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THEORETICAL AND EXPERIMENTAL ANALYSIS OF THE CONSTANT-AREA, SUPERSONIC-SUPERSONIC EJECTOR

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by

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A preliminary theoretical and experimental analysis was conducted of the constant-area, supersonic-supersonic ejector wherein one supersonic stream is pumped directly by another inside a confining duct. The theoretical analysis, based on a one-dimensional treatment of the constant-area mixing section and inviscid interaction region, is well suited to parametric evaluations and ejector optimization procedures. The experimental investigation of four, small-scale, axisymmetric ejector configuarations show (i) that the one-dimensional

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theory predicts maximum ejector compression ratios which are approximately 15 to 20 percent higher than the corresponding experimental values and (ii) that this ejector appears to be particularly susceptible to secondary flow separation.

The one-dimensional analysis of the constant-area, supersonic-supersonic ejector was incorporated with a one-dimensional analysis of the conventional constant-area, subsonic-supersonic ejector into a pumping system optimization procedure applicable to high-energy, chemical laser systems and supersonic wind tunnel systems. A comparison of optimum pumping system data shows that under certain conditions, a supersonic-supersonic pumping system has the potential for improved performance over that of a subsonic-supersonic pumping system.

THEORETICAL AND EXPERIMENTAL ANALYSIS OF THE CONSTANT-AREA, SUPERSONIC-SUPERSONIC EJECTOR*

Final Technical Report

by

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NOMENCLATURE

Symbols

A	Area.
C_P	Specific heat at constant pressure.
C_V	Specific heat at constant volume.
D	Diameter.
$f_1(\ ),\cdots,f_4(\ )$	Gas dynamic functions defined in text.
F	Force.
g	Gravitational constant.
h	Specific enthalpy.
M	Mach number.
Mw	Molecular weight.
P	Pressure.
Q	Heat.
r	Radial coordinate.
R	Radius.
Re	Reynolds number.
R	Universal gas constant.
t	Time.
T	Temperature.
u	Specific internal energy.
v	Volume.
V	Magnitude of velocity.
W	Mass flow rate.
W_{ss}	Work, shaft and shear.
x	Longitudinal coordinate or flow-direction coordinate.

z	Elevation.
γ	Ratio of specific heats.
μ	Absolute viscosity.
ρ	Density.
$( )^*$	Signifies state at which the Mach number is unity.

Subscripts

0	Stagnation state.
1,2,3	System locations.
CS	Control surface.
CV	Control volume.
M	Mixed.
P	Primary.
S	Secondary.
T	Nozzle throat.
$( )_x$	Signifies quantity in the flow direction coordinate.

For Sections 4.2 and 4.3 only:

Symbols

f( )	Gas dynamic functions defined in text.
R_{NSD}	Normal shock diffuser coefficient.
η	Subsonic diffuser efficiency.

Subscripts

1	Laser cavity entrance location.
2	Laser cavity exit location.
3	Normal shock diffuser exit and subsonic diffuser entrance location

4	Subsonic diffuser exit location.
5	Secondary nozzle exit location.
6	Primary nozzle exit location.
7	Mixing tube exit and subsonic diffuser entrance location.
8	Subsonic diffuser exit location.

1.0 INTRODUCTION

This theoretical and experimental analysis of the constant-area, supersonic-supersonic ejector was prompted by current interest in the high-energy, chemical laser and the unique gas dynamic problems associated with that device.

In a typical high-energy, chemical laser, Figs. 1.0-1 and 1.0-2, hydrogen and flourine are precombusted to form free flourine atoms which, with the other gaseous products of combustion, accelerate into the laser cavity through a series of supersonic nozzles. Additional streams of secondary gases enter the laser cavity through a series of supersonic nozzles to form alternate interleaved streams of precombustor and secondary gases. These streams, initially at high Mach numbers (3 to 7) and low static pressures (5 to 200 Torr) mix and react to establish the lasing zone by chemically producing population inversions of selected species. Accompanying these chemical reactions, a significant quantity of heat is released into the laser cavity flow which tends, qualitatively, to increase the static pressure, to decrease the stagnation pressure, and to decrease the Mach number of the "mixed" supersonic flow. At the laser cavity exit, the hot ($T \simeq 1500$ K), corrosive, supersonic ($1.5 < M < 3.5$) "mixed" flow at low pressure ($10 < P < 60$ Torr) must be "pumped" by some form of diffuser-ejector system to atmospheric discharge conditions (760 Torr) in order to start and sustain the lasing process. A pumping system which is ideally suited to this application would have:

1. A potential compression ratio in the range 80 to 8,
2. Simplicity of design with high resistance to hot, corrosive gases,

3. The capability to isolate the laser cavity flow from minor perturbations in the downstream conditions and/or pumping system,
4. The flexibility in operating point and performance to allow for variations in laser performance and flow conditions,
5. The capability for short-duration, transient start-up,
6. Minimum pumping resource requirements, and
7. Compact design with portability and mobility as goals.

Current high-energy chemical laser designs have incorporated the constant-area, supersonic diffuser coupled with the constant-area,subsonic-supersonic ejector, Fig. 1.0-3, as a pumping system since the operation of this system is fairly well understood while providing the most obvious, if not satisfactory, solution to the above requirements. Nevertheless, the quest for an improved pumping system continues with various modifications of the conventional diffuser-ejector as candidates [1].

One such candidate for a high-performance chemical laser pumping system is the supersonic-supersonic ejector, Fig. 1.0-4, the subject of this investigation. In this system, the diffuser is eliminated and the supersonic laser cavity stream is pumped directly by the ejector. Thus, the supersonic-supersonic ejector offers a potential alternative in that the desirable characteristics of the conventional diffuser-ejector are retained with a reduction of size and a possible increase in performance.

1.1 REVIEW OF PREVIOUS WORK

The ejector has been in use for many years; indeed, the literature is filled with a virtual multitude of ejector related papers*, the author

*See APPENDIX 7.0.

having compiled over 300 entries dating from 1892. With the exception of three supersonic wind tunnel studies, none of these papers, to the author's knowledge, have addressed the problem of pumping a supersonic stream directly by an ejector, which is not particularly surprising since most commercial applications involve the pumping of subsonic or nearly stagnate streams.

The three wind tunnel studies [2,3,4] were part of an experimental investigation to study the effects of auxiliary air injection on the pressure recovery of variable geometry, supersonic wind tunnel systems. In each case, the auxiliary air was injected through a supersonic nozzle at the downstream end of the supersonic test section, thus in essence forming a supersonic-supersonic ejector. The first two investigations [2,3] showed that the resultant pressure recovery with injection was not as good as those attained with variable-geometry diffuser tunnels; however, the later study by Hasel and Sinclair [4] demonstrated a significant improvement in total system pressure recovery with auxiliary injection.

The general methods of analysis employed in existent subsonic-supersonic ejector models apply equally well to the supersonic-supersonic ejector provided their application is consistent with the physical phenomena. These methods of analysis are:

1. The one-dimensional analysis,
2. The method-of-characteristics,
3. The method of integral relations, and
4. The finite-difference method.

In the one-dimensional model of the subsonic-supersonic ejector as executed by Fabri, et al. [5,6], the conservation equations were applied

to a control volume contained within the ejector mixing tube assuming uniform velocity and pressure distributions of the primary and secondary streams at the tube entrance and a uniformly mixed stream at the tube exit. A second control volume was used to predict the operation of the ejector when the secondary stream choked within the mixing tube. The primary and secondary streams were assumed to remain distinct and to be isentropic from their point of confluence to the secondary choking location. Consequently, the condition that the static pressures be equal at the boundary between the primary and secondary streams is not satisfied.

A modified or quasi-one-dimensional model has also been applied to ejectors with short mixing tubes in which case the secondary and primary streams are assumed to remain distinct from entrance to exit [7].

Addy and Chow [8-11] developed a more sophisticated approach for the prediction of secondary stream choking within the mixing tube. In this model, the secondary stream was treated by the conventional methods of one-dimensional gas dynamics while the primary flow field was obtained from the two-dimensional method-of-characteristics for steady, irrotational, supersonic axisymmetric flows. This method allows the static pressures to be matched at the boundary of the streams since the primary stream may have a nonuniform pressure profile; although, the pressure must be uniform across the secondary stream. The simultaneous solution of the two flow fields satisfies the choking criteria, i.e., a Mach number of unity at the minimum flow area, was then corrected for viscous effects by superimposing the mixing layer on the inviscid boundary between the primary and secondary streams.

Howlett and Chow [12] added more detail to the Addy and Chow model using the method of integral relations for computation of the secondary stream but retaining the method-of-characteristics for the primary stream; the static pressure was matched at the boundary of the streams. The choking criteria for the secondary stream was developed based on a singularity in the integral relations describing the secondary flow.

Hill, et al. [13], applied the method of integral relations to both the secondary and primary streams but later [14,15] adopted a finite-difference model which does not attempt to separate the secondary and primary flows.

Each of the models discussed has its own particular advantages and disadvantages.

The one-dimensional model is well suited to broad-band parametric studies of ejector operation since:

1. It is computationally simple, each operating point being determined by the direct solution of a set of algebraic equations;
2. It applies equally well, at least in theory, to any constant-area ejector configurations; and
3. It is quite reliable as long as the assumption of one-dimensional or quasi-one-dimensional flow is satisfied.

The one-dimensional model has certain disadvantages in that:

1 It is restricted to the constant-area and constant-pressure ejectors where any pressure-area surface forces acting in the flow direction are eliminated from the momentum equation;

2. It may seriously error in flow regimes which are highly two-dimensional in nature;

3. It provides no insight into the actual flow phenomena; and
4. It requires some a priori knowledge of ejector operation to predict any limiting conditions such as choking of the secondary stream.

The method-of-characteristics, method of integral relations, and finite-difference models have all the advantages of sophistication in that:

1. They may be applied to all ejector configurations including variable-area geometries;
2. They provide field descriptions of increasing detail;
3. They satisfy the physical condition of continuity of static pressure across the boundary between the primary and secondary streams; and
4. They produce good results over all phases of ejector operation.

On the other hand, these models require:

1. Considerable knowledge, even empirical relations, taken from prior experimentation for their development; and
2. Significant amounts of computer time for program development and convergence problems which restricts their use for parametric studies.

1.2 STATEMENT OF THE PROBLEM

This theoretical and analytical analysis of the constant-area, supersonic-supersonic ejector was conducted to:

1. Develop a simplified mathematical model for predicting the operating characteristics of a constant-area, supersonic-supersonic ejector which is suitable for parametric evaluations and optimization procedures;

2. Provide quantitative and experimental data for verification of the theoretical model and identification of problem areas not indicated by the theoretical analysis; and
3. Compare the performance of the constant-area, supersonic-supersonic ejector with that of the constant-area, subsonic-supersonic ejector as applied to high-energy, chemical laser systems.

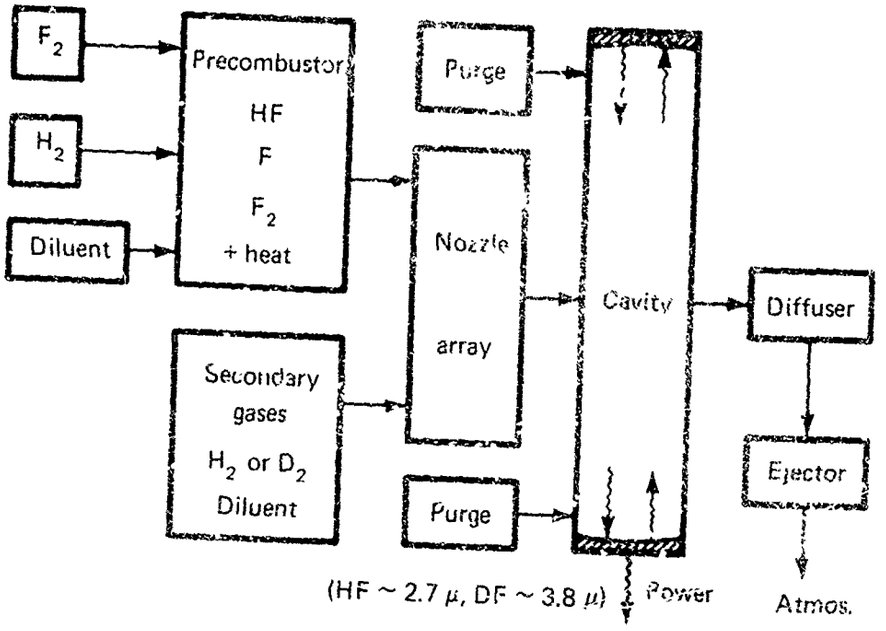


Figure 1.0-1 Typical Flow Diagram for a High-Energy, Chemical Laser System

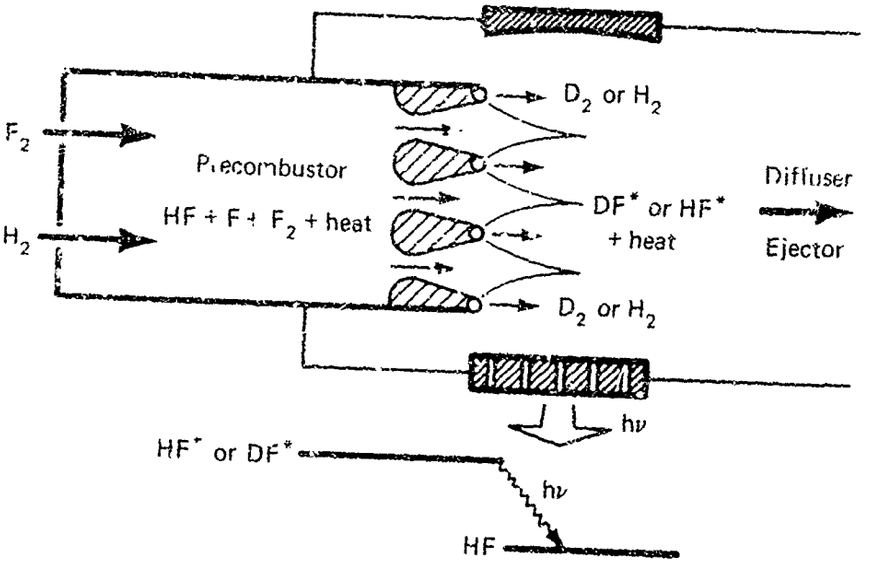


Figure 1.0-2 Laser Cavity Schematic

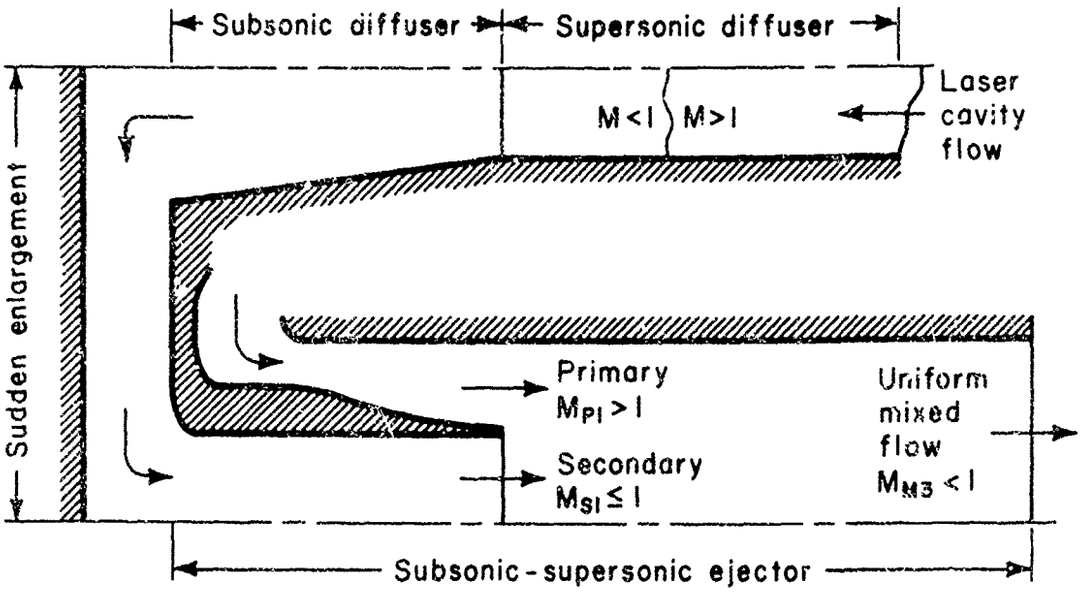


Figure 1.0-3 Subsonic-Supersonic Pumping System

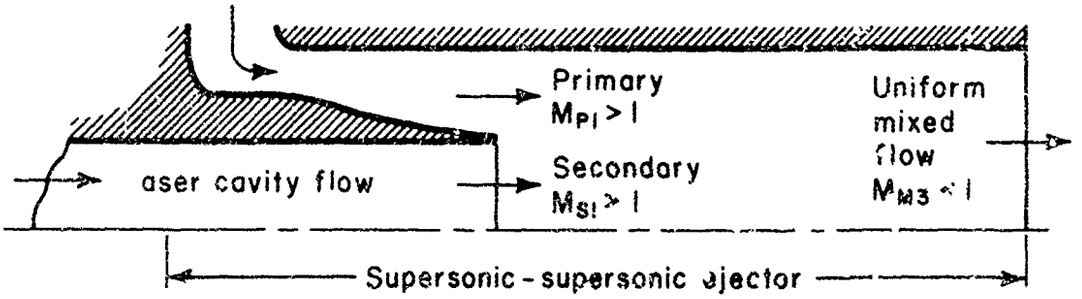


Figure 1.0-4 Supersonic-Supersonic Pumping System

2.0 THEORETICAL ANALYSIS OF THE CONSTANT-AREA, SUPERSONIC-SUPERSONIC EJECTOR

In the constant-area, supersonic-supersonic ejector of Fig. 2.0-1, the primary and secondary streams enter at supersonic Mach numbers where they begin to interact, mix, and diffuse. Proceeding through the ejector, these streams continue to mix and diffuse, thus approaching a uniform flow at the ejector exit. The result of this interaction, mixing, and diffusion process can be described by a one-dimensional, compressible flow model consisting of two components, an overall analysis of the constant-area mixing section, stations 1 to 3, and an analysis of the nearly inviscid interaction region just downstream of the confluence of the primary and secondary streams.

By tradition, the governing equations for subsonic-supersonic ejector models are nondimensionalized by the appropriate primary flow variables to allow for a zero secondary mass flow rate, and this tradition is maintained in the following analysis, however, in preference to people in the chemical laser field, the results are presented as nondimensionalized by the secondary flow variables.

2.1 ONE-DIMENSIONAL OVERALL MIXING SECTION ANALYSIS

By hypothesis, the streams entering the ejector must be supersonic. This criteria restricts the ejector operation to a plane as illustrated in Fig. 2.1-1, and prescribes the boundaries of this plane. So long as the entering streams remain supersonic, the ejector mass-flow ratio W_P/W_S is established independent of the ejector exit-plane pressure but directly proportional to the primary-to-secondary static pressure ratio P_{P1}/P_{S1} at the confluence point. The right-most boundary of the plane of operation

defines the maximum compression ratio and is determined by applying the conservation equations to the control volume of Fig. 2.1-2 together with the following assumptions:

(1) Steady flow, $\frac{\partial(\ )}{\partial t} \equiv 0$.

(2) Piecewise uniform flows at station 1 and uniform flow at station 3.

(3) The primary and secondary gases obey the perfect gas relationships.

(4) The primary and secondary streams mix ideally to form a mixed gas at station 3.

(5) Negligible wall shear stresses.

(6) Adiabatic flow between stations 1 and 3.

(7) No shaft or shear work between stations 1 and 3.

(8) Negligible body forces.

(9) The flow in the primary nozzle is isentropic from its stagnation state to the state at station 1.

The fundamental equations of continuity, momentum, in the flow direction, and energy are, respectively:

$$\frac{\partial}{\partial t}\int_{CV} \rho dv + \oint_{CS} \rho \bar{V} \cdot d\bar{A} = 0 \ , \qquad (2.1\text{-}1)$$

$$\rightarrow \sum F_x = \frac{\partial}{\partial t}\int_{CV} V_x(\rho dv) + \oint_{CS} V_x(\rho \bar{V} \cdot d\bar{A}) \ , \qquad (2.1\text{-}2)$$

$$\frac{\not\partial Q}{\not\partial t} - \frac{\not\partial W_{ss}}{\not\partial t} = \frac{\partial}{\partial t}\int_{cv}\left(u + \frac{V^2}{2} + gz + \cdots\right)(\rho dV)$$

$$+ \oint_{cs}\left(h + \frac{V^2}{2} + gz + \cdots\right)(\rho\bar{V} \cdot d\bar{A}) \quad . \tag{2.1-3}$$

Applying assumptions (1,2) to Eqn. (2.1-1) yields

$$-\rho_{S1} V_{S1} A_{S1} - \rho_{P1} V_{P1} A_{P1} + \rho_{M3} V_{M3} A_{M3} = 0 \ ,$$

or in terms of the mass flow rate $W = \rho AV$,

$$\frac{W_M}{W_P} = 1 + \frac{W_S}{W_P} \quad . \tag{2.1-4}$$

Applying assumptions (1,2,5) to Eqn. (2.1-2) gives

$$P_{S1} A_{S1} + P_{P1} A_{P1} - P_{M3} A_{M3} = - V_{S1}(\rho_{S1} V_{S1} A_{S1})$$

$$- V_{P1}(\rho_{P1} V_{P1} A_{P1}) + V_{M3}(\rho_{M3} V_{M3} A_{M3}) \ ,$$

or in terms of the Mach number,

$$P_{S1} A_{S1}(1 + \gamma_S M_{S1}^2) + P_{P1} A_{P1}(1 + \gamma_P M_{P1}^2) = P_{M3} A_{M3}(1 + \gamma_M M_{M3}^2) \ .$$

Since $A_{S1} + A_{P1} = A_{M3}$ for a constant-area mixing tube, the result is

$$\frac{P_{M3}}{P_{P1}} = \frac{\dfrac{P_{S1}}{P_{P1}} \cdot \dfrac{A_{S1}}{A_{P1}} \cdot f_1(\gamma_S, M_{S1}) + f_1(\gamma_P, M_{P1})}{\left(1 + \dfrac{A_{S1}}{A_{P1}}\right) f_1(\gamma_M, M_{M3})} \tag{2.1-5}$$

where $f_1(\gamma, M) = 1 + \gamma M^2$. (2.1-6)

Equation (2.1-3) together with assumptions (1,2,6,7,8) yields

$$- (h_{S1} + \frac{V_{S1}^2}{2})(\rho_{S1} V_{S1} A_{S1}) - (h_{P1} + \frac{V_{P1}^2}{2})(\rho_{P1} V_{P1} A_{P1})$$

$$+ (h_{M3} + \frac{V_{M3}^2}{2})(\rho_{M3} V_{M3} A_{M3}) = 0 ,$$

or in terms of the mass flow rate and stagnation enthalpy $h_0 = h + \frac{V^2}{2}$,

$$h_{S0} W_S + h_{P0} W_P = h_{M0} W_M .$$

But since $h_0 = C_P T_0$ + constant for an ideal gas, the result is

$$\frac{T_{M0}}{T_{P0}} \cdot \frac{W_M}{W_P} \cdot \frac{(C_P)_M}{(C_P)_P} = 1 + \frac{T_{S0}}{T_{P0}} \cdot \frac{W_S}{W_P} \cdot \frac{(C_P)_S}{(C_P)_P} \quad . \tag{2.1-7}$$

Using assumptions (3,4), the specific heats of the mixed flow are related to their primary and secondary stream counterparts by

$$W_M (C_P)_M = W_S (C_P)_S + W_P (C_P)_P , \tag{2.1-8}$$

$$W_M (C_V)_M = W_S (C_V)_S + W_P (C_V)_P . \tag{2.1-9}$$

Rearranging Eqn. (2.1-8) as

$$\frac{W_M}{W_P} \cdot \frac{(C_P)_M}{(C_P)_P} = 1 + \frac{W_S}{W_P} \cdot \frac{(C_P)_S}{(C_P)_P} ,$$

and noting that $C_P = (\frac{\gamma}{\gamma-1}) \frac{R}{Mw}$ for a perfect gas, gives the useful relations

$$\frac{(C_p)_S}{(C_p)_P} = \frac{Mw_P}{Mw_S}\left(\frac{\gamma_S}{\gamma_S - 1}\right)\left(\frac{\gamma_P - 1}{\gamma_P}\right) , \tag{2.1-10}$$

$$\frac{W_M}{W_P} \cdot \frac{(C_p)_M}{(C_p)_P} = 1 + \frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S}\left(\frac{\gamma_S}{\gamma_S - 1}\right)\left(\frac{\gamma_P - 1}{\gamma_P}\right) . \tag{2.1-11}$$

Similarly, rearranging Eqn. (2.1-9) as

$$\frac{W_M}{W_P} \cdot \frac{(C_v)_M}{(C_v)_P} = 1 + \frac{W_S}{W_P} \cdot \frac{(C_v)_S}{(C_v)_P}$$

and noting that $C_v = (\frac{1}{\gamma-1})\frac{R}{Mw}$ for a perfect gas, gives the useful reiations

$$\frac{(C_v)_S}{(C_v)_P} = \frac{Mw_P}{Mw_S}\left(\frac{\gamma_P - 1}{\gamma_S - 1}\right) , \tag{2.1-12}$$

$$\frac{W_M}{W_P} \cdot \frac{(C_v)_M}{(C_v)_P} = 1 + \frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S}\left(\frac{\gamma_P - 1}{\gamma_S - 1}\right) . \tag{2.1-13}$$

The mass flow rate, W, is expressed in terms of the mass flow function by

$$\frac{W}{PA}\left[\frac{R}{Mw} \cdot T_0\right]^{1/2} = M\left\{\gamma\left[1 + \frac{(\gamma-1)}{2}M^2\right]\right\}^{1/2} \equiv f_2(\gamma, M) . \tag{2.1-14}$$

Then using this relation, the secondary-to-primary mass flow ratio is related to the static pressure ratio at the confluence point by

$$\frac{W_S}{W_P} = \frac{P_{S1}}{P_{P1}} \cdot \frac{A_{S1}}{A_{P1}}\left[\frac{Mw_S}{Mw_P} \cdot \frac{T_{P0}}{T_{S0}}\right]^{1/2} \frac{f_2(\gamma_S, M_{S1})}{f_2(\gamma_P, M_{P1})} . \tag{2.1-15}$$

Since $\gamma = \frac{C_P}{C_V}$ for a perfect gas, the mixed gas property is given by

$$\gamma_M = \frac{(C_P)_M}{(C_V)_M} = \frac{(C_P)_P}{(C_V)_P} \cdot \frac{\frac{W_M}{W_P} \cdot \frac{(C_P)_M}{(C_P)_P}}{\frac{W_M}{W_P} \cdot \frac{(C_V)_M}{(C_V)_P}} ,$$

which, with Eqns. (2.1-11) and (2.1-13), becomes

$$\gamma_M = \frac{\frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} \left(\frac{\gamma_S}{\gamma_S - 1}\right) + \left(\frac{\gamma_P}{\gamma_P - 1}\right)}{\frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} \left[\left(\frac{\gamma_S}{\gamma_S - 1}\right) - 1\right] + \left[\left(\frac{\gamma_P}{\gamma_P - 1}\right) - 1\right]} . \qquad (2.1\text{-}16)$$

Subtracting Eqn. (2.1-8) from Eqn. (2.1-9) and using the perfect gas relation $\frac{R}{Mw} = C_P - C_V$ yields

$$\frac{W_M}{W_P} \cdot \frac{Mw_P}{Mw_M} = 1 + \frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} .$$

Then applying Eqn. (2.1-4) and rearranging results in

$$\frac{Mw_M}{Mw_P} = \frac{\frac{W_S}{W_P} + 1}{\frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} + 1} . \qquad (2.1\text{-}17)$$

Substituting relations (2.1-10) and (2.1-11) into Eqn. (2.1-7) gives

$$\frac{T_{M0}}{T_{P0}} = \frac{\frac{T_{S0}}{T_{P0}} \cdot \frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} \left(\frac{\gamma_S}{\gamma_S - 1}\right) + \left(\frac{\gamma_P}{\gamma_P - 1}\right)}{\frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} \left(\frac{\gamma_S}{\gamma_S - 1}\right) + \left(\frac{\gamma_P}{\gamma_P - 1}\right)} . \qquad (2.1\text{-}18)$$

Using the mass flow function (2.1-14), the mixed-to-primary mass flow ratio is expressed as

$$\frac{W_M}{W_P} = \frac{P_{M3}}{P_{P1}} \cdot \frac{A_{M3}}{A_{P1}} \left[\frac{Mw_M}{Mw_P} \cdot \frac{T_{P0}}{T_{M0}}\right]^{1/2} \frac{f_2(\gamma_M, M_{M3})}{f_2(\gamma_P, M_{P1})} .$$

Applying Eqn. (2.1-4) and the relation $A_{S1} + A_{P1} = A_{M3}$, this equation becomes

$$\frac{P_{M3}}{P_{P1}} \left[1 + \frac{A_{S1}}{A_{P1}}\right] \left[\frac{Mw_M}{Mw_P} \cdot \frac{T_{P0}}{T_{M0}}\right]^{1/2} \frac{f_2(\gamma_M, M_{M3})}{f_2(\gamma_P, M_{P1})} = 1 + \frac{W_S}{W_P} .$$

Then eliminating $\frac{P_{M3}}{P_{P1}}$ with Eqn. (2.1-5) yields

$$f_3(\gamma_M, M_{M3}) = \frac{\left[\frac{Mw_M}{Mw_P} \cdot \frac{T_{P0}}{T_{M0}}\right]^{1/2} \left[\frac{P_{S1}}{P_{P1}} \cdot \frac{A_{S1}}{A_{P1}} \cdot f_2(\gamma_2, M_{S1}) + f_1(\gamma_P, M_{P1})\right]}{\left[1 + \frac{W_S}{W_P}\right] f_2(\gamma_P, M_{P1})} \qquad (2.1\text{-}19)$$

where $$f_3(\gamma, M) \equiv \frac{f_1(\gamma, M)}{f_2(\gamma, M)} = \frac{1 + \gamma M^2}{M\left[\gamma\left(1 + \left(\frac{\gamma-1}{2}\right)M^2\right)\right]^{1/2}} . \qquad (2.1\text{-}20)$$

The exit Mach number is obtained by solving the quadratic equation

$$\left[\frac{(\gamma_M - 1)}{2} f_3^2 - \gamma_M\right] (M_{M3}^2)^2 + \left[f_3^2 - 2\right] M_{M3}^2 - \left[\frac{1}{\gamma_M}\right] = 0 . \qquad (2.1\text{-}21)$$

Then the mixed-to-primary static pressure ratio is found by solving, in order:

(1) Equation (2.1-15) for $\frac{W_S}{W_P}$,

(2) Equation (2.1-16) for γ_M ,

(3) Equation (2.1-17) for $\frac{Mw_M}{Mw_P}$,

(4) Equation (2.1-18) for $\frac{T_{M0}}{T_{P0}}$,

(5) Equation (2.1-19) for $f_3(\gamma_M, M_{M3})$,

(6) Equation (2.1-21) for M_{M3}^2 , and

(7) Equation (2.1-5) for $\frac{P_{M3}}{P_{P1}}$,

where γ_S, γ_P, $\frac{Mw_S}{Mw_P}$, $\frac{T_{S0}}{T_{P0}}$, M_{S1}, M_{P1}, $\frac{A_{S1}}{A_{P1}}$, and $\frac{P_{S1}}{P_{P1}}$ are the independent variables or ejector parameters. For computational purposes, the static pressure P_{P1} may be obtained from the stagnation pressure P_{P0} using assumption (9) and the isentropic flow relation

$$\frac{P_0}{P}(\gamma, M) = \left[1 + \left(\frac{\gamma-1}{2}\right) M^2\right]^{\frac{\gamma}{\gamma-1}} . \qquad (2.1\text{-}22)$$

For chemical laser applications, relation (2.1-22) may not be applied to the secondary stream unless P_{S0} is taken at station 1 in Fig. 2.0-1 since the laser cavity flow will not be isentropic.

It should be noted that Eqn. (2.1-21) has two roots for M_{M3}^2 giving subsonic and supersonic values of M_{M3}. The right-most boundary of the plane of operation, Fig. 2.1-1, is calculated from the subsonic value of M_{M3}, whereas the supersonic value of M_{M3} divides the plane into supersonic solutions and subsonic solutions. It is also interesting to note that when supersonic solutions along the supersonic-subsonic dividing line are

diffused through a normal shock wave, they yield exactly the subsonic solutions along the right-most boundary of the plane. Of course, the ejector may operate anywhere within the boundaries of the plane of supersonic-supersonic operation; however, given W_p/W_s or P_{P0}/P_{S1}, the most desirable operation is at the right-most boundary since the potential exists for operation at this, the maximum compression ratio.

2.2 ONE-DIMENSIONAL ANALYSIS OF THE INVISCID INTERACTION REGION

The upper boundary of the plane of operation, Fig. 2.1-1, is also dictated by the requirement that both the secondary and primary streams remain supersonic. If the primary-to-secondary static pressure ratio at the confluence point is greater than 1 ($P_{P1}/P_{S1} > 1$), the secondary flow is compressed by the mutual interaction of the primary and secondary streams within the mixing tube. This process is limited, in a one-dimensional sense, to a "nearly" reversible recompression to sonic flow at the minimum area as determined by the control volumes shown in Fig. 2.2-1. Thus, the constant-area, supersonic-supersonic ejector couples the effect of an ideal aerodynamic, supersonic diffuser and momentum transfer through viscous mixing.

The control volume of Fig. 2.2-1(a) extends from station 1 to station 2. In addition to the assumptions listed in Section 2.1, the following additional assumptions are made:

(10) The streams remain distinct and do not mix between stations 1 and 2.

(11) The flow is isentropic for each stream between stations 1 and 2.

(12) The average pressures of the streams can be different at each cross-section; thus, continuity of static pressure at the boundary between the streams is not satisfied by this flow model.

(13) The Mach number of the secondary flow at station 2 is $M_{S2} = 1$.

(14) The static pressures are such that $P_{P1} > P_{S1}$.

For an isentropic, compressible flow, the area ratio, A/A*, is expressed in terms of the area ratio function by

$$\frac{A}{A^*} = \frac{1}{M}\left\{\left(\frac{2}{\gamma+1}\right)\left[1 + \left(\frac{\gamma-1}{2}\right) M^2\right]\right\}^{\frac{\gamma+1}{2(\gamma-1)}} \equiv f_4(\gamma, M) \quad . \tag{2.2-1}$$

since $M_{S2} = 1$, $A_{S2} = A_S^*$, and for a constant-area mixing tube $A_{S1} + A_{P1} = A_{S2} + A_{P2}$. Then

$$\frac{A_{P2}}{A_P^*} = \frac{A_{P1}}{A_P^*}\left\{1 + \frac{A_{S1}}{A_{P1}}\left[1 - \frac{A_S^*}{A_{S1}}\right]\right\} \text{ , or}$$

$$\frac{A_{P2}}{A_P^*} = f_4(\gamma_P, M_{P1})\left\{1 + \frac{A_{S1}}{A_{P1}}\left[1 - \left(\frac{1}{f_4(\gamma_S, M_{S1})}\right)\right]\right\} \quad ; \tag{2.2-2}$$

and

$$f_4(\gamma_P, M_{P2}) = \frac{A_{P2}}{A_P^*} \tag{2.2-3}$$

can be solved for the supersonic value of M_{P2}.

By assumptions (10,11), W_S, W_P, T_{S0}, and T_{P0} are constant from station 1 to station 2 in Fig. 2.2-1(a). Then the mass flow function (2.1-14) gives

$$\frac{P_{S2}}{P_{S1}} \cdot \frac{A_{S2}}{A_{S1}} = \frac{f_2(\gamma_S, M_{S1})}{f_2(\gamma_S, M_{S2})} \text{ , and} \tag{2.2-4}$$

$$\frac{P_{P2}}{P_{P1}} \cdot \frac{A_{P2}}{A_{P1}} = \frac{f_2(\gamma_P, M_{P1})}{f_2(\gamma_P, M_{P2})} \quad . \tag{2.2-5}$$

Applying the momentum equation (2.1-2) to the combined control volume of Fig. 2.2-1(b) together with assumptions (1,2,5,10) yields

$$P_{S1}A_{S1} + P_{P1}A_{P1} - P_{S2}A_{S2} - P_{P2}A_{P2} = - V_{S1}(\rho_{S1}V_{S1}A_{S1})$$

$$- V_{P1}(\rho_{P1}V_{P1}A_{P1}) + V_{S2}(\rho_{S2}V_{S2}A_{S2}) + V_{P2}(\rho_{P2}V_{P2}A_{P2}) ,$$

or in terms of the Mach number,

$$P_{S1}A_{S1}(1 + \gamma_S M_{S1}^2) + P_{P1}A_{P1}(1 + \gamma_P M_{P1}^2) =$$

$$P_{S2}A_{S2}(1 + \gamma_S M_{S2}^2) + P_{P2}A_{P2}(1 + \gamma_P M_{P2}^2) \quad .$$

Then using the function (2.1-6), the result is

$$\frac{P_{S1}}{P_{P1}} \cdot \frac{A_{S1}}{A_{P1}} \frac{f_1(\gamma_S, M_{S1})}{f_1(\gamma_P, M_{P1})} + 1 = \frac{P_{S2}}{P_{S1}} \cdot \frac{A_{S2}}{A_{S1}} \cdot \frac{P_{S1}}{P_{P1}} \cdot \frac{A_{S1}}{A_{P1}} \frac{f_1(\gamma_S, M_{S2})}{f_1(\gamma_P, M_{P1})}$$

$$+ \frac{P_{P2}}{P_{P1}} \cdot \frac{A_{P2}}{A_{P1}} \frac{f_1(\gamma_P, M_{P2})}{f_1(\gamma_P, M_{P1})} \quad . \qquad (2.2\text{-}6)$$

Combining Eqns. (2.2-4), (2.2-5), and (2.2-6) with $M_{S2} = 1$ yields

$$\frac{P_{S1}}{P_{P1}} = \frac{f_2(\gamma_P, M_{P1}) \cdot f_3(\gamma_P, M_{P2}) - f_1(\gamma_P, M_{P1})}{\frac{A_{S1}}{A_{P1}}\left[f_1(\gamma_S, M_{S1}) - f_2(\gamma_S, M_{S1}) \cdot f_3(\gamma_S, 1)\right]} \qquad (2.2\text{-}7)$$

where $f_3(\gamma, M)$ is the function (2.1-20).

Then the static pressure ratio P_{S1}/P_{P1} for an isentropic recompression of the secondary stream to sonic conditions at station 2 is obtained by solving, in order:

(1) Equation (2.2-2) for $\frac{A_{P2}}{A_P^*}$,

(2) Equation (2.2-1) for $M_{P2} > 1$, and

(3) Equation (2.2-7) for $\frac{P_{S1}}{P_{P1}}$,

where γ_S, γ_P, M_{S1}, M_{P1}, and $\frac{A_{S1}}{A_{P1}}$ are the independent variables or ejector parameters; and P_{P1} may again be related to P_{P0} by the isentropic flow function (2.1-22).

2.3 PARAMETRIC RESULTS

The maximum compression ratio for a given supersonic-supersonic ejector configuration, i.e. given γ_S, γ_P, Mw_S/Mw_P, T_{S0}/T_{P0}, M_{S1}, M_{P1}, and A_{S1}/A_{P1}, is defined by the intersection of the upper boundary or "upper limit line" of the plane of operation as calculated from Section 2.2, and the right-most boundary of the plane as calculated from Section 2.1. This intersection point is termed the "upper limit point" or "ULP" in Fig. 2.1-1.

The static pressure ratio P_{P1}/P_{S1} may take on values less than 1; however, the roles of driver and driven streams are interchamged and the plane of operation, Fig. 2.1-1, would be reproduced with the primary and secondary subscripts interchanged. Then for practical purposes, the lower boundary of the plane of supersonic-supersonic operation was taken to be the "matched pressure line" where $P_{P1} = P_{S1}$. The intersection of the matched pressure line with the right-most boundary of the plane is termed the "matched pressure point" or "MPP" in Fig. 2.1-1.

The influence of the input variables, γ_S, γ_P, Mw_S/Mw_P, T_{S0}/T_{P0}, M_{S1}, M_{P1}, and A_{S1}/A_{P1}, on the plane of operation is illustrated in

Figs. 2.3-1 to 2.3-6. The procedure for producing each figure was to hold all the ejector parameters at constant values, save one, and to vary this parameter over a wide range. Rather than plot the resultant planes of operation, only the loci of upper limit and matched pressure points are given. The base values for the input variables were in all figures:

$$\gamma_S = 1.40, \quad MW_S/MW_P = 1.00, \quad \gamma_P = 1.40, \quad T_{S0}/T_{P0} = 1.00,$$

$$M_{S1} = 2.00, \quad A_{S1}/A_{P1} = 2.00, \quad M_{P1} = 4.00,$$

while each point on the graphs represent valid solutions to the equations of Sections 2.1 and 2.2, the figures with γ_S, γ_P, and MW_S/MW_P as the abcissa may not represent physically realistic solutions except at the base value, indicated by the vertical dashed line, since only limited combinations of γ and MW occur in nature. It should also be noted that the identical influence of MW_S/MW_P and T_{S0}/T_{P0} on the plane of operation, as shown in Fig. 2.3-3, is simply a coincidence of the choice of base values. The most significant information given by Figs. 2.3-1 to 2.3-6 is the slope of each curve at the base value or vertical dashed line, since this slope indicates the partial derivative of the dependent variable, P_{P0}/P_{S1}, W_P/W_S, or $P_{M\Sigma}/P_{S1}$, with respect to the independent variable.

2.4 COMPUTER PROGRAMS

The analyses of Sections 2.1 and 2.2 were the bases for the development of computer programs for analyzing the performance of constant-area, supersonic-supersonic ejectors. These programs along with sample input and output are presented in detail in APPENDICES 7.2 and 7.3 for programs CASSE and CASSEP, respectively.

These computer programs were used to calculate the parametric results presented in Section 2.3.

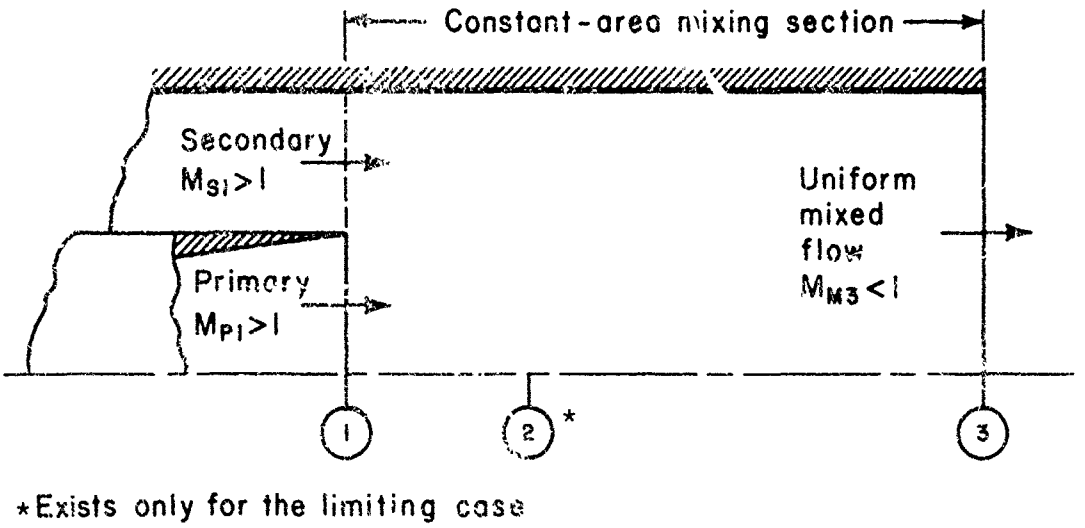


Figure 2.0-1 Constant-Area, Supersonic-Supersonic Ejector Configuration

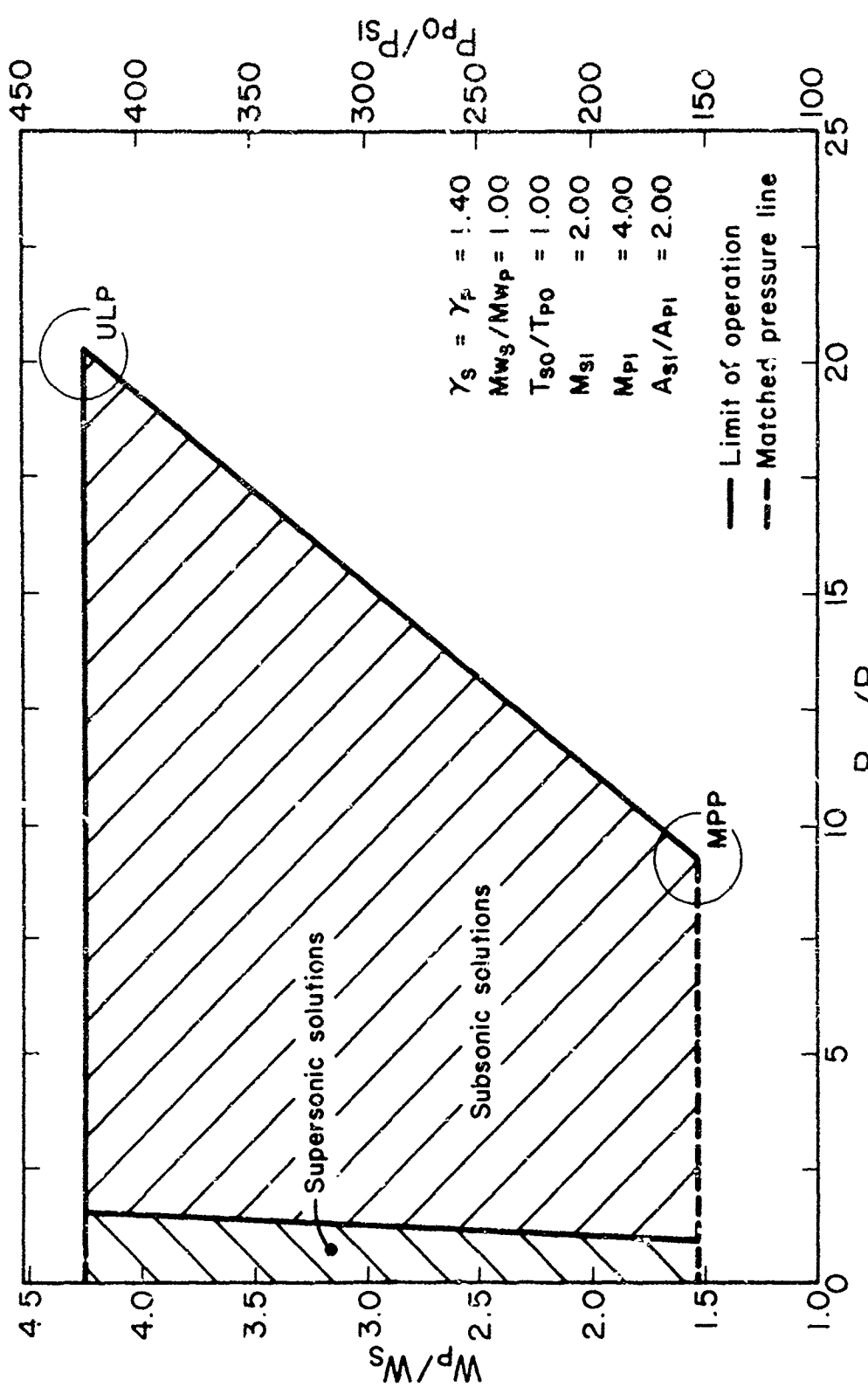
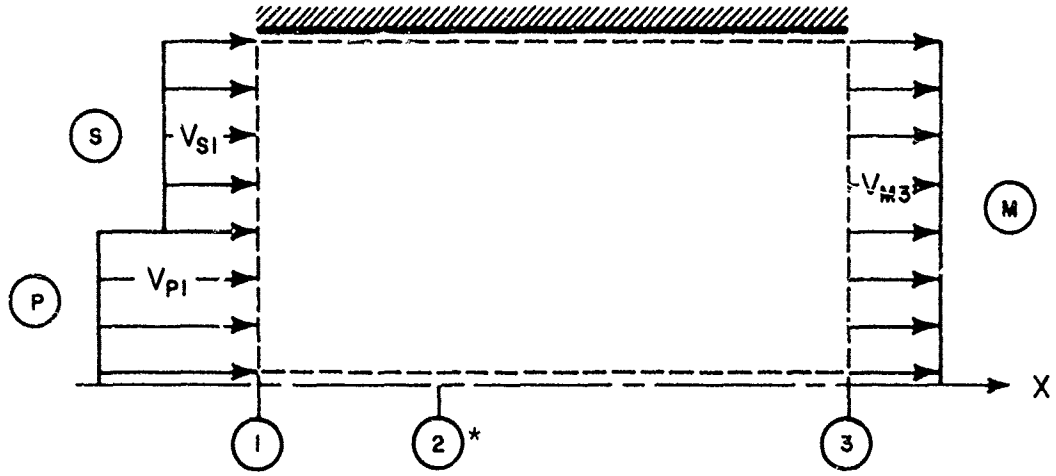


Figure 2.1-1 Typical Plane of Supersonic-Supersonic Operation

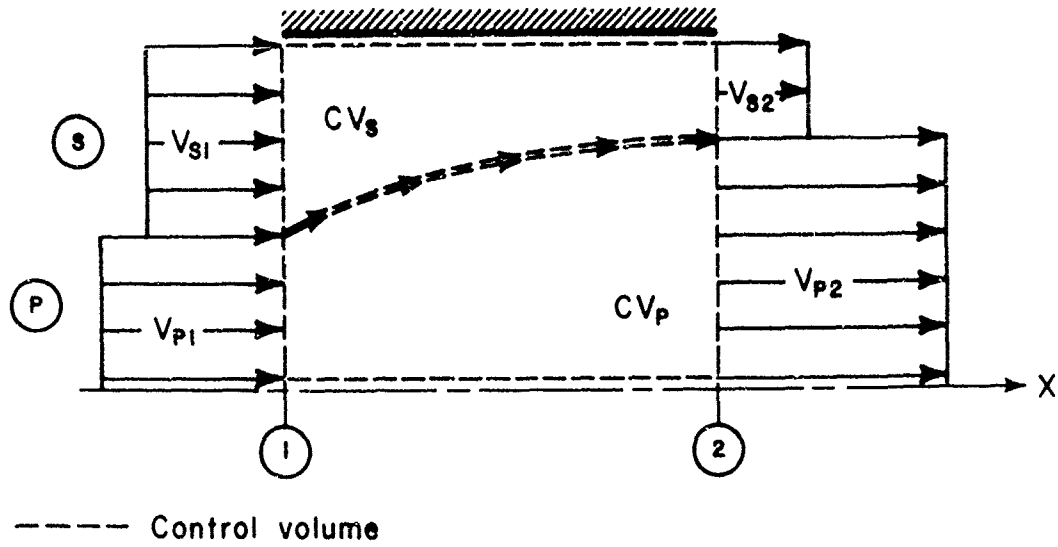


----- Control volume

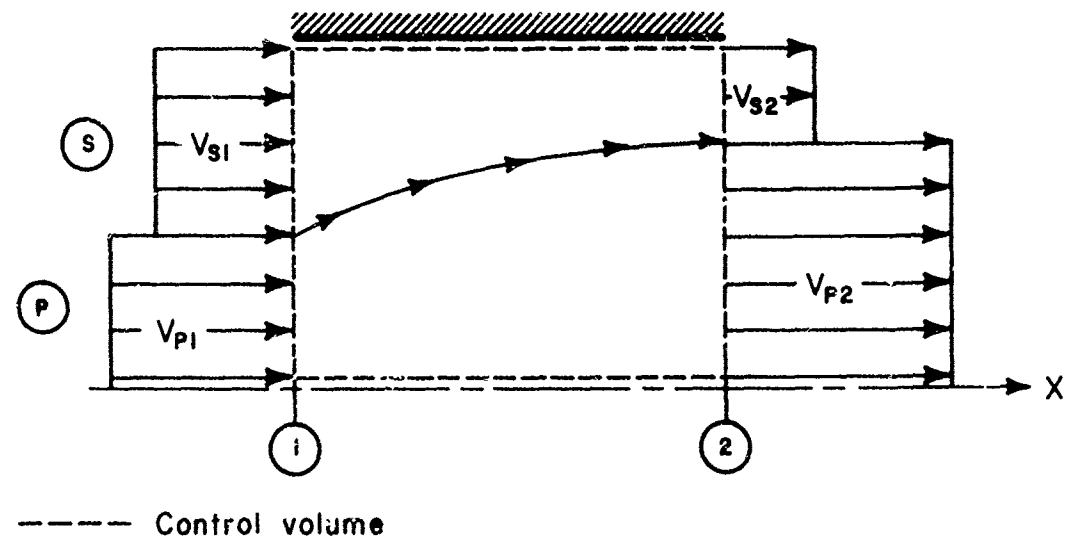
P, ρ, A, V, T, M, etc. are defined for each stream at sections 1 and 3.

* If the limiting condition exists

Figure 2.1-2 Constant-Area Mixing Section Control Volume



(a) Control Volume for the Distinct Streams



(b) Control Volume for the Combined Streams

Figure 2.2-1 Control Volumes for the Inviscid Interaction Region

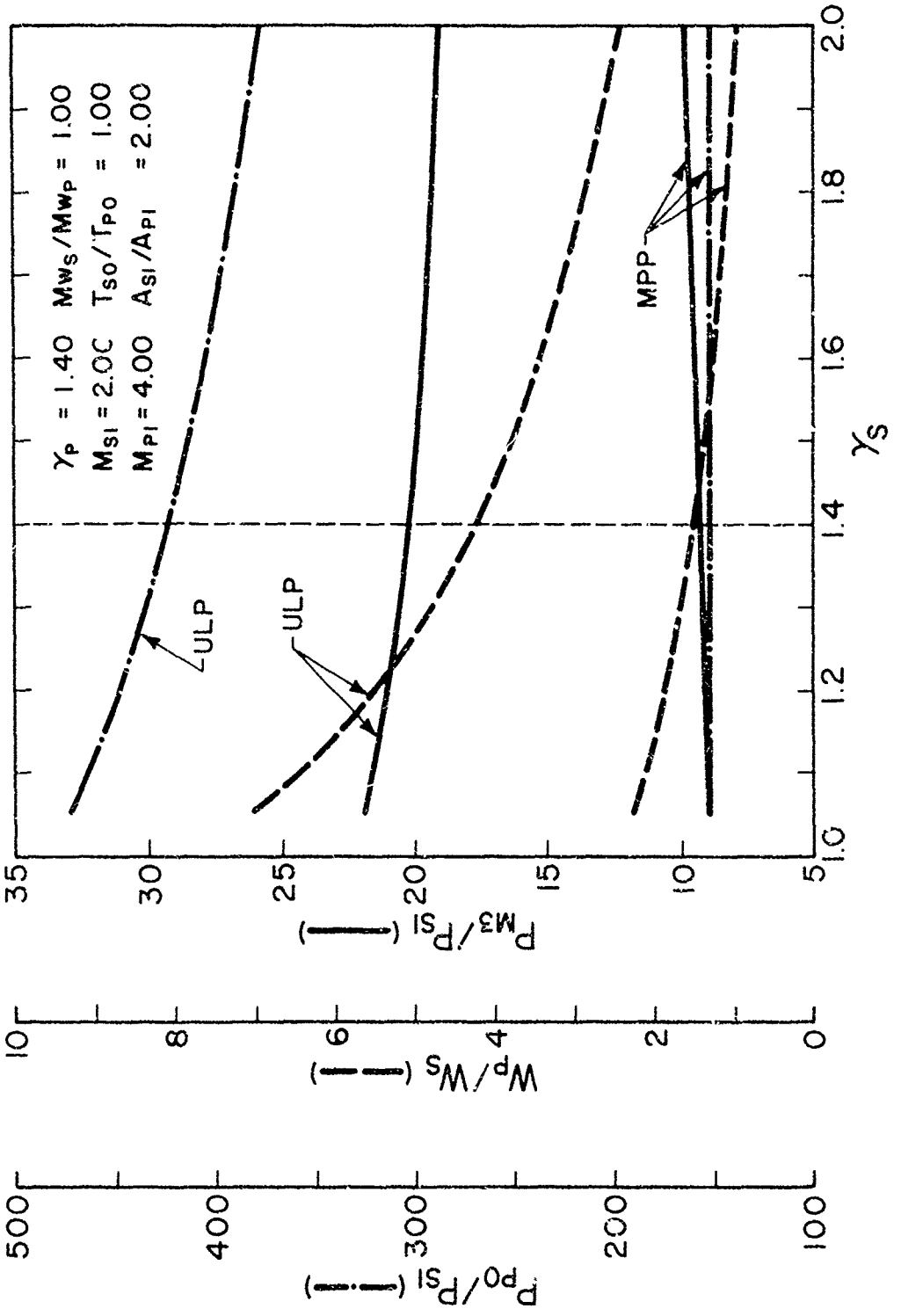


Figure 2.3-1 Influence of γ_s on the Plane of Supersonic-Supersonic Operation

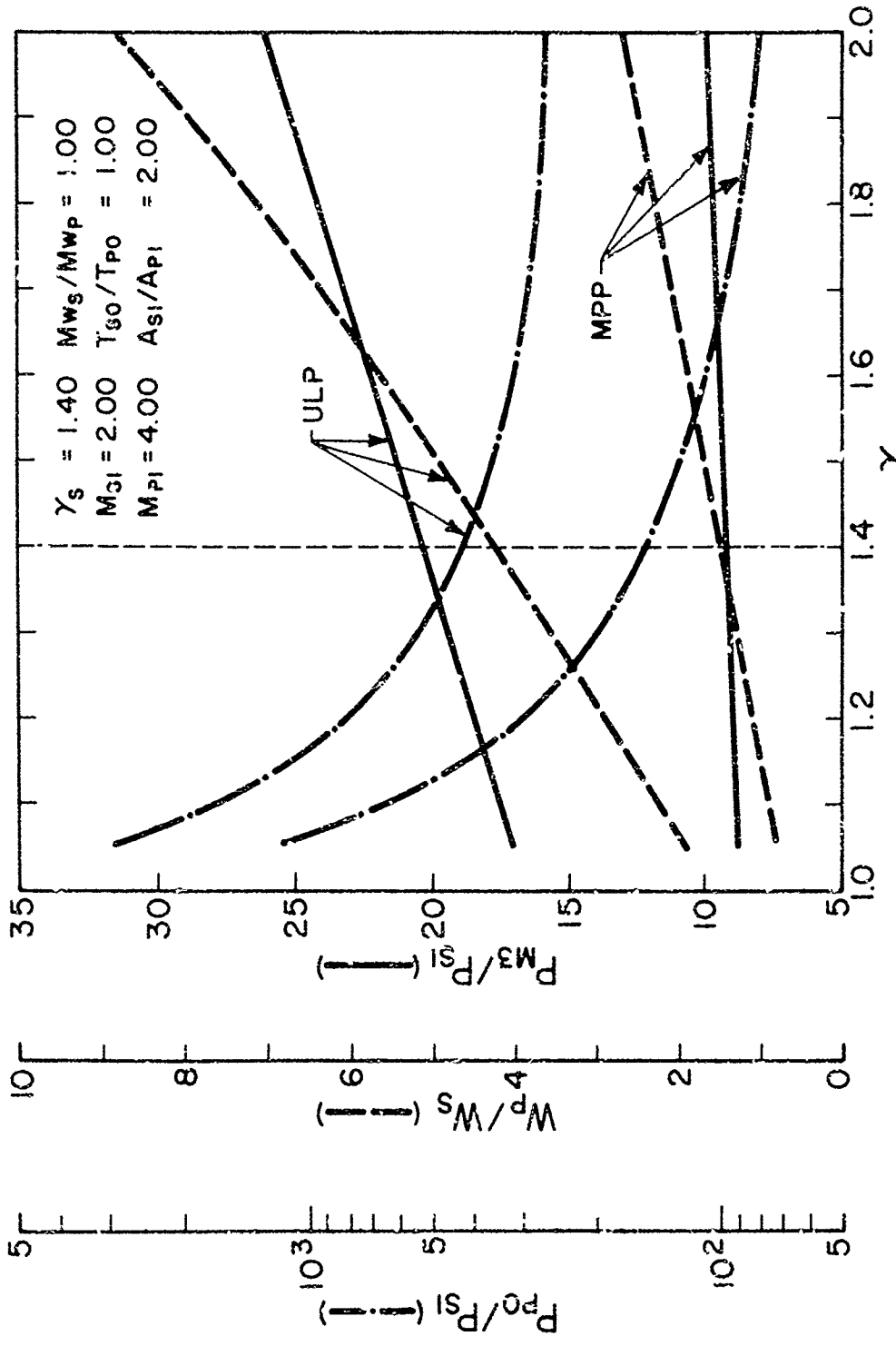


Figure 2.3-2 Influence of γ_p on the Plane of Supersonic-Supersonic Operation

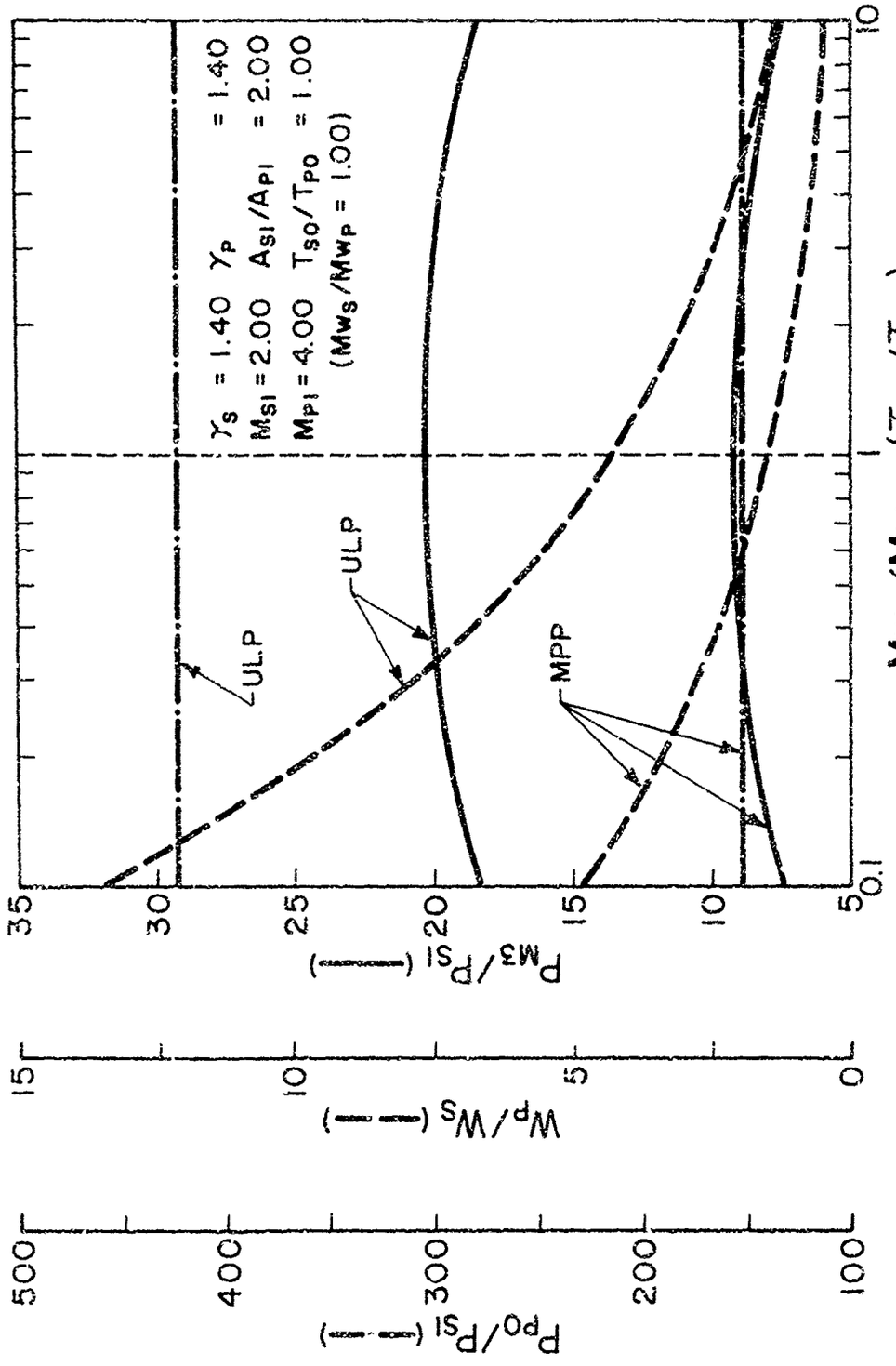


Figure 2.3-3 Influence of Mw_S/Mw_P and T_{SO}/T_{PO} on the Plane of Supersonic-Supersonic Operation

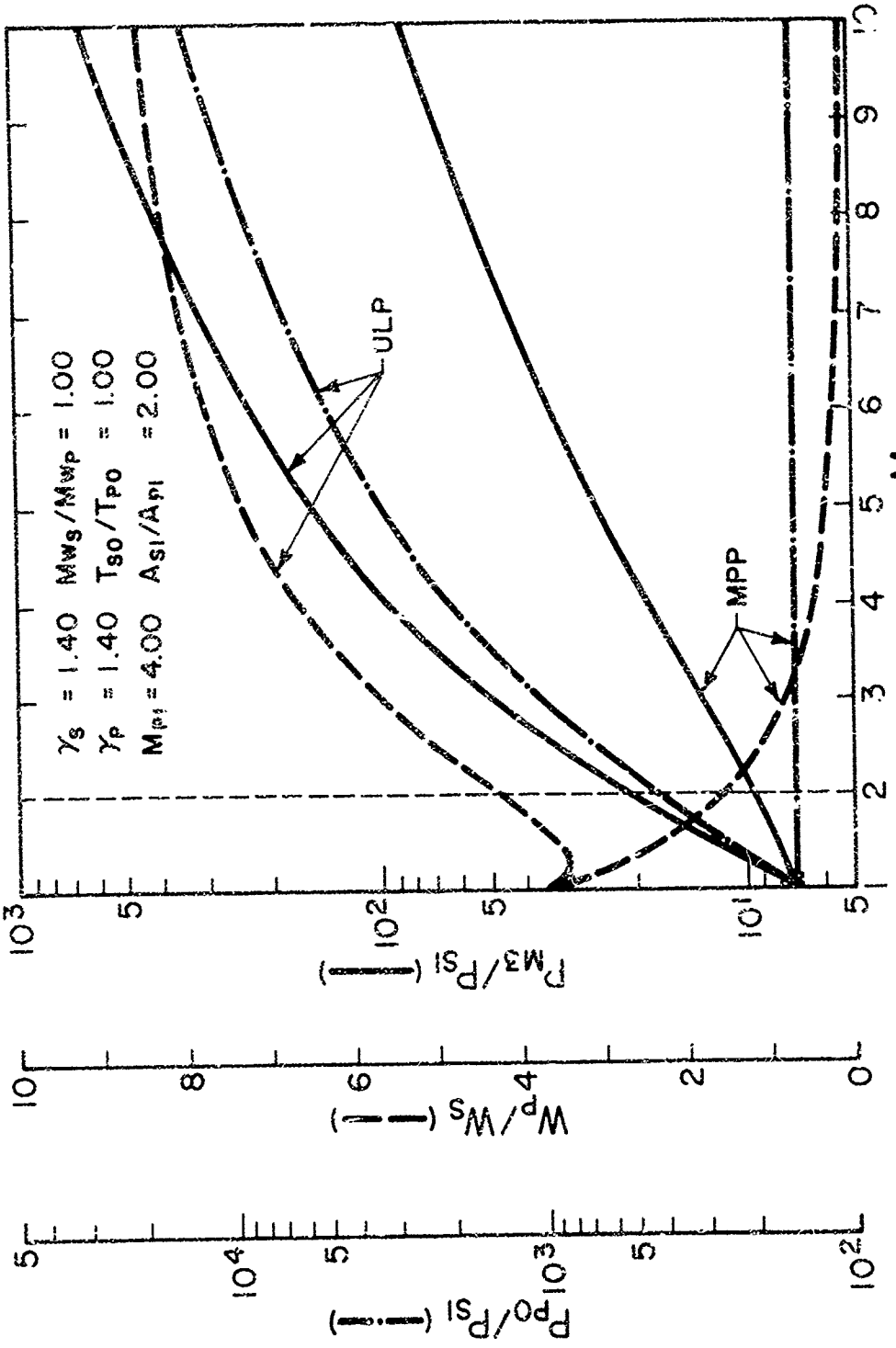


Figure 2.3-4 Influence of M_{s1} on the Plane of Supersonic-Supersonic Operation

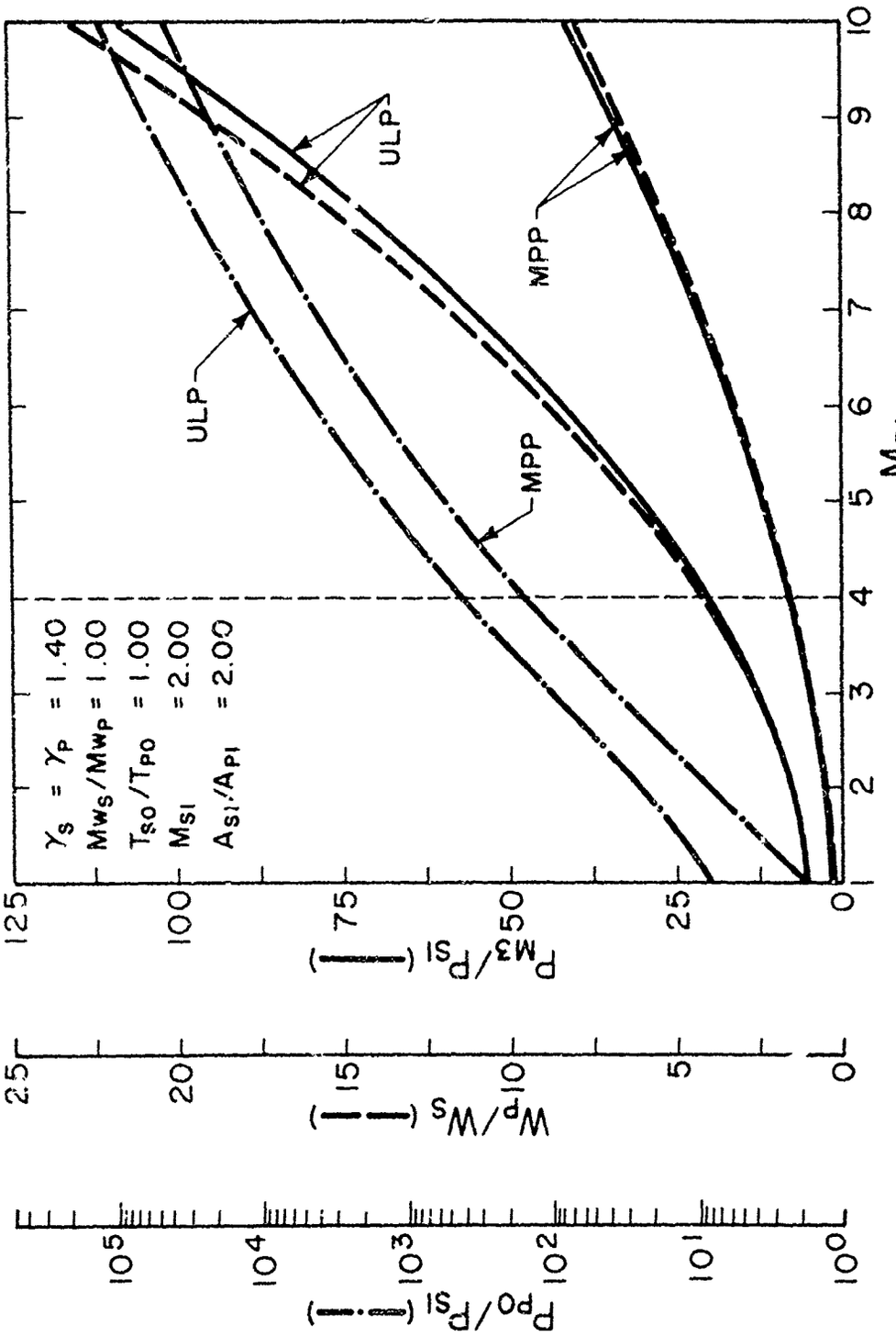


Figure 2.3-5 Influence of M_{p1} on the Plane of Supersonic-Supersonic Operation

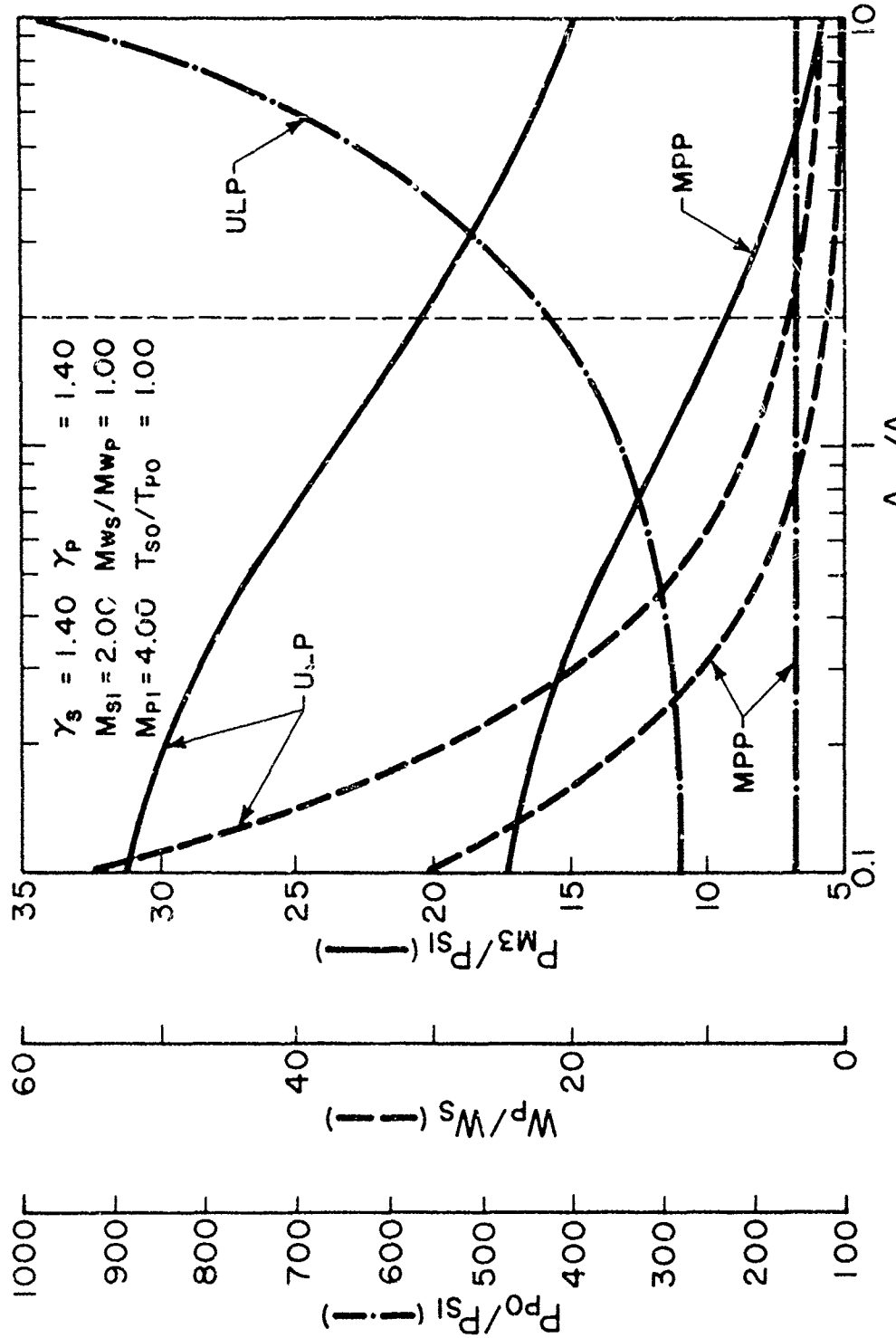


Figure 2.3-6 Influence of A_{S1}/A_{P1} on the Plane of Supersonic-Supersonic Operation

3.0 EXPERIMENTAL ANALYSIS OF THE CONSTANT-AREA, SUPERSONIC-SUPERSONIC EJECTOR

A series of small-scale, cold-flow, air-to-air ejector experiments were conducted to verify the theory of Section 2.0 and to provide a more detailed description of the flow field than necessarily allowed by a one-dimensional analysis.

3.1 EXPERIMENTAL APPARATUS

A half-section of the axisymmetric, supersonic-supersonic, ejector model is given in Fig. 3.1-1. This ejector model was designed and fabricated to facilitate a rapid replacement of nozzles and mixing tubes. Primary flow enters the ejector from a large stagnation chamber and is accelerated through an elliptical entrance section into the interchangeable nozzle. Secondary flow enters the secondary stagnation chamber from two sides and is accelerated between the nozzle wall and elliptical entrance section at the mixing tube base. Static pressure taps were installed along the mixing tube wall from the nozzle exit plane to the mixing tube exit at increments of one tube radius. A series of six static pressure taps, not shown, were equally spaced about the mixing tube axis at the nozzle exit plane to check the concentricity of the nozzle and mixing tube. In addition, five static pressure wall taps, not shown, were located upstream of the nozzle exit plane at increments of 2.54 mm to ensure that the entering secondary flow was supersonic.

For experimental purposes, the supersonic primary and secondary flows were produced by concentric nozzles of the continuous-slope type, as shown in Fig. 3.1-2. The primary stream was directed through the central nozzle, while the secondary flow was accelerated through the annular passage

formed by the outer nozzle wall and the constant-area mixing tube. Nozzle and mixing tube specifications are also given in Fig. 3.1-2 with the corresponding dimensionless parameters summarized in Table 3.1-1. While confined to an axisymmetric geometry and narrow Mach number range due to test facility limitations, these experimental configurations should be adequate for an initial evaluation of supersonic-supersonic ejector performance.

The continuous-slope nozzles constructed for these experiments were designed by the method-of-characteristics to produce uniform velocity and pressure distributions at the confluence of the secondary and primary streams, thus satisfying, at least ideally, the assumptions for the one-dimensional theory of Section 2.0. A photographic enlargement of one of these nozzles emphasizing the secondary or outer nozzle wall profile is presented in Fig. 3.1-3. As a design simplification, all four nozzles were machined to the same length which necessitated the addition of constant-area sections at the nozzle throat and exit segments as specified

Table 3.1-1 Dimensionless Parameters for the Experimental, Supersonic-Supersonic Ejector Model

	M_{P1}	M_{S1}	A_{S1}/A_{P1}
1	2.50	1.50	1.95
2	2.50	1.75	1.95
3	2.50	2.00	0.88
4	2.50	2.50	0.88

in Fig. 3.1-4. Although these constant-area sections would have no effect for a truly inviscid flow, they would promote boundary layer growth under actual experimental conditions. Figure 3.1-5 is a near actual size photograph of all four supersonic-supersonic nozzles showing their similarity in size and shape.

