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CASEFILE

COMPUTER PROGRAMS FOR PREDICTING SUPERSONIC AND HYPERSONIC INTERFERENCE FLOW FIELDS AND HEATING

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COMPUTER PROGRAMS FOR PREDICTING SUPERSONIC AND HYPERSONIC INTERFERENCE FLOW FIELDS AND HEATING

By Dana J. Morris and J. Wayne Keyes Langley Research Center

SUMMARY

This paper describes computer programs which calculate peak pressure and heating for six types of two-dimensional interference flow patterns. These programs were used to obtain the theoretical values used in NASA TN D-7139. Depending upon the type of inviscid flow pattern, the pressure and heat-transfer peaks occurring at the impingement point are a result of shock—boundary-layer interaction, free shear-layer attachment, or supersonic jet impingement. Peak-heating correlations for laminar and turbulent shock boundary-layer interactions are included in the programs for types I, II, V, and VI interference patterns. Heating correlations for laminar and turbulent shear layers obtained from separation studies are included in the program for type III interference.

INTRODUCTION

Shock interference heating is a problem in the design of the thermal protection system and structural components of supersonic and hypersonic vehicles (refs. 1 and 2) such as the space shuttle, hypersonic research aircraft, and hypersonic cruise vehicle. Small areas of high heat transfer and pressure can occur on the vehicle surface because of the influence of an impinging shock upon the local flow. Edney (ref. 1) made a detailed study of interference flows and defined six types of shock interference patterns. He found that the peaks of surface pressure and heat transfer are caused by shock—boundary-layer interactions, free shear-layer attachments, or supersonic jet impingement, depending on the type of pattern.

Edney also developed flow models and methods of calculating the flow field for each type. Methods were developed to compute the peak pressure for the shear-layer attackment and the peak pressure and heat transfer for the supersonic jet impingement. Semiempirical methods for calculating peak pressures and heat transfer for all six types of interference patterns were developed in reference 2 by using the flow models of reference 1 and the heat-transfer correlations of Bushnell and Weinstein (shear-layer attachment, ref. 3) and Markarian (shock-boundary interaction, ref. 4). Methods similar to those of reference 1 are also discussed in reference 5. This report describes computer programs generated during the investigation reported in reference 2 for six types of interference patterns. The flow model for each type was developed on the basis of two-dimensional flow. Perfect-gas relations from reference 6 were used to obtain the flow conditions in the inviscid flow field. Sutherland's viscosity formula for air (from ref. 6) is included in the programs; however, any perfect gas can be used by inserting an alternate viscosity law. Peak pressure and heat transfer are nondimensionalized with respect to reference values (at the stagnation point on a hemisphere or values ahead of the impingement point on a wedge). Each program requires certain input based on shock and model geometries.

These programs are written in FORTRAN IV language for the Control Data Corporation 6000 series computer under the SCOPE 3.0 operating system. The standard FORTRAN NAMELIST is used with \$DATAIN as the NAMELIST name. Each program is presented in a separate part of the report (parts I to VI), and the subprograms common to more than one program are presented in part VII. A discussion concerning the application of the programs for a typical configuration is given in part VIII.

SYMBOLS

А	constant in equation (2)
a	speed of sound
cp	specific heat at constant pressure
c _v	specific heat at constant volume
$\left(\frac{du_w}{ds}\right)_{stag}$	stagnation velocity gradient on a sphere (eq. (6))
L_{SH}	shock displacement length (see figs. 5 and 6)
ι_{SL}	shear-layer length (see eqs. (3) and (4) and fig. 5)
М	Mach number
N	exponent in equations (1) and (2)
Npr	Prandtl number

р	pressure
Q	heat-transfer rate
R _b	radius of sphere
R _{bj}	radius of "jet body" (see fig. 8)
R _c	radius of curvature of jet bow shock (see fig. 8)
S	surface coordinate (see fig. 8)
Т	temperature
u	velocity
w	jet width at jet bow shock (see figs. 7 and 8)
X _i	impingement locations on wedge (see fig. 3)
x	jet coordinate in horizontal plane (see fig. 7)
У	jet coordinate in vertical plane (see fig. 7)
α_{j}	jet impingement angle relative to local body slope (figs. 6 and 8)
β	shock angle
β_{b}	bow shock angle
$\beta_{\mathbf{i}}$	impinging shock angle
γ	ratio of specific heats
$^{\delta}$ js	standoff distance of jet bow shock at stagnation streamline (see fig.
$\delta_{ m SL}$	shear-layer thickness at wall (eqs. (2) to (4))
θ	flow deflection angle

3

8)

$\theta_{\mathbf{b}}$	local body slope	ia .	
$\theta_{\mathbf{i}}$	shock generator angle		
$ar{ heta}_5$	shear-layer angle relative to local body slope (see fig. 5 and e	q. (2))	t r
μ	viscosity		
ρ	density		
Subscripts:	• A second s		
1 to 8	regions		
aw	adiabatic wall		
j	jet		
pk	peak		
ref	reference		
stag	stagnation-point value on sphere		
u	undisturbed value		
W	wall		
wedge	wedge value (undisturbed)		· . · .
80	free stream		
	SPECIAL NOTATION		- -
BS #	bow shock (fig. 1)	ľ.	
IP	impingement point (fig. 1)		
IS	impinging shock (fig. 1)		
4			

SL shear layer (fig. 1)

TS transmitted shock (fig. 1)

wrt with respect to

 $(1, 2, 3, \ldots, 8)$ regions in shock pattern (figs. 3 to 5, 7, 9, and 10)

TYPES OF INTERFERENCE

The six types of interference flow patterns from reference 1 are shown in figure 1. The peak heating at the impingement point IP for types I, II, and V is the result of a shock—boundary-layer interaction. Type III interference is characterized by an attaching shear layer. The impinging supersonic jet of type IV interference causes the most intense heating. An expansion-fan—boundary-layer interaction occurs in type VI and results in a reduction in pressure and heat transfer. Figure 2 shows how the types of interference patterns change on a hemisphere as the impinging shock moves around the body.

PART I – TYPE I INTERFERENCE

PROBLEM DISCUSSION

A type I interference pattern occurs when two weak shocks of opposite families (BS and IS) intersect, as illustrated in figure 1(a). The actual heating rise is the result of the transmitted impinging shock TS interacting with the boundary layer. This type of interference pattern will occur when the flow upstream of the impingement point is supersonic, or in the case of a blunt body, it will take place well below the sonic point. (See fig. 2.)

Since the flow field associated with type I interference is supersonic throughout, it is described in some detail. The following discussion concerns both the calculation of the inviscid flow field and the prediction of the associated peak pressure and heat transfer.

The flow model used in the present analysis consisted of weak bow and impinging shocks generated by two wedges. A shear layer bounded by the transmitted bow and impinging shocks occurs at the shock intersection A, as shown in figure 3. Across the shear layer it is necessary that the static pressures be equal $(p_4 = p_5)$ and the flow velocities be parallel. An iterative procedure is utilized to obtain the strength of the

transmitted shocks and the orientation of the shear layer relative to the free-stream direction which satisfy these conditions.

The flow conditions in regions 2 and 3 are calculated from the Rankine-Hugoniot equations of reference 6 once the flow conditions in region 1 and the strengths of the bow shock and impinging shocks are specified. These flow conditions (region 1) consist of Mach number, stagnation or static pressure and temperature, ratio of specific heats, and various other constants associated with the free-stream gas. To start the iterative procedure, a value of the flow deflection is assumed and conditions in regions 4 and 5 are computed, again by using the Rankine-Hugoniot equations. If the pressures are equal, within a specified tolerance, the calculation is terminated; if not equal, the shear-layer deflection angle is increased incrementally toward the region with the lower pressure, and the procedure is repeated. From the strength of the transmitted impinging shock and the orientation of the body surface at the impingement point, it is possible to calculate conditions in region 6 by use of the Rankine-Hugoniot equations. Two cases must be considered: regular reflection and Mach reflection (ref. 7). The former occurs for local Mach numbers sufficiently high and shock angles sufficiently low to insure an attached shock system at the wall. The latter case occurs if this condition is not satisfied, and the pressure rise at the wall is approximated by using normal-shock relations.

The increase in heating resulting from the shock—boundary-layer interaction at IP is determined from the empirical correlations of Markarian (ref. 4), which are based upon the inviscid pressure rise across the interaction region. These correlations are of the form

$$\frac{Q_{pk}}{Q_u} = \left(\frac{p_{pk}}{p_u}\right)^N \tag{1}$$

where N is a constant which is dependent upon whether the interaction is laminar or turbulent and the ratio p_{pk}/p_u is p_6/p_2 . For laminar and turbulent interactions, N is 1.29 and 0.85, respectively. Calculation of the peak heating requires a knowledge of the undisturbed, or reference, heat transfer Q_u ahead of the interaction. The location of the impingement point X_i and the state of the boundary layer (laminar or turbulent) on the wedge (present flow model) must be specified in order to determine Q_u . Values of Q_u are obtained by using the reference temperature method of Eckert (ref. 8) for laminar and turbulent boundary layers.

PROGRAM DESCRIPTION

The main program reads the input, calls the various subprograms, controls the iterative solution to determine the deflection angle of the shear layer at point A (fig. 3),

and computes the heat transfer. Subprogram FTHETA is called to compute the flow deflection angles, and FINDB is called to compute the shock angles in each region. The subprograms OBLIQ, MLTRT, ABSVAL, PRATIO, and ISTROP compute flow variables and ratios of the flow variables. PINPUT prints input variables. The flow charts and listings of these subprograms are presented in part VII. The flow diagram and listing for the main program follow.

Program Flow Chart - Main









Program Listing – Main

```
PREGRAM SHOCK (INPUT, OUTPUT, TAPES=INPUT, TAPE6=OUTPUT)
                                                                                   Δ
                                                                                       1
                                                                                   Δ
                                                                                       2
С.
       Δ
                                                                                       3
C
      THIS PROGRAM PERFORMS A TYPE I SHOCK INTERFERENCE PATTERN
                                                                                       4
C
                                                                                   Δ
                                                                                   Δ
                                                                                       5
      FOR TWO DIMENSIONAL FLOW
C.
                                                                                   ۸
                                                                                       6
С
                                                                                   Δ
                                                                                       7
C
      DIMENSION TESTAP(2), RECESTR(2), VESTAR(2), REVESTR(2), HR(2), QFP
                                                                                       8
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                                                                                       0
                                                                                   Δ
     1(2), HPK(2), QPK(2), STN2(2)
                                                                                   Δ
                                                                                      10
      CIMENSION STN1(2)
                                                                                   А
                                                                                      11
      DIMENSION PN(2)
                                                                                   Δ
                                                                                      12
      DIMENSION AA(2), EN(2)
                                                                                   Δ
                                                                                      13
      DIMENSION RP(2), TR(2), HFP(2)
                                                                                   4
                                                                                      14
               PZ, PHCZ, TZ, PIOPZ, RHOLOZ, TIOTZ,
      COMMEN
               PZ2, PHOZ2, TZ2, P20PZ2, RH02Z2, T20TZ2,
PZ3, RH0Z3, TZ3, P30PZ3, RH03Z3, T30TZ3,
                                                                                   Δ
                                                                                      15
     1
                                                                                   A
                                                                                      16
     2
                PZ4, RH074, TZ4, P40PZ4, RH04Z4, T40TZ4,
                                                                                   4
                                                                                      17
     3
                                                                                   Δ
               PZ5, RH0Z5, TZ5, P50PZ5, RH05Z5, T50TZ5,
                                                                                      18
      4
               PZ6, RHDZ6, TZ6, P60PZ6, RH06Z6, T60TZ6,
                                                                                   4
                                                                                      19
      5
               P20P1, FH0201, T20T1, A20A1, U2CU1,
P30P2, RH0302, T30T2, A30A2, U30U2,
P30P1, FH0301, T30T1, A30A1, U30U1,
                                                                                   Δ
                                                                                      20
      6
                                                                                   Δ
                                                                                      21
      7
                                                                                   Δ
                                                                                      22
      8
                P40P2, RH0402, T40T2, A40A2, U40U2,
                                                                                   Δ
                                                                                      23
      9
                                                                                   Δ
                                                                                      24
                P40P1, RH0401, T40T1, A40A1, U40U1,
      $
                P50P3, RH0503, T50T3, A50A3, U50U3,
                                                                                   ۸
                                                                                      25
      $
                                                                                   Δ
                                                                                      26
                P6CP2, PH0602, T60T2, A60A2, U60U2,
      $
                P60P4, PH0604, T60T4, A60A4, U60U4, P50P1, RH0501, T50T1, A50A1, U50U1,
                                                                                   Δ
                                                                                      27
      $
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                                                                                      28
      $
                P60P1, RH0601, T60T1, A60A1, U60U1
                                                                                   Δ
                                                                                      29
      £
       COMMON
                P1, RHO1, T1, A1, U1, VISC1, REY1,
                                                                                   Δ
                                                                                      30
                P2, RH02, T2, 42, U2, VISC2, REY2,
                                                                                   Δ
                                                                                      31
      1
               P3, RH03, T3, A3, U3, VISC3, REY3,
P4, RH04, T4, A4, U4, VISC4, REY4,
P5, RH05, T5, A5, U5, VISC5, REY5,
                                                                                   Δ
                                                                                      32
      2
      3
                                                                                   Δ
                                                                                      33
                                                                                   A
                                                                                      34
      4
                P6, RH06, T6, A6, U6, VISC6, REY6
                                                                                   Δ
                                                                                      35
      5
      NAMELIST /DATAIN/ RM1, GAMMA, THETAB, THETAI, TINCP, NTIMES, IPT, T, P, AMW
                                                                                   Δ
                                                                                      36
      1, TPFF, VREF, XL, S, TWALL, CP, PR, PUN, ANGLE, ANGLE2, TOL
                                                                                   Δ
                                                                                      37
       TOL IS THE CONVERGENCE CRITERION FOR CONDITION 1 AND 2
                                                                                   Δ
                                                                                      38
С
                                                                                      39
                                                                                   4
C
       INITIALIZE CONSTANTS
       BETA=4FBETA
                                                                                   Δ
                                                                                      40
                                                                                   Δ
                                                                                      41
       10=1
                                                                                   Δ
                                                                                      42
       PN(1)=1.29
                                                                                   Δ
                                                                                       43
       PN(2)=0.85
                                                                                   Δ
                                                                                      44
       AA(1)=0.332
                                                                                      45
                                                                                   Δ
       AA(2) = .185
                                                                                   Δ
                                                                                      46
       RN(1)=-.5
                                                                                   ۸
                                                                                      47
       RN(2) = -2.584
                                                                                       48
       Δ
C
                                                                                       49
                                                                                   Δ
С
                                                                                       50
Ċ.
                                                                                   ۸
       INPUT CATA
                                                                                       51
                                                                                   Δ
C
                                                                                   Δ
                                                                                       52
                   С
       .....
                                                                                   ۸
                                                                                       53
       READ (5,DATAIN)
101
                                                                                   Δ
                                                                                       54
       IF (ENCFILE 5) 102,103
                                                                                   Д
                                                                                       55
102
       STOP
                                                                                       56
                                                                                   ۵
       CONTINUE
103
```

	WRIE(C,DAHAIN)		
	RR(1)=SGPT(PR)	A	57
	RR(2)=PR**(1./3.)	Δ	58
	THEDEG=THETAB	А	59
	THIDEG=THETAI	Δ.	60
	WRITE (6,144) RUN	Α	61
С	GAS CONSTANT (FT+LBF/LBM-R)	Δ	62
	R=1544.3/AMW	Ą	63
С	DENSITY (SLUG/CU-FT)	A	64
	RH(1 = P * 1.44 - 1.42 - 2*R * T)	۵	65
	TE (IPT) 104-104-105	Â	66
c	STAGNATION CONDITIONS	~	67
104		*1 A	60
104		4- A	60
		А	. 0.7
		д	70
~		Δ.	/1
C	FREE STPEAM CUNDITIONS	4	72
105	T 1 = T	А	73
	P1=P	Δ	74
	RHCl=RHC	Δ	75
106	CONTINUE	Δ	76
	CALL ISTROP (GAMMA, RM1, P1, PZ, P10PZ, IPT)	4	77
С	PRINT OUT INPUT VARIABLES	Δ	78
	CALL FINPUT (RM1.GAMMA.IPT.T.P.AMW.TREE.VREE.XI.S.TWALL.CP.PR)	Δ	79
	WRITE (A.145) XI	Â	80
		-4 - A	91
r		A A	01
ř		4	02
0	CONVERT ANGLES TO RADIANS	4	00
	11NCF=11NCF/5/0296	۵,	84
	THETAP=THBDEG/57.296	Ą	85
	THETAI=THETAI/57.296	Δ	86
	INPR = O	۵	87
	INPRI=0	~	88
С	SAVE THETA AND TINCE TO PESTORE AFTER CONDITION 2		00 00
	SINCE=TINCE	•	0.2
		4	90
c	INITIALIZE THEOLO AND THISLO EOD INITIAL ESTIMATE FOR THETAE	4	41
Ŭ	THEORET AND THE AND THEORET ON THE LOTTAGE FOR THE AF	4	92
		4	93
c		4	94
ι.	THEFT SAVES OFIGINAL THETAL IN CASE MULTIPLE THETABLES ARE READ	Ą	95
	HIFSI = FAIDEG	4	96
	00 142 I=1,NTIMES	Δ.	97
107	WP J TE (6,148)	4	98
	IF (ANGLE-NE-BETA) GO TO 108	4	99
С	BETAI WAS INPUT INSTEAD OF THETAI	4	100
	BETAI=THETAI	۵	101
	INPBI=1	~	102
	THE TAI = ETHETA (GAMMA, RM1, BETAI)		102
	G0 T0 109	4	100
108	BETAT-EINDR/CANMA. PM1 THETAT. TEOCODI	4	105
100		4	100
100	I = (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) + (1 + 2) +	4	106
109	IF (ANGLE2:NE:BEIA) SU (U II)	A	107
C.	DESAD WAS INPUT INSTEAD OF THETAB	4	108
		Д	109
		Ą	110
	THETAB = -ETHETA(GAMMA, RN1, ABS(BETAB))	Ą	111
	GO TO 112	4	112
110	BETAB=-FINDB(GAMMA, RM1, -THETAB, IERROF)	Δ	112
	IF (IERROP-2) 112,112,111	٨	114
111	G0 T0 143	A	115

112	THBDFG=THETA8*57.296 THIDFG=THETA1*57.296	4] A]
	WRITE (6.146) THIDEG,THEDEG WRITE (6.147)	4 1 A 1
ç		4 1
Ç	EPPURS IN FINDING BETA TERROP - I ONE SCHUTTON WAS ECHNO, CONTINUE	Δ 1
C C	SCHUTTON NOT CONFERCE. USE LAST & COMPUTE	
C C	2 STRUCTION MAS FOUND, START NEW CASE	Δ.
с с	A NOT DEFINED	Δ
C C		Δ
L.	SINCI=SIN(BETAI)	4
	SINEB=SIN(BETAB)	4 1
	BBDEC=BETAB*57.206	A
	BIDEC=BETAI*57.296	4
C	FIND RATIOS FOR PEGION 2 WITH RESPECT TO REGION 1	A]
	CALL CBLIQ (GAMMA, RMI, THETAB, BETAB, FMZ, P2UPI, 1, 2, 10)	4 J
C	FINE RAVIOS FOR REGION 3 WITH RESPECT OF REGION 1	A 1
	UALE USESQ (640004,801,) (FETA1, SETA1,805,800,800,1,1,5,5,107 ISM=0	Δ
с	• • • • • • • • • • • • • • • • • • •	4 1
r,		4 1
С	CONDITION 1	4 1
C	TTERATE ON THETAF UNTIL P4 = P5	A 1
C		A 1
Ç.	TT=1	A :
	0T+ET4=.01	Δ.
	THETAF=THFOLC+TETAI-TEIOLD	Δ 1
113	THE TA4 =- THE TAB + THE TAF	Δ]
	BETA4=FINOB(GAMMA, PM2, THETA4, IERROR)	Δ .
	IF (IERROR-3) 114,127,111	A .
114	P4UP2=PK3+1U(GAMMA;FM2;SIN(BC+4477 D40D1=D40D2+D2CD1	A 1
	ΤΗΕΤΛ5=-(ΤΗΕΤΔΙ-ΤΗΕΤΔΕ)	Δ
	BETA5=-FINDR(GAMMA.RM3.ABS(THETA5).IERROR)	Δ :
	IF (IEPROR-3) 115,127,111	A
115	P50P3=P9ATIO(GAMMA, PM3, SIN(BETA5))	4 ز
	P50P1=P50P3*P30P1	A
		4
114	IF (485(P50P1-P40P1)C01) 128,128,116	а, а
110	UP (1/=20)/ 120(11/) WDITE ///14C) D50D1.04CD1	Δ.
	GD TO 143	4
Ç.	INCREASE THETAE IN THE DIRECTION OF THE SMALLER PRESSURE	Δ
118	IF (P5CF1-P4CP1) 119,128,123	A
С	HAVE SIGNS SWITCHED	4
119	IF (ISW) 122,120,121	4
120	15WF-1 Co To 122	4 . A
121	THETAE=IHETAE=DTHETA	Δ
	DTHETA=CTHETA/10.0	Δ.
	GO TO 113	L
122	THE TAE = THE TAE - D THE TA	A 1
	GO TO 113	Δ]
123	IF (ISW) 125,124,126	A .
124	15W=1 CD TC 126	л.; л 1
125	ΤΗΕΤΔΕ=ΤΗΕΤΔΕ+ΟΤΗΕΤΔ	A I
an bar r'	DTHETA=DTHETA/10.0	Δ
	GO TO 113	Δ

126	ΤΗΕΊΑF=ΤΗΕΊΑF +DTHΕΤΛ	A 177
	60 70 113	A 178
127	TFDEC=7+9TAF*57.296	4 179
	WRITE (6.150)	A 180
	I TYP2=4	A 181
	TINCP=TINCP/2	A 182
		A 182
	$I = (T I N C_{P} + T 0) + 162, 107, 107$	A 100
c		4 10 4
č	• • • • • • • • • • • • • • • • • • • •	
r	TTERATION ON DA AND OF IS COMPLETED USE COMPLETED THETAE TO CALCUM	4 100
r r	CONDITIONS ALA	L 4 101
r	CONDITIONS 4-0.	A 100
r r		4 109
128	CT N D CT N/ D CT N/ A	• 4 190 A 101
120		A 191
c	SINCE-SINCE 427	4 192
U U	FIND BATTUS FOR REGION 4 WITH RESPECT TO REGION 2	A 193
r	CALL CHEIN (GAMMA)PM2)INTEIA4)SEIA4)RM4)P4UP2)2(4,1U)	A 194
Ç	FIND RATIES FOR PEGIEN 5 WITH RESPECT TO REGION 3	A 195
	LALL COLLU IGAMMA, FM3, ADS('HE (AD), ABS(BE (AD), KM3, P3GP3, 3,5,10)	A 196
		A 197
		A 198
r	THUEDETHE AT	A 199
L.	FIND RATIUS FOR REGION 4 WITH RESPECT TO REGION 1	A 200
~	CALL METRI (P40P2,P20P1,P40P1,1,4,10)	4 201
L	FIND KATTOS FOR REGION 5 WITH RESPECT TO REGION I	4 202
		A 203
	TEROP A	A 204
		4 205
	$BF = a_6 = F (NUB (GAMMA, KM4, ABS(THETA6), TEVEVUR)$	A 206
~	$1 \in (1 \in \mathbb{R}^{9} \cup \mathbb{R}^{-3}) = 123, 129, 133$	4 207
Č		4 208
	CONDITION 2	4 209
() C	SHOCK PEFLECTION NUT PESSIBLE. ITERATE ON THETAI TO FIND LAST	A 210
(POSSIBLE SHOCK PEFLECTION.	4 211
1.00		4 212
156	R M 2 SQ = F M 2 * F M 2	4 213
	BETA6=1.57C8	4 214
	WRITE (6,151)	A 215
C	IF ITYP2.GT.3 THEN ITERATION ON CONDITION 2 IS COMPLETED.	4 216
	IF (ITYP2-3) 130,132,132	A 217
130	I T Y P 2 = 1	4 218
	THETAI=THETAI-TINCR	A 219
	IF (TINCE-TOL) 131,132,132	A 220
С	ITERATION HAS CONVERGED. RETURN TO INCREMENTING THETA NORMALLY	4 221
131	TINCP=SINCR	A 222
	THETAI=STHETA+TINCR	4 223
	ITYP2=3	A 224
С	BECAUSE OBLIQUE SHOCK REFLECTION NOT POSSIBLE BETWEEN 4 AND 6 USE	A 225
C	NORMAL SHOCK RELATIONS BETWEEN 6 AND 2	A 226
132	P60P2=1.+2.*GAMMA/(GAMMA+1.)*(RM2SQ-1.)	A 227
	RH0602=(GAMMA+1.)*RM2SG/((GAMMA-1.)*RM2SQ+2.)	A 228
	T60T2=(2.*GAMMA*FM2SQ-(GAMMA-1.))*((3AMMA-1.)*RM2SQ+2.)	4 229
	T60T2=T60T2/((GAMMA+1.)**2*RM2SQ)	4 230
	A6GA2=ARATIC(16012)	A 231
	5M6=SQRT(((GAMMA-1.)*RN2SQ+2.)/(2.*GAMMA*PM2SQ-(GAMMA-1.)))	A 232
	U6CU2=A60A2*RM6/RM2	A 233
	WRITE (6,152) P60P2,R4C602,T60T2,A60A2,U60U2	4 234
C	FIND PATIOS FOR REGION 6 WITH RESPECT TO REGION 1	A 235
	CALL MLTRT (P6CP2, P2OP1, P6OP1, 1, 6, IO)	A 236
	GO TC 134	A 237

C 133	SHOCK REFLECTION POSSIBLE. USE OBLIQUE SHOCK RELATION BETWEEN 6 AN	A 238 A 239
135	P6GP2=P6UP4*P40P2	A 240
С	FIND RATIOS FOR REGION 6 WITH RESPECT TO REGION 1	4 241
	CALL MLTRT (P60P4,P40P1,P60P1,1,6,I0)	A 242
C		A 243
C C	WOTTE THETA AND BETA ECO BACH REGION	Δ 245
r	WRITE THETA AND DEVE FUR LAGI REGION	A 246
č		A 247
134	WRITE (6,153)	4 248
C	WRITE THETA AND BETA FOR REGION 2	A 249
	THFDEC=THETAF*57.296	A 250
	THDEG=THBDEG	A 251
		4 202 1 253
	ABS/HE/FODEG	Δ 254
	J=2	A 255
	WRITE (6,154) J,THDEG.BETDEG,ABSTH,ABSBT,RM1,RM2	A 256
C	WPITE THETA AND BETA FCR REGION 3	A 257
	ABSTHETHIDEG	4 258
	ABSBT=BIDEG	A 259
		4 260
-	WRITE (6,154) J,THIDES,BIDEG,ABSTH,ABSBT,VML,RM3	A 261
C	WRITE TELLS AND PETA FUK REGIUM 4	Δ 263
)HUEVELPETA4407.296	A 264
	ABSTH=THEOFG	A 265
	ABSPT=BETDEG+TEBDEG	A 266
	J=4	4 267
	WRITE (6,154) J,THDEG,BETDEG,ABSTH,ABSBT,PM2,RM4	A 268
C	WRITE THETA AND BETA FOR REGION 5	A 269
	THDEC=THETA5*57.296	A 270
	BETDEG≈BET45*57.206	A 272
		1 273
	1=5	A 274
	WRITE (6.154) J.THDEG. BETDEG. ABSTH, ABSBT, PM3, RM5	A 275
ç	WRITE THETA AND BETA FOR REGION 6	A 276
	THFEG=THET46*57.296	A 277
	BETDEG=BETA6*57.296	A 278
	ABSTH=THRDEG	A 279
	IF (85146.FQ.1.5708) 50 10 135	A 281
	ARSETERE DEGTTERDED	A 282
		A 283
135	ABSBT=BETDEG+THBDEG	A 284
1.22	RM=RM2	A 285
136	J=6	4 286
	WRITE (6,154) J,THDEG,BETDEG,ABSTH,ABSBT,RM,RM6	A 287
C		4 288
C		A 289
ç	CALCULATE AND WRITE PAPAMETER VALUES FUR EACH REGION	Δ 291
L. C		A 292
(VISCI=VISCI(VREF.TREF.TI.S)	A 293
	41=SQPT(32.2*GAMMA*P*T1)	4 294
	U1 = A1 * O M1	4 295
	REY1=FHO1*U1/VISC1	A. 296
	WRITE (6,155)	A 297
	WPITE (6,156)	A 298
C	WRITE ABSOLUTE VALUES FOR REGION I	a 299

	J = 1		A 30	0
	WPITE (6,157) J,P1,RH01,T1,41,U1,VISC1,REY1,RM1		A 30	11
С	WRITE ABSOLUTE VALUES FOR REGION 2		4 30	12
	J=2		A 30	13
	CALL ABSVAL (P20P1,P1,P2,VREF,TREF,S,J,IO,RM2)		A 30)4
C	WRITE ARSOLUTE VALUES FOR REGION 3		A 30)5
	J=3		A 30	16
	CALL ABSVAL (P30P1,P1,P3,VREF,TREF,S,J,IC,RM3)		A 30	17
C.	WRITE ABSOLUTE VALUES FOR REGION 4		4 30)8
	J = 4		A 30	19
	CALL ABSVAL (P40P1,P1,P4,VREF,TREF,S,J,I0,RM4)		A 31	0
Ç	WPITE ABSOLUTE VALUES FOR REGION 5		4 31	. 1
	J=5		4 31	. 2
	CALL ABSVAL (P50P1,P1,P5,VREF,TREF,S,J,IC,RM5)		4 31	.3
С	WRITE ABSOLUTE VALUES FOR REGION 6		4 31	.4
	J=6		4 31	5
-	CALL APSVAL (PGOP1,P1,P6,VREF,TREF,S,J,IO,RM6)		A 31	.6
C			A 31	7
C.			A 31	.8
C	CALCULATE AND WRITE STAGNATION VALUES FOR EACH REGION		4 31	9
Ç			4 32	0
С			••• A 32	1
	WPITE (6,159)		4 32	2
			A 32	.3
	WRITE (6,157) J.PZ.RHOZ.TZ		4 32	:4
			A 32	:5
	CALL ISTRUP (GAMMA, RM2, P2, PZ2, P2UPZ2, 2)		4 32	:6
			4 32	7
	WRITE (6,158) J.PZ2,EHUZ2,TZ2,PZ20Z		A .32	8
	JES All Tathan (Alluk sub na aza pappia al		A 32	.9
	(ALL IS FUP (GAMMA, EM3, P3, P23, P30P23, 3)		4.33	0
			A 33	1
	WEITE (6,158) J, 23, KHUZ3, 123, 23, 2302		A 33	2
			A 33	3
	CALL 111800 (GAMMA, RM4, P4, P24, P40P24, 4)		4 33	4
	P24U2=P247P2 V0170 (7.160) 1 D77 D0077 T77 D7707		<u>A</u> 33	2
	WRITE (0,1987 J,224,89024,124,92402		A 33	C J
	JED CAN ISTROD (CANNA DHE DE DIE DEGDIE EN		4 55	1
	UALL ISTRUP (SAMMA+KMS+PS+P25+P25+P3UP25+5)		A 33	8 0
	PLDUZ=PLD/PL NOTTO // 160) / DIE DUCZE TZE DZEOZ		A 33	9
	MR1 / E (C)1207 J/KAC20/KAC20/(20/P2002	3	4 34 A 34	0
	J = c		. A 34 A 34	1
	CALL ISTRUP TOAMMARRHOPPOPPZCOPOUPZCOO	1	A . 34	2
	PZ60Z=PZ6/PZ		4 34	3
~	WRITE (Cal58) J.PZC.PHCZC.TZC.PZCOZ	:	4 34	4
С УС			••• A 34	5
0			A 34	6
C C	CALCULATE AND WRITE STANTUN NUMBER, FLAT PLATE HEAT TRAN	ISFER	A 34	7
ĉ	CUEFFICIEN (HEPT, AND FEATING RATE (QEP) IN REGIUN 2		A 34	8
C .			A 34	9
r	- • • • • • • • • • • • • • • • • • • •		•• 4 35	0
C .	U T I IS LAMINAR AND JEZ IS LUKBULENT Do 137 1-1 2		A 35	1
ſ			A 35	2
v	TR (J)=T2+RR (J)×(T7=T2)		A 35	3
r	$FCKFRT \neq C \ CFFFCFNCF \ TFMCFDATUCC$		A 35	4
÷	T2STAP(1) = Sx(TWA(1) + T2) = 22 + (TP(1)) = T2STAP(1) = Sx(TWA(1) + T2) = 22 + (TP(1)) = T2		4 35 A 35	2
	RH02STR[1] = 144. *D2/(32.2*0*72CTAD(3))		۹.35 ۵.55	0
	V2 STAR(1) = VI SC 1(VR EE, TREE, T2 STAR(3))		4 35 4 35	1
	REVOSTOTIS-CONTRACTINES - CONTRACTINES		A 35	8
	CETEO CITTER DE COLECTER COLEC		A 35	9

С	LOCAL INCOMPRESSIBLE STANTON NUMBER IN REGION 2 AT IMPINGEMENT	A 360
	CF2=AA(J)*REY2STR**PN(J)	A 361
	IF (J.EQ.2) CF2=AA(J)*ALOG10(REY2ST?)**RN(J)	A 362
	STN2(J)=CF2*PR**(-2./3.)	A 363
С	COMPRESSIBLE FLAT PLATE HEAT TRANSFER COEF(BTU/SEC-FT2-R)	A 364
	HFP(J)=STN2(J)*RHO2STR*U2*CP/778.	A 365
С	FREE STREAM STANTON NUMBER	A 366
	STN1(J)=778。*HFP(J)/(RHO1*U1*CP)	A 361
С	FLAT PLATE HEATING RATE(BTU/SEC-FT2)	A 368
	OFP(J) = HFP(J) * (TR(J) - TWALL)	A 369
С	MAPKARIAN HEAT TRANSFER RATIOS	4 370
	HR(J)=P60P2**PN(J)	A 371
C	PEAK FEATING RATE	A 372
-	0 P K (J) = F R (J) * 0 F P (J)	A 373
С	PEAK HEAT TRANSFER COEF	A 374
137	HPK(J)=HFP(J)H+(J)	A 375
	WRITE (6,160)	A 376
	WRITE (6,161) GEP(1), HEP(1), STN2(1), STN1(1), P60P2, HR(1), QPK(1), HPK	A 371
	1(1)	A 378
	WRITE (6,162) SFP(2), HEP(2), STN2(2), STN1(2), P60P2, HR(2), QPK(2), HPK	A 379
	1(2)	A 380
	WRITE (6,163)	A 381
C		A 382
Ċ		A 383
č	ITYP2 = 0 INCREMENT THETAL NORMALLY	A 384
ĉ	1 AM ITEPATING ON CONDITION 2,	A 385
~	2 THETAT IS DETHERN CONDITION 1 AND 2 INCREMENT THETAT	1 384
C C	A M LEGATING ON CONDITION I AND 2. INCREMENT THETAT	A 381
C C	4 AM ITERATING UN CONDITION 1	A 384
C C		A 380
120	• • • • • • • • • • • • • • • • • • •	Δ 390
120	$\frac{1}{1} \frac{1}{1} \frac{1}$	A 201
r	BU THE THE STATE AT CONTENTS OF THE STATE AND A CONTENT ON 2 DETUDENT OF THE STATE AND A CONTENT ON 2 DETUDENT OF THE STATE AND A CONTENT OF THE STATE AND A	Δ 393
C C	MODALLY	A 303
		A 200
134		A 30F
	THE FATESTHE FATETOR	A 204
	1 + 1 + 2 = 1 + 1 + 2 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 = 1 + 2 =	V 30.
110		A 200
140		A 200
		Δ <u>4</u> Ωι
141	TE (TINCK-CL) 137, TUT, 107 CTUETA TUETA T	Δ 40
141		Δ 403
142	CONTINUE	A 401
143	CUNTINUE	A 404
L.	REFURN THE AT AND FINCE TO CRIGINAL VALUES	A 40
		A 40
		Δ 400
~	O IU IUI	Δ 40
111	CODNAT (141 OF CONTHIS DEDCOAN DEDEDENS & TYDE I CHITCH INTEDEEDENC	A 400
144	TO THE ALL DATED ALL AND DIN NUMBED - EK 271	A 41
145	17007 PHILEMN9//0107 KUN NUMBER (070477) Eodnat (144 Vi/Uali Lengtu) 15V 515 4 44 51)	Δ 41
140	Ευνημή (10η Αμιναμί μενσιητήτρας)100990 - Ε'Τ Εορνατ (101 ορμινρήτ γαριαρίες ασε του τμετάιεο Δ.1ου δερ. Ανδ	5 TL
146	FURMAT (INL)ZUMINFUL VERTABLES AFE /97 THETAL SPE7049138 DEBY AND THETAD - FO & AN DEC//Y	A 41
1 / 7	$\frac{1}{1} HE1AE = \frac{1}{2} E^{3} + \frac{1}{2} E^{3} + \frac{1}{2} E^{3} = \frac{1}{2} E^{3} + \frac{1}{2} E^{2$	4 41. A 41.
141	FURMA! [//12m KATIUS AKE /]	A 41
148	FURMAL [1H /]	A 411
149	$\frac{1}{1000} = \frac{1}{1000} = \frac{1}{1000} = \frac{1}{1000} = \frac{1}{10000} = \frac{1}{10000} = \frac{1}{10000000000000000000000000000000000$	A 7910
150	FUYMAL (//IX.) 3/HIPIN IN A TYPE 2 INTERFERENCE PATTERNY	A 491
121	- FURMAL (/IX,8245HUK, REFLECTION NUT PUSSIBLE AT THIS PUINT - NURMA	A 410
	IL SHULK MELWEEN & AND 2 ASSUMED/1	4 41 A 20
125		A 42
	16/A2=+H8+4+5X+6HU6/U2=+H8+4)	42

153	FORMAT (//7H REGION,5X,14HRELATIVE ANGLE,10X,14HABSOLUTE ANGLE/9X,	A 422
	15HTHETA, 8X, 4HBETA, 7X, 5HTHETA, 8X, 4HBETA, 29H UPSTREAM MACH LOCAL	A 423
	2 MACH)	A 424
154	FORMAT (1X,11,4F12.4,2F15.4)	4 425
155	FORMAT (//7H PEGION, 10X, 1HP, 12X, 3HRHO, 11X, 1HT, 11X, 1HA, 11X, 1HU, 13X,	A 426
	12HMU, 3X, 11HREYNOLDS NO, 9H MACH NO)	A 427
156	FORMAT (14X.3HPSI,4X,10HSLUG/CU FT,5X,7HRANKINE,6X,6HFT/SEC,6X,6HF	4 428
	1T/SEC,4X,11HSLUG/FT-SEC,11X,4H1/FT)	A 470
157	FORMAT (1X, 15, F12, 4, E15, 5, 3F12, 4, 2E15, 5, F8, 4)	A 430
158	F0°MAT (1X, 15, F12, 4, E15, 5, 3F12, 6, 2F15, 5)	A 430
159	FORMAT (/1X, 25HSTAGNATION CONDITIONS ARE/7H REGION, 6X, 5HPSTAG, 12Y,	A 437
	13H3H0.7X.5HTSTAG.4X.12HPSTAG/PSTAG1./.14X.4HPSTA.4X.11HSLUGS/CULET	A 432
	2.5X.7HRANKINE)	A 433
160	FURMAT 1//14H HEAT TRANSEES./17Y.1HO.14Y.3HHED.12Y.8HSTANTON2.7Y &	A 434
100	1+STANTONI, 7Y, 5+D6/D2, 10X, 2+D0, 12Y, 3+OPV, 12Y, 3+UPV)	4 4 5 5
1.61		4 4 5 0
162		A 437
162	O_{COMMAT} (100 - ORBOTING OLEN) (011) O_{COMMAT}	A 438
105	THEAT TONNEED (ATTONS OF A CONTRANSFER COEFIETO/SQ FI-SEC-R)/35H Q =	A 439
		A 440
~		A 441-
Č		B 1
C		B 2

USAGE

Program SHOCK for a type I interference pattern uses the standard FORTRAN NAMELIST input with \$DATAIN as the NAMELIST name. The input includes the flow conditions, gas properties, impinging flow deflection or shock angle, body angle, and impingement location on the body. The program can increase incrementally the shock generator angle and also predict when a type II interference pattern will occur.

