

USERS MANUAL FOR
STREAMTUBE CURVATURE ANALYSIS
ANALYTICAL METHOD FOR
PREDICTING THE PRESSURE DISTRIBUTION
ABOUT A NACELLE AT TRANSONIC SPEEDS

VOLUME II

by D.R. Ferguson

CASE FILE
COPY

Developed under contract to NASA Langley
Research Center, Contract NAS 1-10804, and
prepared by General Electric Company
Aircraft Engine Group, Cincinnati, Ohio

for

National Aeronautics and Space Administration

TABLE OF CONTENTS

<u>VOLUME II - Bowshock Program</u>	<u>PAGE</u>
1.0 INTRODUCTION	1
2.0 GENERAL DESCRIPTION	2
2.1 Moeckel Bow Shock	2
2.2 STC-Bow Shock Implementation	7
2.3 Bow Shock Subroutines	7
3.0 PROGRAM NOMENCLATURE	10
3.1 Labeled Commons	10
3.2 Revised STC Subroutines	11
3.3 Revised Field Point Connections/STC Tables	12
4.0 STC-BOW SHOCK PROGRAM INPUT	13
4.1 Overall Input Data	13
4.2 Boundary Input	14
4.3 Sample Input	14
5.0 STC-BOWSHOCK PROGRAM OUTPUT	17
6.0 STC-BOWSHOCK PROGRAM USAGE	18
7.0 REFERENCES	19
APPENDIX I - PROGRAM INPUT SHEETS	20

1.0 INTRODUCTION

A special version of the STC program has been constructed to include a detached bow shock upstream of a plane or axisymmetric inlet. The bow wave is modeled using the method of Moeckel (Reference 1) in conjunction with an approximate definition of the shock stand-off distance. The following sections deal with the description of the Moeckel method and its implementation in the STC program. Specific modifications to STC, limitations/restrictions, and revised input output are described in ensuing sections.

2.0 GENERAL DESCRIPTION

The detached bow wave calculation has been merged with the existing STC program to evaluate total pressure loss and show the effects of streamline deflection through the shock. In implementation, the shock origin is placed on the stagnation streamline upstream of the inlet. The ingested flow is passed through a normal shock, whereas the spilled flow passes through the Moeckel hyperbolic bow wave. The STC solution is only carried out in the region enclosed by the shock, the lower boundary, and the cowl and inlet surfaces.

2.1 Moeckel Bow Shock

As indicated previously, the bow wave is included in an approximate fashion using the method of Moeckel (Reference 1) in conjunction with an approximate stand-off distance. The pertinent geometry is shown in the following Figure 1:

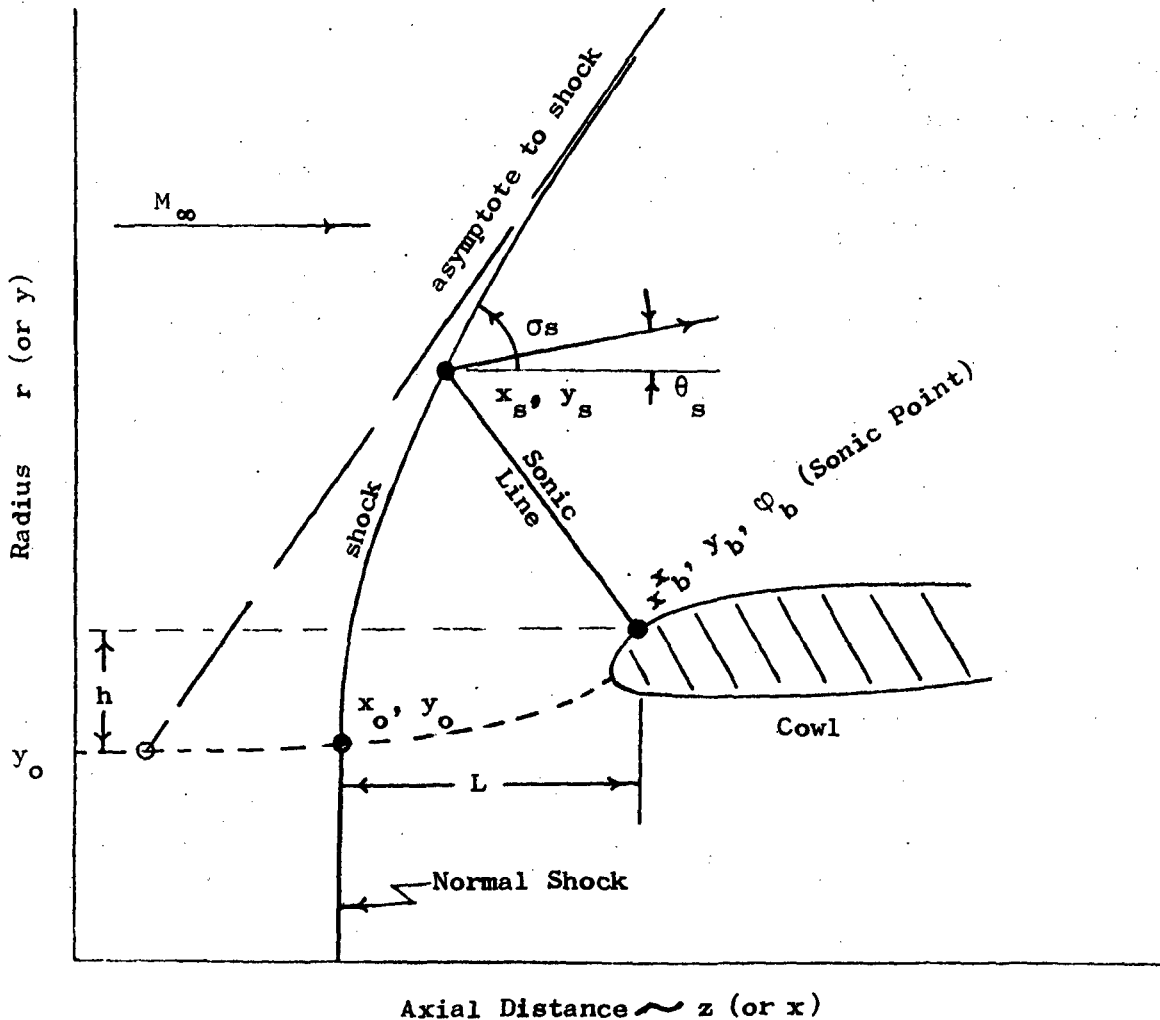


FIGURE 1. Bow Shock Geometry

After Moeckel, the following assumptions are made concerning the shock.