Photographs of the ejector components are given in Fig. 3.1-6 showing both front and rear views of the secondary stagnation chamber. It should be noted from Fig. 3.1-2 that the two constant-area mixing tubes are 10 tube diameters in length and that the interchangeable nozzles were constructed with a separate elliptical entrance section. A view of the ejector model in a partially assembled state is given in Fig. 3.1-7 showing the position of the supersonic-supersonic nozzle in the secondary stagnation chamber, one of two side entrance ports for the secondary flow, and one of two "U"-shaped baffles, the visible one surrounding the secondary stagnation pressure tap, which prevent the formation of a large circular vortex about the nozzle axis. All the ejector components were precision machined to design specifications with less than 1.27 mm clearance and O-ring seals at all the mating surfaces to ensure proper alignment and sealing.

Figure 3.1-8 is a flow diagram for the experimental program. Air from a common supply branched to two automatic control valves which maintained a constant stagnation pressure in the primary and secondary chambers. The air then passed through standard VDI nozzles for measurement of the primary and secondary mass flow rates. A final stagnation chamber was located at the mixing tube exit immediately upstream of a back pressure control valve to prevent local disturbances at this valve

from influencing the velocity and pressure distributions of the mixed, subsonic flow at the tube exit. The back pressure control valve was a sliding block arrangement with two blocks closing symmetrically across the exit duct.

Figure 3.1-9 is a photograph of the small-scale, ejector model installed on the test chamber, which served as the primary stagnation chamber, with a balance handle for manual adjustment of the back pressure control valve visible in the upper portion of the photo. Also visible are the pressure lines leading to the mixing tube wall taps and a portion of the silencer which supports the final stagnation chamber and back pressure control valve. For one experiment, a traversing pitot probe, as shown in Fig. 3.1-10, was added between the mixing tube and final stagnation chamber for measurement of the exit Mach number distribution.

3.2 EXPERIMENTAL PROCEDURE

The experimental, supersonic-supersonic ejector model was installed on a test chamber of the continuous flow facility in the Mechanical Engineering Laboratory and was operated with dry, compressed air. The tests were run at secondary stagnation pressures of 98 to 270 kPa absolute, primary stagnation pressures of 269 to 741 kPa absolute, and stagnation temperatures of approximately 294 K. The primary nozzle Reynolds number, based on the throat diameter, varied from 4.3×10^5 at P_{P0} = 269 kPa to 1.2×10^6 at P_{P0} = 741 kPa. Secondary nozzle throat Reynolds numbers are indicated in the experimental results.

Pressure data were taken from Bourdon-tube gauges and manometers or with a strain gauge transducer-digital counter system. The primary and secondary stagnation pressures and static pressures upstream of the

standard VDI nozzles were measured with Bourdon-tube gauges except at levels near atmospheric pressure, in which case a mercury manometer was used. Pressure differences across the standard VDI nozzles were measured with either mercury, Meriam 3†, or water filled U-tube manometers, depending on the magnitude of the pressure difference. Photographic records of all static pressures along the mixing tube wall were taken from mercury manometer boards. Stagnation pressure readings for the traversing pitot probe were taken with the strain gauge transducer-digital counter system.

Although six static pressure taps were available for the measurement of P_{S1}, only one was used in each experiment, and this pressure was read with both a mercury manometer and a strain gauge transducer. An attempt was made to measure an average value of P_{S1} by manifolding all six pressure taps; however, the resultant readings were lower than for any one given pressure tap.

Since the stagnation temperatures T_{P0} and T_{S0} are primarily dependent on the supply temperature, the primary stagnation temperature was measured with a dial thermometer and values for T_{S0} and the temperature of the air upstream of the standard VDI nozzles were assumed to equal this value for T_{P0}.

Maximum compression ratio data for each experimental ejector configuration were obtained in the following manner. With the back pressure control valve fully open, the secondary stagnation pressure P_{S0} was set at a fixed value to be maintained by the secondary automatic controller (see Fig. 3.1-8). The automatic controller for the primary stagnation

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†Product of the Meriam Instrument Company, Cleveland, Ohio.

pressure P_{P0} was then set at a fixed value such that the static pressure ratio P_{P1}/P_{S1} would lie, at least theoretically, in the range between the matched pressure and upper limit lines. The back pressure valve was then closed until the value of P_{S1}, as indicated by the digital counter, began to rise, at which point the mercury manometer board was photographed. This process was repeated for different combinations of P_{S0} and P_{P0} until the full range of P_{P1}/P_{S1} was covered unless otherwise restricted by the maximum supply pressure.

While the above process is necessarily transient in nature, the results are thought to be good since the point at which P_{S1} begins to rise rapidly, indicating a transition from supersonic to subsonic flow, was quite well defined and the time constant for the mercury manometer boards is much greater than for the strain gauge transducer-digital counter system. Thus, measurements of P_{S1} and P_{M3} from the mercury manometers should be very close to the limit of supersonic-supersonic operation. This thought is also supported on the basis of data repeatability which was about $\pm$ 1% for P_{M3}/P_{S1} with $M_{S1} = 1.50$.

Traverses with the pitot probe at the mixing tube exit could not be completed at exactly maximum back pressure conditions. The above procedure was followed until P_{S1} began to rise, and then the back pressure valve was opened slightly to reach a stable state for the traverse.

3.3 EXPERIMENTAL RESULTS

Maximum compression characteristics for the experimental, constant-area, supersonic-supersonic ejector configurations listed in Table 3.1-1 are presented in Figs. 3.3-1 to 3.3-4. In each figure, the data points are plotted on the plane of supersonic-supersonic operation as predicted

by the one-dimensional analysis of Section 2.0 and illustrated in Fig. 2.1-1. These data points indicate the maximum compression ratio, P_{M3}/P_{S1}, for subsonic values of M_{M3} and, therefore, should lie on the right-most boundary of the plane of supersonic-supersonic operation. Also, given the compression ratio P_{M3}/P_{S1}, the mass flow ratio data points should lie on the pressure ratio data points, i.e. the triangles should lie on the circles directly below them, since W_P/W_S is theoretically proportional to P_{P0}/P_{S1}. In all cases, given P_{P0}/P_{S1}, the experimental values for the maximum compression ratio P_{M3}/P_{S1} were 15 to 18 percent less than the theoretical, except for M_{S1} = 1.50, in which case the error was 21 to 22 percent, and the experimental values of W_P/W_S were 0 to 44 percent greater than the theoretical. It should also be noted that the percent errors in P_{M3}/P_{S1} and especially W_P/W_S increase with a decrease in the secondary nozzle throat Reynolds number as defined by

$$Re_{ST} = \frac{\rho V}{\mu} (D_{M3} - D_S^*) \quad .$$

Wall pressure distributions at maximum compression conditions for the ejector configurations listed in Table 3.1-1 are given in Figs. 3.3-5 to 3.3-8. Three pressure distributions are plotted in each figure which correspond to data points near the matched pressure point, upper limit point, and at some point midway between in Figs. 3.3-1 to 3.3-4.

At the matched pressure point, the wall pressure is initially constant followed by a near linear rise which levels off at the mixing tube exit. The linear rise covers a smaller portion of the mixing tube at the larger values of M_{S1} corresponding to the higher initial velocity of the

secondary stream and the fact that viscous mixing of the primary and secondary streams is accomplished in a shorter length as M_{S1} approaches M_{P1}.

At the upper limit point, the secondary stream undergoes a large initial recompression followed by a near linear rise which again levels off at the mixing tube exit. The initial pressure rise can be attributed to the aerodynamic diffuser formed by the primary stream as it expands into the mixing tube. As noted for the matched pressure data, the linear portion of the pressure rise occupies a smaller segment of the mixing tube as M_{S1} approaches M_{P1}, though the total pressure rise is much greater since more energy is transferred to the secondary stream as P_{P0}/P_{S1} is increased.

The wall pressure distributions of Figs. 3.1-5 to 3.1-8 also show that the low experimental values for the maximum compression ratio in Figs. 3.1-1 to 3.1-4 may be due, in part, to the mixing tube length which was equal to 10 tube diameters in all the experimental ejector configurations, 8 to 12 tube diameters being sufficient for most subsonic-supersonic ejectors. If the mixing tube is long enough for completion of the viscous mixing process, yet not too long such that wall friction becomes important, then the wall pressure distributions should exhibit a near linear rise which levels off to a constant value as the primary and secondary streams mix to a uniform flow. With the exception of Fig. 3.3-8, where $M_{S1} = M_{P1}$, it appears that the linear portion of the wall pressure distributions end at the mixing tube exit, that the viscous mixing and diffusion process may not have been completed, and that the compression ratio might be increased with a longer mixing tube. This conclusion is,

moreover, supported by the exit Mach number distributions at maximum compression conditions in Fig. 3.3-9 which show that for $M_{S1} = 2.00$, the potential exists for further mixing and diffusion even for P_{P1}/P_{S1} near the matched pressure line.†

The large percent errors in W_P/W_S and the changes in compression characteristics with Re_{ST} noted in Figs. 3.3-1 to 3.3-4 are probably due to separation of the secondary flow upstream of the confluence point. In the one-dimensional theory of Section 2.0, it is assumed that the secondary stream would undergo an isentropic recompression to, at the least, sonic conditions for $P_{P1} \leq P_{S1}$ as shown schematically in Fig. 3.3-10(a). In the real situation, however, the secondary stream may not be able to change directions at station 1 without separating the boundary layer as illustrated in Fig. 3.3-10(b). The flow losses through the oblique shock structure may not be significant even with secondary separation, but the area A_{S1} is effectively reduced with a corresponding increase in P_{S1} and decrease in M_{S1}; hence, larger secondary stagnation pressures and mass flow rates are required to obtain the desired values of P_{P_0}/P_{S1}. The region of secondary separation should grow with increasing values of P_{P1}/P_{S1} and decreasing secondary Reynolds number, and this fact is evident in Fig. 3.3-11 where M_{S1}, as calculated from the isentropic flow function $\frac{P}{P_0}\frac{A}{A^*}(\gamma,M)$, is plotted versus P_{P_0}/P_{S1} for the experimental data of Figs. 3.3-1 to 3.3-4. Some methods, such as Zukoski's [16] are available for description of the separation region, but prediction of the static pressure ratio P_{P1}/P_{S1} at the actual onset of separation requires empirical data, thus defeating most simple models for parametric evaluation of supersonic-supersonic ejector performance.

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†The results of an experimental investigation of a typical ejector configuration for variations in length-to-diameter ratio(L/D = 5, 7.5, 10, 12.5, 15) are presented in APPENDIX 7.6.

Near the matched pressure point, separation should not be a problem and the mass flow ratio data (triangles) of Figs. 3.3-1 to 3.3-4 should lie on the pressure data (circles). For M_{S1} = 1.75 and 2.50, this is indeed true; but for M_{S1} = 1.50 and 2.00, there is a small deviation. This deviation is apparently due to boundary layer growth in these two nozzles caused by the constant-area, exit segments which were added to the secondary nozzle contours as specified in Fig. 3.1-4.

As mentioned previously, the one-dimensional theory of Section 2.0 employed an isentropic recompression model for prediction of the upper limit to the plane of supersonic-supersonic operation. In Fig. 3.3-12, the wall pressure distributions near the upper limit point in Figs. 3.3-5 to 3.3-8 have been replotted with P_{S0} as the characteristic pressure in order to compress the scale. The initial recompression of the secondary stream to Mach numbers probably less than 1 ($P(x)/P_{S0} < 0.5283$) as shown in Fig. 3.3-12 suggests another simple model, a "two shock model" as illustrated in Fig. 3.3-13, which is also suitable for a one-dimensional analysis and, in addition, accounts for the irreversibilities in two oblique shocks. Of course, this model does not allow for secondary flow separation, nor would it apply to large turning angles where the two oblique shocks are replaced by a single, normal shock wave.

An attempt was made to compare the one-dimensional theory of Section 2.0 with the extensive supersonic wind tunnel-injector data of Hasel and Sinclair [4]. Unfortunately, these investigators did not measure the secondary stagnation pressure P_{S0} or include the static pressure P_{S1} at the injector, which makes any comparison impossible.

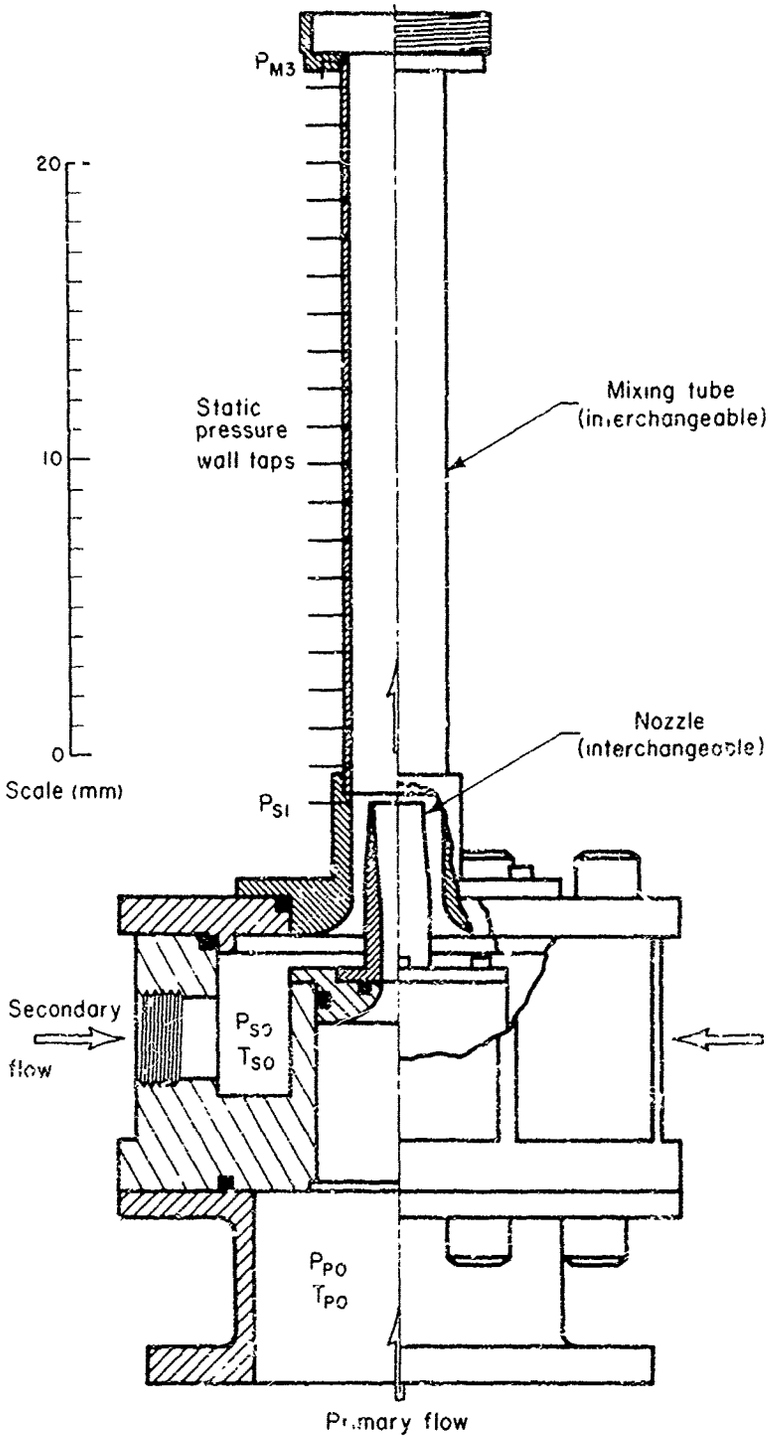
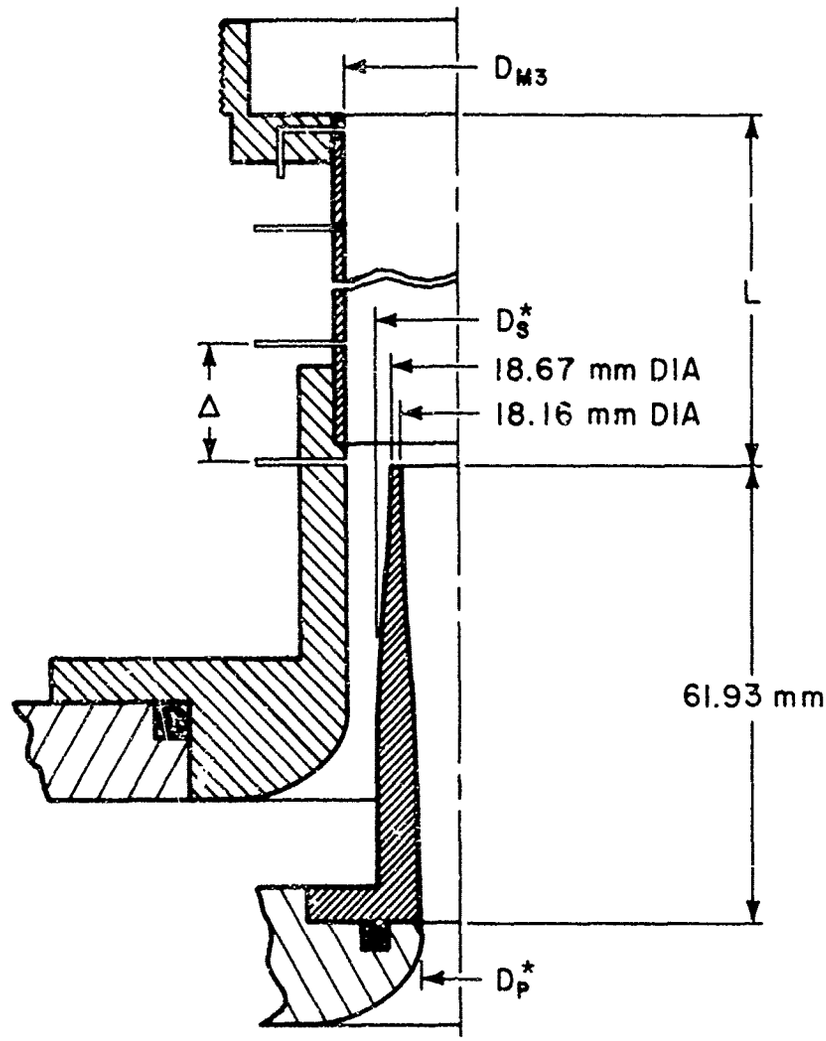


Figure 3.1-1 Half-Section of the Axisymmetric, Supersonic-Supersonic Ejector Model



	Nozzle				Mixing tube		
	M_{PI}	D_P^* (mm)	M_{SI}	D_S^* (mm)	D_{M3}(mm)	L (mm)	Δ (mm)
1	2.50	11.18	1.50	21.13	31.62	316.2	15.81
2	2.50	11.18	1.75	23.01	31.62	316.2	15.81
3	2.50	11.18	2.00	21.59	25.27	252.7	12.64
4	2.50	11.18	2.50	22.39	25.27	252.7	12.64

Figure 3.1-2 Section View and Specifications of the Continuous-Slope Nozzle and Constant-Area Mixing Tube Configurations

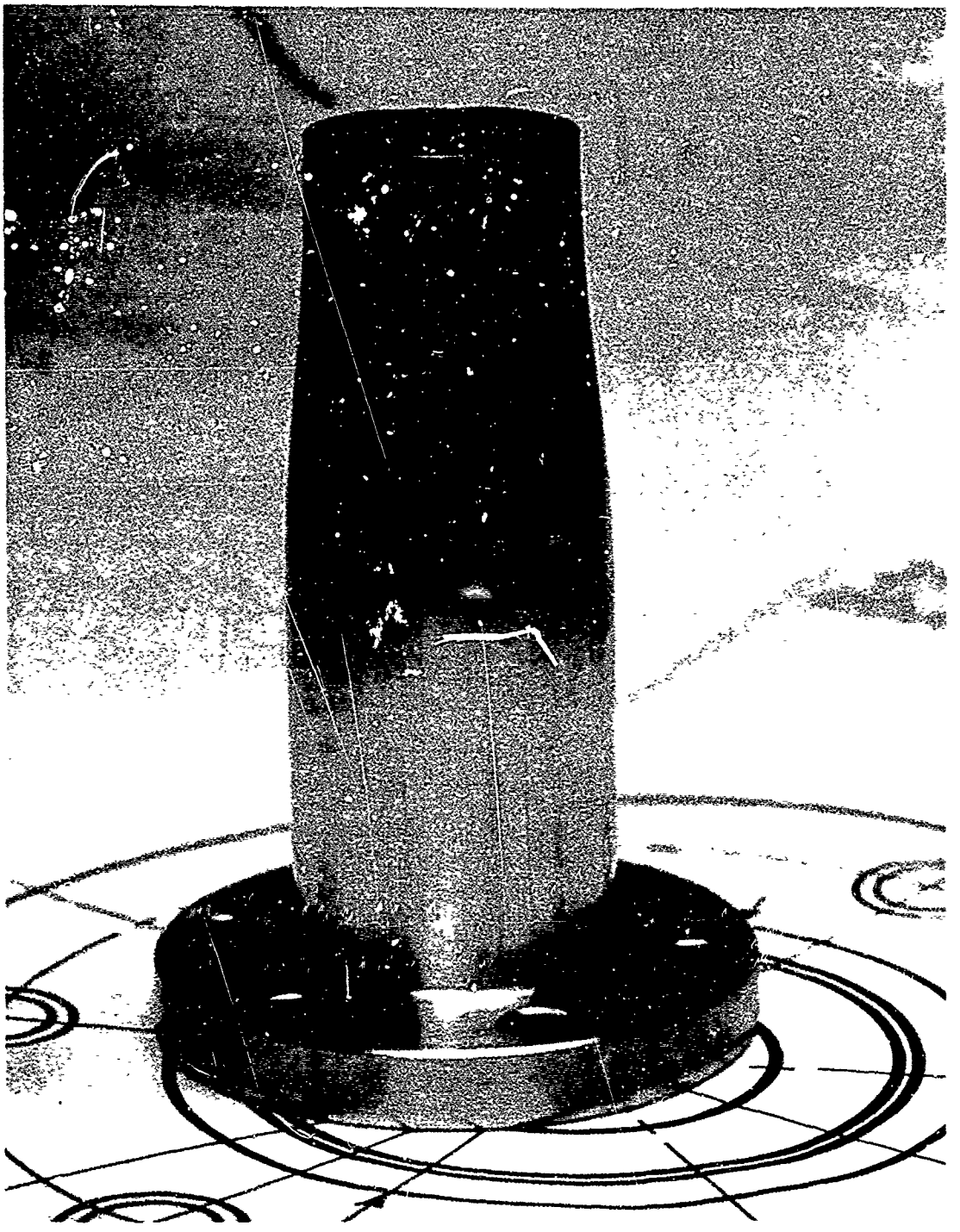
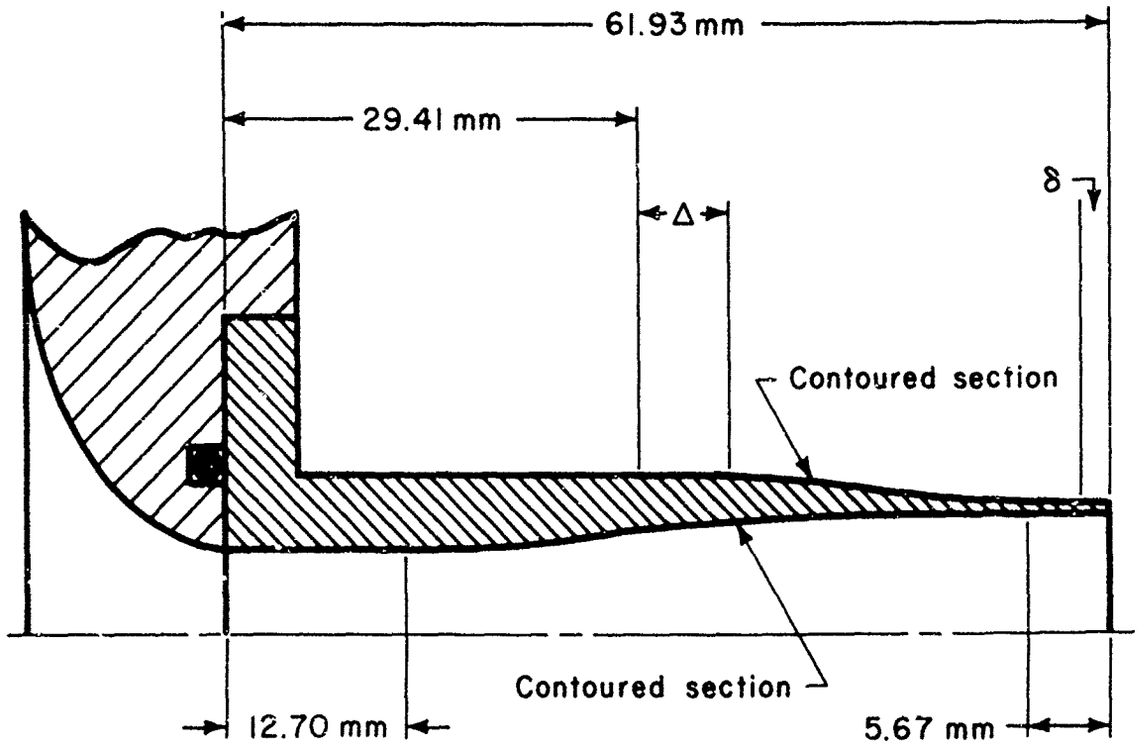


Figure 3.1-3 Enlargement of a Typical Continuous-Slope, Supersonic-Supersonic Nozzle



	Nozzle		
	M_{SI}	Δ (mm)	δ (mm)
1	1.50	6.35	2.14
2	1 75	0	0
3	2.00	6.35	2.18
4	2.50	2.11	0

Figure 3.1-4 Section View for the Continuous-Slope Nozzles with Specifications for the Nozzle Wall Profiles

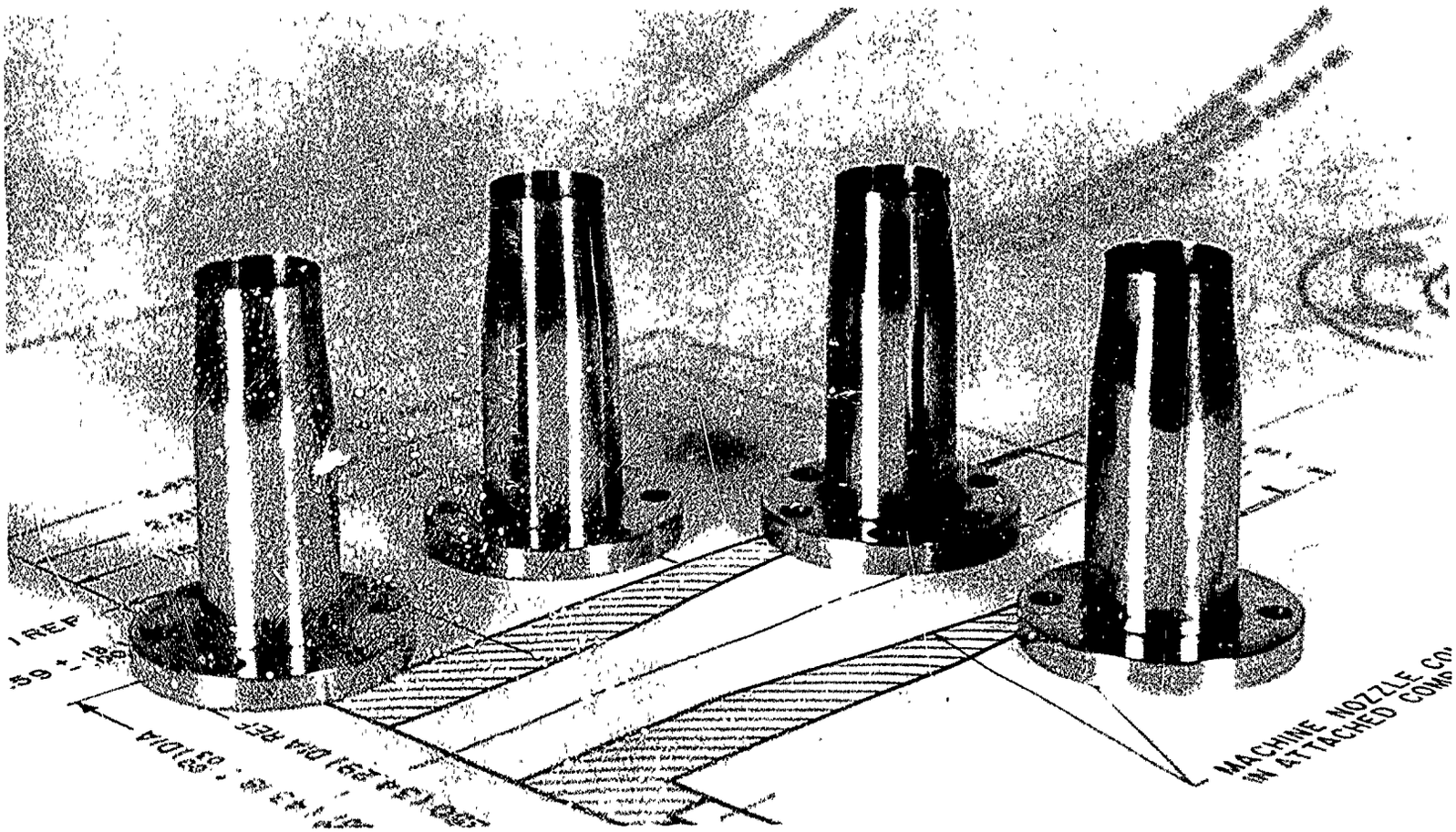
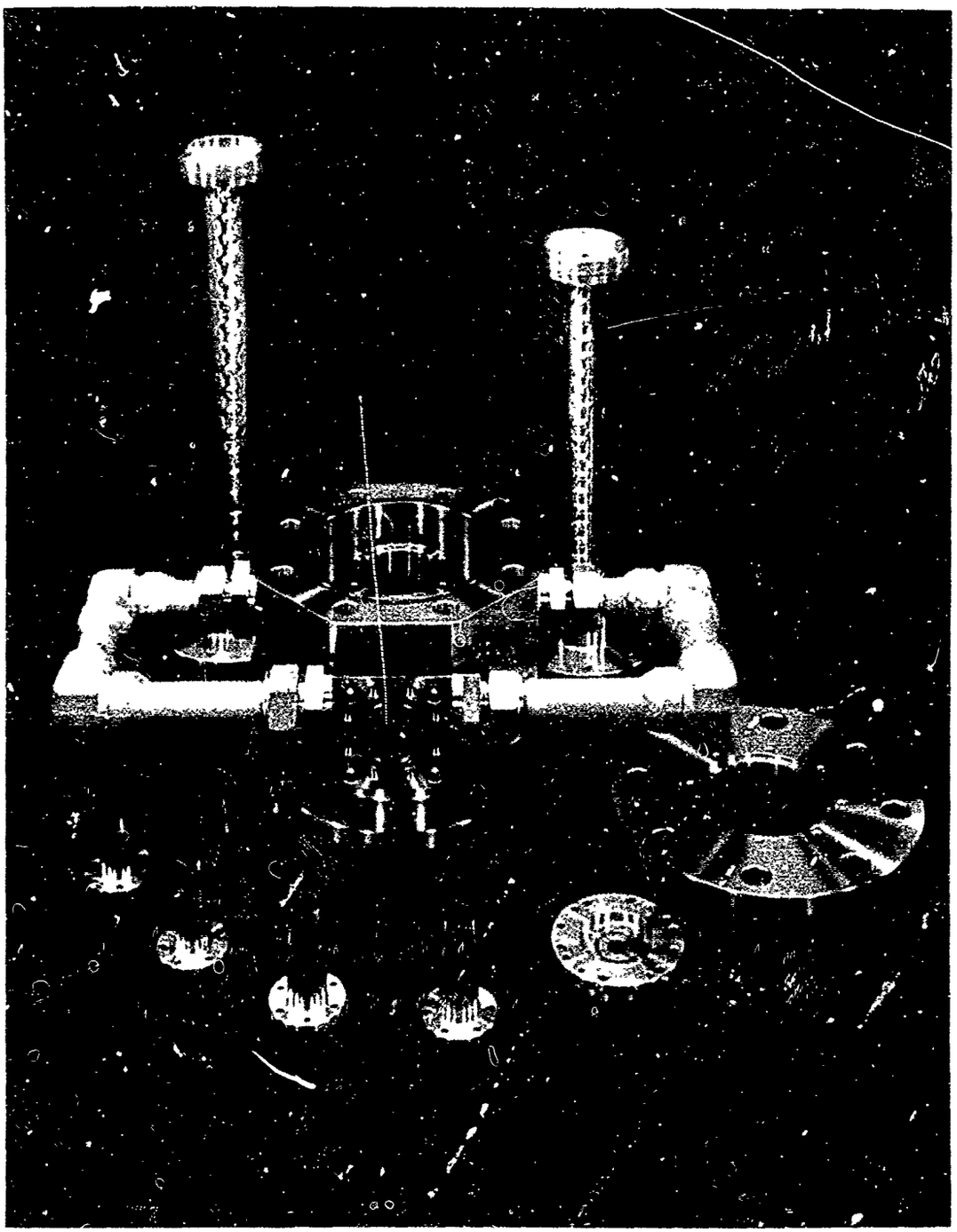
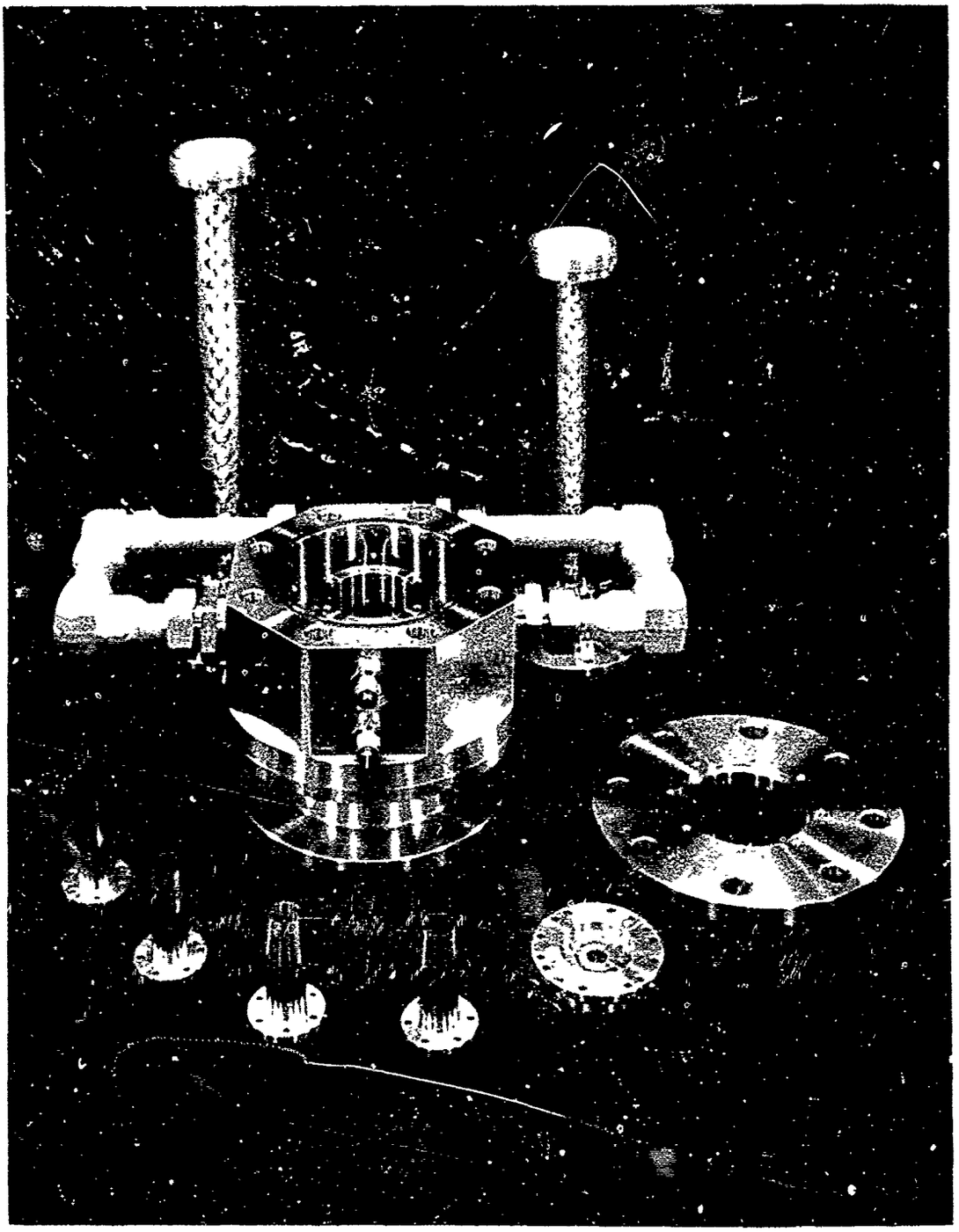


Figure 3.1-5 Photograph of the Continuous-Slope, Supersonic-Supersonic Nozzles



(a) Front View of the Secondary Stagnation Chamber

Figure 5.1-6 Photographs of the Injector Model Components



(b) Rear View of the Secondary Stagnation Chamber

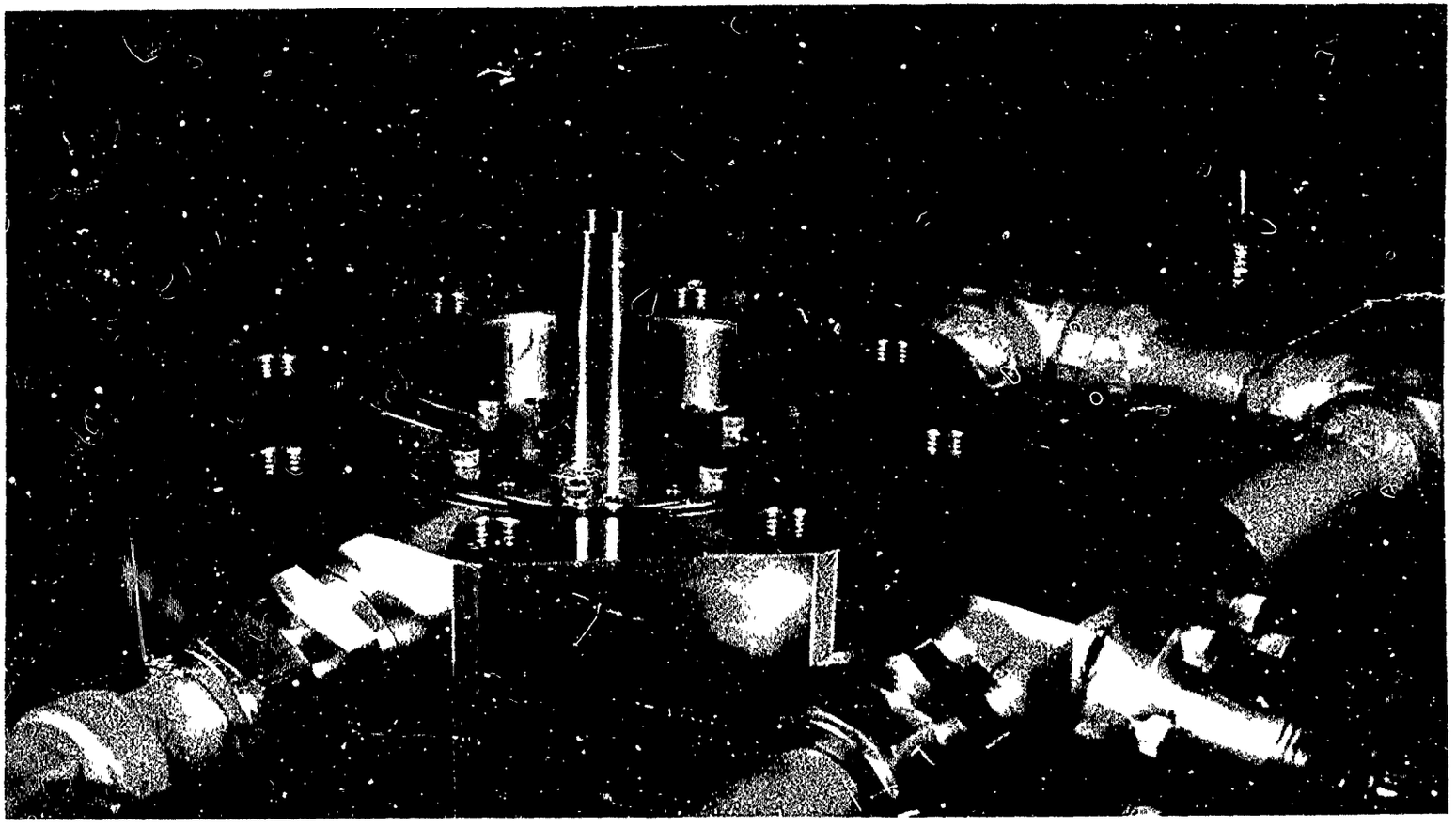


Figure 3.1-7 Partial Assembly of the Axisymmetric Ejector Model Showing the Position of the Supersonic-Supersonic Nozzle in the Secondary Stagnation Chamber

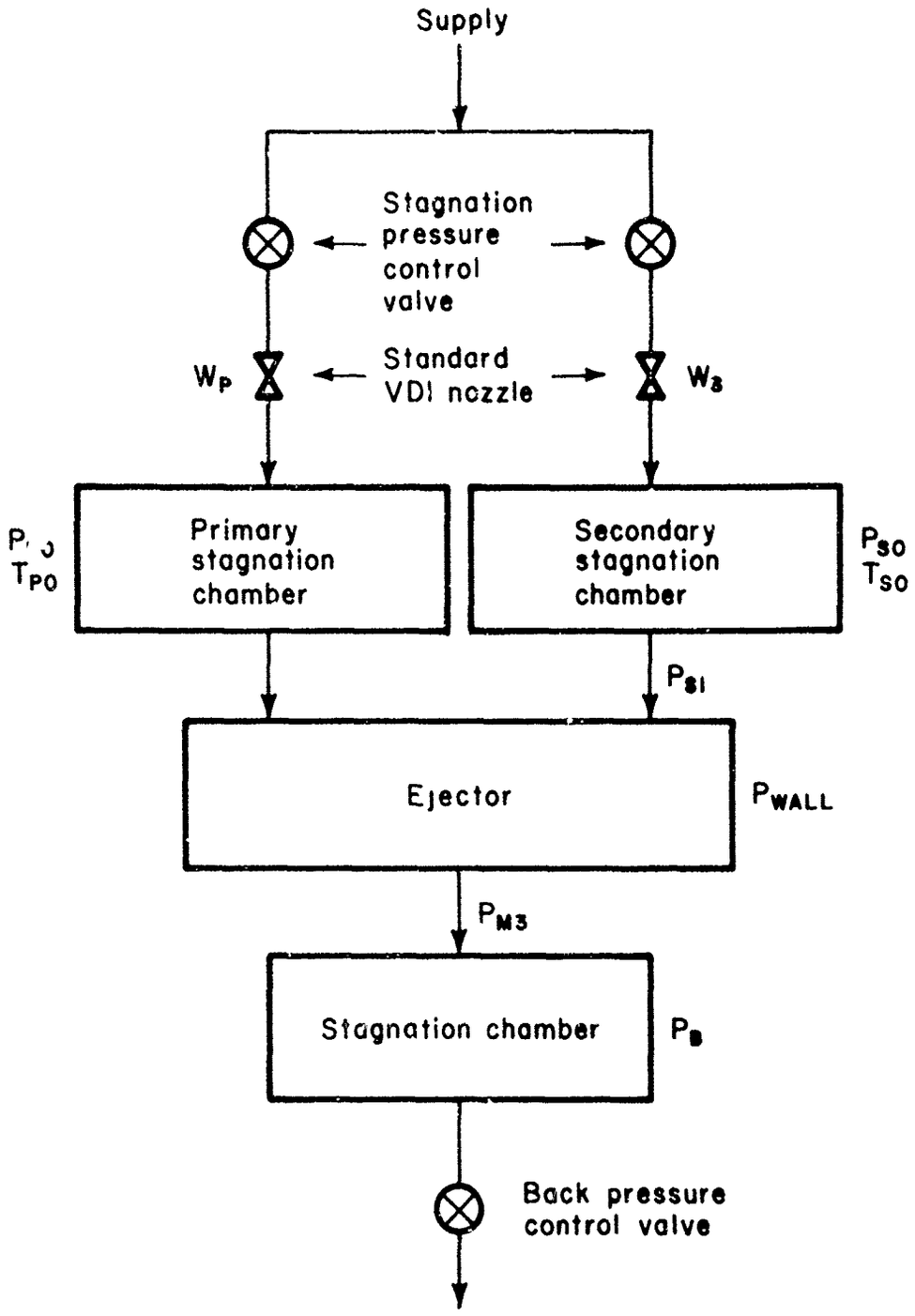


Figure 3.1-8 Ejector Experiment Flow Diagram

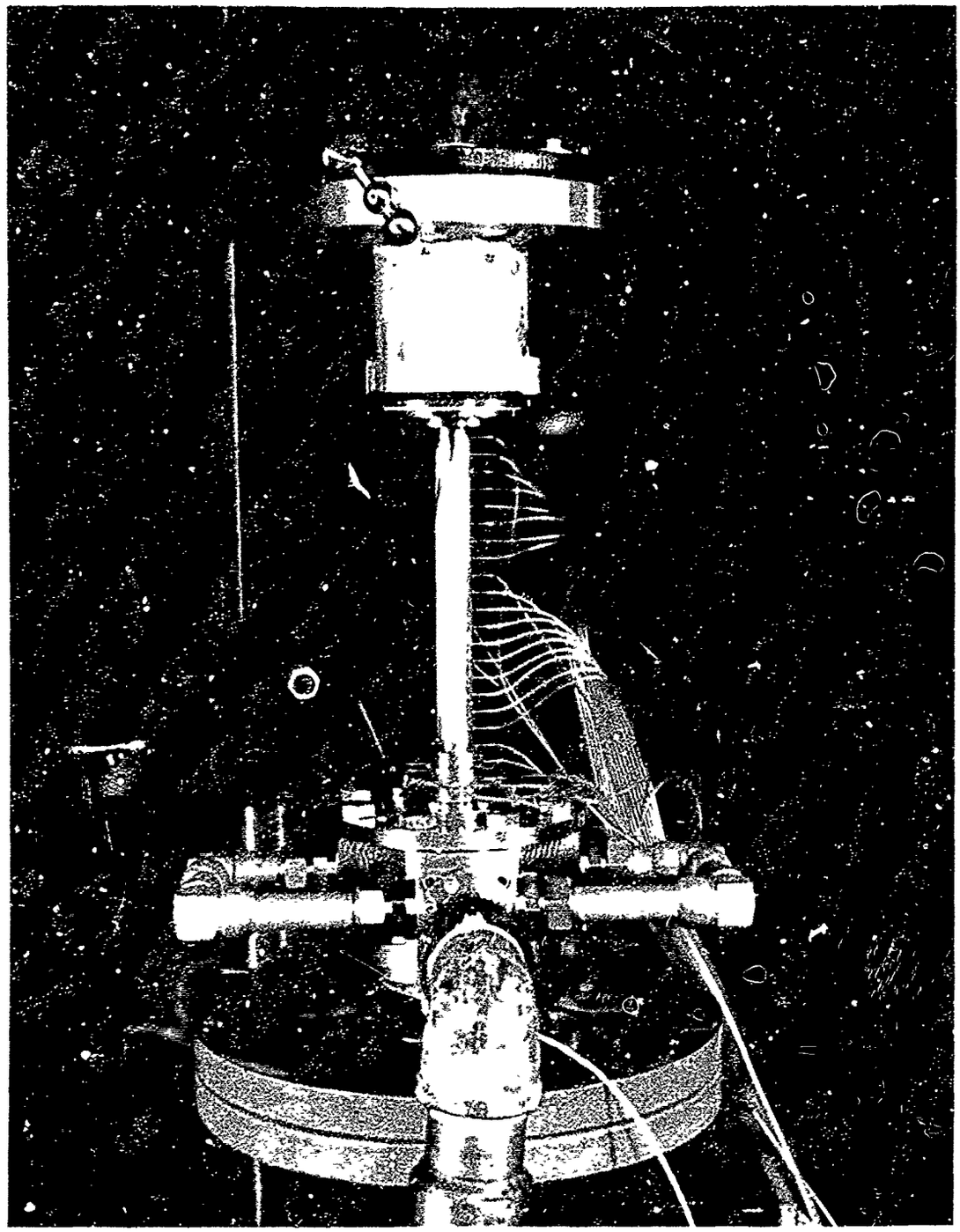


Figure 5.1-9 Photograph of the Ejector Model Installed on the Test Chamber with the Back Pressure Control Valve Located Downstream of the Mixing Tube

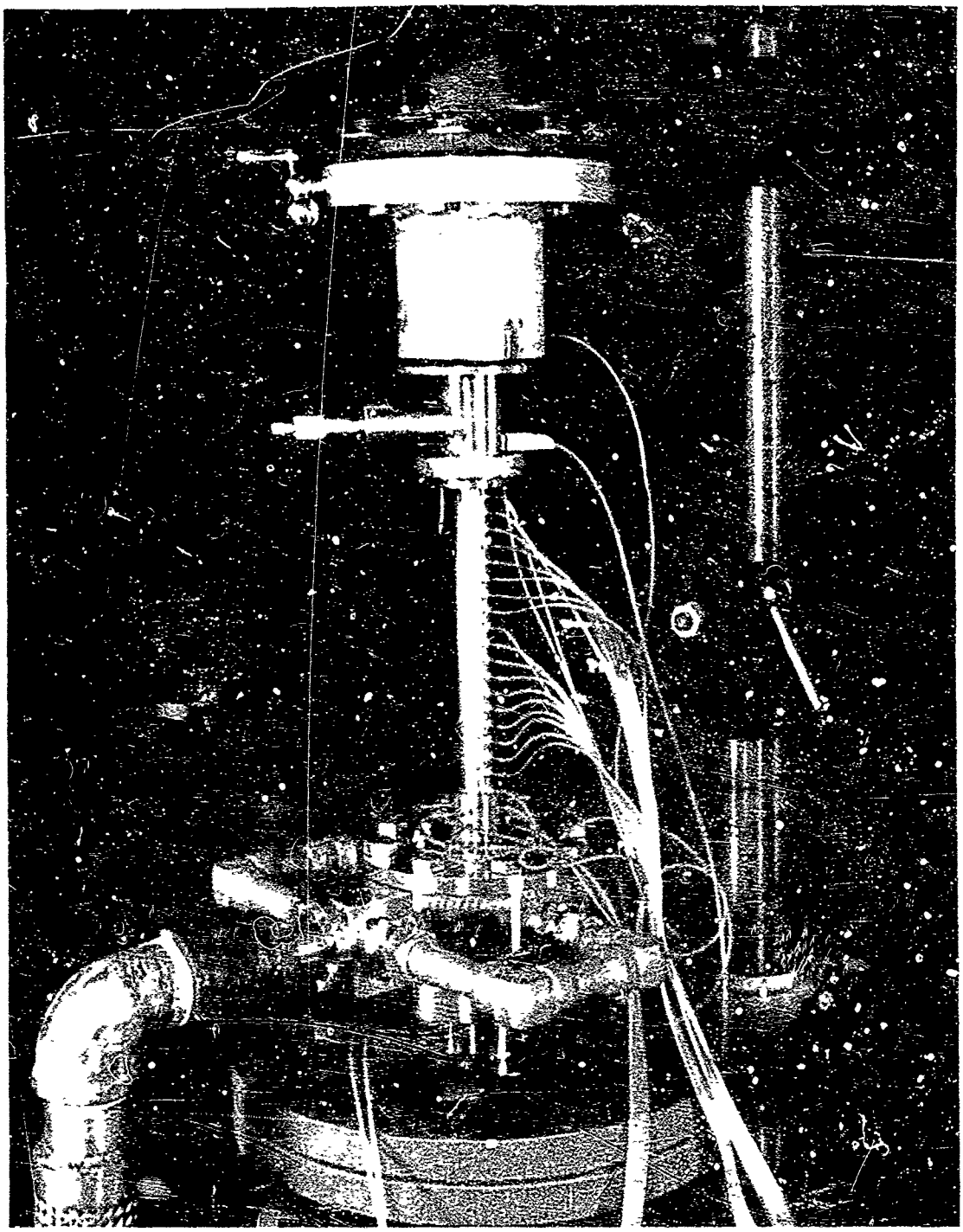


Figure 3.10 Photograph of the Ejector Model Installed on the Test Chamber with the Pitot Probe Located between the Mixing Tube and Back Pressure Control Valve

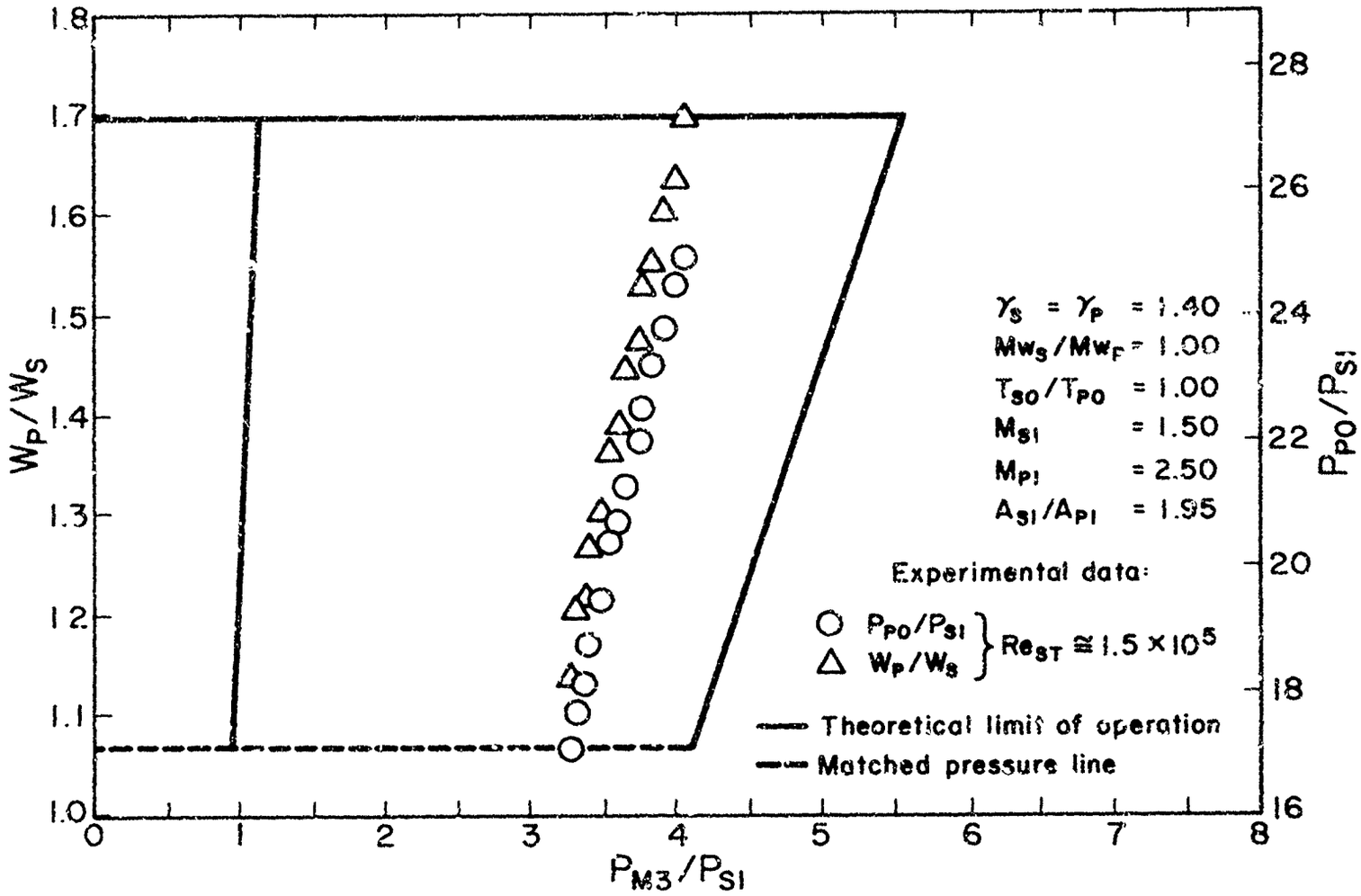


Figure 3.3-1 Maximum Compression Characteristics for the Constant-Area, Supersonic-Supersonic Ejector ($M_{SI} = 1.50$)

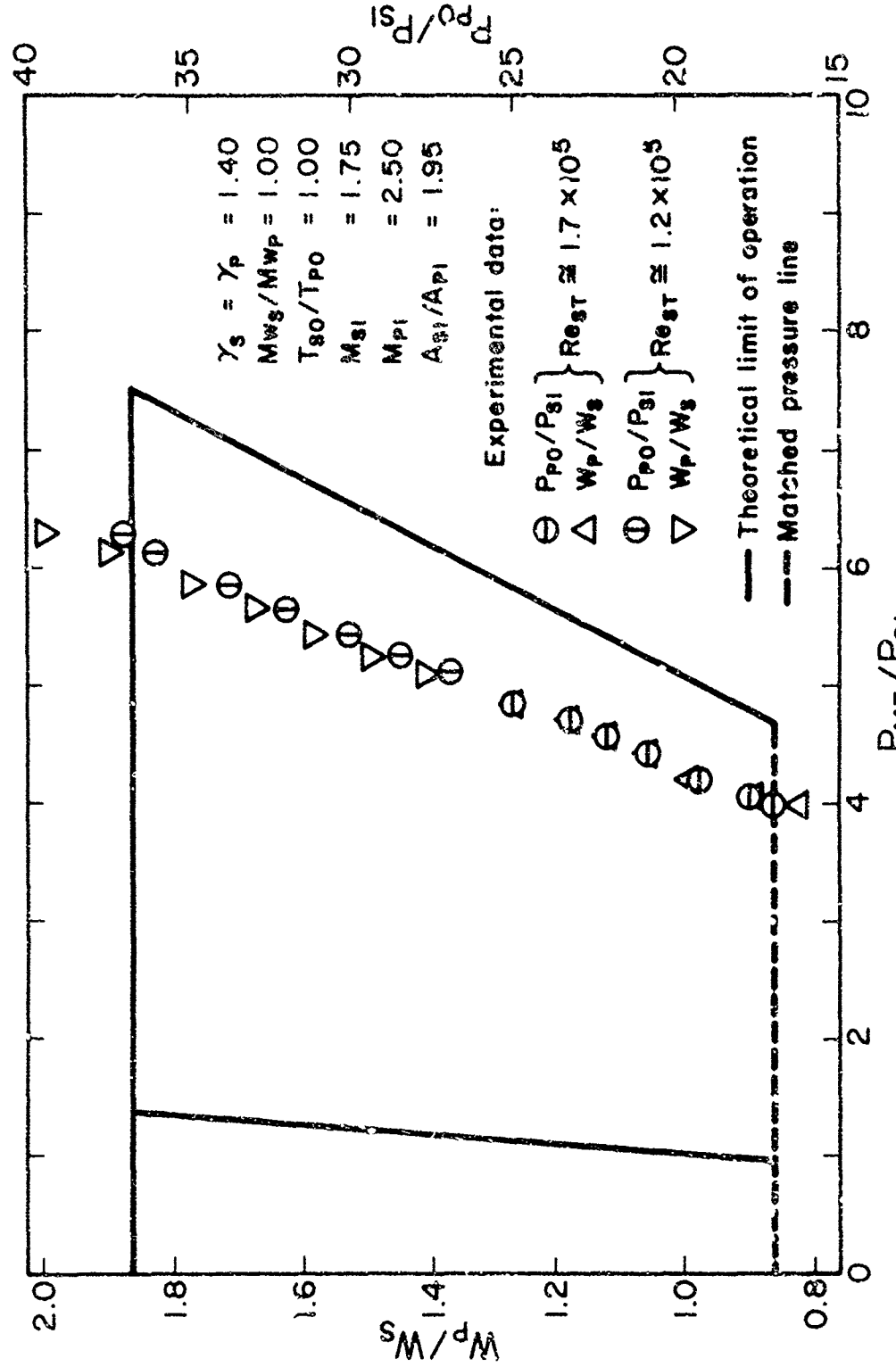


Figure 3.3-2 Maximum Compression Characteristics for the Constant-Area, Supersonic-Supersonic Ejector ($M_{S1} = 1.75$)

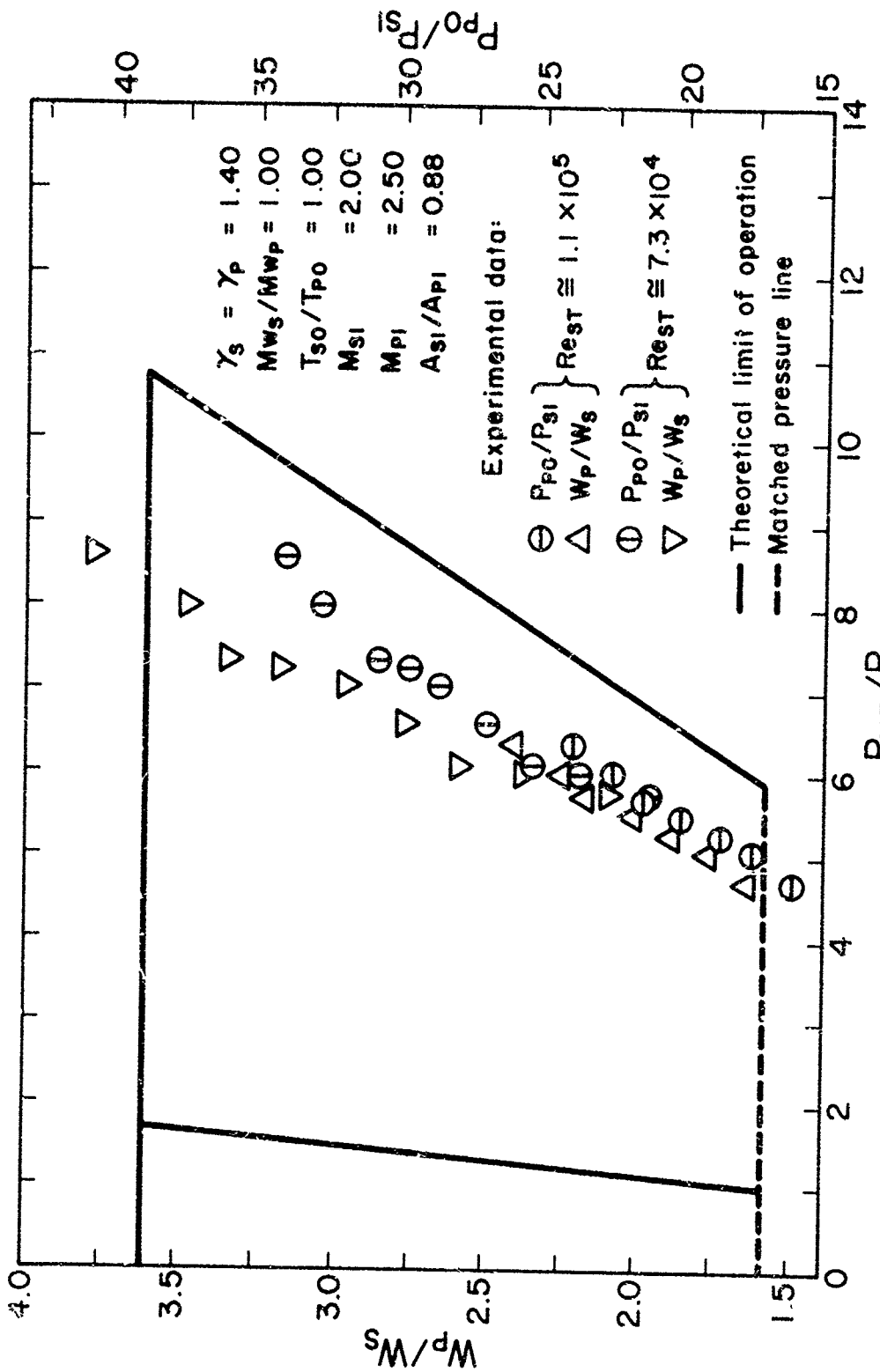


Figure 3.3-3 Maximum Compression Characteristics for the Constant-Area, Supersonic-Supersonic Ejector ($M_{S1} = 2.00$)

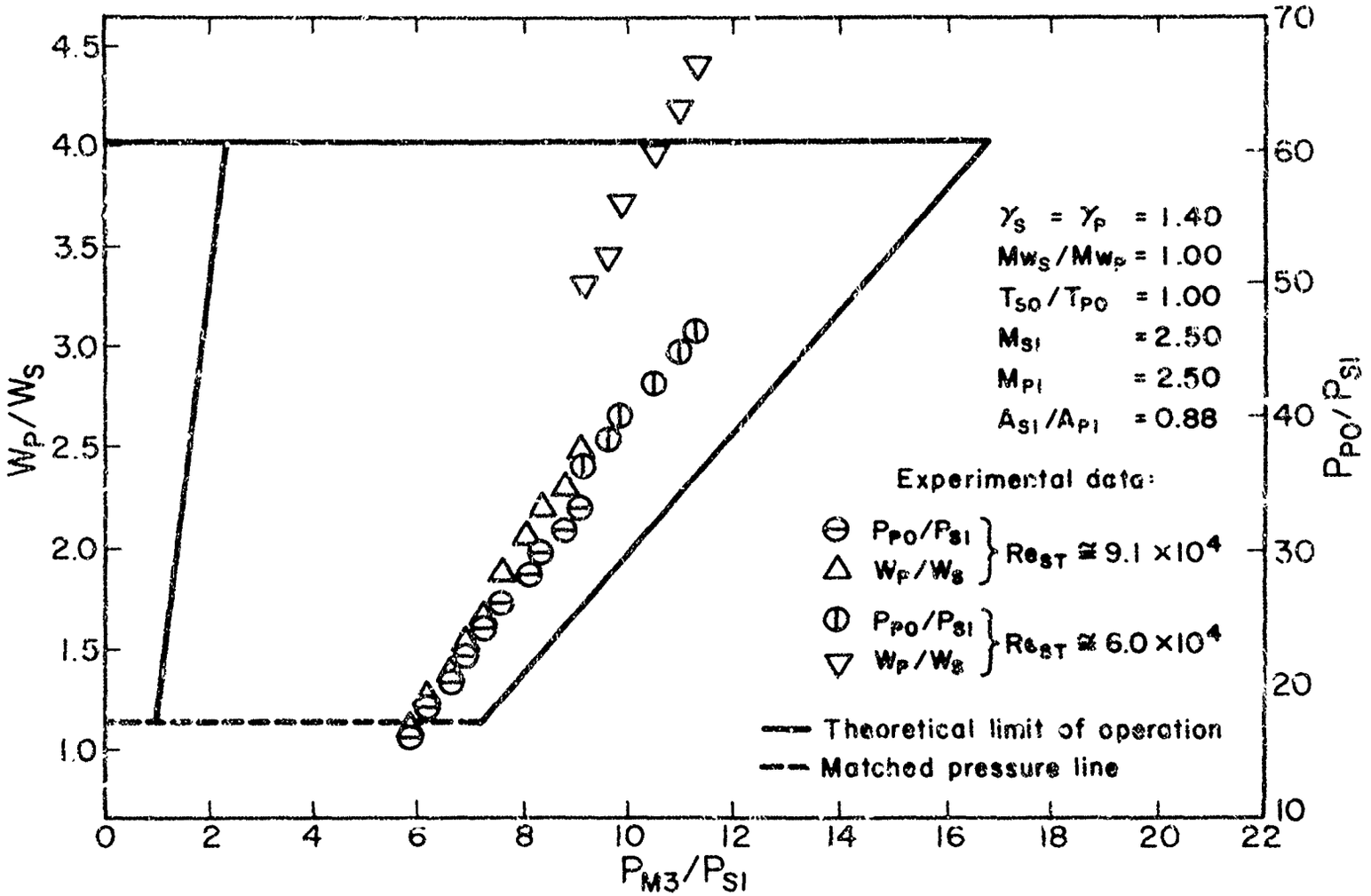


Figure 3.3-4 Maximum Compression Characteristics for the Constant-Area, Supersonic-Supersonic Ejector (M_{S1} = 2.50)

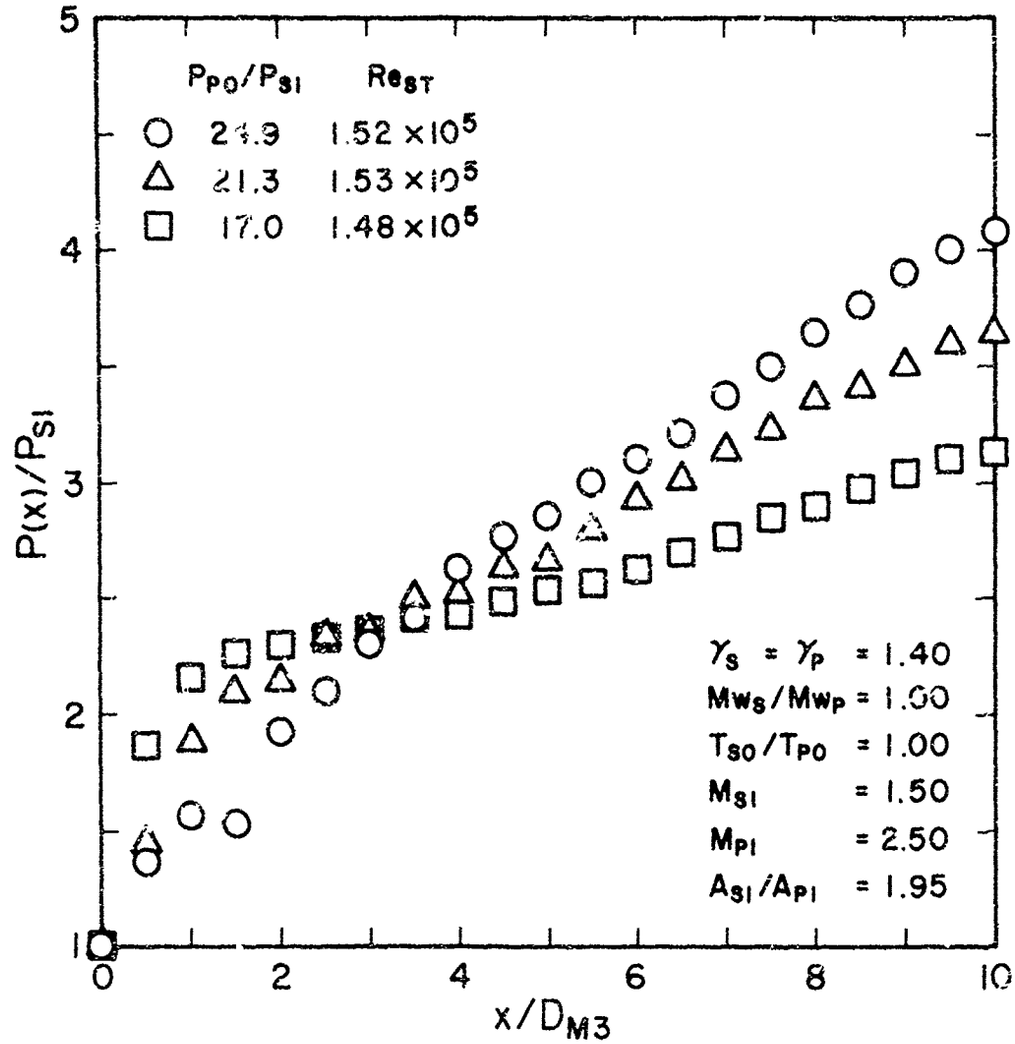


Figure 3.3-5 Wall Pressure Distributions for the Constant-Area, Supersonic-Supersonic Ejector at Maximum Compression Conditions (M_{S1} = 1.50)

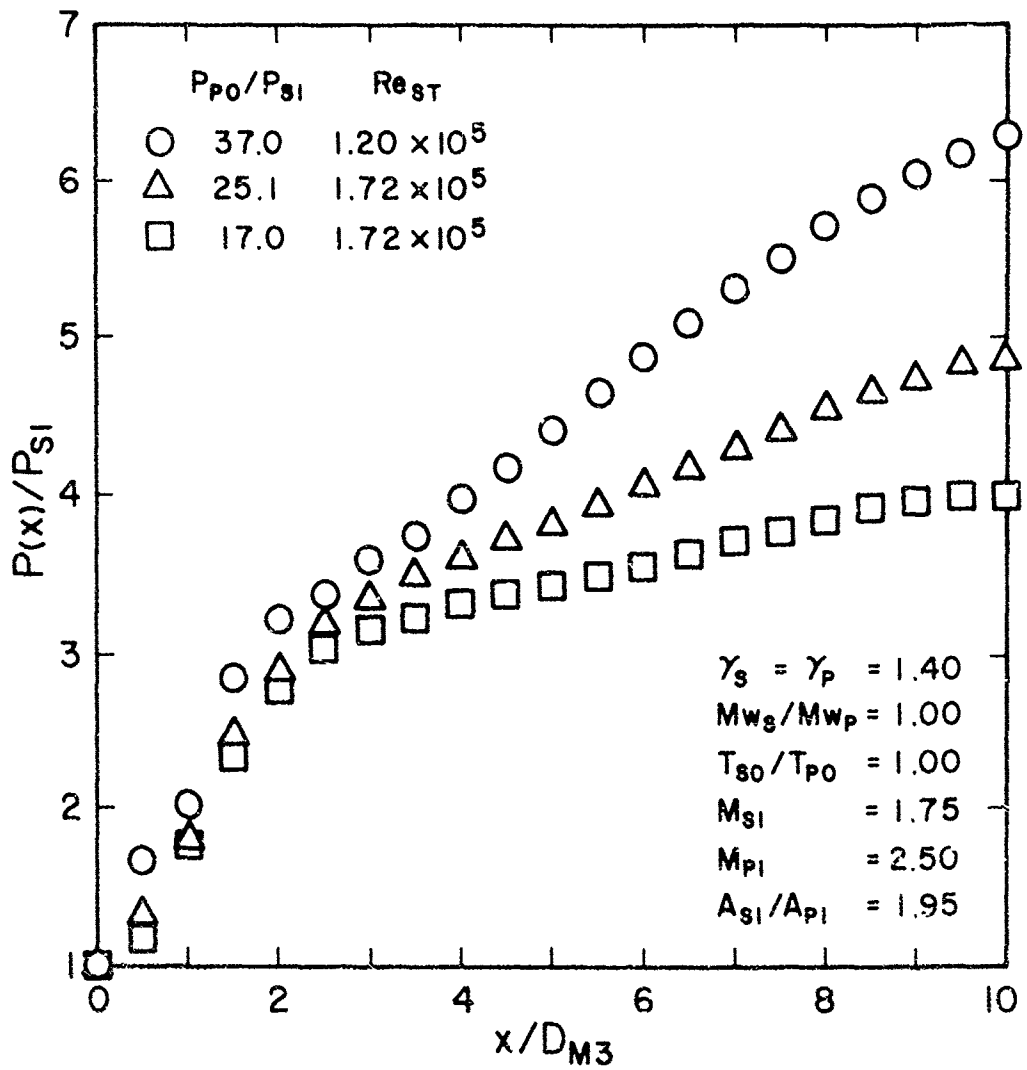


Figure 3.3-6 Wall Pressure Distributions for the Constant-Area, Supersonic-Supersonic Ejector as Maximum Compression Conditions ($M_{SI} = 1.75$)

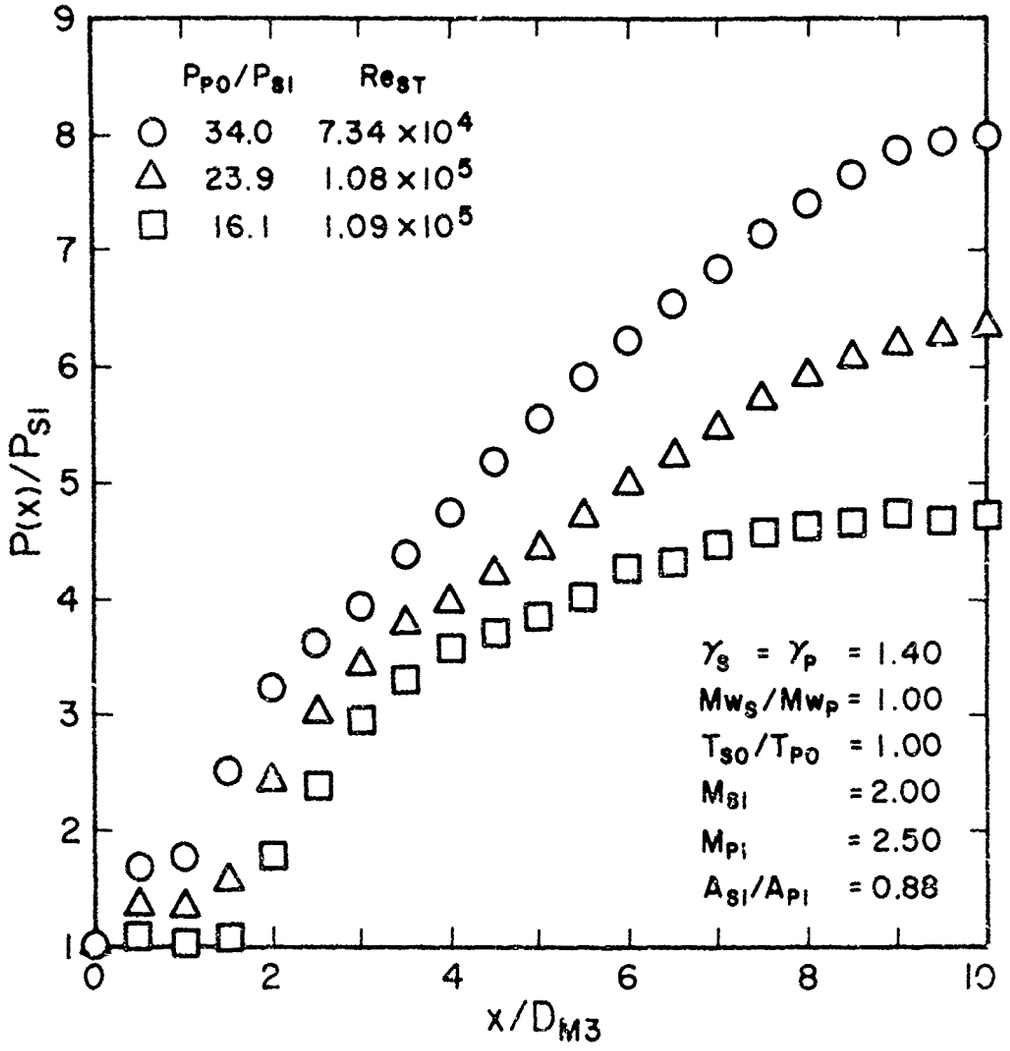


Figure 3.3-7 Wall Pressure Distributions for the Constant-Area, Supersonic-Supersonic Ejector at Maximum Compression Conditions (M_{S1} = 2.00)

