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DESIGN OF ROUND-TO-SQUARE TRANSITION SECTION; ANALYSIS AND COMPUTER CODE

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A generalized analytical form of the surface of a transition section which interfaces round and square cross sections of a wind tunnel is presented. Also included is a listing of the computer code which generates the surface coordinates in the format required by the vax computer at the Air Force Machine Shop at Wright-Patterson Air Force Base.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

PREFACE

The authors would like to thank Messrs. J. Nourse, R. Truesdale, B. More, and M. Lovejoy of the Air Force Machine Shop for helping in data transfer from the PC to the VAX computer and for fabricating the product flawlessly. A very warm thanks also to M. Whitaker for editing this manuscript.

Section 1

INTRODUCTION

In fluid-dynamics experiments the need to provide a smooth transition from a round cross section to a square one is often encountered. Recent advances in experimental and computational studies have shown that the shape of the transition section dramatically impacts the downstream flow conditions. The Advanced Propulsion Division of the Aero Propulsion and Power Directorate (WL/POPT), Wright-Patterson Air Force Base, funded a task to design such a transition section for a water tunnel.[1] The resulting section, although successful, was for a very specific design parameter.

The purpose of this report is to provide 1) a generalized formula which will generate a transition surface for any given diameter of the round end, the width of the square end, and the length of the transition section and 2) a computer code which will generate the surface coordinates in a format suitable for direct input to the front-end VAX computer currently employed in the Air Force Machine Shop in Bldg. 5 at Wright-Patterson Air Force Base. This automatic procedure benefits the design task of the test sections, the inlet diffusers, and the converging part of the converging-diverging section of a supersonic nozzle.

Section 2

ANALYTICAL FORMULATIONS

The criteria for designing the transition section are: 1) a zero slope in the longitudinal direction at either end of the nozzle and 2) an inflection point along the length of the transition section at a specified location. Generally, the maximum inflection occurs about two-thirds of the way down the transition section.

AXIAL CUT

The coordinate system chosen for the analysis is displayed in Fig. 1. The axial direction is denoted by x, the distance from a surface point to the x-axis is denoted by R, which is a function of x and the tangential angle (θ) between the point and the x-z plane. The width of the square end is denoted by SW1, the diameter of the round end by RD1, and the length of the transition section by XLN. Based upon these notations and criteria, a formula for R as a function of x and θ was given [1] in non-dimensional form as follows:

$$\bar{r} = 80.4375 \left[\frac{\bar{x}^{4.5}}{4.5} - \frac{\bar{x}^{5.5}}{2.75} + \frac{\bar{x}^{6.5}}{6.5}\right] \qquad (1)$$

where $\bar{r} = R / SW1 / \sqrt{2}$, $\bar{x} = x / XLN$.

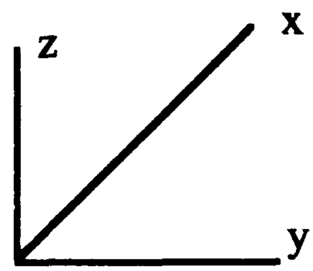

Figure 1. Coordinate System Used in Analysis.
x - Downstream Direction.

CROSS-SECTIONAL CUT

The shape of the cross section of the design transition will vary from round to square. The general form describing this cut is:

$$\left[\frac{y}{B(\bar{x})}\right]^{n(\bar{x})} + \left[\frac{z}{B(\bar{x})}\right]^{n(\bar{x})} = 1. \qquad (2)$$

Since B(x) must fulfill Eq. (1) and two end-point conditions, it must follow the form:

$$B(\bar{x}) = BK1\left[\frac{\bar{x}^{4.5}}{4.5} - \frac{\bar{x}^{5.5}}{2.75} + \frac{\bar{x}^{6.5}}{6.5}\right] + BK2 \qquad (3)$$

where BK1 = 40.2187 * (RD1 - SW1),
and BK2 = SW1 / 2.0

In obtaining the expression for $n(\bar{x})$, another condition must be considered--the axial line going through the corner of the square section. Since this line is in a symmetric plane, the following condition is satisfied:

$$y = Z_S \qquad (4)$$

Again, this line must fulfill Eq. (1) and two end-point conditions; thus,

$$Z_s(\bar{x}) = ZK1\left[\frac{\bar{x}^{4.5}}{4.5} - \frac{\bar{x}^{5.5}}{2.75} + \frac{\bar{x}^{6.5}}{6.5}\right] + ZK2 \qquad (5)$$

where $ZK1 = 80.4375\left(\frac{RD1}{2.} - \frac{SW1}{\sqrt{2.}}\right) / \sqrt{2.}$

and $ZK2 = \frac{SW1}{2.}$

Combining Eqs. (5) and (2) yields:

$$n(\bar{x}) = \frac{\log(\frac{1}{2})}{\log(\frac{Z_s(\bar{x})}{B(\bar{x})})} \qquad (6)$$

