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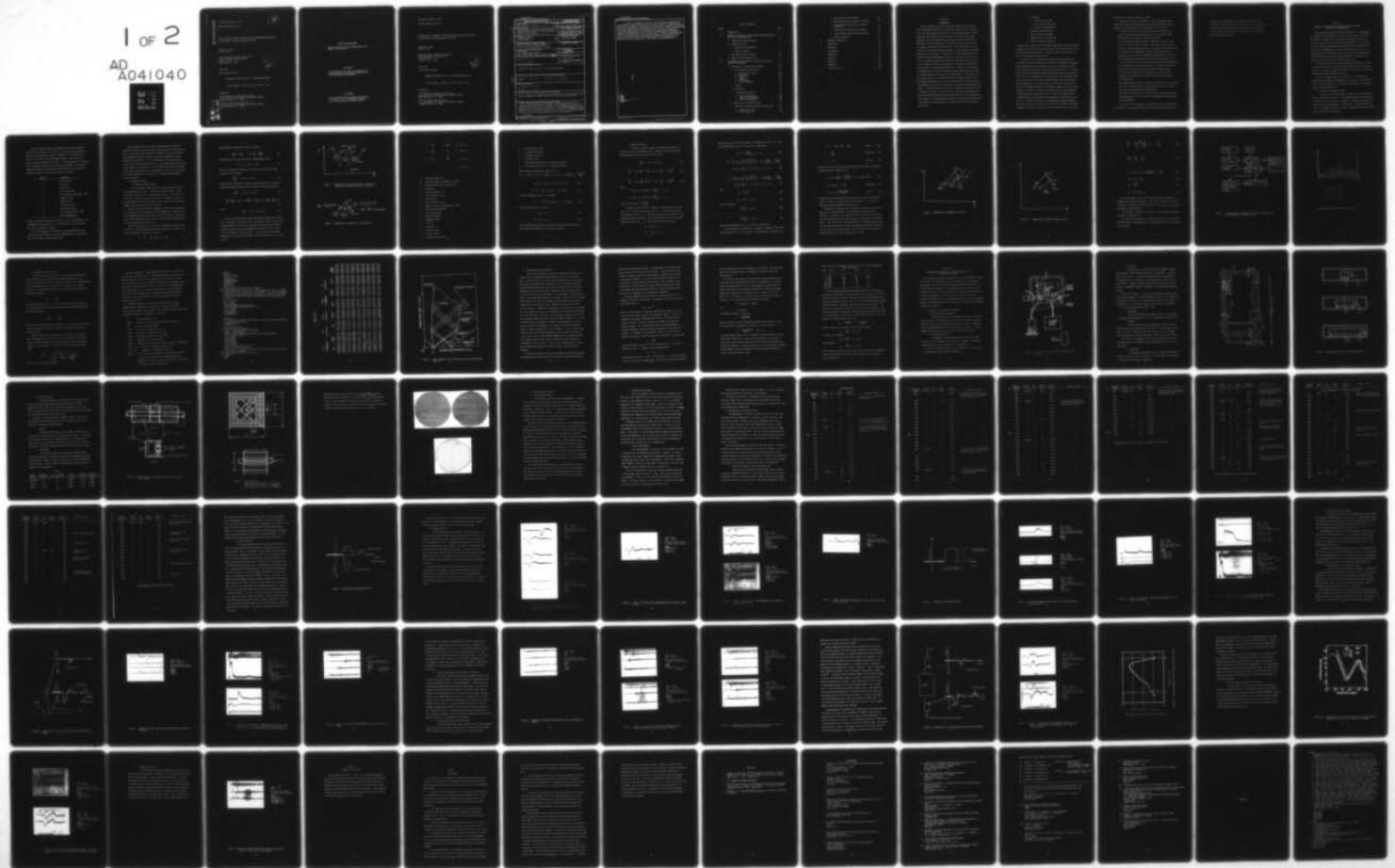
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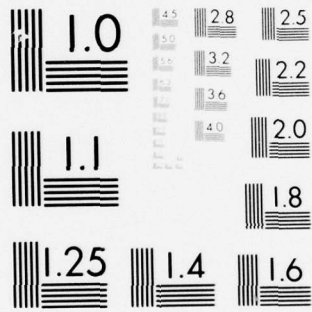
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UAH Research Report No. 199

Technical Report H-CR-77-9

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INVESTIGATION OF TRANSIENT FLOW AND HEATING PROBLEMS CHARACTERISTIC
OF HIGH ENERGY LASER GAS CIRCULATION SYSTEMS

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Prepared for

High Energy Laser Systems Project Office
U. S. Army Missile Research and Development Command
Redstone Arsenal, AL 35809

Army High Energy Laser Laboratory
U. S. Army Missile Research and Development Command
Redstone Arsenal, AL 35809

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In order to accomplish this goal, the UAH team has expended efforts in developing a subscale closed cycle laser gas circulator; constructing a muffler and reflectors and testing their effectiveness as acoustic and thermal attenuators; experimentally investigating the fluid and thermal characteristics of the recirculating flow associated with the pulsed wave propagation; studying the effectiveness of the blower and simulating heat exchangers; numerically simulating the recirculating flows for steady and unsteady cases as well as one-dimensional wave propagation models; and assisting in the design of the laser cavity to be incorporated with the Rocketdyne-built circulator from the standpoints of gas dynamics and thermodynamics.

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Chapter I

INTRODUCTION

Based on numerous studies of laser system applications in recent years, important applications of pulsed laser operation of all types of lasers have been apparently identified. The pulsed operation of a high energy gas laser presents special problems in the area of shock wave generation due to the sudden energy deposition and the interaction of these waves with other components of the laser system. These problems are present in both closed and open cycle laser systems and in all gas lasers such as electric discharge, chemical, and gas dynamic lasers when operated in a pulsed mode. In addition to shock wave generation, other transient gas flow thermodynamic problems are involved during the start up of a high energy gas laser system from a room temperature, zero flow initial condition until the establishment of "steady" flow conditions corresponding to sustained pulsed operation. These start up transients are characteristic of all high energy gas laser systems, both pulsed and CW and both open and closed cycle to varying degrees. The purpose of the work reported here is to investigate some of the major transient fluid and thermal characteristics of high energy pulsed laser operation and to study methods of reducing or eliminating the problems associated with such systems. The pulsed closed cycle electric discharge laser (EDL) was used as the basis for study in this work since it has most of the major fluid and thermal operating characteristics associated with all high energy gas laser systems. The following major technical issues were determined to be associated with the development of the pulsed closed cycle high energy laser system:

- A. Transients
 - 1. Start up recirculator
 - 2. Start up laser input power
 - 3. Acoustic waves/Attenuation
- B. Boundary Layer Interaction
- C. Heat Exchanger Performance
- D. Medium Quality, Clearing Time
- E. Plasma - Chemistry Stability

To answer some of these issues, fundamental knowledge of fluid and thermal characteristics of the recirculating gas flow in the closed cycle circulator during the laser operation is considered essential and necessary as one of basic engineering design tools.

To the best of our knowledge, experimental data and theoretical understanding directly attributable to the gain of fundamental knowledge and the substantiation of technical feasibility are lacking for the recirculating gas flow peculiar to the pulsed laser operation. At present, some of the major technical problems associated with the laser development of this kind are related to the questions of flow and thermal stabilities of the recirculating gas, plasma formation, pressure and thermal waves attenuations. For these reasons, a program was initiated at the Army Missile Command to design and fabricate a unique small scale closed cycle gas circulator for repetitively pulsed electric discharge lasers at 200⁰K temperature and high pressures in order that these potential problem areas can be identified and investigated at relatively low cost and risk. Results of this small scale program may, through comparison with other programs of larger scale circulators, contribute to the establishment of a realistic similarity law for the design of the full-scale

circulator at a saving of weight and volume.

As a part of the overall team effort in the program under the direction of the Army High Energy Laser Directorate, the UAH team has expended best-possible efforts in the following areas of concern.

- (1) Design and fabricate a subscale closed cycle laser gas circulator to be incorporated with the Army's single pulsed E-beam controlled laser to conduct simulation experiments.
- (2) Design and fabricate an acoustic attenuator (or muffler) and acoustic reflectors to be installed in the closed cycle circulator in order to study the wave attenuation and interaction characteristics.
- (3) Develop an instrumentation system including capabilities to measure and record pressure, temperature and velocities of the flow.
- (4) Experimentally investigate fluid and thermal characteristics of the recirculating flow associated with the pulsed wave propagation.
- (5) Experimentally determine the effects of muffler and reflectors upon the wave attenuation of both acoustic and thermal types.
- (6) Study experimentally the effectiveness of the blower and simulating heat exchangers as interacting elements with acoustic and thermal waves.
- (7) Develop computer models to numerically simulate the recirculating gas flows in laser operation, including steady flow case, unsteady flow case, and one-dimensional wave analysis.
- (8) Assist in the design of a laser cavity to be incorporated with the Rocketdyne-built circulator from the standpoints of gas dynamics and thermodynamics.

To the best of our knowledge, the experimental results reported here are the first to show the transient fluid and thermal characteristics of

a pulsed electric discharge in a functioning closed cycle gas circulator. These results should be of interest to those concerned with the design and operation of all types of pulsed gas lasers either closed or open cycle and including the electric discharge and chemical laser systems.

Chapter II

NUMERICAL SIMULATION OF THE RECIRCULATING AND UNSTEADY GAS FLOW IN LASER OPERATION

The experimental program described in Chapter III was supplemented by a numerical investigation of the fluid-thermal behavior of the gas. The numerical simulation work involved three computer programs. The first to be described is the steady state program which is a modification of a computer program which was available at UAH but needed modifications to accommodate the low temperature operating range. This computer program is designed to predict the steady state performance of the system which means that the pulsed operation of the system could only be simulated by assuming an average power input.

The second computer program to be described is designed to simulate the unsteady flow resulting from the sudden deposition of energy in the cavity. This program is capable of predicting the pressure, temperature, and velocity waves generated at the cavity.

The third computer program is the result of a one-dimensional analysis of the unsteady flow generated at the cavity. This program was used to provide estimates of the pressure and temperature environments expected in the cavity region.

A. Steady State Computer Program

The basic steady state computer program was first developed by AVCO for application to the MTU. This program was modified at UAH under a previous contract in order to accommodate a different heat exchanger design than originally employed in the program. Under the present contract, this program was modified further to simulate the 200 K gas system under consideration in this work.

The basic computer program is adequately described in Reference 1 and will not be covered in this report. A listing of the program with the current modifications is given in Appendix A. The results for a typical run is given in the tables which follow. Table 1 shows the input list used to generate the results. The system dimensions are those which correspond to the system being built by Rocketdyne. The computer program calculates the fluid-thermal characteristics at eleven points around the system. The stations are located as follows:

Station	Location
1	Cavity Entrance
2	Cavity Exit
3	Diffuser Exit
4	Constant Area Duct
5	Heat Exchanger (Room Temp.) Inlet
6	Compressor Inlet
7	Compressor Exit
8	Constant Area Duct
9	Constant Area Duct
10	Heat Exchanger (200 K) Inlet
11	Heat Exchanger Exit

The gas is loaded with energy at the cavity at the rate of 450 KW. This corresponds to about 900 J/l on a continuous basis. The results for this run are presented in Table 2.

The results show that the pressure in the system doesn't vary a great deal and the thermal load can be accommodated on a steady state basis with the heat exchanger loads shown.

The gas properties for the range of temperature and pressure encountered by the gas in traveling about the system were investigated carefully to ensure that large errors were not made. No major difficulties were encountered since the pressure remains near atmospheric and the temperature is above 200 K. This investigation also revealed that the system could likely be operated at even a lower temperature without danger of CO₂ snowing out of the gas. This can be seen from the phase diagrams for the laser gas mixtures given in Appendix B. This work was performed by Mr. David Washington as an exercise in an advanced thermodynamics course taken at UAH.

B. Unsteady Flow Case

1. Theoretical Considerations

Fluid and thermal characteristics are to be studied along the recirculating gas flow path as a function of time and space. As the laser pulses, energy will be input into the laser gas. The effect of the pulse will be felt along the fluid loop. Disturbances in the form of shock waves will travel out from the cavity, as well as other thermal changes that travel with the fluid particles.

The basic equations which are combined into the governing equations are one-dimensional fluid mechanics and thermodynamics. Together with the accompanying boundary conditions and initial conditions, these equations form a mathematical model of the fluid and thermal characteristics of the recirculating laser gas flow.

Based on the principles of similitude, the pertinent quantities of the flow are in non-dimensionalized form and presented as follows. The continuity equation is written in the form

$$\frac{1}{\rho} \frac{\partial \rho}{\partial t} + \frac{\partial \rho}{\partial x} + \frac{\partial u}{\partial x} + \frac{u}{\alpha} \frac{\partial \alpha}{\partial x} = 0 \quad (1)$$

and the dynamical equation of motion is given as

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} = - \frac{1}{\rho} \frac{\partial P}{\partial x} - \frac{f u |u|}{2D} \quad (2)$$

Combining the first and second laws of thermodynamics gives

$$dS = C_V \frac{dT}{T} - R \frac{d\rho}{\rho} \quad (3)$$

The rate of change of entropy may be a function of position and time as shown implicitly below,

$$\frac{DS}{Dt} = f(x, t, a, u, S) \quad (4)$$

Normalizing and rearranging the above equations yield a set of partial differential equations governing the transient flow in one-dimension.

$$\frac{DS}{D\tau} = f(\xi, \tau, A, U, S) \quad (5)$$

$$\frac{\delta^+}{\delta\tau} \left(\frac{2}{\gamma-1} A^+ U \right) = - AU \frac{\partial \ln d}{\partial \xi} + A \frac{\delta^+ S}{\delta\tau} + (\gamma-1) A \frac{DS}{D\tau} - \frac{f L_0}{2D} U |U| \quad (6)$$

where

$$\frac{\delta^+}{\delta\tau} = \frac{\partial}{\partial \tau} + (U \pm A) \frac{\partial}{\partial \xi} \quad (7)$$

Since two of the governing partial differential equations are hyperbolic, they possess "characteristics," invariants in time. At each point in time and space, there are two invariants moving away from the point. A numerical solution can take advantage of this very fact and is thus called, the method of characteristics. It uses invariants from nearby known points to calculate other points. These characteristics are called P and Q.

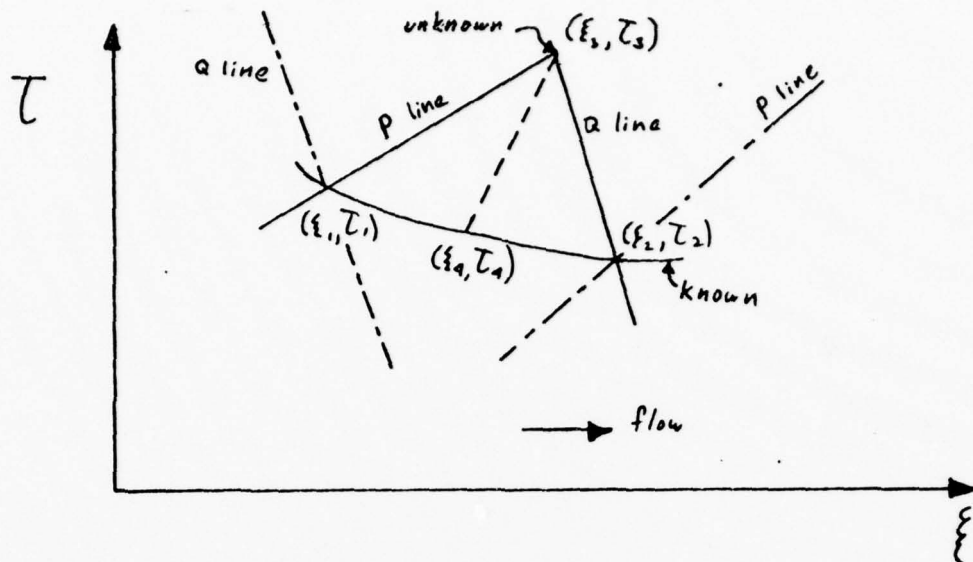


FIGURE 1. DETERMINATION OF FLOW CONDITIONS AT "LATER" OR AT "EARLIER" POINT FROM GIVEN INITIAL CONDITIONS.

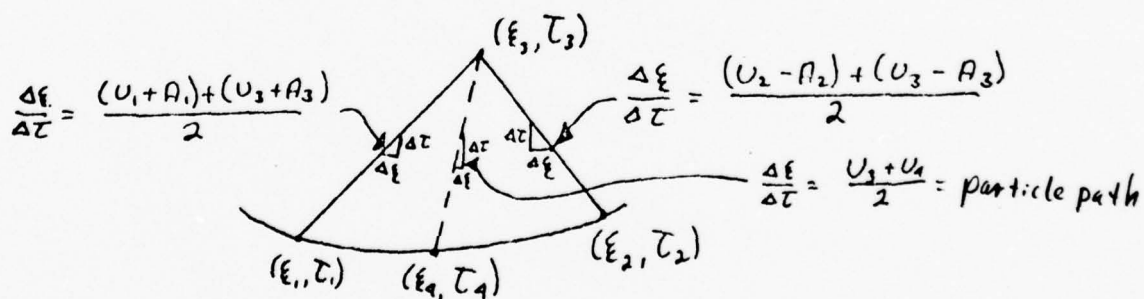


FIGURE 2. CHARACTERISTIC DIAGRAM FOR THE FLOW ANALYSIS.

$$\begin{aligned}
 A &= \frac{a}{a_0} & Q' &= \frac{q}{\gamma R T} & P &= \frac{2}{\gamma-1} A + U \\
 U &= \frac{u}{a_0} & \xi &= \frac{x}{L_0} & Q &= \frac{2}{\gamma-1} A - U \\
 S &= \frac{s}{\gamma R} & \tau &= \frac{a_0 t}{L_0} & U &= \frac{1}{2} (P - Q) \\
 & & & & A &= \frac{\gamma-1}{4} (P + Q)
 \end{aligned}$$

- L_0 = reference length (ft)
- a_0 = reference speed of propagation (ft/sec)
- x = one-dimensional space coordinate (ft)
- t = time (sec)
- s = entropy (Btu/lbm - °R)
- u = flow velocity (ft/sec)
- R = gas constant
- γ = ratio of specific heats
- a = speed of sonic wave propagation (ft/sec)
- q = heat transfer (Btu/lbm)
- p = pressure (lb_f/ft²)
- ρ = density (slug/ft³)
- T = temperature (°R)
- a = $(\gamma R T)^{1/2}$
- α = area ratio
- f = friction factor
- A = speed of sound
- U = fluid particle velocity

S = fluid particle entropy

Q' = fluid particle heating

ξ = coordinate distance

τ = coordinate time

P = right moving characteristic of governing equation

Q = left moving characteristic of governing equation

Their respective mathematical definitions are:

$$\text{Let } I = \frac{2}{\gamma-1} A_{\pm} U; N_A = -AU \frac{\partial \ln \alpha}{\partial t}; N_B = A; N_C = (\partial - DA \frac{DS}{Dt}); N_D = \frac{f L_0 U |U|}{2D}$$

$$\frac{\delta}{\delta \tau} (I) = N_A + N_B \frac{\delta}{\delta \tau} (S) + N_C + N_D \quad (8)$$

$$\delta (I) = (N_A + N_C + N_D) \delta \tau + \delta (S) N_B \quad (9)$$

In finite difference form, Eq. (9) becomes

$$\Delta I = (N_A + N_C + N_D)_{\text{ave}} \Delta \tau + \Delta S (N_B)_{\text{ave}} \quad (10)$$

Let the characteristics be given as

$$P = \frac{2}{\gamma-1} A + U \quad (11)$$

$$Q = \frac{2}{\gamma-1} A - U \quad (12)$$

Now the governing equations can be applied to the numerical solution of the unsteady one-dimensional flow in the circulator.

2. Numerical Analysis

To apply a numerical scheme, the governing equations are written in the finite difference form. Equation (5) then becomes (13) and Equation (6) produces Equations (14) and (15).

$$\frac{DS}{D\tau} = \sigma(\xi, \tau, A, U, S) \quad (13)$$

$$\frac{\delta_+ P}{\delta \tau} = -AU \frac{\partial \ln \alpha}{\partial \xi} + A \frac{\delta_+ S}{\delta \tau} + (\gamma - 1) A \frac{DS}{D\tau} - f \frac{L_0 U |U|}{2D} \quad (14)$$

$$\frac{\delta_- Q}{\delta \tau} = -AU \frac{\partial \ln \alpha}{\partial \xi} + A \frac{\delta_- S}{\delta \tau} + (\gamma - 1) A \frac{DS}{D\tau} - f \frac{L_0 U |U|}{2D} \quad (15)$$

where

$$P = \frac{2}{\gamma - 1} A + U \text{ moving at } \left(\frac{d\xi}{d\tau} \right)_P = U + A$$

$$Q = \frac{2}{\gamma - 1} A - U \text{ moving at } \left(\frac{d\xi}{d\tau} \right)_Q = U - A$$

and a particle moves at $\left(\frac{d\xi}{d\tau} \right)_S = U$.

Two known points are used to calculate a third new point, located at (ξ_3, τ_3) . The P characteristic from (ξ_1, τ_1) intersects with the Q characteristic from (ξ_2, τ_2) , since the slopes of the invariants, called Riemann variables, are known. By knowing that the P and Q are constant, they must exist at (ξ_3, τ_3) . Now we can calculate U_3 and A_3 by

$$U_3 = \frac{1}{2} (P - Q)$$

$$A_3 = \frac{\gamma - 1}{4} (P + Q).$$

Iteration of this principle continues as follows with Eq. (16), (17), and (18) representing Eq. (13), (14), and (15), respectively.

$$S_3 = S_4 + \left(\frac{DS}{D\tau} \right)_{43} (\tau_3 - \tau_4) \quad (16)$$

$$P_3 = \left[-A_{13} U_{13} \left(\frac{\partial \ln(D_3/D_1)}{\xi_3 - \xi_1} \right) + (\gamma-1) A_{13} \left(\frac{DS}{D\tau} \right)_{13} - \frac{f_{13} L_0}{2 D_{13}} \right. \\ \left. U_{13} |U_{13}| \right] (\tau_3 - \tau_1) + A_{13} (S_3 - S_1) + P_1 \quad (17)$$

$$Q_3 = \left[-A_{23} U_{23} \left(\frac{\partial \ln(D_3/D_2)}{\xi_3 - \xi_2} \right) + (\gamma-1) A_{23} \left(\frac{DS}{D\tau} \right)_{23} - \frac{f_{23} L_0}{2 D_{23}} \right. \\ \left. U_{23} |U_{23}| \right] (\tau_3 - \tau_2) + A_{23} (S_3 - S_2) + Q_2 \quad (18)$$

Then,

$$U_3 = \frac{P_3 - Q_3}{2} \quad (19)$$

$$A'_3 = \frac{\gamma-1}{4} (P_3 + Q_3) \quad (20)$$

Test for iteration:

$$\frac{U'_3 - U_3}{U'_3} \leq 0.001 \quad (21)$$

$$\frac{A'_3 - A_3}{A'_3} \leq 0.001 \quad (22)$$

where the primed quantities are the newly calculated ones.

Once the method of characteristics solution is completed, the thermodynamic quantities can be calculated. The thermodynamics equations are:

$$d \ln \rho = \frac{2}{\gamma-1} \frac{da}{a} - \frac{ds}{R} \quad \text{density} \quad (23)$$

$$T = \frac{a^2}{\gamma R g_c} \quad \text{temperature} \quad (24)$$

$$P = \rho R T \quad \text{pressure} \quad (25)$$

Equations (23) to (25) are modified according to the numerical scheme of calculation of the unknown point as

$$\rho_3 = \rho_1 \exp \left[\frac{2}{\gamma-1} \ln \left(\frac{A_3}{A_1} \right) - \gamma (S_3 - S_1) \right] \quad \text{density} \quad (26)$$

$$T_3 = (A_3 a_0)^2 / (\gamma R g_c) \quad \text{temperature} \quad (27)$$

$$P_3 = \rho_3 R T_3 \left(\frac{32.17 \text{ lbm}}{1 \text{ slug}} \right) \quad \text{pressure} \quad (28)$$

Now the solution scheme moves on to two more known points to calculate a third. Finally, an entire new line is calculated. It, in turn, is then used to generate another line, and so on.

The method of characteristics only breaks down when it must cross a shock wave or contact surface. Any discontinuity requires special attention. The solution must find the intersection of the discontinuity with the characteristics and "jump" across to a new point to continue as before. This "jump" across the characteristics is accomplished by using Eqs. (29) and (30) which are derived from the Rankine-Hugoniot relations for the case of shock waves and Eqs. (31) through (34) for the case of contact surfaces as illustrated in Figures 3 and 4.

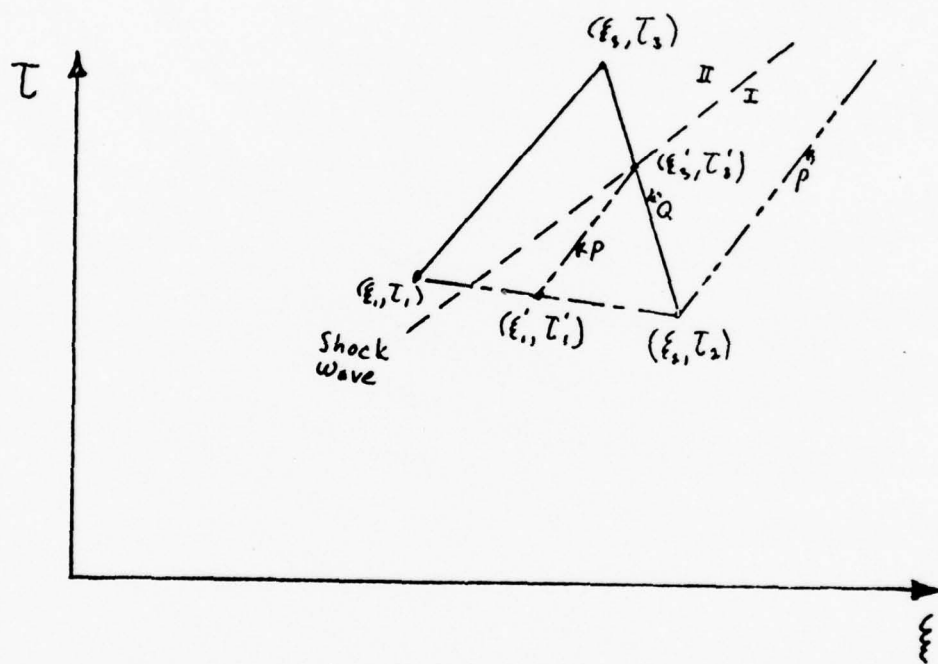


FIGURE 3. CHARACTERISTIC DIAGRAM FOR SHOCK WAVE.

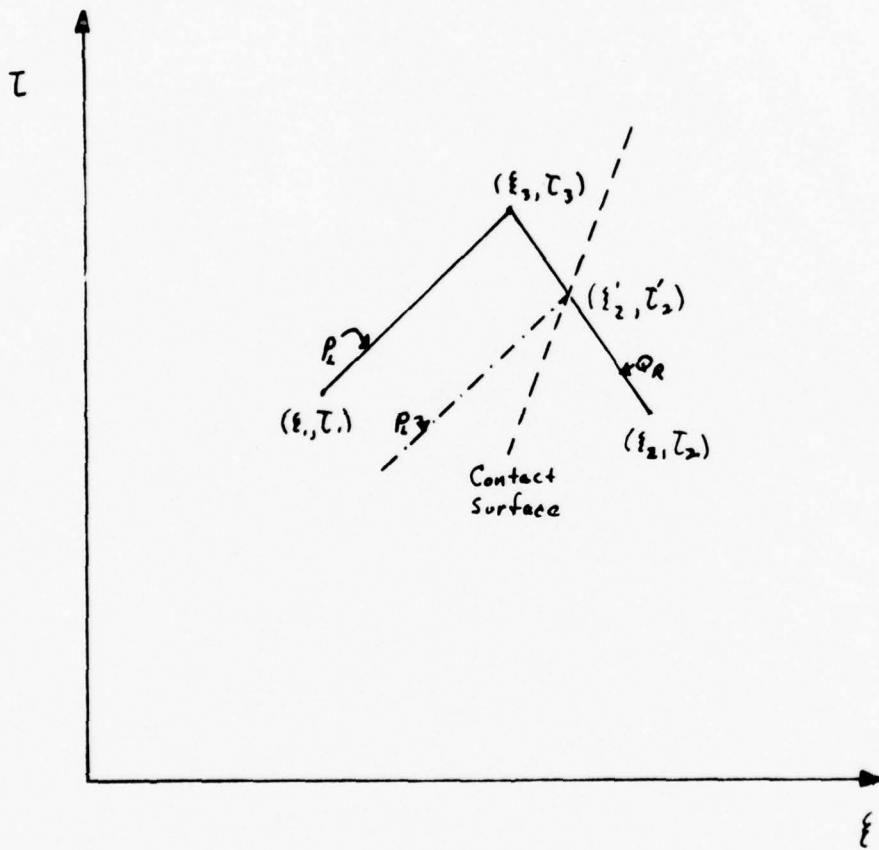


FIGURE 4. CHARACTERISTIC DIAGRAM OF CONTACT SURFACE.

$$\frac{\rho_{II}}{\rho_I} = \frac{1 + \frac{\gamma+1}{\gamma-1} \frac{\rho_{II}}{\rho_I}}{\frac{\gamma+1}{\gamma-1} + \frac{\rho_{II}}{\rho_I}} = \frac{u_I}{u_{II}} \quad (29)$$

$$\frac{T_{II}}{T_I} = \frac{P_{II}}{P_I} \frac{\rho_I}{\rho_{II}} \quad (30)$$

$$Q_L = Q_R + (P_L + Q_R) \tanh \left[\frac{\gamma-1}{4} (S_L - S_R) \right] \quad (31)$$

$$P_R = P_L + Q_R - Q_L \quad (32)$$

$$u_2' = \frac{P_R - Q_L}{2} \quad (33)$$

$$A_2' = \frac{\gamma-1}{4} (P_R + Q_L) \quad (34)$$

Each shock wave and interface must be continually followed and updated as the solution progresses. The "cut off" known point must be replaced by a new point on the other side of a discontinuity to continue the method of characteristics.

A flow diagram is presented in Figure 5 to illustrate the numerical procedure for the solution.

The final results should be a location-time history of the velocity, pressure, density, and temperature of the unsteady flow in the circulator as shown below.

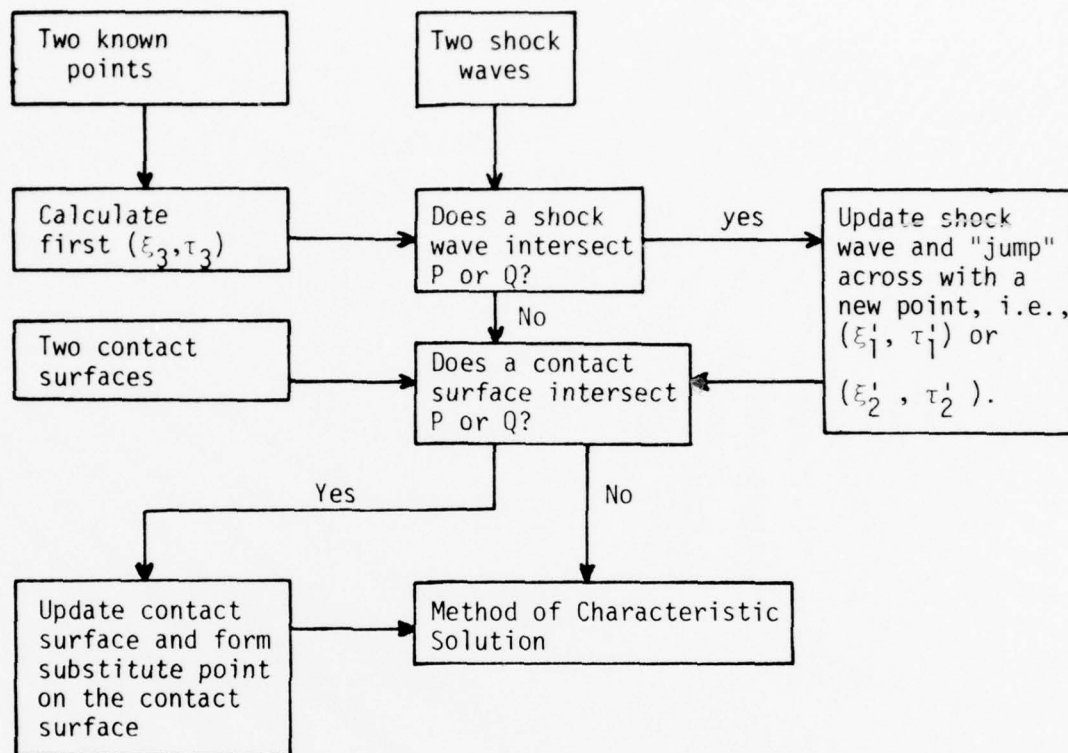
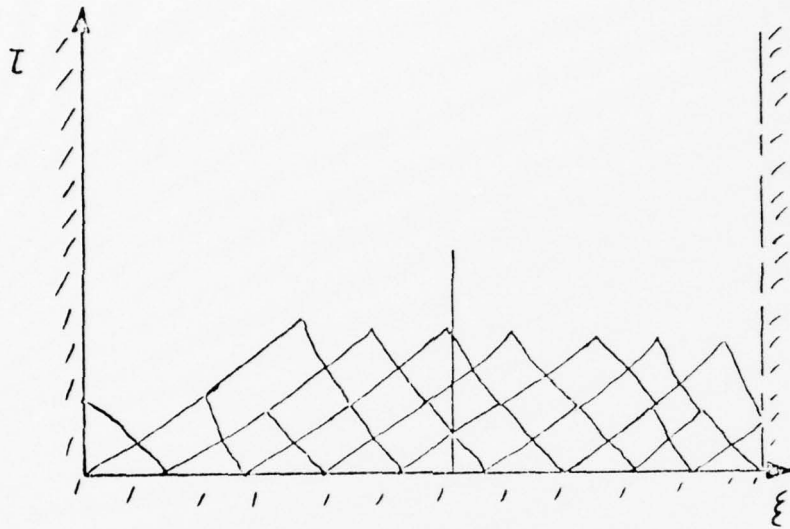


FIGURE 5. FLOW DIAGRAM OF THE NUMERICAL SOLUTION OF UNSTEADY FLOWS USING THE METHOD OF CHARACTERISTICS.



$$P = P(\xi, \tau) = P(x, t)$$

$$\rho = \rho(\xi, \tau) = \rho(x, t)$$

$$T = T(\xi, \tau) = T(x, t)$$

$$U = U(\xi, \tau) = U(x, t)$$

The computer program is attached as Appendix C.

C. One-Dimensional Wave Analysis

Following the work of Foa (Ref. 2), a one-dimensional analysis was performed on the waves produced by the energy deposition in the cavity. The initial conditions are assumed to result from an instantaneous-constant-volume heating of a region of gas of length L in a constant area duct. The energy deposited goes into heating the gas according to the following equation

$$\dot{Q} = C_v \frac{dT}{dt}$$

Using the perfect gas law, $p = \rho RT$, and using the fact that the initial and final density are the same, we obtain the following relationship for the change in pressure

$$\frac{\Delta P}{P_0} = \frac{q}{C_v T_0}$$

where q is the energy per unit mass deposited. Thus, the equations above can be used to find the initial temperature and pressures produced by the energy pulse.

The over pressure at the boundaries of the region cause a shock wave to propagate away from the cavity. The Mach number of this shock wave is determined uniquely from the pressure ratio using normal shock relations. For a pressure ratio of P_1/P_0 , the following relationship holds

$$\frac{P_1}{P_0} = \frac{2k M_s^2 - k + 1}{(k+1) \left[1 - \frac{k-1}{k+1} \left(M_s - \frac{1}{M_s} \right) \right] \frac{2k}{k-1}}$$

The value of M_s is found numerically.

The wave propagation is shown sketched in Figure 6 for flow from left to right. The shock waves travel in both directions away from the cavity. Behind the shock is a hot-cold interface which initially moves in the same directions as the shocks. Behind the interface is an expansion fan which moves in the opposite direction of the shocks. The expansion fans cross at the center of the cavity (for no flow case) and then interact with the hot-cold interface which was generated at the opposite end of the cavity. This interaction has the effect of stopping the outward movement of the hot gas.

A computer program was developed to calculate the shock speed, pressure ratios, temperatures, and expansion of the hot gas region. This program is given on the next page. The results are given in the table following the program. The notation is as follows:

- QV = the pulse energy in J/l
 $U3MU1$ = velocity in region 3 minus the velocity in region 1
 FM = M_s , the shock Mach number
 $P1VP0$ = the initial pressure ratio p_1/p_0
 $T1VT0$ = the initial temperature ratio T_1/T_0
 $P3VP0$ = the pressure ratio across the shock
 $T3VT0$ = temperature ratio across shock
 $T2VT0$ = temperature of hot gas with respect to initial temperature
 $P0, P1$, etc. = pressure in respective region, N/m^2
 $T0, T1$, etc. = temperature in respective region, K.
 $EXPAN$ = $\frac{\Delta X}{L}$, a point at which the hot-cold interface is intersected by the expansion wave, thereby stopping the expansion of the hot gas region. The value is normalized with respect to the cavity length, L.

```

QV=0.0
P0=14.7
ACK = 0.000001
T0=200.
RH00=1.7658
CSUBV=718.285
GAMMA=1.4
WAT=22.4
FAC = 1.15
WRITE(6,100) ACK,RH00,CSUBV,GAMMA,WAT
100 FORMAT(1H1,59X,'LASER SHOCK',/,60X,'-----',/,/,/,/,34X,
1 'ACK',12X,'RH00',10X,'CSUBV',10X,'GAMMA',11X,'WAT',/,/,26X,
2 5E15.6,/,/,/,/,/,/,12X,'QV',11X,'U3MU1',12X,'FM',11X,'P1VP0',
3 10X,'T1VT0',10X,'P3VP0',10X,'T3VT0',10X,'T2VT0',/,12X,'P0',
4 12X,'T0',14X,'P1',12X,'T1',13X,'P3',13X,'T3',13X,'T2',12X,
5 'EXPAN')
DO 20 J=1,100
QV = J*50.
QF = QV*FAC
A0=SQRT(GAMMA*8314.34*T0/WAT)
P1VP0=QF*1000./((RH00*CSUBV*T0)+1.0)
T1VT0=P1VP0
TG=2.*GAMMA
GM1=GAMMA-1.0
GP1=GAMMA+1.0

FM=1.0
9 FMS=SQRT(GM1/TG+(GP1/TG)*T1VT0*(1.0-(GM1/GP1)*SQRT(1./T1VT0)*
1 (FM-1./FM))**(TG/GM1))
FCH=ABS(FMS-FM)
FM=FMS
IF(FCH-ACK)10,10,9
10 P3VP0=(TG*FM+FM-GM1)/GP1
T1VT2 = (P1VP0/P3VP0)**(GM1/GAMMA)
T2VT0 = P1VP0/T1VT2
T3VT0 = P3VP0*(1.0+(GM1/GP1)*P3VP0)/(P3VP0+GM1/GP1)
A1 = A0*SQRT(P1VP0)
T3=T3VT0*T0
P3=P3VP0*P0
P1=T1VT0*P0
T1=T1VT0*T0
T2 = T2VT0*T0
U3MU1=(2.*A0/GP1)*(FM-1./FM)
EXPAN = A1/(A1-U3MU1)-1.0
WRITE(6,101) QV,U3MU1,FM,P1VP0,T1VT0,P3VP0,T3VT0,T2VT0,P0,T0,
1 P1,T1,P3,T3,T2,EXPAN
101 FORMAT(1H0,2X,8E15.6,/,3X,8E15.6)
20 CONTINUE
STOP
END

```

LASER SHOCK

ACK RH00 CSUBV GAMMA WAT
 .10000-05 .176580+01 .718285+03 .160000+01 .224000+02

QV PO	USMU1 TO	FM P1	P1VPO T1	T1VTO P3	P3VPO T3	T3VTO T2	T2VTO EXPLAN
.50000+02	.247414+02	.104711+01	.122667+01	.122667+01	.111251+01	.103097+01	.119291+01
.147000+02	.200000+03	.180321+02	.245335+03	.163538+02	.206193+03	.238582+03	.744521-01
.100000+03	.471752+02	.109165+01	.145335+01	.145335+01	.122364+01	.105962+01	.138364+01
.147000+02	.200000+03	.213642+02	.290669+03	.179876+02	.211923+03	.276727+03	.138153+00
.150000+03	.677674+02	.113405+01	.168002+01	.168002+01	.133374+01	.108652+01	.157280+01
.147000+02	.200000+03	.246963+02	.336004+03	.196060+02	.217303+03	.314560+03	.193572+00
.200000+03	.868519+02	.117462+01	.190669+01	.190669+01	.144303+01	.111207+01	.176079+01
.147000+02	.200000+03	.260284+02	.381338+03	.212126+02	.222413+03	.352158+03	.242399+00
.250000+03	.104677+03	.121362+01	.213336+01	.213336+01	.155169+01	.113654+01	.194788+01
.147000+02	.200000+03	.313605+02	.426673+03	.228098+02	.227308+03	.369576+03	.285852+00
.300000+03	.121431+03	.125122+01	.236004+01	.236004+01	.165982+01	.116014+01	.213425+01
.147000+02	.200000+03	.346925+02	.472007+03	.243993+02	.232029+03	.426850+03	.324836+00
.350000+03	.137264+03	.128759+01	.258671+01	.258671+01	.176753+01	.118303+01	.232004+01
.147000+02	.200000+03	.360246+02	.517342+03	.259826+02	.236607+03	.464008+03	.360058+00
.400000+03	.152294+03	.132284+01	.281338+01	.281338+01	.187488+01	.120533+01	.250536+01
.147000+02	.200000+03	.413567+02	.562677+03	.275607+02	.241067+03	.501072+03	.392067+00
.450000+03	.166617+03	.135708+01	.304006+01	.304006+01	.198194+01	.122713+01	.269029+01
.147000+02	.200000+03	.446888+02	.608011+03	.291345+02	.245426+03	.538057+03	.421307+00

D. Muffler Design Considerations

Mufflers are described as devices to reduce the transmission of sound while at the same time allowing the free flow of gas in a duct or pipe. An ideal muffler for a pulsed laser system would be a device which would reduce considerably the transmission of the shock waves produced by the high energy deposition while at the same time allow for the free unobstructed flow of the laser gas. Mufflers of this type employ holes in the side of the duct which connect to a closed region. Through proper design, the pressure wave energy can be directed from the gas flow, through the side holes, and into the dissipation region without disturbing the steady flow of the gas in the duct. Mufflers of this type are called volume resonators. Parameters of importance in the design of such mufflers are: the frequency of waves to be attenuated, the volume of the resonator, the size of the holes in the duct, and the length (if other than zero) of the tubes which connect the holes with the resonator volume.⁴ As is typical of muffler design, the geometric parameters are dependent upon the frequency of sound to be attenuated. For example, the required resonator volume is inversely proportional to the frequency. For this reason, high frequency sound can often be attenuated by simply making the duct walls out of acoustic tile or other commonly employed sound proofing materials. Low frequency pressure waves require volumes much larger than can be accommodated in wall coverings. Thus, for low frequency sound, the duct must have openings along the side which connect to the large volume resonator.