A description of the input and output variables and a sample case are presented.

Input Description

The \$DATAIN input for type I is as follows:

RUN	run number for identification
RM1	M_{∞} , free-stream Mach number
GAMMA	c_p/c_v , ratio of specific heats
THETAI	θ_i , shock generator angle, deg; or β_i , impinging shock angle, deg
THETAB	$\theta_{\rm b},$ body angle, deg (input as negative angle); or $~\beta_{\rm b},$ bow shock angle, deg (input as negative angle)

TINCR	increment for θ_i , deg							
NTIMES	number of times to increment θ_i							
IPT	initial point; 0 for stagnation conditions, 1 for free-stream static conditions							
Т	temperature at IPT, ^O R							
Р	pressure at IPT, psia							
AMW	molecular weight (used to compute gas constant)							
TREF	reference temperature for computing viscosity, $^{O}\!R$							
VREF	reference viscosity for computing viscosity, slugs/ft-sec							
S	Sutherland's constant in viscosity equation							
XL	X_i , distance from leading edge to impingement point, ft							
TWALL	temperature at wall, ^O R							
СР	c _p , specific heat at constant pressure, ft-lbf/slug- ⁰ R							
PR	N _{Pr} , Prandtl number							
ANGLE	THET if θ_i input; BETA if β_i input							
ANGLE2	THET if θ_{b} input; BETA if β_{b} input							
TOL	acceptable tolerance for equal pressures (0.001)							

Output Description

The output consists of printing only. A heading and pertinent input for identification are printed before the calculated results. RUN NUMBER run number for identification

M1 M_{∞} , Mach number in free stream

GAMMA(CP/CV) ratio of specific heats

TEMP AT POINT "IPT" input as T, ^OR

PRES AT POINT "IPT" input as P, psia

MOLECULAR WEIGHT molecular weight (used to compute gas constant)

REFERENCE TEMP reference temperature for computing viscosity, ^oR

REFERENCE VISCOSITY reference viscosity for computing viscosity, slugs/ft-sec

S(SUTHERLAND NUMBER) Sutherland's constant in viscosity equation

TEMP AT WALL T_w , O_R

CP c_p, specific heat at constant pressure, ft-lbf/slug-^OR

PRANDTL NUMBER Npr, Prandtl number

XL(WALL LENGTH) X_i, length from leading edge to impingement point, ft

THETAI θ_i , shock generator angle, deg

THETAB θ_b , body angle, deg

P2/P1, etc. p_2/p_1 , etc., pressure ratios for regions listed

RHO2/1, etc. ρ_2/ρ_1 , etc., density ratios for regions listed

T2/T1, etc. T_2/T_1 , etc., temperature ratios for regions listed

A2/A1, etc. a_2/a_1 , etc., ratios of speeds of sound in regions listed

U2/U1, etc. u_2/u_1 , etc., velocity ratios for regions listed

RELATIVE ANGLE

THETA	flow angle relative to flow in upstream region, deg
BETA	shock angle relative to flow in upstream region, deg
ABSOLUTE ANGLE	
THETA	flow angle relative to free-stream flow, deg
BETA	shock angle relative to free-stream flow, deg
UPSTREAM MACH	Mach number in upstream region
LOCAL MACH	local Mach number
REGION	region in shock pattern
Р	static pressure in region, psia
RHO	static density in region, $slugs/ft^3$
Т	static temperature in region, ^O R
A	speed of sound in region, ft/sec
U	velocity in region, ft/sec
MU	static viscosity in region, slugs/ft-sec
REYNOLDS NO	Reynolds number per foot in region
MACH NO	Mach number in region
The following sta	gnation conditions are then listed:
PSTAG	total pressure in region, psia

RHO total density in region, slugs/ft³

TSTAG total temperature in region, ^OR

PSTAG/PSTAG1 ratio of total pressure in region to free-stream total pressure

The pressure ratio and heat transfer for laminar and turbulent flow are listed as

Q	heat-transfer rate, Btu/ft ² -sec
HFP	flat-plate heat-transfer coefficient, Btu/ft ² -sec- ⁰ R
STANTON2	local incompressible Stanton number
STANTON1	compressible free-stream Stanton number
P6/P2	peak pressure ratio
HR	Markarian heat-transfer ratio
QPK	peak heating rate
НРК	peak heat-transfer coefficient

Sample Case - Input

SDATAIN

R M1	=	0.6E+01,
GAMMA	2	0.146+01,
THETAB	÷	-0.15E+02,
THETAI	Ħ	0.5E+01,
TINCR		0.5E+01,
NTIMES	Ξ	1,
IPT	=	Ο,
T		0.9E+03,
P	=	0.46+03,
AMW	ative Vez.	0.2897E40?
TREF	E.	0.535+03,

VREF =	0.3301E-0	36,
--------	-----------	-----

ХL	=	0.25E+00,
S	=	0.1986E+03,
TWALL	=	0.55E+C3,
Co	=	0.6006E+04,
PR	=	0.72E+00,
RUN	=	0.1E+01,
ANGLE	=	0.69404725765109E+93,
ANGLE2	=	0.69404725765109E+93,
TOL	=	0.1E-02,

\$END

Sample Case – Output

THIS PROGRAM PERFORMS & TYPE I SHOCK INTERFERENCE PATTERN

PUN NUMBER 1.00

INPUT VARIABLES ARE

M1

GAMMA(CP/CV) TEMP AT POINT O PRES AT POINT O MOLECULAR WEIGHT REFERENCE TEMP REFERENCE VISCOSITY S(SUTHERLAND NUMBER) TEMP AT WALL CP PRANDTL NUMBER XL(WALL LENGTH)

6.000 1.400000 90C.000000 RANKINE 40C.000000 PSI 28.970000 53C.000000 RANKINE 3.801000E-07 SLUG/(FT-SEC) 198.600 550.000 RANKINE 6006.000 FT-LBE/(SLUG-RANKINE) .720000 .250000 FT

INPUT VARIABLES ARE THETAI = 5.0000 DEG, AND THETAB = -15.0000 DEG

RATIOS ARE

P2/P1= P3/P1= P4/P2= P5/P3= P4/P1= P5/P1= P6/P1=	6.0734 2.0103 1.6648 5.0297 10.1109 10.1111 1.5933	RH02/1= RH03/1= RH04/2= RH05/3= RH04/1= RH05/1= RH06/1=	3.1011 1.6306 1.4337 2.8268 4.4459 4.6093 1.3907 6.1828	T2/T1= T3/T1= T4/T2= T5/T3= T4/T1= T6/T4=	1.9585 1.2328 1.1612 1.7793 2.2742 2.1936 1.1457 2.6056	A2/A1= A3/A1= A4/A2= A5/A3= A4/A1= A5/A1= A6/A4=	1.3995 1.1103 1.0776 1.3339 1.5081 1.4811 1.0704 1.6162	U2/U1= U3/U1= U4/U2= U5/U3= U4/U1= U5/U1= U6/U4=	.9311 .9837 .9744 .9285 .9072 .9134 .9716
P6/P1=	16.1097	RH06/1=	6.1828	T6/T1=	2.6056	A6/A1=	1.6142	U6/U1=	.8815

REG	ION RELA	TIVE ANGLE	4 B S O	LUTE ANGLE		
	THETA	BETA	THETA	BETA	UPSTREAM MACH	LOCAL MACH
2	-15.0000	-22.6719	-15.0000	-22.6719	6.0000	3.9918
3	5.0000	13.1598	5.0000	13.1598	6.0000	5.3157
4	5.3083	18.2928	-9.6917	3.2928	3.9918	3.6095
5	-14.6917	-23.3922	-9.6917	-18.3922	5.3157	3.7001
6	-5.3083	-19.8941	-15.0000	-29.5858	3.6095	3.2765

REGION	Р	RHO	т	Δ.	U	MU	REYNOLDS NO	MACH NO
	PSI	SLUG/CU FT	RANKINE	FT/SEC	FT/SEC	SLUG/FT-SEC	1/FT	
1	.2533	1.93645E-04	109,7561	513.5679	3081.4074	8.46377E-08	7.05004E+06	6.0000
2	1.5387	6.00506E-04	214.9563	718.7182	2868.9832	1.72967E-07	9.96052E+06	3.9918
3	.5093	3.15760E-04	135,3111	570.2302	3031.1919	1.06990E-07	8.94597E+06	5.3157
4	2.5615	8.60919E-04	249.6093	774.4866	2795.4826	1.99702E-07	1.20513E+07	3.6095
	2.5616	8,92574E-04	240,7624	760.6377	2814.4446	1.92989E-07	1.30168E+07	3.7001
6	. 4.0813	1.19726E-03	285.9789	828.9924	2716,2005	2.26522E-07	1.43563E+07	3.2765

STAGNATION CONCITIONS ARE

REGION		PSTAG	. RHO	TSTAG	PSTAG/PSTAG1
		PSIA	SLUGS/CU FT	RANKINE	
	1	400.0000	3.72856E-02	900.0000	
	2	231.0837	2.15402E-02	900.001065	.577709
	3	386.5123	3.60280E-02	900.008771	.966281
	4	228.0034	2.12530E-02	900.003197	.570008
			2.41152E-02	900.009631	.646777
	. 6	. 225.6772	2.10362E-02	900.004664	.564193

	_	 	
manager and the second s		 	
MEAT TOANCEED			

	Q	HFP	STANTON2	STANTON1	P6/P2	HR	QPK	НРК
LAMINAR	8.13165E-01	3.30239E-03	5.89526E-04	7.16914E-04	2.65250E+00	3.51978E+00	2.86216E+00	1.16237E-02
TUR BUL ENT	4.02372E+00	1.44246E-02	2.57501E-03	3.13143E-03	2.65250E+00	2.29143E+00	9.22008E+00	3.30530E-02

HFP = HEAT TRANSFER COEF(BTU/SQ FT-SEC-R)

Q = HEAT TRANSFER(BTU/SQ FT-SEC)

PART II – TYPE II INTERFERENCE

PROBLEM DISCUSSION

A type II interference pattern occurs when two shocks of opposite families (BS and IS) intersect, as shown in figure 1(b). Both shocks are weak as in type I but are of such strength that in order to turn the flow, a Mach reflection must exist in the center of the flow field with an embedded subsonic region occurring between the intersection points (A and B) and the accompanying shear layers. (See p. 557 of ref. 7.) Type II interference occurs on a blunt body when the impinging shock intersects the bow shock near the sonic point, as shown in figure 2.

As for type I interference, the flow model consisted of a weak impinging shock and a stronger bow shock $(M_3 > M_2)$ generated by two wedges, as illustrated in figure 4. A detailed analysis of the complete flow field is difficult because the extent of subsonic region 5 is unknown and depends on the size and shape of the body (ref. 1). The conditions in the supersonic regions (4 and 6) and the pressure ratio p_6/p_2 across the transmitted impinging shock at the shock—boundary-layer interaction IP can be calculated since the influence of the impinging shock on these regions is small compared with the influence of the bow shock (ref. 1).

Given the free-stream conditions in region 1 and either the body angle θ_b or bow shock angle β_b , the triple-shock configuration with a shear layer at point A is determined by an iterative procedure similar to that discussed for a type I interference in part I with the exception that strong-shock relations are used between regions 1 and 5. Flow data presented in references 1 and 2 indicate that the shocks and shear layer at point A are nearly straight; therefore, the conditions in region 4 are approximately those calculated by assuming no shock or shear-layer curvature and a nearly normal shock between A and B. When the regular shock reflection between regions 4 and 6 is no longer possible, it is replaced by a Mach reflection and a normal shock is assumed near the wall. Once the pressure rise from region 2 to region 6 is known, the heat-transfer rise is determined with the same procedure as used for type I (eq. (1)). The reference, or undisturbed, heating ahead of the shock—boundary-layer interaction at IP is calculated in the same manner as for type I.

PROGRAM DESCRIPTION

The main program reads the input, calls the various subprograms, and computes the heat transfer. The TYP4 subprogram computes the flow deflection angle of the shear layer at point A (fig. 4). FTHETA is called to compute the flow deflection angle and FINDB is called to compute the shock angles in each region. The subprograms OBLIQ, MLTRT, ABSVAL, and ISTROP compute flow variables and ratios of the flow variables. PINPUT prints input variables. The flow charts and listings of these subprograms are presented in part VII. The flow diagram and listing for the main program are given in the following sections.









Program Listing – Main

	PROGRAM SHOCK(INPUT.JUTPUT.TAPEJ=INPUT.TAPED=UUIPUT)	Δ	1
C	6 • • • • • • • • • • • • • • • • • • •	Â	Ž
C		А	3
C	THIS PROGRAM PERFORMS A TYPE II SHOCK INTERFERENCE PATTERN	Α	4
L C	FUK IWU DIMENSILNAL FLUW	A	5
с С		A	07
Ŭ	DIMENSION TESTAR(2), RHOESTR(2), VESTAR(2), REVESTR(2), HR(2), QFP	A	8
	1(2), HPK(2), QPK(2), STN2(2)	A	9
	DIMENSION PN(2)	А	10
	DIMENSION AA(2), RN(2)	Α	11
	DIMENSION SINI(Z) DIMENSION DOADA TRADA DEDAGA	A	12
	COMMON 127, 14(2), 14(2), 144(2) COMMON 127, 1407, 17, 1002, 140107, 10017,	A	13
	PZ2, RHUZ2, TZ2, P20P22, RHUZ22, T20TZ2,	Δ	15
	2 PZ3, RHOZ3, TZ3, P30PZ3, RHO3Z3, T30TZ3,	Â	16
	3 PZ4, RHUZ4, TZ4, P40PZ4, RH04Z4, T4UTZ4,	Α	17
	4 PZ5, RHOZ5, TZ5, P50PZ5, RH05Z5, T50TZ5,	Α	18
	5 PZ6, RH026, TZ6, P60PZ6, RH06Z6, T60TZ6,	A	19
	$7 \qquad \mathbf{P}_{2}\mathbf{U}\mathbf{P}_{1}, \mathbf{K}\mathbf{H}\mathbf{U}_{2}\mathbf{U}1, \mathbf{I}_{2}\mathbf{U}1, \mathbf{A}_{2}\mathbf{U}\mathbf{A}_{1}, \mathbf{U}_{2}\mathbf{U}\mathbf{U}1, \mathbf{I}_{2}\mathbf{U}\mathbf{I}_{2}$	А ^	20
	8 P30P1, RHB301, T30T1, Δ30Δ1, U30U1,	А Д	22
	9 P40P2, RH0402, T4UT2, A4UA2, U40U2,	A	23
	\$ P40P1, RH0401, T40T1, A40A1, U40U1,	Α	24
	\$ P50P3, RH0503, T50T3, A50A3, U5003,	А	25
	3 P60P2, RH0602, T6uT2, A6ùA2, U80U2, P60P2, RH0602, T6uT2, A6ùA2, U80U2,	A	26
	POUP4; KHUOU4; Iou14; AouA4; UouU4; \$ D5001; Phot1; AboA1; D5001;	A	- 21
	\Rightarrow P60P1, RH0601, T60T1, A60A1, U60U1	Δ	20
	COMMUN P1, RHUI, T1, A1, U1, VISCI, REYL,	A	30
	1 P2, RH02, T2, A2, U2, VISC2, REY2,	А	31
	2 P3, RH03, F3, A3, U3, VISC3, REY3,	Α	32
	3 P4, RHO4, T4, A4, U4, VISC4, REY4,	A	33
	4 PD; KHUD; 1D; AD; UD; VISCD; KEYD; 5 P6, RHD6, T6, A6, H6, VISC6, REY6	A	- 34 - 25
	NAMELIST /DATAIN/ RMI.GAMMA.THETAB.THETAL.TINUR.NTIMES.IPT.T.P.AMW	Â	30
	L, TREF, VREF, XL, S, TWALL, CP, PR, RUN, ANGLE, ANGLEZ, TUL	A	-37
C,	TOL IS THE CONVERGENCE CRITERION FOR CONDITION 1 AND 2	А	38
С	INITIALIZE CONSTANTS	Α	39
		A	40
	$P_{N(1)=1,29}$	Δ	42
	PN(2) = 0.85	~	
	AA(1) = 0.332	A	43
	AA(2)= .185	A	45
	RN(1)=5	A	46
	RN(2) = -2.584	Α	47
Ç	, , , , , , , , , , , , , , , , , , ,	А	48
6		A	49
ы С	INFUL VALA	A A	50 51
č	****	Å	52
101	READ (5.DATAIN)	A	53
	IF (ENDFILE 5) 102,103	Α	54
102	STOP	А	55

103		À	56
	$WK_{1} \in \{0\} DA \{A \mid N\}$	٨	F 7
-		A. A	21 6 J
	THROFTLETAR	А Л	50
	THIDEGETHETAL	Å	60
	WRITE (6.120) RUN	. <u>Μ</u>	61
C.	GAS CONSTANT (ET-LBEZIBM-R)	Δ	62
.	R=1544, 37AMW	Δ	63
C	DENSITY (SLUG/CU-FT)	Δ	64
	$RH(3=P*144)/(32_2*k*T)$. Δ	65
	IE (1PT) 104-104-105	Δ	66
C	STAGNATION CONDITIONS	Δ	67
104		Δ	68
	KH0Z=KH0	Ā	69
	P P	Ă	70
	GU TU 106	A	71
C.	FREE STREAM CUNDITIONS	A	72
105	Tl=T	A	73
	P1=P	A	74
-	RHU1=RHO	A	75
106	CUNTINUE.	A	76
	GALL ISTROP (GAMMA,RM1,P1,P2,P10PZ,IPT)	Α	77
C .	PRINT OUT INPUT VARIABLES	Α	78
	GALL PINPUT (RM1,GAMMA,IPT,T,P,AMW,FREF,VREF,XL,S,TWALL,CP,PR)	Α	79
	WRITE (6,121) XL	Α	80
	ITYP2=0 Watch	Α	81
<u>C</u>	$1TYP2 \equiv 0$ NORMAL	Α	82
C .	1 COULD NOT FIND BETAG	Α	83
C.	2 CALCULATE LAST PUINT BEFORE CONDITION 1	Α	84
C.	3 INCREMENT NORMALLY UNTIL CONDITION 4	Α	85
C	4 COULD NOT FIND BETA4 UK BETA5	A	86
C	5 CALCULATE LAST POINT BEFORE CONDITION 4	A	87
<u> </u>	CONVERT ANGLES TO RADIANS	A	88
	TINCR = TINCR / 57 - 296	A	89
	THETAB=THBDEG/57.296	Α	90
	THE TAI = THE TAI / 57.296	Α	91
	INPBB=0	Α	92
	INPBI=0	Α	93
C	SAVE THETA AND TINCE TO RESTORE AFTER CONDITION 2	Α	94
	SINCR=TINCR	Α	95
	STHETA=THETAI	Α	96
C	INITIALIZE THFOLD AND THIOLD FOR INITIAL ESTIMATE FOR THETAF	Α	97
	THFOLD=THETAI+THETAB	Α	98
	THIOLD=THETAI	Α	99
C	THIFST SAVES ORIGINAL THETAL IN CASE MULTIPLE THETABAS ARE READ	Α	100
	THIFST=THIDEG	Α	101
	00.118 I=1.NTIMES	Α	102
	WRITE (6,125)	Α	103
	IF (ANGLE-NE-BETA) GO TU 107	Α	104
C	BETAI WAS INPUT INSTEAD OF THETAI	Α	105
	BETA1=THETAI	A	106
	<u>INP81=1</u>	Α	107
	THETAI=FTHETA(GAMMA, RM1, BETAI)	Α	108
	GO TO 108	Α	109
107	BETAI=FINDB(GAMMA, RM1, THETAI, 1, LERROR)	Α	110
	IF (IERROR-2) 108,108,110	Α	111
108	IF (ANGLE2.NE.BETA) GO TO 109	А	112
<u>C</u>	BETAB WAS INPUT INSTEAD OF THETAB	A	113
	BETAB=THETAB	А	114
	<u>INPBB=1</u>	A :	
----------	-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	------------	
	THETAB =- FTHETA(GAMMA, RM1, ABS(BETAB))	A	
	<u>60 TO 111</u>	Α.	
109	BETAB=-FINDB (GAMMA, RML, -THE TAB, 1, IERKUR)	A.	
	IF (IERROR-2) III, III, IIO	A	
110	WKITE (6,122)	Α.	
	GO TU 119	Α.	
111	THBDEG=THETAB*57.296	Α	
	THIDEG=THETA1*57.296	A	
	WRITE (6.123) THIDEG.THBDEG	Α	
	WRITE (6.124)	Α	
<u>с</u>		A	
		A	
-	FRADES IN FINDING HETA	Δ	
.	I = 1 ONE SOLITION WAS FOUND. CONTINUE	Δ	
	2 = SG(4) + 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 +	Ā	
	2 SECTION DE NOT CONVENCE OSE LAST D'CONVENCE	Â.	
,	A NOT DECINED	~	
-	4 NOT DEFINED	~	
		А	
•	8 8 8 8 9 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	A A	
	SINDL-SINDETAL/	A 	
	SINDESINVELADI	- A - A	
		A .	
	BIDEG=BEIA*2	A .	
•	FIND RAILUS FUR REGION 2 WITH RESPECT TO REGION I	A	
	CALL UBLIQ (GAMMA, RMI, THETAB, BETAB, RMZ, P20P1, 1, 2, 10)	A	
	FIND RATIOS FOR REGION 3 WITH RESPECT TO REGION 1	A	
	LALL OBLIQ (GAMMA,RM1,THETAI,BETAI,RM3,P30P1,1,3,10)	Α	
	ISW=0	А	
		Α	
-	A second s	Α	
2	CUNDITION 1	A	
	ITERATE ON THETAF UNTIL P4 = $P5$	Α	
		A	
		Α	
	0THETA==01	Α	
	THE TAE =0.	Δ	
	85145=1-5708	Δ	
	CALL TYPE (THETAE RETAS RML RM2.ABS/THETAK).THETA4.BETA4.P20P1.CAM	Δ	
	TAL THE FREDA	<u></u>	
	PROFILE ALCONT	A .	
	$D \subseteq (A)^{-1} D \subseteq (A)$	A.	
		A .	
	ΤΕΡΑΤΙΩΣΙΑΓ Ττερατισμού στο στο στο το τ	A .	
	TTERATION ON P4=P5 IS COMPLETED	A .	
	• • • • • • • • • • • • • • • • • • • •	A .	
		A	
	TTERATION ON P4 AND P5 IS COMPLETED. USE COMPUTED THETAF TO CALCUL	A	
	LUNUIIIUNS 4-6.	A	
•		Α.	
		Α	
	SINB4=SIN(BETA4)	Α	
	SINB5=SIN(BETA5)	Α	
	TFDEG=THETAF*180./3.1416	A	
	THFULD=THETAF	A	
	THIULDETHETAI	A	
	FIND RATIUS FOR REGION 4 WITH RESPECT TO REGION 2	A	
	CALL ORLIG (CAMMA, DEC THETAG, RETAG, DAG DADD, 2, A 10)	٨	
	VALE ODLIG (VANMA)KMZ)INCIAN, CCIAN, KM3/Y4072/2/49107 CIND VATIOS CON NECLON S VITU DECOSCY TO NECLON	A 	
	FIND NATIUS FOR REGION 5 WITH RESPECT TO REGION I	A ^	
	CALL UBLIQ (GAMMA, KMI, ABS(IHEIAF), ABS(BEIA5), KM5, P50P1, 1, 5, 10)	A.	
,	FIND KALLUS FUR REGION 4 WITH RESPECT TO REGION 1	A	
	CALL MLIRT (P4GP2,P20P1,P40P1,1,4,10)	A	

	THETA6=THETAB-THETAF	AL
	BETA6=-FINDB(GAMMA,RM4,ABS(THETA6),1,IERKOR)	A 1
	IF (IERROR-3) 113,112,113	A 1
C		A 1
C		Δ 1
č	CONDITION 2	
с	SUBJECTION AS STREET AND NOT DOCCLOSE	AL
5	STOCK REFLECTION NOT PUSSIBLE.	AL
Ç		A 11
C	* * * * * * * * * * * * * * * * * * * *	A 11
112	RM2SQ=RM2*RM2	A 11
	BETAb=1.5708	Δ 1 /
	WRITE (6.125)	
· · ·	REALS FOULT AND FOR FOR THE NOT ODESTARE OFFICER A AND A DES MODIAL	- A _ L (
	BECAUSE UBLIQUE REFLECTION NUT PUSSIBLE BETWEEN 4 AND 6 USE NURMAL	AL
L	SHOCK RELATIONS BETWEEN 6 AND 2	A 11
	P6UP2=1.+2.+CAMMA/(GAMMA+1.)+(RM2SQ-1.)	A 19
	RH0602=(GAMMA+1。)*RM25Q7((GAMMA-1))*KM25G+2。)	AL
	T6OT2=(2,*GAMMA*RM2SQ-(GAMMA-1.))*((GAMMA-1.)*RM2SQ+2.)	A 19
	$I_{OUT} = T_{OUT} / ((G_{A}MMA+1)) * * 2 * RM2SU)$	Δ 1 9
	A = A + T + T + T + T + T + T + T + T + T +	
	AMORE = ARMITEDATIONTET $EMAE = CDETET = CMAE = CDETET = CMAE = CDETET = C$	AL
	NIG-5WNILLIGADDA 10/TRD25W720///20*0000000000000000000000000000000	AL
		A 19
	WKITE (6,127) P6UP2,RHU602,T60T2,A6UA2,U6UU2	A 19
C	FIND RATIOS FOR REGION 6 WITH RESPECT TO REGION 1	ALS
	CALL MLTRT (P60P2,P20P1,P60P1,1,6,Iu)	AIG
	GU T() 114	A 20
C	SHOCK REFECTION POSSIBLE USE OBLIGHE SHOCK RELATION RETWEEN 6 AN	1 20
112	Shock Refelection Possible OSE OBEIGOS SHOCK RELATION DETMEND ON	A 20
113	CALL UDLIV (GAMMA, KM4, ADS(I HEI AO), ABS(BEI AO), KM0, POUP4, 4, 6, 10)	AZ
	P60P2=P60P4*P40P2	A 20
C -	FIND RATIOS FUR REGION 6 WITH RESPECT TO REGION 1	A 20
	CALL MLTRT (P60P4,P40P1,P60P1,1,6,I0)	A 20
C		A 20
C.		A 20
(WRITE THETA AND BETA FOR FACH RECLON	A 20
C C	RATE HERA AND DETA FOR LACH REDION	A 20
С С		AZU
· ،		A 21
114	WRITE (6,128)	A 21
C	WRITE THETA AND BETA FOR REGION 2 1999	A 21
	THEDE6=THETAF*57.296	A 21
	THDEG = THBDEG	A 21
	RETIEC-RETARKET 204	· A 21
		ACL
	ADSIN=INDUEG	A 21
	ABSBI = BEIDEG	A 21
·		A 21
	WRITE (6,129) J,THDEG,BETDEG,ABSTH,ABSBT,RM1,RM2	A 21
C	WRITE THETA AND BETA FOR REGION 3	A 22
	ABSTHETHIDEG	Δ 22
	ARSAT - RIDEC	1 2
		H 22
	J=2	A 22
	WKITE (0,129) J, HIDEG, BIDEG, ABSTH, ABSBT, RML, RM3	A 22
С	WRITE THETA AND BETA FOR REGION 4	A 22
2	THDE6=THETA4*57.296	A 22
	BETDEG=BETA4*57.296	A 22
	ABSTH=THFDEG	A 22
		A 00
*		A 66
		A 23
v	MRIIE (6,129) J,THDEG,BETDEG,ABSTH,ABSBT,RM2,RM4	A 23
<u>C</u>	WRITE THETA AND BETA FOR REGION 5	A 23
	THDEG=THETA5 *57 . 296	A 23
	BETDEG-BETA5*57.296	A 23
	ABSTHETHEDEG	A 22
		_ ~ ~ ~ √ ∧ ⊃ "
		A ZJ
	J=)	A 23

	WRITE (6,129) J. THDEG. BETDEG. ABSTH. ABSBT. RM3. RM5	А	238
C	WRITE THETA AND BETA FOR REGION 6	Α	239
	THDEG=THETA6*57.296	А	240
	BETDEG=BETA6*57.296	A	241
	ABSTH=THBDEG	A	242
	IF (BETA6.EQ.1.5708) GO TU 115	A	243
	ABSBT=BETDEG+THFDEG	A	244
		A	245
		A	240
112	ABSBI=BEIDEG+IHBDEG	A	241
		A	240
110	UTO UTE (7 1301 I THORE BETORE ARTH ANAL MAN	A ^	247
	WRITE (0,129) J, THUEG, BEIDEG, ABSTH, ABSDI, KM, KM,	A A	250
<u> </u>	. , , , , , , , , , , , , , , , , , , ,	Δ	252
	CALCHLATE AND WRITE PARAMETER VALUES FOR FACH REGION	Δ	253
·····	CALCOLATE AND WRITE FARALLER VALUES FOR EACH RESIDN	Δ	254
<u> </u>		A	255
· ¥	VISCI=VISCJ(VREF.TREF.TI.S)	Δ	256
	$\Lambda 1 = 5 (1 \times T (3 2) - 2 \times (3 \times M M A + R \times T))$	۵	257
		δ	258
	REVI=RH01×U1×V1SC1	Δ	259
	WRITE (6.130)	Δ	260
	MRITE (6.131)	A	261
2	WRITE ABSOLUTE VALUES FOR REGION 1	A	262
	J=1	A	263
	WRITE (6,132) J,P1,RH01,T1,A1,U1,V1SC1,REY1,RM1	A	264
C	WRITE ABSOLUTE VALUES FOR REGION 2	Α	265
	j = 2	Α	266
	CALL ABSVAL (P20P1,P1,P2,VREF,TREF,S,J,IU,RM2)	Α	267
Ç	WRITE ABSOLUTE VALUES FOR REGION 3	Α	268
		Α	269
	CALL ABSVAL (P3OP1,P1,P3,VREF,TREF,S,J,IU,RM3)	Α	270
<u> </u>	WRITE ABSOLUTE VALUES FOR REGION 4	Α	271
	.J=4,	Α	272
	<u>GALL ABSVAL (P40P1,P1,P4,VREF,TKEF,S,J,I0,RM4)</u>	Α	273
C	WRITE ABSOLUTE VALUES FOR REGION 5	Α	274
······	J=5	A	275
	CALL ABSVAL (PSOP1,P1,P5,VREF,TREF,S,J,IU,RMS)	A	276
.C	WRITE ABSOLUTE VALUES FOR REGION 6	A	277
		A	278
	CALL ABSVAL (POUPL, PI, PO, VK EF, IKEF, S, J, IU, KM6)	A	219
<u> </u>	<u> </u>	A	200
v	CALCULATE AND HOTTE STACHATION WALLES FOR FACE DECION	A ^	201
<u>с</u>	CALCULATE AND WRITE STAGNATION VALUES FOR EACH REGION	A A	202
Cherry and an		Ā	200
. ₩		Ā	285
		~	286
	₩RITE (6.132) J.P7.RH0/.T7	δ	287
		Δ	288
and the tree of the state	CALL (STRUP (GAMMA.RM2.P2.P72.P2UP72.2)	Δ	289
	P/20/=P/2/P/	A	290
	WRITE (6,133) J. PZ2, RH0Z2, TZ2, PZ202	A	291
	J=3	A	292
	CALL ISTROP (GAMMA, RM3, P3, PZ3, P30PZ3, 3)	A	293
	PZ30Z=PZ3/PZ	Α	294
	WRITE (6,133) J, PZ3, RH0Z3, TZ3, PZ30Z	Α	295
		Α	296
	CALL ISTROP (GAMMA, RM4, P4, PZ4, P40PZ4, 4)	A	297
	<u>PZ4UZ=PZ4/PZ</u>	А	298
	<u>WRITE (6.133)</u> J. PZ4, RHOZ4, TZ4, PZ402	Α	299

	J=5
	CALL ISTRUP (GAMMA, RM5, P5, P25, P50P25, 5)
	P2502=P25/P2
	WKITE (6,133) J,PZ5,RHUZ5,FZ5,PZ5UZ
	J=6
	CALL ISTRUP (GAMMA,RM6,Po,PZ6,PoUPZ6,o)
	P2602=P26/P2
	WRITE (6,133) J,PZ6,RHUZ6,FZ6,PZ6UZ
	CALCULATE AND WRITE STANTUN NUMBER, FLAT PLATE HEAT TRANSFER
	CUEFFICIENT(HFP), AND HEATING RATE(QFP) IN REGION 2
	J = 1 15 LAMINAR AND $J=2$ IS TURBULENT
	DU 117 J=1,2
	RECUVERY TEMPERATURE
	TR(J) = T2 + RR(J) + (T2 - T2)
	ECKERT≠S REFERENCE TEMPERATURE
	T2STAR(J)=.5*(TWALL+T2)+.22*(TR(J)-T2)
	RHG2STK(J)=144。*P2/(32。2*R*T2STAR(J))
	V2STAR(J)=VISCJ(VREF,TREF,T2SIAR,S)
	REY2STR(J)=RHG2STR(J)*U2*XL/V2STAR(J)
	LUCAL STANTON NUMBER IN REGIUN 2 AT IMPINGEMENT
	CF2=AA(J)*REY2STR**RN(J)
	lf (J.EQ.2) CF2=AA(J)*ALUG10(REY2STR)**RN(J)
	STN2(J)=CF2*PR**(-2./3.)
	FLAT PLATE HEAT TRANSFER CUEF(BTU/SEC-FT2-K)
	HFP(J)=STN2(J)*RHC2STR*U2*CP/778。
	FREE STREAM STANTON NUMBER
	STN1(J)=778。*HFP(J)/(RHU1*CP)
	FLAT PLATE HEATING RATE(BTU/SEC-FT2)
	QFP(J) = HFP(J) * (TR(J) - TWALL)
	MARKARIAN HEAT TRANSFER RATIOS
	$HK(J) = P_{0}OP_{2} \times PN(J)$
	PEAK HEATING RATE
	PEAK HEAT TRANSFER CUEF
	$HPK(J) = HFP(J) \neq HR(J)$
	WRITE (6,136) GFP(1), HFP(1), SIN2(1), SIN1(1), POUP2, HR(1), QPK(1), HPK
	WRITE (0,13/) UPP(2), HEP(2), SIN2(2), SIN1(2), POUP2, HR(2), OPR(2). HPK
	1(2)
	WRITE (6,138)
8	THE TATE THE TATE TINCE
9	CONTINUE
	RETURN THETAT AND TINCE TO ORIGINAL VALUES
	I INCR = SINCR
J	FURMAI (1H1, 9X, 49HIHIS PRUGRAM PERFORMS A TYPE 2 SHOCK INTERFERENC
	LE, 8H PATTERN, //, 13H RUN NUMBER , F5.2/)
L	FORMAT (16H XL(WALL LENGTH), 15X, F15.0, 4H FT)
2	FURMAT (//33H NO SOLUTION - BOW SHOCK DETACHED)
3	FORMAT (1H1, 20HINPUT VARIABLES ARE /9H THETAI =, F9.4, 19H DEG, AND
	LIHETAB = 9F9.4.9H DEG//1
4	FURMAI (//12H RATIOS ARE /)
>	FURMAT (1H /)
2	FURMAT (/1X+43HSHOCK REFLECTION NOT PUSSIBLE AT THIS POINT/)

127	FÜRMAT (1X,6HP6/P2=,F8.4,5X,7HRHÜ6/2=,F8.4,5X,0HT6/T2=,F8.4,5X,6HA	A 361
	16/A2=,F8.4,5X,6HU6/U2=,F8.4)	A 362
128	FURMAT (//7H REGION, 5X, 14HRELATIVE ANGLE, 10x, 14HABSOLUTE ANGLE/9X,	A 363
	15HTHETA,8X,4HBETA,7X,5HTHETA,8X,4HBETA,2YH UPSTREAM MACH LOCAL	A 364
	2 MACH)	A 365
129	FORMAT (1x, 11, 4F12.4, 2F15.4)	A 366
130	FORMAT (//7H REGION, 10X, 1HP, 12X, 3HRHJ, 11X, 1HT, 11X, 1HA, 11X, 1HU, 13X,	A 367
	12HMU, 3X, 11HREYNOLDS ND, 9H MACH NO)	A 368
131	FURMAT (14X, 3HPSI, 4X, 10HSLUG/CU FT, 5X, 7HRANKINE, 6X, 6HFT/SEC, 6X, 6HF	A 369
	1T/SEC,4X,11HSLUG/FT-SEC,11X,4H1/FT)	A 370
132	FURMAT (1X,15,F12.4,E15.5,3F12.4,2E15.5,F8.4)	A 371
133	FURMAI (1X,15,F12.4,E15.5,3F12.6,2E15.5)	A 372
134	FORMAT (/1X,25HSTAGNATION CONDITIONS ARE/7H REGION,0X,5HPSTAG,12X,	A 373
	13HRHU, 7X, 5HT STAG, 4X, 12HPSTAG/PSTAG1, /, 14X, 4HPSIA, 4X, 11HSLUGS/CU FT	A 374
	2,5X,7HKANKINE)	A 375
135	FORMAT (//14H HEAT TRANSFER,/17X,1HQ,14X,3HHFP,12X,8HSTANTON2,7X,8	A 376
	1HSTANTUN1,7X,5HP6/P2,10X,2HHR,12X,3HuPK,12X,3HHPK)	A 377
136	FURMAI (8H LAMINAR, 2X, 8(E15.5))	A 378
137	FURMAT (10H TURBULENT,8(E15.5))	A 379
138	FURMAT (1H0,41HHFP = HEAT TRANSFER COEF(BTU/SQ FT-SEC-R)/35H Q =	A 380
	1 HEAT TRANSFER(BTU/SQ FT-SEC))	A 381
	END	A 382-
C	•••••••••••••••••••••••••••••••••••••••	B 1
C	*****	B 2
C C	***************************************	D Z

USAGE

Program SHOCK for a type II interference pattern uses the standard FORTRAN NAMELIST input with \$DATAIN as the NAMELIST name. The input includes the flow conditions, gas properties, impinging-flow deflection or shock angle, and impingement location on the body. The program has an option to increment the body angle. These input variables should be applied first to the type I program to determine whether the interference is type I or II.

