NASA Contractor Report 3157

GIM Code User's Manual for the STAR-100 Computer

Lawrence Spradley and Mark Pearson

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Lawrence Spradley and Mark Pearson
Lockheed Missiles and Space Company, Inc.
Huntsville, Alabama

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NOMENCLATURE

a	local sonic velocity
A, B, C, D	coefficient matrices for discrete equations
C	species mass fraction
E, F, G	flux vectors in Navier-Stokes equations
$\mathcal{D}$	binary diffusion coefficient
$\mathcal{E}$	total energy
h	static enthalpy
I	general interpolant functions
J	Jacobian matrix of transformation
k	thermal conductivity of gas
P	pressure
$\vec{P}, \vec{S}, \vec{E}$	point, surface and edge for general hexahedral element
$\mathfrak{R}$	full flow domain
q	diffusion flux terms
t, Δt	time, time step for finite differences
u, v, w	velocity components in x, y, z directions
U	flow vector of conservation variables
V	volume
W	arbitrary weight function
x, y, z	Cartesian coordinates
<u>Greek</u>	
α	weight function coefficients
γ	ratio of specific heats

σ	artificial diffusion terms
τ	real diffusion terms
μ, λ	first and second coefficients of viscosity
ρ	mass density
η_i	local element coordinates
Δ_J	determinant of Jacobian matrix J
ϵ	NDC coefficient
Φ	differential equation to be solved

<u>Subscripts</u>

i, j	node numbers in local element coordinates
m, n	node numbers in full flow domain
e	element
r	real value
d	artificial (NDC) value

<u>Superscript</u>

n	time step $n\Delta t$
$\bullet$	time derivative

1. INTRODUCTION

The General Interpolants Method (GIM) computer code was developed to analyze complex flow fields which defy solution by approximate methods. The code uses numerical techniques to solve the full three-dimensional time-averaged elliptic Navier-Stokes equations in arbitrary geometric domains. The equations are cast in Conservation Law Form and written in an orthogonal Cartesian coordinate system. A generalized three-dimensional geometry package is used to model the flow domain, generate the numerical grid of discrete points and to compute the local transformation metrics. Computation is done in physical space by explicit finite-difference operators. The approach taken in developing GIM is akin to the Method of Weighted Residuals which can produce discrete analogs classically termed finite-element methods. The GIM approach essentially combines the finite element geometric point of departure with finite difference explicit computation analogs. This provides a capability which takes advantage of the geometric flexibility on an element description and the superior computation speed of difference representations.

The numerical analogs of the differential equations are derived by representing each flow variable with general interpolation functions. The point of departure then requires that a weighted integral of interpolants be zero over the flow domain. By choosing the weight functions to be the interpolants themselves, the GIM formulation produces identically the classical implicit finite-element discrete equations. We do not use these forms in the GIM/STAR code due to their fully implicit nature. Rather, we choose the weight functions to be orthogonal to the interpolant functions. This choice reproduces explicit finite-difference type discrete analogs. By appropriate choice of constants in the orthogonal weight functions, the GIM becomes analogous to known finite difference schemes such as centered differences, windward schemes, and the two-step MacCormack technique. The GIM analogs, however, are automatically produced for arbitrary geometric flow domains. For pure Cartesian domains, the GIM method exactly reproduces these known schemes, but is a more general point of departure and provides greater flexibility in choice of difference scheme.

A motivation for developing this code on these principles was to provide an analytical tool which is more user oriented than the basic research tools which exist. A fully production-line code to solve the complex Navier-Stokes equations does not exist today. In developing the GIM code, we have attempted to bridge the gap somewhat between the pure research codes and the ultimate production tool. The code was originally developed for a CDC 7600 computer system. It has subsequently been converted to execute on Univac 1108 and 1110 systems. The most recent activity, which is the subject of this contract, has been the conversion of the GIM code to the STAR-100 computer at NASA-Langley Research Center.

Development of the GIM/STAR code is motivated by a number of factors: (1) NASA-Langley currently has a need for an analysis tool to aid in its research programs in hypersonic aerodynamics and propulsion; (2) The STAR machine has the potential of increased speed over a 7600 for flow field computation; (3) the virtual memory concept of the STAR machine is well suited for codes requiring large data bases; and (4) the GIM formulation and concepts are readily vectorizable for a machine such as the STAR. A feasibility study of the compatibility of the GIM concept with the STAR machine resulted in the conclusion that definite and significant advantages could be achieved.

The objectives of this contract were threefold: (1) convert the GIM code into STAR vector FORTRAN and implement it on the computer system at NASA-Langley; (2) upgrade the code to include a two-gas capability and a sharp corner boundary treatment; and (3) provide a compatible graphics package for operation on the CDC 6000 series machines. These objectives have been met with the code being successfully implemented on the STAR system. Two primary example problems have been computed: (1) a two-dimensional simulation of a Scramjet exhaust interacting with a supersonic free stream flow, and (2) a three-dimensional Scramjet simulation. Comparison of the STAR CP run times for these and other problems with a CDC 7600 have given improvement factors of up to 5 for the STAR code. The resulting calculations are identical to the 7600 solutions. The wall-clock time required to complete a GIM/STAR run is also significantly lower than a typical 7600 job for cases which do not require large page faulting on STAR. Large page faults occur when a problem size is too large to fit "into core" and must be stored on external media. For larger problems which require page faults, the throughput time is comparable to the GIM/7600 code. This ratio could be significantly improved by adding more high speed memory to the STAR system. The additional technical capability tasks and the graphics module addition have also been implemented and verified.

This report documents the results of the contract and also serves as a User's manual for the GIM/STAR code. Decks for the program modules reside on permanent files in the STAR computer system. FORTRAN listings can be obtained from these files. Section 2 of this report summarizes the contract study results and conclusions. Section 3 presents a general discussion of the GIM formulation, the structure of the code for STAR and example runstreams for executing the code. The input guides constitute Sections 4, 5 and 6 for the Geometry, Integration and Graphics Modules respectively. Hints on using the code and example problem setups are given in Sections 7 and 8. Section 9 contains a list of referenced documents which provide more details of the GIM theory and methods development.

The version of the GIM code documented in this report is designated SE-1 (STAR-Elliptic No. 1). The User's Manual is valid only for this version of the GIM code.

2. SUMMARY OF CONTRACT STUDY

2.1 OBJECTIVES

The objective of this contract is threefold: (1) code the GIM formulation to allow longer vector lengths and to take full advantage of the STAR vectorized multiplications; (2) update the GIM code to allow the treatment of internal sharp corners and also to include a two-gas capability (each having different transport properties) for computing exhaust/freestream interaction; (3) deliver the modified code and a compatible graphics package (to operate on CDC 6000) with appropriate documentation and demonstrate its capabilities through the use of a sample case prepared by NASA-Langley.

The following tasks were performed to accomplish these objectives:

<u>Task 1</u>

The standard Lockheed-Huntsville elliptic GIM code was implemented on the STAR system. This capability includes arbitrary two- and three-dimensional geometries, inviscid Euler and full Navier-Stokes equations, laminar viscosity model, ideal gas law for two streams with different specific heat ratios and explicit finite-difference analogs. Four modules were implemented: (1) module 1 — geometry and mesh generation; (2) module 2 — matrix assembly module; (3) module 3 — unsteady integration module and (4) Module 4 — graphics package on CDC 6000.

<u>Task 2</u>

The current standard GIM code was upgraded to handle gas stream interactions with different specific heat ratios, γ. An additional equation was added to compute the relative composition of the two gases at local grid stations. The ideal gas law is used to relate the local gamma in the shear layer to the two "pure" gas gammas, and compute pressure from the energy, density and velocity fields. The second modification that was made is an option on handling flows over sharp corners through the addition of a Prandtl-Meyer like expansion equation.

Task 3

A graphics package compatible with GIM outputs was implemented on the Langley CDC 6000.

Task 4

The GIM code as implemented on the STAR computer and associated graphics package as implemented on CDC 6000 is documented in a User's Manual and Input Guide.

Task 5

Test cases (two) which were computed by the GIM code on the STAR computer system are two- and three-dimensional Scramjet exhaust plume problems already analyzed with GIM on a CDC 7600 as reported in Ref. 1. The sample cases were compared with ones previously run on a CDC 7600 system for a comparison of run time and computational results.

2.2 RESULTS

The GIM code was implemented on the STAR-100 system at Langley. The following are the major modifications which were made to the code:

- Combined GEOM and MATRIX Modules to Eliminate Large Data File Transfers.
- Recoded Portions of GEOM Module to Use STAR Vector FORTRAN and Interleaved Large Pages.
- Added Algorithms to Diagonalize Coefficient Matrices into One-Dimensional Arrays.

- Eliminated Implicit Solution Algorithms (Finite Element).
- Recoded INTEG Module in STAR FORTRAN. Eliminated Large Data Files — Used Large Core.
- Added Algorithms to Use Operations with Vector Lengths Equal to Number of Nodes.
- Restructured Large Arrays in Common Blocks to Interleave Data Base Layout.

Most of these modifications were programming changes. There was, however, one item which was completely reformulated. This item is the matrix storage and multiplication operations. Scalar operations on the 7600 code were replaced with vector multiplies and adds to take full advantage of the STAR features. This basic operation involves the following calculations:

$$\frac{\partial U}{\partial t} + \frac{\partial E}{\partial x} + \frac{\partial F}{\partial y} + \frac{\partial G}{\partial z} + H = 0$$

$$\dot{U}_i^n = B_{ij} E_j^n + C_{ij} F_j^n + D_{ij} G_j^n - H_i^n$$

$$U_i^{n+1} = U_i^n + f(\dot{U}_i^n, \dot{U}_i^{n+1/2}, \Delta t)$$

Most of the CP time is spent in forming the vector products and sums, i.e.,

$$\sum_j B_{ij} E_j \; .$$

The GIM/STAR code was vectorized by arranging the B, C, D matrices as shown in Fig. 2-1. The order of operation proceeds down each of the diagonals with elements a, b, c, d, respectively. The elements designated with X are off-diagonal terms due to boundary conditions. These are treated by scalar operations. The example shown in this figure is for a two-dimensional, 20-node sample case. Three-dimensional cases can have up to eight diagonals.

$$\begin{bmatrix} \dot{U}_1 \\ \dot{U}_2 \\ \dot{U}_3 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \dot{U}_{19} \\ \dot{U}_{20} \end{bmatrix} = \left[\text{B Matrix}\right] \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ E_{19} \\ E_{20} \end{bmatrix}$$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	a	b	O	O	c	d														
2	O	a	b	O	O	c	d													
3		O	a	b	O	O	c	d												
4			X	a	O	O	X	c	O											
5				O	a	b	O	O	c	d										
6					O	a	b	O	O	c	d									
7						O	a	b	O	O	c	d								
8							X	a	O	O	X	c	O							
9								O	a	b	O	O	c	d						
10									O	a	b	O	O	c	d					
11										O	a	b	O	O	c	d				
12											X	a	O	O	X	c	O			
13												O	a	b	O	O	c	d		
14													O	a	b	O	O	c	d	
15														O	a	b	O	O	c	d
16															X	a	O	O	X	c
17													X	X	O	O	a	b	O	O
18														X	X	O	O	a	b	O
19															X	X	O	O	a	b
20															X	X	O	O	X	a

B Matrix

Fig. 2-1 - Matrix Diagonalization Technique Used in Vectorizing the Basic GIM Code Calculation

The vectorized GIM/STAR was run using four test problems. The first two of these are "simple" cases used mostly for debugging. They consist of two-dimensional supersonic source flow in a 15 deg. duct and a converging-diverging nozzle flow. The two primary test cases consist of the problems already solved with GIM and reported in Ref. 1. These are termed the two-dimensional Scramjet and the three-dimensional Scramjet cases, respectively. The GIM/STAR calculations reproduced the results previously obtained on the CDC 7600.

A study was made of CP time improvement of the GIM/STAR code over the 7600 version. The results of this study are shown in Fig. 2-2 for the four test cases just described. This data is shown in Fig. 2-3 plotted as CP times versus number of nodes in the problem. As seen from these data, a CP ratio of 5.5 was obtained for test case 1 with ratios generally from 3 to 5 for the other problems. This is a significant improvement in CP time especially since GIM/STAR is coded entirely in vector FORTRAN.

		CP Seconds for 100 Time Steps		
Case	Nodes	7600	STAR	Ratio
2-D Source Flow	121	4.2	2.0	2.1
	442	15.4	4.0	3.9
	961	33.6	6.8	4.9
	1681	58.8	10.6	5.5
2-D Nozzle	1932	70.8	13.6	5.2
2-D Scramjet	940	29.3	9.6	3.1
3-D Scramjet	7904	480.0	124.0	3.9

Fig. 2-2 - Summary of CP Time Comparison of GIM/STAR Code and CDC 7600

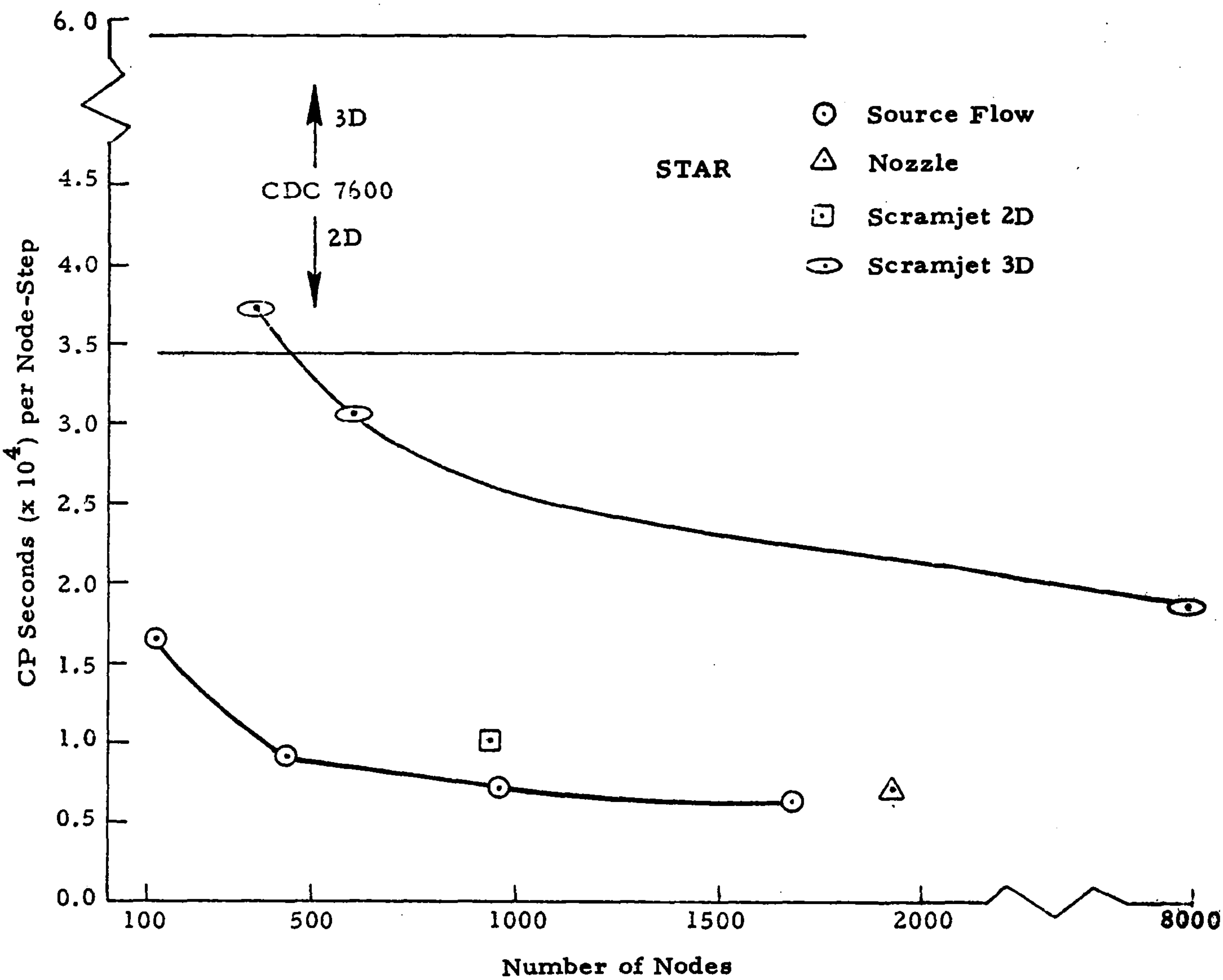


Fig. 2-3 - CP Time vs Problem Size for STAR and 7600 Computer

The other significant study of machine efficiency involves the "large page fault" feature of the STAR virtual memory system. For problems which are small enough to fit into "core," i.e., no large page faulting, the throughput time of a GIM/STAR job is approximately two times faster than a typical CDC 7600 job. For large problems which require some large page faults, the throughput time is about the same as a typical CDC 7600 job. The cost of a GIM/STAR job is then strongly influenced by the size of problem, i.e., number of nodes.

2.3 CONCLUSIONS AND RECOMMENDATIONS

All tasks of the contract have been completed. This report constitutes the final report and User's Manual as required by the contract. The following is a summary of the conclusions reached and recommendations for further utilization of the GIM code on the STAR computer at NASA-Langley.

- The GIM formulation proved to be ideally suited to the structure of the STAR-100 system.
- Vectorization was easily implemented using vector lengths equal to the number of nodes.
- STAR FORTRAN coding resulted in CP time ratios of approximately 5 over a CDC 7600 version of the code.
- Problem sizes which do not require large page faults run about two times faster than a typical 7600 GIM run.
- Large problem sizes do cause page faulting of the GIM/STAR code and hence total run times comparable to the 7600 code.
- The GIM/STAR code has successfully computed Scramjet nozzle-exhaust flows which have not been previously attempted.
- For flows which are entirely supersonic, a hyperbolic GIM algorithm should be added to the STAR code to reduce the cost of a run.
- For viscous flow in which downstream influences are negligible, a GIM parabolic solution algorithm should be added to further reduce the run time.
- A "partially-elliptic" algorithm can also be added to solve viscous flows with some downstream feed-back effects.
- The special STAR language SL1 should be investigated for potential use in GIM to further reduce the run time.
- Turbulence models, eddy viscosity and TKE, should be incorporated in GIM/STAR to allow turbulent viscous flows to be computed.
- An equilibrium chemistry model should be added in addition to the ideal gas model now used.
- The GIM/STAR code should now be run for additional problems such as Scramjet inlet flows, flows in the combustor area and some simplified external aerodynamic flows.

3. GIM CODE STRUCTURE

3.1 SUMMARY OF GIM THEORY

A formal development of the General Interpolants Method (GIM) is given in Refs. 1 and 2. The following discussion summarizes the theory, equation sets and numerical approach used in the GIM code for use on the STAR-100 computer.

GIM is a new methodology for constructing numerical analogs of the partial differential equations of continuum mechanics. A general formulation is provided which permits classical finite element methods and many of the finite difference methods to be derived directly. The GIM approach is new in the sense that it combines the best features of finite element and finite difference methods. The technique allows complex geometries to be handled in the finite element manner and operates on the integral form of the conservation laws. Solutions can be generated implicitly with the finite element analogs or by explicit finite difference analogs, which do not require a reduction of large systems of linear algebraic equations (no matrix inverse). The STAR version of GIM contains only the explicit finite difference analogs.

As is the case with all attempts to solve partial differential equations by numerical approximations, the domain of interest is first discretized by appropriate subdivision into an assemblage of interconnected finite elements. A mesh generation is used in the GIM approach which incorporates general curvilinear coordinates, stretching transformations and bivariate blending to produce an automated mesh/element generation. Shape functions based on a set of generalized interpolants are then chosen to describe the behavior over each element. We then proceed, as in the Method of Weighted Residuals (Ref. 3), by multiplying the discretized equations by a set of weight functions and integrating over the volume of the element. By choosing the weight functions equal to the shape functions, we reproduce via Galerkin (Ref. 3), the classical finite element nodal analogs. It is at this point that we introduce one of the important concepts of GIM: orthogonal weight/shape functions. By appropriately choosing the weight functions to be orthogonal to the shape functions, we can obtain explicit nodal analogs. Further, by a choice of arbitrary constants in the orthogonal weight functions, we can produce known finite difference nodal analogs, such as centered difference, upwind/downwind differences and the two-step MacCormack algorithm (Ref. 4). As a result of this spatial discretization, we have reduced the partial differential equations to ordinary differential equations with "time" as the independent variable. Any forward marching algorithm such as Euler, Runge-Kutta or predictor-corrector can be used to advance the solution profiles in time.

The GIM formulation is <u>not</u> a Finite Element method in the classical sense. Rather, finite difference methods are used exclusively but the equations are written in general orthogonal curvilinear coordinates. Transformations are used to transform the physical planes into regions of unit cubes. The mesh is generated on this unit cube and the local metric coefficients generated. Each region of the flow domain is likewise transformed and then blended to form the full flow domain. In order to treat "completely-artibrary" geometric domains, different transformations may be employed in different regions. For this reason, we then transform the blended domain back to physical space. This allows the same set of equations to be solved in each region, with the local Jacobian of the transformation being the coefficients.

<u>Equation Sets:</u> The partial differential equations solved by the GIM code are the Navier-Stokes written in three-dimensional Conservation Law Form for a Cartesian coordinate system. The full set of differential equations solved by the GIM code is shown in Fig. 3-1. These will be referred to as the Navier-Stokes equations, although they include continuity and energy conservation as well as momentum. For inviscid flow calculations without shock waves, the τ terms can be set to zero to produce the Euler set. Fig. 3-1 lists the viscous

$$\frac{\partial U}{\partial t} + \frac{\partial E}{\partial x} + \frac{\partial F}{\partial y} + \frac{\partial G}{\partial z} = 0$$

$$U = \begin{bmatrix} \rho \\ \rho u \\ \rho v \\ \rho w \\ \rho \mathcal{E} \\ \rho C \end{bmatrix}$$

$$E = \begin{bmatrix} \rho u \\ \rho u^2 + P - \tau_{xx} \\ \rho uv - \tau_{xy} \\ \rho uw - \tau_{xz} \\ (\rho \mathcal{E} + P)u - u\tau_{xx} - v\tau_{xy} - w\tau_{xz} - q_x \\ \rho uC - R_x \end{bmatrix}$$

$$F = \begin{bmatrix} \rho v \\ \rho vu - \tau_{xy} \\ \rho v^2 + P - \tau_{yy} \\ \rho vw - \tau_{yz} \\ (\rho \mathcal{E} + P)v - u\tau_{xy} - v\tau_{yy} - w\tau_{yz} - q_y \\ \rho vC - R_y \end{bmatrix}$$

$$G = \begin{bmatrix} \rho w \\ \rho wu - \tau_{xz} \\ \rho wv - \tau_{yz} \\ \rho w^2 + P - \tau_{zz} \\ (\rho \mathcal{E} + P)w - u\tau_{xz} - v\tau_{yz} - w\tau_{zz} - q_z \\ \rho wC - R_z \end{bmatrix}$$

$$\tau_{xx} = 2\mu \frac{\partial u}{\partial x} + \lambda \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)$$

$$\tau_{yy} = 2\mu \frac{\partial v}{\partial y} + \lambda \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)$$

$$\tau_{zz} = 2\mu \frac{\partial w}{\partial z} + \lambda \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)$$

$$\tau_{xy} = \mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)$$

$$\tau_{xz} = \mu\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)$$

$$\tau_{yz} = \mu\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)$$

$$q_x = k \frac{\partial T}{\partial x} + \rho \mathcal{D} (h_1 - h_2) \frac{\partial C}{\partial x}$$

$$q_y = k \frac{\partial T}{\partial y} + \rho \mathcal{D} (h_1 - h_2) \frac{\partial C}{\partial y}$$

$$q_z = k \frac{\partial T}{\partial z} + \rho \mathcal{D} (h_1 - h_2) \frac{\partial C}{\partial z}$$

$$R_x = \mathcal{D} \frac{\partial C}{\partial x}$$

$$R_y = \mathcal{D} \frac{\partial C}{\partial y}$$

$$R_z = \mathcal{D} \frac{\partial C}{\partial z}$$

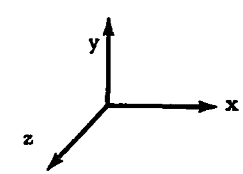


Fig. 3-1 - Three-Dimensional Full Elliptic Navier-Stokes System in Cartesian Conservation Law Form terms with coefficients, μ, λ, k for the first and second coefficients of viscosity and the thermal conductivity, respectively. These are specified by the user as "laminar" constants. For reasons of numerical stability and capture of strong shock waves, additional components of the diffusion coefficients are added automatically by the GIM code. Figure 3-2 is a list of currently used Numerical Diffusion Cancellation (NDC) coefficients. These are added to the real diffusion coefficients. The purpose of these NDC coefficients is to cancel low order truncation error terms which arise in the numerics. Reference 5 presents the basic principles of the NDC technique in more detail.

