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WYLE LABORATORIES
TESTING DIVISION, HUNTSVILLE FACILITY



research

WYLE LABORATORIES - RESEARCH STAFF
TECHNICAL MEMORANDUM 69-1

DIGITAL COMPUTATION OF DOWNSTREAM
MODES GENERATED BY THE INTERACTION OF A
SHOCK WAVE WITH AN UPSTREAM FLOW
CONTAINING THE THREE DISTURBANCE MODES
(VORTICITY, ENTROPY AND SOUND)

By

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Work Performed Under Contract No. NAS8-21100

March 1969



WYLE LABORATORIES
RESEARCH DIVISION, HUNTSVILLE FACILITY

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SUMMARY

A Fortran computer program has been written for the CDC 3300 which computes the values of the modes of the perturbed downstream flow field resulting from the interaction of an infinite, plane shock wave with an upstream flow containing perturbations in all three modes: vorticity, entropy and sound.

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1.0 INTRODUCTION

A Fortran computer program has been written for the CDC 3300 which computes the values of the modes of the perturbed downstream flow field resulting from the interaction of a field of turbulence and sound waves with an infinite shock plane. Various other quantities associated with the flow are computed and output. This program supersedes the one reported in Reference 1, which was able to accommodate only one of the possible upstream modes -- the entropy mode -- as an input disturbance, and only for specified values of δ , the inclination angle of the incoming disturbance wavefront. In the present program, the effects of the upstream entropy, pressure and vorticity modes on the downstream entropy, pressure and vorticity modes are computed, and the downstream intensities and levels are obtained for a random field of upstream perturbations, by numerically integrating over all wavefront inclination angles. The output is designed to exhibit not only the resulting downstream intensities of vorticity and entropy, plus the overall sound pressure level, but also to show the proportion that is due to each of the upstream modes, and to show the portion of the generated near field pressure fluctuation level that will be radiated to the far field as sound. The theoretical model, and justification of the mathematical expressions used, are given in Reference 2. Schematic representation of the basic flow coordinate system and the interaction process are given in Figures 1 and 2, respectively.

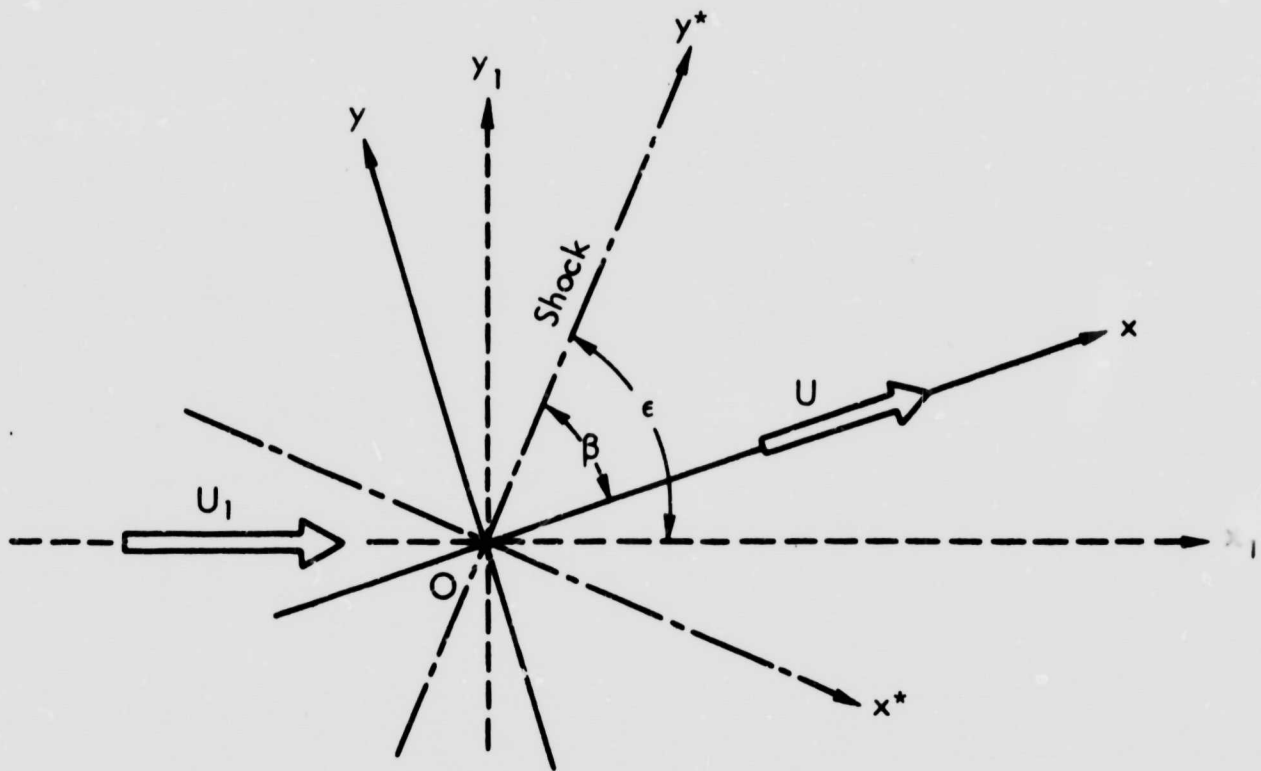


Figure 1. Basic Flow Coordinate Systems

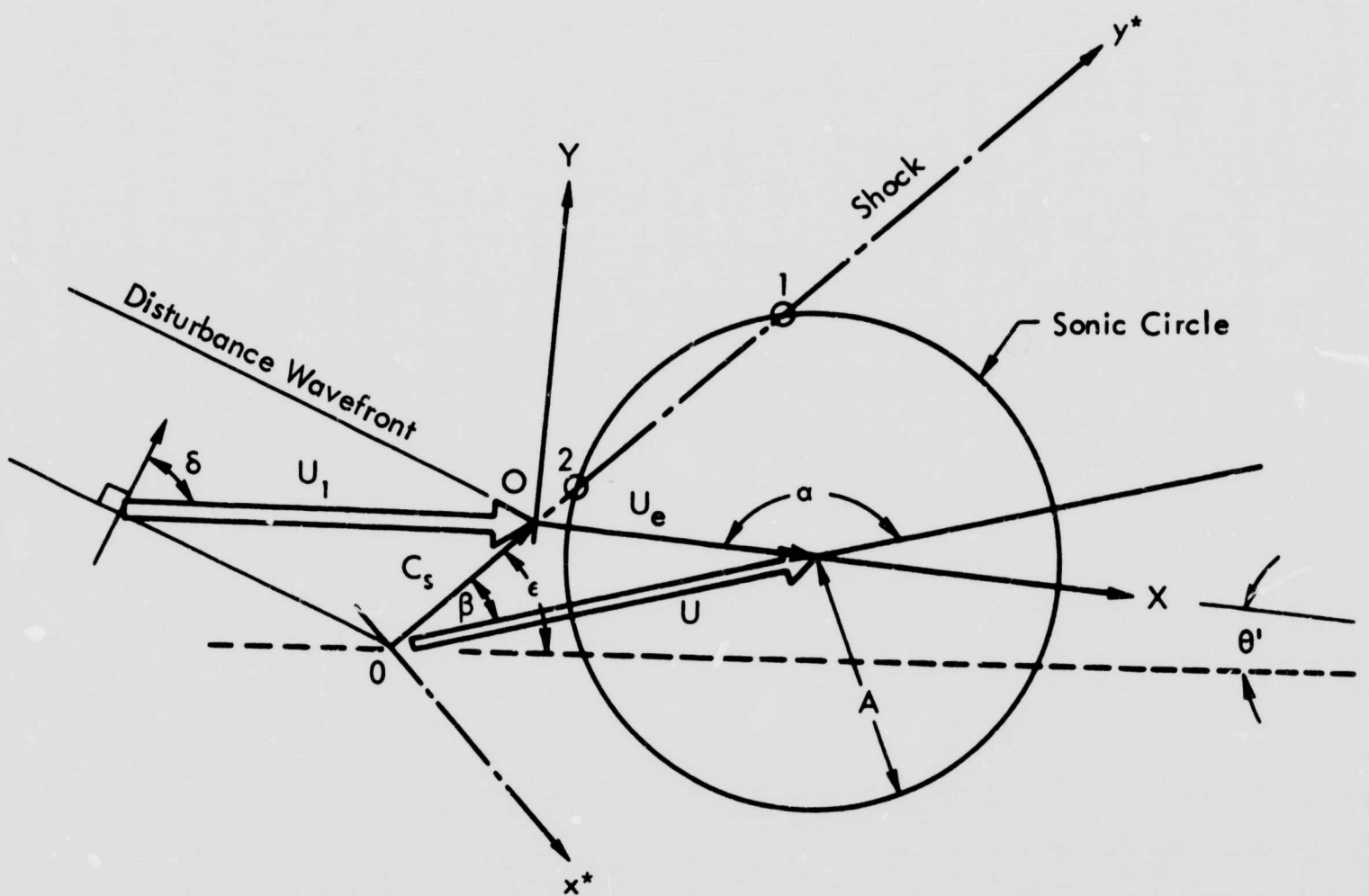


Figure 2. Intrinsic Frame of Reference with Respect to Downstream Flow Field

2.0 LIST OF SYMBOLS

These are best exhibited in tabular form: -

TABLE OF SYMBOLS, THEIR COMPUTER CODE EQUIVALENTS, AND DEFINITIONS

Symbol	Computer Code	Definition
ϵ	EPI EPIR	(degrees) } Shock wave angle, referenced to the x_1 - axis. (radians) }
β	BETA BETAR	(degrees) } Angle between the shock wave and the downstream (radians) } flow velocity vector.
δ	DELTA DELTAR DB DBR DS DSR DE DER	(degrees) } Inclination of upstream disturbance wave with respect to (radians) } mean flow direction. (degrees) } The initial values of δ ; i.e., the lower limit of (radians) } integration. (degrees) } The step length of δ for the numerical integration. (radians) } The final value of δ ; i.e., the upper limit of inte- (radians) } gration.
α	ALPHA ALPHAR	(degrees) } Inclination of U_e with respect to the downstream mean (radians) } flow direction U (exterior angle).
μ_e	EMEWE EMEWER	(degrees) } Effective Mach angle corresponding to M_e (radians) }
γ	GAMMA	Ratio of specific heats.
M_1	EM1	Upstream flow Mach number.
M	EM	Downstream flow Mach number.
N_1	EN1	Upstream Mach number corresponding to a normal shock of equivalent strength.
N	EN	Downstream Mach number corresponding to a normal shock of equivalent strength.
M_e	EME	Effective Mach number corresponding to U_e .
A_1	A1	Speed of sound in the flow field upstream of the shock.

Symbol	Computer Code	Definition
A	A	Speed of sound in the flow field downstream of the shock.
A/A1	ARAT	Ratio of acoustic velocities across the shock, downstream to upstream.
U_1	U1	Mean flow velocity upstream of the shock.
U	U	Mean flow velocity downstream of the shock.
U_e	UE	Apparent mean flow velocity downstream of the shock with respect to an observer moving with C_s .
u_{-}^*	USM	Dimensionless magnitude of the upstream velocity perturbation along the x^* -axis.
v_{-}^*	VSM	Dimensionless magnitude of the upstream velocity perturbation along the y^* -axis.
u_1	UL1	Dimensionless magnitude of the downstream velocity perturbation along the x_1 -axis.
v_1	V1	Dimensionless magnitude of the downstream velocity perturbation along the y_1 -axis.
VORT	VORT	$\sqrt{(UL1^2 + V1^2)}$
u_{+}^*	USP	Dimensionless magnitude of the downstream velocity perturbation along the x^* -axis.
v_{+}^*	VSP	Dimensionless magnitude of the downstream velocity perturbation along the y^* -axis.
U_{+}	UP	Dimensionless magnitude of the downstream velocity perturbation component along downstream mean flow velocity vector.
V_{+}	VP	Dimensionless magnitude of the downstream velocity perturbation component normal to downstream mean flow velocity vector.
I_{U1}	EYEU1	The upstream turbulence intensity along the x_1 -axis.
I_{V1}	EYEV1	The upstream turbulence intensity, normal to the x_1 -axis.

Symbol	Computer Code	Definition
I_U	TIU	The downstream turbulence intensity along the x_1 -axis.
I_V	TIV	The downstream turbulence intensity normal to the x_1 -axis.
C_s	CS	Drift speed of the upstream disturbance wave along the shock.
C_{s1}	CS1	Intersection of shock plane and sonic circle lying farthest from the origin.
C_{s2}	CS2	Intersection of shock plane and sonic circle lying nearest the origin.
χ	CHI	Shock strength in terms of the ratio of pressure of the unperturbed flow across the shock
p_-	PM	Dimensionless magnitude of upstream pressure perturbation.
$p]_{x^*=0}$	PCS	Dimensionless pressure perturbation immediately behind the shock.
p_+	PP	Dimensionless magnitude of the downstream generated pressure perturbation.
p_m	PM1	The ambient static upstream pressure.
SPL_1	SPL1	The overall upstream sound pressure level.
SPL	TSPL	The overall downstream sound pressure level.
q	Q	A dimensionless parameter related to the downstream pressure perturbation, one member of the pair making up the Riemann invariants.
ρ_n / ρ_{1m}	RORAT	Density ratio across the shock, downstream to upstream.
I_{T1}	EYET1	The upstream entropy fluctuation intensity; i.e., the r.m.s. fluctuation in static temperature, referenced to the local <u>total</u> temperature.
S_-	SM	The dimensionless magnitude of the upstream entropy perturbation.
S_+	SP	The dimensionless magnitude of the downstream entropy perturbation.
I_T	TIT	The downstream entropy fluctuation intensity.

Symbol	Computer Code	Definition
π_{ij}	PIE(I)	Transfer coefficients for the interaction.
λ_{ij}	ALAM(I,J)	Transfer coefficient for the interaction.
D C	D } C }	Convenient groupings of parameters in the solution for the equivalent source function $g(y^*)$; see Reference 2.
$g(y^*)$	GYS	A function related to the strength of an equivalent source located on the shock plane. See Reference 2, Case $M_e < 1$.
$P(x^*=0)$	PCS	Dimensionless pressure perturbation immediately behind the shock, for the case $M_e > 1$.