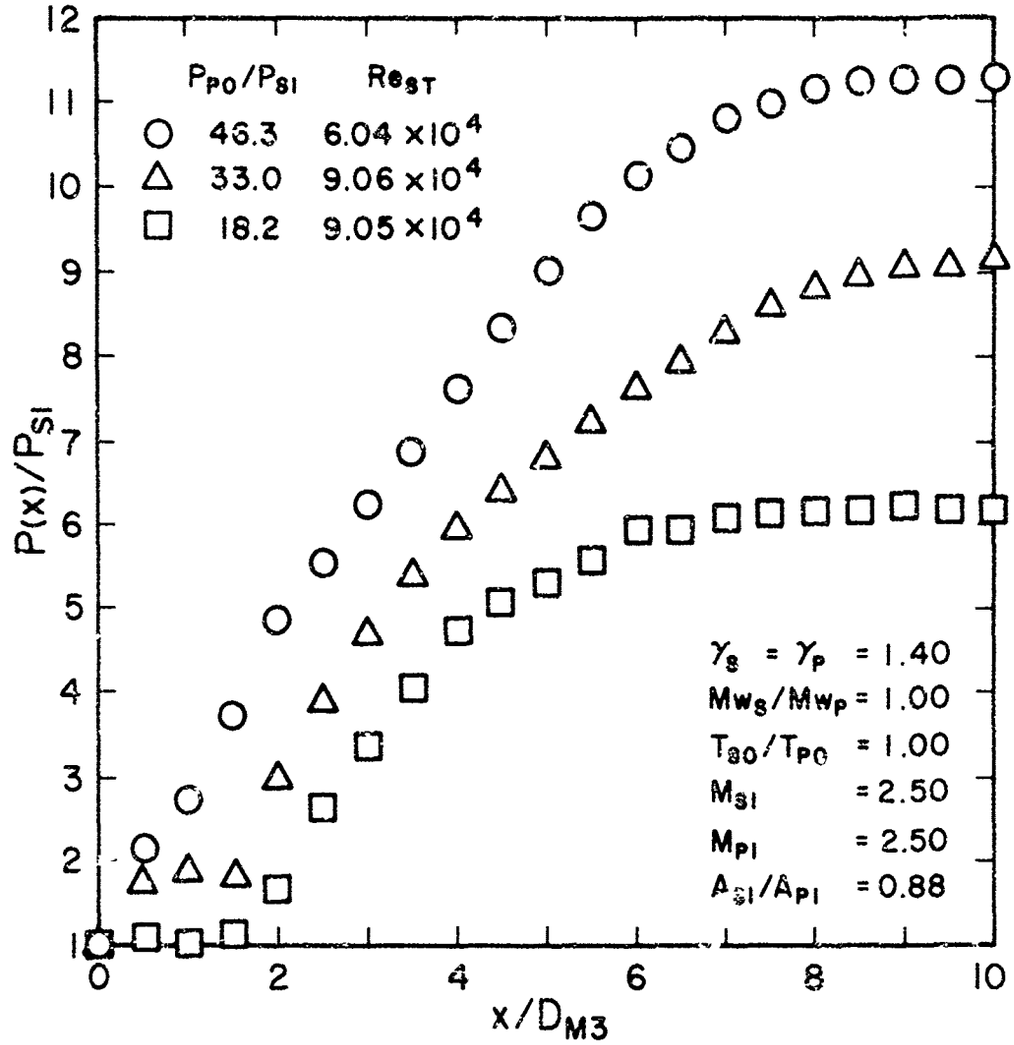


Figure 3.3-8 Wall Pressure Distributions for the Constant-Area, Supersonic-Supersonic Ejector at Maximum Compression Conditions ($M_{S1} = 2.50$)

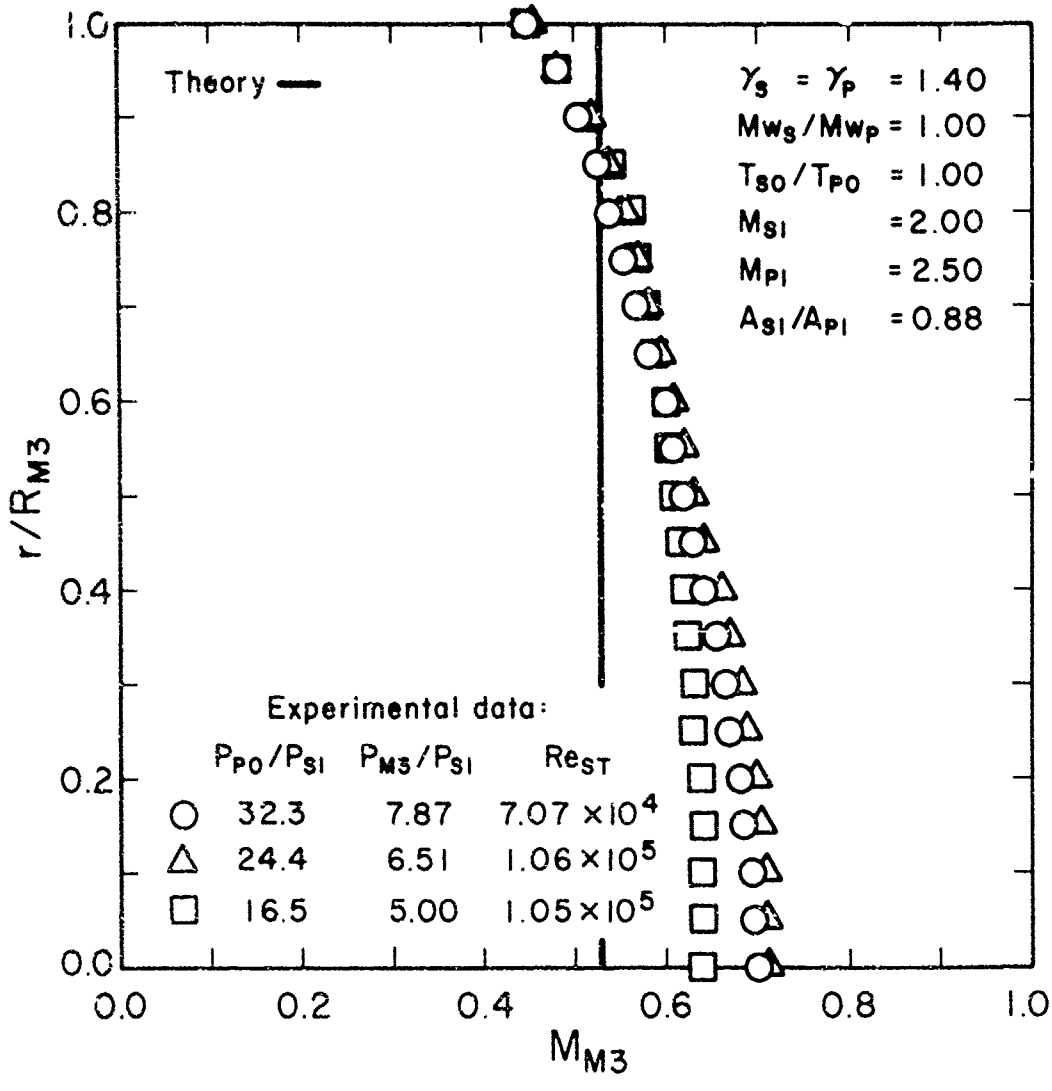
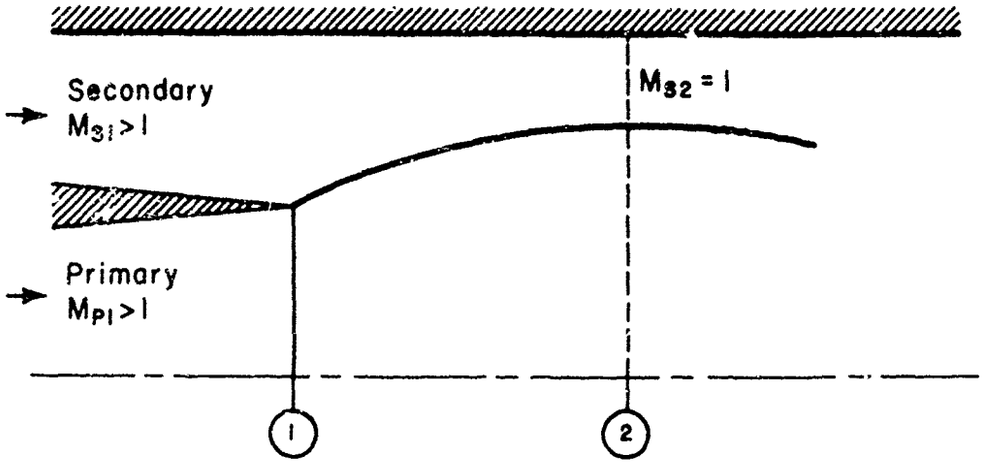
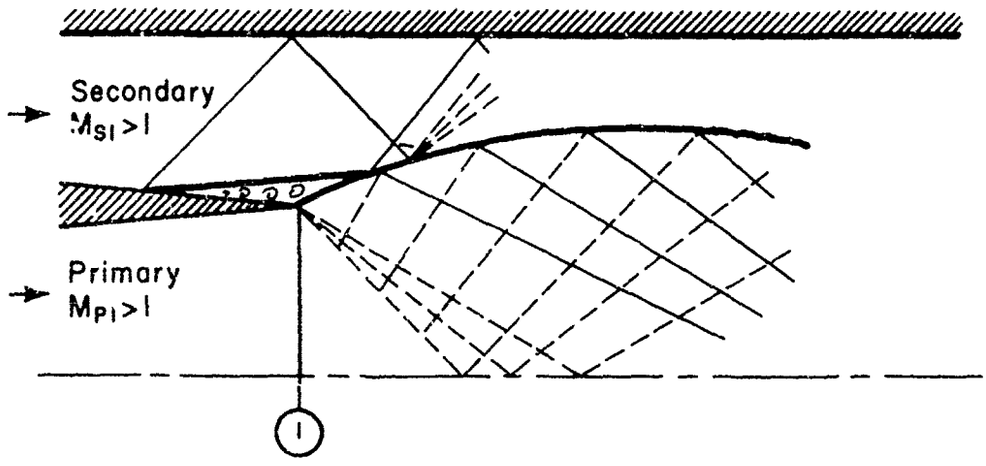


Figure 3.3-9 Exit Mach Number Distributions for the Constant-Area, Supersonic-Supersonic Ejector at Maximum Compression Conditions (M_{S1} = 2.00)



(a) Without Secondary Separation



(b) With Secondary Separation

Figure 3.3-10 Schematic of Secondary Flow Separation Induced by the Primary Flow

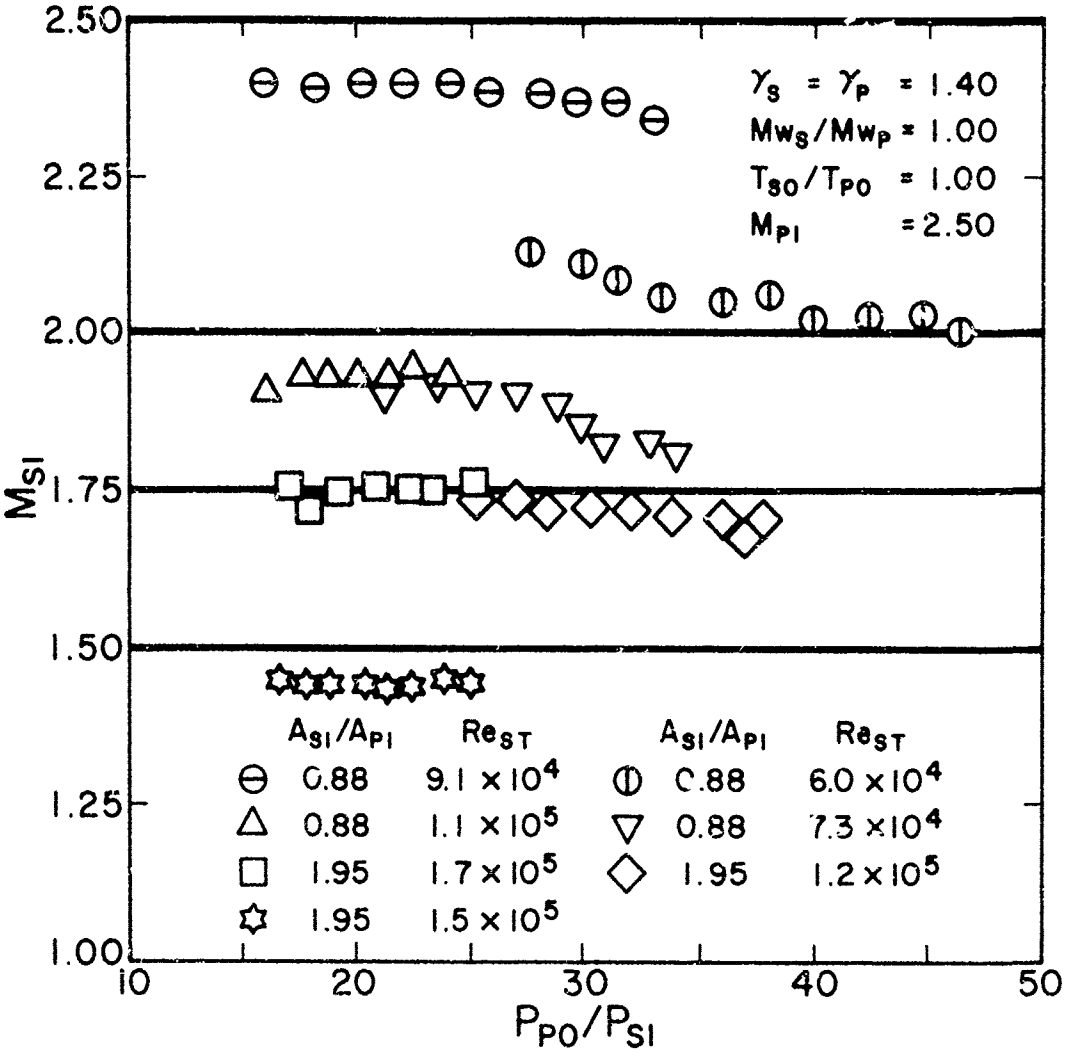


Figure 3.3-11 Variation in the Secondary Mach Number at the Mixing Tube Entrance with Primary Stagnation Pressure and Secondary Nozzle Reynolds Number

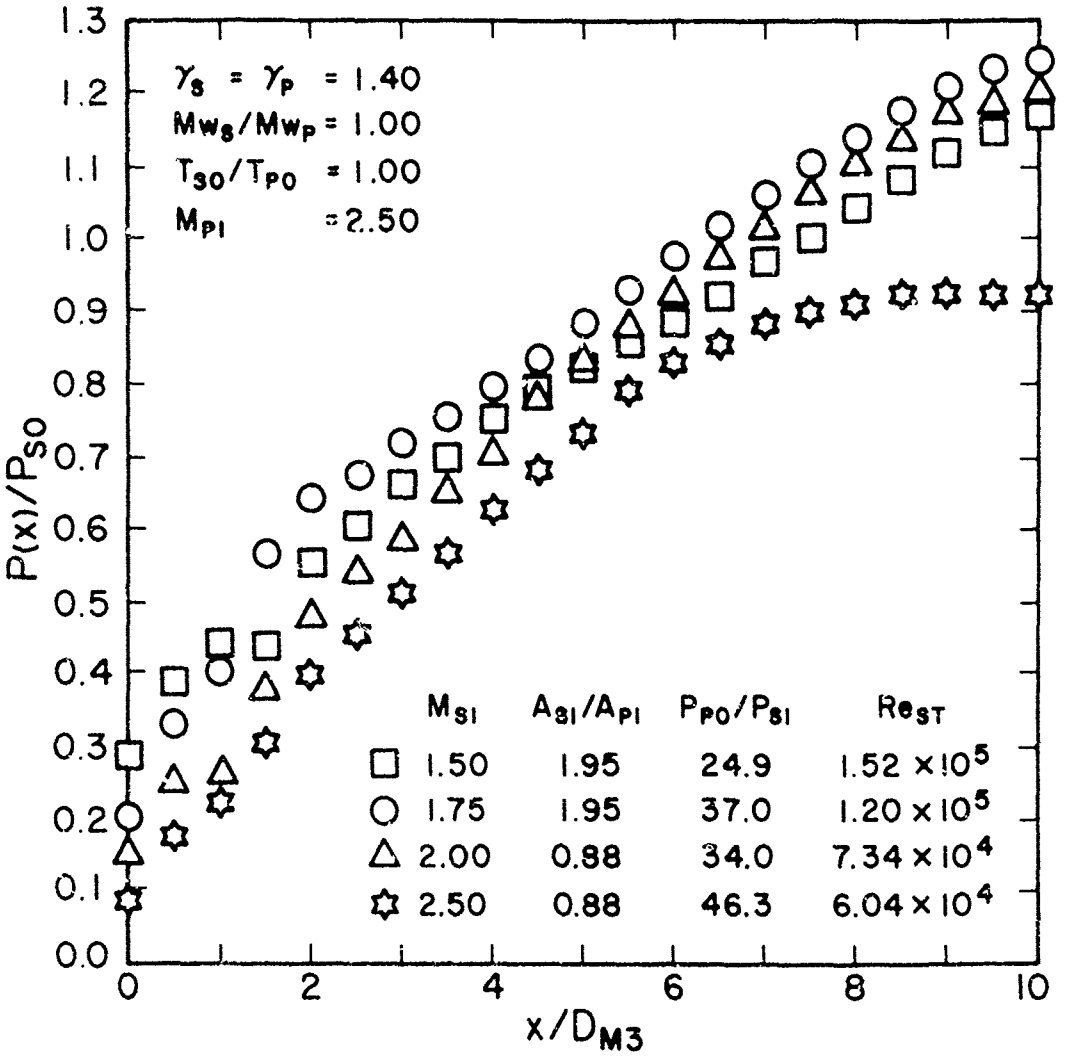


Figure 3.3-12 Wall Pressure Distributions for the Constant-Area, Supersonic-Supersonic Ejector Near the Upper Limit Point

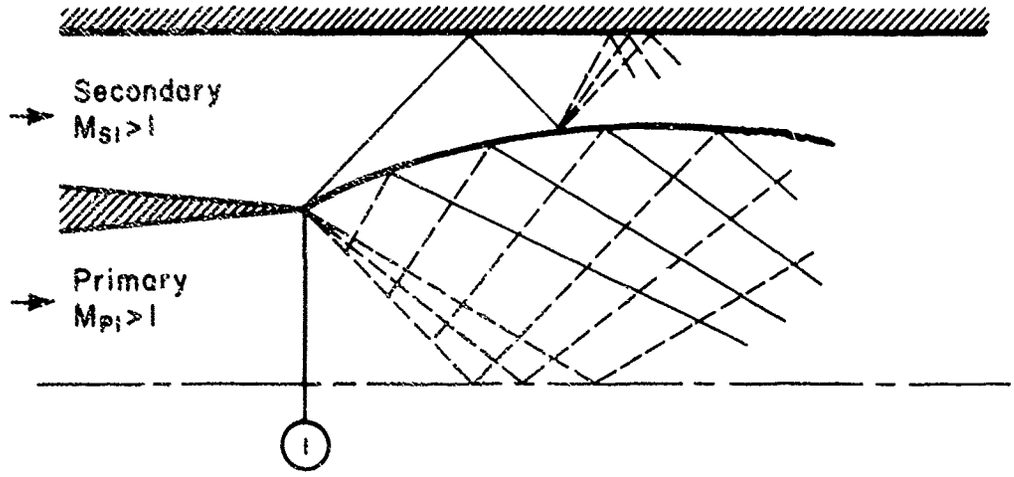


Figure 3.3-13 Schematic of a "Two Shock" Model for the Constant-Area, Supersonic-Supersonic Ejector

4.0 EJECTOR OPTIMIZATION AND COMPARISON OF THE CONSTANT-AREA, SUBSONIC-SUPERSONIC AND SUPERSONIC-SUPERSONIC EJECTORS

One purpose of this investigation was to compare the performance of the constant-area, supersonic-supersonic ejector with that of the constant-area, subsonic-supersonic ejector as applied to high-energy chemical laser systems. Because of the large number of parameters involved, it appears that the only fair comparison of the two ejectors must be based on optimum data for a supersonic-supersonic pumping system and a subsonic-supersonic pumping system. To this end, a method was developed for optimizing these two pumping systems within a given set of constraints. This method is based entirely on one-dimensional, compressible flow theory with a limited use of empirical data.

4.1 RELATIONSHIP OF THE CONSTANT-AREA SUBSONIC-SUPERSONIC EJECTOR TO THE CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR

The performance characteristics of the constant-area, subsonic-supersonic ejector and constant-area, supersonic-supersonic ejector are quite similar, the primary difference being the range of M_{S1}.

Given γ_S, γ_P, Mw_S/Mw_P, T_{S0}/T_{P0}, and A_{S1}/A_{P1}, the performance characteristics of the constant-area, subsonic-supersonic ejector, as shown schematically in Fig. 4.1-1, are described by a three-dimensional surface with axis M_{S1}, P_{S1}/P_{P0}, and P_{M3}/P_{P0}. Since the secondary entrance forms a converging nozzle, M_{S1} may take on any value in the range 0 to 1. For $P_{P1} > P_{S1}$, the primary stream expands inside the mixing tube and the secondary stream is reaccelerated to, at most, sonic conditions. Should the secondary stream be thus choked, the ejector operation becomes independent of P_{M3}/P_{P0} as indicated by two faces of the characteristic

surface which lie parallel to the P_{M3}/P_{P0} axis. The curve marking the transition from the P_{M3}/P_{P0} independent to dependent regimes is known as the "break-off" curve and is considered to represent the optimum conditions for ejector operation.†

Given γ_S, γ_P, Mw_S/Mw_P, T_{S0}/T_{P0}, and A_{S1}/A_{P1}, the performance characteristics of the constant-area, supersonic-supersonic ejector, as shown schematically in Fig. 4.1-2, are also described by a three-dimensional surface with axis M_{S1}, P_{S1}/P_{P0}, and P_{M3}/P_{P0}; however, the ejector operation is restricted to only a portion of the surface. So long as the entering secondary stream remains supersonic, as assumed in Section 2.0, M_{S1} will be at the supersonic design value as produced by the generating device, e.g. a laser cavity, and the ejector is confined to the plane of supersonic-supersonic operation. If P_{M3}/P_{P0} is increased beyond the limit of maximum P_{M3}/P_{P0} for supersonic-supersonic operation, then a normal shock wave will pass into the secondary entrance and M_{S1} must undergo a step change to the normal shock value as indicated in Fig. 4.2-2(a). If, alternately, P_{S1}/P_{P0} is decreased beyond the upper limit line for supersonic-supersonic operation, then the secondary stream is recompressed in the mixing tube to an area less than A* for the supersonic design value of M_{S1}, and M_{S1} must drop to the subsonic design value of the generating device. However, if P_{S1}/P_{P0} is now increased, the entering secondary flow will again go supersonic, similar to a second-throat, supersonic diffuser, with M_{S1} first increasing to the normal shock value before a step change to the supersonic design value.

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†See references [1,8,10,11] for a complete description of constant-area, subsonic-supersonic ejector operation.

The similarity in performance characteristics of the constant-area, subsonic-supersonic ejector and constant-area, supersonic-supersonic ejector becomes even more apparent as the supersonic design value of M_{S1} in Fig. 4.1-2(a) approaches 1 since the normal shock value also approaches 1 and, in the limit, Fig. 4.1-2(a) becomes identical to Fig. 4.1-1(a).

4.2 OPTIMIZATION OF THE CONSTANT-AREA, SUBSONIC-SUPERSONIC AND SUPERSONIC-SUPERSONIC EJECTORS

Referring to the high-energy, chemical laser system schematic of Fig. 4.2-1, the laser cavity, stations 1 to 2, has no influence on the pumping system other than establishing the flow conditions at point 2. Hence, the laser cavity can be replaced by a supersonic wind tunnel or any other device producing a uniform, supersonic stream. A one-dimensional analysis for laser cavity flows with heat addition is available [1] and was included in a computerized version of the optimization procedure.

The constant-area, normal shock diffuser, stations 2 to 3 of Fig. 4.2-1, diffuses the entering supersonic stream to its normal shock value. The static pressure ratio across the duct is expressed by

$$P_3/P_2 = R_{NSD}\, f(\gamma_s, M_2)$$

where R_{NSD} is an empirical normal shock coefficient and $f(\gamma_s, M_2)$ is the usual normal shock static pressure ratio function. Values of R_{NSD} in the range $0.75 \leq R_{NSD} \leq 1.25$ are commonly used for parametric studies [1].

The static pressure rise across the subsonic diffuser, stations 3 to 4 of Fig. 4.2-1, is given by

$$(P_4 - P_3)_{ACTUAL} = \eta (P_4 - P_3)_{IDEAL}$$

where η is an empirical diffuser efficiency and $(P_4 - P_3)_{IDEAL}$ is a function of γ_S, M_3, and A_4/A_3. As a simplification, η was taken from a curve fit of experimental data given in [17,18] for 15° conical, subsonic diffusers with

$$\eta = 1.048992 - 0.027229\ (A_4/A_3) - 0.024461\ (A_4/A_3)^2 + 0.002685\ (A_4/A_3)^3 ,$$

$$1.0 \leq A_4/A_3 \leq 5.2 \quad .$$

This empirical relation was also applied to the subsonic diffuser at stations 7 to 8.

Although stagnation pressure losses are encountered in sudden enlargements, these losses were ignored in the subsonic-supersonic pumping system of Fig. 4.2-1.

Finally, the one-dimensional analysis for the constant-area, supersonic-supersonic ejector of Fig. 4.2-1 was taken from Section 2.0, and the corresponding analysis for the constant-area, subsonic-supersonic ejector was taken from Addy and Mikkelsen [1].

Then given γ_S, M_2, R_{NSD}, A_4/A_3, γ_P, Mw_P/Mw_S, T_{60}/T_{50}, A_8/A_7, P_{60}/P_2, and P_8/P_2 for the subsonic-supersonic pumping system, or γ_S, M_2, γ_P, Mw_P/Mw_S, T_{60}/T_{20}, A_8/A_7, P_{60}/P_2, and P_8/P_2 for the supersonic-supersonic pumping system, the optimum is considered to be that ejector, as specified by M_6 and A_7/A_6 which requires the minimum W_P/W_S; or, alternately, the minimum P_{60}/P_2 when W_P/W_S is specified. In general, γ_S, M_2, γ_P, Mw_P/Mw_S, and T_{60}/T_{50} (or T_{60}/T_{20}) are known and P_8/P_2 and P_{60}/P_2 (or W_P/W_S) are the constraints of primary interest.

Now consider the simplified supersonic-supersonic pumping system of Fig. 4.2-1 with $A_8/A_7 = 1$, i.e. with no subsonic diffuser and γ_S, γ_P,

Mw_P/Mw_S, T_{60}/T_{20}, and M_2 as known constants. Then given M_6 and A_2/A_6, upper limit point values of P_7/P_2, P_{60}/P_2, and W_P/W_S are obtained from the one-dimensional theory of Section 2.0. Figure 4.2-2 is a plot of M_6 vs. P_7/P_2 at the upper limit point over a range of A_2/A_6 for this system. If the compression ratio P_7/P_2 is chosen to be, say, 20, then all possible combinations of M_6 and A_2/A_6 satisfying this constraint are determined by the verticle dashed line.

Figure 4.2-3 is a cross plot of P_{60}/P_2 and W_P/W_S vs. A_2/A_6 for the combinations of M_6 and A_2/A_6 of Fig. 4.2-2 satisfying the constraint on P_7/P_2. From this graph it is apparent that P_{60}/P_2 varies inversely with W_P/W_S and that if an upper limit is established for P_{60}/P_2, say, at 1000, then the minimum value of W_P/W_S, in this case $W_P/W_S = 3.2$, will occur at that upper limit. The optimum ejector is, therefore, fully determined since $A_2/A_6 = 4.4$ for $P_{60}/P_2 = 1000$ and $M_6 = 4.4$ from Fig. 4.2-2. If, for example, an upper limit of 6 is set for W_P/W_S, then the minimum value of P_{60}/P_2, in this example $P_{60}/P_2 = 217$, will occur at $A_2/A_6 = 1$, corresponding to the upper limit value of W_P/W_S in Fig. 4.2-3 and $M_6 = 3.7$ from Fig. 4.2-2.

This procedure for optimizing the supersonic-supersonic pumping system of Fig. 4.2-1 is not significantly altered by the addition of a subsonic diffuser at stations 7 to 8. Figures 4.2-2 and 4.2-3 are still sufficient; however, the overall compression ratio P_8/P_2 is substituted for P_7/P_2.

The optimization procedure for the subsonic-supersonic pumping system of Fig. 4.2-1 is nearly identical to the procedure outlined above for the supersonic-supersonic pumping system, with Figs. 4.2-4 and 4.2-5

corresponding to Figs. 4.2-2 and 4.2-3, respectively; however, one additional variable is involved since M_5 may take on any value in the range $0 \leq M_5 \leq 1$. The result is that Figs. 4.2-4 and 4.2-5 must be reproduced for all values of M_5 which give solutions satisfying the constraints on P_7/P_2 and P_{60}/P_2 (or alternately W_P/W_S). Once this is accomplished, the minimum values of W_P/W_S (or alternately P_{60}/P_2) can be cross plotted vs. M_5 to find the absolute minimum as shown in Figs. 4.2-6 and 4.2-7. This process completes the ejector specification since, for example, W_P/W_S and M_5 from Fig. 4.2-6 determine A_5/A_6 from Fig. 4.2-5, which in turn specifies M_6 from Fig. 4.2-4.

As an example of the optimization procedure for a subsonic-supersonic pumping system of Fig. 4.2-1 with R_{NSD}, A_4/A_3 and A_8/A_7 equal to 1, let $M_5 = 0.9$ as in Figs. 4.2-4 and 4.2-5 with constraints of $P_7/P_2 = 20$ and $P_{60}/P_2 = 1000$. Since P_{60}/P_2 varies inversely with W_P/W_S in Fig. 4.2-5, the minimum value of W_P/W_S is 2.8 at $A_5/A_6 = 3.8$ and $M_6 = 4.5$ from Fig. 4.2-4. Repeating this process for all suitable values of M_5 and plotting the results, shown in Fig. 4.2-6, it can be seen that the absolute minimum value of W_P/W_S occurs at $M_5 = 0.9$ and the optimization is complete.

If in the preceding example an upper limit of $W_P/W_S = 6$ was selected rather than the constraint on P_{60}/P_2, then for $M_5 = 0.9$, the minimum value of P_{60}/P_2 would be 105 at $A_5/A_6 = 0.8$ from Fig. 4.2-5 and $M_6 = 2.8$ from Fig. 4.2-4. Now repeating this process for all values of M_5 yielding solutions which satisfy the system constraints and plotting the results shown in Fig. 4.2-7, it can be seen that the absolute minimum value of

P_{60}/P_2 occurs at $M_5 = 0.7$, rather than at $M_5 = 0.9$, and that the solution at $M_5 = 0.9$ is merely one step in the optimization process.

While this graphical method of ejector optimization is necessarily quite tedious, the entire process is readily adaptable to standard computer programing procedures. Some care, however, must be taken in the selection of M_5, A_5/A_6, and M_6 (or A_2/A_6 and M_6) since only certain combinations will yield solutions satisfying any one system constraint.

4.3 COMPARISON OF OPTIMUM CONSTANT-AREA, SUBSONIC-SUPERSONIC AND SUPERSONIC-SUPERSONIC EJECTOR DATA

Three sets of optimum data, as listed in Tables 4.3-1, 4.3-2, and 4.3-3, were calculated by the procedure of Section 4.2 for comparison of a supersonic-supersonic pumping system with a subsonic-supersonic pumping system as shown in Fig. 4.2-1. The first two cases represent typical high-energy, chemical laser system data while the third case demonstrates a supersonic wind tunnel application. In each case, the appropriate variable, either W_p/W_s or P_{60}/P_2, was minimized for the supersonic-supersonic pumping system and for the subsonic-supersonic pumping system with $R_{NSD} = 1.0$, 0.85, and 0.75. The exit-to-entrance area ratio for all the subsonic diffusers was arbitrarily set at 2.0. The optimum ejector for each case is specified by M_6 and A_7/A_6. The area ratio A_8/A_2 was also tabulated as an indication of the overall size of the pumping systems.

In selecting data for the hypothetical, supersonic wind tunnel configuration of Table 4.3-3, it was assumed that the secondary, or test section, nozzle and the ejector primary nozzle would both be supplied from a common source at the same stagnation pressure, in this case

790.8 kPa, and that the ejector system would pump to atmospheric conditions. This assumption precludes a minimization of P_{60}/P_2 since the compression ratio P_8/P_2 would be unknown.

The optimization method of Section 4.2 used only theoretical, supersonic-supersonic ejector data computed at upper limit point conditions. In defense of this procedure, Cases No. 1 and 2 were also calculated for a supersonic-supersonic pumping system at matched pressure conditions. A matched pressure calculation was unrealistic for the supersonic wind tunnel, Case No. 3, since this condition would only be satisfied if the secondary, or test section, nozzle and primary ejector nozzle (operating at equal stagnation pressures) had identical design Mach numbers.

Examination of the optimum data for Cases No. 1, 2, and 3 leads to several important conclusions:

1. For a fixed value of P_{60}/P_2, the minimum value of W_P/W_S for the supersonic-supersonic pumping system lies between the minimum value of W_P/W_S for the subsonic-supersonic pumping systems with $R_{NSD} = 1.0$ and 0.85. Since a value of $R_{NSD} \leq 0.85$ is most realistic, it appears that the supersonic-supersonic pumping system gives the best performance.

For a fixed value of W_P/W_S, the minimum value of P_{60}/P_2 for the supersonic-supersonic pumping system is equal to or greater than the minimum value of P_{60}/P_2 for the subsonic-supersonic pumping system with $R_{NSD} = 0.75$ indicating that the performance of the subsonic-supersonic pumping system is superior.

Clearly, the only conclusion to be drawn from this limited data is that the selection of one pumping system over the other on the bases of

mass flow ratio and primary stagnation pressure depends entirely on the system constraints and that no broad statement can be made as to one pumping system performing better than the other.

2. Upper limit point conditions are preferred over matched pressure conditions in the optimization of supersonic-supersonic pumping systems since the resultant system requires much lower values of W_P/W_S and P_{60}/P_2. The same conclusion, though not proven, should apply to all values of P_6/P_2 between the matched pressure and upper limit points since P_7/P_2 varies linearly with W_P/W_S and P_{60}/P_2 (see Section 2.0).

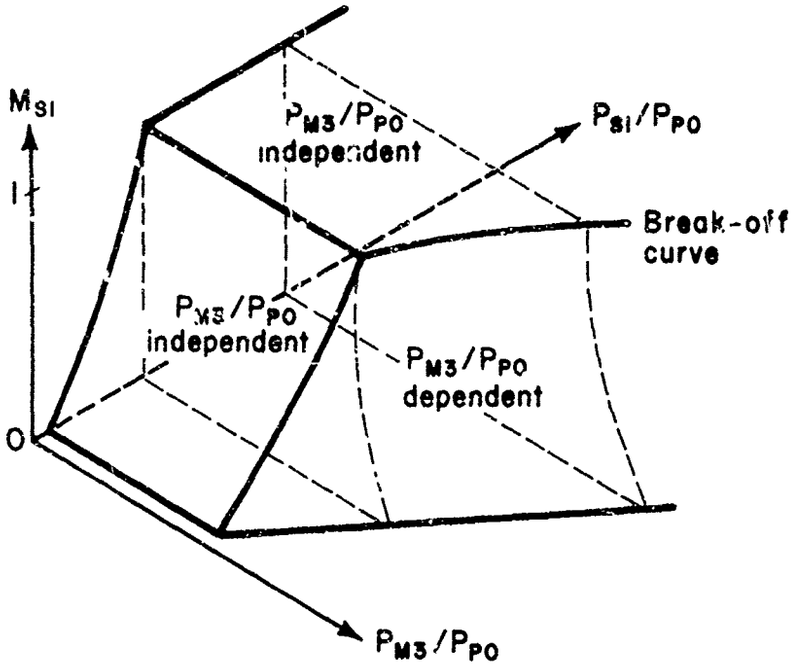
3. Based on the area ratio A_8/A_2, that pumping system with the best performance, or the smallest W_P/W_S or P_{60}/P_2 requirements, is also physically the smallest system.

4. The normal shock coefficient has a significant influence on the performance of subsonic-supersonic pumping systems and points to supersonic diffuser design as an area for careful attention.

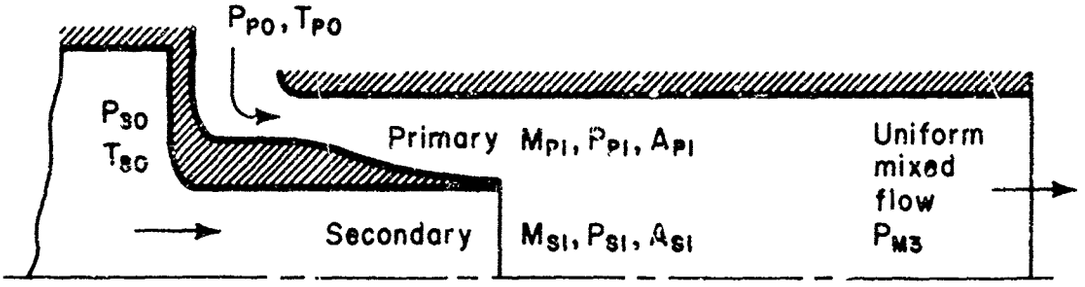
5. The comparison of a constant-area, subsonic-supersonic ejector with a constant-area supersonic-supersonic ejector on the bases of primary Mach number, M_6, and mixing tube area ratio, A_7/A_6, alone has little if any value.

4.4 COMPUTER PROGRAMS

Two computer programs were developed to conduct the foregoing optimization and system studies. The optimization program, CLGDOP, and the systems program, CLGDSP, along with sample input and output data are presented in detail in APPENDICES 7.4 and 7.5, respectively.

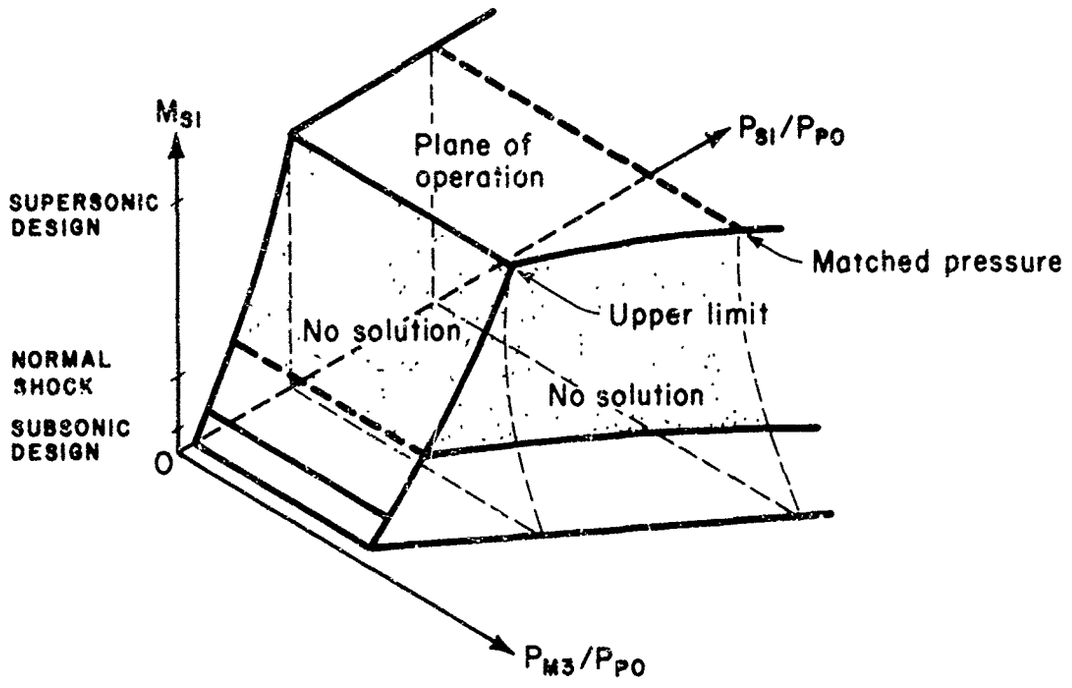


(a) Ejector Characteristic Surface

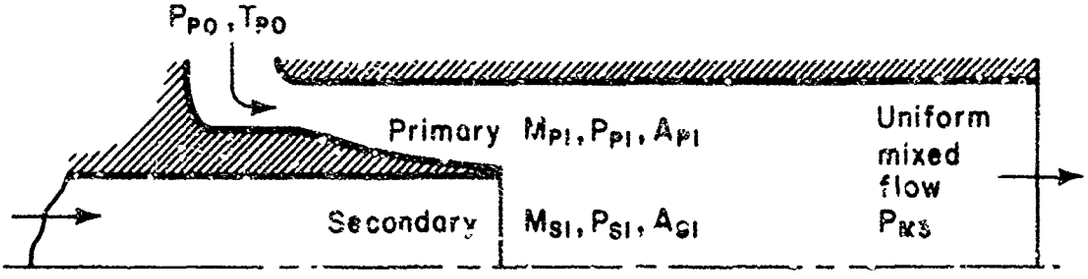


(b) Ejector Configuration and Notation

Figure 4.1-1 Constant-Area, Subsonic-Supersonic Ejector Performance Characteristics



(a) Ejector Characteristic Surface



(b) Ejector Configuration and Notation

Figure 4.1-2 Constant-Area, Supersonic-Supersonic Ejector Performance Characteristics

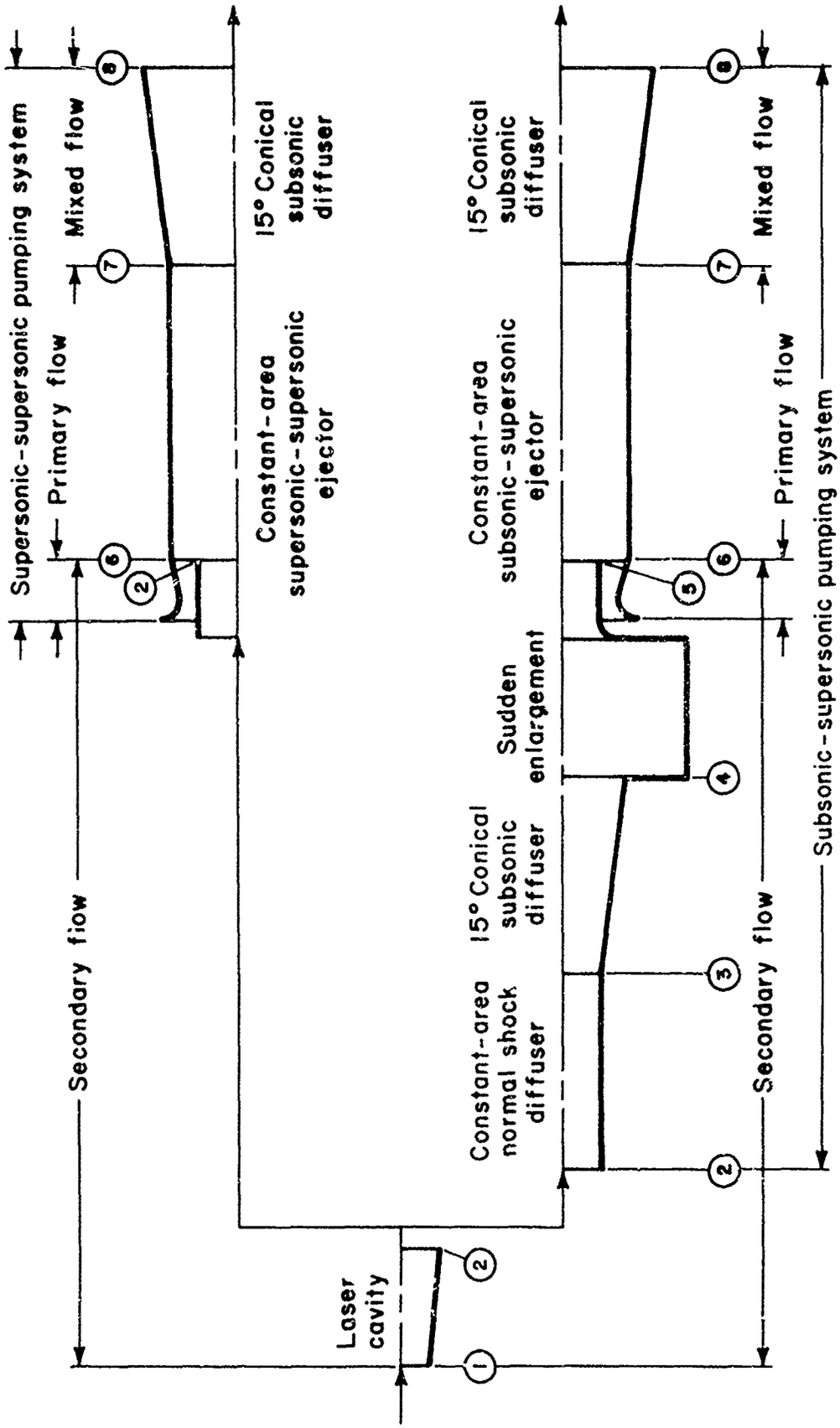


Figure 4.2-1 High-Energy, Chemical Laser System Schematic

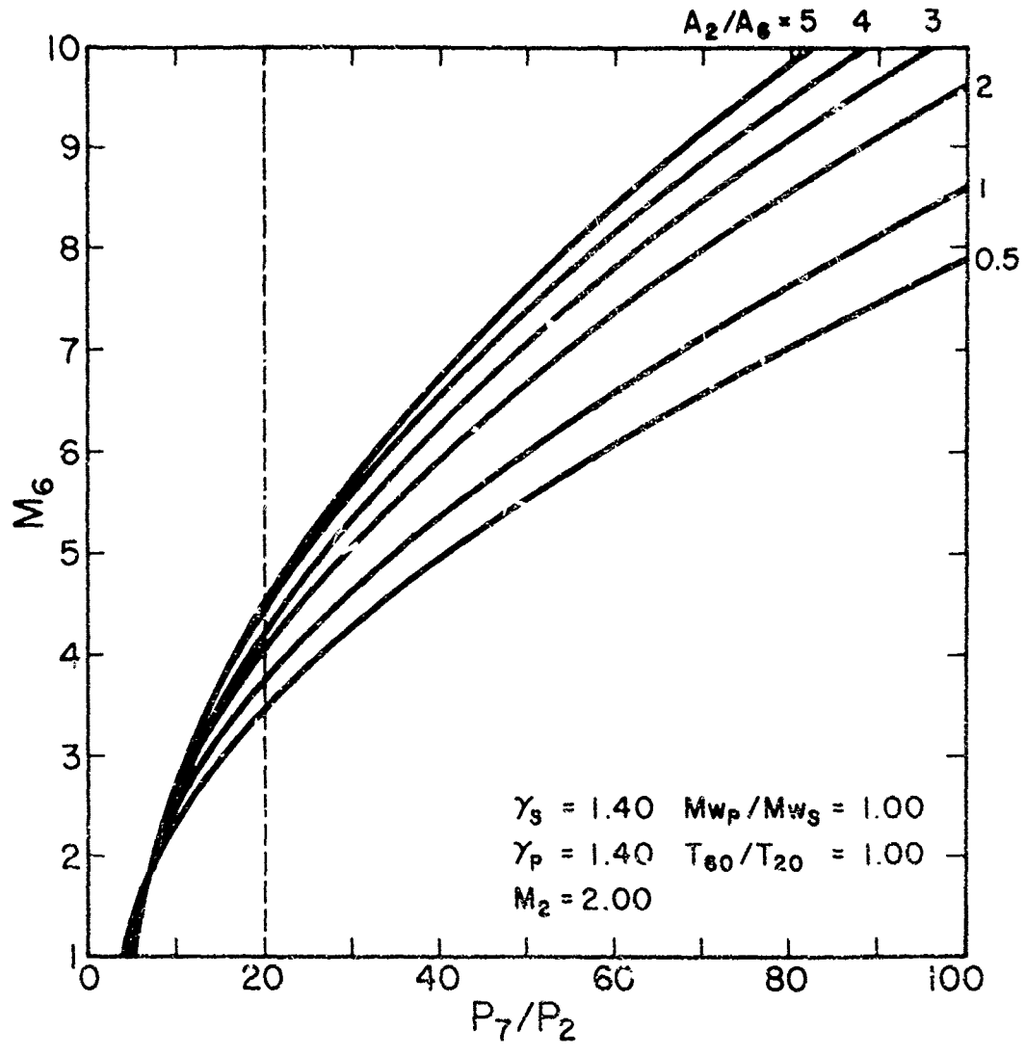


Figure 4.2-2 Typical Upper Limit Point Data for Optimization of a Supersonic-Supersonic Pumping System (M_6 vs. P_7/P_2)

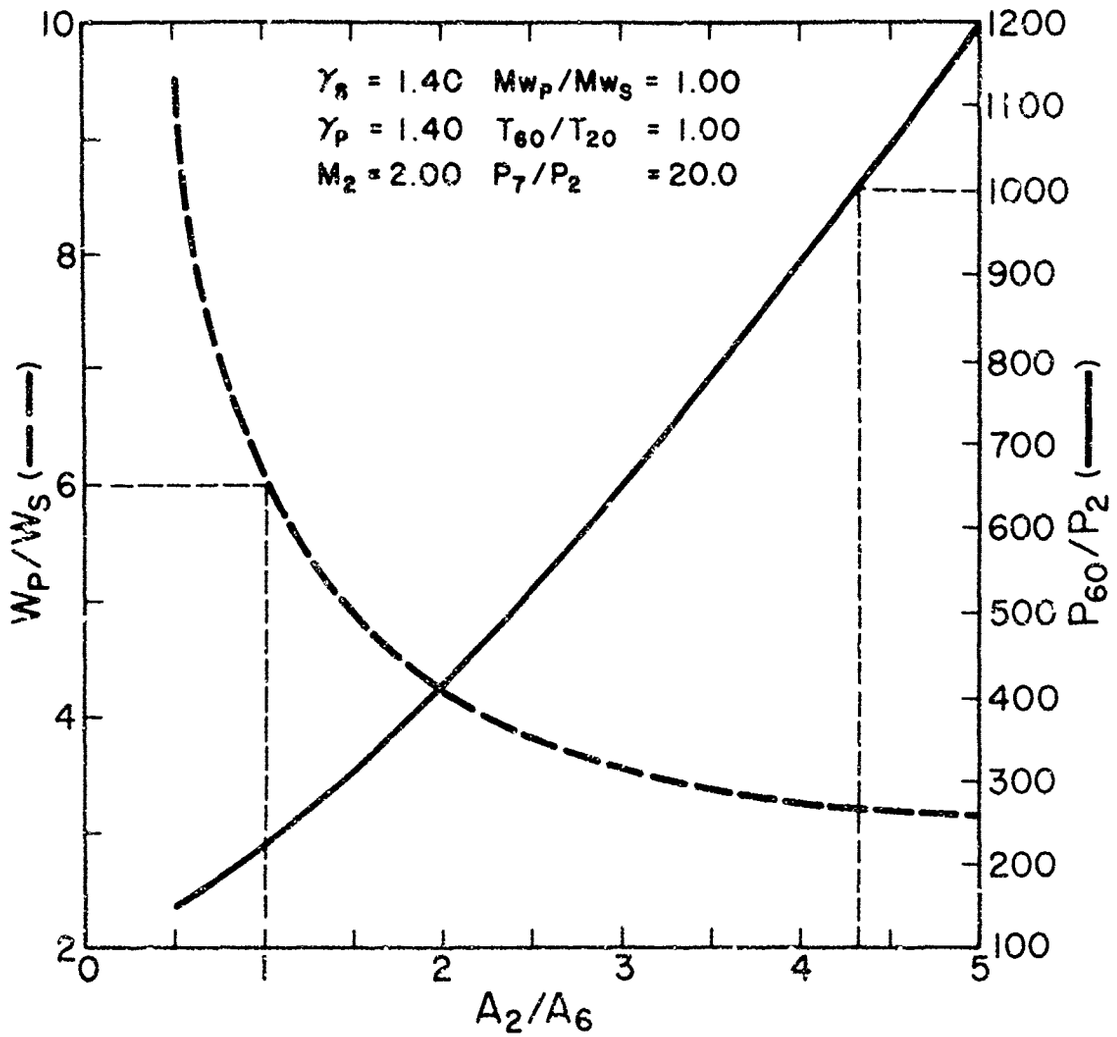


Figure 4.2-3 Typical Upper Limit Point Data for Optimization of a Supersonic-Supersonic Pumping System (W_p/W_s and P_{60}/P_2 vs. A_2/A_6)

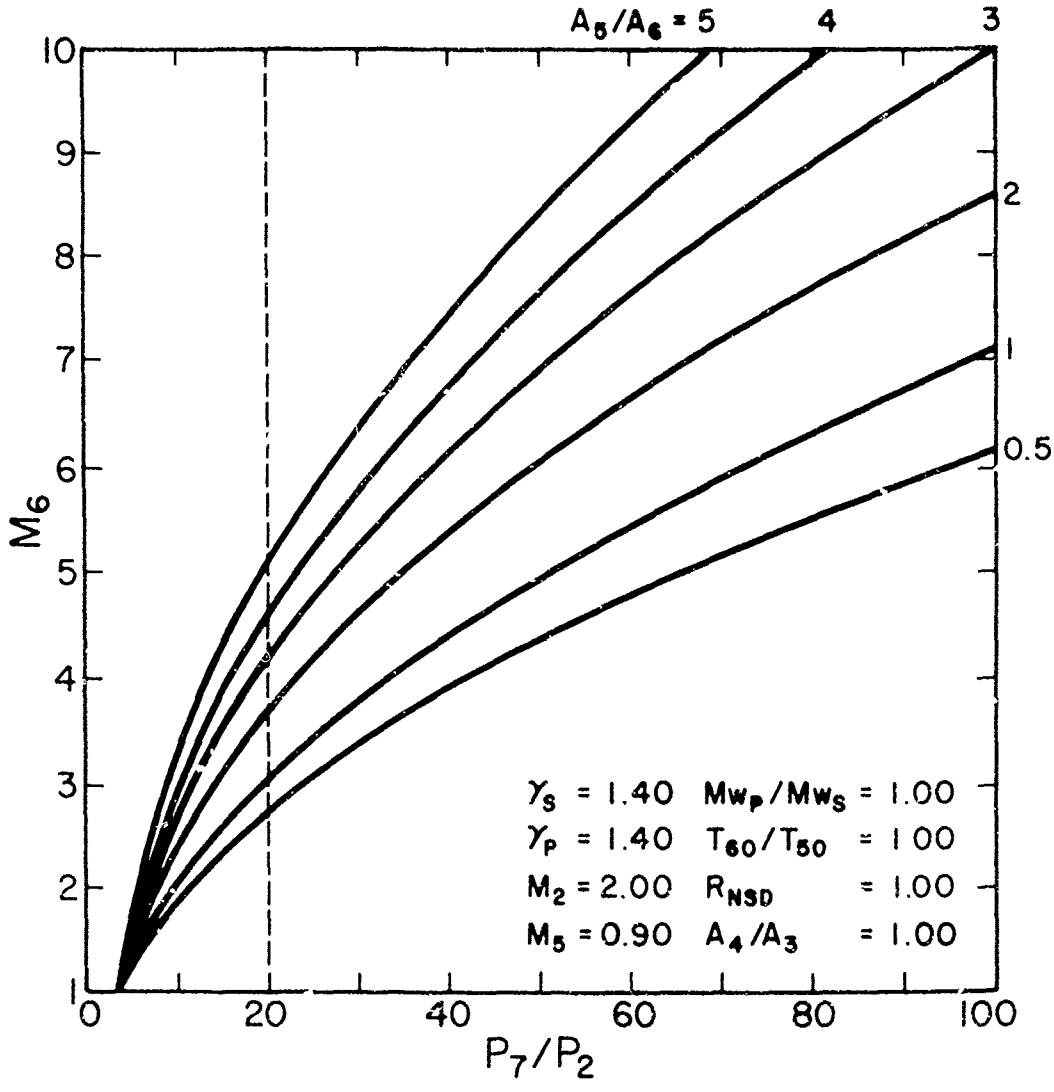


Figure 4.2-4 Typical Break-Off Data for Optimization of a Subsonic-Supersonic Pumping System (M_6 vs. P_7/P_2)

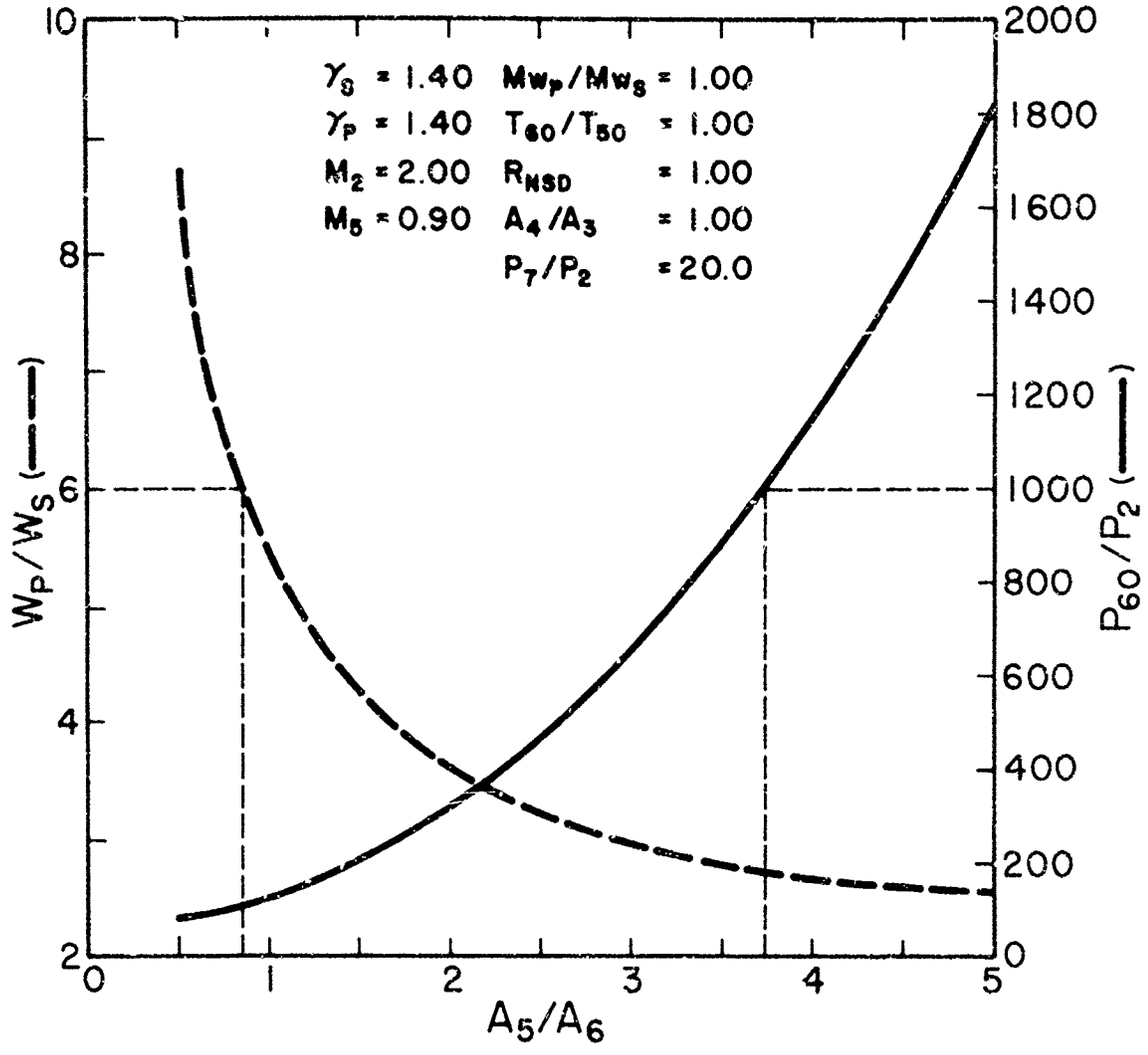


Figure 4.2-5 Typical Break-Off Data for Optimization of a Subsonic-Supersonic Pumping System (W_P/W_S and P_{60}/P_2 vs. A_5/A_6)

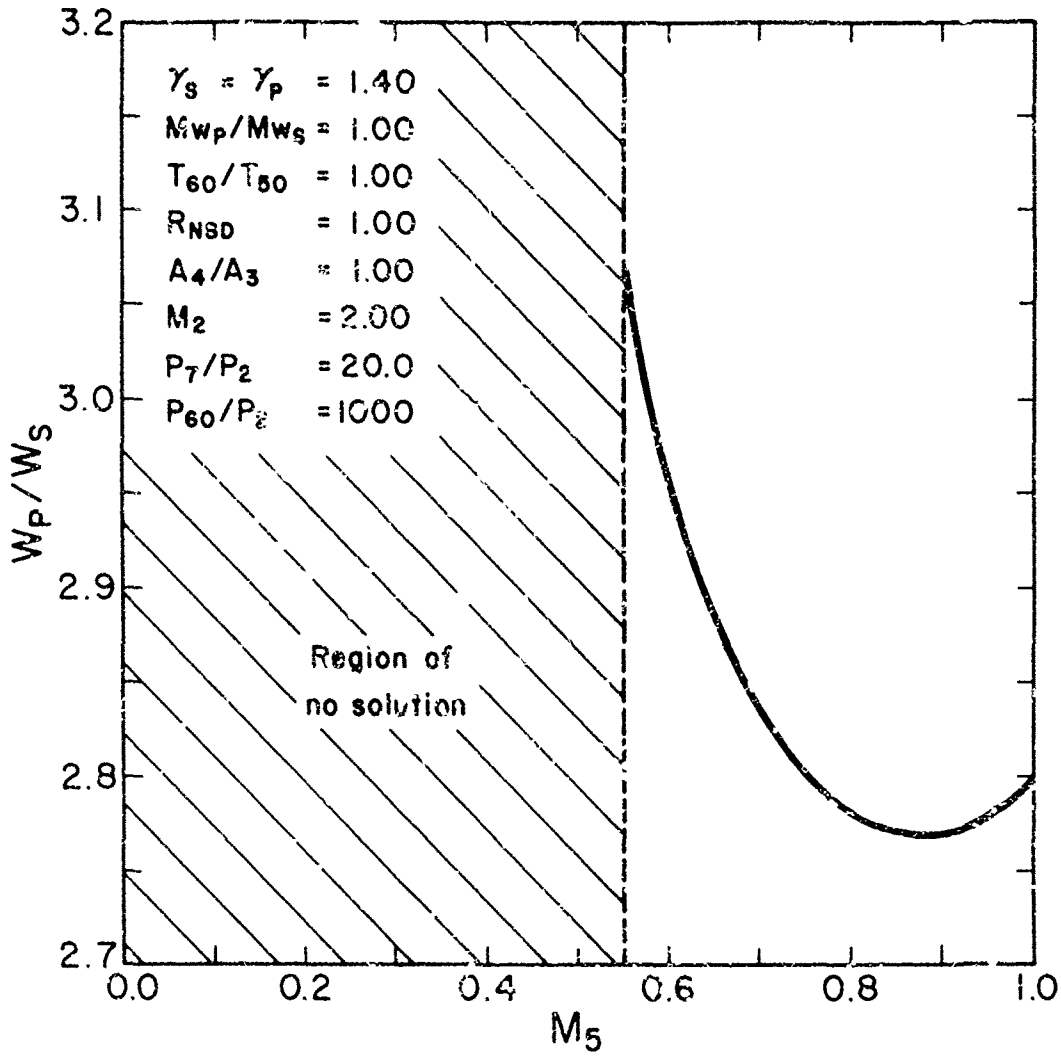


Figure 4.2-6 Typical Break-Off Data for Optimization of a Subsonic-Supersonic Pumping System (W_P/W_S vs. M_5)

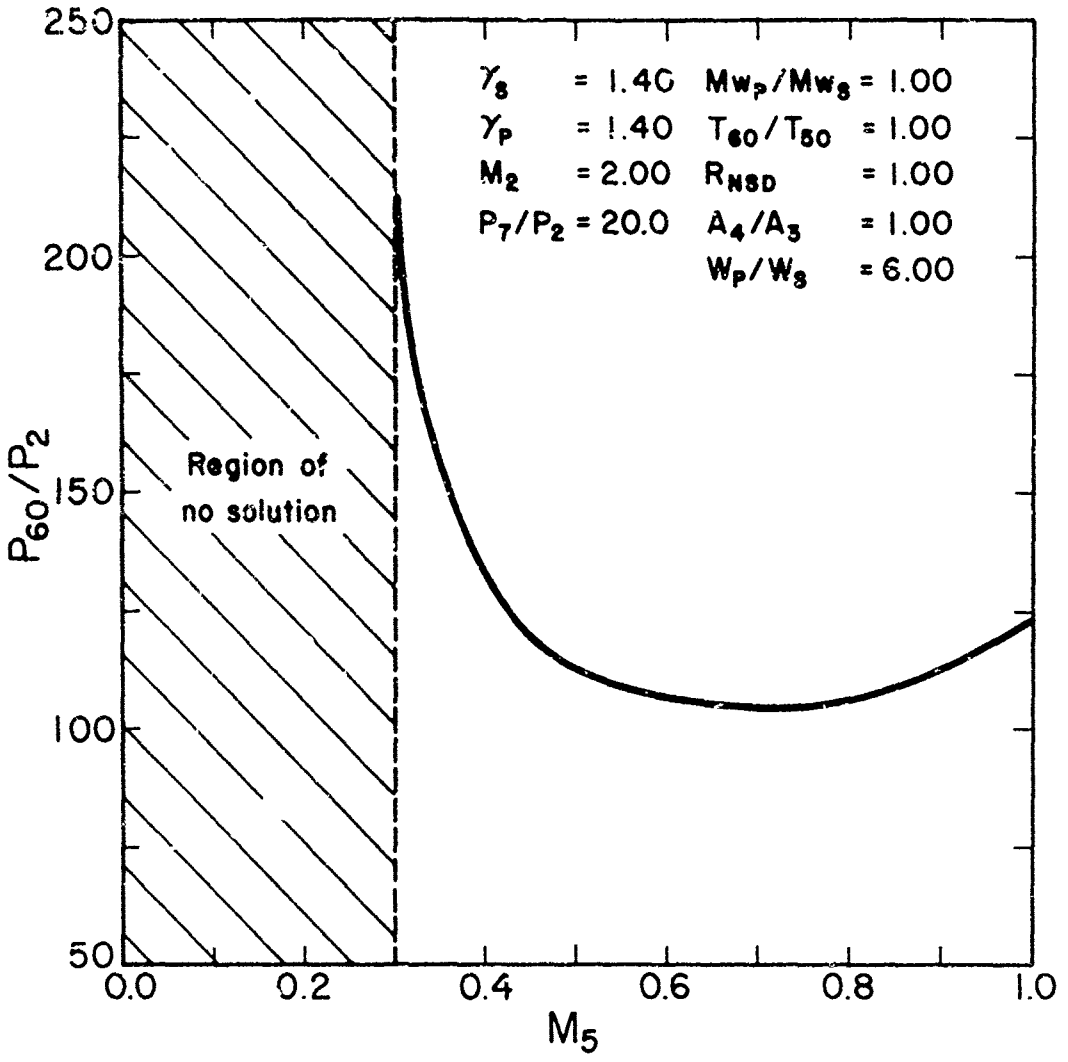


Figure 4.2-7 Typical Break-Off Data for Optimization of a Subsonic-Supersonic Pumping System (P_{60}/P_2 vs. M_5)

Table 4.3-1 Optimum Chemical Laser System Data, Case No. 1

(a) Minimum W_P/W_S

CASE NO. 1(a)

Optimum Chemical Laser System Data
for Minimum W_P/W_S

γ_S = 1 562	Mw_P/Mw_S = 1.684
γ_P = 1.340	A_8/A_7 = 2.000
M_2 = 2.180	P_{60}/P_2 = 1937

P_8/P_2 = 28.06

Supersonic-Supersonic Pumping System
at Upper Limit Point Conditions

T_{60}/T_{20} = 0.761

W_P/W_S	M_6	A_7/A_6	A_8/A_2
4.408	4.690	5.028	2.496

Subsonic-Supersonic Pumping System
at Break-Off Conditions

T_{60}/T_{50} = 0.761 A_4/A_3 = 2.000

R_{NSD}	W_P/W_S	M_6	A_7/A_6	A_8/A_2
1.00	3.747	4.734	4.828	2.125
0.85	4.792	4.858	4.136	2.614
0.75	5.777	4.955	3.695	3.079

Table 4.3-1 (Cont.)

(b) Minimum P_{60}/P_2

CASE NO. 1(b)

Optimum Chemical Laser System Data
for Minimum P_{60}/P_2

$\gamma_S = 1.562$	$Mw_P/Mw_S = 1.684$
$\gamma_P = 1.340$	$A_8/A_7 = 2.000$
$M_2 = 2.180$	$W_P/W_S = 10.00$

$P_8/P_2 = 28.06$

Supersonic-Supersonic Pumping System
at Upper Limit Point Conditions

$T_{60}/T_{20} = 0.761$

P_{60}/P_2	M_6	A_7/A_6	A_8/A_2
318.6	3.797	1.705	4.838

Subsonic-Supersonic Pumping System
at Break-Off Conditions

$T_{60}/T_{50} = 0.761$ $A_4/A_3 = 2.000$

R_{NSD}	P_{60}/P_2	M_6	A_7/A_6	A_8/A_2
1.00	110.2	2.660	1.729	4.319
0.85	174.0	3.047	1.903	4.515
0.75	270.6	3.410	2.085	4.665

Table 4.3-1 (Cont.)

(c) Minimum W_P/W_S at Matched Pressure Conditions

CASE NO. 1(c)

Optimum Chemical Laser System Data
for Minimum W_P/W_S

$\gamma_S = 1.562$	$Mw_P/Mw_S = 1.684$
$\gamma_P = 1.340$	$A_8/A_7 = 2.000$
$M_2 = 2.180$	$P_{60}/P_2 = 1937$

$P_8/P_2 = 28.06$

Supersonic-Supersonic Pumping System
at Matched Pressure Conditions ($P_6/P_2 = 1.0$)

$T_{60}/T_{20} = 0.761$

W_P/W_S	M_6	A_7/A_6	A_8/A_2
9.665	5.853	1.654	5.058

Table 4.3-1 (Cont.)

(d) Minimum P_{60}/P_2 at Matched Pressure Conditions

CASE NO. 1(d)

Optimum Chemical Laser System Data
for Minimum P_{60}/P_2

$\gamma_S = 1.562$	$Mw_P/Mw_S = 1.684$
$\gamma_P = 1.340$	$A_8/A_7 = 2.000$
$M_2 = 2.180$	$W_P/W_S = 10.00$

$P_8/P_2 = 28.06$

Supersonic-Supersonic Pumping System
at Matched Pressure Conditions ($P_6/P_2 = 1.0$)

$T_{60}/T_{20} = 0.761$

P_{60}/P_2	M_6	A_7/A_6	A_8/A_2
1836	5.807	1.623	5.209

Table 4.3-2 Optimum Chemical Laser System Data, Case No. 2

(a) Minimum W_P/W_S

CASE NO. 2(a)

Optimum Chemical Laser System Data
for Minimum W_P/W_S

$\gamma_S = 1.562$	$Mw_P/Mw_S = 1.478$
$\gamma_P = 1.340$	$A_8/A_7 = 2.000$
$M_2 = 2.230$	$P_{60}/P_2 = 1430$

$P_8/P_2 = 20.71$

Supersonic-Supersonic Pumping System
at Upper Limit Point Conditions

$T_{6C}/T_{20} = 0.807$

W_P/W_S	M_6	A_7/A_6	A_8/A_2
2.228	4.055	1.059	2.209

Subsonic-Supersonic Pumping System
at Break-Off Conditions

$T_{60}/T_{50} = 0.807$ $A_4/A_5 = 2.000$

P_{NSD}	W_P/W_S	M_6	A_7/A_6	A_8/A_2
1.00	1.968	4.476	7.000	1.952
0.85	2.559	4.596	5.838	2.375
0.75	3.108	4.690	5.128	2.771

Table 4.3-2 (Cont.)

(b) Minimum P_{60}/P_2

CASE NO. 2(b)

Optimum Chemical Laser System Data for Minimum P_{60}/P_2

$\gamma_S = 1.562$	$Mw_P/Mw_S = 1.478$
$\gamma_P = 1.340$	$A_8/A_7 = 2.000$
$M_2 = 2.230$	$W_P/W_S = 6.000$

$P_8/P_2 = 20.71$

Supersonic-Supersonic Pumping System at Upper Limit Point Conditions

$T_{60}/T_{20} = 0.807$

P_{60}/P_2	M_6	A_7/A_6	A_3/A_2
123.0	3.127	1.801	4.497

Subsonic-Supersonic Pumping System at Break-Off Conditions

$T_{60}/T_{50} = 0.807$ $A_4/A_3 = 2.000$

R_{NSD}	P_{60}/P_2	M_6	A_7/A_6	A_8/A_2
1.00	56.38	2.223	1.844	3.951
0.85	84.21	2.568	2.047	4.160
0.75	125.7	2.894	2.262	4.323

Table 4.3-2 (Cont.)

(c) Minimum W_P/W_S at Matched Pressure Conditions

CASE NO. 2(c)

Optimum Chemical Laser System Data
for Minimum W_P/W_S

$\gamma_S = 1.562$	$Mw_P/Mw_S = 1.476$
$\gamma_P = 1.340$	$A_8/A_7 = 2.000$
$M_2 = 2.230$	$P_{60}/P_2 = 1430$

$P_8/P_2 = 20.71$

Supersonic-Supersonic Pumping System
at Matched Pressure Conditions ($P_6/P_2 = 1.0$)

$T_{60}/T_{20} = 0.807$

W_P/W_S	M_6	A_7/A_9	A_8/A_2
3.920	5.593	2.302	3.536

Table 4.3-2 (Cont.)

(d) Minimum P_{60}/P_2 at Matched Pressure Conditions

CASE NO. 2(d)

Optimum Chemical Laser System Data
for Minimum P_{60}/P_2

$\gamma_S = 1.562$	$Mw_P/Mw_S = 1.478$
$\gamma_P = 1.340$	$A_8/A_7 = 2.000$
$M_2 = 2.230$	$W_P/W_S = 6.000$

$P_8/P_2 = 20.71$

Supersonic-Supersonic Pumping System
at Matched Pressure Conditions ($P_6/P_2 = 1.0$)

$T_{60}/T_{20} = 0.807$

P_{60}/P_2	M_6	A_7/A_6	A_8/A_2
633.0	4.934	1.677	4.955

Table 4.3-3 Optimum Supersonic Wind Tunnel Data

CASE NO. 3

Optimum Supersonic Wind Tunnel Data
for Minimum W_P/W_S

$\gamma_S = 1.400$	$Mw_P/Mw_S = 1.000$
$\gamma_P = 1.400$	$A_8/A_7 = 2.000$
$M_2 = 5.000$	$P_{60}/P_2 = 529.1$

$P_8/P_2 = 67.81$

Supersonic-Supersonic Pumping System
at Upper Limit Point Conditions

$T_{60}/T_{20} = 1.000$

W_P/W_S	M_5	A_7/A_6	A_8/A_2
1.810	2.063	8.758	2.258

Subsonic-Supersonic Pumping System
at Break-Off Conditions

$T_{60}/T_{50} = 1.000$ $A_4/A_3 = 2.000$

R_{NSD}	W_P/W_S	M_6	A_7/A_6	A_8/A_2
1.00	1.349	2.811	4.450	1.700
0.85	1.852	2.918	3.669	2.130
0.75	2.336	3.001	3.217	2.549

5.0 CONCLUSIONS

As a result of this preliminary theoretical and experimental analysis of the constant-area, supersonic-supersonic ejector, the following conclusions may be drawn.

1. A one-dimensional theory was developed which predicts the performance characteristics of all constant-area, supersonic-supersonic ejector configurations.

2. Due to the simplified analysis of the constant-area, mixing section and inviscid interaction region, the present one-dimensional theory is particularly well-suited to parametric evaluations of constant-area, supersonic-supersonic ejector performance.

3. The present one-dimensional theory predicts maximum compression ratios which are 15 to 21 percent greater than experimental measurements.

4. The constant-area, supersonic-supersonic ejector is particularly susceptible to secondary flow separation which requires a more sophisticated method of analysis than the present one-dimensional theory.

5. Continued experimentation is needed to:

   a) Establish a sufficient length for constant-area, supersonic-supersonic ejector mixing tubes.

   b) Obtain supersonic-supersonic ejector data over a wide range of operation, particularly under simulated high-energy, chemical laser system conditions.

   c) Verify the present one-dimensional theory for plane, two-dimensional ejector configurations which are more consistent with current high-energy, chemical laser designs.

d) Develop more advanced theoretical models, including a "two-shock" model, through flow visualization studies of the mixing and interaction phenomena.

e) Evaluate the effects of variable mixing tube wall profiles which have proved advantageous in subsonic-supersonic ejector development.

6. The constant-area, supersonic-supersonic ejector is an extension of the constant-area, subsonic-supersonic ejector with similar characteristic surfaces.

7. The constant-area, subsonic-supersonic and supersonic-supersonic ejectors must be compared on an optimum, overall pumping system basis.

8. Present one-dimensional theories for both the constant-area, subsonic-supersonic and supersonic-supersonic ejectors may be incorporated into a single high-energy, chemical laser system optimization procedure.

9. Conclusions as to the relative performance of optimum subsonic-supersonic and supersonic-supersonic pumping systems are included in Section 4.3; but in summary, a supersonic-supersonic pumping system has the potential for improved performance over that of a subsonic-supersonic pumping system on the basis of mass flow ratio and primary stagnation pressure; however, this depends on

a) The high-energy chemical laser system constraints,

b) The source of disagreement between the present one-dimensional, supersonic-supersonic ejector theory and experiment as noted in item 3, preceding, and

c) An adequate solution to the secondary flow separation problems encountered during high compression ratio operation of the constant-area, supersonic-supersonic ejector.