The differential equations are solved in strong conservation or divergence law form. The solution is started at some time t where the entire flowfield mesh is specified. The unsteady or relaxation of the equations is then done using the user-specified nodal analogs. At this time, the pressure is computed from the ideal gas law for a single or two component gas.

Geometry and Coordinate Treatment: The underlying concept of the theory of finite elements relates to the classical notion of "piecewise approximation." A real continuum, R, can be considered as an infinite number of interconnecting points. A piecewise approximation to the continuous region, R, consists of a finite number of interconnecting points which, in some manner, resembles R itself. We are also concerned with a continuous field, f, whose domain of interest is the region R; for example, the region R can be a body over which a flow field is to be determined. The function f(X) prescribes a unique value of f at an infinite number of points X in R. The problem of piecewise approximation is to construct a discrete model of the region R and the function f such that the field is represented approximately at a finite number of points in R.

An important concept of the theory of finite elements is the "disconnectness" property. This means that a domain can be divided into a finite number of pieces called elements and the approximation to the functional distribution

Coefficients for Stress Terms

$$\mu = \mu_r + \mu_d$$

$$\mu_r = \text{laminar, constant viscosity}$$

$$\mu_d = \epsilon_1 \rho \Delta t (u^2 + v^2 + w^2) \qquad \text{NDC Value}$$

$$k = k_r + k_d$$

$$k_r = \text{thermal conductivity}$$

$$k_d = \gamma^2 C_v \mu_d \qquad \text{NDC Value}$$

Coefficients for Species Equation

$$\mathcal{D} = \mathcal{D}_r + \mathcal{D}_d$$

$$\mathcal{D}_r = \text{binary diffusion coefficient}$$

$$\mathcal{D}_d = \left\{\begin{matrix} \epsilon_2 \Delta t (u^2 + a^2)\rho & \text{x-component} \\ \epsilon_2 \Delta t (v^2 + a^2)\rho & \text{y-component} \\ \epsilon_2 \Delta t (w^2 + a^2)\rho & \text{z-component} \end{matrix}\right\} \qquad \text{NDC Values}$$

Coefficients for Continuity Equation

$$\rho u - \sigma_x \qquad \rho v - \sigma_y \qquad \rho w - \sigma_z$$

$$\left.\begin{matrix} \sigma_x = \epsilon_3 \Delta t (u^2 + a^2)\, \partial\rho/\partial x \\ \sigma_y = \epsilon_3 \Delta t (v^2 + a^2)\, \partial\rho/\partial y \\ \sigma_z = \epsilon_3 \Delta t (w^2 + a^2)\, \partial\rho/\partial z \end{matrix}\right\} \qquad \text{NDC Values}$$

Fig. 3-2 - NDC Coefficients Used in the GIM/STAR Code

over each element can be studied independently. Thus the approximating functions for each element completely define the behavior of the function profile within the element without consideration of its ultimate location in the full model. After each element is defined, the complete discrete model of the body is obtained by "assembling the system." The assembly is performed by means of mathematical blending of each subdomain while maintaining continuity at the junctions.

The General Interpolants Method uses these concepts, borrowed from finite element theory, to obtain discrete finite difference models of the Navier-Stokes equations in arbitrary geometric domains. The development is done in local curvilinear <u>intrinsic</u> coordinates based on:

1. Analytical regions such as rectangles, spheres, cylinders, hexahedrals, etc., which have intrinsic or natural coordinates.
2. Complex regions that can be subdivided into a number of smaller regions which can be described by analytic functions. The degenerate case is to subdivide small enough to use very small straight-line segments.
3. Intrinsic curvilinear coordinate systems that result in constant coordinate lines throughout a simply connected, bounded domain R in Euclidean space.
4. The intersection of the lines of constant coordinates that produce nodal points evenly spaced in the domain R.
5. Intrinsic curvilinear coordinate systems that can be produced by a univalent mapping of a unit cube onto the simply-connected bounded domain R.

Thus, if a transformation can be found which will map a unit cube univalently onto a general analytical domain, then any complex region can be piecewise transformed and blended using general interpolants.

Consider the general hexahedral configuration shown in Fig. 3-3. The local intrinsic coordinates are η_1, η_2, η_3 with origin at point P_1. The shape of the geometry is defined by

1. Eight corner points, $\vec{P}_1$ through $\vec{P}_8$ as shown (Fig. 3-3a)

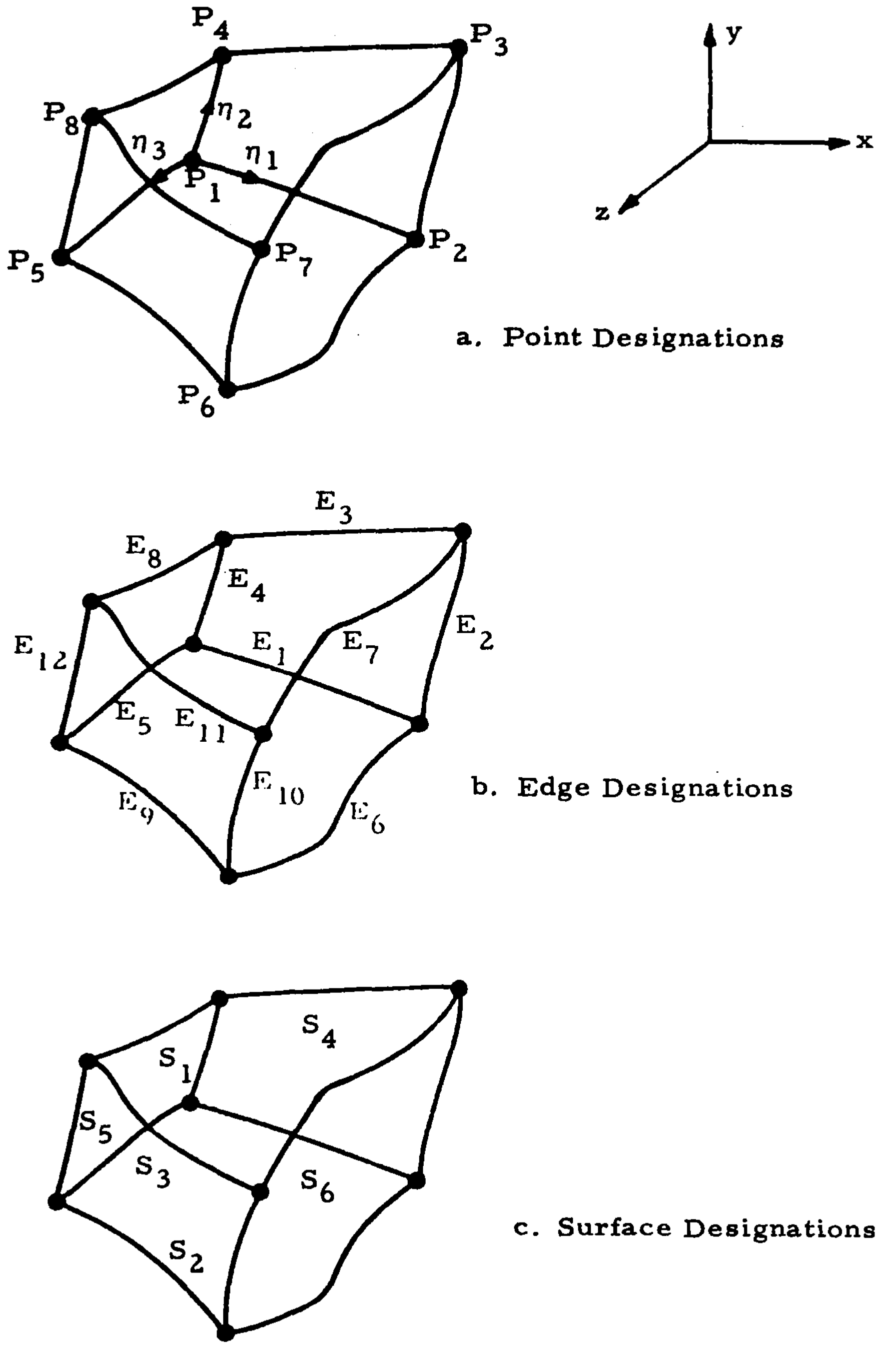


Fig. 3-3 - General Hexahedral Showing Local Intrinsic Coordinates, Point, Edge and Surface Designations

2. Twelve edge functions, $\vec{E}$ (Fig. 3-3b)
3. Six surface functions, $\vec{S}$ (Fig. 3-3c)

This shape is then fully described if the edges and surfaces can be specified as continuous analytic vector functions

$$\vec{S}_i(x, y, z), \quad \vec{E}_i(x, y, z) .$$

Based on the work of Gordon and Hall (Ref. 6) we have developed a general relationship between physical Cartesian space and local curvilinear intrinsic coordinates. This relation is given by the following general trilinear interpolant:

$$\begin{aligned}
&\underline{\bar{X}}(\eta_1, \eta_2, \eta_3) = \\
&(1-\eta_1)\vec{S}_5 + \eta_1 \vec{S}_6 + (1-\eta_2)\vec{S}_2 + \eta_2 \vec{S}_4 \\
&+ (1-\eta_3)\vec{S}_1 + \eta_3 \vec{S}_3 \\
&- (1-\eta_1)(1-\eta_2)\vec{E}_5 - (1-\eta_1)\eta_2 \vec{E}_8 - \eta_1 (1-\eta_2)\vec{E}_6 \\
&- \eta_1 \eta_2 \vec{E}_7 - (1-\eta_1)(1-\eta_3)\vec{E}_4 - (1-\eta_1)\eta_3 \vec{E}_{12} \\
&- \eta_1 (1-\eta_3)\vec{E}_2 - \eta_1 \eta_3 \vec{E}_{10} - (1-\eta_2)(1-\eta_3)\vec{E}_1 \\
&- (1-\eta_2)\eta_3 \vec{E}_9 - \eta_2 (1-\eta_3)\vec{E}_3 - \eta_2 \eta_3 \vec{E}_{11} \\
&+ (1-\eta_1)(1-\eta_2)(1-\eta_3)\vec{P}_1 + (1-\eta_1)(1-\eta_2)\eta_3 \vec{P}_5 \\
&+ (1-\eta_1)\eta_2 (1-\eta_3)\vec{P}_4 + (1-\eta_1)\eta_2 \eta_3 \vec{P}_8 \\
&+ \eta_1 (1-\eta_2)(1-\eta_3)\vec{P}_2 + \eta_1 (1-\eta_2)\eta_3 \vec{P}_6 \\
&+ \eta_1 \eta_2 (1-\eta_3)\vec{P}_3 + \eta_1 \eta_2 \eta_3 \vec{P}_7
\end{aligned} \tag{3.1}$$

$$\underline{X}(\eta_1, \eta_2, \eta_3) = \begin{bmatrix} x(\eta_1, \eta_2, \eta_3) \\ y(\eta_1, \eta_2, \eta_3) \\ z(\eta_1, \eta_2, \eta_3) \end{bmatrix}$$

and $\vec{S}_i$, $\vec{E}_i$ are the vector functions defining the surfaces and edges, respectively, and $\vec{P}_i$ are the (x, y, z) coordinates of the corner points. Edge and surface functions are currently included in the GIM code as summarized in Fig. 3-4.

- HEXAHEDRAL BUILDING BLOCKS
  - EDGES (Combinations of up to Five Types)

    Linear Segment
    Circular Arc
    Conic (Elliptical, Parabolic, Hyperbolic) Arc
    Helical Arc
    Sinusoidal Segment
  - SURFACES (Bounded by Above Edges)

    Flat Plate
    Cylindrical Surface
    Edge of Revolution
- REGION OF INTEREST DESCRIBED BY UNLIMITED NUMBER OF HEXAHEDRAL BUILDING BLOCKS

Fig. 3-4 - GIM Three-Dimensional Geometry Package Edge and Surface Function Types

With this transformation, any point in local coordinates η_1, η_2, η_3 can be related to global Cartesian coordinates x, y, z. Likewise any derivatives of functions in local coordinates can be related to that derivative in physical space, i.e.,

$$\begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \\ \frac{\partial f}{\partial z} \end{bmatrix} = \begin{bmatrix} J \end{bmatrix}^{-1} \begin{bmatrix} \frac{\partial f}{\partial \eta_1} \\ \frac{\partial f}{\partial \eta_2} \\ \frac{\partial f}{\partial \eta_3} \end{bmatrix} \tag{3.2}$$

where J, the Jacobian matrix, is easily computed from Eq. (3.1);

$$J = \begin{bmatrix} \frac{\partial x}{\partial \eta_1} & \frac{\partial y}{\partial \eta_1} & \frac{\partial z}{\partial \eta_1} \\ \frac{\partial x}{\partial \eta_2} & \frac{\partial y}{\partial \eta_2} & \frac{\partial z}{\partial \eta_2} \\ \frac{\partial x}{\partial \eta_3} & \frac{\partial y}{\partial \eta_3} & \frac{\partial z}{\partial \eta_3} \end{bmatrix} \qquad \Delta_J = \det|J| \tag{3.3}$$

Discretization of Equations: Equations (3.2) and (3.3) then relate any flow gradient in η_1, η_2, η_3 space back to physical space. We then need a method of approximating the flowfield function f in local coordinates. This is done with a set of general interpolation functions $I(\eta_1, \eta_2, \eta_3)$ such that

$$f(\eta_1, \eta_2, \eta_3) = \sum_{j=1}^{8} I_j(\eta_1, \eta_2, \eta_3)\, f_j \tag{3.4}$$

where f_j are the flow variables at the corner points of the element. The simplest form for the I_j are the trivariable Lagrange interpolants. The theory itself does not restrict the I_j to be linear, but in the elliptic GIM code we currently have only the trilinear interpolants. Any flow gradient can then be simply computed as

$$\frac{\partial f}{\partial \eta_i} = \sum_{j=1}^{8} \frac{\partial I_j}{\partial \eta_i}\, f_j \tag{3.5}$$

The elliptic GIM code uses these concepts to produce a discrete analog of the Navier-Stokes equations for a single analytical region. Proceeding as in Ref. 1, the point of departure is the requirement that

$$\Re = \int_V W\, \Phi \; dV = 0 \tag{3.6}$$

where W is an arbitrary weight function and Φ is the differential equation

$$\Phi = \frac{\partial U}{\partial t} + \frac{\partial E}{\partial x} + \frac{\partial F}{\partial y} + \frac{\partial G}{\partial z} . \tag{3.7}$$

The general interpolants I are used to approximate each of the flow variables U, E, F, G and are substituted into Eq. (3.6) to obtain a discrete analog:

$$[A_{ij}]\,\dot{U}_j + [B_{ij}]\,E_j + [C_{ij}]\,F_j + [D_{ij}]\,G_j = 0 \tag{3.8}$$

where $\dot{U}_j$, E_j, F_j, G_j are the flow variables at the node points of an element and the coefficient matrices, geometrically dependent, are given by the following integrals.

$$[A_{ij}] = \int_0^1\!\int_0^1\!\int_0^1 W_i\, I_j\, \Delta_J\, d\eta_1\, d\eta_2\, d\eta_3 \tag{3.9}$$

$$[B_{ij}] = \int_0^1\!\int_0^1\!\int_0^1 W_i \left[\left(\frac{\partial y}{\partial \eta_2}\frac{\partial z}{\partial \eta_3} - \frac{\partial z}{\partial \eta_2}\frac{\partial y}{\partial \eta_3}\right)\frac{\partial I_j}{\partial \eta_1} + \left(\frac{\partial z}{\partial \eta_1}\frac{\partial y}{\partial \eta_3} - \frac{\partial y}{\partial \eta_1}\frac{\partial z}{\partial \eta_3}\right)\frac{\partial I_j}{\partial \eta_2} + \left(\frac{\partial y}{\partial \eta_1}\frac{\partial z}{\partial \eta_2} - \frac{\partial z}{\partial \eta_1}\frac{\partial y}{\partial \eta_2}\right)\frac{\partial I_j}{\partial \eta_3}\right] d\eta_1\, d\eta_2\, d\eta_3$$

$$[C_{ij}] = \int_0^1\!\int_0^1\!\int_0^1 W_i \left[\left(\frac{\partial z}{\partial \eta_2}\frac{\partial x}{\partial \eta_3} - \frac{\partial x}{\partial \eta_2}\frac{\partial z}{\partial \eta_3}\right)\frac{\partial I_j}{\partial \eta_1} + \left(\frac{\partial x}{\partial \eta_1}\frac{\partial z}{\partial \eta_3} - \frac{\partial z}{\partial \eta_1}\frac{\partial x}{\partial \eta_3}\right)\frac{\partial I_j}{\partial \eta_2} + \left(\frac{\partial z}{\partial \eta_1}\frac{\partial x}{\partial \eta_2} - \frac{\partial x}{\partial \eta_1}\frac{\partial z}{\partial \eta_2}\right)\frac{\partial I_j}{\partial \eta_3}\right] d\eta_1\, d\eta_2\, d\eta_3$$

$$[D_{ij}] = \int_0^1\!\int_0^1\!\int_0^1 W_i \left[\left(\frac{\partial x}{\partial \eta_2}\frac{\partial y}{\partial \eta_3} - \frac{\partial y}{\partial \eta_2}\frac{\partial x}{\partial \eta_3}\right)\frac{\partial I_j}{\partial \eta_1} + \left(\frac{\partial y}{\partial \eta_1}\frac{\partial x}{\partial \eta_3} - \frac{\partial x}{\partial \eta_1}\frac{\partial y}{\partial \eta_3}\right)\frac{\partial I_j}{\partial \eta_2} + \left(\frac{\partial x}{\partial \eta_1}\frac{\partial y}{\partial \eta_2} - \frac{\partial y}{\partial \eta_1}\frac{\partial x}{\partial \eta_2}\right)\frac{\partial I_j}{\partial \eta_3}\right] d\eta_1\, d\eta_2\, d\eta_2$$

The procedure is then to obtain individual element matrices by numerical Gaussian quadrature evaluation of Eq. (3.9). We thus have a Cartesian-like finite difference equation (Eq. (3.8)) with all the geometric transformation data as coefficients of the finite difference operator. The A, B, C, D matrices may be viewed as "derivative takers" or finite difference operators which contain both the difference scheme and the transformation metrics.

To model a complex three-dimensional domain, it is first subdivided into regions and Eq. (3.8) obtained for each region. After all regions are so processed, the final order of business is to "assemble the system" to obtain a consistent set of coefficient matrices for the full complex region. This is accomplished by the so-called quasi-variational procedure.

Since the choice of the weight function W is arbitrary, the integral, (Eq. (3.6)) must be stationary for variations in W. The so-called quasi-variational approach determines the conditions under which the integral is stationary. That is to say that if $W' = W + \delta W$ then

$$\delta \Re = \sum_{e=1}^{N} \int_{R_e} \delta W \;\Phi\; dx\, dy\, dz = 0$$

Now let

$$\left.\begin{aligned} W &= W_j\,(\eta_1, \eta_2, \eta_3)\, \dot{U}_j \qquad \text{or} \\ \delta W &= W_j\, \delta \dot{U}_j \end{aligned}\right. \tag{3.10}$$

so that

$$\delta \Re = \sum_{e=1}^{N} \left\{ \int_{R_e} W_j \;\Phi\; dx\, dy\, dz\; \delta \dot{U}_j \right\} = 0$$

For the $\delta\Re$ to be stationary, the sum of the coefficients of $\delta \dot{U}_j$ must be zero. This provides a rationale for the classical assembly procedure for MWR derived finite element schemes.

In mathematics, this can be written as

$$\left[A_{mn}\right] = \sum_{e} \delta_{mi} \left[A_{ij}^{e}\right] \delta_{nj} \tag{3.11}$$

where

$$\delta_{mi} = \begin{cases} 1 & \text{if node } i \text{ of element } e \text{ coincides with node } m \text{ of the region } R \\ 0 & \text{otherwise} \end{cases}$$

and similarly for the B, C, D matrices. The rationale for doing this is directly derivable from the quasi-variational procedure.

Upon assembly then the finite difference equations for the full domain have the form

$$\boxed{\left[A_{mn}\right] \dot{U}_n + \left[B_{mn}\right] E_n + \left[C_{mn}\right] F_n + \left[D_{mn}\right] G_n = 0} \tag{3.12}$$

At this point, the weight functions W are arbitrary. Thus, in general, Eq. (3.12) is an implicit difference operator. If we choose the weight functions W to be the general interpolants I, i.e., W = I, then equation (3.12) is a classical Galerkin finite element model. We do not, however, use this description in the GIM code. Rather, we choose the weight functions W to be orthogonal to the general interpolants

$$(W * \Delta_J) \perp I$$

Now, inspection of Eq. (3.9) shows immediately that the $[A]$ matrix becomes diagonal. Likewise then Eq. (3.12) becomes an explicit finite difference operator. The GIM formulation thus allows either explicit or implicit operators with the finite difference coefficients containing all of the geometric transformations.

The GIM/STAR code contains only the explicit finite-difference analogs. A fully implicit scheme for three-dimensional problems requires the simultaneous solution of a large system of algebraic equations. These operations are not as readily vectorizable on a machine such as STAR as are the fully explicit schemes. Reference 1 contains examples of the types of explicit schemes which the GIM code can generate. The interpolant functions, I, described in this section are general in the formulation. The current GIM/STAR code contains only the trilinear interpolants with their corresponding orthogonal weight functions. Figure 3-5 shows these interpolant and weight functions that are presently coded in the STAR program. The α_i are constants, read into the program, which determine the specific type of finite difference algorithm (see Section 4).

3.2 CODE LAYOUT ON STAR

The GIM code is split into three separate modules for execution on the STAR-100 system. These are the geometry module, GEOM, the numerical integration module, INTEG and the graphics module, GIMPLT. Figure 3-6 is a block diagram of the modular structure. All program files reside on the STAR Access Station permanent file system in UPDATE format.

The GEOM and INTEG modules have variable dimensions in the source code which are replaced by the actual dimensions by preprocessing the COMPILE file before compilation. This is done on the "Z" side by a "dynamic dimension" routine. The names of these routines are DYNMAT and DYNDIM for the GEOM and INTEG modules, respectively. The input data required for these programs is described in the sections on the GEOM module and INTEG module. DYNMAT and DYNDIM read the compile file on unit 8 and write the "processed" compile file on unit 3. Therefore the UPDATE command must have the parameter C = TAPE8 specified. TAPE3 is then passed over to STAR via the TOSTAR command for compilation.

The GEOM and INTEG modules are compiled and executed on STAR, hence the "processed" compile files for these modules must be passed over to STAR via the TOSTAR command. The GIMPLT module is executed on the "Z" machine itself so that no TOSTAR command is needed.