3.0 LIST OF EQUATIONS

The following equations were used in the model to express the downstream modal values in terms of the upstream modal values. Many of the equations are the same as those used in Reference 1. The principal equation which is the basis of the model is Equation 3.38. Most of the remainder of the equations were used to supply values of the parameters used in Equation 3.38.

$$3.1 \quad N_1 = M_1 \sin \epsilon$$

$$3.2 \quad M = \left[\frac{N_1^2 + 5}{(7N_1^2 - 1) \sin^2 \beta} \right]^{1/2}$$

$$3.3 \quad N = M \sin \beta$$

$$3.4 \quad x = \left(\frac{p_m}{p_{1m}} \right) = \frac{7N_1^2 - 1}{6}$$

$$3.5 \quad \left(\frac{p_m}{p_{1m}} \right) = \frac{6x + 1}{x + 6}$$

$$3.6 \quad \left[\begin{aligned} \Lambda_{11} &= \left(\frac{p_m}{p_{1m}} \right)^2 \left(\frac{N}{N_1} \right)^2 - (\gamma - 1) \left(1 - \frac{p_m}{p_{1m}} \right) N^2 \\ \Lambda_{21} &= \frac{N^2}{1 - N^2} \left\{ \left(1 - \frac{p_m}{p_{1m}} \right) [1 + (\gamma - 1) N^2] + \left[1 - \left(\frac{p_m}{p_{1m}} \right)^2 \left(\frac{N}{N_1} \right)^2 \right] \right\} \\ \Lambda_{31} &= \frac{-N}{1 - N^2} \left\{ \left[1 - \left(\frac{p_m}{p_{1m}} \right)^2 \left(\frac{N}{N_1} \right)^2 \right] + \left(1 - \frac{p_m}{p_{1m}} \right) \gamma N^2 \right\} \\ \Lambda_{12} &= (\gamma - 1) \left(1 - \frac{p_m}{p_{1m}} \right) \left(1 - \frac{1}{N_1^2} \frac{p_m}{p_{1m}} \right) N^2 \end{aligned} \right.$$

$$\Lambda_{22} = \frac{-Z^2}{1-Z^2} \left\{ \left(1 - \frac{p_m}{p_{im}}\right) + \left(1 - \frac{1}{Z_1^2} \frac{p_m}{p_{im}}\right) \left[1 + (\gamma-1) \left(1 - \frac{p_m}{p_{im}}\right) Z^2\right] \right\}$$

$$\Lambda_{32} = \frac{Z}{1-Z^2} \left\{ \left[1 - \left(\frac{p_m}{p_{im}}\right)^2 \left(\frac{Z}{Z_1}\right)^2\right] + \gamma \left(1 - \frac{p_m}{p_{im}}\right) \left(1 - \frac{1}{Z_1^2} \frac{p_m}{p_{im}}\right) Z^2 \right\}$$

$$\Lambda_{13} = (\gamma-1) \left(1 - \frac{p_m}{p_{im}}\right)^2 \frac{Z^2}{Z_1}$$

$$\Lambda_{23} = \frac{-Z}{1-Z^2} \left(1 - \frac{p_m}{p_{im}}\right) \left\{ 2 + (\gamma-1) \left(1 - \frac{p_m}{p_{im}}\right) Z^2 \right\} \frac{Z}{Z_1}$$

$$\Lambda_{33} = \frac{1}{1-Z^2} \frac{Z}{Z_1} \left\{ 1 - \left(\frac{p_m}{p_{im}}\right)^2 Z^2 + \gamma \left(1 - \frac{p_m}{p_{im}}\right)^2 Z^2 \right\}$$

$$\Lambda_{44} = \left(\frac{p_m}{p_{im}}\right) \frac{Z}{Z_1}$$

3.7

$$\Pi_{11} = -(\gamma-1) \left(1 - \frac{p_m}{p_{im}}\right)^2 \left(\frac{p_m}{p_{im}}\right) Z$$

$$\Pi_{22} = \frac{-Z}{1-Z^2} \left(1 - \frac{p_m}{p_{im}}\right) \left[2 + (\gamma-1) \left(1 - \frac{p_m}{p_{im}}\right) Z^2\right]$$

$$\Pi_{31} = \frac{1}{1-Z^2} \left(1 - \frac{p_m}{p_{im}}\right) \left[1 + Z^2 + (\gamma-1) \left(1 - \frac{p_m}{p_{im}}\right) Z^2\right]$$

$$\Pi_{41} = \left(\frac{p_m}{p_{im}} - 1\right) Z$$

$$3.8 \quad \left(\frac{A}{A_1}\right) = \left[\frac{(7N_1^2 - 1)(N_1^2 + 5)}{36N_1^2} \right]^{1/2}$$

$$3.9 \quad A = \left(\frac{A}{A_1}\right) \cdot A_1$$

$$3.10 \quad U_1 = M_1 A_1$$

$$3.11 \quad U = MA$$

$$3.12 \quad S_- = I_{t1} \left(1 + \frac{(\gamma-1)}{2} M_1^2 \right)$$

$$3.13 \quad P_- = \frac{1.45 \times 10^{-5}}{\gamma p_{m1}} \text{antilog} \left[\frac{SPL_1 - 74}{20} \right]$$

$$3.14 \quad u_- = I_{u1} M_1$$

$$3.15 \quad v_- = I_{v1} M_1$$

$$3.16 \quad u_* = u_- \sin \epsilon - v_- \cos \epsilon$$

$$3.17 \quad v_* = u_- \cos \epsilon + v_- \sin \epsilon$$

$$3.18 \quad C_s = \frac{\cos \delta}{\cos(\delta - \epsilon)} \cdot U_1$$

$$3.19 \quad \alpha = \arctan \left[\frac{C_s \sin \beta}{C_s \cos \beta - U} \right]$$

$$3.20 \quad U_e = \frac{U \sin \beta}{\sin(\alpha - \beta)}$$

$$3.21 \quad M_e = \frac{U_e}{A}$$

$$3.22 \quad \mu_e = \arcsin\left(\frac{1}{M_e}\right)$$

$$3.23 \quad C_{s1} = \sqrt{U^2 + A^2 - 2U \left[U \sin^2 \beta - \cos \beta \sqrt{A^2 - U^2 \sin^2 \beta} \right]}$$

$$3.24 \quad C_{s2} = C_{s1} - 2 \sqrt{A^2 - U^2 \sin^2 \beta}$$

$$3.25 \quad D = \frac{M_e K_1}{2 \sqrt{1 - M_e^2}}$$

$$3.26 \quad C = K_2 s_- + K_3 p_- + K_4 u_-^* + K_5 v_-^*$$

$$3.27 \quad K_1 = \frac{-\left[\Pi_{31} \left(M \cos \beta - \frac{C_s}{A} \right) \cos(\alpha - \beta) - \Pi_{41} \sin(\alpha - \beta) \right]}{\Pi_{21} \left(M \cos \beta - \frac{C_s}{A} \right)}$$

$$3.28 \quad K_2 = -\Lambda_{31} \cos(\alpha - \beta) + \Lambda_{21} K_1$$

$$3.29 \quad K_3 = -\Lambda_{32} \cos(\alpha - \beta) + \Lambda_{22} K_1$$

$$3.30 \quad K_4 = -\Lambda_{33} \cos(\alpha - \beta) + \Lambda_{23} K_1$$

$$3.31 \quad K_5 = -\Lambda_{44} \sin(\alpha - \beta)$$

$$3.32 \quad g(Y^*) = \frac{D \cdot C}{1 + D^2}$$

$$3.33 \quad p]_{x^*=0} = \frac{0.5 M_e}{\sqrt{1 - M_e^2}} g(Y^*)$$

$$3.34 \quad q = \left\{ - \left[(\Lambda_{31} s_- + \Lambda_{32} p_- + \Lambda_{33} u_-^*) \cos(\alpha - \beta) + \Lambda_{44} v_-^* \sin(\alpha - \beta) \right] \right. \\ \left. \left/ \left[1 - \frac{[\Pi_{31} (M \cos \beta - C_s/A) \cos(\alpha - \beta) - \Pi_{41} \sin(\alpha - \beta)]}{\Pi_{21} (M \cos \beta - C_s/A) \cos \mu_e} \right] \right\} - \\ - \left\{ \left[(\Lambda_{21} s_- + \Lambda_{22} p_- + \Lambda_{23} u_-^*) \cos \mu_e \right] \times \right. \\ \left. \times \frac{[\Pi_{31} (M \cos \beta - C_s/A) \cos(\alpha - \beta) - \Pi_{41} \sin(\alpha - \beta)]}{[\Pi_{21} (M \cos \beta - C_s/A) \cos \mu_e]} \right\} \\ \left/ \left[1 - \frac{[\Pi_{31} (M \cos \beta - C_s/A) \cos(\alpha - \beta) - \Pi_{41} \sin(\alpha - \beta)]}{\Pi_{21} (M \cos \beta - C_s/A) \cos \mu_e} \right] \right\}$$

Note that the above equation is used for $M_e > 1$ and $C_s \leq C_{s2}$.

$$\begin{aligned}
3.35 \quad q = & \left\{ \left[(\Lambda_{31} s_- + \Lambda_{32} p_- + \Lambda_{33} u_-^*) \cos(\alpha - \beta) + \Lambda_{44} v_-^* \sin(\alpha - \beta) \right] / \right. \\
& \left. / \left[1 + \frac{[\Pi_{31} (M \cos \beta - C_s/A) \cos(\alpha - \beta) - \Pi_{41} \sin(\alpha - \beta)]}{\Pi_{21} (M \cos \beta - C_s/A) \cos \mu_e} \right] \right\} + \\
& + \left\{ \left[(\Lambda_{21} s_- + \Lambda_{22} p_- + \Lambda_{23} u_-^*) \cos \mu_e \right] \times \right. \\
& \times \left. \frac{[\Pi_{31} (M \cos \beta - C_s/A) \cos(\alpha - \beta) - \Pi_{41} \sin(\alpha - \beta)]}{[\Pi_{21} (M \cos \beta - C_s/A) \cos \mu_e]} / \right. \\
& \left. / \left[1 + \frac{[\Pi_{31} (M \cos \beta - C_s/A) \cos(\alpha - \beta) - \Pi_{41} \sin(\alpha - \beta)]}{[\Pi_{21} (M \cos \beta - C_s/A) \cos \mu_e]} \right] \right\}
\end{aligned}$$

Note that the above equation is used for $M_e > 1$ and $C_s \geq C_{s1}$.

$$3.36 \quad \psi_y = - \left[\frac{q + (\Lambda_{21} s_- + \Lambda_{22} p_- + \Lambda_{23} u_-^*) \cos \mu_e}{\Pi_{21} (M \cos \beta - C_s/A) \cos \mu_e \sin(\alpha - \beta)} \right]$$

Note that the above equation is used for $M_e > 1$.

$$3.37 \quad \psi_y = \frac{p \Big|_{x=0} - (\Lambda_{21} s_- + \Lambda_{22} p_- + \Lambda_{23} u_-^*)}{\Pi_{21} (M \cos \beta - C_s/A) \sin(\alpha - \beta)}$$

Note that the above equation is used for $M_e < 1$.

$$\begin{aligned}
3.38 \quad \begin{bmatrix} s_+ \\ p_+ \\ U_+ \\ V_+ \end{bmatrix} &= \begin{bmatrix} \Lambda_{11} \\ \Lambda_{21} \\ \Lambda_{31} \sin(\alpha - \beta) \\ \Lambda_{31} \cos(\alpha - \beta) \end{bmatrix} s_- + \begin{bmatrix} \Lambda_{12} \\ \Lambda_{22} \\ \Lambda_{32} \sin(\alpha - \beta) \\ \Lambda_{32} \cos(\alpha - \beta) \end{bmatrix} p_- + \\
&+ \begin{bmatrix} \Lambda_{13} \\ \Lambda_{23} \\ \Lambda_{33} \sin(\alpha - \beta) \\ \Lambda_{33} \cos(\alpha - \beta) \end{bmatrix} u_+^* + \begin{bmatrix} 0 \\ 0 \\ -\Lambda_{44} \cos(\alpha - \beta) \\ \Lambda_{44} \sin(\alpha - \beta) \end{bmatrix} v_+^* + \\
&+ \begin{bmatrix} \Pi_{11} (M \cos \beta - C_s / A) \\ \Pi_{21} (M \cos \beta - C_s / A) \\ \Pi_{31} (M \cos \beta - C_s / A) \sin(\alpha - \beta) - \Pi_{41} \cos(\alpha - \beta) \\ \Pi_{31} (M \cos \beta - C_s / A) \cos(\alpha - \beta) - \Pi_{41} \sin(\alpha - \beta) \end{bmatrix} \sin(\alpha - \beta) \psi_y
\end{aligned}$$

$$3.39 \quad u_+^* = \sin(\alpha - \beta) \cdot U_+ + \cos(\alpha - \beta) \cdot V_+$$

$$3.40 \quad v_+^* = -\cos(\alpha - \beta) \cdot U_+ + \sin(\alpha - \beta) \cdot V_+$$

$$3.41 \quad u_1 = \sin \epsilon \cdot u_+^* + \cos \epsilon \cdot v_+^*$$

$$3.42 \quad v_1 = -\cos \epsilon \cdot u_+^* + \sin \epsilon \cdot v_+^*$$

$$3.43 \quad \text{vort} = \sqrt{u_1^2 + v_1^2}$$

$$3.44 \quad I_u = \langle u_+^* \rangle / M$$

$$3.45 \quad I_v = \langle v_+^* \rangle / M$$

$$3.46 \quad I_t = \langle s_+ \rangle / \left[1 + \frac{\gamma-1}{2} \cdot M^2 \right]$$

$$3.47 \quad \text{SPL} = 20 \log_{10} \left[\langle p_+ \rangle \gamma P_{ml} X / (1.45 \times 10^{-5}) \right] + 74$$

Note that in the above four equations $\langle \rangle$ implies root-mean square values, (summed over delta).

