WANL-TME-1689
November 1, 1967

Process

Westinghouse Astronuclear Laboratory

A COMPUTER PROGRAM FOR CALCULATING
THE BOUNDARY LAYER PROPERTIES ALONG
THE SURFACE OF TURBOMACHINERY BLADES

MASTER

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CONTRACT NAS 7-390

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A COMPUTER PROGRAM FOR CALCULATING
THE BOUNDARY LAYER PROPERTIES ALONG
THE SURFACE OF TURBOMACHINERY BLADES

Prepared for:

JET PROPULSION LABORATORY
Pasadena, California

Contract NAS 7-390

Basic Investigation of Turbine Erosion Phenomena

By:

W. K. Fentress
Development Engineering Department
Westinghouse Steam Divisions

INFORMATION CATEGORY:

UNCLASSIFIED

Authorized Classifier

11-3-67

Date

MASTER

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ABSTRACT

This report describes a computer program for calculating the boundary layer properties along the suction and pressure surface of turbomachinery blades. These properties include the momentum thickness, displacement thickness, full thickness, and the form factor.

A necessary input to the program is the surface velocity at a number of points on the suction and pressure side of the blade.

The calculation is by the method of Truckenbrodt, but assumes that the boundary layer is turbulent along the entire blade surface. This assumption is justified in turbomachinery, but not in the case of cascades.

INTRODUCTION

The WANL has conducted an analytical investigation of the turbine erosion phenomenon. As a part of this investigation, calculations were made in the various areas of turbine flow. These were performed by a number of computer programs including the present program. While this investigation has been described by a number of WANL-PR-(DD) reports, these reports do not give a detailed account of the programs.

This report is therefore to describe the boundary layer program. It describes the use of the program, the assumptions, and the method of calculation. No attempt has been made to explain the basis of the calculation as this is fully explained in references 1 and 2.

The only notable assumption is as to the turbulent boundary layer, without regard to the possible laminar region at the inlet of the blade. Usually, this assumption has little effect on the properties at the trailing edge extremity. Further, it is probable that laminar flow does not occur in actual turbines, due to the turbulence and unsteady flow at the inlet of the blade row, contrary to the situation in cascades where there is undisturbed flow to the blades (ref. 4).

It is shown by ref. 5 that the Truckenbrodt calculation is in reasonable agreement with other methods of calculation.

NOMENCLATURE

The symbols in column 1 are used in the computer program; those to the right are used in the Analysis section. Generally, symbols are shown in the order of the program listing.

S, P	subscript S, P	suction, pressure surface
(I)	subscript 1, 2, -- M	surface points
--	l	surface length
--	$l_2, l_3, -- l_M$	surface length from point 1 to point 2, 3, -- M.
X	l/l_M	referred surface length
XS(I)	$(l_2/l_M)_S, (l_3/l_M)_S, -- (l_M/l_M)_S$	
XP(I)	$(l_2/l_M)_P, (l_3/l_M)_P, -- (l_M/l_M)_P$	
--	u	free stream velocity
V	u/u_M	referred free stream velocity with respect to exit velocity.
VS(I)	$(u_2/u_M)_S, (u_3/u_M)_S, -- (u_M/u_M)_S$	
VP(I)	same, subscript P	
D, E		D, E in Statement DATA correspond to F, H.
SS, SP	$(l_M)_S, (l_M)_P$	suction, pressure surface length - in.

-- n exponent = 6 in eq. 1, 2, and 4.

T θ/δ_M referred momentum thickness of boundary layer, Eq. 1.

TS(I) $(\theta_2/\delta_M)_S, (\theta_3/\delta_M)_S, \text{ -- } (\theta_M/\delta_M)_S$

TP(I) same, subscript P

SUMSI $\int_0^{(\delta/\delta_M)_S} (u/u_M)_S^{3+2/n} d(\delta/\delta_M)_S$ - term in Eq. 1 and 4.

SUMP1 same, subscript P

-- ν_M kinematic viscosity at point M.

RE $Re = (\delta_{M,S}/2. + \delta_{M,P}/2.) u_M/\nu_M$ - Reynolds no.

-- C_f friction factor - Eq. 2.