General Trilinear Interpolant Functions, I

$$I = \begin{cases} (1-\eta_1)\,(1-\eta_2)\,(1-\eta_3) \\ \eta_1\,(1-\eta_2)\,(1-\eta_3) \\ \eta_1\,\eta_2\,(1-\eta_3) \\ (1-\eta_1)\,\eta_2\,(1-\eta_3) \\ (1-\eta_1)\,(1-\eta_2)\,\eta_3 \\ \eta_1\,(1-\eta_2)\,\eta_3 \\ \eta_1\,\eta_2\,\eta_3 \\ (1-\eta_1)\,\eta_2\,\eta_3 \end{cases}$$

Trilinear Orthogonal Weight Functions, W

$$W * \Delta_J = \begin{cases} \alpha_1\,(2/3-\eta_1)\,(2/3-\eta_2)\,(2/3-\eta_3) \\ \alpha_2\,(1/3-\eta_1)\,(2/3-\eta_2)\,(2/3-\eta_3) \\ \alpha_3\,(1/3-\eta_1)\,(1/3-\eta_2)\,(2/3-\eta_3) \\ \alpha_4\,(2/3-\eta_1)\,(1/3-\eta_2)\,(2/3-\eta_3) \\ \alpha_5\,(2/3-\eta_1)\,(2/3-\eta_2)\,(1/3-\eta_3) \\ \alpha_6\,(1/3-\eta_1)\,(2/3-\eta_2)\,(1/3-\eta_3) \\ \alpha_7\,(1/3-\eta_1)\,(1/3-\eta_2)\,(1/3-\eta_3) \\ \alpha_8\,(2/3-\eta_1)\,(1/3-\eta_2)\,(1/3-\eta_3) \end{cases}$$

Fig. 3-5 - General Interpolants and Weight Functions Used in the GIM/STAR Code

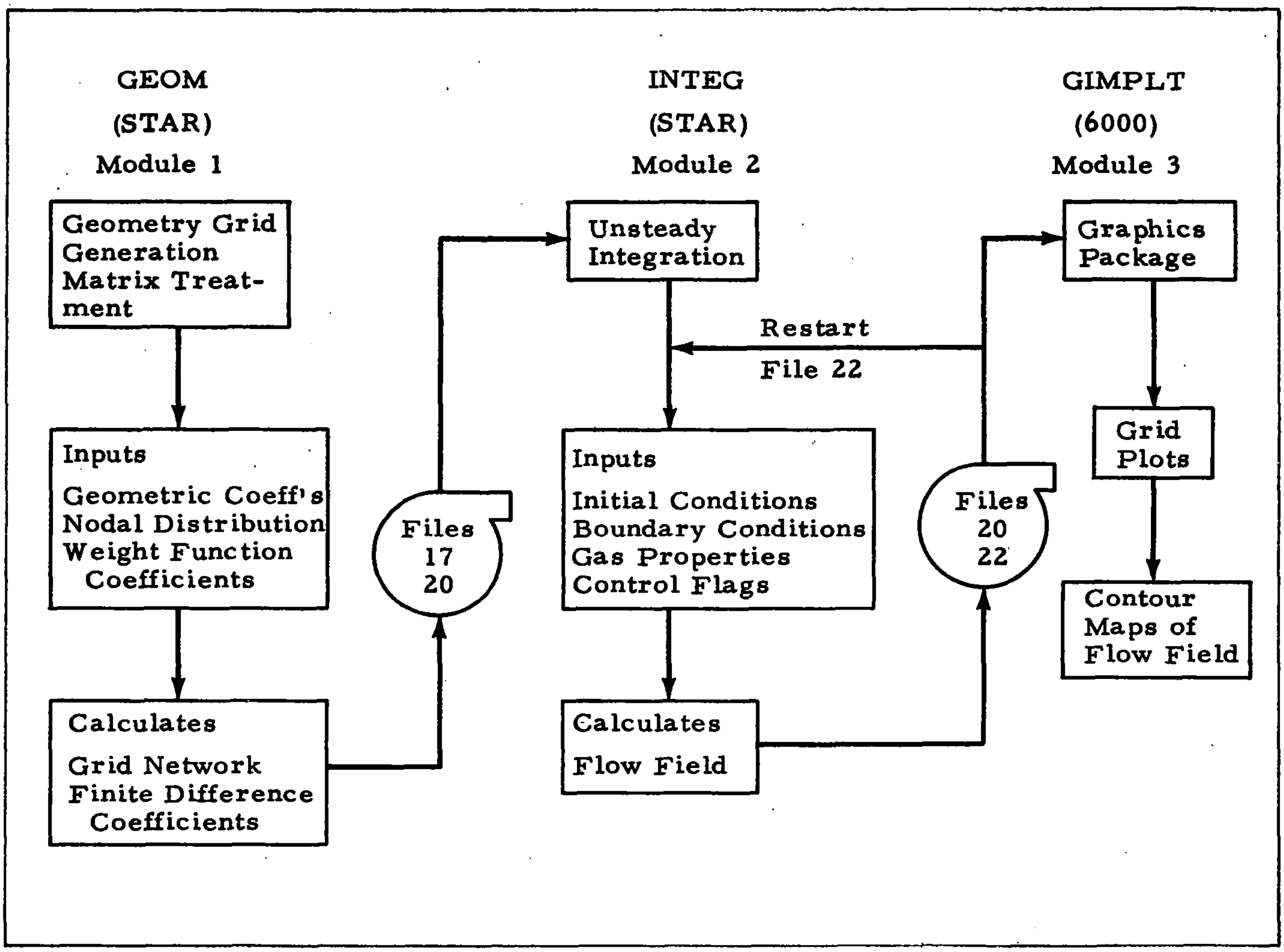


Fig. 3-6 - GIM Code Modular Structure on STAR

3.3 EXECUTING GIM ON STAR

Executing GIM on the STAR computer system involves the preparation of several items other than the input data. These include: (1) the dynamic dimension routine data; (2) preparation of the LOAD card; (3) use of CREATE cards for data files; and (4) the remainder of the runstream which is generally standard. The description of the dynamic dimension data is given in the sections describing the individual modules. Example runstreams are presented and discussed in Section 3.4 which provides a guide in runstream preparation for GIM runs. This section deals in some detail with items (2) and (3) above. The LOAD card involves the specification of large or small pages, page boundary allocation for common blocks and the size allocation for the controllee file. These are discussed in detail along with a description of the data files and how to calculate their size requirements. This will determine whether a CREATE card is needed.

File space is created automatically for small files. Larger files must be created by a CREATE card. The current default file allocation at NASA-Langley is 128 small pages (512 words each). The file allocation will be extended up to three times, adding 85 small pages each time, if the original allocation is exceeded. Files which require more than the maximum of 384 small pages (196608 words) must be created with a CREATE command. (See STAR Programming Manual and example runstreams.)

3.3.1 File Descriptions

File 16: Work file used in GEOM module only. Contains geometry information blocked with 500 nodes (NN) or less, per block.

$$\text{Size} = 10 * NN + 1 \quad \text{words minimum}$$

If less than 500 nodes per block are used, the total file size will be larger since records of length 5001 are used even if they are not full. The number of nodes per block is determined automatically by the GEOM module based on the zone/region configuration and is not controlled directly by the user.

File 17: This file contains the nodal analog coefficients. It is generated in the GEOM module and used by the INTEG module. It consists of a single unformatted binary record of length (NWDS) given below.

$$\begin{aligned} NWDS &= 16*NN + 18*NSP + 6 \quad (2D) \\ &= 48*NN + 18*NSP + 6 \quad (3D) \end{aligned}$$

where

NN is the total number of nodes, and

NSP is the number of special boundary terms (see GEOM and INTEG input guides).

The record length is adjusted upward to be a multiple of large pages (65536 words). File 17 is mapped onto the nodal analog common block /Q3MAP/ in INTEG via the Q3OPNMAP call. (See STAR Programming Manual, Section 5.2.2.)

File 20: This file is created in the GEOM module and contains all geometry data. It is read by both the INTEG and GIMPLT modules. It is a formatted file written using a 6E22.14 format. The number of words (NWDS) contained in the file is given by the formula below.

$$\begin{aligned} NWDS &= 6*NN \quad (2D) \\ &= 9*NN \quad (3D) \end{aligned}$$

Since the file is formatted with 22-character word lengths, the file size is increased by a factor of approximately 2.2.

File 22: This file created by INTEG contains the flowfield solution data. It is used as a restart file by INTEG and as a flowfield data file by

GIMPLT for plotting velocity vectors and contours. It consists of one or more records of length NWDS given below.

$$\text{NWDS} = 5*\text{NN} \quad (2D)$$
$$= 6*\text{NN} \quad (3D)$$

For a two-gas case, additional NN words are contained in each record. The number of records is determined by the iteration increment at which the file is written. This file is also formatted (6E22.14), so its length is increased by a factor of approximately 2.2.

3.3.2 Controllee File Sizes

An adequate length for the controllee file must be specified on the LOAD card. This requires that some estimate of the size of the controllee file must be made prior to execution. Approximate formulas are given for estimating the sizes for GEOM and INTEG.

GEOM

$$\begin{array}{l}\text{Number of} \\ \text{large pages}\end{array} = \begin{cases} \dfrac{125 * \text{NN}}{65536} + 3 & (2D) \\ \dfrac{307 * \text{NN}}{65536} + 3 & (3D) \end{cases}$$

The value on the LOAD card is specified in small pages (512 words). The GRLPALL parameter is always used in the LOAD card for the GEOM module, however, indicating the use of large pages (65536 words, or 128 small pages). Therefore, the number of large pages required should be calculated based on the number of nodes NN and then multiplied by 128 to obtain the value to use on the LOAD card. (See example runstreams in Section 3.4).

INTEG

Most of the space required by the INTEG controllee file is taken up by seven common blocks. The size, L, of these common blocks is given by the set of formulas on the following page.

/PRIM/	L =	6 MN + MNZ + MNS
/EBUF/	L =	MEQ (2 MN + MNZ)
/UBUF/	L =	MEQ (2 MN + MNZ)
/XBUF/	L =	6 MN + 3 MNZ
/TAU/	L =	7 MN + 5 MNZ
/AXSYM/	L =	MNA (4 + MEQ)
/VTEMP/	L =	4 MN + 2 MNS.

Where

MN	=	total number of nodes	
MNS	=	MN	for two gas case
	=	1	for single gas case
MNZ	=	MN	if 3D
	=	1	if 2D
MNA	=	MN	if axisymmetric
	=	1	if not axisymmetric
MEQ	=	4	2D -single gas
	=	5	2D -two gas or 3D -single gas
	=	6	3D -two gas

These common blocks should be assigned to large pages via the GRLP parameter in the LOAD card. Unless the total space for these common blocks occupies less than two or three pages, these blocks should be assigned to page boundaries as in Runstream Example 3. For a small problem they may be grouped together as in Runstream Example 2.

The remaining large common block in INTEG, /Q3MAP/, is assigned to a large page boundary via the GROL parameter in the LOAD card which causes no space to be allocated in the controllee file. File 17, which contains the analog coefficients, is mapped onto this common block via a call to Q3OPNMAP in INTEG.

The space needed for the INTEG controllee file is then the total number of large pages required for the set of common blocks above plus one additional large page for the remainder of the program. The space parameter is given in small pages, therefore, the number of large pages should be multiplied by 128. If in doubt, add an additional large page. Any unused space allocated for the controllee file will be released.

3.4 EXAMPLE RUNSTREAMS

3.4.1 Example Runstream 1 (Fig. 3-7)

This runstream illustrates execution of the GEOM module by itself for a large three-dimensional problem (3D shear layer — 7904 nodes). The output files, FILE17 and FILE20, are saved back on the "Z" side via the TOAS command. Note that FILE17 is a binary file (FILE17=BI) and FILE20 is a formatted file. Any updates to the GEOM module would follow the *ID GEOMODS card.

Calculation of File Sizes:

File 16

$$
\begin{aligned}
L &= (10)(7904) + 1 \\
&= 79041 \text{ words minimum} \\
&= 155 \text{ small pages minimum}
\end{aligned}
$$

use 200 in CREATE card

File 17

$$
\begin{aligned}
L &= (48)(7904) + (18)(7904) + 6 \\
&= 521665 \text{ words} \\
&= 1019 \text{ small pages}
\end{aligned}
$$

```
GEOM3D,CM60000,T100.
USER,680077C.
CHARGE,101857,LRC.
GET(OLDPL=GEOMAT)
GET(DYNMAT=DYNMAT)
UPDATE(F,C=TAPE8)
DYNMAT.
TOSTAR(INPUT,TAPE3)
7/8/9
*ID GEOMODS
7/8/9
 7904     3
7/8/9
STORE 680077 400SDS GEOMDECK B
STRGEOM,T200.
FORTRAN(I=TAPE3,B=GEOMB,O=LB)
CREATE(FILE16,200,T=P)
CREATE(FILE17,1019,T=P)
CREATE(FILE20,306,T=P)
LOAD(GEOMB,CN=GEOMGO,5120,GRLPALL= )
GEOMGO.
TOAS(Z=680077C,FILE17=BI,FILE20)

*** GEOM DATA ***

6/7/8/9/
```

Fig. 3-7 - GEOM Module Execution for a Large Three-Dimensional Problem

File 20

$$L = (9)(7904)(2.2)$$
$$= 156500 \text{ words}$$
$$= 306 \text{ small pages}$$

Controllee File Size Calculation:

$$L = (307)(7904) + 3 \text{ large pages}$$
$$= 2426528 \text{ words} + 3 \text{ large pages}$$
$$= 40 \text{ large pages}$$
$$= 5120 \text{ small pages}$$

Note that the GRLPALL parameter is used in the LOAD card.

3.4.2 Example Runstream 2 (Fig. 3-8)

This runstream illustrates the execution of GEOM and INTEG together for a small problem (340 node 3D). No files are saved on this run. All file sizes are small, thus no CREATE cards are needed.

Calculation of Controllee File Sizes:

GEOM

$$L = (307)(340) + 3 \text{ large pages}$$
$$= 104380 \text{ words} + 3 \text{ large pages}$$
$$= 5 \text{ large pages}$$
$$= 640 \text{ small pages}$$

INTEG

This problem is three-dimensional, single gas. Hence,

```
GEOINT,CM60000,T100.
USER,680077C.
CHARGE,101857,LRC.
GET(OLDPL=GEOMAT)
GET(DYNMAT=DYNMAT)
UPDATE(F,C=TAPE8)
DYNMAT.
COPYCF(TAPE3,GEOMC)
REWIND(GEOMC)
RETURN(OLDPL)
RETURN(TAPE3)
RETURN(TAPE8)
GET(OLDPL=INTEG)
GET(DYNDIM=DYNDIM)
UPDATE(F,C=TAPE8)
DYNDIM.
COPYCF(TAPE3,INTEGX)
REWIND(INTEGX)
RETURN(OLDPL)
RETURN(TAPE3)
RETURN(TAPE8)
TOSTAR(INPUT,GEOMC,INTEGX)
7/8/9
*ID GEOMODS
7/8/9
   340     3
7/8/9
*ID INTMODS
7/8/9
   340     3     0   340
7/8/9
STORE 680077 400SDS TESTDECK B
STRSIDE,T100.
FORTRAN(I=GEOMC,B=GEOMB,O=LB)
LOAD(GEOMB,CN=GEOMGO,640,GRLPALL= )
GEOMGO.
FORTRAN(I=INTEGX,B=INTEGB,O=LB)
LOAD(INTEGB,CN=INTEGO,256
,GRLP=*PRIM,*EBUF,*UBUF,*XBUF,*TAU,*VTEMP
,GROL=*Q3MAP)
INTEGO.
7/8/9

*** GEOM DATA ***

7/8/9

*** INTEG DATA ***

6/7/8/9
```

Fig. 3-8 - GEOM and INTEG Modules for a Small Three-Dimensional Problem

MN = 340

MNZ = 340

MNS = 1

MNA = 1

MEQ = 5

The common block sizes are:

/PRIM/	L	= (6) (340) + 340 + 1
		= 2381 words
/EBUF/	L	= (5) [(2) (340) + 340]
		= 5100 words
/UBUF/	L	= (5) [(2) (340) + 340]
		= 5100 words
/XBUF/	L	= (6) (340) + (3) (340)
		= 3060 words
/TAU/	L	= (7) (340) + (5) (340)
		= 4080 words
/AXSYM/	L	= (1) (4 + 5)
		= 9 words
/VTEMP/	L	= (4) (340) + (2) (1)
		= 1362 words

The total for common is 21092 words which is less than one large page. Therefore, all six common blocks are grouped on one large page. (COMMON/ AXSYM/ is not used.) The controllee file size requirement is two large pages, hence 256 small pages.

3.4.3 Example Runstream 3 (Fig. 3-9)

This runstream illustrates execution of INTEG for a large problem (3D shear layer, 7904 nodes) utilizing files created and saved in a previous GEOM execution. Note that FILE17 and FILE20 are attached as FILE17A and FILE20A. When files are saved on the access station ("Z" side) a letter

```
INTEGM,CM60000,T200.
USER,680077C.
CHARGE,101857,LRC.
GET(OLDPL=INTEG)
GET(DYNDIM=DYNDIM)
UPDATE(F,C=TAPE8)
DYNDIM.
ATTACH(FILE17=FILE17A)
ATTACH(FILE20=FILE20A)
TOSTAR(INPUT,TAPE3,FILE17=BI//U,FILE20)
7/8/9/
*ID MODS
7/8/9
STORE 680077 400SDS INTEGDCK B
STRINTE,T150.
FORTRAN(I=TAPE3,B=INTEGB,O=LB)
LOAD(INTEGB,CN=INTEGO,1536
,GRLP=*PRIM,GRLP=*EBUF,GRLP=*UBUF,GRLP=*XBUF,GRLP=*TAU,GRLP=*VTEMP
,GROL=*Q3MAP)
INTEGO.
TOAS(Z=680077C,FILE22)
7/8/9

*** DATA ***

6/7/8/9
```

Fig. 3-9 - INTEG Module for a Large Three-Dimensional Problem is added to make the file name unique if a file by that name already exists. Note also that FILE22, the restart file, is being saved via the TOAS command. Following are the common block length calculations and controllee file size calculation.

/PRIM/	L	=	(6) (7904) + (7904) + 1
		=	55329 words $\approx$0.85 large pages
/EBUF/	L	=	(5) [(2) (7094) + 7904)]
		=	118560 words $\approx$1.81 large pages
/UBUF/	L	=	same as /EBUF/
		=	118560 words $\approx$1.81 large pages
/XBUF/	L	=	(6) (7904) + 3 (7904)
		=	71136 words $\approx$1.09 large pages
/TAU/	L	=	(7) (7904) + 5 (7904)
		=	94848 words $\approx$1.45 large pages
/VTEMP/	L	=	(4) (7904) + 2
		=	31618 words $\approx$0.48 large pages

Since the total requirement for the common storage is approximately 7.5 large pages, these common blocks are assigned to large page boundaries via the GRLP parameters. Since the common blocks are assigned to page boundaries, the total space required is 10 large pages for the common plus 1 for the remainder of the program, or 11 large pages. This converts to 1408 small pages. On a problem this size, allow 1 extra large page in the controllee file to be sure it is large enough. Hence, use 1536 as the length in the LOAD card.

3.4.4 Example Runstream 4 (Fig. 3-10)

This runstream illustrates the execution of the GIMPLT module utilizing files created and saved on a previous execution. Note that the GIMPLT module resides entirely and is executed on the STAR Access Station. Nó TOSTAR command is needed. The TAPE22 attach statement is not needed if grid

```
PLOTXX,CM111000,T100.                                    BLDG1247A JL HUNT
USER,680077C.
CHARGE,101857,LRC.
GET(OLDPL=PLOT1)
UPDATE(F)
FTN(I=COMPILE,L=0)
ATTACH(TAPE20=FILE20)
ATTACH(TAPE22=FILE22)
ATTACH(LRCGOSF/UN=LIBRARY)
RFL(111000)
LDSET(LIB=LRCGOSF,PRESET=INDEF)
LGO.
ATTACH(PLOT/UN=LIBRARY)
PLOT,VARIAN
7/8/9
*ID KORCHG
*D KORE.1
      COMMON A(21040)
*D KORE.2
      KMAX=21040
7/8/9

*** DATA ***

6/7/8/9
```

Fig.3-10 - GIMPLT Example Run Stream

plots only are being generated. This execution illustrates the use of the Varian post processor. Other post processors are available and the user should refer to the Graphic Output System User's Guide for details.

The example illustrated is for a model with 2000 nodes. The calculations necessary for the field length (memory requirements) and the common block dimension are given below. Refer to Section 6.5 for discussion of these calculations.

$$
\begin{aligned}
NX &= 2000 \text{ nodes} \\
KMAX_{10} &= 5040_{10} + 8*NX \\
&= 5040_{10} + (8)\,(2000) \\
&= 21040_{10} \\
KFL_{10} &= KMAX_{10} + 16000_{10} \\
&= 21040_{10} + 16000_{10} \\
&= 37040_{10} \\
\text{Choose} \quad CM &= 111000_{8} \\
&= 37376_{10} > 37040_{10} \,.
\end{aligned}
$$

The A array dimension in blank common, KMAX, is calculated to be 21040. The runstream illustrates the UPDATE cards to set this dimension. The corresponding field length requirement is 111000_8. This must be set in two places: the job card CM parameter, and in the RFL card immediately preceding the LDSET card.

4. GEOMETRY MODULE GUIDE (GEOM)

4.1 USE OF THE MODULE

Module 1 of the GIM/STAR code calculates the geometry, grid and nodal analogs for the problem. This module is always executed first and produces two output files of data for use in Modules 2 and 3. The GIM code GEOM module as implemented on the STAR system at NASA-Langley has a "dynamic dimension" capability. A preprocessor, called DYNMAT, must be executed with GEOM to provide dimensions to the problem. Figure 4-1 illustrates the logic sequence for using Module 1.

The output files from GEOM are the following:

- File 20 — Contains the grid point description
- File 17 — Contains the nodal analog matrices

If GEOM is executed in a runstream, in a stand alone mode, these files must be saved for later input to the INTEG and/or GIMPLT modules (see Section 3).

The execution time for the GEOM module is very strongly dependent upon the dimensionality of the problem and the number of nodes used. The following information is provided from execution of the two example problems.

Configuration	Nodes	User CP Sec.	CRU
2-D Scramjet Simulation	940	27	22
3-D Scramjet Simulation	7904	1009	449

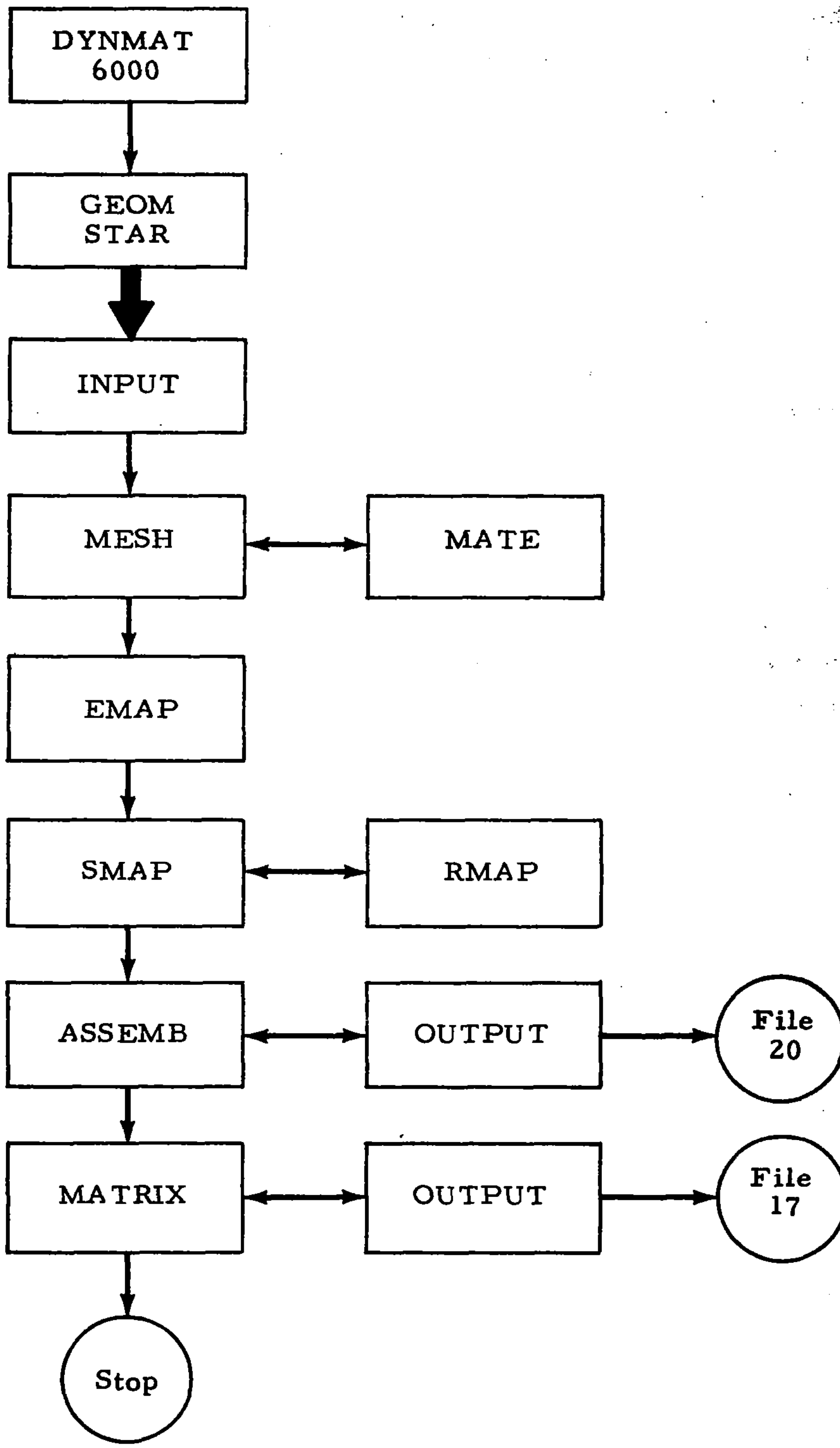


Fig. 4-1 - Logic Sequence for GEOM Module

Thus for small, two-dimensional problems, the execution time for GEOM is negligible compared to INTEG. However, for larger, three-dimensional cases, the GEOM run time can be comparable to the INTEG run times. Further experience with the STAR version of GIM should provide more information on run times.