Since $B(\bar{x})$ and $n(\bar{x})$ in Eq. (2) have been derived, the following relation can be utilized to calculate the surface:[1]

$$R(\bar{x},\theta) = \frac{B(\bar{x})}{\cos\theta}\left(\frac{1.}{1. + \tan^{n(\bar{x})}\theta}\right)^{\frac{1.}{n(\bar{x})}} \qquad (7)$$

Then, the physical coordinates y and z can be obtained as:

$$y = R \sin(\theta), \qquad z = R \cos(\theta) \qquad (8)$$

Determination of the four constants (BK1, BK2, ZK1, ZK2) in Eqs. (3) and (5) is dependent upon the geometric constraints. In this case, the round end is larger than the square one. For the reverse condition, the values of those constants must be reformulated as follows:

$$BK1 = 80.4375 * (SW1 - RD1) / 2.$$
$$BK2 = RD1 / 2$$
$$ZK1 = 80.4375 * (SW1 / 2. - RD1 / 2. / \sqrt{2})$$
$$ZK2 = RD1 / 2. / \sqrt{2}$$

Section 3

COMPUTER CODE AND DATA FORMAT

A computer code which yields the surface coordinate of the transition section was developed and is listed in the Appendix. The input parameters are as follows:

RD1: length of the diameter of the round end
SW1: width of the square end
XLN: length of the transition section
NS: number of axial cuts
NC: number of cross-sectional cuts

The units for the diameter, the width, and the length should be the same, e.g., inches. The choice of NS and NC will depend upon the precision required. Assigning higher values to NS and NC will result in a finer grid. For example, there is a need to design a 6-inch-long transition section to interface a rounded settling chamber having a diameter of 5.875 inch and a square test section having a width of 1 inch. Values of 31 and 15 were assigned to NS and NC, respectively. The computation process takes advantage of geometric symmetry. Only one-eighth of the entire circumference was actually computed. Due to the symmetry, the output yields the grid of an entire quarter. Thus, in this quarter, the number of the axial cuts is two times NC, i.e., 30.

The output of the computer code is the grid positions which are the interception points of the axial and cross-sectional cuts. An automatic machining device used in the Air Force Machine Shop reads in the grid point of each individual cross section following the ASCII format:

x1, y1, z1
x2, y2, z2
....
xn, yn, zn A

At the end of a cross section, the last grid coordinate is followed by a space and a capital letter A. This format is used repeatedly for the remainder of the cross-sectional cuts.

The three-dimensional plot of the grid generated for a quarter of the transition section described in the above example is displayed in Fig. 2. The grid coordinates were stored on magnetic tape at a density of 1600 BPI using a non-compressed format and given to the shop. The completed transition section were installed in a supersonic combustion testing facility.