AS, AP $(C_f/2.)^{(1+n)/n}$ term in Eq. 1 and 4.

BS, BP -- terms in Eq. 3.

Z ξ Eq. 4.

ZS(I) $(\xi_2)_S, (\xi_3)_S, \text{ -- } (\xi_M)_S$

ZP(I) same, subscript P

SUMS2 $\int_0^{\xi_S} \ln (u/u_M)_S d\xi_S$ term in Eq. 3.

SUMP2 same, subscript P

F	$L(\xi)$	shape factor, Eq. 3
--	$L(H, E)$	shape factor, Eq. 5
FS(I)	$(L_2)_S, (L_3)_S, \dots (L_M)_S$	
FP(I)	same, subscript P	
--	E	energy form factor, Eq. 6
H	H	form factor, Eq. 5
HS(I)	$(H_2)_S, (H_3)_S, \dots (H_M)_S$	
HP(I)	same, subscript P	
N	$N = 2./(H-1)$	Eq. 7
NS(I)	$(N_2)_S, (N_3)_S, \dots (N_M)_S$	
NP(I)	same subscript P	
TSIN, TPIN	$\theta = (\theta/\rho_M)\rho_M$	momentum thickness - in.
TSIN(I)	$(\theta_2)_S, (\theta_3)_S, \dots (\theta_M)_S$	
TPIN(I)	same, subscript P	
DSIN, DPIN	$\delta^* = \theta H$	displacement thickness - in. Eq. 8
DSIN(I)	$(\delta_2^*)_S, (\delta_3^*)_S, \dots (\delta_M^*)_S$	
DPIN(I)	same, subscript P	
DFSIN, DFPIN	$\delta = \delta^* (1+N)$	full thickness - in. Eq. 9
DFSIN(I)	$(\delta_2)_S, (\delta_3)_S, \dots (\delta_M)_S$	
DFPIN(I)	same, subscript P	

ANALYSIS

The momentum thickness of the boundary layer is specified by the Truckenbrodt equation as:

$$\theta/x_M = (u/u_M)^{-3} \left((C_f/2.)^{(n+1)/n} \int_0^{x/x_M} (u/u_M)^{3+2/n} d(x/x_M) \right)^{n/(1+n)} \quad \text{Eq. 1}$$

where the exponent n is 6, corresponding to large Reynolds nos., and the friction factor is specified by the empirical expression for flat plate, turbulent flow -

$$C_f = 0.074/Re^{0.2}. \quad \text{Eq. 2}$$

This statement of the Truckenbrodt equation is identical to that in ref. 1 save for the fact that the boundary layer is regarded as turbulent along the entire blade length. Hence the laminar term does not appear in the above equation and the integration is performed to the inlet edge of the blade rather than to the point of transition.

By this equation the momentum thickness is calculated for a number of points on the suction and pressure side of the blade by applying point by point values for the surface velocity and performing the integration.

Similarly, the boundary layer shape factor and form factor are calculated by the following equations. First the quantity L , referred to as the shape factor, is specified by ref. 3 as -

$$L = -.23 - .0076 \, n/(n+1) + .0304 \ln Re + \ln (u/u_M) \\ + .0076 \left(n/(n+1) \right) \ln \xi - (1.0608/\xi) \int_0^\xi \ln (u/u_M) d\xi$$

Eq. 3

where

$$\xi = (C_f/2.)^{(1+n)/n} \int_0^{\xi/\xi_M} (u/u_M)^{3+2/n} d(\xi/\xi_M)^4.$$

Eq. 4

As before, $n = 6$ and C_f is as specified by Eq. 2. The laminar terms do not appear in the equations and the integration is performed to the inlet edge of the blade. Note that Eq. 3 is obtained in ref. 3 by introducing θ/δ_M (Eq. 1) into the expression for L given by ref. 1 page 474. In this modified form the equation is more amenable to integration.