The following subsections describe the input data and output listings for this module. Section 4.2 describes the input for the DYNMAT deck and Section 4.3 gives a "mini-manual" of the input format for GEOM. A detailed discussion of the input variables is provided in Section 4.4. The output listings are described in Section 4.5.

4.2 DYNMAT DECK

The GEOM module of the GIM/STAR code has a "dynamic-dimensioning" feature. The larger dimensional variables and arrays have parameters in place of actual integers. The DYNMAT program uses the UPDATE feature of the CDC software to replace these parameters with real dimensions so that GEOM can be compiled. These dimensions are under user control via input to the DYNMAT program. Execution of this "pre-processor" routine must be made before executing GEOM as explained in Section 3.4. This section describes the input data for the DYNMAT program.

The required data are input on one card with the following format:

FORMAT (2I5) .

<u>NX</u>

The total number of nodes in the problem. All flow variables are dimensioned by NX.

IDIM

The dimensionality of the problem.

IDIM = 2 for two-dimensional geometries
= 3 for three-dimensional geometries.

This flag controls the number of coefficient matrices which are dimensioned.

The remaining dimensions that are required are calculated internal to DYNMAT from these two input parameters.

4.3 INPUT CARD SUMMARY

This subsection presents a summary of the input cards and formats for the GEOM module. A description of each input parameter and its options aredetailed in the following subsection (4.4). After a user becomes familiar with the GEOM inputs, this summarized input guide can be used to quickly identify each card and its contents.

Three basic formats are used to input the data to GEOM:

ALPHANUMERIC	A6
INTEGER	I5
DECIMAL	E10.4

Integers are thus right justified in five column increments. Decimal, or floating point data occupy ten columns each with, preferably, a decimal point punched on the card (see examples, Section 8).

Card Type	Parameter List/Format
1	HEADER(I), I = 1, 72 (12A6)
2	NZONES, IDIM, ISTEP, IMATRX, IMATE (5I5)

Card Type	Parameter List/Format
3	IWRITE, LWRITE, NWRITE (3I5)
4	ALPHA(I), I = 1, 4 (or 8) (8E10.4)
5	NSECTS (I5)
6	MAPE(I), I = 1, 12 (12I5)
7	MAPS(I), I = 1, 6 (6I5)
8	(IBWL(I), I = 1, 6), ITRAIN (7I5)
9	(NNOD(I), I = 1, 3), (ISTRCH(I), I = 1, 3) (6I5)
10	DIVPI(I), I = 1, 3 (3E10.4)
11	[AETA(J, I), I = 1, NNOD(J)], J = 1, IDIM (8E10.4)
12	[(AC(I, K, J), I = 1, 8), J = 1, 4 or 12], K = 1, 5 (8E10.4)
13	[AS(I, J), I = 1, 8], J = 1, 6 (8E10.4)
14	(PT(I, J), I = 1, 5), J = 1, 4 or 12 (8E10.4)
15	[(PMAX(I, K, J), I = 1, 5), ETAMAX(K, J), K = 1, 4], J = 1, 4 or 12 (6E10.4)

Notes: Card types 14, 15 are repeated for each point and edge.

Card types 6 through 15 are repeated for each of NSECT sections in a zone

Card types 12, 13, 14, 15 are not re-input for points, edges and surfaces in common with the preceding section.

Card types 5 through 15 are repeated for each zone of NZONES to be processed.

Card Type	Parameter List/Format
16	NDX, NDY, NDZ, ISNOPT (4I5)
17	N1, IC, NT (3I5)

4.4 DESCRIPTION OF INPUT DATA

This subsection presents a description of the input parameters listed in Section 4.3. Each parameter is identified as to its usage in the GEOM module with options of each shown. Reference to the figures and tables must be made to explain some of the input parameters and order of input. All of the card types are not necessarily input for a specific case. Much of the input depends on the dimensionality of the problem (two- or three-dimensional). Also, certain of the input flags on early cards dictate which of the latter ones are read. Section 8 gives examples of the GEOM input, which can be used as a guide for setting up a new problem.

In the subsequent description of the input parameters, a nomenclature is used for describing the geometry that is key to understanding the sequence of events. The key words are

ZONE, SECTION and SEGMENT.

The full flow domain may be input as one or more zones. A "zone" is herein defined as a first level partitioning of a full domain for the purpose of analytically describing a shape. A full domain is thus partitioned into "sub-domains" called zones, such that each zone can be readily defined by suitable analytical functions.

A "section" is defined herein as a second level partitioning of a full domain or equivalently, a first level partitioning of a zone. This further breakdown is done to facilitate easier handling of geometrical changes.

A problem, for example, may be best described by one zo
subdivided into many sections.

Zones can be set up independently and either left th
with other zones. Thus, a building block modular concep
completely general geometries can be treated.

A "segment" is defined as a partitioning of an edge,
general, for the purpose of grid distribution. An edge of
sist of one segment in which case the nodal distribution w
segmenting an edge into more than one nonuniform piece,
irregular grid patterns is made easier.

Three other names of extreme importance in under
input are:

POINT, EDGE and SURFACE.

Figure 4-2 illustrates each of these for a general hexahe
defined as the x, y, z coordinates of the corner of the gen
An edge is a line segment connecting two points. A surf
shape formed by connecting four points with an analytica
should be studied before proceeding with the card-by-ca

CARD TYPE 1

Format (12A6)

Problem Identification Labels

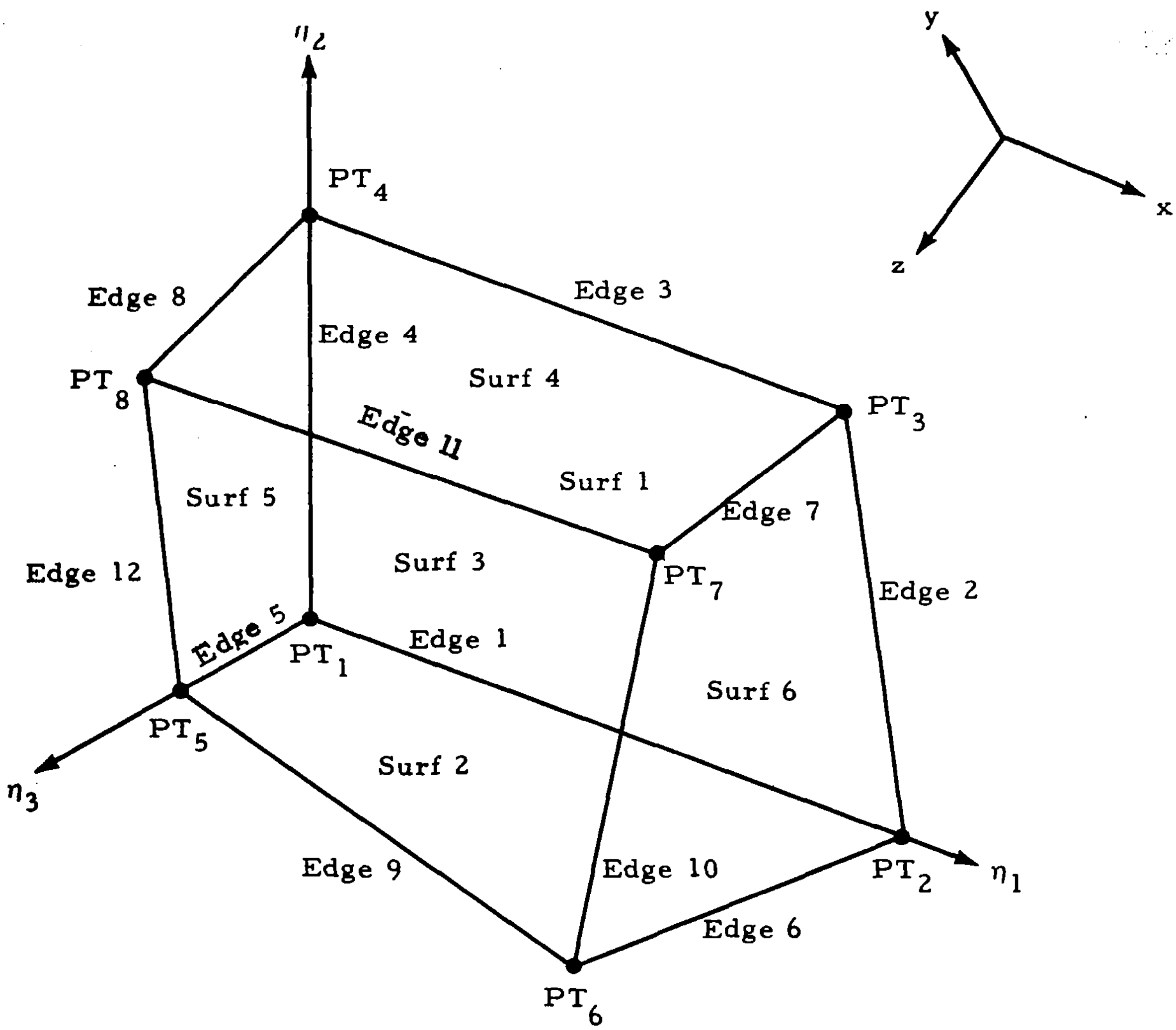
HEADER

Any alphanumeric information that the user wants
specifics of the problem. Columns 1-72 are read and p

CARD TYPE 2

Format (5I5)

Problem Option Control Flags



Note: Surf 1 — Back Wide Face $(\eta_1, \eta_2, 0)$
Surf 2 — Bottom $(\eta_1, 0, \eta_3)$
Surf 3 — Front Wide Face $(\eta_1, \eta_2, 1)$
Surf 4 — Top $(\eta_1, 1, \eta_3)$
Surf 5 — Back Narrow Face $(0, \eta_2, \eta_3)$
Surf 6 — Front Narrow Face $(1, \eta_2, \eta_3)$

Fig. 4-2 - General Hexahedral Showing Point, Edge and Surface Numbering Sequence

NZONES

Number of zones into which the full domain geometry is broken. Regular regions can usually be input as one zone, but highly irregular shapes require NZONES > 1. (No limit.) (See Section 8 for examples of zones, sections and segments.)

IDIM

Flag indicating the dimensionality of the problem being run.

IDIM = 2	Two-Dimensional
= 3	Three-Dimensional

The INTEG module has an option for IDIM = 1 which is axisymmetric flow. The GEOM module does not need to know if the flow is to be planar or axisymmetric. Only 2, 3 are used for IDIM in the GEOM module.

ISTEP

A flag indicating whether a one-step or two-step time integration scheme is to be used.

ISTEP = 1	One Step
= 2	Two Step

The GEOM module will output either one or two sets of finite difference matrices depending on ISTEP.

IMATRX

A flag which allows only a geometry and grid to be generated or both a grid and the finite difference matrices.

IMATRX = 0 Provide both a grid network and matrices

= 1 Only compute grid points and nodal connections; do not assemble matrices

Common use of the GEOM module is to set IMATRX = 0. For some large problems, the user may want to wait until a good grid is obtained before assembling the matrices. For current use on STAR, it is suggested that the zero value be used.

IMATE

GEOM has the option of processing more than one zone in a given run. The IMATE parameter allows the user to either mate the zones together to form a full domain; or to keep the zones separate — unmated.

IMATE = 1 Mate zones together

= 0 Do not mate the zones

Ordinarily, the user will want IMATE = 1 to form a full region. For some complex shapes/grids, certain zones may need to be kept separate. (See Section 8 for examples of zones, sections and segments.)

CARD TYPE 3 Format (3I5)

Output Print Options

IWRITE

A flag used for debugging printout only.

IWRITE = 0 No debug print

= 1 Provides intermediate output

The user should probably set IWRITE = 0 for all cases unless a problem occurs during execution.

LWRITE

An option controlling the printout of each element matrix.

LWRITE	= 0	Do not print element matrices
	= N > 0	Print element matrices for every N^{th} element

The user will probably use LWRITE = 0 most of the time unless a problem occurs during execution of the GEOM module.

NWRITE

This flag is the more important of the three print options. This controls the amount of grid point printout that is given for a run.

NWRITE	= 0	Print only those grid points which lie on a boundary
	= N > 0	Causes every N^{th} node point to be printed out

The output format of the GEOM data is described in Section 4.5. For large problems with many thousands of nodes, NWRITE should be chosen carefully to restrict the amount of paper produced on STAR. A plot of the grid is usually more instructive than a massive nodal printout.

CARD TYPE 4 Format (8E10.4)

Weight Function Coefficients, α_i

ALPHA(I)

These coefficients are used to define the weight functions and hence the finite difference method. The reader may want to review the theory in Section 3 and Ref. 1 for definition of the ALPHA parameters.

Table 4-1 gives values for ALPHA which produce several useful schemes, such as MacCormack, etc.

For two-dimensional cases, only four values of α are input for each step of the method. All values are input on one card in Format (8E10.4). For one-step methods, only input four values of ALPHA; for two step methods, input eight values of ALPHA.

For three-dimensional problems, eight values of α are needed for each step. One step methods require all eight values on one card. Two step methods requires two cards type 4 with eight values each.

CARD TYPE 5 Format (I5)

Number of Sections

NSECTS

Number of sections within a zone for the zone currently being input. Recall that a flow region may be broken into zones. Further, each zone can be subdivided into a number of sections such that analytic functions describe the shape of each section. There is no limit to the value of NSECTS within a zone.

CARD TYPE 6 Format (12I5)

Edge Shape Function Indicators

MAPE(I)

These are integer flags that define the edge shape functions for the section being read-in. The edges are input in numerical order according to Fig. 4-2. The user should study this figure before setting up an edge and surface input deck.

The values of MAPE depend on the type of analytic function describing the edge. The library of edge shape functions in the GIM/STAR code are

Table 4-1

VALUES OF ALPHA FOR SEVERAL USEFUL FINITE DIFFERENCE SCHEMES (CARD TYPE 4)

Forward-Forward-(Forward)(FFF)

2-D		3-D	
$\underline{\alpha}$	Value	$\underline{\alpha}$	Value
1	1.0	1	1.0
2	1.0E-8	2	1.0E-8
3	1.0E-16	3	1.0E-12
4	1.0E-8	4	1.0E-8
		5	1.0E-8
		6	1.0E-12
		7	1.0E-16
		8	1.0E-12

Backward-Backward-(Backward)(BBB)

2-D		3-D	
$\underline{\alpha}$	Value	$\underline{\alpha}$	Value
1	1.0E-16	1	1.0E-16
2	1.0E-8	2	1.0E-12
3	1.0	3	1.0E-8
4	1.0E-8	4	1.0E-12
		5	1.0E-12
		6	1.0E-8
		7	1.0
		8	1.0E-8

Table 4-1 (Concluded)

Backward-Forward-(Forward)(BFF)

2-D		3-D	
α	Value	α	Value
1	1.0E-8	1	1.0E-8
2	1.0	2	1.0
3	1.0E-8	3	1.0E-8
4	1.0E-16	4	1.0E-12
		5	1.0E-12
		6	1.0E-8
		7	1.0E-12
		8	1.0E-16

Centered Scheme 2-D		Forward-Backward 2-D	
α	Value	α	Value
1	1.0	1	1.0E-8
2	-1.0	2	1.0E-16
3	1.0	3	1.0E-8
4	-1.0	4	1.0

Note: Standard MacCormack scheme will use FFF on step 1 and BBB on step 2.

listed in Table 4-2. Three-dimensional problems require all 12 edges while two-dimensional problems require only edges 1, 2, 3 and 4. If any shape function other than a linear segment is used, then coefficients must be input on card type 12 to define this function.

An option is provided to allow distribution of grid points in each coordinate direction. This is done by segmenting each edge. Each of the edges may consist of up to five segments with each of these segments having its own shape function. The values of MAPE then can consist of up to five integers packed into one word MAPE(I). The segment indicators are input in chronological order of increasing η for each edge with the final packed integer being right adjusted. For example, if MAPE(4) = 312, then edge 4 consists of three segments; the first segment being type 3, the second segment type 1 and the third segment type 2. If a single shape function describes an edge, the only one indicator is used, right adjusted. The example problems of Section 8 show how this segmenting procedure can be used.

CARD TYPE 7 Format (6I5)

Surface Shape Function Indicators

MAPS(I)

These flags are input only for three-dimensional problems since two-dimensional geometries are defined completely by the edge functions.

The input sequence for the surfaces are shown in Fig. 4-2 for designation 1 to 6. The surfaces must be input in this order. The values for MAPS are given in Table 4-3. There are three basic types; flat plate, cylinder and edge of revolution. The latter case requires input of coefficients on card type 13 to define the revolution axis, etc. The user should refer to Fig. 4-2, Table 4-3 and the examples given in Section 8.

Table 4-2

EDGE SHAPE FUNCTION INDICATORS AND COEFFICIENT DEFINITIONS

Type	Map (Card 6)	Coefficients (Card 12)
Linear	1	None. Omit Card 12
Circular Arc	2	$AC_1 - AC_3$ are (x, y, z) coordinates of center of arc. AC_4 is the expansion angle from nozzle, if any.
Conics (Parabola, Ellipse, Hyperbola)	3	$AC_1 - AC_3$ are (x, y, z) coordinates of focal point. $AC_4 - AC_6$ are (x, y, z) components of unit vector along axis of conic.
Helical Arc	4	$AC_1 - AC_3$ are coordinates of center of arc. $AC_4 - AC_6$ are components of unit vector along axis.
Trignometric Function of X_e	5	$AC_1 - AC_3$ arc coordinates of reference point corresponding to $X_e = 0$. $AC_4 - AC_7$ are used in equation $y = y_o + AC_4 \sin(AC_6 X_e + AC_7) + AC_5 \cos(AC_6 X_e + AC_7)$
Trignometric Function of θ	6	$AC_1 - AC_3$ are coordinates of center of sweep angle θ. $AC_4 - AC_8$ are used in equation $y = AC_4 + AC_5 \sin(AC_7 \theta + AC_8) + AC_6 \cos(AC_7 \theta + AC_8)$
Special Functions	7	The user can modify the GEOM code to include any special function.

Table 4-3

SURFACE SHAPE FUNCTION INDICATORS AND COEFFICIENT DEFINITIONS

Type	Map (Card 7)	Coefficients (Card 13)
Flat Plate	1	None. Omit Card 13 for this surface.
Cylindrical	2	None. Omit Card 13.
Special Application	3	The user can supply special function by modifying the code for a specific application.
Edge of Revolution	4	Surface formed by revolving edge about an axis. $AS_1 - AS_3$ is origin of surface coordinate system. $AS_4 - AS_6$ are components of unit vector along axis of revolution. AS_7 indicates which η_I direction the edge will revolve in.

CARD TYPE 8 Format (7I5)

Boundary Indicators and Node Numbering Sequence Specification

IBWL(I)

These integer indicators are used to tell the INTEG module which boundary conditions to apply to an edge/surface. Table 4-4 lists the allowable boundary types.

IBWL(I) is the flag for edge I or surface I. If IDIM = 2, then the IBWL flags are for edges and if IDIM = 3 then IBWL is for surfaces. For two-dimensional problems, there will be four edges to define, I = 1, 4. For three-dimensional problems, there are six surfaces to define, I = 1, 6.

Each value of IBWL(I) contains a packed integer which contains two flags. The right-most integer is the boundary indicator listed in Table 4-4. The single digit integer just to the left is a flag which designates the zone number to which the edge is to be mated. For example,

IBWL(3) = 14

says that edge 3 is a boundary type 4 (wall tangency) and that edge 3 is to be mated with zone 1 of a previous input sequence.

The boundary flags are input in numerical order according to the edge/surface description in Fig. 4-2. Columns 4-5 thus describe edge 1, columns 9 and 10 for edge 2, etc.

ITRAIN

This flag is always input in column 35 of card type 8. The value of ITRAIN specify the node numbering sequence in the coordinate directions.

Table 4-4

BOUNDARY NODE DESIGNATORS AND THEIR MEANING FOR USE IN THE INTEG MODULE

IBWL	Boundary Type	Remarks
0	Constant Node	All flow variables are held fixed at the input value.
1	Axis Node	Designates the axis points for axisymmetric flow.
2	No-Slip/Stagnation Node	The density times velocity values are held fixed, ($\rho u, \rho v, \rho w$) but pressure, energy and density equations are integrated.
3	Corner Node (3-D)	For internal 3-D corners, the flow is forced to go down the corner and hence tangent to both planes.
4	Free Slip/ Tangency	Velocity vectors are forced to be tangent to a wall (or = 0).
5-7	Not Currently Used	The user may modify INTEG for special cases.
8	One-Sided Differences	A boundary is computed from only information inside the region. Good for supersonic downstream condition.
9	Interior Node	No constraints. All flow variables computed from the equations.

The table below shows the values of ITRAIN for numbering along each of three coordinate axes for two- and three-dimensional problems.

IDIM	ITRAIN	Numbering Sequence
2	1	η_2, η_1
2	2	η_1, η_2
3	1	η_3, η_2, η_1
3	2	η_1, η_3, η_2
3	3	η_2, η_1, η_3

An example of the use of this table is: IDIM = 2, ITRAIN = 1; all nodes in the η_2 direction are numbered first at the initial η_1 line. Then the nodes are numbered along η_2 at the next η_1 station etc.

CARD TYPE 9

<u>Format (6I5)</u>

Node Point Distribution Indicators

<u>NNOD(I)</u>

For I = 1, 2, 3, NNOD(I) is the number of nodes in the η_I direction for the current <u>section</u> being input. The limit is 100 nodes in each coordinate direction or 10^6 nodes total.

<u>ISTRCH(I)</u>

An option is provided to allow unequal distribution of nodes in each of the coordinate directions.

ISTRCH	=	0	uniform spacing
	=	-1	reduce spacing in η_I direction
	=	+1	increase spacing in η_I direction
	=	NNOD	user input location of nodes on card type 11.

For uniform spacing, Cards 10 and 11 are not needed and are not input. If ISTRCH = ± 1, Card 10 is needed but not Card 11. If ISTRCH = NNOD, then Card 10 is not needed, but Card 11 is required.

CARD TYPE 10 Format (3E10.4)

Stretching Function Values

DIVPI(I)

The values for each coordinate direction which are used to determine the degree of stretching by the TANGENT transformation given in Fig. 4-3. Typical values of 2.0 and 3.0 are shown as to the relative uniformity of a grid. Large values of DIVPI produce essentially uniform spacing while a small value gives drastic stretching of the grid points. This card is input if and only if ISTRCH = ± 1 on card type 9. There are either two or three values depending on IDIM = 2 or 3.