The theoretical justification for all the above equations is given in Reference 2.

4.0 OBJECT OF THE PROGRAM

Consider a turbulent fluid flow, plus a field of sound waves, passing through a shock wave. Then given certain of the upstream parameters of the flow the object of the program is to predict the downstream values of certain of these parameters. In particular it is of interest to find the individual contributions of the upstream values of entropy, pressure and vorticity to the downstream values of entropy, pressure and vorticity, and the total resulting downstream intensity or level for each of the three modes. The principal equation involved in this process is Equation (3.38). As α is a function of δ then this equation applies for only one particular value of δ . To find the total effect, the equation is numerically integrated over the range $0 \leq \delta \leq \pi/2$.

Two methods of integration are used and the results of both printed. The first method merely computes the root-mean-square values of the various parameters involved. The second method is best illustrated by example:

$$\langle p_+ \rangle = \sqrt{\left[\sum_{\delta_i} \left(\sum_j (p_{ij}^2) \cos \delta_i \right) \times \Delta \delta_i \right]}$$

where

$\langle p_+ \rangle$ is the downstream pressure

p_{ij}^2 is the downstream pressure for a particular j th modal upstream change at a particular value of δ .

$\Delta \delta_i$ is the step length in δ in radians.

Note that for the downstream pressure due to upstream entropy (say) then the summation over j will contain one value only.

In practice $\Delta \delta$ was taken as one degree but this is an input parameter and can therefore be changed. The summation for both methods was taken from:

$$\delta = \frac{\Delta \delta}{2} \quad \text{up to} \quad \delta = \left[N \Delta \delta + \frac{\Delta \delta}{2} \right]$$

where

$$\left[N \Delta \delta + \frac{\Delta \delta}{2} \right] \leq \frac{\pi}{2} \quad \text{but} \quad \left[(N+1) \Delta \delta + \frac{\Delta \delta}{2} \right] > \frac{\pi}{2}$$

The results produced by the above two methods compare very well. In fact in many cases there is agreement to three significant figures.

The author refers the reader to Reference 2 for a more detailed discussion of the methods used herein.

5.0 INPUT TO THE PROGRAM

Card	Parameter	Description	Format	Columns
1	DATE	The date of the run	A8	1-8
1	JN	The job number	I5	11-15
1	NN	The number of sets for this job	I5	16-20
1	DB	The initial value of delta-degrees (Usually Zero)	F10.0	21-30
1	DS	The step length in delta-degrees (Usually Unity)	F10.0	31-40
1	DE	The final value of delta-degrees (Usually 90)	F10.0	41-60
2	EMI	M_1 the upstream flow Mach number	F10.0	1-10
2	EPI	The shock wave angle - degrees	F10.0	11-20
2	BETA	The angle between shock wave and the downstream near flow velocity vector - degrees	F10.0	21-30
2	A1	Speed of sound in the flow field upstream of the shock, ft/sec	F10.0	31-40
2	EYEU1	The upstream turbulence intensity along x_1 -axis, r.m.s. velocity fluctuation referenced to the upstream mean velocity	F10.0	41-50
2	EYEV1	The upstream turbulence intensity along y_1 -axis, r.m.s. velocity fluctuation referenced to the upstream mean velocity	F10.0	51-60
2	SPL1	The overall upstream sound pressure level, dB re: 0.0002 dyne/cm ²	F10.0	61-70
2	EYET1	The upstream entropy fluctuation intensity, r.m.s. fluctuation in static temperature, referenced to the local total temperature, °R	F10.0	71-80

Card	Parameter	Description	Format	Columns
3	GAMMA	Ratio of specific heats of fluid	F10.0	1-10
3	PM1	The ambient static upstream pressure, psi	F10.0	11-20

Repeat cards two and three NN times in all, then input another card type one. To end run NN should be less than unity.

6.0 OUTPUT FROM THE PROGRAM

The output from the program is well annotated. The results for method 1 described in Section 4.0 are given at the top of the second page of output for each set. The results from method 2 described in Section 4.0 are given at the bottom of the second page of output for each set and are referred to as the "alternative method of integration."

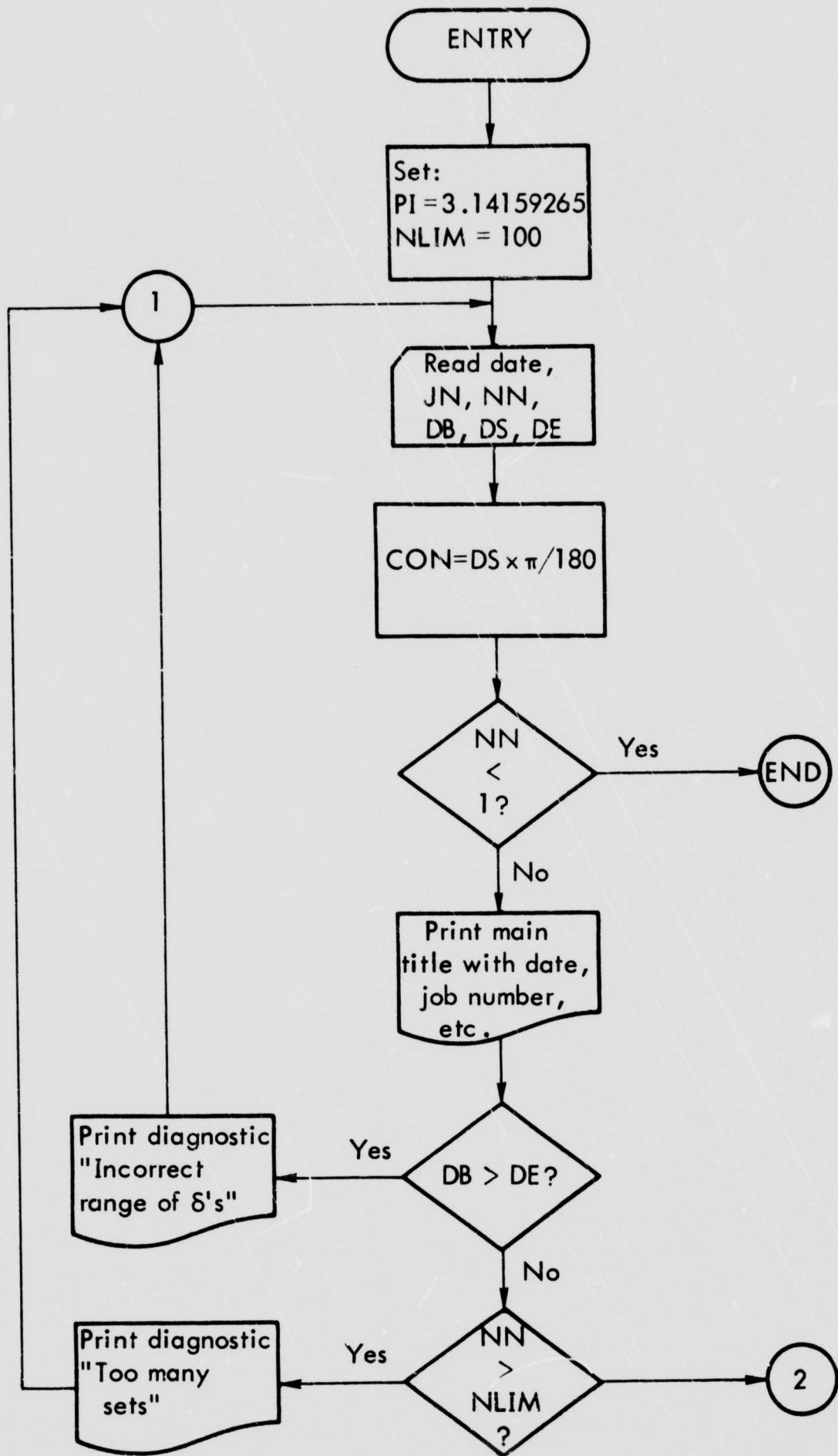
ACKNOWLEDGEMENTS

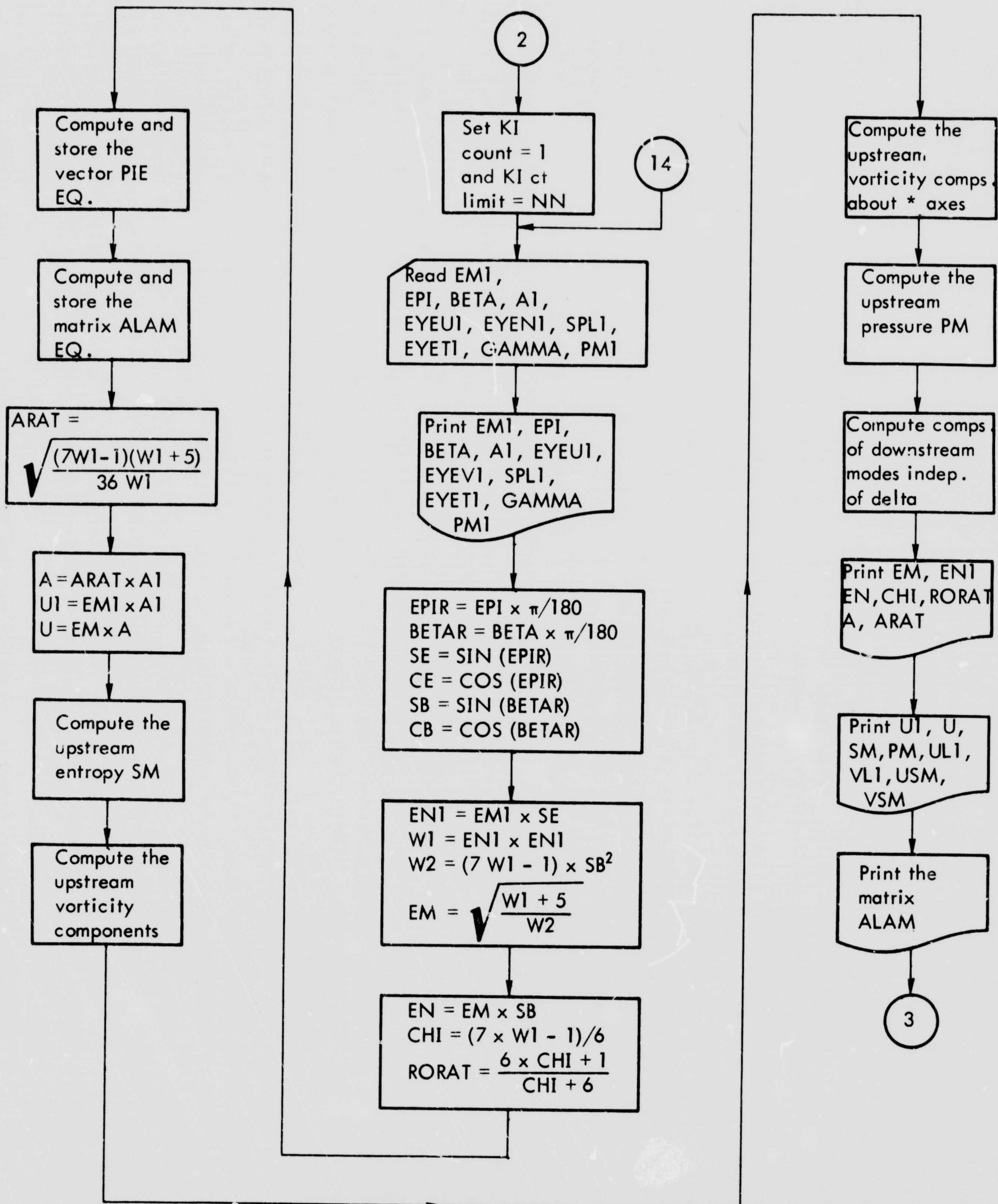
The author wishes to thank Mrs. Elizabeth Cuadra of Wyle Laboratories for assembling the equations for the model used herein and for her guidance and critique throughout this project. Thanks are also offered to Mr. Jack Robertson, Dr. Sam Radcliffe and Dr. Paul Pao for their help and comments during the early stages of the project.