A description of the input and output variables and a sample case are presented.

Input Description

The \$DATAIN input for type II is as follows:

- RUN run number for identification
- RM1 M_{∞} , free-stream Mach number
- GAMMA c_p/c_v , ratio of specific heats

THETAI θ_i , shock generator angle, deg; or β_i , impinging shock angle, deg

- THETAB θ_b , body angle, deg (input as negative angle); or β_b , bow shock angle, deg (input as negative angle)
- TINCR increment for θ_i , deg
- NTIMES number of times to increment θ_i
- IPT initial point; 0 for stagnation conditions, 1 for free-stream static conditions
- T temperature at IPT, ^OR
- P pressure at IPT, psia
- AMW molecular weight (used to compute gas constant)
- TREF reference temperature for computing viscosity, ^OR
- VREF reference viscosity for computing viscosity, slugs/ft-sec
- S Sutherland's constant in viscosity equation
- XL X_i, distance from leading edge to impingement point, ft
- TWALL temperature at wall, ^OR
- CP c_p, specific heat at constant pressure, ft-lbf/slug-^OR
- PR N_{Pr}, Prandtl number
- ANGLE THET if θ_i input; BETA if β_i input
- ANGLE2 THET if θ_{b} input; BETA if β_{b} input
- TOL acceptable tolerance for equal pressures (0.001)

Output Description

The output is printing only. A heading and pertinent input for identification are printed before the calculations.

RUN NUMBER	run number for identification
M1	M_{∞} , Mach number in free stream
GAMMA(CP/CV)	ratio of specific heats
TEMP AT POINT ''IPT''	input as T, ^O R
PRES AT POINT "IPT"	input as P, psia
MOLECULAR WEIGHT	molecular weight (used to compute gas constant)
REFERENCE TEMP	reference temperature for computing viscosity, ^{O}R
REFERENCE VISCOSITY	reference viscosity for computing viscosity, slugs/ft-sec
S(SUTHERLAND NUMBER)	Sutherland's constant in viscosity equation
TEMP AT WALL	T _w , ^o R
СР	c_p , specific heat at constant pressure, ft-lbf/slug- OR
PRANDTL NUMBER	N _{Pr} , Prandtl number
XL(WALL LENGTH)	X_i , length from leading edge to impingement point, ft
THETAI	θ_i , shock generator angle, deg
THETAB	$\theta_{\rm b}$, body angle, deg
P2/P1, etc.	p_2/p_1 , etc., pressure ratios for regions listed
RHO2/1, etc.	$ ho_2/ ho_1$, etc., density ratios for regions listed

T2/T1, etc. T_2/T_1 , etc., temperature ratios for regions listedA2/A1, etc. a_2/a_1 , etc., ratios of speeds of sound in regions listedU2/U1, etc. u_2/u_1 , etc., velocity ratios for regions listed

RELATIVE ANGLE

THETA	flow angle relative to flow in upstream region, deg
BETA	shock angle relative to flow in upstream region, deg
ABSOLUTE ANGLE	
THETA	flow angle relative to free-stream flow, deg
BETA	shock angle relative to free-stream flow, deg
UPSTREAM MACH	Mach number in upstream region
LOCAL MACH	local Mach number
REGION	region in shock pattern
Р	static pressure in region, psia
RHO	static density in region, slugs/ft ³
Т	static temperature in region, ^O R
Α	speed of sound in region, ft/sec
U	velocity in region, ft/sec
MU	static viscosity in region, slugs/ft-sec
REYNOLDS NO	Reynolds number per foot in region

MACH NO Mach number in region

The following stagnation conditions are then listed:

PSTAG	total pressure in region, psia
RHO	total density in region, slugs/ft ³
TSTAG	total temperature in region, ^O R
PSTAG/PSTAG1	ratio of total pressure in region to free-stream total pressure

The pressure ratio and heat transfer for laminar and turbulent flow are listed as

Q	heat-transfer rate, Btu/ft ² -sec
HFP	flat-plate heat-transfer coefficient, Btu/ft ² -sec- ⁰ R
STANTON2	local incompressible Stanton number
STANTON1	compressible free-stream Stanton number
P6/P2	peak pressure ratio
HR	Markarian heat-transfer ratio
QPK	peak heating rate
НРК	peak heat-transfer coefficient

Sample Case - Input

\$DATAIN

RM1	= 0.6E+	01,
GAMMA	= 0.14E	+01,
THETAB	= -0.35E	+02,
THETAI	= 0.5E+	01,

TINCR		0.5E+01;
NTIMES	P 2	1,0
IPT	Nice Water	U ş
T	10	0.9E+03,
Ρ		0.4E+03,
АМы	4	0.2897E+02,
TREF	*	0.53E+03,
VREF		0.3801E-06,
XL	=	0.25E+00,
S	-	0.1986E+03,
TWALL	=	0.55E+03,
CP	8	0.6006E+04,
PR	=	U.72E+00,
RUN	=	0.1E+01,
ANGLE	=	0.69404725765109E+93,
ANGLE2		0.69404725765109E+93,
TOL	=	0.1E-02,

\$END

Sample Case - Output

THIS PROGRAM PERFORMS A TYPE 2 SHOCK INTERFERENCE PATTERN

RUN NUMBER 1.00

INPUT VARIABLES ARE

Ml	6.000	
GAMMA(CP/CV)	1.400000	
TEMP AT PUINT O	900.00000	RANK INE
PRES AT POINT O	400.000000	PSI
MOLECULAR WEIGHT	28.970000	
REFERENCE TEMP	530.00000	RANK INE
REFERENCE VISCOSITY	3.801000E-07	SLUG/(FT-SEC)
S(SUTHERLAND NUMBER)	198.600	
TEMP AT WALL	550.000	RANKINE
CP	6006.000	FT-LBF/(SLUG-RANKINE)
PRANDTL NUMBER	.720000	
XL(WALL LENGTH)	.250000	FT

INPUT VARIABLES ARE THETAI = 5.0000 DEG, AND THETAB = -35.0000 DEG

RATICS ARE

P2/P1= 23.0772	KHU2/1= 4.7963	T2/T1= 4.81	14 A2/A1=	2.1935	U2/U1=	•6860
P3/P1= 2.0103	RHU3/1= 1.6306	T3/T1= 1.23	28 A3/A1=	1.1103	U3/U1=	.9837
P4/P2= 1.7913	RH04/2= 1.5078	T4/T2 = 1.18	80 A4/A2=	1.0900	U4/U2=	.8562
P5/P1= 41.3370	RH05/1= 5.2606	T5/T1= 7.85	78 A5/A1=	2.8032	U5/U1=	-2180
P4/P1= 41.3371	RH04/1= 7.2318	T4/T1= 5.71	60 A4/A1=	2.3908	U4/U1=	.5874
P6/P4= 1.9068	RHU6/4= 1.5734	T6/T4= 1.21	19 A6/A4=	1.1008	06/04=	.7159
P6/P1= 78.8202	RHU6/1= 11.3786	T6/T1= 6.92	71 A6/A1=	2.6319	U6/U1=	.4205

REG	IGN RELA	TIVE ANGLE	ABSO	LUTE ANGLE			
	THETA	BETA	THETA	BETA	UPSTREAM MACH	LOCAL MACH	
2	-35.0000	-48.0670	-35.0000	-48.0670	6.0000	1.8765	
3	5.0000	13.1598	5.0000	13.1598	6.0000	5.3157	
40	11.3299	43.6580	-23.6701	8.6580	1.8765	1.4741	
5	-23.6701	-83.7595	-23.6701	-83.7595	5, 3157	• 4666	
6	-11.3299	-64.7425	-35.0000	-88.4127	1.4741	•9585	

REGION	Ρ	RHO	Т	Α	U	MU	REYNOLDS NO	MACH NO
	PSI	SLUG/CU FT	RANKINE	FT/SEC	FT/SEC	SLUG/FT-SEC	1/FT	
1	.2533	1.93645E-04	109.7561	513.5679	3081.4074	8.46377E-08	7.05004E+06	6.0000
2	5.8465	9.28781E-04	528.0852	1126.5113	2113.9285	3.79038E-07	5.17989E+06	1.8765
3	.5093	3.15760E-04	135.3111	570.2302	3031.1919	1.06990E-07	8.94597E+06	5.3157
4	10.4725	1.40040E-03	627.3680	1227.8483	1809.9101	4.31811E-07	5.86970E+06	1.4741
5	10.4725	1.01869E-03	862.4436	1439.6234	671.7546	5.41796E-07	1.26304E+06	.4666
6	19.9687	2.20341E-03	760.2870	1351.6752	1295.6479	4.96218E-07	5.75321E+06	•9585

STAGNATION CONDITIONS ARE	STAGNATION	I CONDITIONS	AR E
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JINONAIL	OW CONDITION	IJ ANC		
REGION	PSTAG	RHO	TSTAG	PSTAG/PSTAG1
	PSIA	SLUGS/CU FT	RANKINE	
1	400.0000	3.72856E-02	900.0000	
2	37.7814	3.52176E-03	900.000039	.094454
3	386.5123	3.60280E-02	900.008771	.966281
4	37.0316	3.45186E-03	900.000057	.092579
5	12.1574	1.13324E-03	899.999987	.030394
6	36.0393	3.35937E-03	900.000056	.090098

HEAT TRANSFER

	Q	HEP	STANTON2	STANTON 1	P6/P2	HR	QPK	HPK
LAMINAR	1.58922E+00	5.41165E-03	4.11392E-04	1.17481E-03	3.41551E+00	4.87705E+00	7.75069E+00	2.63929E-02
TURBULENT	9.18804E+00	2.95032E-02	2.24282E-03	6.40483E-03	3.41551E+00	2.84078E+00	2.61012E+01	8.38120E-02

HEP = HEAT TRANSFER CUEF(BTU/Sw FT-SEC-R) Q = HEAT TRANSFER(BTU/SQ FT-SEC)

PART III – TYPE III INTERFERENCE

PROBLEM DISCUSSION

A type III shock-interference pattern occurs when a weak impinging shock intersects a strong detached bow shock, as illustrated in figure 1(c). The shear layer emanating from the shock intersection attaches to the surface with subsonic flow above the shear layer turning upward and supersonic flow below the layer passing through an oblique shock in order to turn parallel with the surface. On a blunt body the shock intersection occurs near or above the lower sonic point, as shown in figure 2.

Once the flow conditions in region 1 and either the angle θ_i or β_i are specified, the triple-shock configuration at point A shown in figure 5 is solved by using an iterative procedure similar to that discussed for type I. The iterative procedure for type III differs in that the strong-shock solutions of the Rankine-Hugoniot equations are used in going from region 1 to region 2. The reflected shock at the attachment point C intersects the transmitted bow shock at point B and results in another triple shock. The analysis thus far is exact. Results from this analysis are used in the following approximate analytic technique to determine the peak pressure and heat transfer at the shear-layer attachment point. The reflected-shock angle at point C is obtained once the flow deflection angle $\bar{\theta}_5$ is specified. The reflected-shock angle and wall pressure (peak pressure) in region 5 are obtained from the Rankine-Hugoniot relations for attachment on a two-dimensional body. For attachment on a body of revolution, tangent-cone approximations (ref. 9) are used to determine the shock angle and wall pressure. In the present analysis, the flow model consists of a plane shock intersecting the bow shock of a sphere in the vertical plane of symmetry.

Peak heating at the wall is caused by the attaching shear layer, which is similar to the case of a reattaching shear layer in a separation region. Correlations proposed by Bushnell and Weinstein (ref. 3) for reattachment heating on two-dimensional ramps are used. The peak heat transfer at attachment is

$$Q_{pk} = A \rho_w u_5 c_p \left(T_{aw} - T_w \right) \left(\frac{\mu_w \sin \bar{\theta}_5}{\rho_w u_5 \bar{\delta}_{SL}} \right)^N$$
(2)

where u_5 is the velocity in region 5, the subscript w indicates wall values, and δ_{SL} is the shear-layer thickness at attachment. The constants A and N (from data in ref. 3) are 0.19 and 0.5 for a laminar shear-layer reattachment, and 0.021 and 0.2 for a turbulent interaction. For the present case (ref. 2) the attachment angles are higher than those of reference 3 and the attachment is three dimensional in nature. Therefore,

values of A obtained from correlations of peak-heating data for free shear layers reported in references 2 and 10 are used (0.40 for laminar and 0.06 for turbulent interactions).

The shear-layer thickness at attachment is obtained from the following expressions in reference 3:

Laminar,

$$\delta_{\rm SL} = 5.0 \left(\frac{l_{\rm SL} \mu_4}{\rho_4 u_4} \right)^{0.5} \tag{3}$$

Turbulent,

$$\delta_{\rm SL} = 0.123\ell_{\rm SL} \tag{4}$$

where $l_{\rm SL}$ is the length of the shear layer from A to C in figure 5. The shear-layer length is determined from the geometry of the triangle ABC formed by the shock and the shear layer and from the shock length AB (or $L_{\rm SH}$), which must be obtained experimentally or from some approximate method. Shear-layer transition data discussed in reference 11 are useful in determining the state of the shear layer at attachment.

The reference heating used is the stagnation-point value on a sphere obtained from reference 12:

$$Q_{stag} = 0.76 (N_{Pr})^{-0.6} c_p (\rho_w \mu_w)^{0.1} (\rho_{stag} \mu_{stag})^{0.4} (T_{stag} - T_w) \sqrt{\left(\frac{du_w}{ds}\right)_{stag}}$$
(5)

where (from ref. 13)

$$\left(\frac{\mathrm{du}_{\mathrm{W}}}{\mathrm{ds}}\right)_{\mathrm{stag}} = \frac{\mathrm{u}_{\infty}}{\mathrm{R}_{\mathrm{b}}} \left\{ \left(\frac{\gamma - 1}{\gamma}\right) \left[1 + \frac{2}{(\gamma - 1)\mathrm{M}_{\infty}^{2}}\right] \left(1 - \frac{1}{\gamma \mathrm{M}_{\infty}^{2}}\right) \right\}^{0.5}$$
(6)

PROGRAM DESCRIPTION

The main program reads the input, calls the various subprograms, and computes the heat transfer. TYP4 computes the flow deflection angle of the shear layer. FTHETA is called to compute the flow angle and FINDB is called to compute the shock angles in each region. The subprograms OBLIQ, FINDM, PRATIO, MLTRT, ABSVAL, AND ISTROP compute flow variables and ratios of the flow variables. PINPUT prints the input variables. The flow charts and listings of these subprograms are presented in part VII. For the axisymmetric option, FINDBC computes the conical shock angle at the shear-layer attachment and PRATC computes the ratio of the pressure at the wall to the static pressure upstream of the conical shock by use of a tangent-cone approximation. The flow diagrams and listings for the main program, PRATC, and FINDBC follow.

Program Flow Chart - Main





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Program Listing - Main

		Α	2
		A	3
PURPOSE		4	4
THIS PR	ROGRAM PERFORMS A TYPE III SHOCK INTERFERENCE PATTERN	Α	5
		Α	6
		A	1
СОММОN	PZ, RHOZ, TZ, PIOPZ, RHO10Z, TIOTZ,	A	8
СОММОN 1	PZ, RHOZ, TZ, P10PZ, RH010Z, T10TZ, PZ2, RH0Z2, TZ2, P20PZ2, RH02Z2, T20TZ2,	А А А	7 8 9
СОММОN 1 2	PZ, RHOZ, TZ, P10PZ, RH010Z, T10TZ, PZ2, RH0Z2, TZ2, P20PZ2, RH02Z2, T20TZ2, PZ3, RH0Z3, TZ3, P30PZ3, RH03Z3, T30TZ3,	А А А А	8 9 10
гоммол 1 2 3	PZ, RHOZ, TZ, P10PZ, RH010Z, T10TZ, PZ2, RH0Z2, TZ2, P20PZ2, RH02Z2, T20TZ2, PZ3, RH0Z3, TZ3, P30PZ3, RH03Z3, T30TZ3, PZ4, RH0Z4, TZ4, P40PZ4, RH04Z4, T40TZ4,	А А А А Д	8 9 10 11
соммол 1 2 3 4	PZ, RHOZ, TZ, P10PZ, RH010Z, T10TZ, PZ2, RH0Z2, TZ2, P20PZ2, RH02Z2, T20TZ2, PZ3, RH0Z3, TZ3, P30PZ3, RH03Z3, T30TZ3, PZ4, RH0Z4, TZ4, P40PZ4, RH04Z4, T40TZ4, PZ5, RH0Z5, TZ5, P50PZ5, RH05Z5, T50TZ5,	А А А А А	8 9 10 11 12

	6 P30P1, RH0301, T30T1, A30A1, U30U1,	A
	7 P40P3, RH0403, T40T3, A40A3, U40U3,	А
	8 P40P1, RH0401, T40T1, A40A1, U40U1,	Α
	9 P50P4, RH0504, T50T4, A50A4, U50U4,	A
	\$ P50P1, RH0501, T50T1, A50A1, U50U1,	Α
	\$ P1, RH01, T1, A1, U1, VISC1, REY1,	A
	\$ P2, RH02, T2, A2, U2, VISC2, REY2,	Α
	\$ P3, RH03, T3, A3, U3, VISC3, REY3,	Α
	\$ 94, RH04, T4, A4, U4, VISC4, REY4,	Δ
	\$ P5, RH05, T5, A5, U5, VISC5, REY5	Α
	DIMENSION RAT (30)	A
	DIMENSION VALU1(7), VALUZ(7), RATIO(7), VALUJ(7)	Δ
	DIMENSION DELTA(2), CHWALL(2), TR(2), ORATE(2)	A
	SET DEFAILUTS FOR INPUT VARIABLES	Δ
	DATA GAMMA/1.4/.SVINC/5.0/.NTIMES/1/.IPT/0/.AMW/28.97/	A
	DATA THSVI/0. /.BTSVI/0./	Δ
	DATA TREE/532.98/.VREE/.3807E-6/.RB/1.0/.S/216./.TWALL/530./	A
	DATA XI / 1.0/. CP/6006. /. PB/. 72/	Α
	DATA ANGLE/4HTHET/.TOL/.001/	Δ
	DATA XLRB/0./	Δ
	DATA BETA/4HBETA/	Δ
	DATA CODE/4HAXIS/,CODE1/4HNONE/	A
	DATA THETA5/0-/-CKTH5/0/-BUN/1-/	Δ
	NAMELIST /DATAIN/ RM1.GAMMA.THETAI.TINCR.NTIMES.IPT.T.P.AMW.TRFF.V	Δ
	IREE.B.B.S.TWALL.XL.CP.PR. NPTION.TOL.ANGLE.XLRB.THETA5.CKTH5.RUN	۵
		Δ
	· · · · · · · · · · · · · · · · · · ·	۵
		Â
		~
		2
	· · · · · · · · · · · · · · · · · · ·	A A
)1	INCRESVINC	A A
	THETATETHSVI	A
	BETAI=BTSVI	A A
	XLRB=0.	A
	10=1	A
	READ (5,DATAIN)	A
	(F) (ENDEILE 5) 102,103	A
)?	STOP	A
) 3	CONTINUE	A
	WRITE(6, DATAIN)	
	WRITE (6,125) RUN	A
	THSVI=THETAI	A
	RTSVI=BETAT	A
	SVINC=TINCR	A
	IF (XLRB.NE.0.) GO TO 104	A
	XLRB=XL/RB	A
	GO TO 105	A
04	XL=XLRB*RB	A
)5	CONTINUE	Δ.
	XI 12=XL	A
	GAS CONSTANT(FT-LBF/LBM-R)	A
	R=1544.3/AMW	A
	DENSITY (SLUG/(CU FT)	A
	RHN=P*144./(32.2*R*T)	Α
	CALL PINPUT (RM1,GAMMA,IPT,T,P,AMW,TREF,VREF,XL,S,TWALL,CP,PR)	A
	WRITE (6,126) XL12	Α
	WRITE (6,127) RB	Α
	WRITE (6,129) OPTION	A
	INPB=0	А
	TINCR=TINCR/57, 296	А
	THETA 1=THETA 1/57-296	A
	RETAI = RETAI / 57.296	A
	(1) 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	

С

	THE TATATUETAT TINCO	A	76
		A A	10
	$\frac{\partial c}{\partial t} = \frac{1}{10} \frac{1}{$	A	77
104	T_{7-T}	A A	78
100	2407=240	A	79
		Ā	80
		Δ	81
107		A	82
	2H01= RH0	A	83
		4	84
108	CONTINUE	Δ	85
• •	CALL ISTROP (GAMMA, RM1, P1, PZ, P10PZ, IPT)	Α	86
	00 124 I=1, NTIMES	Α	87
	1 S W = O	Α	88
	TE (ANGLE-NE-BETA) GO TO 109	Α	89
С	BETAL WAS INPUT INSTEAD OF THETAL	A	90
	INP8=1	A	91
	PETAI=BETAI+TINCR	A	92
	THETAI=FTHETA(GAMMA,PM1,BETAI)	Α.	93
	60 TO 111	A	94
109	THETAI = THETAI + TINCR	A A	95
	PFTAL=FINDB(GAMMA, RM1, THFTAL, L, TERROR)	д л	90
110	$(1 + (1 + RK^{-1}K^{-2}) + (1 + (1 + 1)) + (1 + RK^{-1}K^{-1}) +$	А А	99
110	GD TO TIOI,IOI,IOI,IOI, TERFOR	Δ	90
r	ECROPE - 1 ONE SOLUTION WAS FOUND. CONTINUE	Δ	100
c c	2 SOLITION DID NOT CONVERGE. USE LAST BETA COMPIL	Δ	101
ř	3 NO SOLUTION WAS FOUND. START NEW CASE	A	102
n	4 NOT DEFINED	A	103
111	BIDEG=BETAI*180./3.1416	Α	104
	THIDEG=THETAI*180./3.1416	Α	105
	WRITE (6,129)	Α	106
	WRITE (6,130) THIDEG, BIDEG	Α	107
С		A	108
C	2	A	109
С	ITERATE ON THETAE UNTIL $P2 = P4$	A	110
ç		A	111
С		A A	112
		А А	110
	N+1AZ=1.5703	A A	115
	MM3=FINDM(GAMMA,KMI)SIN(DFIAI))DE(AI)DE(AI)	Ā	116
c	23UPL=PRAILUUGAMMA,RML,SINUUGIALUY A TYDE A INTEREOFNICE DATTEDN WITH INITIAL MACH NO RM1	Δ	117
r r	ENTEDING AT ANGLE O DEGREES	Δ	118
(CALL TYPE (THETAF. BETA2. PM). RM3. THETA1. THETA4. BETA4. P30P1. GAMMA. TO	Â	119
	11. JERBOR)	A	120
	IF (IERROR-3) 112,101,101	Α	121
С		Α	122
С		Α	123
С	CALCULATE AND WRITE PARAMETER RATIOS FOR 2/1, 4/3, 4/1	Α	124
С		Α	125
С	- • • • • • • • • • • • • • • • • • • •	A	126
112	WRITE (6,131)	A	127
	10=1	Α	128
	CALL OBLIG (GAMMA,RM1,ABS(THETAF),BETA2,RM2,P20P1,1,2,IO)	A	129
	CALL OBLIQ (GAMMA, RM1, THETAI, BETAI, RM3, P30P1, 1, 3, IO)	A	130
	CALL OBLIQ (GAMMA, RM3, THETA4, BETA4, RM4, P40P3, 3, 4, 10)	A	131
_	CALL MLTRT (P40P3, P30P1, P40P1, 1, 4, 10)	Α	132
с	WRITE THETA AND BETA ANGLES AND MACH NUMBER	A	155
	WRITE (6,132)	Д А	134
	111111111111111111111111111111111111111	A	133

```
IF (THETAF.LT.O.) BFTA2=3.14159-BETA2
                                                             A 150
RETDEG=BETA2*57.296
                                                             A 137
J = 2
                                                             A 138
WRITE (6,133) J, THEDEG, BETDEG, THEDEG, BETDEG, RM1, RM2
                                                             A 139
THDEG=THETAI*57.296
                                                             A 140
BETDEG=BETA1*57.296
                                                             A 141
1=3
                                                             A 142
WRITE (6,133) J,THDFG,BETDEG,THDEG,BETDEG,RM1,RM3
                                                             A 143
THDEG=-THETA4*57.296
                                                             A 144
BETDEG=-BETA4*57.296
                                                             A 145
ABSTH=THEDEG
                                                             A 146
ABSBT=THIDEG+BETDEG
                                                             A 147
1=4
                                                             A 148
WRITE (6,133) J.THDEG, BETDEG, ABSTH, ABSBT, RM3, RM4
                                                             A 149
A 150
                                                             A 151
CALCULATE ABSOLUTE VALUES FOR POINTS O THRU 4
                                                             4 152
                                                             4 153
WRITE (6,134)
                                                            A 155
WRITE (6,135)
                                                             4 156
VISC1=VISCJ(VREF, TREF, T1, S)
                                                            A 157
A1=SQRT(32.2*GAMMA*R*T1)
                                                            Å 158
U1=A1*PM1
                                                            A 159
PFY1=RH01*U1/VISC1
                                                            A 160
                                                            A 161
J=1
WRITE (6,136) J.P1.RHO1.T1.A1.U1.VISC1.REV1.RM1
                                                            A 162
1=2
                                                            A 163
CALL ABSVAL (P20P1,P1,P2,VREF,TREF,S,J,I0,RM2)
                                                            A 164
.1≈3
                                                            A 165
CALL ABSVAL (P30P1,P1,P3,VREF,TREF,S,J,I0,RM3)
                                                            A 166
1=4
                                                            A 167
CALL ABSVAL (P40P1,P1,P4,VREF,TREF,S,J,I0,RM4)
                                                            A 168
WRITE (6.137)
                                                            A 169
1=1
                                                            A 170
WRITE (6,136) J, PŽ, RHOZ, TZ
                                                            A 171
1 = 2
                                                            A 172
CALL ISTROP (GAMMA, RM2, P2, P22, P20P22, 2)
                                                            A 173
PZ2DZ=PZ2/PZ
                                                            A 174
WRITE (6,136) J, PZ2, RHOZ2, TZ2, PZ2DZ
                                                            A 175
                                                            A 176
1=3
CALL ISTROP (GAMMA, RM3, P3, PZ3, P30PZ3, 3)
                                                            A 177
PZ302=PZ3/9Z
                                                            A 178
WRITE (6,136) J, PZ3, RH0Z3, TZ3, PZ30Z
                                                            A 179
                                                            A 180
J = 4
CALL ISTROP (GAMMA, RM4, P4, PZ4, P40PZ4, 4)
                                                            A 181
PZ4OZ=PZ4/PZ
                                                            A 182
WRITE (6,136) J, P74, RH024, T24, P7402
                                                            A 183
                                                            A 184
IF (OPTION.EO.CODE1) GO TO 124
                                                            A 185
A 186
CONDITION 1
                                                            A 187
INCREMENT THETA 5 UNTIL REFLECTION AT PT 5 NOT POSSIBLE AT WHICH
                                                            A 188
TIME REFINE THETAS TO FIND MORE PRECISELY WHEN THIS OCCURS
                                                            A 189
                                                            A 190
                                                            A 191
IF (CKTH5.EQ.0) GO TO 113
                                                            A 192
DTHETA=THETA5/57.296
                                                            A 193
                                                            A 194
THETA5=DTHETA
ISW=1
                                                            A 195
GO TO 114
                                                            A 196
DTHETA=5.0/57.296
                                                             A 197
```

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	THETAS=DTHETA	Д	198
	1 S W=0	А	199
114	THPEG=-THET45*180./3.1416	A	200
	THE TAB = THETAF - THE TAS	Α	201
	THPDEG = THETAB * 180./3.1416	A	202
	WRITE (6,129)	A	203
	IF (RM4.LF.1.) WRITE (6,138)	A	204
	IF (RM4.LF.1.) GO TO 124	A	205
	WRITE (6,139)	A	206
	IF (OPTION.NE.CODE) GO TO 115	A	207
ç		A	208
c		A	209
C C	AXISYMMETRIC CASE. THETAS, KMS, PSUP4 ARE INPUT	A	210
с С		A	211
L L		A A	212
	WRITE (0)140)	А	213
	BETA5=FINDBC(RM4,GAMMA,THETA5,IERROR)	Α	214
	TF (IERROR.GT.2) GO TO 123	A	215
С	PRESSURE RATIO AT SURFACE	A	216
	P50P4=PRATC(RM4,GAMMA,THETA5)	Α	217
	THETA=FTHETA(GAMMA,RM4,BETA5)	Α	218
С	AACH NUMBER ALONG SHOCK	Α	219
	RMSQ=FINDM(GAMMA,RM4,SIN(BETA5),BETA5,THETA)**2	Α	220
	GM1H=(GAMMA-1.)/2.	Α	221
	P5P4=PRATIO(GAMMA, RM4, SIN(BETA5))	Α	222
-	P5SP5=P5DP4/P5P4	A	223
C	MACH NUMBER AT SURFACE	Α	224
	PM5=SQRT((P5SP5**(-GM1H)*(1.+GM1H*RMSQ)-1.)/GM1H)	A	225
	150125=1./(1.+(GAMMA-1.)*RM5**2/2.)	A	226
	$15 = 12 \times 150125$	A	221
		A	228
	RHD5=P5*144./(32.2*R*15)	A	229
	VISCJ=VISCJ(VREF, IREF, IS, S)	A	230
	$\Delta 5 = SQR1(32.2\times GAMM4 \times K \times 15)$	A	231
		A	232
	PET0=NH02*U2/VI365	A	223
r ·		A A	224
c		A A	233
с. С.		A A	230
r	THOTOTHENSTUNAL CASE.	A A	220
r	CALCULATE AND WRITE PARAMETER RATIOS FOR 574 571	A A	230
r		Ā	240
115	BETA5=FINDB(GAMMA, BM4, THETA5, 1, LEBROR)	Δ	241
1	IF (JERROR-3) 116.121.121	Δ	242
116	BETDEG=BETA5*180 - /3 - 1416	Δ	243
	THSV=THETA5	A	244
	WRITE (6.141) BETDEG	A	245
	10=-1	Δ	246
	CALL OPLIQ (GAMMA.RM4.THETA5.BETA5.RM5.P50P4.4.5.IO)	Α	247
	CALL MLTRT (P50P4,P40P1,P50P1,1,5,10)	A	248
С	CALCULATE ABSOLUTE VALUES AT 5	A	249
	CALL ABSVAL (P50P1,P1,P5,VREF,TRFF,S,5,-1)	Α	250
117	BETDEG=-BETA5*57.296	A	251
	BBDEG= (THETAF-BETA5)*57.296	Α	252
	WRITE (6,142) THDEG, THBDEG, BETDEG, BBDEG	A	253
	WRITE (6,143) P50P4	Α	254
	WRITE (6,144) P5,RH05,T5,A5,U5,VISC5,REY5,RM5	А	255
C		A	256