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7.0 APPENDICES

7.1 A LITERATURE SURVEY OF EJECTOR SYSTEMS AND RELATED TOPICS

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7.2 CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR COMPUTER PROGRAM

7.2.1 Computer Program (CASSE)

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C     ***********************************************************
C     *                                                         *
C     *   CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR (CASSE)   *
C     *                                                         *
C     *                      C.D. MIKKELSEN                     *
C     *                        9 MARCH 75                       *
C     *                                                         *
C     *            MECHANICAL ENGINEERING DEPARTMENT            *
C     *        UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN       *
C     *                  URBANA, ILLINOIS 61801                 *
C     *                                                         *
C     *  CASSE IS A PROGRAM FOR CALCULATING THE PLANE OF        *
C     *  OPERATION OF A CONSTANT-AREA SUPERSONIC-SUPERSONIC     *
C     *  EJECTOR BY ONE-DIMENSIONAL ANALYSIS.  CASSE IS A       *
C     *  FORTRAN IV PROGRAM WRITTEN FOR DEC SYSTEM-10 (F40).    *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *                      NOTATION SCHEME                    *
C     *                                                         *
C     *  VARIABLES ARE DEFINED AS FOLLOWS:                      *
C     *                                                         *
C     *  A : AREA                                               *
C     *  G : (GAMMA) SPECFIC HEAT RATIO                         *
C     *  M : MACH NUMBER                                        *
C     *  MW: MOLECULAR WEIGHT RATIO                             *
C     *  P : PRESSURE                                           *
C     *  T : TEMPERATURE                                        *
C     *  W : MASS FLOW RATE                                     *
C     *                                                         *
C     *  REPEATED LETTERS INDICATE RATIOS.                      *
C     *  EXAMPLE: AS1AP1=AS1/AP1                                *
C     *                                                         *
C     *  S: INDICATES SECONDARY OR DRIVEN STREAM PROPERTIES     *
C     *  P: IN ICATES PRIMARY OR DRIVING STREAM PROPERTIES      *
C     *  M: INDICATES MIXED STREAM PROPERTIES                   *
C     *  EXAMPLE: GM=MIXED STREAM SPECIFIC HEAT RATIO           *
C     *                                                         *
C     *  VARIABLES ARE DESIGNATED AS TO LOCATION AS FOLLOWS:    *
C     *                                                         *
C     *  1: MIXING TUBE ENTRANCE, THE CONFLUENCE POINT OF THE   *
C     *     SECONDARY AND PRIMARY STREAMS                       *
C     *  2: POINT IN THE MIXING TUBE AT WHICH THE SECONDARY     *
C     *     STREAM IS RECOMPRESSED TO SONIC CONDITIONS          *
C     *  3: MIXING TUBE EXIT                                    *
C     *  EXAMPLE: PS1PP1=SECONDARY-TO-PRIMARY STATIC PRESSURE   *
C     *           RATIO AT STATION 1                            *
C     *                                                         *
```

```
C     *   0: INDICATES STAGNATION CONDITIONS                          *
C     *   EXAMPLE: TM0TP0=MIXED-TO-PRIMARY STAGNATION                 *
C     *            TEMPERATURE RATIO                                  *
C     *                                                               *
C     *   S: INDICATES "*" CONDITIONS                                 *
C     *   EXAMPLE: AP1APS=AP1/AP*                                     *
C     *                                                               *
C     *   VARIABLES NOT FOLLOWING THIS SCHEME ARE DEFINED AS          *
C     *   REQUIRED.                                                   *
C     *                                                               *
C     *****************************************************************
C
      IMPLICIT REAL*8(A-H,M,O-Z)
C
      DIMENSION MM3(21,3),PM3PP0(21,3),PM3PS0(21,3),PM3PS1(21,3)
C
      DIMENSION GM(21),MWMMWP(21),MWMMWS(21),PS0PP0(21),
     -PS1PP0(21),PS1PP1(21),PP0PS0(21),PP0PS1(21),PP1PS1(21),
     -TM0TP0(21),TM0TS0(21),WPWS(21),WSWP(21)
C
C     *****************************************************************
C     *                                                               *
C     *                      SPECIAL FUNCTIONS                        *
C     *                                                               *
C     *****************************************************************
C
      F(GX,MXX)=1.0+GX*MXX*MXX
      G(GX,MXX)=MXX*DSQRT(1.0+0.5*(GX-1.0)*MXX*MXX)
      H(MM,TT,GG)=DSQRT(MM*GG/TT)
      MDMU(GX,MXX)=DSQRT((MXX*MXX+2.0/(GX-1.0))/(2.0*GX*MXX*MXX
     -/(GX-1.0)-1.0))
      PDPUMU(GX,MXX)=(2.0*GX*MXX*MXX-GX+1.0)/(GX+1.0)
      PPOM(GX,MXX)=(1.0+0.5*(GX-1.0)*MXX*MXX)**(GX/(1.0-GX))
      AASM(GX,MXX)=((2.0*(1.0+0.5*(GX-1.0)*MXX*MXX)/(GX+1.0))**
     -(0.5*(GX+1.0)/(GX-1.0)))/MXX
C
C     *****************************************************************
C     *                                                               *
C     *                        INITIAL DATA                           *
C     *                                                               *
C     *   GS      = SECONDARY GAMMA                                   *
C     *   GP      = PRIMARY GAMMA                                     *
C     *   MWSMWP  = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO       *
C     *   TS0TP0  = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE       *
C     *             RATIO                                             *
C     *   MS1     = SECONDARY MACH NO. AT STATION 1                   *
```

```
CASSE  05100
CASSE  05200
CASSE  05300
CASSE  05400
CASSE  05500
CASSE  05600
CASSE  05700
CASSE  05800
CASSE  05900
CASSE  06000
CASSE  06100
CASSE  06200
CASSE  06300
CASSE  06400
CASSE  06500
CASSE  06600
CASSE  06700
CASSE  06800
CASSE  06900
CASSE  07000
CASSE  07100
CASSE  07200
CASSE  07300
CASSE  07400
CASSE  07500
CASSE  07600
CASSE  07700
CASSE  07800
CASSE  07900
CASSE  08000
CASSE  08100
CASSE  08200
CASSE  08300
CASSE  08400
CASSE  08500
CASSE  08600
CASSE  08700
CASSE  08800
CASSE  08900
CASSE  09000
CASSE  09100
CASSE  09200
CASSE  09300
CASSE  09400
CASSE  09500
CASSE  09600
CASSE  09700
CASSE  09800
CASSE  09900
CASSE  10000
```

```
C     *   MP1     = PRIMARY MACH NO. AT STATION 1                    *
C     *   AS1AP1  = SECONDARY-TO-PRIMARY AREA RATIO AT STATION 1     *
C     *   RD      = NORMAL SHOCK DIFFUSER COEFFICIENT                *
C     *   ERROR   = MAX PERCENT DEVIATION IN M(G,AAS)                *
C     *   NDATA   = NUMBER OF INCREMENTS INTO WHICH THE PLANE OF     *
C     *             OPERATION IS DIVIDED                             *
C     *                                                              *
C     ****************************************************************
C
      WRITE(5,200)
      READ(5,201)GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1
      WRITE(5,202)
      READ(5,203)RD,ERROR,NDATA
C
C     ****************************************************************
C     *                                                              *
C     *              CHECK CONSISTENCY OF INITIAL DATA               *
C     *                                                              *
C     ****************************************************************
C
      IF(MS1.LE.1.0) GO TO 105
      IF(MP1.LE.1.0) GO TO 106
C
C     ****************************************************************
C     *                                                              *
C     *                     OUTPUT - INITIAL DATA                    *
C     *                                                              *
C     ****************************************************************
C
      WRITE(3,300)
      WRITE(3,301)GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1,RD,ERROR,
     -NDATA
C
C     ****************************************************************
C     *                                                              *
C     *                     CALCULATE CONSTANTS                      *
C     *                                                              *
C     ****************************************************************
C
      GP1=(GP-1.0)/2.0
      GP1I=1.0/GP1
      GP2=2.0/(GP+1.0)
      GP2I=1.0/GP2
```

CASSE 10100
CASSE 10200
CASSE 10300
CASSE 10400
CASSE 10500
CASSE 10600
CASSE 10700
CASSE 10800
CASSE 10900
CASSE 11000
CASSE 11100
CASSE 11200
CASSE 11300
CASSE 11400
CASSE 11500
CASSE 11600
CASSE 11700
CASSE 11800
CASSE 11900
CASSE 12000
CASSE 12100
CASSE 12200
CASSE 12300
CASSE 12400
CASSE 12500
CASSE 12600
CASSE 12700
CASSE 12800
CASSE 12900
CASSE 13000
CASSE 13100
CASSE 13200
CASSE 13300
CASSE 13400
CASSE 13500
CASSE 13600
CASSE 13700
CASSE 13800
CASSE 13900
CASSE 14000
CASSE 14100
CASSE 14200
CASSE 14300
CASSE 14400
CASSE 14500
CASSE 14600
CASSE 14700
CASSE 14800
CASSE 14900
CASSE 15000

```
      GS3=GS/(GS-1.0)                                                   CASSE  15100
      GP3=GP/(GP-1.0)                                                   CASSE  15200
      GP4=(GP+1.0)/(2.0*(GP-1.0))                                       CASSE  15300
      GP4I=1.0/GP4                                                      CASSE  15400
      GSGP=GS/GP                                                        CASSE  15500
      MWPMWS=1.C/MWSM??                                                 CASSE  15600
      PS1PS0=PP0M(GS,MS1)                                               CASSE  15700
      PP1PP0=PP0M(GP,MP1)                                               CASSE  15800
      AS1ASS=AASM(GS,MS1)                                               CASSE  15900
      AP1AP5=AASM(GP,MP1)                                               CASSE  16000
      ASSAS1=1.0/AS1ASS                                                 CASSE  16100
      FGSMS1=F(GS,MS1)                                                  CASSE  16200
      FGPMP1=F(GP,MP1)                                                  CASSE  16300
      GGSMS1=G(GS,MS1)                                                  CASSE  16400
      GGPMP1=G(GP,MP1)                                                  CASSE  16500
C                                                                       CASSE  16600
CCC                                                                     CASSE  16700
CCC   ***************************************************************   CASSE  16800
CCC   *                                                             *   CASSE  16900
CCC   *  CALCULATE PS1PP1(1) FOR AN ISENTROPIC RECOMPRESSION        *   CASSE  17000
CCC   *  OF THE SECONDARY STREAM TO SONIC CONDITIONS AT             *   CASSE  17100
CCC   *  STATION 2.  MP2 IS OBTAINED FROM AP2AP2 BY LINEAR         *   CASSE  17200
CCC   *  ITERATION.                                                 *   CASSE  17300
CCC   *                                                             *   CASSE  17400
CCC   ***************************************************************   CASSE  17500
CCC                                                                     CASSE  17600
C                                                                       CASSE  17700
      AP2APS=AP1APS*(1.0+AS1AP1*(1.0-ASSAS1))                           CASSE  17800
      MP2=MP1                                                           CASSE  17900
      DO 100 I=1,200                                                    CASSE  18000
      C1=(MP2*AP2APS)**GP4I                                             CASSE  18100
      XMP2=DSQRT(GP1I*(GP2I*C1-1.0))                                    CASSE  18200
      XERROR=(XMP2-MP2)*100.0/MP2                                       CASSE  18300
      MP2=XMP2                                                          CASSE  18400
      IF(DABS(XERROR).LT.ERRCR) GO TO 101                               CASSE  18500
100   CONTINUE                                                          CASSE  18600
      GO TO 107                                                         CASSE  18700
101   MS2=1.0                                                           CASSE  18800
      C1=-FGPMP1+F(GP,MP2)*GGPMP1/G(GP,MP2)                             CASSE  18900
      C2=FGSMS1-F(GS,MS2)*GGSMS1/G(GS,MS2)                              CASSE  19000
      PS1PP1(1)=C1/(AS1AP1*C2)                                          CASSE  19100
C                                                                       CASSE  19200
CCC                                                                     CASSE  19300
CCC   ***************************************************************   CASSE  19400
CCC   *                                                             *   CASSE  19500
CCC   *  DIVIDE THE PLANE OF OPERATION INTO NDATA INCREMENTS        *   CASSE  19600
CCC   *  FROM PS1PP1(1) TO PS1PP1=1.0, THE MATCHED PRESSURE        *   CASSE  19700
CCC   *  CONDITION.                                                 *   CASSE  19800
CCC   *                                                             *   CASSE  19900
CCC   ***************************************************************   CASSE  20000
```

7.2.1 CASSE (Cont.)

```
C
C
      C1=(1.0-PS1PP1(1))/NDATA
      NDATA=NDATA+1
      DO 102 I=2,NDATA
102   PS1PP1(I)=PS1PP1(1)+(I-1)*C1
C
C
C     ***********************************************************
C     *                                                         *
C     *            OVERALL CONTROL VOLUME CALCULATIONS          *
C     *                                                         *
C     ***********************************************************
C
C
      DO 104 I=1,NDATA
      WSWP(I)=PS1PP1(I)*AS1AP1*H(MWSMWP,TSOTPO,GSGP)*GGSMS1
     -/GGPMP1
      WPWS(I)=1.0/WSWP(I)
      C1=WSWP(I)*MWPMWS*GS3+GP3
      C2=WSWP(I)*MWPMWS*(GS3-1.0)+(GP3-1.0)
      GM(I)=C1/C2
      GMGP=GM(I)/GP
      MWMMWP(I)=(WSWP(I)+1.0)/(WSWP(I)*MWPMWS+1.0)
      MWMMWS(I)=MWMMWP(I)*MWPMWS
      C1=TSOTPO*WSWP(I)*MWPMWS*GS3+GP3
      C2=WSWP(I)*MWPMWS*GS3+GP3
      TMOTPO(I)=C1/C2
      TMOTSO(I)=TMOTPO(I)/TSOTPO
      FFX=H(MWMMWP(I),TMOTPO(I),GMGP)*(PS1PP1(I)*AS1AP1*FGSMS1
     -+FGPMP1)/((1.0+WSWP(I))*GGPMP1)
      C1=0.5*(GM(I)-1.0)*FFX*FFX-GM(I)*GM(I)
      C2=FFX*FFX-2.0*GM(I)
      C3=(-C2+DSQRT(C2*C2+4.0*C1))/(2.0*C1)
      C4=(-C2-DSQRT(C2*C2+4.0*C1))/(2.0*C1)
C
C
C     ***********************************************************
C     *                                                         *
C     *      IDENTIFY THE SUPERSONIC AND SUBSONIC SOLUTIONS     *
C     *                                                         *
C     ***********************************************************
C
C
      MM3(I,1)=DSQRT(DMIN1(C3,C4))
      MM3(I,2)=DSQRT(DMAX1(C3,C4))
      DO 103 J=1,2
      PM3PP1=(PS1PP1(I)*AS1AP1*FGSMS1+FGPMP1)/((1.0+AS1AP1)
     -*F(GM(I),MM3(I,J)))
      PM3PS1(I,J)=PM3PP1/PS1PP1(I)
```

```
      PM3PS0(I,J)=PM3PF1*PS1PS0/PS1PP1(I)                                CASSE  25100
103   PM3PP0(I,J)=PM3PF1*PP1PP0                                         CASSE  25200
      PP1PS1(I)=1.0/PS1PP1(I)                                            CASSE  25300
      PS1PP0(I)=PS1PP1(I)*PP1PP0                                         CASSE  25400
      PP0PS1(I)=1.0/PS1PP0(I)                                            CASSE  25500
      PS0PP0(I)=PS1PP1(I)*PP1PP0/PS1PS0                                  CASSE  25600
      PP0PS0(I)=1.0/PS0PP0(I)                                            CASSE  25700
C                                                                        CASSE  25800
C     ******************************************************************CASSE  25900
C     *                                                                *CASSE  26000
C     *  DIFFUSE THE SUPERSONIC SOLUTION TO RD OF NORMAL SHOCK         *CASSE  26100
C     *  CONDITIONS                                                    *CASSE  26200
C     *                                                                *CASSE  26300
C     ******************************************************************CASSE  26400
C                                                                        CASSE  26500
      C1=RD*PDPUMU(GM(I),MM3(I,2))                                       CASSE  26600
      PM3PS1(I,3)=C1*PM3PS1(I,2)                                         CASSE  26700
      PM3PS0(I,3)=C1*PM3PS0(I,2)                                         CASSE  26800
      PM3PP0(I,3)=C1*PM3PP0(I,2)                                         CASSE  26900
104   MM3(I,3)=MDMU(GM(I),MM3(I,2))                                      CASSE  27000
C                                                                        CASSE  27100
C     ******************************************************************CASSE  27200
C     *                                                                *CASSE  27300
C     *                  OUTPUT - SUBSONIC SOLUTION                    *CASSE  27400
C     *                                                                *CASSE  27500
C     ******************************************************************CASSE  27600
C                                                                        CASSE  27700
      WRITE(3,302)                                                       CASSE  27800
      WRITE(3,303)                                                       CASSE  27900
      WRITE(3,304)(I,PS1PP1(I),PS1PP0(I),PS0PP0(I),WSWP(I),              CASSE  28000
     -PM3PP0(I,1),MM3(I,1),I=1,NDATA)                                    CASSE  28100
      WRITE(3,305)                                                       CASSE  28200
      WRITE(3,306)(I,PP1PS1(I),PP0PS1(I),PP0PS0(I),WPWS(I),              CASSE  28300
     -PM3PS0(I,1),PM3PS1(I,1),MM3(I,1),I=1,NDATA)                        CASSE  28400
C                                                                        CASSE  28500
C     ******************************************************************CASSE  28600
C     *                                                                *CASSE  28700
C     *                OUTPUT - SUPERSONIC SOLUTION                    *CASSE  28800
C     *                                                                *CASSE  28900
C     ******************************************************************CASSE  29000
C                                                                        CASSE  29100
      WRITE(3,307)                                                       CASSE  29200
      WRITE(3,303)                                                       CASSE  29300
      WRITE(3,304)(I,PS1PP1(I),PS1PP0(I),PS0PP0(I),WSWP(I),              CASSE  29400
```

7.2.1 CASSE (Cont.)

```
     -PM3PPO(I,2),MM3(I,2),I=1,NDATA)
      WRITE(3,305)
      WRITE(3,306)(I,PP1PS1(I),PP0PS1(I),PP0PS0(I),WPWS(I),
     -PM3PS0(I,2),PM3PS1(I,2),MM3(I,2),I=1,NDATA)
C
C
C     ***********************************************************
C     *                                                         *
C     *  OUTPUT - SUPERSONIC SOLUTION AT RD OF NORMAL SHOCK     *
C     *  CONDITIONS                                             *
C     *                                                         *
C     ***********************************************************
C
C
      WRITE(3,308)RD
      WRITE(3,303)
      WRITE(3,304)(I,PS1PP1(I),PS1PP0(I),PS0PP0(I),WSWP(I),
     -PM3PP0(I,3),MM3(I,3),I=1,NDATA)
      WRITE(3,305)
      WRITE(3,306)(I,PP1PS1(I),PP0PS1(I),PP0PS0(I),WPWS(I),
     -PM3PS0(I,3),PM3PS1(I,3),MM3(I,3),I=1,NDATA)
C
C
C     ***********************************************************
C     *                                                         *
C     *                 OUTPUT - MIXED PROPERTIES               *
C     *                                                         *
C     ***********************************************************
C
C
      WRITE(3,309)
      WRITE(3,310)
      WRITE(3,306)(I,PS1PP1(I),PS1PP0(I),PS0PP0(I),WSWP(I),
     -MWMMWP(I),TMOTPO(I),GM(I),I=1,NDATA)
      WRITE(3,311)
      WRITE(3,306)(I,PP1PS1(I),PP0PS1(I),PP0PS0(I),WPWS(I),
     -MWMMWS(I),TMOTSO(I),GM(I),I=1,NDATA)
      STOP
C
C
C     ***********************************************************
C     *                                                         *
C     *                     FAILURE INDICATORS                  *
C     *                                                         *
C     ***********************************************************
C
C
105   WRITE(5,400)MS1
      STOP
106   WRITE(5,401)MP1
```

```
      STOP                                                              CASSE  35100
107   WRITE(5,402)MP2,XERROR,ERROR                                      CASSF  35200
      STOP                                                              CASSE  35300
C                                                                       CASSE  35400
C                                                                       CASSE  35500
C     ****************************************************************  CASSE  35600
C     *                                                              *  CASSE  35700
C     *                      FORMAT STATEMENTS                       *  CASSE  35800
C     *                                                              *  CASSE  35900
C     ****************************************************************  CASSE  36000
C                                                                       CASSE  36100
C                                                                       CASSE  36200
200   FORMAT('0',T2,'INPUT GS,GP,MWSMWP,TS0TP0,MS1,MP1,AS1AP1')         CASSE  36300
201   FORMAT(7F)                                                        CASSE  36400
202   FORMAT('0',T2,'INPUT RC,ERROR,NDATA')                             CASSE  36500
203   FORMAT(F,D,I)                                                     CASSE  36600
C                                                                       CASSE  36700
300   FORMAT('1',T44,'CONSTANT-AREA SUPERSONIC-SUPERSONIC ',            CASSE  36800
     -'EJECTOR',/,T46,'PLANE OF SUPERSONIC-SUPERSONIC ',               CASSE  36900
     -'OPERATION',/,T54,'ONE-DIMENSIONAL ANALYSIS',//,T59,             CASSE  37000
     -'C.O. MIKKELSEN',/,T61,'9 MARCH 75',//,T49,'MECHANICAL ',        CASSE  37100
     -'ENGINEERING DEPARTMENT',/,T45,'UNIVERSITY OF ILLINOIS ',        CASSE  37200
     -'AT URBANA-CHAMPAIGN',/,T55,'URBANA, ILLINOIS 61801')            CASSE  37300
301   FORMAT('0',T44,'GS      =',D13.6,T67,'GP      =',D13.6,/,       CASSE  37400
     -T44,'MWSMWP =',D13.6,T67,'TS0TP0 =',D13.6,/,                     CASSE  37500
     -T44,'MS1    =',D13.6,T67,'MP1    =',D13.6,/,                     CASSE  37600
     -T44,'AS1AP1 =',D13.6,T67,'RD     =',D13.6,/,                     CASSE  37700
     -T44,'ERROR  =',D13.6,T67,'NDATA  =',I13)                         CASSE  37800
302   FORMAT('0',T57,'SUBSONIC SOLUTIONS')                              CASSE  37900
303   FORMAT('0',T15,'NO',T22,'PS1PP1',T36,'PS1PP0',T50,                CASSE  38000
     -'PS0PP0',T65,'WSWP',T78,'PM3PP0',T108,'MM3',/)                   CASSE  38100
304   FORMAT(' ',T15,I2,5D14.6,T101,D14.6)                              CASSE  38200
305   FORMAT('0',T15,'NC',T22,'PP1PS1',T36,'PP0PS1',T50,                CASSE  38300
     -'PP0PS0',T65,'WPWS',T78,'PM3PS0',T92,'PM3PS1',T108,              CASSE  38400
     -'MM3',/)                                                         CASSE  38500
306   FORMAT(' ',T15,I2,7D14.6)                                         CASSE  38600
307   FORMAT('1',T58,'SUPERSONIC SOLUTIONS')                            CASSE  38700
308   FORMAT('1',T38,'SUPERSONIC SOLUTIONS AT',F6.3,                    CASSE  38800
     -' OF NORMAL SHOCK CONDITIONS')                                   CASSE  38900
309   FORMAT('1',T58,'MIXED PROPERITIES')                               CASSE  39000
310   FORMAT('0',T15,'NO',T22,'PS1PP1',T36,'PS1PP0',T50,                CASSE  39100
     -'PS0PP0',T65,'WSWP',T78,'MWMMWP',T92,'TM0TP0',T108,'GM',/)       CASSE  39200
311   FORMAT('0',T15,'NO',T22,'PP1PS1',T36,'PP0PS1',T50,                CASSE  39300
     -'PP0PS0',T65,'WPWS',T78,'MWMMWS',T92,'TM0TS0',T108,'GM',/)       CASSE  39400
C                                                                       CASSE  39500
400   FORMAT('0',' INPUT ERROR: MS1 =',E13.6,2X,'MS1 MUST BE ',         CASSE  39600
     -'SUPERSONIC')                                                    CASSE  39700
401   FORMAT('0',' INPUT ERROR: MP1 =',E13.6,2X,'MP1 MUST BE ',         CASSE  39800
     -'SUPERSONIC')                                                    CASSE  39900
402   FORMAT('0',T2,'CONVERGENCE FAILURE',/,T2,'MP2 =',E13.6,2X,        CASSE  40000
```

7.2.1 CASSE (Cont.)

```
      CASSE  40100
      CASSE  40200
-'XERROR =',E13.6,2X,'ERRGR =',E13.6)
      END
```

7.2.2 CASSE Sample Input

```
INPUT GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1
1.562, 1.34, 0.593912, 1.31341, 2.18, 4.690, 4.02823

INPUT RD,ERROR,NDATA
0.75, 5.0E-06, 10
```

CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR
PLANE OF SUPERSONIC-SUPERSONIC OPERATION
ONE-DIMENSIONAL ANALYSIS

C.D. MIKKELSEN
9 MARCH 75

MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
URBANA, ILLINOIS 61801

GS	= 0.156200D+01	GP	= 0.134000D+01
MWSMWP	= 0.593912D+00	TSOTPO	= 0.131341D+01
MS1	= 0.218000D+01	MP1	= 0.469000D+01
AS1AP1	= 0.402823D+01	RD	= 0.750000D+00
ERROR	= 0.500000D-05	NDATA	= 10

SUBSONIC SOLUTIONS

NO	PS1PP1	PS1PP0	PS0PP0	WSWP	PM3PP0	MM3
1	0.237707D+00	0.516320D-03	0.565432D-02	0.226836D+00	0.132029D-01	0.434615D+00
2	0.313936D+00	0.681897D-03	0.720344D-02	0.299580D+00	0.139613D-01	0.442472D+00
3	0.390165D+00	0.847474D-03	0.895257D-02	0.372323D+00	0.147178D-01	0.449454D+00
4	0.466395D+00	0.101305D-02	0.107017D-01	0.445066D+00	0.154725D-01	0.455703D+00
5	0.542624D+00	0.117863D-02	0.124508D-01	0.517810D+00	0.162258D-01	0.461330D+00
6	0.618853D+00	0.134420D-02	0.141999D-01	0.590553D+00	0.169779D-01	0.466425D+00
7	0.695083D+00	0.150978D-02	0.159491D-01	0.663296D+00	0.177288D-01	0.471062D+00
8	0.771312D+00	0.167536D-02	0.176982D-01	0.736040D+00	0.184788D-01	0.475301D+00
9	0.847541D+00	0.184094D-02	0.194473D-01	0.808783D+00	0.192280D-01	0.479192D+00
10	0.923771D+00	0.200651D-02	0.211964D-01	0.881526D+00	0.199765D-01	0.482776D+00
11	0.100000D+01	0.217209D-02	0.229456D-01	0.954269D+00	0.207243D-01	0.486089D+00

NO	PP1PS1	PP0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.420686D+01	0.193678D+04	0.183341D+03	0.440847D+01	0.242063D+01	0.255711D+02	0.434615D+00
2	0.318536D+01	0.146650D+04	0.138823D+03	0.333801D+01	0.193815D+01	0.204743D+02	0.442472D+00
3	0.256302D+01	0.117998D+04	0.111700D+03	0.268584D+01	0.164397D+01	0.173666D+02	0.449454D+00
4	0.214411D+01	0.987117D+03	0.934432D+02	0.224686D+01	0.144540D+01	0.152732D+02	0.455703D+00
5	0.184290D+01	0.848444D+03	0.803160D+02	0.193121D+01	0.130319D+01	0.137667D+02	0.461330D+00
6	0.161589D+01	0.743934D+03	0.704228D+02	0.169333D+01	0.119563D+01	0.126304D+02	0.466425D+00
7	0.143868D+01	0.662347D+03	0.626996D+02	0.150762D+01	0.111159D+01	0.117426D+02	0.471062D+00
8	0.129649D+01	0.596887D+03	0.565030D+02	0.135862D+01	0.104411D+01	0.110298D+02	0.475301D+00
9	0.117988D+01	0.543202D+03	0.514210D+02	0.123643D+01	0.988724D+00	0.104447D+02	0.479192D+00
10	0.108252D+01	0.498377D+03	0.471777D+02	0.113440D+01	0.942446D+00	0.995583D+01	0.482776D+00
11	0.100000D+01	0.460386D+03	0.435814D+02	0.104792D+01	0.903194D+00	0.954118D+01	0.486089D+00

7.2.3 CASSE Sample Output (Cont.)

SUPERSCNIC SOLUTIONS

NO	PS1PP1	PS1PP0	PS0PP0	WSWP	PM3PP0	MM3
1	0.237707D+00	0.516320D-03	0.545432D-02	0.226836D+00	0.777751D-03	0.384307D+01
2	0.313936D+00	0.681897D-03	0.720344D-02	0.299580D+00	0.893705D-03	0.368285D+01
3	0.390165D+00	0.847474D-03	0.895257D-02	0.372323D+00	0.101142D-02	0.355134D+01
4	0.466395D+00	0.101305D-02	0.107017D-01	0.445066D+00	0.113064D-02	0.344136D+01
5	0.542626D+00	0.117863D-02	0.124508D-01	0.517810D+00	0.125112D-02	0.334797D+01
6	0.618853D+00	0.134420D-02	0.141999D-01	0.590553D+00	0.137270D-02	0.326764D+01
7	0.695083D+00	0.150978D-02	0.159491D-01	0.663296D+00	0.149523D-02	0.319779D+01
8	0.771312D+00	0.167536D-02	0.176982D-01	0.736040D+00	0.161859D-02	0.313648D+01
9	0.847541D+00	0.184094D-02	0.194473D-01	0.808783D+00	0.174268D-02	0.308221D+01
10	0.923771D+00	0.200651D-02	0.211964D-01	0.881526D+00	0.186741D-02	0.303383D+01
11	0.100000D+01	0.217209D-02	0.229456D-01	0.954269D+00	0.199272D-02	0.299043D+01

NO	PP1PS1	PF0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.429686D+01	0.193678D+04	0.183341D+03	0.440847D+01	0.142594D+00	0.150633D+01	0.384307D+01
2	0.318536D+01	0.146650D+04	0.138823D+03	0.333601D+01	0.124066D+00	0.131061D+01	0.368285D+01
3	0.256702D+01	0.117998D+04	0.111700D+03	0.268584D+01	0.112976D+00	0.119346D+01	0.355134D+01
4	0.214411D+01	0.987117D+03	0.934432D+02	0.224686D+01	0.105650D+00	0.111607D+01	0.344136D+01
5	0.184290D+01	0.848444D+03	0.803160D+02	0.193121D+01	0.100485D+00	0.106150D+01	0.334797D+01
6	0.161589D+01	0.743934D+03	0.704228D+02	0.169333D+01	0.966693D-01	0.102120D+01	0.326764D+01
7	0.143868D+01	0.662347D+03	0.626996D+02	0.150762D+01	0.937501D-01	0.990360D+00	0.319779D+01
8	0.129649D+01	0.596887D+03	0.565030D+02	0.135662D+01	0.914549D-01	0.966113D+00	0.313648D+01
9	0.117988D+01	0.543202D+03	0.514210D+02	0.123643D+01	0.896101D-01	0.946625D+00	0.308221D+01
10	0.108252D+01	0.498377D+03	0.471777D+02	0.113440D+01	0.881002D-01	0.930675D+00	0.303383D+01
11	0.100000D+01	0.460386D+03	0.435814D+02	0.104792D+01	0.868455D-01	0.917420D+00	0.299043D+01

SUPERSONIC SOLUTIONS AT 0.750 OF NORMAL SHOCK CONDITIONS

NO	PS1PP1	PS1PP0	PS0PP0	WSWP	PM3PP0	MM3
1	0.237707D+00	0.516320D-03	0.545432D-02	0.226836D+00	0.990217D-02	0.434615D+00
2	0.313936D+00	0.681897D-03	0.720344D-02	0.299580D+00	0.104710D-01	0.442472D+00
3	0.390165D+00	0.847474D-03	0.895257D-02	0.372323D+00	0.110383D-01	0.449454D+00
4	0.466395D+00	0.101305D-02	0.107017D-01	0.445066D+00	0.116044D-01	0.455703D+00
5	0.542624D+00	0.117863D-02	0.124508D-01	0.517810D+00	0.121694D-01	0.461330D+00
6	0.618853D+00	0.134420D-02	0.141999D-01	0.590553D+00	0.127334D-01	0.466425D+00
7	0.695083D+00	0.150978D-02	0.159491D-01	0.663296D+00	0.132966D-01	0.471062D+00
8	0.771312D+00	0.167536D-02	0.176982D-01	0.736040D+00	0.138591D-01	0.475301D+00
9	0.847541D+00	0.184094D-02	0.194473D-01	0.808783D+00	0.144210D-01	0.479192D+00
10	0.923771D+00	0.200651D-02	0.211964D-01	0.881526D+00	0.149824D-01	0.482776D+00
11	0.100000D+01	0.217209D-02	0.229456D-01	0.954269D+00	0.155432D-01	0.486089D+00

NO	PP1PS1	PP0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.420686D+01	0.193678D+04	0.183341D+03	0.440847D+01	0.181547D+01	0.191783D+02	0.434615D+00
2	0.318536D+01	0.146650D+04	0.138823D+03	0.333801D+01	0.145361D+01	0.153557D+02	0.442472D+00
3	0.256302D+01	0.117998D+04	0.111700D+03	0.268584D+01	0.123298D+01	0.130250D+02	0.449454D+00
4	0.214411D+01	0.987117D+03	0.934432D+02	0.224686D+01	0.108435D+01	0.114549D+02	0.455703D+00
5	0.184290D+01	0.848444D+03	0.803160D+02	0.193121D+01	0.977395D+00	0.103250D+02	0.461330D+00
6	0.161589D+01	0.743934D+03	0.704228D+02	0.169333D+01	0.896722D+00	0.947281D+01	0.466425D+00
7	0.143868D+01	0.662347D+03	0.626996D+02	0.150762D+01	0.833693D+00	0.880698D+01	0.471062D+00
8	0.129649D+01	0.596887D+03	0.565030D+02	0.135862D+01	0.783082D+00	0.827234D+01	0.475301D+00
9	0.117988D+01	0.543202D+03	0.514210D+02	0.123643D+01	0.741543D+00	0.783353D+01	0.479192D+00
10	0.108252D+01	0.498377D+03	0.471777D+02	0.113440D+01	0.706834D+00	0.746687D+01	0.482776D+00
11	0.100000D+01	0.460386D+03	0.435814D+02	0.104792D+01	0.677396D+00	0.715589D+01	0.486089D+00

7.2.3 CASSE Sample Output (Cont.)

MIXED PROPERTIES

NO	PSIPP1	PSIPP0	PSOPP0	WSWP	MWMMWP	TMOTP0	GM
1	0.237707D+00	0.516220D-03	0.545432D-02	0.226836D+00	0.887766[00	0.106650D+01	0.138167D+01
2	0.313936D+00	0.681897D-03	0.720344D-02	0.299568D+00	0.863842D+00	0.108223D+01	0.139191D+01
3	0.390165D+00	0.847474D-03	0.895257D-02	0.372323D+00	0.843521D+00	0.109608D+01	0.140104D+01
4	0.466395D+00	0.101305D-02	0.107017D-01	0.445066D+00	0.826044D+00	0.110836D+01	0.140925D+01
5	0.542624D+00	0.117863D-02	0.124508D-01	0.517810D+00	0.810655D+00	0.111933D+01	0.141666D+01
6	0.618853D+00	0.134200D-02	0.141999D-01	0.590553D+00	0.797532D+00	0.112918D+01	0.142339D+01
7	0.695083D+00	0.150978D-02	0.159491D-01	0.663255D+00	0.785750D+00	0.113809D+01	0.142951D+01
8	0.771312D+00	0.167536D-02	0.176982D-01	0.735904D+00	0.775257D+00	0.114617D+01	0.143513D+01
9	0.847541D+00	0.184094D-02	0.194473D-01	0.808763D+00	0.765853D+00	0.115354D+01	0.144028D+01
10	0.923771D+00	0.200651D-02	0.211964D-01	0.881526D+00	0.757376D+00	0.116028D+01	0.144503D+01
11	0.100000D+01	0.217209D-02	0.229456D-01	0.954269D+00	0.749595D+00	0.116648D+01	0.144943D+01

NO	PPIPS1	PPOPS1	PEOPS0	WPWS	MWMMWS	TMOTS0	GM
1	0.420686D+01	0.193678C+04	0.183341D+02	0.440847D+01	0.149478D+01	0.812011D+00	0.138167D+01
2	0.318536D+01	0.146650D+04	0.138823D+03	0.333801D+01	0.145450D+01	0.823988D+00	0.139191D+01
3	0.256302D+01	0.117998D+04	0.111700D+03	0.268584D+01	0.142028D+01	0.834530D+00	0.140104D+01
4	0.214111D+01	0.587117D+03	0.934432D+02	0.224686D+01	0.139085D+01	0.843881D+00	0.140925D+01
5	0.184290D+01	0.846444D+03	0.803160D+02	0.193121D+01	0.136528D+01	0.852232D+00	0.141666D+01
6	0.161589D+01	0.743934D+03	0.704228D+02	0.169333D+01	0.134285D+01	0.859734D+00	0.142339D+01
7	0.143868D+01	0.662347D+03	0.626996D+02	0.150762D+01	0.132301D+01	0.866512D+00	0.142951D+01
8	0.129649D+01	0.596887D+03	0.565030D+02	0.135862D+01	0.130534D+01	0.872665D+00	0.143513D+01
9	0.117988D+01	0.543202D+03	0.514210D+02	0.123643D+01	0.128951D+01	0.878275D+00	0.144028D+01
10	0.108252D+01	0.498377C+03	0.471777D+02	0.113440D+01	0.127523D+01	0.883412D+00	0.144503D+01
11	0.100000D+01	0.460386D+03	0.435814D+02	0.104792D+01	0.126230D+01	0.888133D+00	0.144943D+01

7.3 CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR PARAMETERS COMPUTER PROGRAM

7.3.1 Computer Program (CASSEP)

```
C     ***********************************************************
C     *                                                         *
C     *          CONSTANT-AREA SUPERSONIC-SUPERSONIC            *
C     *              EJECTOR PARAMETERS (CASSEP                 *
C     *                                                         *
C     *                      C.D. MIKKELSEN                     *
C     *                         1 MAY 75                        *
C     *                                                         *
C     *           MECHANICAL ENGINEERING DEPARTMENT             *
C     *       UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN        *
C     *                 URBANA, ILLINOIS 61801                  *
C     *                                                         *
C     *  CASSEP IS A PROGRAM FOR EVALUATING THE INFLUENCE OF    *
C     *  CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR            *
C     *  PARAMETERS ON THE PLANE OF OPERATION AS CALCULATED BY  *
C     *  ONE-DIMENSIONAL ANALYSIS.  THE MAXIMUM COMPRESSION     *
C     *  RATIO IS CALCULATED AT THE UPPER AND LOWER LIMITS OF   *
C     *  THE PLANE WITH VARIATIONS IN THE SELECTED EJECTOR      *
C     *  PARAMETER.  CASSEP IS A FORTRAN IV PROGRAM WRITTEN     *
C     *  FOR DEC SYSTEM-10 (F40).                               *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *                      GENERAL NOTATION                   *
C     *                                                         *
C     * CATALG(I) = ALPHANUMERIC CATALOG OF EJECTOR PARAMETERS  *
C     * TITLE(I)  = ALPHANUMERIC CATALOG OF EJECTOR PARAMETERS  *
C     *             FOR WRITING COLUMN HEADINGS                 *
C     * VARBLE    = ALPHANUMERIC IMAGE OF THE INDEPENDENT       *
C     *             VARIABLE AS SELECTED FROM CATALG            *
C     * INDVAR    = NUMERICAL LOCATION OF VARBLE IN CATALG AND  *
C     *             TITLE                                       *
C     * LIST(I)   = NUMERICAL SEQUENCE IN WHICH THE EJECTOR     *
C     *             PARAMETERS ARE TO BE READ AND WRITTEN       *
C     * X(I)      = NUMERICAL VALUE OF THE EJECTOR PARAMETERS   *
C     * Y(I)      = NUMERICAL VALUE OF VARBLE                   *
C     *                                                         *
C     *                      EJECTOR NOTATION                   *
C     *                                                         *
C     * ERROR   = MAX PERCENT DEVIATION IN M(G,ASS)             *
C     * FLOW    = "UL" FOR AN ISENTROPIC RECOMPRESSION OF THE   *
C     *           SECONDARY STREAM TO SONIC CONDITIONS, THE     *
C     *           UPPER LIMIT OF THE PLANE OF OPERATION         *
C     *         = "MP" FOR MATCHED PRESSURE CONDITIONS, THE     *
C     *           LOWER LIMIT OF THE PLANE OF OPERATION         *
C     * FAIL    = ERROR FLAG                                    *
C     *                                                         *
C     *  OTHER EJECTOR NOTATION IS GIVEN IN SUBROUTINE CASSE.   *
```

```
C     *                                                               *
CCC   *****************************************************************
C
      IMPLICIT REAL*8(A-H,M,O-Z)
C
      DIMENSION CATALG(8),FLOW(2),LIST(8),TITLE(8),X(8),Y(51)
C
      COMMON/BLOCK1/MM3(51,2,3),PM3PP0(51,2,3),PM3PS0(51,2,3),
     -PM3PS1(51,2,3)
      COMMON/BLOCK2/GM(51,2),MWMMWP(51,2),MWMMWS(51,2),
     -PS0PP0(51,2),PS1PP0(51,2),PS1PP1(51,2),PP0PS0(51,2),
     -PP0PS1(51,2),PP1PS1(51,2),TM0TP0(51,2),TM0TS0(51,2),
     -WPWS(51,2),WSWP(51,2)
      COMMON/BLOCK3/GS,GP,MWSMWP,TS0TP0,MS1,MP1,AS1AP1,RD,ERROR,
     -FAIL,I
C
      EQUIVALENCE (X(1),GS),(X(2),GP),(X(3),MWSMWP),(X(4),
     -TS0TP0),(X(5),MS1),(X(6),MP1),(X(7),AS1AP1),(X(8),RD)
C
      DATA CATALG/'GS    ','GP    ','MWSMWP','TS0TP0','MS1   ',
     -'MP1   ','AS1AP1','RD    '/
      DATA TITLE/'  GS  ','  GP  ','MWSMWP','TS0TP0','  MS1 ',
     -'  MP1 ','AS1AP1','  RD  '/
      DATA FLOW/'   UL ','   MP '/,FAIL/'NG    '/,YES/'YES   '/
C
CCCC
```

```
      DO 101 K=1,8                                                      CASSEP 10100
      IF(VARBLE.EQ.CATALG(K)) GO TO 102                                 CASSEP 10200
  101 CONTINUE                                                          CASSEP 10300
      GO TO 107                                                         CASSEP 10400
  102 INDVAR=K                                                          CASSEP 10500
C                                                                       CASSEP 10600
C     ****************************************************************  CASSEP 10700
C     *                                                              *  CASSEP 10800
C     *              DETERMINE THE READ/WRITE SEQUENCE               *  CASSEP 10900
C     *                                                              *  CASSEP 11000
C     ****************************************************************  CASSEP 11100
C                                                                       CASSEP 11200
      LIST(1)=INDVAR                                                    CASSEP 11300
      K=1                                                               CASSEP 11400
      DO 103 L=2,8                                                      CASSEP 11500
      IF(K.EQ.INDVAR) K=K+1                                             CASSEP 11600
      LIST(L)=K                                                         CASSEP 11700
  103 K=K+1                                                             CASSEP 11800
C                                                                       CASSEP 11900
C     ****************************************************************  CASSEP 12000
C     *                                                              *  CASSEP 12100
C     *             INPUT - EJECTOR PARAMETERS AND ERROR             *  CASSEP 12200
C     *                                                              *  CASSEP 12300
C     ****************************************************************  CASSEP 12400
C                                                                       CASSEP 12500
      WRITE(5,202)(CATALG(LIST(K)),K=2,8)                               CASSEP 12600
      READ(5,203)(X(LIST(K)),K=2,8),ERROR                               CASSEP 12700
      WRITE(5,204)CATALG(INDVAR)                                        CASSEP 12800
      READ(5,205)XLOW,DELX,XHIGH                                        CASSEP 12900
C                                                                       CASSEP 13000
C     ****************************************************************  CASSEP 13100
C     *                                                              *  CASSEP 13200
C     *                 PERFORM EJECTOR CALCULATIONS                 *  CASSEP 13300
C     *                                                              *  CASSEP 13400
C     ****************************************************************  CASSEP 13500
C                                                                       CASSEP 13600
      DO 104 I=1,52                                                     CASSEP 13700
      X(INDVAR)=XLOW+(I-1)*DELX                                         CASSEP 13800
      IF(X(INDVAR).GT.XHIGH) GO TO 105                                  CASSEP 13900
      Y(I)=X(INDVAR)                                                    CASSEP 14000
      CALL CASSE                                                        CASSEP 14100
  104 IF(FAIL.EQ.YES) GO TO 108                                         CASSEP 14200
      GO TO 109                                                         CASSEP 14300
  105 I=I-1                                                             CASSEP 14400
```

7.3.1 CASSEP (Cont.)

```
C
C
C     ***********************************************************
C     *                                                         *
C     *                  OUTPUT - INITIAL DATA                  *
C     *                                                         *
C     ***********************************************************
C
C
      WRITE(3,300)
      WRITE(3,301)(CATALG(LIST(K)),X(LIST(K)),K=2,8),ERROR
C
C
C     ***********************************************************
C     *                                                         *
C     *                 OUTPUT - SUBSONIC SOLUTION              *
C     *                                                         *
C     ***********************************************************
C
C
      DO 106 L=1,2
      IF(L.EQ.1) WRITE(3,302)
      IF(L.EQ.2) WRITE(3,303)
      WRITE(3,304)FLOW(L)
      WRITE(3,310)TITLE(INDVAR)
      WRITE(3,308)(K,Y(K),PS1PP1(K,L),PS1PP0(K,L),PS0PP0(K,L),
     -WSWP(K,L),PM3PP0(K,L,1),MM3(K,L,1),K=1,I)
      WRITE(3,311)TITLE(INDVAR)
      WRITE(3,309)(K,Y(K),PP1PS1(K,L),PP0PS1(K,L),PP0PS0(K,L),
     -WPWS(K,L),PM3PS0(K,L,1),PM3PS1(K,L,1),MM3(K,L,1),K=1,I)
C
C
C     ***********************************************************
C     *                                                         *
C     *                OUTPUT - SUPERSONIC SOLUTION             *
C     *                                                         *
C     ***********************************************************
C
C
      WRITE(3,305)FLOW(L)
      WRITE(3,310)TITLE(INDVAR)
      WRITE(3,308)(K,Y(K),PS1PP1(K,L),PS1PP0(K,L),PS0PP0(K,L),
     -WSWP(K,L),PM3PP0(K,L,2),MM3(K,L,2),K=1,I)
      WRITE(3,311)TITLE(INDVAR)
      WRITE(3,309)(K,Y(K),PP1PS1(K,L),PP0PS1(K,L),PP0PS0(K,L),
     -WPWS(K,L),PM3PS0(K,L,2),PM3PS1(K,L,2),MM3(K,L,2),K=1,I)
C
C
C     ***********************************************************
C     *                                                         *
```

```
C     *  OUTPUT - SUPERSONIC SOLUTION AT RD OF NORMAL SHOCK     *        CASSEP 20100
C     *  CONDITIONS                                             *        CASSEP 20200
C     *                                                         *        CASSEP 20300
C     ***********************************************************        CASSEP 20400
C                                                                        CASSEP 20500
C                                                                        CASSEP 20600
      WRITE(3,306)FLOW(L)                                                CASSEP 20700
      WRITE(3,310)TITLE(INDVAR)                                          CASSEP 20800
      WRITE(3,308)(K,Y(K),PS1PP1(K,L),PS1PP0(K,L),PS0PP0(K,L),           CASSEP 20900
     -WSWP(K,L),PM3PP0(K,L,3),MM3(K,L,3),K=1,I)                          CASSEP 21000
      WRITE(3,311)TITLE(INDVAR)                                          CASSEP 21100
      WRITE(3,309)(K,Y(K),PP1PS1(K,L),PP0PS1(K,L),PP0PS0(K,L),           CASSEP 21200
     -WPWS(K,L),PM3PS0(K,L,3),PM3PS1(K,L,3),MM3(K,L,3),K=1,I)            CASSEP 21300
C                                                                        CASSEP 21400
C     ***********************************************************        CASSEP 21500
C     *                                                         *        CASSEP 21600
C     *                  OUTPUT - MIXED PROPERTIES              *        CASSEP 21700
C     *                                                         *        CASSEP 21800
C     ***********************************************************        CASSEP 21900
C                                                                        CASSEP 22000
C                                                                        CASSEP 22100
      WRITE(3,307)FLOW(L)                                                CASSEP 22200
      WRITE(3,312)TITLE(INDVAR)                                          CASSEP 22300
      WRITE(3,309)(K,Y(K),PS1PP1(K,L),PS1PP0(K,L),PS0PP0(K,L),           CASSEP 22400
     -WSWP(K,L),MWMMWP(K,L),TMOTP0(K,L),GM(K,L),K=1,I)                   CASSEP 22500
      WRITE(3,313)TITLE(INDVAR)                                          CASSEP 22600
106   WRITE(3,309)(K,Y(K),PP1PS1(K,L),PP0PS1(K,L),PP0PS0(K,L),           CASSEP 22700
     -WPWS(K,L),MWMMWS(K,L),TMOTS0(K,L),GM(K,L),K=1,I)                   CASSEP 22800
      STOP                                                               CASSEP 22900
C                                                                        CASSEP 23000
C     ***********************************************************        CASSEP 23100
C     *                                                         *        CASSEP 23200
C     *                     FAILURE INDICATORS                  *        CASSEP 23300
C     *                                                         *        CASSEP 23400
C     ***********************************************************        CASSEP 23500
C                                                                        CASSEP 23600
107   WRITE(5,400)(CATALG(K),K=1,8)                                      CASSEP 23700
      GO TO 100                                                          CASSEP 23800
108   WRITE(5,401)VARBLE,Y(I)                                            CASSEP 23900
      STOP                                                               CASSEP 24000
109   WRITE(5,402)I,VARBLE                                               CASSEP 24100
      STOP                                                               CASSEP 24200
C                                                                        CASSEP 24300
C     ***********************************************************        CASSEP 24400
C     *                                                         *        CASSEP 24500
C     *                     FORMAT STATEMENTS                   *        CASSEP 24600
C     *                                                         *        CASSEP 24700
C     ***********************************************************        CASSEP 24800
C     *                                                         *        CASSEP 24900
C     *                     FORMAT STATEMENTS                   *        CASSEP 25000
```

```
C     *                                                              *
C     ****************************************************************
C
C
200    FORMAT('0',T2,'INPUT INDEPENDENT VARIABLE - TYPE "H" FOR',
     -' HELP')
201    FORMAT(A6)
202    FORMAT('0',T2,'INPUT ',7(A6,', '),'ERROR')
203    FORMAT(7F,D)
204    FORMAT('0',T2,'INPUT LOW VALUE, INCREMENT, AND HIGH ',
     -'VALUE OF ',A6)
205    FORMAT(3F)
C
300    FORMAT('1',T44,'CONSTANT-AREA SUPERSONIC-SUPERSONIC ',
     -'EJECTOR',/,T58,'PARAMETRIC DATA',/,T54,'ONE-DIMENSIONAL',
     -' ANALYSIS',//,T59,'C.D. MIKKELSEN',/,T62,'1 MAY 75',//,
     -T49,'MECHANICAL ENGINEERING DEPARTMENT',/,T45,
     -'UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN',/,T55,
     -'URBANA, ILLINOIS 61801')
301    FORMAT('0',3(T44,A6,T51,'=',D13.6,T67,A6,T74,'=',D13.6,/),
     -T44,A6,T51,'=',D13.6,T67,'ERROR',T74,'=',D13.6)
302    FORMAT('-',T45,'BO INDICATES THE UPPER LIMIT OF THE ',
     -'PLANE',/,T49,'OF SUPERSONIC-SUPERSONIC OPERATION')
303    FORMAT('1',T45,'MP INDICATES THE LOWER LIMIT OF THE ',
     -'PLANE',/,T49,'OF SUPERSONIC-SUPERSONIC OPERATION')
304    FORMAT('-',T53,A6,'SUBSONIC SOLUTIONS')
305    FORMAT('1',T51,A6,'SUPERSONIC SOLUTIONS')
306    FORMAT('1',T35,A6,'SUPERSONIC SOLUTIONS AT RD OF NORMAL',
     -' SHOCK CONDITIONS')
307    FORMAT('1',T54,A6,'MIXED PROPERTIES')
308    FORMAT(' ',T9,I2,6D14.6,T109,D14.6)
309    FORMAT(' ',T9,I2,8D14.6)
310    FORMAT('0',T9,'NC',T16,A6,T30,'PS1PP1',T44,'PS1PP0',T58,
     -'PSOPP0',T73,'WSWP',T86,'PM3PP0',T116,'MM3',/)
311    FORMAT('0',T9,'NC',T16,A6,T30,'PP1PS1',T44,'PP0PS1',T58,
     -'PP0PS0',T73,'WPWS',T86,'PM3PS0',T100,'PM3PS1',T116,'MM3',
     -/)
312    FORMAT('0',T9,'NO',T16,A6,T30,'PS1PP1',T44,'PS1PP0',T58,
     -'PSOPP0',T73,'WSWP',T86,'MWMMWP',T100,'TM0TP0',T116,'GM',
     -/)
313    FORMAT('0',T9,'NO',T16,A6,T30,'PP1PS1',T44,'PP0PS1',T58,
     -'PP0PS0',T73,'WPWS',T86,'MWMMWS',T100,'TM0TS0',T116,'GM',
     -/)
C
400    FORMAT('0',T2,'SELECT THE INDEPENDENT VARIABLE FROM THE ',
     -'FOLLOWING',/,T2,'CATALOG OF EJECTOR PARAMETERS:',//,T2,
     -7(A6,', '),A6)
401    FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CASSE ',
     -'FOR ',A6,'=',D13.6)
402    FORMAT('0',T2,I3,' VALUE OF ',A6,' EXCEEDS THE PROGRAM ',
```

```
CASSEP 25100
CASSEP 25200
CASSEP 25300
CASSEP 25400
CASSEP 25500
CASSEP 25600
CASSEP 25700
CASSEP 25800
CASSEP 25900
CASSEP 26000
CASSEP 26100
CASSEP 26200
CASSEP 26300
CASSEP 26400
CASSEP 26500
CASSEP 26600
CASSEP 26700
CASSEP 26800
CASSEP 26900
CASSEP 27000
CASSEP 27100
CASSEP 27200
CASSEP 27300
CASSEP 27400
CASSEP 27500
CASSEP 27600
CASSEP 27700
CASSEP 27800
CASSEP 27900
CASSEP 28000
CASSEP 28100
CASSEP 28200
CASSEP 28300
CASSEP 28400
CASSEP 28500
CASSEP 28600
CASSEP 28700
CASSEP 28800
CASSEP 28900
CASSEP 29000
CASSEP 29100
CASSEP 29200
CASSEP 29300
CASSEP 29400
CASSEP 29500
CASSEP 29600
CASSEP 29700
CASSEP 29800
CASSEP 29900
CASSEP 30000
```

7.3.1 CASSEP (Cont.)

```
CASSEP 30100
CASSEP 30200
```

```
-'DIMENSIONS')
  END
```

7.3.1 CASSEP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *          CONSTANT-AREA SUPERSONIC-SUPERSONIC            *
C     *               EJECTOR SUBROUTINE (CASSE)                *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  CASSE IS A SUBROUTINE FOR CALCULATING THE PLANE OF     *
C     *  OPERATION OF A CONSTANT-AREA SUPERSONIC-SUPERSONIC     *
C     *  EJECTOR BY ONE-DIMENSIONAL ANALYSIS.                   *
C     *                                                         *
C     *  INPUT DATA:                                            *
C     *                                                         *
C     *  GS      = SECONDARY GAMMA                              *
C     *  GP      = PRIMARY GAMMA                                *
C     *  MWSMWP  = SECONDARY TO-PRIMARY MOLECULAR WEIGHT RATIO  *
C     *  TSOTPO  = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE  *
C     *            RATIO                                        *
C     *  MS1     = SECONDARY MACH NO. AT STATION 1              *
C     *  MP1     = PRIMARY MACH NO. AT STATION 1                *
C     *  AS1AP1  = SECONDARY-TO-PRIMARY AREA RATIO AT STATION 1 *
C     *  RD      = NORMAL SHOCK DIFFUSER COEFFICIENT            *
C     *  ERROR   = MAX PERCENT DEVIATION IN M(G,AAS)            *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *                     NOTATION SCHEME                     *
C     *                                                         *
C     *  VARIABLES ARE DEFINED AS FOLLOWS:                      *
C     *                                                         *
C     *  A : AREA                                               *
C     *  G : (GAMMA) SPECFIC HEAT RATIO                         *
C     *  M : MACH NUMBER                                        *
C     *  MW: MOLECULAR WEIGHT RATIO                             *
C     *  P : PRESSURE                                           *
C     *  T : TEMPERATURE                                        *
C     *  W : MASS FLOW RATE                                     *
C     *                                                         *
C     *  REPEATED LETTERS INDICATE RATIOS.                      *
C     *  EXAMPLE: AS1AP1=AS1/AP1                                *
C     *                                                         *
C     *  S: INDICATES SECONDARY OR DRIVEN STREAM PROPERTIES     *
C     *  P: INDICATES PRIMARY OR DRIVING STREAM PROPERTIES      *
C     *  M: INDICATES MIXED STREAM PROPERTIES                   *
C     *  EXAMPLE: GM=MIXED STREAM SPECIFIC HEAT RATIO           *
C     *                                                         *
```

```
C     *   VARIABLES ARE DESIGNATED AS TO LOCATION AS FOLLOWS:    *          CASSE  05100
C     *                                                          *          CASSE  05200
C     *   1: MIXING TUBE ENTRANCE, THE CONFLUENCE POINT OF THE   *          CASSE  05300
C     *      SECONDARY AND PRIMARY STREAMS                       *          CASSE  05400
C     *   2: POINT IN THE MIXING TUBE AT WHICH THE SECONDARY     *          CASSE  05500
C     *      STREAM IS RECOMPRESSED TO SONIC CONDITIONS          *          CASSE  05600
C     *   3: MIXING TUBE EXIT                                    *          CASSE  05700
C     *   EXAMPLE: PS1PP1=SECONDARY-TO-PRIMARY STATIC PRESSURE   *          CASSE  05800
C     *            RATIO AT STATION 1                            *          CASSE  05900
C     *                                                          *          CASSE  06000
C     *   0: INDICATES STAGNATION CONDITIONS                     *          CASSE  06100
C     *   EXAMPLE: TM0TP0=MIXED-TO-PRIMARY STAGNATION            *          CASSE  06200
C     *            TEMPERATURE RATIO                             *          CASSE  06300
C     *                                                          *          CASSE  06400
C     *   S: INDICATES "*" CONDITIONS                            *          CASSE  06500
C     *   EXAMPLE: AP1APS=AP1/AP*                                *          CASSE  06600
C     *                                                          *          CASSE  06700
C     *   VARIABLES NOT FOLLOWING THIS SCHEME ARE DEFINED AS     *          CASSE  06800
C     *   REQUIRED.                                              *          CASSE  06900
C     *                                                          *          CASSE  07000
C     ************************************************************          CASSE  07100
C                                                                           CASSE  07200
      SUBROUTINE CASSE                                                      CASSE  07300
C                                                                           CASSE  07400
      IMPLICIT REAL*8(A-H,M,O-Z)                                            CASSE  07500
C                                                                           CASSE  07600
      COMMON/BLOCK1/MM3(51,2,3),PM3PP0(51,2,3),PM3PS0(51,2,3),              CASSE  07700
     -PM3PS1(51,2,3)                                                        CASSE  07800
      COMMON/BLOCK2/GM(51,2),MWMMWP(51,2),MWMMWS(51,2),                     CASSE  07900
     -PS0PP0(51,2),PS1PP0(51,2),PS1PP1(51,2),PP0PS0(51,2),                  CASSE  08000
     -PP0PS1(51,2),PP1PS1(51,2),TM0TP0(51,2),TM0TS0(51,2),                  CASSE  08100
     -WPWS(51,2),WSWP(51,2)                                                 CASSE  08200
      COMMON/BLOCK3/GS,GP,MWSMWP,TS0TP0,MS1,MP1,AS1AP1,RD,ERROR,            CASSE  08300
     -FAIL,I                                                                CASSE  08400
C                                                                           CASSE  08500
      DATA YES/'YES    '/                                                   CASSE  08600
C                                                                           CASSE  08700
C                                                                           CASSE  08800
C     ************************************************************          CASSE  08900
C     *                                                          *          CASSE  09000
C     *                     SPECIAL FUNCTIONS                    *          CASSE  09100
C     *                                                          *          CASSE  09200
C     ************************************************************          CASSE  09300
C                                                                           CASSE  09400
      F(GX,MXX)=1.0+GX*MXX*MXX                                              CASSE  09500
      G(GX,MXX)=MXX*DSQRT(1.0+0.5*(GX-1.0)*MXX*MXX)                         CASSE  09600
      H(MM,TT,GG)=DSQRT(MM*GG/TT)                                           CASSE  09700
      MDMU(GX,MXX)=DSQRT((MXX*MXX+2.0/(GX-1.0))/(2.0*GX*MXX*MXX             CASSE  09800
                                                                            CASSE  09900
                                                                            CASSE  10000
```

```
-/(GX-1.0)-1.0))                                                        CASSE  10100
 PDPUMU(GX,MXX)=(2.C*GX*MXX*MXX-GX+1.0)/(GX+1.0)                        CASSE  10200
 PPOM(GX,MXX)=(1.0+0.5*(GX-1.0)*MXX*MXX)**(GX/(1.0-GX))                 CASSE  10300
 AASM(GX,MXX)=((2.0*(1.0+0.5*(GX-1.0)*MXX*MXX)/(GX+1.0))**              CASSE  10400
-(0.5*(GX+1.0)/(GX-1.0)))/MXX                                           CASSE  10500
C                                                                       CASSE  10600
C                                                                       CASSE  10700
C     ****************************************************************  CASSE  10800
C     *                                                              *  CASSE  10900
C     *              CHECK CONSISTENCY OF INPUT DATA                 *  CASSE  11000
C     *                                                              *  CASSE  11100
C     ****************************************************************  CASSE  11200
C                                                                       CASSE  11300
      IF(MS1.LE.1.0) GO TO 104                                          CASSE  11400
      IF(MP1.LE.1.0) GO TO 105                                          CASSE  11500
C                                                                       CASSE  11600
C     ****************************************************************  CASSE  11700
C     *                                                              *  CASSE  11800
C     *                     CALCULATE CONSTANTS                      *  CASSE  11900
C     *                                                              *  CASSE  12000
C     ****************************************************************  CASSE  12100
C                                                                       CASSE  12200
      GP1=(GP-1.0)/2.0                                                  CASSE  12300
      GP1I=1.0/GP1                                                      CASSE  12400
      GP2=2.0/(GP+1.0)                                                  CASSE  12500
      GP2I=1.0/GP2                                                      CASSE  12600
      GS3=GS/(GS-1.0)                                                   CASSE  12700
      GP3=GP/(GP-1.0)                                                   CASSE  12800
      GP4=(GP+1.0)/(2.0*(GP-1.0))                                       CASSE  12900
      GP4I=1.0/GP4                                                      CASSE  13000
      GSGP=GS/GP                                                        CASSE  13100
      MWPMWS=1.0/MWSMWP                                                 CASSE  13200
      PS1PS0=PPOM(GS,MS1)                                               CASSE  13300
      PP1PP0=PPOM(GP,MP1)                                               CASSE  13400
      AS1ASS=AASM(GS,MS1)                                               CASSE  13500
      AP1APS=AASM(GP,MP1)                                               CASSE  13600
      ASSAS1=1.0/AS1ASS                                                 CASSE  13700
      FGSMS1=F(GS,MS1)                                                  CASSE  13800
      FGPMP1=F(GP,MP1)                                                  CASSE  13900
      GGSMS1=G(GS,MS1)                                                  CASSE  14000
      GGPMP1=G(GP,MP1)                                                  CASSE  14100
C                                                                       CASSE  14200
C     ****************************************************************  CASSE  14300
C     *                                                              *  CASSE  14400
C     *  CALCULATE PS1PP1(I,1) FOR AN ISENTROPIC RECOMPRESSION       *  CASSE  14500
C     *  OF THE SECONDARY STREAM TO SONIC CONDITIONS AT              *  CASSE  14600
C     *                                                              *  CASSE  14700
C     ****************************************************************  CASSE  14800
C                                                                       CASSE  14900
C                                                                       CASSE  15000
```

7.3.1 CASSEP (Cont.)

```
C     *  STATION 2.  MP2 IS OBTAINED FROM AP2AP2 BY LINEAR        *
C     *  ITERATION.                                                *
C     *                                                            *
C     ************************************************************
C
C
      AP2APS=AP1APS*(1.0+AS1AP1*(1.0-ASSAS1))
      MP2=MP1
      DO 100 J=1,200
      C1=(MP2*AP2APS)**GP4I
      XMP2=DSQRT(GP1I*(GP2I*C1-1.0))
      XERROR=(XMP2-MP2)*100.0/MP2
      MP2=XMP2
      IF(DABS(XERROR).LT.ERROR) GO TO 101
100   CONTINUE
      GO TO 106
101   MS2=1.0
      C1=-FGPMP1+F(GP,MP2)*GGPMP1/G(GP,MP2)
      C2=FGSMS1-F(GS,MS2)*GGSMS1/G(GS,MS2)
      PS1PP1(I,1)=C1/(AS1AP1*C2)
C
C
C     ************************************************************
C     *                                                            *
C     *    SET PS1PP1(I,2) FOR MATCHED PRESSURE CONDITIONS.        *
C     *                                                            *
C     ************************************************************
C
C
      PS1PP1(I,2)=1.0
C
C
C     ************************************************************
C     *                                                            *
C     *            OVERALL CONTROL VOLUME CALCULATIONS             *
C     *                                                            *
C     ************************************************************
C
C
      DO 103 L=1,2
      WSWP(I,L)=PS1PP1(I,L)*AS1AP1*H(MWSMWP,TSOTPO,GSGP)*GGSMS1
     -/GGPMP1
      WPWS(I,L)=1.0/WSWP(I,L)
      C1=WSWP(I,L)*MWPMWS*GS3+GP3
      C2=WSWP(I,L)*MWPMWS*(GS3-1.0)+(GP3-1.0)
      GM(I,L)=C1/C2
      GMGP=GM(I,L)/GP
      MWMMWP(I,L)=(WSWP(I,L)+1.0)/(WSWP(I,L)*MWPMWS+1.0)
      MWMMWS(I,L)=MWMMWP(I,L)*MWPMWS
      C1=TSOTPO*WSWP(I,L)*MWPMWS*GS3+GP3
```

```
      C2=WSWP(I,L)*MWPMWS*GS3+GP3                                       CASSE  20100
      TMOTPO(I,L)=C1/C2                                                 CASSE  20200
      TMOTSO(I,L)=TMOTPO(I,L)/TSOTPO                                    CASSE  20300
      FFX=H(MWMMWP(I,L),TMOTPO(I,L),GMGP)*(PS1PP1(I,L)*AS1AP1           CASSE  20400
     -*FGSMS1+FGPMP1)/((1.0+WSWP(I,L))*GGPMP1)                          CASSE  20500
      C1=0.5*(GM(I,L)-1.0)*FFX*FFX-GM(I,L)*GM(I,L)                      CASSE  20600
      C2=FFX*FFX-2.0*GM(I,L)                                            CASSE  20700
      C3=(-C2+DSQRT(C2*C2+4.0*C1))/(2.0*C1)                             CASSE  20800
      C4=(-C2-DSQRT(C2*C2+4.0*C1))/(2.0*C1)                             CASSE  20900
C                                                                       CASSE  21000
CCCCC                                                                   CASSE  21100
CCCCC ****************************************************************  CASSE  21200
CCCCC *                                                              *  CASSE  21300
CCCCC *       IDENTIFY THE SUPERSONIC AND SUBSONIC SOLUTIONS         *  CASSE  21400
CCCCC *                                                              *  CASSE  21500
CCCCC ****************************************************************  CASSE  21600
CCC                                                                     CASSE  21700
                                                                        CASSE  21800
      MM3(I,L,1)=DSQRT(DMIN1(C3,C4))                                    CASSE  21900
      MM3(I,L,2)=DSQRT(DMAX1(C3,C4))                                    CASSE  22000
      DO 102 J=1,2                                                      CASSE  22100
      PM3PP1=(PS1PP1(I,L)*AS1AP1*FGSMS1+FGPMP1)/((1.0+AS1AP1)           CASSE  22200
     -*F(GM(I,L),MM3(I,L,J)))                                           CASSE  22300
      PM3PS1(I,L,J)=PM3PP1/PS1PP1(I,L)                                  CASSE  22400
      PM3PS0(I,L,J)=PM3PP1*PS1PS0/PS1PP1(I,L)                           CASSE  22500
102   PM3PP0(I,L,J)=PM3PP1*PP1PP0                                       CASSE  22600
      PP1PS1(I,L)=1.0/PS1PP1(I,L)                                       CASSE  22700
      PS1PP0(I,L)=PS1PP1(I,L)*PP1PP0                                    CASSE  22800
      PP0PS1(I,L)=1.0/PS1PP0(I,L)                                       CASSE  22900
      PS0PP0(I,L)=PS1PP1(I,L)*PP1PP0/PS1PS0                             CASSE  23000
      PP0PS0(I,L)=1.0/PS0PP0(I,L)                                       CASSE  23100
C                                                                       CASSE  23200
CCCCC                                                                   CASSE  23300
CCCCC ****************************************************************  CASSE  23400
CCCCC *                                                              *  CASSE  23500
CCCCC *  DIFFUSE THE SUPERSONIC SOLUTION TO RD OF NORMAL SHOCK       *  CASSE  23600
CCCCC *  CONDITIONS                                                  *  CASSE  23700
CCCCC *                                                              *  CASSE  23800
CCCCC ****************************************************************  CASSE  23900
CCC                                                                     CASSE  24000
                                                                        CASSE  24100
      C1=RD*PDFUMU(GM(I,L),MM3(I,L,2))                                  CASSE  24200
      PM3PS1(I,L,3)=C1*PM3PS1(I,L,2)                                    CASSE  24300
      PM3PS0(I,L,3)=C1*PM3PS0(I,L,2)                                    CASSE  24400
      PM3PP0(I,L,3)=C1*PM3PP0(I,L,2)                                    CASSE  24500
103   MM3(I,L,3)=MOMU(GM(I,L),MM3(I,L,2))                               CASSE  24600
      RETURN                                                            CASSE  24700
C                                                                       CASSE  24800
CCC                                                                     CASSE  24900
C     ****************************************************************  CASSE  25000
```

7.3.1 CASSEP (Cont.)

```
C     *                                                                  *
C     *                        FAILURE INDICATORS                        *
C     *                                                                  *
C     ******************************************************************
C
C
104   WRITE(5,200)MS1
      GO TO 107
105   WRITE(5,201)MP1
      GO TO 107
106   WRITE(5,202)MP2,XERROR,ERROR
107   FAIL=YES
      RETURN
C
C
C     ******************************************************************
C     *                                                                  *
C     *                        FORMAT STATEMENTS                         *
C     *                                                                  *
C     ******************************************************************
C
C
200   FORMAT('0','INPUT ERROR: MS1 =',E13.6,2X,'MS1 MUST BE ',
     -'SUPERSONIC')
201   FORMAT('0','INPUT ERROR: MP1 =',E13.6,2X,'MP1 MUST BE ',
     -'SUPERSONIC')
202   FORMAT('0',T2,'CONVERGENCE FAILURE',/,T2,'MP2 =',E13.6,2X,
     -'XERROR =',E13.6,2X,'ERROR =',E13.6)
      END
```

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7.3.2 CASSEP Sample Input

```
INPUT INDEPENDENT VARIABLE - TYPE "H" FOR HELP
H

SELECT THE INDEPENDENT VARIABLE FROM THE FOLLOWING
CATALOG OF EJECTOR PARAMETERS:

GS     ,GP     ,MWSMWP,TSOTPO,MS1    ,MP1    ,AS1AP1,RD

INPUT INDEPENDENT VARIABLE - TYPE "H" FOR HELP
AS1AP1

INPUT GS     ,GP     ,MWSMWP,TSOTPO,MS1    ,MP1    ,RD     ,
ERROR
1.562, 1.34, 0.593912, 1.31341, 2.18, 4.690, 0.75, 5.0E-06

INPUT LOW VALUE, INCREMENT, AND HIGH VALUE OF AS1AP1
1.0, 1.0, 10.0
```

CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR
PARAMETRIC DATA
ONE-DIMENSIONAL ANALYSIS

C.D. MIKKELSEN
1 MAY 75

MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
URBANA, ILLINOIS 61801

GS	= 0.156200D+01	GP	= 0.134000D+01
MWSMWP	= 0.593912D+00	TSOTPO	= 0.131341D+01
MS1	= 0.218000D+01	MP1	= 0.469000D+01
RD	= 0.750000D+00	ERROR	= 0.500000D-05

UL INDICATES THE UPPER LIMIT OF THE PLANE
OF SUPERSONIC-SUPERSONIC OPERATION

UL SUBSONIC SOLUTIONS

NO	AS1AP1	PS1PP0	PS0PP0	WSWP	PM3PP0	MM3
1	0.100000D+01	0.843536D-03	0.891096D-02	0.919989D-01	0.296420D-01	0.417080D+00
2	0.200000D+01	0.692846D-03	0.731910D-02	0.151126D+00	0.208017D-01	0.425312D+00
3	0.300000D+01	0.591519D-03	0.624870D-02	0.193539D+00	0.161594D-01	0.430679D+00
4	0.400000D+01	0.518105D-03	0.547316D-02	0.226025D+00	0.133689D-01	0.434522D+00
5	0.500000D+01	0.462163D-03	0.488220D-02	0.252025D+00	0.112848D-01	0.437445D+00
6	0.600000D+01	0.417952D-03	0.441517D-02	0.273499D+00	0.983354D-02	0.439764D+00
7	0.700000D+01	0.382032D-03	0.403572D-02	0.291660D+00	0.872327D-02	0.441662D+00
8	0.800000D+01	0.352208D-03	0.372067D-02	0.307304D+00	0.784502D-02	0.443252D+00
9	0.900000D+01	0.327008D-03	0.345445D-02	0.320981D+00	0.713209D-02	0.444610D+00
10	0.100000D+02	0.305405D-03	0.322624D-02	0.333085D+00	0.654126D-02	0.445787D+00

NO	AS1AP1	PP0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.100000D+01	0.118549D+04	0.112221D+03	0.108697D+02	0.332646D+01	0.351402D+02	0.417080D+00
2	0.200000D+01	0.144332D+04	0.136629D+03	0.661689D+01	0.284211D+01	0.300235D+02	0.425312D+00
3	0.300000D+01	0.169056D+04	0.160033D+03	0.516691D+01	0.258604D+01	0.273185D+02	0.430679D+00
4	0.400000D+01	0.193011D+04	0.182710D+03	0.442429D+01	0.242436D+01	0.256105D+02	0.434522D+00
5	0.500000D+01	0.216374D+04	0.204826D+03	0.396786D+01	0.231142D+01	0.244174D+02	0.437445D+00
6	0.600000D+01	0.239262D+04	0.226492D+03	0.365631D+01	0.222722D+01	0.235279D+02	0.439764D+00
7	0.700000D+01	0.261758D+04	0.247787D+03	0.342865D+01	0.216152D+01	0.228339D+02	0.441662D+00
8	0.800000D+01	0.283923D+04	0.268769D+03	0.325410D+01	0.210850D+01	0.222738D+02	0.443252D+00
9	0.900000D+01	0.305803D+04	0.289481D+03	0.311544D+01	0.206461D+01	0.218101D+02	0.444610D+00
10	0.100000D+02	0.327435D+04	0.309958D+03	0.300224D+01	0.202752D+01	0.214184D+02	0.445787D+00

7.3.3 CASSEP Sample Output (Cont.)

UL SUPERSONIC SOLUTIONS

NO	ASIAP1	PSIPP0	PSOPP0	WSWP	PM3PP0	MM3
1	0.100000D+01	0.84353 6D-03	0.891096D-02	0.919989D-01	0.142989D-02	0.425724D+01
2	0.200000D+01	0.692846D-03	0.731910D-02	0.151128D+00	0.110508D-02	0.405200D+01
3	0.300000D+01	0.591519D-03	0.624870D-02	0.193539D+00	0.911814D-03	0.392875D+01
4	0.400000D+01	0.510 5D-03	0.547315D-02	0.226025D+00	0.780853D-03	0.384505D+01
5	0.500000D+01	0.448163D-03	0.488220D-02	0.252225D+00	0.685249D-03	0.378377D+01
6	0.600000D+01	0.3979 2D-03	0.441517D-02	0.273499D+00	0.611945D-03	0.373653D+01
7	0.700000D+01	0.3582 0D-03	0.403572D-02	0.291660D+00	0.553727D-03	0.369875D+01
8	0.800000D+01	0.3522 8D-03	0.372067D-02	0.307304D+00	0.506246D-03	0.366767D+01
9	0.900000D+01	0.3270 8D-03	0.345445D-02	0.320981D+00	0.466705D-03	0.364155D+01
10	0.100000D+02	0.3054 5D-03	0.322624D-02	0.333085D+00	0.433216D-03	0.361921D+01

NO	ASIAP1	PPCPS1	PPOPS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.100000D+01	0.11E549D+04	0.112221D+03	0.108697D+02	0.160465D+00	0.169512D+01	0.425724D+01
2	0.200000D+01	0.144332D+04	0.136629D+03	0.661689D+01	0.150985D+00	0.159498D+01	0.405200D+01
3	0.300000D+01	0.169056D+04	0.160033D+03	0.516691D+01	0.145921D+00	0.154142D+01	0.392875D+01
4	0.400000D+01	0.193011D+04	0.182710D+03	0.442429D+01	0.142669D+00	0.150713D+01	0.384505D+01
5	0.500000D+01	0.216374D+04	0.204826D+03	0.396786D+01	0.140357D+00	0.148270D+01	0.378377D+01
6	0.600000D+01	0.239262D+04	0.226492D+03	0.365631D+01	0.138601D+00	0.146415D+01	0.373653D+01
7	0.700000D+01	0.261758D+04	0.247767D+03	0.342865D+01	0.137207D+00	0.144943D+01	0.369875D+01
8	0.800000D+01	0.283923D+04	0.268769D+03	0.325410D+01	0.136063D+00	0.143735D+01	0.366767D+01
9	0.900000D+01	0.305803D+04	0.289481D+03	0.311544D+01	0.135102D+00	0.142720D+01	0.364155D+01
10	0.100000D+02	0.327435D+04	0.309958D+03	0.300224D+01	0.134279D+00	0.141850D+01	0.361921D+01

UL SUPERSONIC SOLUTIONS AT RD OF NORMAL SHOCK CONDITIONS

NO	AS1AP1	PS1PP0	PS0PP0	WSWP	PM3PP0	MM3
1	0.100000D+01	0.843536D-03	0.891096D-02	0.919989D-01	0.222315D-01	0.417080D+00
2	0.200000D+01	0.692846D-03	0.731910D-02	0.151128D+00	0.156013D-01	0.425312D+00
3	0.300000D+01	0.591519D-03	0.624870D-02	0.193539D+00	0.121195D-01	0.430679D+00
4	0.400000D+01	0.518105D-03	0.547316D-02	0.226025D+00	0.995168D-02	0.434522D+00
5	0.500000D+01	0.462163D-03	0.488220D-02	0.252025D+00	0.846362D-02	0.437445D+00
6	0.600000D+01	0.417952D-03	0.441517D-02	0.273499D+00	0.737516D-02	0.439764D+00
7	0.700000D+01	0.382032D-03	0.403572D-02	0.291660D+00	0.654245D-02	0.441662D+00
8	0.800000D+01	0.352208D-03	0.372067D-02	0.307304D+00	0.588377D-02	0.443252D+00
9	0.900000D+01	0.327008D-03	0.345445D-02	0.320981D+00	0.534907D-02	0.444610D+00
10	0.100000D+02	0.305405D-03	0.322624D-02	0.333085D+00	0.490595D-02	0.445787D+00