As discussed in previous sections, the ideal one-dimensional pressure wave generated by the laser pulse will appear as a square wave pressure

pulse traveling through the system. The square wave can be approximated by an infinite series of sine and cosine waves. Thus, the muffler must be able to attenuate waves over a wide band in frequency to be effective in pulsed laser operation. In order to make the muffler effective over a wide band, it was decided to couple the duct to the resonator volume through the use of horn amplifiers rather than the tubes normally used. The straight tube design would be effective at only one frequency while the horn has the potential for a wide band of frequencies.

The ideal exponential horn amplifier has the characteristic of a high pass filter with no reflection. The geometry of the area variation of the ideal horn is

$$A(x) = A_0 e^{Bx}$$

where $A(x)$ is the area at a position x away from the throat, A_0 is the area at the horn throat, and B is the exponential factor. The cut off frequency of the horn is determined by the value of B and the total length of the horn. For zero reflection, the ideal horn must be infinite in length. For a finite length horn, the reflected energy is frequency dependent, with the reflection increasing for the lower frequencies. For example, if the exponential factor B is such that the radius of the horn of circular cross section at the exit, r_e , were to be

$$r_e = \frac{2}{B}$$

then the reflection at $\omega/B = 4 \times 10^4$ is 10% but at $\omega/B = 2 \times 10^4$ the reflection is 30%. If, however, the relationship were

$$r_e = \frac{1}{B}$$

the reflection at $\omega/B = 4 \times 10^4$ is 25% and at $\omega/B = 2 \times 10^4$ the reflection is 55%. Thus, the horn geometry for a finite horn has considerable effect

on the filtering and reflection capabilities of the horn. The table below gives a more complete picture of the geometric influence on the horn characteristics.

For pulsed laser operation at 200 pulses per second maximum, all of the energy in the resulting pressure waves is expected to be in the frequency range above 200 Hz. Thus, a horn designed for 200 Hz should remove from the flow all the pressure wave energy in the 200 Hz and above range since a horn acts as a high pass filter. Consider a design in which $\omega/B = 4 \times 10^4$ and $r_e = 2/B$ which gives a 5% reflection as seen in the table. If this design were to be effective at 200 Hz,

$$B = 1257/4 \times 10^4 = .037 \text{ cm}^{-1}$$

and

$$r_e = 63.66 \text{ cm}$$

The length of the horn is given by

$$L = \frac{\ln(Ae/Ao)}{B}$$

where the length is seen to be dependent upon the throat area A_o . Take the throat area to correspond to a radius of 1 cm and we obtain

$$L = \frac{\ln(63.66/1)^2}{.03} = 276.9 \text{ cm}$$

which shows that a horn 9 ft long is needed to be 95% effective at 200 Hz. An effective length of 9 ft could likely be obtained in a folded horn design which would occupy a reasonable volume and thus be applicable for pulsed laser systems. Therefore, theoretically, the horn-coupled-resonator muffler appears to have the potential for the wide band performance required in the pulsed laser systems.

Table of Percent Reflection as a Function of ω/B for Three Exponential Horn Shape Factors

cm/sec ω/B \ r_e	1/B	4/3B	2/B
2×10^4	55%	40%	33%
4×10^4	25%	12%	5%
6×10^4	15%	8%	3%
8×10^4	11%	5%	2%
16×10^4	6%	3%	1%
24×10^4	4%	2%	0%
32×10^4	3%	1%	0%

A horn-coupled-resonator was designed and built for the purpose of investigating experimentally the performance of such a muffler in the UAH subscale recirculation system. Available materials were employed which limited the length of the horn to 6.5 cm. The horn was designed to be two dimensional with a rectangular cross section rather than circular. The width at the opening was limited to 11.5 cm plus the throat width. Thus, with these geometric constraints, the horn expansion factor was restricted to be approximately .3 for values of throat width of about 1 to 2 cm. For example, for a throat width of 1.5 cm,

$$B = \frac{\ln Ae/Ao}{L} = \frac{\ln (13/1.5)}{6.5} = .33$$

For this value of B, the value of ω/B for 200 Hz becomes,

$$\frac{\omega}{B} = \frac{1252}{.3} = .42 \times 10^4,$$

at 1000 Hz, this becomes

$$\frac{\omega}{B} = \frac{6283}{.3} = 2.1 \times 10^4$$

and at 2000 Hz,

$$\frac{\omega}{B} = \frac{12570}{.3} = 4.2 \times 10^4$$

Thus, we expect the horn described above to be effective for frequencies above 1000 Hz based on the ω/B ratio and reference to the table on percent reflection.

Chapter III

EXPERIMENTAL INVESTIGATION OF SUBSCALE CLOSED CYCLE LASER GAS CIRCULATOR

A recirculation system was designed for use with the MICOM S³ single pulse laser. This system was built for the purpose of investigating experimentally the transient flow and heating problems characteristic of a high energy laser system. The equipment employed in this work is described in Section A of the following which includes a description of the recirculation apparatus, a muffler used in wave attenuation tests, acoustic reflectors, and the instrumentation employed in the experimental program. The experimental data collected by this system will be described in general in Section B.

A. Description of Experimental Equipment

1. Recirculating Flow Apparatus

The recirculation system consisted of a blower, PVC piping, mounting flanges for attachment to the S³ laser, an E-beam mask, and a plastic structure which was mounted inside the S³ cavity. A schematic of the system attached to the S³ laser is given in Figure 7. The flow through the cavity region is from right to left in that figure.

a. Blower Specifications

The blower is a Dayton Model 4C108 with a 10 5/8" wheel. The inlet is 6½" in diameter. The outlet is 2½" square. The outside of the blower casing is approximately 13" in diameter.

The motor is connected directly to the blower wheel. The motor is a 1 hp Dayton Model 6K232 operated at 3450 rpm.

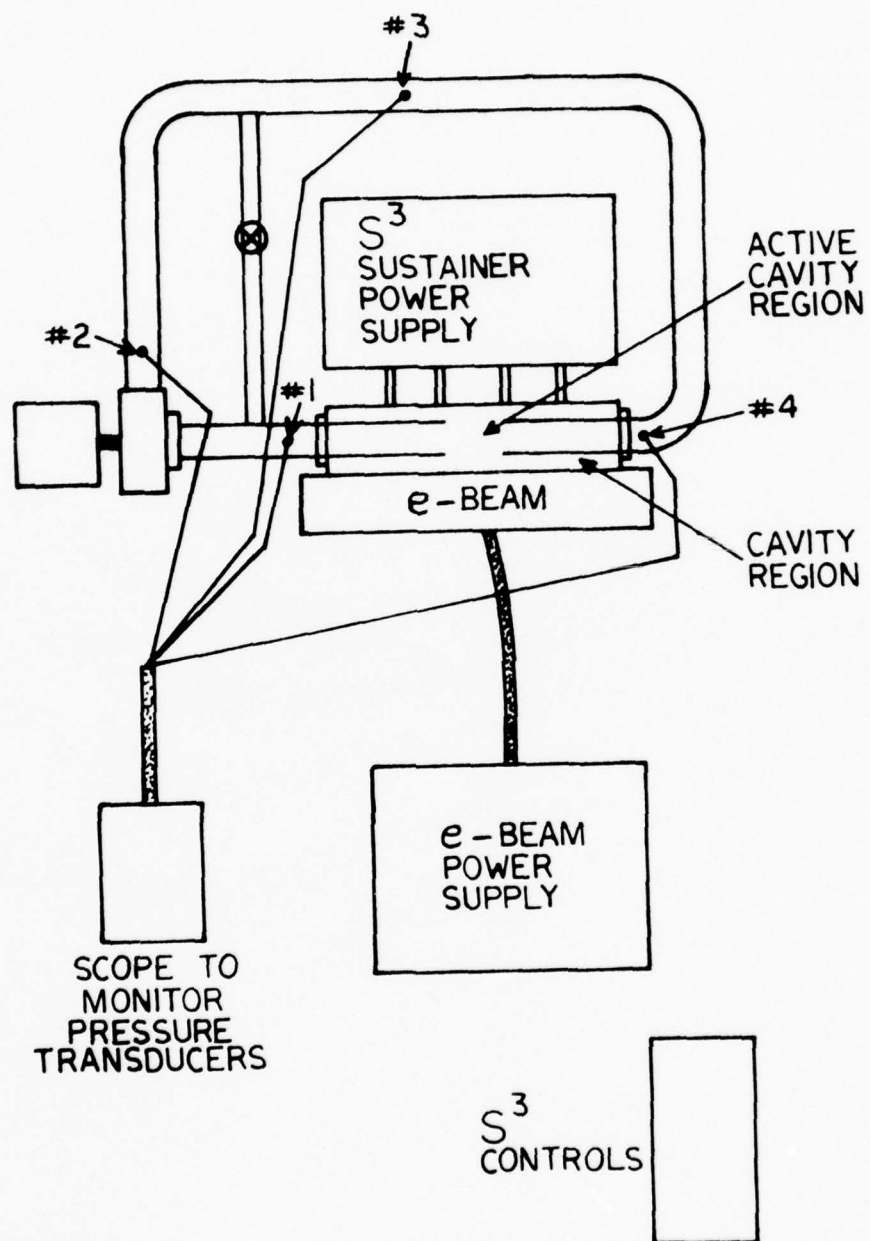


FIGURE 7. TOP VIEW OF PVC SUBSCALE MODEL ATTACHED TO THE S³ LASER.

b. PVC Piping

The majority of the piping consisted of 3109662 "Certain-Teed Plastics" 4" PVC 1120 Schedule 40 220 psi ASTM D-2665. This pipe has 4" ID and 4½" OD. The 90° turns were achieved using standard PVC fittings which have a 4" radius of curvature along the center line of the 90° bend. A number of couplings were employed throughout the path length to accommodate assembly, disassembly, and modification during the testing.

Also shown in Figure 7 is a cross-over or by-pass pipe with valve. This pipe was J24G264 1" PVC 1120 Schedule 80 630 psi at 73°F ASTM D 1785. The pipe was 1" ID and 1¼" OD and was attached to the 4" PVC through a standard 4" to 2" tee with a reducer used to bring the size down to 1". A 1" gate valve was used in the 1" line.

c. Dimensions

The piping dimensions are shown on Figure 8 in centimeters. Total path length around the 4" circuit is approximately 1140 cm (37 ft.)

d. Flanges

Special flanges had to be constructed in order to attach the PVC pipe to the blower and to the S³ laser. For the blower attachment, a 6" to 4" reducer was used on the inlet side and an aluminum piece was machined to go from the square to the circular cross-section.

The flanges for attachment to the S³ were constructed from aluminum consisting of 4½" diameter holes with suitable bolt circle and o-ring groove.

e. E-beam Masks

The purpose of the E-beam mask is to contain the E-beam to within a specified region of the cavity. Figure 9 shows the dimensions of the three masks employed in this work.

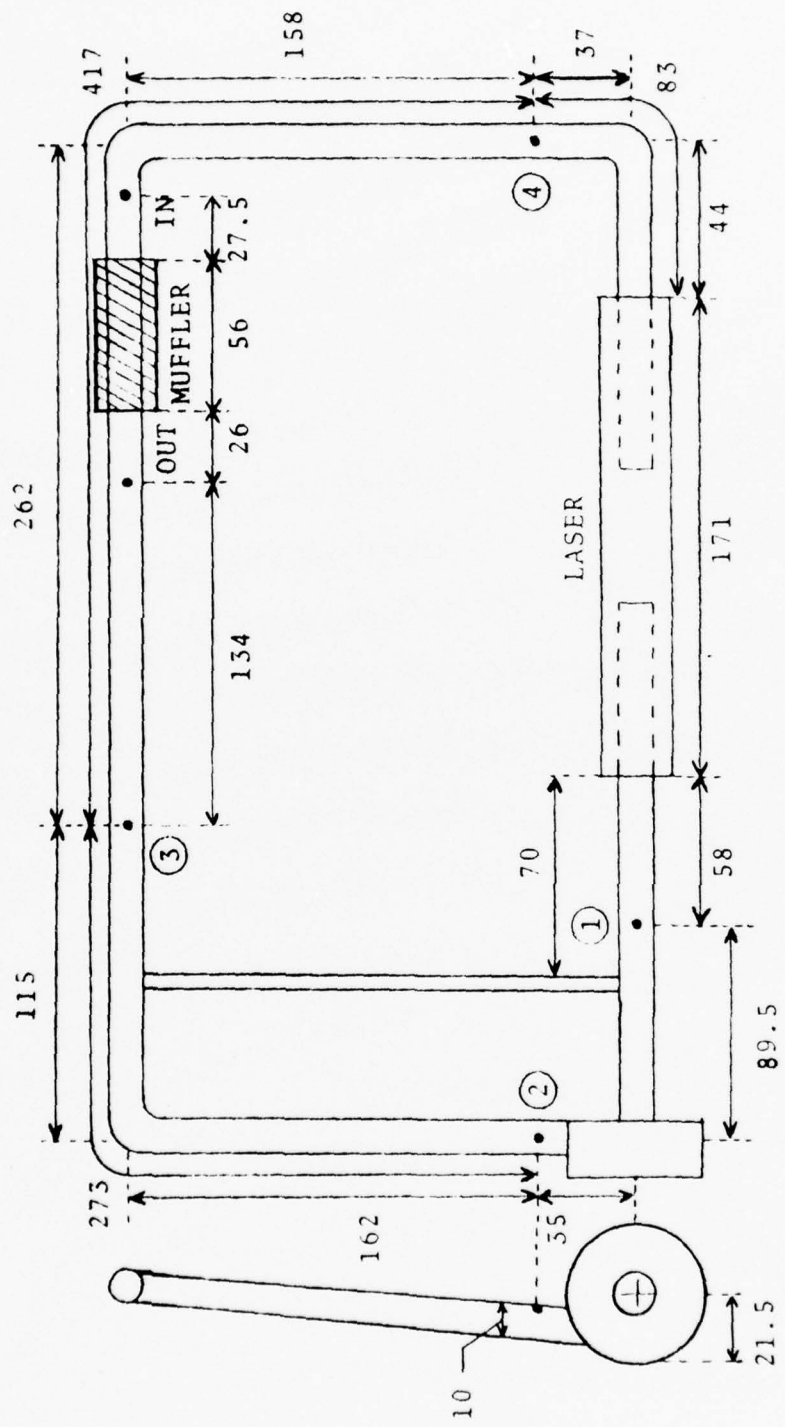


FIGURE 8. PROBE LOCATION MEASUREMENTS ON PVC MODEL WITH MUFFLER ADDED
(Dimensions in cm)

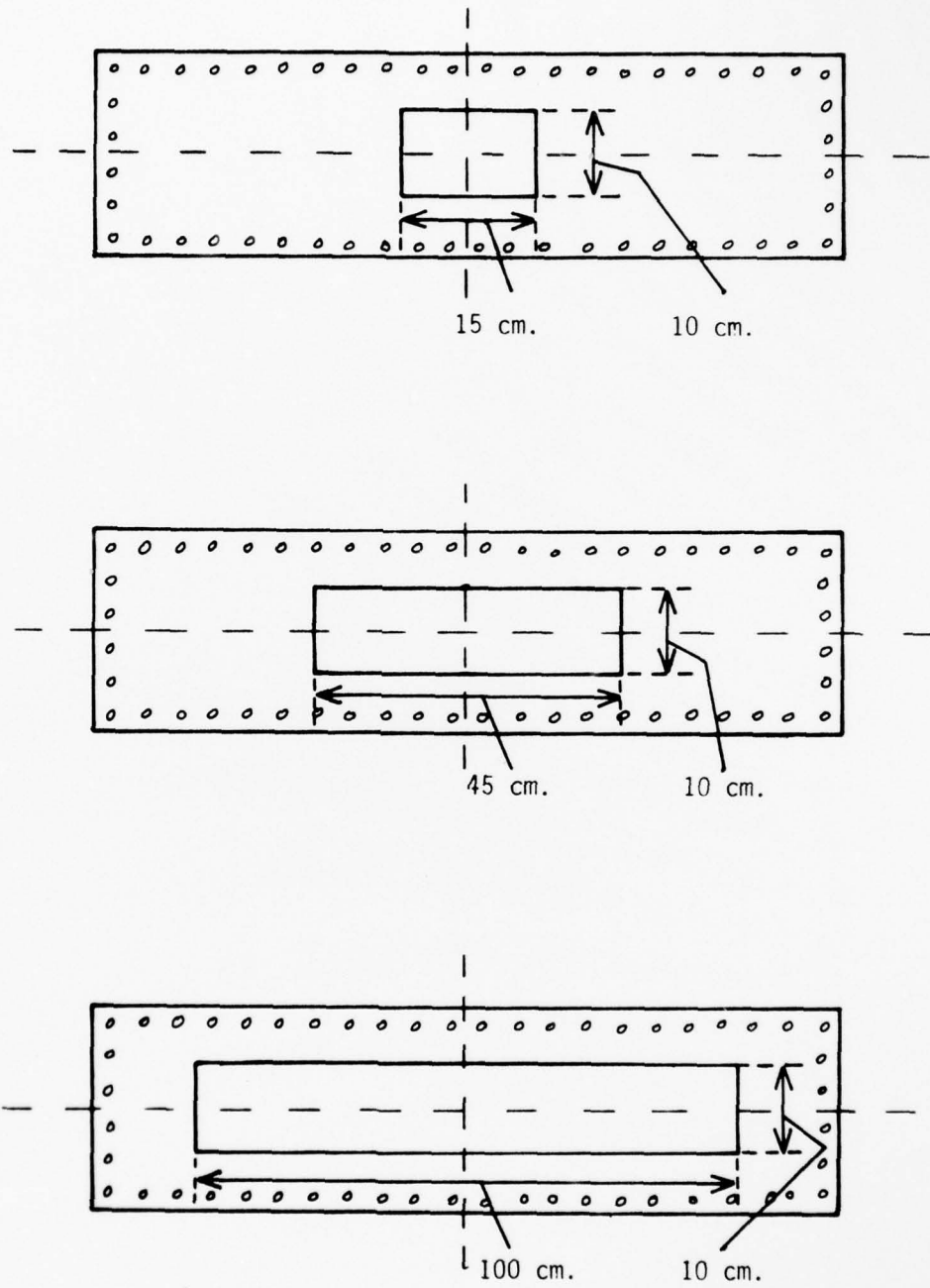


FIGURE 9. E-BEAM MASKS USED ON S^3 LASER FOR UAH TESTS.

f. Cavity Structures

The cavity structures serve to box-in the discharge region in the vertical and longitudinal directions and also to provide a support for the PVC pipe. Two structures were employed in this work; the 15 cm structure was used with the 15 cm mask while the 100 cm structure was used with both the 45 cm and 100 cm masks.

A sketch of a cavity structure is shown in Figure 10. Both the 15 and 100 cm structure were constructed in the same manner with only the dimension of the opening being different.

2. Muffler

In consultation with Mr. Cason of MICOM, a muffler was designed, constructed, and tested in the recirculation system. The location of the muffler in the system is shown on Figure 8. The muffler has no obstructions to the flow and was constructed to attach easily to the 4" PVC system. The physical dimensions of the muffler are shown in Figure 11.

3. Reflectors

The reflectors tested are shock wave attenuating and/or reflecting materials with frontal configurations of honeycomb and square. The honeycomb is made of aluminum and the square is made of THERMACOMB alumina ceramics. Table I presents the measured and calculated physical properties of the materials.

Table I

Type of Openings	Specimen Thickness(in)	No. of Openings per linear in.	Wall Thickness(in)	Percent Open Area	Hyd.Rad. per Open.(in)
Honeycomb	2.0	4.5	0.00075	92.86	0.0245
Square I	0.5	9	0.0044	85.14	0.0146
Square II	1.068	7.5	0.0090	74.29	0.0170

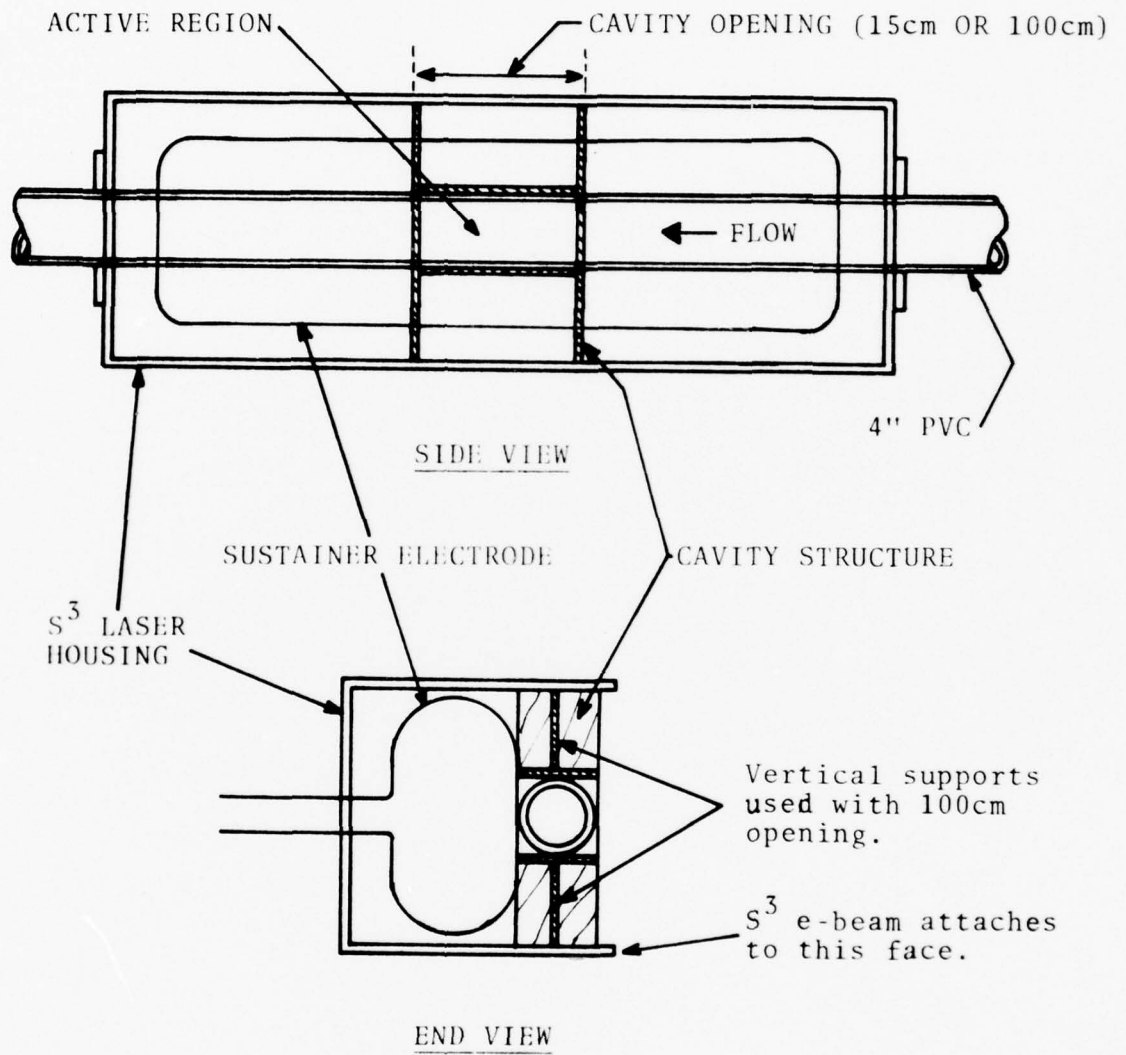


FIGURE 10. SKETCH OF CAVITY STRUCTURE AND INSTALLATION INSIDE THE S^3 LASER HOUSING.

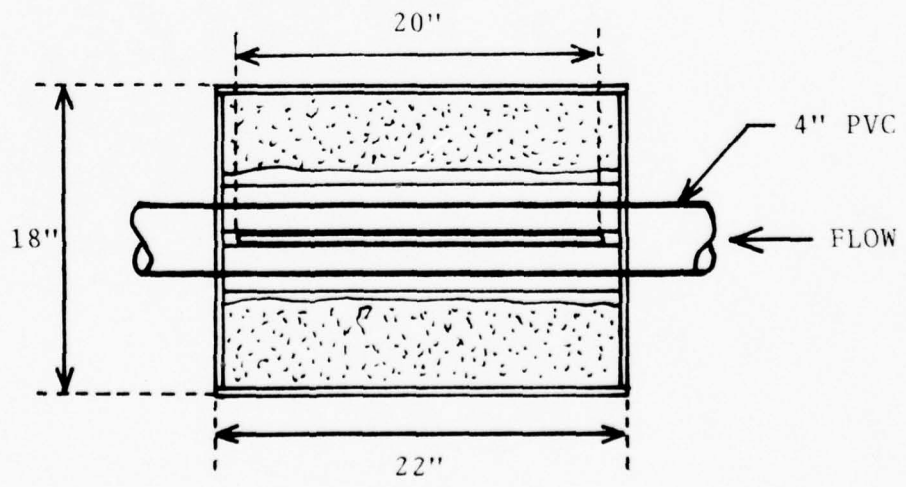
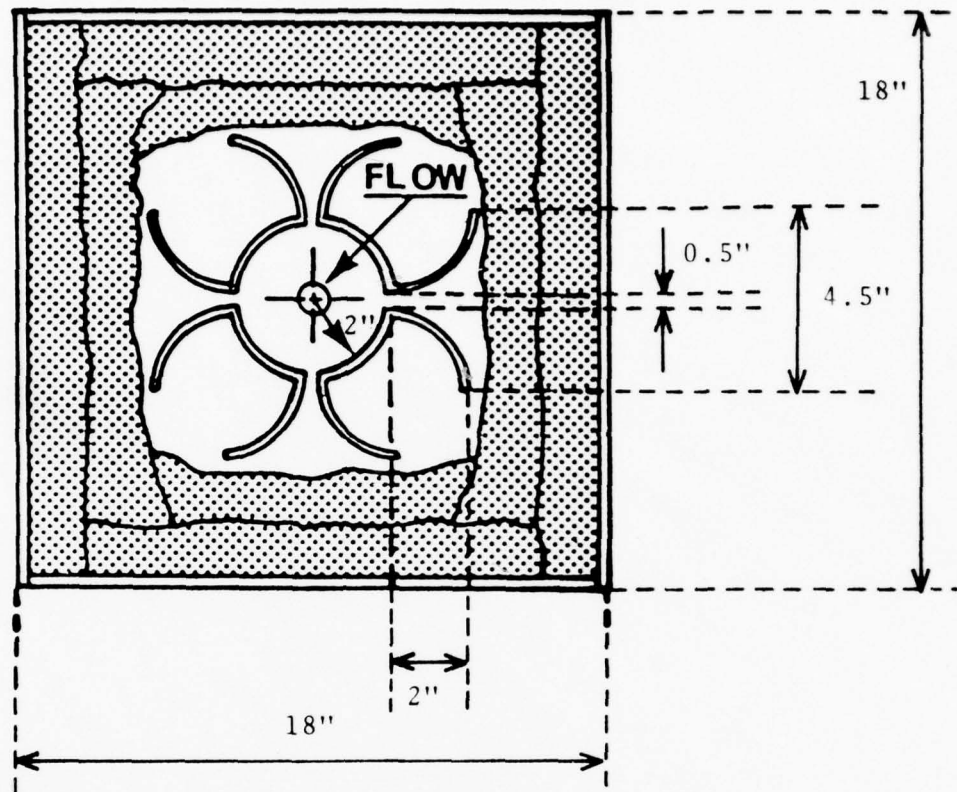
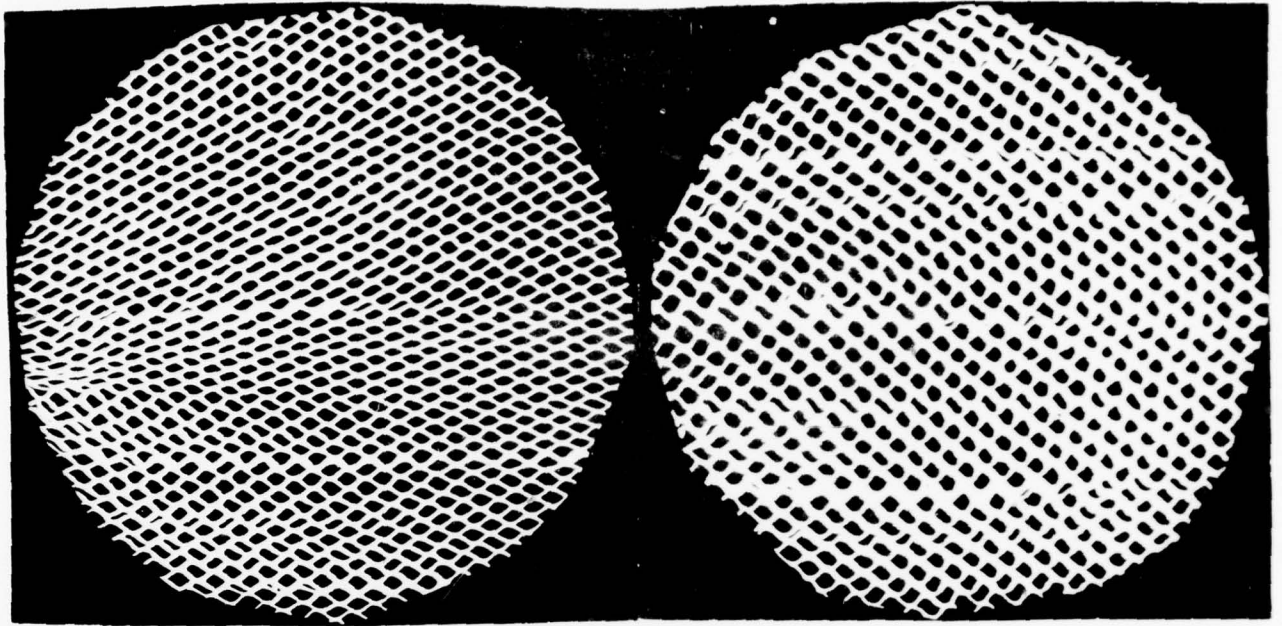


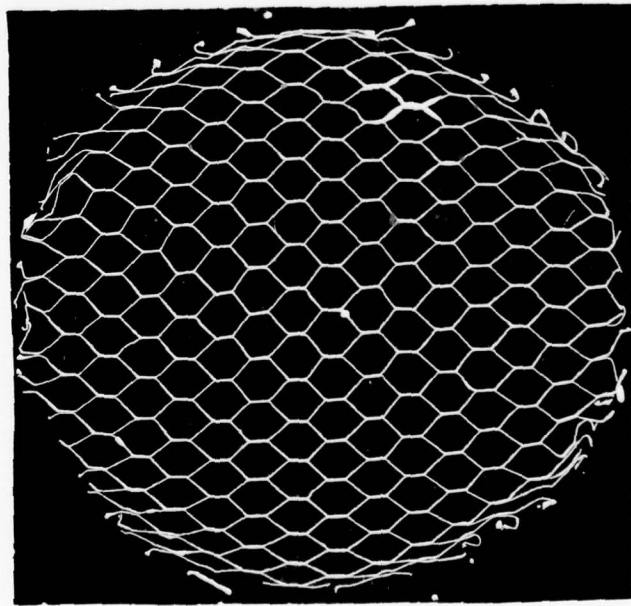
FIGURE 11. SKETCH OF MUFFLER.
 Curved pieces constructed of 4" PVC piping,
 sides of box constructed of $\frac{1}{4}$ " plywood,
 and end pieces constructed of $\frac{1}{2}$ " plexiglass.

Calculated values of the hydraulic radius $\left(\frac{\text{Area}}{\text{Wetted Perimeter}}\right)$ and percent open area are based on an average of the appropriate measured values. Frontal appearances of these grates materials are shown in Figure 12. These reflectors are placed in the flow apparatus for a series of tests to determine the effectiveness of wave attenuation.



Square I

Square II



Honeycomb

Figure 12. Frontal Appearances of Reflectors

4. Instrumentation System

a. Pressure Measurement

The instrument used for pressure measurements is a battery of four Piezotron pressure sensing units each of which consists of a piezoelectric pressure transducer (Type 201B5) and a coupler (549B) connected with a 128M cable. The unit is then connected to an oscilloscope for the readout of voltage signals. Specifications of the Piezotron miniature pressure sensor or transducer, the Piezotron coupler, and the Tektronix oscilloscope are presented in Appendix D.

The pressure of up to 100 psi was sensed by the mini-gage which gives a direct, high level, voltage signal with less than 100 ohms output impedance and high frequency response of 50 K HZ and low frequency response of 0.005 HZ. The sensor then converts the pressure into electrical voltage with bias of up to 11 ± 2 volts. The power required by the transducer to operate is supplied by the coupler, and the signal from the transducer to the readout equipment is transmitted through the coupler over a single inexpensive cable. This eliminates all of the inherent piezoelectric high impedance problems of electrical leakage, cable noise and signal attenuation and allows the transducers to be used in contaminated environments and with long and moving cables at low noise and without use of charge amplifiers.

The calibration of the transducers was performed at the factory, and the values of the calibration were noted to be, on the average for all probes, 50 mv per psi for the pressure measurement up to 100 psi. The calibration curve relating the voltage output and the pressure is noted to be quite lenient.

b. Temperature Measurement

Due to the extremely transient nature of temperature variation in the recirculating flow as a result of the pulsed laser operation, a sensor of high frequency response in excess of 1 K HZ is considered necessary for the temperature measurement. Search of an adequate sensor resulted in the selection of a hot-wire sensor made of 0.00015 in diameter tungsten wire coated with platinum powdery film. The hot-wire sensor is connected to the Temperature and Switching Module (Thermo-Systems Model 1040) which is in turn connected to the power supply (Model 1031-10A).

The Module consists of a bridge circuit and amplifier in an open loop configuration so the hot-wire sensor which is ordinarily used as an anemometer probe can be switched to function as a resistance thermometer. Since there is a linear proportionality between the voltage output and the temperature, the calibration can be simply performed by adjusting the zero and gain set potentiometers to a desired temperature range using the calibrate pots of two temperatures.

c. Velocity Measurement

For the measurement of velocities, hot-wire probes the same as those used for the temperature measurement is applied. The probe is connected to the constant temperature anemometer module (Model 1010A). The amplified output signal from the anemometer is sent to the Linearizer (Model 1005B) so that the voltage signal is processed in such a way that it became linearly related to velocity of the gas flow.

The use of these modules ensures the frequency response above 500 K HZ with power output as high as 1.5 amps. The noise associated with the anemometer is noted to be less than 0.007% equivalent turbulent intensity. Frequency response to the Linearizer is found to be up to 400 K HZ and the accuracy of linearization can reach $\pm 0.2\%$.

With these special features of the instrument, it is able to measure both average velocity and turbulence in one-dimension.

Calibration of the probe is performed by using a Thermo-Systems Calibrator (Model 1125) in accordance with the furnished instructions. The readout system for both temperature and velocity is the Tektronix type oscilloscope (Type 564-3A74-3B3).

B. Presentation of Experimental Data

An experimental run typically involved firing the S^3 laser and recording pressure, temperature or velocity at various locations in the recirculation system. Besides the pressure, temperature and velocity data, the laser discharge current was also monitored in order to determine the power put into the gas. Each firing of the S^3 laser was logged with respect to the sequence number. The first UAH experiment began with sequence number 3043 on December 7, 1976 and the last experiment was with shot number 3238 on February 2, 1977. The log of all the UAH shots is given in the table.

The tests were designed to investigate the fluid-thermal disturbances produced by the sudden energy deposition in the cavity region. In the following sections, we describe the wave forms produced by the laser, the wave interactions with the system components, and the wave attenuations within the system. Each of these topics will be divided into the pressure wave results and the thermal-velocity wave results if appropriate.

