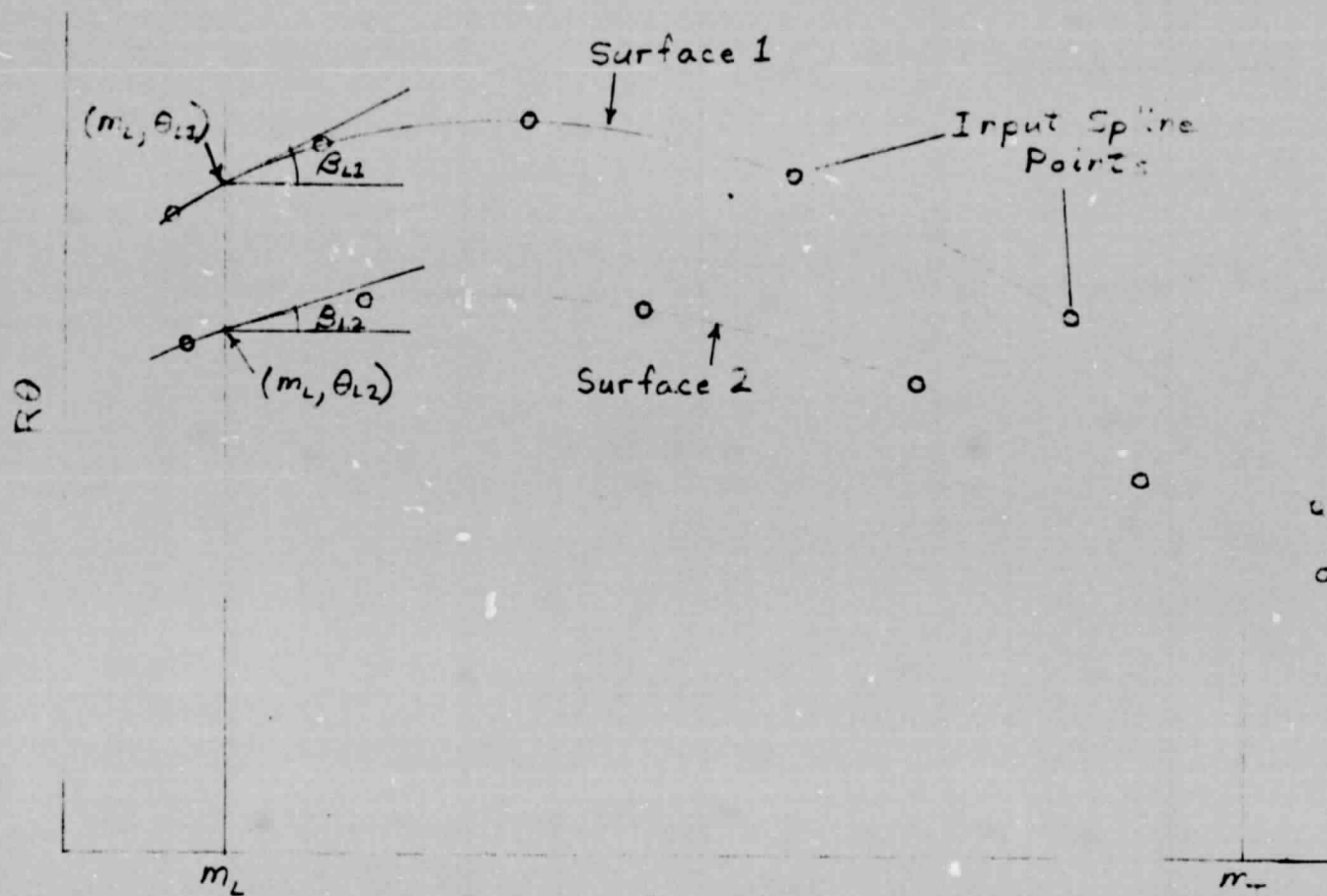
$$m = m - m_L \quad (12)$$

$$\theta = \theta - \delta \quad (13)$$

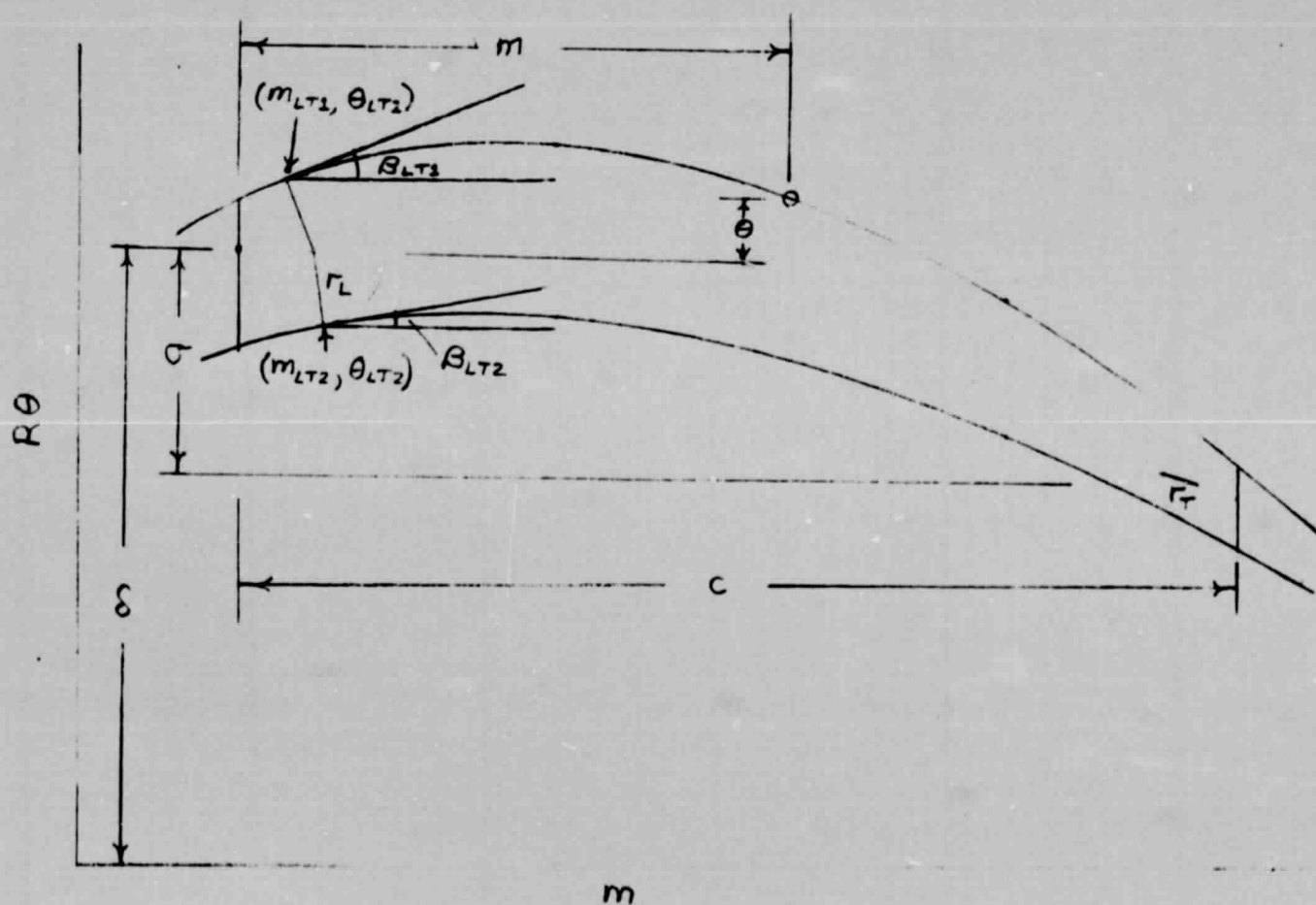
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6. Katsanis, Theodore; and McNally, William D.: Revised FORTRAN Program for Calculating Velocities and Streamlines on the Hub-Shroud Midchannel Stream Surface of an Axial-, Radial-, or Mixed-Flow Turbomachine or Annular Duct. II - Programmer's Manual. NASA TN D-8431, 1977.