NO	AS1AP1	PPOPS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.100000D+01	0.118549D+04	0.112221D+03	0.108697D+02	0.249485D+01	0.263551D+02	0.417080D+00
2	0.200000D+01	0.144332D+04	0.136629D+03	0.661689D+01	0.213158D+01	0.225177D+02	0.425312D+00
3	0.300000D+01	0.169056D+04	0.160033D+03	0.516691D+01	0.193953D+01	0.204889D+02	0.430679D+00
4	0.400000D+01	0.193011D+04	0.182710D+03	0.442429D+01	0.181827D+01	0.192079D+02	0.434522D+00
5	0.500000D+01	0.216374D+04	0.204826D+03	0.396786D+01	0.173357D+01	0.183131D+02	0.437445D+00
6	0.600000D+01	0.239262D+04	0.226492D+03	0.365631D+01	0.167041D+01	0.176460D+02	0.439764D+00
7	0.700000D+01	0.261758D+04	0.247787D+03	0.342865D+01	0.162114D+01	0.171254D+02	0.441662D+00
8	0.800000D+01	0.283923D+04	0.268769D+03	0.325410D+01	0.158137D+01	0.167054D+02	0.443252D+00
9	0.900000D+01	0.305803D+04	0.289481D+03	0.311544D+01	0.154845D+01	0.163576D+02	0.444610D+00
10	0.100000D+02	0.327435D+04	0.309958D+03	0.300224D+01	0.152064D+01	0.160638D+02	0.445787D+00

7.3.3 CASSEP Sample Output (Cont.)

UL MIXED PROPERTIES

NO	AS1AP1	PS1PP1	PS1PP0	WSWP	MWMMWP	TMOTP0	GM
1	0.1000000D+01	0.3883520+00	0.8435360-03	0.9199890-01	0.9455330+00	0.1030870+01	0.1359020+01
2	0.2000000D+01	0.3189770+00	0.6928460-03	0.1511280+00	0.9176270+00	0.1047680+01	0.1369620+01
3	0.3000000D+01	0.2723270+00	0.5915190-03	0.1935390+00	0.9001920+00	0.1058570+01	0.1376560+01
4	0.4000000D+01	0.2385280+00	0.5181050-03	0.2266250+00	0.8880570+00	0.1066320+01	0.1381550+01
5	0.5000000D+01	0.2127730+00	0.4621630-03	0.2520250+00	0.8790170+00	0.1072190+01	0.1385350+01
6	0.6000000D+01	0.1924190+00	0.4179520-03	0.2734990+00	0.8719580+00	0.1076830+01	0.1388370+01
7	0.7000000D+01	0.1758820+00	0.3820320-03	0.2916600+00	0.8662560+00	0.1080620+01	0.1390850+01
8	0.8000000D+01	0.1621520+00	0.3522080-03	0.3073040+00	0.8615290+00	0.1083790+01	0.1392930+01
9	0.9000000D+01	0.1505500+00	0.3270080-03	0.3209810+00	0.8575280+00	0.1086490+01	0.1394700+01
10	0.1000000D+02	0.1406040+00	0.3054050-03	0.3330850+00	0.8540860+00	0.1088820+01	0.1396240+01

NO	AS1AP1	PP1PS1	PPOPS1	WPWS	MWMMWS	TMOTSO	GM
1	0.1000000D+01	0.2574980+01	0.1185490+04	0.1086970+02	0.1592040+01	0.7848770+00	0.1359020+01
2	0.2000000D+01	0.3135020+01	0.1443320+04	0.6016890+01	0.1545060+01	0.7976830+00	0.1369620+01
3	0.3000000D+01	0.3672050+01	0.1690560+04	0.5166910+01	0.1515700+01	0.8059670+00	0.1376560+01
4	0.4000000D+01	0.4159238D+01	0.1930110+04	0.4424290+01	0.1495270+01	0.8118680+00	0.1381550+01
5	0.5000000D+01	0.4699840+01	0.2163740+04	0.3967860+01	0.1480050+01	0.8163380+00	0.1385350+01
6	0.6000000D+01	0.5196990+01	0.2392620+04	0.3656310+01	0.1468160+01	0.8198740+00	0.1388370+01
7	0.7000000D+01	0.5685620+01	0.2617580+04	0.3426650+01	0.1458560+01	0.8227590+00	0.1390850+01
8	0.8000000D+01	0.6167060+01	0.2839230+04	0.3254100+01	0.1450600+01	0.8251710+00	0.1392930+01
9	0.9000000D+01	0.6642310+01	0.3058030+04	0.3115440+01	0.1443860+01	0.8272270+00	0.1394700+01
0	0.1000000D+02	0.7112170+01	0.3274350+04	0.3002240+01	0.1438070+01	0.8290060+00	0.1396240+01

MP INDICATES THE LOWER LIMIT OF THE PLANE
OF SUPERSONIC-SUPERSONIC OPERATION

MP SUBSONIC SOLUTIONS

NO	AS1AP1	PS1PP0	PSOPP0	WSWP	PM3PP0	MM3
1	0.100000D+01	0.217209D-02	0.229456D-01	0.236895D+00	0.334576D-01	0.435760D+00
2	0.200000D+01	0.217209D-02	0.229456D-01	0.473791D+00	0.264320D-01	0.457993D+00
3	0.300000D+01	0.217209D-02	0.229456D-01	0.710686D+00	0.229005D-01	0.473865D+00
4	0.400000D+01	0.217209D-02	0.229456D-01	0.947582D+00	0.207722D-01	0.485795D+00
5	0.500000D+01	0.217209D-02	0.229456D-01	0.118448D+01	0.193481D-01	0.495102D+00
6	0.600000D+01	0.217209D-02	0.229456D-01	0.142137D+01	0.183276D-01	0.502574D+00
7	0.700000D+01	0.217209D-02	0.229456D-01	0.165827D+01	0.175602D-01	0.508708D+00
8	0.800000D+01	0.217209D-02	0.229456D-01	0.189516D+01	0.169620D-01	0.513836D+00
9	0.900000D+01	0.217209D-02	0.229456D-01	0.213206D+01	0.164824D-01	0.518189D+00
10	0.100000D+02	0.217209D-02	0.229456D-01	0.236895D+01	0.160894D-01	0.521931D+00

NO	AS1AP1	PP0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.100000D+01	0.460386D+03	0.435814D+02	0.422127D+01	0.145813D+01	0.154034D+02	0.435760D+00
2	0.200000D+01	0.460386D+03	0.435814D+02	0.211064D+01	0.115194D+01	0.121689D+02	0.457993D+00
3	0.300000D+01	0.460386D+03	0.435814D+02	0.140709D+01	0.998036D+00	0.105431D+02	0.473865D+00
4	0.400000D+01	0.460386D+03	0.435814D+02	0.105532D+01	0.905282D+00	0.956323D+01	0.485795D+00
5	0.500000D+01	0.460386D+03	0.435814D+02	0.844254D+00	0.843216D+00	0.890758D+01	0.495102D+00
6	0.600000D+01	0.460386D+03	0.435814D+02	0.703545D+00	0.798743D+00	0.843778D+01	0.502574D+00
7	0.700000D+01	0.460386D+03	0.435814D+02	0.603039D+00	0.765300D+00	0.808449D+01	0.508708D+00
8	0.800000D+01	0.460386D+03	0.435814D+02	0.527659D+00	0.739227D+00	0.780906D+01	0.513836D+00
9	0.900000D+01	0.460386D+03	0.435814D+02	0.469030D+00	0.718327D+00	0.758828D+01	0.518189D+00
10	0.100000D+02	0.460386D+03	0.435814D+02	0.422127D+00	0.701197D+00	0.740732D+01	0.521931D+00

MP SUPERSONIC SOLUTIONS

NO	AS1AP1	PS1PP0	PS0PP0	WSWP	PM3PP0	MM3
1	0.100000D+01	0.217209D-02	0.229456D-01	0.236895D+00	0.199537D-02	0.381885D+01
2	0.200000D+01	0.217209D-02	0.229456D-01	0.473791D+00	0.197454D-02	0.340272D+01
3	0.300000D+01	0.217209D-02	0.229456D-01	0.710686D+00	0.198050D-02	0.315698D+01
4	0.400000D+01	0.217209D-02	0.229456D-01	0.947582D+00	0.199236D-02	0.299423D+01
5	0.500000D+01	0.217209D-02	0.229456D-01	0.118446D+01	0.200493D-02	0.287832D+01
6	0.600000D+01	0.217209D-02	0.229456D-01	0.142137D+01	0.201675D-02	0.279147D+01
7	0.700000D+01	0.217209D-02	0.229456D-01	0.165827D+01	0.202744D-02	0.272395D+01
8	0.800000D+01	0.217209D-02	0.229456D-01	0.189516D+01	0.203698D-02	0.266992D+01
9	0.900000D+01	0.217209D-02	0.229456D-01	0.213206D+01	0.204548D-02	0.262569D+01
10	0.100000D+02	0.217209D-02	0.229456D-01	0.236895D+01	0.205305D-02	0.258881D+01

NO	AS1AP1	PP0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.100000D+01	0.460386D+03	0.435814D+02	0.422127D+01	0.869612D-01	0.918642D+00	0.381885D+01
2	0.200000D+01	0.460386D+03	0.435814D+02	0.211064D+01	0.860531D-01	0.909049D+00	0.340272D+01
3	0.300000D+01	0.460386D+03	0.435814D+02	0.140709D+01	0.863130D-01	0.911795D+00	0.315698D+01
4	0.400000D+01	0.460386D+03	0.435814D+02	0.105532D+01	0.868300D-01	0.917256D+00	0.299423D+01
5	0.500000D+01	0.460386D+03	0.435814D+02	0.844254D+00	0.873778D-01	0.923044D+00	0.287832D+01
6	0.600000D+01	0.460386D+03	0.435814D+02	0.703545D+00	0.878927D-01	0.928483D+00	0.279147D+01
7	0.700000D+01	0.460386D+03	0.435814D+02	0.603039D+00	0.883585D-01	0.933403D+00	0.272395D+01
8	0.800000D+01	0.460386D+03	0.435814D+02	0.527659D+00	0.887745D-01	0.937798D+00	0.266992D+01
9	0.900000D+01	0.460386D+03	0.435814D+02	0.469030D+00	0.891448D-01	0.941710D+00	0.262569D+01
10	0.100000D+02	0.460386D+03	0.435814D+02	0.422127D+00	0.894749D-01	0.945197D+00	0.258881D+01

MP SUPERSONIC SOLUTIONS AT RD OF NORMAL SHOCK CONDITIONS

NO	AS1AP1	PS1PP0	PS0PP0	WSWP	PM3PP0	MM3
1	0.100000D+01	0.217209D-02	0.229456D-01	0.236895D+00	0.250932D-01	0.435760D+00
2	0.200000D+01	0.217209D-02	0.229456D-01	0.473791D+00	0.198240D-01	0.457993D+00
3	0.300000D+01	0.217209D-02	0.229456D-01	0.710686D+00	0.171754D-01	0.473865D+00
4	0.400000D+01	0.217209D-02	0.229456D-01	0.947582D+00	0.155792D-01	0.485795D+00
5	0.500000D+01	0.217209D-02	0.229456D-01	0.118448D+01	0.145110D-01	0.495102D+00
6	0.600000D+01	0.217209D-02	0.229456D-01	0.142137D+01	0.137457D-01	0.502574D+00
7	0.700000D+01	0.217209D-02	0.229456D-01	0.165827D+01	0.131702D-01	0.508708D+00
8	0.800000D+01	0.217209D-02	0.229456D-01	0.189516D+01	0.127215D-01	0.513836D+00
9	0.900000D+01	0.217209D-02	0.229456D-01	0.213206D+01	0.123618D-01	0.518189D+00
10	0.100000D+02	0.217209D-02	0.229456D-01	0.236895D+01	0.120670D-01	0.521931D+00

NO	AS1AP1	PP0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.100000D+01	0.460386D+03	0.435814D+02	0.422127D+01	0.109360D+01	0.115526D+02	0.435760D+00
2	0.200000D+01	0.460386D+03	0.435814D+02	0.211064D+01	0.863957D+00	0.912668D+01	0.457993D+00
3	0.300000D+01	0.460386D+03	0.435814D+02	0.140709D+01	0.748527D+00	0.790730D+01	0.473865D+00
4	0.400000D+01	0.460386D+03	0.435814D+02	0.105532D+01	0.678961D+00	0.717243D+01	0.485795D+00
5	0.500000D+01	0.460386D+03	0.435814D+02	0.844254D+00	0.632412D+00	0.668069D+01	0.495102D+00
6	0.600000D+01	0.460386D+03	0.435814D+02	0.703545D+00	0.599058D+00	0.632834D+01	0.502574D+00
7	0.700000D+01	0.460386D+03	0.435814D+02	0.603039D+00	0.573975D+00	0.606336D+01	0.508708D+00
8	0.800000D+01	0.460386D+03	0.435814D+02	0.527659D+00	0.554420D+00	0.585680D+01	0.513836D+00
9	0.900000D+01	0.460386D+03	0.435814D+02	0.469030D+00	0.538745D+00	0.569121D+01	0.518189D+00
10	0.100000D+02	0.460386D+03	0.435814D+02	0.422127D+00	0.525898D+00	0.555549D+01	0.521931D+00

MP MIXED PROPERTIES

NO	AS1AP1	PS1PP1	PS1PP0	WSWP	MWMMWP	TMOTPO	GM
1	0.1000000D+01	0.1000000D+01	0.2172C9D-02	C.236895D+00	0.884209D+00	0.106880D+01	0.138316D+01
2	0.2000000D+01	0.1000000D+01	0.2172C9D-02	0.473791D+00	0.819799D+00	0.111284D+01	0.141227D+01
3	0.3000000D+01	0.1000000D+01	0.2172C9D-02	C.710686D+00	C.778782D+00	0.114344D+01	0.143322D+01
4	0.4000000D+01	0.1000000D+01	0.2172C9D-02	0.947582D+00	0.750371D+00	0.116593D+01	0.144904D+01
5	0.5000000D+01	0.1000000D+01	0.2172C9D-02	C.118448D+01	0.729529D+00	0.118317D+01	0.146139D+01
6	C.6000000D+01	0.1000000D+01	0.2172C9D-02	C.1421370+01	0.713588D+00	0.119680D+01	0.147131D+01
7	0.7000000D+01	0.1000000D+01	0.2172C9D-02	0.165827D+01	0.701000D+00	C.120785D+01	0.147945D+01
8	0.8000000D+01	0.1000000D+01	0.2172C9D-02	C.189516D+01	0.690808D+00	0.121699D+01	0.148624D+01
9	0.9000000D+01	0.1000000D+01	0.2172C9D-02	0.213206D+01	0.682387D+00	0.122467D+01	0.149201D+01
10	0.1000000D+02	0.1000000D+01	0.2172C9D-02	0.236895D+01	0.675313D+00	0.123121D+01	0.149696D+01

NO	AS1AP1	PP1PS1	PP0PS1	WPWS	MWMMWS	TMOTSO	GM
1	0.1000000D+01	0.1000000D+01	0.460386D+03	C.422127D+01	0.148879D+01	0.813763D+00	0.138316D+01
2	C.2000000+01	0.1000000D+01	0.460386D+03	C.211064D+01	0.138034D+01	0.847289D+00	0.141227D+01
3	0.3000000D+01	0.1000000D+01	0.460386D+03	C.140709D+01	0.131127D+01	0.870586D+00	0.143322D+01
4	0.4000000D+01	0.1000000D+01	0.460386D+03	0.105532D+01	0.126344D+01	0.887?15D+00	0.144904D+01
5	0.5000000D+01	0.1000000D+01	0.460386D+03	C.844254D+00	0.122835D+01	0.900840D+00	0.146139D+01
6	C.6000000D+01	0.1000000D+01	0.460386D+03	C.703545D+00	0.120150D+01	0.911218D+00	0.147131D+01
7	C.7000000D+01	0.1000000D+01	0.460386D+03	0.603039D+00	0.118031D+01	0.919629D+00	0.147945D+01
8	0.8000000D+01	0.1000000D+01	0.460386D+03	C.527659D+00	0.116315D+01	0.926585D+00	0.148624D+01
9	0.9000000D+01	0.1000000D+01	0.460386D+03	0.469030D+00	0.114897D+01	0.932432D+00	0.149201D+01
10	0.1000000D+02	0.1000000D+01	0.460386D+03	C.422127D+00	0.113706D+01	0.937417D+00	0.149696D+01

7.4 CHEMICAL LASER GAS DYNAMICS OPTIMIZATION COMPUTER PROGRAM

7.4.1 Computer Program

```
C     ***********************************************************
C     *                                                         *
C     *     CHEMICAL LASER GAS DYNAMICS OPTIMIZATION PROGRAM    *
C     *                        (CLGDOP)                         *
C     *                                                         *
C     *                WRITTEN BY: A.L. ADDY                    *
C     *                            C.D. MIKKELSEN               *
C     *                            M.R. SANDBERG                *
C     *                                                         *
C     *                        1 JANUARY 76                     *
C     *                                                         *
C     *            MECHANICAL ENGINEERING DEPARTMENT            *
C     *        UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN       *
C     *                URBANA, ILLINOIS 61801                   *
C     *                                                         *
C     *    CLGDOP IS A PROGRAM FOR OPTIMIZING THE PRESSURE      *
C     *    RECOVERY SUBSYSTEM OF HIGH ENERGY CHEMICAL LASER     *
C     *    SYSTEMS BY ONE-DIMENSIONAL ANALYSIS.  THE OPTIMUM    *
C     *    IS TAKEN TO BE THAT CONFIGURATION WHICH REQUIRES     *
C     *    THE MINIMUM DRIVER MASS FLOW FOR A GIVEN DRIVER      *
C     *    STAGNATION PRESSURE (OR VICE VERSA) AND GIVEN        *
C     *    COMPRESSION RATIO. CLGDOP IS A FORTRAN IV PROGRAM    *
C     *    WRITTEN FOR DEC SYSTEM-10 (F40).                     *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *                      NOTATION SCHEME                    *
C     *                                                         *
C     *  VARIABLES ARE DEFINED AS FOLLOWS:                      *
C     *                                                         *
C     *  A : AREA                                               *
C     *  G : (GAMMA) SPECIFIC HEAT RATIO                        *
C     *  M : MACH NUMBER                                        *
C     *  MW: MOLECULAR WEIGHT                                   *
C     *  P : PRESSURE                                           *
C     *  T : TEMPERATURE                                        *
C     *  W : MASS FLOW RATE                                     *
C     *                                                         *
C     *  REPEATED LETTERS INDICATE RATIOS.                      *
C     *  EXAMPLE: A2A1=A2/A1                                    *
C     *                                                         *
C     *  VARIABLES ARE DESIGNATED AS TO LOCATION BY THE         *
C     *  FOLLOWING:                                             *
C     *                                                         *
C     *  POINT 1: LASER CAVITY ENTRANCE                         *
C     *  POINT 2: LASER CAVITY EXIT                             *
C     *  POINT 3: NORMAL SHOCK DIFFUSER EXIT                    *
C     *  POINT 4: SUBSONIC DIFFUSER EXIT                        *
```

```
C     *   POINT 5: EJECTOR SECONDARY NOZZLE EXIT                    *        CLGDOP 05100
C     *   POINT 6: EJECTOR PRIMARY NOZZLE EXIT                      *        CLGDOP 05200
C     *   POINT 7: EJECTOR MIXING TUBE EXIT                         *        CLGDOP 05300
C     *   POINT 8: SUBSONIC DIFFUSER EXIT                           *        CLGDOP 05400
C     *   EXAMPLE: P8P2= SUBSONIC DIFFUSER EXIT-TO-LASER CAVITY     *        CLGDOP 05500
C     *            EXIT STATIC PRESSURE RATIO                       *        CLGDOP 05600
C     *                                                             *        CLGDOP 05700
C     *   S: INDICATES SECONDARY OR DRIVEN STREAM PROPERTIES        *        CLGDOP 05800
C     *   P: INDICATES PRIMARY OR DRIVING STREAM PROPERTIES         *        CLGDOP 05900
C     *   M: INDICATES MIXED STREAM PROPERTIES                      *        CLGDOP 06000
C     *   EXAMPLE: GM= MIXED STREAM SPECIFIC HEAT RATIO             *        CLGDOP 06100
C     *                                                             *        CLGDOP 06200
C     *   0: INDICATES STAGNATION CONDITIONS                        *        CLGDOP 06300
C     *   EXAMPLE: T20T10= LASER CAVITY EXIT-TO-ENTRANCE            *        CLGDOP 06400
C     *            STAGNATION TEMPERATURE RATIO                     *        CLGDOP 06500
C     *                                                             *        CLGDOP 06600
C     *   VARIABLES NOT FOLLOWING THIS SCHEME ARE DEFINED           *        CLGDOP 06700
C     *   AS REQUIRED.                                              *        CLGDOP 06800
C     *                                                             *        CLGDOP 06900
C     ***************************************************************        CLGDOP 07000
C                                                                            CLGDOP 07100
C                                                                            CLGDOP 07200
      IMPLICIT REAL*4 (M)                                                    CLGDOP 07300
      REAL*4 NO                                                              CLGDOP 07400
C                                                                            CLGDOP 07500
      COMMON/TTY1/A2A1,A3A1,A4A1,A4A3,A5A1,A5A6,A6A1,A7A1,A7A2,              CLGDOP 07600
     -A7A6,A8A1,A8A7                                                         CLGDOP 07700
      COMMON/TTY2/COEFF,CQ1,CQ2,EJECT,GM,GP,GS                               CLGDOP 07800
      COMMON/TTY3/M1,M2,M3,M4,M5,M6,M7,M8,MWMMWS,MWPMWS,NPTS                 CLGDOP 07900
      COMMON/TTY4/P1P10,P2P1,P20P10,P3P1,P30P10,P3P2,P30P20,                 CLGDOP 08000
     -P4P1,P40P10,P4P3,P40P30,P5P1,P50P10,XP60P1,P60P10,P60P2,               CLGDOP 08100
     -P60P20,P60P50,P7P1,P70P10,P7P2,P70P20,P7P50,P70P50,XP8P1,              CLGDOP 08200
     -P80P10,P8P2,P80P20,P8P7,P80P70                                         CLGDOP 08300
      COMMON/TTY5/RNSD,RSD34,RSD78                                           CLGDOP 08400
      COMMON/TTY6/T1T10,T2T1,T20T10,T3T1,T30T10,T3T2,T30T20,                 CLGDOP 08500
     -T4T1,T40T10,T4T3,T40T30,T5T1,T50T10,T60T1,T60T10,T60T20,               CLGDOP 08600
     -T60T50,T7T1,T70T10,T7T2,T70T20,T7T50,T70T50,T8T1,                      CLGDOP 08700
     -T80T10,T8T2,T80T20,T8T7,T80T70                                         CLGDOP 08800
      COMMON/TTY7/WMWS,XWPWS                                                 CLGDOP 08900
C                                                                            CLGDOP 09000
      DATA P60P1C/'P60P1'/,WPWSC/'WPWS'/,CAE/'CAE'/,SSE/'SSE'/,              CLGDOP 09100
     -YES/'YES'/,NO/'NO'/,PART/'PART'/                                       CLGDOP 09200
C                                                                            CLGDOP 09300
      DATA GS,M1,A2A1,CQ1,CQ2,NPTS/1.400,2.0,1.0,2*0.0,21/                   CLGDOP 09400
      DATA P8P1,P60P1,WPWS/76.0,2.5E+03,1.0/                                 CLGDOP 09500
      DATA RNSD,A4A3/2*1.0/                                                  CLGDOP 09600
      DATA GP,MWPMWS,T60T50,T60T20,A8A7/1.400,4*1.0/                         CLGDOP 09700
C                                                                            CLGDOP 09800
      NAMELIST/CAV/GS,M1,A2A1,CQ1,CQ2,NPTS                                   CLGDOP 09900
      NAMELIST/CONST1/P8P1,P60P1                                             CLGDOP 10000
```

```
      NAMELIST/CONST2/P8P1,WPWS                                          CLGDOP 10100
      NAMELIST/DIFUSR/RNSD,A4A3                                          CLGDOP 10200
      NAMELIST/EJECT1/GP,MWPMWS,T60T50,A8A7                              CLGDOP 10300
      NAMELIST/EJECT2/GP,MWPMWS,T60T20,A8A7                              CLGDOP 10400
C                                                                        CLGDOP 10500
      TOTM(GX,MX)=1.0+((GX-1.0)/2.0)*MX*MX                               CLGDOP 10600
      POPM(GX,MX)=(1.0+((GX-1.0)/2.0)*MX*MX)**(GX/(GX-1.0))              CLGDOP 10700
      WM(GX,MX)=MX*SQRT(GX*(1.0+((GX-1.0)/2.0)*MX*MX))                   CLGDOP 10800
C                                                                        CLGDOP 10900
CCCCCC*****************************************************************CLGDOP 11000
CCCCCC*                                                               *CLGDOP 11100
CCCCCC*              SECTION I: LASER CAVITY ANALYSIS                 *CLGDOP 11200
CCCCCC*                                                               *CLGDOP 11300
CCCCCC*     VARIABLES USED IN THIS SECTION AND THEIR DEFAULT          *CLGDOP 11400
CCCCCC*     VALUES ARE:                                               *CLGDOP 11500
CCCCCC*                                                               *CLGDOP 11600
CCCCCC*     1. GS(1.400)  : RATIO OF SPECIFIC HEATS                   *CLGDOP 11700
CCCCCC*     2. M1(2.0)    : CAVITY ENTRANCE MACH NUMBER               *CLGDOP 11800
CCCCCC*     3. A2A1(1.0)  : CAVITY EXIT-TO-ENTRANCE AREA RATIO        *CLGDOP 11900
CCCCCC*     4. CQ1(0.0)   : HEAT ADDITION COEFFICIENT                 *CLGDOP 12000
CCCCCC*     5. CQ2(0.0)   : HEAT ADDITION COEFFICIENT                 *CLGDOP 12100
CCCCCC*     6. NPTS(21)   : CAVITY INTEGRATION INCREMENTS             *CLGDOP 12200
CCCCCC*                                                               *CLGDOP 12300
CCCCCC*     NOTES:                                                    *CLGDOP 12400
CCCCCC*     1. VALUES OF ALL INPUT VARIABLES MUST BE DEFINED          *CLGDOP 12500
CCCCCC*        EITHER BY INPUT OR DEFAULT.                            *CLGDOP 12600
CCCCCC*     2. ALL VARIABLE INPUT IS BY NAMELIST.                     *CLGDOP 12700
CCCCCC*     3. THE MAXIMUM NUMBER OF INTEGRATION STEPS IS 25.         *CLGDOP 12800
CCCCCC*                                                               *CLGDOP 12900
CCCCCC*****************************************************************CLGDOP 13000
C                                                                        CLGDOP 13100
100   WRITE(5,200)                                                       CLGDOP 13200
      WRITE(5,CAV)                                                       CLGDOP 13300
      READ(5,CAV)                                                        CLGDOP 13400
      X1=0.0                                                             CLGDOP 13500
      X2=1.0                                                             CLGDOP 13600
      A1=1.0                                                             CLGDOP 13700
      A2=A2A1                                                            CLGDOP 13800
      FAIL=NO                                                            CLGDOP 13900
C                                                                        CLGDOP 14000
CCCCCC*****************************************************************CLGDOP 14100
CCCCCC*                                                               *CLGDOP 14200
CCCCCC*                CALCULATIONS FOR LASER CAVITY                  *CLGDOP 14300
CCCCCC*                                                               *CLGDOP 14400
CCCCCC*****************************************************************CLGDOP 14500
C                                                                        CLGDOP 14600
                                                                         CLGDOP 14700
                                                                         CLGDOP 14800
                                                                         CLGDOP 14900
                                                                         CLGDOP 15000
```

```
      CALL CAVITY(GS,M1,X1,X2,A1,A2,CQ1,CQ2,NPTS,M2,T2T1,T20T10,
     -P2P1,P20P10,FAIL)
      T1T10=1.0/T0TM(GS,M1)
      P1P10=1.0/P0PM(GS,M1)
      T20T2=T0TM(GS,M2)
      P20P2=P0PM(GS,M2)
      IF(FAIL.EQ.YES) GO TO 119
C
CCCC
```

7.4.1 CLGDOP (Cont.)

```
C     *                SECTION II: EJECTOR ANALYSIS                *
C     *                                                            *
C     *   ONE OF TWO EJECTOR CONFIGURATIONS MAY BE CHOSEN          *
C     *   TO REPRESSURIZE THE LASER CAVITY FLOW.  THESE            *
C     *   CONFIGURATIONS ARE:                                      *
C     *                                                            *
C     *   CAE: NORMAL SHOCK DIFFUSER - SUBSONIC DIFFUSER -         *
C     *        CONSTANT-AREA SUBSONIC-SUPERSONIC EJECTOR -         *
C     *        SUBSONIC DIFFUSER                                   *
C     *   SSE: CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR -       *
C     *        SUBSONIC DIFFUSER                                   *
C     *                                                            *
C     *     VARIABLES USED IN THIS SECTION AND THEIR DEFAULT       *
C     *     VALUES ARE:                                            *
C     *                                                            *
C     *  1. RNSD(1.0)   : NORMAL SHOCK DIFFUSER COEFFICIENT        *
C     *  2. A4A3(1.0)   : SUBSONIC DIFFUSER EXIT-TO-ENTRANCE       *
C     *                   AREA RATIO                               *
C     *  3. GP(1.400)   : RATIO OF SPECIFIC HEATS                  *
C     *  4. MWPMWS(1.0): PRIMARY-TO-SECONDARY MOLECULAR            *
C     *                   WEIGHT RATIO                             *
C     *  5. T60T50(1.0): PRIMARY-TO-SECONDARY STAGNATION           *
C     *                   TEMPERATURE RATIO (FOR CAE)              *
C     *  5. T60T20(1.0): PRIMARY-TO-SECONDARY STAGNATION           *
C     *                   TEMPERATURE RATIO (FOR SSE)              *
C     *  6. A8A7(1.0)   : SUBSONIC DIFFUSER EXIT-TO-ENTRANCE       *
C     *                   AREA RATIO                               *
C     *                                                            *
C     *     ALL VARIABLE INPUT IS BY NAMELIST.                     *
C     *                                                            *
C     ************************************************************
C
C
102   WRITE(5,204)
      READ(5,205)EJECT
      IF(EJECT.EQ.SSE) GO TO 103
      WRITE(5,206)
      WRITE(5,DIFUSR)
      READ(5,DIFUSR)
      WRITE(5,207)
      WRITE(5,EJECT1)
      READ(5,EJECT1)
      GO TO 104
103   WRITE(5,207)
      WRITE(5,EJECT2)
      READ(5,EJECT2)
104   MWSMWP=1.0/MWPMWS
      T50T60=1.0/T60T50
      T20T60=1.0/T60T20
C
```

7.4.1 CLGDOP (Cont.)

```
C
C     ***********************************************************
C     *                                                         *
C     *          CACULATIONS FOR NORMAL SHOCK DIFFUSER          *
C     *                                                         *
C     ***********************************************************
C
C
      IF(EJECT.EQ.SSE) GO TO 105
      CALL NSDS(GS,M2,RNSD,M3,P3P2,P30P20,T3T2,T30T20)
      P3P1=P3P2*P2P1
      T3T1=T3T2*T2T1
      P30P10=P30P20*P20P10
      T30T10=T30T20*T20T10
      A3A1=A2A1
C
C
C     ***********************************************************
C     *                                                         *
C     *             CALCULATIONS FOR SUBSONIC DIFFUSER          *
C     *                                                         *
C     ***********************************************************
C
C
      CALL SDS(GS,M3,A4A3,M4,P4P3,P40P30,T4T3,T40T30,RSD34,FAIL)
      IF(FAIL.EQ.YES) GO TO 120
      P4P1=P4P3*P3P1
      T4T1=T4T3*T3T1
      P40P10=P40P30*P30P10
      T40T10=T40T30*T30T10
      A4A1=A4A3*A3A1
C
C
C     ***********************************************************
C     *                                                         *
C     *            CALCULATIONS FOR SUDDEN ENLARGEMENT          *
C     *                                                         *
C     ***********************************************************
C
C
      P50P40=1.0
      T50T40=1.0
      P50P20=P50P40*P40P30*P30P20
      T50T20=T50T40*T40T30*T30T20
      P50P10=P50P20*P20P10
      T50T10=T50T20*T20T10
C
C
C     ***********************************************************
C     *                                                         *
```

```
C     *         ITERATE M5 TO FIND MINIMUM XWPWS (XP60P1)          *
C     *                                                            *
C     ************************************************************
C
      NTYPE1=1
      NIT1=1
      M5=1.0
      DO 114 ITER1=1,100
C
C     ************************************************************
C     *                                                          *
C     *       ITERATE A7A6 TO FIND XP60P1=P60P1 (XWPWS=WPWS)     *
C     *                                                          *
C     ************************************************************
C
105   NTYPE2=1
      NIT2=1
      A7A6=20.0
      DO 111 ITER2=1,100
C
C     ************************************************************
C     *                                                          *
C     *                 ITERATE M6 TO FIND XP8P1=P8P1            *
C     *                                                          *
C     ************************************************************
C
      NTYPE3=1
      NIT3=1
      M6=1.01
      DO 109 ITER3=1,100
C
C     ************************************************************
C     *                                                          *
C     *           CALCULATIONS FOR CONSTANT-AREA EJECTOR         *
C     *                                                          *
C     ************************************************************
C
      IF(EJECT.NE.CAE) GO TO 107
      AGA7=1.0/A7A6
      CALL CAES(GS,GP,MWSMWP,T50T60,M5,M6,A6A7,WSWP,GM,MWMMWP,
     -T70T60,M7,P60P50,P7P50,FAIL)
      IF(FAIL.EQ.YES) GO TO 121
      P7P1=P7P50*P50P20*P20P2*P2P1
```

CLGDOP 30100
CLGDOP 30200
CLGDOP 30300
CLGDOP 30400
CLGDOP 30500
CLGDOP 30600
CLGDOP 30700
CLGDOP 30800
CLGDOP 30900
CLGDOP 31000
CLGDOP 31100
CLGDOP 31200
CLGDOP 31300
CLGDOP 31400
CLGDOP 31500
CLGDOP 31600
CLGDOP 31700
CLGDOP 31800
CLGDOP 31900
CLGDOP 32000
CLGDOP 32100
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CLGDOP 32300
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CLGDOP 32600
CLGDOP 32700
CLGDOP 32800
CLGDOP 32900
CLGDOP 33000
CLGDOP 33100
CLGDOP 33200
CLGDOP 33300
CLGDOP 33400
CLGDOP 33500
CLGDOP 33600
CLGDOP 33700
CLGDOP 33800
CLGDOP 33900
CLGDOP 34000
CLGDOP 34100
CLGDOP 34200
CLGDOP 34300
CLGDOP 34400
CLGDOP 34500
CLGDOP 34600
CLGDOP 34700
CLGDOP 34800
CLGDOP 34900
CLGDOP 35000

```
      P60P2=P60P50*P50P20*P20P2                                          CLGDOP 35100
      IF(FAIL.EQ.NO) GO TO 108                                          CLGDOP 35200
C                                                                       CLGDOP 35300
CCCCC ***************************************************************** CLGDOP 35400
CCCCC *                                                               * CLGDOP 35500
CCCCC *       NO CAE SOLUTION EXISTS FOR CURRENT VALUE OF             * CLGDOP 35600
CCCCC *       M6.  INCREMENT M6 AND SEARCH FOR SOLUTION.              * CLGDOP 35700
CCCCC *                                                               * CLGDOP 35800
CCCCC ***************************************************************** CLGDOP 35900
C                                                                       CLGDOP 36000
      M6=M6+0.5                                                         CLGDOP 36100
      IF(M6.GT.10.0) GO TO 106                                          CLGDOP 36200
      FAIL=NO                                                           CLGDOP 36300
      GO TO 109                                                         CLGDOP 36400
C                                                                       CLGDOP 36500
CCCCC ***************************************************************** CLGDOP 36600
CCCCC *                                                               * CLGDOP 36700
CCCCC *    NO CAE SOLUTION EXISTS FOR CURRENT VALUE OF A7A6.          * CLGDOP 36800
CCCCC *    INCREMENT A7A6 AND SEARCH FOR SOLUTION.                    * CLGDOP 36900
CCCCC *                                                               * CLGDOP 37000
CCCCC ***************************************************************** CLGDOP 37100
C                                                                       CLGDOP 37200
106   A7A6=A7A6-0.5                                                     CLGDOP 37300
      IF(A7A6.LE.1.0) GO TO 113                                         CLGDOP 37400
      FAIL=NO                                                           CLGDOP 37500
      GO TO 111                                                         CLGDOP 37600
C                                                                       CLGDOP 37700
CCCCC ***************************************************************** CLGDOP 37800
CCCCC *                                                               * CLGDOP 37900
CCCCC *       CALCULATIONS FOR SUPERSONIC-SUPERSONIC EJECTOR          * CLGDOP 38000
CCCCC *                                                               * CLGDOP 38100
CCCCC ***************************************************************** CLGDOP 38200
C                                                                       CLGDOP 38300
107   A2A6=A7A6-1.0                                                     CLGDOP 38400
      CALL SSES(GS,GP,MWSMWP,T20T60,M2,M6,A2A6,WSWP,GM,MWMMWP,          CLGDOP 38500
     -T70T60,M7,P60P2,P7P2,FAIL)                                        CLGDOP 38600
      IF(FAIL.EQ.YES) GO TO 122                                         CLGDOP 38700
      P7P1=P7P2*P2P1                                                    CLGDOP 38800
C                                                                       CLGDOP 38900
CCCCC ***************************************************************** CLGDOP 39000
CCCCC *                                                               * CLGDOP 39100
CCCCC *             CALCULATIONS FOR SUBSONIC DIFFUSER                * CLGDOP 39200
C     *                                                               * CLGDOP 39300
```

7.4.1 CLGDOP (Cont.)

```
C     ***********************************************************
C
C
108   CALL SDS(GM,M7,A8A7,M8,P8P7,P80P70,T8T7,T80T70,RSD78,FAIL)
      IF(FAIL.EQ.YES) GO TO 123
      XP8P1=P8P7*P7P1
C
C
C     ***********************************************************
C     *                                                         *
C     *            TEST FOR XP8P1=P8P1  AND INCREMENT M6        *
C     *                                                         *
C     ***********************************************************
C
C
      CALL ITER(M6,0.5,5.0E-06,+1.0,XP8P1,P8P1,1.0E-01,NIT3,
     -NTYPE3,XNEG3,YNEG3,XPOS3,YPOS3,NSIGN3,NSIGN4)
      IF(NTYPE3.EQ.3) GO TO 110
109   CONTINUE
      GO TO 125
C
C
C     ***********************************************************
C     *                                                         *
C     *  TEST FOR XP60P1=P60P1 (XWPWS=WPWS) AND INCREMENT A7A6 *
C     *                                                         *
C     ***********************************************************
C
C
110   XP60P1=P60P2*P2P1
      XWPWS=1.0/WSWP
      IF(COEFF.EQ.WPWSC) CALL ITER(A7A6,0.5,5.0E-06,-1.0,XP60P1,
     -P60P1,1.0E-01,NIT2,NTYPE2,XNEG2,YNEG2,XPOS2,YPOS2,NSIGN1,
     -NSIGN2)
      IF(COEFF.EQ.P60P1C) CALL ITER(A7A6,0.5,5.0E-06,-1.0,XWPWS,
     -WPWS,1.0E-01,NIT2,NTYPE2,XNEG2,YNEG2,XPOS2,YPOS2,NSIGN1,
     -NSIGN2)
      IF(NTYPE2.EQ.3) GO TO 112
111   CONTINUE
      GO TO 126
C
C
C     ***********************************************************
C     *                                                         *
C     *  IF NO CAE SOLUTION EXISTS FOR CURRENT VALUE OF M5,     *
C     *  INCREMENT M5 AND SEARCH FOR SOLUTION.  IF SOLUTION     *
C     *  FOUND, TEST FOR MINIMUM XWPWS (XP60P1) AND INCREMENT   *
C     *  M5.                                                    *
C     *                                                         *
C     ***********************************************************
```

7.4.1 CLGDOP (Cont.)

```
C
C
112   IF(EJECT.EQ.SSE) GO TO 115
113   IF(COEFF.EQ.WPWSC) CALL MIN(M5,XWPWS,NTYPE1,NIT1,COEFF,
     -FAIL)
      IF(COEFF.EQ.P60P1C) CALL MIN(M5,XP60P1,NTYPE1,NIT1,COEFF,
     -FAIL)
      IF(FAIL.EQ.YES) GO TO 124
114   IF(NTYPE1.EQ.4) GC TO 115
      GO TO 127
115   MWMMWS=MWMMWP*MWPMWS
      WMWS=1.0+XWPWS
C
C
C     ***********************************************************
C     *                                                         *
C     *                FINAL CALCULATIONS FOR CAE               *
C     *                                                         *
C     ***********************************************************
C
C
      IF(EJECT.EQ.SSE) GO TO 116
      P5P1=P50P20*P20P2*P2P1/P0PM(GS,M5)
      T5T1=T50T20*T2CT2*T2T1/T0TM(GS,M5)
      A5A1=SQRT(T50T10)*WM(GS,M1)/(P5P1*WM(GS,M5))
      P70P50=P0PM(GM,M7)*P7P50
      T70T50=T7CT60*T60T50
      T7T50=T70T50/TCTM(GM,M7)
      GO TO 117
C
C
C     ***********************************************************
C     *                                                         *
C     *                FINAL CALCULATICNS FOR SSE               *
C     *                                                         *
C     ***********************************************************
C
C
116   P60P20=P6CP2/P20P2
      P70P20=P0PM(GM,M7)*P7P2/P20P2
      T70T20=T7CT60*T60T20
      T7T2=T20T2*T70T20/T0TM(GM,M7)
      A7A2=A7A6/A2A6
      GO TO 118
C
C
C     ***********************************************************
C     *                                                         *
C     *            FINAL CALCULATIONS FOR NSD-SD-SE-CAE         *
C     *                                                         *
```

7.4.1 CLGDOP (Cont.)

```
C     ***********************************************************
C
C
117   P60P20=P60P50*P50P20
      T60T20=T60T50*T50T20
      P7P2=P7P50*P50P20*P20P2
      P70P20=P70P50*P50P20
      T7T2=T7T50*T50T20*T20T2
      T70T20=T70T50*T50T20
      A7A2=WMWS*SQRT(T70T20/MWMMWS)*WM(GS,M2)/(P7P2*WM(GM,M7))
C
C
C     ***********************************************************
C     *                                                         *
C     *    FINAL CALCULATIONS FOR NSD-SD-SE-CAE-SD OR SSE-SD    *
C     *                                                         *
C     ***********************************************************
C
C
118   P8P2=P8P7*P7P2
      P80P20=P80P70*P70P20
      T8T2=T8T7*T7T2
      T80T20=T80T70*T70T20
C
C
C     ***********************************************************
C     *                                                         *
C     *                FINAL SYSTEM CALCULATIONS                *
C     *                                                         *
C     ***********************************************************
C
C
      A7A1=A7A2*A2A1
      A6A1=A7A1/A7A6
      A8A1=A8A7*A7A1
      P60P10=P60P20*P20P10
      T60T1=T60T20*T20T2*T2T1
      T60T10=T60T20*T20T10
      P7P1=P7P2*P2P1
      P70P10=P70P20*P20P10
      T7T1=T7T2*T2T1
      T70T10=T70T20*T20T10
      P80P10=P80P20*P20P10
      T8T1=T8T2*T2T1
      T80T10=T80T20*T20T10
C
C
C     ***********************************************************
C     *                                                         *
C     *                       OUTPUT RESULTS                    *
```

```
C     *                                                               *
CCC   *****************************************************************
CCC
C
      CALL TTY
      GO TO 128
C
CCC   *****************************************************************
CCC   *                                                               *
CCC   *                      FAILURE INDICATORS                       *
CCC   *                                                               *
CCC   *****************************************************************
CCC
C
119   WRITE(5,300)
      GO TO 128
120   WRITE(5,301)
      GO TO 128
121   WRITE(5,302)
      GO TO 128
122   WRITE(5,303)
      GO TO 128
123   WRITE(5,304)
      GO TO 128
124   WRITE(5,305)
125   WRITE(5,306)M5,A7A6,M6,XP8P1,P8P1
      GO TO 128
126   IF(COEFF.EQ.WPWSC) WRITE(5,307)M5,M6,A7A6,XP60P1,P60P1
      IF(COEFF.EC.P60P1C) WRITE(5,308)M5,M6,A7A6,XWPWS,WPWS
      GO TO 128
127   IF(COEFF.EQ.WPWSC) WRITE(5,309)M6,A7A6,M5,XWPWS
      IF(COEFF.EQ.P60P1C) WRITE(5,310)M6,A7A6,M5,XP60P1
128   WRITE(5,208)
      READ(5,209)RUN
      IF(RUN.EQ.YES) GO TO 100
C
CCC   *****************************************************************
CCC   *                                                               *
CCC   *                      FORMAT STATEMENTS                        *
CCC   *                                                               *
CCC   *****************************************************************
CCC
C
200   FORMAT('0',T2,'INPUT DATA FOR LASER CAVITY ANALYSIS BY ',
     -'NAMELIST.',/,T2,'CURRENT VALUES ARE:',/)
201   FORMAT('0',T2,'INPUT THE VARIABLE TO BE MINIMIZED FROM ',
     -'THE FOLLOWING LIST:',//,T2,
     -'"P60P1" DIMENSIONLESS PRIMARY STAGNATION PRESSURE',/,T2,
```

```
CLGDOP 55100
CLGDOP 55200
CLGDOP 55300
CLGDOP 55400
CLGDOP 55500
CLGDOP 55600
CLGDOP 55700
CLGDOP 55800
CLGDOP 55900
CLGDOP 56000
CLGDOP 56100
CLGDOP 56200
CLGDOP 56300
CLGDOP 56400
CLGDOP 56500
CLGDOP 56600
CLGDOP 56700
CLGDOP 56800
CLGDOP 56900
CLGDOP 57000
CLGDOP 57100
CLGDOP 57200
CLGDOP 57300
CLGDOP 57400
CLGDOP 57500
CLGDOP 57600
CLGDOP 57700
CLGDOP 57800
CLGDOP 57900
CLGDOP 58000
CLGDOP 58100
CLGDOP 58200
CLGDOP 58300
CLGDOP 58400
CLGDOP 58500
CLGDOP 58600
CLGDOP 58700
CLGDOP 58800
CLGDOP 58900
CLGDOP 59000
CLGDOP 59100
CLGDOP 59200
CLGDOP 59300
CLGDOP 59400
CLGDOP 59500
CLGDOP 59600
CLGDOP 59700
CLGDOP 59800
CLGDOP 59900
CLGDOP 60000
```

```
     -'"WPWS"  PRIMARY-TO-SECONDARY MASS FLOW RATIO',/)                  CLGDOP 60100
202   FORMAT(A5)                                                        CLGDOP 60200
203   FORMAT('0',T2,'INPUT SYSTEM CONSTRAINTS BY NAMELIST.',/,          CLGDOP 60300
     -T2,'CURRENT VALUES ARE:',/)                                       CLGDOP 60400
204   FORMAT('0',T2,'INPUT THE EJECTOR MODEL FROM THE ',                CLGDOP 60500
     -'FOLLOWING LIST:',//,T2,                                          CLGDOP 60600
     -'"CAE" CONSTANT-AREA EJECTOR',/,T2,                               CLGDOP 60700
     -'"SSE" SUPERSONIC-SUPERSONIC EJECTOR',/)                          CLGDOP 60800
205   FORMAT(A3)                                                        CLGDOP 60900
206   FORMAT('0',T2,'INPUT DATA FOR SUPERSONIC-SUBSONIC ',              CLGDOP 61000
     -'DIFFUSER SECTION BY NAMELIST.',/,T2,'CURRENT VALUES ARE:',       CLGDOP 61100
     -/)                                                                CLGDOP 61200
207   FORMAT('0',T2,'INPUT DATA FOR EJECTOR ANALYSIS BY ',              CLGDOP 61300
     -'NAMELIST.',/,T2,'CURRENT VALUES ARE:',/)                         CLGDOP 61400
208   FORMAT('1',T2,'TO RESTART PROGRAM ENTER "YES"',/,T2,              CLGDOP 61500
     -'TO STOP PROGRAM ENTER "NO"')                                     CLGDOP 61600
209   FORMAT(A3)                                                        CLGDOP 61700
C                                                                       CLGDOP 61800
300   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CAVITY')          CLGDOP 61900
301   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SDS',/,           CLGDOP 62000
     -T2,'AT STATION 3 TO 4 IN CHEMICAL LASER SYSTEM')                  CLGDOP 62100
302   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CAES')            CLGDOP 62200
303   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SSES')            CLGDOP 62300
304   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SDS',/,           CLGDOP 62400
     -T2,'AT STATION 7 TO 8 IN CHEMICAL LASER SYSTEM')                  CLGDOP 62500
305   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE MIN')             CLGDOP 62600
306   FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,            CLGDOP 62700
     -T2,'FOR M6 SUCH THAT XP8P1=P8P1',//,                              CLGDOP 62800
     -T2,'M5      =',E13.6,T26,'A7A6    =',E13.6,/,                   CLGDOP 62900
     -T2,'M6      =',E13.6,T26,'XP8P1   =',E13.6,/,                   CLGDOP 63000
     -T2,'P8P1    =',E13.6)                                           CLGDOP 63100
307   FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,            CLGDOP 63200
     -T2,'FOR A7A6 SUCH THAT XP60P1=P60P1',//,                          CLGDOP 63300
     -T2,'M5      =',E13.6,T26,'M6      =',E13.6,/,                   CLGDOP 63400
     -T2,'A7A6    =',E13.6,T26,'XP60P1  =',E13.6,/,                   CLGDOP 63500
     -T2,'P60P1   =',E13.6)                                           CLGDOP 63600
308   FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,            CLGDOP 63700
     -T2,'FOR A7A6 SUCH THAT XWPWS=WPWS',//,                            CLGDOP 63800
     -T2,'M5      =',E13.6,T26,'M6      =',E13.6,/,                   CLGDOP 63900
     -T2,'A7A6    =',E13.6,T26,'XWPWS   =',E13.6,/,                   CLGDOP 64000
     -T2,'WPWS    =',E13.6)                                           CLGDOP 64100
309   FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,            CLGDOP 64200
     -T2,'FOR M5 SUCH THAT XWPWS = MINIMUM WPWS',//,                    CLGDOP 64300
     -T2,'M6      =',E13.6,T26,'A7A6    =',E13.6,/,                   CLGDOP 64400
     -T2,'M5      =',E13.6,T26,'XWPWS   =',E13.6)                     CLGDOP 64500
310   FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,            CLGDOP 64600
     -T2,'FOR M5 SUCH THAT XP60P1 = MINIMUM P60P1',//,                  CLGDOP 64700
     -T2,'M6      =',E13.6,T26,'A7A6    =',E13.6,/,                   CLGDOP 64800
     -T2,'M5      =',E13.6,T26,'XP60P1  =',E13.6)                     CLGDOP 64900
      END                                                               CLGDOP 65000
```

```
C     ****************************************************************      CAVITY 00100
C     *                                                              *      CAVITY 00200
C     *                LASER CAVITY SUBROUTINE (CAVITY)              *      CAVITY 00300
C     *                                                              *      CAVITY 00400
C     ****************************************************************      CAVITY 00500
C                                                                            CAVITY 00600
C     ****************************************************************      CAVITY 00700
C     *                                                              *      CAVITY 00800
C     *   SUBROUTINE CAVITY IS A SIMPLIFIED FLOW MODEL TO            *      CAVITY 00900
C     *   ASSESS QUALITATIVELY THE EFFECTS OF HEAT RELEASE AND       *      CAVITY 01000
C     *   AREA CHANGE ON THE LASER CAVITY FLOW.  THE FLOW MODEL      *      CAVITY 01100
C     *   IS BASED ON THE ASSUMPTION OF A 1-D FLOW OF AN IDEAL       *      CAVITY 01200
C     *   HOMOGENEOUS GAS THROUGH A CHANNEL WITH A LINEAR            *      CAVITY 01300
C     *   VARIATION IN AREA AND HEAT ADDITION.                       *      CAVITY 01400
C     *                                                              *      CAVITY 01500
C     *   INPUT VARIABLES:                                           *      CAVITY 01600
C     *                                                              *      CAVITY 01700
C     *   G       = SPECIFIC HEAT RATIO                              *      CAVITY 01800
C     *   M1      = ENTRANCE MACH NUMBER                             *      CAVITY 01900
C     *   X1      = ENTRANCE COORDINATE                              *      CAVITY 02000
C     *   X2      = EXIT COORDINATE                                  *      CAVITY 02100
C     *   A1      = ENTRANCE AREA                                    *      CAVITY 02200
C     *   A2      = EXIT AREA                                        *      CAVITY 02300
C     *   CQ1     = HEAT ADDITION COEFFICIENT                        *      CAVITY 02400
C     *   CQ2     = HEAT ADDITION COEFFICIENT                        *      CAVITY 02500
C     *   NPTS    = CAVITY INTEGRATION INCREMENTS                    *      CAVITY 02600
C     *                                                              *      CAVITY 02700
C     *   OUTPUT VARIABLES:                                          *      CAVITY 02800
C     *                                                              *      CAVITY 02900
C     *   M2      = EXIT MACH NUMBER                                 *      CAVITY 03000
C     *   T2      = EXIT STATIC TEMPERATURE                          *      CAVITY 03100
C     *   T02     = EXIT STAGNATION TEMPERATURE                      *      CAVITY 03200
C     *   P2      = EXIT STATIC PRESSURE                             *      CAVITY 03300
C     *   P02     = EXIT STAGNATION PRESSURE                         *      CAVITY 03400
C     *   FAIL    = ERROR FLAG                                       *      CAVITY 03500
C     *                                                              *      CAVITY 03600
C     ****************************************************************      CAVITY 03700
C                                                                            CAVITY 03800
      SUBROUTINE CAVITY(G,M1,DUMMY1,DUMMY2,A1,A2,CQ1,CQ2,NPTS,               CAVITY 03900
     -M2,T2,T02,P2,P02,FAIL)                                                 CAVITY 04000
C                                                                            CAVITY 04100
      EXTERNAL FMSQD                                                         CAVITY 04200
      IMPLICIT REAL*4(L,M)                                                   CAVITY 04300
      DIMENSION T0(25)                                                       CAVITY 04400
      COMMON/FVD/ZI(3),XI(3),X(25),M(25),P(25),P0(25),T(25)                  CAVITY 04500
      COMMON/COEFF/X1,CA(2),CT0(2)                                           CAVITY 04600
      DATA YES/'YES'/                                                        CAVITY 04700
C                                                                            CAVITY 04800
C                                                                            CAVITY 04900
                                                                             CAVITY 05000
```

```
C     ****************************************************************      CAVITY 05100
C     *                                                              *      CAVITY 05200
C     *            INITIALIZE VARIABLES AT STATION (1).              *      CAVITY 05300
C     *                                                              *      CAVITY 05400
C     ****************************************************************      CAVITY 05500
C                                                                           CAVITY 05600
      X1=DUMMY1                                                             CAVITY 05700
      X2=DUMMY2                                                             CAVITY 05800
      X(1)=X1                                                               CAVITY 05900
      M(1)=M1                                                               CAVITY 06000
      P(1)=1.0                                                              CAVITY 06100
      P0(1)=1.0                                                             CAVITY 06200
      T(1)=1.0                                                              CAVITY 06300
      T0(1)=1.0                                                             CAVITY 06400
      XRKI=X1                                                               CAVITY 06500
      YRKI=M1**2                                                            CAVITY 06600
C                                                                           CAVITY 06700
C     ****************************************************************      CAVITY 06800
C     *                                                              *      CAVITY 06900
C     *  CALCULATE THE CAVITY AREA COEFFICIENTS.  A LINEAR           *      CAVITY 07000
C     *  VARIATION WITH X IS ASSUMED.                                *      CAVITY 07100
C     *                                                              *      CAVITY 07200
C     ****************************************************************      CAVITY 07300
C                                                                           CAVITY 07400
      CA(1)=(A1*X2-A2*X1)/(X2-X1)                                           CAVITY 07500
      CA(2)=(A2-A1)/(X2-X1)                                                 CAVITY 07600
C                                                                           CAVITY 07700
C     ****************************************************************      CAVITY 07800
C     *                                                              *      CAVITY 07900
C     *  CALCULATE THE RATE OF HEAT ADDITION COEFFICIENTS.  A        *      CAVITY 08000
C     *  LINEAR VARIATION OF RATE OF HEAT ADDITION WITH X IS         *      CAVITY 08100
C     *  ASSUMED.                                                    *      CAVITY 08200
C     *                                                              *      CAVITY 08300
C     ****************************************************************      CAVITY 08400
C                                                                           CAVITY 08500
      CT0(1)=(CQ1*X2-CQ2*X1)/(X2-X1)                                        CAVITY 08600
      CT0(2)=(CQ2-CQ1)/(X2-X1)                                              CAVITY 08700
C                                                                           CAVITY 08800
C     ****************************************************************      CAVITY 08900
C     *                                                              *      CAVITY 09000
C     *         INITIALIZE FLOW VARIABLES FOR INTEGRATION.           *      CAVITY 09100
C     *                                                              *      CAVITY 09200
C     ****************************************************************      CAVITY 09300
C                                                                           CAVITY 09400
                                                                            CAVITY 09500
                                                                            CAVITY 09600
                                                                            CAVITY 09700
                                                                            CAVITY 09800
                                                                            CAVITY 09900
                                                                            CAVITY 10000
```

7.4.1 CLGDCP (Cont.)

```
C
      LNP=0.0
      LNP0=0.0
      LNT=0.0
C
C
C     ***********************************************************
C     *                                                         *
C     *  SET INCREMENT SIZE FOR R-K AND SIMPSON INTEGRATIONS.   *
C     *                                                         *
C     ***********************************************************
C
C
      DX=(X2-X1)/FLOAT(NPTS-1)
      DXRKI=DX/2.0
C
C
C     ***********************************************************
C     *                                                         *
C     *                    INTEGRATION SECTION                  *
C     *                                                         *
C     ***********************************************************
C
C
      DO 60 I=2,NPTS
C
C
C     ***********************************************************
C     *                                                         *
C     *         SET-UP FOR D(M**2)/DX INTEGRATION BY R-K.       *
C     *                                                         *
C     ***********************************************************
C
C
      ZI(1)=YRKI
      XI(1)=XRKI
      DO 50 J=1,2
C
C
C     ***********************************************************
C     *                                                         *
C     *                INTEGRATE D(M**2)/DX BY R-K.             *
C     *                                                         *
C     ***********************************************************
C
C
      CALL RKI1(G,DXRKI,XRKI,YRKI,FMSQD,FAIL)
      IF(FAIL.EQ.YES) GO TO 110
      XI(J+1)=XRKI
      ZI(J+1)=YRKI
```

```
50    CONTINUE                                                          CAVITY 15100
C                                                                       CAVITY 15200
C     ****************************************************************  CAVITY 15300
C     *                                                              *  CAVITY 15400
C     *       INTEGRATE TO FIND P,P0,T BY SIMPSON'S RULE.            *  CAVITY 15500
C     *                                                              *  CAVITY 15600
C     ****************************************************************  CAVITY 15700
C                                                                       CAVITY 15800
      CALL FVI(I,G,DX,LNP,LNP0,LNT)                                     CAVITY 15900
C                                                                       CAVITY 16000
C     ****************************************************************  CAVITY 16100
C     *                                                              *  CAVITY 16200
C     *  EVALUATE THE STAGNATION TEMPERATURE RATIO BASED ON A        *  CAVITY 16300
C     *  RATE OF HEAT ADDITION THAT IS ASSUMED TO BE A LINEAR        *  CAVITY 16400
C     *  FUNCTION OF X.                                              *  CAVITY 16500
C     *                                                              *  CAVITY 16600
C     ****************************************************************  CAVITY 16700
C                                                                       CAVITY 16800
      T0(I)=(1.0+CT0(1)*(X(I)-X1)+0.5*CT0(2)*                           CAVITY 16900
     -(X(I)**2-X1**2))                                                  CAVITY 17000
60    CONTINUE                                                          CAVITY 17100
      T02=T0(NPTS)                                                      CAVITY 17200
      T2=T(NPTS)                                                        CAVITY 17300
      P02=P0(NPTS)                                                      CAVITY 17400
      P2=P(NPTS)                                                        CAVITY 17500
      M2=M(NPTS)                                                        CAVITY 17600
110   END                                                               CAVITY 17700
                                                                        CAVITY 17800
                                                                        CAVITY 17900
                                                                        CAVITY 18000
                                                                        CAVITY 18100
```

7.4.1 CLGDOP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *        RUNGE-KUTTA INTEGRATION SUBROUTINE (RKI1)        *
C     *                  (OF SUBROUTINE CAVITY)                 *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE RKI1 PERFORMS A FOURTH-ORDER RUNGE-KUTTA    *
C     *  INTEGRATION OF A FIRST-ORDER DIFFERENTIAL EQUATION... *
C     *  DY/DX=F(P,X,Y) WHERE P IS A PARAMETER. THE SUBROUTINE *
C     *  IS SPECIALIZED FOR 1-D FLOW WITH AREA CHANGE AND HEAT *
C     *  ADDITION.                                              *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE RKI1(P,DX,X,Y,F,FAIL)
C
      DATA YES/'YES'/
C
      N=0
      C1=F(P,X,Y)*DX
      XRK=X+0.5*DX
      YRK=Y+0.5*C1
      GO TO 40
10    C2=F(P,XRK,YRK)*DX
      YRK=Y+0.5*C2
      GO TO 40
20    C3=F(P,XRK,YRK)*DX
      XRK=X+DX
      YRK=Y+C3
      GO TO 40
30    C4=F(P,XRK,YRK)*DX
      YRK=Y+(C1+2.0*(C2+C3)+C4)/6.0
40    IF((Y .GT. 1) .AND. (YRK .LE. 1)) GO TO 50
      IF((Y .LT. 1) .AND. (YRK .GE. 1)) GO TO 50
      N=N+1
      GO TO (10,20,30,70), N
C
C
C     ***********************************************************
C     *                                                         *
C     *  TRANSITIONS FROM SUBSONIC-TO-SUPERSONIC FLOW OR        *
C     *  SUPERSONIC-TO-SUBSONIC FLOW ARE NOT ALLOWED IN THIS    *
C     *  PROGRAM.                                               *
C     *                                                         *
C     ***********************************************************
C
```

7.4.1 CLGDOP (Cont.)

```
C                                                                       RKI1   05100
50    WRITE(5,60)                                                       RKI1   05200
60    FORMAT(//,5X,'.....R-K INTEGRATION TERMINATED BECAUSE ',          RKI1   05300
     -'CHOKING WAS ENCOUNTERED.'/)                                      RKI1   05400
      FAIL=YES                                                          RKI1   05500
      RETURN                                                            RKI1   05600
70    Y=YRK                                                             RKI1   05700
      X=XRK                                                             RKI1   05800
      END                                                               RKI1   05900
```

7.4.1 CLGDOP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *        FLOW VARIABLE INTEGRATION SUBROUTINE (FVI)       *
C     *                  (OF SUBROUTINE CAVITY)                 *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE FVI PERFORMS AN INTEGRATION BY SIMPSON'S    *
C     *  RULE TO FIND THE FLOW VARIABLES (M,P,PO,T) ALONG THE   *
C     *  LASER CAVITY AS A FUNCTION OF X.  THE VARIABLES ARE    *
C     *  FOUND BY INTEGRATING EQUATIONS OF THE FORM...          *
C     *  DY/DX=F(G,Z(X),X).  REFERENCE: SHAPIRO, PAGE 231.      *
C     *                                                         *
C     *  ALL VARIABLES ARE NON-DIMENSIONALIZED WITH RESPECT TO  *
C     *  THE LASER CAVITY ENTRANCE CONDITIONS.                  *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE FVI(I,G,DX,LNP,LNPO,LNT)
C
      IMPLICIT REAL*4(L,M)
      COMMON/FVD/ZI(3),XI(3),X(25),M(25),P(25),PO(25),T(25)
C
C
C     ***********************************************************
C     *                                                         *
C     *          FUNCTIONS TO BE INTEGRATED WHERE Z=M**2.       *
C     *                                                         *
C     ***********************************************************
C
C
      FP(G,Z,X)=(G*Z/(1.-Z))*(FA(X)-(1.+0.5*(G-1.)*Z)*FTO(X))
      FPO(G,Z,X)=-0.5*G*Z*FTO(X)
      FT(G,Z,X)=((G-1.0)*Z/(1.0-Z))*FA(X)
     -+((1.0-G*Z)*(1.0+0.5*(G-1.0)*Z)/(1.0-Z))*FTO(X)
C
C
C     ***********************************************************
C     *                                                         *
C     *                  SIMPSON'S RULE INTEGRATION.            *
C     *                                                         *
C     ***********************************************************
C
C
      DLNP=(DX/6.0)*(FP(G,ZI(1),XI(1))+4.0*FP(G,ZI(2),XI(2))
     -+FP(G,ZI(3),XI(3)))
      DLNT=(DX/6.0)*(FT(G,ZI(1),XI(1))+4.0*FT(G,ZI(2),XI(2))
```

```
     -+FT(G,ZI(3),XI(3)))                                                FVI     05100
      DLNP0=(DX/6.0)*(FP0(G,ZI(1),XI(1))+4.0*FP0(G,ZI(2),XI(2))          FVI     05200
     -+FP0(G,ZI(3),XI(3)))                                               FVI     05300
C                                                                        FVI     05400
C                                                                        FVI     05500
C     ***************************************************************  FVI     05600
C     *                                                             *  FVI     05700
C     *    FIND THE NEW VALUES OF THE INTEGRATION VARIABLES.        *  FVI     05800
C     *                                                             *  FVI     05900
C     ***************************************************************  FVI     06000
C                                                                        FVI     06100
      LNP=LNP+DLNP                                                       FVI     06200
      LNP0=LNP0+DLNP0                                                    FVI     06300
      LNT=LNT+DLNT                                                       FVI     06400
C                                                                        FVI     06500
C     ***************************************************************  FVI     06600
C     *                                                             *  FVI     06700
C     *  LASER CAVITY FLOW VARIABLES...V(I)-VS-X(I), I=1,NPTS.      *  FVI     06800
C     *                                                             *  FVI     06900
C     ***************************************************************  FVI     07000
C                                                                        FVI     07100
      X(I)=XI(3)                                                         FVI     07200
      P(I)=EXP(LNP)                                                      FVI     07300
      P0(I)=EXP(LNP0)                                                    FVI     07400
      T(I)=EXP(LNT)                                                      FVI     07500
      M(I)=SQRT(ZI(3))                                                   FVI     07600
      END                                                                FVI     07700
                                                                         FVI     07800
                                                                         FVI     07900
                                                                         FVI     08000
```

7.4.1 CLGDOP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *                  FUNCTION SUBPROGRAMS                   *
C     *                 (OF SUBROUTINE CAVITY)                  *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *          NOTE...Y=M**2 AND DY/DX=FMSQD(G,X,Y)           *
C     *                                                         *
C     ***********************************************************
C
C
      FUNCTION FMSQD(G,X,Y)
      FMSQD=(Y*(1.0+0.5*(G-1.0)*Y)/(1.0-Y))*
     -(-2.0*FA(X)+(1.0+G*Y)*FT0(X))
      END
C
C
C     ***********************************************************
C     *                                                         *
C     *  FUNCTION FOR EVALUATING...(1.0/A)(DA/DX).  THE LASER   *
C     *  CAVITY AREA IS ASSUMED TO BE A LINEAR FUNCTION OF X.   *
C     *                                                         *
C     ***********************************************************
C
C
      FUNCTION FA(X)
      COMMON/COEFF/X1,CA(2),CT0(2)
      FA=CA(2)/(CA(1)+CA(2)*X)
      END
C
C
C     ***********************************************************
C     *                                                         *
C     *  FUNCTION FOR EVALUATING...(1.0/T0)(DT0/DX).  THE RATE  *
C     *  OF HEAT ADDITION IS ASSUMED TO BE A LINEAR FUNCTION    *
C     *  OF X.                                                  *
C     *                                                         *
C     ***********************************************************
C
C
      FUNCTION FT0(X)
      COMMON/COEFF/X1,CA(2),CT0(2)
      FT0=(CT0(1)+CT0(2)*X)/(1.0+CT0(1)*(X-X1)+0.5*CT0(2)*
     -(X**2-X1**2))
      END
```

7.4.1 CLGDOP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *          NORMAL SHOCK DIFFUSER SUBROUTINE (NSDS)        *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE NSDS CALCULATES THE PRESSURE RATIO ACROSS   *
C     *  A CONSTANT-AREA, SUPERSONIC DIFFUSER.  THE STATIC      *
C     *  PRESSURE RATIO IS TAKEN AS RD*(PY/PX) FOR A NORMAL     *
C     *  SHOCK AT THE ENTERING MACH NO.  ALL OTHER PROPERTIES   *
C     *  ARE CALCULATED FROM THE ISENTROPIC FLOW RELATIONS TO   *
C     *  BE CONSISTENT WITH THE ENTRANCE AND EXIT MACH NO.S.    *
C     *                                                         *
C     * INPUT VARIABLES:                                        *
C     *                                                         *
C     * G       = GAMMA                                         *
C     * M1      = ENTRANCE MACH NUMBER                          *
C     * RD      = NORMAL SHOCK DIFFUSER COEFFICIENT             *
C     *                                                         *
C     * OUTPUT VARIABLES:                                       *
C     *                                                         *
C     * M2      = EXIT MACH NUMBER                              *
C     * P2P1    = EXIT-TO-ENTRANCE STATIC PRESSURE RATIO        *
C     * P20P10  = EXIT-TO-ENTRANCE STAGNATION PRESSURE RATIO    *
C     * T2T1    = EXIT-TO-ENTRANCE STATIC TEMPERATURE RATIO     *
C     * T20T10  = EXIT-TO-ENTRANCE STAGNATION TEMPERATURE RATIO *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE NSDS(G,M1,RD,M2,P2P1,P20P10,T2T1,T20T10)
C
      IMPLICIT REAL*4(M)
C
      TOTM(GX,MX)=1.0+0.5*(GX-1.0)*MX*MX
      POPM(GX,MX)=(1.0+0.5*(GX-1.0)*MX*MX)**(GX/(GX-1.0))
C
      M2=SQRT((2.0+(G-1.0)*M1*M1)/(2.0*G*M1*M1-G+1.0))
      P2P1=RD*(2.0*G*M1*M1-G+1.0)/(G+1.0)
      P10P1=POPM(G,M1)
      P20P2=POPM(G,M2)
      P20P10=P20P2*P2P1/P10P1
      T20T10=1.0
      T10T1=TOTM(G,M1)
      T20T2=TOTM(G,M2)
      T2T1=T10T1*T20T10/T20T2
      END
```

```
C     ****************************************************************      SDS     00100
C     *                                                              *      SDS     00200
C     *             SUBSONIC DIFFUSER SUBROUTINE (SDS)               *      SDS     00300
C     *                                                              *      SDS     00400
C     ****************************************************************      SDS     00500
C                                                                             SDS     00600
C     ****************************************************************      SDS     00700
C     *                                                              *      SDS     00800
C     *  SUBROUTINE SDS CALCULATES THE PRESSURE RATIO ACROSS A       *      SDS     00900
C     *  CONICAL, SUBSONIC DIFFUSER WITH AN INCLUDED ANGLE OF        *      SDS     01000
C     *  15 DEGREES.  THE STATIC PRESSURE RATIO IS COMPUTED          *      SDS     01100
C     *  USING AN EMPERICAL DIFFUSER EFFICIENCY.  ALL OTHER          *      SDS     01200
C     *  PROPERTIES ARE CALCULATED FROM THE ISENTROPIC FLOW          *      SDS     01300
C     *  RELATIONS TO BE CONSISTENT WITH THE ENTRANCE AND EXIT       *      SDS     01400
C     *  MACH NO.S.                                                  *      SDS     01500
C     *                                                              *      SDS     01600
C     *  THE SUBSONIC DIFFUSER EFFICIENCY GIVEN BY:                  *      SDS     01700
C     *                                                              *      SDS     01800
C     *                    EFF=(P2'-P1)/(P2-P1)                      *      SDS     01900
C     *                                                              *      SDS     02000
C     *  IS LIMITED TO THE RANGE: 0.2<M1<0.5, 2.34<A2/A1<5.2         *      SDS     02100
C     *  AND IS DERIVED FROM DATA IN THE FOLLOWING REFERENCES:       *      SDS     02200
C     *                                                              *      SDS     02300
C     *  HENRY,J.R., WOOD,C.C., AND WILBUR,S.W., "SUMMARY OF         *      SDS     02400
C     *  SUBSONIC-DIFFUSER DATA," NACA RM L56F05 (1956).             *      SDS     02500
C     *                                                              *      SDS     02600
C     *  PATTERSON,G.N., "MODERN DIFFUSER DESIGN," AIRCRAFT          *      SDS     02700
C     *  ENGINEERING, 9(9):267-273 (1938).                           *      SDS     02800
C     *                                                              *      SDS     02900
C     *  THE SUBSONIC DIFFUSER COEFFICIENT IS DEFINED AS:            *      SDS     03000
C     *                                                              *      SDS     03100
C     *                    RD=(P2'/P1)/(P2/P1)                       *      SDS     03200
C     *                                                              *      SDS     03300
C     * INPUT VARIABLES:                                             *      SDS     03400
C     *                                                              *      SDS     03500
C     * G       = GAMMA                                              *      SDS     03600
C     * M1      = ENTRANCE MACH NUMBER                               *      SDS     03700
C     * A2A1    = EXIT-TO-ENTRANCE AREA RATIO                        *      SDS     03800
C     *                                                              *      SDS     03900
C     * OUTPUT VARIABLES:                                            *      SDS     04000
C     *                                                              *      SDS     04100
C     * M2      = EXIT MACH NUMBER                                   *      SDS     04200
C     * P2P1    = EXIT-TO-ENTRANCE STATIC PRESSURE RATIO             *      SDS     04300
C     * P20P10  = EXIT-TO-ENTRANCE STAGNATION PRESSURE RATIO         *      SDS     04400
C     * T2T1    = EXIT-TO-ENTRANCE STATIC TEMPERATURE RATIO          *      SDS     04500
C     * T20T10  = EXIT-TO-ENTRANCE STAGNATION TEMPERATURE RATIO      *      SDS     04600
C     * RD      = SUBSONIC DIFFUSER COEFFICIENT                      *      SDS     04700
C     * FAIL    = ERROR FLAG                                         *      SDS     04800
C     *                                                              *      SDS     04900
C     ****************************************************************      SDS     05000
```

7.4.1 CLGDOP (Cont.)

```
C
C
      SUBROUTINE SDS(G,M1,A2A1,M2,P2P1,P20P10,T2T1,T20T10,RD,
     -FAIL)
C
      IMPLICIT REAL*4(M)
      DATA YES/'YES'/,SUB/'SUB'/
C
C
C     ***********************************************************
C     *                                                         *
C     *                  GAS DYNAMIC FUNCTIONS                  *
C     *                                                         *
C     ***********************************************************
C
C
      TOTM(GX,MX)=1.0+0.5*(GX-1.0)*MX*MX
      POPM(GX,MX)=(1.0+0.5*(GX-1.0)*MX*MX)**(GX/(GX-1.0))
C
C
C     ***********************************************************
C     *                                                         *
C     *         CALCULATIONS FOR CONSTANT-AREA DIFFUSER         *
C     *                                                         *
C     ***********************************************************
C
C
      IF(A2A1.NE.1.0) GO TO 1
      M2=M1
      P2P1=1.0
      P20P10=1.0
      T2T1=1.0
      T20T10=1.0
      RD=1.0
      RETURN
C
C
C     ***********************************************************
C     *                                                         *
C     *                  CALCULATE CONSTANTS                    *
C     *                                                         *
C     ***********************************************************
C
C
1     G2=2.0/(G+1.0)
      G4=(G+1.0)/(2.0*(G-1.0))
C
C
C     ***********************************************************
C     *                                                         *
```

7.4.1 CLGDOP (Cont.)

```
C     *                    SOLVE A2A2S FOR M2                    *
C     *                                                          *
C     ************************************************************
C
C
      A1A1S=(1.0/M1)*(G2*TOTM(G,M1))**G4
      A2A2S=A2A1*A1A1S
      CALL MAAS(G,M1,A2A2S,SUB,5.0E-06,M2,FAIL)
      IF(FAIL.EQ.YES) RETURN
C
C
C     ************************************************************
C     *                                                          *
C     *            CALCULATE THE DIFFUSER EFFICIENCY             *
C     *                                                          *
C     ************************************************************
C
C
      EFF=0.002685*A2A1*A2A1*A2A1-0.024461*A2A1*A2A1-0.027229*
     -A2A1+1.048992
C
C
C     ************************************************************
C     *                                                          *
C     *        CALCULATE THE IDEAL STATIC PRESSURE RATIO         *
C     *                                                          *
C     ************************************************************
C
C
      P10P1=POPM(G,M1)
      P20P2=POPM(G,M2)
      P2P1=P10P1/P20P2
      RD=EFF+(1.0-EFF)/P2P1
C
C
C     ************************************************************
C     *                                                          *
C     *        CALCULATE THE ACTUAL STATIC PRESSURE RATIO        *
C     *                                                          *
C     ************************************************************
C
C
      P2P1=RD*P2P1
      P20P10=P20P2*P2P1/P10P1
      T20T10=1.0
      T10T1=TOTM(G,M1)
      T20T2=TOTM(G,M2)
      T2T1=T10T1*T20T10/T20T2
      END
```

7.4.1 CLGDOP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *          CONSTANT-AREA EJECTOR SUBROUTINE (CAES)        *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE CAES CALCULATES THE BREAK-OFF COMPRESSION   *
C     *  RATIO FOR A CONSTANT-AREA, SUBSONIC-SUPERSONIC         *
C     *  EJECTOR BY A ONE-DIMENSIONAL ANALYSIS.                 *
C     *                                                         *
C     *  INPUT VARIABLES:                                       *
C     *                                                         *
C     *  GS      = SECONDARY GAMMA                              *
C     *  GP      = PRIMARY GAMMA                                *
C     *  MWSP    = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO  *
C     *  TS0P0   = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE  *
C     *            RATIO                                        *
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE        *
C     *            ENTRANCE                                     *
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE *
C     *  AP1M3   = PRIMARY-TO-MIXING TUBE AREA RATIO            *
C     *                                                         *
C     *  OUTPUT VARIABLES:                                      *
C     *                                                         *
C     *  WSP     = SECONDARY-TO-PRIMARY MASS FLOW RATIO         *
C     *  GM      = MIXED STREAM GAMMA                           *
C     *  MWMP    = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT     *
C     *            RATIO                                        *
C     *  TM0P0   = MIXED STREAM-TO-PRIMARY STAGNATION           *
C     *            TEMPERATURE RATIO                            *
C     *  MM3     = MIXED STREAM MACH NO. AT THE MIXING TUBE     *
C     *            EXIT                                         *
C     *  PP0S0   = PRIMARY-TO-SECONDARY STAGNATION PRESSURE     *
C     *            RATIO                                        *
C     *  PM3S0   = MIXED STREAM STATIC-TO-SECONDARY STAGNATION  *
C     *            PRESSURE RATIO                               *
C     *  FAIL    = ERROR FLAG                                   *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE CAES(GS,GP,MWSP,TS0P0,MS1,MP1,AP1M3,WSP,GM,
     -MWMP,TM0P0,MM3,PP0S0,PM3S0,FAIL)
C
      IMPLICIT REAL*4(M)
      REAL*4 NO
      DATA NO/'NO'/
C
```

7.4.1 CLGDOP (Cont.)