- 1.) The shock shape is hyperbolic with the origin on the stagnation streamline a distance L from the sonic point on the body.
- 2.) The shock is asymptotic to the free stream mach lines.
- 3.) The sonic line is straight.

With the above assumptions, the coordinates of the center of the hyperbolic shock are determined by applying continuity to the flow through the sonic line. The equation of the shock in the X-Y co-ordinate system is:

$$\frac{(x-h)^2}{a^2} + \frac{(y-y_0)^2}{b^2} = 1 \quad (1.)$$

where: a , b , and h must be determined.

The equation for the linear shock asymptote may be written:

$$y-y_0 = \frac{a}{b} (x-h)$$
$$\frac{a}{b} = \beta = \sqrt{M_\infty^2 - 1}$$
$$(x-h)^2 - \beta^2 (y-y_0)^2 = a^2$$

At the point, $x = x_0$, $y = y_0$,

$$a^2 = (x_0-h)^2 \text{ or } a = x_0 - h$$

Substituting in (1.)

$$\beta (y-y_0) = \sqrt{(x-h)^2 - (x_0-h)^2} \quad (2.)$$

From (2.), the local shock angle is:

$$\tan \sigma = \frac{dy}{dx} = \frac{\sqrt{\beta^2 (y-y_0)^2 + (x_0-h)^2}}{\beta^2 (y-y_0)}$$

Evaluating at the sonic point on the shock and solving for h,

$$h = x_0 - \beta (y_s - y_0) \sqrt{\beta^2 \tan^2 \sigma_s - 1} \quad (3.)$$

The shock angle to give sonic conditions downstream of the shock may be determined using the oblique shock relation:

$$\sin^2 \sigma_s = \frac{1}{4\gamma M_\infty^2} \left\{ (\gamma+1) M_\infty^2 - (3-\gamma) + \sqrt{(\gamma+1) [(\gamma+1) M_\infty^4 - 2(3-\gamma) M_\infty^2 + \gamma+9]} \right\} \quad (4.)$$

The two unknowns in equation (3.) are h, the center x-coordinate of the hyperbolic shock, and y_s , the y-coordinate of the sonic point on the shock. The latter quantity may be expressed in terms of known parameters by applying continuity to the flow passing through the straight sonic line between (x_B, y_B) and (x_s, y_s) .

Assume that the average stagnation pressure downstream of the bow shock in the subsonic zone is that which occurs on the centroidal streamline. The shock angle at this point is:

$$\tan \sigma_c = \frac{\sqrt{\beta^2 (y_c - y_0)^2 + (x_0 - h)^2}}{\beta^2 (y_c - y_0)}$$

or, multiplying and dividing by $(y_s - y_0)$,

$$\tan \sigma_c = \frac{\sqrt{\frac{\beta^2 (y_c - y_0)^2}{(y_s - y_0)^2} + \frac{(x_0 - h)^2}{(y_s - y_0)^2}}}{\beta^2 \frac{(y_c - y_0)}{(y_s - y_0)}} \quad (5.)$$

Using equation (3.) and the geometric relations for the centroidal streamline,

$$\frac{(x_0 - h)^2}{(y_s - y_0)^2} = \beta^2 (\beta^2 \tan^2 \sigma_s - 1)$$

$$\frac{(y_c - y_0)}{(y_s - y_0)} = \frac{1}{2} \quad (\text{plane})$$

$$\frac{(y_c - y_0)}{(y_s - y_0)} = \frac{2}{3} \quad (\text{axisymmetric})$$

Then,

$$\tan \sigma_c = \frac{1}{\beta} \sqrt{1 + 4(\beta^2 \tan^2 \sigma_s - 1)} \quad (\text{plane}) \quad (6a.)$$

$$\tan \sigma_c = \frac{1}{2\beta} \sqrt{4 + 9(\beta^2 \tan^2 \sigma_c - 1)} \quad (\text{axisymmetric}) \quad (6b.)$$

After determination of the centroidal streamline shock angle σ_c , the stagnation pressure loss is given by:

$$\frac{P_{oc}}{P_{o\infty}} = \left\{ \frac{(\gamma+1) M_\infty^2 \sin^2 \sigma_c}{(\gamma-1) M_\infty^2 \sin^2 \sigma_c + 2} \right\}^{\gamma/(\gamma-1)} \left\{ \frac{\gamma+1}{2\gamma M_\infty^2 \sin^2 \sigma_c - \gamma + 1} \right\}^{\gamma/(\gamma-1)} \quad (7.)$$

Denoting the flow area of the straight sonic line by A_s , the continuity equation may be written as:

$$\frac{A_\infty}{A_s} = \frac{\rho_s V_s}{\rho_\infty V_\infty} = \left(\frac{A}{A^*} \right)_i \left(\frac{P_{oc}}{P_{o\infty}} \right) \quad (8.)$$

where $\left(\frac{A}{A^*} \right)_i$ is given by the isentropic relation:

$$\left(\frac{A^*}{A} \right)_i = \left(\frac{\gamma+1}{2} \right)^{\frac{\gamma+1}{2(\gamma-1)}} M_\infty \left\{ 1 + \frac{\gamma-1}{2} M_\infty^2 \right\}^{-\frac{\gamma+1}{2(\gamma-1)}} \quad (9.)$$