1. Wave Forms Produced by the High Energy Laser

The S^3 laser was operated as normal except that no attempt was made to produce lasing action. The S^3 laser merely served to deposit energy into the gas at the cavity section, thereby simulating the energy pulse that takes place in such a laser. The E-beam was operated at 90 KV,

LOG OF UAH SHOTS

Reference Number	Date of Test	Gas Used	Blower Status	Energy of Pulse, J	Purpose of Test
3043	12/7/76	N ₂	Off		Pressure wave propagation with no obstructions
3044	"	"	On	41	"
3045	"	"	"	26.45	"
3046	"	"	Off	10.11	"
3047	"	"	"	28.22	"
3048	"	"	"	28.27	"
3053	12/8/76	"	Off	-----	Pressure wave propagation with large pore metal honeycomb placed at heat exchanger locations
3054	"	"	On	-----	
3058	12/9/76	"	-	9.46	Pressure & temperature wave propagation tests with large pore metal honeycomb at heat exchanger locations
3059	"	"	On	15.51	"
3060	"	"	"	18.45	"
3061	"	"	"	15.83	"
3062	"	"	"	13.88	"
3064	"	"	"	14.67	"
3065	"	"	"	10.13	"
3066	"	"	"	10.33	"
3067	"	"	"	14.63	"
3068	"	"	"	14.67	"
3069	"	"	-	11.50	"
3070	"	"	Off	11.00	"
3071	"	"	On	13.32	"
3075	12/10/76	Ar	Off	56.65	"
3076	"	"	On	56.65	"
3077	"	"	"	-----	"

Reference Number	Date of Test	Gas Used	Blower Status	Energy of Pulse, J	Purpose of Test
3079	"	"	"	8.20	Pressure wave tests with two 27 mm sections of cer honeycomb between stations 3 and 4
3080	"	"	Off	9.24	"
3082	"	"	"	7.04	"
3083	"	"	"	8.80	"
3084	"	He	"	8.67	"
3085	"	"	On	9.35	"
3086	"	"	"	12.97	"
3087	"	"	"	12.97	"
3088	"	"	Off	19.59	"
3089	"	"	"	12.07	"
3090	"	Ar	On	30.12	"
3092	"	"	"	26.60	"
3093	"	"	Off	22.63	"
3094	"	"	"	26.10	"
3095	"	"	On	27.9	"
3096	12/14/76	"	"	39.2	Pressure wave propagation tests with 4 sections of cer honeycomb between stations 3 and 4
3097	"	"	"	25.66	"
3098	"	"	Off	17.87	"
3099	"	"	"	13.32	"
3100	"	"	"	9.75	"
3101	12/17/76	"	On	19.76	Pressure wave propagation tests with muffler placed between stations 3 and 4
3102	"	"	"	21.88	"
3103	"	"	"	12.00	"

Reference Number	Date of Test	Gas Used	Blower Status	Energy of Pulse, J	Purpose of Test
3104	12/17/76	Ar	Off	9.93	"
3105	"	"	"	18.5	"
3106	"	"	"	27.28	"
3107	12/20/76	"	"	42.90	Pressure wave propagation through muffler to get good record of wave history
3108	"	"	"	51.73	
3109	"	"	"	49.07	"
3110	"	"	"	54.75	"
3111	"	"	"	49.07	"
3112	"	"	On	32.55	"
3113	"	"	"	26.35	"
3114	"	"	"	13.78	"
3115	"	"	"	37.40	"
3116	"	"	"	25.6	"
3117	"	"	"	-----	"
3119	12/21/76	"	Off	58.88	"
3120	"	"	"	62.06	"
3121	"	"	"	70.40	"
3122	"	"	"	55.15	"
3123	"	"	"	50.17	"
3124	"	"	"	61.60	"
3125	"	"	"	66.67	"
3127	"	"	On	58.67	"
3128	"	"	"	60.00	"
3129	"	"	"	53.40	"
3130	"	"	"	54.40	"

Reference Number	Date of Test	Gas Used	Blower Status	Energy of Pulse, J	Purpose of Test
3131	12/22/76	Ar	Off	91.87	Pressure wave tests with new probe location near muffler and time delayed signals
3132	"	"	"	83.33	"
3133	"	"	"	79.12	"
3134	"	"	"	98.58*	"
3135	"	"	On	66.75	"
3136	"	"	"	52.13	"
3137	"	"	"	40.13*	"
3138	"	N ₂	"	53.67	"
3139	"	"	"	35.00*	"
3140	"	"	Off	48.42*	"
3141	"	He	On	55.73	"
3142	"	"	"	45.68*	"
3143	"	"	Off	52.70*	"

*Enlargements made of scope traces for purpose of data analysis

Reference Number	Date of Test	Gas Used	Blower Status	Energy of Pulse, J	Purpose of Test
3144	1/7/77	N ₂	Off		All four pressure probes put at same location to test relative responses.
3145	"			50.0	
3146	"			49.9	
3147	"			53.	
3150	1/25/77	Argon		51.3	Installed new probe at up-stream of discharge to test effect of corner. Also, thermal wave tests.
3151	"	"		32.0	
3152	"	"	On		
3153	"	"	"	30.7	
3154	"	"	"	30.8	
3155	1/26/77	N ₂	"	47.6	
3156	"	"	"		
3157	1/27/77	"	"	23.1	
3158	"			17.8	Corner and thermal wave test in N ₂ .
3159	"	N ₂	Off	17.5	
3160	"	"	"		Thermal wave at different locations around system.
3161	"	"	On	29.0	
3162	"	"	"	34.8	
3163	"	"	"	22.7	
3164	"	"	"	26.9	
3165	"	"	"	34.0	
3166	"	"	On	26.5	Wave near muffler.
3167	"	"	"	25.3	
3168	"	He	"	52.8	Wave propagation and thermal wave.
3169	"	"	"	18.0	
3170	"	"	"	20.7	
3171	"	"	"	38.5	
3172	1/28/77	N ₂	"	62.0	Muffler incident and reflection test and thermal wave.
3173	"			53.6	
3174	"	N ₂	Off	39.6	
3175	"	"		31.2	
3176	"	"	Off	25.3	

ALL OF THE ABOVE TESTS USED A 15 CM CAVITY REGION

Reference Number	Date of Test	Gas Used	Blower Status	Energy of Pulse, J	Purpose of Test
<u>THE FOLLOWING TESTS USE A 100 CM CAVITY REGION</u>					
3177	2/1/77	N ₂		>>126	Muffler incident reflection tests and thermal wave tests.
3178	"	"	On	208	
3179	"	"	"	312	
3180	"	"		182	
3181	"	"	On	186	
3182	"			300	Corner test and thermal wave.
3183	"	N ₂		303	
3184	"	"		308	
3185	"	"	On	280	
3186	"	"	"	288	
3187	"	"	Off	303	Corner test with probes reversed.
3188	"	"	On	325	
3189	"	"	"	221	Muffler transmission test.
3190	"			165	
3191	"	N ₂	On	187	
3192	"	"	"	194	
3193	"	"	"	184	
3194	"	"	"		
3195	"	"	"	294	
3196	"	"	"	128	
3198	"	"		290	Muffler reflection and incident test
3199	"				
3200	"	N ₂	On		
3201	2/2/77	Argon	On	333	
3202	"	"	"	277	

Reference Number	Date of Test	Gas Used	Blower Status	Energy of Pulse, J	Purpose of Test
3203	2/2/77	Argon		280	
3204	"	"	On	232	
3205	"	"	"	242	
3206	"	"	"	294	Muffler transmission test
3207	"	"	"	239	
3208	"	"		305	
3209	"	"		260	Thermal wave tests
3210	"			400	
3211	"	Argon	On	390	Thermal wave and corner test
3212	"	"	"	347	
3213	"	"	"	372	Thermal wave and Fan Reflection Test
3214	"	"	"	260	
3215	"	"	"	371	
3216	"	"	"	307	
3217	"	"		322	Fan transmission test and thermal wave test
3218	"	"		300	
3219	"	"		289	
3220	"	"		350	

Reference Number	Date of Test	Gas Used	Blower Status	Energy of Pulse, J	Purpose of Test
3221	2/2/77	Argon		146	Fan transmission test and thermal test
3222	"	"		154	
3223	"	"		158	
3224	"	"		183	Fan reflection and incident test
3225	"	"		128	
3226	"	"	On	172	Corner test and thermal wave tests
3227	"	"	"	154	
3228	"	"	"	135	
3229	"	"	"	131	Muffler reflection and incident test
3230	"	"	"	197	
3231	"	"	"	179	
3232	"	"	"	171	
3233	"	"	"	203	Muffler transmission test
3234	"	"	"	168	
3236	"	"	"	205	
3237	"	"	"	104	Corner test
3238	"	"	"	122	

THE ABOVE TESTS USE A 45 CM CAVITY REGION

the sustainer voltage was varied between 15-30 KV, and the pulse width was varied between 2 and 3 μ sec. As pertains to the fluid dynamics of the cavity flow, the energy deposition is instantaneous and, therefore, the process can be described as an instantaneous constant volume heating process. The gas pressure and temperature are instantaneously increased by the energy deposition while the density remains unchanged. The following describes waves found produced by these initial conditions.

a. Pressure Wave Form

The pressure wave produced by the energy deposition consists of a sharp pressure rise followed by a sharp pressure drop and a negative phase. This is illustrated in Figure 13 where the pressure shown is positive in the negative direction since this is the way the data from the pressure transducers are recorded on the scope pictures. The width of the positive pressure pulse is typically 1 m sec and the negative phase has about the same width. The amplitude of the positive phase was a function of the energy deposited in the gas which varied between 7 and 100 J for the 15 cm cavity, between 120 and 400 J for the 100 cm cavity, and between 100 and 205 for the 45 cm cavity. (See log). The amplitude of the negative phase was generally proportional to the amplitude of the positive phase. Figures 14, 15, and 16 show a typical pressure wave for the 15, 45, and 100 cm cavity lengths respectively. Figure 14 for the 15 cm cavity shows the wave for the three different gases used in those tests (N_2 , Ar, and He). Only Ar gas was used in the 45 cm tests and a typical wave form is shown in Figure 15. Both N_2 and Ar were used in the 100 cm tests and these results are shown in Figure 16. The 100 cm wave form shows two additional positive pressure pulses following the negative phase of the wave. This feature is not present in the 15 or 45 cm results.

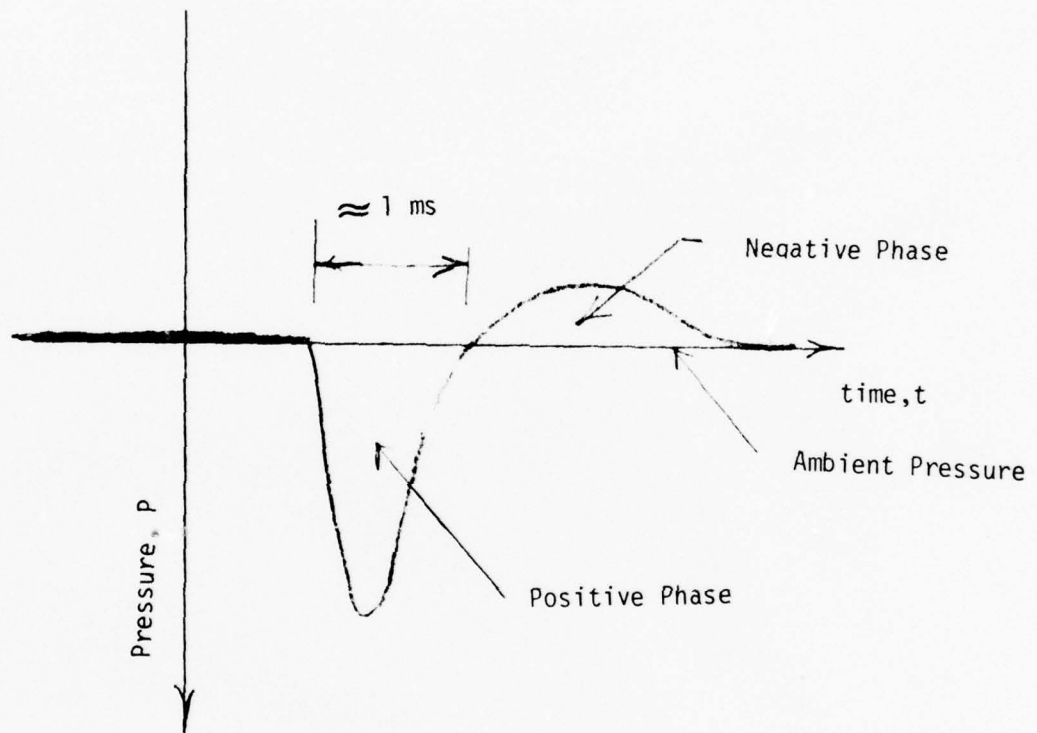


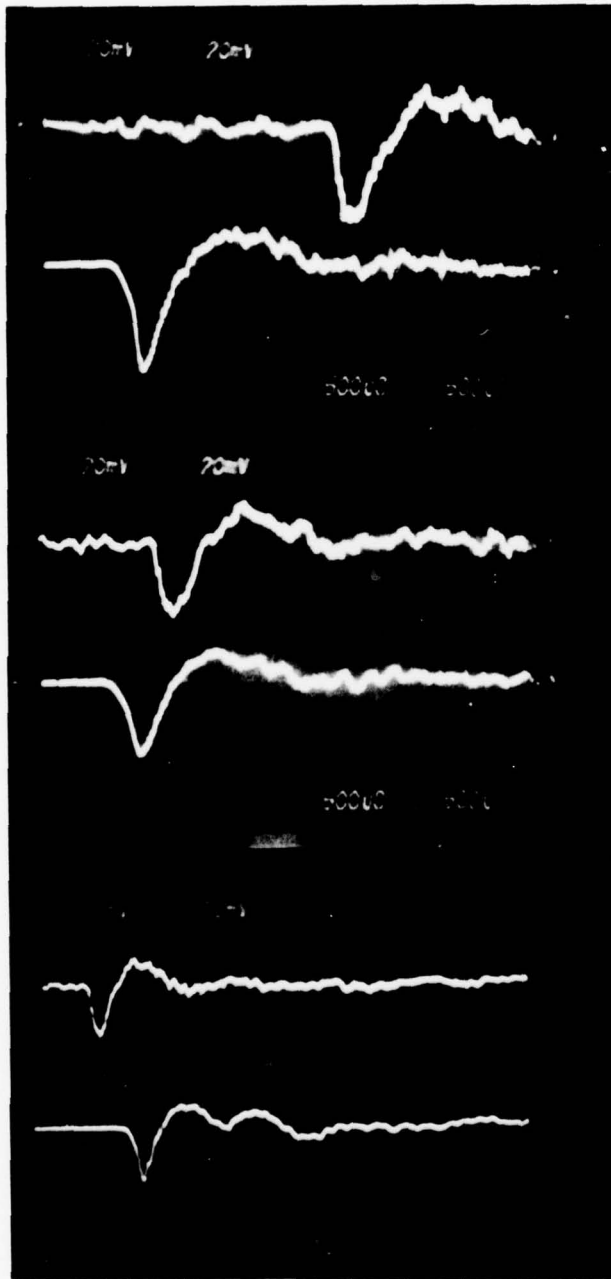
FIGURE 13. PRESSURE WAVE FORM CHARACTERISTICS.

All the results shown in Figures 14, 15, and 16 are for the case with the fan on. The character of the wave generated by the laser with the fan off is shown in Figure 17 for the 15 cm case and He gas.

b. Thermal Wave Form

The pressure waves described above travel away from the cavity, both upstream and downstream, at speeds greater than sonic. The pressure in the cavity region is adjusted back to a value near ambient in a short period of time. The temperature discontinuities created by the energy deposition do not, however. A hot region of gas remains long after the pressure waves have traveled away. The center of this hot region of gas moves away from the cavity at the speed of flow of the gas through the cavity. In measurements made very near the laser cavity, the hot region of gas was found to have the general shape as sketched in Figure 18.

Figure 19 shows the actual measured profiles for the 15 cm cavity for the N_2 , Ar, and He gases. The probe was located at location # 1 which is 143.5 cm away from the center line of the discharge region. Figure 20 shows the profile for the 45 cm cavity using Ar gas. Figure 21 shows the measured temperature profiles for the 100 cm case for N_2 and Ar gas.



Shot # 3155
 Date 1/26/77
 Vertical Scale .02v/d
 Horizontal Scale .5 msec/d

Notes

N₂
 Fan On

Shot # 3154
 Date 1/25/77
 Vertical Scale .02v/d
 Horizontal Scale .5 msec/d

Notes

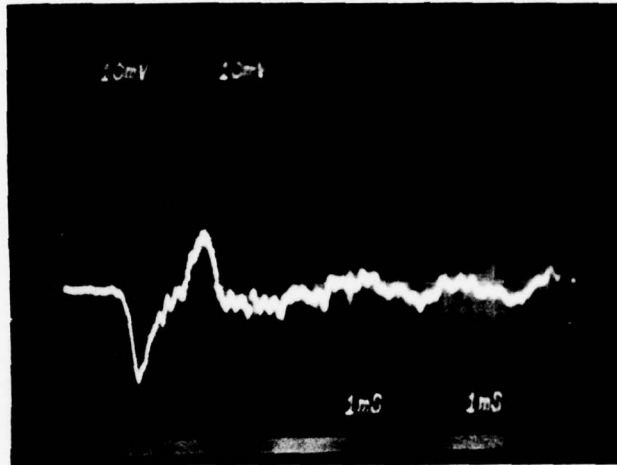
Argon
 Fan On

Shot # 3170
 Date 1/27/77
 Vertical Scale .02v/d
 Horizontal Scale 1 msec/d

Notes

He
 Fan On

FIGURE 14. EXAMPLES FOR PRESSURE WAVE FORM FOR THE 15 CM CAVITY WITH N₂, Ar, AND He.

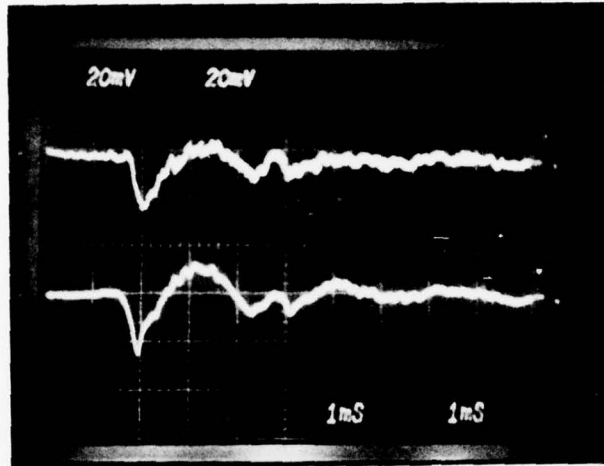


Shot # 3227
Date 2/2/77

Vertical Scale .01v/d
Horizontal Scale 1 msec/d

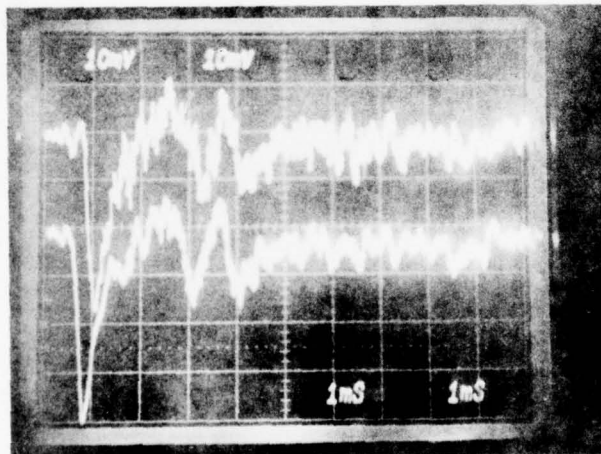
Notes
Argon (45 cm)
Fan On
Corner Test

FIGURE 15. EXAMPLE OF PRESSURE WAVE FORM GENERATED BY 45 CM CAVITY USING Ar GAS.



Shot # 3181
 Date 2/1/77
 Vertical Scale .02v/d
 Horizontal Scale 1 msec/d

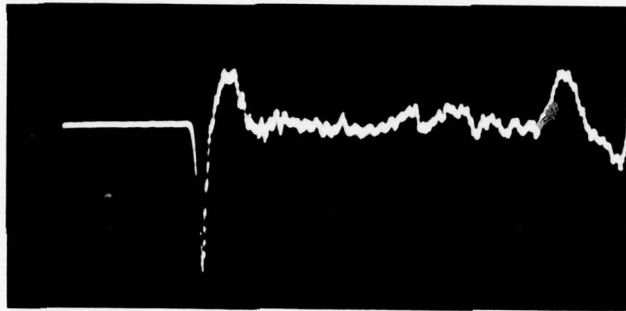
Notes
 N₂ (100 cm)
 Fan On
 A After Laser
 B Before Muff



Shot # 3211
 Date 2/2/77
 Vertical Scale .01v/d
 Horizontal Scale 1. msec/d

Notes
 Argon (100 cm)
 Fan On
 Corner Test

FIGURE 16. EXAMPLES OF PRESSURE WAVE FORM GENERATED BY 100 CM CAVITY USING N₂ AND Ar GASES.



Shot # 3143

Vertical Scale .02v/d
Horizontal Scale 2 msec/d

Notes
Muffler

FIGURE 17. EXAMPLE OF PRESSURE WAVE WHEN FAN IS OFF. THIS IS FOR 15 CM CAVITY AND He GAS.

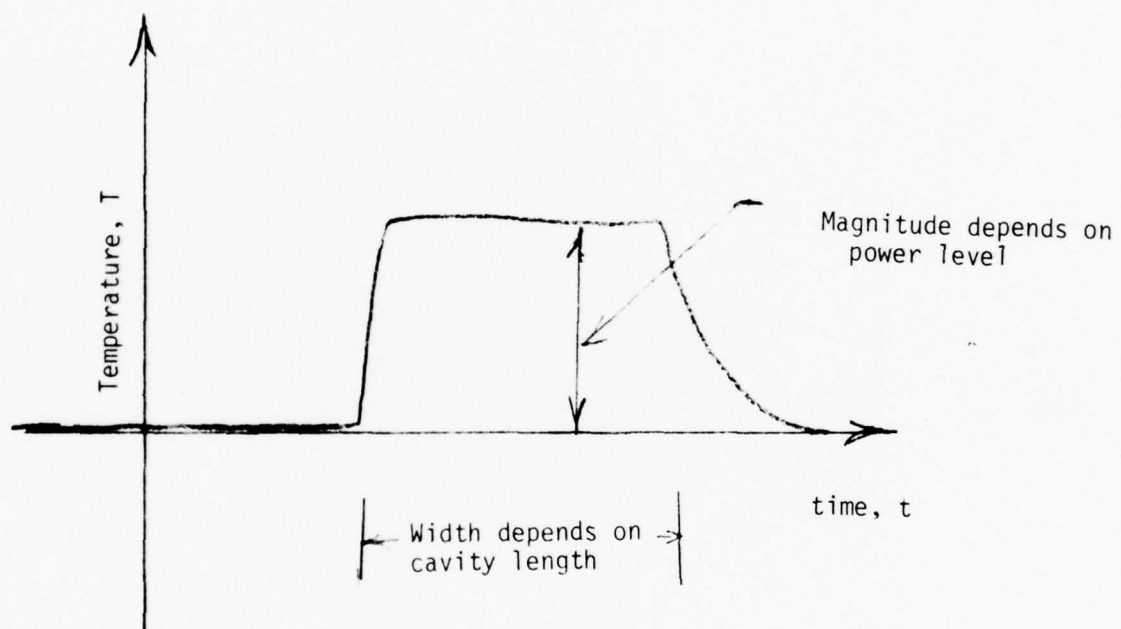
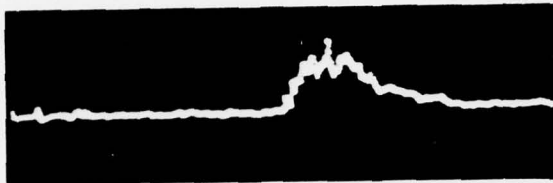


FIGURE 18. THERMAL WAVE FORM CHARACTERISTICS.



Shot # 3154
Date 1/25/77
Vertical Scale on picture
Horizontal Scale 10 msec/d

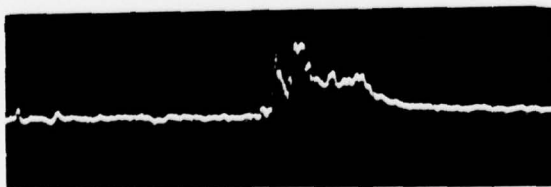
Notes
Argon
Fan On



Shot # 3155
Date 1/26/77
Vertical Scale
Horizontal Scale 10 msec/d

Notes
N₂

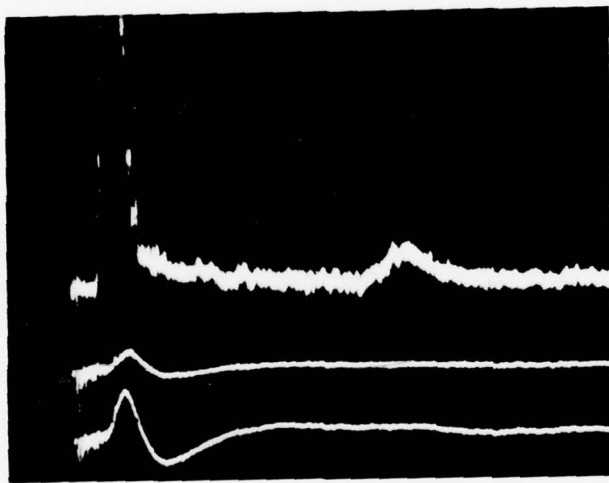
Fan On



Shot # 3170
Date 1/27/77
Vertical Scale
Horizontal Scale 10 msec/d

Notes
He
Med. power

FIGURE 19. EXAMPLES OF THERMAL WAVE FORM FOR THE 15 CM CAVITY WITH Ar, N₂, AND He GAS.



Shot # 3226
Date 2/2/77

Vertical Scale below
Horizontal Scale .1 sec/d

Notes

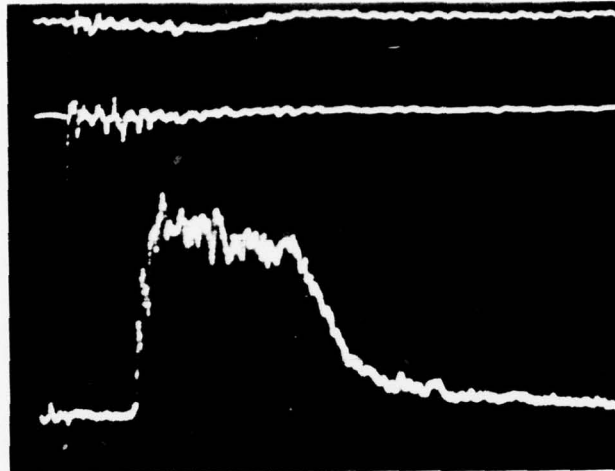
Argon

T @ ① .1v/d

P_a @ ① .02v/d

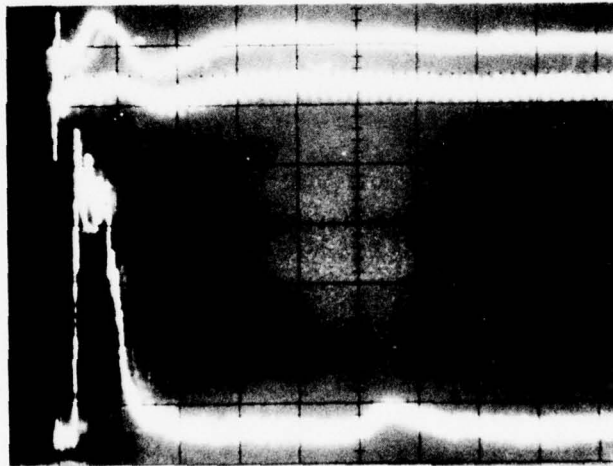
P_c @ ① .02v/d

FIGURE 20. EXAMPLE OF THERMAL WAVE (UPPER TRACE) GENERATED BY 45 CM CAVITY USING Ar GAS.



Shot # 3180
 Date 2/1/77
 Vertical Scale
 Horizontal Scale 20 msec/d

Notes
 N_2 Medium Power
 T .2v/d
 P_C @ A Mu .02v/d
 P_2 @ bend .02 v/d



Shot # 3217
 Date 2/2/77
 Vertical Scale below
 Horizontal Scale .1 sec/d

Notes
 Argon Medium Power
 T @ ① .2v/d
 P_A @ ① a (upstream of
 blower) .02v/d
 P_C @ ① .02v/d

FIGURE 21. EXAMPLES OF THERMAL WAVE (LOWER TRACE IN BOTH EXAMPLES)
 GENERATED BY 100 CM CAVITY IN N_2 AND Ar GAS.

2. Wave Interaction with Blower

The blower is the first system component the waves encounter upon leaving the downstream side of the cavity. The experimental results show that much of the pressure wave is reflected back toward the cavity. The thermal wave passes through the fan without reflection but is reduced in amplitude and spread over a larger distance.

The general characteristic of the pressure wave interaction with the fan is illustrated in Figure 22. All these features can be seen on a typical trace shown in Figure 23 where the upper trace is from a probe on the upstream side of the fan and the second trace is from a probe on the downstream side.

The thermal wave interaction with the blower is illustrated by the data shown in Figure 24 for shot numbers 3217 and 3219. For shot number 3217, the temperature probe is on the upstream side of the blower while for shot number 3219 the probe is on the downstream side of the blower. The power levels for the two shots are 322J and 289J respectively.

3. Wave Attenuation with Respect to Distance

Figure 24 illustrates the effect of distance of propagation on the thermal wave in the record for shot number 3217. The time sweep was set at .1 s/div so that the second passage of the wave could be observed at this same location. The experiment shows that the thermal wave took about .5 sec to travel around the system and was reduced in magnitude by a factor of about 8 after a single pass.

The attenuation of the pressure wave as it travels around the open system is shown in Figure 25 for shot number 3079 which shows the pressure probe records at the four major locations in the system. The effect of distance is seen by following the wave that travels upstream from the

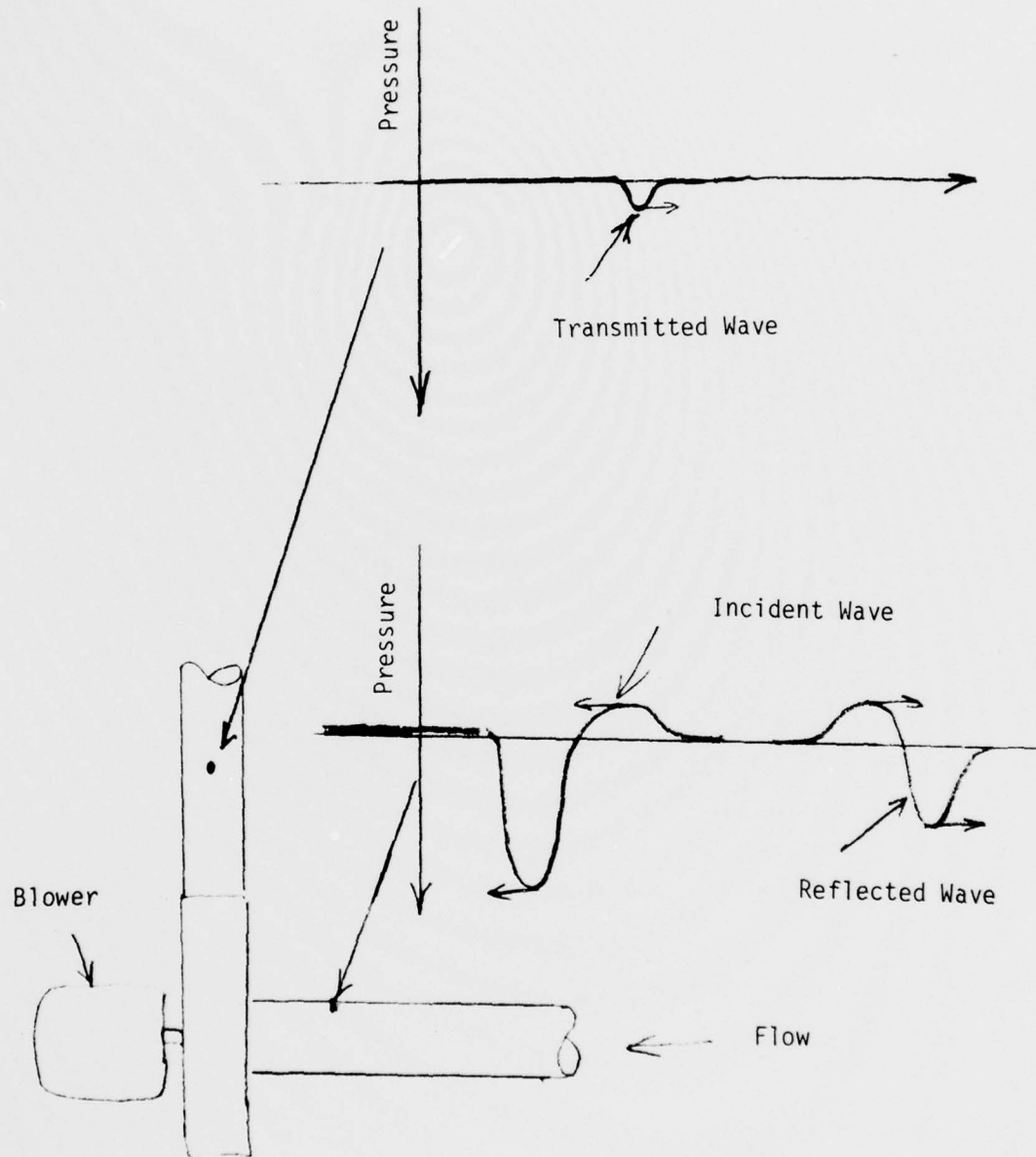
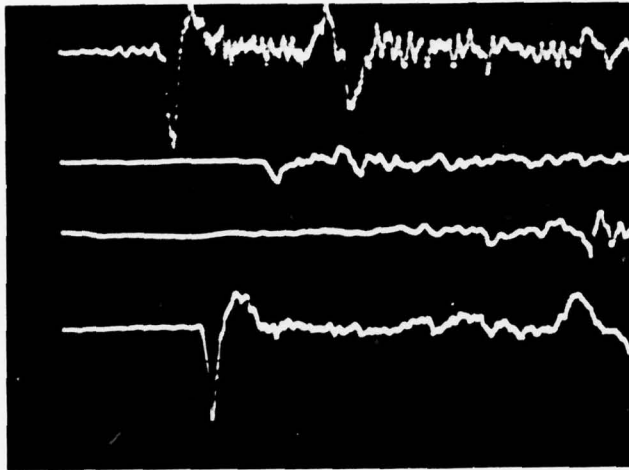


FIGURE 22. CHARACTERISTICS OF THE PRESSURE WAVE INTERACTION WITH THE BLOWER.



Shot # 3117

Date 12/20/76

Vertical Scale .02v/d

Horizontal Scale 2 msec/d

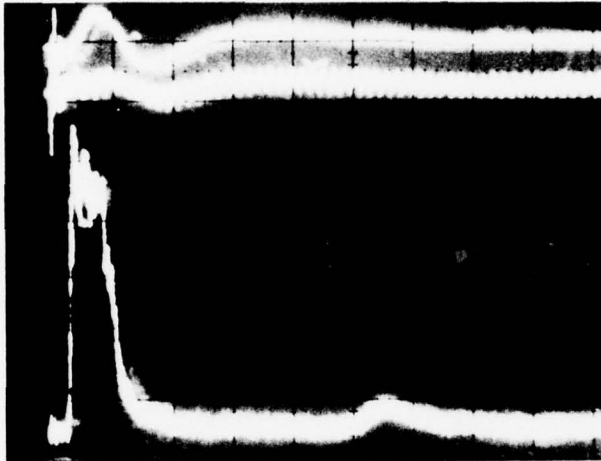
Notes

Argon

Muffler

Fan On

FIGURE 23. EXAMPLE OF PRESSURE WAVE INTERACTION WITH FAN (15 CM CAVITY ARGON GAS).



Shot # 3217

Date 2/2/77

Vertical Scale below

Horizontal Scale .1 sec/d

Notes

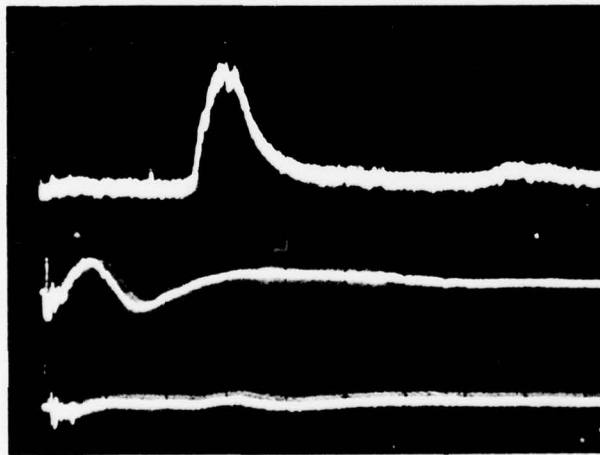
Argon

Medium Power

T @ ① .2v/d

P_A @ ① a(upstream of blower)
.02 v/d

P_C @ ① .02 v/d



Shot # 3219

Date 2/2/77

Vertical Scale below

Horizontal Scale .1 sec/d

Notes

Argon

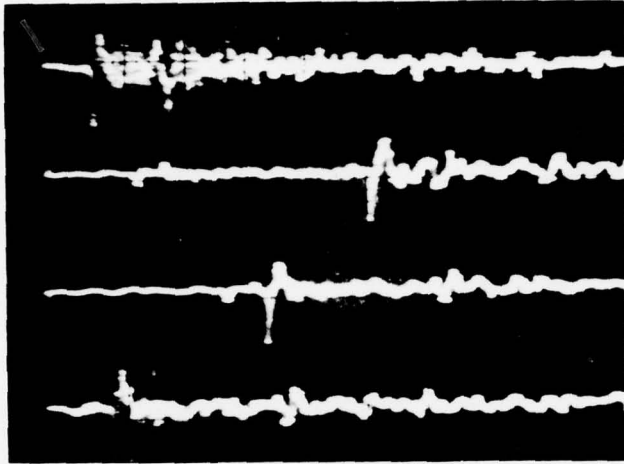
Medium Power

T @ uM .1v/d

P_A @ uM .02v/d

P_C @ ① .02v/d

FIGURE 24. EXAMPLES OF INTERACTION OF THERMAL WAVE WITH THE FAN. LOWER TRACE OF #3217 IS TEMPERATURE PROBE UPSTREAM OF FAN WHILE UPPER TRACE OF 3219 IS TEMPERATURE PROBE DOWNSTREAM OF FAN.



Shot # 3079

Date

Vertical Scale .02 v/d

Horizontal Scale 5 msec/d

Notes

Argon

2 x 27 mm

Fan On

Cer honeycomb

90

Next to #4

15

FIGURE 25. EXAMPLE OF PRESSURE WAVE PROPAGATION IN OPEN SYSTEM WITH THE FAN ON.

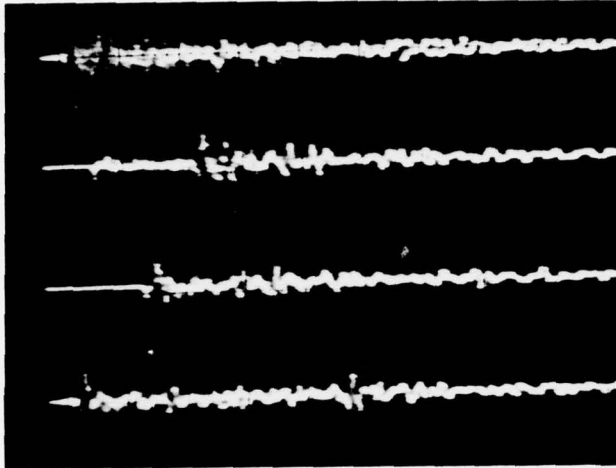
cavity beginning at station 4 then appearing at station 3 and finally at station 2. Taking the amplitude at station 4 as a reference, the positive phase amplitude at 3 and 2 is .718 and .684 respectively. These results are with the fan on. For the case when the fan is off, refer to Figure 26 which shows the results for shot number 3083. In this case, the amplitude at 3 and 2 relative to 4 is .814 and .804 respectively. This comparison shows that the pressure wave attenuation is much greater when the wave is traveling against the flow as compared to when there is no flow.

4. Pressure Wave Interaction with Ceramic Reflectors

The ceramic reflectors were installed between stations 3 and 4 in the recirculation system. The thin walled metal honeycomb was found to have no measurable effect on the wave propagation. The pressure wave was found to be attenuated by the square celled ceramic. They were not found to cause any measurable reflection of the pressure wave, however. Examples of the results are shown in Figure 27 for shot number 3097 with the fan on and number 3098 with the fan off. For these shots, all four sections (8 cm in total length) of the square celled ceramic were placed between stations 3 and 4. Using the amplitude at station 4 as the reference, the amplitude ratio across the ceramic was .562 with the fan on and .632 with the fan off. Compared with the same ratios discussed in part 3 above, the ceramic is found to reduce the amplitude of the pressure wave by a factor of .78 compared to the open pipe.