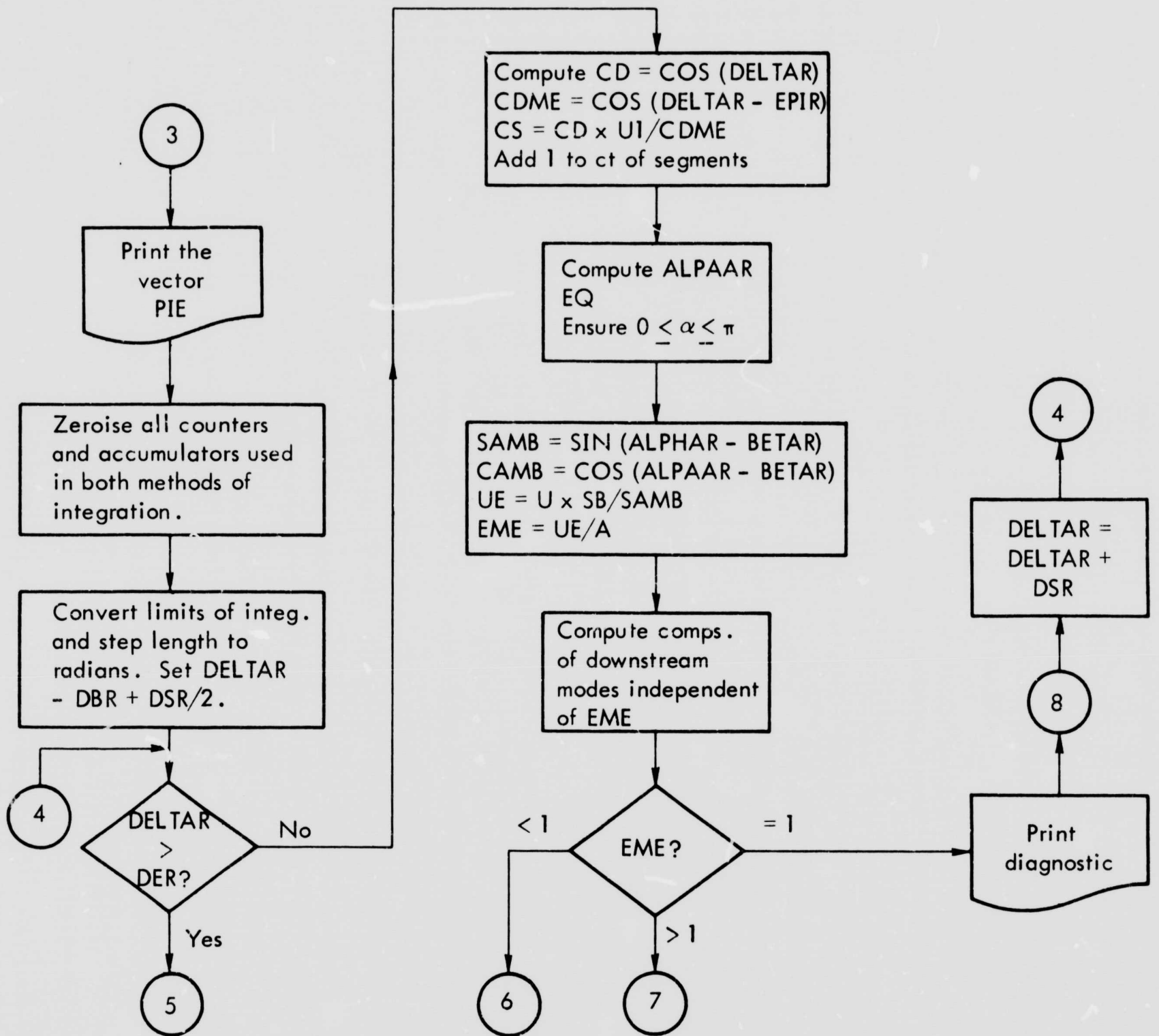
REFERENCES

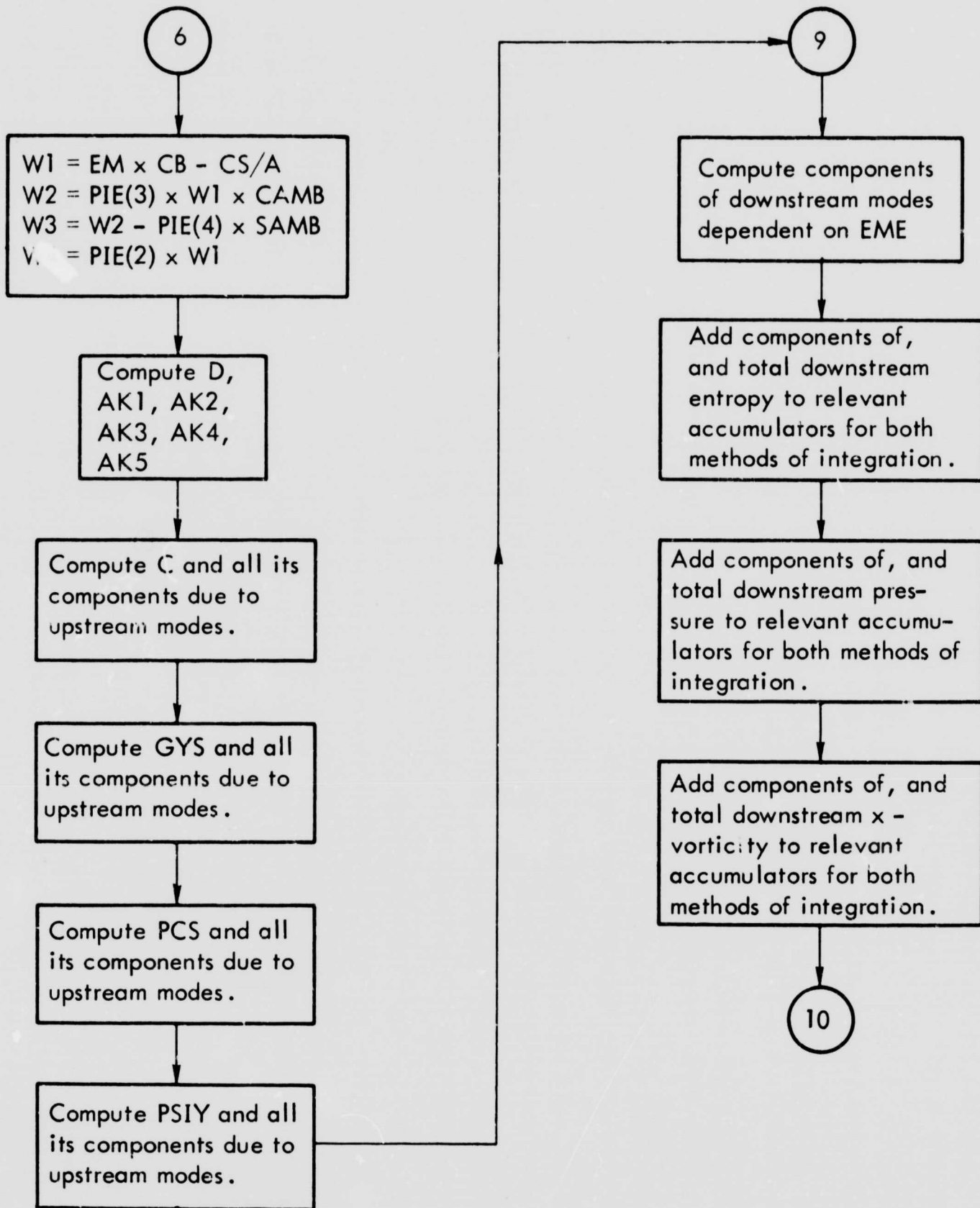
1. Cuadra, Elizabeth, "Flow Perturbations Generated by a Shock Wave Interacting with an Entropy Wave," Proceedings of the AFOSR-UTIAS Symposium on Aerodynamic Noise, Toronto, May 1968. (Same as Wyle Laboratories Research Staff Report WR 67-17, "Interactions of a Shock Wave with an Entropy Discontinuity," February 1968).
2. Cuadra, Elizabeth, "Flow Perturbation Intensities and Noise Levels Downstream of a Shock Wave Interacting with a Random Upstream Field Containing Turbulence, Entropy Fluctuations, and Sound Waves," Wyle Laboratories Research Staff Report WR 69-5, March 1969.

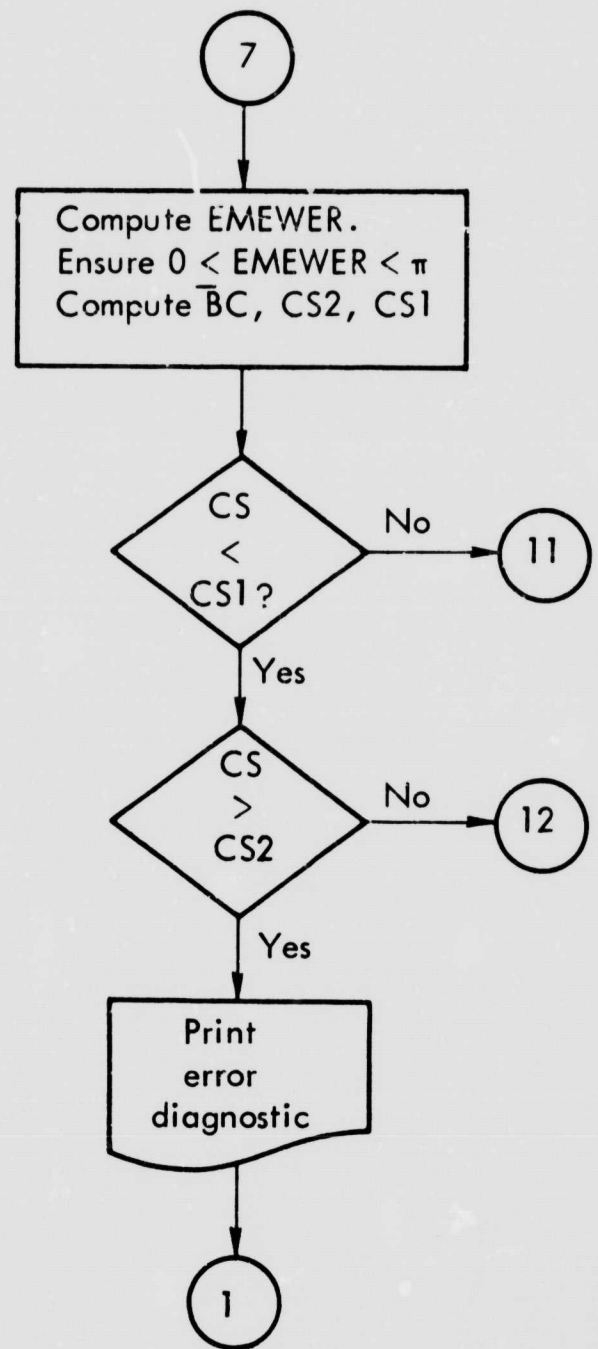
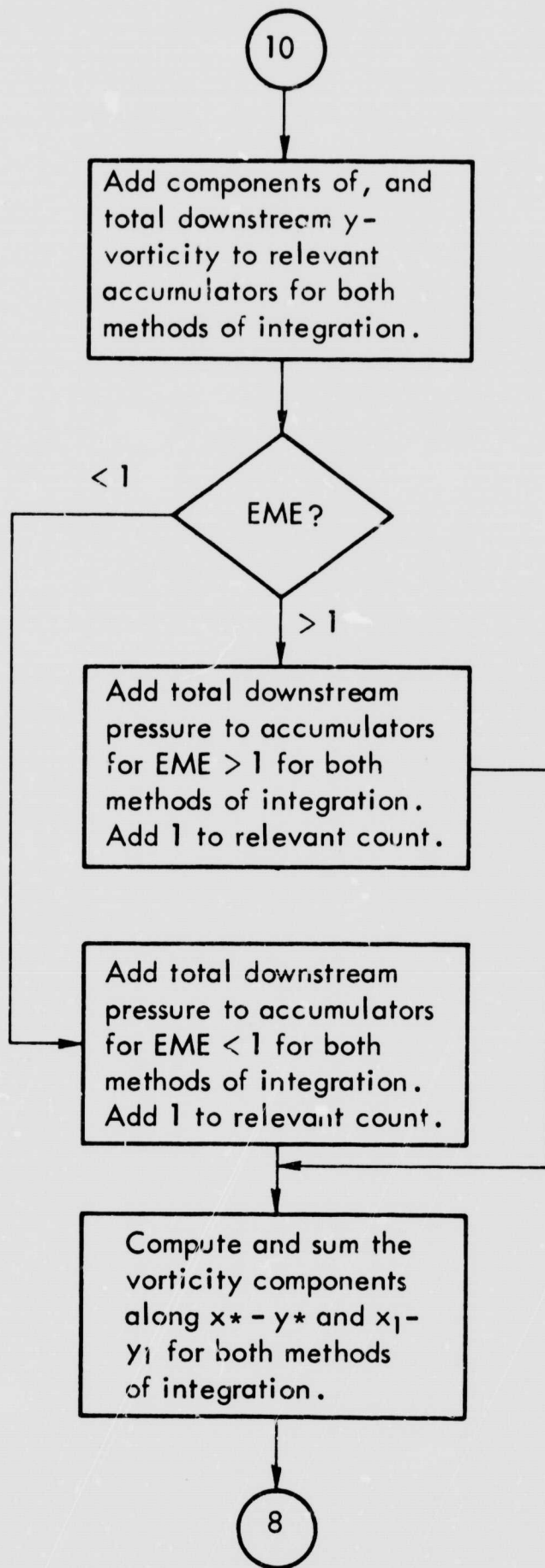
APPENDIX A
Flow Diagrams
of
Program DIONE