C		A
С.	CALCULATE AND WRITE STANTON NUMBER.HEAT TRANSFER COEFFICIENT(H).	Α
r	HEATING RATE(ORATE), AND SHEAR LAYER THICKNESS (DELTA) EDP	Δ.
r r	AND	4 ·
-	LAMINAK ANG (UKBULEN) FLUW.	A
Ľ –		A
0		Α
С	VISCOSITY AT WALL (SLUG/FT-SEC)	Α
	VWAII = VISCI(VREF, TREF, TWAII, S)	۵
r	DENSITY AT WALL (SLUC / T CUBE)	Â
	VHIW=P5*L44.7(32.2*R*1WALL)	A
	WRITE (6,145) RHOW, VWALL	Α
	WRITE (6,146)	A
0	SHEAR LAYER LENGTH (FEET)	Α
	X! 13=X! 12*COS (ΒΕΤΔ4-ΤΗΕΤΔ4)-X! 12*SIN(ΒΕΤΔ4-ΤΗΕΤΔ4)/ΤΔΝ(ΒΕΤΔ5)	Δ
-	SHEAD I AVED THICKNESS AT MAIL (ET)	Â
		/4 A
	$\frac{1}{2} = \frac{1}{2} \cdot \frac{1}$	A .
	$0 + 1 + 4(2) = 1 \cdot 6 + \times 1 \cdot 3 + 1 \cdot 3 \cdot 3$	Α
C	STANTON NUMBER IN REGION 5	Α
	CH=RHOW*U5/(VWALL*SIN(THETA5))	Α
	(HWALL(1) = .19/(CH*0ELTA(1)) **.5	۵
	C = WA + (2) = 0.21 / (C = 200 + 7.12) + 20 = 0.22	
~	$\bigcup_{i=1}^{n} A_i \cap A_i$	<u>д</u>
	RECUVERY LEMPERALURE (DEG-K)	Α.
	TR(L)=T5+(TZ-T5)*SQRT(PR)	Α
	TR(2)=T5+(T2-T5)*(PR**(1。/3。))	Α
2	HEAT FLOW(BTU/FT2-SEC)	Α
	OR = RHOW + 15 + CP / 778	۵
	OD ATE(1) = OD * (TD(1)) = TUAL(1) * C UUAL(1) A	Â
		A .
	ORATE(Z) = ORA(TR(Z) - TWALL) + UHWALL(Z)	A
	HI=QR*CHWALL(1)	Α.
	H2=QR*CHWALL(2)	Α :
•	FIND HEAT TRANSFER FOR A BLUNT BODY WITH NO IMPINGING SHOCK	A
•		Δ
	GM1=GAMMA~1.	Ā
	OP I-OAMMATL.	А.,
	25=12	A
	VISCOSITY AT STAGNATION COND IN REGION 5(SLUG/FT-SEC)	Α.
	V5S=VISCJ(VREF,TREF,T75,S)	Α.
,	CONVERSION FACTOR ((BTU-SEC2)/(FT2-LBF))	A :
	$\Delta \Omega = \{, 76/PR**(, 6)\}/(778, *SQRT(32, 2))$	Δ
•	DELTA HEAT RETUREN TWALL AND T76/FT_(RE/SINC)	~
,	DELTA HEAT DETWEEN TWALL AND TZD(FT~LDF/SLUG)	A .
		A
	× M T 2Ø= K M T * K M T	Α :
5	CALC STAGNATION PRESSURE RATIO ACROSS A NORMAL SHOCK FOR FREE	Δ.
		۸ :
•	5 (N CAR) (CONVELLINES) TV-/CONVENT/CONVENT/CONVENT/CONVENT/CONVENT/CONVENT/CONVENT/CONVENT/CONVENT/CONVENT/CONVENT/CONVENT/CONVENT/CONV	м.: А
	T = T	A .
	IX=GPI/(2.*GAMMA*RMISQ-GMI)	A
	P7S=PZ*TY**(GAMM4/GM1)*TX**(1./GM1)	A
	BQS=((144.*VWALL)/(R*TWALL))**(.1)	A
	COS=((144,*V5S)/(8*T7S))**(,4)	Δ
	STACHATION VEHICLEY/ CONTENT	Ā -
,	STAGNATION VELOCITI GRADIENT	A :
	UGKUIS=UI/KK*SQKI(GMI/GAMMA*(I•+2•/(GMI*KMISQ))*(I•+1•/(GAMMA*RMIS	A
		A :
	10)))	A -
	STAGNATION HEATING-3D(BTU/FT2-SEC)	A :
,	STAGNATION HEATING-3D(BTU/FT2-SEC) OWS3D=AQ*BQS*CQS*DQ*SQRT(PZS*UGRDTS)	A
	10))) STAGNATION HEATING-3D(BTU/FT2-SEC) OWS3D=AQ*BQS*CQS*DQ*SORT(PZS*UGRDTS) Q-PEAK RATIOS	A : A : A :
	10))) STAGNATION HEATING-3D(BTU/FT2-SEC) OWS3D=AQ*BQS*CQS*DQ*SORT(PZS*UGRDTS) O-PEAK RATIOS OR3DL=ORATE(1)/OWS3D	A : A : A :
	10))) STAGNATION HEATING-3D(BTU/FT2-SEC) OWS3D=AQ*BQS*CQS*DQ*SQRT(PZS*UGRDTS) O-PEAK RATIOS OR3DL=QRATE(1)/QWS3D OR3DL=ORATE(1)/QWS3D	A : A : A :
	<pre>ID))) STAGNATION HEATING-3D(BTU/FT2-SEC) OWS3D=AQ*BQS*CQS*DQ*SORT(PZS*UGRDTS) D-PEAK RATIOS OR3DL=QRATE(1)/QWS3D QR3DT=QRATE(2)/QWS3D CTUTEDE UP AT ATABASEED COEF(DTUISOFT AFE D)</pre>	A A A A
	TAGNATION HEATING-3D(BTU/FT2-SEC) OWS3D=AQ*BQS*CQS*DQ*SQRT(PZS*UGRDTS) D-PEAK RATIOS OR3DL=ORATE(1)/QWS3D OR3DT=ORATE(2)/QWS3D STAGNATION HEAT TRANSFER COEF(BTU/SQFT-SEC-R)	А А А А А
	ID))) STAGNATION HEATING-3D(BTU/FT2-SEC) DWS3D=AQ*BQS*CQS*DQ*SORT(PZS*UGRDTS) D-PEAK RATIDS OR3DL=ORATE(1)/QWS3D QR3DT=ORATE(2)/QWS3D STAGNATION HEAT TRANSFER COEF(BTU/SQFT-SEC-R) HS3=QWS3D/(TZ5-TWALL)	А А А А А
	TOTION HEATING-3D(BTU/FT2-SEC) WWS3D=AQ*BQS*CQS*DQ*SORT(PZS*UGRDTS) O-PEAK RATIOS OR3DL=ORATE(1)/QWS3D OR3DT=ORATE(2)/QWS3D STAGNATION HEAT TRANSFER COEF(BTU/SQFT-SEC-R) HS3=QWS3D/(TZ5-TWALL) H-PEAK RATIOS	А А А А А А
	10))) STAGNATION HEATING-3D(BTU/FT2-SEC) OWS3D=AQ*BQS*CQS*DQ*SORT(PZS*UGRDTS) O-PEAK RATIOS OR3DL=ORATE(1)/QWS3D OR3DT=ORATE(2)/QWS3D STAGNATION HEAT TRANSFER COEF(BTU/SQFT-SEC-R) HS3=QWS3D/(TZ5-TWALL) H-PEAK RATIOS H1HS3=H1/HS3	А А А А А А А

С	PEAK PRESSURE RATIO	A 3
	P5OPZS=P5/PZS	A 3
	WRITE (6.147) P50PZS	A 3
	WRITE (6.148) XL13	A 3
	WRITE (6.149) QWS3D.HS3	A 3
	WRITE (6.150)	A 3
	WRITE (6,151) CHWALL(1), QRATE(1), DELTA(1), QR3DL, H1HS3, CHWALL(2), QR	A 3
<u>.</u>	LATE(2), DELTA(2), QR3D1, H2H53	A 3
C	ARE WE ITERATING IN THETAS TO FIND PLAT WHICH CONDITION I OCCURS	A 3
C	IF NOT, CONTINUE INCPEMENTING THETAS.	A 3
	IF (CKIH5.NE.0.) IHEIA5=IHEIA5*57.296	A 3
	1F (ISW) 119,119,118	ۆ A
118	60 10 124	A 3
ΤĻà		A 3
~	60 19 114	C A C
C C	• • • • • • • • • • • • • • • • • • • •	A 3
ι. r		C A C
c r	TTEDATE ON THETAE	A 3
r.	TIERATE UN THETAD	A 3
r r		כא
120	••••••••••••••••••••••••••••••••••••••	C A c A
120	$\frac{1}{1} = \frac{1}{1} $	A 2
-		A 3
L,	INGREASE THE AJ	A J A 7
	$\frac{1}{1} = \frac{1}{2} = \frac{1}$	A 3
) Γ (DIMETARLI (DIMET) GU (U 122)	A 3
		A 3
		A 3
	$\frac{1}{2} \sum_{i=1}^{n} \frac{1}{2} \sum_{i=1}^{n} \frac{1}$	ر بر د ۸
		ر بہ ۸ ک
		A 3
1	$ \begin{array}{c} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 $	Δ 3
		A 3
		Α 3
		A 3
22		A 3
L ¢ /		A 3
	G0 T0 114	Α 3
•	EIND LARGEST THETAS FOR AXIS CASE	4 3
23	PM SQ = RM4 *P M4	A 3
6 6	THE TAS=ASIN(SORT((11./RMSQ)/(GAMMA*(1+1./RMSQ))))	A 3
	THETA5=THETA5001	A 3
	7 S W=1	Α3
	60 TT 114	Α 3
24	CONTINUE	Α 3
- ·	GO TO 101	Α3
•		Α3
125	FORMAT (1H1,25X,7H* * *,//1X,57HTHIS PROGRAM PERFORMS A TYPE 3 S	Α3
	1UOCK INTERFERENCE PATTERN,//26X,7H* * */,11H RUN NUMBER,F7.2)	Α3
26	FORMAT (30H XL(SHOCK DISPLACEMENT LENGTH),F16.6,4H FT)	Α3
27	FORMAT (12H NOSE RADIUS,20X,F15.5,4H FT)	Α3
28	FORMAT (1X, SHOPTION, 35X, A4)	Α3
29	FORMAT (1H1)	Α 3
130	FORMAT (//1X,19HINPUT VARIABLES ARE/8H THETAL=,F9.4,4H DEG,5X,6HBE	Α3
	1TA (=, E9.4, 4H DEG/)	A 3
31	FORMAT (//1X, 10HRATIOS ARE/)	Α3
132	FORMAT (//7H REGION, 5X, 14HRELATIVE ANGLE, 10X, 14HABSOLUTE ANGLE, /9X	A 3
	1,5HTHFTA,8X,4HBETA,7X,5HTHETA,8X,4HBETA,5X,13HUPSTREAM MACH,2X,10H	43
	2LOCAL MACH)	A 3
133	EARMAT (1X.T1.4F12.4.2F15.4)	A 3

134	FORMAT (//7H REGION, 10X, 1HP, 12X, 3HRHO, 11X, 1HT, 11X, 1HA, 11X, 1HU, 13X,	<u>A</u>	367
	12HMU, 3X, 11H3EYNOLDS NO, 9H MACH NO)	Α	368
135	FORMAT (14X, 3HPSI, 4X, 10HSLUG/CU FT, 5X, 7HRANKINE, 6X, 6HFT/SEC, 6X, 6HF	A	369
	1 // SEC,4X,11HSLUG/FT-SEC,11X,4H1/FT)	Α	370
136	CORMAT (1X, I5, F12.4, F15.5, 3F12.4, 2E15.5, F8.4)	A	371
137	FORMAT (/1X+25HSTAGNATION CONDITIONS ARE/7H REGION,6X,5HPSTAG,12X,	Α	386
	13HRHD, 7X, 5HTSTAG, 4X, 12HPSTAG/PSTAG1, /, 14X, 4HPSIA, 4X, 11HSLUGS/CU FT	Α	387
	2,5X,7HRANKINE)	A	388
138	FORMAT (51H REGION 5 DOES NOT EXIST SINCE REGION 4 IS SUBSONIC)	٨	389
139	FORMAT (/16X,45H * * * * * * * * * * * * * * * * * * *	Α	390
140	FORMAT (//46H FOR A 3-DIMENSIONAL CASE THE FOLLOWING VALUES,28H RE	Α	391
	1FER TO SURFACE CONDITIONS)	A	392
141	FORMAT $(1X,7HBETA5 =,F10.3)$	Α	393
142	FORMAT (17H THETA5 RELATIVE=,F10.3,10H,ABSOLUTE=,F10.3/16H BETA5 R	Α	394
	1+LATIVE=, F10.3, 10H, ABSOLUTE=, F10.3)	4	395
143	FORMAT (7H P50P4=,F10.4,/)	Α	396
144	FORMAT (1X,30HABSOLUTE VALUES AT CONDITION 5/1X,2HP=,F9.4,2X,4HRHO	Α	397
	1=,E11.4,2X,2HT=,F9.4,2X,2HA=,F9.4,2X,2HU=,F9.4,2X,3HMU=,E11.4,2X	Α	398
	2,12HREYNOLDS NO=,511.4,2X,8HMACH NO=,58.4)	Α	399
145	FORMAT (14H RHO WALL = $, E11.4/15H$ VISC WALL = $, E11.4$)	A	400
146	FORMAT (1H)	Ą	401
147	FORMAT (723H PEAK PRESSURE RATIO ,F8.4)	Α	402
148	FORMAT (25H XI13(SHEAR LAYER LENGTH),7X,F15.5,4H FT)	Α	403
149	FORMAT (48H STAG HEATING-3D NO INTERFERENCE (BTU/SQ FT-SEC),E15.5,	Α	404
	120H H(BTU/SQ-FT-SEC-R),E15.5,/)	Α	405
150	FORMAT (//17X,26HSTANTON Q(BTU/SQ FT-SEC),6X,9HDELTA(FT),6X,9HQR	Α	406
	1ATIO-3D,6X,9HHRATIO-3D,)	Α	407
151	FORMAT (1X,7HLAMINAR,2E18.5,3E15.5/10H TURBULENT,E16.5,E18.5,3E15.	Α	408
	15)	Α	409
	END	A	410-
С		8	1

Program Flow Chart – PRATC

Function PRATC computes the pressure ratio across a conical shock. The flow diagram is as follows:



Program Listing - PRATC

	FUNCTION PRATE (RM.GAMMA.THETA)	D	2
С	CALCULATE PRESSURE RATIOS(P2S/P1) FCP AXISYMMETRICAL CASE ALONG	D	3
c	THE SHEAR LAYER	D	4
Ŭ		D	5
	RM6=RM**6	С	6
	$G2=1 \cdot -1 \cdot / PMSQ$	D	7
	$G_3 = G_{AMMA*}(1.+1.)(F_{NSQ})$	D	8
	F1=(GAMMA+7.)/4(GAMMA-1.)**2/16.+6./RM6+(RMSQ-1.)/(RM**4*SIN(THE	D	9
	1 TA))	D	10
	F2=.5*(GAMMA+7.)/(GAMMA+1.)*G2*(1.+1./RME)	D	11
	F3=.5*(GAMMA+7.)/(GAMMA+1.)*G3*(1.+1./FME)	D	12
	SINSC=SIN(THETA) * 2	D	13
	CP2S=.5*(F2+F1*SINSG-SGRT((F2-F1*SINSQ)**2-((F3-F1)*SINSQ)**2))	۵·	14
С	PRESSURE ON SHEAR LAYER - P2S/P1	D	15
•	PRATC=CP2S*RMSC*CAMMA/2.+1.	D	16
	FETURN	D	17
	FND	D	18-
С		Ε	1

Program Flow Chart - FINDBC

Function FINDBC calculates the shock angle when a conical shock is assumed. The flow diagram is as follows:



Program Listing - FINDBC

	FUNCTION FINDBC (RM, GAMMA, THETA, IERROR)	С	2
С	CALCULATE BETA USING A CONICAL RELATIONSFIP	С	3
	PRINT=IERROR	С	4
	IERFCR=C	С	5
	FMSQ=RM*RM	С	6
	$G_1 = (GAMMA+1)/2$	С	7
	$G_{2}=1 - 1 + RMSQ$	С	8
	$G_3 = G_A M M A * (1 + 1 + / F M S G)$	С	5
C	CHECK EDB STAND-CEE	C	10
°	IE (THETA-GT-ASIN(SQRT(G2/G3))) GC TO 1	C	11
	SINSO=SIN(THETA) **2	С	12
	$\Gamma_1 = G_2 + G_1 + S_1 N S_0$	C	13
		Ċ	14
	$C_{3} = (C_{3} - C_{1}) * S(C) * * 2$	Ċ	15
	$E = \{1, 0\}, 0 \in [1, 1], 0 \in $	C	16
	PETHEN	č	17
1		č	18
r r		č	19
L		č	20
	TE DETAT CE AN LETTE (4.2) DN.CANNA, TEREC	ř	21
	IF (PAINI-GESUS WAITE (0)27 RESOAFPASTIOLO	č	22
c	"ETOKN	r	22
5	CONVAL LIGUNO SOLUTION FOUND FOR DV. CANNA, THETA-3610 41	ř	24
2	ELEMAT (SOUND SULLITEN FLOND FOR RET GAMMA) THETAJSECON	r	25.
~	END		2.5
L	6	0	L

USAGE

Program SHOCK for a type III interference pattern uses the standard FORTRAN NAMELIST input with \$DATAIN as the NAMELIST name. The input includes the flow conditions, gas properties, impinging flow deflection or shock angle, shock displacement length, nose radius, and shear-layer angle relative to the local body slope. (See fig. 5.) The program can also increase the shock generator angle θ_i incrementally and the shear-layer angle $\bar{\theta}_5$ (if $\bar{\theta}_5$ is not specified) up to the maximum value for a type III interference. The ratio of shock displacement length to nose radius may also be used as an input instead of the individual lengths.

A description of the input and output variables and a sample case are presented.

Input Description

The \$DATAIN input for type III is as follows:

RUN	run	number	for	identification

- RM1 M_{∞} , free-stream Mach number
- GAMMA c_p/c_v , ratio of specific heats
- THETAI θ_i , shock generator angle, deg; or β_i , impinging-shock angle, deg
- TINCR increment for θ_i (Default = 5^o)
- **NTIMES** number of times to increment θ_i

IPT initial point; 0 for stagnation conditions, 1 for free-stream static conditions

T temperature at IPT, ^OR

P pressure at IPT, psia

- AMW molecular weight (used to compute gas constant)
- TREF reference temperature for computing viscosity, ^OR
- VREF reference viscosity for computing viscosity, slugs/ft-sec

S	Sutherland's constant in viscosity equation
RB	nose radius, ft
TWALL	temperature at wall, ^O R
XL	L _{SH} , shock displacement length, ft
СР	c _p , specific heat at constant pressure, ft-lbf/slug- ⁰ R
PR	N _{Pr} , Prandtl number
OPTION	AXIS for conical shock at shear-layer attachment; 2-D for plane shock at shear-layer attachment
TOL	acceptable tolerance for equal pressures (0.001)
ANGLE	THET if θ_i input; BETA if β_i input
XLRB	ratio of shock displacement length to nose radius (0 if XL and RB input)
THETA5	$\bar{\theta}_5,$ shear-layer angle relative to local body slope, deg (optional, input as negative angle)
CKTH5	0 if $\bar{\theta}_5$ not input; 1 if $\bar{\theta}_5$ input

Output Description

The output from this program consists of printing only. A heading and pertinent input for identification are printed before the results of the calculations.

RUN NUMBER	run number for identification
M1	$M_\infty,$ Mach number in free stream
GAMMA(CP/CV)	ratio of specific heats
TEMP AT POINT ''IPT''	input as T, ^O R
PRES AT POINT "IPT"	input as P, psia

MOLECULAR WEIGHT	molecular weight (used to compute gas constant)
REFERENCE TEMP	reference temperature for computing viscosity, $^{\mathrm{O}}\mathrm{R}$
REFERENCE VISCOSITY	reference viscosity for computing viscosity, slugs/ft-sec
S(SUTHERLAND NUMBER)	Sutherland's constant in viscosity equation
TEMP AT WALL	T_w , ^{o}R
СР	c_p , specific heat at constant pressure, ft-lbf/slug- ⁰ R
PRANDTL NUMBER	N _{Pr} , Prandtl number
XL(SHOCK DISPLACEMENT	LENGTH) length, ft
NOSE RADIUS	nose radius, ft
OPTION	type of calculation chosen (AXIS or 2-D)
THETAI	θ_{i} , shock generator angle, deg
BETAI	β_{i} , impinging shock angle, deg
P2/P1, etc.	p_2/p_1 , etc., pressure ratios for regions listed
RHO2/1, etc.	$ ho_2/ ho_1$, etc., density ratios for regions listed
T2/T1, etc.	T_2/T_1 , etc., temperature ratios for regions listed
A2/A1, etc.	a_2/a_1 , etc., ratios of speeds of sound in regions listed
U2/U1, etc.	u_2/u_1 , etc., velocity ratios for regions listed
RELATIVE ANGLE	
THETA	flow angle relative to flow in upstream region, deg
BETA	shock angle relative to flow in upstream region, deg

ABSOLUTE ANGLE

THETA	flow angle relative to free-stream flow, deg
BETA	shock angle relative to free-stream flow, deg
UPSTREAM MACH	Mach number in upstream region
LOCAL MACH	local Mach number
REGION	region in shock pattern
Р	static pressure in region, psia
RHO	static density in region, $slugs/ft^3$
Т	static temperature in region, ^O R
A	speed of sound in region, ft/sec
U	velocity in region, ft/sec
MU	static viscosity in region, slugs/ft-sec
REYNOLDS NO	Reynolds number per foot in region
MACH NO	Mach number in region
The following stagnation	conditions are then listed:
PSTAG	total pressure in region, psia
RHO	total density in region, slugs/ft ³
TSTAG	total temperature in region, ^O R
PSTAG/PSTAG1	ratio of total pressure in region to free-stream total pressure

The pressure ratios and heat transfer for laminar and turbulent flow are listed as a function of conditions in region 5:

THET	A5
------	----

RELATIVE	flow angle in region 5 relative to upstream flow, deg
ABSOLUTE	flow angle in region 5 relative to free-stream flow, deg
BETA5	
RELATIVE	shock angle in region 5 relative to upstream flow, deg
ABSOLUTE	shock angle in region 5 relative to free-stream flow, deg
PEAK PRESSURE RATIO	ratio of peak pressure p ₅ to stagnation pressure on sphere
XL13(SHEAR-LAYER LENGTI	H) length of shear layer, ft
STAG HEATING 3D NO INTER	FERENCE stagnation-point heat-transfer rate on sphere, Btu/ft ² -sec
Н	stagnation-point heat-transfer coefficient on sphere, Btu/ft^2 -sec- ${}^{O}R$
STANTON	peak Stanton number
ବ	peak heat-transfer rate, Btu/ft ² -sec
DELTA	shear-layer thickness at wall, ft
QRATIO-3D	Q_{pk}/Q_{stag} , ratio of peak heat-transfer rate to stagnation- point value
HRATIO-3D	H _{pk} /H _{stag} , ratio of peak heat-transfer coefficient to stagnation-point value

RHO WALL	density based on T_W
VISC WALL	viscosity based on $\ {\rm T}_{W}$
	Sample Case - Input

\$DATAIN

FM1	=	0.6E+C1,
GAMMA	63	0.145+01,
THETAI	Ħ	0.5E+01,
TINCR	=	0.5E+01,
NTIMES	=	l ,
IPT	91	0,
T	#	0.9E+03,
Р	2	0.4E+03,
ANW	94	0.2897E+02.
TREF	=	0.53E+03;
VREF	=	0.3801E-06,
RB	=	0.5E+00,
S	=	0.1986E+03,
TWALL	=	0.55E+C3,
XL	=	0.2E+00,
CF	=	0.6006E+04,
PR	8	0.72E+00,
OFTION	12	0.14095221760901-267,
TOL	Ş9	0.1E-02,
ANGLE	15	0.69404725765109E+93;
XLRB	100	0 • 0 •
THETAS	-	C.2E+02,
CKTH5	400 809	0.1E+01,
RUN	43 83	0.1E+01,
\$ E ND		

* * *

THIS PREGRAM PERFORMS A TYPE 3 SHOCK INTERFERENCE PATTERN

RUN NUMBER 1.CO
INPUT VARIABLES ARE
M1 6.000 GAMMA(CF/CV) 1.400000 TEMP AT POINT O 900.000000 PRES AT POINT O 400.000000 MCLECULAR WEIGHT 28.570000 PEFERENCE TEMP 530.000000 REFERENCE VISCOSITY 3.801000E-C7 SUTFERLAND NUMBER) 158.600 TEMP AT WALL 550.000 CF 6006.0000 PRANDTL NUMBER .720000 XL(SFCCK DISPLACEMENT LENGTH) .20000 FT CFTICN AXIS
INPUT VARIABLES ARE THETAI= 5.0000 DEG BETAI= 13.1597 DEG
RATICS ARE
F2/P1= 40.7108RH02/1=5.2507T2/T1=7.7534A2/A1=2.7845U2/U1=.2491F3/P1=2.0103RHC3/1=1.6306T3/T1=1.2328A3/A1=1.1103U3/U1=.5837F4/P3=20.2512RHC4/3=4.6667T4/T3=4.3355A4/A3=2.0831U4/U3=.6396F4/P1=40.7104FHC4/1=7.6056T4/T1=5.3499A4/A1=2.3130U4/U1=.6292
REGICN RELATIVE ANGLE ABSOLUTE ANGLE THETA BETA THETA BETA UPSTREAM MACH LOCAL MACH 2 -31.6177 99.4093 6.0000 .5367 3 5.0000 13.1598 6.0000 5.3157 4 -36.6177 -31.6177 -46.9052 5.3157
PEGICN P RHC T A U MU FEYNOLDS NO MACH NO PSI SLUG/CU FT RANK INE FT/SEC FT/SEC SLUG/FT-SEC 1/FT 1 .2533 1.93645E-04 109.7561 513.5679 3081.4074 8.46377E-C8 7.05004E+C6 6.0000 2 10.3139 1.01677E-03 850.5825 1430.0257 767.4393 5.36831E-07 1.45355E+C6 .5367 3 .5053 3.15760E-04 135.3111 570.2302 3031.1919 1.6699CE-07 8.94597E+C6 5.3157 4 10.3138 1.47356E-03 587.18C4 1187.8711 1938.7491 4.10988E-07 6.95122E+06 1.6321
STAGNATICN CONDITIONS ARE REGIEN PSTAG REGIEN PSTAG REGIEN SLUGS/CU FT RANKINE 1 400.0000 2 12.5472 1.6958E-03 900.0000 .0214 3 366.5123 4 4.28605E-03 900.0028 .1150

* * * * * * * * * * * * * *

FCR A 3-DIMENSIONAL CASE THE FOLLOWING VALUES REFER TO SURFACE CONDITIONS THETA5 RELATIVE= -20.000, ABSOLUTE= -51.617 BETA5 RELATIVE= -46.119, ABSOLUTE= -77.737 F50P4= 1.6763

ABSOLLTE VALUES AT CONDITION 5 P= 17.2853 RHC= 2.1550E-03 T= 673.0642 A=1271.7754 U=1651.2774 MU= 4.5468E-07 REYNCLDS NO= 7.8263E+06 MACH NC= 1.2984 RHC WALL = 2.6372E-03 VISC WALL = 3.9108E-07

FEAK PRESSURE RATIO1.4577XL13(SHEAR LAYER LENGTH).14221STAG HEATING-3D NC INTERFERENCE (BTU/SQ FT-SEC)3.71457E+CC H(BTU/SQ-FT-SEC-R)1.06130E-02

	STANTON Q	(BTU/SQ FT-SEC)	CELTA(FT)	QRATIO-3D	FRATIO-3D
LAMINAF	1.24518E-03	1.32119E+01	7.15164E-04	3.55679E+00	3.94415E+0C
TURBULENT	1.48276E-03	1.62729E+01	1.75029E-02	4.38084E+00	4.69669E+00

PART IV - TYPE IV INTERFERENCE

PROBLEM DISCUSSION

Type IV interference can occur when the weak impinging shock intersects a strong bow shock ahead of a subsonic flow region, as shown in figure 1(d). In general, on a blunt body this shock intersection is located between the lower sonic point and just above the body axis, as shown in figure 2. The impinging shock causes a displacement of the bow shock and the formation of a supersonic jet that is embedded in the subsonic region. (See figs. 1(d) and 6.) A jet bow shock is produced when the jet impinges on the surface, creating a small region with high stagnation heating.

The flow model used in this discussion consists of a two-dimensional impinging shock intersecting the bow shock of a sphere in the vertical plane of symmetry. A sketch of the shock and jet pattern is shown in figure 7. The geometry of this complex flow pattern is calculated by using the following methods. The solution of the triple shock at point J_1 (flow conditions in regions 2, 3, and 4 and the shear-layer deflection angle) is obtained in the same manner discussed for type III in part III. As for type III, the free-stream flow conditions in region 1 and the angle θ_i or β_i are specified. The continuation of the triple-point solution at point J_2 . It is assumed that at point J_2 a shear layer (jet boundary) exists between regions 5 and 6 ($p_5 = p_6$). The flow up through region 6 is supersonic with the exception that the flow in regions 2 and 5 is subsonic.

The location of point J₃ is determined from the shear-layer and shock angles surrounding region 4 and the shock displacement length L_{SH} (J₁ - J₂), which must be obtained experimentally or by some approximate method. The pressure differential between regions 5 and 2 causes the jet to turn upward ($p_5 > p_2$). Since the flow in region 7 must turn upward and the pressure p_7 must equal p_2 (shear layer between regions 7 and 2), a Prandtl-Meyer expansion fan centered at point J_3 occurs between regions 6 and 7. The line between J_3 and J_4 used to describe the jet geometry is constructed so that it bisects the expansion fan. Details of the intersection of the expansion fan with the reflected compression waves at point J_4 on the lower jet boundary are neglected because of the small distances and turning angles involved. Instead, a single compression wave centered at J_4 is used to turn the flow upward further and increase the pressure from region 7 to region 8. The pressure p_8 must equal p_5 since a shear layer exists between regions 8 and 5. Therefore, the conditions in regions 6 and 8 and all subsequent even-numbered regions in the jet are the same. Likewise, the conditions in all oddnumbered regions are the same. Also, the incremental increase in the flow deflection angle between adjacent regions is constant (i.e., $\theta_8 - \theta_7 = \theta_7 - \theta_6$, etc.). These approximations are justified since it was assumed that the mixing between the jet flow and the

slowly moving flow in regions 2 and 5 is negligible. On the basis of this reasoning, an expansion fan centered at J₅ and intersecting the lower jet boundary at J₆ completes the jet geometry through region 8. (See ref. 7.) Peak heating at jet impingement is analogous to that on a blunt body submerged in a supersonic flow field of width \overline{w} . In order to calculate the heating, the location of the jet bow shock in the jet and the resulting jet stagnation velocity gradient at the wall must be determined. The location of the jet bow shock within the jet depends on the standoff distance of the complete shock configuration. Results obtained in reference 2 for $M_{\infty} = 6$ to 20 indicate that the nominal location of the jet bow shock is in either region 7 or region 8.

A flow model of the impingement of a supersonic jet on a plane surface is shown in figure 8. The flow conditions upstream of the jet bow shock are known from the previous analysis once the location of the jet bow shock is specified. The inclination of the jet α_j is assumed to be normal to the wall on the basis of measurements made in reference 2. The jet width \overline{w} is the perpendicular distance from the jet boundary to the opposite junction for a specified region, as shown in figure 7. The jet bow shock is assumed to be a circular arc of radius R_c . At the wall the sonic line must be normal to the surface, and at the shock the jet-boundary streamline lies between the sonic line and the constant-pressure boundary, as shown in figure 8. It was shown in references 14 and 15 that this orientation of the sonic line is possible for $M_i < 2.8$ and $\gamma = 1.4$.

The velocity gradient along the wall in the jet stagnation region is calculated by using equation (6), where the Mach number and velocity are the values in the jet ahead of the bow shock for a specified region and the "jet body" radius R_{bj} is computed in the following manner: The data from references 1 and 2 indicate that the ratio of the standoff distance of the jet bow shock to the jet width δ_{js}/\overline{w} is approximately 0.45 for jet Mach numbers from 1.2 to 2.5 and $\gamma = 1.4$. The shock standoff distance is determined by multiplying the ratio by the calculated jet width for a specified region. The radius of the jet body, which in this case is assumed to be a sphere, is calculated by using the correlation shown in figure 17(a) of reference 16 for δ_{js}/R_{bj} as a function of the inverse of the normal-shock density ratio for a specified jet region and this value of δ_{js} . Therefore, the velocity gradient at the jet stagnation point is computed once the necessary quantities are known for the given region that includes the jet bow shock.

Another approach for calculating the velocity gradient at the jet stagnation point utilizes the Belotserkovskii strip integral method (refs. 17 and 18). It has been shown in reference 14 that this approach does not work for the low supersonic jet Mach numbers encountered in the present study $(M_j < 2.5)$. Therefore, empirical methods, such as the present relation between δ_{is} and \overline{w} , must be used to obtain the velocity gradient.

The heat transfer at the jet stagnation point for a given region (7 or 8) is calculated by using equation (5) of part III and the computed flow conditions and velocity gradient for that jet region. Equation (5) and the velocity-gradient equation (6) are also used to calculate the reference stagnation heating on a sphere by use of the physical body radius.

A simple expression for Q_{pk}/Q_{stag} derived in reference 1 is useful for predicting peak heating levels. This method is based on the same analogy as the present method but assumes a two-dimensional jet body at the impingement location. The expression from reference 1 is

$$\frac{Q_{pk}}{Q_{stag}} = 1.03 \left(\frac{R_b}{\overline{w}} \frac{p_{pk}}{p_{stag}} \right)^{0.5}$$
(7)

For the derivation of this expression, a wall to total temperature ratio of 0.5 and a Prandtl number of 0.7 were assumed.

PROGRAM DESCRIPTION

The main program reads the input, calls the various subprograms, and computes the heat transfer. TYP4 calculates the flow deflection angle of the shear layer. FTHETA is called to compute the flow deflection angle, and FINDB is called to compute the shock angles in each region. The subprograms OBLIQ, FINDM, PRATIO, MLTRT, ABSVAL, and ISTROP compute flow variables and ratios of the flow variables. PINPUT prints the input variables. The flow charts and listings of these subprograms are presented in part VII. The main program for type IV interference calls JET to calculate the layout of the jet regions. JET calls HEAT to compute the jet stagnation and the reference heat-transfer values. The flow diagrams and listings for these two subprograms are presented after the main program listing. The flow diagram and listing for the main program follow.