Assuming the flow normal to the sonic line, the area ratio $\left(\frac{A_\infty}{A_s} \right)$ may be related to the geometry of the sonic line.

$$\frac{A_\infty}{A_s} = \left(\frac{y_s - y_o}{y_s - y_B} \right) \cos \eta \quad (\text{plane}) \quad (10a.)$$

$$\frac{A_\infty}{A_s} = \frac{(y_s^2 - y_o^2)}{(y_s^2 - y_B^2)} \cos \eta \quad (\text{axisymmetric}) \quad (10b.)$$

Substituting equations (7), (9), and (10a) or (10b) into (8) and solving for y_s gives:

$$y_s = \frac{y_B - y_o \left(\frac{A^*}{A} \right)_i \left(\frac{P_{o\infty}}{P_{oc}} \right) \cos \eta}{\left[1 - \left(\frac{A^*}{A} \right)_i \left(\frac{P_{o\infty}}{P_{oc}} \right) \cos \eta \right]} \quad (\text{plane}) \quad (112.)$$

$$y_s = \left\{ \frac{y_B^2 - y_0^2 \left(\frac{A^*}{A} \right) \left(\frac{P_{00}}{P_{0s}} \right) \cos \eta}{\left[1 - \left(\frac{A^*}{A} \right) \left(\frac{P_{00}}{P_{0s}} \right) \cos \eta \right]} \right\}^{1/2} \quad (\text{axisymmetric}) \quad (11b.)$$

The angle η may be approximated by the average of the flow deflection at the sonic point (x_s, y_s) and the body slope φ_B .

$$\eta = \frac{1}{2} (\theta_s + \varphi_B) \quad (12.)$$

$$\theta_s = \frac{1}{\sqrt{2}(\gamma+1)} \frac{(M_{\infty}^2 - 1)^{3/2}}{M_{\infty}^2} \quad (13.)$$

If desired, the point (x_B, y_B) may be located such that φ_B corresponds to the maximum possible deflection at the given upstream mach number:

$$\varphi_B \approx \delta_{\max} = \frac{4}{3\sqrt{3}(\gamma+1)} \frac{(M_{\infty}^2 - 1)^{3/2}}{M_{\infty}^2} \quad (14.)$$

Summarizing, the location of the center of the hyperbolic shock is given by equation (4.):

$$h = x_0 - \beta (y_s - y_0) \sqrt{\beta^2 \tan^2 \sigma_s - 1} \quad (4.)$$

where: y_s is determined using either (11a.) or (11b.).

The shock shape determined by equation (2.) may be solved for either x or y using

$$y = y_0 + \frac{1}{\beta} \sqrt{(x-h)^2 - (x_0-h)^2} \quad (15.)$$

$$x = h + \sqrt{\beta^2 (y-y_0)^2 + (x_0-h)^2} \quad (16.)$$

2.2 STC-Bow Shock Implementation

The STC program and its use are described in References 2 and 3. The general procedure for including the detached shock in the STC solution is as follows:

1. Initially the STC program is executed to obtain an initial supersonic solution at a given refinement level.
2. The STC solution is then restarted with MAXIT increased by 1. The detached shock is inserted in the existing flow field, and the remainder of the calculation is carried out in the region bounded by the shock, the cowl and inlet surfaces and the lower boundary. No attempt is made to refine the grid further. The schematic flow chart for the STC-Bow Shock program is shown in Figure 2.

The limitations of the combined solution are manifest:

1. The restricted refinement capability of this version results in a sparse distribution of points on the surface of interest.
2. Use of the Moeckel shock approximation and an empirically defined stand-off distance forces continuity to be violated. The fixed shock position will not allow convergence of the STC inner iterations; viz., ES2 will not approach zero.
3. In the interest of stability, the curvature at the first two points downstream of the shock was set to zero for each streamline. This artifice was used to simulate a constant pressure boundary and weaken the influence of the shock on the adjacent flow field.

2.3 Bow Shock Subroutines

The Bow Shock subroutines are located in the main calculation overlay (3, 0). The sequence of subroutine calls for insertion of the detached shock is as follows:

1. Initially, BOWSHK is called to calculate the geometry of the shock using the Moeckel method. Pertinent inputs to this routine are the free stream Mach number, the location of the sonic point on the cowl surface, and the vertical location of the stagnation streamline. The output consists of the parameters defining the equation of the detached shock in the x, y or r, z coordinate system.