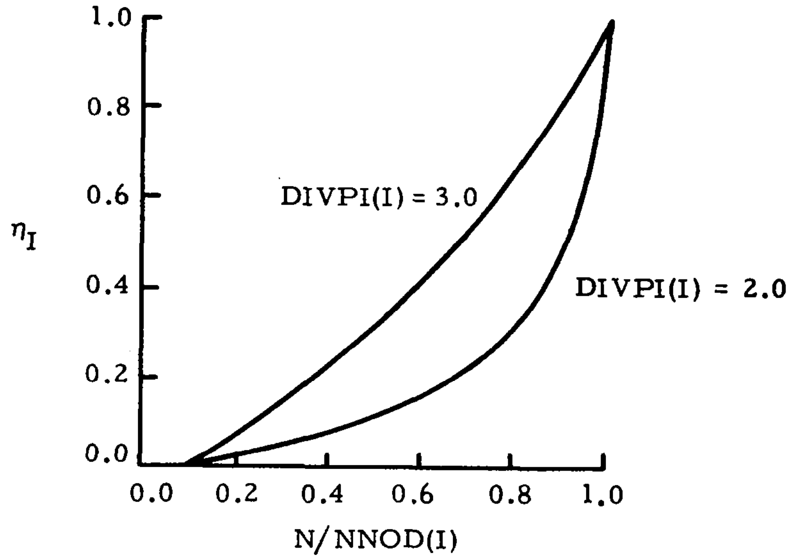
CARD TYPE 11 Format (8E10.4)

Optional Grid Point Input

AETA(I)

The actual η_1, η_2, η_3 coordinates of the grid for the section being constructed. These are input if and only if any of the ISTRCH(I) were read in as NNOD(I). For example, the η_1 coordinate line could be equally spaced, the η_2 coordinates calculated with a stretching transformation and the η_3 coordinate line could be read into AETA(I), I = 1, NNOD(3).

The AETA values are read in the order η_1 then η_2 then η_3 as required in Format 8E10.4 using as many cards as required to get them all read. The AETA values are normalized to range from 0.0 to 1.0 and hence give a relative spacing of nodes. The AETA values are not the actual x, y, z coordinates For three-dimensional cases, there are up to three sets of AETA for each coordinate line. For two-dimensional cases there are up to two sets of AETA cards. Remember to input card type 11 if any of the ISTRCH(I) are set to NNOD(I) on card type 9.



Note: Stretching functions are tangent functions of the form:

- for reducing nodal spacing

$$\eta_I = 1.0 - \frac{\tan\left[\frac{\pi}{\mathrm{DIVPI(I)}}\left(\frac{\mathrm{NNOD(I)} - \mathrm{N}}{\mathrm{NNOD(I)}}\right)\right]}{\tan\left[\frac{\pi}{\mathrm{DIVPI(I)}}\left(\frac{\mathrm{NNOD(I)} - 1.0}{\mathrm{NNOD(I)}}\right)\right]}, \quad \mathrm{N} = 1, 2, \ldots, \mathrm{NNOD(I)}$$

- for increasing nodal spacing

$$\eta_I = \frac{\tan\left[\frac{\pi}{\mathrm{DIVPI(I)}}\left(\frac{\mathrm{N} - 1.0}{\mathrm{NNOD(I)}}\right)\right]}{\tan\left[\frac{\pi}{\mathrm{DIVPI(I)}}\left(\frac{\mathrm{NNOD(I)} - 1.0}{\mathrm{NNOD(I)}}\right)\right]}$$

Fig. 4-3 - Stretching Function Illustrated

CARD TYPE 12 Format (8E10.4)

Coefficients for Edge Shape Functions

AC

The ACs are coefficients which describe the shape functions for each edge of the section being constructed. If an edge is segmented, the coefficients for each segment are input on separate cards in the same order as the indicators on card type 6. Card type 12 is input if and only if MAPE > 1 on card type 6. MAPE = 1 defines the edge as linear and no coefficients are required.

Table 4-2 defines the AC values to be input for each type of edge. The examples of Section 8 should clarify the AC input sequence.

CARD TYPE 13 Format (8E10.4)

Coefficients for Surface Shape Functions

AS

The AS values are the coefficients which define the shape functions for each surface of the section being constructed. This card may be input if and only if IDIM = 3 since surfaces are not present in two-dimensional geometries. Table 4-3 gives a description of the AS coefficients for each type of surface.

Note that AS coefficients are required only if MAPS > 2 in Table 4-2. For linear or cylindrical surfaces, no coefficients are necessary to describe the surface. Only for edges of revolution (MAPS = 4) or special cases (MAPS = 3) is a card type 13 required.

Each surface which has MAPS > 2 on Card 7 is input on a separate card in the same order as the surface indicators on card type 7.

CARD TYPE 14 Format (5E10.4)

Coordinates of Points

PT(I, J), J = 1, Number of Points
I = 1, 5

The PT values are the coordinate points which define each corner of a general hexahedral. Figure 4-2 shows this configuration with the points numbered from 1 to 8.

PT(1, J) — the x coordinate of point J

PT(2, J) — the y coordinate of point J

PT(3, J) — the z coordinate of point J

PT(4, J) — flow angle in the x-y plane at point J

PT(5, J) — flow angle in the x-z plane at point J

For two-dimensional problems there will be four cards of type 14 to be input. For three-dimensional problems there are eight cards of type 14 to be input.

Important Note: All cards type 14 are not input consecutively. They are grouped with cards type 15. See Table 4-5 for the exact sequence of types 14 and 15 and the order in which they must be input. Section 8 has examples of this usage.

CARD TYPE 15 Format (6E10.4)

Segment Extremals for Edges

PMAX(1, K, J)

The extremal x coordinate, in the η_1 direction, for the K^{th} segment of edge J.

Table 4-5

INPUT SEQUENCE FOR CARDS TYPE 14 AND 15 TO DESCRIBE ALL POINTS AND EXTREMALS OF SEGMENTS

Order	Card Type	Description
1	14	Point 1
2	15	Extremals for Edge 1
3	14	Point 2
4	15	Extremals for Edge 2
5	14	Point 3
6	15	Extremals for Edge 3
7	14	Point 4
8	15	Extremals for Edge 4
9	15	Extremals for Edge 5
10	14	Point 5
11	15	Extremals for Edge 6
12	14	Point 6
13	15	Extremals for Edge 7
14	14	Point 7
15	15	Extremals for Edge 8
16	14	Point 8
17	15	Extremals for Edge 9
18	15	Extremals for Edge 10
19	15	Extremals for Edge 11
20	15	Extremals for Edge 12

Note: For two-dimensional geometries, the order of input stops after 8 since no other points or edges exist.

PMAX(2, K, J)

The extremal y coordinate, in the η_2 direction, for the K^{th} segment of edge J.

PMAX(3, K, J)

The extremal z coordinate, in the η_3 direction, for the K^{th} segment of edge J.

PMAX(4, K, J)

The flow angle in the x-y plane at the extremal point on the K^{th} segment of edge J.

PMAX(5, K, J)

The flow angle in the x-z plane at the extremal point on the K^{th} segment of edge J.

ETAMAX(K, J)

The maximum value of the η coordinate on the K^{th} segment of edge J.

Notes on Card Type 15:

Each edge may be segmented up to five times. Therefore, cards type 15 are repeated for each successive segment on edge J. Each segment must be input on a separate card type 15. The extremal for the final segment of an edge is not to be input since this point is already defined by the PT input. The number of cards type 15 for each edge will thus be one less than the number of segments on that edge. In particular, if an edge consists of only one segment, no cards of type 15 are input for that edge.

Table 4-5 should be consulted for the input order of cards type 14 and 15. For two-dimensional problems, the order of input stops after 8; for three-dimensional problems the order goes up to 20 as shown in the table. The points are input on a single card, followed by up to five cards containing the extremals. Be sure to note the change of order of the input pairs after order 8. Up to order 8, the points are input first — then the extremals. After order 8, the extremals are input first — then the points. At order 17, the input of card type 14 ceases since all points have been input. Only extremals are input for orders 17-20.

Notes on Input Sequence of Cards Type 5 Through 15

- Cards type 6-15 are repeated for each of NSECT sections in a zone.
- Cards type 5-15 are repeated for each zone of NZONES to be constructed.
- Cards type 12-15 are not re-input for points, edges and surfaces in common with the preceding section. Since these have already been input, the code transfers the entries from one section to another.
- The first section of each new zone however, must be input since zones are considered to be independent. Zones can of course be mated as previously discussed.
- When inputting card type 10 for successive sections, only the value of DIVPI (ITRAIN) may be changed among the sections. The other DIVPI must be the same as for the preceding section.
- When inputting card type 11 for successive sections, only the value of AETA (ITRAIN) may be changed among the sections. The other AETA must be the same as for the preceding section.

CARD TYPE 16 Format (4I5)

Coefficient Matrix Parameters

NDX

This parameter is the nodal decrement in the x coordinate direction for the full flow domain. NDX is used by the STAR/GEOM module to perform the matrix diagonalization. NDX is thus the difference in node number of adjacent nodes along the x axis. See the two-dimensional Scramjet simulation case in Section 8 for an example.

NDY

The nodal decrement in the y coordinate direction for the matrix diagonalization.

NDZ

The nodal decrement in the z coordinate direction for the matrix diagonalization. Set NDZ = 0 for two-dimensional problems.

ISNOPT

The parameter is used to provide an option on the treatment of off-diagonal terms in the matrix handling on STAR. If

$$ISNOPT = 0$$

then the GEOM module will set the number of special boundary terms equal to the number of nodes. In general this will produce a dimension greater than is needed. This option should be used only if the INTEG module is to be run immediately following the GEOM module. If

$$ISNOPT = 1$$

then the GEOM module will calculate the exact number of special off-diagonal terms and print out this number. The number can then be input to the INTEG module to produce an exact dimension for the special terms. This option should be used if the GEOM module is to run in a separate execution stream before running the INTEG module.

The reason for having this option is to reduce the amount of storage in the INTEG module. For small two-dimensional problems, it is unimportant, but for larger three-dimensional problems the large page faults can be reduced by using ISNOPT = 1.

CARD TYPE 17 Format (3I5)

Nodal Analog Print Control

N1

This is the first node of a sequence for which the nodal analog output is desired.

IC

The nodal analog print increment to use, starting with node N1, to printout the nodal analogs.

NT

The total number of nodes, in this sequence, for which analog printout is wanted.

Notes:

- Any number of cards type 17 can be input. The last card must have a -1 in columns 4 and 5 to tell the code that no more cards are coming.
- The analogs can be printed out in any order.
- Example of cards type 17:

15	1	2
684	2	5
-1		

  This sequence will produce analog printout for nodes 15, 16, 684, 686, 688, 690, 692.
- Any number of nodal analogs may be printed up to the total number of nodes in the problem.

4.5 OUTPUT DESCRIPTION

The output of the GEOM module consists of two types:

- Printed grid and nodal analog descriptions
- Two save files on which the grid and nodal analogs are stored.

The output save files from the GEOM module are 17 and 20. File 17 contains the nodal analogs and File 20 contains the grid points and descriptions. These files must be saved by user for later (or immediate) input to the INTEG (17 and 20) or GIMPLT (20 only) modules.

The printed output from GEOM consists of two basic types:

- Geometry/grid description
- Nodal analog definitions

Each of these types is now briefly described. The reader should refer to the corresponding figures while reading this section.

The first few pages of output from the GEOM module consists of summaries of the input data. The control parameters, the zone and section data, edge and surface designators are printed (see Figs. 4-4 and 4-5).

The major portion of the geometry output consists of node point locations and geometric data. The pages are headed by the statement

MESH POINTS FOR RECORD N .

Figures 4-6 and 4-7 are examples of this output for the two-dimensional Scramjet problem. As these figures show, the first column is the node number followed by the following list:

X, Y, Z — Cartesian coordinates of the node

THXY, THXZ — Flow angle descriptors in the x-y and x-z planes for the node

```
MESH GENERATION PROGRAM-                                          SCRAMJET-1

INPUT DATA FOR THIS CASE

          NZONES=       2
          IDIM=         2
          ISTEP=        2
          IMATRX=       0
          IMATE=        1

          ALPHA(I)=     .1000E+01
                        .1000E-07
                        .1000E-15
                        .1000E-07
                        .1000E-15
                        .1000E-07
                        .1000E+01
                        .1000E-07


MESH GENERATION PROGRAM-                              SCRAMJET-1

                            DATA FOR ZONE  1

                  NUMBER OF SECTIONS IN ZONE=  2

       SECTION    FACE     MAPS      IBWL   EDGE     MAPE      NODES

          1        123  FLAT PLATE   24      14    LINEAR        16
                                                   LINEAR
                                             12    LINEAR        23
                                                   LINEAR
                                                   LINEAR
                                             23    LINEAR        16
                                             43    LINEAR        23


MESH GENERATION PROGRAM-                              SCRAMJET-1

                   SECTOR    1 OF    2 FOR ZONE    1

                   POINT       X           Y           Z        TXY          TXZ
                     1     .20000E+00  .21021E+00  .0        .0             .0
                     2     .30000E+01  .0          .0       -.60000E+01     .0
                     3     .30000E+01  .23021E+01  .0        .20000E+02     .0
                     4     .20000E+00  .12830E+01  .0        .20000E+02     .0
```

Fig. 4-4 - GEOM Input Card Printout/Summary

```
MESH GENERATION PROGRAM-                           SCRAMJET-1

      SECTION   FACE      MAPS       THAL   EDGE      MAPE      NODES
-----------------------------------------------------------------------
         2       123   FLAT PLATE     29      14    LINEAR        16
                                              12    LINEAR        21
                                              23    LINEAR        16
                                              43    LINEAR        21

MESH GENERATION PROGRAM-                           SCRAMJET-1

                      SECTOR    2 OF    2 FOR ZONE    1
-----------------------------------------------------------------------
                      POINT        X           Y            Z          TXY          TXZ
                        1     .30000E+01   .0           .0        -.60000E+01    .0
                        2     .60000E+01   .0           .0          .0           .0
                        3     .60000E+01   .33940E+01   .0          .20000E+02   .0
                        4     .30000E+01   .23021E+01   .0          .20000E+02   .0
-----------------------------------------------------------------------
STORE  496 POINTS ON RECORD    1 OF UNIT 16 TOTAL POINTS STORED=  496


MESH GENERATION PROGRAM-                           SCRAMJET-1

                            DATA FOR ZONE  2
-----------------------------------------------------------------------
                   NUMBER OF SECTIONS IN ZONE=  1
-----------------------------------------------------------------------
      SECTION   FACE      MAPS       IB*L   EDGE      MAPE      NODES

         1       123   FLAT PLATE      8      14    LINEAR        13
                                              12    LINEAR        21
                                              23    LINEAR        13
                                              43    LINEAR        21


MESH GENERATION PROGRAM-                           SCRAMJET-1

                      SECTOR    1 OF    1 FOR ZONE    2
-----------------------------------------------------------------------
                      POINT        X           Y            Z          TXY          TXZ
                        1     .30000E+01  -.20000E+01   .0          .0           .0
                        2     .60000E+01  -.20000E+01   .0          .0           .0
                        3     .60000E+01   .0           .0          .0           .0
                        4     .30000E+01   .0           .0          .0           .0
```

Fig. 4-5 - GEOM Input Card Summary

MESH GENERATION PROGRAM-   SCRAMJET-1

MESH POINTS FOR RECORD 2

NODE	X	Y	Z	THXY	THXZ	VOL	NX	NY	NZ	BC
641	.5700E+01	.0	.0	-.6000E+00	.0	.1232E-01	.0	.0	.0	9
642	.5700E+01	.1642E+00	.0	.4300E+00	.0	.2464E-01	.0	.0	.0	9
643	.5700E+01	.3285E+00	.0	.1460E+01	.0	.2464E-01	.0	.0	.0	9
644	.5700E+01	.4927E+00	.0	.2490E+01	.0	.2464E-01	.0	.0	.0	9
645	.5700E+01	.6570E+00	.0	.3520E+01	.0	.2464E-01	.0	.0	.0	9
646	.5700E+01	.8212E+00	.0	.4550E+01	.0	.2464E-01	.0	.0	.0	9
647	.5700E+01	.9855E+00	.0	.5580E+01	.0	.2464E-01	.0	.0	.0	9
648	.5700E+01	.1150E+01	.0	.6610E+01	.0	.2464E-01	.0	.0	.0	9
649	.5700E+01	.1314E+01	.0	.7640E+01	.0	.2464E-01	.0	.0	.0	9
650	.5700E+01	.1478E+01	.0	.8670E+01	.0	.2464E-01	.0	.0	.0	9
651	.5700E+01	.1642E+01	.0	.9700E+01	.0	.3695E-01	.0	.0	.0	9
652	.5700E+01	.1971E+01	.0	.1176E+02	.0	.4927E-01	.0	.0	.0	9
653	.5700E+01	.2299E+01	.0	.1382E+02	.0	.4927E-01	.0	.0	.0	9
654	.5700E+01	.2628E+01	.0	.1588E+02	.0	.4927E-01	.0	.0	.0	9
655	.5700E+01	.2956E+01	.0	.1794E+02	.0	.4927E-01	.0	.0	.0	9
656	.5700E+01	.3285E+01	.0	.2000E+02	.0	.2464E-01	.3420E+00	-.9397E+00	.0	4
657	.5850E+01	.0	.0	-.3000E+00	.0	.1252E-01	.0	.0	.0	9
658	.5850E+01	.1670E+00	.0	.7150E+00	.0	.2505E-01	.0	.0	.0	9
659	.5850E+01	.3339E+00	.0	.1730E+01	.0	.2505E-01	.0	.0	.0	9
660	.5850E+01	.5009E+00	.0	.2745E+01	.0	.2505E-01	.0	.0	.0	9
661	.5850E+01	.6679E+00	.0	.3760E+01	.0	.2505E-01	.0	.0	.0	9
662	.5850E+01	.8349E+00	.0	.4775E+01	.0	.2505E-01	.0	.0	.0	9
663	.5850E+01	.1002E+01	.0	.5790E+01	.0	.2505E-01	.0	.0	.0	9
664	.5850E+01	.1169E+01	.0	.6805E+01	.0	.2505E-01	.0	.0	.0	9
665	.5850E+01	.1336E+01	.0	.7820E+01	.0	.2505E-01	.0	.0	.0	9
666	.5850E+01	.1503E+01	.0	.8835E+01	.0	.2505E-01	.0	.0	.0	9
667	.5850E+01	.1670E+01	.0	.9850E+01	.0	.3757E-01	.0	.0	.0	9
668	.5850E+01	.2004E+01	.0	.1188E+02	.0	.5009E-01	.0	.0	.0	9
669	.5850E+01	.2338E+01	.0	.1391E+02	.0	.5009E-01	.0	.0	.0	9
670	.5850E+01	.2672E+01	.0	.1594E+02	.0	.5009E-01	.0	.0	.0	9
671	.5850E+01	.3005E+01	.0	.1797E+02	.0	.5009E-01	.0	.0	.0	9
672	.5850E+01	.3339E+01	.0	.2000E+02	.0	.2505E-01	.3420E+00	-.9397E+00	.0	4
673	.6000E+01	.0	.0	.0	.0	.6313E-02	.0	.0	.0	8
674	.6000E+01	.1697E+00	.0	.1000E+01	.0	.1263E-01	.0	.0	.0	8
675	.6000E+01	.3394E+00	.0	.2000E+01	.0	.1263E-01	.0	.0	.0	8
676	.6000E+01	.5091E+00	.0	.3000E+01	.0	.1263E-01	.0	.0	.0	8
677	.6000E+01	.6788E+00	.0	.4000E+01	.0	.1263E-01	.0	.0	.0	8
678	.6000E+01	.8485E+00	.0	.5000E+01	.0	.1263E-01	.0	.0	.0	8
679	.6000E+01	.1018E+01	.0	.6000E+01	.0	.1263E-01	.0	.0	.0	8
680	.6000E+01	.1188E+01	.0	.7000E+01	.0	.1263E-01	.0	.0	.0	8
681	.6000E+01	.1358E+01	.0	.8000E+01	.0	.1263E-01	.0	.0	.0	8
682	.6000E+01	.1527E+01	.0	.9000E+01	.0	.1263E-01	.0	.0	.0	8
683	.6000E+01	.1697E+01	.0	.1000E+02	.0	.1894E-01	.0	.0	.0	8
684	.6000E+01	.2036E+01	.0	.1200E+02	.0	.2525E-01	.0	.0	.0	8
685	.6000E+01	.2376E+01	.0	.1400E+02	.0	.2525E-01	.0	.0	.0	8
686	.6000E+01	.2715E+01	.0	.1600E+02	.0	.2525E-01	.0	.0	.0	8
687	.6000E+01	.3055E+01	.0	.1800E+02	.0	.2525E-01	.0	.0	.0	8
688	.6000E+01	.3394E+01	.0	.2000E+02	.0	.1263E-01	.3420E+00	-.9397E+00	.0	4

Fig. 4-6 - Example Grid Output (Page 1)

MESH GENERATION PROGRAM- SCRAMJET-1

MESH POINTS FOR RECORD 3

NODE	X	Y	Z	THXY	THXZ	VOL	NX	NY	NZ	BC
881	.5400E+01	-.2000E+01	.0	.0	.0	.2250E-01	.0	.0	.0	8
882	.5400E+01	-.1700E+01	.0	.0	.0	.4500E-01	.0	.0	.0	9
883	.5400E+01	-.1400E+01	.0	.0	.0	.3750E-01	.0	.0	.0	9
884	.5400E+01	-.1200E+01	.0	.0	.0	.3000E-01	.0	.0	.0	9
885	.5400E+01	-.1000E+01	.0	.0	.0	.2475E-01	.0	.0	.0	9
886	.5400E+01	-.8700E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
887	.5400E+01	-.7500E+00	.0	.0	.0	.1838E-01	.0	.0	.0	9
888	.5400E+01	-.6250E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
889	.5400E+01	-.5000E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
890	.5400E+01	-.3750E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
891	.5400E+01	-.2500E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
892	.5400E+01	-.1250E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
893	.5550E+01	-.2000E+01	.0	.0	.0	.2250E-01	.0	.0	.0	8
894	.5550E+01	-.1700E+01	.0	.0	.0	.4500E-01	.0	.0	.0	9
895	.5550E+01	-.1400E+01	.0	.0	.0	.3750E-01	.0	.0	.0	9
896	.5550E+01	-.1200E+01	.0	.0	.0	.3000E-01	.0	.0	.0	9
897	.5550E+01	-.1000E+01	.0	.0	.0	.2475E-01	.0	.0	.0	9
898	.5550E+01	-.8700E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
899	.5550E+01	-.7500E+00	.0	.0	.0	.1837E-01	.0	.0	.0	9
900	.5550E+01	-.6250E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
901	.5550E+01	-.5000E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
902	.5550E+01	-.3750E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
903	.5550E+01	-.2500E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
904	.5550E+01	-.1250E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
905	.5700E+01	-.2000E+01	.0	.0	.0	.2250E-01	.0	.0	.0	8
906	.5700E+01	-.1700E+01	.0	.0	.0	.4500E-01	.0	.0	.0	9
907	.5700E+01	-.1400E+01	.0	.0	.0	.3750E-01	.0	.0	.0	9
908	.5700E+01	-.1200E+01	.0	.0	.0	.3000E-01	.0	.0	.0	9
909	.5700E+01	-.1000E+01	.0	.0	.0	.2475E-01	.0	.0	.0	9
910	.5700E+01	-.8700E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
911	.5700E+01	-.7500E+00	.0	.0	.0	.1838E-01	.0	.0	.0	9
912	.5700E+01	-.6250E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
913	.5700E+01	-.5000E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
914	.5700E+01	-.3750E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
915	.5700E+01	-.2500E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
916	.5700E+01	-.1250E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
917	.5850E+01	-.2000E+01	.0	.0	.0	.2250E-01	.0	.0	.0	8
918	.5850E+01	-.1700E+01	.0	.0	.0	.4500E-01	.0	.0	.0	9
919	.5850E+01	-.1400E+01	.0	.0	.0	.3750E-01	.0	.0	.0	9
920	.5850E+01	-.1200E+01	.0	.0	.0	.3000E-01	.0	.0	.0	9
921	.5850E+01	-.1000E+01	.0	.0	.0	.2475E-01	.0	.0	.0	9
922	.5850E+01	-.8700E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
923	.5850E+01	-.7500E+00	.0	.0	.0	.1838E-01	.0	.0	.0	9
924	.5850E+01	-.6250E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
925	.5850E+01	-.5000E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
926	.5850E+01	-.3750E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
927	.5850E+01	-.2500E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9
928	.5850E+01	-.1250E+00	.0	.0	.0	.1875E-01	.0	.0	.0	9

Fig. 4-7 - Example Grid Output (Page 2)

VOL — A volume parameter associated with the node (average only and not a true volume).