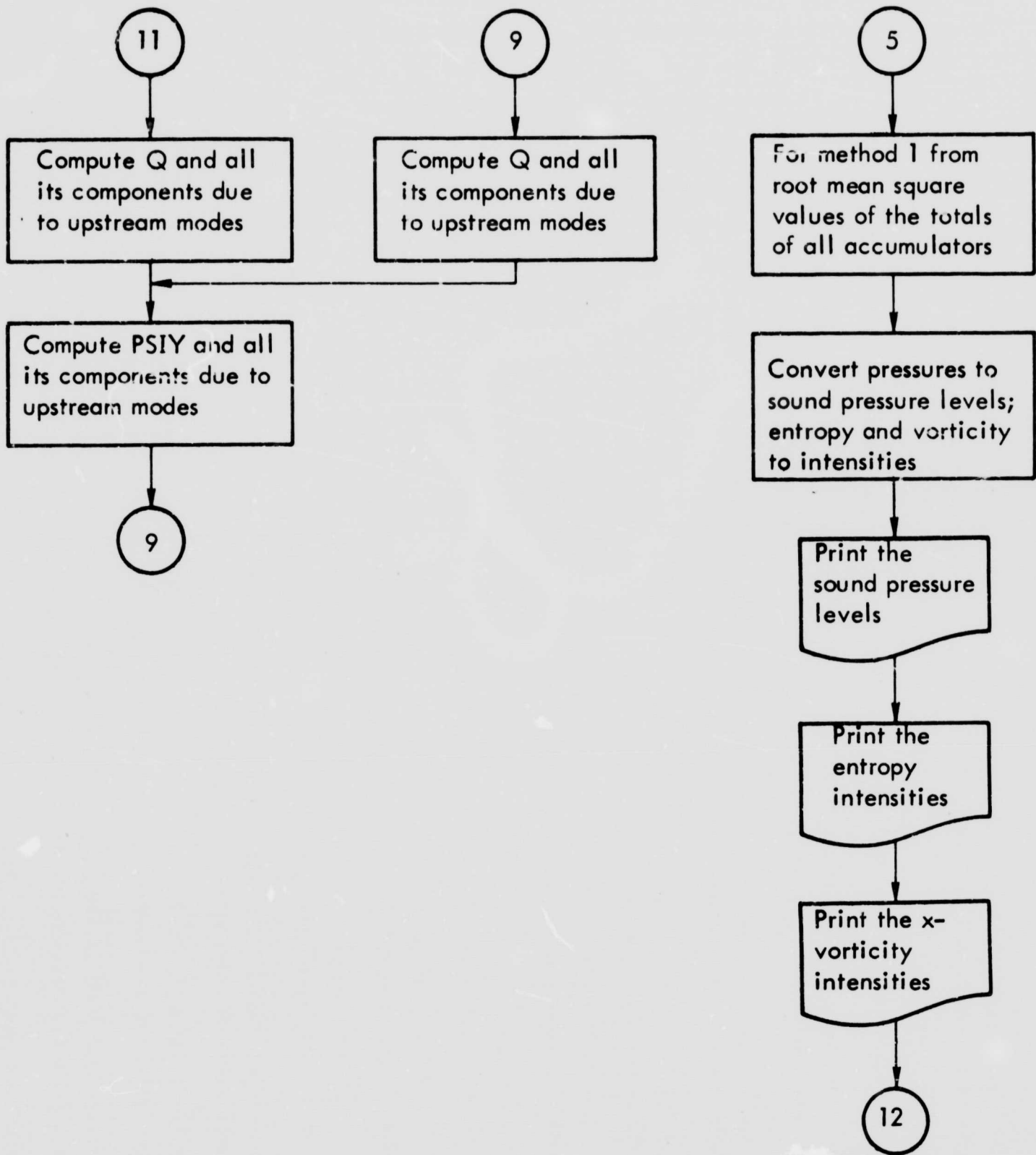


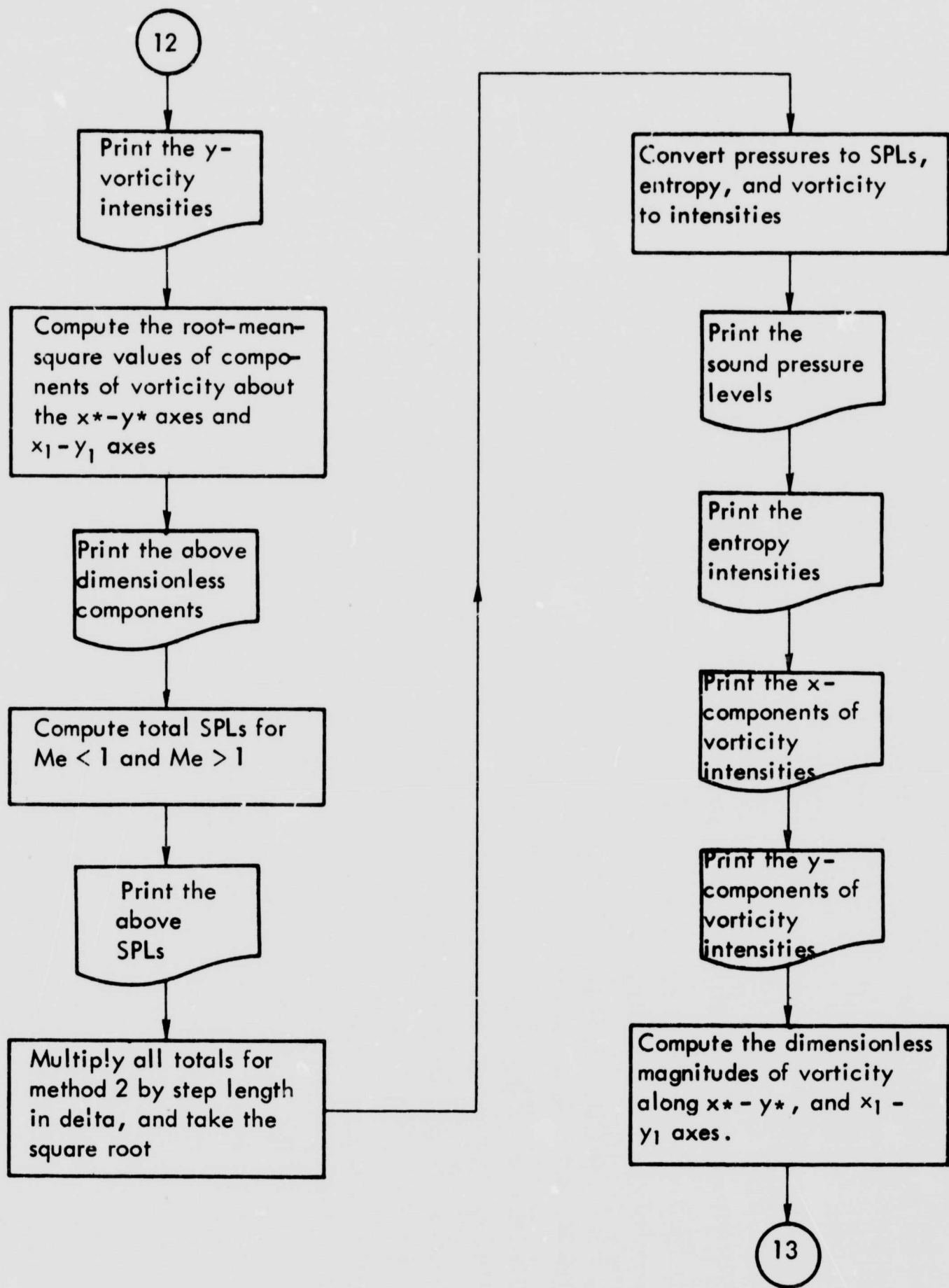


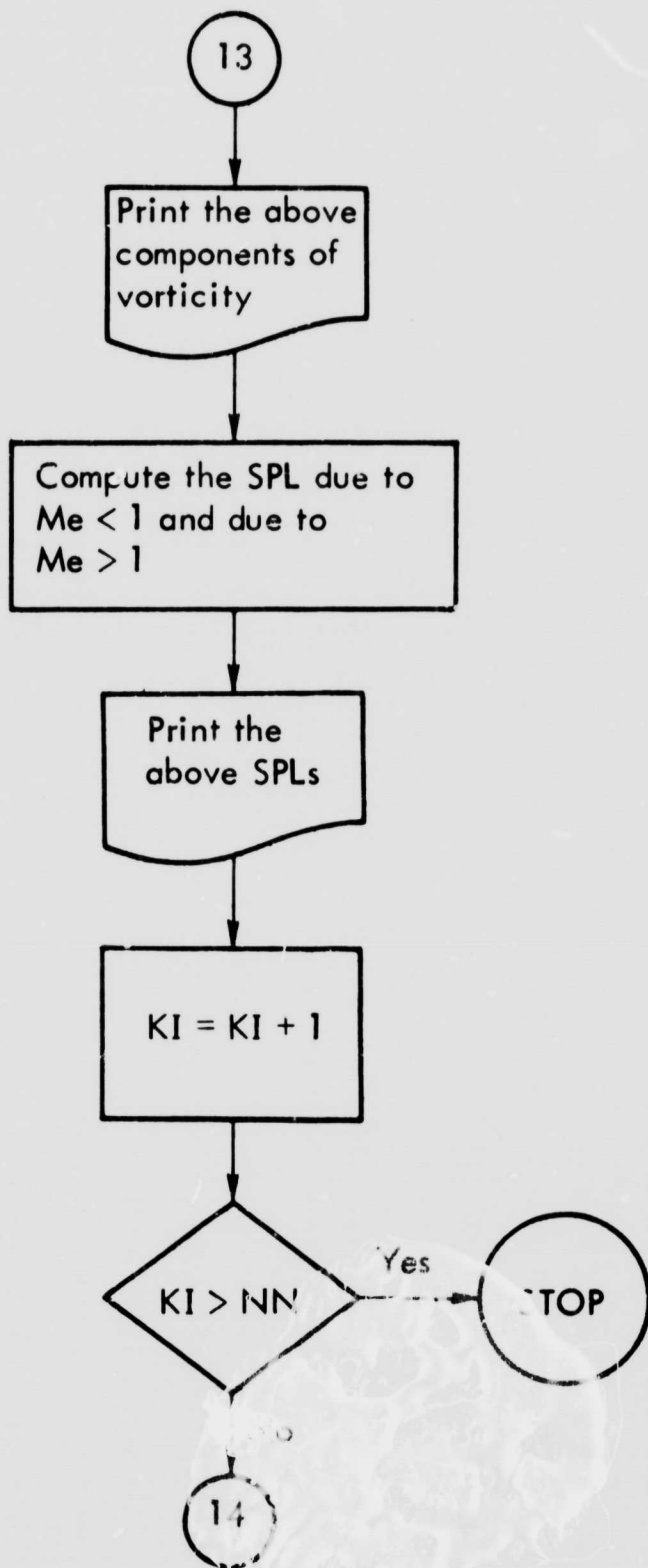












APPENDIX B
Fortran Listing
of
Program DIONE

27687

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FOURTRAN (3,0)/MASTER

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PROGRAM DIONE
COMMON ALAM(4,4),PIE(4)
COMMON/DATA/PI
DATA (PI=3.14159265)
NLM=100
9995 WRITE(61,19)
2 READ(60,2)DATE,J,NM,UB,US,DE
  FORMAT(A8,2A,2I5,3F10.0)
  CON=CS*PI/180.0
  IF(NM.LT.1)9999,999
998 WRITE(61,3)DATE,JN,NN,DB,US,DE
3  FORMAT(10X,A8,37X,26HSHOCK
      INTERACTION,,37A,10HRUN NUMBER
      1,14/10X,8(1H-),37X,26(1H-),37X,14(1H-)//10X,22HNUMBER OF SETS OF
      2DATA,70X,2H ,15/10X,22HINITIAL VALUE OF DELTA,70X,2H ,E12.4,2X,6
      3-DEGREES./10X,20HSTEP LENGTH IN DELTA,72X,2H ,E12.4,2X,8HDEGREES.
      4/10X,20HFINAL VALUE OF DELTA,72X,2H ,E12.4,2X,8HDEGREES.)
      IF(UB.GT.DE)4,6
4  WRITE(61,5)
5  FORMAT(//10X,19HLOOK AT THE DELTAS./10X,11HEND OF RUN.)
  GO TO 9999
6  IF(NM.GT.NLI)7,9
7  WRITE(61,8)
8  FORMAT(10X,20HNM IS TOO MUCH BARY,//10X,11HEND OF RUN.)
  GO TO 9999
9  DO 921 KI=1,NM
10 READ(60,10)EM1,EPI,BETA,A1,EYEU1,EYEV1,SPL1,EYET1,GAMMA,PM1
  FORMAT(DF10.0)
11 WRITE(61,11)EM1,EPI,BETA,A1,EYEU1,EYEV1,SPL1,EYET1,GAMMA,PM1
  12  FORMAT(10X,33HEM1 THE UPSTREAM FLOW MACH NUMBER,59X,2H ,E12.4/10
      13  2H ,E12.4/10X,82HETA THE ANGLE BETWEEN THE SHOCK WAVE AND THE DOWN
      14  4STREAM MEAN FLOW VELOCITY VECTOR,10X,2H ,E12.4/10X,61HAI THE SPEE
      15  4F OF SOUND IN THE FLOW FIELD UPSTREAM OF THE SHOCK,31X,2H ,E12.4/
      16  510X,55HIU1 THE UPSTREAM TURBULENCE INTENSITY ALONG THE X1 AXIS,37X
      17  6,2H ,E12.4/10X,33X,2H ,E12.4/10X,37HSPL1 THE OVERALL UPSTREAM SOUND
      18  7 THE X1 AXIS,33X,2H ,E12.4/10X,40HI1 THE UPSTREAM ENTROPY FLUCTUATION
      19  8 FIELD,55X,2H ,E12.4/10X,33HGAMMA THE RATIO OF SPECIFIC HEATS,
      20  9 INTENSITY,40X,2H ,E12.4/10X,33HGAMMA THE RATIO OF SPECIFIC HEATS,
      21  A59X,2H ,E12.4/10X,40HPM1 THE AMBIENT STATIC UPSTREAM PRESSURE,52X
      22  B,2H ,E12.4/10X,40HPM1 THE AMBIENT STATIC UPSTREAM PRESSURE,52X
      23  EPIR=EPI*PI/180.0
      24  BETAR=BETA*PI/180.0
      25  SE=SIGN(EPIR)
      26  CE=CCSF(EPIR)
      27  SB=SIGN(BETAR)
      28  CB=CCSF(BETAR)
      29  EM1=EM1*SE
      30  A1=EM1*ENI
      31  M2=(A1*7.0-1.0)*SB*SR
      32  EN=SQRT((M1+5.0)/M2)
      33  EN=EM*SB
      34  CHI=(M1*7.0-1.0)/6.0
      35  RORAT=(CHI*6.0+1.0)/(CHI*6.0)
      36  FC 12 I=1,4