The form factor H is related to L by the ref. 1 equation -

$$L = \int_{E_0=1.74}^E dE / ((H-1)E) \quad \text{Eq. 5}$$

where E is related to H by the empirical expression -

$$E = 1.269H / (H - .379). \quad \text{Eq. 6}$$

E_0 is chosen as 1.74 to make $L = 0$. correspond to the case of flat plate, zero pressure gradient; i.e., to $H = 1.4$. Eq. 6 is in good agreement with experimental data in the range $H < 1.7$ (ref. 1), but deviates by increasing amounts at larger values of H . Values of $L(H)$ by integration of Eq. 5 are shown by Table 1; also shown by the tabulation are values of $L(H)$ from experimental data in ref. 3 for the range $1.6 < H < 2.6$. Thus, equation values were fed into the program for $H < 1.6$ and experimental values for $H > 1.6$.

The remaining boundary layer properties were calculated by ref. 1 equations for the general case of the velocity profile equation $(u/U = (y/\delta)^{1/n})$ in the symbols of ref. 1).

$$N = 2/(H-1) \quad \text{Eq. 7}$$

$$\zeta^* = \theta H \quad \text{Eq. 8}$$

$$\zeta = \zeta^* (1+N) \quad \text{Eq. 9}$$

As noted in the Numerical Procedure, L is assumed to be equal to zero at point 2 on the blade surface in the solution of Eq. 3. This assumption is based on the fact that the initial value of L has very little effect on its final value at point M in the numerical integration of the equation. Further an initial value of $L = 0$. (corresponding to $H = 1.4$) is recommended in ref. 5.

TABLE I

SHAPE FACTOR L - H GREATER THAN 1.4

<u>H</u>	<u>E¹</u>	<u>L¹</u>	<u>L²</u>
1.400000	1.740059	0.000000	
1.450000	1.718067	-0.030020	
1.500000	1.698037	-0.054770	
1.550000	1.679718	-0.075473	
1.600000	1.662899	-0.093004	-0.0900
1.650000	1.647404	-0.108005	-0.1030
1.700000	1.633081	-0.120957	-0.1145
1.750000	1.619803	-0.132230	-0.1230
1.800000	1.607460	-0.142109	-0.1300
1.900000	1.585207	-0.158560	-0.1450
2.000000	1.565700	-0.171626	-0.1555
2.100000	1.548460	-0.182192	-0.1650
2.220000	1.530244	-0.192418	-0.1720
2.300000	1.519365	-0.198086	-0.1770
2.400000	1.506977	-0.204158	-0.1800
2.500000	1.495757	-0.209317	-0.1802
2.600000	1.485547	-0.213740	-0.1803

Notes: 1. By Eqs. 5 and 6.

2. By experimental curve ref. 3.

TABLE I (Continued)

SHAPE FACTOR L - H LESS THAN 1.4

<u>H</u>	<u>E</u>	<u>L</u>
1.400000	1.740059	0.000000
1.350000	1.764315	0.037065
1.300000	1.791205	0.083859
1.250000	1.821183	0.144673
1.200000	1.854811	0.226930
1.150000	1.892802	0.345038
1.125000	1.913706	0.425548
1.100000	1.936061	0.530005
1.080000	1.955093	0.639996
1.060000	1.975242	0.789418
1.040000	1.996611	1.013354
1.030000	2.007788	1.176106
1.020000	2.019314	1.414472
1.010000	2.031204	1.854390
1.005000	2.037292	2.303073

By Equations 5 and 6

NUMERICAL PROCEDURE

The computer program is written in Fortran language and has been run on the CDC 3600 machine. The following explanation is to supplement the enclosed listing of the program, pages 14 through 18.

Symbols in this section of the report correspond to the listing. See Nomenclature for the tie in with symbols in the Analysis section.

The listing consists of the main program and two subroutines. Generally, the main program consists of four groups of statements: (1) the input data statements, (2) calculation statements for the suction surface, (3) calculation statements for the pressure surface, and (4) the format statements. Note that the suction and pressure surface characters are distinguished by the letters S and P, but aside from this difference the statements for both surfaces are the same. The subroutines, ENTRY and GRS, are later explained.

The tabulation in the Analysis section, which relates the boundary layer form factors F and H, is fed into the program by statement DATA. In this statement D and E correspond to F and H. Then by statements 25 and 26, the value of H as a function of F is determined by the GRS interpolation routine from the above data.