THE STREAMTUBE CURVATURE PROGRAM

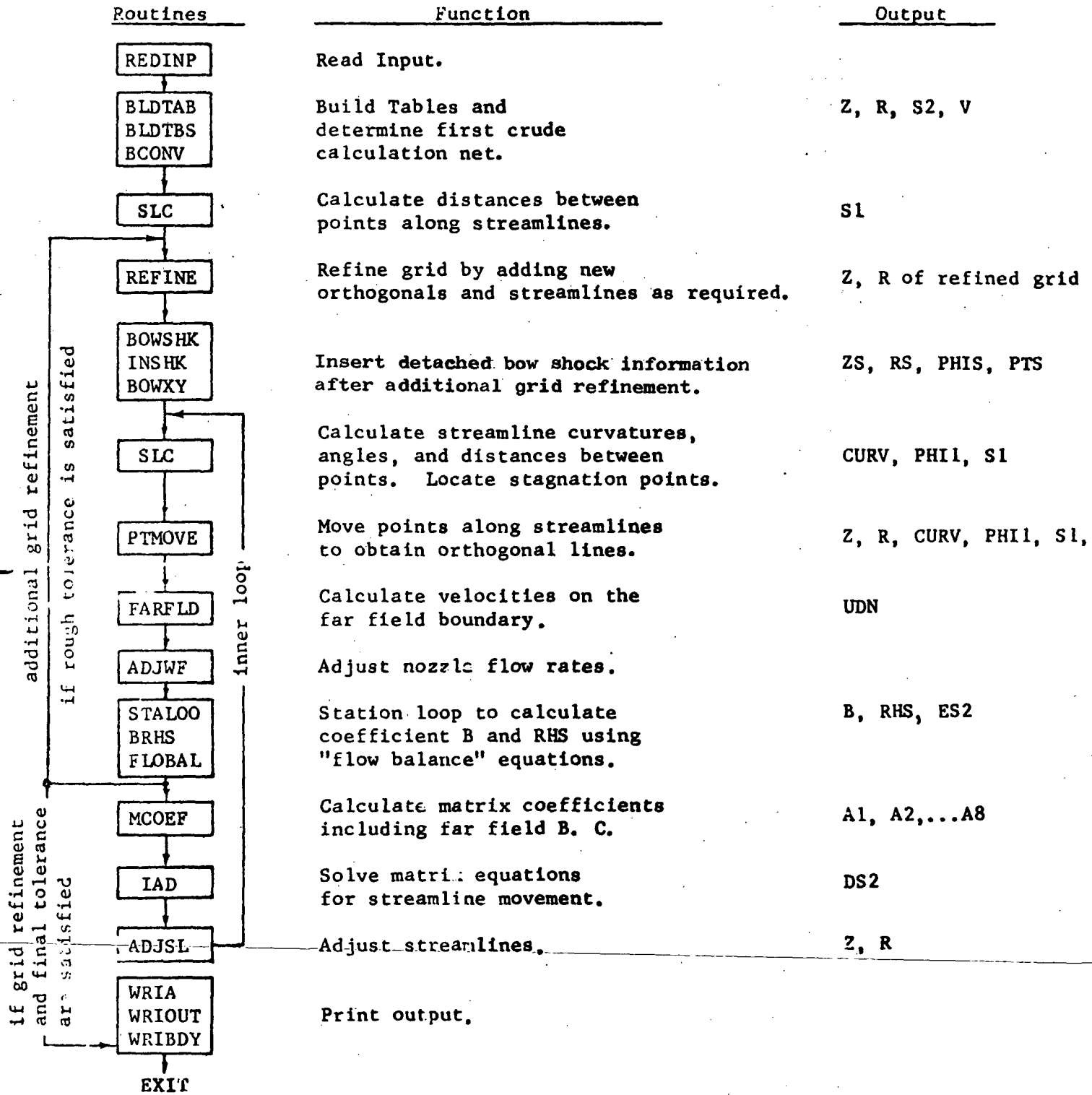


FIGURE 2. Flow Diagram

2. Following calculation of the shock parameters, INSHK is called to insert the detached bow wave and update the field point connections to reflect the presence of the shock. Subroutine BOWXY (overlay 0, 0) is used to calculate (r, y) or (z, x) for points on the shock, as well as flow deflection total pressure ratio, and velocity on the downstream side of the shock. Two types of shock points are constructed:
 - a.) Streamline shock points - Connected to upstream and downstream points. Field data are stored at the end of the field tables (NM + 1) and consist of the coordinates and the flow angle. The total pressure ratio is stored in the RHS array.
 - b.) Orthogonal shock points - Terminal shock points are stored in the field tables in sequence with the normal orthogonal data. The upstream and downstream connections are set to 0, a condition which is used to detect a shock point as one travels up an orthogonal.

A shock table consisting of the first and last streamline shock M indices is constructed and stored at the end of the normal STC station table.

3. Additional functions and subroutines pertinent to the shock calculation are located in overlay (0, 0) and the flow balance overlay (2, 0). Function LSHOCKO is used to detect a terminal shock point on an orthogonal and modify the upper boundary index (MB) obtained from the station table. Subroutine SHKPT is used to calculate the total pressure loss as a streamline passes through a shock.

3.0 PROGRAM NOMENCLATURE

Communication between the STC routines and the bow shock routines is accomplished by the use of labeled common. The principal storage areas utilized by these routines is described in detail in this section. The pertinent type and dimension information are included with the variable name (R \equiv Real, I \equiv Integer, L \equiv Logical).

3.1 Labeled Commons

Bow Shock Input/Initialization Region

The bow shock input/initialization region stored in labeled common CBOW and consists of data read on the overall input sheet 1 and initial calculated shock parameters.

<u>Variable Name</u>	<u>Type</u>	<u>Description</u>
BSHOCK	L	Shock Calculation Switch T - Initiate bow shock calculation (F) - No bow shock calculation
XBSON	R	(X, Z) location of sonic point on cowl surface
YBSON	R	(Y, R) location of sonic point on cowl surface
PHISON	R	Angle of cowl surface at sonic point
YO	R	Vertical distance from sonic point to upstream coordinate of stagnation streamline
XH	R	(X, Z) coordinate of the center of the hyperbolic shock
CZ	R	Axial distance from shock origin to center of the hyperbolic shock
BETA	R	Slope of linear shock asymptote $\beta = \sqrt{M_b^2 - 1}$
DUM (1)	-	Dummy location

Bow Shock Communication Region

The bow shock communication region is stored in labeled commons CBOWXY and VSHOCK and are used to return shock coordinates (X, Z) or (Y, R), the flow deflection, total pressure ratio and velocity on the downstream side of the shock.