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12  PIE(I)=0,0
    TO 12 J=1,4
    ALAM(I,J)=0,0
    CONTINUE
    ALAM(1,1)=(HORAT*RORAT/EN1/EN1-(GAMMA-1,0)*(1,0-RORAT))*EN*EN
    ALAM(2,1)=EN*EN/(1,0-EN*EN)*(1,0-RORAT)*(1,0+(GAMMA-1,0)*EN*EN)+(
11  1,0-RORAT*RORAT*EN*EN/EN1/EN1)
    ALAM(3,1)=EN/(1,0-EN*EN)*(1,0-RORAT*RORAT*EN*EN/FM1/EN1)+(1,0-ROR
1RAT)*GAMMA*EN*EN)
    ALAM(1,2)=(GAMMA-1,0)*(1,0-RORAT)*(1,0-RORAT/EN1/EN1)*EN*EN
    ALAM(2,2)=EN*EN/(1,0-EN*EN)*(1,0-RORAT)*(1,0-RORAT/EN1/EN1)*(1,0
1+(GAMMA-1,0)*(1,0-RORAT)*EN*EN)
    ALAM(3,2)=EN/(1,0-EN*EN)*(1,0-RORAT*RORAT*EN*EN/EN1/EN1)+GAMMA*(1
1,0-RORAT)*(1,0-RORAT/EN1/EN1)*EN*EN
    ALAM(1,3)=(GAMMA-1,0)*(1,0-RORAT)*(1,0-RORAT)*EN*EN/EN1
    ALAM(2,3)=EN/(1,0-EN*EN)*(1,0-RORAT)*(2,0+(GAMMA-1,0)*(1,0-RORAT)
1*EN*EN)*EN/EN1
    ALAM(3,3)=1,0/(1,0-EN*EN)*EN/EN1*(1,0-RORAT*RORAT*EN*EN+GAMMA*(1,0
1-RORAT)*(1,0-RORAT)*EN*EN)
    ALAM(4,4)=RORAT*EN/EN1
    PIE(1)=(GAMMA-1,0)*(1,0-1,0/RORAT)*(1,0-1,0/RORAT)*RORAT*EN
    PIE(2)=EN/(1,0-EN*EN)*(1,0-1,0/RORAT)*(2,0+(GAMMA-1,0)*(1,0-RORAT
1)*EN*EN)
    PIE(3)=1,0/(1,0-EN*EN)*(1,0-1,0/RORAT)*(1,0-EN*EN*(GAMMA-1,0)*(1,0
1-RORAT)*EN*EN)
    RORCAT*(EN*EN)
    PIE(4)=(RORAT-1,0)*EN
    AHAT=SQRT((W1*7,0-1,0)*(W1+5,0)/W1/36,0)
    A=AHAT*AI
    U1=EM1*AI
    U=EM*A
    SM=EYET1*(1,0+(GAMMA-1,0)/2,0*EM1*EM1)
    LL1=EYEU1*EM1
    VL1=EYEV1*EM1
    LSM=LL1*SE-VL1*SE
    VSM=VL1*CE-VL1*SE
    FM=1,0/GAMMA/PH1*1,45E-5*10,0*((SPL1-74,0)/20,0)
    SPDTSM1=ALAM(1,1)*SM
    PPDTSM1=ALAM(2,1)*SM
    SPDTPM1=ALAM(1,2)*PM
    PPDTPM1=ALAM(2,2)*PM
    SPDTLM1=ALAM(1,3)*USH
    PPDTLM1=ALAM(2,3)*USH
    WRITE(61,13)EM,EN1,EN,CHI,RORAT,A,AHAT
13  FORMAT (10X,33H THE DOWNSTREAM FLOW MACH NUMBER,59X,2H ,E12,4/10
    1X,62H THE UPSTREAM MACH NUMBER CORRESPONDING TO A NORMAL SHOCK 0
    2F EQUIVALENT STRENGTH,10X,2H ,E12,4/10X,83H THE DOWNSTREAM MACH
    3NUMBER CORRESPONDING TO A NORMAL SHOCK OF EQUIVALENT STRENGTH,9X,2
    4H ,E12,4/10X,85HCHI SHOCK STRENGTH IN TERMS OF RATIO OF PRESSURE
    5CF UNPERTURBED FLOW ACROSS THE SHOCK,7X,2H ,E12,4/10X,64HORAT TM
    6E DENSITY RATIO ACROSS THE SHOCK, DOWNSTREAM TO UPSTREAM,28X,2H ,
    7E12,4/10X,60H THE SPEED OF SOUND IN THE FLOW FIELD DOWNSTREAM OF
    8 SHOCK,32X,2H ,E12,4/10X,78HARAT THE RATIO OF ACOUSTIC VELOCITIE
    9S ACROSS THE SHOCK, DOWNSTREAM TO UPSTREAM,14X,2H ,E12,4)
    WRITE(61,14)U1,U,SM,PM,U,VL1,USH,VSM

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14  FORMAT (10X,47H)1 THE MEAN FLOW VELOCITY UPSTREAM OF THE SHOCK,45X
    1,2H= ,E12,4/10X,48H) THE MEAN FLOW VELOCITY DOWNSTREAM OF THE SHOC
    2K,44X,2H= ,E12,4/10X,66H) THE DIMENSIONLESS MAGNITUDE OF THE UPST
    3REAM ENTRUPTU PERTUBATION,26X,2H= ,E12,4/10X,67H) THE DIMENSIONLES
    4S MAGNITUDE OF THE UPSTREAM PRESSURE PERTUBATION,25X,2H= ,E12,4/10
    5X,84H)1 THE DIMENSIONLESS MAGNITUDE OF THE DOWNSTREAM VELOCITY PE
    6RTUBATION ALONG X1 AXIS,8X,2H= ,E12,4/10X,84H)1 THE DIMENSIONLESS
    7 MAGNITUDE OF THE DOWNSTREAM VELOCITY PERTUBATION ALONG Y1 AXIS,8X
    8,2H= ,E12,4/10X,82H) THE DIMENSIONLESS MAGNITUDE OF THE UPSTREAM
    9 VELOCITY PERTUBATION ALONG X= AXIS,10X,2H= ,E12,4/10X,82H) THE
    ADIMENSIONLESS MAGNITUDE OF THE UPSTREAM VELOCITY PERTUBATION ALONG
    B Y= AXIS,10X,2H= ,E12,4/10X,2H= ,E12,4/10X,2H= ,E12,4/10X,2H=
    WRITE(61,15)
15  FORMAT (10X,62H)MATRIX LAMBDA(I,J) TRANSFER COEFFICIENTS FOR THE I
    INTERACTION, /10X,62(1H=) //
    DO 16 I=1,4
16  WRITE(61,17)(ALAM(I,J),J=1,4)
    CONTINUE
17  FORMAT (10X,4(E12,4,5X))
    WRITE(61,18)
18  FORMAT (//10X,59H)VECTOR OF PI(I) TRANSFER COEFFICIENTS OF THE IN
    TERACTION, /10X,59(1H=) //
19  WRITE(61,17)(PI(I),I=1,4)
    FORMAT(1H)
    SUSP=SVSP=SUL1=SVL1=SVORT=0,0
    SSP=SSP1=SSP2=SSP3=SSP4=0,0
    SPP=SPP1=SPP2=SPP3=SPP4=0,0
    SUP=SUP1=SUP2=SUP3=SUP4=0,0
    SVP=SVP1=SVP2=SVP3=SVP4=0,0
    SSP1A=SSP2A=SSP3A=SSP4A=0,0
    SPP1A=SPP2A=SPP3A=SPP4A=0,0
    SUP1A=SUP2A=SUP3A=SUP4A=0,0
    SVP1A=SVP2A=SVP3A=SVP4A=0,0
    SUSPA=SVSPA=SUL1A=SVL1A=SVORTA=0,0
    ACP=NCM=0
    SPPF=SPPM=0,0
    SPPA=SPPMA=0,0
    ACOUNT=0
    CBR=C8*PI/180,0
    CSR=CS*PI/180,0
    CER=CE*PI/180,0
    DELTAR=DR+USR*0.5
20  IF(DELTA,GT,DEK)21,22
21  WRITE(61,19)
    AN=FLOAT(NCOUNT)
    SPP=SQRT(SPP/AN)
    SPP1=SQRT(SPP1/AN)
    SPP2=SQRT(SPP2/AN)
    SPP3=SQRT((SPP4+SPP3)/AN)
    SSP=SQRT(SSP/AN)
    SSP1=SQRT(SSP1/AN)
    SSP2=SQRT(SSP2/AN)
    SSP3=SQRT((SSP3+SSP4)/AN)
    SUP=SQRT(SUP/AN)

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FORTRAN (3,0)/MASTER

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SUP1=SQRT(SUP1/AN)
SUP2=SQRT(SUP2/AN)
SUP3=SQRT((SUP3+SUP4)/AN)
SVP=SQRT(SVP/AN)
SVP1=SQRT(SVP1/AN)
SVP2=SQRT(SVP2/AN)
SVP3=SQRT((SVP3+SVP4)/AN)
SPL1T=74,0+20,0*ALOG10(SPP*GAMMA+PM1*CHI/1,45E-5)
SPL1S=74,0+20,0*ALOG10(SPP1*GAMMA+PM1*CHI/1,45E-5)
SPL1P=74,0+20,0*ALOG10(SPP2*GAMMA+PM1*CHI/1,45E-5)
SPL1U=74,0+20,0*ALOG10(SPP5*GAMMA+PM1*CHI/1,45E-5)
TIT=SSP/(1,0+(GAMMA-1,0)/2,0*EM*EM)
SIT=SSP1/(1,0+(GAMMA-1,0)/2,0*EM*EM)
PIT=SSP2/(1,0+(GAMMA-1,0)/2,0*EM*EM)
LIT=SSP5/(1,0+(GAMMA-1,0)/2,0*EM*EM)
TIU1=SUP/EM
SIU1=SUP1/EM
PIU1=SUP2/EM
LIU1=SUP5/EM
TIV1=SVI/EM
SIV1=SVI1/EM
PIV1=SVI2/EM
LIV1=SVI5/EM
WRITE(61,100)SPL1T,SPL1S,SPL1P,SPL1U
100  FORMAT (5X,41H THE TOTAL DOWNSTREAM SOUND PRESSURE LEVEL,56X,2H= ,E12,
112,4/5X,73H THE DOWNSTREAM SOUND PRESSURE LEVEL DUE TO UPSTREAM ENT
2ROPY PERTURBATIONS,24X,2H= ,E12,4/5X,74H THE DOWNSTREAM SOUND PRESS
3URE LEVEL DUE TO UPSTREAM PRESSURE PERTURBATIONS,23X,2H= ,E12,4/5X
4,75H THE DOWNSTREAM SOUND PRESSURE LEVEL DUE TO UPSTREAM VELOCITY
5PERTURBATIONS,22X,2H= ,E12,4/)
WRITE(61,101)TIT,SIT,PIT,UIT
101  FORMAT (5,36H THE TOTAL DOWNSTREAM ENTROPY INTENSITY,59X,2H= ,E12,
14/5X,70H THE DOWNSTREAM ENTROPY INTENSITY DUE TO UPSTREAM ENTROPY P
2ERTURBATIONS,27X,2H= ,E12,4/5X,71H THE DOWNSTREAM ENTROPY INTENSITY
3 DUE TO UPSTREAM PRESSURE PERTURBATIONS,26X,2H= ,E12,4/5X,72H THE D
4OWNSTREAM ENTROPY INTENSITY DUE TO UPSTREAM VELOCITY PERTURBATION
5S,25X,2H= ,E12,4/)
WRITE(61,102)TIU1,SIU1,PIU1,LIU1
102  FORMAT (5X,53H THE TOTAL DOWNSTREAM VORTICITY COMPONENT ALONG X-AXI
1S,44X,2H= ,E12,4/5X,85H THE DOWNSTREAM VORTICITY COMPONENT ALONG X
2-AXIS DUE TO UPSTREAM ENTROPY PERTURBATIONS,12X,2H= ,E12,4/5X,90HT
3HE DOWNSTREAM VORTICITY COMPONENT ALONG THE X-AXIS DUE TO UPSTREAM
4 PRESSURE PERTURBATIONS,7X,2H= ,E12,4/5X,81H THE DOWNSTREAM VORTICI
5TY ALONG THE X-AXIS DUE TO UPSTREAM VELOCITY PERTURBATIONS,16X,2H
6= ,E12,4/)
WRITE(61,103)TIV1,SIV1,PIV1,LIV1
103  FORMAT (5X,57H THE TOTAL DOWNSTREAM VORTICITY COMPONENT ALONG THE Y
1-AXIS,40X,2H= ,E12,4/5X,89H THE DOWNSTREAM VORTICITY COMPONENT ALON
26 THE Y-AXIS DUE TO UPSTREAM ENTROPY PERTURBATIONS,8X,2H= ,E12,4/5
3X,90H THE DOWNSTREAM VORTICITY COMPONENT ALONG THE Y-AXIS DUE TO UP
4STREAM PRESSURE PERTURBATIONS,7X,2H= ,E12,4/5X,91H THE DOWNSTREAM V
5ORTICITY COMPONENT ALONG THE Y-AXIS DUE TO UPSTREAM VELOCITY PERT
6URBATIONS,6X,2H= ,E12,4/)
SUSP=SQRT(SUSP/AN)

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FORTRAN (3,0)/MASTER

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SVSP=SQRT(SVSP/AN)
SUL1=SQRT(SUL1/AN)
SVL1=SQRT(SVL1/AN)
SVORT=SQRT(SVORT/AN)
WRITE(61,200)SVSP,SVSP,SUL1,SVL1,SVORT
200  FORMAT (5X,B3HDIMENSIONLESS MAGNITUDE OF DOWNSTREAM VELOCITY PERTUR-
      BATION COMPONENT ALONG X=AXIS,14X,2H= ,E12,4/5X,B3HDIMENSIONLESS
      2 MAGNITUDE OF DOWNSTREAM VELOCITY PERTURBATION COMPONENT ALONG Y=
      3AXIS,14X,2H= ,E12,4/5X,B3HDIMENSIONLESS MAGNITUDE OF DOWNSTREAM VE-
      4LOCITY PERTURBATION COMPONENT ALONG X1-AXIS,14X,2H= ,E12,4/5X,B3HD
      5IMENSIONLESS MAGNITUDE OF DOWNSTREAM VELOCITY PERTURBATION COMPONE
      6NT ALONG Y1-AXIS,14X,2H= ,E12,4/5X,41HDOWNSTREAM VORTICITY BASED O
      7A UL1 AND VL1,50X,2H= ,E12,4/)
      AN=FLOAT(NCP)
      AM=FLOAT(NCM)
      SPPP=SQRT(SPPP/ANP)
      SPPM=SQRT(SPPM/ANM)
      SPLP=74,0+20,0+ALOG10((SPPP+GAMMA+PM1+CHI/1,45E-5)
      SPLM=74,0+20,0+ALOG10((SPPM+GAMMA+PM1+CHI/1,45E-5)
      WRITE(61,403)SPLP,SPLM
403  FORMAT (5X,44HDOWNSTREAM SOUND PRESSURE LEVEL FOR ME GT, 1,53X,2H=
      1 ,E12,4/5X,44HDOWNSTREAM SOUND PRESSURE LEVEL FOR ME LT, 1,53X,2H=
      2 ,E12,4/)
      WRITE(61,201)
201  FORMAT(10I,107HNOTE THAT THE FOLLOWING RESULTS HAVE BEEN COMPUTED
      16Y USING AN ALTERNATIVE METHOD OF NUMERICAL INTEGRATION,/)
      SSP1A=SSP1A*CON
      SSP2A=SSP2A*CON
      SSP3A=SSP3A*CON
      SSP4A=SSP4A*CON
      SSPA=SSP1A+SSP2A+SSP3A+SSP4A
      SPP1A=SPP1A*CON
      SPP2A=SPP2A*CON
      SPP3A=SPP3A*CON
      SPP4A=SPP4A*CON
      SPPA=SPP1A+SPP2A+SPP3A+SPP4A
      SUP1A=SUP1A*CON
      SUP2A=SUP2A*CON
      SUP3A=SUP3A*CON
      SUP4A=SUP4A*CON
      SUPA=SUP1A+SUP2A+SUP3A+SUP4A
      SVP1A=SVP1A*CON
      SVP2A=SVP2A*CON
      SVP3A=SVP3A*CON
      SVP4A=SVP4A*CON
      SVPA=SVPA1A+SVP2A+SVP3A+SVP4A
      SPPA=SQRT(SPPA)
      SPP1A=SQRT(SPP1A)
      SPP2A=SQRT(SPP2A)
      SPP5A=SQRT (SPP4A+SPP3A)
      SSPA=SQRT (SSPA)
      SSP1A=SQRT(SSP1A)
      SSP2A=SQRT(SSP2A)
      SSP5A=SQRT (SSP4A+SSP3A)