Subroutine ENTRY gives print out and format instructions for the first three cards of the input (identification cards).

Integration of equations 1 and 3 by the trapezoidal rule is performed by statements 13 through 15 plus 1 and by statements 20 through 22 plus 1 which are contained in the DO loops. Note that for I2, the integral term in Eq. 3, statement 15 and 22, is indeterminate as the $\ln$ term for $I(2-1)$ is $\ln 0$. So in Step I2,

Eq. 3 is made equal to zero, by specifying $FS(2) = FP(2) = 0$, and solved for the integral term by statements 14 and 21. This procedure, which assumes that shape factor L is zero at point 2, is discussed in the Analysis. Note also that the calculation is stopped if $F < -.18$ at any point, corresponding to the probable point of flow separation (statements 15 plus 2 and 22 plus 2). Statements 25 plus 1 through 16 and statements 26 plus 1 through 23 are for Equations 7, 8, and 9.

Generally the remaining statements are print out and format instructions.

```

PROGRAM PMU142
C  PMU142 TWO DIMENSIONAL BOUNDARY LAYER CALCULATION
      DIMENSION XS(21),VS(21),TS(21),ZS(21),FS(21),XP(21),VP(21),
      1TP(21),ZP(21),FP(21),D(31),F(31),HS(21),HP(21),
      2US(21),TSIN(21),DSIN(21),FSIN(21),NP(21),TPIN(21),DPIN(21),
      3DFPTN(21)
      DATA D=-.1803, -.1802, -.18, -.177, -.172, -.165,
      1-.1555, -.145, -.130, -.123, -.1145, -.103, -.090,
      2-.075473, -.054770, -.030020, .0, .037065, .083859, .144673,
      3.226930, .345038, .425548, .530005, .639906, .789418, 1.013354,
      41.176106, 1.414472, 1.854305, 2.303073,
      5(F= 2.6, 2.5, 2.4, 2.3, 2.2, 2.1, 2.0, 1.9, 1.8, 1.75, 1.7, 1.65,
      61.60, 1.55, 1.50, 1.45, 1.40, 1.35, 1.30, 1.25, 1.20, 1.15, 1.125,
      71.10, 1.05, 1.06, 1.04, 1.03, 1.02, 1.01, 1.005)
      TYPE=REAL NS, NP
      32 CALL ENTRY
      READ(5,100)RF, SS, SP, M
      3 READ (5,101) (XS(I),VS(I),XP(I),VP(I),I=2,M)
      WRITE(6,112)
      WRITE(6,110)RF, SS, SP, M
C  SUCTION SURFACE
      11 SUMS1=0.0
      XS(1)=0.0
      VS(1)=0.0
      FS(2)=0.
      DO16 I=2,M
      13 SUMS1=SUMS1+(XS(I)-XS(I-1))*(VS(I)**3.33+VS(I-1)**3.33)/2.0
      AS=((0.074/(RE**0.2))/2.0)**1.166
      BS=0.0304*(NLOG(RF))-0.23651
      TS(I)=(AS*SUMS1)**0.8571/V5(I)**3
      ZS(I)=(AS*SUMS1)**4
      IF (I-2)14,14,15
      14 SUMS2=(BS+NLOG(VS(I))+0.00651*NLOG(ZS(I))-FS(2))*ZS(I)/1.0608
      GO TO 25
      15 SUMS2=SUMS2+(ZS(I)-ZS(I-1))*(NLOG(VS(I))+NLOG(VS(I-1)))/2.0
      FS(I)=BS+NLOG(VS(I))+0.00651*NLOG(ZS(I))-1.0608*SUMS2/ZS(I)
      IF (FS(I)+0.18)17,17,25
      25 HS(I)=GRS(D(I),1,F(I),1,FS(I),31,K)
      NS(I)=2./(HS(I)-1.)
      TSIN(I)=TS(I)*SS
      DSIN(I)=TSIN(I)*4S(I)