5. Pressure Wave Interaction with Muffler

The muffler was found to have a dramatic effect on the pressure wave as can be seen in Figure 28 which shows the results for shot numbers 3102 and 3106 for fan and no fan respectively. The pressure wave



Shot # 3083

Date

Vertical Scale .02v/d

Horizontal Scale 10 msec/d

Notes

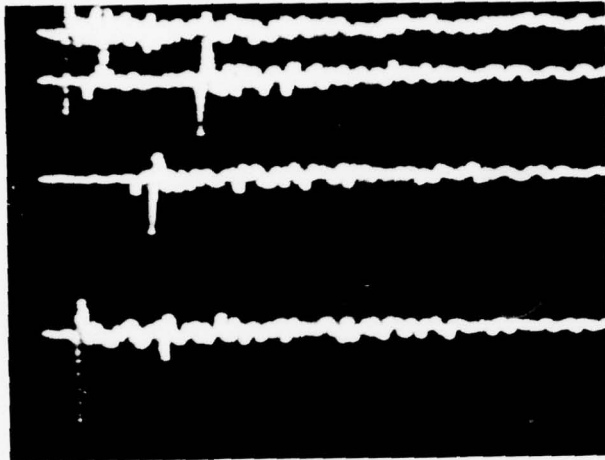
90

115.8

No Fan

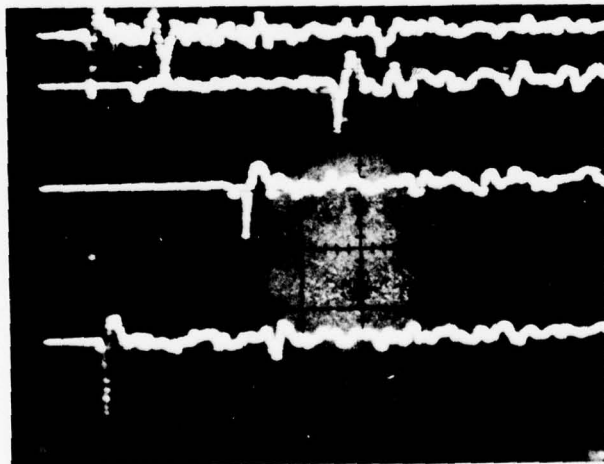
Argon

FIGURE 26. EXAMPLE OF PRESSURE WAVE PROPAGATION IN OPEN SYSTEM WITH THE FAN OFF.



Shot # 3097
 Date 12/14/76
 Vertical Scale .02v/d
 Horizontal Scale 10 msec/d

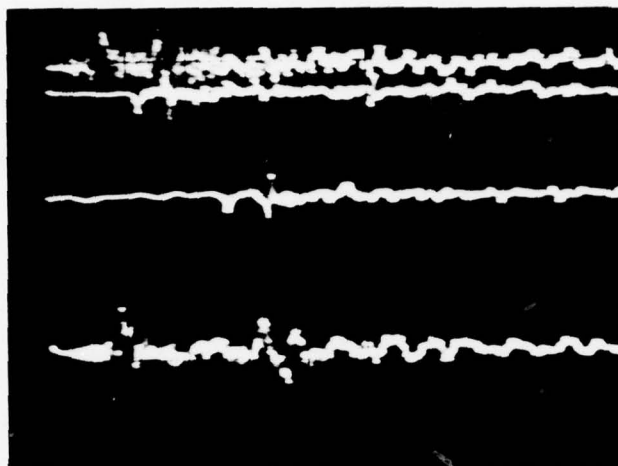
Notes
 Argon
 4 sections of cer, fine
 & coarse



Shot # 3098
 Date 12/14/76
 Vertical Scale .02v/d
 Horizontal Scale 5 msec/d

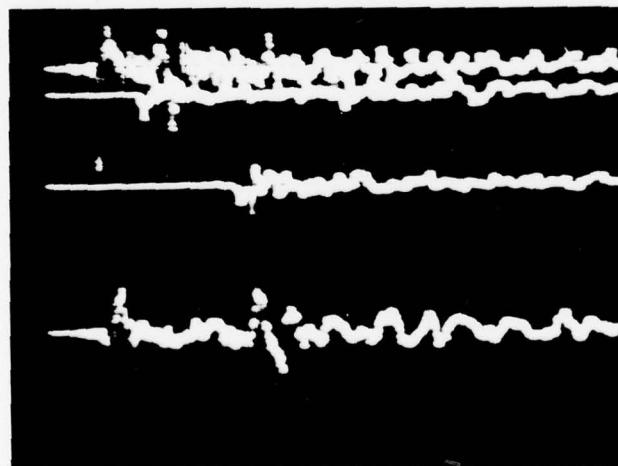
Notes
 Argon
 Fan Off
 4 sections of Cer Honeycomb,
 Coarse & Fine

FIGURE 27. EXAMPLES OF PRESSURE WAVE PROPAGATION THROUGH CERAMIC REFLECTORS WITH FAN ON (#3097) AND FAN OFF (#3098).



Shot # 3102
 Date 12/17/76
 Vertical Scale .02 v/d
 Horizontal Scale 5 msec/d

Notes
 Argon
 Muffler
 Fan
 90
 21.8
 Strong



Shot # 3106
 Date 12/17/76
 Vertical Scale .02v/d
 Horizontal Scale 5msec/d

Notes
 Argon
 Muffler
 28.9/90
 No Fan
 Long Pulse

FIGURE 28. EXAMPLES OF PRESSURE WAVE PROPAGATION THROUGH THE MUFFLER WITH THE FAN ON (#3102) AND FAN OFF (#3106).

amplitude ratio across the muffler is found to be .143 with the fan on (#3102) and .181 with the fan off (#3106).

Pressure probes were relocated nearer the muffler and a more detailed study was made of the pressure wave interaction with the muffler. This study showed that there is a negative phase pressure wave reflected from the muffler when the pressure wave travels into the muffler. The positive phase of the pressure wave is attenuated considerably in the muffler while the negative phase is not reduced as much. A sketch of the pressure wave interaction is given in Figure 29. Figure 30 shows data which supports the general view of the muffler interaction as shown in Figure 29. In Figure 30, data from shot numbers 3172 and 3143 are shown. For #3172, the two pressure probes are placed at the same side of the muffler spaced about 22 cm apart. In the lower trace of #3172, the reflected negative wave is on top of the negative phase of the incident wave. In the top trace, the reflected negative wave is seen separated from the incident pressure wave. The data on shot #3143 was taken with one pressure probe on each side of the muffler. The upper trace shows the transmitted wave and the lower trace shows the incident wave. The second negative phase wave on the lower trace of #3143 is the reflected negative phase wave as has been discussed.

The performance of the muffler was investigated in more detail with the assistance of Mr. Cason and Dr. Werkheiser of MICOM. They provided a pressure spectrum of the pulse which is typical of that generated in a laser pulse shown in Figure 30a. This figure shows that much of the energy in the pressure pulse is contained in the 100 to 1000 Hz range. The pressure wave data taken in laser firings Number 3134, 3137, 3139, 3140, 3142 and 3143 was photographically enlarged and over 100 data points taken from

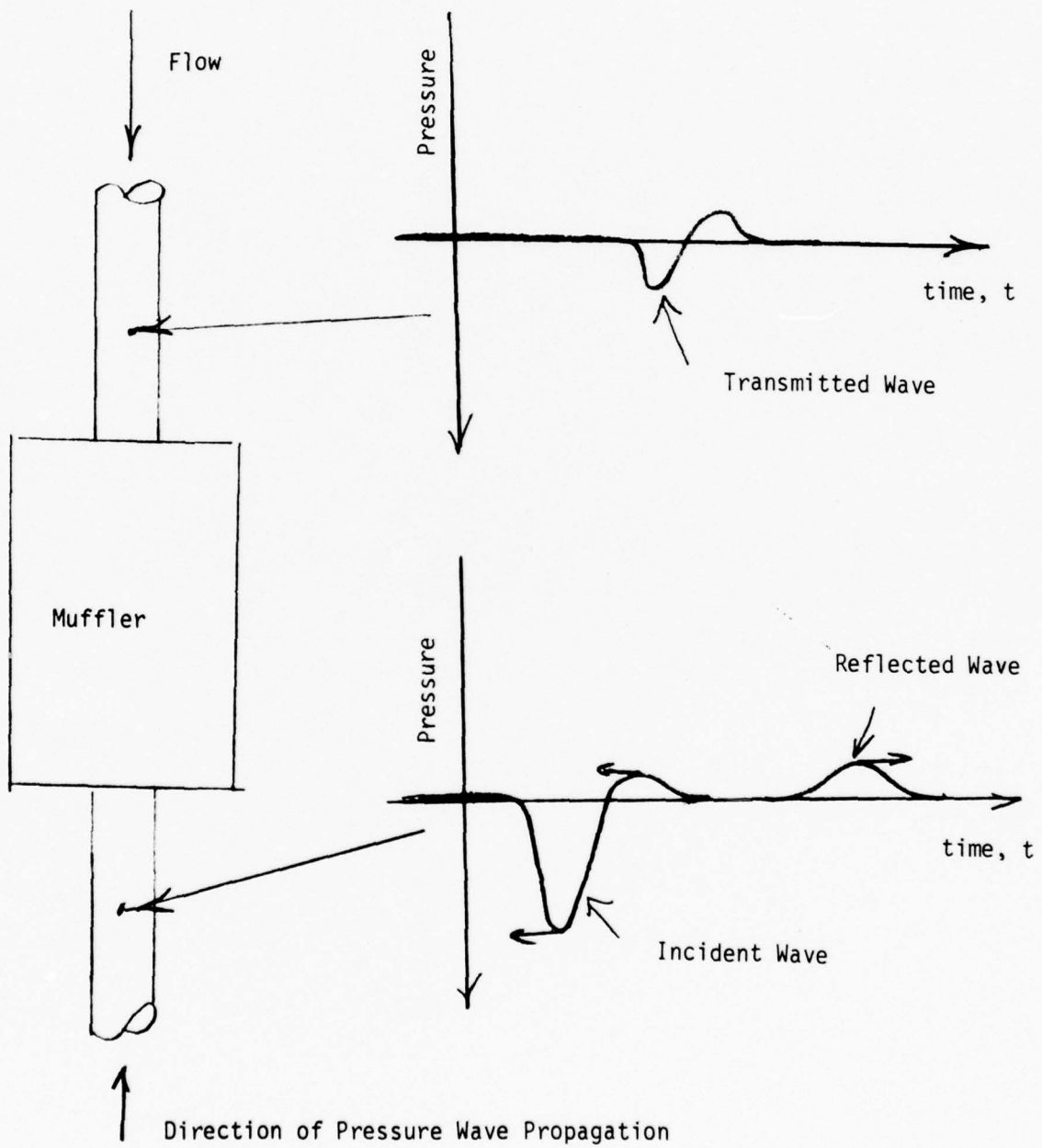
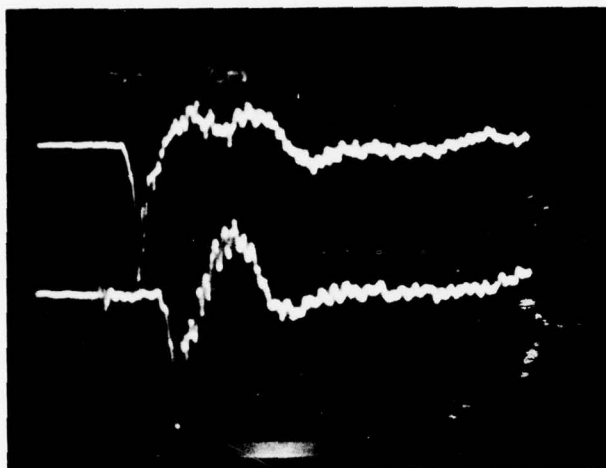


FIGURE 29. CHARACTERISTICS OF PRESSURE WAVE INTERACTION WITH MUFFLER.



Shot # 3172
 Date 1/28/77
 Vertical Scale .02 v/d
 Horizontal Scale 1 msec/d

Notes
 Both delayed 8 msec
 N₂, Fan On
 Muff Test



Shot # 3143
 Date 12/22/76
 Vertical Scale .02 v/d
 Horizontal Scale .5 msec/d

Notes
 He
 Fan Off

FIGURE 30. EXAMPLE OF PRESSURE WAVE INTERACTION WITH MUFFLER; #3172 SHOWS THE INCIDENT AND REFLECTED WAVE, #3143 SHOWS THE TRANSMITTED WAVE.

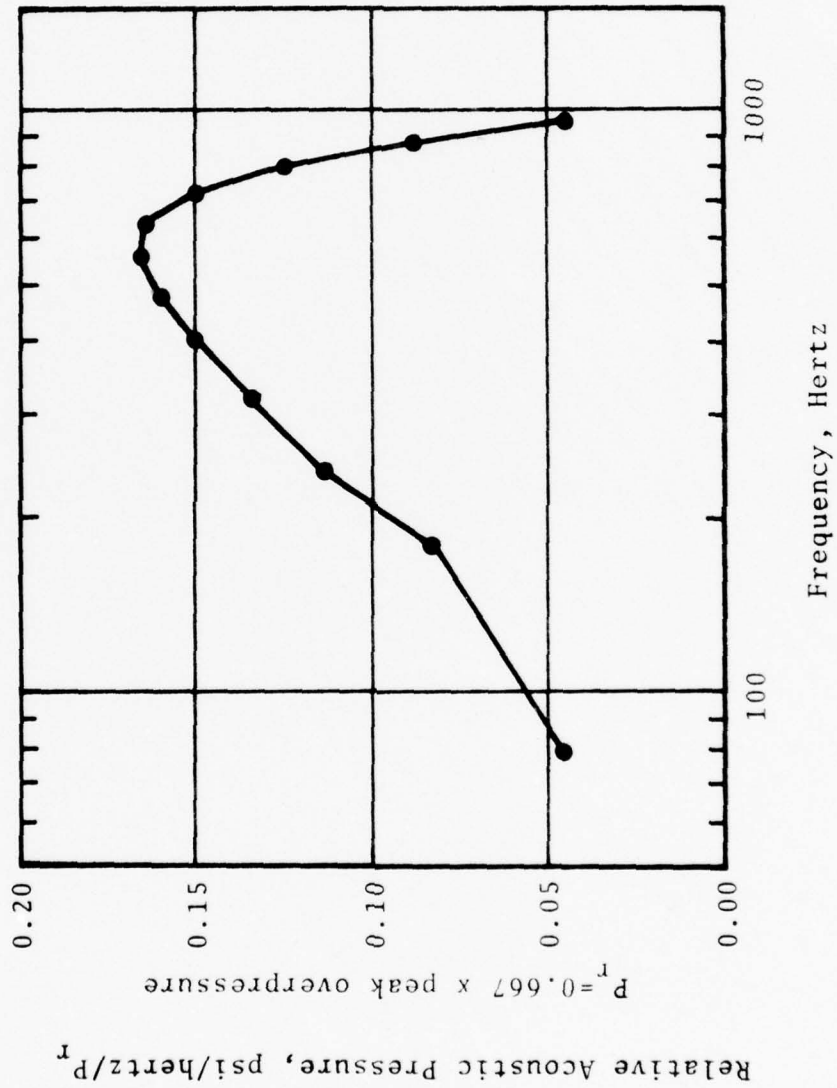


FIGURE 30a. ACOUSTIC PRESSURE SPECTRUM RESULTING FROM LASER FIRINGS.

each trace. These data were input into a computer program to obtain the power spectrum density of the incident and transmitted waves. From this data, the attenuation characteristics of the muffler was determined as a function of frequency. The results are shown in Figure 30b for three different gas mixtures.

The results show that nearly 40 db attenuation was obtained at the low frequency end and a 12 db peak at near 500 Hz. The first peak is likely due to the large volume available for resonance and the 500 Hz peak is likely resulting from the horn characteristics. The results show a need to design for the 100 to 200 Hz frequency range since this muffler had little effect on energy in that range. The range above 1000 Hz can likely be increased by lining the duct or other standard approaches for high frequency energy.

6. Pressure Wave Interaction with 90° Turns

Data was taken on the pressure wave at a location before and after it passed a 90° turn. No measurable change in the wave form could be observed and no measurable reflection could be observed. Samples of the data are presented in Figure 31 which shows data for shot numbers 3211 and 3238 for the 100 and 45 cm cavity cases with the fan on. The upper traces show the wave form before the corner and the lower traces show the wave form after the corner.

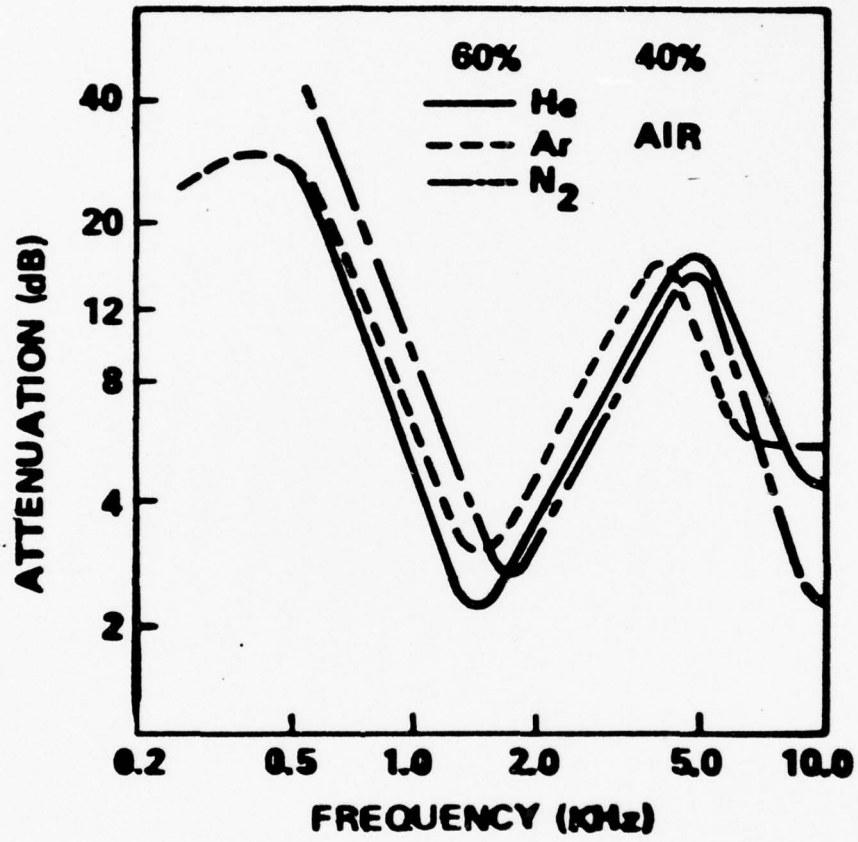
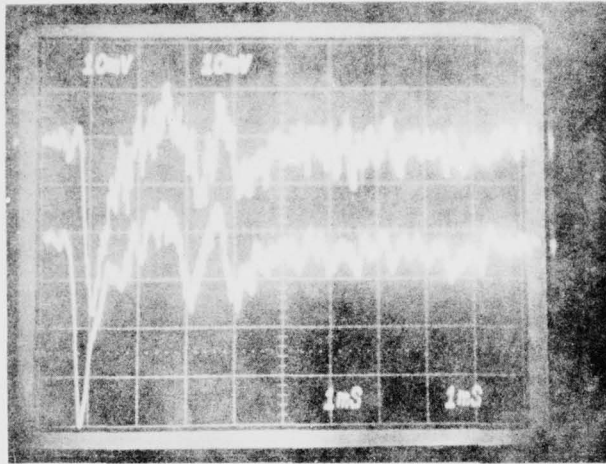
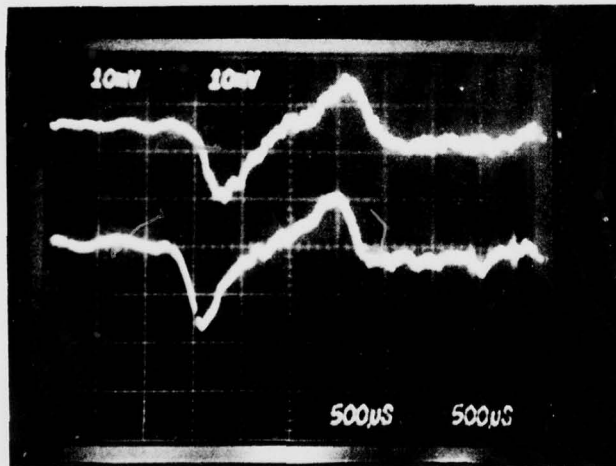


FIGURE 30b. ATTENUATION AS A FUNCTION OF FREQUENCY FOR THE HORN-COUPLED-RESONATOR MUFFLER WITH THREE DIFFERENT GAS MIXTURES.



Shot # 3211
 Date 2/2/77
 Vertical Scale .01 v/d
 Horizontal Scale 1. msec/d

Notes
 Argon
 Fan On (100 cm)
 Corner Test



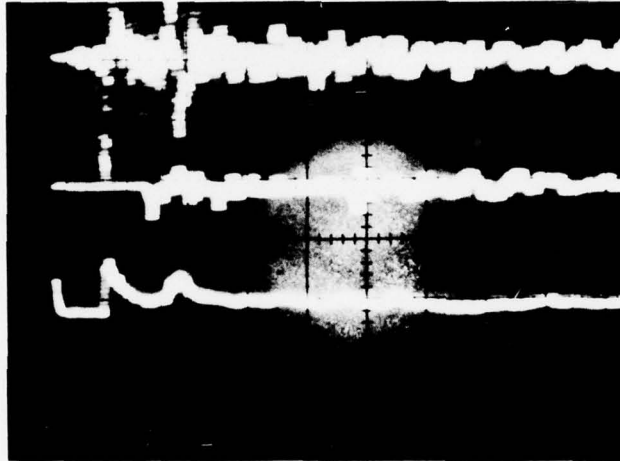
Shot # 3238
 Date 2/2/77
 Vertical Scale .01 v/d
 Horizontal Scale .5 msec/d

Notes
 Argon (45 cm)
 Fan On
 Corner Test

FIGURE 31. EXAMPLES OF PRESSURE WAVE INTERACTION WITH CORNER. TOP TRACES SHOW WAVE BEFORE CORNER AND LOWER TRACE SHOWS SAME WAVE AFTER CORNER.

7. Velocity Wave Form

A limited amount of data was obtained from the hot wire on velocity waves in the system. An example of the results obtained on the velocity wave is shown in Figure 32 for shot number 3125. The third trace shows the velocity as measured at station 1. The upper trace is the pressure record at that same location. The results show the sudden change in velocity caused by the shock, the decay in velocity caused by the expansion wave following the shock, the sudden velocity increase caused by the shock traveling back past station 1 after reflecting off the fan, and the decay in velocity due to the traveling expansion fan.



Shot # 3125
Date

Vertical Scale below
Horizontal Scale 5 msec/d

Notes

90-26 power

Vertical Scale
p. ① & ② .2 v/d
vel ④ .5 v/d

FIGURE 32. EXAMPLE OF RESULTS OBTAINED ON VELOCITY WAVE TAKEN AT STATION # 1 NEAR THE EXIT TO THE LASER.

Chapter IV
DESIGN OF LASER CAVITY

The UAH team assisted Mr. H. C. Tom in the engineering design of the laser cavity to be incorporated in the laser system under design and construction. Periodical meetings were held to provide technical information and design guidance in the detail flow calculations, thermo analysis, and configuration design of the laser cavity. Some laboratory analyses using a water table was employed during this period in obtaining pertinent technical data for the design.

Chapter V

CONCLUSIONS

The theoretical and experimental program which was begun during the duration of this contract is not complete at this time but the following conclusions have been drawn based on the subscale testing and the numerical modeling work.

1. Impulsive high energy deposition in a flowing gas, characteristic of a high energy laser pulse, produces shock waves which travel at supersonic speeds, both upstream and downstream, away from the cavity. The energy pulse also produces a region of hot gas which travels with the flowing gas.

2. The shock waves travel throughout the recirculation system, travel around 90° turns with little or no attenuation, reflect off a compressor with little or no attenuation, and can likely be absorbed by mufflers of suitable design.

3. The hot gas region (or thermal wave) moves at the flow velocity, is attenuated by the compressor, and will return to the cavity in one recirculation cycle unless suitable heat transfer takes place in the circuit.

4. One dimensional modeling of the transient flow behavior is able to predict the major qualitative characteristics of pulsed operation (i.e., the shock wave and thermal wave generation) but quantitative comparisons show a need for improved gas dynamic modeling of the transient behavior.

5. Acoustic absorbers of the honeycomb type tested in this work were found to be of little influence in the attenuation or reflection of the shock wave or the thermal wave. Either a much more closed honeycomb

or many more of the ones employed would be required to attenuate the shock wave. This would be at the expense of significantly higher pressure drop.

6. A low-pressure-drop muffler can likely be designed to eliminate the shock waves produced by the pulsed laser operation. The muffler tested in this work was successful in attenuating the shock wave by 40 db and better performance can likely be obtained by redesign and further testing.

7. The numerical simulation of steady state operation and transient fluid and thermal behavior needs further development which could come about from imperial relations based on actual system performance. The subscale system employed in the work reported here was not appropriate for development of the data needed on start up transients and heat exchanger performance.

The work reported here has revealed the major transient fluid and thermal characteristic of high energy gas laser systems operated in a pulsed mode. While the closed cycle EDL has been the basis for the study, the results should be of interest and application to the design of both closed and open cycle systems including electric discharge, chemical, and gas dynamic high energy systems. The closed cycle system presents the most severe environment in terms of pulsed operation since waves can travel around the system or reflect back to the cavity and thus spoil beam quality or otherwise degrade the gas properties desired for efficient laser operation. Wave attenuation is required in order to prevent waves from returning to the cavity region or from traveling into the upstream regions of the system. Such attenuation can most likely be performed using high pressure drop screens, honeycomb material, or orifice plates. The overall

efficiency of the laser system is, however, reduced by the use of high pressure drop devices and a better solution would be to employ low pressure drop muffler concepts. The muffler concept employed in the work reported here was of the straight flow type having no structure to impede the flow of laser gas. The waves are attenuated by designing resonate cavities and horn amplifiers to transmit the A. C. energy in the flow to be disipated in acoustic absorbing material while not effecting the D. C. energy contained in the flow. Improvements on this concept and design are confidently predicted and such devices should find wide application in pulsed laser operation.

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APPENDIX A

1) .MAIN

```
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION AMT(16,16), NN(16), SVR(16), TDIF(16), BMT(16)
COMMON /VAR/ T01G, T02G, T06G, T07G, T1, T2, T3, T4, T6, T8,
A T10, T14, T16, T18, T20, TA2,
P T03G, T04G, T05G, T08G, T09G, T010G, T011G, T5, T7, T9, T11,
C T12, T13, T15, T17, T19, T1G, T2G, T3G, T4G, T5G, T6G, T7G,
D T8G, T9G, T10G, T11G, TA1, EFFL, P01G, P02G, P03G, P04G, P05G,
E P06G, P07G, P08G, P09G, P010G, P011G, P1G, P2G, P3G, P4G, P5G,
F P6G, P7G, P8G, P9G, P10G, P11G, P(20), AC(20), VC(20), FM1,
G FM2, FM3, FM4, FM5, FM6, FM7, FM8, FM9, FM10, FM11, A(11),
H GAM1G, GAM2G, GAM3G, GAM4G, GAM5G, GAM6G, GAM7G, GAM8G, GAM9G,
I GAM10G, GAM11G, TGMI, TGMII, TMA, GIMU, GIIMU, AMU, PRGI,
J PRGII, PRA, CPGI, CPGII, CPA, TMI, TMII, TM, ZIMU, ZIIMU, ZMU,
K PRI, PRII, PR, CPI, CPII, CP, GGI, GGII, GA, GI, GII, G, REGI,
L REGII, REA, REI, REII, RE, GFI, GFII, AF, FI, FII, F, GJI,
M GJII, AJ, ZJI, ZJII, ZJ, HGI, HGII, HA, HI, HII, H, CGI, CGII,
N CA, CI, CII, C, UI, UII, U, AGI, AGII, AA, TUNI, TUNII, TUN,
O TOWI, TOWII, TOW, EPSI, EPSII, EPSA, ESSI, ESSII, ESS, WG,
P Q6G, QCORR, BPR, ALT, PAT, PA2, RH, FN(4), EFFLP, VI, VIM,
Q PIGA, H1M, CL1M, WT1M, DCM, BLPR, BLPRM, CPP, CPPM, PF, PFM,
R R01, PLKW, WI, WII, WB, WM, WV1, WV2, WE, WS, WA, QP, QCM,
S QM, QV1, QV2, QE, QS, CF23, CF34, CF45, CF78, CF89, CF910
COMMON /VAR/ CF111, ATAP, H1, CL1, WT1, ACN(20), DC, DL(3),
A DH(3), DW(3), DDHG(3), DALG(3), DAFOA(3), DSIG(3), DDEL(3),
B DA(3), DK(3), DSL(3), DSI(3), DALF(3), DDH(3), CONV(16), DELM,
C ROLIM, PLIM, FG, TITLE(28), DP, DPI, DPII, PPR, PPRM,
D TA1F, RHP, TIGM, DKH(3), ETIG, ET02G, ET06G, ET07G, ET1,
E ET2, ET3, ET4, ET6, ET8, ET10, ET14, ET16, ET18, ET20, ETA2,
F EDPR, CWA, DNP(3), QDI, QDII, QDA, EVIM, RRPM, VLIM, ROA1,
G ROA2, DAFAL(3), DSSL(3), AB(3)
COMMON /IVAR/ NTAM, NDSGN, NCS, KI, KO, NLIM, NP(3), NFULL,
1 NBS, NBPS, JCPRO
EQUIVALENCE (SVR( 1),T01G)

2 CALL ENPUT
T2G=T02G
T6G=T06G
T5G=T02G
T10G=T07G
JV=0
501 II=0
CALL GASP(TIG, FN, GAMIG, CFIG, Z1, Z1, GMU)
IF (JCPRO .GE. 0)
1 PIG=R01*TIG/(.093178*GMU)
IF (JCPRO .LT. 0)
1 R01=.093178*PIG*GMU/TIG
WG=R01*VI*A(1)
FM1=WG*DSQRT(TIG/(GAMIG*GMU))/(20.7774*PIG*A(1))
T01G=TIG*(1.+FM1*FM1*(GAMIG-1.)/2.)
T11G=T01G
WRITE(6,198)R01,GMU,PIG,TIG
198 FORMAT(1H0,3X,'R01=',E15.7,5X,'GMU=',E15.7,5X,'PIG=',E15.7,
1 5X,'TIG=',E15.7)
10 DO 3 I=1,16
DO 4 J=1,16
4 AMT(I,J)=0.
```

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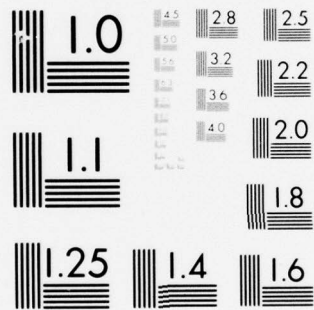
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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3 BMT(I)=0.0
WRITE(6,122) T02G
122 FORMAT(1H0,3X,'T02G=',E15.7)
WRITE(6,121) T1,T2,T3,T4,T6,T8,T10,T14,T16,T18,T20
121 FORMAT(1H0,5X,'T1,T2,T3,T4,T6,T8,T10,T14,T16,T18,T20',/,3X,
1 9E13.6,/,3X,2E13.6)
TMI=.5*(T2+T4)
TMII=.5*(T2+T6)
TM=.5*(T3+T1)
Z1=T5G-T4
Z2=T6G-T2
IF (Z1 .LE. 0. .OR. Z2 .LE. 0.) GO TO 11
IF (Z1 .EQ. Z2) GO TO 12
TGM I=TMI+(Z1-Z2)/(DLOG(Z1)-DLOG(Z2))
GO TO 13
11 TGM I=.5*(T5G+T6G)
GO TO 13
12 TGM I=.5*(T5G+T6G)
13 Z1=T10G-T6
Z2=T11G-T2
IF (Z1 .LE. 0. .OR. Z2 .LE. 0.) GO TO 14
IF (Z1 .EQ. Z2) GO TO 15
TGM II=TMII+(Z1-Z2)/(DLOG(Z1)-DLOG(Z2))
GO TO 16
14 TGM II=.5*(T10G+T11G)
GO TO 16
15 TGM II=.5*(T10G+T11G)
16 Z1= T1-TA1
Z2=T3-TA2
IF (Z1 .LE. 0. .OR. Z2 .LE. 0.) GO TO 17
IF (Z1 .EQ. Z2) GO TO 18
TMA=TM-(Z1-Z2)/(DLOG(Z1)-DLOG(Z2))
GO TO 19
17 TMA=.5*(TA1+TA2)
GO TO 19
18 TMA=.5*(TA1+TA2)
19 CALL GASP(TGM I, FN, Z1, CPGI, PRGI, GIMU, GMU)
CALL GASP(TGM II, FN, Z1, CPGII, PRGII, GIIMU, GMU)
WRITE(6,199)GIMU,GIIMU,VI
199 FORMAT(1H0,3X,'GIMU=',E15.7,5X,'GIIMU=',E15.7,5X,'VI=',E15.7)
CALL AIRP(TA1, PAT, TMA, RH, PRA, AMU, CPA, Z1, AML)
CALL LIQP(TMI, FG, ZIMU, PRI, CPI)
CALL LIQP(TMII, FG, ZIIMU, PRII, CPII)
CALL LIQP(TM, FG, ZMU, PR, CP)
AFRGI=DL(1)*DH(1)
AFRGII=DL(2)*DH(2)
AFRA=DL(3)*DH(3)
GGI=WG/(DSIG(1)*AFRGI)
GGII=WG/(DSIG(2)*AFRGII)
GA=WA/(DSIG(3)*AFRA)
AFRI=DW(1)*DH(1)/DNP(1)
AFRII=DW(2)*DH(2)/DNP(2)
AFR=DW(3)*DH(3)/DNP(3)
GI=WI/(DSI(1)*AFRI)
GII=WII/(DSI(2)*AFRII)
W3=WI+WII+WR+WM+WV1+WV2+WE+WS
G=W3/(DSI(3)*AFR)

```

```

REGI=GGI*DDHG(1)/GIMU
REGII=GGII*DDHG(2)/GIIMU
REA=GA*DDHG(3)/AMU
REI=GI*DDH(1)/ZIMU
REII=GII*DDH(2)/ZIIMU
RE=G*DDH(3)/ZMU
WRITE(6,197)REGI,REGII,REA,REI,REII,RE
197 FORMAT(1H0,3X,'REGI=',E13.6,4X,'REGII=',E13.6,4X,'REA=',E13.6,4X,
1 'REI=',E13.6,4X,'REII=',E13.6,4X,'RE=',E13.6)
Z1=DLOG(REGI)
Z2=-750.2946+629.2028*Z1-219.5279*Z1**2+40.7569*Z1**3-4.253034*Z1*
1*4+.2364432*Z1**5-.005466298*Z1**6
GFI=DEXP(Z2)
Z1=-360.4224+335.276*Z1-129.1436*Z1**2+26.20469*Z1**3-2.961196*Z1*
1*4+.1766745*Z1**5-.004345743*Z1**6
GJI=DEXP(Z1)
Z1=DLOG(REGII)
Z2=-750.2946+629.2028*Z1-219.5279*Z1**2+40.7569*Z1**3-4.253034*Z1*
1*4+.2364432*Z1**5-.005466298*Z1**6
GFII=DEXP(Z2)
Z1=-360.4224+335.276*Z1-129.1436*Z1**2+26.20469*Z1**3-2.961196*Z1*
1*4+.1766745*Z1**5-.004345743*Z1**6
GJII=DEXP(Z1)
Z1=DLOG(REA)
Z2=-7.652462+6.206772*Z1-1.715187*Z1**2+.1756196*Z1**3-.006207806*
1Z1**4
AF=DEXP(Z2)
Z1=2.123751-1.083736*Z1-.05205297*Z1**2+.01646661*Z1**3-.000782202
11*Z1**4
AJ=DEXP(Z1)
Z1=DLOG(REI)
Z1=-22.04452+12.84988*Z1-3.122052*Z1**2+.3159152*Z1**3-.01161237*Z
11**4
ZJI=DEXP(Z1)
Z1=DLOG(REII)
Z1=-22.04452+12.84988*Z1-3.122052*Z1**2+.3159152*Z1**3-.01161237*Z
11**4
ZJII=DEXP(Z1)
Z1=DLOG(RE)
Z1=-22.04452+12.84988*Z1-3.122052*Z1**2+.3159152*Z1**3-.01161237*Z
11**4
ZJ=DEXP(Z1)
T03=-2./3.
HGI=GGI*CPGI*GJI*PRGI**T03
HGII=GGII*CPGII*GJII*PRGII**T03
HA=GA*CPA*AJ*PRA**T03
HI=GI*CPI*ZJI*PRI**T03
HII=GII*CPII*ZJII*PRII**T03
H=G*CP*ZJ*PR**T03
GMI=DSQRT(2.*HGI/(DK(1)*DDEL(1)))
GMII=DSQRT(2.*HGII/(DK(2)*DDEL(2)))
AM=DSQRT(2.*HA/(DK(3)*DDEL(3)))
T03=GMI*DSL(1)
ATFI=DTANH(T03)/T03
T03=GMII*DSL(2)
ATFII=DTANH(T03)/T03
T03=AM*DSL(3)

```

```

ATFA=DTANH(TO3)/TO3
ATOI=1.-DAFOA(1)*(1.-ATFI)
ATOII=1.-DAFOA(2)*(1.-ATFII)
ATO=1.-DAFOA(3)*(1.-ATFA)
GM1=DSQRT(2.*HI/(DK(1)*DA(1)))
GM2=DSQRT(2.*HII/(DK(2)*DA(2)))
AMN=DSQRT(2.*H/(DK(3)*DA(3)))
TO3=GM1*DSLL(1)
ATF1L=DTANH(TO3)/TO3
TO3=GM2*DSLL(2)
ATF2L=DTANH(TO3)/TO3
TO3=AMN*DSLL(3)
ATFAL=DTANH(TO3)/TO3
ATO1=1.-DAFAL(1)*(1.-ATF1L)
ATO2=1.-DAFAL(2)*(1.-ATF2L)
ATOL=1.-DAFAL(3)*(1.-ATFAL)
UI=1./(1./(ATOI*HGI)+AB(1)/(DK(1)*(1.-DAFOA(1)))+DALG(1)/(DALF(1)
1)*HI*ATO1))
UII=1./(1./(ATOII*HGII)+AB(2)/(DK(2)*(1.-DAFOA(2)))+DALG(2)/(DALF(
12)*HI*ATO2))
U=1./(1./(ATO*HA)+AB(3)/(DK(3)*(1.-DAFOA(3)))+DALG(3)/(DALF(3)*HI*
1ATOL))
CGI=WG*CPGI
CGII=WG*CPGII
CA=WA*CPA
CI=WI*CPI
CII=WII*CPII
C=W3*CP
CMINI=DMIN1(CGI,CI)
CMAXI=DMAX1(CGI,CI)
CMINII=DMIN1(CGII,CII)
CMAXII=DMAX1(CGII,CII)
CMIN=DMIN1(CA,C)
CMAX=DMAX1(CA,C)
AGI=DL(1)*DH(1)*DW(1)*DALG(1)
AGII=DL(2)*DH(2)*DW(2)*DALG(2)
AA=DL(3)*DH(3)*DW(3)*DALG(3)
TUNI=AGI*UI/CMINI
TUNII=AGII*UII/CMINII
TUN=AA*U/CMIN
TOWI=1.-DEXP(-TUNI*CMINI/(CMAXI*DNP(1)))
TOWII=1.-DEXP(-TUNII*CMINII/(CMAXII*DNP(2)))
TOW=1.-DEXP(-TUN*CMIN/(CMAX*DNP(3)))
ESSI=1.-DEXP(-TOWI*CMAXI/CMINI)
ESSII=1.-DEXP(-TOWII*CMAXII/CMINII)
ESS=1.-DEXP(-TOW*CMAX/CMIN)
IF (CMINI/CMAXI .GT. .9999) GO TO 31
EPSI=((1.-ESSI*CMINI/CMAXI)/(1.-ESSI))*NP(1)
EPSI=(EPSI-1.)/(EPSI-CMINI/CMAXI)
GO TO 32
31 EPSI=DNP(1)*ESSI/(1.+ESSI*(DNP(1)-1.))
32 IF (CMINII/CMAXII .GT. .9999) GO TO 33
EPSII=((1.-ESSII*CMINII/CMAXII)/(1.-ESSII))*NP(2)
EPSII=(EPSII-1.)/(EPSII-CMINII/CMAXII)
GO TO 34
33 EPSII=DNP(2)*ESSII/(1.+ESSII*(DNP(2)-1.))
34 IF (CMIN/CMAX .GT. .9999) GO TO 35