Program Flow Chart - Main






Program Listing - Main

C	PROGRAM SHOCK (INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT)	A	1
C C	DHEDASE	A	3
c	THIS PROCRAM PERFORMS & TYPE 4 SHOCK INTERFERENCE PATTERN WITH	A	4
č	NORMAL TYPINGEMENT	А	5
č		Α	6
-	COMMON PZ, RHOZ, TZ, PIOPZ, RHOIDZ, TIOTZ,	Α	7
	1 PZ2, RHOZ2, TZ2, P2OPZ2, RHO2Z2, T2CTZ2,	Α	8
	2 PZ3, RHOZ3, TZ3, P30PZ3, RH03Z3, T3CTZ3,	Α	9
	3 PZ4, RH0Z4, TZ4, P40PZ4, RH04Z4, T4CTZ4,	A	10
	4 PZ5, RHOZ5, TZ5, P50PZ5, RHO5Z5, T5CTZ5,	A	11
	5 PZ6, RHDZ6, 1Z6, P60PZ6, RH06Z6, 1601Z5,	A	12
	$6 \qquad P_{2}(P_{1}, RH0201, 12011, A20A1, 02001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 12001, 120000000000$	А Л	14
	γ γ_{3} γ_{3} γ_{1} γ_{2} γ_{2} γ_{1}	Δ	15
	\circ PT_{C} ,	A	16
	\$ P50P3. BH05C3. T50T3. A50A3. U50U3.	A	17
	\$ P60P4, RH0604, T60T4, A60A4, U60U4,	Α	18
	\$ P50P1, RH0501, T50T1, A50A1, U50U1,	Α	19
	\$ P60P1, RH0601, T60T1, A60A1, U60U1	Α	20
	COMMON P1, RHO1, T1, A1, U1, VISC1, REY1,	Α	21
	1 P2, RH02, T2, A2, U2, VISC2, REY2,	A	22
	2 P3, RH03, T3, A3, U3, VISC3, REY3,	A	23
	$3 \qquad P4, RHJ4, I4, A4, U4, VISC4, REY4, \\ 05 \qquad 0005, T5 \qquad A5, U5, VISC5, D5V5$	A A	24
	4 P5, RHU2, 15, A5, U3, VI3C5, RET5,	٨	20
	DIMENSION VARI(17), VARD(17.1)	Â	27
	DIMENSION RAT(30)	A	28
	EQUIVALENCE (RAT(1),P1)	Α	29
	DIMENSION VALU1(7), VALUZ(7), RATIO(7), VALUJ(7)	Α	30
	DIMENSION DELTA(2), CHWALL(2), TR(2), QRATE(2)	A	31
С	SET DEFAULTS FOR INPUT VARIABLES	A	32
	DATA GAMMA/1.4/, SVINC/5.0/, NTIMES/1/, IPT/0/, AMW/28.9//	A	33
	DATA THSV1/0./,BISV1/0./ DATA TREE/EDO DOV VREE/ 3901E-6/.28/1.0/.S/198.6/.TWALL/530./	A	34
	DATA TREF/ 550.007 , VREF/ 450012-07 (RD/1.07 (57 190.07) TRACC/ 550.07	Ā	36
	DATA 10/ 30/07/ 6006 / PR / 70/	A	37
		Α	38
	DATA ANGLE/4HTHET/, TOL/.001/	Α	39
	DATA RUN/1./	Α	40
	DATA XLEB/0.0/	Α	41
	NAMELIST /DATAIN/ RMI,GAMMA,THETAI,TINCR,NTIMES,IPT,T,P,AMW, TREF,V	A	42
-	1REF, RB, S, TWALL, XL, CP, PR, TOL, IPRINT, XLRB, RUN, ANGLE	A	43
C		A	44
Ē		Ā	45
C	INPUT DATA	Δ	47
C C		A	48
101		A	49
101	THETAI=THSVI	Α	50
	BETAI=BTSVI	Α	51
	READ (5,DATAIN)	Α	52
	IF (ENDFILE 5) 102,103	A	53
102	STOP	A	- 24 55
103	CONTINUE	A	55 56
	WKITE (0)UATAENT	Δ	57
	WRITE TOTING AUTOR	۵	58
	RTSVI=INLIAL BTSVI=RFT∆I	A	59

	SVINC=TINCR	Α	60
	IF (XLRB.NE.0.0) GO TO 104	Α	61
	XLRB=XL/RB	A	62
à	GO TO 105	A	63
104	XL=XLRB*RB	A	64
105	CONTINUE	A	65
	XL12=XL	A	66
C	GAS_CONSTANT(FT-LBF/LBM-R)	A	67
_	R=1544.3/AMW	A	68
C	DENSITY (SLUG/(CU FT)	A	69
	PHD=P*144./(32.2*R*T)	Α	70
	CALL PINPUT (RM1,GAMMA, IPT, T, P, AMW, TREF, VREF, XL, S, TWALL, CP, PR)	A	71
	WRITE (6,117) XL12	A	72
	WRITE (6,118) RB	A	73
	THIDEGETHETAL	A	74
	THE TAL = THE TAL / 57.296	A	75
	INPB=0	A	76
	TINCR=TINCR/57-296	A	77
	IF (IPT) 106,106,107	A	78
106		A.	79
	RHUZ=RHU	A	80
		A	81
107	GU 19 108	A	82
107		A	83
		A	84
100		A	85
108	CAN LINDE	A	80
	CALL ISTRUP (GAMMA,KMI)PI)PZ,PIUPZ,IPI)	A	01
		A	0.0
	ISWED TE /ANGLE NE BETA) OF TO 100	A A	לס 00
C	RETAILWAS INPUT INSTAD DE THETAT	8	01
•	BETALETHETAL	2	-92
		Ñ	03
	THE TAL = ETHETA(GAMMA.BM1.BETAL)	Δ	94
109	THIDEG=THETAI*57.296	Δ	95
	WRITE (6,119) THIDEG	Δ	96
С		A	97
С		A	98
C	CALCULATE AND WRITE PARAMETER RATIOS FOR 3/1	A	99
C		A	100
C	•••••••••••••••••••••••••••••••••••••••	A	101
	BETAI=FINDB(GAMMA,RM1,THETAI,1,IERROR)	Α	102
	IF (IEFROP-2) 111,111,110	Α	103
110	GO TO (101,101,101), IERROR	Α	104
C	ERRORS IN FINDING BETA	Α	105
С	IERROR = 1 ONE SOLUTION WAS FOUND, CONTINUE	A	106
C	2 SOLUTION DID NOT CONVERGE, USE LAST B COMPUTED	Α	107
C	3 NO SOLUTION WAS FOUND, START NEW CASE	Α	108
C	4 NOT DEFINED	A	109
111	BIDEG=BETAI*180./3.1416	Α	110
	THIDEG=THETAI*180./3.1416	A	111
<u>C</u> .		Α	112
C		A	113
C a	ITERATE ON THETAF UNTIL P2 = P4	A	114
C		A	115
C		A	116
		A	117
		A	118
	KMJ=FLINUMIGAMMA,KML,SIN(BELAI),BETAI,THETAI)	A	119
c	POURLERRAILUIGAMMA, KML, SINIBELALI)	A	120
<u>с</u>	A TTPE 4 INTERPERENCE PATTERN WITH INITIAL MACH NO RMI	A	121

ENTERING AT ANGLE U DEGREES
CALL TYP4 (THETAF, BETA2, RM1, RM3, THETAI, THETA4, BETA4, P30P1, GAMMA, TO
1L . IERROR)
IF (IERROR-3) 112,101,101
A TYPE 4 INTERFERENCE PATTERN WITH INITIAL MACH NO M3
ENTERING AT ANGLE THETAL RADIANS
BETA5=1.57C8
THETA5=Q.
RM4=FINDM(GAMMA,RM3,SIN(BETA4),BETA4,THETA4)
P40P3=PRATIO(GAMMA, RM3, SIN(BETA4))
CALL TYP4 (THETA5, BETA5, RM3, RM4, THE TA4, THETA6, BETA6, P40P3, GAMMA, TO
1L, IERROP)
IF (IERROR-3) 113,101,101
WRITE THETA AND BETA ANGLES AND MACH NUMBER
WRITE (6,120)
THFI)EG=THETAF*57.296
THEP=THETA5*57.296
RM2=FINDM(GAMMA,RM1,SIN(BETA2),BETA2,ABS(THEIAF))
$ H EG= H AZ = AU - 3 \cdot A = 1 \cdot A = 2 \cdot A $
$\frac{1}{1} + \frac{1}{1} + \frac{1}$
ABSBT=BETDEG
WRITE (6,121) J,THDEG,BETDEG,ABSTH,ABSBT,RM1,RM2
THDEG=THETAI*57.296
BETDEG=BETA1*57.296
ABSTH=THIDEG
ABSBT=BIDEG
J=3
WRITE (6,121) J,THDEG,BETDEG,ABSTH,ABSBT,RM1,RM3
THDEG=THE TA4*180./3.1416
BETDEG=BETA4*180./3.1416
ABSTHETHFDEG
ABS BI = THIDEG BEIDEG
J-4 WDITE (6,121) 1.THDEC.RETDEC.ARSTH.ARSRT.RM3.RM4
RMS = EINDMAA, RMS, SIN (RETAS), RETAS, ARS(THETAS))
TE (THETA5.1 T.0) BE TA5= 3.1416-BETA5
BETDEG=BETA5*57-296
ABSTH=THIDEG-THEP
ABSBT=THIDEG-BETDEG
J=5
WRITE (6,121) J,THDEG,BETDEG,ABSTH,ABSBT,RM3,RM5
RM6=FINDM(GAMMA, RM4, SIN(BETA6), BETA6, THETA6)
THDEG=THETA6*57.296
BETDEG=BETA6*57.296
ABSTH=THIDEG-THFP
AAAT6=ABSTH
ABSBT=THFDEG+BETDEG
ARR/= ARVR 1
J=6

17. 2 17. 2

C C C C

C C C C C

	A	184
CALCULATE AND WRITE PARAMETER RATIUS FOR 2/1, 4/3, 4/1	A	185
* 2 · · · · · · · · · · · · · · · · · ·	A	186
	A	187
	Α	188
WRITE (6,122)	A	189
CALL OBLIQ (GAMMA, RM1, ABS(THETAF), BETA2, RM2, P20P1, 1, 2, IO)	Α	190
CALL OBLIQ (GAMMA, RM1, THETAI, BETAI, RM3, P30P1, 1, 3, IO)	A	191
CALL OBLIQ (GAMMA .R M3. THETA4. BETA4. RM4. P40P3.3.4.10)	Δ	192
CALL 081 10 (GAMMA.RM3.ABS(THETA5).BETA5.RM5.P50P3.3.5.10)	Δ	193
CALL OBLID (CAMMA R NA THETAG, BETAG, RMG, DGCPA, A, G, ID)	Â	194
CALL MLTQT (DAGD3, D30D1, DAGD1, 1, 4, 1)	Â	105
	<u> </u>	195
	A	190
CALL ML191 (P60P4, P40P1, P60P1, 1, 6, 1)	A	197
	A	198
	A	199
CALCULATE ABSOLUTE VALUES FOR POINTS O THRU 4	Α	200
	Α	201
	Α	202
WRITE (6,123)	Α	203
WRITE (6,124)	A	204
VISCI=VISCI(V2FF.TRFF.TI.S)	Δ	205
$A1 = SORT(32, 2) \times (AMMA \times R \times T)$	Â	206
	Ä	200
	A A	201
KETI=KHUL*UL/VISCI	A	208
J=1	A	209
WRITE (6,125) J,P1,RH01,T1,A1,U1,V1SC1,REY1,RM1	Α	210
10=1	Α	211
J=2	A	212
CALL ABSVAL (P2OP1,P1,P2,VREF,TREF,S,J,IO,RM2)	Α	213
J=3	Α	214
CALL ABSVAL (P30P1,P1,P3,VREF,TREF,S,J,IC,RN3)	Α	215
J=4	A	216
CALL ABSVAL (P40P1.P1.P4.VREE.TREE.S.L.TO.RN4)	Δ	217
	7	218
	7	210
Ince Aboval reporting the practice of the provide the providence of the providence o		220
	A .	220
URITE (COUPI, PI, PG, VREF, TREF, S, J, LU, KMG)	A	221
WRITE (0,120)	A	222
J=1	A	223
WRITE (6,125) J,PZ,RHOZ,TZ	Α	224
J=2	A	225
CALL ISTROP. (GAMMA, RM2, P2, P22, P20P22, 2)	A	226
PZ20Z=PZ2/PZ ⁻	A	227
WRITE (6,125) J,PZ2,RH0Z2,TZ2,PZ20Z	A	228
J=3	Δ	229
CALL ISTROP (GAMMA.RM3.P3.PZ3.P30PZ3.3)	Ă	230
P7307=P73/P7	Ā	231
WRITE (6.125) 1.073.0H073.773.07307		222
	- <u>(1</u>)	222
U-7 CALL ISTROD (CANNA DHA DA DZA DA0074 A)	<u>A</u>	222
CALL 15/NUF (GAMMA) KM4) F4)F24)F4UF24)4/	A	234
	<u>A</u> .	235
WRITE (6,125) J,P24,RHU24,T24,P2402	A	236
J=5	A .	237
CALL ISTROP (GAMMA,RM5,P5,PZ5,P50PZ5,5)	A	238
PZ50Z=PZ5/PZ	A	239
WRITE (6,125) J,PZ5,RH0Z5,TZ5,PZ50Z	Α	240
J=6	A	241
CALL ISTROP (GAMMA, RMG, P6, PZ6, P60PZ6, 6)	A	242
PZ60Z=PZ6/PZ	A	243
WRITE (6,125) J.PZ6.8H0Z6.T76.P7607	Å	244
	Ā	245
an anger an	-	

	WRITE (6,127)	A	246
	GO TO 115	A	247
C	CALCULATE AMPLIFICATION FACTOR	_A	248
114			
	CALL JET (GAMMA, AAAB4, AAAT2, P2, PZ6, RM6, AAAT6, CP, TZ6, PR, VREF, TWALL,	<u>A</u>	252
	1TREF,AMW,S,PZ2,RM1,T1,PZ,ABB6,XLRB,RB,IPRINT)	A	253
115	THE TAI = THE TAI + TINCR	. A .	254.
	XLRB≈0.	Α.	255
	GO TO 101	A	256
C		A	257
116	FORMAT (1H1,25X,9H* * * ,//1X,81HTHIS PROGRAM PERFORMS A TYPE 4	A	258
	ISHOCK INTERFERENCE PATTERN WITH NORMAL IMPINGEMENT,//26X, 7H* * *	A	259
	2/,11H RUN NUMBER, F7.2)	A.	260
117	FORMAT (30H XL(SHOCK DISPLACEMENT LENGTH),F16.6,4H FT)	Α	261
118	FORMAT (12H NOSE RADIUS,18X,F15.5,4H FT)	Α	262
119	FORMAT (1H1,19HTHETAI = ,F8.4,6H DEG)	_A_	263
120	FORMAT (//12X,14HRELATIVE ANGLE,10X,14HABSOLUTE ANGLE,/9X,5HTHETA,	A	264
	18X, 4HBETA, 7X, 5HTHETA, 8X, 4HBETA, 5X, 13HUPSTREAM MACH, 2X, 10HLOCAL MAC	A	265
	2H)	A	266
121	FORMAT (1X, I1, 4F12.4, 5X, F12.4, 5X, F12.4)	A	267
122	FORMAT (//1X,10HRATIOS ARE/)	A	268
123	FORMAT (//7H REGION, 11X, 1HP, 12X, 3HRHO, 11X, 1HT, 11X, 1HA, 11X, 1HU, 13X,	A	269
	12HMU, 3X, 11HREYNOLDS NO, 9H MACH NO)	Α	270
124	FORMAT (15X, 3HPSI, 4X, 11HSLUGS/CU FT, 5X, 7HRANKINE, 6X, 6HFT/SEC, 6X, 6H	A	271
	LFT/SEC,4X,11HSLUG/FT-SEC,11X,4H1/FT)	A	272
125	FORMAT (1X,15,F12.4,E15.5,3F12.4,2E15.5,F8.4)	Α	273
126	FORMAT (/1X,25HSTAGNATION CONDITIONS APE/7H REGION,6X,5HPSTAG,12X,	Α	274
	13HRH0,7X,5HTSTAG,4X,12HPSTAG/PSTAG1,/,14X,4HPSIA,4X,11HSLUGS/CU FT	Α	275
	2,5X,7HFANKINE)	Α	276
127	FORMAT (1H0,57HMACH NO. IN REGION 6 IS LESS THAN 1.0 GO TO NEX	Á	277
	IT CASE)	A	278
	END	·A	279-

Program Flow Chart - JET



Program Listing – JET

	SUBROUTINE JET (GAMMA, B4, THET2, P2, P06, AM6, THET6, CP, T06, PR, AMUR, TW,	D	1
	1TR, AMWT, S, PO2, AM1, T1, PO1, B6, XLRB, RB, IPRINT)	D	- 2
	DIMENSION XJ(15), YJ(15), THET(15)	D	3
	DIMENSION VARI(11), VARD(11,1)	D	4
	DATA VARI/.12,.24,.34,.42,.495,.56,.605,.65,.69,.725,.76/	D	5
	DATA VARD/.1,.2,.3,.4,.5,.6,.7,.8,.9,1.,1.1/	D.	6
1	IF (IPRINT-EQ.0) GO TO 2	D	7
	WRITE (6,10) GAMMA, B4, THET2, P2, P06, AM6, CP, T06, PR, AMUK, IW, IR, AMWI, S	D	8
_	1, THET6, PD2, AML, 11, B6	U	
2	KUDE=1	U	10
	P1=3-1415927	0	12
		0	12
		0	1.0
		n	15
		n	16
		ň	17
	$A = 2^{-}A = 0^{-}A = 0^{-}A$	Ď	18
	TIAN (RADI)	ō	19
	X1(1)=0.	D	20
	$\mathbf{Y}_{1}(1) = 0$	D	21
	$x_1(2) = x_1(2) = x$	D	22
	$Y_{J}(2) = X_{L}(2 \times S_{L}(2 \times S_{L}))$	D	23
	XJ(3)=XL13*COS(THET(2))	D	24
	YJ(3)=XL13*SIN(THET(2))	D	25
	GP1=GAMMA+1.	D	26
	GM1=GAMMA-1.	D	27
	GPOM=GP1/GM1	D	28
	GMOP=GM1/GP1	D	29
	P 7 =P2	D	30
	07=P06 و07	D	31
	PR7=P7/P)7	υ	32
	Z = PR7**(-GM1/GAMMA) - 1.	U	33
	IF (Z1.GE.0.) GU 10 3	0	34
		0	22
~		0	20
د		D D	28
		n	20
		n	40
		D	41
		Ď	42
	I = (AM6 - GE - 1 - O) GO TO 4	D	43
	WRITE (6.12) AM6	D	44
	CALLEXIT	D	45
4	IF (AM7.GF.1.0) GG TG 5	Ď	46
	WRITE (6,13) AM7	D	47
	CALL EXIT	D	48
5	Z2=SQRT(GMOP*(AM6**2-1.))	D	49
	Z3=SQRT(AM6**2-1.)	D	50
	ANU6R = SOPT(GPOM) * ATAN(Z2) - ATAN(Z3)	D	51
	ANUED=ANUER*RTD	D	52
	24=SORT(GMOP*(AM7**2-1.))	D	53
	Z5=SQR1(AM7**2-1.)	D	54
	ANUTESUFI (GPOMI*ATAN(Z4)-ATAN(Z5)	D	>5
		U) 5
		U D	21 50
	EPS=DELTA-DTHET-THET(6)	ה	- 50 - 50
	COULDER CONTRACTORY	-	

AN7=EPS	D	60
DTHETD=PTD*DTHET	ñ	61
DELTAD=RTD*DELTA	Ď	62
EPSD=RTD*EPS	Ď	63
$\Delta N T C = B T C \star \Delta N T$	n	64
$X_{1}(4) = (Y_{1}(3) - Y_{1}(2) + X_{1}(2) + TAN(THET(6)) + Y_{1}(3) + TAN(AN7))/(TAN(AN7)) + TA$	0	45
IN (THET(A)))	0	44
$\nabla (1, 0, 1, 0)$	0	00
$(0, \tau) = (0, 2) \cdot (0, 3) \tau = (0, 2) \tau = (0, 1) \cdot (0, 1)$	U	01
	0	68
	U	69
	U	10
	U	11
	D	72
ZW/=ZLJ*SIN(DELIA)	D	73
115=5QK1(2.*CP*106)	D	74
CONSTANT INPUT TO SUBROUTINE HEAT	D	75
	D	76
P.G=1545./AMWT	D	77
AQ=(0.76/PR**(.6))/(778.26*SQRT(32.2))	D	78
AMUW=VISCJ(AMUR,TR,TW,S)	D	79
AMU1=VISCJ(AMUR,TR,TO6,S)	D	80
DQ=CP*(TO6-TW)	D	81
AM12=AM1**2	D	82
	D	83
CALCULATION OF UGRDTS	D	84
	D	85
U1=AM1*SQRT(GAMMA*RG*T1*32.2)	D	86
WRITE (6,14)	D	87
CALL HEAT (RG,TW,TO6,AMUW,AMU1,AQ,DQ,UGPDTS,PSNI,PO1,AM12,GP1,GM1.	D	88
1GAMMA, QWS, U1, RB)	ñ	89
	้อ	90
BEGIN LOOPING	ñ	01
	n n	02
MAXR=2	ň	72
NREG=6	U D	- C F
DO 9 I=1.0 MAXB	0	- 247
NBEG=NBEG+1	0	90
NREGMI=NREG-1	0	90
NREGM2=NREG-2	0	91
	U	98
	U	99
	U	100
	U	101
	U	102
	D	103
	D	104
	D	105
	D	106
	. D	107
	Ð	108
	D	109
IF (MUD(NREG)2).EQ.C) GU 10 /	D	110
XJINE GM2 J = XJINE GM4 J + ZLK * CUS(I HEI (NREG))	D	111
TJINACOMZIFTJINKEGM41+ZLK#SIN(THET(NREG)) 71 M-747	D	112
	D	113
	D	114
	D	115
	D	116
HMACH=AM6	D	117
XJ(NKEGM2)=XJ(NREGM4)+ZLM*COS(THET(NREG))	D	118
YJ(NFEGM2)=YJ(NREGM4)+ZLM*SIN(THET(NREG))	D	119
WRITE (6,15) NREG	D	120
T7=T06/(1.+GM1/2.*RMACH**2)	D	121

C C

C C C

C C C

76

6

7

	U7=RMACH*SQRT(3AMMA*RG*T7*32.2)	D	122
	DEL 9W= 45	D	123
	SDS=DELOW*ZLW	D	124
	SMACH=FMACH**2	D	125
	ABC=2.+GM1*SMACH	D	126
	RHOJOS=ABC/(GP1*SMACH)	D	127
	CALL MILUP (RHOJUS, DELOR, 1, 11, 11, 1, -1, VARI, VARD)	D	128
	PN=SDS/DELOR	D	129
	WRITE (6,16) THETD, ZLW, RMACH, RN	D	130
	CALL HEAT (RG, TW, TOG, AMUW, AMU1, AQ, DQ, UGRDT, PW, POG, SMACH, GP1, GM1, GA	D	131
	1 MMA • QW • U7 • RN)	D	132
	RQW=QW/QWS	D	133
	RL=RB/ZLW	D	134
	PWR I = PW/PSNI	D	135
	FTLR=RB/XL13	D	136
	PLJ=XL13/ZLW	D	137
	FATLJ=FLJ*PWRI	D	138
	PWR=PSNI/PW	υ	139
	QRED=1.03*SQRT(RL/PWR)	D	140
	WRITE (6,17) RL,PWRI,ROW,QRED	D	141
9	CONTINUE	D	142
	WRITE (6,18) (XJ(I),YJ(I),I=1,6)	D	143
	RETURN	D	144
С		D	145
10	FORMAT (1H0,8HGAMMA = ,E12.5,9X,5HB4 = ,E12.5,13X,8HTHET2 = ,E12.5	D	146
	1,10X,5HP2 = ,E12.5,/,1H ,6HP06 = ,E12.5,11X,6HAM6 = ,E12.5,12X,5HC	D	147
-	2P = ,E12.5,13X,6HT06 = ,E12.5,/,1H ,5HPR = ,E12.5,12X,7HAMUR = ,E1	0	148
	32.5,11X,5HTW = ,E12.5,13X,5HTR = ,E12.5,/,1H ,7HAMWT = ,E12.5,10X,	D	149
	44HS = ,E12.5,14X,8HTHET6 = ,E12.5,10X,6HP02 = ,E12.5,/,1H ,6HAM1 =	D	150
	5 ,E12.5,11X,5HT1 = ,E12.5,13X,5HB6 = ,E12.5,//)	D	151
11	FORMAT (1H0,23HERROR MESSAGE \cdots Z1 = $,E12 \cdot 5, //)$	D	152
12	FORMAT (1H0,24HERROR MESSAGE \dots AM6 = $,E12.5,//)$	D	153
13	FORMAT (1H0,24HERROR MESSAGE \dots AM7 = $,E12.5,//)$	0	154
14	FORMAT (1H0,41HCONDITIONS WITHOUT SHECK INTERFERENCE ARE)	D	155
15	FORMAT (//,1HO,21HCONDITIONS IN REGION ,12)	D	156
16	FORMAT (1H0,8HTHETA = ,E12.5,4H DEG,3X,12HJET WIDTH = ,E12.5,5H FE	D	157
	1ET, 3X,11HMACH NO. = ,E12.5,3X,15H NOSE RADIUS = ,E12.5,5H FEET)	D	158
17	FORMAT (1H , 30HRATIO NOSE RADIUS TO JET WIDTH, 24X, 3H = , E12.5, /, 1H	D	159
	1,26HP WALL/P PITOT FREE STREAM,28X,3H = ,E12.5,/,1H ,57HHEAT TRAN	D	160
	2SFER RATIO (WITH INTERFERENCE TO 3-D WITHOUT) = ,E12.5,/,1H ,26HHE	D	161
	3AT TRANSFER RATIO(EDNEY), $27X$, $3H = , E12.5$	D	162
18	FORMAT (//27H COORDINATES OF THE JET ARE,/, 1HO, 4HJ1 (,E12.5,1H,,E1	D	163
	12.5,1H),/,1H,4HJ2 (,E12.5,1H,,E12.5,1H),/,1H,4HJ3 (,E12.5,1H,,E1	D	164
	22.5,1H),/,1H,4HJ4 (,E12.5,1H,+E12.5,1H),/,1H,4HJ5 (,E12.5,1H,,E1	0	105
	32.5,1H),/,1H ,4HJ6 (,E12.5,1H,,E12.5,1H)	D	166
	END	D	167-





Program Listing - HEAT

С		С	1
	SUBROUTINE HEAT (RG, TW, TO6, AMUW, AMU1, AQ, DQ, UGRDY, PW, PO1, AM12, GP1, G	С	2
	1M1, GAMMA, QW, U, R)	С	3
	TERM1=(GP1*AM12)/(GN1*AM12+2.)	С	4
	TERM2=GP1/(2.*GAMMA*AM12-GM1)	С	5
	PW=P01*TERM1**(GAMMA/GM1)*TERM2**(1./GM1)	С	6
	UGRDT=U/R*SQRT(GM1/GAMMA*(1.+2./(GM1*AM12))*(11./(GAMMA*AM12)))	С	7
	BQ=((144.*AMUW)/(RG*TW))**(.1)	С	8
	CQ=((144.*AMU1)/(RG*T06))**(.4)	С	9
	EQ1=PW**•5	С	10
	QW=AQ*BQ*CQ*DQ*EQ1*SQRT(UGRDT)	С	11
	WRITE (6,1) PW, UGRDT, QW	С	12
	PETURN	С	13
С		С	14
1	FORMAT (1H0,22HWALL PRESSURE = ,E12.5,4H PSI,/1H ,22HVELOCIT	С	15
	1Y GRADIENT = ,E12.5,6H 1/SEC,/,1H ,22HSTAGNATION HEATING = ,E12	С	16
	2.5,14H BTU/SQ.FT-SEC,/)	С	17
	END	С	18-

USAGE

Program SHOCK for a type IV interference pattern uses the standard FORTRAN NAMELIST input with \$DATAIN as the NAMELIST name. The input includes the flow conditions, gas properties, flow deflection or shock angle, shock displacement length L_{SH} (see fig. 6), and nose radius. The program can increment the shock generator angle and lists the peak pressure and heat transfer in regions 7 and 8 (see fig. 7) for each angle.

A description of the input and output variables and a sample case are presented.

Input Description

The \$DATAIN input for type IV is as follows:

RUN	run number for identification		
RM1	$\mathrm{M}_{\infty},$ free-stream Mach number		
GAMMA	c_p/c_v , ratio of specific heats		
THETAI	θ_{i} , shock generator angle, deg; or β_{i} , impinging shock angle, deg		
TINCR	increment for θ_i (Default = 5 ^o)		
NTIMES	number of times to increment θ_i		
IPT	initial point; 0 for stagnation conditions, 1 for free-stream static conditions		
т	temperature at IPT, ^O R		
Р	pressure at IPT, psia		
AMW	molecular weight (used to compute gas constant)		
TREF	reference temperature for computing viscosity, ^O R		
VREF	reference viscosity for computing viscosity, slugs/ft-sec		
RB	nose radius, ft		
S	Sutherland's constant in viscosity equation		
TWALL	temperature at wall, ^O R		
XL	L_{SH} , shock displacement length ($J_1 - J_2$ in fig. 7), ft		
XLRB	ratio of shock displacement length to nose radius (may be input in place of XL)		

СР	c _p , specific h	eat at constant pressure, ft-lbf/slug- ^O R	
PR	N _{Pr} , Prandtl	number	
TOL	acceptable tol	erance for equal pressures (0.001)	
ANGLE	THET if θ_i	input; BETA if β_i input	
IPRINT	0 to suppress	extra printout; 1 for complete printout	
		Output Description	
RUN NUMBER	ł	run number for identification	
M1		$\mathrm{M}_{\infty},$ Mach number in free stream	
GAMMA (CP/	CV)	ratio of specific heats	
TEMP AT PO	INT ''IPT''	input as T, ^{O}R	
PRES AT POI	NT ''IPT''	input as P, psia	
MOLECULAR	WEIGHT	molecular weight (used to compute gas constant)	
REFERENCE	TEMP	reference temperature for computing viscosity, ⁰	R
REFERENCE	VISCOSITY	reference viscosity for computing viscosity, slug	s/ft-sec
S(SUTHERLAI	ND NUMBER)	Sutherland's constant in viscosity equation	1
TEMP AT WALL		T _w , ^o R	
СР		c _p , specific heat at constant pressure, ft-lbf/slug	- ⁰ R
PRANDTL NUMBER		N _{Pr} , Prandtl number	
XL(SHOCK DI MENT I	SPLACE- LENGTH)	distance from J_1 to J_2 (see fig. 7), ft	

NOSE RADIUS	nose radius, ft
THETAI	θ_{i} , shock generator angle, deg
RELATIVE ANGLE	
THETA	flow angle relative to flow in upstream region, deg
BETA	shock angle relative to flow in upstream region, deg
ABSOLUTE ANGLE	
THETA	flow angle relative to free-stream flow, deg
BETA	shock angle relative to free-stream flow, deg
UPSTREAM MACH	Mach number in upstream region
LOCAL MACH	local Mach number
P2/P1, etc.	p_2/p_1 , etc., pressure ratios for regions listed
RHO2/1, etc.	$ ho_2/ ho_1$, etc., density ratios for regions listed
T2/T1, etc.	T_2/T_1 , etc., temperature ratios for regions listed
A2/A1, etc.	a_2/a_1 , etc., ratios of speeds of sound in regions listed
U2/U1, etc.	u_2/u_1 , etc., velocity ratios for regions listed
REGION	region in shock pattern
Р	static pressure for region, psia
RHO	static density for region, $slugs/ft^3$
т	static temperature for region, ^O R
А	speed of sound for region, ft/sec

U	velocity for region, ft/sec
MU	static viscosity in region, slugs/ft-sec
REYNOLDS NO	Reynolds number per foot in region
MACH NO	Mach number in region
The following stagnatio	on conditions are then listed:
PSTAG	total pressure in region, psia
RHO	total density in region, $slugs/ft^3$
TSTAG	total temperature in region, ^O R
PSTAG/PSTAG1	ratio of total pressure in region to free-stream total pressure
Reference conditions w	rithout interference are listed as
WALL PRESSURE	p _{stag} , stagnation pressure on sphere, psia
VELOCITY GRADIENT	stagnation velocity gradient on sphere, 1/sec
STAGNATION HEATING	Q_{stag} , stagnation-point heat-transfer rate on sphere, Btu/ft ² -sec
The peak conditions for	r regions 7 and 8 are listed as follows:
THETA	jet flow angle, deg
JET WIDTH	$\overline{\mathbf{w}}$, jet width, ft
MACH NO.	jet Mach number
NOSE RADIUS	R _{bj} , nose radius of "jet body," ft
WALL PRESSURE	peak pressure at wall (jet stagnation pressure), psia
82	

VELOCITY GRADIENT		$\left(\frac{du_W}{ds}\right)_{stag}$, jet	stagnation velocity gradient, 1/sec	
STAGNAT	FIOI	N HEATING	Q _{pk} , jet stagna	ation heat-transfer rate, Btu/ft^2 -sec
RATIO N	OSE	RADIUS TO JE	T WIDTH	R_{b}/\overline{w}
PWALL/	ΡP	ITOT FREE STR	REAM	^p pk/ ^p stag
HEAT TH	RAN	SFER RATIO	Q _{pk} /Q _{stag} , ra heating on s	tio of peak heating in region to reference phere
HEAT TF	RAN	SFER RATIO (E	DNEY)	Q_{pk}/Q_{stag} , heating ratio calculated from equation (7)
COORDIN	IAT	ES OF JET (J1	to J6)	coordinates of jet as defined in figure 7
			Sample C	ase — Input
\$DATAIN				
RM1	2	0.6E+01,		
GAMMA	=	0.14E+01,		
THETAI	=	0.5E+01,		
TINCR	=	0.5E+01,		
NT I ME S	=	1,		
IPT	Ħ	Ο,		
T		0.9E+03,		
P	=	0.4E+03,		
AMW	=	0.2897E+02,		
TREF	=	0.53E+C3,		
VREF		0.3801E-C€,		
RB	=	0.5E+0C,		
S	*	0.1986E+03;		
TWALL	11	0.55E+C3,		
XL	-	0.15E+CC,		

СР		0.600600404,
PR	=	0.72E+00,
TOL	=	0.1E-02,
IPRINT	=	0,
XLRB	Ξ	0.0.
RUN	=	0.1E+01,
ANGLE	=	0.69404725765109E+93,
\$END		

Sample Case - Output

÷

THIS PROGRAM PERFORMS A TYPE 4 SHOCK INTERFERENCE PATTERN WITH NORMAL IMPINGEMENT

* * * RUN NUMBER 1.00 INPUT VARIABLES ARE MI
6.000
GAMMA(CP/CV)
1.400000
TEMP AT POINT 0
900.000000 RANKINE
PRES AT POINT 0
400.000000 PSI
MOLECULAR WEIGHT
28.970000
REFERENCE VISCOSITY
3.801000E-07
SLUG/(FT-SEC)
198.600
TEMP AT WALL
CP
PRANDTL NUMBER
XL(SHOCK DISPLACEMENT LENGTH)
NOSE RADIUS THETAI = 5.0000 DEG

2	RELATI THETA 31.6175 5.0000 36.6174 27.2706 9.3470	VE ANGLE BETA 99.4092 13.1598 51.9049 82.1113 48.7307	THE -31.61 5.00 -31.61 -22.27 -22.27	ABSOLUTE AN TA B 77 99.4 00 13.1 77 -46.9 06 -77.1 06 17.1	GLE ET 4 092 597 049 114 131	UPSTREAM M 6.00 6.00 5.31 5.31 1.63	ACH LC 00 00 57 57 21	DCAL MACH • 5367 5•3157 1•6321 • 5036 1•3018			
PATIOS	ARE										
P2/P1= P3/P1= P4/P3= P5/P3= P5/P4= P4/P1= P5/P1= P6/P1=	40.7107 2.0103 20.2512 32.1738 1.5890 40.7104 64.6882 64.6890	RH02/1 = RH02/1 = RH04/3 = RH05/3 = RH06/4 = RH05/1 = RH05/1 = RH06/1 =	5.2507 1.6306 4.6667 5.0833 1.3881 7.6096 8.2888 10.5626	T2/T1= T3/T1= T4/T3= T5/T3= T6/T4= T4/T1= T5/T1= T6/T1=	7.7534 1.2328 4.3395 6.3303 1.1448 5.3499 7.8043 6.1243	A 2/A 1 = A 3/A 1 = A 5/A 3 = A 6/A 4 = A 4/A 1 = A 5/A 1 = A 6/A 1 =	2.784 1.110 2.083 2.516 1.069 2.313 2.793 2.474	95 U2 /U1 = 03 U3 /U1 = 81 U4 /U3 = 90 U5 /U3 = 99 U6 /U4 = 80 U4 /U1 =	.2491 .9837 .6396 .2383 .8534 .6292 .2345 .5369		
REGION 1 2 3 4 5 6	PSI •2533 10•3138 •5093 10•3138 16•3884 16•3884	P SLUGS/ 1.9364 1.0167 3.1576 1.4735 1.6050 2.0454	PHO CU FT 5E-04 77E-03 60E-04 66E-03 09E-03 40E-03	T RANKINE 109.7561 950.9807 135.3111 587.1804 956.5663 672.1822	FT/S 513.56 1430.02 570.23 1187.87 1434.70 1270.94	Δ EC FT 79 3081. 42 767. 02 3031. 11 1938. 97 722. 59 1654.	U / S EC 4 0 7 4 4 3 8 5 1 9 1 9 7 4 9 1 4 7 9 6 5 1 5 1	MU SLUG/FT-SEC 8.46377E-08 5.36830E-07 1.06990E-07 4.10988E-07 5.39255E-07 4.54249E-07	REYNDLDS NO 1/FT 7.05004E+06 1.453555E+06 8.94597E+06 6.95122E+06 2.15046E+06 7.44998E+06	MACH NO 6.0000 .5367 5.3157 1.6321 .5036 1.3018	
STAGNAT		ICNS APE									
REGICN 1 2 3 4 5 6	PSTAG PSIA 400.0C00 12.5472 386.5123 45.9812 15.4866 45.5199	SLUGS/ 3.7255 1.1695 3.6029 4.2860 1.8164 4.2430	RHO CU FT 56E-02 58E-03 80E-02 05E-03 1E-C3 05E-03	TSTAG 9CC.0000 859.9981 9C0.0088 9C0.0088 9C0.0088 9C0.0088	03 .96 .11 .04 .11	PSTAG1 14 63 50 87 39					
CONDITI	IONS WITHOUT	T SHOCK IN	IT ERFEREN	CE ARE							
WALL PP VELOCIT STAGNAT CONDITI	PESSURE TY GRADIENT TION HEATING LONS IN REG	= 1.19 = 3.49 G = 3.71 ION 7	86C4E+01 8123E+03 8299E+00	PSI 1∕SEC BTU∕SQ.FT-S	EC						
THETA =	= -1.28803E	+01 DEG	JET WIDT	H = 3.9574	7E-02 FE	ЕТ МАСН	NO. =	1.62535E+00	NOSE RADIUS =	3.68847E-02 FEE	T
WALL PR VELOCIT STAGNAT	RESSURE TY GRADIENT TION HEATING	= 4.03 = 4.07 G = 2.34	3125E+01 7153E+04 +103E+01	PSI 1/SEC BTU/SQ.FT-S	EC						
RATIO N P. WALL/ HEAT TR HEAT TR	NOSE RADIUS PPITOT FRI ANSFER RAT	TC JET WI EE STREAM IC (WITH I IC(EDNEY)	IDTH INTERFERE	NCE TO 3-D	WITHOUT)	= 1.2634 = 3.3989 = 6.3049 = 6.74970	3E+01 3E+00 7E+00 E+00				

CONDITIONS IN REGION 8

THETA = -3.48998E+00 DEG JET WIDTH = 3.33868E-02 FEET MACH ND. = 1.30180E+00 NOSE RADIUS = 1.82996E-02 FEET

.

WALL PRESSURE = 4.45667E+01 PSI VELOCITY GRADIENT = 7.30754E+04 1/SEC STAGNATION HEATING = 3.29761E+01 BTU/SQ.FT-SEC

RATIO NOSE RADIUS TO JET WIDTH= 1.49760E+01P WALL/P PITOT FREE STREAM= 3.75762E+00HEAT TRANSFER RATIO (WITH INTERFERENCE TO 3-D WITHDUT)= 8.88128E+00HEAT TRANSFER RATIO(EDNEY)= 7.72665E+00

COORDINATES OF THE JET ARE

J1 (0. , 0.) J2 (1.02482E-01:-1.09533E-01) J3 (1.52770E-01:-9.40498E-02) J4 (1.77751E-01:-1.40358E-01) J5 (2.0376E-01:-1.09509E-01) J6 (2.58936E-01:-1.45310E-01)

PART V – TYPE V INTERFERENCE

PROBLEM DISCUSSION

Type V interference involves the interaction of two weak shocks of the same family. The interaction produces a shear layer, a supersonic jet, and a transmitted impinging shock, as shown in figure 1(e). On a blunt body the shock interaction occurs near the upper sonic point, as shown in figure 2. A complete solution of the type V flow field shown in figure 9 is not presently available because of the embedded subsonic flow (region 4). It is possible, however, to follow the treatment for type II interference and solve only the supersonic regions adjacent to the body surface in order to obtain the peak values of pressure and heat transfer at the shock—boundary-layer interaction IP.