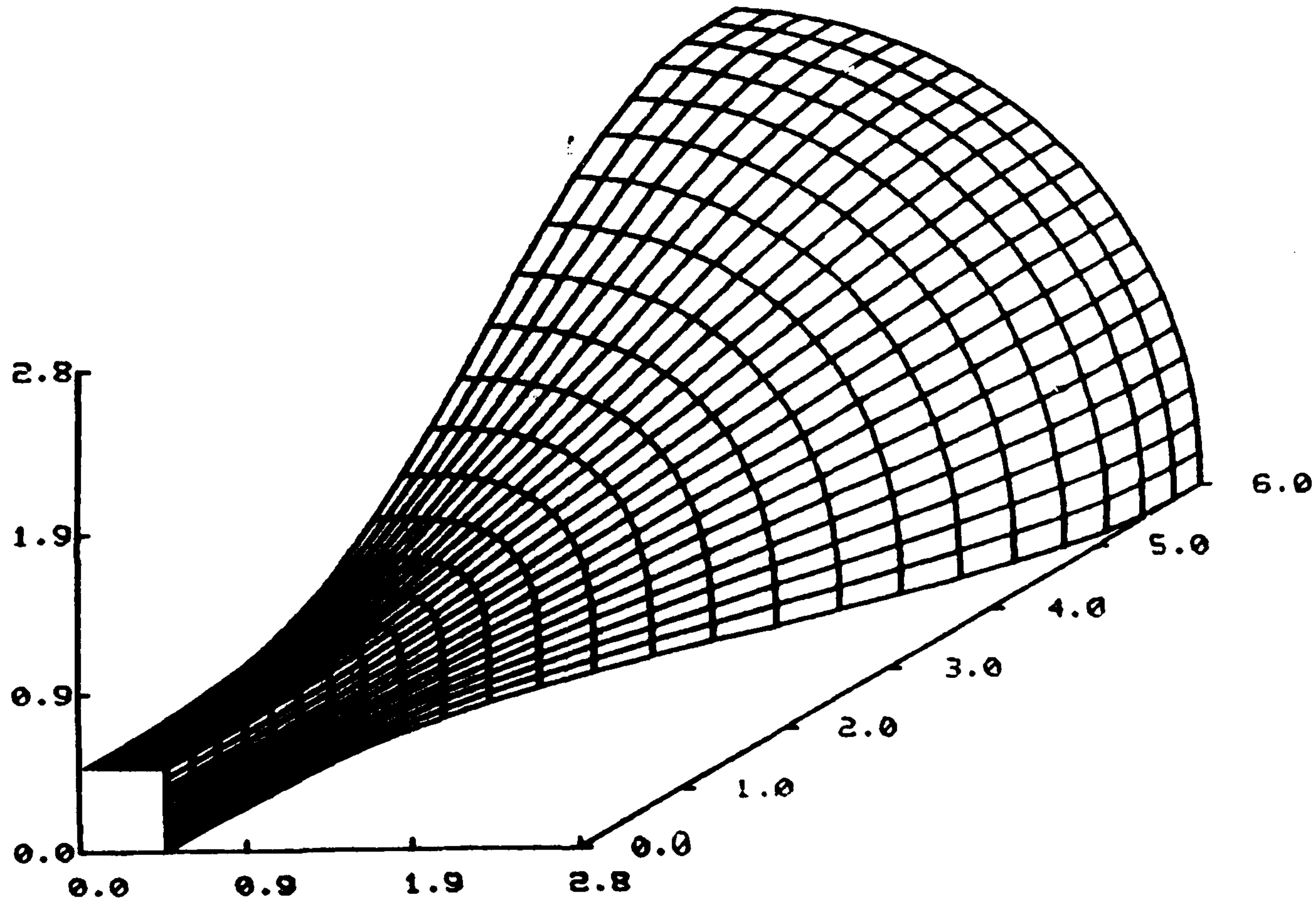

Figure 2. Three-Dimensional Plot of One-Quarter Portion of Transition Section Designed by Computer Code Given in the Appendix

Section 4

SUMMARY

A computer code was developed for the design of a transition section interfacing round and square sections of a wind tunnel--a design challenge which is encountered constantly. The output data have been formatted to be readable to the computer currently in use in the Air Force Machine Shop at Wright-Patterson Air Force Base. The procedure involved in converting design to product has been successfully tested in association with the personnel at the Air Force Machine Shop. Since the program was written in standard FORTRAN language, it can be run on any computer. The output format can be changed according to the requirements of different facilities and presented using the available graphics package.

REFERENCE

[1] K. A. Lautenbach, "Design of Water Tunnel to Measure Wall Pressure Signatures Due to Tunnel Blockage and Wake Effects," Masters Thesis, AFIT/GAE/AA/88D-20 (Air Force Institute of Technology, Wright-Patterson Air Force Base OH, 1988).