Common CBOWXY

<u>Variable Name</u>	<u>Type</u>	<u>Description</u>
XBOW	R	(X, Z) coordinate on shock. Calculated as output if input value is BITS = 1.E + 15
YBOW	R	(Y, R) coordinate on shock. Calculated as output if input value is BITS = 1.E + 15
PHI1SD	R	Flow deflection through shock (radians)
PTQPT1	R	Total pressure ratio across shock; P_{T2} / P_{T1}

Common VSHOCK

<u>Variable Name</u>	<u>Type</u>	<u>Description</u>
V2	R	Absolute velocity downstream of shock

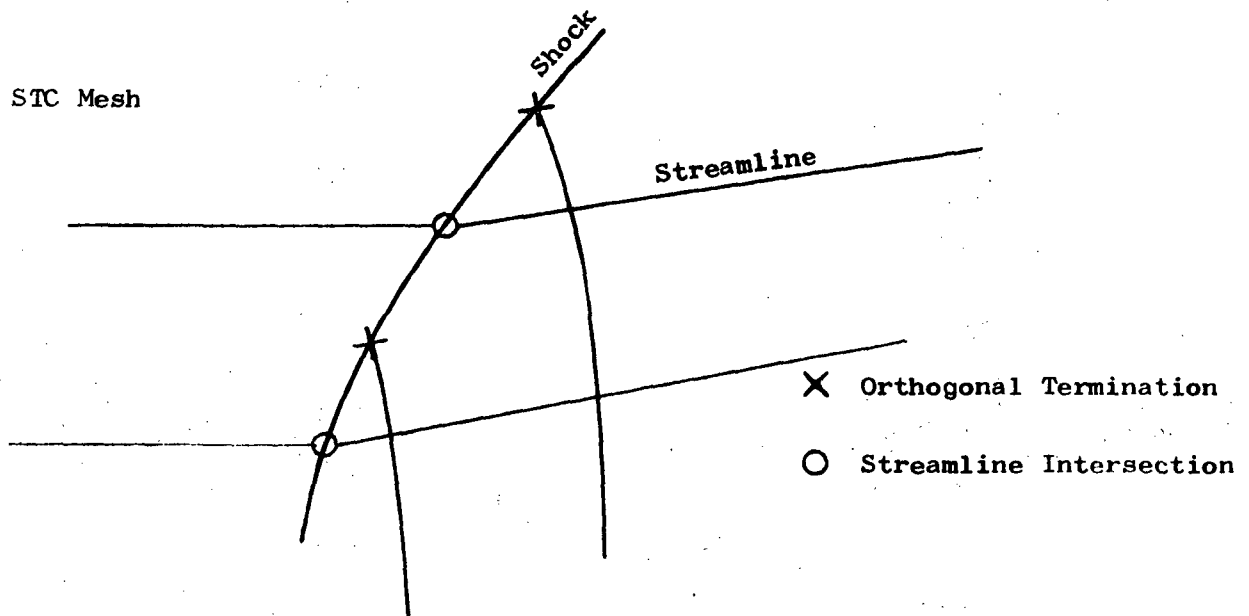
3.2 Revised STC Subroutines

The detached shock was incorporated in the STC program at the expense of "special" modification to a large number of the standard STC subroutines. Rather than describe in detail the modifications, only a list of modified routines will be given.

STCA	WRIA
STCBLK	WRIBDY
ERRORK	WRIOUT
EDUMPS (ERROR 1)	STCXX
EDUMPN (ERROR 1)	ADDFPT
REDINP	EDUMPY (ERROR 1)
RBD	ADJSL
EDUMPX (ERROR 1)	PTMOVE
ADJWF2	SLC
BRHS	EDUMPM (ERROR 1)
FLOBAL	MCOEF
	IAD

3.3 Revised Field Point Connections/STC Tables

The insertion of the detached shock into an existing STC flow field requires modification of the field point tables and the JMS connection array. Orthogonal points terminating on the shock and streamline points intersecting the shock are stored in separate areas.



Shock points on the orthogonals are treated as an upper boundary and have no upstream and downstream connections ($M_U = M_D = 0$). Field data for a given M index are stored in their normal position in the field tables with the total pressure ratio across the shock stored in RHS (M). Data for the streamline intersections are stored at the end of the field tables; viz, starting at $NM + 1$. The limits of the streamline shock points are LSO and LSE, respectively. Index LSO points to the location of a shock table which has the same format as the station table. MLB and MJB in this shock table denote the limits of the M indices along the shock.

4.0 STC - BOW SHOCK PROGRAM INPUT

Input to the STC program is essentially unchanged for the STC - Bow Shock version and is described in detail in Reference 2. The four (4) distinct card input sets read by the program are:

1. Input sheet 0 Identification information
2. Input sheet 1 Overall input data
3. Input sheet 2 Boundary coordinates
4. Input sheet 3 Channel flow properties

The above input sheets, revised for the bow shock option, are given in Appendix I. Since the revised sheets are nearly identical to the original STC input sheets, only changes applicable to the bow shock calculation will be discussed.

4.1 Overall Input Data

Bow shock input is supplied in the second set of overall input data to restart the STC program after a suitable mesh of grid points has been established at a given iteration level.

<u>Parameter</u>	<u>Description</u>	<u>Preset Value</u>
BSHOCK	Shock Calculation Switch T - Initiate bow shock calculation F - No bow shock calculation	F
XBSON	(X, Z) location of sonic point on cowl surface	--
YBSON	(Y, R) location of sonic point on cowl surface	--
PHISON	Angle of cowl surface at sonic point	(10) ¹⁵
PDUM (16)	Print initial shock if = 10	0

The shock calculation indicator must be input as T in the second set of overall input data. Also, the coordinates of the sonic point on the surface must be specified. The surface angle (PHISON) is arbitrary. If not input, this quantity

will be calculated as the maximum deflection through the shock at the specified upstream Mach number.