The method of solution for type V is similar to that for type II interference with the exception that the impinging shock is of the same family and directly influences the flow on the model. As in the case of types I and II, the flow model consisted of two wedges creating the bow and impinging shocks. The flow conditions in regions 2 and 3 are obtained by using the Rankine-Hugoniot equations once the free-stream conditions in region 1 and the flow angles (θ_i, θ_3) or shock angles (β_i, β_3) are specified. The triple-point configuration at point B is solved in the same manner as discussed in part II for a type II interference. The transmitted impinging shock may reflect as a shock or a Mach reflection depending on the Mach number in region 5 and the surface inclination. Once the pressure ratio across the shock—boundary-layer interaction p_6/p_3 is calculated and the state of the boundary layer and the impingement point are specified, the peak heating ratio is obtained from equation (1).

PROGRAM DESCRIPTION

The main program reads the input, calls the various subprograms, and computes the heat transfer. TYP4 calculates the flow deflection angle of the shear layer at point B (fig. 9). FTHETA is called to compute the flow angle and FINDB is called to compute the shock angles in each region. The subprograms OBLIQ, FINDM, PRATIO, MLTRT, ABSVAL, AND ISTROP compute flow variables and ratios of the flow variables. PINPUT prints the input variables. The flow charts and listings of these subprograms are presented in part VII. The flow diagram and listing for the main program follow.







Program Listing – Main

	PROGRAM SHOCK (INPUT, GUTPUT, TAPE5 = INPUT, TAPE6 = OUTPUT)	A A	1
C C		A	3
C	THIS PROGRAM PERFORMS A TYPE V SHOCK INTERFERENCE PATTERN	A A	4
C C	FOR TWU DIMENSIONAL FLUW	A	6
č		A	7
	COMMON PZ, RHOZ, TZ, P10PZ, RHO10Z, T10TZ,	А А	8 9
	2 P73, RH073, T73, P30PZ3, RH02Z3, T30TZ3,	A	15
	3 PZ4, RH0Z4, TZ4, P40PZ4, RH04Z4, T40TZ4,	Α	11
	4 PZ5, RHOZ5, TZ5, P50PZ5, RH05Z5, T50TZ5,	A	12
	5 PZ6, RHOZ6, TZ6, P60PZ6, RH06Z6, T60TZ6,	A A	13
	$6 \qquad P_2UP_1, \text{ KHU}_2U_1, \text{ I}_2U_1L, \text{ A}_2UAL, \text{ U}_2UU_1, \text{ I}_2U_1L, \text{ A}_2UAL, \text{ U}_2UU_1, \text{ I}_2U_1L, \text{ A}_2UAL, \text{ U}_2U_1L, \text{ A}_2U_1L, \text{ A}$	Ă	15
	8 P30P1, RH0301, T30T1, A30A1, U30U1,	Α	16
	9 P4DP2, RH04C2, T4OT2, A40A2, U40U2,	A	17
	\$ P40P1, RH0401, T40T1, A40A1, U40U1,	А Л	19
		Ā	20
	\$ P50P1, RH0501, T50T1, A50A1, U50U1,	A	21
	\$ P60P1, RH06C1, T60T1, A60A1, U60U1	Α.	22
	COMMON P60P3, RH0603, T60T3, A60A3, U60U3	A ^	23
	CCMMEN Pl, RHOL, IL, AL, UL, VISCI, REVI,	A	25
	2 P3. RH03, T3, A3, U3, VISC3, REY3,	A	26
	3 P4, RH04, T4, A4, U4, VISC4, REY4,	Α	27
	4 P5, RH05, T5, A5, U5, VISC5, REY5,	A ^	28
	5 \oplus P6, RHU6, 16, A6, U6, VISCO, RETO DIMENSION TASTAR(2), RH03STR(2), V3STAR(2), REV3STR(2), STN3(2), S	Ā	30
	1TN1(2), 9FP(2), QPK(2), HFP(2), HPK(2), TR(2), RR(2), AA(2), RN(2)	A	31
	DIMENSION PN(2), HR(2)	A	32
С	SET DEFAULTS FOR INPUT VARIABLES	A	33
	DATA BETA/4HBETA/,IUL/.UUI/	Å	35
	DATA GAMMA/1.4/.N2.N3.N6/1.1.1/.ANGLE2.ANGLE3/2*4HTHET/	A	36
	DATA 1PT/0/, AMW/28.97/, TREF/532.98/, VREF/.3807E-6/, XL/1.0/	A	37
	DATA TWALL/530./,S/216./,CP/6006./,PR/.72/	A	38 20
	DATA TH2SV, B12SV, 1H3SV, B13SV/4#0+/ 3SV INCK/3+0/	Ā	40
C	ISW3 USED TO INDICATE ITERATION ON THETA3 HAS BEGUN	Α	41
-	NAMELIST /DATAIN/ RM1,GAMMA, THE TA2, THE TA3, TINCK, N2, N3, TOL, ANGLE	Α	42
~	12, ANGLE3, BETA2, BETA3, IPT, T, P, AMW, TREF, VREF, XL, S, TWALL, CP, PR, RUN	A A	45
L	SEL CUNSTANTS FOR STANTON NOMBERS	A	46
	SIGN=1.	Α	47
	PN(1) = 1.29	A	48
	PN(2)=0.85	A	50
	RN(2) = -2.584	A	51
	AA(1)=0.332	Α	52
	AA(2)=.185	A	53
<u> </u>	SIGN3=1.	Å	55
L01	TINCR=SVINCR	A	56
* 4 1	THE TA 3= TH 3 SV* 57. 296+ TI NC R	A	57
	BETA3=BT3SV*57.296+TINCR	Д А	58 50
	HE IAZ=IHZSV BET AZ=BTZSV	A	60

	READ (5.DATAIN)	Α	61
	IF (ENDFILE 5) 102,103	Α	62
102	STOP	Α	63
103	CONTINUE	Α	64
	RR (1) = SQR T (PR)	Α	65
	RR(2)=PR**(1./3.)	Α	66
	WRITE (6,123) RUN	Α	67
	R=1544.3/AMW	Α	68
С	DENSITY(SLUG/CU FT)	Α	69
	RHO=P*144./(32.2*R*T)	A	70
	IF (IPT) 104,104,105	Α	71
C	STAGNATION CONDITIONS	Α	72
104	T Z=T	Α	73
	RHOZ=RHO	Α	74
•	P Z= P	Α	75
	GO TO 106	Α	76
С	FREE STREAM CONDITIONS	Α	77
105	T1=T	A	78
	P1=P	Α	79
	RH01=RH0	Α	80
106	CONTINUE	Α	81
	CALL ISTROP (GAMMA,FM1,P1,PZ,P10PZ,IPT)	Α	82
С	PRINT OUT INPUT VARIABLES	Α	83
	CALL PINPUT (RM1, GAMMA, IPT, T, P, AMW, TREF, VREF, XL, S, TWALL, CP, PR)	Α	84
	WRITE (6,124) XL	Α	85
	ITYP2=0	Α	86
С	CONVERT ANGLES TO RADIANS	А	87
	TH2SV=THETA2	А	88
	BT2SV=BETA2	Α	89
	SVINCR=TINCR	4	90
	T INCR=TINCR/57.296	А	92
	THETA2=THETA2/57.296-TINCR	Α	93
	THE TA 3= THE TA 3/57.256-TI NCR	Д	-94
	BETA2=BETA2/57.296-TINCR	· A	95
	BETA 3=BETA 3/57.296-TINCR	Α	96
	TH3SV=THETA3	А	97
	BT3SV=BETA3	Α	98
	TINCR3=TINCR	А	99
С		A	100
C	BEGIN DO LOOP TO INCREMENT THETA2	А	101
C		Α	102
	DO 121 II=1,N2	Α	103
C	CALC NEEDED VALUES IN REGION 2	A	104
	IF (ANGLE2.NE.BETA) GO TO 107	A	105
	BETA2=BETA2+SIGN*TINCR	А	106
	THETA2=FTHETA(GAMMA,RM1,BETA2)	A	107
	GC TC 108	A	108
107	THE TA 2=TH E TA 2+SIGN * TINC R	A	109
	IERROR=1	A	110
	BETA2=FINDB(GAMMA,RM1,THETA2,1,IERROR)	A	111
	IF (IERROR.GT.2) GO TO 122	А	112
108	SINB=SIN(BETA2)	A	113
	P2OP1=PRATIO(GAMMA, FM1, SINB)	А	114
	KM2=+INDM(GAMMA,RM1,SINB,BETA2,THETA2)	А	115
	THETA3=TH3SV-THETA2	А	116
	BE 1A3 = B13 SV-THE TA2	А	117
_	I SW 3= 0	Α	118
С		А	119
C	BEGIN DU LOOP TU INCREMENT THETA3	A	120
C		A	121
	DU = 120 I = 10N3	Α	122
	THE ETNERS FEED (1) FEED (2)	Λ	122

109	IF (ANGLE3.NE.BETA) GC TO 110		A I	124
	BET A3=BET A3+SIGN3*T INCR3		A 1	123
	IF (BETA3.LT.O.) GO TO 120		A	126
	THETA3=ETHETA(GAMMA, $RM2$, $RETA3$)		Δ 1	127
			- A 1	120
110	THETA2-THETA24CICN2#TINCD2	s	A 1	しんし
110	$\frac{1}{10}$		A 1	123
	IF THEIADOLIOUOF GL TU 120		AI	131
	IERKUR=1		A	131
	BEIA3=FINDB(GAMMA, KM2, IHE IA3, 1, IEKKUR)		AI	1 32
	IF (IERROR.GT.2) GC TO 112		A 1	133
111	SINB=SIN(BETA3)		AI	134
	T2DEG=THET A2*57.296		A	135
	T3DEG=THE TA3*57.296+T2DEG		AI	136
	P3 CP2 = PRATIC (GAMMA, RM2, SINB)		AI	137
	RN3=EINDM/CAMMA, RM2, SINB, BETA3, THETA3)		A 1	135
c			A 1	130
c c	***************************************		A 1	2013
L C			A 1	141
C	IIERALE UN THETAF UNLIL P5 = P4		AI	141
C			A	142
C	* * * * * * * * * * * * * * * * * * * *		AI	143
	THE TAF =0.		AJ	144
	BETA4=1.5708		A 1	145
	IERROR=1		A I	146
	CALL TYPE (THETAF, BETA4, RM2, RM3, THETA3, THETA5, BI	TAS. P3 NP2. GAMMA. TO	ΔΙ	47
			A 1	1 4 5
	$\mathbf{I} = \left(\mathbf{I} = \mathbf{D} \mathbf{D} \mathbf{D} \right) (\mathbf{T} = \mathbf{D} \mathbf{D} \mathbf{D} \mathbf{D} \mathbf{D} \mathbf{D} \mathbf{D} \mathbf{D}$			1.40
	$IF (IEKKUK \circ 01 \circ 2) UU IU IIZ$		- A - 1 - A - 1	1.43
~	IF (ISW3.EQ.0) GU TU II4		AI	150
L	LIERATION UN THETAS HAS BEGUN.		AI	151
С	د		A 1	152
С	INCREMENT THE TA 3		AI	153
	TINCR3=TINCR3/2.		A J	1.54
	SIGN3=1.		A I	155
	IF (TINCR3.GT.TOL) GO TO 109		A	156
	I SW3=-1		Δ	157
	CO TO 114		<u> </u>	153
r	DECDEASE THETAD		A 1	150
110				123
112	1 INURS = 11 NURS/2		AI	100
	SIGN3 = -1.		A I	161
	ISW 3= 1		A I	162
	IF (TINCR3.GT.TOL) GO TO 109		A	163
	IF (TINCR3.LT.1.E-10) GO TO 113		A 1	164
	ISW3=-1		AI	165
	GO 10 109	1	Δ 1	166
112	THDEC=THET A3*57, 296		A 1	167
117	1-3		~ 1	169
	USITE // 1/01 / TUSEC DMD DMD		A 1	100
	WRITE 1091407 J9THUE09 RM29 RM3		A 1	105
	60 10 121		AI	110
C			AI	1/1
С			A 1	172
С	CALC AND WRITE RATICS FOR POINTS 1-5		AI	173
С			A I	174
Ċ		* * * * * * * * * * * * * * * * * * * *	A J	175
114	CONTINUE		Δ	176
	WDITE 14.1251 T205C.T30FC		A 1	177
	WRITE (0912)/ 12000910000		н. 	1 1 1 1 7 U
	WK11E 101121		A	110
	10=2		A	11
	CALL OBLIQ (GAMMA, RM1, THETA2, BETA2, RM2, P20P1, 1, 2	2,10)	A I	180
	CALL OBLIQ (GAMMA, RM2, ABS (THETA3), BETA 3, RM3, P 30	P2,2,3,10)	A 1	181
	10=1		A I	182
	CALL OBLID (GAMMA, RM2, ABS(THETAE), BETA4, RM4, P40	2.2.4.10)	A 1	1.8^{-1}
	CALL OBITO IGAMMA, RM3, ABS(THETAS), BETAS, RM5, PSO	P3.3.5.10)	Δ 1	184
	CALL MITOR (D2002, D2001 02001 1 2 101		A 1	1.00
	UNEL MEINE IFOURSPROURSPROURSSIDE		- HA - S	4 O.

```
CALL MLTRT (P40P2, P20P1, P40P1, 1, 4, 10)
                                                                       A 186
     CALL MLTRT (P50P3, P30P1, P50P1, 1, 5, 10)
                                                                       A 187
     THE TA6=THE TA5
                                                                       A 188
     IERROR=1
                                                                       A 189
     BETA6=FINDB(GAMMA, RM5, THETA6, 1, IERPOR)
                                                                       A 190
     IF (IERROR.GT.2) GO TO 119
                                                                      A 191
     ITYP2=4
                                                                       A 192
С
     CALC AND WRITE RATIOS FOR 6/5 AND 6/1
                                                                       A 193
     10 = 1
                                                                       A 194
     CALL OBLIQ (GAMMA, RM5, THETA6, BETA6, RM6, P60P5, 5, 6, IO)
                                                                       A 195
     CALL MLTRT (P60P5, P50P1, P60P1, 1, 6, 10)
                                                                       A 196
     P60P3=P60P5*P50P3
                                                                       A 197
115
     CONTINUE
                                                                       A 198
С
                                                                      A 199
     С
                                                                       A 200
С
     PRINT RELATIVE, ABSOLUTE ANGLES AND MACH NUMBER AT POINTS 2-5
                                                                       A 201
С
                                                                       A 202
С
      A 203
     hRITE (6,133)
                                                                       A 204
     THDEG=THETA2*AR
                                                                       A 205
     BETDEG=BETA2*AR
                                                                      A 206
     ABSTH=THDEG
                                                                       A 207
     ABSBT = BETDEG
                                                                       A 208
     J=2
                                                                       A 209
     WRITE (6,134) J, THDEG, BETDEG, ABSTH, ABSBT, RM1, RM2
                                                                    A 210
     THDEG=THE TA 3*AR
                                                                       A 211
     BETDEG=BET A3*AR
                                                                      A 212
     ABSTH=AR*(THE TA3+THE TA2)
                                                                       A 213
     ABSBT=AR \neq (THETA2+BETA3)
                                                                       A 214
     J = 3
                                                                       A 215
     WRITE (6,134) J,THDEG,BETDEG,ABSTH,ABSBT,RM2,RM3
                                                                      A 216
     THETA4=THETAF
                                                                       A 217
     THDEG=AR*THETA4
                                                                       A 218
     IF (THETA4.LT.O) BETA4=3.14159-BETA4
                                                                       A 219
     BETDEG=AR*BETA4
                                                                       A 220
     ABSTH=AR*(THETA4+THETA2)
                                                                       A 221
     ABSBT=AR*(PETA4+THETA2)
                                                                       A 222
     J=4
                                                                       A 223
     WRITE (6,134) J, THDEG, BETDEG, ABSTH, ABSBT, RM2, RM4
                                                                       A 224
     THDEG=-AR * THE TA 5
                                                                       A 225
     BETDEG=-AR*BETA5
                                                                       A 226
     ABSTH=AR*(THE TAF+THE TA2)
                                                                       A 227
     T5ABS = ABSTH
                                                                       A 228
     AB SB T=AR*( THE TA 2+THE TA 3-BE TA 5)
                                                                       A 229
     1=5
                                                                       A 230
     WRITE (6,134) J, THDEG, BETDEG, ABSTH, ABSBT, RM3, RM5
                                                                       A 231
С
     PRINT THETA6 AND BETA6 IN REL AND-ABS DEGREES
                                                                       A 232
     THDEG=THETA6*AR
                                                                       A 233
     BETDEG=BETA6*AR
                                                                       A 234
     ABSTH=T5ABS+AR*THETA6
                                                                       A 235
     IF (BETA6.EQ.1.5708) GO TO 116
                                                                       A 236
     ABSBT=T5ABS+AR*BETA6
                                                                       A 237
     RM=RM5
                                                                       A 238
     GO TO 117
                                                                       A 239
116
     RM = RM3
                                                                       A 240
     ABSBT=ABSTH+BETDEG
                                                                       A 241
117
     J=6
                                                                       A 242
     WRITE (6,134) J, THDEG, BETDEG, ABSTH, ABS BT, RM, RM6
                                                                       A 243
C
                                                                      A 244
     С
                                                                       A 245
С
     CALC AND WRITE ABSOLUTE VALUES FOR P,T,DENSITY,VEL,VISC,REYNOLDS
                                                                       A 246
С
                                                                       A 247
```

c		A	248
C	WRITE (6.135)	А	249
		А	250
		A	251
		Α	252
		Α	253
		А	254
		A	255
		Δ	256
	WRITE (0,157) J, FI, KOU, FI, KUU, FI	Δ	257
		Δ	258
	J=Z	Ā	259
	LALL ABSVAL (P2UPI,PI,P2,VKEF, IKEF, 3, 3, 10, KM2)	1	260
	J-5 CALL ARSVAL (D3/D01,D1,D3,VREE,TREE,S,L,L),RM3)	Δ	261
		Δ	262
	$J \rightarrow J$	Ā	263
	LEE ADSVAL (FTUFLIFTIITIITIITIITIITIITIITIITIITIITIITIITI	Λ	205
	J-J CALL ARSVAL (DEOD) DI DE VOEE TREE S. L.T.) DNE)	λ Α	204
		-4 - A	205
	J-O CALL ARCYAL (D/OD) OF D/ VDCE TREE S (10 DM4)		200
	LALL ADSVAL (POUPLIPLIPO)VKEFITKEFISIJIU)KMOJ	· A	201
	WRITE (6,138)	4	200
		A	209
	WRITE (6,137) J.PZ., RHUZ, 12	A	270
	CALL ISTRUP (GAMMA, FM2, P2, P22, P30P22, 2)	. A	271
	PZ2UZ=PZ27PZ	A	212
	J=2	A	213
	WRITE (6,137) J, PZ2, RHUZ2, 1Z2, PZ2UZ	. A	214
	CALL ISTROP (GAMMA, RM3, P3, PZ3, P30PZ3, 3)	A	275
	PZ 30Z=PZ3/PZ	. A	276
	J=3	А	277
	WRITE (6,137) J,PZ3,RH0Z3,TZ3,PZ30Z	Α	278
	CALL ISTROP (GAMMA,RM4,P4,PZ4,P40PZ4,4)	Ą	279
	PZ40Z=PZ4/PZ	А	280
	J= 4	- A	281
	WRITE (6,137) J,PZ4,RHOZ4,TZ4,PZ4OZ	Α	282
	CALL ISTROP (GAMMA,RM5,P5,PZ5,P50PZ5,5)	Α	283
	PZ50Z=PZ5/PZ	A	284
	J=5	Α	285
	WRITE (6,137) J,PZ5,RHUZ5,TZ5,PZ50Z	Α	286
С		A	287
Č		Ą	288
Č	CALCULATE AND WRITE STANTON NUMBER, FLAT PLATE HEAT TRANSFER	Α	289
Ċ	COEFFICIENT (HEP). AND HEATING RATE(QEP) IN REGION 2	Α	290
Ċ.		Δ	291
č		Δ	292
č	I = 1 IS IAMINAR AND I=2 IS THREHIENT	Δ	293
C		Â	204
C ·		~	295
C		м л	204
c		А	290
C	EUNERIAS REFERENCE LEMPERATURE Toetaditas substantiatore $2000000000000000000000000000000000000$	A A	271
	1331AR(1)/	A A	290
	NDUJUINUJ/~1440772/122027N71J31AK1J// V237AD/11-V1571/VD55.7055 7257AD/31	A	200
	¥2314R1JJ-¥136J1 ¥KEF11KEF14314R131 DE V26TD1 11-41025T1118112#V1 //26T10111	- А - А	200
c	ΝΕΙΣΣΙΝΙΟΙ-ΚΠΟΣΣΙΚΙΟΙΥΟΣΥΧΙ/ΥΣΣΙΑΚΙΟΙ Ιοςαι ΙΝΟΟΜΝΟΓΕςΙΝΙΕ σταμτού Αυμορό το οροτού ο Α.Τ. Συρτώσουσις	A •	202
L	LUCAL INCOMPRESSIBLE STANTON NUMBER IN REGION 2 AT IMPINGEMENT	A *	202
	UF Z=AA (J) *KEY 33 K # KN (J) TE _ J _ EA _ 2 _ CEAA / I MAALEC 10 / BEV2CTE \ **DN/ + \	A ^	202
	17 [J=E4=2] UTZ=AA\J}*ALUGIU\RETJSTRJ**KN(J] [TN=2] _CT_JAD**(2 \Z)	А ^	204
~		A.	303
ι	UMPRESSIBLE FLAT PLATE HEAT TRANSFER CUEF(BIU/SEC+FIZ-R)	А	200
-		A	307
С	FREE STREAM STANION NUMBER	A	308
	SIN1(J)=778.*HFP(J)/(RHO1*U1*CP)	А	309

C	FLAT PLATE HEATING RATE(BTU/SEC-FT2)	A 310
	QFP(J) = HFP(J) * (TR(J) - TWALL)	A 311
С	MARKARIAN HEAT TRANSFER BATIOS	A 312
Ĩ.	HB(.1) = PADP 3 * PN(.1)	A 313
c	DEAK HEATING RATE	Δ 314
c		A 315
c		A 316
110	PEAN DEAL TRANSFER COEF	A 310
119	HPK(J) = HPY(J) * HK(J)	ADII
		A 318
	WRITE (6,127) QFP(1), HFP(1), SIN3(1), SIN1(1), P6UP3, HR(1), QPR(1), HPR	A 319
	1(1)	A 320
	WRITE (6,128) QFP(2),HFP(2),STN3(2),STN1(2),P60P3,HR(2),QPK(2),HPK	A 321
	1(2)	A 322
	WRITE (6,129)	A 323
С		A 324
	GU TU 120	A 325
С	BECAUSE OBLIQUE REFLECTION NOT POSSIBLE BETWEEN 4 AND 6 USE NORMAL	A 326
C	SHOCK RELATIONS BETWEEN 6 AND 3	A 327
119	RM3SQ = RM3 + RM3	A 328
	BETA6 = 1 - 57.08	A 329
	WRITE (6-130)	A 330
	$D(C_{1}) = (C_{1}) + 2 + 2 + C_{1} + M + A + (C_{1}) + (C_$	A 331
		A 332
	(C+022WG± (L-MWMA7))*#((L-MWMA7)) (2CEM7*(2TEMP) AC)+C UOUIN	A 223
	10013-42.************************************	A 234
	10013-10013/((GAMMA+1.))**2*KM33Q)	A 224
		A 333
	RM6 = SQRI(((GAMMA - 1.) + RM3SQ+2.))(2. + GAMMA + RM3SQ - (GAMMA - 1.)))	A 3.30
		A 331
	WRITE (6,131) P60P3, RH0603, 16013, A60A3, 06003	A 338
	CALL MLTRT (P60P3,P30P1,P60P1,1,6,10)	A 339
	I SW6=-2	4 340
	GO TO 115	A 341
120	CONTINUE	A 342
С	HAVE FINISHED INCREMENTING THETA3	A 343
121	CONTINUE	A 344
C	HAVE FINISHED INCREMENTING THETA2	4 345
	GD TO 101	A 346
122	THDEG=THETA2*57.296	A 347
	J=2	A 348
	WRITE (6,140) J,THDEG,RMI	A 349
	GU TO 101	A 350
С		A 351
123	FORMAT (1H1.33H TYPE 5 SHOCK IMPINGEMENT PATTERN//11H RUN NUMBER.2	A 352
	1X*F5*2*/)	Δ 353
124	FORMAT (16H XI (WALL LENGTH) 15X F15 6 4 H FT)	Δ 354
125	FORMAT (1H1, 20H INPUT VARIABLES ARE/8H THETA 2=, E9, 4, 13H DEG, THETA	A 355
	13= ES. 4. 4H DEG)	A 356
126	FORMAT (//14H HEAT TRANSEER./17X.1HD.14X.3HHEP.12X.8H STANTON3.7X.8	A 357
120	HISTANTONI, 7Y, 5H06/ D3, 10Y, 2HH9, 12Y, 3H0DK, 12Y, 3H0DK	A 350
127	$\begin{array}{c} \text{Instantion1} \\ \text{Instantion2} \\$	A 330
120	$FORMAT = \{0\} \in LAMINAR(2X) \cup \{0\} \in [1] \cup [2] \cup$	A 339
120	FURMAT (100 TUNBULENT (0(EI)))	A 360
172	UNDAL (110) ATULLE - DEAL INANSEK UDER BUUSS FI-SEC-KI/35H Q =	A 301
120	I DEAL INANSFERIDIU/SU FEISELII	A 362
120	TURMAL (714, 82 MADUL REFLECTION NOT PUSSIBLE AT THIS POINT - NORMA	A 363
1 2 1	IL SHULK BEIWEEN 6 AND 3 ASSUMED/J	A 364
121	TUKMAI (1.1, 6 0HPO/P3= , F 8.4, 5 X, (HKHU6/3= , F 8.4, 5 X, 6 1 1 6/13= , F 8.4, 5 X, 6 HA	A 365
1.7.5	$10/A3 = \frac{1}{2}Fb = 4 + \frac{1}{2}X + \frac{1}{2}BH + \frac{1}{2}B + \frac{1}{2$	A 366
132	FURMAI (//IX, LOHRATIOS ARE/)	A 367
133	FURMAT (//12X,14HRELATIVE ANGLE,10X,14HABSOLUTE ANGLE,/9X,5HTHETA,	A 368
	18X,4HBETA,7X,5HTHETA,8X,4HBETA,3OH UPSTREAM MACH LOCAL MACH	A 369
134	FCRMAT (1X,11,4F12.4,2F15.4)	A 370
135	FURMAT (//7H REGION,11X,1HP,12X,3HRHO,11X,1HT,11X,1HA,11X,1HU,13X,	A 371

	12HMU,3X,11HREYNOLDS NO,9H MACH NO)	A	372
136	FORMAT (15X, 3HP SI, 4X, 11H SLUG S/CU FT, 5X, 7HRANK INE, 6X, 6HFT/SEC, 6X, 6H	А	373
	LFT/SEC,4X,11HSLUG/FT-SEC,11X,4H1/FT)	Α	374
137	FURMAT (1X,I5,F12.4,E15.5,3F12.4,2E15.5)	Α	375
138	FORMAT (/1X,25HSTAGNATION CONDITIONS ARE/7H REGIUN,11X,1HP,12X,3HR	A	376
	1H0,11X,1HT,8X,4HP/P0/15X,3HPSI,4X,11HSLUGS/CU_FT,5X,7HRANKINE)	Α	377
139	FORMAT (1X,15,F12.4,E15.5,3F12.4,2E15.5,F8.4)	Α	378
140	FORMAT (1H0,46HNG SOLUTION FOUND GIVEN THETA AND MACH NUMBER , 10HF	A	379
	10R REGION, 12,10X,3F10.4)	A	380
	END	Α	381-
С		8	1

USAGE

Program SHOCK for a type V interference pattern uses the standard FORTRAN NAMELIST input with \$DATAIN as the NAMELIST name. The input includes the flow conditions, gas properties, impinging flow deflection or shock angle, and impingement location on the body. The program can increment the shock generator angle and the body angle.

A description of the input and output variables and a sample case are presented.

Input Description

The DATAIN input for type V is as follows:

RUN	run number for identification
RM1	M_{∞} , free-stream Mach number
GAMMA	c_p/c_v , ratio of specific heats
THETA2	θ_i , shock generator angle, deg
BETA2	β_i , impinging shock angle, deg
ANGLE2	THET if θ_i input; BETA if β_i input
THETA3	θ_{b} , body angle, deg
BETA3	β_{b} , bow shock angle, deg
ANGLE3	THET if θ_b input; BETA if β_b input

TINCR	increment for θ_2 and θ_b , deg
N2	number of times to increment θ_i
N3	number of times to increment θ_b
TOL	acceptable tolerance for equal pressures (0.001)
IPT	initial point; 0 for stagnation conditions, 1 for free-stream static conditions
Т	temperature at IPT, ^O R
Р	pressure at IPT, psia
AMW	molecular weight (used to compute gas constant)
TREF	reference temperature for computing viscosity, ^O R
VREF	reference viscosity for computing viscosity, slugs/ft-sec
XL	X_i , distance from leading edge to impingement point, ft
S	Sutherland's constant in viscosity equation
TWALL	temperature at wall, ^O R
СР	c _p , specific heat at constant pressure, ft-lbf/slug- ⁰ R
PR	N _{Pr} , Prandtl number

Output Description

The output consists of printing only. A heading and pertinent input are printed for identification before the calculations.

RUN NUMBER	run number for identification
M1	M_{∞} , Mach number in free stream

GAMMA (CP/CV)	ratio of specific heats
TEMP AT POINT "IPT"	input as T, ^O R
PRES AT POINT ''IPT''	input as P, psia
MOLECULAR WEIGHT	molecular weight (used to compute gas constant)
REFERENCE TEMP	reference temperature for computing viscosity, ^{O}R
REFERENCE VISCOSITY	reference viscosity for computing viscosity, slugs/ft-sec
S(SUTHERLAND NUMBER)	Sutherland's constant in viscosity equation
TEMP AT WALL	T _w , ^o R
СР	c _p , specific heat at constant pressure, ft-lbf/slug- ⁰ R
PRANDTL NUMBER	N _{Pr} , Prandtl number
XL(WALL LENGTH)	$\mathbf{X}_{\mathbf{i}}$, length from leading edge to impingement point, ft
THETA2	θ_i , shock generator angle, deg
THETA3	$\theta_{\mathbf{b}}$, body angle, deg
P2/P1, etc.	p_2/p_1 , etc., pressure ratios for regions listed
RHO2/1, etc.	ρ_2/ρ_1 , etc., density ratios for regions listed
T2/T1, etc.	T_2/T_1 , etc., temperature ratios for regions listed
A2/A1, etc.	a_2/a_1 , etc., ratios of speeds of sound in regions listed
U2/U1, etc.	u_2/u_1 , etc., velocity ratios for regions listed
RELATIVE ANGLE	
THETA	flow angle relative to flow in upstream region, deg

BETA	shock angle relative to flow in upstream region, deg	
ABSOLUTE ANGLE		
THETA	flow angle relative to free-stream flow, deg	
BETA	shock angle relative to free-stream flow, deg	
UPSTREAM MACH	Mach number in upstream region	
LOCAL MACH	local Mach number	
REGION	region in shock pattern	
P	static pressure in region, psia	
RHO	static density in region, $slugs/ft^3$	
Т	static temperature in region, ^O R	
А	speed of sound in region, ft/sec	
U	velocity in region, ft/sec	
MU	static viscosity in region, slugs/ft-sec	
REYNOLDS NO	Reynolds number per foot in region	
MACH NO	Mach number in region	
The following stagnation of	conditions are then listed:	
Р	total pressure in region, psia	
RHO	total density in region, $slugs/ft^3$	
Т	total temperature in region	
Р/Р0	ratio of total pressure in region to free-stream total pressure	
100		

The peak pressure ratio and heat transfer for laminar and turbulent flow are listed as

Q	heat-transfer rate, Btu/ft ² -sec	
HFP	flat-plate heat-transfer coefficient, Btu/ft^2 -sec- ^{O}R	
STANTON3	local incompressible Stanton number	
STANTON1	compressible free-stream Stanton number	
P6/P3	peak pressure ratio	
HR	Markarian heat-transfer ratio	
QPK	peak heating rate	
НРК	peak heat-transfer coefficient	

Sample Case - Input

\$DATAIN

RM1	=	0.6E+01,
G А ММА	=	0.14E+01,
THETA2	=	0.5E+01,
THETA3	=	0.35E+02,
TINCE	=	0.5E+01,
N 2	=	1,
N 3	a	1,
TOL	=	0.1E-02.
ANGLE2	n	0.69404725765109E+93.
ANGLE3	8	0.69404725765109E+93,
BETA2	*	0.0,
B ETA 3	1	0.5E+01,
IPT	1	0,

Т	103 634	0.9E+03,
ρ	=	0.4E+03,
A MW	3	0.2897E+02,
TREF	5	0.53E+03,
VREF	8	0.3801E-06,
XL	=	0.25E+00,
S	=	0.1986E+03,
TWALL	=	0.55E+03,
CP	=	0.6006E+04.
PR	=	0.72E+00,
RUN	=	0.1E+01,
\$ ENU		

Sample Case - Output

TYPE 5 SHOCK IMPINGEMENT PATTERN

RUN NUMBER 1.00

INPUT VARIABLES ARE

M1	6.000	
GAMMA (CP/CV)	1.400000	
TEMP AT PUINT O	900.000000	RANKINE
PRES AT POINT O	400.000000	PSI
MOLECULAR WEIGHT	28.970000	
REFERENCE TEMP	530.000000	RANKINE
REFERENCE VISCUSITY	3.801000E-07	SLUG/(FT-SEC)
S(SUTHERLAND NUMBER)	198.600	
TEMP AT WALL	550.000	RANKINE
CP	6006.000	FT-LBF/(SLUG-RANKINE)
PRANDTL NUMBER	.720000	
XL(WALL LENGTH)	.250000	FT
INPUT VARIABLES ARE THETA2= 5.0000 DEG. THETA3= 35.0000 DEG

RATIOS ARE

P2/P1≈ 2	.0103	RH02 /1 =	1.6306	T2/T1=	1.2328	A2/A1=	1.1103	U2/U1=	.9837
P3/P2= 14	.4557	RHQ3/2=	4.2890	T3/T2≈	3.3704	A3/A2=	1.8359	U3/U2=	.7619
P4/P2= 32	.5463	RH04/2=	5.0944	T4/T2=	6.4083	A4/A2=	2.5315	U4/U2=	.2074
P5/P3≈ 2	.2584	RH35/3=	1.7619	T5/T3=	1.2818	A5/A3=	1.1322	U5/U3=	.8429
P3/P1= 29	.0599	RH03/1=	6.9937	T3/T1=	4.1552	A3/A1=	2.0384	U3/U1=	.7495
P4/P1= 65	.6280	RH04 /1 =	8.3069	T4/T1=	7.9004	A4/A1=	2.8108	U4/U1=	.2040
P5/P1= 65	6287	RH05/1=	12.3221	T5/T1=	5.3261	A5/A1=	2.3078	U5/U1=	.6318
P6/P5= 2	.1516	RHD6/5=	1.7064	T6/T5≈	1.2609	A6/A5=	1.1229	U6/U5=	.7186
P6/P1=141	.2090	RH06 /1=	21.0261	T6/TI≈	6.7159	A6/A1=	2.5915	06/01=	.4540

	RELA	TIVE ANGLE	ABSOL	UTE ANGLE			
	THETA	8ETA	THETA	BETA	UPSTREAM MACH	LOCAL MACH	
2	5.0000	13.1598	5.0000	13.1598	6.0000	5.3157	
3	30.0000	41.7590	35.0000	46.7590	5.3157	2.2062	
4	15,2998	86.0870	20.2998	91.0870	5.3157	•4355	
5	-14.7002	-40.8059	20.2998	-5.8059	2.2062	1.6426	
6	14.7002	59.11 59	35.0000	79.4157	1-6426	1.0512	

REGION	Р	RHO	т	۵	U	MU	REYNOLDS NO	MACH ND
	PSI	SLUGS/CU FT	RANKINE	FT/SEC	FT/SEC	SLUG/FT-SEC	1/FT	
1	.2533	1.93645E-04	109.7561	513.5679	3081.4074	8,46377E-08	7.05004F+06	6.0000
2	. 50 93	3.15760E-04	135.3111	570.2302	3031.1919	1.06990E-07	8.94597E+06	5.3157
3	7.3622	1.3542 SE-03	456.0559	1046.8696	2309.6012	3.37666E-07	9.26320E+06	2.2062
4	16.6265	1.60859E-03	867.1188	1443.5201	628.6374	5.43812E-07	1.85950E+06	•4355
5	16.6267	2.38610E-03	584.5741	1185.2319	1946.8091	4.09613E-07	1.13407E+07	1.6426
6	35.7745	4.07161E-03	737.1088	1330.9120	1399.0370	4.85434E-07	1.17345F+07	1.0512

STAGNATION CONDITIONS ARE REGION Р RHO Т P/PO SLUGS/CU FT RANKINE PSI 400.0000 3.72856E-02 1 900.0000 3. 60280E-02 2 386.5123 900.0088 .9663 79.4888 7.40940E-03 900.0089 .1987 3 .0474 4 18.9404 1.76549E-03 900.0088 5 75.2889 7.01791E-03 900.0089 .1882

HEAT TRANSFER P6/P3 QPK HPK Q HFP STANTON3 STANTON1 HR 4.85924E+00 4.90159E-02 LAMINAR 1.80333E+00 6.37771E-03 3.39326E-04 1.38453E-03 7.68551E+00 L.38595E+01 2.08909E-03 8.52398E~03 4.85924E+00 3.83339E+00 4.57504E+01 1.50517E-01 TURBULENT 1.19347E+01 3.92648E-02 HFP = HEAT TRANSFER COEF(BTU/SC FT-SEC-R) Q = HEAT TRANSFER(BTU/SQ FT-SEC)

PART VI – TYPE VI INTERFERENCE

PROBLEM DISCUSSION

Type VI interference involves the intersection of two weak shocks of the same family, which leads to the entirely supersonic flow field shown in figures 1(f) and 10. The expansion fan emanating from this intersection interacts with the boundary layer at IP and results in a local decrease in pressure and heating. A study of this type of interference is important because it provides a means for predicting the onset of type V, which does lead to significant increases in local heating.