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a) Input Geometry



b) Output Geometry

Figure 1 - Blade Geometry

1	5	6	10	11	20	21	30	31	40	41	50	51	60	61	70	71	80
TITLE CARD																	
EXAMPLE 1 - CENTRIFUGAL COMPRESSOR HUB SECTION																	
NP1		NP2															
6		6															
M1 ARRAY																	
0.		.025748		.085269		.14989		.20782		.23172							
THETA1 ARRAY																	
.50474		.83365		1.10168		1.17271		1.25245		1.29961							
M2 ARRAY																	
0.		.025748		.085269		.14989		.20782		.23172							
THETA2 ARRAY																	
.42024		.76123		1.05180		1.13873		1.22981		1.28139							
ML		MT		RL		RT											
0.		.23172		.08323		.2645											

Figure 2 - Input Form

REPRODUCIBILITY OF THE
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Figure 3(a) EXAMPLE OUTPUT

EXAMPLE 1 - CENTRIFUGAL COMPRESSOR HUB SECTION

NP1	NP2					
6	6					
M1 ARRAY						
0.000000	0.257480E-01	0.852690E-01	0.149890	0.207820	0.231720	
THETA1 ARRAY						
0.504740	0.833650	1.10168	1.17271	1.25245	1.29961	
M2 ARRAY						
0.000000	0.257480E-01	0.852690E-01	0.149890	0.207820	0.231720	
THETA2 ARRAY						
0.420240	0.761230	1.05180	1.13873	1.22981	1.28139	
ML	MT	RL	RT			
0.000000	0.231720	0.833300E-01	0.264500			

** COMPUTED BLADE DATA **

RLE	BETAL1	BETAL2	RTE	BETAT1	BETAT2
0.217386E-02	51.2904	51.2865	0.213013E-02	28.8679	31.1841
CHORD	STGR	DELTA			
0.231720	0.790331	0.495592			

* BLADE COORDINATES *
(ORIGIN AT BLADE LEADING EDGE)

SURFACE 1

	I	M	THETA	DTDM	D2TDM2
TANGENCY POINT	1	0.477540E-03	0.163135E-01	14.9739	-134.296
	2	0.257480E-01	0.338058	9.94511	-263.702
	3	0.852690E-01	0.606088	1.46705	-21.1741
	4	0.149890	0.677117	1.04757	8.19146
	5	0.207820	0.756858	1.79708	17.6848
TANGENCY POINT	6	0.228561	0.797385	2.08430	10.0110

SURFACE 2

	I	M	THETA	DTDM	D2TDM2
TANGENCY POINT	1	0.387008E-02	-0.163153E-01	14.9718	-152.893
	2	0.257480E-01	0.265638	10.3914	-265.830
	3	0.852690E-01	0.556208	1.77377	-23.7373
	4	0.149890	0.643137	1.25508	7.68391
	5	0.207820	0.734218	1.98404	17.4830
TANGENCY POINT	6	0.230693	0.783442	2.28825	9.11722

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Figure 3(b). - EXAMPLE OUTPUT

EXAMPLE 2 - CENTRIFUGAL COMPRESSOR HUB SECTION - SPLITTER BLADE

NP1	NP2					
6	6					
M1 ARRAY						
0.000000	0.257480E-01	0.852690E-01	0.149890	0.207820	0.231720	
THETA1 ARRAY						
0.504740	0.833650	1.10168	1.17271	1.25245	1.29961	
M2 ARRAY						
0.000000	0.257480E-01	0.852690E-01	0.149890	0.207820	0.231720	
THETA2 ARRAY						
0.420240	0.761230	1.05180	1.13873	1.22981	1.28139	
ML	MT	RL	RT			
0.517320E-01	0.231720	0.102740	0.264500			

** COMPUTED BLADE DATA **

RLE	BETAL1	BETAL2	RTE	BETAT1	BFTAT2
0.284874E-02	23.3568	23.5919	0.213013E-02	28.8679	31.1841
CHORD	STGR	DELTA			
0.179988	0.288974	0.996949			