4.2 Boundary Input

Boundary input to the STC - Bow Shock program is identical to that of the standard STC program. The only exception is that the header card preceding the coordinate data for the outer boundary must be:



2



BDY



SHOCK



External Channel Name

The external boundary must be named SHOCK to set the proper boundary conditions along the shock.

4.3 Sample Input

A set of sample input for a NASA 8 inlet at $M = 1.29$ is as follows:

NAME= DAVE FERGUSON
ADDRESS= EVENDALE
IDENT= BOW SHOCK TEST CASE
1 STC F T

\$A

RHL=7.682, RM=9.,
TOLRL=5.0E-3,
MACHO=1.2904,
PSO=5.36208, TSO=400.048, RG=1716.32,
IADM=1, RHOBAS=1, RHOAMP=0,
SSFML=-1,
TOLEST=.1,
SSDLE=F,
CRX(3)=0,
VMG1=100., VMG2=100.,
NGR=5, GR(1)=0., 7., 8.5, 10., 20., SGR(1)=3., 1., 1., 3., 12.,
NGZ=5, GZ(1)=-2., -5, 1., 20., 27.5, SGZ(1)=16., 4., 1., 2., 12.,
MAXIT=3,

\$

2 BDY CNTLN W2

\$A

UPPER=F,
B(1)=-30., 0., 0., 18., 0., 0.,

\$

2 BDY NACA1 W2

\$A

UPPER=T,
B(1)=0., 7.682, -90.,
.01721, 7.6100, -64.068,
.03790, 7.57593, -53.751,
.05404, 7.55603, -48.309,
.08320, 7.52723, -41.353,
.11560, 7.50136, -36.031,
.1980, 7.45181, -26.448,
.3830, 7.38728, -13.081,
.5340, 7.36163, -6.630,
.7610, 7.3480, -0.831,
2.500, 7.378, 0.995,
4.500, 7.413, 1.010,
6.300, 7.44856, 1852,
8.1000, 7.52971, 3.320,
10.800, 7.73329, 5.172,
14.400, 8.09178, 5.742,
16.200, 8.26233, 4.956,
18.000, 8.400, 3.791,

\$

2 BDY CLEX EXT

\$A

UPPER=F,
B(1)=0., 7.682, 90.,
.0018, 7.6968, 76.2433,
.0054, 7.7070, 67.0607,
.0117, 7.7182, 57.1584,
.0234, 7.7331, 46.1042,
.0360, 7.7453, 39.5391,
.0720, 7.7694, 30.6720,
.1080, 7.7890, 25.6708,
.1800, 7.8188, 20.4128,

.3600,7.8760,15.7191,
.6300,7.9448,13.0833,
1.0800,8.0380,10.5705,
2.1600,8.2104,7.8881,
4.1400,8.4288,5.3347,
5.5800,8.5515,4.4806,
7.0200,8.6553,3.8005,
8.4600,8.7430,3.1725,
10.0800,8.8251,2.6273,
11.5200,8.8844,2.0963,
13.3200,8.9404,1.4845,
15.8400,8.9880,.6968,
18.000,9.000,0.000,
18,000,9.000,0.000,
27.50,9.000,0.000,

\$

2 BDY SHOCK EXT

\$A

UPPER=T,

B(1)=-30.,60.,0.,

\$

3 CHN W2

\$A

AO=.885,

\$

1 STC T F

\$A

MAXIT=4,NINNER(4)=3,

BSHOCK=T,XBSON=3.,YBSON=8.3,

\$

5.0 STC - BOW SHOCK PROGRAM OUTPUT

The output from the STC - Bow Shock version is identical to that produced by the standard STC version with the following exceptions:

1. When PDUM (16) =10, the coordinates of the inserted bowshock, the flow deflection, and the total pressure loss are printed. The format is:

```
OL } SHOCK POINT - M=III Z=XXX R=XXX PHI=XXX PT2/PT1=XXX  
SL }
```

2. Upon either normal or abnormal termination, the following comment is printed as a warning to the user:

"The solution for the bow shock is based on Moeckel's approximate solution (NACA TN 1921) and includes the following assumptions -

1. Hyperbolic bow wave shape
2. Stand-off distance defined empirically
3. Upstream boundary conditions defined at bow shock. Due to fixed shock shape and position of the shock, the continuity equation is violated between the shock and the body. STC grid refinement and streamline curvature is restricted in the vicinity of the bow shock.

Severe difficulties were encountered in running the STC - Bowshock program, hence, no test case results are given.

6.0 STC - BOW SHOCK PROGRAM USAGE

The inherent limitations of the combined STC - detached shock calculation are given in Section 2.2 and its use is not recommended. For Mach numbers up to ~ 1.2 it is recommended that the standard STC program be run in the supersonic mode. At Mach 1.2 the nominal deflection through the shock is 4° with a maximum total pressure ratio of .9928. These conditions could be approximated using the standard STC program.

7.0 REFERENCES

1. W.E. Moeckel, "Approximate Method for Predicting Form and Location of Detached Shock Waves Ahead of Plane or Axially Symmetric Bodies", NACA TN 1921, July 1949.
2. Keith, J.S.; Ferguson, D.R., and Heck, P.H., "Users Manual for Streamtube Curvature Analysis - Analytical Method for Predicting the Pressure Distribution about a Nacelle at Transonic Speeds", NASA CR-112239, General Electric Company.
3. Keith, J.S.; Ferguson, D.R.; Merkle, C.L.; Heck, P.H., and Lahti, D.J, "Analytical Method for Predicting the Pressure Distribution about a Nacelle at Transonic Speeds", Final Report, NASA CR-2217, General Electric Company.