The flow conditions in region 3 are determined by using the oblique-shock relations of reference 6 and the specified free-stream conditions and flow angle θ_i or shock angle β_i , in a manner similar to that for type I. Once the body angle θ_b is specified, the flow in region 4 is calculated. An iterative scheme is used to determine the location of the bow shock that separates regions 1 and 2 so as to satisfy continuity of the pressures and flow direction across the shear layer between regions 2 and 5. The flow from region 4 must pass through an expansion fan to turn parallel to the shear layer. The relations for a Prandtl-Meyer expansion from reference 6 are used in the above iteration to go from region 4 to region 5. In order to turn parallel with the surface, the flow passes through a series of reflected expansion waves in going from region 5 to region 6. For low Mach numbers and small turning angles, the total reduction in pressure from region 4 to region 6 at the wall is approximately twice the decrease across the first expansion fan. (See p. 451 of ref. 7.)

The heat-transfer relation (eq. (1)) is used to calculate the reduction in heating with p_6/p_4 used as the pressure ratio. This expression can be used since it has been shown in references 2 and 19 that the equation gives good predictions of the heating reduction for laminar and turbulent expansion-fan—boundary-layer interactions.

PROGRAM DESCRIPTION

The main program reads the input, calls the various subprograms, and computes the heat transfer. FTHETA is called to compute the flow angle and FINDB is called to compute the shock angles in each region. The subprograms OBLIQ, FINDM, PRATIO, MLTRT, ABSVAL, and ISTROP compute flow variables and ratios of the flow variables. PINPUT prints the input variables. The flow charts and listings of these subprograms are presented in part VII. TYP6 using EXPNS calculates the deflection angle of the shear layer. The flow diagrams and listings for the main program, TYP6, and EXPNS follow. Program Flow Chart - Main







Program Listing - Main

	PROGRAM SHOCK (INPUT. OUTPUT. TAPES=INPUT. TAPE6=OUTPUT)	A	1
C		A	2
C		A	3
C	PURPUSE	A	4
C	THIS PRUGRAM PERFURMS A TYPE VI SHUCK INTERFERENCE PATTERN	A	2
C C	FUR TWO DIMENSIONAL FLUW	А Л	07
C C		Ā	8
•	COMMUN PZ, RHOZ, TZ, PIOPZ, RHOIOZ, TIOTZ,	A	9
	1 PZ2, RHOZ2, TZ2, P20PZ2, RH02Z2, T2CTZ2,	Α	10
	2 PZ3, RH0Z3, TZ3, P30PZ3, RH03Z3, T3GTZ3,	Α	11
	3 PZ4, RHOZ4, TZ4, P40PZ4, RHO4Z4, T4CTZ4,	Α	12
	4 PZ5, RHOZ5, TZ5, P50PZ5, RHO525, T5CTZ5,	Α	13
	5 P20P1, RH02C1, T20T1, A20A1, U20U1,	A	14
	6 P30P1, RH0301, T30T1, A3CAL, U30U1,	A	15
	7 P40P3, RH0403, T40T3, A40A3, U40U3,	A	10
	$8 \rightarrow P40P1$, KHU4U1, T4U11, A4UA1, U4UU1,	A ^	10
		A ^	10
		Â	20
		δ	21
	\$ P3. RH03. I3. A3. U3. VISC3. REY3.	Ā	22
	\$ P4. RH04. T4. A4. U4. VISC4. REY4.	Ā	23
	\$ P5, RH05, T5, A5, U5, VISC5, REY5	Α	24
	DIMENSION T4STAR(2), RH04STR(2), V4STAR(2), REY4STR(2), HR(2), QFP	Α	25
	1(2), HPK(2), QPK(2), STN4(2)	Α	26
	DIMENSION STN1(2)	Α	27
	DIMENSIUN PN(2)	Α	28
	DIMENSIUN AA(2), RN(2)	Α	29
	DIMENSION RR(2), TR(2), HFP(2)	A	30
	NAMELIST /CATAIN/ RMI, GAMMA, THE TAB, THETAI, TINCR, NIIMES, IPT, I, P, AMW	A	31
6	1, TREF, VREF, XL, S, TWALL, CP, PR, RUN, ANGLE, ANGLE2, TUL	A	32
L.	SET CUNSIANTS FUR STANIUN NUMBERS	A A	20
	DELA-400ELA DN(1)=1 - 20	Å	25
	PN(1) = 10.23	Δ	36
	$\Delta \Delta (1) = 0.332$	Â	37
		A	38
	RN(1) = -2	Α	39
	RN(2) = -2.584	Α	40
C	CONVERGENCE TEST FOR THETAF	À	41
	TOL=.001	A	42
	NTIMES=1	A	43
- ·	TINCR=5.	A	44
<u>م</u> ا	• • • • • • • • • • • • • • • • • • •	A •	4:
يا ت		A A	40
C C	INPUT DATA	Δ	45
с С		Â	49
ioi	READ (5-DATAIN)	A	50
	IF (ENDFILE 5) 102,103	A	51
102	STOP	A	52
103	CONTINUE	Α	53
	WRITE(6,DATAIN)		
	$RR(1) = S \subseteq RT(PR)$	A	54
	RR(2)=PR**(1./3.)	A	55
	WRITE (6,133) RUN	A	56
	THUDEG=THETAU	A	51
	THEOEG=THETAI	A	58

	THIFST=THIDEG	A 59
	SINCR=TINCR	A 60
С	GAS CONSTANT (FT-LBF/LBM-R)	A 61
-	R=1544.3/AMW	A 62
C.	DENSITY(SLUG/CU_FT)	A 63
•	RH(1) = P + 1 + 4 + a / (3 + a + 2 + R + T)	A 64
	IF (1PT) 104.104.105	A 65
С	STAGNATION CONDITIONS	A 60
104		A 67
101	2 HO 2 = 2 HO	A 68
	T = D	A 69
		A 70
c		A 7
105		A 7
102		A 73
		A 7/
<u> </u>	KHUL-KHU	A 1-
ا ۱۹۷	GUISENIRUPICALLY IU ETIMER FREESIREAM UR IU STAGNATION	A 12
1.16	CALL ISINUP (GAMMA, KMI, PI, PZ, PIUPZ, IPI)	A 10
L	PRINI UUI INPUT VARIABLES	A 1
_	CALL PINPUT (RMI, GAMMA, IPI, I, P, AMW, IKEF, VKEF, KL, S, IWALL, CP, PK)	A 10
C	CONVERT ANGLES TO RADIANS	A
	TINCR=11NCK/57.296	A 80
	THETAB=THBDEG/57.296	A 8.
	THE TAI = THETAI / 57.296	A 8.
	INPB I=0	A 8.
	INPBB=0	A 84
	I SW=0	A 8
	DO 113 I=1,NTIMES	A 80
C	BETAI WAS INPUT INSTEAD OF THETAI	A 8
	IF (ANGLE.NE.BETA) GO TO 107	A 8'
	BETAI=THETAI	A 8
	INPBI=1	A 90
	THETAI=FTHETAIGAMMA, RM1, BETAI)	A 9
107	THIDEG=THETAI*57.296	A 9
C	WAS BETAI INPUT	A 93
	IF (INPBI.GT.0) GO TO 108	A 9
	BETAI=FINDB(GAMMA,RM1,THETAI,1,FERROR)	A 95
С	THETAI TOO LARGE	A 9
	IF (IERROR.GT.2) GO TO 121	A 9
108	RM3=FINDM(GAMMA,RM1,SIN(BETAI),BETAI,THETAI)	A 9
	IF (ANGLE2.NE.BETA) GU TO 109	A 9
C	BETAB WAS INPUT INSTEAD OF THETAB	A 10
Ŭ	HETA4=+THBI)FG/57-296-THETAI	A 10
	INPABE1	A 10
	THETAN=ETHETA(GAMNA,RM3,ABS(BETA4))+THETAI	A 10
109	CONTINUE	A 10
***		A 10
C		A 10
C C		A 10
ĉ	ITERATE ON THETAE UNTIL 02=05	A 10.
r r		A 10
c c		A 11
6	**************************************	A 33
c	TNOTAT-THETAD-THETAA	Α Α.Δ. Λ 1 3
L.	INFUT ENNUM LE INETAN NEUALIVE Te /Theta/ (t n) (n) to 100	A 22.
	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	A 22.
	IF LINEDS $disuble uit U U U U U U U U U U U U U U U U U U U$	ALL
c	DEIA4-FINDBIGAMMA,KMJ/IMEIA4/1/IEKKUR/	A 11
6		ALL
	IF (IEKKUK.01.2) GU IU IZZ	ALL
110	KM4=FINDMIGAMMA, KM3, SINIBEIA4, BEIA4, HEIA4	ALL
	PJUPI=PRAILU(GAMMA, RML, SIN(BEIAL))	A LL
	P4UPj=PKAIIU(GAMMA,KMJ,SIN(BEIA4])	A 12

	P40P1=P40P3*P30P1	A 121
	P4=P40P1*P1	A 122
	CALL TYP6 (THETAF,BETA2,RM1,RM4,RM5,THETAB,P1,P4,P5,GAMMA,TOL,IERR	A 123
	lor, option, p2sol)	A 124
C	WAS A SOLUTION FOUND	A 125
	IF (IERROR) 111,111,115	A 126
C	HAS ITERATION ON THETAI BEGUN	A 127
111	IF (ISW.EQ.1) GO TU 119	A 128
C	HAS ITERATION ON THETAB BEGUN	A 129
	IF (ISW.EU.2) 60 TO 116	A 130
	1F (ISW.LE.O) WRITE (6,134)	A 131
	IF (ISW.LE.O) WRITE (6,135) THIDEG, THDEG	A 132
C		A 133
C		A 134
C	CALCULATE AND WRITE PARAMETER RATIOS FOR 2/1, 3/1, 4/3, 4/1	A 135
С		A 136
C	• • • • • • • • • • • • • • • • • • • •	A 137
	10=2	A 138
	WRITE (6,124)	A 139
	THETA2=AUS(THETAF)	A 140
	CALL OBLIQ (GAMMA,RMI,ABS(THETA2),BETA2,RM2,P2OP1,1,2,IG/2)	A 141
	CALL ÜBLIÜ (GAMMA,RM1,THETAI,BETAI,RM3,P3OP1,1,3,IO)	A 142
	CALL OBLIQ (GAMMA,RM3,THETA4,BETA4,RM4,P40P3,3,4,IO)	A 143
	CALL MLTRT (P40P3,P30P1,P40P1,1,4,1)	A 144
C	* * * * * * * * * * * * * * * * * * * *	A 145
C		A 146
Û	WRITE THETA AND BETA ANGLES AND MACH NUMBER	A 147
Ç		A 148
C	• • • • • • • • • • • • • • • • • • • •	A 149
	WRITE (6,125)	A 150
	THFDEG=THETAF*57.296	A 151
	THETA2=THETAF	A 152
	THDEG=THETA2*180°/3°1419	A 153
	BETDEG=BETA2*180./3.1416	A 154
	ABSTH=THFDEG	A 155
	ABSBT=BETDEG	A 156
	J=2	A 157
	WRITE (6,138) J, THDEG, BETDEG, ABSTH, ABSBT, RM1, RM2	A 158
	THDEG=THETAI*57.296	A 159
	BETDEG=BETAI*>7.296	A 160
	ABSTH=THIDEG	A 161
	ABS BT = B ET DE G	A 162
	6=L	A 163
	WRITE (6,138) J,THDEG,BETDEG,ABSTH,ABSBT,RM1,RM3	A 164
	THDEG=THETA4*57.296	A 165
	8ETDEG=BETA4*57.296	A 166
	ABSTH=THETAB*57.296	A 167
	ABSBT=BETDEG+THIDEG	A 168
	4= ل	A 169
	WRITE (6,138) J,THDEG,BETDEG,ABSTH,ABSBT,RM3,RM4	A 170
	THDEG=(THETAF-THETA4)*57.296	A 171
	ABSTH=THETAF*57.296	A 172
	ζ=L	A 173
	WRITE (6,138) J,THDEG,BETDEG,ABSTH,ABSBT,RM4,RM5	A 174
C		A 175
C		A 176
C	CALCULATE ABSOLUTE VALUES FOR POINTS O THRU 4	A 177
C		A 178
C		A 179
	WRITE (6,126)	A 180
	WRITE (6,127)	A 181
	VISC1=VISCJ[VREF, TREF, TL, S]	A 182

AI=SQRT(32.2*GAMMA*R*T1)	
Ul=Al*RMI	
REY1=RH01*U1/VISC1	
J= <u>1</u>	
WRITE (6,128) J,P1,RHO1,T1,A1,U1,VISC1,REY1,RM	42
10=1	
J=2	
CALL ABSVAL (P20P1, P1, P2, VREF, TREF, S, J, IU, RM2)	
J=3	
CALL ABSVAL (P30P1,P1,P3, VREF, TREF, S, J, IO, RM3)	
j=4	
CALL ABSVAL (P40P1.P1.P4.VRFF.TRFF.S.J.IO.RM4)	
$P_{A} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1, +\} = \{1$	·
$D74=D74(A \pm D4)$	
D75=D74	
T 25-1 27	
1442-14 Dug76-D144144 //22 2404771	
RAULJ-P24+144+/(J2+2+R+12/ CALL ISTROD (CANNA DME DE 07- DE007E 0)	
CALL ISTRUP (GAMMA; KM5; P5; P2); P50P25; U1	
VISCS=VISCJ(VREF, IREF, 15, S)	
A5=5QR1(32.2*GAMMA*R*T5)	
U5=A5*RM5	
REY5=RHU5*U5/VISC5	
J=5	
WRITE (6,128) J,P5,RH05,T5,A5,U5,VISC5,REY5,RM	45
WRITE (6,129)	
J=1	
WRITE (6.128) J.PZ.RHDZ.TZ	
.1=2	
CALL ISTRUP (GAMMA, RM2, P2, P72, P20P72, 2)	
07007=070707	
FLLUL-FLL/FL Woite 16,1201 (.872.04072.172.0720/	1
HRITE (0/120/ J/FLZ/RAULZ//LZ/FLZUL	
ער לוסטבס גוס בס גאס אאאא וי "סטבס גוס". רג לוסטבס גוס בס גאס אאאא וי	
DALL ISINUP IDAMMAINMOJPOJPOJPOJPOJPOJJOJ	
WRITE (0,128) J,P23, RHU23,123, P2302	
CALL ISTRUP (GAMMA, RM4, P4, P24, P4UP24, 4)	
PZ4UZ=PZ4/PZ	
WRITE (6,128) J,PZ4,RHOZ4,TZ4,PZ4OZ	
J=5	
PZ5UZ=PZ5/PZ	
WRITE (6,128) J,P25,RH025,T25,P250Z	
P50P4=P5/P4	· · · ·
PRESSURE DROP FOR REGION 6 IS SAME AS FOR REGI	IUN 5
P60P4=2.0*P50P4-1.0	1. A.
CALCULATE AND WRITE STANTON NUMBER. FLAT PLATE	E HEAT TRANSEER
GOEFEICIENT(HEP), AND HEATING RATE(DEP) IN PR	EGIAN 4
A A A A A A A A A A A A A A A A A A A	
99999999999999999999999999999999999999	
U - I IS LAMINAK AND J=2 IS IUKBULENI	
UU IIZ JEIJZ	
KEUVERY IEMPERATURE	
IR(J)=14+RR(J)*(TZ-T4)	
ECKERT≠S REFERENCE TEMPERATURE	
T4STAR(J)=.5*(TwALL+T2)+.22*(TR(J)-T2)	
RHU4STR(J)=144.*P4/(32.2*R*T4STAR(J))	
V4STAR(J)=VISCJ(VREF,TREF,T4STAR,S)	
KEY4STK(J)=RHO4STR(J)*U4*XL/V4STAR(J)	
LOCAL INCOMPRESSIBLE STANTON NUMBER IN REGION	4 AT IMPINGEMENT
CF2=AA(J)*RFY4STR**RN(J)	
and the second states a second state of the second states and second states and second states and second states	

C ن

С

	IF (J.EQ.2) CF2=AA{J}*ALOGLO(REY4STR)**RN(J)	
	STN4(J)=CF2*PR**(-2./3.)	
	COMPRESSIBLE FLAT PLATE HEAT TRANSFER COEF(BTU/SEC-FT2-R)	
	HFP(J) = SIN4(J) * RHG4STR * U4 * CP/778.	
	FREE STREAM STANTON NUMBER	
	STN1(J)=778。*HFP(J)/(RH01*U1*CP)	
	FLAT PLATE HEATING RATE(BTU/SEC-FT2)	
	QFP(J)=HFP(J)*(TR(J)-TWALL)	
	MARKARIAN HEAT TRANSFER RATIOS	1
	$HR(J) = PODP4 \neq PN(J)$	
	PEAK HEATING RATE	
	QPK(J)=HR(J)*QFP(J)	
	PEAK HEAT TRANSFER COEF	
12	HPK(J) = HFP(J) * HR(J)	
	WRITE (6,130)	
	WRITE (6,131) QFP(1),HFP(1),STN4(1),STN1(1),P60P4,HR(1),QPK(1),H	нрк
	1(1)	
	WRITE (6,132) QFP(2),HFP(2),STN4(2),STN1(2),P60P4,HR(2),QPK(2),	нрк
	1(2)	
	IF (ISWALTAO) GO TO 114	
13	THETAI=THETAI+TINCR	
	RESTORE THETAL TO STARTING VALUE	
14	THIDEG=IHIFST	
	I INCR=SINCR	
	GU TO 101	
	NO TYPE 6 SOLUTION WAS FOUND.	
15	$IF (ISW_{\circ}EQ_{\circ}O) WRITE (6,137)$	
	ISW=2	
•	1 (ABS(11NCR)-10L) 118,107,107	
10		
	IHE IAB = IHE IAB + IINGR	
17	$\frac{1}{1} = \frac{1}{1} + \frac{1}$	
11		
	11NCR=11NCR/2.	
	IF (ADSTIINCK)-IULI IIBJIZUJIZU ITERATION COMPTETE DO CALCULATIONS FOR LARCEST TUETAT	
10	ITERATION COMPLETE. DU CALCULATIONS FOR LARGEST THETAT	
19	1 Sw = -1	
	GU TU TUT	
10	TINCA-TINCA (2)	
17	$\frac{11}{100}$	
20	$\frac{1}{1} = \frac{1}{1} + \frac{1}$	
20		
21	CO TO LIZ	
<u> </u>	SU TU TIT THETAR - THETAT TOD LADCE	
22	CO TO 117	
66		
22	UDITE /6.1361	
60	MILLE LUILUI CO TO 114	
	00 10 LTT	
24	EODWAT (//12H DATIOS ADE /)	
67 25	FUNDAL 177120 RATIUS ARE 77 FORMAT (7/129,1200 ELATIVE ANDLE 109,120000000000000000000000000000000000	۳.٨
63	INVIAL AVILLANGETAL BY ANDLED EVAN ANDLED EVAN MACH CONTAINAAN AACH CONTAINAANAAN AACH CONTAINAAN AACH CONTAINAANAAN AACH CONTAINAAN AACH CONTAINAAN AACH CONTAINAAN AACH CONTAINAAN AACH CONTAINA	1 A 9 1
26	- LUNATABOLIATINA DAIALETATONTALATAAN ANDELATATONTALATAAN MAGA - LULAL MACH - FÜRMAT 1//7H REGIGNATOXATHPATYAARHETTIYATHAATTYATHAATTYATHAATTYA	1 3 Y -
-0	12HMU. 3% THREEVNOLDS NO.9H MACH NOT	2 A 9
27	FURMAT (14X.3HPS1.4X.10HSLUG/CU FT.5X.7HRANKINF.6X.6HET/SEC.6Y.A	6HE
	1T/SEC.4X.11HS116/FT-SEC.11X.4H1/FT)	<i></i>
28	FURMAT (1X+12+F12+4+E12+5+3F12+4+2F15+5+F8+4)	
-	· · · · · · · · · · · · · · · · · · ·	

129	FURMAT (/1X,25HSTAGNATION CUNDITIONS ARE/7H REGIUN,5X,5HPSTAG,12X,	A	306
	13HRHU, 7X, 5HTSTAG, 4X, 12HPSTAG/PSTAG1, /, 14X, 4HPSIA, 4X, 11HSLUGS/CUFT	А	307
	2,5X,7HRANKINE)	A	308
130	FORMAT (//14H HEAT TRANSFER,/17X,1Hu,14X,3HHFP,12X,8HSTANTGN4,7X,8	Α	309
	1H STANTUN1 •7X•5HP6/P4 • 10X •2HHR • 12X • 3H QPK • 12X • 3HHPK)	Α	310
131	FORMAT (JH LAMINAR,2X,3(E15.5))	Α	311
132	FORMAT (LOH TURBULENT,8(EL5.5))	A	312
133	FURMAT (1H1,50H THIS) PREGRAM PERFORMS A TYPE 6 SHUCK INTERFERENCE,	Α	313
	18H PATTERN//12H RUN NUMBER "F5.2//)	Α	314
134	FORMAT (1H1)	Α	315
135	FORMAT (IH0,20HINPUT VARIABLES ARE /9H THETAI =,F9.4,19H DEG, AND	А	316
	1THETAB = ,F9.4,4H DEG//)	Α	317
136	FORMAT (728H THETAB IS LESS THAN THETAI)	Α	318
137	FORMAT (743H NO SULUTION WAS FOUND FOR A TYPE 6 PATTERN)	Α	319
138	FORMAT (1X,11,4F12,4,2F15,4)	Α	320
	END	Α	321-
C		В	1

Subroutine EXPNS

Subroutine EXPNS calculates the Mach number across an expansion layer by using an iterative procedure. The flow diagram and listing follow.



	SUBROUTINE EXPNS (RNU, RM, GAMMA, IERROR)	В	2
С		В	3
С	PURPOSE	В	4
C	FIND MACH NUMBER ACROSS EXPANSION LAYER KNOWING NU AND GAMMA.	8	5
C i	RM SHOULD ORIGINALLY HOLD INITIAL GUESS.	B	6
С	F(M) = A * ATAN(SQRT(B*(RM2-1.))) - ATAN(SQRT(RM2-1.)) - NU	В	7
С		В	8
	GP1=GAMMA+1.	В	9
	GM1=GAMMA-1.	В	10
C	CALCULATE THE 2 COEFFICIENTS IN F(M)	В	11
	A=SQRT(GP1/GM1)	В	12
	B=GM1/GP1	8	13
	IERROR=0	В	14
	IT=0	в	15
	TOL=.0001	В	16
С	CALCULATE NEW VALUE FOR RM	В	17
1	CONTINUE		
	RM2M1=RM*RM-1.	C	3
	DFM=A*B*RM/(SQRT(B*RM2M1)*(1.+B*RM2M1))-1./(RM*SQRT(RM2M1))	Ð	4
	FM=A*ATAN(SQRT(B*RM2M1))-ATAN(SQRT(RM2M1))-RNU	С	4
	RM1=RM-FM /DFM		
С	HAS RM CONVERGED	В	19
	IF (ABS(RM1-RM)-TOL) 3,3,2	В	20
C	CONTINUE ITERATING	в	21

2	RM=RM1	В	22
	1 T = 1 T + 1	в	23
	IF (IT.GT.50) GO TO 4	в	24
	IF (RM.LE.I.) GO TO 5	8	25
	GO TO 1	8	26
С	ITERATION IS COMPLETE	8	27
3	RM=RM1	8	28
	RETURN	в	29
C	HAS EXCEEDED NUMBER OF ITERATIONS ALLOWED	в	30
4	IERROK=1	в	31
	RETURN	В	32
С	THE MACH NUMBER HAS FALLEN BELJN THE LOWER LIMIT OF 1.	8	33
5	IERROR=2	в	34
	RETURN	8	35
	END	в	36-
С		ε	1

Subroutine TYP6

Subroutine TYP6 calculates the shear-layer angle for a type VI flow interference pattern. The flow diagram and listing follow.



```
SUBRUUTINE TYP6 (THEIAF, BETA2, RM1, RM4, RM5, TFETAB, P1, P4, P5, GAMMA, TO E
                                                                                      2
     1L, IERROK, UPTION, P20P1)
                                                                                  E
                                                                                      3
                                                                                  Ē
                                                                                      4
C
      PURPUSE
      CALCULATE THEFAF FOR A TYPE & SHOCK INTERFERENCE PATTERN
                                                                                  E
                                                                                      5
C
0
0
0
0
      DESCRIPTION OF VARIABLES
                                                                                  E
                                                                                      6
                                                                                  Ε
                                                                                      7
      THETAF = DEFLECTION ANGLE FOR PUINT 2 IN RADIANS, DUTPUT
      BETA2 = SHOCK (WEAK) ANGLE FOR POINT 2 IN RADIANS, OUTPUT
                                                                                  Ε
                                                                                      8
Ĉ
      KM1
              = INITIAL MACH NUMBER, INPUT
                                                                                  Е
                                                                                      9
              = MACH NUMBER AT PUINT 4, INPUT
                                                                                  Е
С
                                                                                     10
      RM4
              = MACH NUMBER AT POINT 5, OUTPUT
C
                                                                                  Ε
                                                                                     11
      RM5
      THETAB = ANGLE OF SECOND SHUCK DEFLECTION. USED AS INITIAL
                                                                                  Ε
ն
С
                                                                                     12
                                                                                  E
                ESTIMATE FOR THETAF
                                                                                     13
              = ABSOLUTE PRESSURE AT POINT 1, INPUT
= ABSOLUTE PRESSURE AT PUINT 4, INPUT
C
                                                                                  Ε
      P1
                                                                                     14
C
      P4
                                                                                  ε
                                                                                     15
Ĉ
              = ABSOLUTE PRESSURE AT POINT 5, OUTPUT
                                                                                  Ē
                                                                                     16
      Ρ5
C
      GAMMA = CP/CV
                                                                                  Ε
                                                                                     17
С
      TUL
              = CONVERGENCE CRITERIA FOR THETAF
                                                                                  Ε
                                                                                     18
                                                                                  Ε
                                                                                     19
С
       IERROR = 0 NO ERROR
                                                                                  Е
С
                   EXCEEDED ALLOWABLE NUMBER OF ITERATIONS
                                                                                     20
                 1
                   NO SOLUTION FOUND FOR THETAF
                                                                                  Ε
                                                                                     21
C
                 2
                                                                                  E
      DATA UPT/4HAXIS/
                                                                                     22
       ISENTROPIC PRESSURE RATIO ( P STAGNATION / P )
                                                                                  Ε
                                                                                     23
С
       PZOP(GAMMA,GM1,RM)=(1.+GM1*RM*RM/2.)**(GAMMA/GM1)
                                                                                  E
                                                                                     24
                                                                                  Ε
C
       FOR EXTRA PRINTOUT SET DEBUG TO 1.
                                                                                     25
                                                                                  Ε
                                                                                     26
       DEBUG=0.
                                                                                  ε
                                                                                     27
       KM42M1=RM4*RM4-1.
                                                                                  Е
       GP1=GAMMA+1.
                                                                                     28
                                                                                  E
                                                                                     29
       GM1=GAMMA-1.
С
                 CALCULATE COEFFICIENTS FOR EQ OF NU
                                                                                  Ε
                                                                                     30
                                                                                  F
       A=SQRT(GP1/GM1)
                                                                                     31
                                                                                  E
                                                                                     32
       B=GM1/GP1
                                                                                  Ε
                 CALCULATE NU4
                                                                                     33
C.
       RNU4=A*AT AN (SQRT (B*RM42M1))-ATAN (SQRT (RM42M1))
                                                                                  F
                                                                                     34
       IERROR=0
                                                                                  Ε
                                                                                     35
       IT=0
                                                                                  E
                                                                                     36
                 SET INITIAL ESTIMATE FOR RM5
                                                                                  E
                                                                                     37
С
                                                                                  Е
                                                                                     38
       RM5 = RM4
                                                                                  Ε
                                                                                     39
                 SET INITIAL ESTIMATE FOR THETAF
С
       THE TAF = THETAB
                                                                                  E
                                                                                     40
                                                                                  F
G
       THETAF INCREMENT
                                                                                     41
       DTHETA=.1
                                                                                  Е
                                                                                     42
                                                                                  Ε
                                                                                     43
       ISW=0
                                                                                  Ε
       FIND WEAK SHOCK ANGLE FOR 2
                                                                                     44
C
                                                                                  Ε
       IERR=1
                                                                                      45
1
       BETA2=FINDB(GAMMA, RM1, ABS(THETAF), 1, IERR)
                                                                                  ε
                                                                                      46
ù
       WAS A SOLUTION FOUND
                                                                                  F
                                                                                      47
       IF (IERR.GT.2) GO TO 8
                                                                                  Е
                                                                                      48
С
       FIND PRESSURE AT PT 2
                                                                                  E
                                                                                      49
                                                                                  Е
                                                                                      50
       SINB2=SIN(BETA2)
       P20P1=PRATIO(GAMMA, RM1, SINB2)
                                                                                  Е
                                                                                      51
       ISW=1
                                                                                  Ε
                                                                                      52
                                                                                  ε
                                                                                      53
       P2=P20P1*P1
С
        FIND PRESSURE AT PT 5
                                                                                  Е
                                                                                     54
       RNU5=RNU4+ABS(THETAF-THETAB)
                                                                                  Ε
                                                                                      55
                                                                                  Ε
       CALL EXPNS (RNU5, RM5, GAMMA, IERR)
                                                                                      56
       IF (IERR.GT.O) GO TO 10
                                                                                  Ε
                                                                                      57
C
                                                                                  ε
                                                                                      58
       STAGNATION PRESSURE AT 4
       PZOP4=PZOP(GAMMA, GM1, RM4)
                                                                                  Е
                                                                                      59
                                                                                     60
       P40=P20P4*P4
                                                                                  F
                                                                                  Ε
       PZOP5=PLOP(GAMMA, GM1, RM5)
                                                                                      61
```

С	P50 IS SAME AS P40 P5=P60/P70P5	E	62
r		E	63
Ċ	IE (DERIG OF A) WDITE (6.11) THETAE A2 DE ONDE DAME	t	64
	I = I = I = I = I = I = I = I = I = I =	E	65
C	CONTINUE ITEDATING	E	66
6		E	67
		E	68
		E	69
c	$\frac{1}{1} = \frac{1}{1} = \frac{1}$	E	70
6	THETAE-THETAE DEUKASE INCLAF	E	71
		E	72
	IF (ISW) 19392 DTNETA-UTUETA/2	E	73
2		E	74
		E	75
3		E	76
2		E	77
c	DE CE DU - INCREASE TUETAE	E	78
یا \	PD-61-62 - INURASE THETAF	E	79
4		E	80
æ		E	81
2		E	82
		ε	83
,		E	84
0		E	. 85
~ ·		£	86
ե 7	HAS EXCEEDED ALLUWABLE NOMBER OF ITERATIONS	E	87
4		E	88
c	NETURN	E	89
	NO SUCULIAN WAS FOUND FOR BELAZ. THETAF IS TOU LARGE. IF ISW IS	E	90
5	U - THEN URIGINAL ESTIMATE FUR THETAF WAS TOU LARGE	E	91
3		E	92
	AF (LSW) L(L)Y OTHETA-OTHETA/2	E	93
7	$\int \frac{d^2}{dt} = \int $	E	94
~	IF (DIMEIA-GI-0.0001) GU (U)	E	95
6	A TYPE 6 INTERFERENCE PATTERN WAS NOT POSSIBLE. HAS DEGENERATED	E	96
C		E	97
		E	98
10		E	99
15	WRITE (0,12) IERR, KNU4, KNU4, KNU5, KM5	E	100
c		E	101
с 11	EQUMAT $I = 0$	Ε	102
1.2	FURMAT 110F12000 FURMAT 116 (F10 F FY DANNE FALLTYNG ARDER FOR MET	ε	103
. <	FUNITAL (10)4712.0)0X124HINU SULUTIUN FUUND FUR M5)	E	104
c		E	105-
6		F	1

USAGE

Program SHOCK for a type VI interference pattern uses the standard FORTRAN NAMELIST input with \$DATAIN as the NAMELIST name. The input includes the flow conditions, gas properties, flow deflection or shock angle, impingement location on the body, and body angle. The program can increment the shock generator angle and also predict when a type V interference pattern will occur.

A description of the input and output variables and a sample case are presented.

Input Description

The \$DATAIN input for type VI is as follows:

RUN	run number for identification
RM1	M_{∞} , free-stream Mach number
GAMMA	c_p/c_v , ratio of specific heats
THETAI	θ_i , shock-generator angle, deg; or β_i , impinging shock angle, deg
THETAB	θ_{b} , body angle, deg; or β_{b} , bow shock angle, deg
TINCR	increment for θ_i , deg (Default = 5 ^o)
NTIMES	number of times to increment θ_i
IPT	initial point; 0 for stagnation conditions, 1 for free-stream static conditions
Т	temperature at IPT, ^O R
P	pressure at IPT, psia
AMW	molecular weight (used to compute gas constant)
TREF	reference temperature for computing viscosity, ^{O}R
VREF	reference viscosity for computing viscosity, slugs/ft-sec
S	Sutherland's constant in viscosity equation
XL	X_i , distance from leading edge to impingement point, ft
TWALL	temperature at wall, ^O R
СР	c_p , specific heat at constant pressure, ft-lbf/slug- ^O R

PR	Npr, Prandtl number
ANGLE	THET if θ_i input; BETA if β_i input
ANGLE2	THET if θ_b input; BETA if β_b input
TOL	acceptable tolerance for equal pressures (0.001)
	Output Description
The output consis	sts of printing only. A heading and pertinent input for i

The output consists of printing only. A heading and pertinent input for identification are printed before the results of the calculations.