NX, NY, NZ — Geometric parameters which are non-zero only for boundary nodes. If BC = 4, these are unit normal vector components to the surface. If BC = 3, these are unit tangent vectors.

BC — Boundary condition types (see Table 4-4).

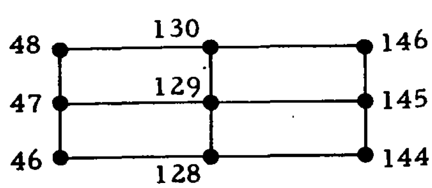
The user can control the number of nodes printed on the input cards previously described.

Following the grid point printout is a summary of the matrix diagonalization data and nodal analog print flags. The actual nodal analogs, the finite difference coefficient matrices, are printed next. Figures 4-8 through 4-11 are examples from the two-dimensional Scramjet problem. The analog printout is headed by statements of the form:

NODAL ANALOG FOR X DIRECTION, STEP 1.

The first integer on a line is the node number for which the analog is being printed. Following this node number is a list of the connecting nodes and the finite difference coefficient. Refer to Fig. 4-8 (line 1 node 129) while the following example is given.

<u>Example:</u>



```
NODE POINT INFORMATION
      NN        NDX       NDY        NDZ        ND1        ND2
     940         16         1          0         16          0

ANALOG PRINT NODES
     129          1         1
     145          1         1
     146          1         1
     337          1         2
     353          1         2
     369          1         2
     699          1         2
     712          1         2

NODAL ANALOG FOR X DIRECTION, STEP 1
 129       129 -.10895807E+02    130  .10085480E+01    145  .98651875E+01    146  .22070995E-01
 145       145 -.10873726E+02    146  .99941780E+00    161  .985247763E+01   162  .21832088E-01
 146       146 -.10663612E+02    147  .91139376E+00    162  .97310314E+01    163  .21186788E-01
 337       337 -.75875660E+01    338  .92792338E+00    353  .66669513E+01    354 -.73087073E-02
 338       338 -.75840199E+01    339  .87312219E+00    354  .67184047E+01    355 -.75069986E-02
 353       353 -.66666652E+01    369  .66666652E+01
 354       354 -.65091851E+01    355 -.15748169E+00    370  .66672728E+01    371 -.60604191E-03
 369       369 -.66666652E+01    385  .66666652E+01
 370       370 -.65128193E+01    371 -.15384752E+00    386  .66672453E+01    387 -.57859417E-03
 699       711  .66666651E+01    699 -.66666651E+01
 700       712  .66666651E+01    700 -.66666651E+01
 712       712 -.66666653E+01    724  .66666652E+01
 713       713 -.66666653E+01    725  .66666652E+01
NSNODES=  368
```

Fig. 4-8 - Matrix Coefficient – Nodal Analog Output (X, Step 1)

NODAL ANALOG FOR Y DIRECTION, STEP 1

129	129 -.87210051E+01	130 .97906150E+01	145 -.10822219E+01	146 .12611936E-01
145	145 -.85096422E+01	146 .97019800E+01	161 -.12044503E+01	162 .12112544E-01
146	146 -.85351982E+01	147 .97127911E+01	162 -.11896030E+01	163 .12010091E-01
337	337 -.86805509E+01	338 .87468143E+01	353 -.78197883E-01	354 .11934447E-01
338	338 -.86804959E+01	339 .87472685E+01	354 -.78799526E-01	355 .12026798E-01
353	353 -.86534671E+01	354 .86534670E+01	369 -.33385776E-01	370 .33385776E-01
354	354 -.86534671E+01	355 .86534670E+01	370 -.33385776E-01	371 .33385776E-01
369	369 -.84537713E+01	370 .84537712E+01	385 -.31877534E-01	386 .31877534E-01
370	370 -.84537713E+01	371 .84537712E+01	386 -.31877534E-01	387 .31877534E-01
699	699 -.79999983E+01	700 .79999982E+01		
700	700 -.79999983E+01	353 .79999982E+01		
712	712 -.79999983E+01	369 .79999982E+01		
713	713 -.33333326E+01	714 .33333326E+01		

NSNODES= 138

Fig. 4-9 - Matrix Coefficient — Nodal Analog Output (Y, Step 1)

NODAL ANALOG FOR X DIRECTION, STEP 2

129	113 -.99778003E+01	129 .99778501E+01	130 .21846959E-01	114 -.21896573E-01
145	129 -.98524914E+01	145 .88312419E+01	146 .10431156E+01	130 -.21865975E-01
146	129 .21809047E-01	145 -.95438360E+00	146 .10706640E+02	130 -.97740653E+01
337	321 -.66669272E+01	337 .57463128E+01	338 .91533009E+00	322 .72843881E-02
338	321 -.73278362E-02	337 -.85828587E+00	338 .75691850E+01	322 -.67035712E+01
353	337 -.33369306E+01 369 .33333326E+01	353 -.45296715E+00	354 .45294328E+00	338 .36218757E-02
354	337 -.72866685E-02	353 -.85123628E+00	354 .75687434E+01	338 -.67102204E+01
369	353 -.66666652E+01	369 .66666653E+01		
370	353 -.61475092E-03	369 .15504003E+00	370 .65116268E+01	354 -.66660520E+01
699	711 .66666651E+01	699 -.66666651E+01		
700	712 .66666651E+01	700 -.66666651E+01		
712	712 .66666653E+01	700 -.66666652E+01		
713	701 -.66666652E+01	713 .66666653E+01		

NSNODES= 330

Fig. 4-10 - Matrix Coefficient – Nodal Analog Output (X, Step 2)

NODAL ANALOG FOR Y DIRECTION, STEP 2

129	113	.10836563E+01	129	-.10998488E+02	130	.99168475E+01	114	-.20158344E-02
145	129	.12047769E+01	145	-.10918867E+02	146	.97265189E+01	130	-.12429259E-01
146	129	.12247726E-01	145	-.97370468E+01	146	.85594455E+01	130	.11653537E+01
337	321	.78427435E-01	337	-.88371743E+01	338	.87709126E+01	322	-.12165766E-01
338	321	.12260223E-01	337	-.87715536E+01	338	.87047828E+01	322	.54510709E-01
353	337	.58969644E-02	353	-.34967175E+00	354	.43497159E+01	338	-.59419792E-02
	700	-.39999991E+01						
354	337	.11975591E-01	353	-.86995220E+01	354	.86996135E+01	338	-.12067008E-01
369	369	.79999983E+01	712	-.79999982E+01				
370	353	.33696282E-01	369	-.85193029E+01	370	.85193029E+01	354	-.33696283E-01
699	698	-.79999982E+01	699	.79999983E+01				
700	699	-.79999982E+01	700	.79999983E+01				
712	711	-.79999982E+01	712	.79999983E+01				
713	713	-.33333326E+01	714	.33333326E+01				

Reading from Fig. 4-8 on line 1, we see that the x-derivative at node 129 is given by:

$$\left.\frac{\partial E}{\partial x}\right|_{129} = (-10.895807)\, E_{129} + (10.085480)\, E_{130} + (9.8651875)\, E_{145} + (0.022070995)\, E_{146}$$

This is a type of forward-forward operator in the finite difference sense.

Nodal analogs for the y and z coordinates are printed next for step 1. These are then followed by the analogs for step 2, if a two-step method is being used. (See the remaining Figs. 4-9 through 4-11.) This concludes the printout of the GEOM module.

5. INTEGRATION MODULE GUIDE (INTEG)

5.1 USE OF THE MODULE

Module 2 of the GIM/STAR code performs the actual integration of the differential equations. The "derivative taker" matrices from module 1 provide the type of finite difference scheme such that the integration module can be considered a general purpose equation solver. Boundary conditions are treated in this module via input flags specified by the user in the GEOM module. The output is a tape containing the flow field at user specified time increments. This tape can then be printed, or contour maps obtained.

The GIM numerical analog has the form:

$$[A_{mn}]\ \dot{U}_n + [B_{mn}]\ E_n + [C_{mn}]\ F_n + [D_{mn}]\ G_n = 0$$

where the matrices $[A_{mn}]$, etc., are obtained from the output tape of module 1. It is these coefficients which determine the finite difference scheme to be used. Schemes which have been tried to date include Galerkin, MacCormack, Hopscotch algorithms, centered schemes and Euler methods.

The calculation can start at time = 0 with initial conditions as input or it can be restarted from the output solution of previous iterations. The solution proceeds for a specified number of time integration steps.

Module 2, INTEG, must be executed after the GEOM, Module 1, has been run. Also, the DYNDIM deck must also be run on the 6000 side of the STAR system to provide dimension information to INTEG. Figure 5-1 shows the logic path of execution for the INTEG module. The requirements are Files 17 and 20 from the GEOM Module 1 and the dynamic dimensioning information from DYNDIM (discussed in the next subsection).

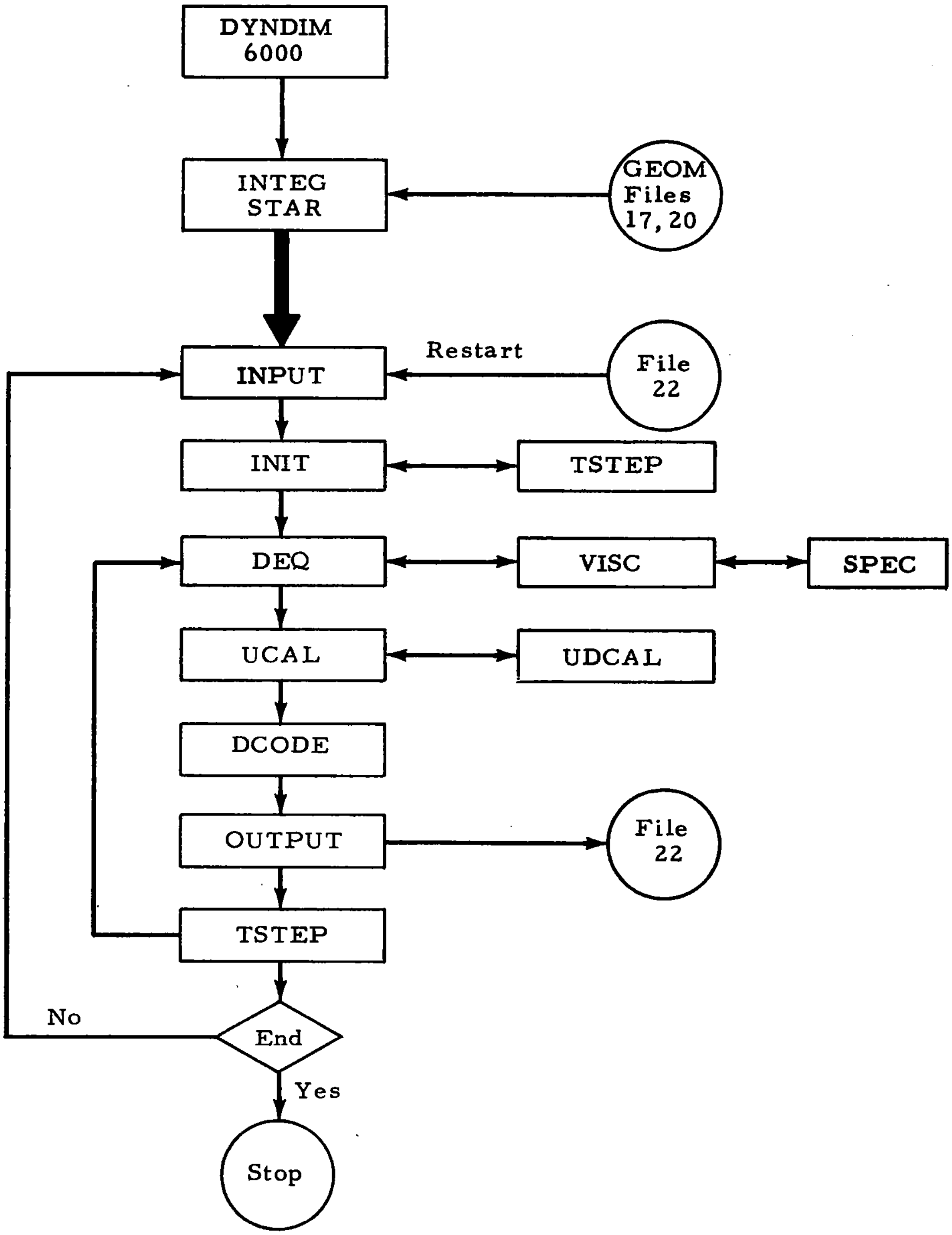


Fig. 5-1 - Logic Sequence for INTEG Module

After this "preprocessing" is done, the INTEG module is executed on STAR and reads data cards in subprogram INPUT. For a restart case, File 22 from a previous execution is also input. The code is then executed in a loop as shown in Fig. 5-1 until the maximum number of iterations is reached.

This module of the GIM/STAR code usually requires the largest run time of the code. The actual CP time is a strong function of the problem itself, the grid construction and the options chosen. The following numbers are a rough guideline for execution of INTEG on STAR. The numbers are the CP seconds required for one iteration of one node point. Total CP is obtained by multiplying these estimates by the number of nodes in the problem times the number of iterations being run.

Mode	Inviscid	Viscous
2-D	0.6E-4	1.0E-4
3-D	1.0E-4	1.8E-4

The actual wall clock time is even more difficult to estimate and is very problem dependent. For two-dimensional problems, wall clock times of twice the CP have been found. For three-dimensional flows, ratios of up to 10 could be obtained for highly irregular grids.

The following subsections describe the input data and the output formats of the INTEG module. Section 5.2 describes the required inputs for the DYNDIM deck and Section 5.3 gives a summary or "mini-manual" of the input formats. A detailed discussion of each input variable is then given in Section 5.4. The various types of output, with examples, are described in Section 5.5.

5.2 DYNDIM DECK

The INTEG module of the GIM/STAR code has a "dynamic-dimension" feature. Each dimensioned variable has a parameter in place of an actual integer. The DYNDIM program uses the UPDATE feature of CDC software to replace these parameters with real dimensions so that INTEG can then be compiled. The dimensions are under user control via input to the DYNDIM program. Execution of this "preprocessor" routine must be made before executing INTEG as explained in Section 3.4. This section describes the input data for the DYNDIM program.

The required data are input on one card with the following format:

FORMAT (4I5)

<u>MN</u>

The total number of nodes in the problem. Each flow vector used in INTEG is then dimensioned by MN. Thus, for "small" problems, the code is dimensioned small and will fit in the main memory of the STAR-100. For "large" problems the code is dimensioned large and the virtual memory handles the storage.

<u>IDIM</u>

The spatial dimension of the problem.

IDIM	= 1	axisymmetric flow
	= 2	two-dimensional planar flow
	= 3	three-dimensional flow

This parameter is used to set the number of equations and vectors required for solution. For two-dimensional problems, a dimension of 1 is set for all variables in the third dimension. This results in a storage savings since the third dimension is not to be used.

ISPEC

A flag denoting whether a single gas or a two-gas is to be run.

ISPEC = 0 single ideal gas
= 1 two ideal gases

This parameter also controls the dimensioning of the INTEG module. If ISPEC = 0, the specie continuity equation variables are dimensioned by 1: if ISPEC = 1, these variables are dimensioned by MN.

NSP

The dimension of the "special node" variables. The INTEG module uses vectors of length MN for most of the calculations. However, for boundary points some of the operations are not vectorizable. These special cases are treated by scalar operations. The dimension of these scalar variables is NSP.

The value for NSP can be set in either of two ways:

1. NSP is output from the GEOM module. This value is subsequently input to DYNDIM.
2. If NSP = 0 is input to the GEOM module, and the INTEG module then NSP = MN is the default value.

For larger problems in which GEOM is executed in a single runstream, the user should set NSP from the GEOM output. If a smaller case is to be run, with GEOM and INTEG in the same runstream, set NSP = 0 and use the default value of MN.

If a particular problem, with fixed dimensions, is to be executed many times, then the compiled INTEG code can be saved. On subsequent executions then the DYNDIM program will not be needed since the relocatable INTEG will be called in rather than the source deck. Compiling the module however, does not require much CP time so that this procedure is not usually required.

5.3 INPUT CARD SUMMARY

This subsection presents a summary of the input cards and formats for the INTEG module. A description of each input parameter and its options is detailed in Section 5.4. After a user becomes familiar with the INTEG inputs, this summarized input guide can be used to quickly identify each card and its contents.

Three basic formats are used to input the data to INTEG:

ALPHANUMERIC	A1
INTEGER	I5
DECIMAL	E10.0

Integers are thus right justified in five column increments. Decimal, or floating point data occupy ten columns each with, preferably, a decimal point punched on the card (see examples, Section 8).

Card Type	Parameter List/Format
1	ICASE, (ITITLE(I), I = 1, 78) (I2, 78A1)
2	IDIM, METHOD, ITMAX, IPRNT, ITSAVE, ISTART, IOTYPE, IUNITS, ITSTRT, IVISC, IDIST, ISPEC (12I5)
3	NN, NNX, NDX, NNY, NDY, NNZ, NDZ, NPM (8I5)
4	DTIME, DTFAC, INCDT (2E10.0, I5)
5	REALMU, REALK, GAMS1, GAMS2, WM1, WM2, DK, RK (8E10.0)
6	EMU, ELAM, ERHO, ESPEC (4E10.0)

Card Type	Parameter List/Format
7	NNPM(I), NCPM(I), (NNCPM(I, J), J = 1, 5), ANGPM(I); I = 1, NPM
	(7I5, E10.0)
8	(NCT(I, J, K), PXPM(I, J, K), PYPM(I, J, K), K = 1, 4); J = 1, NCPM(I); I = 1, NPM.
	(I5, 2E10.0)
9	RHOZ, PZ, ASTAR, NINC, A, B
	(3E10.0, I5, 2E10.0)
10	NJ, INC, NTOT, ITAN, ITYPE
	(5I5)
11	RI, UI, VI, WI, PI, CSI
	(6E10.0)
12	N1, IC, NT
	(3I5)

5.4 DESCRIPTION OF INPUT DATA

This section presents a description of the input parameters listed in Section 5.3. Each parameter is identified as to its usage in the INTEG module with options and standard values also given. All 12 card types are not necessarily input for a given problem. Some of the control parameters on card type 2, for example, dictate which options have been selected and hence which input cards are required. This information is given in the discussion of each parameter to be input. Each input card which is read by INTEG is then immediately printed out to aid the user in debugging a problem setup.

5.4.1 Card and Parameter Descriptions

CARD TYPE 1 Format (I2, 78A1)

Problem Identification Labels

ICASE

The numerical number assigned to the given specific problem. This is used only for user identification of the case being run.

ICASE	≥ 0	identifies the case
	< 0	terminates the run

Any number of cases can be stacked and run in sequence with the INTEG module. After the last case to be processed, the user can set ICASE = -1 to allow a normal termination of the run stream.

ITITLE

Any alphanumeric information that the user wants to assign to identify specifics of the problem. The title should start in Column 3 and can extend through Column 80 of the card. This title is used only for identification of the problem.

CARD TYPE 2 Format (12I5)

Program Option Control Parameters

IDIM

Flag indicating the dimensionality of the problem being run.

IDIM	= 1	indicates that the two-dimensional axisymmetric option is to be used
	= 2	for two-dimensional planar flow
	= 3	for full three-dimensional flow

The only restrictions on the use of IDIM is that the input files 17 and 20 from the GEOM module must have been generated consistent with two- or three-dimensional flow. IDIM is also an input in GEOM and must be consistent with its use in INTEG.

METHOD

A flag indicating whether a one-step or a two-step time integration method is to be used.

= 1 one-step method
= 2 two-step method

The only restriction to use of METHOD is again a consistency with the GEOM module. If METHOD = 2, then the INTEG module expects to find two sets of matrices on the input file 17 from GEOM. One step methods probably should not be used for problems involving shock waves, or for viscous flows.

ITMAX

The maximum number of iterations to run on this execution of INTEG. There is no method currently in the module to stop a run other than on the specified number of iterations. A suggestion is to run, say, 100 iterations and check the results, then restart and run several hundred more steps.

Nominal Values: ITMAX = 50
= 500
= 1000, etc.

Discussions on "when a case has converged" are given in Section 7.

IPRNT

The print control flag. Output of the entire flow field, at selected nodes, is made by the INTEG module every (IPRNT)th iteration. For example,

IPRNT = 100

provides a flowfield printout every 100 time steps.

A suggestion is to printout often on a debugging run and then on subsequent production runs only printout every several hundred steps.

ITSAVE

The flowfield save flag. Output of the flow field is written on File 22 at every (ITSAVE)th iteration. For example,

ITSAVE = 500

will write every 500th time step out on file 22. This file can then be saved on permanent files or rolled out to tape. This file 22 can then be used in two ways:

1. Plotting of the flow field by Module 3 is done from file 22.
2. Restarting an INTEG run requires that file 22 be saved from the previous run.

A good idea is to always save file 22 on any long run and then delete it if no longer needed.

ISTART

The restart control flag. This controls the input data sequence for the INTEG module.

ISTART = 0 indicates a "cold" start run with all initial flowfield data read from cards.

= $N > 0$ indicates a restart run.

If $N > 0$, then file 22 must be available for INTEG to read. The numerical value of N is the block number of the record on file 22 to be used as the starting data.

Example: A previous run has saved file 22 at every 100 iterations for a 1000 iteration run. A restart case is wanted starting at iteration 800.

Then N = 9 since block 9 will contain the 800th iteration. Iteration 0 is the first block on file 22 if the user has flagged IOTYPE < 0. If IOTYPE > 0, then N = 8 in the example because iteration 0 has not been written on the file 22.

IOTYPE

Indicator of the type of flowfield output to be printed. An example of each available type of output is shown in Section 5.5. There are three basic types:

- One-line output prints only the basic flowfield variables such as velocity, density, pressure, etc.
- Two-line output prints extra flow variables which are calculated after the calculation such as Mach number, flow angle, etc.
- Simplified output consisting primarily of supersonic flow quantities of interest such as Mach number, pressure, etc.

IOTYPE	$= \pm 1$	gives one-line output
	$= \pm 2$	gives two-line output
	$= \pm 3$	gives the special purpose output

If IOTYPE	> 0	then the zeroth iteration is <u>not</u> printed
	< 0	the zeroth or starting iteration is printed.

The user should refer to Section 5.5 for examples of the various types of output than INTEG can print.

IUNITS

A flag indicating the units to be used on all flow variables.

IUNITS	= 1	English units are assumed
	= 2	CGS metric units are assumed

Either system may be used but all inputs must be in that consistent set. If dimensionless variables are used, then set IUNITS = 2. The assumed units are:

Variable	English	Metric
Velocity	ft/sec	cm/sec
Density	lbm/ft^3	gm/cm^3
Pressure	lbf/ft^2	dyne/cm^2
Viscosity	lbm/ft-sec	gm/cm-sec
Thermal Conductivity	lbm/ft-sec^3-R	gm/ft-sec^3-K
Gas Constant	ft^2/sec^2-R	cm^2/sec^2-K
Binary Diffusion Coefficient	ft^2/sec	cm^2/sec
Time	sec	sec

ITSTRT

Number of the iteration at which the run is to start. This is used only for printout purposes to help the user keep track of the iterations on a sequence of multi-iteration restart cases. For the example restart problem discussed in the ISTART card, the value of ITSTRT is 800. To keep all iteration numbers in order, the values of ITSTRT and ISTART should be consistent, i.e.,

ISTART = 9

ITSTRT = 800

is consistent for the example problem. Again, this is for accounting purposes only, and an error in ITSTRT will not affect the run or the answers.