APPENDIX I - PROGRAM INPUT SHEETS

STREAMTUBE CURVATURE PROGRAM
WITH BOW SHOCK
Channel Flow Properties

Feb. 1973

Page _____ of _____.
STC/Sheet-3

channel
name



3 CHN _____

\$A

ratio of specific heats (1.4)	gas constant (1.0)	flow rate may be adjusted? (T) or F
--	--------------------------	--

GAM= _____, RG= _____, VARY= _____,

stagnation properties, see notes 3 and 4

total temp total pressure

TT ϕ = _____, PT ϕ = _____,

Mach no. static temp static pressure

MACH ϕ = _____, TS ϕ = _____, PS ϕ = _____,

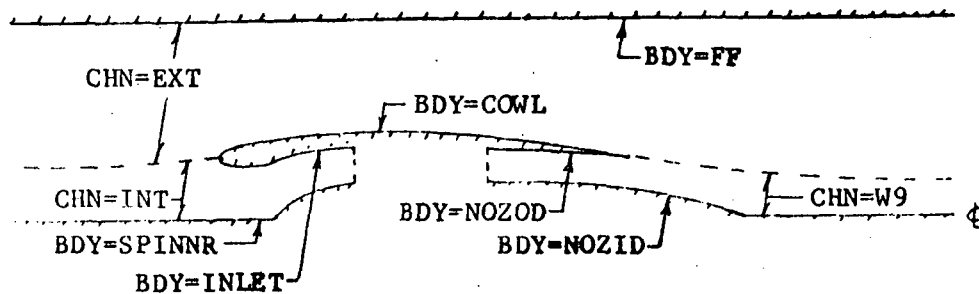
flow area normalized by A_{HL} .

A ϕ = _____,

\$

General Instruction and Notes for Sheet-1 of the STC Input Forms

- 1) The STC Program computes the subsonic and transonic field of inviscid flow past (and within) arbitrarily shaped planar and axisymmetric bodies. Inlet and exhaust nozzle flows wherein there may exist jet streams with differing energies are typical applications.
- 2) The total flow is composed of one or more streams, the properties of which are to be listed on Sheet-3 (except as noted below). Each stream occupies a "channel" which is identified by a one to six character alphanumeric word. Each channel must be bounded, at least in part, by an "upper boundary" and a "lower boundary". Each boundary is also given an identifying one to six character name and the coordinates are listed on Sheet-2. The following sketch illustrates the naming of channels (CHN) and boundaries (BDY).



An external flow channel must be named EXT, the recommended name for the inlet capture flow channel is INT, and the far-field interface boundary must be named FF. Otherwise the selection of the channel and boundary names is arbitrary. The special channel names EXT and INT cause extra streamlines to be placed in the first refined grid. The boundary name FF indicates that the boundary condition on FF is to be obtained from an analytic far-field solution.

There is no specific limit to the complexity of the flow field in regard to the number of channels or the number of boundaries. Limits are set on the total amount of data which may be input.

- 3) The solution method consists of constructing a grid of streamlines and orthogonal lines. Starting with two streamlines per channel (one for each boundary) and an orthogonal passing through the first and last point of each boundary, the grid is automatically refined by dividing the grid intervals in half and in half again as required. The numerical resolution, the solution accuracy and the computer execution cost are all directly related to the extent of grid refinement. The input variable MAXIT determines the maximum number of refinements. Providing this limit is not exceeded, the grid will be refined, locally as required, until the spacing of orthogonals and streamlines is less than the value determined from the SGR and SGZ tables and the Mach number difference between any two points on a streamline or an orthogonal line is less than VMG1 and VMG2, respectively. Grid size values versus radius (or y-ordinate) are to be tabulated after SGR and GR, respectively. NGR is the number of entries in each list. Grid size versus the axial coordinate is to be tabulated after SGZ and GZ, respectively. NGZ is the number of GZ values. If dimensional values of RG, TSO and PSO are input (see Note 6), then VMG1 and VMG2 must have units of velocity rather than Mach number. See supplemental notes for additional details.

A partially refined grid may be saved on tape by specifying a T in column 24 of the first card, or read from a previously created tape by specifying a T in column 14.

If TAPE 1 and/or TAPE 2 are not assigned via a REQUEST card, they are assigned to disc. This allows the user to obtain output for a given refinement level and provides the option of changing input parameters on the restart. For the restart case, specify a T in column 14 of the first data card and include in the \$A list only those input quantities (viz; MAXIT) which differ from those originally input.

- 4) In the initial calculation grid, an orthogonal line will pass through each leading and trailing edge point and through each sharp corner point (i.e. a point on the boundary with an angle discontinuity). It is not possible to analyze a configuration in which two or more of these points

are approximately opposite to each other. For example, if a configuration contains more than one leading edge, the edges must be staggered relative to the streamwise direction.

- 5) A free stream Mach number is specified by supplying a value of MACHØ.
- 6) Perfect gas assumptions are employed and the levels of ambient pressure and temperature may be dimensionless (TSO=PSO=RG=1) or dimensional.
- 7) A reference (or highlight) area is calculated from the input value of R_{HL} as follows:

axisymmetric: $A_{HL} = \pi R_{HL}^2$

planar: $A_{HL} = \Delta y_{HL} = R_{HL}$

This reference area (or Δy in the planar case) is used for defining the mass flow for each channel. See STC/Sheet-3 note ____.

- 8) Computed pressure drag forces are normalized by the (maximum) body area where

axisymmetric: $A_m = \pi R_m^2$

planar: $A_m = \Delta y_m = R_m$

- 9) Finite trailing edge thickness is permitted; the maximum thickness, or body closure tolerance, is to be supplied after TTE.
- 10) On this and the following input sheets, the values in parenthesis are used if other values are not input.