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EPSA=((1.-ESS*CMIN/CMAX)/(1.-ESS))*NP(3)
EPSA=(EPSA-1.)/(EPSA-CMIN/CMAX)
GO TO 36
35 EPSA=DNP(3)*ESS/(1.+ESS*(DNP(3)-1.))
36 CONTINUE
T03=FM1*FM1
P01G=PIG*(1.+T03*(GAMIG-1.)/2.)*(GAMIG/(GAMIG-1.))
GO TO (30, 40, 50), NDSGN
C CAVITY OPTION 1 CONST. MACH NUMBER
30 FM2=FM1
A(2)=A(1)*(T02G/T01G)**((1.+GAMIG*T03)/2.)
GO TO 60
C CAVITY OPTION 2 CONST. AREA
40 A(2)=A(1)
Z1=T01G*(1.+GAMIG*T03)**2/(2.*(GAMIG+1.)*T03*
1 (1.+T03*(GAMIG-1.)/2.))
Z1=T02G/Z1
IF (Z1 .GT. 1.) GO TO 10000
I=0
12000 I=I+1
CALL GASP(T2G , FN, GAM2G, CP2G, T03, T03, GMU)
Z2 = 2.*GAM2G*Z1-2.*GAM2G-2.
Z3=GAM2G*GAM2G*(Z1-1.)+1.
IF (Z3 .NE. 0.) GO TO 41
FM2=DSQRT(-Z1/Z2)
GO TO 60
41 Z4=(-Z2+DSQRT(Z2*Z2-4.*Z1*Z3))/(2.*Z3)
Z5=(-Z2-DSQRT(Z2*Z2-4.*Z1*Z3))/(2.*Z3)
Z6=DMIN1(Z4, Z5)
IF (Z6 .LT. 0.) Z6=DMAX1(Z4, Z5)
WRITE(6,174)T02G,T03,PR
174 FORMAT(1H0,3X,'T02G=',E15.7,5X,'T03=',E15.7,5X,'PR=',E15.7)
WRITE(6,173)Z1,Z2,Z3,Z4,Z5,Z6
173 FORMAT(1H0,3X,'Z1=',E15.7,5X,'Z2=',E15.7,5X,'Z3=',E15.7,5X,
1/,4X,'Z4=',E15.7,5X,'Z5=',E15.7,5X,'Z6=',E15.7)
FM2=DSQRT(Z6)
GO TO 60
C CAVITY OPTION 3 GENERAL SHAPE
50 Z5=(GAMIG+GAM2G)/2.
Z6=FM1*FM1
N=NCS-1
DO 51 J=1,N
Z1=-2.*(1.+Z6*(Z5-1.)/2.)/(1.-Z6)
Z2=(1.+Z5*Z6)*(-.5*Z1)
Z3=(ACN(J+1)-ACN(J))/(2.*(ACN(J+1)+ACN(J)))
Z4=(T02G-T01G)/((NCS-1.)*T01G-(J-.5)*(T02G-T01G))
Z6=Z6*(1.+Z3*Z1+Z2*Z4)
IF (Z6 .LE. 1.) GO TO 51
10000 WRITE(K0,105)
105 FORMAT(41H**** CHOKED CAVITY - READ NEW DATA *****)
GO TO 2
51 CONTINUE
FM2=DSQRT(Z6)
A(2)=ACN(NCS)
60 T2GOLD=T2G
T2G=T02G/(1.+FM2*FM2*(GAM2G-1.)/2.)
T2GDIFF=T2GOLD-T2G

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IF(DABS(T2GDIF).LE..5D0) GO TO 11000
IF(I.LE.NLIM) GO TO 12000
PRINT 13000,I,T2GDIF
13000 FORMAT(58H****FAILURE TO CONVERGE IN STATIC TEMP. LOOP 1 - CYCLES
' = ,I3,' - ERROR=' ,E12.5)
GO TO 2
11000 P2G=WG*DSQRT(T2G/(GAM2G*GMU))/(20.7774*A(2)*FM2)
P02G=P2G*(1.+FM2*FM2*(GAM2G-1.)/2.)*(GAM2G/(GAM2G-1.))
C FIRST DIFFUSER
P03G=P02G-CF23*(P02G-P2G)
FM3=FM2*A(2)/A(3)
GAM3G=GAM2G
CALL MACH(DELM, NLIM, P03G, GAM3G, FM3, T02G, WG, GMU,
1 A(3), P3G, T3G, FN, CP3G)
C SECOND DIFFUSER
P04G=P03G-CF34*(P03G-P3G)
FM4=FM3*A(3)/A(4)
GAM4G=GAM3G
CALL MACH(DELM, NLIM, P04G, GAM4G, FM4, T02G, WG, GMU,
1 A(4), P4G, T4G, FN, CP4G)
C THIRD DIFFUSER
P05G=P04G-CF45*(P04G-P4G)
FM5=FM4*A(4)/A(5)
GAM5G=GAM4G
CALL MACH(DELM, NLIM, P05G, GAM5G, FM5, T02G, WG, GMU,
1 A(5), P5G, T5G, FN, CP5G)
R05=.093178*P5G*GMU/T5G
R06=R05
FM6=WG*DSQRT(T06G/GAM5G/GMU)/(20.7774*P05G*A(6))
I=0
70 Z1=R06
P06G=P05G-GGI*GGI*((1.+DSIG(1)*DSIG(1))*(R05/R06-1.)+
1 GFI*DALG(1)*DW(1)*R05/(.5*DSIG(1)*(R06+R05)))/
2 (9266.11*R05)
GAM6G=GAM5G
CALL MACH(DELM, NLIM, P06G, GAM6G, FM6, T06G, WG, GMU, A(6), P6G, T6G, FN,
* CP6G)
R06=.093178*P6G*GMU/T6G
I=I+1
Z3=R06-Z1
IF (DABS(Z3) .LE. ROLIM) GO TO 71
IF (I .LT. NLIM) GO TO 70
WRITE(KO,101) Z3
101 FORMAT(53H**** FAILURE TO CONVERGE IN DENSITY LOOP 1 - ERROR = ,
1 E12.5,6H*****)
71 CALL GASP(T07G, FN, GAM7G, CP7G, T03, T03, GMU)
WRITE(KO,150) I, Z3
150 FORMAT(10X,'DENSITY LOOP 1 - CYCLES =' ,I3,' - ERROR =' ,E12.5)
P07G=P06G*BPR
J=0
80 FM7=WG*DSQRT(T07G/(GAM7G*GMU))/(20.7774*P07G*A(7))
CALL MACH(DELM, NLIM, P07G, GAM7G, FM7, T07G, WG, GMU,
1 A(7), P7G, T7G, FN, CP7G)
FM8=FM7*A(7)/A(8)
P08G=P07G-CF78*(P07G-P7G)
GAM8G=GAM7G
CALL MACH(DELM, NLIM, P08G, GAM8G, FM8, T07G, WG, GMU,

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1  A(8), P8G, T8G, FN, CP8G)
  P09G=P08G-CF89*(P08G-P8G)
  FM9=FM8*A(8)/A(9)
  GAM9G=GAM8G
  CALL MACH(DELM, NLIM, P09G, GAM9G, FM9, T07G, WG, GMU,
1  A(9), P9G, T9G, FN, CP9G)
  P010G=P09G-CF910*(P09G-P9G)
  FM10=FM9*A(9)/A(10)
  GAM10G=GAM9G
  CALL MACH(DELM, NLIM, P010G, GAM10G, FM10, T07G, WG, GMU,
1  A(10), P10G, T10G, FN, CP10G)
  R010=.093178*P10G*GMU/T10G
  R011=R010
  FM11=WG*DSQRT(T011G/GAM10G/GMU)/(20.7774*P010G*A(10))
  I=0
75 Z1=R011
  P011G=P010G-GGII*GGII*((1.+DSIG(2)*DSIG(2))*(R010/R011-1.))+
1  GFII*DALG(2)*DW(2)*R010/(.5*DSIG(2)*(R010+R011)))/
2  (9266.11*R010)
  GAM11G=GAM10G
  WRITE(6,183)P011G,GAM11G,FM11,T01G,WG
183 FORMAT(1H0,3X,'P011G=',E15.7,5X,'GAM11G=',E15.7,5X,'FM11=',
1  E15.7-5X,'T01G=',E15.7,5X,'WG=',E15.7)
  CALL MACH(DELM, NLIM, P011G, GAM11G, FM11, T01G, WG, GMU, A(10), P11G,
* T11G, FN, CP11G)
  R011=.093178*P11G*GMU/T11G
  I=I+1
  Z3=R011-Z1
  IF (DABS(Z3) .LE. ROLIM) GO TO 76
  IF (I .LT. NLIM) GO TO 75
  WRITE(K0,120) Z3
120 FORMAT(53H**** FAILURE TO CONVERGE IN DENSITY LOOP 2 - ERROR = ,
1  E12.5,6H*****)
76 FM11=WG*DSQRT(T01G/(GAMIG*GMU))/(20.7774*P011G*A(11))
  WRITE(K0,151) I, Z3
151 FORMAT(10X,'DENSITY LOOP 2 - CYCLES =',I3,' - ERROR =',E12.5)
  CALL MACH(DELM, NLIM, P011G, GAM11G, FM11, T01G, WG, GMU,
1  A(11), P11G, T11G, FN, CP11G)
  IF (JCPR0 .GE. 0)
1  Z1=R01*TIG/(.093178*GMU)*(1.+(GAMIG-1.)*FM1*FM1/2.)
2  *(GAMIG/(GAMIG-1.))
  Z1=P011G-CF111*(P011G-P11G)-Z1
  IF (JCPR0 .LT. 0)
1  Z1=P011G-CF111*(P011G-P11G)-P01G
  P011G=P011G-Z1
  P010G=P010G-Z1
  P09G=P09G-Z1
  P08G=P08G-Z1
  P07G=P07G-Z1
  CALL GASP(T6G, FN, GAM6G, CP6G, Z2, Z2, GMU)
  BPR=P07G/P06G
  Q6G=60.*A(6)*FM6*DSQRT(GAM6G*T6G*32.174*1545.43/GMU)
  ATAB=.730-7.09843*(DABS(Q6G/BRPM/NBS-.5355))*2.08014
  ATAB=0.6
  WRITE(6,186)Z1,P07G,P06G,Q6G
186 FORMAT(1H0,3X,'Z1=',E15.7,5X,'P07G=',E15.7,5X,'P06G=',E15.7,5X,
1  'Q6G=',E15.7)

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WRITE(6,187) T06G,BPR,GAM6G,ATAB
187 FORMAT(1H0,3X,'T06G=',E15.7,5X,'BPR=',E15.7,5X,'GAM6G=',E15.7,5X,
1 'ATAB=',E15.7)
T07G=T06G*(BPR**((GAM6G-1.)/(ATAB*GAM6G)))
WRITE(6,180) T06G,BPR,GAM6G,ATAB,T07G
180 FORMAT(1H0,3X,'T06G=',E15.7,5X,'BPR=',E15.7,5X,'GAM6G=',E15.7,5X,
1 'ATAB=',E15.7,5X,'T07G=',E15.7)
J=J+1
IF (DABS(Z1) .LT. PLIM) GO TO 85
IF (J .LT. NLIM) GO TO 80
WRITE(KO,103) Z1
103 FORMAT(52H**** FAILURE TO CONVERGE IN PRESSURE LOOP - ERROR = ,
1 E12.5,6H*****)
85 CALL AIRP(TA1, PAT, TA1, RH, Z2, Z2, CPA1, Z2, AML)
WRITE(KO,152) J, Z1
152 FORMAT(10X,'TOTAL PASSES THROUGH PRESSURE LOOP =',I3,
1 ' - ERROR =',E12.5)
CALL AIRP(TA1, PAT, TA2, RH, Z1,Z1, CPA2, GAMZA, AML)
CALL LIQP(T1, FG, Z1, Z1, CP1)
CALL LIQP(T2, FG, Z1, Z1, CP2)
CALL LIQP(T3, FG, Z1, Z1, CP3)
CALL LIQP(T4, FG, Z1, Z1, CP4)
CALL LIQP(T6, FG, Z1, Z1, CP6)
CALL LIQP(T8, FG, Z1, Z1, CP8)
CALL LIQP(T10, FG,Z1, Z1, CP10)
CALL LIQP(T14, FG,Z1, Z1, CP14)
CALL LIQP(T16, FG,Z1, Z1, CP16)
CALL LIQP(T18, FG,Z1, Z1, CP18)
CALL LIQP(T20, FG,Z1, Z1, CP20)
AMT( 1, 1)=WG*(CPIG+CP2G)/2.
AMT( 1, 2)=-AMT(1,1)
BMT( 1)=QS-.948*PLKW*(1./EFFL-1.)
AMT(2,2)=CGI
AMT(2,3)=-AMT(2,2)
AMT(2,6)=WI*.5*(CP2+CP4)
AMT(2,8)=-AMT(2,6)
AMT(3,2)=EPSI*CMINI-CGI
AMT(3,6)=-EPSI*CMINI
AMT(3,3)= CGI
AMT(4,4)=1.
AMT(4,3)=- (P07G/P06G)**((GAM6G-1.)/(ATAB*GAM6G))
AMT(5,4)=CGII
AMT(5,1)=-AMT(5,4)
AMT(5,6)=WII*.5*(CP2+CP6)
AMT(5,9)=-AMT(5,6)
AMT(6,4)=EPSII*CMINII-CGII
AMT( 6, 6)=-EPSII*CMINII
AMT(6,1)=CGII
AMT(7,7)=W3*.5*(CP1+CP3)
AMT(7,5)=-AMT(7,7)
AMT(7,16)=-CA
BMT(7)=AMT(7,16)*TA1
AMT( 8, 7)=EPSA*CMIN
AMT(8,16)=-CA
BMT(8)=(EPSA*CMIN-CA)*TA1
AMT(9,5)=W3*.5*(CP1+CP2)
AMT(9,6)=-AMT(9,5)

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BMT(9)=-QP
AMT(10,8)=-WI*.5*(CP4+CP3)
AMT(10,9)=-WII*.5*(CP6+CP3)
AMT(10,13)=-WM*.5*(CP16+CP3)
AMT(10,6)=-WB*.5*(CP2+CP3)
AMT(10,10)=-WV1*.5*(CP8+CP3)
AMT(10,11)=-WV2*.5*(CP10+CP3)
AMT(10,14)=-WE*.5*(CP18+CP3)
AMT(10,15)=-WS*.5*(CP20+CP3)
AMT(10,7)=-AMT(10,8)-AMT(10,9)-AMT(10,13)-AMT(10,6)-AMT(10,10)-
* AMT(10,11)-AMT(10,14)-AMT(10,15)
AMT(11,6)=WM*.5*(CP2+CP14)
AMT(11,12)=-AMT(11,6)
BMT(11)=-QCM
AMT(12,12)=WM*.5*(CP14+CP16)
AMT(12,13)=-AMT(12,12)
BMT(12)=-QM
AMT(13,6)=WV1*.5*(CP2+CP8)
AMT(13,10)=-AMT(13,6)
BMT(13)=-QV1
AMT(14,6)=WV2*.5*(CP2+CP10)
AMT(14,11)=-AMT(14,6)
BMT(14)=-QV2
AMT(15,6)=WE*.5*(CP2+CP18)
AMT(15,14)=-AMT(15,6)
BMT(15)=-QE
AMT(16,6)=WS*.5*(CP2+CP20)
AMT(16,15)=-AMT(16,6)
BMT(16)=-QS
CALL SIMQ(AMT, PMT, 16, KS)
WRITE(6,122) T02G
JJ=0
6 Z2=FM1
TIG=BMT(1)/(1.+(GAMIG-1.)*FM1*FM1/2.)
CALL GASP(TIG, FN, GAMIG, CPIG, Z1, Z1, GMU)
IF (JCPRO .GE. 0)
1 PIG=R01*TIG/(.093178*GMU)
IF (JCPRO .LT. 0)
1 R01=.093178*PIG*GMU/TIG
WG=R01*VI*A(1)
WRITE(6,160)TIG,GAMIG,GMU,WG
160 FORMAT(1H0,3X,'TIG=',E14.6,5X,'GAMIG=',E14.6,5X,'GMU=',E14.6,5X,
1 'WG=',E14.6)
WRITE(6,162)
162 FORMAT(1H0,8X,'SVR',16X,'BMT')
WRITE(6,161)(SVR(MP),BMT(MP),MP=1,16)
161 FORMAT(3X,E14.6,5X,E14.6)
FM1=WG*DSQRT(TIG/(GAMIG*GMU))/(20.7774*PIG*A(1))
JJ=JJ+1
Z3=Z2-FM1
IF (DABS(Z3) .LT. DELM) GO TO 7
IF (JJ .LT. NLIM) GO TO 6
WRITE(K0,400) Z3
400 FORMAT(54H**** FAILURE TO CONVERGE IN FINAL MACH LOOP - EPROR = ,
1 E12.5,6H*****)
7 WRITE(K0,301) JJ, Z3
301 FORMAT(10X,'TOTAL PASSES IN FINAL MACH LOOP =',I3,' - ERROR =',

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1  E12.5)
  II=II+1
  IF (KS .EQ. 1) GO TO 91
  DO 93 KS=1,16
  NN(KS)=-1
  TDIF(KS)=SVR(KS)-BMT(KS)
  IF (DABS(TDIF(KS)) .GT. CONV(KS)) NN(KS)=1
93 CONTINUE
  WRITE(KO,201)
201 FORMAT(10X,'STATE VARIABLE ERRORS')
  WRITE(KO,300) TDIF
300 FORMAT(10X,10E12.4)
  WRITE(KO,153) II
153 FORMAT(10X,'END OF SIMQ PASS NO.',I3/)
  IF (II .GT. NLIM) GO TO 92
  DO 94 KS=1,16
  IF (NN(KS) .GE. 0) GO TO 95
94 CONTINUE
  GO TO 90
92 WRITE(KO,104)
104 FORMAT(48H**** FAILURE TO CONVERGE IN STATE VARIABLE LOOP*,
1 6H*****)
90 FM6=WG*DSQRT(T06G/(GAM6G*GMU))/(20.7774*P06G*A(6))
  CALL MACH(DELM, NLIM, P06G, GAM6G, FM6, T06G, WG, GMU,
1  A(6), P6G, T6G, FN, CP6G)
  FNBPS=DFLOAT(NBPS)
  FNBS=DFLOAT(NBS)
  DPSS=((P07G-P06G)*T06G*28.966)/(P06G*BRPM*BRPM*518.7*GMU*FNBPS)
  DPSB=.8396-3.2323*(DABS(Q6G/(BRPM*FNBS))-0.46875)**1.42327
  DPSB=DPSB*1.E-9
  ERR=DPSB-DPSS
  GC=11.661E-7/(BRPM*FNBS)+11.589E-5*VIM**0.667/(BRPM*BRPM*FNBPS)
  GC=ERR/GC
  JV=JV+1
  WRITE(KO,204) JV, GC
204 FORMAT(5X,'PASS NO.',I3,' THROUGH VELOCITY LOOP, CORRECTION =',
1  E12.5)
  WRITE(6,175)Q6G,BRPM, FNBS
175 FORMAT(1H0,3X,'Q6G=',E15.7,5X,'BRPM=',E15.7,5X,'FNBS=',E15.7)
  GC=0.0
  IF (DABS(GC) .LE. VLIM) GO TO 502
  IF (JV .GE. NLIM) GO TO 503
  GO TO 506
  IF (GC .LT. 0. .AND. Q6G/(BRPM*FNBS) .LT. 0.46875) GO TO 504
506 CONTINUE
  VIM=VIM+GC
  VI=VIM*3.281
  GO TO 501
504 WRITE(KO,205)
205 FORMAT(50H**** FLOWERS ARE CHOKED - PROCESS NEXT CASE *****)
  GO TO 2
503 WRITE(KO,203) GC
203 FORMAT(52H**** FAILURE TO CONVERGE IN VELOCITY LOOP - ERROR = ,
1  E12.5,6H*****)
502 CONTINUE
  T03G=T02G
  T04G=T02G

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T05G=T02G
T08G=T07G
T09G=T07G
T010G=T07G
T011G=T01G
BLPR=WG*.5*(CP6G+CP7G)*T06G*(RPP**((1.-2./(GAM6G+GAM7G))
1 /ATAB)-1.)*778./550.
BLPRM=BLPR*.7457
DPI=4.317E-4*GI*GI*FI*DL(1)*DNP(1)/(ROLI*DDH(1))
DPII=4.317E-4*GII*GII*FII*DL(2)*DNP(2)/(ROLII*DDH(2))
DP=4.317E-4*G*G*F*DL(3)*DNP(3)/(ROL*DDH(3))
ROA1=144.*PAT*AML/(1545.32*TA1)
ROA2=ROA1
LL=0
37 Z1=ROA2
PA2=PAT-GA*GA*((1.+DSIG(3)**2)*(ROA1/ROA2-1.)+
1 AF*DALG(3)*DW(3)*ROA1/(.5*DSIG(3)*(ROA1+ROA2)))/
2 (ROA1*2.*32.174*144.)
ROA2=144.*PA2*AML/(1545.32*TA2)
LL=LL+1
Z3=ROA2-Z1
IF (DABS(Z3) .LT. ROLIM) GO TO 38
IF (LL .LE. NLIM) GO TO 37
WRITE(KO,401) Z3
401 FORMAT(49H**** FAILURE TO CONVERGE IN AUX. DENSITY LOOP - *,
1 "ERROR =",E12.5,6H*****))
GO TO 39
38 WRITE(KO,202) LL, Z3
202 FORMAT(10X,"TOTAL PASSES THROUGH AUX. DENSITY LOOP =",I3,
1 " - ERROR =",E12.5)
39 PF=WA*CPA2*TA2*((PAT/PA2)**((1.-1./GAM2A)/ATAP)-1.)*778./550.
PFM=.7457*PF
R06G=.093178*P6G*GMU/T6G
QCORR=60.*WG*DSQRT(1.4*GMU*518.7/(GAM6G*28.97*T06G))/R06G
DO 99 KS=1,16
99 SVR(KS)=BMT(KS)
QDI=WI*1800.*(CP2+CP4)*(T4-T2)
QDII=WII*1800.*(CP2+CP6)*(T6-T2)
QDA=W3*1800.*(CP3+CP1)*(T3-T1)
CALL OUTPUT
GO TO 2
95 DO 96 KS=1,16
96 SVR(KS)=BMT(KS)
GO TO 10
91 WRITE(KO,102)
102 FORMAT(" SINGULAR MATRIX")
GO TO 2
END

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ENPUT

) .ENPUT

```
SUBROUTINE ENPUT
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION SVR(19)
DIMENSION ESVR(16)
COMMON /VAR/ T01G, T02G, T06G, T07G, T1, T2, T3, T4, T6, T8,
A T10, T14, T16, T18, T20, TA2,
P T03G, T04G, T05G, T08G, T09G, T010G, T011G, T5, T7, T9, T11,
C T12, T13, T15, T17, T19, TIG, T2G, T3G, T4G, T5G, T6G, T7G,
D T8G, T9G, T10G, T11G, TA1, EFFL, P01G, P02G, P03G, P04G, P05G,
E P06G, P07G, P08G, P09G, P010G, P011G, PIG, P2G, P3G, P4G, P5G,
F P6G, P7G, P8G, P9G, P10G, P11G, P(20), AC(20), VC(20), FM1,
G FM2, FM3, FM4, FM5, FM6, FM7, FM8, FM9, FM10, FM11, A(11),
H GAM1G, GAM2G, GAM3G, GAM4G, GAM5G, GAM6G, GAM7G, GAM8G, GAM9G,
I GAM10G, GAM11G, TGMI, TGMII, TMA, GIMU, GIIMU, AMU, PRGI,
J PRGII, PRA, CPGI, CPGII, CPA, TMI, TMII, TM, ZIMU, ZIIMU, ZMU,
K PRI, PRII, PR, CPI, CPII, CP, GGI, GGII, GA, GI, GII, G, REGI,
L REGII, REA, REI, REII, RE, GFI, GFII, AF, FI, FII, F, GJI,
M GJII, AJ, ZJI, ZJII, ZJ, HGI, HGII, HA, HI, HII, H, CGI, CGII,
N CA, CI, CII, C, UI, UII, U, AGI, AGII, AA, TUNI, TUNII, TUN,
O TOWI, TOWII, TOW, EPSI, EPSII, EPSA, ESSI, ESSII, ESS, WG,
P Q6G, QCORR, EPR, ALT, PAT, PA2, RH, FN(4), EFFLP, VI, VIM,
Q PIGA, H1M, CL1M, WT1M, DCM, BLPR, BLPRM, CPP, CPPM, PF, PFM,
R RO1, PLKW, WI, WII, WB, WM, WV1, WV2, WE, WS, WA, QP, QCM,
S QM, QV1, QV2, QE, QS, CF23, CF34, CF45, CF78, CF89, CF910,
COMMON /VAR/ CF111, ATAP, H1, CL1, WT1, ACN(20), DC, DL(3),
A DH(3), DW(3), DDHG(3), DALG(3), DAFOA(3), DSIG(3), DDEL(3),
R DA(3), DK(3), DSL(3), DSI(3), DALF(3), DDH(3), CONV(16), DELM,
C ROLIM, PLIM, FG, TITLE(28), DP, DPI, DPII, PPR, PPRM,
D TA1F, RHP, TIGM, DKH(3), ETIG, ET02G, ET06G, ET07G, ET1,
E ET2, ET3, ET4, ET6, ET8, ET10, ET14, ET16, ET18, ET20, ETA2,
F EBPR, CWA, DNP(3), QDI, QDII, QDA, EVIM, BRPM, VLIM, ROA1,
G ROA2, DAFAL(3), DSLL(3), AR(3)
COMMON /IVAR/ NTAM, NDSGN, NCS, KI, KO, NLIM, NP(3), NFULL,
1 NBS, NBPS, JCPRO
```

```
EQUIVALENCE (ESVR(1), ETIG)
EQUIVALENCE (SVR(1), T01G)
NAMELIST /FPT/ NTAM, TA1F, PLKW, ETIG, ET02G, ET06G, ET07G, ET1,
A ET2, ET3, ET4, ET6, ETA2, ET14, ET16, ET8, ET10, ET18, ET20,
P EFFLP, WI, WII, WB, WM, WV1, WV2, WE, WS, CWA,
C GP, QCM, QM, QV1, QV2, QE, QS, CF23, CF34,
D CF45, CF78, CF89, CF910, CF111,
E EVIM, ATAP, PIGA, H1M, CL1M, WT1M, FN, ACN, DCM,
F DL, DH, DW, DDHG, DALG, DAFOA, DSIG, DDEL,
G DA, DKH, DSL, DSI, DALF, DDH, NP,
H PAT, RHP, EBPR, A, CONV, DELM, NDSGN, NCS,
I NLIM, ROLIM, PLIM, FG, BRPM, VLIM, NBS, NBPS, JCPRO, RO1,
J DAFAL, DSLL, AR
```

```
KI=5
KC=6
READ(KI,200) (TITLE(J),J=1,14)
READ(KI,200) (TITLE(J),J=15,28)
200 FORMAT(13A6,A2)
READ(KI,FPT)
TA1=TA1F+459.69
```

```

TIG=TA1+20.
T02G=TA1+210.
T06G=TA1+30.
T07G=TA1+70.
T1=TA1+20.
T2=TA1+20.
T3=TA1+40.
T4=TA1+55.
T6=TA1+30.
T8=TA1+65.
T10=TA1+65.
T14=TA1+30.
T16=TA1+75.
T18=TA1+65.
T20=TA1+65.
TA2=TA1+30.
BPR=1.17
VIM=120.
DO 30 K=1,16
30 IF (ESVR(K) .GT. 0.) SVR(K)=ESVR(K)
   IF (EBPR .GT. 0.) BPR=EBPR
   IF (EVIM .GT. 0.) VIM=EVIM
   IF (NTAM .LT. 0) CALL EXIT
   IF (NTAM .LE. 0) GO TO 10
   DO 20 J=1,19
20 SVR(J)=TA1
10 CONTINUE
   PIG=PIGA*14.7
   RH=RHP*.01
   EFFL=EFFLP*.01
   VI=VIM*3.281
   DC=DCM*.03281
   H1=H1M*.03281
   WT1=WT1M*.03281
   CL1=CL1M*.03281
   CALL AIRP(TA1, PAT, TA1, RH, X, X, X, X, AML)
   ROA1=PAT*AML*.09317/TA1
   WA=ROA1*CWA*DSQRT(TA1/518.7)/60.
   DK(1) = DKH(1)/3600.
   DK(2) = DKH(2)/3600.
   DK(3) = DKH(3)/3600.
   DNP(1)=NP(1)
   DNP(2)=NP(2)
   DNP(3)=NP(3)
   A(1)=H1*CL1
   Q6G=VI*A(1)*60.
   WRITE(KO,102)
102 FORMAT('1')
   WRITE(KO,FPT)
101 FORMAT(21X,14A6)
   WRITE(KO,101) TITLE
   RETURN
   END

```

.GASP

```
SUBROUTINE GASP(T, FN, GAM, CP, PR, UM, GMU )
  IMPLICIT REAL*8 (A-H,O-Z)
  DIMENSION FN(4), WM(4), TB(4), C(4), U(4), FK(4),
1  G(4), X(4), CN(4), S(4)
  1 = HE
  2 = N2
  3 = CO2
  4 = CO
  DATA TB /4.21500,77.400,194.6600,81.500/
  DATA WM /4.0000,28.01600, 44.01000, 28.01000/ , R /1.9864600/

  C(1) = 1.2406

  IF (T .LE. 650.)
1  FK(1)=(.8+(T-475.)*( .97-.8)/175.)*.1
  IF (T .GT. 650.)
1  FK(1)=(.97+(T-650.)*(1.13-.97)/200.)*.1
  FK(1)=FK(1)/3600.

  G(1)=1.6667

  U(1)=1.12+(T-400.)*(1.955-1.12)/500.
  U(1)=U(1)*1.E-5

  IF (T .LE. 600)
1  C(2)=3.502+(T-400.)*(3.5065-3.502)/200.
  IF (T .GT. 600. .AND. T .LE. 800.)
1  C(2)=3.5065+(T-600.)*(3.5315-3.5065)/200.
  IF (T .GT. 800.)
1  C(2)=3.5315+(T-800.)*(3.559-3.5315)/100.
  C(2)=C(2)*R/WM(2)

  IF (T .LE. 650.)
1  FK(2)=.925+(T-450.)*(1.265-.925)/200.
  IF (T .GT. 650.)
1  FK(2)=1.265+(T-650.)*(1.573-1.265)/200.
  FK(2)=FK(2)*1.4E-2/3600.

  G(2)=1.4
  IF (T .GT. 600.)
1  G(2)=1.4+(T-600.)*(1.391-1.4)/300.

  IF (T .LE. 550.)
1  U(2)=.933+(T-450.)*(1.087-.933)/100.
  IF (T .GT. 550. .AND. T .LE. 725.)
1  U(2)=1.087+(T-550.)*(1.33-1.087)/175.
  IF (T .GT. 725)
1  U(2)=1.33+(T-725.)*(1.545-1.33)/175.
  U(2)=U(2)*1.1172E-5

  IF (T .LE. 600.)
1  C(3)=4.195+(T-450.)*(4.653-4.195)/150.
  IF (T .GT. 600. .AND. T .LE. 750.)
1  C(3)=4.653+(T-600.)*(5.045-4.653)/150.
```

```
IF (T .GT. 750.)
1 C(3)=5.045+(T-750.)*(5.365-5.045)/150.
C(3)=C(3)*R/WM(3)
```

```
IF (T .LE. 600.)
1 FK(3)=.82+(T-425.)*(1.32-.82)/175.
IF(T.LE.140.)FK(3)=5.714E-3
IF (T .GT. 600.)
1 FK(3)=1.32+(T-600.)*(2.12-1.32)/250.
FK(3)=FK(3)*8.407E-3/3600.
```

```
IF (T .LE. 450.)
1 G(3)=1.334+(T-400.)*(1.315-1.334)/50.
IF (T .GT. 450. .AND. T .LE. 550.)
1 G(3)=1.315+(T-450.)*(1.286-1.315)/100.
IF (T .GT. 550. .AND. T .LE. 650.)
1 G(3)=1.286+(T-550.)*(1.2645-1.286)/100.
IF (T .GT. 650. .AND. T .LE. 750.)
1 G(3)=1.2645+(T-650.)*(1.248-1.2645)/100.
IF (T .GT. 750. .AND. T .LE. 850.)
1 G(3)=1.248+(T-750.)*(1.235-1.248)/100.
IF (T .GT. 850.)
1 G(3)=1.235+(T-850.)*(1.2295-1.235)/50.
```

```
IF (T .LE. 575.)
1 U(3)=.9175+(T-450.)*(1.152-.9175)/125.
IF (T .GT. 575. .AND. T .LE. 700.)
1 U(3)=1.152+(T-575.)*(1.375-1.152)/125.
IF (T .GT. 700.)
1 U(3)=1.375+(T-700.)*(1.541-1.375)/100.
U(3)=U(3)*9.2067E-6
```

```
FT=FN(1)+FN(2)+FN(3)
NGAS=3
IF (FN(4) .LE. 0.) GO TO 10
FT=FT+FN(4)
NGAS=4
```

```
IF (T .LE. 540.)
1 C(4)=3.503+(T-400.)*(3.506-3.503)/140.
IF (T .GT. 540. .AND. T .LE. 630.)
1 C(4)=3.506+(T-540.)*(3.513-3.506)/90.
IF (T .GT. 630. .AND. T .LE. 720.)
1 C(4)=3.513+(T-630.)*(3.529-3.513)/90.
IF (T .GT. 720. .AND. T .LE. 810.)
1 C(4)=3.529+(T-720.)*(3.552-3.529)/90.
IF (T .GT. 810.)
1 C(4)=3.552+(T-810.)*(3.583-3.552)/90.
C(4)=C(4)*.0708989
```

```
IF (T .LE. 540.)
1 U(4)=.84+(T-400.)*(1.075-.84)/140.
IF (T .GT. 540. .AND. T .LE. 720.)
1 U(4)=1.075+(T-540.)*(1.34-1.075)/180.
IF (T .GT. 720.)
1 U(4)=1.34+(T-720.)*(1.575-1.34)/180.
U(4)=U(4)*1.1132E-5
```

```

      IF (T .LE. 530.)
1     G(4)=1.4
      IF (T .GT. 530.)
1     G(4)=1.4+(T-530.)*(1.3885-1.4)/370.

      IF (T .LE. 540.)
1     FK(4)=.825+(T-400.)*(1.087-.825)/140.
      IF (T .GT. 540. .AND. T .LE. 720.)
1     FK(4)=1.087+(T-540.)*(1.385-1.087)/180.
      IF (T .GT. 720.)
1     FK(4)=1.385+(T-720.)*(1.665-1.385)/180.
      FK(4)=FK(4)*.01342/3600.

0    CP=0.
      DAM=0.
      GAM=0.
      UM=0.
      GMU=0.
      Z3=0.
      DO 11 I=1,NGAS
      S(I)=1.5*TB(I)*1.8
      X(I)=FN(I)/FT
1    GMU=GMU+X(I)*WM(I)
      DO 50 I=1,NGAS
      CN(I)=X(I)*WM(I)/GMU
      CP=CP+CN(I)*C(I)
      GAM=GAM+CN(I)*C(I)+GAM
      DAM=DAM+CN(I)*C(I)/G(I)+DAM
      Z1=0.
      Z2=0.
      DO 30 J=1,NGAS
      IF (J .NE. I) GO TO 12
      P=1.
      AM=1.
      GO TO 29
2    D=X(J)/X(I)
      E=DSQRT(S(I)*S(J))
      UR=U(I)/U(J)
      WR1=DSQRT(8.*(1.+WM(I)/WM(J)))
      WR=(WM(J)/WM(I))**.25
      P=D*(1.+DSQRT(UR)*WR)**2/WR1
      AM=.25*D*(1.+DSQRT(UR*WR**3*(T+S(I))/(T+S(J))))**2*(T+E)/(T+S
9    Z1=Z1+P
      Z2=Z2+AM
0    CONTINUE
      Z3=Z3+FK(I)/Z2
      UM=UM+U(I)/Z1
0    CONTINUE
      GAM=GAM/DAM
      PR=CP*UM/Z3
      RETURN
      END

```

RP

AIRP

```
SUBROUTINE AIRP(TAMB, PAMB, T, RH, P, AMU, CPA, GAM, AML)
IMPLICIT REAL*8 (A-H,O-Z)
T2=DEXP(-38.09873+.1057402*TAMB-.674864E-4*TAMB*TAMB)
WF=RH*18.016*T2/(28.966*(PAMB-T2))
T2=T*T
P=.5552+.134633E-2*T-.031E-4*T2+.20666E-8*T*T2
AMU=1.E-5+.175E-7*(T-400.)
CPA=.2421-.0015E-2*T+2.E-8*T2
GAMA=CPA/(CPA-.0685545)
CPW=.4509-.0054E-2*T+.0008E-4*T2
GAMW=CPW/(CPW-.11022)
A=WF*CPW
B=(1.-WF)*CPA
CPA=WF*CPW+(1.-WF)*CPA
GAM=(A+B)/(A/GAMW+B/GAMA)
AML=18.016*WF+28.966*(1.-WF)
RETURN
END
```

CH

```

MACH
  SUBROUTINE MACH(DELM, NLIM, POG, GAM, FM, TOG, WG, GMU, A, PG,
1  TG, FN, CP)
  IMPLICIT REAL*8 (A-H, O-Z)
  DIMENSION FN(4)
  DATA KO /6/
  I=0
10  FMG=FM
    TG=1.+FMG*FMG*(GAM-1.)/2.
    WRITE(6,11)POG, TG, GAM
11  FORMAT(1HD, 3X, 'POG=', E15.7, 5X, 'TG=', E15.7, 5X, 'GAM=', E15.7)
    PG=POG/TG**((GAM/(GAM-1.))
    TG=TOG/TG
    FM=WG*DSQRT(TG/(GAM*GMU))/(20.7774*PG*A)
    WRITE(6,12)PG, TG, FM
12  FORMAT(1HD, 3X, 'PG=', E15.7, 5X, 'TG=', E15.7, 5X, 'FM=', E15.7)
    CALL GASP(TG, FN, GAM, CP, DUM, DUM, GMU)
    I=I+1
    FMG1=FMG-FM
    IF (DABS(FMG1) .LT. DELM) RETURN
    IF (I .LT. NLIM) GO TO 10
    WRITE(KO,100) FMG1
00  FORMAT('          FAILURE TO CONVERGE IN MACH NO. SUBROUTINE',
1  ' - ERROR =', F12.5)
    RETURN
  END

```

QP

LIQP

```
SUBROUTINE LIQP(T, FG, UM, PR, CP)
IMPLICIT REAL*8 (A-H,O-Z)
C=T/1.8-273.
F=FG*FG
CP=1.-.465*FG+C*(.00115-.00105*(1.-FG)**3.0596)
SF=1301./(998.33+8.1855*(C-20.)+.00585*(C-20.)**2)
UM=DEXP(-3.01174+.49287*FG+(2.30854+1.18556*FG+.806*F)*SF)
FK=137.-82.91667*FG+17.91667*F
FK=1.*(FK+C*(166.-160.8833*FG+49.0833*F-FK)/100.)
UM=0.014881
PR = 1.0E3*UM*CP/FK
UM=UM*.000672
RETURN
END
```

MG

SIMG

SUBROUTINE SIMG(A, B, N, KS)
IMPLICIT REAL*8 (A-H,O-Z)

SIMG SOLVES A SYSTEM OF LINEAR EQUATIONS AX=B

INPUTS

A - MATRIX OF COEFFICIENTS STORED COLUMNWISE. DESTROYED IN
COMPUTATION

B - VECTOR OF ORIGINAL CONSTANTS. DESTROYED IN COMPUTATION
SOLUTION IS RETURNED IN B

N - NUMBER OF EQUATIONS AND VARIABLES

KS - OUTPUT FLAG 0=NORMAL 1=SINGULAR SET OF EQUATIONS

DIMENSION A(1), B(1)

FORWARD SOLUTION

TOL=0.0

KS=0

JJ=-N

DO 65 J=1,N

JY=J+1

JJ=JJ+N+1

BIGA=0.0

IT=JJ-J

DO 30 I=J,N

SEARCH FOR MAXIMUM COEFFICIENT IN COLUMN

IJ=IT+1

IF (DABS(BIGA)-DABS(A(IJ))) 20,30,30

20 BIGA=A(IJ)

IMAX=I

30 CONTINUE

TEST FOR PIVOT LESS THAN TOLERANCE (SINGULAR MATRIX)

IF (DABS(BIGA)-TOL) 35, 35, 40

35 KS=1

RETURN

INTERCHANGE ROWS IF NECESSARY

40 I1=J+N*(J-2)

IT=IMAX-J

DO 50 K=J,N

I1=I1+N

I2=I1+IT

SAVE=A(I1)