IVISC

Flag indicating whether the run is to be made with the inviscid Euler equations or the full Navier-Stokes equations.

IVISC	= 0	indicates an inviscid case to be run
	= 1	signals a full viscous Navier-Stokes run

If a viscous run is called for, then the appropriate coefficients must be input on subsequent cards. For inviscid runs, these coefficients can be read in as zero since they are not used. The only restriction is that IVISC = 1 must be used if a two-gas case is being run. Mixing of the two gas streams could not occur, of course, for an inviscid flow.

There are two viscous options available, both flagged by IVISC = 1.

1. Real laminar viscosity can be input as non-zero and INTEG will use this value.
2. Only NDC type viscosity can be called upon. This is used for numerical stability only and should not affect the problem answers themselves.

Care should be taken when attempting to compute an inviscid supersonic flow with shock waves. This type of problem should be run as viscous with only NDC type artificial viscosity in order to capture the shocks. Methods of inputting real viscosity and NDC coefficients will be given subsequently.

<u>IDIST</u>

This is a special input flag to be used only for nozzle/boundary layer flows.

IDIST	= 0	provides an inviscid type of starting solution for nozzle flows
	= 1	provides for a viscous boundary layer type of starting solution for a nozzle flow.

Details for inputting a nozzle flow starting solution are given in the description of card type 9.

ISPEC

Flag indicating whether the problem to be run consists of one ideal gas or a two-gas system.

ISPEC = 0 indicates a single ideal gas
= 1 indicates a two-gas system

For single ideal gases, only one continuity equation is solved. For two-gas systems, a global and a single species continuity equation are solved. Properties of each of these two ideal gases are input on subsequent cards. For ISPEC = 0, the input of these properties can be zero, since they are not used. For ISPEC = 1, the values of molecular weight and specific heat ratios must be input. The binary diffusion for a species into the mixture is also required. The IVISC = 1 option must also be selected.

CARD TYPE 3 Format (8I5)

Node Point Description

NN

The total number of nodal points in the problem. This input must be consistent with the input to the GEOM module. It is read in on a card in INTEG rather than passed across on a file for convenience.

There is, in theory, no limit on NN except for the external storage devices of the STAR-100 system. In practice, the number of nodes, NN should be selected based on accuracy and resolution of the problem. Keeping NN as small as possible, however, reduces the CP time and the large page faulting on the STAR system.

NNX

The number of nodal points in the x-coordinate direction. This parameter is input (and NNY, NNZ) because of the possible irregular grid system of the GIM code. To compute a time step, the INTEG module must know the dimensions of the grid in each coordinate direction.

For some irregular grid configurations, the number of nodes in each coordinate direction may be different among the regions of the full grid. For this reason, we will sometimes have

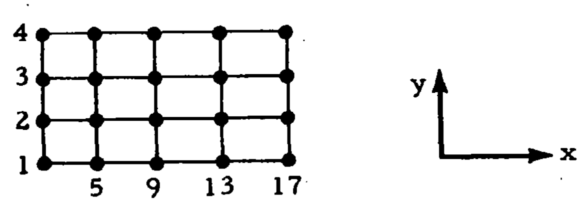
$$NN \neq (NNX)(NNY)(NNZ).$$

As a guideline for irregular grids, the value of NNX (and NNY, NNZ) should be chosen for that part of the grid having the most nodes. These inputs are for computing a time step only. If a constant time step is input by the user, the values of NNX (NNY, NNZ) are not meaningful, but should not be input as zero.

NDX

This nodal parameter (and NDY, NDZ) is input to the INTEG module to indicate the coordinate directions in which the nodes are numbered. The GEOM module has the option, specified by the user, to number the nodal points in any order, i.e., starting along any of the three axes first. For INTEG to set up the vectorization scheme consistent with data provided by GEOM, the program must know the numbering algorithm.

NDX is the nodal point decrement in the x-coordinate direction, i.e., the difference between two node numbers adjacent to one another along the x-axis. Consider the following two-dimensional example:



For this example the input would be

NNX	=	5	NNY	=	4
NDX	=	4	NDY	=	1

and similarly for a three-dimensional problem.

<u>NNY</u>

Number of nodal points in the y-coordinate direction (see discussion of NNX)

<u>NDY</u>

Nodal point number decrement in the y-coordinate direction (see discussion of NDX).

<u>NNZ</u>

Number of nodal points in the z-coordinate direction (see discussion of NNX). For two-dimensional problems set NNZ = 1.

<u>NDZ</u>

Nodal point number decrement in the z-coordinate direction (see discussion of NDX). For two-dimensional problems set NDZ = 0.

<u>NPM</u>

This flag controls the treatment of sharp expansion corners in two-dimensional supersonic flow.

NPM = 0 indicates that no special treatment of corner points is to be made

= N indicates that there are N sharp corners to be treated explicitly

The input data for each corner is given on card types 7 and 8 discussed later. If NPM = 0, then cards 7 and 8 are not input at all. The current limit on the number of special corners is 10, i.e., NPM $\leq$ 10 is the limit.

CARD TYPE 4 Format (2E10.0, I5)

Time Step Control Parameters

DTIME

The value (in seconds) of the time step Δt to be used if the constant step size option is chosen. The user has the option of using this value for Δt or having the code compute Δt based on the CFL condition. The next parameter to be input is DTFAC, which determines the option chosen.

DTFAC

A factor which has two functions. The first function of DTFAC is its multiplication by the minimum CFL number to produce the minimum Δt for each step; i.e.,

$$\Delta t_{min} = |DTFAC| * CFL_{min}$$

The second function depends on the algebraic sign of DTFAC.

If DTFAC > 0	the code will use the user DTIME value as long as it is below the Δt_{min}.
If DTFAC < 0	the code will always use the Δt_{min} itself and ignore the user input value of DTIME.

If the value of DTIME is ever detected to be larger than Δt_{min}, then DTIME is set equal to Δt_{min}.

The CFL condition is calculated in INTEG by the following formula:

$$CFL = \left[\frac{|u|}{\Delta x} + \frac{|v|}{\Delta y} + \frac{|w|}{\Delta z} + a \sqrt{\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} + \frac{1}{\Delta z^2}} \right]^{-1}$$

for each node point, where

Δx, Δy, Δz	are the grid sizes respectively in the x, y, z direction
u, v, w	are the velocity components respectively in the x, y, z directions
a	is the sonic velocity.

No computation is made for a diffusion controlled time step. The DTFAC parameter can be used to adjust the CFL.

INCDT

Iteration counter indicating the frequency at which to update the Δt calculation. The computation of all the CFL conditions for all nodes, and then searching for the minimum, is a costly operation. It is not usually necessary to do this at every time iteration. The value of INCDT can be used to control this calculation. For example,

$$INCDT = 50$$

tells the code to run with a constant time step for 50 iterations and then check the stability value, update the step size if necessary, and then run another 50 iterations. If INCDT = 1, the code will compute the CFL values at every iteration. If the time step is cut to satisfy the CFL, a message is printed to this effect.

CARD TYPE 5 Format (8E10.0)

Gas Thermodynamic and Transport Properties

REALMU

The value of the dynamic viscosity of the ideal gas system. In the current code, this is a constant, laminar-type value. There are no models in this version of GIM to compute the viscosity coefficient. The units of this value depend on IUNITS input on Card 2 (see this discussion).

REALK

The value of the thermal conductivity of the ideal gas system. This value is also currently a constant in the appropriate set of units.

GAMS1

The ratio of specific heats for ideal gas number 1. If a single gas system is being run (ISPEC = 0), GAMS1 is the value of γ for this gas.

GAMS2

The ratio of specific heats for ideal gas number 2. If a single gas system is being run, set GAMS2 = 0.0.

WM1

The molecular weight of gas number 1. If a single gas system is being run, WM1 is the molecular weight of this gas. The code has the option, for a single gas, of reading-in directly the gas constant RK or using WM1 and the universal gas constant (see discussion of RK to follow).

WM2

The molecular weight of gas number 2. The code uses the universal gas constant and molecular weights to compute the individual gas constants for use in the ideal gas equation of state.

DK

The value of the binary diffusion coefficient for species 1 into the mixture.

If	DK $\geq$ 0	the code will use this value in the species continuity and energy equations.
	DK < 0	the code will compute this coefficient as $$DK = \rho\mu/0.7$$ from the dynamic viscosity μ with an assumed Lewis number of 1.0 and Prandtl number of 0.7.

For single gas systems, the value of DK is not used and can be input as 0.0.

RK

The gas constant for a single ideal gas. If RK > 0, the code will use this value for the individual gas constant. If RK = 0, the code will compute RK from the universal gas constant and the molecular weight WM1.

CARD TYPE 6 Format (4E10.0)

NDC Coefficients (See Fig. 3-2.)

EMU (Nominal Value 0.0 to 0.5)

Coefficient for multiplying the computed NDC artificial viscosity. This, and the other NDC coefficients are used to control the amount of numerical diffusion in the solution. The total viscosity is computed as the sum of REALMU and the artificial term:

$$MU = REALMU + EMU*(NDC\ Value)$$

__ELAM__ (Nominal Value = -2/3)

The coefficient to use in computing the "second" viscosity coefficient λ in the Navier-Stokes equation is as follows:

$$\lambda = \text{ELAM}*\mu$$

The value of -2/3 gives the Stokes relation.

__ERHO__ (Nominal Value 0.0 to 0.5)

Coefficient to multiply the computed NDC artificial diffusion term for the global continuity equation. This value is usually set to zero for shock-free flows, but should be about 0.5 for problems which have strong shocks (see Fig. 3-2.)

__ESPEC__ (Nominal Value 0.0 to 0.5)

Coefficient to multiply the computed NDC artificial diffusion term for the species continuity equation. Same usage as ERHO for global conservation of mass.

CARD TYPE 7 __Format (7I5, E10.0)__

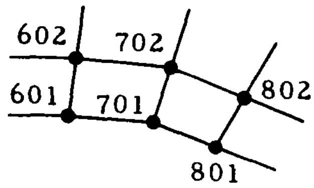
Node Point Information for Special Treatment of Sharp Corners

__Notes__

1. Input card type 7 and 8 __only__ if NPM > 0 on Card 3.
2. For NPM > 0, the input sequence is __one__ card type 7 followed by cards type 8; then repeat the sequence NPM times, Card 7 — then 8, Card 7 — then 8, etc.
3. The number of cards type 8 to be input after each type 7 is a variable specified on card type 7 itself. Thus, for different NPM values, there may be more than one card of type 8 (see description of Card 8).
4. In the subsequent input description, the subscript I runs from 1 to NPM.

NNPM(I)

Node number of the corner point to be specially treated. See the example below.



Node 701 is the corner node itself. Set NNPM(I) = 701.

NCPM(I)

The total number of nodes, connected to the corner node, which the user wants to be computed using the downstream side expanded flow at node NNPM. In the above example, if NCPM(I) = 3, then three of the connecting nodes are assumed to be downstream of the Mach line from the corner.

NNCPM(I, J), J = 1, 5

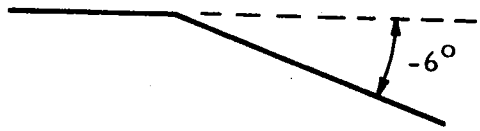
These are the node numbers of those connecting nodes which are to be recomputed. In the above example, NCPM(I) = 3, thus, there are three values of NNCPM to be input. (The J = 1, 5 is for generality, simply set the remaining two values to zero.) For the example, the input would be

NNCPM(I, 1) = 801
NNCPM(I, 2) = 802
NNCPM(I, 3) = 702
NNCPM(I, 4) = 0
NNCPM(I, 5) = 0

This then connects the corner node 701 to surrounding nodes 801, 802 and 702. These nodes will be computed using the downstream flow from the corner. Nodes 601 and 602 are also connected to the corner, but are "upstream" of the expansion and will be computed from the upstream unexpanded flow.

ANGPM(I)

The expansion angle of the corner, measured from the horizontal.



The input angle is in degrees.

CARD TYPE 8 Format (I5, 2E10.0)

Finite Difference Information for Corner Treatment

Notes

1. The number of cards type 8 is

   4*NCPM(I)

   where NCPM(I) was input on Card 7 for I = 1, 2, . . . , NPM.

2. In the subsequent input description, the variable I runs from 1 to NPM, and the variable J runs from 1 to NCPM(I).

NCT(I, J, K), K = 1, 4

The node numbers (4 of them) which are connected to node number J, for treatment of corner node I.

Note that the format is (I5, 2E10.0) for Card 8. This means that the following card sequence is required:

Card 8-1	NCT(I, J, 1), PXPM(I, J, 1), PYPM(I, J, 1)
Card 8-2	NCT(I, J, 2), PXPM(I, J, 2), PYPM(I, J, 2)
Card 8-3	NCT(I, J, 3), PXPM(I, J, 3), PYPM(I, J, 3)
Card 8-4	NCT(I, J, 4), PXPM(I, J, 4), PYPM(I, J, 4)

PXPM(I, J, K), K = 1, 4

The value of the "derivative-taker" matrix B for computing the x-derivative of node J due to the contribution of node K. These values are taken from printout of the GEOM module. The best method of understanding this procedure is to study the example problems of Section 8.

PYPM(I, J, K), K = 1, 4

The value of the "derivative-taker" matrix C for computing the y-derivative of node J due to the contribution of node K. See discussion of NCT and PXPM.

CARD TYPE 9 Format (3E10.0, I5, 2E10.0)

Nozzle Flow Parameter Identification

Notes

1. Card type 9 is input for all cases except a restart run.
2. The data on Card 9 are actually used only if a nozzle-flow starting conditions type is flagged on Card 10.
3. The data on Card 9 can be blank if it is not to be used; but the blank card must be there.

RHOZ

Value of the stagnation density of the gas flow. A one-dimensional isentropic equation is solved to give an initial density distribution in the nozzle. The flow conditions are simply expanded isentropically based on area ratio of the nozzle.

$$\rho/\rho_o = \left[1 + \frac{\gamma-1}{2} M^2\right]^{-1/\gamma-1}$$

PZ

Value of the stagnation pressure of the gas flow. Same usage as RHOZ, where

$$P/P_o = \left[1 + \frac{\gamma-1}{2} M^2\right]^{-\gamma/\gamma-1}$$

ASTAR

The area of the nozzle throat. The isentropic expansion is done in terms of area ratio, i.e., local area to ASTAR. The code uses a subsonic expansion for the converging portion of the nozzle and switches to a supersonic equation after it encounters an area ratio of 1.0. The test that is made is

$$\left|\frac{ASTAR}{A} - 1\right| < 1.0E-4$$

The user should take care to ensure that ASTAR is accurate enough to allow the code to detect the throat of the nozzle. If this test fails, a subsonic expansion will also be used in the diverging section of the nozzle.

NINC

The nodal point number increment between nodes on the nozzle centerline and the upper wall. This is used to obtain the coordinates of the nodes to compute the local area. In general, NINC is the number of nodes in the y (or radial) direction minus 1. If there are 20 nodes radially in the nozzle, then NINC = 19.

A, B

These are parameters that the user can set to obtain a "boundary-layer-like" velocity distribution in the nozzle. These parameters are used if IDIST = 1 was input on card type 2. The equation used is

$$k = A + B * x \quad \text{(x is the axial coordinate)}$$

then

$$M = M_o (1 - y/y_w)^k$$

where

M	=	local Mach number at location (x, y)
M_o	=	local isentropic Mach number at the centerline of the nozzle (x, y = 0)
y	=	local radial coordinate of the node
x	=	local axial coordinate of the node
y_w	=	radial coordinate of the upper wall of the nozzle

This gives a value of M_o at the centerline, $M = 0$ (no slip) on the nozzle wall, and a "boundary-layer-like" distribution in between the boundaries.

CARD TYPE 10 Format (5I5)

Nodal Designators for Initial Conditions Input

Notes

1. Any number of cards type 10 may be used to initialize a flow field. All nodes can be input on a single card or each node can be input on a separate card. The usual case is somewhere between these two extremes.
2. If ITYPE = 0 is input on card type 10, then a card type 11 must immediately follow. If ITYPE $\neq$ 0, no card 11 is input.
3. A -1 card (Columns 4-5) must be input as the last card in a type 10 sequence to terminate reading of initial conditions data.
4. Card type 10 (and 11 if required) are not input for a restart case unless changes are being made (see Section 5.4.2). The -1 card must be present even on a restart case.

NJ

Node number of the first nodal point to be initialized by this card type 10. (NJ = -1 terminates the input of Card 10.)

INC

Node number increment to NJ to be used for inputting a sequence of nodes on one card. Set INC = 0 if only one node is to be set by this card. If INC > 0, this will be added to NJ to allow the user the convenience of incremental inputs.

NTOT

The total number of nodes to be set by this card type 10.

Example: NJ = 600, INC = 2, NTOT = 5 will cause nodes 600, 602, 604 606 and 608 to be initialized to the same values (input on Card 11 to follow).

ITAN

A flag which can be used to allow the user to input either: (1) velocity components, or (2) total velocity. If

ITAN	=	0	the code assumes that the user will input u, v, w velocity components.
	=	1	the code will expect a total velocity to be input. The individual components will be computed by the code using the flow angle information from the Geometry file.

For boundary conditions which require inviscid free slip to be maintained, ITAN = 1 should be input to ensure that accuracy is maintained in applying the "tangency" condition at walls. This option can also be called upon to start the flow in the proper direction to enhance the convergence to steady state.

ITYPE

The critical flag that tells the code which type of initialization is to be done.

ITYPE = 0 allows the user to input the initial conditions on cards (see card type 11).

= 1 signals the code to use the nozzle flow initialization option (see card type 9).

= 2 sets the initial conditions for this card type 10 input to the same values as the previous card type 10 node values.

= 3 allows the user to code a subroutine USERIP in order to initialize the flow field. This subroutine is provided in skeleton form with the code. Often a flow problem can be best initialized from the output of another code, from interpolated data or another source. This option is provided to give the user total flexibility in initializing the flow field. The reason being that the initial data determines to a great extent, the amount of computer time it takes to converge to steady state. (Examples are given in Section 8 of the use of USERIP inputs.)

CARD TYPE 11 Format (6E10.0)

Flowfield Initial Conditions

Notes

1. Card type 11 is input following a card type 10 only if ITYPE = 0 is input on card type 10.
2. If ITYPE = 0 on Card 10, then a type 11 card must follow.
3. Cards type 11 is not input on a restart case unless changes are being made (see Section 5.4.2).

RI

Mass density to be assigned to the nodes specified on the corresponding card type 10.

UI

Velocity component in the x-coordinate direction to be assigned as initial conditions. If ITAN = 1 was input on the corresponding card type 10, the UI is to be the total velocity rather than the x-direction component.

VI

Velocity component in the y-coordinate direction. If ITAN = 1, then set VI = 0.0 and the code will compute the component from geometric inputs.

WI

Velocity component in the z-coordinate direction. If ITAN = 1, then set WI = 0.0 as is the case with VI. For two-dimensional problems, input WI = 0.0.

PI

Static pressure to be assigned to the nodes designated on the corresponding card type 10.

CSI

Mass fraction of gas species number 1 to be assigned as initial conditions. This must be between 0.0 and 1.0. For a single gas case, ISPEC = 0, input CSI = 0.0.

CARD TYPE 12 Format (3I5)

Nodal Output Control

Notes

1. The nodal point flow field can be output in any order for convenience of the user. The nodes do not have to be printed in sequential order.

2. The maximum number of nodes to be printed in NN, the total number in the problem. A given node can be printed more than once, if it is convenient, but the total number of output stations must not be more than NN.
3. Any number of cards of type 12 may be input. For example, each node to be printed can be specified on a separate card, or all nodes to be printed can be specified on a single card. The usual case is somewhere between those two extremes.
4. A -1 card (Columns 4-5) must be last card in the sequence of type 12 cards. This causes the code to start the execution cycle.

N1

The node number of the first nodal point on this card to be printed. For example, N1 = 698, then node 698 will begin the printing controlled by this card.

IC

The node number increment to N1 at which printing is desired. For example, N1 = 100, IC = 3 will cause output of nodes 100, 103, 106, 109, . . .

NT

The total number of nodes to be printed by this card type 12. For example, N = 200, IC = 2, NT = 5 will cause output to be printed for nodes 200, 202, 204, 206 and 208.

Example of Card Type 12 Sequence:

1	1	100
101	2	50
501	5	200
-1		

5.4.2 Special Input Sequence

There are always "special" cases to be input with most any flowfield code. There are often problems which can best be initialized in some non-standard way. There is no known method of single card input which will cover all possibilities. In the GIM/STAR code, we have provided two options for handling these cases. The RSTART option allows a problem to be initialized from the GIM solution of another case. This is described in the subsequent discussion. The second choice is to use the USERIP option. This allows the user to write a special purpose subroutine to initialize a problem. At Lockheed we have found this to be the most efficient way of initializing many problems. The better the initial guess of the flow field, the faster is the convergence to steady state. The USERIP option is also discussed in the following pages.

<u>RSTART Option</u>

The RSTART feature of the code has two basic functions:

1. It allows a problem to be "restarted" from a previous run. If a case does not converge for some reason, the problem can be restarted from some point with different parameters. This also allows a case to be run in segments. A run can be made for, say 200 iterations and then stopped. The run can then be re-started at iteration 200 and run again.
2. It allows parametric studies to be made efficiently. A case for a given set of flow conditions, (pressure, Mach number, etc.), can be converged for a configuration. The output can then be used to initialize a case for different pressure, Mach number, etc. This permits steady state results to be obtained in much less computer time than a "cold start" run.

To use the RSTART option, the user proceeds as follows:

1. On the first run of a sequence, set ITSAVE > 0 and save file 22 on a tape or permanent file.
2. On the second run of a sequence, set ISTART > 0, and copy the previously save file onto file 22.
3. Repeat this sequence for each restart case. There is no limit to the number of times a case can be restarted.

An important item to remember on a restart run is that the initial conditions cards type 10 and 11 are <u>not</u> input unless changes are to be made. For the standard RSTART usage, only the -1 card of sequence types 10 and 11 is needed. The option does exist for allowing the user to restart a run and change some of the conditions if desired. To use this option, the following sequence should be used:

1. Set ISTART > 0 and copy the saved file onto file 22.
2. Input cards type 10 and 11 in the same manner as a "cold start" case.
3. Conclude the type 10 and 11 sequence with the standard -1 card.

The example problems given in Section 8 show an example of the use of the RSTART option.

USERIP Option

This option allows the user to write a special purpose subroutine to initialize a flow field. The skeleton of this subroutine is provided with the GIM/STAR code. To exercise this option, the following procedure is used:

1. On card type 10, set the parameter ITYPE = 3. The subroutine USERIP is then called with arguments, NJ, INC, NTOT, IRTN. The first three of these are just the inputs from the card type 10. (See this section for definitions.) The parameter IRTN should be set by the user in USERIP. If IRTN = 0, the code proceeds to store the flow variables in the standard input manner. If IRTN = 1, the code will assume that the user has stored all data and return is made to read another card type 10.
2. The second step is to code the required data into USERIP. This is done using the UPDATE feature of the CDC software. The IDENT is as follows:

```
*IDENT          USER
*D        PAGE2.142
          User Code}
```

The variables that must be set in this subroutine are RI, UI, VI, WI and PI as defined in the discussion of card type 11. If IRTN = 0 is set, then the above variables must be returned to the INPUT subroutine. If IRTN = 1 is set, the code expects the user to set the following variables:

RHO(I), UVEL(I), VVEL(I),
WVEL(I), P(I), ENER(I)

The example problems given in Section 8 show an example of the USERIP option. To use this particular option of the code efficiently requires some experience and practice with its use. An experienced user will, however, find this to be a very efficient means of inputting the important initial conditions.

5.5 OUTPUT DESCRIPTION

The output of the INTEG module consists of two types:

- Printed flowfield data, and
- Output file on which the flowfield data are stored.