```
C                                                                       CAES   05100
C     ***********************************************************       CAES   05200
C     *                                                         *       CAES   05300
C     *          CALCULATE PS1P1 FOR THE BREAK-OFF POINT.       *       CAES   05400
C     *                                                         *       CAES   05500
C     ***********************************************************       CAES   05600
C                                                                       CAES   05700
C                                                                       CAES   05800
      IF(MS1.NE.1.0) GO TO 100                                          CAES   05900
      PS1P1=1.0                                                         CAES   06000
      GO TO 101                                                         CAES   06100
100   CALL CAEFC(GS,GP,MS1,MP1,AP1M3,PS1P1,FAIL)                        CAES   06200
      IF(FAIL.NE.NO) RETURN                                             CAES   06300
C                                                                       CAES   06400
C                                                                       CAES   06500
C     ***********************************************************       CAES   06600
C     *                                                         *       CAES   06700
C     *  CALCULATE THE DOWNSTREAM CONDITIONS FOR THE BREAK-OFF  *       CAES   06800
C     *  POINT.                                                 *       CAES   06900
C     *                                                         *       CAES   07000
C     ***********************************************************       CAES   07100
C                                                                       CAES   07200
C                                                                       CAES   07300
101   CALL CAEOCV(GS,GP,MWSP,TS0P0,MS1,MP1,AP1M3,PS1P1,WSP,GM,          CAES   07400
     -MWMP,TM0P0,MM3,PP0S0,PM3S0,FAIL)                                  CAES   07500
      END                                                               CAES   07600
```

```
C     ****************************************************************      CAEFC  00100
C     *                                                              *      CAEFC  00200
C     *                    CONSTANT-AREA EJECTOR                     *      CAEFC  00300
C     *              FABRI CRITERION SUBROUTINE (CAEFC)              *      CAEFC  00400
C     *                   (OF SUBROUTINE CAES)                       *      CAEFC  00500
C     *                                                              *      CAEFC  00600
C     ****************************************************************      CAEFC  00700
C                                                                            CAEFC  00800
C     ****************************************************************      CAEFC  00900
C     *                                                              *      CAEFC  01000
C     *  SUBROUTINE CAEFC PERFORMS THE CONSTANT-AREA EJECTOR,        *      CAEFC  01100
C     *  FABRI CRITERION CALCULATIONS BY 1-D ANALYSIS FOR A          *      CAEFC  01200
C     *  SUPERSONIC PRIMARY (MP1>1) AND A SUBSONIC SECONDARY         *      CAEFC  01300
C     *  (MS1<1) WHICH CHOKES IN THE EJECTOR SHROUD (MS2=1).         *      CAEFC  01400
C     *  THIS EJECTOR ANALYSIS IS BASED ON THE CONSTANT-AREA         *      CAEFC  01500
C     *  SHROUD, EJECTOR ANALYSIS OF FABRI,  REFERENCE:              *      CAEFC  01600
C     *  NACA TM 1410.                                               *      CAEFC  01700
C     *                                                              *      CAEFC  01800
C     *  INPUT VARIABLES:                                            *      CAEFC  01900
C     *                                                              *      CAEFC  02000
C     *  GS      = SECONDARY GAMMA                                   *      CAEFC  02100
C     *  GP      = PRIMARY GAMMA                                     *      CAEFC  02200
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE             *      CAEFC  02300
C     *            ENTRANCE                                          *      CAEFC  02400
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE      *      CAEFC  02500
C     *  AP1M3   = PRIMARY-TO-MIXING TUBE AREA RATIO                 *      CAEFC  02600
C     *                                                              *      CAEFC  02700
C     *  OUTPUT VARIABLES:                                           *      CAEFC  02800
C     *                                                              *      CAEFC  02900
C     *  PS1P1   = SECONDARY-TO-PRIMARY STATIC PRESSURE RATIO        *      CAEFC  03000
C     *  FAIL    = ERROR FLAG                                        *      CAEFC  03100
C     *                                                              *      CAEFC  03200
C     ****************************************************************      CAEFC  03300
C                                                                            CAEFC  03400
      SUBROUTINE CAEFC(GS,GP,MS1,MP1,AP1M3,PS1P1,FAIL)                       CAEFC  03500
C                                                                            CAEFC  03600
      IMPLICIT REAL*4(M)                                                     CAEFC  03700
      DATA YES/'YES'/,PART/'PART'/,SUP/'SUP'/                                CAEFC  03800
C                                                                            CAEFC  03900
C                                                                            CAEFC  04000
C     ****************************************************************      CAEFC  04100
C     *                                                              *      CAEFC  04200
C     *                    GAS DYNAMIC FUNCTIONS                     *      CAEFC  04300
C     *                                                              *      CAEFC  04400
C     ****************************************************************      CAEFC  04500
C                                                                            CAEFC  04600
C                                                                            CAEFC  04700
C                                                                            CAEFC  04800
      PP0M(G,M)=(1.+.5*(G-1.)*(M**2))**(-G/(G-1.))                           CAEFC  04900
      AASM(G,M)=(1./M)*((2./(G+1.))*(1.+0.5*(G-1.)*(M**2)))                  CAEFC  05000
```

7.4.1 CLGDOP (Cont.)

```
     -**(0.5*(G+1.)/(G-1.)))
      MMS(G,MS)=SQRT(((2./(G+1.))*(MS**2))/
     -(1.-((G-1.)/(G+1.))*(MS**2)))
C
C
C     ***********************************************************
C     *                                                         *
C     *            FABRI'S CRITERION APPLIES ONLY WHEN          *
C     *            (MS1.LE.1.0) AND (PS1P1.LE.1.0).             *
C     *                                                         *
C     ***********************************************************
C
C
      IF(MS1.GT.(1.0)) GO TO 101
      IF((1.-MS1).LT.(1.E-4)) GO TO 100
C
C
C     ***********************************************************
C     *                                                         *
C     *    CALCULATE MP2 AT STATION (2) WHERE MS2=1.0 FROM      *
C     *    THE AREA RATIO FOR STREAM (P) AT STATION (2).        *
C     *                                                         *
C     ***********************************************************
C
C
      AP2PS=(AASM(GP,MP1)/AP1M3)*(1.-(1.-AP1M3)/AASM(GS,MS1))
      CALL MAAS(GP,MP1,AP2PS,SUP,5.0E-06,MP2,FAIL)
      IF(FAIL.EQ.YES) GO TO 105
      IF(MP2.LT.MP1) GO TO 108
      IF((MP2/MP1-1.).LT.(1.E-4)) GO TO 100
C
C
C     ***********************************************************
C     *                                                         *
C     *              CALCULATE STATIC PRESSURE RATIO            *
C     *              PS1P1 BASED ON FABRI'S CRITERION.          *
C     *                                                         *
C     ***********************************************************
C
C
      VD=(1.0-AP1M3)*((1.0+GS*(MS1**2))-
     -(PP0M(GS,1.0)/PP0M(GS,MS1))*((1.0+GS)/AASM(GS,MS1)))
      VN=(PP0M(GP,MP2)/PP0M(GP,MP1))*AP1M3*(AASM(GP,MP2)/
     -AASM(GP,MP1))*(1.+GP*(MP2**2))-AP1M3*(1.+GP*(MP1**2))
      PS1P1=VN/VD
      IF(PS1P1.LE.(0.0)) GO TO 103
      IF(PS1P1.GT.(1.0)) GO TO 100
      RETURN
C
C
```

7.4.1 CLGDOP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *                MS1 IS APPROXIMATELY 1.0 AND             *
C     *                MP1 IS APPROXIMATELY MP1.                *
C     *                                                         *
C     ***********************************************************
C
C
100   PS1P1=1.0
      RETURN
C
C
C     ***********************************************************
C     *                                                         *
C     *                      ERROR MESSAGES                     *
C     *                                                         *
C     ***********************************************************
C
C
101   WRITE(5,102)
102   FORMAT(/,5X,'...ERROR IN CAEFC: (MS1.GT.(1.0)) .',//)
      GO TC 107
103   WRITE(5,104)
104   FORMAT(/,5X,'...ERROR IN CAEFC: (PS1P1.LT.(0.0)).',//)
      GO TC 107
105   WRITE(5,106)
106   FORMAT('0',T2,'SUBROUTINE MAAS WAS CALLED FROM ',
     -'SUBROUTINE CAEFC')
107   FAIL=YES
      RETURN
108   FAIL=PART
      END
```

```
C     ****************************************************************      CAEOCV 00100
C     *                                                              *      CAEOCV 00200
C     *                    CONSTANT-AREA EJECTOR                     *      CAEOCV 00300
C     *          OVERALL CONTROL VOLUME SUBROUTINE (CAEOCV)          *      CAEOCV 00400
C     *                  (OF SUBROUTINE CAES)                        *      CAEOCV 00500
C     *                                                              *      CAEOCV 00600
C     ****************************************************************      CAEOCV 00700
C                                                                            CAEOCV 00800
C     ****************************************************************      CAEOCV 00900
C     *                                                              *      CAEOCV 01000
C     *  SUBROUTINE CAEOCV PERFORMS THE CONSTANT-AREA EJECTOR,       *      CAEOCV 01100
C     *  OVERALL CONTROL VOLUME CALCULATIONS BY 1-D ANALYSIS         *      CAEOCV 01200
C     *  FROM INLET SECTION (1) TO MIXED SECTION (3).                *      CAEOCV 01300
C     *                                                              *      CAEOCV 01400
C     *  INPUT VARIABLES:                                            *      CAEOCV 01500
C     *                                                              *      CAEOCV 01600
C     *  GS      = SECONDARY GAMMA                                   *      CAEOCV 01700
C     *  GP      = PRIMARY GAMMA                                     *      CAEOCV 01800
C     *  MWSP    = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO       *      CAEOCV 01900
C     *  TS0P0   = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE       *      CAEOCV 02000
C     *            RATIO                                             *      CAEOCV 02100
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE             *      CAEOCV 02200
C     *            ENTRANCE                                          *      CAEOCV 02300
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE      *      CAEOCV 02400
C     *  AP1M3   = PRIMARY-TO-MIXING TUBE AREA RATIO                 *      CAEOCV 02500
C     *  PS1P1   = SECONDARY-TO-PRIMARY STATIC PRESSURE RATIO        *      CAEOCV 02600
C     *                                                              *      CAEOCV 02700
C     *  OUTPUT VARIABLES:                                           *      CAEOCV 02800
C     *                                                              *      CAEOCV 02900
C     *  WSP     = SECONDARY-TO-PRIMARY MASS FLOW RATIO              *      CAEOCV 03000
C     *  GM      = MIXED STREAM GAMMA                                *      CAEOCV 03100
C     *  MWMP    = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT          *      CAEOCV 03200
C     *            RATIO                                             *      CAEOCV 03300
C     *  TM0P0   = MIXED STREAM-TO-PRIMARY STAGNATION                *      CAEOCV 03400
C     *            TEMPERATURE RATIO                                 *      CAEOCV 03500
C     *  MM3     = MIXED STREAM MACH NO. AT THE MIXING TUBE          *      CAEOCV 03600
C     *            EXIT                                              *      CAEOCV 03700
C     *  PP0S0   = PRIMARY-TO-SECONDARY STAGNATION PRESSURE          *      CAEOCV 03800
C     *            RATIO                                             *      CAEOCV 03900
C     *  PM3S0   = MIXED STREAM STATIC-TO-SECONDARY STAGNATION       *      CAEOCV 04000
C     *            PRESSURE RATIO                                    *      CAEOCV 04100
C     *  FAIL    = ERROR FLAG                                        *      CAEOCV 04200
C     *                                                              *      CAEOCV 04300
C     ****************************************************************      CAEOCV 04400
C                                                                            CAEOCV 04500
C                                                                            CAEOCV 04600
      SUBROUTINE CAEOCV(GS,GP,MWSP,TS0P0,MS1,MP1,AP1M3,PS1P1,                CAEOCV 04700
     -WSP,GM,MWMP,TM0P0,MM3,PP0S0,PM3S0,FAIL)                                CAEOCV 04800
C                                                                            CAEOCV 04900
      IMPLICIT REAL*4(M)                                                     CAEOCV 05000
```

```
      DATA PART/'PART'/                                                  CAEOCV 05100
C                                                                        CAEOCV 05200
C     ***************************************************************  CAEOCV 05300
C     *                                                             *  CAEOCV 05400
C     *                    GAS DYNAMIC FUNCTIONS                    *  CAEOCV 05500
C     *                                                             *  CAEOCV 05600
C     ***************************************************************  CAEOCV 05700
C                                                                        CAEOCV 05800
      WM(G,M)=M*SQRT(G*(1.+.5*(G-1.)*(M**2)))                            CAEOCV 05900
      T(G,M)=(1.+G*(M**2))/(M*SQRT(1.+.5*(G-1.)*(M**2)))                 CAEOCV 06000
      PPOM(G,M)=(1.+.5*(G-1.)*(M**2))**(-G/(G-1.))                       CAEOCV 06100
C                                                                        CAEOCV 06200
C     ***************************************************************  CAEOCV 06300
C     *                                                             *  CAEOCV 06400
C     *                  EJECTOR MASS FLOW RATIO                    *  CAEOCV 06500
C     *                                                             *  CAEOCV 06600
C     ***************************************************************  CAEOCV 06700
C                                                                        CAEOCV 06800
      C0=SQRT(MWSP/TSOPO)                                                CAEOCV 06900
      WSP=PS1P1*((1.-AP1M3)/AP1M3)*C0*(WM(GS,MS1)/WM(GP,MP1))            CAEOCV 07000
      CPSP=(GS/GP)*((GP-1.)/(GS-1.))/MWSP                                CAEOCV 07100
C                                                                        CAEOCV 07200
C     ***************************************************************  CAEOCV 07300
C     *                                                             *  CAEOCV 07400
C     *                    MIXED FLOW PROPERTIES                    *  CAEOCV 07500
C     *                                                             *  CAEOCV 07600
C     ***************************************************************  CAEOCV 07700
C                                                                        CAEOCV 07800
      MWMP=(1.+WSP)/(1.+(WSP/MWSP))                                      CAEOCV 07900
      GM=1./(1.-((GP-1.)/GP)*((1.+(WSP/MWSP))/(1.+CPSP*WSP)))            CAEOCV 08000
      TMOPO=(1.+WSP*CPSP*TSOPO)/(1.+WSP*CPSP)                            CAEOCV 08100
C                                                                        CAEOCV 08200
C     ***************************************************************  CAEOCV 08300
C     *                                                             *  CAEOCV 08400
C     *                       SOLVE FOR MM3                         *  CAEOCV 08500
C     *                                                             *  CAEOCV 08600
C     ***************************************************************  CAEOCV 08700
C                                                                        CAEOCV 08800
      C1=SQRT((TSOPO/MWSP)*(GP/GS))                                      CAEOCV 08900
      C2=SQRT(TMOPO/MWMF*(GP/GM))                                        CAEOCV 09000
      TM3=(T(GP,MP1)+C1*WSP*T(GS,MS1))/((1.+WSP)*C2)                     CAEOCV 09100
      TM3MIN=SQRT(2.*(GM+1.))                                            CAEOCV 09200
                                                                         CAEOCV 09300
                                                                         CAEOCV 09400
                                                                         CAEOCV 09500
                                                                         CAEOCV 09600
                                                                         CAEOCV 09700
                                                                         CAEOCV 09800
                                                                         CAEOCV 09900
                                                                         CAEOCV 10000
```

7.4.1 CLGDOP (Cont.)

```
      IF(TM3.LT.TM3MIN) GO TC 10
      C3=(TM3**2-2.*GM)
      C4=(((GM-1.)/2.)*(TM3**2)-GM**2)
      C5=SQRT(C3**2+4.*C4)
      MSQD3M=(-C3-C5)/(2.*C4)
      MSQD3P=(-C3+C5)/(2.*C4)
C
C
C     ***********************************************************
C     *                                                         *
C     *       DETERMINE TWO POSSIBLE MIXED-FLOW MACH NO.        *
C     *       SOLUTICNS.  USE ONLY SUBSONIC RESULT AT (3).      *
C     *                                                         *
C     ***********************************************************
C
C
      IF(MSQD3M.GE.(0.C)) MM3M=SQRT(MSQD3M)
      IF(MSQD3P.GE.(0.0)) MM3P=SQRT(MSCD3P)
      MM3=MM3P
C
C
C     ***********************************************************
C     *                                                         *
C     *                 CALCULATE PRESSURE RATIOS               *
C     *                                                         *
C     ***********************************************************
C
C
      C6=SQRT(TMOPO/MWMP)
      PM3P1=C6*AP1M3*(1.+WSP)*(WM(GP,MP1)/WM(GM,MM3))
      PP0S0=(PP0M(GS,MS1)/PP0M(GP,MP1))/PS1P1
      PM3S0=PM3P1*(PP0M(GS,MS1)/PS1P1)
      PM0S0=PM3S0/PP0M(GM,MM3)
      RETURN
C
C
C     ***********************************************************
C     *                                                         *
C     *                       ERROR MESSAGES                    *
C     *                                                         *
C     ***********************************************************
C
C
10    FAIL=PART
      END
```

7.4.1 CGLDOP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *     SUPERSONIC-SUPERSONIC EJECTOR SUBROUTINE (SSES)     *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE SSES CALCULATES THE MAXIMUM COMPRESSION     *
C     *  RATIO FOR A CONSTANT-AREA, SUPERSONIC-SUPERSONIC       *
C     *  EJECTOR, BY ONE-DIMENSIONAL ANALYSIS, ASSUMING AN      *
C     *  ISENTROPIC RECOMPRESSION OF THE SECONDARY STREAM TO    *
C     *  SONIC CONDITIONS.                                      *
C     *                                                         *
C     *  INPUT VARIABLES:                                       *
C     *                                                         *
C     *  GS      = SECONDARY GAMMA                              *
C     *  GP      = PRIMARY GAMMA                                *
C     *  MWSMWP  = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO  *
C     *  TSOTPO  = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE  *
C     *            RATIO                                        *
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE        *
C     *            ENTRANCE                                     *
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE *
C     *  AS1AP1  = SECONDARY-TO-PRIMARY AREA RATIO              *
C     *                                                         *
C     *  OUTPUT VARIABLES:                                      *
C     *                                                         *
C     *  WSWP    = SECONDARY-TO-PRIMARY MASS FLOW RATIO         *
C     *  GM      = MIXED STREAM GAMMA                           *
C     *  MWMMWP  = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT     *
C     *            RATIO                                        *
C     *  TMOTPO  = MIXED STREAM-TO-PRIMARY STAGNATION           *
C     *            TEMPERATURE RATIO                            *
C     *  MM3     = MIXED STREAM MACH NO. AT THE MIXING TUBE     *
C     *            EXIT                                         *
C     *  PPOPS1  = PRIMARY STAGNATION-TO-SECONDARY STATIC       *
C     *            PRESSURE RATIO                               *
C     *  PM3PS1  = STATIC PRESSURE COMPRESSION RATIO            *
C     *  FAIL    = ERROR FLAG                                   *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE SSES(GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1,WSWP,
     -GM,MWMMWP,TMOTPO,MM3,PPOPS1,PM3PS1,FAIL)
C
      IMPLICIT REAL*4(M)
      DATA YES/'YES'/,SUP/'SUP'/
C
```

7.4.1 CGLDOP (Cont.)

```
C
C     ***********************************************************
C     *                                                         *
C     *                    SPECIAL FUNCTIONS                    *
C     *                                                         *
C     ***********************************************************
C
C
      F(GX,MXX)=1.0+GX*MXX*MXX
      G(GX,MXX)=MXX*SQRT(1.0+0.5*(GX-1.0)*MXX*MXX)
      H(MM,TT,GG)=SQRT(MM*GG/TT)
      PP0(GX,MXX)=(1.0+0.5*(GX-1.0)*MXX*MXX)**(GX/(1.0-GX))
      AAS(GX,MXX)=((2.0*(1.0+0.5*(GX-1.0)*MXX*MXX)/(GX+1.0))**(0.5*(GX+1
     -.0)/(GX-1.0)))/MXX
C
C
C     ***********************************************************
C     *                                                         *
C     *                   CALCULATE CONSTANTS                   *
C     *                                                         *
C     ***********************************************************
C
C
      GS3=GS/(GS-1.0)
      GP3=GP/(GP-1.0)
      GSGP=GS/GP
      MWPMWS=1.0/MWSMWP
      PP1PP0=PP0(GP,MP1)
      AS1ASS=AAS(GS,MS1)
      AP1APS=AAS(GP,MP1)
      ASSAS1=1.0/AS1ASS
      FGSMS1=F(GS,MS1)
      FGPMP1=F(GP,MP1)
      GGSMS1=G(GS,MS1)
      GGPMP1=G(GP,MP1)
C
C
C     ***********************************************************
C     *                                                         *
C     *  CALCULATE PS1PP1 FOR AN ISENTROPIC RECOMPRESSION TO    *
C     *  SONIC CONDITIONS.  MP2 IS OBTAINED FROM AP2APS.        *
C     *                                                         *
C     ***********************************************************
C
C
      IF(AS1AP1.GE.0.0) GO TO 1
      WRITE(5,2)AS1AP1
      FAIL=YES
      RETURN
1     AP2APS=AP1APS*(1.0+AS1AP1*(1.0-ASSAS1))
```

```
      CALL MAAS(GP,MP1,AP2APS,SUP,5.0E-06,MP2,FAIL)                    SSES   10100
      IF(FAIL.EQ.YES) RETURN                                           SSES   10200
      MS2=1.0                                                          SSES   10300
      C1=-FGPMP1+F(GP,MP2)*GGPMP1/G(GP,MP2)                            SSES   10400
      C2=FGSMS1-F(GS,MS2)*GGSMS1/G(GS,MS2)                             SSES   10500
      PS1PP1=C1/(AS1AP1*C2)                                            SSES   10600
C                                                                      SSES   10700
CCCCCCCC**************************************************************SSES   10800
CCCCCCCC*                                                            *SSES   10900
CCCCCCCC*            OVERALL CONTROL VOLUME CALCULATIONS             *SSES   11000
CCCCCCCC*                                                            *SSES   11100
CCCCCCCC**************************************************************SSES   11200
C                                                                      SSES   11300
      WSWP=PS1PP1*AS1AP1*H(MWSMWP,TS0TP0,GSGP)*GGSMS1/GGPMP1           SSES   11400
      C1=WSWP*MWPMWS*GS3+GP3                                           SSES   11500
      C2=WSWP*MWPMWS*(GS3-1.0)+(GP3-1.0)                               SSES   11600
      GM=C1/C2                                                         SSES   11700
      GMGP=GM/GP                                                       SSES   11800
      MWMMWP=(WSWP+1.0)/(WSWP*MWPMWS+1.0)                              SSES   11900
      C1=TS0TP0*WSWP*MWPMWS*GS3+GP3                                    SSES   12000
      C2=WSWP*MWPMWS*GS3+GP3                                           SSES   12100
      TM0TP0=C1/C2                                                     SSES   12200
      FFX=H(MWMMWP,TM0TP0,GMGP)*(PS1PP1*AS1AP1*FGSMS1+FGPMP1)/(        SSES   12300
     -(1.0+WSWP)*GGPMP1)                                               SSES   12400
      C1=0.5*(GM-1.0)*FFX*FFX-GM*GM                                    SSES   12500
      C2=FFX*FFX-2.0*GM                                                SSES   12600
      C3=(-C2+SQRT(C2*C2+4.0*C1))/(2.0*C1)                             SSES   12700
      C4=(-C2-SQRT(C2*C2+4.0*C1))/(2.0*C1)                             SSES   12800
      MM3=SQRT(AMIN1(C3,C4))                                           SSES   12900
      PM3PP1=(PS1PP1*AS1AP1*FGSMS1+FGPMP1)/((1.0+AS1AP1)*F(GM,MM3))    SSES   13000
      PM3PS1=PM3PP1/PS1PP1                                             SSES   13100
      PS1PP0=PS1PP1*PP1PP0                                             SSES   13200
      PP0PS1=1.0/PS1PP0                                                SSES   13300
C                                                                      SSES   13400
CCCCCCCC**************************************************************SSES   13500
CCCCCCCC*                                                            *SSES   13600
CCCCCCCC*                     FORMAT STATEMENTS                      *SSES   13700
CCCCCCCC*                                                            *SSES   13800
CCCCCCCC**************************************************************SSES   13900
C                                                                      SSES   14000
    2 FORMAT('0',T2,'IMPOSSIBLE VALUE...AS1AP1 =',E13.6)               SSES   14100
      END                                                              SSES   14200
                                                                       SSES   14300
                                                                       SSES   14400
                                                                       SSES   14500
                                                                       SSES   14600
```

7.4.1 CGLDOP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *              MINIMIZATION SUBROUTINE (MIN)              *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE MIN, AS APPLIED TO A CONSTANT-AREA          *
C     *  SUBSONIC-SUPERSONIC EJECTOR, PERFORMS A SEARCH AND     *
C     *  INTERVAL HALVING PROCEDURE TO FIND MS1 SUCH THAT       *
C     *  FUNC(MS1) IS A MINIMUM.                                *
C     *                                                         *
C     *  VARIABLES:                                             *
C     *                                                         *
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE        *
C     *            ENTRANCE                                     *
C     *  FUNC    = FUNCTION OF MS1                              *
C     *  NTYPE   = 1,2 - SEARCH                                 *
C     *          = 3,4 - SOLUTION                               *
C     *  NIT     = INCREMENT NUMBER                             *
C     *  COEFF   = ALPHANUMERIC IMAGE OF FUNC                   *
C     *  FAIL    = ERROR FLAG                                   *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE MIN(MS1,FUNC,NTYPE,NIT,COEFF,FAIL)
C
      IMPLICIT REAL*4(M)
      REAL*4 NO
      DATA DX,XLOW,XERROR,YERROR/0.1,1.0E-03,0.025,1.0/
      DATA YES/'YES'/,NO/'NO'/,PART/'PART'/
C
      ERROR(ACTUAL,GIVEN)=(ACTUAL-GIVEN)*100.0/GIVEN
C
C
C     ***********************************************************
C     *                                                         *
C     *    NO CAE SOLUTION EXITS FOR CURRENT VALUE OF MS1.      *
C     *    INCREMENT MS1 AND SEARCH FOR SOLUTION.               *
C     *                                                         *
C     ***********************************************************
C
C
      IF(FAIL.NE.PART) GO TO 100
      MS1=MS1-XERROR
      IF(MS1.LT.XLOW) GO TO 108
      FAIL=NO
      RETURN
```

```
100   IF(NIT.NE.1) GO TO 101                                          MIN    05100
      WRITE(5,200)CCEFF                                               MIN    05200
      DMS1=DX                                                         MIN    05300
      MS1LCW=XLCW                                                     MIN    05400
101   WRITE(5,201)NTYPE,MS1,FUNC,DMS1,FAIL                            MIN    05500
      NIT=NIT+1                                                       MIN    05600
      GO TO (102,104,107),NTYPE                                       MIN    05700
C                                                                     MIN    05800
CCCCC ************************************************************   MIN    05900
CCCCC *                                                          *   MIN    06000
CCCCC *                  STORE UPPER BOUND FOR MS1               *   MIN    06100
CCCCC *                                                          *   MIN    06200
CCCCC ************************************************************   MIN    06300
C                                                                     MIN    06400
C                                                                     MIN    06500
102   X1=MS1                                                          MIN    06600
      Y1=FUNC                                                         MIN    06700
103   MS1=MS1-DMS1                                                    MIN    06800
      IF(MS1.LT.MS1LCW) GO TO 108                                     MIN    06900
      NTYPE=2                                                         MIN    07000
      RETURN                                                          MIN    07100
C                                                                     MIN    07200
CCCCC ************************************************************   MIN    07300
CCCCC *                                                          *   MIN    07400
CCCCC *                  STORE LOWER BOUND FOR MS1               *   MIN    07500
CCCCC *                                                          *   MIN    07600
CCCCC ************************************************************   MIN    07700
C                                                                     MIN    07800
C                                                                     MIN    07900
104   X2=MS1                                                          MIN    08000
      Y2=FUNC                                                         MIN    08100
      IF(Y2.GT.Y1) GO TO 105                                          MIN    08200
      GO TO 102                                                       MIN    08300
C                                                                     MIN    08400
CCCCC ************************************************************   MIN    08500
CCCCC *                                                          *   MIN    08600
CCCCC *          TEST FUNC FOR MINIMUM AND INTERVAL HALVE        *   MIN    08700
CCCCC *                                                          *   MIN    08800
CCCCC ************************************************************   MIN    08900
C                                                                     MIN    09000
C                                                                     MIN    09100
105   IF(ABS(ERROR(Y2,Y1)).LE.YERROR) GO TO 106                       MIN    09200
      DMS1=DMS1/2.0                                                   MIN    09300
      IF(DMS'.LT.XERROR) GO TO 106                                    MIN    09400
      MS1LCW=X2                                                       MIN    09500
      MS1=X1                                                          MIN    09600
      GO TO 103                                                       MIN    09700
                                                                      MIN    09800
                                                                      MIN    09900
                                                                      MIN    10000
```

```
C
C     ******************************************************************
C     *                                                                *
C     *  MS1 FOR MIN FUNC HAS BEEN FOUND BUT SOLUTION WAS LOST         *
C     *                                                                *
C     ******************************************************************
C
106   IF(Y2.LE.Y1) GO TO 107
      MS1=X1
      NTYPE=3
      RETURN
C
C     ******************************************************************
C     *                                                                *
C     *    MS1 FOR MIN FUNC HAS BEEN FOUND AND SOLUTION SAVED          *
C     *                                                                *
C     ******************************************************************
C
107   NTYPE=4
      RETURN
C
C     ******************************************************************
C     *                                                                *
C     *            SEARCH FAILURE: NO CAE SOLUTION FOUND               *
C     *                                                                *
C     ******************************************************************
C
108   WRITE (5,202)MS1,MS1LOW,DMS1
      FAIL YES
C
C     ******************************************************************
C     *                                                                *
C     *                        FORMAT STATEMENTS                       *
C     *                                                                *
C     ******************************************************************
C
200   FORMAT('1',T30,'SEARCH DATA:',//,T8,'NTYPE',T21,'MS1',
     -T35,A5,T50,'DMS1',T60,'FAIL',/)
201   FORMAT(' ',T10,I1,T13,3E15.6,T60,A4)
202   FORMAT('0',T2,'MS1 =',E13.6,2X,'BELOW LOWER LIMIT MS1 =',
     -E13.6,/,T2,'FOR DMS1 =',E13.6)
      END
```

```
MIN     10100
MIN     10200
MIN     10300
MIN     10400
MIN     10500
MIN     10600
MIN     10700
MIN     10800
MIN     10900
MIN     11000
MIN     11100
MIN     11200
MIN     11300
MIN     11400
MIN     11500
MIN     11600
MIN     11700
MIN     11800
MIN     11900
MIN     12000
MIN     12100
MIN     12200
MIN     12300
MIN     12400
MIN     12500
MIN     12600
MIN     12700
MIN     12800
MIN     12900
MIN     13000
MIN     13100
MIN     13200
MIN     13300
MIN     13400
MIN     13500
MIN     13600
MIN     13700
MIN     13800
MIN     13900
MIN     14000
MIN     14100
MIN     14200
MIN     14300
MIN     14400
MIN     14500
MIN     14600
MIN     14700
MIN     14800
MIN     14900
MIN     15000
```

7.4.1 CGLDOP (Cont.)

```
C     ***************************************************************
C     *                                                             *
C     *                    SUBROUTINE (MAAS)                        *
C     *                                                             *
C     ***************************************************************
C
C     ***************************************************************
C     *                                                             *
C     *  SUBROUTINE MAAS CALCULATES THE MACH NUMBER (M) GIVEN       *
C     *  THE AREA RATIO (A/A*) BY LINEAR ITERATION.                 *
C     *                                                             *
C     *  INPUT VARIABLES:                                           *
C     *                                                             *
C     *  G       = SPECIFIC HEAT RATIO                              *
C     *  MINI    = INITIAL VALUE OF MACH NUMBER                     *
C     *  AAS     = THE AREA RATIO A/A*                              *
C     *  FLOW    = CONTROL VARIABLE SUCH THAT                       *
C     *          = "SUB" FOR THE SUBSONIC BRANCH                    *
C     *          = "SUP" FOR THE SUPERSONIC BRANCH                  *
C     *  ERROR   = MAX PERCENT DEVIATION IN MOLD AND MNEW FOR       *
C     *            A SOLUTION                                       *
C     *                                                             *
C     *  OUTPUT VARIABLES:                                          *
C     *                                                             *
C     *  MNEW    = FINAL VALUE OF MACH NUMBER                       *
C     *  FAIL    = ERROR FLAG                                       *
C     *                                                             *
C     ***************************************************************
C
C
      SUBROUTINE MAAS(G,MINI,AAS,FLOW,ERROR,MNEW,FAIL)
C
      IMPLICIT REAL*4(M)
      DATA YES/'YES'/,SUP/'SUP'/
C
C
C     ***************************************************************
C     *                                                             *
C     *                    CALCULATE CONSTANTS                      *
C     *                                                             *
C     ***************************************************************
C
C
      G1=(G-1.0)/2.0
      G1I=1.0/G1
      G2=2.0/(G+1.0)
      G2I=1.0/G2
      G4=(G+1.0)/(2.0*(G-1.0))
      G4I=1.0/G4
C
```

7.4.1 CGLDOP (Cont.)

```
C
C     ************************************************************
C     *                                                          *
C     *              CALCULATE THE SUPERSONIC BRANCH             *
C     *                                                          *
C     ************************************************************
C
C
      MOLD=MINI
      IF(FLOW.NE.SUP) GO TO 2
      DO 1 J=1,200
      C1=(MOLD*AAS)**G4I
      MNEW=SQRT(G1I*(G2I*C1-1.0))
      XERROR=(MNEW-MOLD)*100.0/MOLD
      MOLD=MNEW
      IF(ABS(XERROR).LT.ERROR) RETURN
1     CONTINUE
      GO TO 4
C
C
C     ************************************************************
C     *                                                          *
C     *              CALCULATE THE SUBSONIC BRANCH               *
C     *                                                          *
C     ************************************************************
C
C
2     DO 3 J=1,200
      C1=1.0+G1*MOLD*MOLD
      MNEW=((G2*C1)**G4)/AAS
      XERROR=(MNEW-MOLD)*100.0/MOLD
      MOLD=MNEW
      IF(ABS(XERROR).LT.ERROR) RETURN
3     CONTINUE
C
C
C     ************************************************************
C     *                                                          *
C     *                    CONVERGENCE FAILURE                   *
C     *                                                          *
C     ************************************************************
C
C
4     WRITE(5,5)FLOW,G,MINI,MNEW,AAS,XERROR,ERROR
      FAIL=YES
5     FORMAT('0',T2,'CONVERGENCE FAILURE FOR ',A3,'SONIC ',
     -'BRANCH IN SUBROUTINE MAAS',/,
     -T2,'G      =',E13.6,2X,'MINI   =',E13.6,/,
     -T2,'MNEW   =',E13.6,2X,'AAS    =',E13.6,/,
     -T2,'XERROR =',E13.6,2X,'ERROR  =',E13.6)
```

7.4.1 CGLDOP (Cont.)

```
MAAS  !0100

END
```

7.4.1 CGLDOP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *                ITERATION SUBROUTINE (ITER)              *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE ITER PERFORMS AN ITERATION TO FIND X SUCH   *
C     *  THAT THE PERCENT ERROR IN Y AND YGIVEN IS .LE. TO      *
C     *  ERRORY OR THE PERCENT DEVIATION IN X(I+1) AND X(I)     *
C     *  IS .LE. TO ERRORX.                                     *
C     *                                                         *
C     * VARIABLES:                                              *
C     *                                                         *
C     * X       = INDEPENDENT VARIABLE                          *
C     * DX      = INCREMENT IN INDEPENDENT VARIABLE             *
C     * ERRORX  = MAX PERCENT DEVIATION IF X(I+1) AND X(I) FOR  *
C     *           SOLUTION                                      *
C     * SIGN    = +1.0 OR -1.0, +/- INCREMENTING FROM INITIAL X *
C     * Y       = DEPENDENT VARIABLE                            *
C     * YGIVEN  = GIVEN VALUE OF DEPENDENT VARIABLE             *
C     * ERRORY  = MAX PERCENT ERROR IN Y AND YGIVEN FOR         *
C     *           SOLUTION                                      *
C     * NIT     = INCREMENT NUMBER                              *
C     * NTYPE   = 1--INCREMENT,  2--INTERPOLATION,  3--SOLUTION *
C     *                                                         *
C     * NOTE: THE INTERMEDIATE VARIABLES XNEG,YNEG,XPOS,YPOS,   *
C     * NSIGN1,NSIGN2 MUST BE STORED BETWEEN INTERATIONS.       *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE ITER(X,DX,ERRORX,SIGN,Y,YGIVEN,ERRORY,NIT,
     -NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)
C
      ERROR(ACTUAL,GIVEN)=(ACTUAL-GIVEN)*100.0/GIVEN
C
      IF(ABS(ERROR(Y,YGIVEN))-ERRORY) 90,90,10
   10 IF(Y-YGIVEN) 20,90,30
   20 NSIGN2=-1
      XNEG=X
      YNEG=Y
      GO TO 40
   30 NSIGN2=+1
      XPOS=X
      YPOS=Y
   40 GO TO (50,80), NTYPE
   50 IF(NIT-1) 70,70,60
   60 NSIGN=NSIGN1*NSIGN2
```

```
      IF(NSIGN) 80,80,70                                                ITER    05100
   70 NSIGN1=NSIGN2                                                     ITER    05200
      NIT=NIT+1                                                         ITER    05300
C                                                                       ITER    05400
C     ************************************************************      ITER    05500
C     *                                                          *      ITER    05600
C     *           INCREMENT TC FIND SOLUTION INTERVAL            *      ITER    05700
C     *                                                          *      ITER    05800
C     ************************************************************      ITER    05900
C                                                                       ITER    06000
      X=X+SIGN*DX                                                       ITER    06100
      GO TC 100                                                         ITER    06200
C                                                                       ITER    06300
C     ************************************************************      ITER    06400
C     *                                                          *      ITER    06500
C     *                  INTERPOLATION FOR SOLUTION              *      ITER    06600
C     *                                                          *      ITER    06700
C     ************************************************************      ITER    06800
C                                                                       ITER    06900
   80 NTYPE=2                                                           ITER    07000
      NIT=NIT+1                                                         ITER    07100
      XSAVE=X                                                           ITER    07200
      RATIO=(XPOS-XNEG)/(YPOS-YNEG)                                     ITER    07300
      X=XNEG+RATIO*(YGIVEN-YNEG)                                        ITER    07400
C                                                                       ITER    07500
C     ************************************************************      ITER    07600
C     *                                                          *      ITER    07700
C     *          ACCELERATION OF CONVERGENCE OF ITERATION        *      ITER    07800
C     *                REFERENCE - WEGSTEIN, NBS                 *      ITER    07900
C     *                                                          *      ITER    08000
C     ************************************************************      ITER    08100
C                                                                       ITER    08200
      A=1.0/RATIO                                                       ITER    08300
      IF(A-1.0) 82,88,82                                                ITER    08400
   82 Q=A/(A-1.0)                                                       ITER    08500
      XWGSTN=Q*XSAVE+(1.0-Q)*X                                          ITER    08600
      IF(XNEG-XWGSTN) 84,86,88                                          ITER    08700
   84 IF(XWGSTN-XPOS) 86,86,88                                          ITER    08800
   86 X=XWGSTN                                                          ITER    08900
   88 IF(ABS(ERROR(X,XSAVE))-ERRORX) 90,90,100                          ITER    09000
   90 NTYPE=3                                                           ITER    09100
  100 END                                                               ITER    09200
                                                                        ITER    09300
                                                                        ITER    09400
                                                                        ITER    09500
                                                                        ITER    09600
                                                                        ITER    09700
                                                                        ITER    09800
```

7.4.1 CGLDOP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *                    SUBROUTINE (TTY)                     *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE TTY PRINTS THE RESULTS OF PROGRAM CLGDOP    *
C     *  ON TERMINALS WITH A MINIMUM OF 72 CHARACTERS PER       *
C     *  LINE.  SEE MAIN PROGRAM CLGDOP FOR NOTATION.           *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE TTY
C
      IMPLICIT REAL*4(M)
      DATA CAE/'CAE'/,SSE/'SSE'/
C
      COMMON/TTY1/A2A1,A3A1,A4A1,A4A3,A5A1,A5A6,A6A1,A7A1,A7A2,
     -A7A6,A8A1,A8A7
      COMMON/TTY2/COEFF,CQ1,CQ2,EJECT,GM,GP,GS
      COMMON/TTY3/M1,M2,M3,M4,M5,M6,M7,M8,MWMMWS,MWPMWS,NPTS
      COMMON/TTY4/P1P10,P2P1,P20P10,P3P1,P30P10,P3P2,P30P20,
     -P4P1,P40P10,P4P3,P40P30,P5P1,P50P10,P60P1,P60P10,P60P2,
     -P60P20,P60P50,P7P1,P70P10,P7P2,P70P20,P7P50,P70P50,P8P1,
     -P80P10,P8P2,P80P20,P8P7,P80P70
      COMMON/TTY5/RNSD,RSD34,RSD78
      COMMON/TTY6/T1T10,T2T1,T20T10,T3T1,T30T10,T3T2,T30T20,
     -T4T1,T40T10,T4T3,T40T30,T5T1,T50T10,T60T1,T60T10,T60T20,
     -T60T50,T7T1,T70T10,T7T2,T70T20,T7T50,T70T50,T8T1,
     -T80T10,T8T2,T80T20,T8T7,T80T70
      COMMON/TTY7/WMWS,WPWS
C
C
C     ***********************************************************
C     *                                                         *
C     *                    OUTPUT SYSTEM DATA                   *
C     *                                                         *
C     ***********************************************************
C
C
      WRITE(5,200)
      WRITE(5,201)EJECT,COEFF
C
      WRITE(5,202)
      WRITE(5,203)
      WRITE(5,204)M1,GS,P1P10,T1T10
C
```

```
      WRITE(5,205)                                                      TTY     05100
      IF(EJECT.EQ.CAE) WRITE(5,206)                                     TTY     05200
      IF(EJECT.EQ.SSE) WRITE(5,207)                                     TTY     05300
      WRITE(5,208)GS,M2,A2A1,P2P1,T2T1,P20P10,T20T10                    TTY     05400
C                                                                       TTY     05500
      IF(EJECT.EQ.SSE) GO TO 100                                        TTY     05600
      WRITE(5,209)                                                      TTY     05700
      WRITE(5,210)GS,M3,A3A1,P3P1,T3T1,P30P10,T30T10                    TTY     05800
C                                                                       TTY     05900
      WRITE(5,211)                                                      TTY     06000
      WRITE(5,212)GS,M4,A4A1,P4P1,T4T1,P40P10,T40T10                    TTY     06100
C                                                                       TTY     06200
      WRITE(5,213)                                                      TTY     06300
      WRITE(5,214)GS,M5,A5A1,P5P1,T5T1,P50P10,T50T10                    TTY     06400
C                                                                       TTY     06500
      WRITE(5,215)                                                      TTY     06600
      GO TO 101                                                         TTY     06700
100   WRITE(5,216)                                                      TTY     06800
101   WRITE(5,217)GP,MWPMWS,WPWS,M6,A6A1,P60P1,T60T1,P60P10,            TTY     06900
     -T60T10                                                            TTY     07000
C                                                                       TTY     07100
      IF(EJECT.EQ.CAE) WRITE(5,218)                                     TTY     07200
      IF(EJECT.EQ.SSE) WRITE(5,219)                                     TTY     07300
      WRITE(5,220)GM,MWMMWS,WMWS,M7,A7A1,P7P1,T7T1,P70P10,T70T10        TTY     07400
C                                                                       TTY     07500
      WRITE(5,221)                                                      TTY     07600
      WRITE(5,222)GM,MWMMWS,WMWS,M8,A8A1,P8P1,T8T1,P80P10,              TTY     07700
     -T80T10                                                            TTY     07800
C                                                                       TTY     07900
C                                                                       TTY     08000
C     ************************************************************      TTY     08100
C     *                                                          *      TTY     08200
C     *                  OUTPUT DATA FOR EACH DEVICE             *      TTY     08300
C     *                                                          *      TTY     08400
C     ************************************************************      TTY     08500
C                                                                       TTY     08600
C                                                                       TTY     08700
      WRITE(5,300)                                                      TTY     08800
      WRITE(5,301)NPTS,CQ1,CQ2,GS,A2A1,M1,M2,P2P1,T2T1,P20P10,          TTY     08900
     -T20T10                                                            TTY     09000
C                                                                       TTY     09100
      IF(EJECT.EQ.SSE) GO TO 102                                        TTY     09200
      WRITE(5,302)                                                      TTY     09300
      WRITE(5,303)GS,RNSD,M2,M3,P3P2,T3T2,P30P20,T30T20                 TTY     09400
C                                                                       TTY     09500
      WRITE(5,304)                                                      TTY     09600
      WRITE(5,305)RSD34,GS,A4A3,M3,M4,P4P3,T4T3,P40P30,T40T30           TTY     09700
C                                                                       TTY     09800
      WRITE(5,306)                                                      TTY     09900
      WRITE(5,307)GS,GP,GM,MWPMWS,A7A6,WPWS,M6,M7,P60P50,T6CT50,        TTY     10000
```

```
     -P7P50,T7T50,P7CP5C,T7CT50                                                TTY    10100
C                                                                              TTY    10200
      WRITE(5,3C8)                                                             TTY    10300
      WRITE(5,3C9)                                                             TTY    10400
      GO TO 103                                                                TTY    10500
102   WRITE(5,310)                                                             TTY    10600
103   WRITE(5,311)GS,GP,GM,MWPMWS,A7A2,A7A6,WPWS,M2,M6,M7,P6CP2,               TTY    10700
     -P60P20,T60T20,P7P2,T7T2,P70P2C,T70T2C                                    TTY    10800
C                                                                              TTY    10900
      IF(EJECT.EC.CAE) WRITE(5,312)                                            TTY    11000
      IF(EJECT.EQ.SSE) WRITE(5,313)                                            TTY    11100
      WRITE(5,314)GS,GP,GM,MWPMWS,A7A2,A7A6,A8A7,WPWS,M2,M6,M7,                TTY    11200
     -M8,P60P2,P60P2C,T60T20,P8P2,T8T2,P80P2C,T80T20                           TTY    11300
C                                                                              TTY    11400
      WRITE(5,315)                                                             TTY    11500
      WRITE(5,316)RSD78,GM,A8A7,M7,M8,P8P7,T8T7,P80P70,T80T70                  TTY    11600
C                                                                              TTY    11700
C                                                                              TTY    11800
C     ***************************************************************          TTY    11900
C     *                                                             *          TTY    12000
C     *                     FORMAT STATEMENTS                       *          TTY    12100
C     *                                                             *          TTY    12200
C     ***************************************************************          TTY    12300
C                                                                              TTY    12400
C                                                                              TTY    12500
200   FORMAT('1',T14,'HIGH ENERGY CHEMICAL LASER SYSTEM ',                     TTY    12600
     -'SIMULATION',/,T24,'ONE-DIMENSIONAL ANALYSIS',//,T29,                    TTY    12700
     -'A.L. ADDY',/,T29,'C.D. MIKKELSEN',/,T29,'M.R. SANDBERG',                TTY    12800
     -//,T30,'1 JANUARY 76',//,T19,'MECHANICAL ENGINEERING ',                  TTY    12900
     -'DEPARTMENT',/,T15,'UNIVERSITY OF ILLINOIS AT URBANA-',                  TTY    13000
     -'CHAMPAIGN',/,T25,'URBANA, ILLINOIS 61801')                              TTY    13100
201   FORMAT('0',T20,A3,' SOLUTION FOR MINIMUM ',A5)                           TTY    13200
C                                                                              TTY    13300
202   FORMAT('0',T14,'SYSTEM DATA:')                                           TTY    13400
203   FORMAT('0',T5,'POINT 1  LASER CAVITY ENTRANCE CONDITIONS')               TTY    13500
204   FORMAT('0',T14,'M1     =',E13.6,T38,'GS     =',E13.6,/,                 TTY    13600
     -T14,'P1P10  =',E13.6,T38,'T1T10  =',E13.6)                               TTY    13700
C                                                                              TTY    13800
205   FORMAT('0',T5,'POINT 2  LASER CAVITY EXIT AND')                          TTY    13900
206   FORMAT('+',T36,'NORMAL SHOCK DIFFUSER',/,T14,'ENTRANCE ',                TTY    14000
     -'CONDITIONS')                                                           TTY    14100
207   FORMAT('+',T36,'SUPERSONIC-SUPERSONIC',/,T14,'EJECTOR ',                 TTY    14200
     -'ENTRANCE CONDITIONS')                                                  TTY    14300
208   FORMAT('0',T14,'GS     =',E13.6,/,                                       TTY    14400
     -T14,'M2     =',E13.6,T38,'A2A1   =',E13.6,/,                            TTY    14500
     -T14,'P2P1   =',E13.6,T38,'T2T1   =',E13.6,/,                            TTY    14600
     -T14,'P20P10 =',E13.6,T38,'T20T10 =',E13.6)                              TTY    14700
C                                                                              TTY    14800
209   FORMAT('0',T5,'POINT 3  NORMAL SHOCK DIFFUSER EXIT AND ',                TTY    14900
     -'SUBSONIC',/,T14,'DIFFUSER ENTRANCE CONDITIONS')                        TTY    15000
```

```
  210   FORMAT('0',T14,'GS      =',E13.6,/,                                  TTY     15100
       -T14,'M3      =',E13.6,T38,'A3A1    =',E13.6,/,                     TTY     15200
       -T14,'P3P1    =',E13.6,T38,'T3T1    =',E13.6,/,                     TTY     15300
       -T14,'P30P10 =',E13.6,T38,'T30T10 =',E13.6)                          TTY     15400
                                                                            TTY     15500
C                                                                           TTY     15600
  211   FORMAT('0',T5,'POINT 4  SUBSONIC DIFFUSER EXIT AND ',               TTY     15700
       -'SUDDEN ENLARGEMENT',/,T14,'ENTRANCE CONDITIONS')                   TTY     15800
  212   FORMAT('0',T14,'GS      =',E13.6,/,                                  TTY     15900
       -T14,'M4      =',E13.6,T38,'A4A1    =',E13.6,/,                     TTY     16000
       -T14,'P4P1    =',E13.6,T38,'T4T1    =',E13.6,/,                     TTY     16100
       -T14,'P40P10 =',E13.6,T38,'T40T10 =',E13.6)                          TTY     16200
C                                                                           TTY     16300
  213   FORMAT('0',T5,'POINT 5  CONSTANT-AREA EJECTOR SECONDARY ',           TTY     16400
       -'NOZZLE EXIT',/,T14,'CONDITIONS')                                   TTY     16500
  214   FORMAT('0',T14,'GS      =',E13.6,/,                                  TTY     16600
       -T14,'M5      =',E13.6,T38,'A5A1    =',E13.6,/,                     TTY     16700
       -T14,'P5P1    =',E13.6,T38,'T5T1    =',E13.6,/,                     TTY     16800
       -T14,'P50P10 =',E13.6,T38,'T50T10 =',E13.6)                          TTY     16900
C                                                                           TTY     17000
  215   FORMAT('0',T5,'POINT 6  CONSTANT-AREA EJECTOR PRIMARY ',             TTY     17100
       -'NOZZLE EXIT',/,T14,'CONDITIONS')                                   TTY     17200
  216   FORMAT('0',T5,'POINT 6  SUPERSONIC-SUPERSONIC EJECTOR ',             TTY     17300
       -'PRIMARY NOZZLE',/,T14,'EXIT CONDITIONS')                           TTY     17400
  217   FORMAT('0',T14,'GP      =',E13.6,T38,'MWPMWS =',E13.6,/,             TTY     17500
       -T14,'WPWS    =',E13.6,/,                                            TTY     17600
       -T14,'M6      =',E13.6,T38,'A6A1    =',E13.6,/,                     TTY     17700
       -T14,'P60P1   =',E13.6,T38,'T60T1   =',E13.6,/,                     TTY     17800
       -T14,'P60P10 =',E13.6,T38,'T60T10 =',E13.6)                          TTY     17900
C                                                                           TTY     18000
  218   FORMAT('0',T5,'POINT 7  CONSTANT-AREA EJECTOR EXIT AND ',            TTY     18100
       -'SUBSONIC',/,T14,'DIFFUSER ENTRANCE CONDITIONS')                    TTY     18200
  219   FORMAT('0',T5,'POINT 7  SUPERSONIC-SUPERSONIC EJECTOR ',             TTY     18300
       -'EXIT AND',/,T14,'SUBSONIC DIFFUSER ENTRANCE CONDITIONS')           TTY     18400
  220   FORMAT('0',T14,'GM      =',E13.6,T38,'MWMMWS =',E13.6,/,             TTY     18500
       -T14,'WMWS    =',E13.6,/,                                            TTY     18600
       -T14,'M7      =',E13.6,T38,'A7A1    =',E13.6,/,                     TTY     18700
       -T14,'P7P1    =',E13.6,T38,'T7T1    =',E13.6,/,                     TTY     18800
       -T14,'P70P10 =',E13.6,T38,'T70T10 =',E13.6)                          TTY     18900
C                                                                           TTY     19000
  221   FORMAT('0',T5,'POINT 8  SUBSONIC DIFFUSER EXIT ',                    TTY     19100
       -'CONDITIONS')                                                       TTY     19200
  222   FORMAT('0',T14,'GM      =',E13.6,T38,'MWMMWS =',E13.6,/,             TTY     19300
       -T14,'WMWS    =',E13.6,/,                                            TTY     19400
       -T14,'M8      =',E13.6,T38,'A8A1    =',E13.6,/,                     TTY     19500
       -T14,'P8P1    =',E13.6,T38,'T8T1    =',E13.6,/,                     TTY     19600
       -T14,'P80P10 =',E13.6,T38,'T80T10 =',E13.6)                          TTY     19700
C                                                                           TTY     19800
  300   FORMAT('0',T14,'LASER CAVITY DATA:')                                TTY     19900
  301   FORMAT('0',T14,'NPTS    =',I13,/,                                   TTY     20000
       -T14,'CQ1     =',E13.6,T38,'CQ2     =',E13.6,/,
```

```
     -T14,'GS      =',E13.6,T38,'A2A1    =',E13.6,/,                    TTY    20100
     -T14,'M1      =',E13.6,T38,'M2      =',E13.6,/,                    TTY    20200
     -T14,'P2P1    =',E13.6,T38,'T2T1    =',E13.6,/,                    TTY    20300
     -T14,'P20P10 =',E13.6,T38,'T20T10 =',E13.6)                        TTY    20400
C                                                                       TTY    20500
302   FORMAT('0',T14,'NORMAL SHOCK DIFFUSER DATA:')                     TTY    20600
303   FORMAT('0',T14,'GS      =',E13.6,T38,'RNSD    =',E13.6,/,         TTY    20700
     -T14,'M2      =',E13.6,T38,'M3      =',E13.6,/,                    TTY    20800
     -T14,'P3P2    =',E13.6,T38,'T3T2    =',E13.6,/,                    TTY    20900
     -T14,'P30P20 =',E13.6,T38,'T30T20 =',E13.6)                        TTY    21000
C                                                                       TTY    21100
304   FORMAT('0',T14,'SUBSONIC DIFFUSER DATA:')                         TTY    21200
305   FORMAT('0',T14,'RSD     =',E13.6,/,                               TTY    21300
     -T14,'GS      =',E13.6,T38,'A4A3    =',E13.6,/,                    TTY    21400
     -T14,'M3      =',E13.6,T38,'M4      =',E13.6,/,                    TTY    21500
     -T14,'P4P3    =',E13.6,T38,'T4T3    =',E13.6,/,                    TTY    21600
     -T14,'P40P30 =',E13.6,T38,'T40T30 =',E13.6)                        TTY    21700
C                                                                       TTY    21800
306   FORMAT('0',T14,'CONSTANT-AREA EJECTOR DATA:')                     TTY    21900
307   FORMAT('0',T14,'GS      =',E13.6,T38,'GP      =',E13.6,/,         TTY    22000
     -T14,'GM      =',E13.6,T38,'MWPMWS =',E13.6,/,                    TTY    22100
     -T14,'A7A6    =',E13.6,T38,'WPWS    =',E13.6,/,                   TTY    22200
     -T14,'M6      =',E13.6,T38,'M7      =',E13.6,/,                   TTY    22300
     -T14,'P60P50 =',E13.6,T38,'T60T50 =',E13.6,/,                     TTY    22400
     -T14,'P7P5C   =',E13.6,T38,'T7T50   =',E13.6,/,                   TTY    22500
     -T14,'P70P50 =',E13.6,T38,'T70T50 =',E13.6)                        TTY    22600
C                                                                       TTY    22700
308   FORMAT('0',T14,'NORMAL SHOCK DIFFUSER - SUBSONIC ',               TTY    22800
     -'DIFFUSER -')                                                     TTY    22900
309   FORMAT(' ',T14,'CONSTANT-AREA EJECTOR DATA:')                     TTY    23000
310   FORMAT('0',T14,'SUPERSONIC-SUPERSONIC EJECTOR DATA:')             TTY    23100
311   FORMAT('0',T14,'GS      =',E13.6,T38,'GP      =',E13.6,/,         TTY    23200
     -T14,'GM      =',E13.6,T38,'MWPMWS =',E13.6,/,                    TTY    23300
     -T14,'A7A2    =',E13.6,T38,'A7A6    =',E13.6,/,                   TTY    23400
     -T14,'WPWS    =',E13.6,T38,'M2      =',E13.6,/,                   TTY    23500
     -T14,'M6      =',E13.6,T38,'M7      =',E13.6,/,                   TTY    23600
     -T14,'P60P2   =',E13.6,/,                                         TTY    23700
     -T14,'P60P20 =',E13.6,T38,'T60T20 =',E13.6,/,                     TTY    23800
     -T14,'P7P2    =',E13.6,T38,'T7T2    =',E13.6,/,                   TTY    23900
     -T14,'P70P20 =',E13.6,T38,'T70T20 =',E13.6)                        TTY    24000
C                                                                       TTY    24100
312   FORMAT('0',T14,'NORMAL SHOCK DIFFUSER - SUBSONIC ',               TTY    24200
     -'DIFFUSER -',/,T14,'CONSTANT-AREA EJECTOR - SUBSONIC ',           TTY    24300
     -'DIFFUSER',/,T14,'DATA:')                                         TTY    24400
313   FORMAT('0',T14,'SUPERSONIC-SUPERSONIC EJECTOR - SUBSONIC',        TTY    24500
     -/,T14,'DIFFUSER DATA:')                                           TTY    24600
314   FORMAT('0',T14,'GS      =',E13.6,T38,'GP      =',E13.6,/,         TTY    24700
     -T14,'GM      =',E13.6,T38,'MWPMWS =',E13.6,/,                    TTY    24800
     -T14,'A7A2    =',E13.6,T38,'A7A6    =',E13.6,/,                   TTY    24900
     -T14,'A8A7    =',E13.6,T38,'WPWS    =',E13.6,/,                   TTY    25000
```

7.4.1 CGLDOP (Cont.)

```
     -T14,'M2      =',E13.6,T38,'M6      =',E13.6,/,                    TTY    25100
     -T14,'M7      =',E13.6,T38,'M8      =',E13.6,/,                    TTY    25200
     -T14,'P60P2   =',E13.6,/,                                           TTY    25300
     -T14,'P60P20  =',E13.6,T38,'T60T2C  =',E13.6,/,                    TTY    25400
     -T14,'P8P2    =',E13.6,T38,'T8T2    =',E13.6,/,                    TTY    25500
     -T14,'P80P20  =',E13.6,T38,'T80T20  =',E13.6)                      TTY    25600
C                                                                        TTY    25700
315   FORMAT('0',T14,'SUBSONIC DIFFUSER DATA:')                          TTY    25800
316   FORMAT('0',T14,'RSD     =',E13.6,/,                                TTY    25900
     -T14,'GM      =',E13.6,T38,'A8A7    =',E13.6,/,                    TTY    26000
     -T14,'M7      =',E13.6,T38,'M8      =',E13.6,/,                    TTY    26100
     -T14,'P8P7    =',E13.6,T38,'T8T7    =',E13.6,/,                    TTY    26200
     -T14,'P80P70  =',E13.6,T38,'T80T70  =',E13.6)                      TTY    26300
      END                                                                TTY    26400
```

7.4.2 CLGDOP Sample Case No. 1

```
CLGDOP SAMPLE INPUT DATA: CASE NO.1

INPUT DATA FOR LASER CAVITY ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$CAV
 GG=1.56200, M1=5.00000, A2A1=2.55724, C01=1.00000,
 C02=0.00000, NPTS=21, $
 $CAV M1=2.23, A2A1=1.0, C01=0.0, NPTS=5$

INPUT THE VARIABLE TO BE MINIMIZED FROM THE FOLLOWING LIST:

'P60P1' DIMENSIONLESS PRIMARY STAGNATION PRESSURE
'WPWS'  PRIMARY-TO-SECONDARY MASS FLOW RATIO

P60P1

INPUT SYSTEM CONSTRAINTS BY NAMELIST.
CURRENT VALUES ARE:

$CONST2
 P8P1=57.1634, WPWS=1.00000, $
 $CONST2 P8P1=20.7141, WPWS=6.0$

INPUT THE EJECTOR MODEL FROM THE FOLLOWING LIST:

'CAE' CONSTANT-AREA EJECTOR
 'SSE' SUPERSONIC-SUPERSONIC EJECTOR

SSE

INPUT DATA FOR EJECTOR ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$EJECT2
 GP=1.34000, MWPMWS=1.68375, T60T20=0.761376, A8A7=2.00000, $
 $EJECT2 MWPMWS=1.47815, T60T20=0.807313$
```

7.4.2 CGLDOP Sample Case No. 1 (Cont.)

CLGDOP SAMPLE OUTPUT DATA: CASE NO.1

SEARCH DATA:

NTYPE	MS1	WPWS	DMS1	FAIL
1	0.1000000E+01	0.595735E+01	0.1000000E+00	NO
2	0.9000000E+00	0.577684E+01	0.1000000E+00	NO
2	0.8000000E+00	0.577978E+01	0.1000000E+00	NO
3	0.9000000E+00	0.577684E+01	0.1000000E+00	NO

HIGH ENERGY CHEMICAL LASER SYSTEM SIMULATION
ONE-DIMENSIONAL ANALYSIS

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1 JANUARY 76

MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
URBANA, ILLINOIS 61801

CAE SOLUTION FOR MINIMUM WPWS

SYSTEM DATA:

POINT 1 LASER CAVITY ENTRANCE CONDITIONS

M1 = 0.5000000E+01 GS = 0.156200E+01
P1P10 = 0.306353E-02 T1T10 = 0.124611E+00

POINT 2 LASER CAVITY EXIT AND NORMAL SHOCK DIFFUSER ENTRANCE CONDITIONS

GS = 0.156200E+01
M2 = 0.218000E+01 A2A1 = 0.255724E+01
P2P1 = 0.203682E+01 T2T1 = 0.515579E+01
P20P10 = 0.658641E-01 T20T10 = 0.150000E+01

7.4.2 CGLDOP Sample Case No. 1 (Cont.)

```
POINT 3  NORMAL SHOCK DIFFUSER EXIT AND SUBSONIC
         DIFFUSER ENTRANCE CONDITIONS

         GS      = 0.156200E+01
         M3      = 0.571838E+00    A3A1    = 0.255724E+01
         P3P1    = 0.851724E+01    T3T1    = 0.110277E+02
         P30P10  = 0.332875E-01    T30T10  = 0.150000E+01

POINT 4  SUBSONIC DIFFUSER EXIT AND SUDDEN ENLARGEMENT
         ENTRANCE CONDITIONS

         GS      = 0.156200E+01
         M4      = 0.242941E+00    A4A1    = 0.511448E+01
         P4P1    = 0.102350E+02    T4T1    = 0.113445E+02
         P40P10  = 0.327969E-01    T40T10  = 0.150000E+01

POINT 5  CONSTANT-AREA EJECTOR SECONDARY NOZZLE EXIT
         CONDITIONS

         GS      = 0.156200E+01
         M5      = 0.900000E+00    A5A1    = 0.287105E+01
         P5P1    = 0.605933E+01    T5T1    = 0.980845E+01
         P50P10  = 0.327969E-01    T50T10  = 0.150000E+01

POINT 6  CONSTANT-AREA EJECTOR PRIMARY NOZZLE EXIT
         CONDITIONS

         GP      = 0.134000E+01    MWPMWS  = 0.166375E+01
         WPWS    = 0.577684E+01
         M6      = 0.495558E+01    A6A1    = 0.106546E+01
         P60P1   = 0.354470E+04    T60T1   = 0.916769E+01
         P60P10  = 0.120751E+02    T60T10  = 0.114206E+01

POINT 7  CONSTANT-AREA EJECTOR EXIT AND SUBSONIC
         DIFFUSER ENTRANCE CONDITIONS

         GM      = 0.137328E+01    MWMMWS  = 0.152944E+01
         WMWS    = 0.677684E+01
         M7      = 0.435520E+00    A7A1    = 0.393733E+01
         P7P1    = 0.520506E+02    T7T1    = 0.938738E+01
         P70P10  = 0.181087E+00    T70T10  = 0.120309E+01

POINT 8  SUBSONIC DIFFUSER EXIT CONDITIONS

         GM      = 0.137328E+01    MWMMWS  = 0.152944E+01
         WMWS    = 0.677684E+01
         M8      = 0.199607E+00    A8A1    = 0.787466E+01
         P8P1    = 0.571155E+02    T8T1    = 0.958629E+01
         P80P10  = 0.179667E+00    T80T10  = 0.120309E+01
```

7.4.2 CGLDOP Sample Case No. 1 (Cont.)

```
LASER CAVITY DATA:

NPTS   =            21
CO1    = 0.100000E+01   CO2    = 0.000000E+00
GS     = 0.156200E+01   A2A1   = 0.255724E+01
M1     = 0.500000E+01   M2     = 0.218000E+01
P2P1   = 0.203682E+01   T2T1   = 0.515579E+01
P20P10 = 0.658641E-01   T20T10 = 0.150000E+01

NORMAL SHOCK DIFFUSER DATA:

GS     = 0.156200E+01   RNSD   = 0.750630E+00
M2     = 0.218000E+01   M3     = 0.571828E+00
P3P2   = 0.418164E+01   T3T2   = 0.213889E+01
P30P20 = 0.505397E+00   T30T20 = 0.100000E+01

SUBSONIC DIFFUSER DATA:

PSD    = 0.985261E+00
GS     = 0.156200E+01   A4A3   = 0.200000E+01
M3     = 0.571828E+00   M4     = 0.242941E+00
P4P3   = 0.120172E+01   T4T3   = 0.107407E+01
P40P30 = 0.985261E+00   T40T30 = 0.100000E+01

CONSTANT-AREA EJECTOR DATA:

GS     = 0.156200E+01   GP     = 0.134000E+01
GM     = 0.137328E+01   MWPMWS = 0.168375E+01
A7A6   = 0.369544E+01   WPWS   = 0.577684E+01
M6     = 0.495558E+01   M7     = 0.435520E+00
P60P50 = 0.368178E+03   T60T50 = 0.761376E+00
P7P50  = 0.485814E+01   T7T50  = 0.774638E+00
P70P50 = 0.552147E+01   T70T50 = 0.802061E+00

NORMAL SHOCK DIFFUSER - SUBSONIC DIFFUSER -
CONSTANT-AREA EJECTOR DATA:

GS     = 0.156200E+01   GP     = 0.134000E+01
GM     = 0.137328E+01   MWPMWS = 0.168375E+01
A7A2   = 0.153968E+01   A7A6   = 0.369544E+01
WPWS   = 0.577684E+01   M2     = 0.218000E+01
M6     = 0.495558E+01   M7     = 0.435520E+00
P60P2  = 0.193669E+04
P60P20 = 0.183383E+03   T60T20 = 0.761376E+00
P7P2   = 0.255548E+02   T7T2   = 0.180911E+01
P70P20 = 0.274940E+01   T70T20 = 0.802061E+00
```

7.4.2 CGLDOP Sample Case No. 1 (Cont.)

```
NORMAL SHOCK DIFFUSER - SUBSONIC DIFFUSER -
CONSTANT-AREA EJECTOR - SUBSONIC DIFFUSER
DATA:

GS      = 0.156200E+01    GP      = 0.134000E+01
GM      = 0.137328E+01    MWPMWS  = 0.168375E+01
A7A2    = 0.153968E+01    A7A6    = 0.369544E+01
A8A7    = 0.200000E+01    WPWS    = 0.577684E+01
M2      = 0.218000E+01    M6      = 0.495558E+01
M7      = 0.435520E+00    M8      = 0.199607E+00
P60P2   = 0.193669E+04
P60P20  = 0.183333E+03    T60T20  = 0.761376E+00
P6P2    = 0.280415E+02    T8T2    = 0.185932E+01
P80P20  = 0.272784E+01    T80T20  = 0.802061E+00

SUBSONIC DIFFUSER DATA:

PSD     = 0.992159E+00
GM      = 0.137328E+01    A8A7    = 0.200000E+01
M7      = 0.435520E+00    M8      = 0.199607E+00
P8P7    = 0.109731E+01    T8T7    = 0.102776E+01
P80P70  = 0.992159E+00    T80T70  = 0.100000E+01
```

```
TO RESTART PROGRAM ENTER "YES"
TO STOP PROGRAM ENTER "NO"
YES
```

7.4.3 CLGDOP Sample Case No. 2

```
CLGDOP SAMPLE OUTPUT DATA: CASE NO.2


          HIGH ENERGY CHEMICAL LASER SYSTEM SIMULATION
                  ONE-DIMENSIONAL ANALYSIS

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                         1 JANUARY 76

              MECHANICAL ENGINEERING DEPARTMENT
          UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
                  URBANA, ILLINOIS 61801

                 SSE SOLUTION FOR MINIMUM P60P1

          SYSTEM DATA:

POINT 1   LASER CAVITY ENTRANCE CONDITIONS

          M1      = 0.223000E+01    GS      = 0.156200E+01
          P1P10   = 0.880182E-01    T1T10   = 0.417121E+00

POINT 2   LASER CAVITY EXIT AND SUPERSONIC-SUPERSONIC
          EJECTOR ENTRANCE CONDITIONS

          GS      = 0.156200E+01
          M2      = 0.223000E+01    A2A1    = 0.100000E+01
          P2P1    = 0.100000E+01    T2T1    = 0.100000E+01
          P20P10  = 0.100000E+01    T20T10  = 0.100000E+01

POINT 6   SUPERSONIC-SUPERSONIC EJECTOR PRIMARY NOZZLE
          EXIT CONDITIONS

          GP      = 0.134000E+01    MWPMWS  = 0.147815E+01
          WPWS    = 0.599726E+01
          M6      = 0.312691E+01    A6A1    = 0.124839E+01
          P60P1   = 0.123006E+03    T60T1   = 0.193544E+01
          P60P10  = 0.108268E+02    T60T10  = 0.807313E+00

POINT 7   SUPERSONIC-SUPERSONIC EJECTOR EXIT AND
          SUBSONIC DIFFUSER ENTRANCE CONDITIONS

          GM      = 0.136881E+01    MWMMWS  = 0.138360E+01
          WMWS    = 0.699726E+01
          M7      = 0.470762E+00    A7A1    = 0.224839E+01
          P7P1    = 0.185762E+02    T7T1    = 0.192517E+01
          P70P10  = 0.189710E+01    T70T10  = 0.835845E+00
```

7.4.3 CLGDOP Sample Case No. 2 (Cont.)

```
CLGDOP SAMPLE INPUT DATA: CASE NO.2

INPUT DATA FOR LASER CAVITY ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$CAV
 GS=1.40000, M1=2.00000, A2A1=1.00000, C01=0.00000,
 C02=0.00000, NPTS=21, $
 $CAV GS=1.562, M1=5.0, A2A1=2.55724, C01=1.0$

INPUT THE VARIABLE TO BE MINIMIZED FROM THE FOLLOWING LIST:

 "P60P1" DIMENSIONLESS PRIMARY STAGNATION PRESSURE
"WPWS"  PRIMARY-TO-SECONDARY MASS FLOW RATIO

WPWS

INPUT SYSTEM CONSTRAINTS BY NAMELIST.
CURRENT VALUES ARE:

$CONST1
 P8P1=76.0000, P60P1=2500.00, $
 $CONST1 P8P1=57.1634, P60P1=3945.83$

INPUT THE EJECTOR MODEL FROM THE FOLLOWING LIST:

'CAE" CONSTANT-AREA EJECTOR
'SSE" SUPERSONIC-SUPERSONIC EJECTOR

CAE

INPUT DATA FOR SUPERSONIC-SUBSONIC DIFFUSER SECTION BY
NAMELIST.  CURRENT VALUES ARE:

$DIFUSR
 PHSD=1.00000, A4A3=1.00000, $
 $DIFUSR PHSD=0.75, A4A3=2.0$

INPUT DATA FOR EJECTOR ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$EJECT1
 GP=1.40000, MWPMWS=1.00000, T60T50=1.00000, A8A7=1.00000, $
 $EJECT1 GP=1.34, MWPMWS=1.68375, T60T50=0.761376, A8A7=2.0$
```

7.4.3 CLGDOP Sample Case No. 2 (Cont.)

```
POINT 8  SUBSONIC DIFFUSER EXIT CONDITIONS

         GM      = 0.136881E+01   MWMMWS = 0.138360E+01
         WWWS    = 0.699726E+01
         M8      = 0.212559E+00   A8A1   = 0.449679E+01
         P8P1    = 0.207098E+02   T8T1   = 0.198729E+01
         P80P10  = 0.187984E+01   T80T10 = 0.835845E+00

         LASER CAVITY DATA:

         NPTS    =              5
         CO1     = 0.000000E+00   CO2    = 0.000000E+00
         GS      = 0.156200E+01   A2A1   = 0.100000E+01
         M1      = 0.223000E+01   M2     = 0.223000E+01
         P2P1    = 0.100000E+01   T2T1   = 0.100000E+01
         P20P10  = 0.100000E+01   T20T10 = 0.100000E+01

         SUPERSONIC-SUPERSONIC EJECTOR DATA:

         GS      = 0.156200E+01   GP     = 0.134000E+01
         GM      = 0.136881E+01   MWPMWS = 0.147815E+01
         A7A2    = 0.224839E+01   A7A6   = 0.180103E+01
         WPWS    = 0.599726E+01   M2     = 0.223000E+01
         M6      = 0.312691E+01   M7     = 0.470762E+00
         P60P2   = 0.123006E+03
         P60P20  = 0.108268E+02   T60T20 = 0.807313E+00
         P7P2    = 0.185762E+02   T7T2   = 0.192517E+01
         P70P20  = 0.189710E+01   T70T20 = 0.835845E+00

         SUPERSONIC-SUPERSONIC EJECTOR - SUBSONIC
         DIFFUSER DATA:

         GS      = 0.156200E+01   GP     = 0.134000E+01
         GM      = 0.136881E+01   MWPMWS = 0.147815E+01
         A7A2    = 0.224839E+01   A7A6   = 0.180103E+01
         A8A7    = 0.200000E+01   WPWS   = 0.599726E+01
         M2      = 0.223000E+01   M6     = 0.312691E+01
         M7      = 0.470762E+00   M8     = 0.212559E+00
         P60P2   = 0.123006E+03
         P60P20  = 0.108268E+02   T60T20 = 0.807313E+00
         P8P2    = 0.207098E+02   T8T2   = 0.198729E+01
         P80P20  = 0.187984E+01   T80T20 = 0.835845E+00

         SUBSONIC DIFFUSER DATA:

         PSD     = 0.990902E+00
         GM      = 0.136881E+01   A8A7   = 0.200000E+01
         M7      = 0.470762E+00   M8     = 0.212559E+00
         P8P7    = 0.111485E+01   T8T7   = 0.103227E+01
         P80P70  = 0.990902E+00   T80T70 = 0.100000E+01


TO RESTART PROGRAM ENTER "YES"
TO STOP PROGRAM ENTER "NO"
NO
```