A(I1)=A(I2)

A(I2)=SAVE

DIVIDE EQUATION BY LEADING COEFFICIENT

50 A(I1)=A(I1)/BIGA

SAVE=P(IMAX)

```

B(IMAX)=B(J)
B(J)=SAVE/BIGA

ELIMINATE NEXT VARIABLE

IF (J-N) 55, 70, 55
55 IQS=N*(J-1)
DO 65 IX=JY,N
IXJ=IQS+IX
IT=J-IX
DO 60 JX=JY,N
IXJX=N*(JX-1)+IX
JJX=IXJX+IT
60 A(IXJX)=A(IXJX)-(A(IXJ)*A(JJX))
65 B(IX)=B(IX)-(B(J)*A(IXJ))

BACK SOLUTION

70 NY=N-1
IT=N*N
DO 80 J=1,NY
IA=IT-J
IB=N-J
IC=N
DO 80 K=1,J
B(IB)=B(IB)-A(IA)*B(IC)
IA=IA-N
80 IC=IC-1
RETURN
END

```

TPUT

.OUTPUT

```
SUBROUTINE OUTPUT
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION VG(11), QG(11), QC(20), QCG(20), DPC(20), DPCR(20)
DIMENSION PDG(11), PP(11), PC(20), PD(11), ROG(11)
COMMON /VAR/ T01G, T02G, T06G, T07G, T1, T2, T3, T4, T6, T8,
A T10, T14, T16, T18, T20, TA2,
B T03G, T04G, T05G, T08G, T09G, T010G, T011G, T5, T7, T9, T11,
C T12, T13, T15, T17, T19, TIG, T2G, T3G, T4G, T5G, T6G, T7G,
D T8G, T9G, T10G, T11G, TA1, EFFL, P01G, P02G, P03G, P04G, P05G,
E P06G, P07G, P08G, P09G, P010G, P011G, PIG, P2G, P3G, P4G, P5G,
F P6G, P7G, P8G, P9G, P10G, P11G, P(20), AC(20), VC(20), FM1,
G FM2, FM3, FM4, FM5, FM6, FM7, FM8, FM9, FM10, FM11, A(11),
H GAM1G, GAM2G, GAM3G, GAM4G, GAM5G, GAM6G, GAM7G, GAM8G, GAM9G,
I GAM10G, GAM11G, TGMI, TGMII, TMA, GIMU, GIIMU, AMU, PRGI,
J PRGII, PRA, CPGI, CPGII, CPA, TMI, TMII, TM, ZIMU, ZIIMU, ZMU,
K PRI, PRII, PR, CPI, CPII, CP, GGI, GGII, GA, GI, GII, G, REGI,
L REGII, REA, REI, REII, RE, GFI, GFII, AF, FI, FII, F, GJI,
M GJII, AJ, ZJI, ZJII, ZJ, HGI, HGII, HA, HI, HII, H, CGI, CGII,
N CA, CI, CII, C, UI, UII, U, AGI, AGII, AA, TUNI, TUNII, TUN,
O TOWI, TOWII, TOW, EPSI, EPSII, EPSA, ESSI, ESSII, ESS, WG,
P Q6G, QCORR, BPR, ALT, PAT, PA2, RH, FN(4), EFFLP, VI, VIM,
Q PIGA, H1M, CL1M, WT1M, DCM, BLPR, BLPRM, CPP, CPPM, PF, PFM,
R RO1, PLKW, WI, WII, WB, WM, WV1, WV2, WE, WS, WA, QP, QCM,
S QM, QV1, QV2, QE, QS, CF23, CF34, CF45, CF78, CF89, CF910,
COMMON /VAR/ CF11, ATAP, H1, CL1, WT1, ACN(20), DC, DL(3),
A DH(3), DW(3), DDHG(3), DALG(3), DAFOA(3), DSIG(3), DDEL(3),
B DA(3), DK(3), DSL(3), DSI(3), DALF(3), DDH(3), CONV(16), DELM,
C ROLIM, PLIM, FG, TITLE(28), DP, DPI, DPII, PPR, PPRM,
D TA1F, RHP, TIGM, DKH(3), ETIG, ET02G, ET06G, ET07G, ET1,
E ET2, ET3, ET4, ET6, ET8, ET10, ET14, ET16, ET18, ET20, ETA2,
F EBPR, CWA, DNP(3), QDI, QDII, QDA, EVIM, BRPM, VLIM, ROA1,
G ROA2, DAFAL(3), DSSL(3), AB(3)
COMMON /IVAR/ NTAM, NDSGN, NCS, KI, KO, NLIM, NP(3), NFULL,
1 NBS, NBPS, JCPRO
WRITE(KO,100)
WRITE(KO,101) TITLE
WRITE(KO,400)
400 FORMAT('D INPUT LIST'/' CAVITY * LASER SPECIFICATIONS'/'
1 ' DESCRIPTION',24X,' NAME VALUE UNITS')
WRITE(KO,403) PIGA
403 FORMAT(' INLET PRESSURE ',12(' '), 'PIGA ',G12.6,' ATM')
WRITE(KO,404) H1M
404 FORMAT(' INLET HEIGHT ',13(' '), 'H1M ',G12.6,' CM')
WRITE(KO,405) WT1M
405 FORMAT(' WIDTH IN FLOW DIRECTION ',8(' '), 'WT1M ',G12.6,
1 ' CM')
WRITE(KO,406) CL1M
406 FORMAT(' LENGTH ',16(' '), 'CL1M ',G12.6,' CM')
WRITE(KO,408) DCM
408 FORMAT(' INLET HYDRAULIC DIAMETER ',7(' '), 'DCM ',G12.6,
1 ' CM')
WRITE(KO,407) PLKW
407 FORMAT(' LASER OUTPUT POWER . . ',8(' '), 'PLKW ',G12.6,
1 ' Kw')
WRITE(KO,401) EFFLP
401 FORMAT(' LASER EFFICIENCY ',11(' '), 'EFFLP ',G12.6,
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1  ' PERCENT')
WRITE(KO,409) NDSGN
409 FORMAT(' DESIGN OPTION ',13(' '), 'NDSGN ',17,5X, ' -')
IF (NDSGN .NE. 3) GO TO 50
WRITE(KO,410) NCS
410 FORMAT(' NUMBER OF AREAS (NDSGN=3) ',7(' '), 'NCS ',
1 17,5X, ' -')
WRITE(KO,411) (ACN(K),K=1,NCS)
411 FORMAT(' AREAS ',17(' '), 'ACN ',6(G12.6,1X),
1 3(51X,6(G12.6,1X)))
WRITE(KO,412)
412 FORMAT(65X, 'FT**2')
50 WRITE(KO,413) FN
413 FORMAT(' GAS MIXTURE ',14(' '), 'FN ',4F6.2,
1 ' HE TO N2 TO CO2 TO CO')
WRITE(KO,414)
414 FORMAT(' INITIAL ESTIMATE OF STEADY STATE QUANTITIES',
1 36X, 'IF = 0.,USES')
WRITE(KO,415) ETIG
415 FORMAT(' GAS STATIC TEMPERATURE - STATION 1 ',3(' '), 'ETIG ',
1 G12.6, ' DEG R',10X, 'TA1 + 20.')
WRITE(KO,416) ET02G
416 FORMAT(' GAS TOTAL TEMPERATURE - STATION 2 ',3(' '), 'ET02G ',
1 G12.6, ' DEG R',10X, 'TA1 + 210.')
WRITE(KO,417) ET06G
417 FORMAT(' GAS TOTAL TEMPERATURE - STATION 6 ',3(' '), 'ET06G ',
1 G12.6, ' DEG R',10X, 'TA1 + 30.')
WRITE(KO,418) ET07G
418 FORMAT(' GAS TOTAL TEMPERATURE - STATION 7 ',3(' '), 'ET07G ',
1 G12.6, ' DEG R',10X, 'TA1 + 70.')
WRITE(KO,419) ET1
WRITE(KO,420) ET2
WRITE(KO,421) ET3
WRITE(KO,422) ET4
WRITE(KO,423) ET6
WRITE(KO,424) ET8
WRITE(KO,425) ET10
WRITE(KO,426) ET14
WRITE(KO,427) ET16
WRITE(KO,428) ET18
WRITE(KO,429) ET20
419 FORMAT(' COOLANT TEMPERATURE - STATION 1 ',3(' '), 'ET1 ',
1 G12.6, ' DEG R',10X, 'TA1 + 20.')
420 FORMAT(' COOLANT TEMPERATURE - STATION 2 ',3(' '), 'ET2 ',
1 G12.6, ' DEG R',10X, 'TA1 + 20.')
421 FORMAT(' COOLANT TEMPERATURE - STATION 3 ',3(' '), 'ET3 ',
1 G12.6, ' DEG R',10X, 'TA1 + 40.')
422 FORMAT(' COOLANT TEMPERATURE - STATION 4 ',3(' '), 'ET4 ',
1 G12.6, ' DEG R',10X, 'TA1 + 55.')
423 FORMAT(' COOLANT TEMPERATURE - STATION 6 ',3(' '), 'ET6 ',
1 G12.6, ' DEG R',10X, 'TA1 + 30.')
424 FORMAT(' COOLANT TEMPERATURE - STATION 8 ',3(' '), 'ET8 ',
1 G12.6, ' DEG R',10X, 'TA1 + 65.')
425 FORMAT(' COOLANT TEMPERATURE - STATION 10 ',3(' '), 'ET10 ',
1 G12.6, ' DEG R',10X, 'TA1 + 65.')
426 FORMAT(' COOLANT TEMPERATURE - STATION 14 ',3(' '), 'ET14 ',
1 G12.6, ' DEG R',10X, 'TA1 + 30.')

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427 FORMAT('      COOLANT TEMPERATURE - STATION 16 ',3(' '),ET16 ',
1 G12.6,' DEG R',10X,'TA1 + 75.')
428 FORMAT('      COOLANT TEMPERATURE - STATION 18 ',3(' '),ET18 ',
1 G12.6,' DEG R',10X,'TA1 + 65.')
429 FORMAT('      COOLANT TEMPERATURE - STATION 20 ',3(' '),ET20 ',
1 G12.6,' DEG R',10X,'TA1 + 65.')
WRITE(KO,430) ETA2
430 FORMAT('      AIP TEMPERATURE AFTER RADIATOR ',4(' '),ETA2 ',
1 G12.6,' DEG R',10X,'TA1 + 30.')
WRITE(KO,431) EBPR
431 FORMAT('      BLOWER PRESSURE RATIO ',9(' '),EBPR ',G12.6,
1 ',14X,'1.17')
WRITE(KO,402) EVIM
402 FORMAT('      INLET VELOCITY ',12(' '),EVIM ',G12.6,' M/SEC',
1 10X,'120.')
WRITE(KO,432)
432 FORMAT('COOLING SYSTEM FLOWS')
WRITE(KO,433) WI
433 FORMAT('      HEAT EXCHANGER 1 (LIQUID) ',7(' '),WI ',
1 G12.6,' LB/SEC')
WRITE(KO,434) WII
434 FORMAT('      HEAT EXCHANGER 2 (LIQUID) ',7(' '),WII ',
1 G12.6,' LB/SEC')
WRITE(KO,435) WP
435 FORMAT('      MIRROR BYPASS ',13(' '),WB ',
1 G12.6,' LB/SEC')
WRITE(KO,436) WM
436 FORMAT('      MIRROR ',16(' '),WM ',
1 G12.6,' LB/SEC')
WRITE(KO,437) WV1
437 FORMAT('      VACUUM PUMP 1 ',13(' '),WV1 ',
1 G12.6,' LB/SEC')
WRITE(KO,438) WV2
438 FORMAT('      VACUUM PUMP 2 ',13(' '),WV2 ',
1 G12.6,' LB/SEC')
WRITE(KO,439) WE
439 FORMAT('      E-BEAM ',16(' '),WE ',
1 G12.6,' LB/SEC')
WRITE(KO,440) WS
440 FORMAT('      SUSTAINER ',15(' '),WS ',
1 G12.6,' LB/SEC')
WRITE(KO,441) CWA
441 FORMAT('      CORRECTED FAN FLOW (AIR) ',7(' '),CWA ',
1 G12.6,' CFM')
WRITE(KO,445)
445 FORMAT('SPECIFICATIONS OF BLOWERS')
WRITE(KO,442) ATAP

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442 FORMAT('      BLOWER POLYTROPIC EFFICIENCY ',5(' '), 'ATAB ',  
1 612.6, ' -')  
    WRITE(KO,446) BRPM  
446 FORMAT('      BLOWER SPEED ',13(' '), 'RRPM ',612.6, ' RPM')  
    WRITE(KO,447) NPS  
447 FORMAT('      NUMBER OF BLOWER SETS ',9(' '), 'NBS ',I6,6X,  
1 ' -')  
    WRITE(KO,448) NBPS  
448 FORMAT('      NUMBER OF BLOWERS PER SET ',7(' '), 'NBPS ',  
1 I6,6X, ' -')
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WRITE(KO,543) VLIM
543 FORMAT('    INLET VELOCITY TOLERANCE ',7(' '), 'VLIM ',
1 612.6, ' M/SEC')
WRITE(KO,444)
444 FORMAT('TUNNEL AREAS')
WRITE(KO,443) A
443 FORMAT('    STATION 1 TO STATION 11 ',8(' '), 'A ',
1 6(1X,612.6 )/50X,5(1X,612.6 ), 'FT**2')
WRITE(KO,100)
WRITE(KO,101) TITLE
WRITE(KO,500)
500 FORMAT('O INPUT LIST (CONT.)')
WRITE(KO,501)
501 FORMAT('HEAT EXCHANGER SPECIFICATIONS',23X, 'EXCHANGER 1',5X,
1 'EXCHANGER 2',7X, 'RADIATOR',3X, 'UNITS')
WRITE(KO,502)
502 FORMAT(9X, 'DESCRIPTION',25X, 'NAME',8X, '(1)',13X, '(2)',14X, '(3)')
WRITE(KO,503) DL
503 FORMAT('    CORE LENGTH (GAS) ',11(' '), 'DL ',
1 3(2X,612.6,2X), 'FT')
WRITE(KO,504) DH
504 FORMAT('    CORE HEIGHT ',14(' '), 'DH ',
1 3(2X,612.6,2X), 'FT')
WRITE(KO,505) DW
505 FORMAT('    CORE WIDTH (LIQUID) ',10(' '), 'DW ',
1 3(2X,612.6,2X), 'FT')
WRITE(KO,506) DDHG
506 FORMAT('    HYDRAULIC DIAMETER (GAS) ',7(' '), 'DDHG ',
1 3(2X,612.6,2X), 'FT')
WRITE(KO,507) DALG
507 FORMAT('    SURFACE AREA / VOLUME (GAS) ',6(' '), 'DALG ',
1 3(2X,612.6,2X), '1/FT')
WRITE(KO,508) DAFOA
508 FORMAT('    FIN AREA / SURFACE AREA (GAS) ',5(' '), 'DAFOA',
1 3(2X,612.6,2X), '-')
WRITE(KO,509) DSIG
509 FORMAT('    FREE FLOW AREA / FACE AREA (GAS) ',3(' '), 'DSIG ',
1 3(2X,612.6,2X), '-')
WRITE(KO,510) DDEL
510 FORMAT('    FIN THICKNESS (GAS) ',10(' '), 'DDEL ',
1 3(2X,612.6,2X), 'FT')
WRITE(KO,511) DSL
511 FORMAT('    FIN LENGTH (GAS) ',11(' '), 'DSL ',
1 3(2X,612.6,2X), 'FT')
WRITE(KO,516) DDH
516 FORMAT('    HYDRAULIC DIAMETER (LIQUID) ',6(' '), 'DDH ',
1 3(2X,612.6,2X), 'FT')
WRITE(KO,514) DALF
514 FORMAT('    SURFACE AREA / VOLUME (LIQUID) ',4(' '), 'DALF ',
1 3(2X,612.6,2X), '1/FT')
WRITE(KO,550) DAFAL
550 FORMAT('    FIN AREA / SURFACE AREA (LIQUID) ',3(' '), 'DAFAL',
13(2X,612.6,2X), '-')
WRITE(KO,515) DSI
515 FORMAT('    FREE FLOW AREA / FACE AREA (LIQUID) ',2(' '),
1 'DSI ',3(2X,612.6,2X), '-')
WRITE(KO,512) DA

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512 FORMAT('      FIN THICKNESS (LIQUID) ',8(' '), 'DA ',
1 3(2X,G12.6,2X),'FT')
WRITE(KO,551) DSSL
551 FORMAT('      FIN LENGTH (LIQUID) ',10(' '), 'DSSL ',
13(2X,G12.6,2X),'FT')
WRITE(KO,552) AE
552 FORMAT('      PARTING PLATE THICKNESS ',8(' '), 'AE ',
13(2X,G12.6,2X),'FT')
WRITE(KO,541) NP
541 FORMAT('      NUMBER OF LIQUID PASSES ',8(' '), 'NP ',
1 3(5X,I4,7X),'--')
WRITE(KO,513) DKH
513 FORMAT('      FIN THERMAL CONDUCTIVITY ',7(' '), 'DKH ',
1 3(2X,G12.6,2X),'BTU/HR-FT-DEG R')
WRITE(KO,517)
517 FORMAT('HEAT INPUT RATES',39X,'VALUE      UNITS')
WRITE(KO,518) QP
518 FORMAT('      PUMP ',17(' '), 'QP ',
1 2X,G12.6,2X,'BTU/SEC')
WRITE(KO,519) QCM
519 FORMAT('      MIRROR CONTROL ',12(' '), 'QCM ',
1 2X,G12.6,2X,'BTU/SEC')
WRITE(KO,520) QM
520 FORMAT('      MIRROR ',16(' '), 'QM ',
1 2X,G12.6,2X,'BTU/SEC')
WRITE(KO,521) QV1
521 FORMAT('      VACUUM PUMP 1 ',13(' '), 'QV1 ',
1 2X,G12.6,2X,'BTU/SEC')
WRITE(KO,522) QV2
522 FORMAT('      VACUUM PUMP 2 ',13(' '), 'QV2 ',
1 2X,G12.6,2X,'BTU/SEC')
WRITE(KO,523) QE
523 FORMAT('      E-BEAM ',16(' '), 'QE ',
1 2X,G12.6,2X,'BTU/SEC')
WRITE(KO,524) QS
524 FORMAT('      SUSTAINER ',15(' '), 'QS ',
1 2X,G12.6,2X,'BTU/SEC')
WRITE(KO,525)
525 FORMAT('ODIFFUSER LOSS COEFFICIENTS')
WRITE(KO,526) CF23
WRITE(KO,527) CF34
526 FORMAT('      STATION 2 TO STATION 3 ',7(' '), 'CF23 ',
1 2X,G12.6,2X,'--')
WRITE(KO,544) CF11
WRITE(KO,531) CF910
WRITE(KO,530) CF89
WRITE(KO,529) CF78
WRITE(KO,528) CF45
527 FORMAT('      STATION 3 TO STATION 4 ',7(' '), 'CF34 ',
1 2X,G12.6,2X,'--')
528 FORMAT('      STATION 4 TO STATION 5 ',7(' '), 'CF45 ',
1 2X,G12.6,2X,'--')
529 FORMAT('      STATION 7 TO STATION 8 ',7(' '), 'CF78 ',
1 2X,G12.6,2X,'--')
530 FORMAT('      STATION 8 TO STATION 9 ',7(' '), 'CF89 ',
1 2X,G12.6,2X,'--')
531 FORMAT('      STATION 9 TO STATION 10 ',7(' '), 'CF910',

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1 2X,G12.6,2X,"-")
544 FORMAT(' STATION 11 TO STATION 1 ',7(' '), 'CF111',
1 2X,G12.6,2X,"-")
WRITE(KO,532)
532 FORMAT('AMBIENT CONDITIONS, DECISION VARIABLES, AND CONVERGENCE',
1 ' TOLERANCES')
WRITE(KO,533) TA1F
533 FORMAT(' AMBIENT TEMPERATURE ',10(' '), 'TA1F ',2X,G12.6,2X,
1 ' DEG F')
WRITE(KO,534) PAT
534 FORMAT(' AMBIENT PRESSURE ',11(' '), 'PAT ',2X,G12.6,2X,
1 ' PSIA')
WRITE(KO,535) RHP
535 FORMAT(' RELATIVE HUMIDITY ',11(' '), 'RHP ',2X,G12.6,2X,
1 ' PERCENT')
WRITE(KO,542) FG
542 FORMAT(' FRACTION OF GLYCOL IN COOLING LIQUID . FG ',
1 G12.6, ' -')
WRITE(KO,536) NLIM
536 FORMAT(' MAXIMUM NUMBER OF LOOP CYCLES ',5(' '), 'NLIM ',
1 5X,I3,8X,"-")
WRITE(KO,537) PLIM
537 FORMAT(' PRESSURE TOLERANCE ',10(' '), 'PLIM ',2X,G12.6,2X,
1 ' PSIA')
WRITE(KO,538) DELM
538 FORMAT(' MACH NUMBER TOLERANCE ',9(' '), 'DELM ',2X,G12.6,2X,
1 '-')
WRITE(KO,539) ROLIM
539 FORMAT(' DENSITY TOLERANCE ',11(' '), 'POLIM',2X,G12.6,2X,
1 ' LB/FT**3')
WRITE(KO,540) CONV
540 FORMAT(' STATE VARIABLE TOLERANCES ',7(' '), 'CONV ',
1 5(2X,G12.6,1X),2(/50X,5(2X,G12.6,1X))/50X,2X,G12.6,2X,
2 ' DEG R')
WRITE(KO,100)
100 FORMAT('1')
WRITE(KO,101) TITLE
101 FORMAT(21X,14A6)
CALL GASP(TIG, FN, GAMIG, Z, Z, Z, GMU)
CALL GASP(T2G, FN, GAM2G, Z, Z, Z, GMU)
CALL GASP(T3G, FN, GAM3G, Z, Z, Z, GMU)
CALL GASP(T4G, FN, GAM4G, Z, Z, Z, GMU)
CALL GASP(T5G, FN, GAM5G, Z, Z, Z, GMU)
CALL GASP(T6G, FN, GAM6G, Z, Z, Z, GMU)
CALL GASP(T7G, FN, GAM7G, Z, Z, Z, GMU)
CALL GASP(T8G, FN, GAM8G, Z, Z, Z, GMU)
CALL GASP(T9G, FN, GAM9G, Z, Z, Z, GMU)
CALL GASP(T10G, FN, GAM10G, Z, Z, Z, GMU)
CALL GASP(T11G, FN, GAM11G, Z, Z, Z, GMU)
CON=32.174*1545.43/GMU
VG(1)=FM1*DSQRT(GAMIG*CON*TIG)
VG(2)=FM2*DSQRT(GAM2G*CON*T2G)
VG(3)=FM3*DSQRT(GAM3G*CON*T3G)
VG(4)=FM4*DSQRT(GAM4G*CON*T4G)
VG(5)=FM5*DSQRT(GAM5G*CON*T5G)
VG(6)=FM6*DSQRT(GAM6G*CON*T6G)
VG(7)=FM7*DSQRT(GAM7G*CON*T7G)

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VG(8)=FM8*DSQRT(GAM8G*CON*T8G)
VG(9)=FM9*DSQRT(GAM9G*CON*T9G)
VG(10)=FM10*DSQRT(GAM10G*CON*T10G)
VG(11)=FM11*DSQRT(GAM11G*CON*T11G)
DO 28 K=1,11
28 QG(K)=VG(K)*A(K)*60.
WRITE(KO,102) ALT
102 FORMAT('0 ALTITUDE ',20(' '),1X,G12.6,' (K FT)')
WRITE(KO,103) PAT
103 FORMAT(' AMBIENT PRESSURE ',16(' '),1X,G12.6,' (PSIA)')
WRITE(KO,104) TA1F
104 FORMAT(' AMBIENT TEMPERATURE ',15(' '),1X,G12.6,' (DEG F)')
WRITE(KO,105) RHP
105 FORMAT(' RELATIVE HUMIDITY ',16(' '),1X,G12.6,' (PERCENT)')
WRITE(KO,107) PIGA
107 FORMAT(' LASER INLET PRESSURE ',14(' '),1X,G12.6,' (ATM)')
TIGM=TIG/1.8
WRITE(KO,108)
108 FORMAT(' LASER INLET TEMPERATURE ',13(' '),1X,G12.6,' (DEG K)')
Z=(T02G-T01G)/1.8
WRITE(KO,142) Z
142 FORMAT(' TEMPERATURE RISE ACROSS CAVITY ',9(' '),1X,G12.6,
1 ' (DEG K)')
WRITE(KO,109) VIM
109 FORMAT(' LASER INLET VELOCITY ',14(' '),1X,G12.6,' (M/SEC)')
WRITE(KO,110) PLKW
110 FORMAT(' LASER OUTPUT POWER . . ',13(' '),1X,G12.6,' (KW)')
WRITE(KO,141) EFFLP
141 FORMAT(' LASER EFFICIENCY ',16(' '),1X,G12.6,' (PERCENT)')
WRITE(KO,114) WG
114 FORMAT(' LASER GAS MASS FLOW RATE ',12(' '),1X,G12.6,
1 ' (LE/SEC)')
WRITE(KO,115) Q6G
115 FORMAT(' VOLUME FLOW RATE AT BLOWER INLET ',8(' '),1X,G12.6,
1 ' (CFM)')
WRITE(KO,116) QCORR
116 FORMAT(' CORRECTED VOLUME FLOW RATE AT BLOWER INLET ',3(' '),
1 1X,G12.6,' (CFM)')
WRITE(KO,139) WA
139 FORMAT(' COOLING AIR FLOW RATE ',14(' '),1X,G12.6,
1 ' (LE/SEC)')
WRITE(KO,140) CWA
140 FORMAT(' COOLING AIR FLOW RATE ',14(' '),1X,G12.6,
1 ' (CFM)')
WRITE(KO,117) BPR
117 FORMAT(' BLOWER PRESSURE RATIO ',14(' '),1X,G12.6,' (-)')
WRITE(KO,111) BLPRM, BLPR
111 FORMAT(' BLOWER POWER REQUIRED ',14(' '),1X,G12.6,' (KW)',
1 8X,G12.6,1X,' (HP)')
WRITE(KO,112) PPRM, PPR
112 FORMAT(' COOLING PUMP POWER REQUIRED ',11(' '),1X,G12.6,
1 ' (KW)',8X,G12.6,1X,' (HP)')
WRITE(KO,113) PFM, PF
113 FORMAT(' COOLING FAN POWER REQUIRED ',11(' '),1X,G12.6,
1 ' (KW)',8X,G12.6,1X,' (HP)')
WRITE(KO,106) FN
106 FORMAT(' LASER GAS MIXTURE ',16(' '),1X,F5.2,3(' TO',F5.2),2X,

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1  '(HE TO N2 TO CO2 TO CO)')
  WRITE(KO,143) GMU
143 FORMAT('  MOLECULAR WEIGHT OF GAS  ',12(' '),1X,G12.6,
1  ' (-)')
  WRITE(KO,118)
118 FORMAT('0',8X,'HEAT EXCHANGER VARIABLES',15X,'EXCHANGER 1',6X,
1  'EXCHANGER 2',7X,'RADIATOR',8X,'UNITS')
  WRITE(KO,119) QDI, QDII, QDA
119 FORMAT('  HEAT TRANSFER RATE  ',11(' '),2X,3(G12.6,5X),
1  ' BTU/HR')
  WRITE(KO,120) DPI, DP11, DP
120 FORMAT('  LIQUID PRESSURE DROP  ',10(' '),2X,3(G12.6,5X),
1  ' PSIA')
  WRITE(KO,121) NP
121 FORMAT('  NUMBER OF LIQUID PASSES ',9(' '),2X,3(6X,12,9X),' -')
  NFULL=0
  IF (NFULL .NE. 0) RETURN
  WRITE(KO,122) TMI, TM11, TM
122 FORMAT('  MEAN TEMPERATURE ',9(' '), '(LIQUID)',4(' '),2X,
1  3(G12.6,5X),' DEG R')
  WRITE(KO,123) TGM1, TGM11, TMA
123 FORMAT(32X,'(GAS)',10X,3(G12.6,5X))
  WRITE(KO,124) ZIMU, ZI1MU, ZMU
124 FORMAT('  VISCOSITY ',16(' '), '(LIQUID)',4(' '),2X,3(G12.6,5X),
1  ' LB/FT-SEC')
  WRITE(KO,123) GIMU, GI1MU, AMU
  WRITE(KO,125) PRI, PR11, PR
125 FORMAT('  PRANDTL NUMBER ',11(' '), '(LIQUID)',4(' '),2X,
1  3(G12.6,5X),' -')
  WRITE(KO,123) PRGI, PRG11, PRA
  WRITE(KO,126) CPI, CP11, CP
126 FORMAT('  SPECIFIC HEAT ',12(' '), '(LIQUID)',4(' '),2X,
1  3(G12.6,5X),' BTU/LB-DEG R')
  WRITE(KO,123) CPGI, CPG11, CPA
  WRITE(KO,127) GI, GI1, G
127 FORMAT('  MASS FLUX ',16(' '), '(LIQUID)',4(' '),2X,
1  3(G12.6,5X),' LB/FT**2-SEC')
  WRITE(KO,123) GGI, GG11, GA
  WRITE(KO,128) REI, RE11, RE
128 FORMAT('  REYNOLDS NUMBER ',10(' '), '(LIQUID)',4(' '),2X,
1  3(G12.6,5X),' -')
  WRITE(KO,123) REGI, REG11, REA
  WRITE(KO,129) FI, FI1, F
129 FORMAT('  FRICTION FACTOR ',10(' '), '(LIQUID)',4(' '),2X,
1  3(G12.6,5X),' -')
  WRITE(KO,123) GFI, GF11, AF
  WRITE(KO,130) ZJI, ZJ11, ZJ
130 FORMAT('  HEAT TRANSFER FACTOR ',5(' '), '(LIQUID)',4(' '),2X,
1  3(G12.6,5X),' -')
  WRITE(KO,123) GJI, GJ11, AJ
  WRITE(KO,131) HI, HI1, H
131 FORMAT('  HEAT TRANSFER COEF. ',6(' '), '(LIQUID)',4(' '),2X,
1  3(G12.6,5X),' BTU/FT**2-SEC-DEG R')
  WRITE(KO,123) HCI, HG11, HA
  WRITE(KO,132) CI, CI1, C
132 FORMAT('  FLUID CAPACITY RATE ',6(' '), '(LIQUID)',4(' '),2X,
1  3(G12.6,5X),' BTU/SEC-DEG R')

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WRITE(KO,123) CGI, CGII, CA
WRITE(KO,133) UI, UII, U
133 FORMAT(' OVERALL HEAT TRANSFER COEF. ',7(' '),2X,3(G12.6,5X),
1 ' BTU/FT**2-SEC-DEG R')
WRITE(KO,134) AGI, AGII, AA
134 FORMAT(' GAS HEAT TRANSFER SURFACE AREA ',5(' '),2X,
1 3(G12.6,5X),' FT**2')
WRITE(KO,135) TUNI, TUNII, TUN
135 FORMAT(' NUMBER OF TRANSFER UNITS ',8(' '),2X,
1 3(G12.6,5X),' -')
WRITE(KO,136) TOWI, TOWII, TOW
136 FORMAT(' CAP GAMMA ',16(' '),2X,3(G12.6,5X),' -')
WRITE(KO,137) ESSI, ESSII, ESS
137 FORMAT(' SINGLE PASS EFFECTIVENESS ',8(' '),2X,
1 3(G12.6,5X),' -')
WRITE(KO,138) EPSI, EPSII, EPSA
138 FORMAT(' TOTAL EFFECTIVENESS ',11(' '),2X,
1 3(G12.6,5X),' -')
WRITE(KO,100)
WRITE(KO,101) TITLE
WRITE(KO,200)
200 FORMAT('O',16X,'GAS FLOW SYSTEM VARIABLES BY STATION')
WRITE(KO,201)
201 FORMAT('O STATION NUMBER',18X,'1',13X,'2',13X,'3',13X,'4',
1 13X,'5',13X,'6',37X,'7',13X,'8',13X,'9',12X,'10',12X,'11')
WRITE(KO,204) P01G, P02G, P03G, P04G, P05G, P06G, P07G, P08G,
1 P09G, P010G, P011G
204 FORMAT('O TOTAL PRESSURE (PSIA)',
1 6(1X,G12.6,1X)/31X,5(1X,G12.6,1X))
WRITE(KO,203) P1G, P2G, P3G, P4G, P5G, P6G, P7G, P8G, P9G, P10G,
1 P11G
203 FORMAT('O STATIC PRESSURE (PSIA)',
1 6(1X,G12.6,1X)/31X,5(1X,G12.6,1X))
WRITE(KO,206) T01G, T02G, T03G, T04G, T05G, T06G, T07G, T08G,
1 T09G, T010G, T011G
206 FORMAT('O TOTAL TEMP. (DEG R)',
1 6(1X,G12.6,1X)/31X,5(1X,G12.6,1X))
WRITE(KO,205) T1G, T2G, T3G, T4G, T5G, T6G, T7G, T8G, T9G, T10G,
1 T11G
205 FORMAT('O STATIC TEMPERATURE (DEG R)',
1 6(1X,G12.6,1X)/31X,5(1X,G12.6,1X))
WRITE(KO,207) FM1, FM2, FM3, FM4, FM5, FM6, FM7, FM8, FM9, FM10,
1 FM11
207 FORMAT('O MACH NUMBER (-)',
1 6(1X,G12.6,1X)/31X,5(1X,G12.6,1X))
WRITE(KO,208) VG
208 FORMAT('O VELOCITY (FT/SEC)',
1 6(1X,G12.6,1X)/31X,5(1X,G12.6,1X))
WRITE(KO,209) QG
209 FORMAT('O VOL. FLOW RATE (CFM)',
1 6(1X,G12.6,1X)/31X,5(1X,G12.6,1X))
Z=GMU*.093178
ROG( 1)=PIG*Z/T1G
ROG( 2)=P2G*Z/T2G
ROG( 3)=P3G*Z/T3G
ROG( 4)=P4G*Z/T4G
ROG( 5)=P5G*Z/T5G

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ROG( 6)=P6G*Z/T6G
ROG( 7)=P7G*Z/T7G
ROG( 8)=P8G*Z/T8G
ROG( 9)=P9G*Z/T9G
ROG(10)=P10G*Z/T10G
ROG(11)=P11G*Z/T11G
WRITE(KO,220) ROG
220 FORMAT('O      DENSITY          (LB/FT**3)',
1 6(1X,G12.6,1X)/31X,5(1X,G12.6,1X))
WRITE(KO,212) A
212 FORMAT('O      ARFA          (FT**2)',
1 6(1X,G12.6,1X)/31X,5(1X,G12.6,1X))
WRITE(KO,213) GAMIG, GAM2G, GAM3G, GAM4G, GAM5G, GAM6G, GAM7G,
1 GAM8G, GAM9G, GAM10G, GAM11G
213 FORMAT('O      GAMMA          (-)',
1 6(1X,G12.6,1X)/31X,5(1X,G12.6,1X))
PD(1) = (P01G-P02G)*27.7
PD(2)=(P02G-P03G)*27.7
PD(3)=(P03G-P04G)*27.7
PD(4)=(P04G-P05G)*27.7
PD(5)=(P05G-P06G)*27.7
PD(6)=(P06G-P07G)*27.7
PD(7)=(P07G-P08G)*27.7
PD(8)=(P08G-P09G)*27.7
PD(9)=(P09G-P010G)*27.7
PD(10)=(P010G-P011G)*27.7
PD(11)=(P011G-P01G)*27.7
DO 27 K=1,11
27 PP(K)=PD(K)/(27.7*P06G)
WRITE(KO,210) PD
210 FORMAT('O      PRESSURE DROP      (IN H2O)',6X,
1 6(1X,G12.6,1X)/37X,5(1X,G12.6,1X))
WRITE(KO,211) PP
211 FORMAT('O      PRESSURE DROP / P06      (-)',6X,
1 6(1X,G12.6,1X)/37X,5(1X,G12.6,1X))
WRITE(KO,214)
214 FORMAT('O',12X,'COOLING AIR VARIABLES')
WRITE(KO,215)
215 FORMAT('O      STATION NUMBER',18X,'1A',12X,'2A')
WRITE(KO,216) PAT, PA2
216 FORMAT('O      PRESSURE',12X,'(PSIA)',2(1X,G12.6,1X))
WRITE(KO,217) TA1, TA2
217 FORMAT('O      TEMPERATURE',8X,'(DEG R)',2(1X,G12.6,1X))
WRITE(KO,218) ROA1, ROA2
218 FORMAT('O      DENSITY',9X,'(LB/FT**3)',2(1X,G12.6,1X))
DPPA=(FAT-PA2)*27.7
WRITE(KO,219) DPPA
219 FORMAT('O      PRESSURE DROP      (IN H2O)',7X,G12.6)
WRITE(KO,100)
WRITE(KO,101) TITLE
WRITE(KO,300)
300 FORMAT('O',16X,'COOLING SYSTEM VARIABLES BY STATION')
WRITE(KO,301)
301 FORMAT('O      STATION NUMBER',19X,'1',13X,'2',13X,'3',13X,'4',13X,
1 5',13X,'6',13X,'7',38X,'8',13X,'9',12X,'10',12X,'11',12X,
2 12',12X,'13',12X,'14',/37X,'15',12X,'16',12X,'17',12X,'18',
3 12X,'19',12X,'20')

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WRITE(KO,302) P
302 FORMAT('O PRESSURE (PSIA)',
1 7(1X,G12.6,1X)/31X,7(1X,G12.6,1X)/31X,6(1X,G12.6,1X))
WRITE(KO,303) T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12,
1 T13, T14, T15, T16, T17, T18, T19, T20
303 FORMAT('O TEMPERATURE (DEG R)',
1 7(1X,G12.6,1X)/31X,7(1X,G12.6,1X)/31X,6(1X,G12.6,1X))
WRITE(KO,304) VC
304 FORMAT('O VELOCITY (FT/SEC)',
1 7(1X,G12.6,1X)/31X,7(1X,G12.6,1X)/31X,6(1X,G12.6,1X))
WRITE(KO,305) QC
305 FORMAT('O VOL. FLOW RATE (FT**3/SEC)',
1 7(1X,G12.6,1X)/31X,7(1X,G12.6,1X)/31X,6(1X,G12.6,1X))
WRITE(KO,306) QCG
306 FORMAT('O VOL. FLOW RATE (GAL/MIN)',
1 7(1X,G12.6,1X)/31X,7(1X,G12.6,1X)/31X,6(1X,G12.6,1X))
WRITE(KO,307) DPC
WRITE(KO,309) AC
309 FORMAT('O AREA (FT**2)',
1 7(1X,G12.6,1X)/31X,7(1X,G12.6,1X)/31X,6(1X,G12.6,1X))
307 FORMAT('O PRESSURE DROP (PSIA)',
1 7(1X,G12.6,1X)/31X,7(1X,G12.6,1X)/31X,6(1X,G12.6,1X))
WRITE(KO,308) DPCR
308 FORMAT('O PRESSURE DROP / P1 (-)',
1 7(1X,G12.6,1X)/31X,7(1X,G12.6,1X)/31X,6(1X,G12.6,1X))
RETURN
END