RUN NUMBER	run number for identification
M1	M_{∞} , Mach number in free stream
GAMMA (CP/CV)	ratio of specific heats
TEMP AT POINT ''IPT''	input as T, ^O R
PRES AT POINT "IPT"	input as P, psia
MOLECULAR WEIGHT	molecular weight (used to compute gas constant)
REFERENCE TEMP	reference temperature for computing viscosity, ^{O}R
REFERENCE VISCOSITY	reference viscosity for computing viscosity, slugs/ft-sec
S(SUTHERLAND NUMBER)	Sutherland's constant in viscosity equation
TEMP AT WALL	T _w , ^o R
СР	c _p , specific heat at constant pressure, ft-lbf/slug- ⁰ R
PRANDTL NUMBER	N _{Pr} , Prandtl number
XL(WALL LENGTH)	$\mathbf{X}_{\mathbf{i}}$, length from leading edge to impingement point, ft
THETAI	θ_i , shock generator angle, deg
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THETAB	θ_{b} , body angle, deg
P2/P1, etc.	p_2/p_1 , etc., pressure ratios for regions listed
RHO2/1, etc.	$ ho_2/ ho_1$, etc., density ratios for regions listed
T2/T1, etc.	T_2/T_1 , etc., temperature ratios for regions listed
A2/A1, etc.	a_2/a_1 , etc., ratios of speeds of sound in regions listed
U2/U1, etc.	u_2/u_1 , etc., velocity ratios for regions listed
RELATIVE ANGLE	
THETA	flow angle relative to flow in upstream region, deg
BETA	shock angle relative to flow in upstream region, deg
ABSOLUTE ANGLE	
THETA	flow angle relative to free-stream flow, deg
BETA	shock angle relative to free-stream flow, deg
UPSTREAM MACH	Mach number in upstream region
LOCAL MACH	local Mach number
REGION	region in shock pattern
P	static pressure in region, psia
RHO	static density in region, $slugs/ft^3$
т	static temperature in region, ^O R
A	speed of sound in region, ft/sec
U	velocity in region, ft/sec

MU	static viscosity in region, slugs/ft-sec
REYNOLDS NO	Reynolds number per foot in region
MACH NO	Mach number in region
The following stagnation	n conditions are then listed:
PSTAG	total pressure in region, psia
RHO	total density in region, $slugs/ft^3$
TSTAG	total temperature in region, ^O R
PSTAG/PSTAG1	ratio of total pressure in region to free-stream total pressure
The pressure ratio and as	heat transfer for laminar and turbulent flow are listed
Q	heat-transfer rate, Btu/ft ² -sec
HFP	flat-plate heat-transfer coefficient, Btu/ft^2 -sec- ^{O}R
STANTON4	local incompressible Stanton number
STANTON1	compressible free-stream Stanton number
P6/P4	pressure ratio
HR	Markarian heat-transfer ratio
QPK	peak heating rate
НРК	peak heat-transfer coefficient

SDATAIN		
RM1	=	0.6E+01;
GAMMA	z	0.14E+01;
THETAB	=	0.15E+02;
THETAI	=	0.5E+01,
TINCR	×	0.5E+01,
NTIMES	=	1,
IPT	=	Ο,
ı	=	0.9E+03,
P	=	0.4E+03,
АМы	=	0.2897E+02,
TREF	Ξ.	0.53E+03;
VREF	÷	0.3801E-06,
XL	=	U.25E+00;
S	2	0.1986E+03,
TWALL	=	0.55E+03;
CP	8	0.6006E+04,
PR	=	U.72E+00;
RUN	Ħ	0.1E+01;
ANGLE	=	0.69404725765109E+93,
ANGL E2	=	0.69404725765109E+93,
TOL	Ξ	0.1E-02,
\$END		

Sample Case – Output

THIS PROGRAM PERFORMS A TYPE 6 SHOCK INTERFERENCE PATTERN RUN NUMBER 1.00

INPUT VARIABLES ARE

6.000 MI M1 GAMMA(CP/CV) TEMP AT POINT O PRES AT POINT O MOLECULAR WEIGHT REFERENCE FEMP REFERENCE VISCOSITY S(SUTHERLAND NUMBER) TEMP AT WALL 1.400000 900.000000 RANK INE 400.000000 PSI 28.970000 530.000000 RANK INE 3.801000E-07 SLUG/(FT-SEC) 198.600 TEMP AT WALL 550.000 RANKINE FT-LBF/(SLUG-RANKINE) СР 6006.000 PRANDTL NUMBER .720000 .250000 FT XL(WALL LENGTH)

RATIOS ARE

P2/P1=	6.2657	RH02/1=	3.1465	T2/T1=	1.9913	A2/A1=	1.4111	U2/U1=	.9286
P3/P1=	2. 1103	RH03/1=	1.6306	T3/T1=	1.2328	A3/A1=	1.1103	U3/U1=	.9837
P4/P3=	3.2313	RH04/3=	2.2085	T4/T3=	1.4631	A4/A3=	1.2090	U4/U3=	.9582
P4/P1=	6.4957	KH04/ 1=	3.6013	T4/T1=	1.8037	A4/Al=	1.3430	U4/U1=	.9425

	RELAI	IVE ANGLE	ABSOL	LUTE ANGLE			
	THETA	BETA	THETA	BETA	UPSTREAM MACH	LUCAL MACH	
2	15.3412	23.0383	15.3413	23.0383	6.0000	3.9483	
3	5.0000	13.1598	5.0000	13.1598	6.0000	5.3157	
4 0	10.0000	10.7264	15.0000	23.7264	5.3157	4.2108	
5	5.3413	18.7264	15.3413	23.7264	4-2108	4.2388	

REGION	P	RHO	T	А	U	MU	REYNOLDS NO	MACH NO
	PSI	SLUG/CU FT	RANKINE	FT/SEC	FT/SEC	SLUG/FT-SEC	1/FT	
L	.2533	1.93645E-04	109.7561	513.5679	3081.4074	8.46377E-08	7.05004E+06	6.0000
2	1.5874	6.05309E-04	218.5598	724.7174	2801.4275	1.75803E-07	9.91731E+06	3.9483
3	.5093	3.15760E-04	135.3111	510.2302	3031.1919	1.06990E-07	8.94597E+06	5.3157
40	1.6457	6.47365E-04	197.9706	685.7376	2904.3537	1.59424E-07	1-27045E+07	4.2108
5	1.5870	0.79541E-04	195.9276	686.1694	2908.5544	1.57775E-07	1.25272E+07	4.2388

STAGNATI	ION CONDITION	NS ARE		
REGICN	PSTAG	RHÜ	TSTAG	PSTAG/PSTAG1
	PSIA	SLUGS/CU FT	RANKINE	
1	400.0000	3.728566-02	900.0000	
2	224.9256	2.09662E-02	900.0010	.5623
3	386.5123	3-00280E-02	900.0088	.9663
4	329.6872	3.07311E-02	900.0107	- 8242
5	329.6872	3.07314E-02	900.0000	·8242

HEAT TRANSFER HEP STANTON4 STANTONI P6/P4 Q HR QPK нрк LAMINAR 8.37207E-01 3-43593E-03 5.66997E-04 7.45904E-04 9.28770E-01 9.090798-01 7.61087E-01 3.12353E-03 TURBULENT 4.25952E+00 1.5367CE-02 2.53586E-03 3.33601E-03 9.28770E-01 9.39122E-01 4.00021E+00 1.44315E-02

PART VII – SUBPROGRAMS

A description of each of the subprograms common to more than one main program is presented along with a flow chart and listing.

FTHETA

Function FTHETA computes the flow deflection angle given the Mach number ahead of the shock, the ratio of specific heats, and the shock angle. The flow diagram and listing are as follows:



	FUNCTION FTHETA (GAMMA,RM,BETA)	В	3
С	FIND FLOW ANGLE	в	4
	SINB=SIN(BETA)	8	5
	SINESQ=SINR*SINB	В	6
	CUS2B=COS(2.*BETA)	8	7
	RM SQ=RM*RM	В	8
	RMSB2=RMSQ*SINBSQ	В	9
	TANB = TAN(BETA)	В	10
	TAN TH=2.*(RMSB2-1.)/(TANB*(RMSQ*(GAMMA+CCS2B)+2.))	B	ĩī
	FTHETA=ATAN(TANTH)	B	12
	RETURN	В	13
	END	8	14-
С	• • • • • • • • • • • • • • • • • • • •	A	1

PINPUT

Subroutine PINPUT prints out the input variables. The flow diagram and listing for this subroutine are as follows:



	SUBFOUTINE PINPUT (FM1,GAMMA,IPT,T,P,AMW,TREF,VREF,XL,S,TWALL,CP,P	Д	2
	19,)	А	3
С	PRINT OUT INPUT VAPIABLES	Ą	4
	WRITE (6,1)	A	5
	WRITE (6,11) RM1	A	6
	WRITE (6,12) GAMMA	A	7
	WRITE (6,2) IPT,T	A	8
	WRITE (6,3) IPT,P	4	9
	WRITE (6,4) AMW	Α	10
	WRITE (6,5) TREF	A	11
	WRITE (6,6) VREF	A	12
	WRITE (6,7) S	Α	13
	WRITE (6,8) TWALL	A	14
	WRITE (6,9) CP	Ą	15
	WRITE (6,10) PR	Ą	16
	RETURN	A	17
С		Δ	18
1	FORMAT (1H0,20HINPUT VARIABLES ARE /)	4	19
2	FORMAT (14H TEMP AT POINT, 12, 15X, F15.6.9H PANKINE)	A	20
3	FORMAT (14H PRES AT POINT, 12, 15X, F15.6, 6H PSI)	4	21
4	FORMAT (17H MOLECULAR WEIGHT, 14X, F15.6)	A	22
5	FORMAT (15H REFERENCE TEMP,16X,F15.6,9H RANKINE)	A	23
6	FORMAT (20H REFERENCE VISCOSITY,11X,E15.6,15H SLUG/(FT-SEC))	A	24
7	FORMAT (21H S(SUTHERLAND NUMBER),10X,F15.3)	Δ	25
8	FORMAT (13H TEMP AT WALL, 18X, F15.3,9H RANKINE)	A	26
9	FORMAT (3H CP,28X,F15,3,23H FT-LBF/(SLUG-RANKINE))	A	27
10	FORMAT (15H PRANDTL NUMBER 16X, F15.6)	Δ	28
11	FORMAT (3H M1+28X+F15+3)	Δ	29
12	FORMAT (13H GAMMA(CP/CV).18X.F15.6)	Δ	30
	ENC	A	31-

OBLIQ

Subroutine OBLIQ calculates the flow-property ratios across an oblique shock. The flow diagram and listing are as follows:





SUBROUTINE OBLIQ (GAMMA, RMI, THE TAJ, BE TAJ, RMJ, RAT, I, J, IOPT)	F	1
	F	2
PURPOSE	F	- 3
TC CALCULATE THE OBLIQUE SHOCK RELATIONS FOR PRESSURE, DENSITY,	F	4
TEMPERATURE, SONIC VELOCITY, VELOCITY, AND MACH NUMBER FOR	F	5
CONDITIONS I BEFORE THE SHOCK AND J AFTER THE SHOCK	F	6
	F	7
USAGE	F	8
	F	9
CBLIQ(GAMMA, RMI, THETAJ, BETAJ, RMJ, RAT, I, J, IOPT)	F	10
	F	11

CCCCCCCCCC

C	DESCRIPTION OF VARIABLES
0	GAMMA = RATID OF SPECIFIC HEAT CAPACITIES (CP/CV)
C	RMI = MACH NUMBER BEFORE THE SHOCK
С	THETAJ= DEFLECTION ANGLE OF THE STREAMLINES IN RADIANS
С	BETAJ = SHOCK ANGLE IN RADIANS
С	RMJ ≃ MACH NUMBER AFTER THE SHOCK
С	RAT(1)≈ PJOPI DOWNSTREAM PRESSURE OVER UPSTREAM PRESSURE
C	RAT(2) = RHOJOI DOWNSTREAM DENSITY OVER UPSTREAM DENSITY
C	RAT(3)≈ TJOTI DOWNSTREAM TEMPERATURE OVER UPSTREAM TEMP
C	RAT(4) = AJCAI DOWNSTREAM SONIC VELOCITY OVER UPSTREAM SOMIC
c .	RAT(5)≈ UJOUI DOWNSTREAM VELOCITY OVER UPSTREAM VELOCITY
Č.	I = UPSTREAM CONDITIONS
c	J = DOWNSTREAM CONDITIONS
c.	IOPT = 1,-1 CALCULATE RMJ
Ċ.	2,-2 DO NOT CALCULATE RMJ
č	POSITIVE PRINT RATIOS
č	NEGATIVE DO NOT PRINT RATIOS
č	
C C	
C	COMMON PZ, RHOZ, TZ, PIOPZ, RHOLOZ, TIOTZ,
	1 PZ2, RH0Z2, TZ2, P20PZ2, RH02Z2, T20TZ2,
	2 P73, RH0Z3, TZ3, P30PZ3, RH03Z3, T30TZ3,
	3 P74. RH0Z4. TZ4. P40PZ4. RH04Z4. T40TZ4.
	A P75, RH075, T75, P50P25, RH0525, T50T25,
	5 P76, RH076, TZ6, P60PZ6, RH06Z6, T60TZ6,
	6 P20P1, RH0201, T20T1, A20A1, U20U1,
	7 P 30P2, RH0302, T30T2, A30A2, U30U2,
	e PSDP3, RH0503, TSDT3, A5DA3, U5003,
	\$ P50P3, R00C3, 150T3, A50A1, U50U1,
	COMMON FORST KINGCOST TO IST ACCOST
	LEMMEN FI, NOL, II, AL, UL, VISC2, REV2.
	1 F2, KH02, F2, A2, U3, VISC3, REV3.
	2 P3 RIGS IS RS 05 VISCA REVA.
	3 F4; RIU4; F4; A4; 04; F1205; REV5.
	DIMENSION DAT (5)
<u> </u>	EIND RATIOS USING OBLIQUE SHOCK RELATIONS
C	CTND-CTN/DETAIL
~	SIND=SIN(BELAS)
L	DIODY-DDATIO/CAMMA DMI. SINR)
~	PJUP I=PRATICICAMMA, MILSING, CALCULATE DENSITY RATIOS
L	
~	RHUJUI=DENKAI (GAMMA, KMI) SIND
C	TIOTI-TOATIO/CANNA DAI SINGI
~	1 J U I = 1 RATIO (GAMMA, RM1, SING) CALCULATE SOMEC VELOCITY RATIO
C	CALCOLATE SOUTH OT ANALY
~	AJUAI = ARATIOUTJOTTI
C	CALCULATE MACH NOMBER AT CONDITION C
	$\frac{1}{1} \left(\frac{1}{1000} \left(\frac{1}{1000} \right) - \frac{1}{1000} \right) = \frac{1}{10000000000000000000000000000000000$
1	RMJ=FINDM (GAMMA, RMI, SIND, DELAU, TELAU, TELAU, ATELAU, ATEL
C	
2	
	KAI (4)=AJUAI
	RAT(5)=UJUUL

С С С С С 1 C 2

С	IF IOPT POSITIVE WRITE RATIOS	F	74
	IF (IOPT) 4,3,3	F	75
3	CONTINUE	F	76
	WRITE (6,5) J.I.,PJOPI,J.I.,RHOJOI,J.I.,TJOTI,J.,I.,AJOAI,J.I.,UJOUI	F	77
4	RETURN	F	78
С .		F	79
5	FORMAT (1X,1HP,I1,2H/P,I1,1H=,F8.4,5X,3HRHU,I1,1H/,11,1H=,F8.4,5X,	۴	80
	11HT,I1,2H/T,I1,1H=,F8.4,5X,1HA,I1,2H/A,I1,1H=,F8.4,5X,1HU, I1,2H/U,	F	81
	2I1, 1H=, F8.4)	F	82
	END	۶	83-

PRATIO

Function PRATIO computes the ratios of the static pressures across an oblique shock. The flow diagram and listing are as follows:



DENRAT

Function DENRAT computes the ratios of the static densities across an oblique shock. The flow diagram and listing of this function are as follows:



	FUNCTION DENRAT (GAMMA, RM, SINR)		n	2
r	ETNP DATIAS DE CTATIO PENCITIES CINDESINIDETAL		0	2
C	FINE RATIOS OF STATIC DENSITIES, STADESINGBERAP		U	2
	RMSQ=RM*RM		D	4
	SINESC=SINESINE	1914	D	5
	DENRAT=(GAMMA+1.)*RMSQ*SINBSQ/((GAMMA-1.)*RMSQ*SINBSQ+2.)		D	6
	RETURN		D	7
	END		D	8-
С	• • • • • • • • • • • • • • • • • • • •		E	1

TRATIO

Function TRATIO computes the ratios of the static temperatures across an oblique shock. The flow diagram and listing are as follows:



ARATIO

Function ARATIO computes the ratios of the speeds of sound across an oblique shock. The flow diagram and listing are as follows:



	FUNCTION ARATIO (T2011)	F	2
С	FIND RATIOS OF SPEEDS CF SOUND	F	3
	ARATIC=SQRT(T2011)	F	4
	RETURN	۴	5
	END	F	6-
С		G	1

FINDM

Function FINDM computes the Mach number behind an oblique shock. The flow diagram and listing are as follows:



MLTRT

Subroutine MLTRT computes the ratios of the flow quantities in each region with respect to the free-stream values by multiplying the ratios across oblique shocks. The subroutine flow diagram and listing are as follows:



	SUBROUTINE MLTRT (RATICI,RATICI,RATICI,I,J,IOPT)	н	2
	MULTIPLY RATIOS TO OBTAIN RATIOS WITH RESPECT TO FREE STREAM	н	3
	DIMENSION RATIOJ(5), RATIOI(5), RATJOI(5)	Н	4
	COMMEN PZ, RHOZ, TZ, PIOPZ, RHOLOZ, TIOTZ,	н	5
1	PZ_2 , $RHOZ_2$, TZ_2 , $P2OPZ_2$, RHO_2Z_2 , $T2OTZ_2$,	н	6
2	PZ3, RHOZ3, TZ3, P3CPZ3, RHO3Z3, T3OTZ3,	Н	7
3	PZ4, RHOZ4, TZ4, P4OPZ4, RHO4Z4, T4OTZ4,	н	8
4	PZ5, RH0Z5, TZ5, P50PZ5, RH05Z5, T50TZ5,	н	9
5	PZ6, RH0Z6, TZ6, P60PZ6, RH06Z6, T60TZ6,	н	10
6	P20P1, RH0201, T20T1, A20A1, U2CU1,	н	11
7	P30P2, RH0302, T30T2, A30A2, U30U2,	Н	12
8	P30P1, RH0301, T30T1, A30A1, U30U1,	н	13
9	P40P2, RH0402, T40T2, A40A2, U40U2,	н	14
\$	P40P1, RH0401, T40T1, A40A1, U40U1,	Н	15
\$	P50P3, RH0503, T50T3, A50A3, U50U3,	н	16
\$	P60P2, RH0602, T60T2, A60A2, U6CU2,	н	17
\$	P60P4, PH0604, T60T4, A6044, U60U4,	Н	18
\$	P50P1, RH0501, T50T1, A50A1, U50U1,	н	19
\$	P60P1, PH0601, T60T1, A60A1, U60U1	Н	20
	COMMEN P1, RHO1, T1, A1, U1, VISC1, REY1,	н	21
1	P2, RHO2, T2, A2, U2, VISC2, REY2,	н	22
2	P3, RH03, T3, A3, U3, VISC3, REY3,	н	23
3	P4, RH04, T4, A4, U4, VISC4, REY4,	н	24
4	P5, RH05, T5, A5, U5, VISC5, REY5,	Н	25
5	P6, PH06, T6, A6, U6, VISC6, REY6	н	26
	DO 1 K=1,5	н	27
	RATJOI(K)=RATICJ(K)*RATIOI(K)	н	28
	IF (ICPT) 3,2,2	н	29
	WRITE (6,4) (J,I,RATJOI(K),K=1,5)	н	30
	RETURN	н	31
		н	32
	FORMAT (1X,1HP,I1,2H/P,I1,1H=,F8.4,5X,3HRHO,I1,1H/,I1,1H=,F8.4,5X,	н	33
1	1HT,11,2H/T,I1,1H=,F8.4,5X,1H4,I1,2H/A,I1,1H=,F8.4,5X,1HU,I1,2H/U,	н	34
2	Il, IH=, F8.4)	н	35
	END	н	36-

FINDB

Function FINDB solves a cubic equation for the shock angle by using the upstream Mach number and the deflection angle. A code is provided which allows the user to specify a strong-shock solution or a weak-shock solution. The flow diagram and listing are as follows:

С



FUNCTIC	N FINDB (GAMMA,RM,THETA,IERROR)	I	1
PURPOSE			2
FIND SH	OCK ANGLE	I	3
		ĩ	4
DESCRIP	TICN OF VARIABLES	I	5
GAMMA	CP/CV	I	e
RM	UPSTREAM MACH NUMBER	t	7
THETA	DEFLECTION ANGLE	I	8
ITYPE	2 FOR STRONG SHOCK SOLUTION AND 1 FOR WEAK SHOCK SOLUTION	I	ç
IFRROR	O FOR NO ERROR	I	10
	3 NO SCLUTICN POSSIBLE	I	11
		I	12
DATA PI	/3.1415927/	I	13
DIMENSI	CN BETA(3), ZZ(3), ZANS(3), TANANS(3)	I	14
IPRINT=	IERROR	I	15
JERROR=	0	ľ	16
IF (ABS	(THETA).LT001) GD TD 4	I	17
FMINIT=	RM	Ĩ	18
THE TAC =	ΤΗΕΤΔ	I	19
FMSC=FM	INIT*FMINIT	I	2.0
SINTHE=	SIN(THETAC)	I	21
SINSC=S	INTHE*SINTHE	I	22
PZ=-(FM	SQ+2.0)/FMSQ-GAMMA*SINSQ	I	23
GAMM1=G	AMMA-1.0	1	24
GAMP1=G	AMMA+1.0	I	25
GAMSC=G	AMP1*G4MP1	Ĩ	26
FM4=FMS	C*FMS C	ĩ	27
FM4=FMS	©*FMSQ		ĩ

	QZ=(2.0*FMSQ+1.0)/FM4+(GAMSQ/4.0+GAMM1/FMSQ)*SINSQ	I	28
	COSTHE=COS(THETAC)	I	29
	COSSQ=COSTHE*COSTHE	I	30
	RZ=-COSSQ/FM4	I	31
	PZSQ=PZ*PZ	I	32
	AZ=.3333333*(3.0*QZ-PZSQ)	T	33
	PZ3=PZ*PZSQ	Ï	34
	BZ=1•0/27•0*(2•0*PZ3-9•0*PZ*QZ+27•0*RZ)	Ī	35
	BZ2=EZ/2.0	T	36
	BZSQ=EZ2*BZ2	Ī	37
	AZ3=AZ/3.0	Ĩ	38
	AZCUB=AZ3*AZ3*AZ3	Ĩ	39
	ARGCK=EZSQ+AZCUB	1	40
	IF (ARGCK) 2.1.1	Ĩ	41
1	IERSOR=3	T	42
	THDEG=THETA*57.296	Ť	43
	IF (IPRINT.LE.O) WRITE (6.6) GAMMA.RM.THDEG	ī	44
	RETURN	Ť	45
2	COSPHI =- BZ2/SQRT(-AZCUB)	Ť	46
	PAFT=2.0*SQRT(-AZ3)	Ī	47
	$PHI = \Delta COS(COSPHI)$	Ŧ	48
	PHI3=PHI/3-0	Ť	49
	PZ BY3=PZ/3-0	Ť	50
	ZZ(1) = PART + COS(PHI3) - PZBY3	Ť	51
	ZZ(2) = PART * COS(PHI3+.6666667*PI) - PZRY3	Ť	52
	ZZ (3) = PART*COS (PHI3+1, 3333333*PI) - PZRY3	Ť	52
		Ť	54
3	BETA(I) = ASIN(SCRT(77(I)))	÷	55
-	TEMF1 = AMAX1(BETA(1), BETA(2))	÷	56
	$TEMP2 = \Delta MAX1(BETA(2), BETA(3))$	Ť	57
	TEMP3=AMAX1(BETA(1),BETA(3))	Ť	58
C	WEAK SHOCK	Ť	59
	FINCB=AMIN1(TEMP1.TEMP2.TEMP3)	Ť	60
	RETURN	Ť	61
4	IE (ITYPE, EG.2) GO TO 5	Ť	62
•	FINCB=ASIN(1, /RM)	Ť	62
	RETIRN	- T	64
5	FINE=1,5708	Ť	65
-	RETURN	Ť	66
r		7	67
š	FORMAT (32H NO SOLUTION POSSIBLE FOR CAMMA= FR.4.54. PM- FO 4.124.	T	68
2	1 AND THETA =. FR.4)	Ť	60
		T	70-
	لى بى	1	10-

ABSVAL

Subroutine ABSVAL calculates values of static pressure, static density, static temperature, speed of sound, velocity, static viscosity, and Reynolds number per foot for a region through the use of the ratios of values in that region with respect to free-stream values and the free-stream conditions. The flow diagram and listing are as follows:

> 1. 1. 1.

	ABSVAL		
	Compute values from ratios		
	CALL VISCJ		
	Compute viscosity		
	Compute Reynolds number		
	Is IOPT Yes Write values	7	
	No		
	(Return)-		
С.	SUBROUTINE ABSVAL (RAT, VALU1, VALUJ, VREF, TREF, S, J, IOPT, RMJ)	N	1
C	PURPOSE	N N	3 4
č	CALCULATE ABSOLUTE VALUES FOR PARAMETERS P, RHO, T, A, U, VISC, AND REV FOR POINT & GIVEN VALUES AT POINT 1 AND THE BATLUS FOR	N N	5 6
č	J OVER 1	N	7
č		N	9 10
٠. •	E PZ2, RH0Z2, TZ2, P20PZ2, RH0Z22, T20TZ2,	N	11
	2 PZ3, RHUZ3, IZ3, P30PZ3, RHU3Z3, I30IZ3, 3 PZ4, RHOZ4, TZ4, P40PZ4, RH04Z4, T40TZ4,	N	12
	4 PZ5, RHOZ5, TZ5, P50PZ5, RH05Z5, T50TZ5, 5 PZ6, RH0Z6, TZ6, P60PZ6, RH06Z6, T60TZ6,	N N	14 15
	6 P 20P 1, RH0201, T20T1, A20A1, U20U1, 7 P30P2, RH0302, T30T2, A30A2, U30U2,	N	16
	8 P 30P 1, RH0301, T30T1, A30A1, U30U1,	N	18
ſ	 \$ P40P1, RH0401, T40T1, A40A1, U40U1, 	N	20
	\$ P50P3, RH0503, T50T3, A50A3, U50U3, \$ P60P5, RH0605, T60T5, A60A5, U60U5,	N	21 22
4	 \$ P50P1, RH0501, T50T1, A50A1, U50U1, \$ P60P1, RH0601, T60T1, A60A1, U60U1 	N N	23 24
	COMMON P60P3, RH0603, T60T3, A60A3, U60U3	N N	25 26
	1 P2, RH02, T2, A2, U2, VISC2, REY2,	N	27
	2 P3, KHU3, I3, A3, U3, VISC3, KET3, 3 P4, RH04, T4, A4, U4, VISC4, REY4,	N	29
	4 P5, RHO5, T5, A5, U5, VISC5, REY5, 5 P6, RHO6, T6, A6, U6, VISC6, REY6	N	30 31

	DIMENSION RAT(5), VALUI(7), VALUJ(7)	N	32
С	CALCULATE P, RHO, T, A, AND U AT POINT J	Ν	33
	DO 1 $I=1,5$	N	34
1	VALUJ(I)=RAT(I)*VALUL(I)	Ν	35
C	CALCULATE VISCOSITY	N	36
	VALUJ(6)=VISCJ(VREF,TREF,VALUJ(3),S)	Ň	37
С	CALCULATE REYNOLDS NUMBER(RHO*U*XL/VISC)	N	38
	VALUJ(7)=VALUJ(2)*VALUJ(5)/VALUJ(6)	N	39
	IF (IOPT) 3,2,2	N	40
2	WRITE (6,4) J,(VALUJ(I),I=1,7),RMJ	Ň	41
3	RETURN	N	42
C		Ň	43
4	FORMAT (1X,15,F12.4,E15.5,3F12.4,2E15.5,F8.4)	N	44
	END	N	45

ISTROP

Subroutine ISTROP calculates the static values or the total values of pressure, density, and temperature for a region with the use of isentropic relations. The flow diagram and listing are as follows:



c	VALU	Z VALUE OF P. T. RHO AT CONDITION ZERO	ĸ	12
ř	RATI	RATIO OF P. T. RHO AT CONDITION 1 OVER ZERO	ĸ	13
č	TPT	O DR 1, CONDITION WHICH WAS INPUT. CALCULATE THE OTHER.	κ	14
č		*****	κ	15
Ũ	DINENST	CN VALUT(7), VALUZ(3), RATID(3)	к	16
	COMMEN	P7. RH07. T7. P10P7. RH0102. T10TZ.	K	17
	1	P72. RH072. T72. P20PZ2. RH02Z2. T20TZ2.	ĸ	18
	2	P73. 8H073. T73. P30P73. 8H03Z3. T30TZ3.	κ	19
	2	P74. 8H074. T74. P40P74. 8H0474. T40TZ4.	ĸ	20
	í.	P75. 8H075. T75. P50P75. 8H0525. T50T25.	κ	21
	5	P76. RH076. T76. P60P76. RH06Z6. T60TZ6.	ĸ	22
	6	P20P1, RH0201, T20T1, A20A1, U20U1,	ĸ	23
	7	P30P2. RH0302. T30T2. A30A2. U30U2.	ĸ	24
	8	P30P1. RH0301. T30T1. A30A1. U30U1.	ĸ	25
	9	P40P2, RH0402, T40T2, A40A2, U40U2,	ĸ	26
	¢.	P40P1, RH0401, T40T1, A40A1, U40U1,	ĸ	27
	¢	P50P3, RH0503, T50T3, A50A3, U50U3,	ĸ	28
	\$	P60P2, RH0602, T60T2, A60A2, U60U2,	ĸ	29
	τ. ε	P60P4, RH0604, T60T4, A60A4, U60U4,	ĸ	30
	\$	P50P1, RH0501, T50T1, A50A1, U50U1,	ĸ	31
	•	P60P1, RH0601, T60T1, A60A1, U60U1	ĸ	32
	COMMEN	P1. RH01. T1. A1. U1. VISC1, REY1,	ĸ	33
	1	P2. PHD2. T2. A2. U2. VISC2. REY2.	ĸ	34
	2	P3. RH03. T3. A3. U3. VISC3. REY3.	ĸ	35
	3	P4. RH04. T4. A4. U4. VISC4. REY4.	ĸ	36
	4	P5, RH05, T5, A5, U5, VISC5, REY5,	ĸ	37
	5	P6, PH06, T6, A6, U6, VISC6, REY6	K	38
	C=(1++(GAMMA-1.)*RM1**2/2.)	ĸ	39
	P10PZ=1	./C**(GAMMA/(GAMMA-1.))	ĸ	40
	RHC10Z=	1./C**(1./(GAMMA-1.))	ĸ	41
	T10TZ=1	./C	ĸ	42
	PATIOI	I) = P1CPZ	K	43
	RATIO	2) = R H010Z	K	44
	RATIO	3)=T1CTZ	K	45
	IF (IP)	1) 3,3,1	K	46
1	DO 2 I:	=1,3	K	47
2	VALUZ()	()=VALUI(I)/RATIC(I)	K	48
	PETURN		K	49
3	DO 4 I:	=1,3	K	50
4 1	VALU1()	I)=VALUZ(I)*PATIC(I)	ĸ	51
	RETURN		K.	52
	END		ĸ	-60
С			L	1

VISCJ

2

Function VISCJ computes the viscosity by using Sutherland's formula (eq. (A2) of ref. 6). The flow chart and listing are as follows:



	FUNCTION VISCJ (VREF, TREF, T, S)	L	2
C	FINE VISCOSITY	Ĺ	3
	VISCJ=VREF*(T/TREF)**1.5*(TREF+S)/(T+S)	L	4
	RETURN	L	5
	END	Ĺ	6-

TYP4

Subroutine TYP4 computes the shear-layer deflection angle by iterating until the static pressures in (2) and (4) are equal and the flow directions are parallel on either side of the shear layer for the shock pattern shown in the following sketch:



The flow diagram and listing for this subroutine are as follows:



<u>`</u>~



```
SUBRUUTINE TYP4 (THETAF, BETA2, RMI, RM3, THETAI, THETA4, BETA4, P30P1, GA
                                                                               n
                                                                                    1
     1MMA, TUL, IERROR)
                                                                                0
                                                                                    2
С
      PURPUSE
                                                                                0
                                                                                    3
C
      CALCULATE SHEAR LAYER INCLINATION BY MATCHING STATIC PRESSURE AND
                                                                                Ũ
                                                                                    4
C
      FLOW DIRECTION ON EITHER SIDE OF SHEAR LAYER. ALSO CALCULATES FLOW
                                                                                Ο
                                                                                    5
6
      ANGLES AND SHOCK ANGLES.
                                                                                0
                                                                                    6
C
                                                                                    7
      DESCRIPTION OF VARIABLES
                                                                                U
C
C
                                                                                Ò
                                                                                    8
       INPUT
         THETAF = DEFLECTION ANGLE FOR RM1 IN RADIANS. INPUT ESTIMATE
                                                                                U
                                                                                    9
0000000
         BETA2 = SHOCK(STRONG) ANGLE FOR RML IN RADIANS. INPUT ESTIMATE
                                                                                Ð
                                                                                   .10
                 = MACH NUMBER AT INITIAL PUINT
         KMI
                                                                                Û
                                                                                   11
                                                   WEAK SHOCK BETWEEN 3 AND
         RM3
                 = MACH NUMBER AT CONCITION 3.
                                                                                O
                                                                                   12
         THETAI = DEFLECTION ANGLE FOR RML IN RADIANS
                                                                                Ö
                                                                                   13
         THETA4 = DEFLECTION ANGLE FOR RM3 IN RADIANS
                                                                                Û
                                                                                   14
         BETA4 = SHOCK(WEAK) ANGLE FOR RM3 IN RADIANS
                                                                                0
                                                                                   15
                = CENVERGENCE CRITERIA FOR P4/P1 = P2/P1
                                                                                Ü
         TUL
                                                                                   16
                                                                                0
                                                                                   17
С
С
С
        OUTPUT
                                                                                0
                                                                                   18
          IERROR = 0 NO ERROR
                                                                               0
                                                                                   19
Ç
                   1 ONLY 1 SOLUTION FOUND
                                                                                0
                                                                                   20
C
                   2 CONVERGENGE CRITERIAN NUT FUUND
                                                                                0
                                                                                   21
Ċ
                   3 NO SOLUTION FOUND
                                                                                Û
                                                                                   22
```

C	
	12M=0
	METH2=0
	ISULN=1
	OI HETA = 1
	DIHEI=•I
L	SINB2=SIN(BETA2)
	PZOPI=PRATIU(GAMMA, RM1, SINB2)
	THETAGETHETAT
-	
L L	CALCULATE WEAK SHOCK SULUTION
	IERKUR=-I
	BETA4=FINDB(GAMMA,RM3,ABS(THETA4),ISULN,IERRUK)
	IF (1ERROR-3) 2,14,14
>	$P41P_3 = PRATIO(GAMMA, RM3, SIN(RETA4))$
-	
	IF (ABS(P20PI-P4CPII-I0L) 12,3,3
3	1F (P2CP1-P4CP1) 4,12,7
4	THETAF=THETAF+DTHETA
	1E (ISW) 6.5.10
5	
,	
6	DIHEIA=DIHEIA/IO.
	THETAF=THETAF-DTHETA
	GD TO 10
7	THETAE = THETAE = 0 THE TA
•	
8	DIHE IA=DIHE IA/10.
	THETAF=THETAF+DTHETA
	GU TU 10
Cj.	I S w= - 1
i l	CALCHARTE STORNE SHOCK SOLITIEN
	CAECOLATE STRONG SHOCK SOLOTIEN
10	IERKUR=-1
	BETA2=F1NDB(GAMMA,RML,ABS(THETAF),2,1ERROR)
	1 I = 1 T + 1
	16 (16RROR-3) (1.20.20
11	
C	ITERATION UN P4=P5 IS COMPLETED
12	THEDEG=THETAF*180°/3°141°
	RETURN
C	USE 2 STRONG SHOCK SULULIONS IF PZ-GT-P4
	IE (2000) IT DADDI) OFTION
13	
	IF (METH2.GI.O) KETURN
	ME[H2=1
	BETA∠=1.5708
	DIHEIA=I
	DTHE I = •1
	ISw=0
	1]=1
	WR[TF] (m,2)
74	1F (15W) 19,15,19
Û	BAD INITIAL GUESS
15	THE TAF = THETAF + DT + E T
16	1F (THETAF-THETAI) 10,17,17
r r	THETAE INCREMENTED TOO EAR
17	
11	17 (DINCI-001/ 10/10)
18	DIHET=DIHET/2.
	DIHETA=SIGN(DTHET,DIHETA)
	THETAF = THETAF-DTHET
	AL GL 09

Û
6	HAVE INCREMENTED THETAF TOO FAST	0	86
19	DTHETA=DTHETA/2.	0	87
	IHETAF=THETAF-ISW*DTHETA	0	88
	1F (ABS(DTHETA)001) 13,13,10	• 0	89
<u> </u>	NO_SOLUTION FOR BETA2	0	90
20	IF (ISW) 19,17,19	0	91
Ç.,		0	92
21	FORMAT (/28HTRY 2 STRONG SHOCK SOLUTIONS)	0	93
	END'	۵	94-

PART VIII - PROGRAM APPLICATIONS

This section briefly discusses where the various types of interference patterns may occur and how the programs may be used to compute the peak pressures and peak heat transfer on a practical configuration such as the mated space shuttle (orbiter, rockets, and fuel tank). Shock interference patterns can occur on the nose and between the individual bodies (during the ascent phase of the trajectory), as shown in figure 11. These patterns may also appear on the leading edges of wings and control surfaces, as shown in figure 12. The highest interference heating will exist in regions where subsonic flow is present and either a supersonic jet (type IV) or attaching shear layer (type III) is formed.

The undisturbed flow field over a complex vehicle can be computed with various methods. In fact, complete numerical solutions of the inviscid equations for an arbitrary body at angle of attack are currently under development. Various approximate techniques such as in references 20 and 21 are available now. Once the conditions in the local inviscid flow field, the state of the surface boundary layer, and the approximate location and type of interference pattern are known, the peak pressure and heating can be determined by using the appropriate program. It should be noted, however, that these computer programs must rely on some empirical inputs such as impinging shock angles, shock length, and in the case of the supersonic jet, some relation for the shock standoff distance. Real-gas effects must obviously be considered for high velocities.

Langley Research Center,

National Aeronautics and Space Administration, Hampton, Va., February 12, 1973.

L-8547

Authors' initials

Division Chief's initials

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(a) Type I.







(d) Type IV.

(e) Type V.

Figure 1.- Six types of shock interference patterns.

(f) Type VI.

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Figure 2.- Location of the types of interference on a hemisphere.







Figure 4.- Type II shock interference pattern.



Figure 5.- Type III shock interference pattern.



Figure 6.- Type IV shock interference pattern.

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Figure 7.- Type IV shock and jet configuration.



Figure 8.- Normal jet impingement model for $\mbox{ M}_{j} < 2.8$ (ref. 14).

Mach reflection at wall



Figure 9.- Type V shock interference pattern.



Figure 10.- Type VI shock interference pattern.



Figure 11.- Shock interference heating during ascent of a mated shuttle configuration.



Figure 12.- Locations of types of interference heating on mated configuration at $M_{\infty} \approx 20$.

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