```



```

      DSIN(I)=USIN(I)*(NS(I)+1.)
16 CONTINUE
17 WRITE(6,105)
   WRITE(6,106)
   WRITE(6,107) (XS(I),VS(I),TS(I),FS(I),HS(I),
INS(I), TSIN(I), DSIN(I), DEFIN(I), I=2,M)
   WRITE(6,108)
C PRESSURE SURFACE
18 SUMP1=0.0
   XP(1)=0.0
   VP(1)=0.0
   FP(2)=0.
   DO23 I=2,M
20 SUMP1=SUMP1+(XP(I)-XP(I-1))*(VF(I)**3.33+VP(I-1)**3.33)/2.0
   AP=((0.074/((RE*(SP/SS))**.2))/2.0)**1.146
   BP=0.0304*(NLOG(RE*(SP/SS)))-0.23651
   TP(I)=(AP*SUMP1)**0.8571/VP(I)**3
   ZP(I)=(AP*SUMP1)**4
   IF(I-2)21,21,22
21 SUMP2=(BP+NLOG(VP(I))+0.00651*NLOG(ZP(I))-FP(2))*7P(I)/1.0608
   GO TO 26
22 SUMP2=SUMP2+(ZP(I)-ZP(I-1))*(NLOG(VP(I))+NLOG(VP(I-1)))/2.0
   FP(I)=BP+NLOG(VP(I))+0.00651*NLOG(ZP(I))-1.0608*SUMP2/ZP(I)
   IF(FP(I)+0.18)24,24,26
26 HP(I)=GRS(D(1),1,F(1),1,FP(I),31,K)
   NP(I)=2./(HP(I)-1.)
   TPIN(I)=TP(I)*SP
   DPIN(I)=TPIN(I)*HP(I)
   DEPIN(I)=DPIN(I)*(NP(I)+1.)
23 CONTINUE
24 WRITE(6,109)
   WRITE(6,106)
   WRITE(6,107) (XP(I),VP(I),TP(I),FP(I),HP(I),
INS(I), TPIN(I), DPIN(I), DEPIN(I), I=2,M)
   GOTO32
C
C FOR PLOTS
100 FORMAT(3E14.0,I2)
101 FORMAT(4E14.0)
102 FORMAT(/30X,41HT NO DIMENSIONAL BOUNDARY LAYER CALCULATION)
105 FORMAT(/45X,15H SUCTION SURFACE)
106 FORMAT(/20X,6H REFERRED, 4X,6H REFERRED, 4X,6H REFERRED, 6X,5H SHAPE, 7X,4H FO

```

0710

0740

0750

0760

0770

0820

0830

0840

0850

0880

0920

0930

0950

1240

0200

1180

```

1RM,4X8HEXPONENT, 4X8HMOMENTUM, 5X6HDISPL.,7X4HFULLI, /2X8HDISTANCE,4
2X8HFVELOCITY,4X8HMOMENTUM,5X4HFACTOR, 6X6HFACTOR,8Y1HN,8X9HTHICKNES
3S,3X9HTHICKNESS, 3X9HTHICKNESS/ 26X9HTHICKNESS, 42X3HIN., 9X3HIN.,
49X3HIN.)
107 FORMAT (2XF8.6,4XF8.6, 4XF8.6, 3XF9.6, 4XF8.6, 4XF8.6, 4XF8.6, 4XF
18.6, 4XF8.6)
108 FORMAT(1H1)
109 FORMAT(///45X,16HPRESSURE SURFACE)
110 FORMAT(///11X12HREYNOLDS NO., 5X18HSUCT SURF LGTH IN., 4X19HPRESS S
URF LGTH IN., 10X13HNO. OF POINTS/3F23.3,123)
      END

```

1310

```

      SUBROUTINE ENTRY
      DIMENSION IDC(36)
      GO TO 3
      ENTRY CASES
      GO TO 3
      ENTRY NEXCAS
3     WRITE(6,101)
      READ(5,100) IDC
      IF (EOF,5) 1,2
2     WRITE(6,100) IDC
      RETURN
1     STOP
100  FORMAT(12A6)
101  FORMAT(1H)
      END