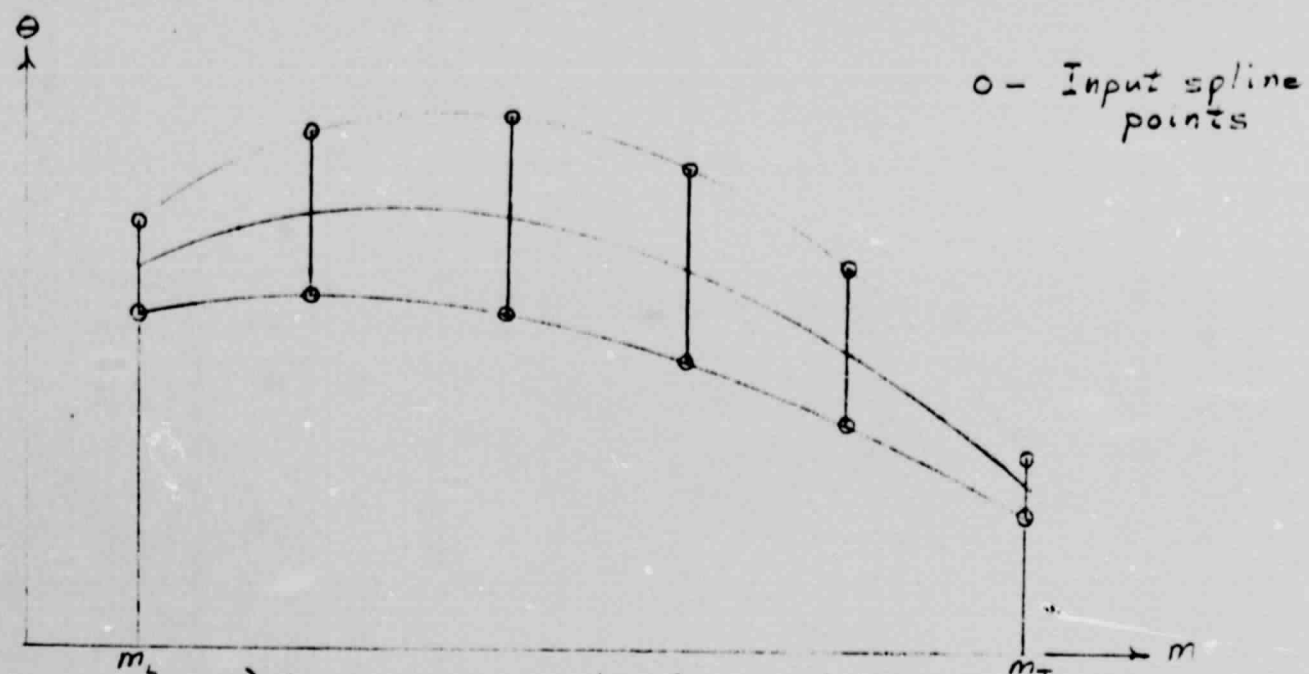
* BLADE COORDINATES *
(ORIGIN AT BLADE LEADING EDGE)

SURFACE 1

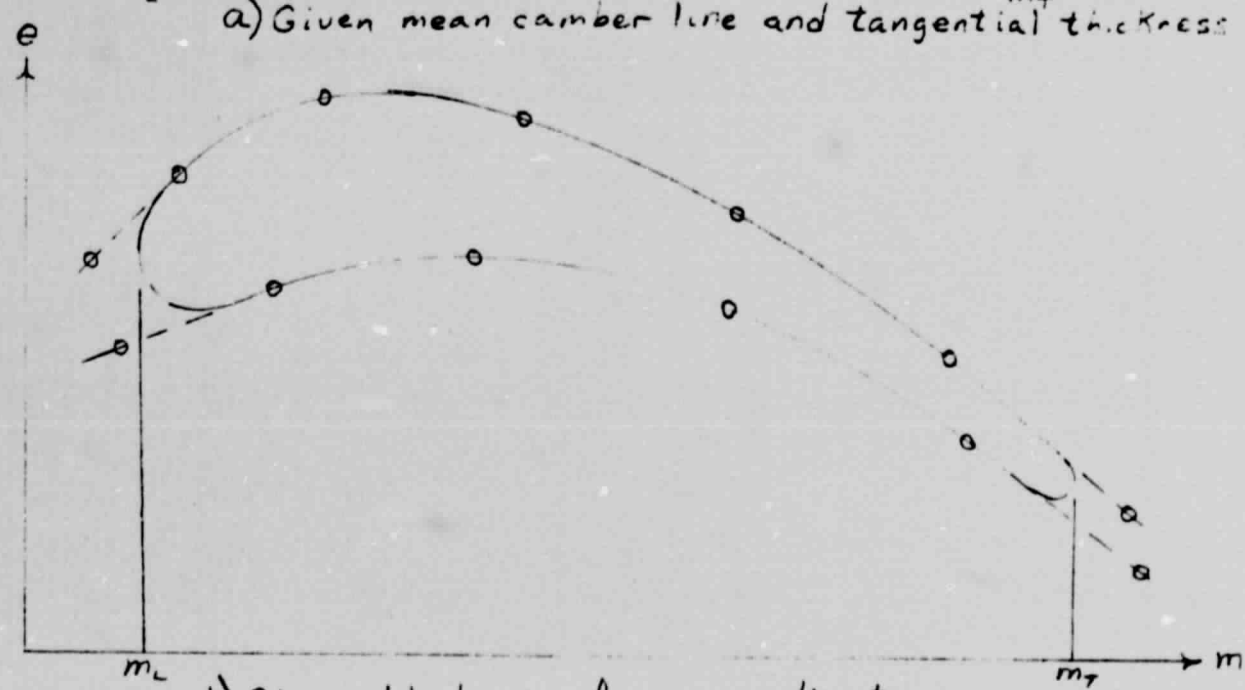
	I	M	THETA	DTDM	D2TDM2
TANGENCY POINT	1	0.171933E-02	0.254581E-01	4.20327	-150.820
	2	0.335370E-01	0.104730	1.46705	-21.1741
	3	0.981579E-01	0.175760	1.04757	8.19146
	4	0.156088	0.255501	1.79708	17.6848
TANGENCY POINT	5	0.176829	0.296028	2.08430	10.0110