7.5 CHEMICAL LASER GAS DYNAMICS SYSTEM PROGRAM

7.5.1 Computer Program (CLGDSP)

```
C     ***************************************************************
C     *                                                             *
C     *   CHEMICAL LASER GAS DYNAMICS SYSTEM PROGRAM (CLGDSP)       *
C     *                                                             *
C     *                WRITTEN BY: A.L. ADDY                        *
C     *                            C.D. MIKKELSEN                   *
C     *                            M.R. SANDBERG                    *
C     *                                                             *
C     *                        1 JANUARY 76                         *
C     *                                                             *
C     *            MECHANICAL ENGINEERING DEPARTMENT                *
C     *        UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN           *
C     *                URBANA, ILLINOIS 61801                       *
C     *                                                             *
C     *  CLGDSP IS A PROGRAM FOR SIMULATING THE GAS DYNAMICS        *
C     *  OF HIGH-ENERGY CHEMICAL LASER SYSTEMS BY ONE-              *
C     *  DIMENSIONAL ANALYSIS. CLGDSP IS A FORTRAN IV PROGRAM       *
C     *  WRITTEN FOR DEC SYSTEM-10 (F40).                           *
C     *                                                             *
C     ***************************************************************
C
C     ***************************************************************
C     *                                                             *
C     *                      NOTATION SCHEME                        *
C     *                                                             *
C     *  VARIABLES ARE DEFINED AS FOLLOWS:                          *
C     *                                                             *
C     *  A : AREA                                                   *
C     *  G : (GAMMA) SPECIFIC HEAT RATIO                            *
C     *  M : MACH NUMBER                                            *
C     *  MW: MOLECULAR WEIGHT                                       *
C     *  P : PRESSURE                                               *
C     *  T : TEMPERATURE                                            *
C     *  W : MASS FLOW RATE                                         *
C     *                                                             *
C     *  REPEATED LETTERS INDICATE RATIOS.                          *
C     *  EXAMPLE: A2A1=A2/A1                                        *
C     *                                                             *
C     *  VARIABLES ARE DESIGNATED AS TO LOCATION BY THE             *
C     *  FOLLOWING:                                                 *
C     *                                                             *
C     *  POINT 1: LASER CAVITY ENTRANCE                             *
C     *  POINT 2: LASER CAVITY EXIT                                 *
C     *  POINT 3: NORMAL SHOCK DIFFUSER EXIT                        *
C     *  POINT 4: SUBSONIC DIFFUSER EXIT                            *
C     *  POINT 5: EJECTOR SECONDARY NOZZLE EXIT                     *
C     *  POINT 6: EJECTOR PRIMARY NOZZLE EXIT                       *
C     *  POINT 7: EJECTOR MIXING TUBE EXIT                          *
C     *  POINT 8: SUBSONIC DIFFUSER EXIT                            *
C     *  EXAMPLE: P8P2= SUBSONIC DIFFUSER EXIT-TO-LASER CAVITY      *
```

```
C     *            EXIT STATIC PRESSURE RATIO                         *
C     *                                                               *
C     *   S: INDICATES SECONDARY OR DRIVEN STREAM PROPERTIES          *
C     *   P: INDICATES PRIMARY OR DRIVING STREAM PROPERTIES           *
C     *   M: INDICATES MIXED STREAM PROPERTIES                        *
C     *   EXAMPLE: GM= MIXED STREAM SPECIFIC HEAT RATIO               *
C     *                                                               *
C     *   0: INDICATES STAGNATION CONDITIONS                          *
C     *   EXAMPLE: T20T10= LASER CAVITY EXIT-TO-ENTRANCE              *
C     *            STAGNATION TEMPERATURE RATIO                       *
C     *                                                               *
C     *   VARIABLES NOT FOLLOWING THIS SCHEME ARE DEFINED             *
C     *   AS REQUIRED.                                                *
C     *                                                               *
C     *****************************************************************
C
      IMPLICIT REAL*4 (M)
      REAL*4 NO
C
      COMMON/TTY1/A2A1,A3A1,A4A1,A4A3,A5A1,A5A6,A6A1,A7A1,A7A2,
     -A7A6,A8A1,A8A7
      COMMON/TTY2/COEFF,CQ1,CQ2,EJECT,GM,GP,GS
      COMMON/TTY3/M1,M2,M3,M4,M5,M6,M7,M8,MWMMWS,MWPMWS,NPTS
      COMMON/TTY4/P1P10,P2P1,P20P10,P3P1,P30P10,P3P2,P30P20,
     -P4P1,P40P10,P4P3,P40P30,P5P1,P50P10,P60P1,P60P10,P60P2,
     -P60P20,P60P50,P7P1,P70P10,P7P2,P70P20,P7P50,P70P50,XP8P1,
     -P80P10,P8P2,P80P20,P8P7,P80P70
      COMMON/TTY5/RCPE,RNSD,RSD34,RSD78
      COMMON/TTY6/T1T10,T2T1,T20T10,T3T1,T30T10,T3T2,T30T20,
     -T4T1,T40T10,T4T3,T40T30,T5T1,T50T10,T60T1,T60T10,T60T20,
     -T60T50,T7T1,T70T10,T7T2,T70T20,T7T50,T70T50,T8T1,
     -T80T10,T8T2,T80T20,T8T7,T80T70
      COMMON/TTY7/WMWS,WPWS
C
      DATA CPE/'CPE'/,CAE/'CAE'/,SSE/'SSE'/,WPWSC/'WPWS'/,
     -M6C/'M6'/,A7A6C/'A7A6'/,YES/'YES'/,NO/'NO'/
C
      DATA GS,M1,A2A1,CQ1,CQ2,NPTS,P8P1/1.400,2.0,1.0,2*0.0,21,
     -10.0/
      DATA RNSD,A4A3/2*1.0/
      DATA GP,MWPMWS,T60T50,T60T20,M6,A7A6,WPWS,RCPE,A8A7/
     -1.400,3*1.0,1.01,10.0,3*1.0/
C
      NAMELIST/CAV/GS,M1,A2A1,CQ1,CQ2,NPTS,P8P1
      NAMELIST/DIFUSR/RNSD,A4A3
      NAMELIST/EJECT1/GP,MWPMWS,T60T50,M6,A7A6,WPWS,RCPE,A8A7
      NAMELIST/EJECT2/GP,MWPMWS,T60T50,M6,A7A6,WPWS,A8A7
      NAMELIST/EJECT3/GP,MWPMWS,T60T20,M6,A7A6,A8A7
C
```

7.5.1 CLGDSP (Cont.)

```
      TOTM(GX,MX)=1.0+((GX-1.0)/2.0)*MX*MX                              CLGDSP 10100
      POPM(GX,MX)=(1.0+((GX-1.0)/2.0)*MX*MX)**(GX/(GX-1.0))             CLGDSP 10200
      WM(GX,MX)=MX*SQRT(GX*(1.0+((GX-1.0)/2.0)*MX*MX))                  CLGDSP 10300
C                                                                       CLGDSP 10400
C                                                                       CLGDSP 10500
C     ***********************************************************       CLGDSP 10600
C     *                                                         *       CLGDSP 10700
C     *             SECTION I: LASER CAVITY ANALYSIS            *       CLGDSP 10800
C     *                                                         *       CLGDSP 10900
C     *    VARIABLES USED IN THIS SECTION AND THEIR DEFAULT     *       CLGDSP 11000
C     *    VALUES ARE:                                          *       CLGDSP 11100
C     *                                                         *       CLGDSP 11200
C     *    1. GS(1.400) : RATIO OF SPECIFIC HEATS               *       CLGDSP 11300
C     *    2. M1(2.0)   : CAVITY ENTRANCE MACH NUMBER           *       CLGDSP 11400
C     *    3. A2A1(1.0) : CAVITY EXIT-TO-ENTRANCE AREA RATIO    *       CLGDSP 11500
C     *    4. CQ1(0.0)  : HEAT ADDITION COEFFICIENT             *       CLGDSP 11600
C     *    5. CQ2(0.0)  : HEAT ADDITION COEFFICIENT             *       CLGDSP 11700
C     *    6. NPTS(21)  : CAVITY INTEGRATION INCREMENTS         *       CLGDSP 11800
C     *    7. P8P1(10.0): SUBSONIC DIFFUSER EXIT-TO-CAVITY      *       CLGDSP 11900
C     *                   ENTRANCE STATIC PRESSURE RATIO        *       CLGDSP 12000
C     *                                                         *       CLGDSP 12100
C     *    NOTES:                                               *       CLGDSP 12200
C     *    1. VALUES OF ALL INPUT VARIABLES MUST BE DEFINED     *       CLGDSP 12300
C     *       EITHER BY INPUT OR DEFAULT.                       *       CLGDSP 12400
C     *    2. ALL VARIABLE INPUT IS BY NAMELIST.                *       CLGDSP 12500
C     *    3. THE MAXIMUM NUMBER OF INTEGRATION STEPS IS 25.    *       CLGDSP 12600
C     *                                                         *       CLGDSP 12700
C     ***********************************************************       CLGDSP 12800
C                                                                       CLGDSP 12900
C                                                                       CLGDSP 13000
100   WRITE(5,200)                                                      CLGDSP 13100
      WRITE(5,CAV)                                                      CLGDSP 13200
      READ(5,CAV)                                                       CLGDSP 13300
      X1=0.0                                                            CLGDSP 13400
      X2=1.0                                                            CLGDSP 13500
      A1=1.0                                                            CLGDSP 13600
      A2=A2A1                                                           CLGDSP 13700
      FAIL=NO                                                           CLGDSP 13800
C                                                                       CLGDSP 13900
C                                                                       CLGDSP 14000
C     ***********************************************************       CLGDSP 14100
C     *                                                         *       CLGDSP 14200
C     *                CALCULATIONS FOR LASER CAVITY            *       CLGDSP 14300
C     *                                                         *       CLGDSP 14400
C     ***********************************************************       CLGDSP 14500
C                                                                       CLGDSP 14600
C                                                                       CLGDSP 14700
      CALL CAVITY(GS,M1,X1,X2,A1,A2,CQ1,CQ2,NPTS,M2,T2T1,T20T10,        CLGDSP 14800
     -P2P1,P20P10,FAIL)                                                 CLGDSP 14900
      T1T10=1.0/TOTM(GS,M1)                                             CLGDSP 15000
```

```
      P1P10=1.0/POPM(GS,M1)                                              CLGDSP 15100
      T20T2=TOTM(GS,M2)                                                  CLGDSP 15200
      P20P2=POPM(GS,M2)                                                  CLGDSP 15300
      IF(FAIL.EQ.YES) GO TO 113                                          CLGDSP 15400
C                                                                        CLGDSP 15500
C     ****************************************************************   CLGDSP 15600
C     *                                                              *   CLGDSP 15700
C     *               SECTION II: EJECTOR ANALYSIS                   *   CLGDSP 15800
C     *                                                              *   CLGDSP 15900
C     *    THE PROGRAMMER MAY CHOOSE ONE OF THREE EJECTOR            *   CLGDSP 16000
C     *    CONFIGURATIONS TO REPRESSURIZE THE CAVITY FLOW.           *   CLGDSP 16100
C     *    THESE CONFIGURATIONS ARE:                                 *   CLGDSP 16200
C     *                                                              *   CLGDSP 16300
C     *    1. CPE: CONSTANT-PRESSURE EJECTOR                         *   CLGDSP 16400
C     *    2. CAE: CONSTANT-AREA EJECTOR                             *   CLGDSP 16500
C     *    3. SSE: SUPERSONIC-SUPERSONIC EJECTOR                     *   CLGDSP 16600
C     *                                                              *   CLGDSP 16700
C     *    AFTER THE CHOICE OF EJECTOR SYSTEM HAS BEEN MADE,         *   CLGDSP 16800
C     *    THE PROGRAMMER MUST CHOOSE AN ITERATION VARIABLE.         *   CLGDSP 16900
C     *                                                              *   CLGDSP 17000
C     *    FOR CPE AND CAE, THE PROGRAMMER MUST CHOOSE AN            *   CLGDSP 17100
C     *    ITERATION VARIABLE FROM THE FOLLOWING LIST:               *   CLGDSP 17200
C     *                                                              *   CLGDSP 17300
C     *    1. M6   : PRIMARY NOZZLE EXIT MACH NUMBER                 *   CLGDSP 17400
C     *    2. A7A6: MIXING TUBE EXIT-TO-PRIMARY NOZZLE EXIT          *   CLGDSP 17500
C     *             AREA RATIO                                       *   CLGDSP 17600
C     *    3. WPWS: PRIMARY-TO-SECONDARY MASS FLOW RATIO             *   CLGDSP 17700
C     *                                                              *   CLGDSP 17800
C     *    FOR SSE, THE PROGRAMMER MUST CHOOSE AN ITERATION          *   CLGDSP 17900
C     *    VARIABLE FROM THE FOLLOWING LIST:                         *   CLGDSP 18000
C     *                                                              *   CLGDSP 18100
C     *    1. M6   : PRIMARY NOZZLE EXIT MACH NUMBER                 *   CLGDSP 18200
C     *    2. A7A6: MIXING TUBE EXIT-TO-PRIMARY NOZZLE EXIT          *   CLGDSP 18300
C     *             AREA RATIO                                       *   CLGDSP 18400
C     *                                                              *   CLGDSP 18500
C     ****************************************************************   CLGDSP 18600
C                                                                        CLGDSP 18700
      WRITE(5,201)                                                       CLGDSP 18800
      READ(5,202)EJECT                                                   CLGDSP 18900
      WRITE(5,203)                                                       CLGDSP 19000
      IF(EJECT.NE.SSE) WRITE(5,204)                                      CLGDSP 19100
      READ(5,205)COEFF                                                   CLGDSP 19200
C                                                                        CLGDSP 19300
C     ****************************************************************   CLGDSP 19400
C     *                                                              *   CLGDSP 19500
C     *      VARIABLES USED IN THIS SECTION AND THEIR DEFAULT        *   CLGDSP 19600
C     *      VALUES ARE:                                             *   CLGDSP 19700
C     *                                                              *   CLGDSP 19800
C     *                                                              *   CLGDSP 19900
C     ****************************************************************   CLGDSP 20000
```

7.5.1 CLGDSP (Cont.)

```
C     *                                                          *
C     *  1. RNSD(1.0)   : NORMAL SHOCK DIFFUSER COEFFICIENT      *
C     *  2. A4A3(1.0)   : SUBSONIC DIFFUSER EXIT-TO-ENTRANCE     *
C     *                   AREA RATIO                             *
C     *  3. GP(1.400)   : RATIO OF SPECIFIC HEATS                *
C     *  4. MWPMWS(1.0): PRIMARY-TO-SECONDARY MOLECULAR          *
C     *                   WEIGHT RATIO                           *
C     *  5. T60T50(1.0): PRIMARY-TO-SECONDARY STAGNATION         *
C     *                   TEMPERATURE RATIO (FOR CPE AND CAE)    *
C     *  5. T60T20(1.0): PRIMARY-TO-SECONDARY STAGNATION         *
C     *                   TEMPERATURE RATIO (FOR SSE)            *
C     *  6. M6(1.01)    : PRIMARY NOZZLE EXIT MACH NUMBER        *
C     *  7. A7A6(10.0)  : MIXING TUBE EXIT-TO-PRIMARY NOZZLE     *
C     *                   EXIT AREA RATIO                        *
C     *  8. WPWS(1.0)   : PRIMARY-TO-SECONDARY MASS FLOW RATIO   *
C     *  9. RCPE(1.0)   : NORMAL SHOCK COEFFICIENT FOR           *
C     *                   CONSTANT-PRESSURE EJECTOR              *
C     * 10. A8A7(1.0)   : SUBSONIC DIFFUSER EXIT-TO-ENTRANCE     *
C     *                   AREA RATIO                             *
C     *                                                          *
C     *      ALL VARIABLE INPUT IS BY NAMELIST.                  *
C     *                                                          *
C     ************************************************************
C
C
      IF(EJECT.EQ.SSE) GO TO 102
      WRITE(5,206)
      WRITE(5,DIFUSR)
      READ(5,DIFUSR)
      WRITE(5,207)
      IF(EJECT.NE.CPE) GO TO 101
      WRITE(5,EJECT1)
      READ(5,EJECT1)
      GO TO 103
101   WRITE(5,EJECT2)
      READ(5,EJECT2)
      GO TO 103
102   WRITE(5,207)
      WRITE(5,EJECT3)
      READ(5,EJECT3)
103   MWSMWP=1.0/MWPMWS
      T50T60=1.0/T60T50
      T20T60=1.0/T60T20
      WSWP=1.0/WPWS
      NIT=1
      NTYPE=1
C
C
C     ************************************************************
C     *                                                          *
```

```
C     *          CACULATIONS FOR NORMAL SHOCK DIFFUSER                *
C     *                                                               *
C     *****************************************************************
C
      IF(EJECT.EQ.SSE) GO TO 104
      CALL NSDS(GS,M2,RNSD,M3,P3P2,P30P20,T3T2,T30T20)
      P3P1=P3P2*P2P1
      T3T1=T3T2*T2T1
      P30P10=P30P20*P20P10
      T30T10=T30T20*T20T10
      A3A1=A2A1
C
C     *****************************************************************
C     *                                                               *
C     *              CALCULATIONS FOR SUBSONIC DIFFUSER               *
C     *                                                               *
C     *****************************************************************
C
      CALL SDS(GS,M3,A4A3,M4,P4P3,P40P30,T4T3,T40T30,RSD34,FAIL)
      IF(FAIL.EQ.YES) GO TO 114
      P4P1=P4P3*P3P1
      T4T1=T4T3*T3T1
      P40P10=P40P30*P30P10
      T40T10=T40T30*T30T10
      A4A1=A4A3*A3A1
C
C     *****************************************************************
C     *                                                               *
C     *            CALCULATIONS FOR SUDDEN ENLARGEMENT                *
C     *                                                               *
C     *****************************************************************
C
      P50P40=1.0
      T50T40=1.0
      P50P20=P50P40*P40P30*P30P20
      T50T20=T50T40*T40T30*T30T20
      P50P10=P50P20*P20P10
      T50T10=T50T20*T20T10
C
C     *****************************************************************
C     *                                                               *
C     *         CALCULATIONS FOR CONSTANT-PRESSURE EJECTOR            *
C     *                                                               *
C     *****************************************************************
```

CLGDSP 25100 CLGDSP 25200 CLGDSP 25300 CLGDSP 25400 CLGDSP 25500 CLGDSP 25600 CLGDSP 25700 CLGDSP 25800 CLGDSP 25900 CLGDSP 26000 CLGDSP 26100 CLGDSP 26200 CLGDSP 26300 CLGDSP 26400 CLGDSP 26500 CLGDSP 26600 CLGDSP 26700 CLGDSP 26800 CLGDSP 26900 CLGDSP 27000 CLGDSP 27100 CLGDSP 27200 CLGDSP 27300 CLGDSP 27400 CLGDSP 27500 CLGDSP 27600 CLGDSP 27700 CLGDSP 27800 CLGDSP 27900 CLGDSP 28000 CLGDSP 28100 CLGDSP 28200 CLGDSP 28300 CLGDSP 28400 CLGDSP 28500 CLGDSP 28600 CLGDSP 28700 CLGDSP 28800 CLGDSP 28900 CLGDSP 29000 CLGDSP 29100 CLGDSP 29200 CLGDSP 29300 CLGDSP 29400 CLGDSP 29500 CLGDSP 29600 CLGDSP 29700 CLGDSP 29800 CLGDSP 29900 CLGDSP 30000

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C                                                                       CLGDSP 30100
C                                                                       CLGDSP 30200
104   DO 108 KOUNT=1,100                                               CLGDSP 30300
      IF(EJECT.NE.CPE) GO TO 105                                        CLGDSP 30400
      CALL CPES(GS,GP,MWSMWP,T50T60,WSWP,M6,A7A6,RCPE,M5,A5A6,          CLGDSP 30500
     -GM,MWMMWP,T70T60,M7,P60P50,P7P50,FAIL)                            CLGDSP 30600
      IF(FAIL.EQ.YES) GO TO 115                                         CLGDSP 30700
      P7P1=P7P5C*P5CP2C*P20P2*P2P1                                      CLGDSP 30800
      GO TO 107                                                         CLGDSP 30900
C                                                                       CLGDSP 31000
CCC   ************************************************************    CLGDSP 31100
CCC   *                                                          *    CLGDSP 31200
CCC   *           CALCULATIONS FOR CONSTANT-AREA EJECTOR         *    CLGDSP 31300
CCC   *                                                          *    CLGDSP 31400
CCC   ************************************************************    CLGDSP 31500
C                                                                       CLGDSP 31600
C                                                                       CLGDSP 31700
105   IF(EJECT.NE.CAE) GO TO 106                                        CLGDSP 31800
      A6A7=1.0/A7A6                                                     CLGDSP 31900
      CALL CAES(GS,GP,MWSMWP,T50T60,WSWP,M6,A6A7,M5,GM,MWMMWP,          CLGDSP 32000
     -T70T60,M7,P60P50,P7P50,FAIL)                                      CLGDSP 32100
      IF(FAIL.EQ.YES) GO TO 116                                         CLGDSP 32200
      P7P1=P7P5C*P5CP20*P20P2*P2P1                                      CLGDSP 32300
      GO TO 107                                                         CLGDSP 32400
C                                                                       CLGDSP 32500
CCC   ************************************************************    CLGDSP 32600
CCC   *                                                          *    CLGDSP 32700
CCC   *      CALCULATIONS FOR SUPERSONIC-SUPERSONIC EJECTOR      *    CLGDSP 32800
CCC   *                                                          *    CLGDSP 32900
CCC   ************************************************************    CLGDSP 33000
C                                                                       CLGDSP 33100
C                                                                       CLGDSP 33200
106   A2A6=A7A6-1.0                                                     CLGDSP 33300
      CALL SSES(GS,GP,MWSMWP,T20T60,M2,M6,A2A6,WSWP,GM,MWMMWP,          CLGDSP 33400
     -T70T60,M7,P60P2,P7P2,FAIL)                                        CLGDSP 33500
      IF(FAIL.EQ.YES) GO TO 117                                         CLGDSP 33600
      P7P1=P7P2*P2P1                                                    CLGDSP 33700
C                                                                       CLGDSP 33800
CCC   ************************************************************    CLGDSP 33900
CCC   *                                                          *    CLGDSP 34000
CCC   *             CALCULATIONS FOR SUBSONIC DIFFUSER           *    CLGDSP 34100
CCC   *                                                          *    CLGDSP 34200
CCC   ************************************************************    CLGDSP 34300
C                                                                       CLGDSP 34400
C                                                                       CLGDSP 34500
107   CALL SDS(GM,M7,A8A7,M8,P8P7,P80P70,T8T7,T80T70,RSD78,FAIL)        CLGDSP 34600
      IF(FAIL.EQ.YES) GO TO 118                                         CLGDSP 34700
                                                                        CLGDSP 34800
                                                                        CLGDSP 34900
                                                                        CLGDSP 35000
```

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      XP8P1=P8P7*P7P1                                                   CLGDSP 35100
C                                                                       CLGDSP 35200
CCCCCC*****************************************************************CLGDSP 35300
CCCCCC*                                                               *CLGDSP 35400
CCCCCC*                        ITERATION SCHEME                       *CLGDSP 35500
CCCCCC*                                                               *CLGDSP 35600
CCCCCC*****************************************************************CLGDSP 35700
C                                                                       CLGDSP 35800
      IF(COEFF.EQ.M6C) CALL ITER(M6,0.5,1.0E-06,1.0,XP8P1,P8P1,         CLGDSP 35900
     -1.0E-01,NIT,NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)              CLGDSP 36000
      IF(COEFF.EQ.A7A6C) CALL ITER(A7A6,0.5,1.0E-06,-1.0,XP8P1,         CLGDSP 36100
     -P8P1,1.0E-01,NIT,NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)         CLGDSP 36200
      IF(COEFF.EQ.WPWSC) CALL ITER(WSWP,0.1,1.0E-06,-1.0,XP8P1,         CLGDSP 36300
     -P8P1,1.0E-01,NIT,NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)         CLGDSP 36400
  108 IF(NTYPE.EQ.3) GO TO 109                                          CLGDSP 36500
      IF(COEFF.EQ.M6C) GO TO 119                                        CLGDSP 36600
      IF(COEFF.EQ.A7A6C) GO TO 120                                      CLGDSP 36700
      IF(COEFF.EQ.WPWSC) GO TO 121                                      CLGDSP 36800
  109 MWMMWS=MWMMWP*MWPMWS                                              CLGDSP 36900
      WPWS=1.0/WSWP                                                     CLGDSP 37000
      WMWS=1.0+WPWS                                                     CLGDSP 37100
C                                                                       CLGDSP 37200
CCCCCC*****************************************************************CLGDSP 37300
CCCCCC*                                                               *CLGDSP 37400
CCCCCC*                FINAL CALCULATIONS FOR CPE/CAE                 *CLGDSP 37500
CCCCCC*                                                               *CLGDSP 37600
CCCCCC*****************************************************************CLGDSP 37700
C                                                                       CLGDSP 37800
      IF(EJECT.EQ.SSE) GO TO 110                                        CLGDSP 37900
      P5P1=P50P20*P20P2*P2P1/P0PM(GS,M5)                                CLGDSP 38000
      T5T1=T50T20*T20T2*T2T1/T0TM(GS,M5)                                CLGDSP 38100
      A5A1=SQRT(T50T10)*WM(GS,M1)/(P5P1*WM(GS,M5))                      CLGDSP 38200
      P70P50=P0PM(GM,M7)*P7P50                                          CLGDSP 38300
      T70T50=T70T60*T60T50                                              CLGDSP 38400
      T7T50=T70T50/T0TM(GM,M7)                                          CLGDSP 38500
      IF(EJECT.EQ.CAE) A7A6=1.0/A6A7                                    CLGDSP 38600
      GO TO 111                                                         CLGDSP 38700
C                                                                       CLGDSP 38800
CCCCCC*****************************************************************CLGDSP 38900
CCCCCC*                                                               *CLGDSP 39000
CCCCCC*                  FINAL CALCULATIONS FOR SSE                   *CLGDSP 39100
CCCCCC*                                                               *CLGDSP 39200
CCCCCC*****************************************************************CLGDSP 39300
C                                                                       CLGDSP 39400
                                                                        CLGDSP 39500
                                                                        CLGDSP 39600
                                                                        CLGDSP 39700
                                                                        CLGDSP 39800
                                                                        CLGDSP 39900
                                                                        CLGDSP 40000
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  110   P60P20=P60P2/P20P2                                                    CLGDSP 40100
        P70P20=P0PM(GM,M7)*P7P2/P20P2                                         CLGDSP 40200
        T70T20=T70T60*T60T20                                                  CLGDSP 40300
        T7T2=T20T2*T70T20/T0TM(GM,M7)                                         CLGDSP 40400
        A7A2=A7A6/A2A6                                                        CLGDSP 40500
        GO TO 112                                                             CLGDSP 40600
C                                                                             CLGDSP 40700
CCCCCC  ***************************************************************     CLGDSP 40800
CCCCCC  *                                                             *     CLGDSP 40900
CCCCCC  *          FINAL CALCULATIONS FOR NSD-SD-SE-CPE/CAE           *     CLGDSP 41000
CCCCCC  *                                                             *     CLGDSP 41100
CCCCCC  ***************************************************************     CLGDSP 41200
C                                                                             CLGDSP 41300
C                                                                             CLGDSP 41400
  111   P60P2=P60P50*P50P20*P20P2                                             CLGDSP 41500
        P60P20=P60P50*P50P20                                                  CLGDSP 41600
        T60T20=T60T50*T50T20                                                  CLGDSP 41700
        P7P2=P7P50*P50P20*P20P2                                               CLGDSP 41800
        P70P20=P70P50*P50P20                                                  CLGDSP 41900
        T7T2=T7T50*T50T20*T20T2                                               CLGDSP 42000
        T70T20=T70T50*T50T20                                                  CLGDSP 42100
        A7A2=WMWS*SQRT(T70T20/MWMMWS)*WM(GS,M2)/(P7P2*WM(GM,M7))              CLGDSP 42200
C                                                                             CLGDSP 42300
CCCCCC  ***************************************************************     CLGDSP 42400
CCCCCC  *                                                             *     CLGDSP 42500
CCCCCC  *        FINAL CALCULATIONS FOR NSD-SD-SE-CPE/CAE-SD          *     CLGDSP 42600
CCCCCC  *        OR SSE-SD                                            *     CLGDSP 42700
CCCCCC  *                                                             *     CLGDSP 42800
CCCCCC  ***************************************************************     CLGDSP 42900
C                                                                             CLGDSP 43000
  112   P8P2=P8P7*P7P2                                                        CLGDSP 43100
        P80P20=P80P7C*P70P20                                                  CLGDSP 43200
        T8T2=T8T7*T7T2                                                        CLGDSP 43300
        T80T20=T80T70*T70T20                                                  CLGDSP 43400
C                                                                             CLGDSP 43500
CCCCCC  ***************************************************************     CLGDSP 43600
CCCCCC  *                                                             *     CLGDSP 43700
CCCCCC  *                  FINAL SYSTEM CALCULATIONS                  *     CLGDSP 43800
CCCCCC  *                                                             *     CLGDSP 43900
CCCCCC  ***************************************************************     CLGDSP 44000
C                                                                             CLGDSP 44100
        A7A1=A7A2*A2A1                                                        CLGDSP 44200
        A6A1=A7A1/A7A6                                                        CLGDSP 44300
        A8A1=A8A7*A7A1                                                        CLGDSP 44400
        P60P1=P60P2*P2P1                                                      CLGDSP 44500
                                                                              CLGDSP 44600
                                                                              CLGDSP 44700
                                                                              CLGDSP 44800
                                                                              CLGDSP 44900
                                                                              CLGDSP 45000
```

```
      P60P10=P6CP20*P20P1C                                              CLGDSP 45100
      T60T1=T60T20*T20T2*T2T1                                           CLGDSP 45200
      T60T10=T60T20*T20T10                                              CLGDSP 45300
      P7P1=P7P2*P2P1                                                    CLGDSP 45400
      P70P10=P70P20*P20P10                                              CLGDSP 45500
      T7T1=T7T2*T2T1                                                    CLGDSP 45600
      T70T10=T70T20*T20T10                                              CLGDSP 45700
      P80P10=P80P20*P20P10                                              CLGDSP 45800
      T8T1=T8T2*T2T1                                                    CLGDSP 45900
      T80T10=T80T20*T20T10                                              CLGDSP 46000
C                                                                       CLGDSP 46100
C     ****************************************************************  CLGDSP 46200
C     *                                                              *  CLGDSP 46300
C     *                        OUTPUT RESULTS                        *  CLGDSP 46400
C     *                                                              *  CLGDSP 46500
C     ****************************************************************  CLGDSP 46600
C                                                                       CLGDSP 46700
      CALL TTY                                                          CLGDSP 46800
      GO TO 122                                                         CLGDSP 46900
C                                                                       CLGDSP 47000
C     ****************************************************************  CLGDSP 47100
C     *                                                              *  CLGDSP 47200
C     *                     FAILURE INDICATORS                       *  CLGDSP 47300
C     *                                                              *  CLGDSP 47400
C     ****************************************************************  CLGDSP 47500
C                                                                       CLGDSP 47600
113   WRITE(5,300)                                                      CLGDSP 47700
      GO TO 122                                                         CLGDSP 47800
114   WRITE(5,301)                                                      CLGDSP 47900
      GO TO 122                                                         CLGDSP 48000
115   WRITE(5,302)                                                      CLGDSP 48100
      GO TO 122                                                         CLGDSP 48200
116   WRITE(5,303)                                                      CLGDSP 48300
      GO TO 122                                                         CLGDSP 48400
117   WRITE(5,304)                                                      CLGDSP 48500
      GO TO 122                                                         CLGDSP 48600
118   WRITE(5,305)                                                      CLGDSP 48700
      GO TO 122                                                         CLGDSP 48800
119   WRITE(5,306)M6,XP8P1,P8P1                                         CLGDSP 48900
      GO TO 122                                                         CLGDSP 49000
120   WRITE(5,307)A7A6,XP8P1,P8P1                                       CLGDSP 49100
      GO TO 122                                                         CLGDSP 49200
121   WRITE(5,308)WSWP,XP8P1,P8P1                                       CLGDSP 49300
122   WRITE(5,200)                                                      CLGDSP 49400
      READ(5,209)RUN                                                    CLGDSP 49500
      IF(RUN.EQ.YES) GO TO 100                                          CLGDSP 49600
                                                                        CLGDSP 49700
                                                                        CLGDSP 49800
                                                                        CLGDSP 49900
                                                                        CLGDSP 50000
```

```
C                                                                       CLGDSP 50100
C                                                                       CLGDSP 50200
C     ***************************************************************   CLGDSP 50300
C     *                                                             *   CLGDSP 50400
C     *                      FORMAT STATEMENTS                      *   CLGDSP 50500
C     *                                                             *   CLGDSP 50600
C     ***************************************************************   CLGDSP 50700
C                                                                       CLGDSP 50800
C                                                                       CLGDSP 50900
200    FORMAT('0',T2,'INPUT DATA FOR LASER CAVITY ANALYSIS BY ',        CLGDSP 51000
     -'NAMELIST.',/,T2,'CURRENT VALUES ARE:',/)                         CLGDSP 51100
201    FORMAT('0',T2,'INPUT THE EJECTOR MODEL FROM THE ',               CLGDSP 51200
     -'FOLLOWING LIST:',//,T2,                                          CLGDSP 51300
     -'"CPE" CONSTANT-PRESSURE EJECTOR',/,T2,                           CLGDSP 51400
     -'"CAE" CONSTANT-AREA EJECTOR',/,T2,                               CLGDSP 51500
     -'"SSE" SUPERSONIC-SUPERSONIC EJECTOR',/)                          CLGDSP 51600
202    FORMAT(A3)                                                       CLGDSP 51700
203    FORMAT('0',T2,'INPUT THE ITERATION VARIABLE FROM THE ',          CLGDSP 51800
     -'FOLLOWING LIST:',//,T2,                                          CLGDSP 51900
     -'"M6" PRIMARY NOZZLE EXIT MACH NUMBER',/,T2,                      CLGDSP 52000
     -'"A7A6" MIXING TUBE EXIT-TO-PRIMARY NOZZLE EXIT AREA ',           CLGDSP 52100
     -'RATIO')                                                          CLGDSP 52200
204    FORMAT(' ',T2,'"WPWS" PRIMARY-TO-SECONDARY MASS FLOW ',          CLGDSP 52300
     -'RATIO')                                                          CLGDSP 52400
205    FORMAT(A4)                                                       CLGDSP 52500
206    FORMAT('0',T2,'INPUT DATA FOR SUPERSONIC-SUBSONIC ',             CLGDSP 52600
     -'DIFFUSER SECTION BY NAMELIST.',/,T2,'CURRENT VALUES ARE:',       CLGDSP 52700
     -/)                                                                CLGDSP 52800
207    FORMAT('0',T2,'INPUT DATA FOR EJECTOR ANALYSIS BY ',             CLGDSP 52900
     -'NAMELIST.',/,T2,'CURRENT VALUES ARE:',/)                         CLGDSP 53000
208    FORMAT('1',T2,'TO RESTART PROGRAM ENTER "YES"',/,T2,             CLGDSP 53100
     -'TO STOP PROGRAM ENTER "NO"')                                     CLGDSP 53200
209    FORMAT(A3)                                                       CLGDSP 53300
C                                                                       CLGDSP 53400
300    FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CAVITY')         CLGDSP 53500
301    FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SDS',/,          CLGDSP 53600
     -T2,'AT STATION 3 TO 4 IN CHEMICAL LASER SYSTEM')                  CLGDSP 53700
302    FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CPES')           CLGDSP 53800
303    FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CAES')           CLGDSP 53900
304    FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SSES')           CLGDSP 54000
305    FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SDS',/,          CLGDSP 54100
     -T2,'AT STATION 7 TO 8 IN CHEMICAL LASER SYSTEM')                  CLGDSP 54200
306    FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,           CLGDSP 54300
     -T2,'M6 =',E13.6,5X,'XP8P1 =',E13.6,5X,'P8P1 =',E13.6)             CLGDSP 54400
307    FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,           CLGDSP 54500
     -T2,'A7A6 =',E13.6,5X,'XP8P1 =',E13.6,5X,'P8P1 =',E13.6)           CLGDSP 54600
308    FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,           CLGDSP 54700
     -T2,'WSWP =',E13.6,5X,'XP8P1 =',E13.6,5X,'P8P1 =',E13.6)           CLGDSP 54800
       END                                                              CLGDSP 54900
```

```
C     ****************************************************************      CAVITY 00100
C     *                                                              *      CAVITY 00200
C     *                LASER CAVITY SUBROUTINE (CAVITY)              *      CAVITY 00300
C     *                                                              *      CAVITY 00400
C     ****************************************************************      CAVITY 00500
C                                                                            CAVITY 00600
C     ****************************************************************      CAVITY 00700
C     *                                                              *      CAVITY 00800
C     *  SUBROUTINE CAVITY IS A SIMPLIFIED FLOW MODEL TO             *      CAVITY 00900
C     *  ASSESS QUALITATIVELY THE EFFECTS OF HEAT RELEASE AND        *      CAVITY 01000
C     *  AREA CHANGE ON THE LASER CAVITY FLOW.  THE FLOW MODEL       *      CAVITY 01100
C     *  IS BASED ON THE ASSUMPTION OF A 1-D FLOW OF AN IDEAL        *      CAVITY 01200
C     *  HOMOGENEOUS GAS THROUGH A CHANNEL WITH A LINEAR             *      CAVITY 01300
C     *  VARIATION IN AREA AND HEAT ADDITION.                        *      CAVITY 01400
C     *                                                              *      CAVITY 01500
C     *  INPUT VARIABLES:                                            *      CAVITY 01600
C     *                                                              *      CAVITY 01700
C     *  G       = SPECIFIC HEAT RATIO                               *      CAVITY 01800
C     *  M1      = ENTRANCE MACH NUMBER                              *      CAVITY 01900
C     *  X1      = ENTRANCE COORDINATE                               *      CAVITY 02000
C     *  X2      = EXIT COORDINATE                                   *      CAVITY 02100
C     *  A1      = ENTRANCE AREA                                     *      CAVITY 02200
C     *  A2      = EXIT AREA                                         *      CAVITY 02300
C     *  CQ1     = HEAT ADDITION COEFFICIENT                         *      CAVITY 02400
C     *  CQ2     = HEAT ADDITION COEFFICIENT                         *      CAVITY 02500
C     *  NPTS    = CAVITY INTEGRATION INCREMENTS                     *      CAVITY 02600
C     *                                                              *      CAVITY 02700
C     *  OUTPUT VARIABLES:                                           *      CAVITY 02800
C     *                                                              *      CAVITY 02900
C     *  M2      = EXIT MACH NUMBER                                  *      CAVITY 03000
C     *  T2      = EXIT STATIC TEMPERATURE                           *      CAVITY 03100
C     *  T02     = EXIT STAGNATION TEMPERATURE                       *      CAVITY 03200
C     *  P2      = EXIT STATIC PRESSURE                              *      CAVITY 03300
C     *  P02     = EXIT STAGNATION PRESSURE                          *      CAVITY 03400
C     *  FAIL    = ERROR FLAG                                        *      CAVITY 03500
C     *                                                              *      CAVITY 03600
C     ****************************************************************      CAVITY 03700
C                                                                            CAVITY 03800
      SUBROUTINE CAVITY(G,M1,DUMMY1,DUMMY2,A1,A2,CQ1,CQ2,NPTS,               CAVITY 03900
     -M2,T2,T02,P2,P02,FAIL)                                                 CAVITY 04000
C                                                                            CAVITY 04100
      EXTERNAL FMSQD                                                         CAVITY 04200
      IMPLICIT REAL*4(L,M)                                                   CAVITY 04300
      DIMENSION T0(25)                                                       CAVITY 04400
      COMMON/FVD/ZI(3),XI(3),X(25),M(25),P(25),P0(25),T(25)                  CAVITY 04500
      COMMON/COEFF/XI,CA(2),CT0(2)                                           CAVITY 04600
      DATA YES/'YES'/                                                        CAVITY 04700
C                                                                            CAVITY 04800
C                                                                            CAVITY 04900
                                                                             CAVITY 05000
```

```
C     ****************************************************************      CAVITY 05100
C     *                                                              *      CAVITY 05200
C     *            INITIALIZE VARIABLES AT STATION (1).              *      CAVITY 05300
C     *                                                              *      CAVITY 05400
C     ****************************************************************      CAVITY 05500
C                                                                           CAVITY 05600
      X1=DUMMY1                                                             CAVITY 05700
      X2=DUMMY2                                                             CAVITY 05800
      X(1)=X1                                                               CAVITY 05900
      M(1)=M1                                                               CAVITY 06000
      P(1)=1.0                                                              CAVITY 06100
      P0(1)=1.0                                                             CAVITY 06200
      T(1)=1.0                                                              CAVITY 06300
      T0(1)=1.0                                                             CAVITY 06400
      XRKI=X1                                                               CAVITY 06500
      YRKI=M1**2                                                            CAVITY 06600
C                                                                           CAVITY 06700
C     ****************************************************************      CAVITY 06800
C     *                                                              *      CAVITY 06900
C     *  CALCULATE THE CAVITY AREA COEFFICIENTS.  A LINEAR           *      CAVITY 07000
C     *  VARIATION WITH X IS ASSUMED.                                *      CAVITY 07100
C     *                                                              *      CAVITY 07200
C     ****************************************************************      CAVITY 07300
C                                                                           CAVITY 07400
      CA(1)=(A1*X2-A2*X1)/(X2-X1)                                           CAVITY 07500
      CA(2)=(A2-A1)/(X2-X1)                                                 CAVITY 07600
C                                                                           CAVITY 07700
C     ****************************************************************      CAVITY 07800
C     *                                                              *      CAVITY 07900
C     *  CALCULATE THE RATE OF HEAT ADDITION COEFFICIENTS.  A        *      CAVITY 08000
C     *  LINEAR VARIATION OF RATE OF HEAT ADDITION WITH X IS         *      CAVITY 08100
C     *  ASSUMED.                                                    *      CAVITY 08200
C     *                                                              *      CAVITY 08300
C     ****************************************************************      CAVITY 08400
C                                                                           CAVITY 08500
      CT0(1)=(CQ1*X2-CQ2*X1)/(X2-X1)                                        CAVITY 08600
      CT0(2)=(CQ2-CQ1)/(X2-X1)                                              CAVITY 08700
C                                                                           CAVITY 08800
C     ****************************************************************      CAVITY 08900
C     *                                                              *      CAVITY 09000
C     *         INITIALIZE FLOW VARIABLES FOR INTEGRATION.           *      CAVITY 09100
C     *                                                              *      CAVITY 09200
C     ****************************************************************      CAVITY 09300
C                                                                           CAVITY 09400
                                                                            CAVITY 09500
                                                                            CAVITY 09600
                                                                            CAVITY 09700
                                                                            CAVITY 09800
                                                                            CAVITY 09900
                                                                            CAVITY 10000
```

```
C
      LNP=0.0                                                           CAVITY 10100
      LNP0=0.0                                                          CAVITY 10200
      LNT=0.0                                                           CAVITY 10300
                                                                        CAVITY 10400
C     ***************************************************************** CAVITY 10500
C     *                                                               * CAVITY 10600
C     *  SET INCREMENT SIZE FOR R-K AND SIMPSON INTEGRATIONS.         * CAVITY 10700
C     *                                                               * CAVITY 10800
C     ***************************************************************** CAVITY 10900
                                                                        CAVITY 11000
      DX=(X2-X1)/FLOAT(NPTS-1)                                          CAVITY 11100
      DXRKI=DX/2.0                                                      CAVITY 11200
                                                                        CAVITY 11300
C     ***************************************************************** CAVITY 11400
C     *                                                               * CAVITY 11500
C     *                    INTEGRATION SECTION                        * CAVITY 11600
C     *                                                               * CAVITY 11700
C     ***************************************************************** CAVITY 11800
                                                                        CAVITY 11900
      DO 60 I=2,NPTS                                                    CAVITY 12000
                                                                        CAVITY 12100
C     ***************************************************************** CAVITY 12200
C     *                                                               * CAVITY 12300
C     *       SET-UP FOR D(M**2)/DX INTEGRATION BY R-K.               * CAVITY 12400
C     *                                                               * CAVITY 12500
C     ***************************************************************** CAVITY 12600
                                                                        CAVITY 12700
      ZI(1)=YRKI                                                        CAVITY 12800
      XI(1)=XRKI                                                        CAVITY 12900
      DO 50 J=1,2                                                       CAVITY 13000
                                                                        CAVITY 13100
C     ***************************************************************** CAVITY 13200
C     *                                                               * CAVITY 13300
C     *                INTEGRATE D(M**2)/DX BY R-K.                   * CAVITY 13400
C     *                                                               * CAVITY 13500
C     ***************************************************************** CAVITY 13600
                                                                        CAVITY 13700
      CALL RKI1(G,DXRKI,XRKI,YRKI,FMSQC,FAIL)                           CAVITY 13800
      IF(FAIL.EQ.YES) GO TO 110                                         CAVITY 13900
      XI(J+1)=XRKI                                                      CAVITY 14000
      ZI(J+1)=YRKI                                                      CAVITY 14100
                                                                        CAVITY 14200
                                                                        CAVITY 14300
                                                                        CAVITY 14400
                                                                        CAVITY 14500
                                                                        CAVITY 14600
                                                                        CAVITY 14700
                                                                        CAVITY 14800
                                                                        CAVITY 14900
                                                                        CAVITY 15000
```

```
50    CONTINUE                                                          CAVITY 15100
C                                                                       CAVITY 15200
CCCCCC*****************************************************************CAVITY 15300
      *                                                               *CAVITY 15400
      *       INTEGRATE TO FIND P,P0,T BY SIMPSON'S RULE.             *CAVITY 15500
      *                                                               *CAVITY 15600
CCCCCC*****************************************************************CAVITY 15700
C                                                                       CAVITY 15800
      CALL FVI(I,G,DX,LNF,LNF0,LNT)                                     CAVITY 15900
C                                                                       CAVITY 16000
CCCCCC*****************************************************************CAVITY 16100
      *                                                               *CAVITY 16200
      *  EVALUATE THE STAGNATION TEMPERATURE RATIO BASED ON A         *CAVITY 16300
      *  RATE OF HEAT ADDITION THAT IS ASSUMED TO BE A LINEAR         *CAVITY 16400
      *  FUNCTION OF X.                                               *CAVITY 16500
      *                                                               *CAVITY 16600
CCCCCC*****************************************************************CAVITY 16700
C                                                                       CAVITY 16800
      T0(I)=(1.0+CT0(1)*(X(I)-X1)+0.5*CT0(2)*                           CAVITY 16900
     -(X(I)**2-X1**2))                                                  CAVITY 17000
60    CONTINUE                                                          CAVITY 17100
      T02=T0(NPTS)                                                      CAVITY 17200
      T2=T(NPTS)                                                        CAVITY 17300
      P02=P0(NPTS)                                                      CAVITY 17400
      P2=P(NPTS)                                                        CAVITY 17500
      M2=M(NPTS)                                                        CAVITY 17600
110   END                                                               CAVITY 17700
                                                                        CAVITY 17800
                                                                        CAVITY 17900
                                                                        CAVITY 18000
                                                                        CAVITY 18100
```

7.5.1 CLGDSP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *        RUNGE-KUTTA INTEGRATION SUBROUTINE (RKI1)        *
C     *                 (OF SUBROUTINE CAVITY)                  *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE RKI1 PERFORMS A FOURTH-ORDER RUNGE-KUTTA    *
C     *  INTEGRATION OF A FIRST-ORDER DIFFERENTIAL EQUATION... *
C     *  DY/DX=F(P,X,Y) WHERE P IS A PARAMETER. THE SUBROUTINE *
C     *  IS SPECIALIZED FOR 1-D FLOW WITH AREA CHANGE AND HEAT *
C     *  ADDITION.
C     *
C     ***********************************************************
C
C
      SUBROUTINE RKI1(P,DX,X,Y,F,FAIL)
C
      DATA YES/'YES'/
C
      N=0
      C1=F(P,X,Y)*DX
      XRK=X+0.5*DX
      YRK=Y+0.5*C1
      GO TO 40
10    C2=F(P,XRK,YRK)*DX
      YRK=Y+0.5*C2
      GO TO 40
20    C3=F(P,XRK,YRK)*DX
      XRK=X+DX
      YRK=Y+C3
      GO TO 40
30    C4=F(P,XRK,YRK)*DX
      YRK=Y+(C1+2.0*(C2+C3)+C4)/6.0
40    IF((Y .GT. 1) .AND. (YRK .LE. 1)) GO TO 50
      IF((Y .LT. 1) .AND. (YRK .GE. 1)) GO TO 50
      N=N+1
      GO TO (10,20,30,70), N
C
C
C     ***********************************************************
C     *                                                         *
C     *  TRANSITIONS FROM SUBSONIC-TO-SUPERSONIC FLOW OR        *
C     *  SUPERSONIC-TO-SUBSONIC FLOW ARE NOT ALLOWED IN THIS    *
C     *  PROGRAM.                                               *
C     *                                                         *
C     ***********************************************************
C
```

7.5.1 CLGDSP (Cont.)

```
C                                                                       RKI1   05100
50    WRITE(5,60)                                                       RKI1   05200
60    FORMAT(//,5X,'.....R-K INTEGRATION TERMINATED BECAUSE ',          RKI1   05300
     -'CHOKING WAS ENCOUNTERED.'/)                                      RKI1   05400
      FAIL=YES                                                          RKI1   05500
      RETURN                                                            RKI1   05600
70    Y=YRK                                                             RKI1   05700
      X=XRK                                                             RKI1   05800
      END                                                               RKI1   05900
```

7.5.1 CLGDSP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *        FLOW VARIABLE INTEGRATION SUBROUTINE (FVI)       *
C     *                  (OF SUBROUTINE CAVITY)                 *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE FVI PERFORMS AN INTEGRATION BY SIMPSON'S    *
C     *  RULE TO FIND THE FLOW VARIABLES (M,P,PO,T) ALONG THE   *
C     *  LASER CAVITY AS A FUNCTION OF X.  THE VARIABLES ARE    *
C     *  FOUND BY INTEGRATING EQUATIONS OF THE FORM...          *
C     *  DY/DX=F(G,Z(X),X).  REFERENCE: SHAPIRO, PAGE 231.      *
C     *                                                         *
C     *  ALL VARIABLES ARE NON-DIMENSIONALIZED WITH RESPECT TO  *
C     *  THE LASER CAVITY ENTRANCE CONDITIONS.                  *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE FVI(I,G,DX,LNP,LNPO,LNT)
C
      IMPLICIT REAL*4(L,M)
      COMMON/FVD/ZI(3),XI(3),X(25),M(25),P(25),PO(25),T(25)
C
C
C     ***********************************************************
C     *                                                         *
C     *         FUNCTIONS TO BE INTEGRATED WHERE Z=M**2.        *
C     *                                                         *
C     ***********************************************************
C
C
      FP(G,Z,X)=(G*Z/(1.-Z))*(FA(X)-(1.+0.5*(G-1.)*Z)*FTO(X))
      FPO(G,Z,X)=-0.5*G*Z*FTO(X)
      FT(G,Z,X)=((G-1.0)*Z/(1.0-Z))*FA(X)
     -+((1.0-G*Z)*(1.0+0.5*(G-1.0)*Z)/(1.0-Z))*FTO(X)
C
C
C     ***********************************************************
C     *                                                         *
C     *                  SIMPSON'S RULE INTEGRATION.            *
C     *                                                         *
C     ***********************************************************
C
C
      DLNP=(DX/6.0)*(FP(G,ZI(1),XI(1))+4.0*FP(G,ZI(2),XI(2))
     -+FP(G,ZI(3),XI(3)))
      DLNT=(DX/6.0)*(FT(G,ZI(1),XI(1))+4.0*FT(G,ZI(2),XI(2))
```

7.5.1 CLGDSP (Cont.)

```
     -+FT(G,ZI(3),XI(3)))                                                FVI
      DLNP0=(DX/6.0)*(FP0(G,ZI(1),XI(1))+4.0*FP0(G,ZI(2),XI(2))          FVI
     -+FP0(G,ZI(3),XI(3)))                                               FVI
C                                                                        FVI
C                                                                        FVI
C     ************************************************************       FVI
C     *                                                          *       FVI
C     *   FIND THE NEW VALUES OF THE INTEGRATION VARIABLES.      *       FVI
C     *                                                          *       FVI
C     ************************************************************       FVI
C                                                                        FVI
C                                                                        FVI
      LNP=LNP+DLNP                                                       FVI
      LNP0=LNP0+DLNP0                                                    FVI
      LNT=LNT+DLNT                                                       FVI
C                                                                        FVI
C                                                                        FVI
C     ************************************************************       FVI
C     *                                                          *       FVI
C     *  LASER CAV'TY FLOW VARIABLES...V(I)-VS-X(I), I=1,NPTS.   *       FVI
C     *                                                          *       FVI
C     ************************************************************       FVI
C                                                                        FVI
C                                                                        FVI
      X(I)=XI(3)                                                         FVI
      P(I)=EXP(LNP)                                                      FVI
      P0(I)=EXP(LNP0)                                                    FVI
      T(I)=EXP(LNT)                                                      FVI
      M(I)=SQRT(ZI(3))                                                   FVI
      END                                                                FVI
```

```
C     ****************************************************************      FUNC    00100
C     *                                                              *      FUNC    00200
C     *                    FUNCTION SUBPROGRAMS                      *      FUNC    00300
C     *                  (OF SUBROUTINE CAVITY)                      *      FUNC    00400
C     *                                                              *      FUNC    00500
C     ****************************************************************      FUNC    00600
C                                                                            FUNC    00700
C     ****************************************************************      FUNC    00800
C     *                                                              *      FUNC    00900
C     *           NOTE...Y=M**2 AND DY/DX=FMSQD(G,X,Y)               *      FUNC    01000
C     *                                                              *      FUNC    01100
C     ****************************************************************      FUNC    01200
C                                                                            FUNC    01300
      FUNCTION FMSQD(G,X,Y)                                                  FUNC    01400
      FMSQD=(Y*(1.0+0.5*(G-1.0)*Y)/(1.0-Y))*                                 FUNC    01500
     -(-2.0*FA(X)+(1.0+G*Y)*FTO(X))                                          FUNC    01600
      END                                                                    FUNC    01700
C                                                                            FUNC    01800
C     ****************************************************************      FUNC    01900
C     *                                                              *      FUNC    02000
C     *  FUNCTION FOR EVALUATING...(1.0/A)(DA/DX).  THE LASER        *      FUNC    02100
C     *  CAVITY AREA IS ASSUMED TO BE A LINEAR FUNCTION OF X.        *      FUNC    02200
C     *                                                              *      FUNC    02300
C     ****************************************************************      FUNC    02400
C                                                                            FUNC    02500
      FUNCTION FA(X)                                                         FUNC    02600
      COMMON/COEFF/X1,CA(2),CTO(2)                                           FUNC    02700
      FA=CA(2)/(CA(1)+CA(2)*X)                                               FUNC    02800
      END                                                                    FUNC    02900
C                                                                            FUNC    03000
C     ****************************************************************      FUNC    03100
C     *                                                              *      FUNC    03200
C     *  FUNCTION FOR EVALUATING...(1.0/TO)(CTO/DX).  THE RATE       *      FUNC    03300
C     *  OF HEAT ADDITION IS ASSUMED TO BE A LINEAR FUNCTION         *      FUNC    03400
C     *  OF X.                                                       *      FUNC    03500
C     *                                                              *      FUNC    03600
C     ****************************************************************      FUNC    03700
C                                                                            FUNC    03800
      FUNCTION FTO(X)                                                        FUNC    03900
      COMMON/COEFF/X1,CA(2),CTO(2)                                           FUNC    04000
      FTO=(CTO(1)+CTO(2)*X)/(1.0+CTO(1)*(X-X1)+0.5*CTO(2)*                   FUNC    04100
     -(X**2-X1**2))                                                          FUNC    04200
      END                                                                    FUNC    04300
                                                                             FUNC    04400
                                                                             FUNC    04500
                                                                             FUNC    04600
                                                                             FUNC    04700
                                                                             FUNC    04800
```

7.5.1 CLGDSP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *          NORMAL SHOCK DIFFUSER SUBROUTINE (NSDS)        *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE NSDS CALCULATES THE PRESSURE RATIO ACROSS   *
C     *  A CONSTANT-AREA, SUPERSONIC DIFFUSER.  THE STATIC      *
C     *  PRESSURE RATIO IS TAKEN AS RD*(PY/PX) FOR A NORMAL     *
C     *  SHOCK AT THE ENTERING MACH NO.  ALL OTHER PROPERTIES   *
C     *  ARE CALCULATED FROM THE ISENTROPIC FLOW RELATIONS TO   *
C     *  BE CONSISTENT WITH THE ENTRANCE AND EXIT MACH NO.S.    *
C     *                                                         *
C     * INPUT VARIABLES:                                        *
C     *                                                         *
C     * G       = GAMMA                                         *
C     * M1      = ENTRANCE MACH NUMBER                          *
C     * RD      = NORMAL SHOCK DIFFUSER COEFFICIENT             *
C     *                                                         *
C     * OUTPUT VARIABLES:                                       *
C     *                                                         *
C     * M2      = EXIT MACH NUMBER                              *
C     * P2P1    = EXIT-TO-ENTRANCE STATIC PRESSURE RATIO        *
C     * P20P10  = EXIT-TO-ENTRANCE STAGNATION PRESSURE RATIO    *
C     * T2T1    = EXIT-TO-ENTRANCE STATIC TEMPERATURE RATIO     *
C     * T20T10  = EXIT-TO-ENTRANCE STAGNATION TEMPERATURE RATIO *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE NSDS(G,M1,RD,M2,P2P1,P20P10,T2T1,T20T10)
C
      IMPLICIT REAL*4(M)
C
      TOTM(GX,MX)=1.0+0.5*(GX-1.0)*MX*MX
      POPM(GX,MX)=(1.0+0.5*(GX-1.0)*MX*MX)**(GX/(GX-1.0))
C
      M2=SQRT((2.0+(G-1.0)*M1*M1)/(2.0*G*M1*M1-G+1.0))
      P2P1=RD*(2.0*G*M1*M1-G+1.0)/(G+1.0)
      P10P1=POPM(G,M1)
      P20P2=POPM(G,M2)
      P20P10=P20P2*P2P1/P10P1
      T20T10=1.0
      T10T1=TOTM(G,M1)
      T20T2=TOTM(G,M2)
      T2T1=T10T1*T20T10/T20T2
      END
```

```
C     ****************************************************************      SDS     00100
C     *                                                              *      SDS     00200
C     *              SUBSONIC DIFFUSER SUBROUTINE (SDS)              *      SDS     00300
C     *                                                              *      SDS     00400
C     ****************************************************************      SDS     00500
C                                                                             SDS     00600
C     ****************************************************************      SDS     00700
C     *                                                              *      SDS     00800
C     *  SUBROUTINE SDS CALCULATES THE PRESSURE RATIO ACROSS A       *      SDS     00900
C     *  CONICAL, SUBSONIC DIFFUSER WITH AN INCLUDED ANGLE OF        *      SDS     01000
C     *  15 DEGREES.  THE STATIC PRESSURE RATIO IS COMPUTED          *      SDS     01100
C     *  USING AN EMPERICAL DIFFUSER EFFICIENCY.  ALL OTHER          *      SDS     01200
C     *  PROPERTIES ARE CALCULATED FROM THE ISENTROPIC FLOW          *      SDS     01300
C     *  RELATIONS TO BE CONSISTENT WITH THE ENTRANCE AND EXIT       *      SDS     01400
C     *  MACH NO.S.                                                  *      SDS     01500
C     *                                                              *      SDS     01600
C     *  THE SUBSONIC DIFFUSER EFFICIENCY GIVEN BY:                  *      SDS     01700
C     *                                                              *      SDS     01800
C     *                    EFF=(P2'-P1)/(P2-P1)                      *      SDS     01900
C     *                                                              *      SDS     02000
C     *  IS LIMITED TO THE RANGE: 0.2<M1<0.5, 2.34<A2/A1<5.2         *      SDS     02100
C     *  AND IS DERIVED FROM DATA IN THE FOLLOWING REFERENCES:       *      SDS     02200
C     *                                                              *      SDS     02300
C     *  HENRY,J.R., WOOD,C.C., AND WILBUR,S.W., "SUMMARY OF         *      SDS     02400
C     *  SUBSONIC-DIFFUSER DATA," NACA RM L56F05 (1956).             *      SDS     02500
C     *                                                              *      SDS     02600
C     *  PATTERSON,G.N., "MODERN DIFFUSER DESIGN," AIRCRAFT          *      SDS     02700
C     *  ENGINEERING, 9(9):267-273 (1938).                           *      SDS     02800
C     *                                                              *      SDS     02900
C     *  THE SUBSONIC DIFFUSER COEFFICIENT IS DEFINED AS:            *      SDS     03000
C     *                                                              *      SDS     03100
C     *                    RD=(P2'/P1)/(P2/P1)                       *      SDS     03200
C     *                                                              *      SDS     03300
C     * INPUT VARIABLES:                                             *      SDS     03400
C     *                                                              *      SDS     03500
C     * G       = GAMMA                                              *      SDS     03600
C     * M1      = ENTRANCE MACH NUMBER                               *      SDS     03700
C     * A2A1    = EXIT-TO-ENTRANCE AREA RATIO                        *      SDS     03800
C     *                                                              *      SDS     03900
C     * OUTPUT VARIABLES:                                            *      SDS     04000
C     *                                                              *      SDS     04100
C     * M2      = EXIT MACH NUMBER                                   *      SDS     04200
C     * P2P1    = EXIT-TO-ENTRANCE STATIC PRESSURE RATIO             *      SDS     04300
C     * P20P10  = EXIT-TO-ENTRANCE STAGNATION PRESSURE RATIO         *      SDS     04400
C     * T2T1    = EXIT-TO-ENTRANCE STATIC TEMPERATURE RATIO          *      SDS     04500
C     * T20T10  = EXIT-TO-ENTRANCE STAGNATION TEMPERATURE RATIO      *      SDS     04600
C     * RD      = SUBSONIC DIFFUSER COEFFICIENT                      *      SDS     04700
C     * FAIL    = ERROR FLAG                                         *      SDS     04800
C     *                                                              *      SDS     04900
C     ****************************************************************      SDS     05000
```

```
C                                                                       SDS     05100
C                                                                       SDS     05200
      SUBROUTINE SDS(G,M1,A2A1,M2,P2P1,P20P10,T2T1,T20T10,RD,           SDS     05300
     -FAIL)                                                             SDS     05400
C                                                                       SDS     05500
      IMPLICIT REAL*4(M)                                                SDS     05600
      DATA YES/'YES'/,SUB/'SUB'/                                        SDS     05700
C                                                                       SDS     05800
CCC                                                                     SDS     05900
CCC   ***************************************************************** SDS     06000
CCC   *                                                               * SDS     06100
CCC   *                     GAS DYNAMIC FUNCTIONS                     * SDS     06200
CCC   *                                                               * SDS     06300
CCC   ***************************************************************** SDS     06400
CCC                                                                     SDS     06500
C                                                                       SDS     06600
      TOTM(GX,MX)=1.0+0.5*(GX-1.0)*MX*MX                                SDS     06700
      POPM(GX,MX)=(1.0+0.5*(GX-1.0)*MX*MX)**(GX/(GX-1.0))               SDS     06800
C                                                                       SDS     06900
CCC                                                                     SDS     07000
CCC   ***************************************************************** SDS     07100
CCC   *                                                               * SDS     07200
CCC   *          CALCULATIONS FOR CONSTANT-AREA DIFFUSER              * SDS     07300
CCC   *                                                               * SDS     07400
CCC   ***************************************************************** SDS     07500
CCC                                                                     SDS     07600
C                                                                       SDS     07700
      IF(A2A1.NE.1.0) GO TO 1                                           SDS     07800
      M2=M1                                                             SDS     07900
      P2P1=1.0                                                          SDS     08000
      P20P10=1.0                                                        SDS     08100
      T2T1=1.0                                                          SDS     08200
      T20T10=1.0                                                        SDS     08300
      RD=1.0                                                            SDS     08400
      RETURN                                                            SDS     08500
C                                                                       SDS     08600
CCC                                                                     SDS     08700
CCC   ***************************************************************** SDS     08800
CCC   *                                                               * SDS     08900
CCC   *                     CALCULATE CONSTANTS                       * SDS     09000
CCC   *                                                               * SDS     09100
CCC   ***************************************************************** SDS     09200
CCC                                                                     SDS     09300
C                                                                       SDS     09400
1     G2=2.0/(G+1.0)                                                    SDS     09500
      G4=(G+1.0)/(2.0*(G-1.0))                                          SDS     09600
C                                                                       SDS     09700
CCC                                                                     SDS     09800
CCC   ***************************************************************** SDS     09900
C     *                                                               * SDS     10000
```

7.5.1 CLGDSP (Cont.)

```
C     *                    SOLVE A2A2S FOR M2                    *
C     *                                                          *
C     ************************************************************
C
C
      A1A1S=(1.0/M1)*(G2*TOTM(G,M1))**G4
      A2A2S=A2A1*A1A1S
      CALL MAAS(G,M1,A2A2S,SUB,5.0E-06,M2,FAIL)
      IF(FAIL.EQ.YES) RETURN
C
C
C     ************************************************************
C     *                                                          *
C     *            CALCULATE THE DIFFUSER EFFICIENCY             *
C     *                                                          *
C     ************************************************************
C
C
      EFF=0.002685*A2A1*A2A1*A2A1-0.024461*A2A1*A2A1-0.027229*
     -A2A1+1.048992
C
C
C     ************************************************************
C     *                                                          *
C     *        CALCULATE THE IDEAL STATIC PRESSURE RATIO         *
C     *                                                          *
C     ************************************************************
C
C
      P10P1=POPM(G,M1)
      P20P2=POPM(G,M2)
      P2P1=P10P1/P20P2
      RD=EFF+(1.0-EFF)/P2P1
C
C
C     ************************************************************
C     *                                                          *
C     *        CALCULATE THE ACTUAL STATIC PRESSURE RATIO        *
C     *                                                          *
C     ************************************************************
C
C
      P2P1=RD*P2P1
      P20P10=P20P2*P2P1/P10P1
      T20T10=1.0
      T10T1=TOTM(G,M1)
      T20T2=TOTM(G,M2)
      T2T1=T10T1*T20T10/T20T2
      END
```

7.5.1 CLGDSP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *       CCNSTANT-PRESSURE EJECTOR SUBROUTINE (CPES)       *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE CPES CALCULATES THE COMPRESSION RATIO FOR   *
C     *  A CCNSTANT-PRESSURE, SUBSONIC-SUPERSONIC EJECTOR WITH  *
C     *  A CCNSTANT-AREA DIFFUSER SECTION BY A ONE-DIMENSIONAL  *
C     *  ANALYSIS.                                              *
C     *                                                         *
C     *  INPUT VARIABLES:                                       *
C     *                                                         *
C     *  GS      = SECONDARY GAMMA                              *
C     *  GP      = PRIMARY GAMMA                                *
C     *  MWSP    = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO  *
C     *  TS0P0   = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE  *
C     *            RATIO                                        *
C     *  WSPI    = SECONDARY-TO-PRIMARY MASS FLOW RATIO         *
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE *
C     *  AM2P1   = PRIMARY-TO-MIXING TUBE MINIMUM AREA RATIO    *
C     *  RD      = NORMAL SHOCK DIFFUSER COEFFICIENT            *
C     *                                                         *
C     *  OUTPUT VARIABLES:                                      *
C     *                                                         *
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE        *
C     *            ENTRANCE                                     *
C     *  AS1P1   = SECONDARY-TO-PRIMARY AREA RATIO AT THE       *
C     *            MIXING TUBE ENTRANCE                         *
C     *  GM      = MIXED STREAM GAMMA                           *
C     *  MWMP    = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT     *
C     *            RATIC                                        *
C     *  TM0P0   = MIXED STREAM-TO-PRIMARY STAGNATION           *
C     *            TEMPERATURE RATIO                            *
C     *  MM3     = MIXED STREAM MACH NO. AT THE MIXING TUBE     *
C     *            EXIT                                         *
C     *  PP0S0   = PRIMARY-TO-SECONDARY STAGNATION PRESSURE     *
C     *            RATIO                                        *
C     *  PM3S0   = MIXED STREAM STATIC-TO-SECONDARY STAGNATION  *
C     *            PRESSURE RATIO                               *
C     *  FAIL    = ERROR FLAG                                   *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE CPES(GS,GP,MWSP,TS0P0,WSPI,MP1,AM2P1,RD,MS1,
     -AS1P1,GM,MWMP,TM0P0,MM3,PP0S0,PM3S0,FAIL)
C
```

7 5.1 CLGDSP (Cont.)

```
      IMPLICIT REAL*4(M)
      DATA YES/'YES'/
C
C
C     ***********************************************************
C     *                                                         *
C     *                  GAS DYNAMIC FUNCTIONS                  *
C     *                                                         *
C     ***********************************************************
C
C
      WM(G,M)=M*SQRT(G*(1.+0.5*(G-1.)*(M**2)))
      PPOM(G,M)=(1.+0.5*(G-1.)*(M**2))**(-G/(G-1.))
      PYXMX(G,MX)=(2.*G/(G+1.))*(MX**2)-((G-1.)/(G+1.))
      MYXMX(G,MX)=SQRT((2.0+(G-1.0)*MX*MX)/(2.0*G*MX*MX-G+1.0))
C
C
C     ***********************************************************
C     *                                                         *
C     *     CALCULATE THE MIXED-GAS PROPERTIES AT SECTION 3.    *
C     *                                                         *
C     ***********************************************************
C
C
      MWMP=(1.+WSPI)/(1.+(WSPI/MWSP))
      CPSP=(GS/GP)*((GP-1.)/(GS-1.))/MWSP
      GM=1./(1.-((GP-1.)/GP)*((1.+(WSPI/MWSP))/(1.+CPSP*WSPI)))
      CPMP=(1.+WSPI*CPSP)/(1.+WSPI)
C
C
C     ***********************************************************
C     *                                                         *
C     *  CALCULATE THE STAGNATION TEMPERATURE RATIO: TMO/TPO.   *
C     *                                                         *
C     ***********************************************************
C
C
      TMOPO=(1.+WSPI*CPSP*TSOPO)/(1.+WSPI*CPSP)
C
C
C     ***********************************************************
C     *                                                         *
C     *      CALCULATE C-P EJECTOR SOLUTION, MM2,MS1,AS1P1.     *
C     *                                                         *
C     ***********************************************************
C
C
      CO=(1.+WSPI)*SQRT(TMOPO/MWMP)*WM(GP,MP1)
C
C
```

7.5.1 CLGDSP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *  CHECK INPUT VALUE OF "AM2P1" FOR CONSISTENCY WITH      *
C     *  OTHER DATA FOR SOLUTIONS TO EXIST.                     *
C     *                                                         *
C     ***********************************************************
C
      AMAX=((C0**2)/(GP*(MP1**2))-0.5*(((GM-1.0)/GM)*
     -GP*(MP1**2)))
      IF(AM2P1 .GT. AMAX) GO TO 120
      C1=C0/AM2P1
      MM2=SQRT((SQRT(GM**2+2.*GM*(GM-1.)*(C1**2))-GM)/
     -(GM*(GM-1.0)))
      IF(MM2 .LT. 1.0) GO TO 60
      D2=(AM2P1*GM*(MM2**2)-GP*(MP1**2))
      IF(D2 .LE. 0.0) GO TO 80
      C2=WSPI*SQRT(TS0P0/MWSP)*WM(GP,MP1)/D2
      MS1=SQRT(2./(1.0+(2.0*(C2**2)-1.0)*GS))
      AS1P1=D2/(GS*(MS1**2))
C
C
C     ***********************************************************
C     *                                                         *
C     *          CALCULATE THE VARIOUS PRESSURE RATIOS.         *
C     *                                                         *
C     ***********************************************************
C
C
      PP0S0=PP0M(GS,MS1)/PP0M(GP,MP1)
      PM2S0=PP0M(GS,MS1)
C
C
C     ***********************************************************
C     *                                                         *
C     *  FOR A DIFFUSER BASED ON A NORMAL SHOCK AT MX=MM2, THE  *
C     *  OVERALL EJECTOR PRESSURE RISE IS PM3S0.                *
C     *                                                         *
C     ***********************************************************
C
C
      PM3S0=PM2S0*RD*PYXMX(GM,MM2)
      MM3=MYXMX(GM,MM2)
      IF(MS1.GT.1.0) GO TO 100
      RETURN
C
C
C     ***********************************************************
C     *                                                         *
C     *                    ERROR MESSAGES                       *
```

7.5.1 CLGDSP (Cont.)