```

```

FUNCTION GRS (X,NDX,Y,NDY,XV,N,NRANGF)
DIMENSION X(NDX,3),Y(NDY,3),DX(3),DY(3),YP(2)
NRANGF=0
IF (XV.LT.X(1,1)) NRANGF=-1
IF (XV.GT.X(1,N)) NRANGF=+1
DO 10 I=1,N$ I=I
IF (XV-X(1,I)) 20,70,10
10 CONTINUE$ I=N
20 IF (I.GT.2) GO TO 30
N1=3$ N2=2$ N3=1$ NP=3$ GO TO 55
30 IF (I.LT.N ) GO TO 40
NP=3$ GO TO 50
40 NP=4$ N4=I+1
50 N1=I-2$ N2=I-1$ N3=I
55 DX(1)=X(1,N2)-X(1,N1)$ DY(1)=Y(1,N2)-Y(1,N1)
DX(2)=X(1,N3)-X(1,N2)$ DY(2)=Y(1,N3)-Y(1,N2)$ R=(XV-X(1,N2))/DX(2)
YP(1)=(DY(1)*DX(2)**2+DY(2)*DX(1)**2)/(DX(1)*(DX(1)+DX(2)))
IF (NP.EQ.4) GO TO 60
GRS=Y(1,N2)+R*(YP(1)+R*(DY(2)-YP(1)))$ GO TO 9999
60 DX(3)=X(1,N4)-X(1,N3)$ DY(3)=Y(1,N4)-Y(1,N3)
YP(2)=(DY(2)*DX(3)**2+DY(3)*DX(2)**2)/(DX(3)*(DX(2)+DX(3)))
GRS=Y(1,N2)+R*(YP(1)+R*(3.*DY(2)-2.*YP(1)-YP(2)+R*(YP(1)+YP(2)-2.*
1 DY(2))))
GO TO 9999
70 GRS=Y(1,I)
9999 RETURN$ END

```

SAMPLE CALCULATION

The use of the program is described by the following sample calculation.

Input

The input format appears on the following page. Note that all data are decimal quantities except M which is an integer.

Cards 1, 2, and 3 are for identification. They need not be punched, but must be included. Note that the column 1 space is blank.

Single dimension quantities appear on card 4 as follows:

RE - blade Reynolds no. based on the blade exit conditions and average surface length.

SS, SP - Developed length of the suction, pressure surface - ins.

M $\leq$ 21 - no. of surface points, each side of blade, including point 1. This quantity is an integer and must be punched in columns 43 and 44.

Cards 5 and on are dimensional quantities for points 2 to M -

XS, XP - referred distance along the suction, pressure side of the blade from point 1 (inlet stagnation point). The referred distance is with respect to SS, SP.

IBM FORTRAN INPUT DATA

73

PROGRAM NO.	D. NO.	CHARGE NO.	DATE	CARD#
☒ PH 0142	☒ D 9403	☒ 013A009564	☒ 09-22-67	01
ENGINEER	DEPARTMENT		PHONE	
☒ FENTRESS	☒ DEV. ENG.		☒ 2248	02
IDENTIFICATION				
☒ SAMPLE CALCULATION				03
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72				
RE	SS	SP	M ≤ 21	
344000.	1.855	1.515	1.1	04
XS	VS	XP	VP	
(2)	(2)	(2)	(2)	
.132	.61	.107	.44	05
.190	.76	.183	.42	06
.244	.88	.261	.41	07
.295	1.02	.340	.42	08
.346	1.13	.424	.44	09
.406	1.12	.512	.49	10
.487	1.26	.607	.51	11
.613	1.18	.715	.56	12
.768	1.14	.842	.65	13
1.00	1.00	1.00	1.00	14

ALL INPUT DATA MUST CONTAIN A DECIMAL POINT. EXCEPT INTEGERS AS DENOTED BY AN ASTERISK.
 VERY LARGE OR SMALL NUMBERS MAY BE ENTERED IN EXPONENTIAL FORM E.G. 0000000123 = 123E-09

FORM # AS
 PAGE 0142 OF

VS, VP - referred velocity along the suction, pressure side of the blade. The referred velocity is with respect to the exit velocity (point M).

Point 1, for which the above values are 0, must not be included in the input, but must be included in the count of M.

The above quantities are defined in the Nomenclature.

For successive calculations repeat as above starting with card no. 1.