SURFACE 2

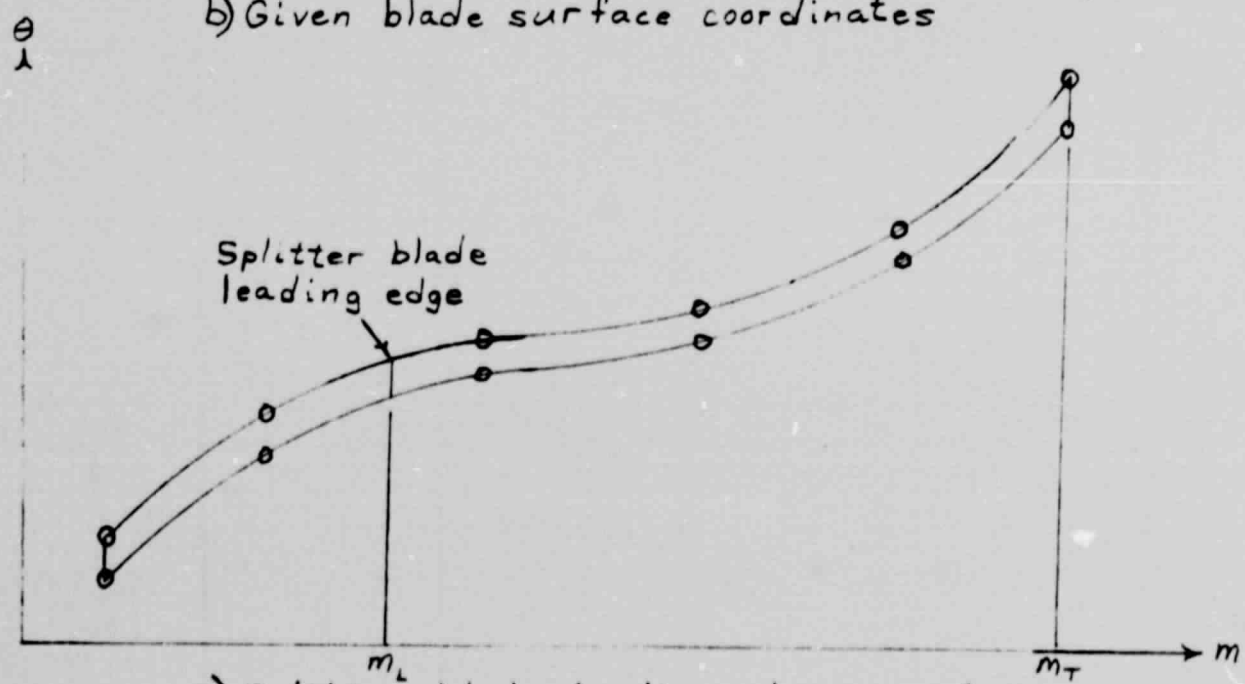
	I	M	THETA	DTDM	D2TDM2
TANGENCY POINT	1	0.398887E-02	-0.254126E-01	4.25075	-143.920
	2	0.335370E-01	0.548503E-01	1.77377	-23.7373
	3	0.981579E-01	0.141780	1.25508	7.68391
	4	0.156088	0.232860	1.98404	17.4830
TANGENCY POINT	5	0.178961	0.282084	2.28925	9.11722



a) Given mean camber line and tangential thickness



b) Given blade surface coordinates



c) Splitter blade leading edge geometry

Figure 4 - Various Applications of the Program