```
C     *                                                          *
C     ************************************************************
C
C
60    WRITE(5,70)
70    FORMAT(5X,'......ERROR: SUBSONIC FLOW AT SECTION 2.'//)
      GO TO 140
80    WRITE(5,90)
90    FORMAT(5X,'.....ERROR: IMPOSSIBLE VALUE OF MS1.'//)
      GO TO 140
100   WRITE(5,110)
110   FORMAT(5X,'.....NOTE: MS1 IS SUPERSONIC.'//)
      GO TO 140
120   WRITE(5,130) AMAX
130   FORMAT(5X,'.....ERROR: AM2P1 >',F7.3,2X,'WAS INPUT.',/,
     -10X,'THIS VALUE OF AM2P1 IS INCONSISTENT WITH THE',/,
     -10X,'REMAINDER OF THE INPUT DATA.'//)
140   FAIL=YES
      END
```

7.5.1 CLGDSP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *          CONSTANT-AREA EJECTOR SUBROUTINE (CAES)        *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE CAES CALCULATES THE BREAK-OFF COMPRESSION   *
C     *  RATIO FOR A CONSTANT-AREA, SUBSONIC-SUPERSONIC         *
C     *  EJECTOR BY A ONE-DIMENSIONAL ANALYSIS.                 *
C     *                                                         *
C     *  PP0S0-VS-PM3S0 AND OTHER EJECTOR CHARACTERISTICS ARE   *
C     *  CALCULATED FOR WSP=WSPI IN THE SUPERSONIC REGIME (SR)  *
C     *  OR THE SATURATED-SUPERSONIC REGIME (SSR).  THE         *
C     *  ASSUMPTION IS MADE THAT MP1 REMAINS AT ITS DESIGN      *
C     *  VALUE.  (MR) IS THE MIXED REGIME.                      *
C     *                                                         *
C     *  INPUT VARIABLES:                                       *
C     *                                                         *
C     *  GS      = SECONDARY GAMMA                              *
C     *  GP      = PRIMARY GAMMA                                *
C     *  MWSP    = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO  *
C     *  TS0P0   = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE  *
C     *            RATIO                                        *
C     *  WSPI    = SECONDARY-TO-PRIMARY MASS FLOW RATIO         *
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE *
C     *  AP1M3   = PRIMARY-TO-MIXING TUBE AREA RATIO            *
C     *                                                         *
C     *  OUTPUT VARIABLES:                                      *
C     *                                                         *
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE        *
C     *            ENTRANCE                                     *
C     *  GM      = MIXED STREAM GAMMA                           *
C     *  MWMP    = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT     *
C     *            RATIO                                        *
C     *  TM0P0   = MIXED STREAM-TO-PRIMARY STAGNATION           *
C     *            TEMPERATURE RATIO                            *
C     *  MM3     = MIXED STREAM MACH NO. AT THE MIXING TUBE     *
C     *            EXIT                                         *
C     *  PP0S0   = PRIMARY-TO-SECONDARY STAGNATION PRESSURE     *
C     *            RATIO                                        *
C     *  PM3S0   = MIXED STREAM STATIC-TO-SECONDARY STAGNATION  *
C     *            PRESSURE RATIO                               *
C     *  FAIL    = ERROR FLAG                                   *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE CAES(GS,GP,MWSP,TS0P0,WSPI,MP1,AP1M3,MS1,GM,
```

```
     -MWMP,TMOPC,MM3,PPOSO,PM3SO,FAIL)                                  CAES    05100
C                                                                       CAES    05200
      IMPLICIT REAL*4(M)                                                CAES    05300
C                                                                       CAES    05400
C                                                                       CAES    05500
C     ****************************************************************  CAES    05600
C     *                                                              *  CAES    05700
C     *                    GAS DYNAMIC FUNCTIONS                     *  CAES    05800
C     *                                                              *  CAES    05900
C     ****************************************************************  CAES    06000
C                                                                       CAES    06100
      WM(G,M)=M*SQRT(G*(1.0+0.5*(G-1.0)*M*M))                           CAES    06200
      PYXMX(G,MX)=(2.*G/(G+1.))*(MX**2)-((G-1.)/(G+1.))                 CAES    06300
C                                                                       CAES    06400
C     ****************************************************************  CAES    06500
C     *                                                              *  CAES    06600
C     *  INITIALIZE THE VARIABLES FOR THE ITERATION TO FIND          *  CAES    06700
C     *  THE BREAK-OFF VALUE OF MS1, MS1B.                           *  CAES    06800
C     *                                                              *  CAES    06900
C     ****************************************************************  CAES    07000
C                                                                       CAES    07100
      DATA DMS1B,MS1BL/0.1,1.0E-03/,YES/'YES'/                          CAES    07200
      DATA ERRMS1,ERRGRY,NITMAX/2*5.0E-06,100/                          CAES    07300
C                                                                       CAES    07400
C     ****************************************************************  CAES    07500
C     *                                                              *  CAES    07600
C     *       LIMIT, PS1P1U, IS BASED ON A NORMAL SHOCK              *  CAES    07700
C     *  STANDING AT THE PRIMARY NOZZLE EXIT WITH: MX=MP1.           *  CAES    07800
C     *                                                              *  CAES    07900
C     ****************************************************************  CAES    08000
C                                                                       CAES    08100
      PS1P1U=PYXMX(GF,MP1)                                              CAES    08200
C                                                                       CAES    08300
C     ****************************************************************  CAES    08400
C     *                                                              *  CAES    08500
C     *  AT THE JUNCTURE (J) BETWEEN THE (SR) AND THE (SSR)          *  CAES    08600
C     *  THE VARIABLES ARE: (MS1=1.0, PS1P1=1.0, MP1=MP1,            *  CAES    08700
C     *  WSP=WSPJ).                                                  *  CAES    08800
C     *                                                              *  CAES    08900
C     ****************************************************************  CAES    09000
C                                                                       CAES    09100
      AS1P1=((1.0/AP1M3)-1.0)                                           CAES    09200
      CONST=SQRT(MWSP/TSOPC)*AS1P1/WM(CP,MP1)                           CAES    09300
                                                                        CAES    09400
                                                                        CAES    09500
                                                                        CAES    09600
                                                                        CAES    09700
                                                                        CAES    09800
                                                                        CAES    09900
                                                                        CAES    10000
```

7.5.1 CLGDSP (Cont.)

```
      WSPJ=CCNST*WM(GS,1.0)
C
C
C     ***********************************************************
C     *                                                         *
C     *  DETERMINE WHETHER THE OPERATING REGIME IS (SR) OR      *
C     *  (SSR).                                                 *
C     *                                                         *
C     ***********************************************************
C
C
      IF(WSPI.LT.WSPJ) GO TO 20
C
C
C     ***********************************************************
C     *                                                         *
C     * FOR THE BREAK-OFF POINT (B) BETWEEN THE (SSR) AND (MR) *
C     *                                                         *
C     ***********************************************************
C
C
      MS1B=1.0
      PS1P1B=WSPI/WSPJ
      IF(PS1P1B.GE.PS1P1U        70
      GO TO 40
C
C
C     ***********************************************************
C     *                                                         *
C     *  DETERMINE THE BREAK-OFF POINT (B) BETWEEN (SR) AND     *
C     *  (MR).  INITIALIZE THE VARIABLES FOR THE ITERATION TO   *
C     *  FIND (MS1B,PS1P1B) IN (SSR).                           *
C     *                                                         *
C     ***********************************************************
C
C
20    NIT=1
      NTYPE=1
C
C
C     ***********************************************************
C     *                                                         *
C     *  INITIALIZE THE ITERATION TO FIND (MS1B) SOLUTION IN    *
C     *  (SR).  THE SOLUTION IS BASED ON FABRI'S CRITERION.     *
C     *                                                         *
C     ***********************************************************
C
C
      MS1B=MS1BL
30    CALL CAEFC(GS,GP,MS1B,MP1,AP1M3,PS1P1B,NTYPE,FAIL)
```

```
      IF(FAIL.EQ.YES) RETURN                                            CAES    15100
      IF(NTYPE.EQ.3) GO TO 32                                           CAES    15200
      WSPB=CONST*PS1P1B*WM(GS,MS1B)                                     CAES    15300
      CALL ITER(MS1B,DMS1B,ERRMS1,+1.0,WSPB,WSPI,ERRORY,NIT,            CAES    15400
     -NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)                          CAES    15500
      IF(MS1B.GT.1.0) MS1B=1.0                                          CAES    15600
      IF(NIT.GT.NITMAX) GO TO 100                                       CAES    15700
      GO TO(30,30,40),NTYPE                                             CAES    15800
C                                                                       CAES    15900
C     ****************************************************************  CAES    16000
C     *                                                              *  CAES    16100
C     *         APPROXIMATE SOLUTION WITH (PS1P1B=1) FOUND.          *  CAES    16200
C     *                                                              *  CAES    16300
C     ****************************************************************  CAES    16400
C                                                                       CAES    16500
C                                                                       CAES    16600
32    A=(WSPI/(CONST*PS1P1B))**2                                        CAES    16700
      MS1B=SQRT((1./(GS-1.))*(SQRT(1.+(2.*(GS-1.)/GS)*A)-1.))           CAES    16800
C                                                                       CAES    16900
C     ****************************************************************  CAES    17000
C     *                                                              *  CAES    17100
C     *         DETERMINE THE REMAINING VARIABLES AT (B).            *  CAES    17200
C     *                                                              *  CAES    17300
C     ****************************************************************  CAES    17400
C                                                                       CAES    17500
C                                                                       CAES    17600
40    MS1=MS1B                                                          CAES    17700
      PS1P1=PS1P1B                                                      CAES    17800
C                                                                       CAES    17900
C     ****************************************************************  CAES    18000
C     *                                                              *  CAES    18100
C     *  CALCULATE THE DOWNSTREAM CONDITIONS FOR THE BREAK-OFF       *  CAES    18200
C     *  POINT.                                                      *  CAES    18300
C     *                                                              *  CAES    18400
C     ****************************************************************  CAES    18500
C                                                                       CAES    18600
      CALL CAECCV(GS,GF,MWSP,TS0P0,MS1,MP1,AP1M3,PS1P1,GM,MWMP,         CAES    18700
     -TM0P0,MM3,PP0S0,PM3S0,FAIL)                                       CAES    18800
      IF(FAIL.EQ.YES) GO TO 80                                          CAES    18900
      RETURN                                                            CAES    19000
C                                                                       CAES    19100
C     ****************************************************************  CAES    19200
C     *                                                              *  CAES    19300
C     *                      ERROR MESSAGES                          *  CAES    19400
C     *                                                              *  CAES    19500
```

7.5.1 CLGDSP (Cont.)

```
C     ***********************************************************
C
C
70    WRITE(5,72)
72    FORMAT(/,5X,'...ERROR IN CAES:(PS1P1B.GE.PS1P1U).')
      GO TC 12C
80    WRITE(5,90)
90    FORMAT(/,5X,'...ERROR CCCURED IN (CAEOCV).',/)
      GO TC 120
100   WRITE(5,11C)
11C   FORMAT(/,5X,'...NCN-CCNVERGENCE OF ITERATIONS FOR',/,
     -5X,'(MS1B,PS1P1B) IN (SR) IN (CAES).',/)
120   FAIL=YES
      END
```

```
C     ****************************************************************      CAEFC  00100
C     *                                                              *      CAEFC  00200
C     *                    CONSTANT-AREA EJECTOR                     *      CAEFC  00300
C     *              FABRI CRITERION SUBROUTINE (CAEFC)              *      CAEFC  00400
C     *                    (OF SUBROUTINE CAES)                      *      CAEFC  00500
C     *                                                              *      CAEFC  00600
C     ****************************************************************      CAEFC  00700
C                                                                            CAEFC  00800
C     ****************************************************************      CAEFC  00900
C     *                                                              *      CAEFC  01000
C     *  SUBROUTINE CAEFC PERFORMS THE CONSTANT-AREA EJECTOR,        *      CAEFC  01100
C     *  FABRI CRITERION CALCULATIONS BY 1-D ANALYSIS FOR A          *      CAEFC  01200
C     *  SUPERSONIC PRIMARY (MP1>1) AND A SUBSONIC SECONDARY         *      CAEFC  01300
C     *  (MS1<1) WHICH CHOKES IN THE EJECTOR SHROUD (MS2=1).         *      CAEFC  01400
C     *  THIS EJECTOR ANALYSIS IS BASED ON THE CONSTANT-AREA         *      CAEFC  01500
C     *  SHROUD, EJECTOR ANALYSIS OF FABRI.  REFERENCE:              *      CAEFC  01600
C     *  NACA TN 1410.                                               *      CAEFC  01700
C     *                                                              *      CAEFC  01800
C     *  INPUT VARIABLES:                                            *      CAEFC  01900
C     *                                                              *      CAEFC  02000
C     *  GS      = SECONDARY GAMMA                                   *      CAEFC  02100
C     *  GP      = PRIMARY GAMMA                                     *      CAEFC  02200
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE             *      CAEFC  02300
C     *            ENTRANCE                                          *      CAEFC  02400
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE      *      CAEFC  02500
C     *  AP1M3   = PRIMARY-TO-MIXING TUBE AREA RATIO                 *      CAEFC  02600
C     *                                                              *      CAEFC  02700
C     *  OUTPUT VARIABLES:                                           *      CAEFC  02800
C     *                                                              *      CAEFC  02900
C     *  PS1P1   = SECONDARY-TO-PRIMARY STATIC PRESSURE RATIO        *      CAEFC  03000
C     *  NTYPE   = ITERATION CONTROL VARIABLE                        *      CAEFC  03100
C     *  FAIL    = ERROR FLAG                                        *      CAEFC  03200
C     *                                                              *      CAEFC  03300
C     ****************************************************************      CAEFC  03400
C                                                                            CAEFC  03500
      SUBROUTINE CAEFC(GS,GP,MS1,MP1,AP1M3,PS1P1,NTYPE,FAIL)                 CAEFC  03600
C                                                                            CAEFC  03700
      IMPLICIT REAL*4(M)                                                     CAEFC  03800
      DATA YES/'YES'/,SUP/'SUP'/                                             CAEFC  03900
C                                                                            CAEFC  04000
C     ****************************************************************      CAEFC  04100
C     *                                                              *      CAEFC  04200
C     *                    GAS DYNAMIC FUNCTIONS                     *      CAEFC  04300
C     *                                                              *      CAEFC  04400
C     ****************************************************************      CAEFC  04500
C                                                                            CAEFC  04600
      PPOM(G,M)=(1.+.5*(G-1.)*(M**2))**(-G/(G-1.))                           CAEFC  04700
                                                                             CAEFC  04800
                                                                             CAEFC  04900
                                                                             CAEFC  05000
```

```
      AASM(G,M)=(1./M)*(((2./(G+1.))*(1.+0.5*(G-1.)*(M**2)))
     -**(0.5*(G+1.)/(G-1.)))                                          CAEFC  05100
      MMS(G,MS)=SQRT(((2./(G+1.))*(MS**2))/                           CAEFC  05200
     -(1.-((G-1.)/(G+1.))*(MS**2)))                                   CAEFC  05300
C                                                                     CAEFC  05400
C     ****************************************************************CAEFC  05500
C     *                                                              *CAEFC  05600
C     *            FABRI'S CRITERION APPLIES ONLY WHEN               *CAEFC  05700
C     *            (MS1.LE.1.0) AND (PS1P1.LE.1.0).                  *CAEFC  05800
C     *                                                              *CAEFC  05900
C     ****************************************************************CAEFC  06000
C                                                                     CAEFC  06100
      IF(MS1.GT.(1.0)) GO TO 10                                       CAEFC  06200
      IF((1.-MS1).LT.(1.E-4)) GO TO 100                               CAEFC  06300
C                                                                     CAEFC  06400
C     ****************************************************************CAEFC  06500
C     *                                                              *CAEFC  06600
C     *    CALCULATE MP2 AT STATION (2) WHERE MS2=1.0 FROM           *CAEFC  06700
C     *    THE AREA RATIO FOR STREAM (P) AT STATION (2).             *CAEFC  06800
C     *                                                              *CAEFC  06900
C     ****************************************************************CAEFC  07000
C                                                                     CAEFC  07100
      AP2PS=(AASM(GP,MP1)/AP1M3)*(1.-(1.-AP1M3)/AASM(GS,MS1))         CAEFC  07200
      CALL MAAS(GP,MP1,AP2PS,SUP,5.0E-06,MP2,FAIL)                    CAEFC  07300
      IF(FAIL.EQ.YES) RETURN                                          CAEFC  07400
      IF(MP2.LT.MP1) GO TO 30                                         CAEFC  07500
      IF((MP2/MP1-1.).LT.(1.E-4)) GO TO 100                           CAEFC  07600
C                                                                     CAEFC  07700
C     ****************************************************************CAEFC  07800
C     *                                                              *CAEFC  07900
C     *              CALCULATE STATIC PRESSURE RATIO                 *CAEFC  08000
C     *              PS1P1 BASED ON FABRI'S CRITERION.               *CAEFC  08100
C     *                                                              *CAEFC  08200
C     ****************************************************************CAEFC  08300
C                                                                     CAEFC  08400
      VD=(1.0-AP1M3)*((1.0+GS*(MS1**2))-                              CAEFC  08500
     -(PPOM(GS,1.0)/PPOM(GS,MS1))*((1.0+GS)/AASM(GS,MS1)))            CAEFC  08600
      VN=(PPOM(GP,MP2)/PPOM(GP,MP1))*AP1M3*(AASM(GP,MP2)/             CAEFC  08700
     -AASM(GP,MP1))*(1.+GP*(MP2**2))-AP1M3*(1.+GP*(MP1**2))           CAEFC  08800
      PS1P1=VN/VD                                                     CAEFC  08900
      IF(PS1P1.LE.(0.0)) GO TO 50                                     CAEFC  09000
      IF(PS1P1.GT.(1.0)) GO TO 100                                    CAEFC  09100
      RETURN                                                          CAEFC  09200
C                                                                     CAEFC  09300
```

7.5.1 CLGDSP (Cont.)

```
C
C     ***********************************************************
C     *                                                         *
C     *                      ERROR MESSAGES                     *
C     *                                                         *
C     ***********************************************************
C
C
10    WRITE(5,20)
20    FORMAT(/,5X,'...ERROR IN CAEFC: (MS1.GT.(1.0)) .',//)
      GO TO 90
30    WRITE(5,40)
40    FORMAT(/,5X,'...ERROR IN CAEFC: (MP2.LT.MP1).',//)
      GO TO 90
50    WRITE(5,60)
60    FORMAT(/,5X,'...ERROR IN CAEFC: (PS1P1.LT.(0.0)).',//)
      GO TO 90
90    FAIL=YES
      RETURN
C
C
C     ***********************************************************
C     *                                                         *
C     *                MS1 IS APPROXIMATELY 1.0 AND             *
C     *                MP1 IS APPROXIMATELY MP1.                *
C     *                                                         *
C     ***********************************************************
C
C
100   NTYPE=3
      PS1P1=1.0
      END
```

```
C     ****************************************************************      CAEOCV 00100
C     *                                                              *      CAEOCV 00200
C     *                    CONSTANT-AREA EJECTOR                     *      CAEOCV 00300
C     *          OVERALL CONTROL VOLUME SUBROUTINE (CAEOCV)          *      CAEOCV 00400
C     *                    (OF SUBROUTINE CAES)                      *      CAEOCV 00500
C     *                                                              *      CAEOCV 00600
C     ****************************************************************      CAEOCV 00700
C                                                                            CAEOCV 00800
C     ****************************************************************      CAEOCV 00900
C     *                                                              *      CAEOCV 01000
C     *  SUBROUTINE CAEOCV PERFORMS THE CONSTANT-AREA EJECTOR,       *      CAEOCV 01100
C     *  OVERALL CONTROL VOLUME CALCULATIONS BY 1-D ANALYSIS         *      CAEOCV 01200
C     *  FROM INLET SECTION (1) TO MIXED SECTION (3).                *      CAEOCV 01300
C     *                                                              *      CAEOCV 01400
C     *  INPUT VARIABLES:                                            *      CAEOCV 01500
C     *                                                              *      CAEOCV 01600
C     *  GS      = SECONDARY GAMMA                                   *      CAEOCV 01700
C     *  GP      = PRIMARY GAMMA                                     *      CAEOCV 01800
C     *  MWSP    = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO       *      CAEOCV 01900
C     *  TSOPO   = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE       *      CAEOCV 02000
C     *            RATIO                                             *      CAEOCV 02100
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE             *      CAEOCV 02200
C     *            ENTRANCE                                          *      CAEOCV 02300
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE      *      CAEOCV 02400
C     *  AP1M3   = PRIMARY-TO-MIXING TUBE AREA RATIO                 *      CAEOCV 02500
C     *  PS1P1   = SECONDARY-TO-PRIMARY STATIC PRESSURE RATIO        *      CAEOCV 02600
C     *                                                              *      CAEOCV 02700
C     *  OUTPUT VARIABLES:                                           *      CAEOCV 02800
C     *                                                              *      CAEOCV 02900
C     *  GM      = MIXED STREAM GAMMA                                *      CAEOCV 03000
C     *  MWMP    = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT          *      CAEOCV 03100
C     *            RATIO                                             *      CAEOCV 03200
C     *  TMOPO   = MIXED STREAM-TO-PRIMARY STAGNATION                *      CAEOCV 03300
C     *            TEMPERATURE RATIO                                 *      CAEOCV 03400
C     *  MM3     = MIXED STREAM MACH NO. AT THE MIXING TUBE          *      CAEOCV 03500
C     *            EXIT                                              *      CAEOCV 03600
C     *  PPOSO   = PRIMARY-TO-SECONDARY STAGNATION PRESSURE          *      CAEOCV 03700
C     *            RATIO                                             *      CAEOCV 03800
C     *  PM3SO   = MIXED STREAM STATIC-TO-SECONDARY STAGNATION       *      CAEOCV 03900
C     *            PRESSURE RATIO                                    *      CAEOCV 04000
C     *  FAIL    = ERROR FLAG                                        *      CAEOCV 04100
C     *                                                              *      CAEOCV 04200
C     ****************************************************************      CAEOCV 04300
C                                                                            CAEOCV 04400
      SUBROUTINE CAEOCV(GS,GP,MWSP,TSOPO,MS1,MP1,AP1M3,PS1P1,GM,             CAEOCV 04500
     -MWMP,TMOPO,MM3,PPOSO,PM3SO,FAIL)                                       CAEOCV 04600
C                                                                            CAEOCV 04700
      IMPLICIT REAL*4(M)                                                     CAEOCV 04800
      DATA YES/'YES'/                                                        CAEOCV 04900
                                                                             CAEOCV 05000
```

```
C
C     ****************************************************************
C     *                                                              *
C     *                    GAS DYNAMIC FUNCTIONS                     *
C     *                                                              *
C     ****************************************************************
C
      WM(G,M)=M*SQRT(G*(1.+.5*(G-1.)*(M**2)))
      T(G,M)=(1.+G*(M**2))/(M*SQRT(1.+.5*(G-1.)*(M**2)))
      PPOM(G,M)=(1.+.5*(G-1.)*(M**2))**(-G/(G-1.))
C
C     ****************************************************************
C     *                                                              *
C     *                  EJECTOR MASS FLOW RATIO                     *
C     *                                                              *
C     ****************************************************************
C
      C0=SQRT(MWSP/TSOP0)
      WSP=PS1P1*((1.-AP1M3)/AP1M3)*C0*(WM(GS,MS1)/WM(GP,MP1))
      CPSP=(GS/GP)*((GP-1.)/(GS-1.))/MWSP
C
C     ****************************************************************
C     *                                                              *
C     *                  MIXED FLOW PROPERTIES                       *
C     *                                                              *
C     ****************************************************************
C
      MWMP=(1.+WSP)/(1.+(WSP/MWSP))
      GM=1./(1.-((GP-1.)/GP)*((1.+(WSP/MWSP))/(1.+CPSP*WSP)))
      TMOP0=(1.+WSP*CPSP*TSOP0)/(1.+WSP*CPSP)
C
C     ****************************************************************
C     *                                                              *
C     *                        SOLVE FOR MM3                         *
C     *                                                              *
C     ****************************************************************
C
      C1=SQRT((TSOP0/MWSP)*(GP/GS))
      C2=SQRT(TMOP0/MWMP*(GP/GM))
      TM3=(T(GP,MP1)+C1*WSP*T(GS,MS1))/((1.+WSP)*C2)
      TM3MIN=SQRT(2.*(GM+1.))
      IF(TM3.LT.TM3MIN) GO TO 10
```

```
CAEOCV 05100
CAEOCV 05200
CAEOCV 05300
CAEOCV 05400
CAEOCV 05500
CAEOCV 05600
CAEOCV 05700
CAEOCV 05800
CAEOCV 05900
CAEOCV 06000
CAEOCV 06100
CAEOCV 06200
CAEOCV 06300
CAEOCV 06400
CAEOCV 06500
CAEOCV 06600
CAEOCV 06700
CAEOCV 06800
CAEOCV 06900
CAEOCV 07000
CAEOCV 07100
CAEOCV 07200
CAEOCV 07300
CAEOCV 07400
CAEOCV 07500
CAEOCV 07600
CAEOCV 07700
CAEOCV 07800
CAEOCV 07900
CAEOCV 08000
CAEOCV 08100
CAEOCV 08200
CAEOCV 08300
CAEOCV 08400
CAEOCV 08500
CAEOCV 08600
CAEOCV 08700
CAEOCV 08800
CAEOCV 08900
CAEOCV 09000
CAEOCV 09100
CAEOCV 09200
CAEOCV 09300
CAEOCV 09400
CAEOCV 09500
CAEOCV 09600
CAEOCV 09700
CAEOCV 09800
CAEOCV 09900
CAEOCV 10000
```

7.5.1 CLGDSP (Cont.)

```
      C3=(TM3**2-2.*GM)
      C4=(((GM-1.)/2.)*(TM3**2)-GM**2)
      C5=SQRT(C3**2+4.*C4)
      MSQD3M=(-C3-C5)/(2.*C4)
      MSQD3P=(-C3+C5)/(2.*C4)
C
C
C     ***********************************************************
C     *                                                         *
C     *       DETERMINE TWO POSSIBLE MIXED-FLOW MACH NO.        *
C     *       SOLUTIONS.  USE ONLY SUBSONIC RESULT AT (3).      *
C     *                                                         *
C     ***********************************************************
C
C
      IF(MSQD3M.GE.(0.0)) MM3M=SQRT(MSQD3M)
      IF(MSQD3P.GE.(0.0)) MM3P=SQRT(MSQD3P)
      MM3=MM3P
C
C
C     ***********************************************************
C     *                                                         *
C     *                 CALCULATE PRESSURE RATIOS               *
C     *                                                         *
C     ***********************************************************
C
C
      C6=SQRT(TM0P0/MWMP)
      PM3P1=C6*AP1M3*(1.+WSP)*(WM(GP,MP1)/WM(GM,MM3))
      PP0S0=(PP0M(GS,MS1)/PP0M(GP,MP1))/PS1P1
      PM3S0=PM3P1*(PP0M(GS,MS1)/PS1P1)
      PM0S0=PM3S0/PP0M(GM,MM3)
      RETURN
C
C
C     ***********************************************************
C     *                                                         *
C     *                       ERROR MESSAGES                    *
C     *                                                         *
C     ***********************************************************
C
C
10    WRITE(5,20)
20    FORMAT(/,5X,'...ERROR IN CAEOCV: NO SOLUTION.',/)
      FAIL=YES
      END
```

```
C     ****************************************************************      SSES    00100
C     *                                                              *      SSES    00200
C     *      SUPERSONIC-SUPERSONIC EJECTOR SUBROUTINE (SSES)         *      SSES    00300
C     *                                                              *      SSES    00400
C     ****************************************************************      SSES    00500
C                                                                             SSES    00600
C     ****************************************************************      SSES    00700
C     *                                                              *      SSES    00800
C     *  SUBROUTINE SSES CALCULATES THE MAXIMUM COMPRESSION          *      SSES    00900
C     *  RATIO FOR A CONSTANT-AREA, SUPERSONIC-SUPERSONIC            *      SSES    01000
C     *  EJECTOR, BY ONE-DIMENSIONAL ANALYSIS, ASSUMING AN           *      SSES    01100
C     *  ISENTROPIC RECOMPRESSION OF THE SECONDARY STREAM TO         *      SSES    01200
C     *  SONIC CONDITIONS.                                           *      SSES    01300
C     *                                                              *      SSES    01400
C     *  INPUT VARIABLES:                                            *      SSES    01500
C     *                                                              *      SSES    01600
C     *  GS      = SECONDARY GAMMA                                   *      SSES    01700
C     *  GP      = PRIMARY GAMMA                                     *      SSES    01800
C     *  MWSMWP  = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO       *      SSES    01900
C     *  TSOTPO  = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE       *      SSES    02000
C     *            RATIO                                             *      SSES    02100
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE             *      SSES    02200
C     *            ENTRANCE                                          *      SSES    02300
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE      *      SSES    02400
C     *  AS1AP1  = SECONDARY-TO-PRIMARY AREA RATIO                   *      SSES    02500
C     *                                                              *      SSES    02600
C     *  OUTPUT VARIABLES:                                           *      SSES    02700
C     *                                                              *      SSES    02800
C     *  WSWP    = SECONDARY-TO-PRIMARY MASS FLOW RATIO              *      SSES    02900
C     *  GM      = MIXED STREAM GAMMA                                *      SSES    03000
C     *  MWMMWP  = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT          *      SSES    03100
C     *            RATIO                                             *      SSES    03200
C     *  TMOTPO  = MIXED STREAM-TO-PRIMARY STAGNATION                *      SSES    03300
C     *            TEMPERATURE RATIO                                 *      SSES    03400
C     *  MM3     = MIXED STREAM MACH NO. AT THE MIXING TUBE          *      SSES    03500
C     *            EXIT                                              *      SSES    03600
C     *  PPOPS1  = PRIMARY STAGNATION-TO-SECONDARY STATIC            *      SSES    03700
C     *            PRESSURE RATIO                                    *      SSES    03800
C     *  PM3PS1  = STATIC PRESSURE COMPRESSION RATIO                 *      SSES    03900
C     *  FAIL    = ERROR FLAG                                        *      SSES    04000
C     *                                                              *      SSES    04100
C     ****************************************************************      SSES    04200
C                                                                             SSES    04300
      SUBROUTINE SSES(GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1,WSWP,              SSES    04400
     -GM,MWMMWP,TMOTPO,MM3,PPOPS1,PM3PS1,FAIL)                              SSES    04500
C                                                                           SSES    04600
      IMPLICIT REAL*4(M)                                                    SSES    04700
      DATA YES/'YES'/,SUP/'SUP'/                                            SSES    04800
C                                                                           SSES    04900
                                                                            SSES    05000
```

7.5.1 CLGDSP (Cont.)

```
C
C     ***********************************************************
C     *                                                         *
C     *                    SPECIAL FUNCTIONS                    *
C     *                                                         *
C     ***********************************************************
C
C
      F(GX,MXX)=1.0+GX*MXX*MXX
      G(GX,MXX)=MXX*SQRT(1.0+0.5*(GX-1.0)*MXX*MXX)
      H(MM,TT,GG)=SQRT(MM*GG/TT)
      PP0(GX,MXX)=(1.0+0.5*(GX-1.0)*MXX*MXX)**(GX/(1.0-GX))
      AAS(GX,MXX)=((2.0*(1.0+0.5*(GX-1.0)*MXX*MXX)/(GX+1.0))**(0.5*(GX+1
     -.0)/(GX-1.0)))/MXX
C
C
C     ***********************************************************
C     *                                                         *
C     *                   CALCULATE CONSTANTS                   *
C     *                                                         *
C     ***********************************************************
C
C
      GS3=GS/(GS-1.0)
      GP3=GP/(GP-1.0)
      GSGP=GS/GP
      MWPMWS=1.0/MWSMWP
      PP1PP0=PP0(GP,MP1)
      AS1ASS=AAS(GS,MS1)
      AP1APS=AAS(GP,MP1)
      ASSAS1=1.0/AS1ASS
      FGSMS1=F(GS,MS1)
      FGPMP1=F(GP,MP1)
      GGSMS1=G(GS,MS1)
      GGPMP1=G(GP,MP1)
C
C
C     ***********************************************************
C     *                                                         *
C     *  CALCULATE PS1PP1 FOR AN ISENTROPIC RECOMPRESSION TO    *
C     *  SONIC CONDITIONS.  MP2 IS OBTAINED FROM AP2APS.        *
C     *                                                         *
C     ***********************************************************
C
C
      IF(AS1AP1.GE.0.0) GO TO 1
      WRITE(5,2)AS1AP1
      FAIL=YES
      RETURN
1     AP2APS=AP1APS*(1.0+AS1AP1*(1.0-ASSAS1))
```

```
      CALL MAAS(GP,MP1,AP2APS,SUP,5.0E-06,MP2,FAIL)                    SSES    10100
      IF(FAIL.EQ.YES) RETURN                                           SSES    10200
      MS2=1.0                                                          SSES    10300
      C1=-FGPMP1+F(GP,MP2)*GGPMP1/G(GP,MP2)                            SSES    10400
      C2=FGSMS1-F(GS,MS2)*GGSMS1/G(GS,MS2)                             SSES    10500
      PS1PP1=C1/(AS1AP1*C2)                                            SSES    10600
C                                                                      SSES    10700
C     ***************************************************************SSES    10800
C     *                                                             *  SSES    10900
C     *            OVERALL CONTROL VOLUME CALCULATIONS              *  SSES    11000
C     *                                                             *  SSES    11100
C     ***************************************************************SSES    11200
C                                                                      SSES    11300
      WSWP=PS1PP1*AS1AP1*H(MWSMWP,TS0TP0,GSGP)*GGSMS1/GGPMP1           SSES    11400
      C1=WSWP*MWPMWS*GS3+GP3                                           SSES    11500
      C2=WSWP*MWPMWS*(GS3-1.0)+(GP3-1.0)                               SSES    11600
      GM=C1/C2                                                         SSES    11700
      GMGP=GM/GP                                                       SSES    11800
      MWMMWP=(WSWP+1.0)/(WSWP*MWPMWS+1.0)                              SSES    11900
      C1=TS0TP0*WSWP*MWPMWS*GS3+GP3                                    SSES    12000
      C2=WSWP*MWPMWS*GS3+GP3                                           SSES    12100
      TM0TP0=C1/C2                                                     SSES    12200
      FFX=H(MWMMWP,TM0TP0,GMGP)*(PS1PP1*AS1AP1*FGSMS1+FGPMP1)/(        SSES    12300
     -(1.0+WSWP)*GGPMP1)                                               SSES    12400
      C1=0.5*(GM-1.0)*FFX*FFX-GM*GM                                    SSES    12500
      C2=FFX*FFX-2.0*GM                                                SSES    12600
      C3=(-C2+SQRT(C2*C2+4.0*C1))/(2.0*C1)                             SSES    12700
      C4=(-C2-SQRT(C2*C2+4.0*C1))/(2.0*C1)                             SSES    12800
      MM3=SQRT(AMIN1(C3,C4))                                           SSES    12900
      PM3PP1=(PS1PP1*AS1AP1*FGSMS1+FGPMP1)/((1.0+AS1AP1)*F(GM,MM3))    SSES    13000
      PM3PS1=PM3PP1/PS1PP1                                             SSES    13100
      PS1PP0=PS1PP1*PP1PP0                                             SSES    13200
      PP0PS1=1.0/PS1PP0                                                SSES    13300
C                                                                      SSES    13400
C     ***************************************************************SSES    13500
C     *                                                             *  SSES    13600
C     *                      FORMAT STATEMENTS                      *  SSES    13700
C     *                                                             *  SSES    13800
C     ***************************************************************SSES    13900
C                                                                      SSES    14000
  2   FORMAT('0',T2,'IMPOSSIBLE VALUE...AS1AP1 =',E13.6)               SSES    14100
      END                                                              SSES    14200
```

7.5.1 CLGDSP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *                    SUBROUTINE (MAAS)                    *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE MAAS CALCULATES THE MACH NUMBER (M) GIVEN   *
C     *  THE AREA RATIO (A/A*) BY LINEAR ITERATION.             *
C     *                                                         *
C     *  INPUT VARIABLES:                                       *
C     *                                                         *
C     *  G       = SPECIFIC HEAT RATIO                          *
C     *  MINI    = INITIAL VALUE OF MACH NUMBER                 *
C     *  AAS     = THE AREA RATIO A/A*                          *
C     *  FLOW    = CONTROL VARIABLE SUCH THAT                   *
C     *          = "SUB" FOR THE SUBSONIC BRANCH                *
C     *          = "SUP" FOR THE SUPERSONIC BRANCH              *
C     *  ERROR   = MAX PERCENT DEVIATION IN MOLD AND MNEW FOR   *
C     *            A SOLUTION                                   *
C     *                                                         *
C     *  OUTPUT VARIABLES:                                      *
C     *                                                         *
C     *  MNEW    = FINAL VALUE OF MACH NUMBER                   *
C     *  FAIL    = ERROR FLAG                                   *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE MAAS(G,MINI,AAS,FLOW,ERROR,MNEW,FAIL)
C
      IMPLICIT REAL*4(M)
      DATA YES/'YES'/,SUP/'SUP'/
C
C
C     ***********************************************************
C     *                                                         *
C     *                    CALCULATE CONSTANTS                  *
C     *                                                         *
C     ***********************************************************
C
C
      G1=(G-1.0)/2.0
      G1I=1.0/G1
      G2=2.0/(G+1.0)
      G2I=1.0/G2
      G4=(G+1.0)/(2.0*(G-1.0))
      G4I=1.0/G4
C
```

7.5.1 CLGDSP (Cont.)

```
C
C     ***********************************************************
C     *                                                         *
C     *              CALCULATE THE SUPERSONIC BRANCH            *
C     *                                                         *
C     ***********************************************************
C
C
      MOLD=MINI
      IF(FLOW.NE.SUP) GO TO 2
      DO 1 J=1,200
      C1=(MOLD*AAS)**G4I
      MNEW=SQRT(G1I*(G2I*C1-1.0))
      XERROR=(MNEW-MOLD)*100.0/MOLD
      MOLD=MNEW
      IF(ABS(XERROR).LT.ERROR) RETURN
1     CONTINUE
      GO TO 4
C
C
C     ***********************************************************
C     *                                                         *
C     *              CALCULATE THE SUBSONIC BRANCH              *
C     *                                                         *
C     ***********************************************************
C
C
2     DO 3 J=1,200
      C1=1.0+G1*MOLD*MOLD
      MNEW=((G2*C1)**G4)/AAS
      XERROR=(MNEW-MOLD)*100.0/MOLD
      MOLD=MNEW
      IF(ABS(XERROR).LT.ERROR) RETURN
3     CONTINUE
C
C
C     ***********************************************************
C     *                                                         *
C     *                   CONVERGENCE FAILURE                   *
C     *                                                         *
C     ***********************************************************
C
C
4     WRITE(5,5)FLOW,G,MINI,MNEW,AAS XERROR,ERROR
      FAIL=YES
5     FORMAT('0',T2,'CONVERGENCE FAILURE FOR ',A3,'SONIC ',
     -'BRANCH IN SUBROUTINE MAAS',/,
     -T2,'G      =',E13.6,2X,'MINI   =',E13.6,/,
     -T2,'MNEW   =',E13.6,2X,'AAS    =',E13.6,/,
     -T2,'XERROR =',E13.6,2X,'ERROR  =',E13.6)
```

7.5.1 CLGDSP (Cont.)

```
MAAS  10100

END
```

7.5.1 CLGDSP (Cont.)

```
C     ******************************************************************
C     *                                                                *
C     *                ITERATION SUBROUTINE (ITER)                     *
C     *                                                                *
C     ******************************************************************
C
C     ******************************************************************
C     *                                                                *
C     *  SUBROUTINE ITER PERFORMS AN ITERATION TO FIND X SUCH          *
C     *  THAT THE PERCENT ERROR IN Y AND YGIVEN IS .LE. TO             *
C     *  ERRORY OR THE PERCENT DEVIATION IN X(I+1) AND X(I)            *
C     *  IS .LE. TO ERRORX.                                            *
C     *                                                                *
C     * VARIABLES:                                                     *
C     *                                                                *
C     * X       = INDEPENDENT VARIABLE                                 *
C     * DX      = INCREMENT IN INDEPENDENT VARIABLE                    *
C     * ERRORX  = MAX PERCENT DEVIATION IF X(I+1) AND X(I) FOR         *
C     *           SOLUTION                                             *
C     * SIGN    = +1.0 OR -1.0, +/- INCREMENTING FROM INITIAL X        *
C     * Y       = DEPENDENT VARIABLE                                   *
C     * YGIVEN  = GIVEN VALUE OF DEPENDENT VARIABLE                    *
C     * ERRORY  = MAX PERCENT ERROR IN Y AND YGIVEN FOR                *
C     *           SOLUTION                                             *
C     * NIT     = INCREMENT NUMBER                                     *
C     * NTYPE   = 1--INCREMENT,  2--INTERPOLATION,  3--SOLUTION        *
C     *                                                                *
C     * NOTE: THE INTERMEDIATE VARIABLES XNEG,YNEG,XPOS,YPOS,          *
C     * NSIGN1,NSIGN2 MUST BE STORED BETWEEN INTERATIONS.              *
C     *                                                                *
C     ******************************************************************
C
C
      SUBROUTINE ITER(X,DX,ERRORX,SIGN,Y,YGIVEN,ERRORY,NIT,
     -NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)
C
      ERROR(ACTUAL,GIVEN)=(ACTUAL-GIVEN)*100.0/GIVEN
C
      IF(ABS(ERROR(Y,YGIVEN))-ERRORY) 90,90,10
   10 IF(Y-YGIVEN) 20,90,30
   20 NSIGN2=-1
      XNEG=X
      YNEG=Y
      GO TO 40
   30 NSIGN2=+1
      XPOS=X
      YPOS=Y
   40 GO TO (50,80), NTYPE
   50 IF(NIT-1) 70,70,60
   60 NSIGN=NSIGN1*NSIGN2
```

```
      IF(NSIGN) 80,80,70                                                ITER    05100
   70 NSIGN1=NSIGN2                                                     ITER    05200
      NIT=NIT+1                                                         ITER    05300
C                                                                       ITER    05400
CCCCCC                                                                  ITER    05500
CCCCCC*****************************************************************ITER    05600
CCCCCC*                                                               *ITER    05700
CCCCCC*            INCREMENT TO FIND SOLUTION INTERVAL                *ITER    05800
CCCCCC*                                                               *ITER    05900
CCCCCC*****************************************************************ITER    06000
C                                                                       ITER    06100
      X=X+SIGN*DX                                                       ITER    06200
      GO TO 100                                                         ITER    06300
C                                                                       ITER    06400
CCCCCC                                                                  ITER    06500
CCCCCC*****************************************************************ITER    06600
CCCCCC*                                                               *ITER    06700
CCCCCC*                   INTERPOLATION FOR SOLUTION                  *ITER    06800
CCCCCC*                                                               *ITER    06900
CCCCCC*****************************************************************ITER    07000
C                                                                       ITER    07100
   80 NTYPE=2                                                           ITER    07200
      NIT=NIT+1                                                         ITER    07300
      XSAVE=X                                                           ITER    07400
      RATIO=(XPOS-XNEG)/(YPOS-YNEG)                                     ITER    07500
      X=XNEG+RATIO*(YGIVEN-YNEG)                                        ITER    07600
C                                                                       ITER    07700
CCCCCC                                                                  ITER    07800
CCCCCC*****************************************************************ITER    07900
CCCCCC*                                                               *ITER    08000
CCCCCC*          ACCELERATION OF CONVERGENCE OF ITERATION              *ITER    08100
CCCCCC*                  REFERENCE - WEGSTEIN, NBS                    *ITER    08200
CCCCCC*                                                               *ITER    08300
CCCCCC*****************************************************************ITER    08400
C                                                                       ITER    08500
      A=1.0/RATIO                                                       ITER    08600
      IF(A-1.0) 82,88,82                                                ITER    08700
   82 Q=A/(A-1.0)                                                       ITER    08800
      XWGSTN=Q*XSAVE+(1.0-Q)*X                                          ITER    08900
      IF(XNEG-XWGSTN) 84,86,88                                          ITER    09000
   84 IF(XWGSTN-XPOS) 86,86,88                                          ITER    09100
   86 X=XWGSTN                                                          ITER    09200
   88 IF(ABS(ERROR(X,XSAVE))-ERRORX) 90,90,100                          ITER    09300
   90 NTYPE=3                                                           ITER    09400
  100 END                                                               ITER    09500
                                                                        ITER    09600
```

```
C     ****************************************************************      TTY     00100
C     *                                                              *      TTY     00200
C     *                        SUBROUTINE (TTY)                      *      TTY     00300
C     *                                                              *      TTY     00400
C     ****************************************************************      TTY     00500
C                                                                             TTY     00600
C     ****************************************************************      TTY     00700
C     *                                                              *      TTY     00800
C     *  SUBROUTINE TTY PRINTS THE RESULTS OF PROGRAM CLGDSP         *      TTY     00900
C     *  ON TERMINALS WITH A MINIMUM OF 72 CHARACTERS PER            *      TTY     01000
C     *  LINE.  SEE MAIN PROGRAM CLGDSP FOR NOTATION.                *      TTY     01100
C     *                                                              *      TTY     01200
C     ****************************************************************      TTY     01300
C                                                                             TTY     01400
      SUBROUTINE TTY                                                        TTY     01500
C                                                                           TTY     01600
      IMPLICIT REAL*4(M)                                                    TTY     01700
      DATA CPE/'CPE'/,CAE/'CAE'/,SSE/'SSE'/                                 TTY     01800
C                                                                           TTY     01900
      COMMON/TTY1/A2A1,A3A1,A4A1,A4A3,A5A1,A5A6,A6A1,A7A1,A7A2,             TTY     02000
     -A7A6,A8A1,A8A7                                                        TTY     02100
      COMMON/TTY2/COEFF,CQ1,CQ2,EJECT,GM,GP,GS                              TTY     02200
      COMMON/TTY3/M1,M2,M3,M4,M5,M6,M7,M8,MWMMWS,MWPMWS,NPTS                TTY     02300
      COMMON/TTY4/P1P10,P2P1,P20P10,P3P1,P30P10,P3P2,P30P20,                TTY     02400
     -P4P1,P40P10,P4P3,P40P30,P5P1,P50P10,P60P1,P60P10,P60P2,               TTY     02500
     -P60P20,P60P50,P7P1,P70P10,P7P2,P70P20,P7P50,P70P50,XP8P1,             TTY     02600
     -P80P10,P8P2,P80P20,P8P7,P80P70                                        TTY     02700
      COMMON/TTY5/RCPE,RNSD,RSD34,RSD78                                     TTY     02800
      COMMON/TTY6/T1T10,T2T1,T20T10,T3T1,T30T10,T3T2,T30T20,                TTY     02900
     -T4T1,T40T10,T4T3,T40T30,T5T1,T50T10,T60T1,T60T10,T60T20,              TTY     03000
     -T60T50,T7T1,T7CT10,T7T2,T70T20,T7T50,T70T50,T8T1,                     TTY     03100
     -T80T10,T8T2,T80T20,T8T7,T80T70                                        TTY     03200
      COMMON/TTY7/WMWS,WPWS                                                 TTY     03300
C                                                                           TTY     03400
C                                                                           TTY     03500
C     ****************************************************************      TTY     03600
C     *                                                              *      TTY     03700
C     *                      OUTPUT SYSTEM DATA                      *      TTY     03800
C     *                                                              *      TTY     03900
C     ****************************************************************      TTY     04000
C                                                                           TTY     04100
C                                                                           TTY     04200
      WRITE(5,200)                                                          TTY     04300
      WRITE(5,201)EJECT,COEFF                                               TTY     04400
C                                                                           TTY     04500
      WRITE(5,202)                                                          TTY     04600
      WRITE(5,203)                                                          TTY     04700
      WRITE(5,204)M1,GS,P1P10,T1T10                                         TTY     04800
C                                                                           TTY     04900
                                                                            TTY     05000
```

```
      WRITE(5,205)                                                      TTY     05100
      IF(EJECT.NE.SSE) WRITE(5,206)                                     TTY     05200
      IF(EJECT.EQ.SSE) WRITE(5,207)                                     TTY     05300
      WRITE(5,208)GS,M2,A2A1,P2P1,T2T1,P20P10,T20T10                    TTY     05400
C                                                                       TTY     05500
      IF(EJECT.EQ.SSE) GO TO 100                                        TTY     05600
      WRITE(5,209)                                                      TTY     05700
      WRITE(5,210)GS,M3,A3A1,P3P1,T3T1,P30P10,T30T10                    TTY     05800
C                                                                       TTY     05900
      WRITE(5,211)                                                      TTY     06000
      WRIT (5,212)GS,M4,A4A1,P4P1,T4T1,P40P10,T40T10                    TTY     06100
C                                                                       TTY     06200
      IF(EJECT.EQ.CPE) WRITE(5,213)                                     TTY     06300
      IF(EJECT.EQ.CAE) WRITE(5,214)                                     TTY     06400
      WRITE(5,215)GS,M5,A5A1,P5P1,T5T1,P50P10,T50T10                    TTY     06500
C                                                                       TTY     06600
      IF(EJECT.EQ.CPE) WRITE(5,216)                                     TTY     06700
      IF(EJECT.EQ.CAE) WRITE(5,217)                                     TTY     06800
      GO TO 101                                                         TTY     06900
100   WRITE(5,218)                                                      TTY     07000
101   WRITE(5,219)GF,MWPMWS,WPWS,M6,A6A1,P60P1,T60T1,P60P10,            TTY     07100
     -T60T10                                                            TTY     07200
C                                                                       TTY     07300
      IF(EJECT.EQ.CPE) WRITE(5,220)                                     TTY     07400
      IF(EJECT.EQ.CAE) WRITE(5,221)                                     TTY     07500
      IF(EJECT.EQ.SSE) WRITE(5,222)                                     TTY     07600
      WRITE(5,223)GM,MWMMWS,WMWS,M7,A7A1,P7P1,T7T1,P70P10,T70T10        TTY     07700
C                                                                       TTY     07800
      WRITE(5,224)                                                      TTY     07900
      WRITE(5,225)GM,MWMMWS,WMWS,M8,A8A1,XP8P1,T8T1,P80P10,             TTY     08000
     -T80T10                                                            TTY     08100
C                                                                       TTY     08200
CCC                                                                     TTY     08300
CCC   ************************************************************    TTY     08400
CCC   *                                                          *    TTY     08500
CCC   *                 OUTPUT DATA FOR EACH DEVICE              *    TTY     08600
CCC   *                                                          *    TTY     08700
CCC   ************************************************************    TTY     08800
CCC                                                                     TTY     08900
C                                                                       TTY     09000
      WRITE(5,300)                                                      TTY     09100
      WRITE(5,301)NFTS,CQ1,CQ2,GS,A2A1,M1,M2,P2P1,T2T1,P20P10,          TTY     09200
     -T20T10                                                            TTY     09300
C                                                                       TTY     09400
      IF(EJECT.EQ.SSE) GO TO 102                                        TTY     09500
      WRITE(5,302)                                                      TTY     09600
      WRITE(5,303)GS,RNSD,M2,M3,P3P2,T3T2,P30P20,T30T20                 TTY     09700
C                                                                       TTY     09800
      WRITE(5,304)                                                      TTY     09900
      WRITE(5,305)RSC34,GS,A4A3,M3,M4,P4P3,T413,P40P30,T40T30           TTY     10000
```

```
C                                                                       TTY     10100
      IF(EJECT.EQ.CPE) WRITE(5,306)                                     TTY     10200
      IF(EJECT.EQ.CAE) WRITE(5,307)                                     TTY     10300
      WRITE(5,308)GS,GP,GM,MWPMWS,A7A6,WPWS,M6,M7,P60P50,T60T50,        TTY     10400
     -P7P50,T7T50,P70P50,T70T50                                         TTY     10500
      IF(EJECT.EQ.CPE) WRITE(5,309)RCPE,A5A6                            TTY     10600
C                                                                       TTY     10700
      WRITE(5,310)                                                      TTY     10800
      IF(EJECT.EQ.CPE) WRITE(5,311)                                     TTY     10900
      IF(EJECT.EQ.CAE) WRITE(5,312)                                     TTY     11000
      GO TO 103                                                         TTY     11100
102   WRITE(5,313)                                                      TTY     11200
103   WRITE(5,314)GS,GP,GM,MWPMWS,A7A2,A7A6,WPWS,M2,M6,M7,P60P2,        TTY     11300
     -P60P20,T60T20,P7P2,T7T2,P70P20,T70T20                             TTY     11400
C                                                                       TTY     11500
      IF(EJECT.NE.SSE) WRITE(5,315)                                     TTY     11600
      IF(EJECT.EQ.CPE) WRITE(5,316)                                     TTY     11700
      IF(EJECT.EQ.CAE) WRITE(5,317)                                     TTY     11800
      IF(EJECT.EQ.SSE) WRITE(5,318)                                     TTY     11900
      WRITE(5,319)GS,GP,GM,MWPMWS,A7A2,A7A6,A8A7,WPWS,M2,M6,M7,         TTY     12000
     -M8,P60P2,P60P2C,T60T20,P8P2,T8T2,P80P20,T80T20                    TTY     12100
C                                                                       TTY     12200
      WRITE(5,320)                                                      TTY     12300
      WRITE(5,321)RSC78,GM,A8A7,M7,M8,P8P7,T8T7,P80P70,T80T70           TTY     12400
C                                                                       TTY     12500
C                                                                       TTY     12600
C     ****************************************************************  TTY     12700
C     *                                                              *  TTY     12800
C     *                      FORMAT STATEMENTS                       *  TTY     12900
C     *                                                              *  TTY     13000
C     ****************************************************************  TTY     13100
C                                                                       TTY     13200
C                                                                       TTY     13300
200   FORMAT('1',T14,'HIGH ENERGY CHEMICAL LASER SYSTEM ',              TTY     13400
     -'SIMULATION',/,T24,'ONE-DIMENSIONAL ANALYSIS',//,T29,             TTY     13500
     -'A.L. ADDY',/,T29,'C.D. MIKKELSEN',/,T29,'M.R. SANDBERG',         TTY     13600
     -//,T30,'1 JANUARY 76',//,T19,'MECHANICAL ENGINEERING ',           TTY     13700
     -'DEPARTMENT',/,T15,'UNIVERSITY OF ILLINOIS AT URBANA-',           TTY     13800
     -'CHAMPAIGN',/,T25,'URBANA, ILLINOIS 61801')                       TTY     13900
201   FORMAT('0',T18,A3,' SOLUTION WITH ITERATION ON ',A4)              TTY     14000
C                                                                       TTY     14100
202   FORMAT('0',T14,'SYSTEM DATA:')                                    TTY     14200
203   FORMAT('0',T5,'POINT 1  LASER CAVITY ENTRANCE CONDITIONS')        TTY     14300
204   FORMAT('0',T14,'M1     =',E13.6,T38,'GS     =',E13.6,/,          TTY     14400
     -T14,'P1P10  =',E13.6,T38,'T1T10  =',E13.6)                        TTY     14500
C                                                                       TTY     14600
205   FORMAT('0',T5,'POINT 2  LASER CAVITY EXIT AND')                   TTY     14700
206   FORMAT('+',T36,'NORMAL SHOCK DIFFUSER',/,T14,'ENTRANCE ',         TTY     14800
     -'CONDITIONS')                                                     TTY     14900
207   FORMAT('+',T36,'SUPERSONIC-SUPERSONIC',/,T14,'EJECTOR ',          TTY     15000
```

7.5.1 CLGDSP (Cont.)

```
     -'ENTRANCE CONDITICNS')                                            TTY    15100
208   FORMAT('0',T14,'GS      =',E13.6,/,                               TTY    15200
     -T14,'M2      =',E13.6,T38,'A2A1    =',E13.6,/,                   TTY    15300
     -T14,'P2P1    =',E13.6,T38,'T2T1    =',E13.6,/,                   TTY    15400
     -T14,'P20P10 =',E13.6,T38,'T20T10 =',E13.6)                        TTY    15500
C                                                                       TTY    15600
209   FORMAT('0',T5,'PCINT 3  NORMAL SHOCK DIFFUSER EXIT AND ',         TTY    15700
     -'SUBSONIC',/,T14,'DIFFUSER ENTRANCE CONDITIONS')                  TTY    15800
210   FORMAT('0',T14,'GS      =',E13.6,/,                               TTY    15900
     -T14,'M3      =',E13.6,T38,'A3A1    =',E13.6,/,                   TTY    16000
     -T14,'P3P1    =',E13.6,T38,'T3T1    =',E13.6,/,                   TTY    16100
     -T14,'P30P10 =',E13.6,T38,'T30T10 =',E13.6)                        TTY    16200
C                                                                       TTY    16300
211   FORMAT('0',T5,'PCINT 4  SUBSONIC DIFFUSER EXIT AND ',             TTY    16400
     -'SUDDEN ENLARGEMENT',/,T14,'ENTRANCE CCNDITIONS')                 TTY    16500
212   FORMAT('0',T14,'GS      =',E13.6,/,                               TTY    16600
     -T14,'M4      =',E13.6,T38,'A4A1    =',E13.6,/,                   TTY    16700
     -T14,'P4P1    =',E13.6,T38,'T4T1    =',E13.6,/,                   TTY    16800
     -T14,'P40P10 =',E13.6,T38,'T40T10 =',E13.6)                        TTY    16900
C                                                                       TTY    17000
213   FORMAT('0',T5,'PCINT 5  CONSTANT-PRESSURE EJECTOR ',              TTY    17100
     -'SECCNDARY NOZZLE',/,T14,'EXIT CCNDITICNS')                       TTY    17200
214   FORMAT('0',T5,'PCINT 5  CONSTANT-AREA EJECTOR SECONDARY ',        TTY    17300
     -'NOZZLE EXIT',/,T14,'CCNDITIONS')                                 TTY    17400
215   FORMAT('0',T14,'GS      =',E13.6,/,                               TTY    17500
     -T14,'M5      =',E13.6,T38,'A5A1    =',E13.6,/,                   TTY    17600
     -T14,'P5P1    =',E13.6,T38,'T5T1    =',E13.6,/,                   TTY    17700
     -T14,'P50P10 =',E13.6,T38,'T50T10 =',E13.6)                        TTY    17800
C                                                                       TTY    17900
216   FORMAT('0',T5,'POINT 6  CONSTANT-PRESSURE EJECTOR ',              TTY    18000
     -'PRIMARY NCZZLE EXIT',/,T14,'CONDITICNS')                         TTY    18100
217   FORMAT('0',T5,'POINT 6  CONSTANT-AREA EJECTOR PRIMARY ',          TTY    18200
     -'NOZZLE EXIT',/,T14,'CCNDITIONS')                                 TTY    18300
218   FORMAT('C',T5,'PCINT 6  SUPERSONIC-SUPERSONIC EJECTOR ',          TTY    18400
     -'PRIMARY NOZZLE',/,T14,'EXIT CONDITIONS')                         TTY    18500
219   FORMAT('C',T14,'GP      =',E13.6,T38,'MWPMWS =',E13.6,/,          TTY    18600
     -T14,'WPWS    =',E13.6,/,                                          TTY    18700
     -T14,'M6      =',E13.6,T38,'A6A1    =',E13.6,/,                   TTY    18800
     -T14,'P60P1   =',E13.6,T38,'T60T1   =',E13.6,/,                   TTY    18900
     -T14,'P60P10 =',E13.6,T38,'T60T10 =',E13.6)                        TTY    19000
C                                                                       TTY    19100
220   FORMAT('C',T5,'PCINT 7  CONSTANT-PRESSURE EJECTOR EXIT ',         TTY    19200
     -'AND SUBSCNIC',/,T14,'DIFFUSER ENTRANCE CONDITIONS')              TTY    19300
221   FORMAT('0',T5,'PCINT 7  CONSTANT-AREA EJECTOR EXIT AND ',         TTY    19400
     -'SUBSONIC',/,T14,'DIFFUSER ENTRANCE CONDITIONS')                  TTY    19500
222   FORMAT('C',T5,'PCINT 7  SUPERSONIC-SUPERSONIC EJECTOR ',          TTY    19600
     -'EXIT AND',/,T14,'SUBSCNIC DIFFUSER ENTRANCE CONDITIONS')         TTY    19700
223   FORMAT('C',T14,'GM      =',E13.6,T38,'MWMMWS =',E13.6,/,          TTY    19800
     -T14,'WMWS    =',E13.6,/,                                          TTY    19900
     -T14,'M7      =',E13.6,T38,'A7A1    =',E13.6,/,                   TTY    20000
```

```
     -T14,'P7P1    =',E13.6,T38,'T7T1    =',E13.6,/,                    TTY     20100
     -T14,'P70P10 =',E13.6,T38,'T70T10 =',E13.6)                        TTY     20200
C                                                                       TTY     20300
224   FORMAT('0',T5,'POINT 8  SUBSONIC DIFFUSER EXIT ',                 TTY     20400
     -'CONDITIONS')                                                     TTY     20500
225   FORMAT('0',T14,'GM      =',E13.6,T38,'MWMMWS =',E13.6,/,           TTY     20600
     -T14,'WMWS    =',E13.6,/,                                         TTY     20700
     -T14,'M8      =',E13.6,T38,'A8A1    =',E13.6,/,                   TTY     20800
     -T14,'P8P1    =',E13.6,T38,'T8T1    =',E13.6,/,                   TTY     20900
     -T14,'P80P10 =',E13.6,T38,'T80T10 =',E13.6)                        TTY     21000
C                                                                       TTY     21100
300   FORMAT('0',T14,'LASER CAVITY DATA:')                              TTY     21200
301   FORMAT('0',T14,'NPTS    =',I13,/,                                 TTY     21300
     -T14,'CQ1     =',E13.6,T38,'CQ2     =',E13.6,/,                   TTY     21400
     -T14,'GS      =',E13.6,T38,'A2A1    =',E13.6,/,                   TTY     21500
     -T14,'M1      =',E13.6,T38,'M2      =',E13.6,/,                   TTY     21600
     -T14,'P2P1    =',E13.6,T38,'T2T1    =',E13.6,/,                   TTY     21700
     -T14,'P20P10 =',E13.6,T38,'T20T10 =',E13.6)                        TTY     21800
C                                                                       TTY     21900
302   FORMAT('0',T14,'NORMAL SHOCK DIFFUSER DATA:')                     TTY     22000
303   FORMAT('0',T14,'GS      =',E13.6,T38,'RNSD    =',E13.6,/,         TTY     22100
     -T14,'M2      =',E13.6,T38,'M3      =',E13.6,/,                   TTY     22200
     -T14,'P3P2    =',E13.6,T38,'T3T2    =',E13.6,/,                   TTY     22300
     -T14,'P30P20 =',E13.6,T38,'T30T20 =',E13.6)                        TTY     22400
C                                                                       TTY     22500
304   FORMAT('0',T14,'SUBSONIC DIFFUSER DATA:')                         TTY     22600
305   FORMAT('0',T14,'RSD     =',E13.6,/,                               TTY     22700
     -T14,'GS      =',E13.6,T38,'A4A3    =',E13.6,/,                   TTY     22800
     -T14,'M3      =',E13.6,T38,'M4      =',E13.6,/,                   TTY     22900
     -T14,'P4P3    =',E13.6,T38,'T4T3    =',E13.6,/,                   TTY     23000
     -T14,'P40P30 =',E13.6,T38,'T40T30 =',E13.6)                        TTY     23100
C                                                                       TTY     23200
306   FORMAT('0',T14,'CONSTANT-PRESSURE EJECTOR DATA:')                 TTY     23300
307   FORMAT('0',T14,'CONSTANT-AREA EJECTOR DATA:')                     TTY     23400
308   FORMAT('0',T14,'GS      =',E13.6,T38,'GP      =',E13.6,/,         TTY     23500
     -T14,'GM      =',E13.6,T38,'MWPMWS =',E13.6,/,                    TTY     23600
     -T14,'A7A6    =',E13.6,T38,'WPWS    =',E13.6,/,                   TTY     23700
     -T14,'M6      =',E13.6,T38,'M7      =',E13.6,/,                   TTY     23800
     -T14,'P60P50 =',E13.6,T38,'T60T50 =',E13.6,/,                      TTY     23900
     -T14,'P7P50   =',E13.6,T38,'T7T50   =',E13.6,/,                    TTY     24000
     -T14,'P70P50 =',E13.6,T38,'T70T50 =',E13.6)                        TTY     24100
309   FORMAT(' ',T14,'RCPE    =',E13.6,T38,'A5A6    =',E13.6)           TTY     24200
C                                                                       TTY     24300
310   FORMAT('0',T14,'NORMAL SHOCK DIFFUSER - SUBSONIC ',               TTY     24400
     -'DIFFUSER -')                                                     TTY     24500
311   FORMAT(' ',T14,'CONSTANT-PRESSURE EJECTOR DATA:')                 TTY     24600
312   FORMAT(' ',T14,'CONSTANT-AREA EJECTOR DATA:')                     TTY     24700
313   FORMAT('0',T14,'SUPERSONIC-SUPERSONIC EJECTOR DATA:')             TTY     24800
314   FORMAT('0',T14,'GS      =',E13.6,T38,'GP      =',E13.6,/,         TTY     24900
     -T14,'GM      =',E13.6,T38,'MWPMWS =',E13.6,/,                    TTY     25000
```

```
     -T14,'A7A2    =',E13.6,T38,'A7A6    =',E13.6,/,                    TTY     25100
     -T14,'WPWS    =',E13.6,T38,'M2      =',E13.6,/,                    TTY     25200
     -T14,'M6      =',E13.6,T38,'M7      =',E13.6,/,                    TTY     25300
     -T14,'P60P2   =',E13.6,/,                                          TTY     25400
     -T14,'P60P20  =',E13.6,T38,'T60T20  =',E13.6,/,                    TTY     25500
     -T14,'P7P2    =',E13.6,T38,'T7T2    =',E13.6,/,                    TTY     25600
     -T14,'P70P20  =',E13.6,T38,'T70T20  =',E13.6)                      TTY     25700
C                                                                       TTY     25800
315   FORMAT('0',T14,'NORMAL SHOCK DIFFUSER - SUBSONIC ',               TTY     25900
     -'DIFFUSER -')                                                     TTY     26000
316   FORMAT(' ',T14,'CONSTANT-PRESSURE EJECTOR - SUBSONIC ',           TTY     26100
     -'DIFFUSER',/,T14,'DATA:')                                         TTY     26200
317   FORMAT(' ',T14,'CONSTANT-AREA EJECTOR - SUBSONIC ',               TTY     26300
     -'DIFFUSER',/,T14,'DATA:')                                         TTY     26400
318   FORMAT('0',T14,'SUPERSONIC-SUPERSONIC EJECTOR - SUBSONIC',        TTY     26500
     -/,T14,'DIFFUSER DATA:')                                           TTY     26600
319   FORMAT('C',T14,'GS      =',E13.6,T38,'GP      =',E13.6,/,         TTY     26700
     -T14,'GM      =',E13.6,T38,'MWPMWS =',E13.6,/,                    TTY     26800
     -T14,'A7A2    =',E13.6,T38,'A7A6    =',E13.6,/,                   TTY     26900
     -T14,'A8A7    =',E13.6,T38,'WPWS    =',E13.6,/,                   TTY     27000
     -T14,'M2      =',E13.6,T38,'M6      =',E13.6,/,                   TTY     27100
     -T14,'M7      =',E13.6,T38,'M8      =',E13.6,/,                   TTY     27200
     -T14,'P60P2   =',E13.6,/,                                          TTY     27300
     -T14,'P60P20  =',E13.6,T38,'T60T20  =',E13.6,/,                    TTY     27400
     -T14,'P8P2    =',E13.6,T38,'T8T2    =',E13.6,/,                   TTY     27500
     -T14,'P80P20  =',E13.6,T38,'T80T20  =',E13.6)                      TTY     27600
C                                                                       TTY     27700
320   FORMAT('0',T14,'SUBSONIC DIFFUSER DATA:')                         TTY     27800
321   FORMAT('0',T14,'RSD     =',E13.6,/,                               TTY     27900
     -T14,'GM      =',E13.6,T38,'A8A7    =',E13.6,/,                   TTY     28000
     -T14,'M7      =',E13.6,T38,'M8      =',E13.6,/,                   TTY     28100
     -T14,'P8P7    =',E13.6,T38,'T8T7    =',E13.6,/,                   TTY     28200
     -T14,'P80P70  =',E13.6,T38,'T80T70  =',E13.6)                      TTY     28300
      END                                                               TTY     28400
```

7.5.2 CLGDSP Sample Input

```
INPUT DATA FOR LASER CAVITY ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$CAV
 GS=    1.400000     ,  M1=    2.000000     ,  A2A1=    1.000000     ,
 CO1=   0.0000000    ,  CO2=   0.0000000    ,  NPTS=                21,
 PSP1=    10.00000    , $

 $CAV NPTS=5,PSP1=20.0 $


INPUT THE EJECTOR MODEL FROM THE FOLLOWING LIST:

"CPE" CONSTANT-PRESSURE EJECTOR
"CAE" CONSTANT-AREA EJECTOR
"SSE" SUPERSONIC-SUPERSONIC EJECTOR

CAE


INPUT THE ITERATION VARIABLE FROM THE FOLLOWING LIST:

"M6" PRIMARY NOZZLE EXIT MACH NUMBER
"A7A6" MIXING TUBE EXIT-TO-PRIMARY NOZZLE EXIT AREA RATIO
"WPWS" PRIMARY-TO-SECONDARY MASS FLOW RATIO

WPWS


INPUT DATA FOR SUPERSONIC-SUBSONIC DIFFUSER SECTION BY NAMELIST.
CURRENT VALUES ARE:

$DIFUSR
 PHSD=    1.000000     ,  A4A3=    1.000000     , $

 $DIFUSR $


INPUT DATA FOR EJECTOR ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$EJECT2
 GP=    1.400000     ,  MWPMWS=    1.000000     ,  T60T50=    1.000000 ,
 M6=    1.0100000    ,  A7A6=    10.00000     ,  WPWS=    1.000000     ,
 A8A7=    1.000000     , $

 $EJECT2 M6=4.5 $
```

7.5.3 CLGDSP Sample Output

```
                HIGH ENERGY CHEMICAL LASER SYSTEM SIMULATION
                        ONE-DIMENSIONAL ANALYSIS

                              H.L. ADDY
                              C.D. MIKKELSEN
                              H.K. SANDBERG

                              1 JANUARY 76

                    MECHANICAL ENGINEERING DEPARTMENT
                 UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
                        URBANA, ILLINOIS 61801

                   CAE SOLUTION WITH ITERATION ON WPWS

            SYSTEM DATA:

POINT 1     LASER CAVITY ENTRANCE CONDITIONS

            M1      = 0.200000E+01    GS      = 0.140000E+01
            P1P10   = 0.127805E+00    T1T10   = 0.555556E+00

POINT 2     LASER CAVITY EXIT AND NORMAL SHOCK DIFFUSER
            ENTRANCE CONDITIONS

            GS      = 0.140000E+01
            M2      = 0.200000E+01    A2A1    = 0.100000E+01
            P2P1    = 0.100000E+01    T2T1    = 0.100000E+01
            P20P10  = 0.100000E+01    T20T10  = 0.100000E+01

POINT 3     NORMAL SHOCK DIFFUSER EXIT AND SUBSONIC
            DIFFUSER ENTRANCE CONDITIONS

            GS      = 0.140000E+01
            M3      = 0.577350E+00    A3A1    = 0.100000E+01
            P3P1    = 0.450000E+01    T3T1    = 0.168750E+01
            P30P10  = 0.720874E+00    T30T10  = 0.100000E+01

POINT 4     SUBSONIC DIFFUSER EXIT AND SUDDEN ENLARGEMENT
            ENTRANCE CONDITIONS

            GS      = 0.140000E+01
            M4      = 0.577350E+00    A4A1    = 0.100000E+01
            P4P1    = 0.450000E+01    T4T1    = 0.168750E+01
            P40P10  = 0.720874E+00    T40T10  = 0.100000E+01
```

7.5.3 CLGDSP Sample Output (Cont.)

```
POINT 5  CONSTANT-AREA EJECTOR SECONDARY NOZZLE EXIT
         CONDITIONS

         GS      = 0.140000E+01
         M5      = 0.646047E+00    A5A1    = 0.936583E+00
         P5P1    = 0.426036E+01    T5T1    = 0.146132E+01
         P50P10  = 0.720874E+00    T50T10  = 0.106700E+01

POINT 6  CONSTANT-AREA EJECTOR PRIMARY NOZZLE EXIT
         CONDITIONS

         GP      = 0.140000E+01    MWPMWS  = 0.100000E+01
         WPWS    = 0.265889E+01
         M6      = 0.450000E+01    A6A1    = 0.104065E+00
         P60P1   = 0.196212E+04    T60T1   = 0.180000E+01
         P60P10  = 0.250768E+03    T60T10  = 0.100000E+01

POINT 7  CONSTANT-AREA EJECTOR EXIT AND SUBSONIC
         DIFFUSER ENTRANCE CONDITIONS

         GM      = 0.140000E+01    MWMMWS  = 0.100000E+01
         WMWS    = 0.365889E+01
         M7      = 0.462037E+00    A7A1    = 0.104065E+01
         P7P1    = 0.199966E+02    T7T1    = 0.172629E+01
         P70P10  = 0.295838E+01    T70T10  = 0.100000E+01

POINT 8  SUBSONIC DIFFUSER EXIT CONDITIONS

         GM      = 0.140000E+01    MWMMWS  = 0.100000E+01
         WMWS    = 0.365889E+01
         M8      = 0.462037E+00    A8A1    = 0.104065E+01
         P8P1    = 0.199966E+02    T8T1    = 0.172629E+01
         P80P10  = 0.295838E+01    T80T10  = 0.100000E+01

         LASER CAVITY DATA:

         NPTS    =              5
         CO1     = 0.000000E+00    CO2     = 0.000000E+00
         GS      = 0.140000E+01    A2A1    = 0.100000E+01
         M1      = 0.200000E+01    M2      = 0.200000E+01
         P2P1    = 0.100000E+01    T2T1    = 0.100000E+01
         P20P10  = 0.100000E+01    T20T10  = 0.100000E+01

         NORMAL SHOCK DIFFUSER DATA:

         GS      = 0.140000E+01    RNSD    = 0.100000E+01
         M2      = 0.200000E+01    M3      = 0.577350E+00
         P3P2    = 0.450000E+01    T3T2    = 0.168750E+01
         P30P20  = 0.720874E+00    T30T20  = 0.100000E+01
```

7.5.3 CLGDSP Sample Output (Cont.)

POINT 8 SUBSONIC DIFFUSER EXIT CONDITIONS (Continued)

SUBSONIC DIFFUSER DATA:

```
PSD     = 0.100000E+01
GS      = 0.140000E+01    A4A3    = 0.100000E+01
M3      = 0.577350E+00    M4      = 0.577350E+00
P4P3    = 0.100000E+01    T4T3    = 0.100000E+01
P40P30  = 0.100000E+01    T40T30  = 0.100000E+01
```

CONSTANT-AREA EJECTOR DATA:

```
GS      = 0.140000E+01    GP      = 0.140000E+01
GM      = 0.140000E+01    MWPMWS  = 0.100000E+01
A7A6    = 0.100000E+02    WPWS    = 0.265889E+01
M6      = 0.450000E+01    M7      = 0.462037E+00
P60P50  = 0.347866E+03    T60T50  = 0.100000E+01
P7P50   = 0.354522E+01    T7T50   = 0.959053E+00
P70P50  = 0.410388E+01    T70T50  = 0.100000E+01
```

NORMAL SHOCK DIFFUSER - SUBSONIC DIFFUSER - CONSTANT-AREA EJECTOR DATA:

```
GS      = 0.140000E+01    GP      = 0.140000E+01
GM      = 0.140000E+01    MWPMWS  = 0.100000E+01
A7A2    = 0.104065E+01    A7A6    = 0.100000E+02
WPWS    = 0.265889E+01    M2      = 0.200000E+01
M6      = 0.450000E+01    M7      = 0.462037E+00
P60P2   = 0.196212E+04
P60P20  = 0.250768E+03    T60T20  = 0.100000E+01
P7P2    = 0.199966E+02    T7T2    = 0.172629E+01
P70P20  = 0.295838E+01    T70T20  = 0.100000E+01
```

NORMAL SHOCK DIFFUSER - SUBSONIC DIFFUSER - CONSTANT-AREA EJECTOR - SUBSONIC DIFFUSER DATA:

```
GS      = 0.140000E+01    GP      = 0.140000E+01
GM      = 0.140000E+01    MWPMWS  = 0.100000E+01
A7A2    = 0.104065E+01    A7A6    = 0.100000E+02
A8A7    = 0.100000E+01    WPWS    = 0.265889E+01
M2      = 0.200000E+01    M6      = 0.450000E+01
M7      = 0.462037E+00    M8      = 0.462037E+00
P60P2   = 0.196212E+04
P60P20  = 0.250768E+03    T60T20  = 0.100000E+01
P8P2    = 0.199966E+02    T8T2    = 0.172629E+01
P80P20  = 0.295838E+01    T80T20  = 0.100000E+01
```

7.5.3 CLGDSP Sample Output (Cont.)

```
POINT 8  SUBSONIC DIFFUSER EXIT CONDITIONS (Continued)


              SUBSONIC DIFFUSER DATA:

              RSD     = 0.100000E+01
              GM      = 0.140000E+01    A8A7    = 0.100000E+01
              M7      = 0.462037E+00    M8      = 0.462037E+00
              P8P7    = 0.100000E+01    T8T7    = 0.100000E+01
              P80P70  = 0.100000E+01    T80T70  = 0.100000E+01




 TO RESTART PROGRAM ENTER "YES"
 TO STOP PROGRAM ENTER "NO"
 NO

 END OF EXECUTION
```

7.6 AN EXPERIMENTAL INVESTIGATION OF THE PERFORMANCE OF A CONSTANT-AREA, SUPERSONIC-SUPERSONIC EJECTOR FOR VARIATIONS IN THE MIXING TUBE LENGTH-TO-DIAMETER (L/D) RATIO

The results presented in Section 3.0 of this report were principally for variations in primary and secondary stream Mach numbers, M_{P1} and M_{S1}, and secondary-to-primary area ratio, A_{S1}/A_{P1}. The effects of variations in the mixing tube length-to-diameter ratio were investigated only indirectly by means of the measurement of the flow non-uniformity at the mixing tube exit and the recompression pressure rise along the mixing tube wall. The need to investigate the effects of length-to-diameter ratio was recognized, and a series of experiments were conducted for an ejector configuration investigated in Section 3.0. This configuration was defined by: $M_{S1} = 2.00$, $M_{P1} = 2.50$, and $A_{S1}/A_{P1} = 0.88$; experimental data were presented for this ejector in Figs. 3.3 - 3,7, and 9. For this series of experiments, the experimental procedure was the same as outlined in Section 3.2, and the mixing tube length-to-diameter-ratios were: L/D = 5, 7.5, 10, 12.5, and 15.

The results of this investigation are presented in Figs. 7.6 - 1,2. As is evident from these figures, the overall ejector performance was nearly identical for all ejector configurations with $L/D \geq 7.5$. The largest values of P_{MS}/P_{S1} versus W_P/W_S were found for a mixing tube L/D = 10 (the configuration investigated in Section 3.0). The values of P_{MS}/P_{S1} versus W_P/W_S for mixing tube L/D =7.5, 12.5 and 15 were slightly less than those for a mixing tube L/D = 10. Ejector performance at a mixing tube L/D = 5 was significantly degraded relative to the mixing tubes with large L/D ratios. This poor performance is due to the inadequate mixing and recompression length within

the L/D = 5 mixing tube. For the longer mixing tubes, frictional losses may tend to reduce the performance more than the gains made in achieving a more uniform velocity profile at the mixing tube exit; compare, for example, the performance results for L/D = 7.5, 10, 12.5, and 15 in light of the known flow non-uniformities for an L/D = 10, Figs. 3.3 - 7,9.

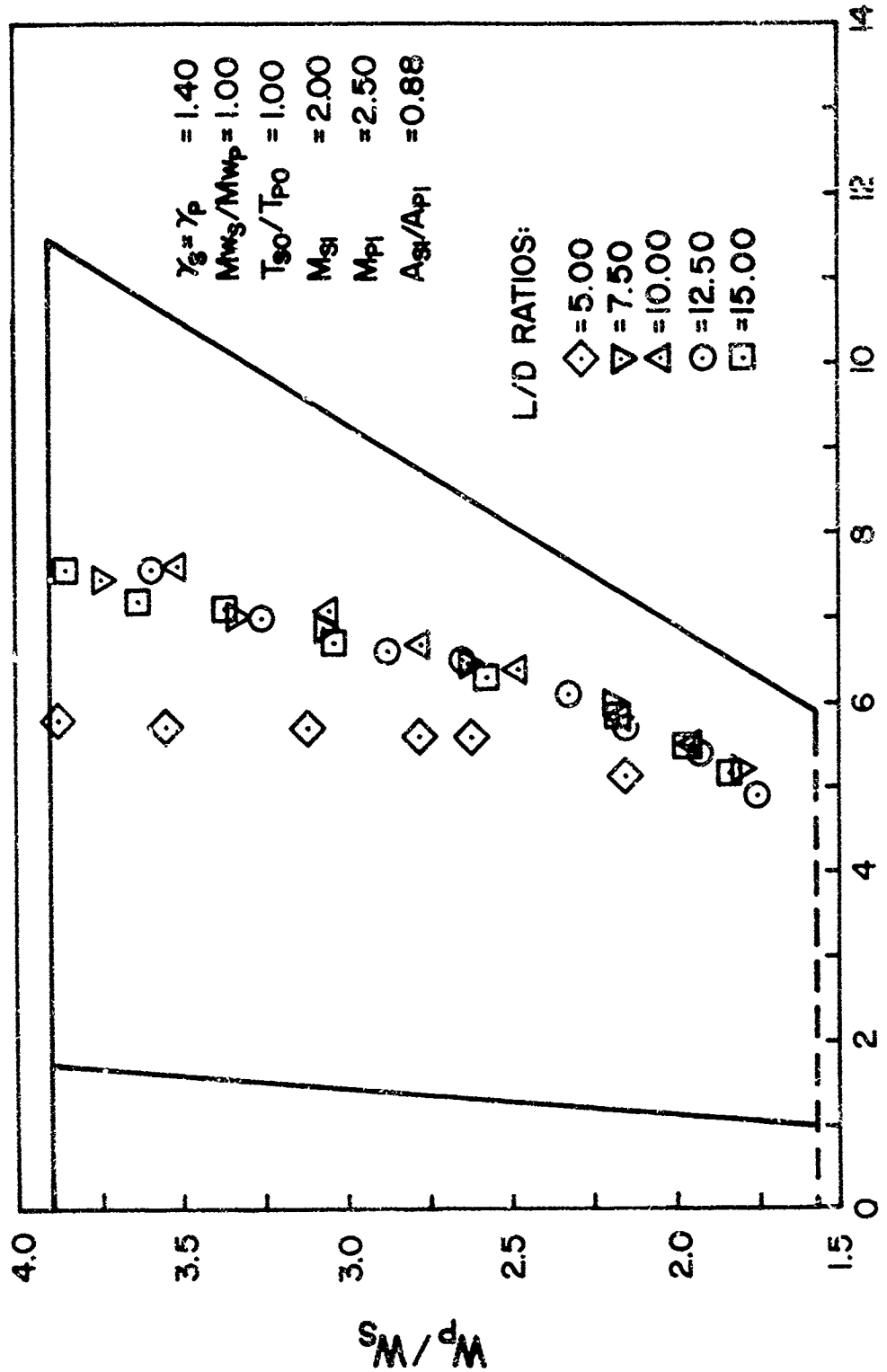

Figure 7.6 - 1. Maximum Ejector Compression Characteristics for Variations in Mixing Tube Length-to-Diameter Ratio (W_p/W_s vs. P_{M3}/P_{s1}).

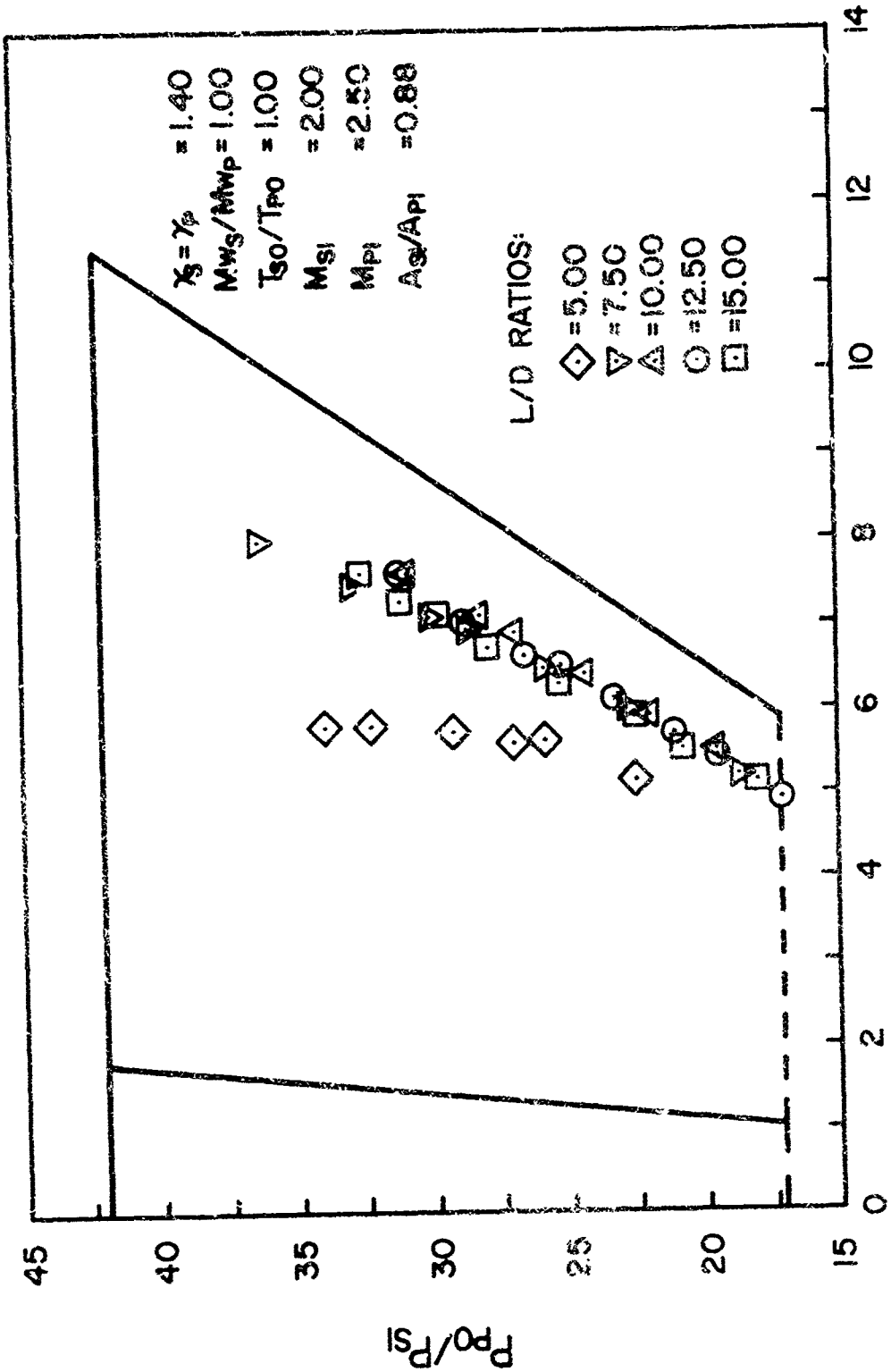

Figure 7.6 - 2. Maximum Ejector Compression Characteristics for Variations in Mixing Tube Length-to-Diameter Ratio (P_{PO}/P_{SI} vs. P_{M3}/P_{SI}).

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