```

5

	=	.000000000000000000000000b+000,	.000000000000000000000000b+000,
	=	.000000000000000000000000b+000,	.000000000000000000000000b+000,
	=	.000000000000000000000000b+000,	.000000000000000000000000b+000,
	=	.000000000000000000000000b+000,	.000000000000000000000000b+000,
	=	.000000000000000000000000b+000,	.000000000000000000000000b+000,
	=	.000000000000000000000000b+000,	.000000000000000000000000b+000,
JCM	=	.862599999999999999999999b+001	
DL	=	.200000000000000000000000b+001,	.200000000000000000000000b+001,
	=	.228125000000000000000000b+001	
DH	=	.666666999999999999999999b+000,	.666666999999999999999999b+000,
	=	.197929170000000000000000b+002	
DW	=	.200000000000000000000000b+001,	.200000000000000000000000b+001,
	=	.604166999999999999999999b+000	
DDHG	=	.255000000000000000000000b-002,	.202000000000000000000000b-002,
	=	.731999999999999999999999b-002	
DALG	=	.244606000000000000000000b+003,	.244606000000000000000000b+003,
	=	.336759999999999999999999b+003	
DAFOA	=	.863000000000000000000000b+000,	.863000000000000000000000b+000,
	=	.808999999999999999999999b+000	
DSIG	=	.769897389999999999999999b+000,	.769897389999999999999999b+000,
	=	.658365799999999999999999b+000	
DDEL	=	.499999999999999999999999b-003,	.499999999999999999999999b-003,
	=	.499999999999999999999999b-003	
DA	=	.499999999999999999999999b-003,	.499999999999999999999999b-003,
	=	.499999999999999999999999b-003	
DKH	=	.100000000000000000000000b+003,	.100000000000000000000000b+003,
	=	.100000000000000000000000b+003	
DSL	=	.226500000000000000000000b-001,	.226500000000000000000000b-001,
	=	.104583000000000000000000b-001	
DSI	=	.727179999999999999999999b-001,	.727179999999999999999999b-001,
	=	.133280000000000000000000b+000	
DALF	=	.727179999999999999999999b+002,	.727179999999999999999999b+002,
	=	.133280000000000000000000b+003	
DDH	=	.999999999999999999999999b-003,	.999999999999999999999999b-003,
	=	.399999999999999999999999b-002	
NP	=	+1,	+4
PAT	=	.146900000000000000000000b+002	
RHP	=	.100000000000000000000000b+003	
FBPR	=	.000000000000000000000000b+000	
A	=	.2152492170000660520b+000,	.000000000000000000000000b+000,
	=	.545399999999999999999999b+000,	.545399999999999999999999b+000,
	=	.545399999999999999999999b+000,	.349100000000000000000000b+000,
	=	.545399999999999999999999b+000,	.545399999999999999999999b+000,
	=	.545399999999999999999999b+000,	.545399999999999999999999b+000,
	=	.430556416000000000000000b+000	
CONV	=	.500000000000000000000000b+000,	.500000000000000000000000b+000,
	=	.500000000000000000000000b+000,	.500000000000000000000000b+000,
	=	.500000000000000000000000b+000,	.500000000000000000000000b+000,
	=	.500000000000000000000000b+000,	.500000000000000000000000b+000,
	=	.500000000000000000000000b+000,	.500000000000000000000000b+000,
	=	.500000000000000000000000b+000,	.500000000000000000000000b+000,
	=	.500000000000000000000000b+000,	.500000000000000000000000b+000,
	=	.500000000000000000000000b+000,	.500000000000000000000000b+000,
	=	.500000000000000000000000b+000,	.500000000000000000000000b+000,
	=	.500000000000000000000000b+000,	.500000000000000000000000b+000,
DELM	=	.999999999999999999999999b-003	
NDSGN	=	+2	
NCS	=	+1	
NLIM	=	+20	

ROLIM	=	.10000000000000000000-004	
PLIM	=	.99999999999999999970-003	
FG	=	.00000000000000000000+000	
RRPM	=	.11200000000000000000+005	
VLIM	=	.50000000000000000000+000	
NBS	=	+7	
NBPS	=	+2	
JCPRO	=	-1	
RO1	=	.41500000000000000000-002	
DAFAL	=	.50799999999999999990+000,	.50799999999999999990+000,
		.50799999999999999990+000	
DSLL	=	.21166700000000000000-002,	.21166700000000000000-002,
		.21166700000000000000-002	
AB	=	.20833000000000000000-002,	.20833000000000000000-002,
		.20833000000000000000-002	

Table 1

LASER TEST CASE
DECEMBER 1976

INPUT LIST					
CAVITY * LASER SPECIFICATIONS					
DESCRIPTION	NAME	VALUE	UNITS		
INLET PRESSURE	PIGA	.100000+001	ATM		
INLET HEIGHT	H1M	.500000+001	CM		
WIDTH IN FLOW DIRECTION	WT1M	.500000+001	CM		
LENGTH	CL1M	.400000+002	CM		
INLET HYDRAULIC DIAMETER	DCM	.962600+001	CM		
LASER OUTPUT POWER	PLKW	.500000+002	KW		
LASER EFFICIENCY	EFFLP	.100000+002	PERCENT		
DESIGN OPTION	NDSGN	2	-		
GAS MIXTURE	FN	3.00 2.00	.50		
		.50 HE	TO N2	TO	CO2 TO CO
INITIAL ESTIMATE OF STEADY STATE QUANTITIES					
GAS STATIC TEMPERATURE - STATION 1	ETIG	.000000	DEG R TA1 + 20. IF = 0.,USES		
GAS TOTAL TEMPERATURE - STATION 2	ET02G	.000000	DEG R TA1 + 210.		
GAS TOTAL TEMPERATURE - STATION 6	ET06G	.000000	DEG R TA1 + 30.		
GAS TOTAL TEMPERATURE - STATION 7	ET07G	.000000	DEG R TA1 + 70.		
COOLANT TEMPERATURE - STATION 1	ET1	.000000	DEG R TA1 + 20.		
COOLANT TEMPERATURE - STATION 2	ET2	.000000	DEG R TA1 + 20.		
COOLANT TEMPERATURE - STATION 3	ET3	.000000	DEG R TA1 + 40.		
COOLANT TEMPERATURE - STATION 4	ET4	.000000	DEG R TA1 + 55.		
COOLANT TEMPERATURE - STATION 6	ET6	.000000	DEG R TA1 + 30.		
COOLANT TEMPERATURE - STATION 8	ET8	.000000	DEG R TA1 + 65.		
COOLANT TEMPERATURE - STATION 10	ET10	.000000	DEG R TA1 + 65.		
COOLANT TEMPERATURE - STATION 14	ET14	.000000	DEG R TA1 + 30.		
COOLANT TEMPERATURE - STATION 16	ET16	.000000	DEG R TA1 + 75.		
COOLANT TEMPERATURE - STATION 18	ET18	.000000	DEG R TA1 + 65.		
COOLANT TEMPERATURE - STATION 20	ET20	.000000	DEG R TA1 + 65.		
AIR TEMPERATURE AFTER RADIATOR	ETA2	.000000	DEG R TA1 + 30.		
FLOWER PRESSURE RATIO	EBPR	.000000	- 1.17		
INLET VELOCITY	EVIM	.250000+002	M/SEC 120.		
COOLING SYSTEM FLOWS					
HEAT EXCHANGER 1 (LIQUID)	WI	.100000+001	LB/SEC		
HEAT EXCHANGER 2 (LIQUID)	WII	.917400+000	LB/SEC		
MIRROR BYPASS	WB	.500000+000	LB/SEC		
MIRROR	WM	.908000+000	LB/SEC		
VACUUM PUMP 1	WV1	.910000-001	LB/SEC		
VACUUM PUMP 2	WV2	.918000+000	LB/SEC		
E-BEAM	WE	.908000+000	LB/SEC		
SUSTAINER	WS	.455000+001	LB/SEC		
CORRECTED FAN FLOW (AIR)	CWA	.500000+005	CFM		
SPECIFICATIONS OF BLOWERS					
BLOWER POLYTROPIC EFFICIENCY	ATAB	.700000+000	-		
BLOWER SPEED	ERPM	.112000+005	RPM		
NUMBER OF BLOWER SETS	NBS	7	-		
NUMBER OF BLOWERS PER SET	NBPS	2	-		
INLET VELOCITY TOLERANCE	VLIM	.500000+000	M/SEC		
TUNNEL AREAS					
STATION 1 TO STATION 11	A	.215299+000	.215299+000		
		.545400+000	.545400+000	.545400+000	.349100+000
		.545400+000	.545400+000	.545400+000	.430556+000FT**2

LASER TEST CASE
DECEMBER 1976

INPUT LIST (CONT.)

HEAT EXCHANGER SPECIFICATIONS

DESCRIPTION	NAME
CORE LENGTH (GAS)	DL
COPE HEIGHT	DH
COPE WIDTH (LIQUID)	DW
HYDRAULIC DIAMETER (GAS)	DDHG
SURFACE AREA / VOLUME (GAS)	DALG
FIN AREA / SURFACE AREA (GAS)	DAFGA
FREE FLOW AREA / FACE AREA (GAS)	DSIG
FIN THICKNESS (GAS)	DDEL
FIN LENGTH (GAS)	DSL
HYDRAULIC DIAMETER (LIQUID)	DDH
SURFACE AREA / VOLUME (LIQUID)	DALF
FIN AREA / SURFACE AREA (LIQUID)	DAFAL
FREE FLOW AREA / FACE AREA (LIQUID)	DSI
FIN THICKNESS (LIQUID)	DA
FIN LENGTH (LIQUID)	DSL
PARTING PLATE THICKNESS	AP
NUMBER OF LIQUID PASSES	NP
FIN THERMAL CONDUCTIVITY	DKH

HEAT INPUT RATES

DESCRIPTION	NAME	VALUE	UNITS
PUMP	GP	350000+001	BTU/SEC
MIRROR CONTROL	GCM	950000+000	BTU/SEC
MIRROR	GM	473000+001	BTU/SEC
VACUUM PUMP 1	GV1	473000+000	BTU/SEC
VACUUM PUMP 2	GV2	426000+001	BTU/SEC
F-PEAR	GE	473000+001	BTU/SEC
SUSTAINER	GS	237000+002	BTU/SEC

EXCHANGER 1 (1)	EXCHANGER 2 (2)	RADIATOR (3)	UNITS
200000+001	200000+001	228125+001	FT
666667+000	666667+000	197929+002	FT
200000+001	200000+001	604167+000	FT
255000-002	202000-002	782000-002	FT
244606+003	244606+003	336760+003	1/FT
863000+000	863000+000	809000+000	-
769897+000	769897+000	658366+000	-
500000-003	500000-003	500000-003	FT
226500-001	226500-001	104583-001	FT
100000-002	100000-002	400000-002	FT
727180+002	727180+002	133280+003	1/FT
508000+000	508000+000	506000+000	-
727180-001	727180-001	133280+000	-
500000-003	500000-003	500000-003	FT
211667-002	211667-002	211667-002	FT
208330-002	208330-002	208330-002	FT
100000+003	100000+003	100000+003	4

100000+003 .100000+003 .100000+003 BTU/HR-FT-DEG R

Table 2

LASER TEST CASE
DECEMBER 1976

ALTITUDE	.000000	(K. FT)
AMBIENT PRESSURE	.14900+002	(PSIA)
AMBIENT TEMPERATURE	-.12000+003	(DEG F)
RELATIVE HUMIDITY	.10000+003	(PERCENT)
LASER INLET PRESSURE	.10000+001	(ATM)
LASER INLET TEMPERATURE	.518021+003	(DEG K)
TEMPERATURE RISE ACROSS CAVITY	.250000+002	(M/SEC)
LASER INLET VELOCITY	.500000+002	(KW)
LASER OUTPUT POWER	.100000+002	(PERCENT)
LASER EFFICIENCY	.119226+001	(LB/SEC)
LASER GAS MASS FLOW RATE	.134604+004	(CFM)
VOLUME FLOW RATE AT BLOWER INLET	.108659+004	(CFM)
CORRECTED VOLUME FLOW RATE AT BLOWER INLET	.787055+002	(LB/SEC)
COOLING AIR FLOW RATE	.500000+005	(CFM)
COOLING AIR FLOW RATE	.102468+001	(-)
BLOWER PRESSURE RATIO	.255385+001	(KW)
BLOWER POWER REQUIRED	.000000	(KW)
COOLING PUMP POWER REQUIRED	.171500+002	(KW)
COOLING FAN POWER REQUIRED	3.00 TO 2.00 TO	.50 TO
LASER GAS MIXTURE	.173403+002	(-)
MOLECULAR WEIGHT OF GAS		
HEAT EXCHANGER VARIABLES		
HEAT TRANSFER RATE	EXCHANGER 1	EXCHANGER 2
LIQUID PRESSURE DROP	.131815+007	.129876+006
NUMBER OF LIQUID PASSES	.000000	.000000
MEAN TEMPERATURE	EXCHANGER 1	EXCHANGER 2
	.523942+003	.361018+003
VISCOSITY	(GAS)	(GAS)
	.787989+003	.389408+003
PRANDTL NUMBER	(LIQUID)	(LIQUID)
	.100000-004	.100000-004
SPECIFIC HEAT	(LIQUID)	(LIQUID)
	.168675-004	.990843-005
	(GAS)	(GAS)
	.104806+000	.127362+000
	(GAS)	(GAS)
	.479389+000	.734821+000
	(GAS)	(GAS)
	.100181+001	.992757+000
	(GAS)	(GAS)
	.360665+000	.348516+000
RADIATOR UNITS		
		BTU/HR
	.160046+007	PSIA
	.000000	-
		DEG R
	.363978+003	LB/FT-SEC
	.356417+003	-
	.100000-004	BTU/LB-DEG R
	.923730-005	
	.126861+000	
	.734821+000	
	.972921+000	
	.2.9295+000	

MASS FLUX	.....(LIQUID)	..	.103138+002	.946189+001	.243254+002	LB/FT**2-SEC
	(GAS)	..	.116155+001	.116155+001	.264762+001	
REYNOLDS NUMBER	.....(LIQUID)	..	.103138+004	.946186+003	.975012+004	
	(GAS)	..	.175601+003	.236801+003	.224139+004	
FRICITION FACTOR	.....(LIQUID)	..	.000000	.000000	.000000	
	(GAS)	..	.829930-001	.764029-001	.405812-001	
HEAT TRANSFER FACTOR	.....(LIQUID)	..	.102923-001	.106279-001	.520734-002	
	(GAS)	..	.241728-001	.189830-001	.106194-001	
HEAT TRANSFER COEF.	.....(LIQUID)	..	.478400+000	.394376+000	.498162+000	BTU/FT**2-SEC-DEG
	(GAS)	..	.165327-001	.135872-001	.826233-002	R
FLUID CAPACITY RATE	.....(LIQUID)	..	.100181+001	.910755+000	.962379+001	BTU/SEC-DEG R
	(GAS)	..	.430044+000	.415558+000	.188338+002	
OVERALL HEAT TRANSFER COEF.	.....	..	.114758-001	.994101-002	.762488-002	BTU/FT**2-SEC-DEG
GAS HEAT TRANSFER SURFACE AREA	.....	..	.652283+003	.652283+003	.918671+004	FT**2
NUMBER OF TRANSFER UNITS	.....	..	.174083+002	.156040+002	.7	859+001
CAP GAMMA	.....	..	.999431+000	.999191+000	.6	371+000
SINGLE PASS EFFECTIVENESS	.....	..	.902531+000	.888069+000	.6	167+000
TOTAL EFFECTIVENESS	.....	..	.902531+000	.888069+000	.9	673+000

LASER TEST CASE
DECEMBER 1976

GAS FLOW SYSTEM VARIABLES BY STATION

STATION NUMBER	1 7	2 8	3 9	4 10	5 11	6
TOTAL PRESSURE (PSIA)	.147491+002 .148668+002	.147336+002 .148673+002	.147191+002 .148659+002	.147148+0 .148656+0	.147140+002 .147509+002	.145106+002
STATIC PRESSURE (PSIA)	.147000+002 .148590+002	.145526+002 .148576+002	.146907+002 .148561+002	.146869+0 .148559+0	.146861+002 .147383+002	.144874+002
TOTAL TEMP. (DEG R)	.352197+003 .439012+003	.128463+004 .438851+003	.128499+004 .438851+003	.128499+0 .438851+0	.128499+004 .352164+003	.433205+003
STATIC TEMPERATURE (DEG R)	.351809+003 .438754+003	.128017+004 .438754+003	.128423+004 .438754+003	.128425+0 .438754+0	.128425+004 .352068+003	.432819+003
MACH NUMBER (-)	.668419-001 .292112-001	.131289+000 .292139-001	.514212-001 .292167-001	.514390-0 .292172-0	.514420-001 .333528-001	.464788-001
VELOCITY (FT/SEC)	.820249+002 .399536+002	.301524+003 .399573+002	.118273+003 .399611+002	.118315+0 .399619+0	.118322+003 .409436+002	.631488+002
VOL. FLOW RATE (CFM)	.105959+004 .130744+004	.389507+004 .130756+004	.387038+004 .130769+004	.387174+0 .130771+0	.387196+004 .105771+004	.132277+004
DENSITY (LB/FT**3)	.675120-001 .547191-001	.183673-001 .547139-001	.184829-001 .547087-001	.184780-0 .547076-0	.184769-001 .676383-001	.540822-001
AREA (FT**2)	.215299+000 .545400+000	.215299+000 .545400+000	.545400+000 .545400+000	.545400+0 .545400+0	.545400+000 .430556+000	.349100+000
GAMMA (-)	.149276+001 .148695+001	.143688+001 .148695+001	.143664+001 .148695+001	.143664+0 .148695+0	.143664+001 .149274+001	.148737+001
PRESSURE DROP (IN H2O)	.429226+000 .391339-001	.401079+000 .391719-001	.117872+000 .783509-002	.23165-001 .3107+001	.563475+001 .507868-001	-.992112+001
PRESSURE DROP / P06 (-)	.106788-002 .973618-004	.997850-003 .974562-004	.293255-003 .194930-004	.5708-004 .7976-002	.140188-001 .126353-003	-.246829-001

APPENDIX B
(David Washington)

Phase Diagram for a Mixture of (a) Carbon Dioxide and (b) Nitrogen,
at (P = 1 atm) Pressure

Condition for Phase Equilibrium

$$\bar{f}_A^1 = \bar{f}_A^2$$

or, at equilibrium the fugacity of a given component is the same in each phase. In general,

$$\bar{f}_A^1 = \bar{f}_A^2 = \bar{f}_A^3 = \dots \text{ for all phases}$$

$$\bar{f}_B^1 = \bar{f}_B^2 = \bar{f}_B^3 = \dots \text{ for all phases}$$

$$\begin{array}{ccc} - & - & - \\ - & - & - \end{array}$$

for all components.

Pure Carbon Dioxide at 1 atm pressure will exist as a vapor or solid, depending on the temperature (See P-T diagram). Pure Nitrogen at 1 atm pressure can exist in all three phases (vapor, liquid, solid), depending on temperature (See P-T diagram). However, the fugacity of compressed liquids and solids can be treated alike, as follows.

For a pure substance at constant temperature,

$$R T (d \ln f)_T = v d P_T$$

integrating between saturation state on Pressure P,

$$R T \int_{f^{\text{SAT}}}^f d(\ln f)_T = \int_{p^{\text{SAT}}}^P v dP_T$$

Assume constant specific volume (v) for liquids and solids.

$$R T \ln \frac{f}{f^{\text{SAT}}} \approx v (P - p^{\text{SAT}})$$

$$\frac{f}{f^{\text{SAT}}} \approx e^{\frac{v (P - p^{\text{SAT}})}{R T}}$$

Since v is small for liquids and solids, the quantity $v (P - p^{\text{SAT}})$ is small for moderate changes of pressure. Therefore,

$$\frac{f}{f^{\text{SAT}}} \approx e^0 = 1$$

liquid
and
solids

or

$$f^L \approx f^{\text{SAT}}, \quad f^S \approx f^{\text{SAT}}$$

For Nitrogen at,

$$T = 200^\circ\text{R}$$

$$p^{\text{SAT}} = 226.853 \frac{\text{Lbf}}{\text{in}^2}$$

$$v = .02613 \text{ ft}^3/\text{Lbm}$$

$$R = 55.15 \frac{\text{ft-Lbf}}{\text{Lbm}^\circ\text{R}}$$

$$P = 1 \text{ atm}$$

$$\frac{f}{f^{\text{SAT}}} \approx e^{-.072} = .93$$

Therefore, $f \approx f^{\text{SAT}}$ with 7% error at this check point.

From the P-T chart for Nitrogen, it is observed that only a small portion of the liquid phase is involved (since 1 atm is near the triple point). Also, since the fugacity of liquids and solids are calculated alike ($f^{\text{L}} = f^{\text{S}} \approx f^{\text{SAT}}$) it is felt that the Nitrogen component can be considered in two phases (solid and vapor) for this problem. Consequently, for this problem (1 atm), consider a Binary Solution (vapor and solid) of two components (A- Carbon Dioxide, and B-Nitrogen). Therefore,

$$\bar{f}_{\text{N}_2}^{\text{L}} = \bar{f}_{\text{N}_2}^{\text{V}}$$

Condition for Equilibrium

$$\bar{f}_{\text{CO}_2}^{\text{S}} = \bar{f}_{\text{CO}_2}^{\text{V}}$$

Additional Assumptions

- 1) Assume Ideal Solution.

$$\bar{f}_i^\phi = y_i^\phi f_i^\phi$$

where

ϕ = phase

i = component

\bar{f}_i^ϕ = fugacity of component (i) in phase (ϕ)

f_i^ϕ = fugacity of Pure (i) in the same phase as the mixture on the same temperature and pressure

y_i^ϕ = mole fraction of (i)

or

$$Z_A f_A^{\text{S}} = y_A f_A^{\text{V}}$$

$$Z_B f_B^{\text{S}} = y_B f_B^{\text{V}}$$

where,

Z_A = mole fraction of (A) in Solid Phase

Z_B = mole fraction of (B) in Solid Phase

y_A = mole fraction of (A) in Vapor Phase

y_B = mole fraction of (B) in Vapor Phase

2) Assume,

$$f_A^S = f_A^{SAT} \quad \text{As discussed earlier}$$

$$f_B^S = f_B^{SAT}$$

3) Assume that pure saturated vapor at T and P^{SAT} behave as an ideal gas. Therefore,

$$f_A^{SAT} = P_A^{SAT} \text{ (Vapor Pressure)}_A$$

$$f_B^{SAT} = P_B^{SAT} \text{ (Vapor Pressure)}_B$$

4) For the Vapor Phase, assume that pure gas (A) and pure gas (B) behave as ideal gases at T and P. Therefore,

$$f_A^V = P$$

$$f_B^V = P$$

Combining (1), (2), (3), and (4),

$$Z_A P_A^{SAT} = y_A P$$

$$Z_B P_B^{SAT} = y_B P$$

Known as (RAOULT'S LAW).
Good for systems at Low
Pressure.

Combined with,
$$\begin{bmatrix} z_A + z_B = 1 \\ y_A + y_B = 1 \end{bmatrix}$$

gives a system of four equations and four unknowns (z_A, z_B, y_A, y_B).

Combining final equations,

$$(1) \quad z_A \frac{p_A^{\text{SAT}}}{P} = y_A \frac{P}{P}$$

$$(2) \quad z_B \frac{p_B^{\text{SAT}}}{P} = y_B \frac{P}{P}$$

$$(3) \quad z_A + z_B = 1$$

$$(4) \quad y_A + y_B = 1$$

$$z_A \frac{p_A^{\text{SAT}}}{P} + z_B \frac{p_B^{\text{SAT}}}{P} = 1$$

$$z_A \frac{p_A^{\text{SAT}}}{p_B^{\text{SAT}}} + (1 - z_A) = \frac{P}{p_B^{\text{SAT}}}$$

$$z_A \left[\frac{p_A^{\text{SAT}}}{p_B^{\text{SAT}}} - 1 \right] = \frac{P}{p_B^{\text{SAT}}} - 1$$

$$z_A = \frac{P - p_B^{\text{SAT}}}{p_A^{\text{SAT}} - p_B^{\text{SAT}}}$$

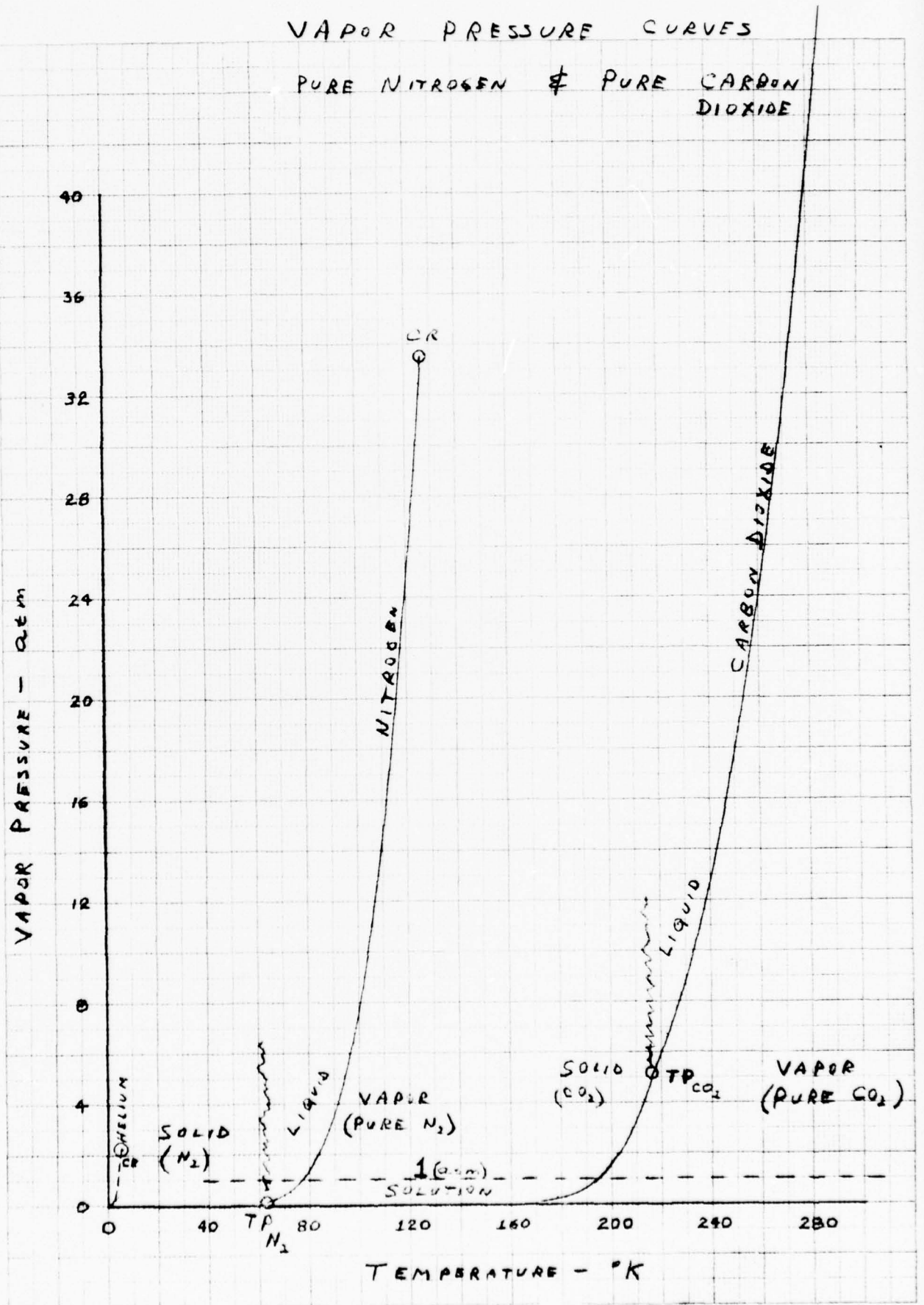
$$y_A = z_A \frac{p_A^{\text{SAT}}}{P}$$

CRITICAL POINT AND TRIPLE POINT PROPERTIES
OF PURE NITROGEN AND CARBON DIOXIDE

		(B) NITROGEN (N ₂)	(A) CARBON DIOXIDE (CO ₂)
MOLECULAR WEIGHT		28.013 $\frac{\text{Lb mass}}{\text{Lb mole}}$	44.01 $\frac{\text{Lb mass}}{\text{Lb mole}}$
CRITICAL POINT	Z _C	.291	.275
	T _C	126.2 ⁰ K	304.2 ⁰ K
	T _C	227.1 ⁰ R	547.5 ⁰ R
	T _C	-232.57 ⁰ F	87.8 ⁰ F
TRIPLE POINT	P _C	33.5 atm	72.9 atm
	P _C	492. Lbf/in ²	1071. Lbf/in ²
	T _{TP}	63.15 ⁰ K (-210 ⁰ C)	216.55 ⁰ K (-56.6 ⁰ C)
	T _{TP}	113.67 ⁰ R	389.79 ⁰ R
	T _{TP}	-345.6 ⁰ F	-69.88 ⁰ F
	P _{TP}	94.01 mmhg	3885.1 mmhg
	P _{TP}	.1237 atm	5.112 atm
SATURATION DATA AT P = 1 atm	P _{TP}	1.818 Lbf/in ²	75.126 Lbf/in ²
	T _{SAT}	139.255 ⁰ R (L-V)	350.3 ⁰ R
		-320.415 ⁰ F (-195.786C)	-109.3 ⁰ F (-78.52 ⁰ C)
	77.364 ⁰ K	194.63 ⁰ K	

VAPOR PRESSURE CURVES

PURE NITROGEN & PURE CARBON DIOXIDE

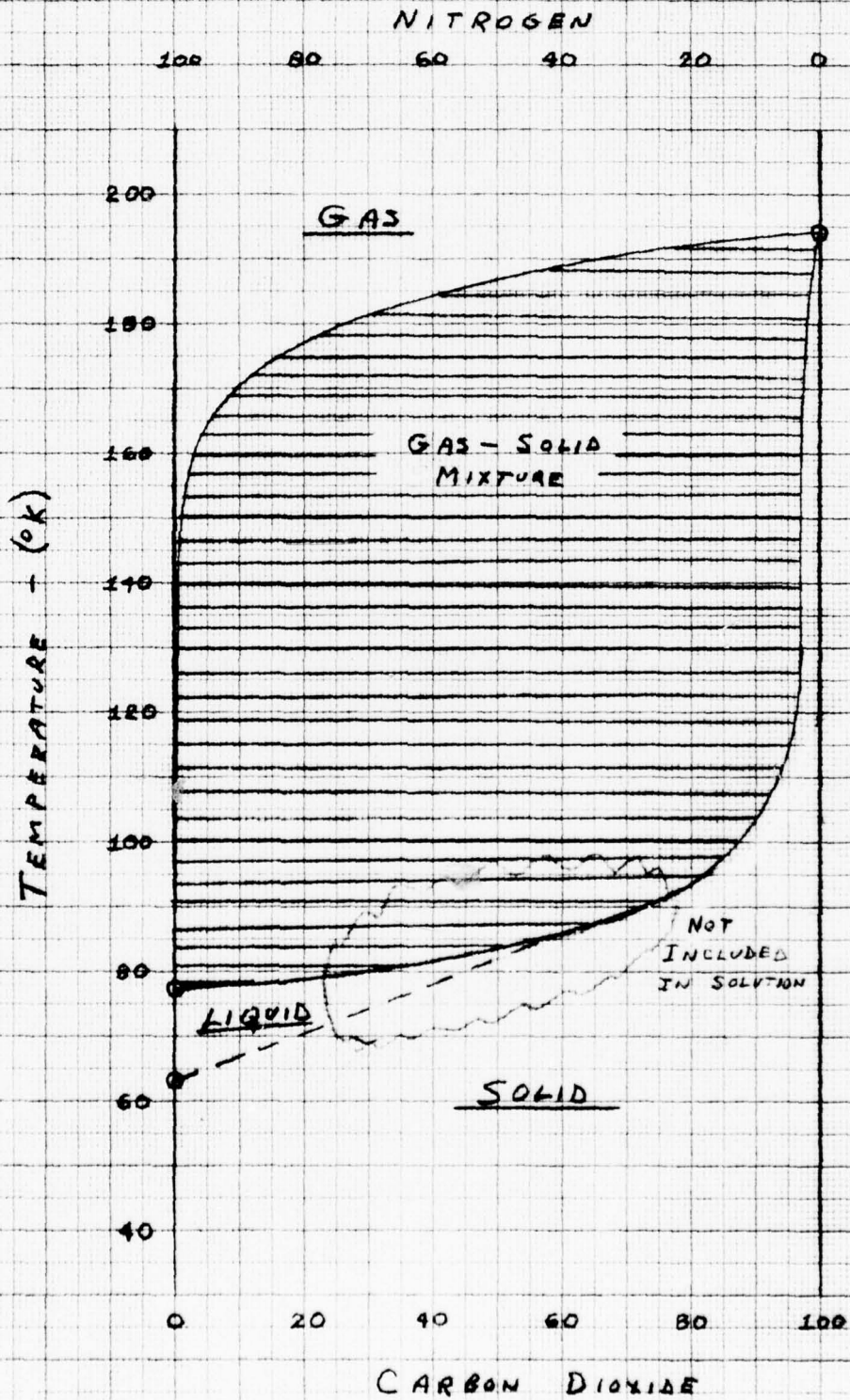


461510

HE HELIUM TO THE CENTIMETER

PHASE DIAGRAM

P = 1 atm



461510

K·E NO. 10 TO THE CENTIMETER KEUFFEL & ESSER CO. N.Y. N.Y.

Phase Diagram for a Mixture of (A) Nitrogen and (B) Helium, at (P = 1 atm)
Pressure

Solution

Assume a binary solution (solid-vapor) at two components. Assume an ideal solution and using Raoult's Law, as in Appendix A, we have,

$$\begin{array}{l} \text{(solid)} \quad \quad \quad \text{(vapor)} \\ z_A p_A^{\text{SAT}} = y_A P \\ z_B p_B^{\text{SAT}} = y_B P \end{array} \quad \text{RAOULT'S LAW}$$

Combine with,

$$z_A + z_B = 1$$

$$y_A + y_B = 1$$

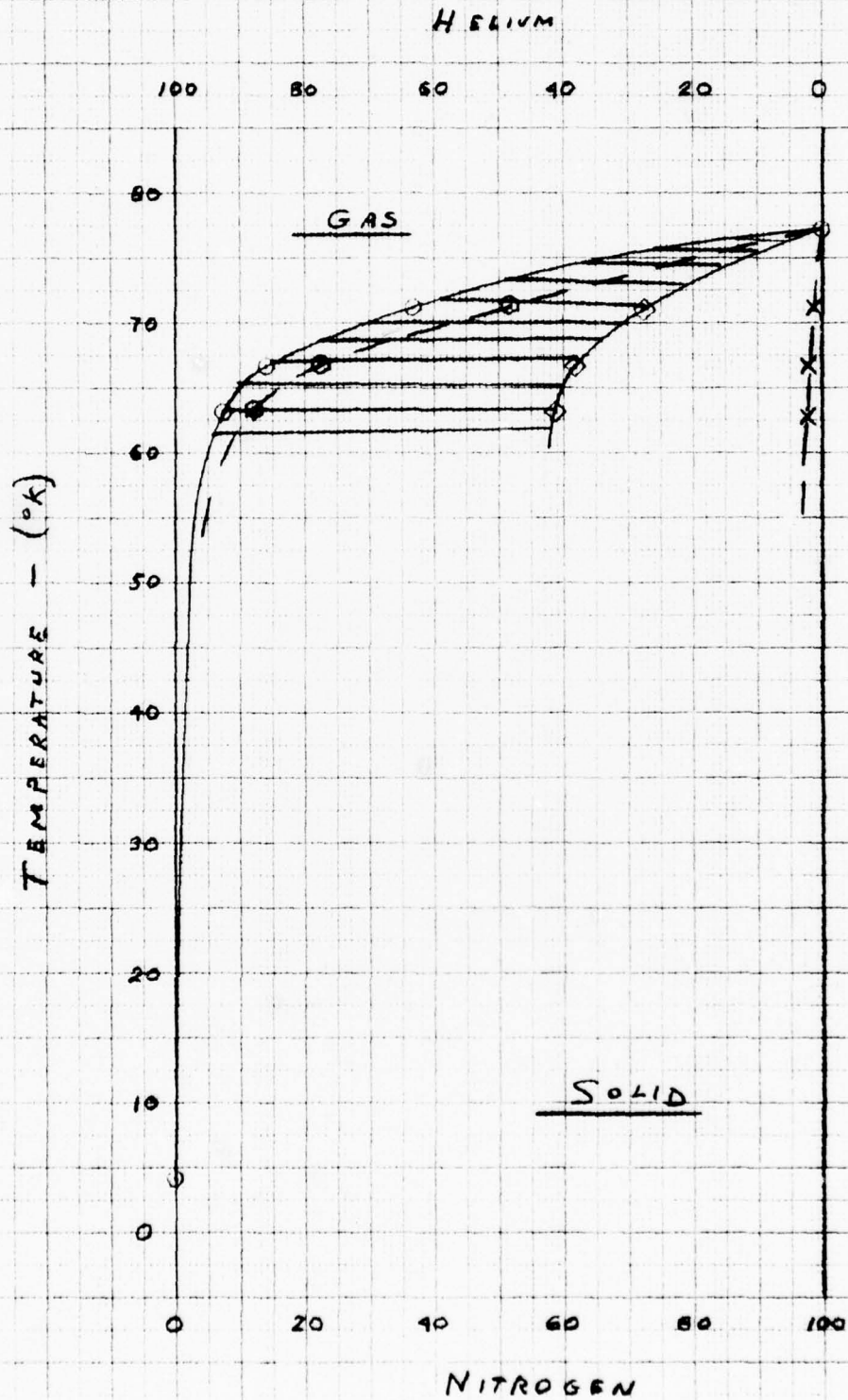
yield

$$z_A = \frac{P - p_B^{\text{SAT}}}{p_A^{\text{SAT}} - p_B^{\text{SAT}}}$$

$$y_A = z_A \frac{p_A^{\text{SAT}}}{P}$$

PHASE DIAGRAM

P = 1 ATM



Phase Diagram for a Mixture of (A) Carbon Dioxide and (B) Helium at
(P = 1 atm) Pressure

Solution

Assume a binary solution (solid-vapor) of two components. Assume an ideal solution and using Raoult's Law, as in Appendix A and B, we have,

$$\begin{array}{l} \text{(solid)} \qquad \text{(vapor)} \\ z_A P_A^{\text{SAT}} = y_A P \\ z_B P_B^{\text{SAT}} = y_B P \end{array} \qquad \text{RAOULT'S LAW}$$

Combine with,

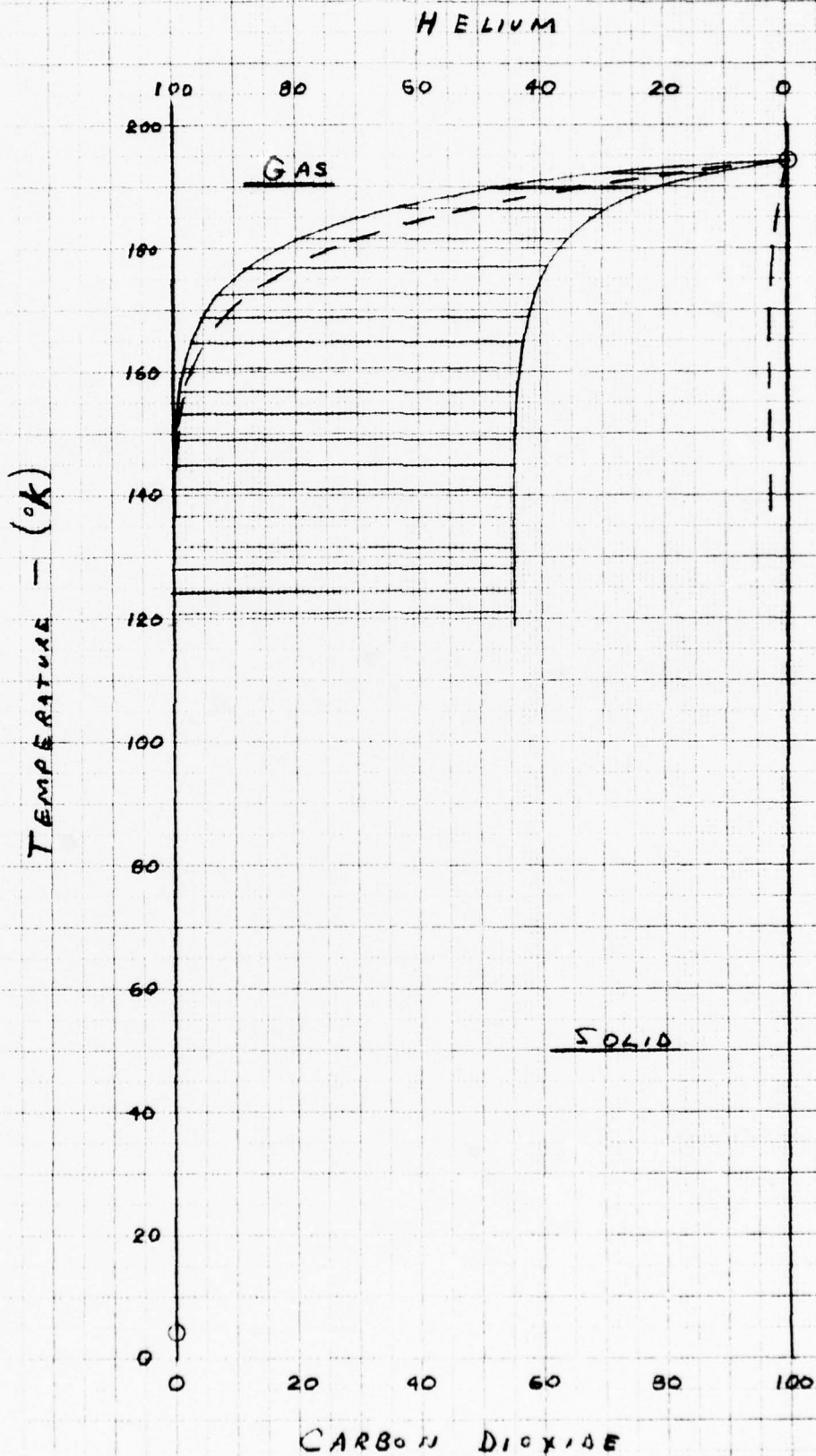
$$\begin{array}{l} z_A + z_B = 1 \\ y_A + y_B = 1 \end{array}$$

$$z_A = \frac{P - P_B^{\text{SAT}}}{P_A^{\text{SAT}} - P_B^{\text{SAT}}}$$

$$y_A = z_A \frac{P_A^{\text{SAT}}}{P}$$

PHASE DIAGRAM

$P = 1 \text{ atm}$



461510

NO. 1. ALL TO THE VENT. METER
K. S. KELLY & COMPANY, INC.