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```
SUPA=SQRT(SUPA)
SUP1A=SQRT(SUP1A)
SUP2A=SQRT(SUP2A)
SUP3A=SQRT(SUP3A+SUP3A)
SVPA=SQRT(SVPA)
SV1A=SQRT(SV1A)
SV2A=SQRT(SV2A)
SV3A=SQRT(SV3A+SVP3A)
SPL1A=74.0+20.0*ALOG10(SPPA*GAMMA*PHI*CHI/1.45E-5)
SPL1SA=74.0+20.0*ALOG10(SPP1A*GAMMA*PHI*CHI/1.45E-5)
SPL1FA=74.0+20.0*ALOG10(SPP2A*GAMMA*PHI*CHI/1.45E-5)
SPL1LA=74.0+20.0*ALOG10(SPP5A*GAMMA*PHI*CHI/1.45E-5)
TITA=SSPA/(1.0+(GAMMA-1.0)/2.0*EM*EM)
SITA=SSP1A/(1.0+(GAMMA-1.0)/2.0*EM*EM)
PITA=SSP2A/(1.0+(GAMMA-1.0)/2.0*EM*EM)
LITA=SSP5A/(1.0+(GAMMA-1.0)/2.0*EM*EM)
TIUA=SUPA/EM
SIUA=SUP1A/EM
FIUA=SUP2A/EM
LIUA=SUP5A/EM
TIVA=SVPA/EM
SIVA=SV1A/EM
FIVA=SV2A/EM
LIVA=SV3A/EM
WRITE(61,100) SPL1A,SPL1SA,SPL1FA,SPL1LA
WRITE(61,101) TITA,SITA,PITA,UITA
WRITE(61,102) TIUA,SIUA,PIUA,LIUA
WRITE(61,103) TIVA,SIVA,PIVIA,LIVIA
SUSPA=SQRT(SUSPA*CON)
SVSPA=SQRT(SVSPA*CON)
SUL1A=SQRT(SUL1A*CON)
SVL1A=SQRT(SVL1A*CON)
SVORTA=SQRT(SVORTA*CON)
WRITE(61,200) SUSPA,SVSPA,SUL1A,SVL1A,SVORTA
SPPPA=SQRT(SPPPA*CON)
SPPMA=SQRT(SPPMA*CON)
SPLMA=74.0+20.0*ALOG10(SPPPA*GAMMA*PHI*CHI/1.45E-5)
SPLMA=74.0+20.0*ALOG10(SPPMA*GAMMA*PHI*CHI/1.45E-5)
WRITE(61,403) SPLPA,SPLMA
921 CONTINUE
GO TO 9999
22 CU=CCSF(DELTA)
CDME=COSF(DELTA-EPIR)
CS=CC*U1/CDME
NCOUNT=NCOUNT+1
ALPHAR=ATAN(CS*SB/(CS*CB*U))
IF(ALPHAR)23,24,24
23 ALPHAR=ALPHAR+PI
24 ALPHAR=ALPHAR+180.0/PI
SAMB=SINF(ALPHAR-BETAR)
CAMB=COSF(ALPHAR-BETAR)
LE=U*SB/SAMB
EMEBLE/A
LPNTSM2=ALAM(J,1)*SAMB*SM
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FORTRAN (3,0)/MASTER

VPDTM2=ALAM(3,1)*CAMB*SM
 LPDTPM2=ALAM(3,2)*SAMB*PM
 VPDTM2=ALAM(3,2)*CAMB*PH
 LPDTLM2=ALAM(3,3)*SAMB*USH
 VPDTLM2=ALAM(3,3)*CAMB*USH
 LPDTVM2=ALAM(4,4)*CAMB*VSM
 VPDTVM2=ALAM(4,4)*SAMB*VSM
 IF(EME=1,0)J3,30,35

30 WHITE(61,31)
 31 FORMAT (10X,41HME = 1,0 WILL IGNORE THIS AND CONTINUE.)
 32 DELTAR=DELTAR+DSR

33 GO TO 20
 K1=CB*CS/A
 K2=PIE(3)*K1*CAMB
 K3=K2*PIE(4)*SAMB
 K4=PIE(2)*K1
 AK1=K3/W4
 C=0.5*FME*AK1/SURT(1,0-EME*EME)
 AK2=ALAM(3,1)*CAMB*ALAM(2,1)*AK1
 AK3=ALAM(3,2)*CAME*ALAM(2,2)*AK1
 AK4=ALAM(3,3)*CAMB*ALAM(2,3)*AK1
 AK5=ALAM(4,4)*SAMB

CS=AK2*SN
 CPM=AK3*PM
 CUM=AK4*US
 CV=AK5*VSN
 C=SP*CPM+CU+CVM
 W=0/(1.-C*0.01)
 GYSS=AW7-JSN
 GYSP=AW7*CPM
 GYSU=AW7*CUH
 GYSV=AW7*CYM
 GYS=7*C

W=0.5*EME/SQRT(1,0-EME*EME)
 FCSS=WH8*GYSSM
 PCSPR=WH8*GYSPH
 PCSU=WH8*GYSUM
 FCSV=WH8*GYSVH
 FCS=8*GYS

LEN=4*SAMB
 FSIYS=(PCSS*ALAM(2,1)*SM)/DEN
 FSIYP=(PCSPH*ALAM(2,2)*PH)/DEN
 FSIYL=(PCSUM*ALAM(2,3)*USM)/DEN
 FSIYV=PCSVH /DEN
 FSIY=PSIYS+PSIYP+PSIYU+PSIYV

34 K5=K1*SAMB
 K6=K5*PIE(1)
 SPNTSM3=K6*PSIYS
 SPDTFM3=K6*PSIYP
 SPDTLM3=K6*PSIYU
 SPDTVM3=K6*PSIYV
 K6=K5*PIE(2)
 PPDTSM3=K6*PSIYS
 PPDTFM3=K6*PSIYP

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PPDTLM3=K6*PSIYU
 PPDTVM3=K6*PSIYV
 K6=(PIE(3)*K5-PIE(4)*CAMB)*SAMB
 LPDTM3=K6*PSIYS
 LPDTPM3=K6*PSIYP
 LPDTLM3=K6*PSIYU
 LPDTVM3=K6*PSIYV
 K6=(PIE(3)*K5-PIE(4)*CAMB)*SAMB
 VPDTM3=K6*PSIYS
 VPDTPM3=K6*PSIYP
 VPDTLM3=K6*PSIYU
 VPDTVM3=K6*PSIYV
 TSPM=SPDTM3+SPDTSM1
 SSP1=SSP1+TSPSM*TSPSM
 SSP1A=SSP1A+TSPSM*TSPSM*CU
 TSPM=SPDTM3+SPDTSM1
 SSP2=SSP2+TSPPM*TSPPM
 SSP2A=SSP2A+TSPPM*TSPPM*CU
 TSPM=SPDTM3+SPDTSM1
 SSP3=SSP3+TSPUM*TSBUM
 SSP3A=SSP3A+TSPUM*TSBUM*CU
 TSPM=SPDTM3
 SSP4=SSP4+TSPVM*TSPPVM
 SSP4A=SSP4A+TSPVM*TSPPVM*CU
 SSP=SSP+(TSPSM*TSPPM+TSPUM*TSPPM+TSPVM*TSPPVM)*TSPPM*TSPPM*TSPPVM
 TSPM=PPDTM3+PPDTSM1
 SPP1=SPPI+TPPS*TPPSM
 SPP1A=SPPIA+TPPS*TPPSM*CU
 TSPM=PPDTM3+PPDTSM1
 SPP2=SPPI+TPPS*TPPSM
 SPP2A=SPPIA+TPPS*TPPSM*CU
 TSPM=PPDTM3+PPDTSM1
 SPP3=SPPI+TPPS*TPPSM
 SPP3A=SPPIA+TPPS*TPPSM*CU
 TSPM=PPDTM3
 SPP4=SPPI+TPPS*TPPSM
 SPP4A=SPPIA+TPPS*TPPSM*CU
 SPP=SPPI+(TPPS*TPPSM+TPPUM*TPPUM+TPPVM*TPPVM)*TPPSM*TPPSM*TPPVM
 TSPM=PPDTM3+PPDTSM2
 SUP1=SUP1+TUPSM*TSUPS
 SUP1A=SUP1A+TUPSM*TSUPS*CU
 TUPM=PPDTM3+PPDTSM2
 SUP2=SUP2+TUPPM*TSUPPM
 SUP2A=SUP2A+TUPPM*TSUPPM*CU
 TUPM=PPDTM3+PPDTSM2
 SUP3=SUP3+TUPUM*TSUPUM
 SUP3A=SUP3A+TUPUM*TSUPUM*CU
 TUPM=PPDTM3+PPDTSM2
 SUP4=SUP4+TUPVM*TSUPVM
 SUP4A=SUP4A+TUPVM*TSUPVM*CU
 SUP=SUP+(TUPSM*TSUPM+TUPUM*TSUPUM+TUPVM*TSUPVM)*TUPSM*TSUPM*TSUPVM
 TSPM=VPDTM3+VPDTSM2
 SVP1=SVPI+TVPS*TVPSM
 SVP1A=SVPIA+TVPS*TVPSM*CU

```

TVPPM=VPDTPM3+VPDTPM2
SVP2=SVP2+TVPPM+TVPPM
SVP2A=SVP2A+TVPPM+TVPPM+CD
TVPUM=VPDTPM3+VPDTPM2
SVP3=SVP3+TVPUM+TVPUM
SVP3A=SVP3A+TVPUM+TVPUM+CD
TVPV=VPDTPM3+VPDTPM2
SVP4=SVP4+TVPV+TVPV
SVP4A=SVP4A+TVPV+TVPV+CD
SVP=SVP+(TVPSM+TVPPM+TVPUM+TVPV)*(TVPSM+TVPPM+TVPUM+TVPV)
IF (EME.GT.1.0)400,401
SPPM=SPPM+(TPPSM+TPPPM+TPPUM+TPPV)*(TPPSM+TPPPM+TPPUM+TPPV)
SPPMA=SPPMA+(TPPSM+TPPS+TPPUM+TPPV+TPPV+TPPPM+TPPPM)*CD
ACPE=ACP+1
GO TC 402
400 SPPM=SPPM+(TPPSM+TPPPM+TPPUM+TPPV)*(TPPSM+TPPPM+TPPUM+TPPV)
SPPMA=SPPMA+(TPPSM+TPPS+TPPUM+TPPV+TPPV+TPPPM+TPPPM)*CD
ACM=ACM+1
402 CONTINUE
LPI=LPI+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3
12 LPIA=SORT((VPDTPM3+VPDTPM2)*(VPDTPM3+VPDTPM2)+(VPDTPM3+VPDTPM2)*(VPDTPM3+VPDTPM2)+(VPDTPM3+VPDTPM2)*(VPDTPM3+VPDTPM2))
2VM2)*(VPDTPM3+VPDTPM2))*CD
VPI=VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3+VPDTPM3
12 VPIA=SORT((VPDTPM3+VPDTPM2)*(VPDTPM3+VPDTPM2)+(VPDTPM3+VPDTPM2)*(VPDTPM3+VPDTPM2)+(VPDTPM3+VPDTPM2)*(VPDTPM3+VPDTPM2))
2VM2)*(VPDTPM3+VPDTPM2))*CD
LSP=LPI+SAYB+VPI+CA+B
VSP=VPI+SAMB+UPI+CA+B
LSPA=UPIA+SAMB+VPIA+CA+B
VSPA=VPIA+SAMB+UPIA+CA+B
LL1=SP+SE+VSP+CE
VL1=VSP+SE+VSP+CE
LL1A=USPA+SE+VSPA+CE
VL1A=VSPA+SE+VSPA+CE
VORTA=SORT(UL1+UL1+VL1+VL1)
SUSP=SUSP+USP+USP
SUSPA=SUSPA+USPA+USPA
SVSP=SVSP+VSP+VSP
SVSPA=SVSPA+VSPA+VSPA
SUL1=SUL1+UL1+UL1
SVL1=SVL1+VL1+VL1
SVL1A=SVL1A+VL1A+VL1A
SVORTA=SVORTA+VORTA+VORTA
GO TC 32
35 EME=ER=ATAN(1.0)/SURT(EME+EME-1.0)
IF (EME=ER)25,26,26
25 EME=ER=EME+ER+PI
26 EME=ER=EME+ER+180.0/PI