Output

The output for the sample calculation is shown by the following print out, page 23 and 24.

Page 1 of the output gives: (1) the data appearing on cards 1 to 4 of the input and (2) the following data for suction surface points 2 to M.

Referred distance, referred velocity - values appearing on input cards starting with card no. 5.

Referred momentum thickness - with respect to suction surface length.

Shape factor - L

Form factor - $H = \delta^*/\theta$

Exponent N - exponent in the velocity profile equation.

Momentum, displacement, full thickness - ins.

Point M values, last line of output, are for the trailing edge extremity. If the form factor exceeds 2.4 at any point, the calculation is stopped and 0.000000 appears in the spaces from that point on.

Page 2 of the output gives similar data for the pressure side of the blade. Referred length dimensions are with respect to the pressure surface length.

The above quantities are defined in the Analysis section.

PH0142 D9403
FENTRESS
SAMPLE CALCULATION

013A009564
DEV. ENG.

09-22-67
2248

TWO DIMENSIONAL BOUNDARY LAYER CALCULATION

REYNOLDS NO.
344000.000

SUCT SURF LGTH IN.
1.855

PRESS SURF LGTH IN.
1.515

NO. OF POINTS
11

SUCTION SURFACE

REFERRED DISTANCE	REFERRED VELOCITY	REFERRED MOMENTUM THICKNESS	SHAPE FACTOR	FORM FACTOR	EXPONENT N	MOMENTUM THICKNESS IN.	DISPL. THICKNESS IN.	FULL THICKNESS IN.
0.132000	0.610000	0.000303	0.000000	1.400000	5.000000	0.000563	0.000788	0.004728
0.190000	0.760000	0.000327	0.022860	1.367905	5.436186	0.000606	0.000829	0.005335
0.244000	0.880000	0.000373	-0.000966	1.401475	4.981636	0.000692	0.000970	0.005801
0.295000	1.020000	0.000387	0.009326	1.386288	5.177480	0.000718	0.000996	0.006153
0.346000	1.130000	0.000435	-0.005260	1.408105	4.900695	0.000808	0.001137	0.006711
0.406000	1.120000	0.000644	-0.060616	1.512863	3.899680	0.001194	0.001806	0.008849
0.487000	1.260000	0.000666	0.009895	1.385482	5.188313	0.001235	0.001711	0.010586
0.613000	1.180000	0.001218	-0.076739	1.553890	3.610825	0.002259	0.003511	0.016187
0.768000	1.140000	0.001794	-0.067959	1.529701	3.775715	0.003327	0.005090	0.024306
1.000000	1.000000	0.003387	-0.123601	1.754017	2.652461	0.006283	0.011020	0.040252

PRFSSURE SIIRFACE

REFERRED DISTANCE	REFFERED VELOCITY	REFERRED MOMENTUM THICKNESS	SHAPE FACTOR	FORM FACTOR	EXPONENT N	MOMENTUM THICKNESS IN.	DISPL. THICKNESS IN.	FULL THICKNESS IN.
0.107000	0.440000	0.000277	0.000000	1.400000	5.000000	0.000419	0.000587	0.003522
0.183000	0.420000	0.000654	-0.125261	1.765436	2.612208	0.000991	0.001750	0.006322
0.261000	0.410000	0.001006	-0.111023	1.683215	2.927334	0.001524	0.002565	0.010072
0.340000	0.420000	0.001207	-0.074765	1.547887	3.650389	0.001828	0.002830	0.013158
0.424000	0.440000	0.001321	-0.044628	1.478357	4.180975	0.002001	0.002958	0.015326
0.512000	0.490000	0.001215	0.007051	1.389545	5.134191	0.001841	0.002559	0.015696
0.607000	0.510000	0.001379	-0.019856	1.431884	4.630870	0.002089	0.002991	0.016839
0.715000	0.560000	0.001353	0.007247	1.389262	5.137933	0.002050	0.002848	0.017483
0.842000	0.650000	0.001206	0.040640	1.345475	5.785777	0.001827	0.002458	0.016681
1.000000	1.000000	0.000674	0.143922	1.236446	8.451425	0.001020	0.001262	0.011927

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