APPENDIX C

```
PARAMETER M=12, JJ=41, ISEG=100, -II=ISEG+1, N=10  
COMMON /DDD/ G,CP,CV,RF,R,RR,U,A,CA,CB,CC,HX,AZ,ZERO,F,XL
```

```
DIMENSION S1(N),S2(N),S3(N),BL(N),BN(N),BC1(M),BC2(M),BIC(M)
```

```
PARAMETER NZ=4  
DIMENSION CSL(NZ),CSR(NZ)
```

```
COMMON /DLL/ CSL,CSR,SL,SR  
DO 50 L=1,2
```

C DEFINE COASTANTS

```
IF(L.EQ.1) XNN=1.0
```

```
IF(L.EQ.2) XNN=-1.0
```

```
SEG=I SEG
```

```
IC=II -1
```

```
MI=II -2
```

```
MJ=JJ -1
```

```
BC11=C.0
```

```
BC21=200.0
```

```
X=BC21-BC11
```

```
DX=X/SEG
```

```
DIS=6.0
```

```
CP=0.24
```

```
G=1.4
```

```
RF=53.34
```

```
XP=2116.8
```

```
XD=0.00234
```

```
XU=100.0
```

```
AZ=0.0
```

```
ZERO=C.0
```

```
HX=4.0
```

```
F=0.02
```

```
XL=1.0
```

```
CV=CP/G
```

```
RR=RF/778.161
```

```
R=RF*32.1739
```

```
XT=XP/XD/R
```

```
A=SQRT(G*R*XT)
```

```
U=XU/A
```

```
CA=(G-1.0)/(2.0*G)
```

```
CB=(G+1.0)/(2.0*G)
```

```
CC=2.0/(G+1.0)
```

C BOUNDARY CONDITIONS (LEFT)

```
BC1(1)=BC11
```

```
BC1(2)=-10.0
```

```
BC1(3)=U
```

```
BC1(4)=1.0
```

```
BC1(5)=0.0
```

```
BC1(6)=0.0
```

```
BC1(7)=0.25
```

```
BC1(8)=XP
```

```
BC1(9)=XD
```

```
BC1(10)=XT
```

```
BC1(11)=0.2
```

C BOUNDARY CONDITIONS (RIGHT)

```
BC2(1)=BC21
```

```
BC2(2)=-10.0
```

```
BC2(3)=U
```

```
BC2(4)=1.0
```

```
BC2(5)=0.0
```

```

BC2(6)=0.0
BC2(7)=0.25
BC2(8)=XP
BC2(9)=XD
BC2(10)=XT
BC2(11)=0.2
C FLOW DIRECTIONS
BC1(3)=BC1(3)*XNN
BC2(3)=BC2(3)*XNN
C LOAD BOUNDARY CONDITIONS
DO 15 J=1,MJ
DO 14 K=1,M
P(K,1,J)=BC1(K)
P(K,I,J)=BC2(K)
14 CONTINUE
15 CONTINUE
C INITIAL CONDITIONS
DO 18 I=2,IC
IM1 = I-1
P(1,I,1)=P(1,IM1,1)+DX
18 CONTINUE
BIC(2)=0.0
BIC(3)=U
BIC(4)=1.0
BIC(5)=0.0
BIC(6)=0.0
BIC(7)=0.25
BIC(8)=XP
BIC(9)=XD
BIC(10)=XT
BIC(11)=0.2
C FLOW DIRECTIONS
BIC(3)=BIC(3)*XNN
C LOAD INITIAL CONDITIONS
DO 17 I=2,IC
DO 16 K=2,M
R(K,I,1)=BIC(K)
16 CONTINUE
17 CONTINUE
C SHOCK WAVE
SW(1)=100.0
SW(2)=0.0
SW(3)=1.13
PRES=1.323
DENS=1.221
TEMP=1.084
SPEED=SQRT(TEMP)
D1=BIC(9)
S1=BIC(5)
T1=BIC(10)
Q0=(200.0)*(9.478E-4)*(28.32)
Q=(Q0/D1)*(1.0/32.1739)
DS=Q/T1
T2=Q/CV+T1
P2=D1*R*T2
A2=SQRT(G*R*T2)/A

```

```

SZ=DS/G/RR+S1
SW(4)=CC*(SW(3)-1.0/SW(3))+BIC(3)
SW(5)=BIC(3)
SW(6)=PRES*BIC(8)
SW(7)=BIC(8)
SW(8)=DENS*BIC(9)
SW(9)=BIC(9)
SW(10)=TEMP*BIC(10)
SW(11)=BIC(10)
SW(12)=SPEED*BIC(4)
SW(13)=BIC(4)
SH=CP*ALOG(TEMP)-RR*ALOG(PRES)
SW(14)=SH/G/RR+BIC(5)
SW(15)=BIC(5)
SW(16)=BIC(6)
SW(17)=BIC(7)
SW(18)=BIC(11)
SL(1)=SW(1)-DIS
SR(1)=SW(1)+DIS
DO 32 IK=2,N
SL(IK)=SW(IK)
SR(IK)=SW(IK)
32 CONTINUE
SL(3)=-SW(3)
SL(4)=SW(5)+(2.0/(G+1.0))*(SL(3)-1.0/SL(3))
C CONTACT SURFACE
YA=PRES-1.0
YB=2. C/G
YC=(G+1.0)*PRES
YD=G-1.0
YF=YA*SQRT(YB/(YC+YD))
YF=0. C
CSL(1)=SL(1)
CSL(2)=SL(2)
CSL(3)=U-YF
CSL(4)=-1.0
CSR(1)=SR(1)
CSR(2)=SR(2)
CSR(3)=U+YF
CSR(4)=+1.0
WRITE(6,300)
300 FORMAT(8X,'LOCATION',8X,'TIME',8X,'MACH',10X,'U2',10X,'U1',10X,
1 'P2',10X,'P1',9X,'R02',9X,'R01')
WRITE(6,301)
301 FORMAT(14X,'T2',10X,'T1',10X,'A2',10X,'A1',10X,'S2',10X,'S1',
1 7X,'DS/DT',4X,'DIAMETER',4X,'FRICTION')
WRITE(6,109) (SW(I),I=1,18)
WRITE(6,109) SL
WRITE(6,109) SR
109 FORMAT(1X,'SW=',2X,9(2X,E10.4),2X,'MAIN')/
DO 33 IK=1,II
HL=SW(1)-DIS
HR=SW(1)+DIS
HHX=P(1,IK,1)
KK=0
IF(HHX.GT.HL.AND.HHX.LT.HR) KK=1

```

```

      IF (HHX.EQ.HL.OR.HHX.EQ.MR) KK=-1
      IF (KK) 35,33,34
34    P(4,IK,1)=A2
      P(5,IK,1)=S2
      P(8,IK,1)=P2
      P(10,IK,1)=T2
      GO TO 33
35    P(4,IK,1)=SPEED*BIC(4)
      BH=CP*ALOG(TEMP)-RR*ALOG(PRES)
      P(5,IK,1)=BH/G/RR+BIC(5)
      P(8,IK,1)=PRES*BIC(8)
      P(9,IK,1)=DENS*BIC(9)
      P(10,IK,1)=TEMP*BIC(10)
33    CONTINUE
      U=XNN*U
C SOLUTION
      IS=ISEG/2
      IW=IS+1
      DO 13 J=1,MJ
      DO 12 IZ=1,MI
      I=IW-IZ
      IF (IZ.GE.IW) I=IZ
      DO 10 K=1,M
      X1(K)=P(K,I,J)
      IP2 = I+2
      X2(K)=P(K,IP2,J)
10    CONTINUE
      DO 30 LI=1,N
      WL(LI)=SL(LI)
      WR(LI)=SR(LI)
30    CONTINUE
      CALL FIG(M,X1,X2,X3,WL,WR)
      DO 31 LI=1,N
      SL(LI)=WL(LI)
      SR(LI)=WR(LI)
31    CONTINUE
      DO 11 K=1,M
      IP1 = I+1
      JP1 = J+1
      P(K,I,J)=X1(K)
      P(K,IP2,J)=X2(K)
      P(K,IP1,JP1) = X3(K)
11    CONTINUE
12    CONTINUE
13    CONTINUE
C END SOLUTION
C PRINTOUT
      WRITE (6,1)
1    FORMAT(1H1,6X,'ARRAY P(K,I,J)')
      WRITE (6,200) XNN
200  FORMAT(2X,'XNN=',F10.3)
      DO 20 J=1,JJ,10
      DO 19 I=1,II
      WRITE (6,2)(I,J,(P(K,I,J),K=1,M))
2    FORMAT(2X,I3,2X,I3,12(2X,E8.3))
19    CONTINUE
      END

```

```

SUBROUTINE RAN(NN,BB1,BB2,PR,XX)
COMMON /DDD/ G,CP,CV,RF,R,RR,U,A,CA,CB,CC,HX,AZ,ZERO,F,XL
DIMENSION BB1(NN),BB2(NN)
XA=1.0/((G+1.0)/(G-1.0))*PR
XB=(G-1.0)/(G+1.0)*PR
BB2(1)=BB1(1)
BB2(2)=BB1(2)
BB2(6)=BB1(6)
BB2(7)=BB1(7)
BB2(8)=PR*BB1(8)
BB2(9)=BB1(9)*(XA/XB)
BB2(10)=BB1(10)*PR*(XB/XA)
BB2(11)=BB1(11)
V1=SQRT(CA+CB*PR)
V2=V1*(BB1(9)/BB2(9))
BB2(3)=U+XX*(V1-V2)
BB2(4)=SQRT(G*R*BB2(10))/A
BH=CP*ALOG(BB2(10)/BB1(10))-RR*ALOG(PR)
BB2(5)=BH/G/RR+BB1(5)
RETURN
END

```

```

SUBROUTINE SUB(N,A,B,C)
COMMON /DLL/ CSL,CSR,SL,SR
DIMENSION A(N),B(N),C(N)
NM=0
CALL CCS(N,A,B,C,CSL,NM)
IF(NM) 109,109,107
109 CONTINUE
MM=0
CALL CCS(N,A,B,C,CSR,MM)
IF(MM) 110,110,107
110 CONTINUE
CALL SSS(N,A,B,C)
107 CONTINUE
END

```

```

SUBROUTINE COM(NN,C1,C2,C3)
DIMENSION C1(NN),C2(NN),C3(NN)
P=(C2(1)-C1(1))/(C3(1)-C1(1))
DO 10 I=3,NN
C2(I)=P*C3(I)+(1.0-P)*C1(I)
10 CONTINUE
RETURN
END

```

```

SUBROUTINE PPP(NN,AA1,AA3)
COMMON /DDD/ G,CP,CV,RF,R,RR,U,A,CA,CB,CC,HX,AZ,ZERO,F,XL
DIMENSION AA1(NN),AA3(NN)
C1=(2.0/(G-1.0))*((AA3(4)-AA1(4))/((AA3(4)+AA1(4))/2.0))
C2=(AA3(5)-AA1(5))*G
AA3(9)=AA1(9)*(C1-C2+1.0)
AA3(10)=A*A*AA3(4)*AA3(4)/G/R
AA3(8)=AA3(9)*R*AA3(10)
RETURN
END

```

```

SUBROUTINE CHKL(NN,AA1,AA2,AA3,AA4,SW,10)
COMMON /DDD/ G,CP,CV,RF,R,RR,U,A,CA,CB,CC,HX,AZ,ZERO,F,XL
PARAMETER M=12, N=18
DIMENSION B2(M),B3(M),C1(M),C3(M),D1(M),D2(M)
DIMENSION AA1(NN),AA2(NN),AA3(NN),AA4(NN),SW(N)
DIMENSION E2(M),E3(M),G1(M),F2(M)
IDD=0
IDR=0
IDL=0
IDD=0

SK=(AA2(2)-AA1(2))/(AA2(1)-AA1(1))
BK=AA1(2)-SK*AA1(1)
CALL GEO(NN,AA1,AA2,AA3,AA4)
CALL SIML(NN,AA3,AA2,SW,C3,IDR)
IF(IDR) 101,101,100
100 RA=AA2(3)+AA2(4)
SA=1.C/RA
BA=C3(2)-SA*C3(1)
C1(1)=(BA-BK)/(SK-SA)
C1(2)=SK*C1(1)+BK
CALL COM(NN,AA1,C1,AA2)
CALL SUB(NN,C1,AA2,C3)
SW(5)=C3(3)
SW(7)=C3(8)
SW(9)=C3(9)
SW(11)=C3(10)
SW(13)=C3(4)
SW(15)=C3(5)
SH=CP*ALOG(SW(10)/SW(11))-RR*ALOG(SW(6)/SW(7))
SW(14)=SH/G/RR+SW(15)
WRITE(6,109) (SW(I),I=1,18)
109 FORMAT(1X,'SW=',2X,9(2X,E10.4),2X,'109L')/)
PR=SW(6)/SW(7)
CALL RAN(NN,C3,D2,PR,XN)
CALL SIML(NN,AA1,AA3,SW,B3,IDL)
IF(IDL) 104,104,103
103 RB=AA1(3)-AA1(4)
SB=1.C/RB
BB=B3(2)-SB*B3(1)
B2(1)=(BB-BK)/(SK-SB)
B2(2)=SK*C1(1)+BK
CALL COM(NN,AA1,B2,AA2)
CALL SUB(NN,AA1,B2,B3)
SW(5)=B3(3)
SW(7)=B3(8)
SW(9)=B3(9)
SW(11)=B3(10)
SW(13)=B3(4)
SW(15)=B3(5)
SH=CP*ALOG(SW(10)/SW(11))-RR*ALOG(SW(6)/SW(7))
SW(14)=SH/G/RR+SW(15)
WRITE(6,110) (SW(I),I=1,18)
110 FORMAT(1X,'SW=',2X,9(2X,E10.4),2X,'110L')/)
PR=SW(6)/SW(7)
CALL RAN(NN,B3,D1,PR,XN)
GO TO 104
101 CALL SIML(NN,AA1,AA3,SW,E3,IDD)
IF(IDD) 104,104,99
99 F2(1)=SW(1)
F2(2)=SW(2)
F2(3)=SW(5)
F2(4)=SW(13)

```

```

F2(5)=SW(15)
F2(6)=SW(16)
F2(7)=SW(17)

F2(8)=SW(7)
F2(9)=SW(9)
F2(10)=SW(11)
F2(11)=SW(18)
F2(12)=-1.0
RC=AA1(3)-AA1(4)
SC=1./RC
BC=E3(2)-SC*E3(1)
SS=(F2(2)-AA1(2))/(F2(1)-AA1(1))
BS=AA1(2)-SS*AA1(1)
E2(1)=(BS-BC)/(SC-SS)
E2(2)=SS*E2(1)+BS
CALL COM(NN,AA1,E2,F2)
CALL SUB(NN,AA1,E2,E3)
SW(5)=E3(3)
SW(7)=E3(8)
SW(9)=E3(9)
SW(11)=E3(10)
SW(13)=E3(4)
SW(15)=E3(5)
SH=CP+ALOG(SW(10)/SW(11))-RR+ALOG(SW(6)/SW(7))
SW(14)=SH/G/RR+SW(15)
WRITE(6,111)(SW(I),I=1,18)
111 FORMAT(1X,'SW=',2X,9(2X,E10.4),2X,'111L')/
PR=SW(6)/SW(7)
CALL FAN(NN,E3,G1,PR,XN)
104 IF(IDR.LE.0.AND.IDD.LE.0)GO TO 105
IF(IDR.GT.0.AND.IDL.LE.0)GO TO 106
IF(IDR.GT.0.AND.IDL.GT.0)GO TO 107
IF(IDR.LE.0.AND.IDD.GT.0)GO TO 108
106 CALL SUB(NN,AA1,D2,AA3)
ID=106
GO TO 105
107 CALL SUB(NN,D1,D2,AA3)
ID=107
GO TO 105
108 CALL SUB(NN,G1,AA2,AA3)
ID=108
105 RETURN
END

```

```

SUBROUTINE CHKR(NN,AA1,AA2,AA3,AA4,SW,ID)
COMMON/7DDD/G,CP,CV,RF,R,RR,U,A,CA,CB,CC,HX,AZ,ZERO,F,XL
PARAMETER M=12, N=18
DIMENSION B2(M),B3(M),C1(M),C3(M),D1(M),D2(M)
DIMENSION AA1(NN),AA2(NN),AA3(NN),AA4(NN),SW(N)
DIMENSION E1(M),E3(M),G2(M),F1(M)
ID=0
IDL=0
IDR=0
IDD=0

```

```

XN=1.C
SK=(AA2(2)-AA1(2))/(AA2(1)-AA1(1))
BK=AA1(2)-SK*AA1(1)
CALL GEO(NN,AA1,AA2,AA3,AA4)
CALL SIMR(NN,AA1,AA3,SW,B3,IDL)
IF(IDL) 101,101,100
100 RA=AA1(3)-AA1(4)
SA=1.C/RA
BA=B3(2)-SA*B3(1)
B2(1)=(BA-BK)/(SK-SA)
B2(2)=SK*B2(1)+BK
CALL COM(NN,AA1,B2,AA2)
CALL SUB(NN,AA1,B2,B3)
SW(5)=B3(3)
SW(7)=B3(8)
SW(9)=B3(9)
SW(11)=B3(10)
SW(13)=B3(4)
SW(15)=B3(5)
SH=CP*ALOG(SW(10)/SW(11))-RR*ALOG(SW(6)/SW(7))
SW(14)=SH/G/RR+SW(15)
WRITE(6,109) (SW(I),I=1,18)
109 FORMAT((1X,'SW=',2X,9(2X,E10.4),2X,'109R'//)
PR=SW(6)/SW(7)
CALL FAN(NN,B3,D1,PR,XN)
CALL SIMR(NN,AA3,AA2,SW,C3,IDR)
IF(IDR) 104,104,103
103 RB=AA2(3)+AA2(4)
SB=1.C/RB
BB=C3(2)-SB*C3(1)
C1(1)=(BB-BK)/(SK-SB)
C1(2)=SK*C1(1)+BK
CALL COM(NN,AA1,C1,AA2)
CALL SUB(NN,C1,AA2,C3)
SW(5)=C3(3)
SW(7)=C3(8)
SW(9)=C3(9)
SW(11)=C3(10)
SW(13)=C3(4)
SW(15)=C3(5)
SH=CP*ALOG(SW(10)/SW(11))-RR*ALOG(SW(6)/SW(7))
SW(14)=SH/G/RR+SW(15)
WRITE(6,110) (SW(I),I=1,18)
110 FORMAT((1X,'SW=',2X,9(2X,E10.4),2X,'110R'//)
PR=SW(6)/SW(7)
CALL FAN(NN,C3,D2,PR,XN)
GO TO 104
101 CALL SIMR(NN,AA3,AA2,SW,E3,IDD)
IF(IDD) 104,104,99
99 F1(1)=SW(1)
F1(2)=SW(2)
F1(3)=SW(5)
F1(4)=SW(13)
F1(5)=SW(15)
F1(6)=SW(16)
F1(7)=SW(17)

```

```

F1(8)=SW(3)
F1(10)=SW(11)
F1(11)=SW(18)
F1(12)=-1.0
RC=AA2(3)+AA2(4)
SC=1.0/RC
BC=E3(2)-SC*E3(1)
SS=(F1(2)-AA2(2))/(F1(1)-AA2(1))
BB=AA2(2)-SS*AA2(1)
E1(1)=(BB-BC)/(SC-SS)
E1(2)=SS*E1(1)+BB
CALL COM(NN,F1,E1,AA2)
CALL SUB(NN,E1,AA2,E3)
SW(5)=E3(3)
SW(7)=E3(8)
SW(9)=E3(9)
SW(11)=E3(10)
SW(13)=E3(4)
SW(15)=E3(5)
SH=CP*ALOG(SW(10)/SW(11))-RR*ALOG(SW(6)/SW(7))
SW(14)=SH/G/RR+SW(15)
WRITE(6,111) (SW(I),I=1,18)
111 FORMAT(1X,'SW=',2X,9(2X,E10.4),2X,'111R'//)
PR=SW(6)/SW(7)
CALL RAN(NN,E3,G2,PR,XN)
104 IF(IDL.LE.0.AND.IDD.LE.0) GO TO 105
IF(IDL.GT.0.AND.IDR.LE.0) GO TO 106
IF(IDL.GT.0.AND.IDR.GT.0) GO TO 107
IF(IDL.LE.0.AND.IDD.GT.0) GO TO 108
106 CALL SUB(NN,D1,AA2,AA3)
ID=106
GO TO 105
107 CALL SUB(NN,D1,D2,AA3)
ID=107
GO TO 105
108 CALL SUB(NN,AA1,G2,AA3)
ID=108
105 RETURN
END

```

```

SUBROUTINE GEO(NN,AA1,AA2,AA3,AA4)
DIMENSION AA1(NN),AA2(NN),AA3(NN),AA4(NN)
R13=(AA1(3)+AA1(4)+AA3(3)+AA3(4))/2.0
S13=1.0/R13
R23=(AA2(3)-AA2(4)+AA3(3)-AA3(4))/2.0
S23=1.0/R23
B13=AA1(2)-S13*AA1(1)
B23=AA2(2)-S23*AA2(1)
AA3(1)=(B23-B13)/(S13-S23)
AA3(2)=S13*AA3(1)+B13
S12=(AA1(2)-AA2(2))/(AA1(1)-AA2(1))
B12=AA1(2)-S12*AA1(1)
R34=(AA3(3)+AA4(3))/2.0
S34=1.0/R34
B34=AA3(2)-S34*AA3(1)
AA4(1)=(B12-B34)/(S34-S12)
AA4(2)=S34*AA4(1)+B34
PF=(AA2(1)-AA4(1))/(AA2(1)-AA1(1))
AA4(5)=(1.0-PF)*AA2(5)+PF*AA1(5)

```

C HEATING

```

XK=0.0
EI=10.0
EO=15.0
AA3(6)=0.0
AA4(6)=0.0
IF(AA3(1).GE.EI.AND.AA3(1).LE.EO) AA3(6)=XK
IF(AA4(1).GE.EI.AND.AA4(1).LE.EO) AA4(6)=XK
PH=(AA2(1)-AA3(1))/(AA2(1)-AA1(1))
AA3(11)=(1.0-PH)*AA2(11)+PH*AA1(11)
AA3(7)=0.25
AA4(7)=0.25

```

RETURN
END

```

SUBROUTINE SIML(NN,AL,AR,SW,AA,ID)
COMMON /DDD/ G,CP,CV,RF,R,RR,U,A,CA,CB,CC,HX,AZ,ZERO,F,XL
PARAMETER N=18
DIMENSION AL(NN),AR(NN),SW(N),AA(NN)
ID=0
IF(AL(1).EQ.SW(1).AND.SW(2).EQ.AZ) GO TO 108
IF(AR(1).EQ.SW(1).AND.AR(2).EQ.SW(2)) GO TO 108
IF(AL(1).GT.SW(1)) GO TO 108
DDX=SW(1)-AR(1)
IF(DDX.GT.HX) GO TO 108
DIA=0.25
S=(AL(2)-AR(2))/(AL(1)-AR(1))
B=AL(2)-S*AL(1)
C INITIALISE
VAS = SW(3)
VA = SW(4)

```

```

      PA = SW(6)
      PP = SW(7)
      LL=0
101  CONTINUE
      VBS = VAS
      VB = VA
      PB = PA
      LL=LL+1
      LMAX=5
      LN=LL-LMAX
      IF(LN) 103,103,105
103  CONTINUE
      R2=0.5*(SW(3)+VBS)+SW(5)
      S2 = 1.0/R2
      B2 = SW(2)-S2*SW(1)
      AA(1)=(B2-B)/(S-S2)
      DIS=SW(1)-AA(1)

      IF(DIS.LT.ZERO) GO TO 108
      VAS=- (CA+CB*(PB/PP))*0.5
      VP=CC*(VAS-1.0/VAS)
      VA=VP+SW(5)
C CONTINUITY FOR A STANDING SHOCK
      V1=VAS
      V2=V1-VP
      D2=SW(9)*V1/V2
      X1=SW(6)/SW(8)
      X2=0.5*(SW(4)*SW(4)*A*A)
      X3=0.5*(VA*VA*A*A)*(1.0+DIS*F/DIA)
      PA=D2*(X1+X2-X3)
C TEST ROUTINE
      TX=0.025
      II=0
      RV=(VA-VB)/VA
      RP=(PA-PB)/PA
      IF(ABS(RV).GT.TX) II=II+1
      IF(ABS(RP).GT.TX) II=II+1
      IF(II) 102,102,101
102  CONTINUE
105  CONTINUE
      IF(AA(1).GE.AL(1).AND.AA(1).LT.AR(1)) IO=1
      IF(IO) 108,108,107
107  AA(2)=S*AA(1)+B
C REDEFINE SHOCK
      SW(1)=AA(1)
      SW(2)=AA(2)
      SW(3)=VAS
      SW(4)=VA
      SW(6)=PA
      SW(8)=D2
      SW(10)=PA/(D2*R)
      SW(12)=SQRT(G*R*SW(10))/A
      SW(16)=0.0
      SW(17)=0.25
      SW(18)=0.2
109  FORMAT(1X,'SW=',2X,9(2X,E10.4),2X,'SIML')/
      IF(LN) 108,108,104

```

```

104 CONTINUE
WRITE (6,106) TX,RV,RP,SW(1),SW(2),LMAX
106 FORMAT(1X,5(2X,E10.4),3X,'LMAX=',I5,2X,'SIML')
108 CONTINUE
RETURN
END

```

```

SUBROUTINE SOL(NN,AA1,AA2,AA3,AA4,HH3)
COMMON /DDD/ G,CP,CV,RF,R,RR,U,A,CA,CB,CC,HX,AZ,ZERO,F,XL
DIMENSION AA1(NN),AA2(NN),AA3(NN),AA4(NN),HH3(NN)
DO 10 I=1,NN
HH3(I)=AA3(I)
10 CONTINUE
S4=AA4(5)
DS43=(AA4(6)+HH3(6))/2.0
T3=HH3(2)
T2=AA2(2)
P1=(2.0/(G-1.0))*AA1(4)+AA1(3)
Q2=(2.0/(G-1.0))*AA2(4)-AA2(3)
A13=(AA1(4)+HH3(4))/2.0
A23=(AA2(4)+HH3(4))/2.0
U13=(AA1(3)+HH3(3))/2.0
U23=(AA2(3)+HH3(3))/2.0
D3=HH3(7)
D1=AA1(7)
D2=AA2(7)
E3=HH3(1)
E1=AA1(1)
E2=AA2(1)
DS13=(AA1(6)+HH3(6))/2.0
DS23=(AA2(6)+HH3(6))/2.0
F13=(AA1(11)+HH3(11))/2.0
F23=(AA2(11)+HH3(11))/2.0
D13=(AA1(7)+HH3(7))/2.0
D23=(AA2(7)+HH3(7))/2.0
T3=HH3(2)
T1=AA1(2)
T2=AA2(2)
T4=AA4(2)
S1=AA1(5)
S2=AA2(5)
S3=S4+DS43*(T3-T4)
P3=P1+(G-1.0)*A13*DS13
1 -(F13*XL/(2.0*D13))*U13*ABS(U13))*(T3-T1)+A13*(S3-S1)
Q3=Q2+(G-1.0)*A23*DS23
1 -(F23*XL/(2.0*D23))*U23*ABS(U23))*(T3-T2)+A23*(S3-S2)
AA3(3)=(P3-Q3)/2.0
AA3(4)=(G-1.0)*(P3+Q3)/4.0
AA3(5)=S3
20 FORMAT(2X,3(3X,E20.12))
RETURN
END

```

```

SUBROUTINE EIG(NNN,AAA1,AAA2,AAA3,SWL,SWR)
PARAMETER N=18
DIMENSION AAA1(NNN),AAA2(NNN),AAA3(NNN)
PARAMETER NX=15
DIMENSION AA1(NX),AA2(NX),AA3(NX),AA4(NX)
DIMENSION SWL(N),SWR(N)
NN=NNN
DO 10 I=1,NN
AA1(I)=AAA1(I)
AA2(I)=AAA2(I)
10 CONTINUE
IF(AA1(2).LT.(0.0)) AA1(2)=AA2(2)
IF(AA2(2).LT.(0.0)) AA2(2)=AA1(2)
AA3(3)=(AA1(3)+AA2(3))/2.0
AA3(4)=(AA1(4)+AA2(4))/2.0
AA4(3)=AA3(3)
NM=0
CALL CHKR(NN,AA1,AA2,AA3,AA4,SWR,NM)
IF(NM) 109,109,107
109 CONTINUE
MM=0
CALL CHKL(NN,AA1,AA2,AA3,AA4,SWL,MM)
IF(MM) 110,110,107
110 CONTINUE
CALL SUB(NN,AA1,AA2,AA3)
107 CONTINUE

DO 11 I=1,NN
AAA1(I)=AA1(I)
AAA2(I)=AA2(I)
AAA3(I)=AA3(I)
11 CONTINUE
WRITE(6,2) AAA3
2 FORMAT(1X,12(2X,E8.3))
RETURN
END

```

```

SUBROUTINE SIMR(NN,AL,AR,SW,AA,ID)
COMMON 7000/6,CP,CV,RF,R,RR,0,A,CA,CB,CC,HX,AZ,ZERO,F,XL
PARAMETER N=18
DIMENSION AL(NN),AR(NN),SW(N),AA(NN)
ID=0
IF(AR(1).EQ.SW(1).AND.SW(2).EQ.AZ) GO TO 108
IF(AL(1).EQ.SW(1).AND.AL(2).EQ.SW(2)) GO TO 108
IF(AR(1).LT.SW(1)) GO TO 108
DDX=AL(1)-SW(1)
IF(DDX.GT.HX) GO TO 108
DIA=0.25
S=(AL(2)-AR(2))/(AL(1)-AR(1))
B=AL(2)-S*AL(1)
C INITIALISE
VAS = SW(3)
VA = SW(4)

```

```

PA = SW(6)
PP=SW(7)
LL=0
101 CONTINUE
VBS = VAS
VB = VA
PB = PA
LL=LL+1
LMAX=5
LN=LL-LMAX
IF(LN) 103,103,105
103 CONTINUE
R2=0.5*(SW(3)+VBS)+SW(5)
S2 = 1.0/R2
B2 = SW(2)-S2*SW(1)
AA(1)=(B2-B)/(S-S2)
DIS=AA(1)-SW(1)
IF(DIS.LT.ZERO) GO TO 108
VAS = (CA+CB*(PB/PP))*0.5
VP=CC*(VAS-1.0/VAS)
VA=VP+SW(5)
C CONTINUITY FOR A STANDING SHOCK
V1=VAS
V2=V1-VP
D2=SW(9)*V1/V2
X1=SW(6)/SW(8)
X2=0.5*(SW(4)*SW(4)*A*A)
X3=0.5*(VA*VA*A*A)*(1.0+DIS*F/DIA)
PA=D2*(X1+X2-X3)
C TEST ROUTINE
TX=0.025
II=0
RV=(VA-VB)/VA
RP=(PA-PB)/PA
IF(ABS(RV).GT.TX) II=II+1
IF(ABS(RP).GT.TX) II=II+1
IF(II) 102,102,101
102 CONTINUE
105 CONTINUE
IF(AA(1).GT.AL(1).AND.AA(1).LE.AR(1)) ID=1
IF(ID) 108,108,107
107 AA(2)=S*AA(1)+B
C REDEFINE SHOCK
SW(1)=AA(1)
SW(2)=AA(2)
SW(3)=VAS
SW(4)=VA
SW(6)=PA
SW(8)=D2
SW(10)=PA/(D2*R)
SW(12)=SQRT(G*R*SW(10))/A
SW(16)=0.0
SW(17)=0.25
SW(18)=0.2
109 FORMAT(1X,'SW=',2X,9(2X,E10.4),2X,'SIMR')/
IF(LN) 108,108,104

```

```

SUBROUTINE CCS(M,X,Y,Z,FACE,IN)
PARAMETER NZ=4
PARAMETER NX=15
DIMENSION X(M),Y(M),Z(M)
DIMENSION FACE(NZ),AB(NX),YY(NX)
IN=0
XHX=4.0
IF(Y(1).LT.FACE(1)) GO TO 200
XXL=X(1)-FACE(1)
IF(XXL.GT.XHX) GO TO 200
IF(X(1).EQ.FACE(1).AND.X(2).EQ.FACE(2)) GO TO 200
IF(Y(1).EQ.FACE(1).AND.Y(2).EQ.FACE(2)) GO TO 200
Z(3)=(X(3)+Y(3))/2.0
Z(4)=(X(4)+Y(4))/2.0
AB(3)=Z(3)

```

```

C RIGHT FACE ONLY
CALL GEOM(M,X,Y,Z,AB)
S23=(Z(2)-Y(2))/(Z(1)-Y(1))
B23=Y(2)-S23*Y(1)
RCS=FACE(3)
SCS=1.0/RCS
BCS=FACE(2)-SCS*FACE(1)
E=(BCS-B23)/(S23-SCS)
T=S23*E+B23
IF(E.GE.Z(1).AND.E.LE.Y(1)) GO TO 101
GO TO 102
101 CONTINUE
IN=101
PL=(2.0/(G-1.0))*X(4)+X(3)
QR=(2.0/(G-1.0))*Y(4)-Y(3)
SL=X(5)
SR=Y(5)
CAL=0.25*(G-1.0)*(SL-SR)
QL=(PL+QR)*TANH(CAL)+QR
PR=(QR-QL)+PL
V=(PR-QL)/2.0
C=0.25*(G-1.0)*(PR+QL)
YY(1)=E
YY(2)=T
YY(3)=V
YY(4)=C
YY(5)=X(5)
YY(6)=0.0
YY(7)=0.25
YY(11)=0.2
CALL SSS(M,X,YY,Z)
FACE(1)=E
FACE(2)=T
FACE(3)=V
WRITE(6,1) FACE
1   FORMAT(1X,4(2X,E10.4),2X,'INTERFACE')
102 CONTINUE
200 CONTINUE
RETURN
END

```

```

104 CONTINUE
WRITE (6,106) TX,RV,RP,SW(1),SW(2),LMAX
106 FORMAT(1X,5(2X,E10.4),3X,'LMAX=',I5,2X,'SIMR')
108 CONTINUE
RETURN
END

```

```

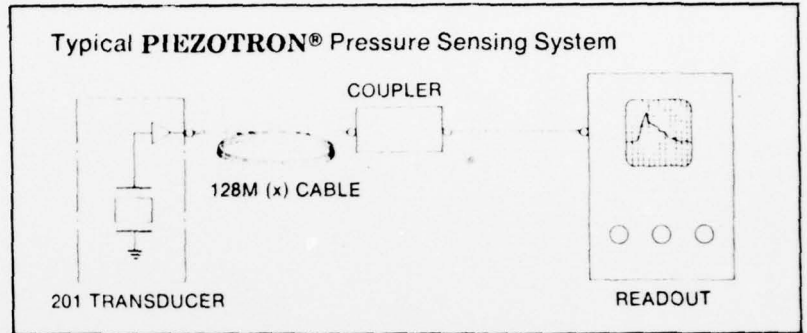
SUBROUTINE SSS(NN,AA1,AA2,AA3)
DIMENSION AA1(NN),AA2(NN),AA3(NN)
DIMENSION HH3(15),AA4(15)
AA4(3)=AA3(3)
AA3(3)=(AA1(3)+AA2(3))/2.0
AA3(4)=(AA1(4)+AA2(4))/2.0
LL=0
101 CONTINUE
LL=LL+1
JMAX=5
LN=LL-LMAX
IF(LN) 103,103,105
103 CONTINUE
CALL GEO(NN,AA1,AA2,AA3,AA4)
CALL SOL(NN,AA1,AA2,AA3,AA4,HH3)
C TEST ROUTINE
TX=0.001
II=0
RV=(AA3(3)-HH3(3))/AA3(3)
RA=(AA3(4)-HH3(4))/AA3(4)
IF(ABS(RV).GT.TX) II=II+1
IF(ABS(RA).GT.TX) II=II+1
IF(II) 102,102,101
102 CONTINUE
GO TO 104
105 WRITE (6,106) TX,RV,RA,AA3(1),AA3(2),LMAX
106 FORMAT(1X,5(2X,E10.4),3X,'LMAX=',I5,2X,'SSS')

104 CONTINUE
CALL PPP(NN,AA1,AA3)
AA3(12)=LL
RETURN
END

```

APPENDIX D

201 SERIES MINI-GAGE



Couplers

To complete the system a wide choice of couplers is offered in the 548 and 549 series. Optional filters and several types of power inputs are available. Model 587D Coupler provides increased capability. Please refer to our Coupler Data Sheet for details.

In addition Models 583, 503D and 504D Laboratory Amplifiers are offered with extensive versatility and many options for more complete pressure studies.

Specifications	UNITS	Model Variation			
		201B1	201B2	201B4	201B5
PERFORMANCE					
Pressure Range, 5V out	psi	5,000	500	200	100
Ovrange	psi	7,500	750	300	150
Resolution (noise)	psi rms	0.05	0.005	0.002	0.001
Maximum Pressure	psi	15,000	5,000	2,000	1,000
Sensitivity	mV/psi	1	10	25	50
Linearity, B.F.S.L.	%	-1	-1	-1	±1
Resonant Frequency, nom.	kHz	500	500	500	250
Rise Time, 10-90%	µ sec	1	1	1	2
Time Constant, R.T.	sec	1,500	400	200	100
Low Frequency Response, -5%	Hz	0.0003	0.001	0.0025	0.005
High Frequency Response, +5%	Hz	100,000	100,000	100,000	50,000
ENVIRONMENTAL					
Common Specs					
Vibration Sensitivity, max.	psi/g	0.002	0.002	0.002	0.002
Shock, 1 ms	g	5,000	5,000	5,000	5,000
Vibration Limit	g	500	500	500	500
Temperature Range	F	-65 to 280	-65 to 280	-65 to 280	-65 to 280
Temperature Sensitivity Shift	/ F	0.03%	0.03%	0.03%	0.03%
ELECTRICAL					
Output Current, min.	mA	2	2	2	2
Polarity, pressure increase		Negative	Negative	Negative	Negative
Bias Voltage	V	11 ± 2	11 ± 2	11 ± 2	11 ± 2
Circuit Return		Case	Case	Case	Case
Output Impedance, max.	ohms	100	100	100	100
MECHANICAL					
Weight	gms	< 10	< 10	< 10	< 10
Case and Diaphragm Material		Stainless St.	Stainless St.	Stainless St.	Stainless St.
Mounting Torque	in-lb	24	24	24	24
Sealing		All Welded	All Welded	All Welded	All Welded
POWER SUPPLY					
Constant Current Source	mA	4 ± 1	4 ± 1	4 ± 1	4 ± 1
Supply Ripple, max.	mV rms	25	25	25	25
Supply Voltage, no load	VDC	20-30	20-30	20-30	20-30
Source Impedance, nom.	ohms	250 k	250 k	250 k	250 k