```

02/21/69

FORTAN (3.0)/MASTER

```

CMEWE=COSF(CMEWE)
EC=SGRT(A*A-U*U*SB*SB)+2.0
CS1=SQRT(U*U+A*A-2.0*U*(U*SB+SB*CB+SQRT(A*A-U*U*SB*SB)))
CS2=CS1-BC
K1=EN*CB=CS/A
DEN1=PIE(2)*W1*CMEWE
DEN2=PIE(3)*W1*CAMB-PIE(4)*SAMB
DEN3=DEN2/DEN1
DEN4=1.0+DEN3
IF(CS.LT.CS1)36,39
IF(CS.GT.CS2)37,41
WRITE(61,38)CS2,CS,CS1
36 FORMAT (10X,2JHUS IN PROHIBITED RANGE.,3(DX,E14.4))
GO TO 9999
39 CSM=ALAM(3,1)*SM*CAMB/DEN4+ALAM(2,1)*SM*CMEWE+DEN3/DEN4
CPM=ALAM(3,2)*PM*CA*CB/DEN4+ALAM(2,2)*PM*CMEWE+DEN3/DEN4
CUM=ALAM(3,3)*US*CAMB/DEN4+ALAM(2,3)*US*CMEWE+DEN3/DEN4
CVM=ALAM(4,4)*VS*SAMB/DEN4
C=OS*OPM*OU*OV
DEN5=DEN1*SAMB
PSIYS=(OS*ALAM(2,1)*SM*CMEWE)/DEN5
PSIYP=(OPM*ALAM(2,2)*PM*CMEWE)/DEN5
PSIYL=(OU*ALAM(2,3)*US*CMEWE)/DEN5
PSIYV=(OV*SAMB)/DEN5
PSIY=PSIYS+PSIYP+PSIYL+PSIYV
GO TO 34
41 DEN4=1.0-DEN3
CSM=ALAM(3,1)*SM*CAMB/DEN4+ALAM(2,1)*SM*CMEWE+DEN3/DEN4
CPM=ALAM(3,2)*PM*CA*CB/DEN4+ALAM(2,2)*PM*CMEWE+DEN3/DEN4
CUM=ALAM(3,3)*US*CAMB/DEN4+ALAM(2,3)*US*CMEWE+DEN3/DEN4
CVM=ALAM(4,4)*VS*SAMB/DEN4
GO TO 40
CONTINUE
999 END

```

FORTAN DIAGNOSTIC RESULTS FOR DIONE

NO ERRORS

DIONE	P	10575	C	00050	D	00002
-------	---	-------	---	-------	---	-------

FORTRAN (3.0)/MASTER

02/21/69

C FUNCTION ALOG10(X)

TENLGE = 0.13429448192

ALOG10 = TENLGE * ALOG(X)

C

RETURN
END

FORTRAN DIAGNOSTIC RESULTS FOR ALOG10

NO ERRORS

ALOG10 P 00042 C 00000 D 00000
X,LGO

27697

APPENDIX C
Typical Set of Results
from
Program DIONE

27709

02/19/69

SHOCK INTERACTION

5

NUMBER OF SETS OF DATA
 INITIAL VALUE OF DELTA
 STEP LENGTH IN DELTA
 FINAL VALUE OF DELTA
 EMI THE UPSTREAM FLOW MACH NUMBER
 EPSILON THE SHOCK WAVE ANGLE REFERENCED TO THE X1 AXIS
 BETA THE ANGLE BETWEEN THE SHOCK WAVE AND THE DOWNSTREAM MEAN FLOW VELOCITY VECTOR
 A1 THE SPEED OF SOUND IN THE FLOW FIELD UPSTREAM OF THE SHOCK
 U1 THE UPSTREAM TURBULENCE INTENSITY ALONG THE X1 AXIS
 V1 THE UPSTREAM TURBULENCE INTENSITY NORMAL TO THE X1 AXIS
 SPL1 THE OVERALL UPSTREAM SOUND FIELD
 IT1 THE UPSTREAM ENTROPY FLUCTUATION INTENSITY
 GAMMA THE RATIO OF SPECIFIC HEATS
 PM1 THE AMBIENT STATIC UPSTREAM PRESSURE

M THE DOWNSTREAM FLOW MACH NUMBER
 N1 THE UPSTREAM MACH NUMBER CORRESPONDING TO A NORMAL SHOCK OF EQUIVALENT STRENGTH
 N THE DOWNSTREAM MACH NUMBER CORRESPONDING TO A NORMAL SHOCK OF EQUIVALENT STRENGTH
 CHI SHOCK STRENGTH IN TERMS OF RATIO OF PRESSURE OF UNPERTURBED FLOW ACROSS THE SHOCK
 RORAT THE DENSITY RATIO ACROSS THE SHOCK, DOWNSTREAM TO UPSTREAM
 A THE SPEED OF SOUND IN THE FLOW FIELD DOWNSTREAM OF SHOCK
 ARAT THE RATIO OF ACOUSTIC VELOCITIES ACROSS THE SHOCK, DOWNSTREAM TO UPSTREAM
 U1 THE MEAN FLOW VELOCITY UPSTREAM OF THE SHOCK
 U THE MEAN FLOW VELOCITY DOWNSTREAM OF THE SHOCK
 SM THE DIMENSIONLESS MAGNITUDE OF THE UPSTREAM ENTROPY PERTURBATION
 PM THE DIMENSIONLESS MAGNITUDE OF THE UPSTREAM PRESSURE PERTURBATION
 UL1 THE DIMENSIONLESS MAGNITUDE OF THE DOWNSTREAM VELOCITY PERTURBATION ALONG X1 AXIS
 VL1 THE DIMENSIONLESS MAGNITUDE OF THE DOWNSTREAM VELOCITY PERTURBATION ALONG Y1 AXIS
 USM THE DIMENSIONLESS MAGNITUDE OF THE UPSTREAM VELOCITY PERTURBATION ALONG X* AXIS
 VSM THE DIMENSIONLESS MAGNITUDE OF THE UPSTREAM VELOCITY PERTURBATION ALONG Y* AXIS

MATRIX LAMBDA(I,J) TRANSFER COEFFICIENTS FOR THE INTERACTION

9.5264E-01	-1.8944E-02	6.8607E-02	0
-7.7252E-01	6.9099E-01	1.1224E 00	0
5.4372E-01	2.1749E-01	-2.4528E-01	0
0	0	0	8.9816E-01

VECTOR OF PI(I) TRANSFER COEFFICIENTS OF THE INTERACTION

-7.6606E-02	-1.2496E 00	1.2731E 00	4.8662E-01
-------------	-------------	------------	------------

1	0
1.0000E 00	0
9.0000E 01	0
2.4000E 00	0
3.5000E 01	0
2.3000E 01	0
1.1200E 03	0
1.0000E-01	0
1.0000E-01	0
1.2000E 02	0
5.0000E-02	0
1.4000E 00	0
1.4600E 01	0

1.9189E 00	0
1.3766E 00	0
7.4978E-01	0
2.0441E 00	0
1.6490E 00	0
1.2470E 03	0
1.1134E 00	0
2.6880E 03	0
2.3929E 03	0
1.0760E-01	0
1.4154E-04	0
2.4000E-01	0
2.4000E-01	0
-5.8936E-02	0
3.3425E-01	0

THE TOTAL DOWNSTREAM SOUND PRESSURE LEVEL = 1.9094E 02
 THE DOWNSTREAM SOUND PRESSURE LEVEL DUE TO UPSTREAM ENTROPY PERTURBATIONS = 1.9112E 02
 THE DOWNSTREAM SOUND PRESSURE LEVEL DUE TO UPSTREAM PRESSURE PERTURBATIONS = 1.2626E 02
 THE DOWNSTREAM SOUND PRESSURE LEVEL DUE TO UPSTREAM VELOCITY PERTURBATIONS = 1.9322E 02

 THE TOTAL DOWNSTREAM ENTROPY INTENSITY = 6.3427E-02
 THE DOWNSTREAM ENTROPY INTENSITY DUE TO UPSTREAM ENTROPY PERTURBATIONS = 6.5617E-02
 THE DOWNSTREAM ENTROPY INTENSITY DUE TO UPSTREAM PRESSURE PERTURBATIONS = 7.9120E-06
 THE DOWNSTREAM ENTROPY INTENSITY DUE TO UPSTREAM VELOCITY PERTURBATIONS = 1.1196E-02

 THE TOTAL DOWNSTREAM VORTICITY COMPONENT ALONG X-AXIS = 1.3982E-01
 THE DOWNSTREAM VORTICITY COMPONENT ALONG X-AXIS DUE TO UPSTREAM ENTROPY PERTURBATIONS = 1.0977E-01
 THE DOWNSTREAM VORTICITY COMPONENT ALONG THE X-AXIS DUE TO UPSTREAM PRESSURE PERTURBATIONS = 5.3271E-05
 THE DOWNSTREAM VORTICITY ALONG THE X-AXIS DUE TO UPSTREAM VELOCITY PERTURBATIONS = 2.0557E-01

 THE TOTAL DOWNSTREAM VORTICITY COMPONENT ALONG THE Y-AXIS = 2.4743E-01
 THE DOWNSTREAM VORTICITY COMPONENT ALONG THE Y-AXIS DUE TO UPSTREAM ENTROPY PERTURBATIONS = 1.4278E-01
 THE DOWNSTREAM VORTICITY COMPONENT ALONG THE Y-AXIS DUE TO UPSTREAM PRESSURE PERTURBATIONS = 1.1472E-04
 THE DOWNSTREAM VORTICITY COMPONENT ALONG THE Y-AXIS DUE TO UPSTREAM VELOCITY PERTURBATIONS = 2.3537E-01

 DIMENSIONLESS MAGNITUDE OF DOWNSTREAM VELOCITY PERTURBATION COMPONENT ALONG X*-AXIS = 3.9230E-01
 DIMENSIONLESS MAGNITUDE OF DOWNSTREAM VELOCITY PERTURBATION COMPONENT ALONG Y*-AXIS = 3.7884E-01
 DIMENSIONLESS MAGNITUDE OF DOWNSTREAM VELOCITY PERTURBATION COMPONENT ALONG X1-AXIS = 3.1434E-01
 DIMENSIONLESS MAGNITUDE OF DOWNSTREAM VELOCITY PERTURBATION COMPONENT ALONG Y1-AXIS = 4.4566E-01
 DOWNSTREAM VORTICITY BASED ON U1 AND V1 = 5.4536E-01

 DOWNSTREAM SOUND PRESSURE LEVEL FOR ME GT, 1 = 1.9384E 02
 DOWNSTREAM SOUND PRESSURE LEVEL FOR ME LT, 1 = 1.8721E 02

NOTE THAT THE FOLLOWING RESULTS HAVE BEEN COMPUTED BY USING AN ALTERNATIVE METHOD OF NUMERICAL INTEGRATION.

THE TOTAL DOWNSTREAM SOUND PRESSURE LEVEL = 1.9099E 02
 THE DOWNSTREAM SOUND PRESSURE LEVEL DUE TO UPSTREAM ENTROPY PERTURBATIONS = 1.8581E 02
 THE DOWNSTREAM SOUND PRESSURE LEVEL DUE TO UPSTREAM PRESSURE PERTURBATIONS = 1.2237E 02
 THE DOWNSTREAM SOUND PRESSURE LEVEL DUE TO UPSTREAM VELOCITY PERTURBATIONS = 1.8941E 02

 THE TOTAL DOWNSTREAM ENTROPY INTENSITY = 6.2596E-02
 THE DOWNSTREAM ENTROPY INTENSITY DUE TO UPSTREAM ENTROPY PERTURBATIONS = 6.2178E-02
 THE DOWNSTREAM ENTROPY INTENSITY DUE TO UPSTREAM PRESSURE PERTURBATIONS = 5.4278E-06
 THE DOWNSTREAM ENTROPY INTENSITY DUE TO UPSTREAM VELOCITY PERTURBATIONS = 7.2249E-03

 THE TOTAL DOWNSTREAM VORTICITY COMPONENT ALONG X-AXIS = 1.6303E-01
 THE DOWNSTREAM VORTICITY COMPONENT ALONG X-AXIS DUE TO UPSTREAM ENTROPY PERTURBATIONS = 7.0590E-02
 THE DOWNSTREAM VORTICITY COMPONENT ALONG THE X-AXIS DUE TO UPSTREAM PRESSURE PERTURBATIONS = 7.3612E-05
 THE DOWNSTREAM VORTICITY ALONG THE X-AXIS DUE TO UPSTREAM VELOCITY PERTURBATIONS = 1.4695E-01

 THE TOTAL DOWNSTREAM VORTICITY COMPONENT ALONG THE Y-AXIS = 2.3935E-01
 THE DOWNSTREAM VORTICITY COMPONENT ALONG THE Y-AXIS DUE TO UPSTREAM ENTROPY PERTURBATIONS = 7.8173E-02
 THE DOWNSTREAM VORTICITY COMPONENT ALONG THE Y-AXIS DUE TO UPSTREAM PRESSURE PERTURBATIONS = 7.7954E-05
 THE DOWNSTREAM VORTICITY COMPONENT ALONG THE Y-AXIS DUE TO UPSTREAM VELOCITY PERTURBATIONS = 2.2623E-01

 DIMENSIONLESS MAGNITUDE OF DOWNSTREAM VELOCITY PERTURBATION COMPONENT ALONG X*-AXIS = 2.4624E-01
 DIMENSIONLESS MAGNITUDE OF DOWNSTREAM VELOCITY PERTURBATION COMPONENT ALONG Y*-AXIS = 4.7633E-01
 DIMENSIONLESS MAGNITUDE OF DOWNSTREAM VELOCITY PERTURBATION COMPONENT ALONG X1-AXIS = 4.3139E-01
 DIMENSIONLESS MAGNITUDE OF DOWNSTREAM VELOCITY PERTURBATION COMPONENT ALONG Y1-AXIS = 3.5032E-01
 DOWNSTREAM VORTICITY BASED ON U1 AND V1 = 5.5572E-01

 DOWNSTREAM SOUND PRESSURE LEVEL FOR ME GT, 1 = 1.8984E 02
 DOWNSTREAM SOUND PRESSURE LEVEL FOR ME LT, 1 = 1.8464E 02