Notes for Sheet-2 of the STC Input Forms

- 1) Use one of these sheets for each boundary. Supply a one to six character name to identify the boundary in column 14 of the first card. Also indicate the name of the channel to which the boundary is adjacent in column 24. On the second card indicate whether the boundary is above (UPPER = T) or below (UPPER = F) the channel.

- 2) The upper or lower "contour" which bounds a given stream may be composed of several "boundaries". In this case, an input sheet must be completed for each boundary; the last point of the first boundary must have the same coordinates as the first point of the second boundary, and so forth. This option is useful when considering variable geometry configurations such as flaps or movable nozzle parts. The movable part may be translated and rotated, as indicated by Note 8, while the fixed part is held stationary.
- 3) List values of Z (or X), R (or Y) and the surface angle in degrees at discrete points along this boundary contour after the symbol "B(1)". Points at sharp corners must be listed twice, one time for each angle which exists at that point. In each interval, the STC Program fits a locally rotated cubic polynomial. The input points must be smooth and consistent with the specified angles.

All points are to be listed in the streamwise direction. For an inlet lip, the points are listed by starting at the highlight point and then proceeding around the nose to the trailing edge or downstream boundary. The internal and external surfaces are listed separately under different boundary names. However, the coordinates of the first point must be the same with ANGD equal to $+90^\circ$ for the external surface and -90° for the internal surface.

It is recommended that the boundary coordinates and angles be obtained from an analytic definition of the contour, and that around the nose, angle variations between points be 20° or less.

- 4) Pressure and Mach number distribution data will be printed at each orthogonal intersection with the boundary, and not at each input boundary point. Orthogonal stations, however, will be placed at any repeated point in the boundary table. List the same points twice if it is desired to have an orthogonal placed in that position. (This option is modified slightly when ZRONLY = T.) Orthogonal stations are always placed at the beginning and end of a boundary and at a juncture point between boundaries along the same contour.
- 5) If the coordinates but not the angles are known, the third column in the B-input array may be omitted. In this case specify ZRONLY = T and list the

coordinates twice at any point where a curvature jump or an angle jump exists. The double points will later be deleted if the angle discontinuity is less than 0.01 degrees. These double points are removed because extra calculation stations (see Note 5) are usually not desired at such points. However, the double point angle tolerance, DBLPTS, preset as 0.01, may be input as zero if such double points are to be retained.

- 6) With either input option, care must be taken to specify the coordinates with precision. The round off or reading error of the coordinate data should be less than $\Delta S^2 / (10 * L)$, where ΔS is the local distance between points and L is some characteristic length, say the length of the cowl. Conversely, the spacing between points should not be less than $(10 \delta L)^{1/2}$ where δ is the relative accuracy of the coordinate data. The tabulated output curvatures may be consulted to verify the smoothness of the input data.
- 7) NACA Series 1 Cowl coordinates are stored internally. With the ZRONLY = T option they may be selected by listing:

```

B(1) = 991, 1,
          X1, Y1,           Series 1 Segment
          Y2, Y2,
          X2, Y2,
          _____, _____, Cowl Aft Segment

```

where X_1, Y_1 are the highlight coordinates and X_2, Y_2 is the position of the maximum diameter at the end of the Series 1 contour segment.

- 8) The input coordinates of a boundary may be adjusted by supplying the following input quantities not shown on the front of this sheet:

ROTATE	angular rotation in degrees
ZPIVOT	pivot coordinates
RPIVOT	
SCALE	multiplicative constant to be applied to the coordinate data
ZTRANS	translation increment in the axial direction
RTRANS	translation on increment in the radial/vertical direction

The order of transformation is rotation, scaling and translation. Hence, the pivot coordinates are in the same coordinate frame as the input data and the translation increments are in the rotated coordinate frame after scaling. It is only necessary to input data for the transformation operations to be executed.

Notes for Sheet-3 of the STC Input Forms

- 1) Use one of these sheets for each channel to supply entrance flow properties. (See exception under Note 5).
- 2) Of the input items shown on the face of the input sheet, use only those which are required for the selected options.
- 3) The total pressure and total temperature may be input by either of the following two procedures:
 - a) Specify TTO and PTO if the stagnation properties are known. These values may be normalized by the free stream ambient temperature and pressure.
 - b) Specify MACHO, TSO and PSO if the static properties and Mach number are known. Again TSO and PSO may be normalized by the free stream ambient values. If only MACHO is supplied (TSO & PSO are omitted) the TSO and PSO values from STC/Sheet-1 will be used.

If neither of the above is input, free stream values as supplied on Sheet-1 are used for MACHO, PTO and TTO.

- 4) If the gas constant, R_G , is different from the value supplied on STC/Sheet-1, supply the value which applies to this channel. R_G , TSO , TTO, PSO and PTO may all be given as dimensionless (normalized by free stream ambient) or dimensional using a consistent set of units.
- 5) Input a value AO for the determination of the channel flow rate. AO is an area fraction normalized by A_{HL} as defined under Note 7 of Sheet-1; the (dimensional) channel flow area is then the product $AO \cdot A_{HL}$. The flow rate for the channel is computed by using one-dimensional relations from the total properties (as determined under Notes 3 & 4), the supplied Mach number, $MACHO$, and the flow area. For internal inlet channels, specify R_{HL} as the highlight radius and AO as the mass flow ratio.

- 6) If for any channel the input data on this sheet is not supplied, the reference properties on STC/Sheet-1 will be employed and the frontal area calculated at the entrance station will be used. This option is suggested for an external stream.
- 7) Although approximate flow rates must always be supplied according to Note 5, the program will adjust channel flow rates as required to meet the zero pressure loading conditions at a trailing edge or to meet a maximum (choked) flow rate. The number of channels which require flow rate adjustment is equal to the number of trailing edges. If the flow rate is not to be varied for this channel, specify VARY = F.