APPENDIX

COMPUTER PROGRAM FOR GENERATING SURFACE OF TRANSITION SECTION

```
      PROGRAM SRNZ3N
C>>>  SQUARE-ROUND-NOZZLE TRANSITION
C>>>
C     Drs. Tzong H. Chen & Abdollah S. Nejad
C     Aero Propulsion & Power Directorate
C     Wright Laboratory
C     Wright-Patterson Air Force Base, Ohio
C
C-----------------------------------------------
      REAL*8 RX, AT1, T1
      DIMENSION  YF(300), XL(300), BX(300), ANX(300),
     # YX(300), RX(300), ZS(300), AX(300), ZC(300), ZF(300)
      DIMENSION X(100), Y(25), Z(100,25), ZW(100),ZR(300),YR(300)
      DIMENSION ICA(300)
      COMMON /CNST1/ RD1, SW1
      OPEN(3,FILE='NOZZLE.XYZ', STATUS = 'UNKNOWN')
 333  CONTINUE
      WRITE(*,701)
 701  FORMAT(1X,'INPUT DIAM. (RND. END), WDTH (SQUARE END)     ')
      READ(*,*) RD1, SW1
      WRITE(*,702)
 702  FORMAT(1X,'INPUT TUNNEL LENGTH     ')
      READ(*,*) XLN
      XMIN = 0.0
      YMIN = 0.0
      XMAX = RD1 / 2.
      YMAX = RD1 / 2.
      WRITE(*,355) XMAX, YMAX
 355  FORMAT(1X,'XMAX, YMAX  ',2(F10.4,2X))
C-----------------------------------------
      BK1 = 80.43750001 * (RD1-SW1) / 2.
      BK2 = SW1 / 2.0
C-----------------------------------------
      ZK2 = SW1 / 2.0
      ZK1 = 80.43750001 * (RD1/2. - SW1/2. *
     # SQRT(2.0)) / SQRT(2.0)
      WRITE(*,703)
703   FORMAT(1X,'BK1, BK2, ZK1, ZK2     ')
      WRITE(*,950) BK1,BK2,ZK1,ZK2
950   FORMAT(1X,4(F10.4,1X))
C-------------------------------------
      WRITE(*,704)
704   FORMAT(1X,'INPUT NS: NO. OF CROSS SECTION     ')
      READ(*,*) NS
C     NS = 25
C     NC = 31
```

```
      WRITE(*,705)
705   FORMAT(1X,'INPUT NO. OF AXIAL CUT    ')
      READ(*,*) NC
      C16 = 1. / (NS - 1)
      CL1 = ALOG10(0.5)
      DO 60 I = 1, NS
      XL(I) = C16 * FLOAT(I-1)
      BX(I) = CBX(BK1,BK2,XL(I))
      ZS(I) = CZS(ZK1,ZK2,XL(I))
C-----------------------------------
      BB = BX(I)
      IF(BX(I).EQ.0.) BB = 1.E-20
      AAL = ZS(I) / BX(I)
       IF(AAL.GT.0.) GO TO 616
      AAL = ABS(AAL)
C--------------------------------------------
 616 ANX(I) = CL1 / ALOG10(AAL)
      WRITE(*,955) XL(I), ANX(I), BX(I), ZS(I)
 955  FORMAT(1X,4(F10.4,1X))
 60   CONTINUE
C-----------------------------------
      NC2 = 2 * NC - 1
      DA1 = 3.14159265 / 4. / (NC - 1)
      DO 70 I = 1, NS
      DO 80 K = 1, NC
      AX(K) = (K - 1) * DA1
      C1 = COS(AX(K)) + 1.E-22
      T1 = TAN(AX(K)) ** ANX(I)
      IF(T1.GT.1.E22) T1 = 1.E22
      AT1 = 1. / (1. + T1)
      RX(K) = BX(I) / C1 * (AT1) ** (1./ANX(I))
      YX(K) = RX(K) * SIN(AX(K))
      ZC(K) = RX(K) * COS(AX(K))
 55   CONTINUE
 910  FORMAT(1X,2(F8.3,1X))
 80   CONTINUE
       IL = I
      DO 133 IN = 1, NC
      YF(IN) = YX(IN)
      ZF(IN) = ZC(IN)
 133  CONTINUE
      NCP1 = NC + 1
      DO 155 IN = NCP1, NC2
      ID = IN - NC
       IA = NC - ID
      YF(IN) = ZC(IA)
      ZF(IN) = YX(IA)
 155  CONTINUE
      NP = NC2
      XLL = XL(IL) * XLN
      DO 273 IIA = 1, NC2
      ICA(IIA) = ' '
 273  CONTINUE
       ICA(NC2) = ' A'
```

```
C>>> REVERSE ORDER TO DO INTERPOLATION
      DO 177 IQ = 1, NC2
      IV = NC2 - IQ + 1
       ZR(IV) = ZF(IQ)
      YR(IV) = YF(IQ)
      WRITE(3,535) XLL, ZF(IQ), YF(IQ), ICA(IQ)
      WRITE(*,535) XLL, ZF(IQ), YF(IQ), ICA(IQ)
 535  FORMAT(1X,F10.4,1X,F10.4,1X,F10.4,A2)
 177  CONTINUE
      ENDFILE 3
 70   CONTINUE
      WRITE(*,735)
 735  FORMAT(1X,' MORE COMPUTATION   1-YES, 0-NO   ')
      READ(*,740) IMORE
 740  FORMAT(A1)
      IF(IMORE.EQ.1) GO TO 333
      STOP
      END
C*********************************************
      FUNCTION CF(X)
      AN = 4.5
      BN = 2.75
      CN = 6.5
      AP = 4.5
      BP = 5.5
      CP = 6.5
      A = X**AP / AN
      B = X**BP / BN
      C = X**CP / CN
      CF =  (A - B + C)
      RETURN
      END
C**************************************************
      FUNCTION CZS(CN1,CN2,X)
C>>> EQ. 6
      CZS = CN1 * CF(X) + CN2
      RETURN
      END
C**************************************************
      FUNCTION CBX(CN1,CN2,X)
C>>> EQ. 4
       CBX = CN1 * CF(X) + CN2
      RETURN
      END
```


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