The output file (22) is a formatted file used in the GIMPLT module to plot contours of the flow field (see Section 6) and for restarting a run. The printed output from INTEG consists of the following types:

- The input cards are printed out to allow the user to check the data.
- At each time iteration, a printout is given of the unsteady derivative parameters.
- At user selected iterations, the flow field itself is printed.

Each of these types of output is now briefly described. The reader should refer to the corresponding figures while reading these descriptions.

5.5.1 Printout of Input Cards (Figs. 5-2 and 5-3)

The first page of output from the INTEG module is a summary of the input cards. The variable names and nomenclature for this printout are the

```
G E N E R A L   I N T E R P O L A N T S   M E T H O D
ELLIPTIC NAVIER-STOKES CODE
LOCKHEED-HUNTSVILLE
STAR 100 VERSION
INTEGRATION MODULE

  1  TWO DIMENSIONAL SCRAMJET SIMULATION  *AIR GAS*  *SHARP CORNER*

PROBLEM CONTROL FLAGS
    IDIM   METHOD    ITMAX    IPRNT    ITSAVE   ISTART   IOTYPE   IUNITS   ITSTRT   IVISC    IDIST    ISPEC
      2       2        10       10        0        1        5        1       100       1        0        0

NODE POINT INFORMATION
      NN      NNX      NDX      NNY      NDY      NNZ      NDZ      NPM      ND1      ND2
     940       43       16       16        1        1        0        1       16        0

DTIME=  .20000000E-04     DTFAC= -.75000000E+00     INCDT=     1

GAS PROPERTIES
REALMU=  .10000000E-02     REALK=  .0                 GAMS1=  .12700000E+01     GAMS2=  .0
WM1=  .23000000E+02      WM2=  .0                OK=  .0                  PK=  .0

NDC COEFFICIENTS
EMU=  .50000000E+00     ELAM= -.67000000E+00     ERHO=  .50000000E+00     ESPEC=  .0

CORNER NODE INFORMATION FOR     1  CORNER NODES

          CORNER NODE NUMBER  129  WITH ANGLE OF -.60000000E+01  DEGREES
             2   DOWNSTREAM NODES ARE    145  146
          DIFFERENCE OPERATORS FOR CONNECTING NODE NUMBER   145
            129 -.96544914E+01  .12047769E+01
            130 -.21865980E-01 -.12429260E-01
            145  .88312419E+01 -.10918867E+02
            146  .10431156E+01  .97265139E+01
          DIFFERENCE OPERATORS FOR CONNECTING NODE NUMBER   146
            129  .21809047E-01  .12247726E-01
            130 -.97740653E+01  .11653537E+01
            145 -.95438360E+00 -.97370468E+01
            146  .10706640E+02  .85590455E+01

NJ=  689     INC=     1     NTOT=  252     ITAN=     1     ITYPE=     0

      RI             UI             VI             WI             PI             CI
 .32230000E-02  .28950000E+04  .0             .0             .10580000E+05  .0

NODES TO BE PRINTED
       1        16        43
      16        16        43
     675         1        16
     689         1        12
```

Fig. 5-2 - Example Printout of Input Cards

```
G E N E R A L   I N T E R P O L A N T S   M E T H O D
          ELLIPTIC NAVIER--STOKES CODE
              LOCKHEED-HUNTSVILLE
              STAR 100 VERSION
              INTEGRATION MODULE

1  TWO DIMENSIONAL SCRAMJET SIMULATION  *ONE GAS*  *SHARP CORNER*


P R O B L E M   S U M M A R Y

TWO DIMENSIONAL PLANAR FLOW

TWO STEP METHOD

VISCOUS OPTION

REAL VISCOUS CASE

ONE IDEAL GAS

TOTAL NUMBER OF NODES IN PROBLEM IS  940

  102   NODES TO BE OUTPUT

NUMBER OF EQUATIONS IS     4

RESTART RUN AT ITERATION   100

UNSTEADY DERIVATIVE REFERENCE VALUES
  .50988861E+05  .19726679E+13  .35429531E+12  .13557704E+21  .41698996E+05
```

Fig. 5-3 - Problem Summary Output

same as described in the INPUT guide (Section 5.4). The user should verify that the intended input got into the code correctly. This page is followed by problem summary statements which give the code's interpretation of the options requested by the user. Again, this should be checked to ensure that the proper options were selected. The final line on the input summary is titled:

"Unsteady Derivative Reference Values."

The quantities are defined at current iteration "zero" and are the sum of squares of the unsteady derivatives;

$$\sum_{i=1}^{NN} (\dot{U}_i)^2$$

The order of this printout is

$$\dot{\rho}^2,\ (\rho\dot{u})^2,\ (\rho\dot{v})^2,\ (\rho\dot{w})^2,\ (\rho\dot{E})^2,\ (\rho\dot{C})^2\ .$$

For two-dimensional problems, the $(\rho\dot{w})^2$ is not printed and for single gas cases, the $(\rho\dot{C})^2$ is not printed. The values of these variables are different for each problem and set of initial conditions, but generally are of the order of 10^5 to 10^{20}. The primary use of this data is for debugging of a new problem set-up and to check for convergence of a set of restarted runs (see Section 7).

5.5.2 Sum of Squares of Unsteady Derivatives (Fig. 5-4)

The output philosophy of the GIM code is to print "some information at all iterations and all information at some iterations." At each time step, the current values of the "sum of squares" of the unsteady derivatives is printed. This information has proved to be very useful in determining convergence of a case. The printed values start at 1.0 since they are normalized by the reference values at iteration zero. In general, these derivatives should start to go down as the solution gets closer to steady state. In some cases, they may go up for a while as the code is adjusting the solution. Convergence is generally obtained after the values drop several orders of magnitude and then stop changing.

SUM OF SQUARES OF UNSTEADY DERIVATIVES

ITER	DIMIN	U DOT	RU DOT	RV DOT	RE DOT	PC DOT
101	.50703447E-05	.10000000E+01	.10000000E+01	.10000000E+01	.10000000E+01	.10000000E+01
102	.50703447E-05	.95817118E+00	.96465120E+00	.95869744E+00	.95814485E+00	.96235404E+00
103	.50703447E-05	.92091641E+00	.93301441E+00	.93327153E+00	.92105137E+00	.92842203E+00
104	.50703447E-05	.88773854E+00	.90455363E+00	.90886851E+00	.88806862E+00	.89794349E+00
105	.50703447E-05	.85816471E+00	.87896666E+00	.88540814E+00	.85874066E+00	.87059159E+00
106	.50703447E-05	.83172606E+00	.85591991E+00	.86283409E+00	.83260526E+00	.84600926E+00
107	.50703447E-05	.80797877E+00	.83507701E+00	.84109898E+00	.80921849E+00	.82380833E+00
108	.50703447E-05	.78651771E+00	.81611319E+00	.82014712E+00	.78816802E+00	.80367247E+00
109	.50703447E-05	.76698425E+00	.79873470E+00	.79992070E+00	.76908631E+00	.78535770E+00
110	.50703447E-05	.74906675E+00	.78268772E+00	.78035942E+00	.75165543E+00	.76852539E+00

Fig. 5-4 - Sum of Squares of Unsteady Derivatives

The iteration number, ITER, is followed by the current value of the minimum time step, DTMIN. The normalized sum of squares of the unsteady derivatives are then given for each variable in the U vector. A header is printed at each new page to identify the derivative being printed. See Section 7 for further comments on the unsteady derivative method for converging a case.

5.5.3 Flowfield Output (Figs. 5-5 through 5-9)

Printout of the flow field is given at user specified iterations. In addition, the user can also select the node points to be printed. These are controlled by flagging the appropriate input cards. A large volume of paper can be generated if all nodes are printed for a three-dimensional problem. Carefully selected nodes could be printed during the convergence of a case, and then all nodes printed after steady state is reached.

The format of this output depends on two input parameters:

IDIM; IOTYPE

If IDIM = 2, only those variables pertinent for two-dimensional flows are printed. If IDIM = 3, the full three-dimensional flow field is output. The value of IOTYPE determines the amount of printout at each node point.

IOTYPE = 1: This will be called the "one line" output and consists of the basic calculated flow parameters; density, velocity, energy and pressure. Figures 5-5 and 5-6 are examples of this output for two- and three-dimensional flow, respectively. The nomenclature for the printout is as follows:

NODE	— node point number
X, Y, Z	— Cartesian coordinates of the NODE
RHO	— density
U, V, W	— velocity components in x, y, z directions
QVEL	— total velocity $(u^2 + v^2 + w^2)^{1/2}$
E	— total energy

ITERATION NUMBER 110 DTIME= .2000000E-05 TIME= .2000000E-04

NODE	X	Y	RHO	U	V	VEL	E	P	18
160	.13454545E+01	.16499127E+01	.29292045E-02	-.13390016E+04	.22325862E+04	.65272651E+04	.49363332E+08	.66593537E+03	4
176	.14727273E+01	.17462369E+01	.29123614E-02	.61324103E+04	.22320221E+04	.65254773E+04	.49302373E+08	.66102038E+03	4
192	.16000000E+01	.17925600E+01	.28118568E-02	.61272690E+04	.22301506E+04	.65205060E+04	.49238105E+08	.66022734E+03	4
208	.17272727E+01	.18368836E+01	.29203126E-02	.61230950E+04	.22286318E+04	.65160641E+04	.49200943E+08	.66214023E+03	4
224	.18545455E+01	.18652073E+01	.28317807E-02	.61199944E+04	.22275031E+04	.65127645E+04	.49179412E+08	.66470958E+03	4
240	.19818182E+01	.19315309E+01	.28423039E-02	.61175882E+04	.22266273E+04	.65102035E+04	.49166031E+08	.66725823E+03	4
256	.21090909E+01	.19776545E+01	.28520333E-02	.61156571E+04	.22259249E+04	.65081489E+04	.49157520E+08	.66965875E+03	4
272	.22363636E+01	.20241782E+01	.28609105E-02	.61140939E+04	.22253555E+04	.65064853E+04	.49152450E+08	.67188128E+03	4
288	.23636364E+01	.20705018E+01	.28659417E-02	.61135545E+04	.22249771E+04	.65053792E+04	.49153923E+08	.67397613E+03	4
304	.24909091E+01	.21168255E+01	.28763675E-02	.61123691E+04	.22247277E+04	.65046498E+04	.49159557E+08	.67597112E+03	4
320	.26181818E+01	.21631491E+01	.28832617E-02	.61118459E+04	.22245372E+04	.65040930E+04	.49166398E+08	.67784450E+03	4
336	.27454545E+01	.22094727E+01	.28896313E-02	.61114056E+04	.22243770E+04	.65036245E+04	.49173740E+08	.67959390E+03	4
352	.28727273E+01	.22557964E+01	.28956929E-02	.61114463E+04	.22243918E+04	.65036678E+04	.49183862E+08	.68125860E+03	4
368	.30000000E+01	.23021200E+01	.29004191E-02	.61081948E+04	.22232184E+04	.65002076E+04	.49163674E+08	.68242673E+03	4
384	.31500000E+01	.23567155E+01	.29156950E-02	.61128729E+04	.22249623E+04	.65051830E+04	.49250995E+08	.68736588E+03	4
400	.33000000E+01	.24113110E+01	.28819301E-02	.61380927E+04	.22340616E+04	.65320213E+04	.49246912E+08	.67628532E+03	4
416	.34500000E+01	.24659065E+01	.28270239E-02	.61641959E+04	.22435823E+04	.65597997E+04	.49254490E+08	.65808054E+03	4
432	.36000000E+01	.25205020E+01	.27673193E-02	.61896604E+04	.22528507E+04	.65868985E+04	.49174180E+08	.63818063E+03	4
448	.37500000E+01	.25750975E+01	.27067693E-02	.62157929E+04	.22623621E+04	.66147081E+04	.49082425E+08	.61796313E+03	4
464	.39000000E+01	.26296930E+01	.26460111E-02	.62430164E+04	.22722706E+04	.66436768E+04	.48985151E+08	.59766738E+03	4
480	.40500000E+01	.26842885E+01	.25851302E-02	.62713920E+04	.22825965E+04	.66738755E+04	.48882546E+08	.57732791E+03	4
496	.42000000E+01	.27388840E+01	.25241430E-02	.63009157E+04	.22933443E+04	.67052939E+04	.48773742E+08	.55695112E+03	4
512	.43500000E+01	.27934795E+01	.24630583E-02	.63315753E+04	.23045034E+04	.67379211E+04	.48657648E+08	.53654018E+03	4
528	.45000000E+01	.28480750E+01	.24018836E-02	.63633579E+04	.23160713E+04	.67717435E+04	.48533046E+08	.51609769E+03	4
544	.46500000E+01	.29026705E+01	.23406257E-02	.63962507E+04	.23280433E+04	.68067473E+04	.48398586E+08	.49562602E+03	4
560	.48000000E+01	.29572660E+01	.22792909E-02	.64302409E+04	.23404148E+04	.68424189E+04	.48252769E+08	.47512735E+03	4
576	.49500000E+01	.30118615E+01	.22178848E-02	.64653161E+04	.23531811E+04	.68802451E+04	.48093925E+08	.45460366E+03	4
592	.51000000E+01	.30664570E+01	.21564126E-02	.65014630E+04	.23663378E+04	.69187130E+04	.47920191E+08	.43405675E+03	4
608	.52500000E+01	.31210525E+01	.20948791E-02	.65386729E+04	.23798807E+04	.69583098E+04	.47729483E+08	.41348828E+03	4
624	.54000000E+01	.31756480E+01	.20332886E-02	.65769313E+04	.23938057E+04	.69990236E+04	.47519458E+08	.39289975E+03	4
640	.55500000E+01	.32302435E+01	.19716460E-02	.66162304E+04	.24081093E+04	.70408447E+04	.47287491E+08	.37229269E+03	4
656	.57000000E+01	.32848390E+01	.19099464E-02	.66565415E+04	.24227614E+04	.70837430E+04	.47030434E+08	.35166641E+03	4
672	.58500000E+01	.33394345E+01	.18482504E-02	.66979980E+04	.24378703E+04	.71278601E+04	.46746295E+08	.33103736E+03	4
688	.60000000E+01	.33940300E+01	.17863383E-02	.67399056E+04	.24531234E+04	.71724571E+04	.46423658E+08	.31033165E+03	4
673	.60000000E+01	.0	.13153127E-02	.72696353E+04	-.19655010E+03	.72722919E+04	.43477973E+08	.18602962E+03	8
674	.60000000E+01	.16970150E+00	.13517101E-02	.73901000E+04	.49252301E+02	.73902641E+04	.45894268E+08	.21083098E+03	8
675	.60000000E+01	.33940300E+00	.14098999E-02	.73667817E+04	.14066351E+03	.73692486E+04	.46037461E+08	.22343623E+03	8
676	.60000000E+01	.50910450E+00	.14637078E-02	.73393586E+04	.32099156E+03	.73463749E+04	.46109122E+08	.23491103E+03	8
677	.60000000E+01	.67880600E+00	.15170244E-02	.73097741E+04	.44951148E+03	.73235824E+04	.46163219E+08	.24628468E+03	8
678	.60000000E+01	.84850750E+00	.15698146E-02	.72785534E+04	.57662466E+03	.73013743E+04	.46211045E+08	.25762462E+03	8
679	.60000000E+01	.10182090E+01	.16215456E-02	.72461355E+04	.70322203E+03	.72801766E+04	.46262577E+08	.26891835E+03	8
680	.60000000E+01	.11879105E+01	.16687705E-02	.72130964E+04	.83240352E+03	.72604679E+04	.46354838E+08	.27999821E+03	8
681	.60000000E+01	.13576120E+01	.17033424E-02	.71756515E+04	.95856602E+03	.72393938E+04	.46349361E+08	.28795655E+03	8
682	.60000000E+01	.15273135E+01	.17341700E-02	.71366581E+04	.10795406E+04	.72178457E+04	.46445850E+08	.29769486E+03	8
683	.60000000E+01	.16970150E+01	.17721976E-02	.70949515E+04	.12060145E+04	.71967220E+04	.46552831E+08	.30720342E+03	8
684	.60000000E+01	.20364180E+01	.18032088E-02	.70241550E+04	.14621501E+04	.71747282E+04	.46622031E+08	.31601778E+03	8
685	.60000000E+01	.23758210E+01	.17991606E-02	.69662178E+04	.17143324E+04	.71740592E+04	.46570145E+08	.31459741E+03	8
686	.60000000E+01	.27152240E+01	.17924646E-02	.69005832E+04	.19592530E+04	.71733340E+04	.46486885E+08	.31225240E+03	8
687	.60000000E+01	.30546270E+01	.17875394E-02	.68266516E+04	.21949924E+04	.71725778E+04	.46429363E+08	.31061291E+03	8
688	.60000000E+01	.33940300E+01	.17863383E-02	.67399056E+04	.24531234E+04	.71724571E+04	.46423658E+08	.31033165E+03	4

CP TIME(SEC)= 1.13 WALL TIME(SEC)= 2.54

Fig. 5-5 - Two-Dimensional One Line Output

ITERATION NUMBER 5 TIME = .2[illegible] TIME = .1[illegible]E-05

NODE	X	Y	Z	[illegible]	U	V	W	P	IB
1	.30000000E+01	-.30000000E+01	.0	.32230000E-02	.57908320E+04	.0	.0	.10581941E+03	0
101	.30000000E+01	-.65000000E+00	.62500000E+00	.32230000E-02	.57906326E+04	.0	.0	.10582055E+03	0
201	.30000000E+01	-.56843419E-13	.12500000E+01	.32230000E-02	.57909221E+04	.0	.0	.10581577E+03	0
301	.33753000E+01	.65000000E+00	.22000000E+01	.32230000E-02	.57909265E+04	.0	.0	.10580611E+03	0
401	.42701667E+01	.22000000E+01	.12500000E+00	.12470000E-02	.71887743E+04	.20259414E+04	.66224936E+02	.19060565E+03	0
501	.32000000E+01	-.30000000E+01	.78333333E+00	.32229948E-02	.57906314E+04	-.68657484E-03	-.13044025E-03	.10580425E+03	8
601	.32000000E+01	-.68133333E+00	.14083333E+01	.32229842E-02	.57908224E+04	-.16520788E-02	.70747279E+01	.10596866E+03	9
701	.32000000E+01	-.33333333E-01	.27173333E+01	.32173071E-02	.57950131E+04	-.10922544E+03	.81444508E+01	.10611786E+03	9
801	.36580489E+01	.82444444E+00	.26666667E+00	.13427151E-02	.74495879E+04	.40329677E+03	.14375829E+02	.21010072E+03	9
901	.43854889E+01	.22044444E+01	.90833333E+00	.12450568E-02	.70438948E+04	.18158664E+04	.46208681E+02	.19213548E+03	9
1001	.34000000E+01	-.30000000E+01	.15666667E+01	.32229989E-02	.57909252E+04	-.63348460E-03	.38051587E-03	.10579779E+03	8
1101	.34000000E+01	-.71266667E+00	.33186667E+01	.32230178E-02	.57909671E+04	.22675285E-02	.41620726E+01	.10580324E+03	9
1201	.34625517E+01	.58333333E-01	.42500000E+00	.17174279E-02	.72437259E+04	-.41934310E+03	.22080963E+02	.28669731E+03	9
1301	.38253311E+01	.79888889E+00	.10666667E+01	.13573331E-02	.72208340E+04	.36937432E+03	.62905475E+02	.21109130E+03	9
1401	.45008111E+01	.22088889E+01	.17126667E+01	.47212947E-03	.59479561E+04	.15333024E+04	.58592489E+02	.92753347E+01	9
1501	.36000000E+01	-.30000000E+01	.40000000E+01	.32230005E-02	.57906303E+04	.15827411E-04	.16022569E-03	.10580362E+03	8
1601	.36000000E+01	-.60000000E+00	.60000000E+00	.32244692E-02	.57909488E+04	.36721281E+00	.16070088E+02	.10586972E+03	9
1701	.36577400E+01	.25000000E-01	.12250000E+01	.32302594E-02	.57402852E+04	-.20465076E+03	.54117705E+02	.10427277E+03	9
1801	.39926133E+01	.77333333E+00	.19360000E+01	.32220074E-02	.57598390E+04	.29758972E+03	.65045155E+02	.10579774E+03	9
1901	.47085067E+01	.24266667E+01	.0	.12192973E-02	.72039291E+04	.20881170E+04	.0	.18468390E+03	4
2001	.38000000E+01	-.23373333E+01	.75833333E+00	.32229909E-02	.57905289E+04	-.14612209E-02	.63702421E+01	.10581278E+03	9
2101	.38000000E+01	-.63333333E+00	.13833333E+01	.32238899E-02	.57896409E+04	.23333021E+00	.29429544E+02	.10592000E+03	9
2201	.38529283E+01	-.83333333E-02	.22960000E+01	.32242769E-02	.57895879E+04	-.95862400E+02	.51708128E+02	.10586414E+03	9
2301	.42869089E+01	.10744444E+01	.15833333E+00	.13015386E-02	.73810023E+04	.71174980E+03	.22581011E+02	.20301570E+03	9
2401	.48161311E+01	.24355556E+01	.88333333E+00	.12135287E-02	.71060634E+04	.20270684E+04	.11613521E+03	.18571143E+03	9
2501	.40000000E+01	-.23466667E+01	.15416667E+01	.32229888E-02	.57905257E+04	-.11454236E-02	.10784883E+02	.10581811E+03	9
2601	.40000000E+01	-.66666667E+00	.27866667E+01	.32236186E-02	.57895025E+04	.12324339E+00	.20720641E+02	.10598240E+03	9
2701	.40962333E+01	.83333333E-01	.33333333E+00	.16318309E-02	.73249925E+04	-.21904079E+03	.42549400E+02	.27000849E+03	9
2801	.44426444E+01	.10555556E+01	.10416667E+01	.13116465E-02	.72312472E+04	.68462154E+03	.13225873E+03	.20673139E+03	9
2901	.49237556E+01	.24444444E+01	.16666667E+01	.39403623E-03	.58919152E+04	.16821065E+04	.16038654E+03	.73487850E+01	9
3001	.42000000E+01	-.23560000E+01	.33560000E+01	.32230196E-02	.57909344E+04	.43206476E-04	.37787004E+01	.10579900E+03	9
3101	.42000000E+01	-.57500000E+00	.52500000E+00	.32249870E-02	.57887602E+04	-.76892788E+02	.30315651E+02	.10612166E+03	9
3201	.42866100E+01	.50000000E-01	.12000000E+01	.16552008E-02	.70707433E+04	-.14468638E+03	.13616811E+03	.27125779E+03	9
3301	.45983800E+01	.10366667E+01	.18380000E+01	.25568950E-02	.58146830E+04	.55258556E+03	.15117082E+03	.80355956E+02	9
3401	.50313800E+01	.24533333E+01	.40000000E+01	.39664099E-03	.59020760E+04	.17102434E+04	.40322612E+00	.79954801E+01	8
3501	.44000000E+01	-.18213333E+01	.73333333E+00	.32229413E-02	.57904501E+04	.18694387E-03	.19560747E+02	.10586121E+03	9
3601	.44000000E+01	-.60833333E+00	.13583333E+01	.32243865E-02	.57901852E+04	-.44197686E+02	.61156368E+02	.10595400E+03	9
3701	.44769867E+01	.16666667E-01	.20506667E+01	.32234043E-02	.57874414E+04	-.55797347E+02	.12064099E+03	.10622953E+03	9
3801	.46464889E+01	.13644444E+01	.0	.13359390E-02	.72851272E+04	.10148709E+04	.0	.21551435E+03	4
3901	.52005867E+01	.26933333E+01	.85833333E+00	.11721841E-02	.71349742E+04	.22425574E+04	.19910603E+03	.17567998E+03	9
4001	.46000000E+01	-.18386667E+01	.15166667E+01	.32229631E-02	.57906611E+04	.13726613E-03	.30722689E+02	.10583955E+03	9
4101	.46000000E+01	-.64166667E+00	.23920000E+01	.32237124E-02	.57902624E+04	-.20248646E+02	.57612373E+02	.10593494E+03	9
4201	.47010450E+01	.10833333E+00	.19166667E+00	.15524479E-02	.73442641E+04	-.73288259E+02	.37853017E+02	.25529130E+03	9
4301	.49906778E+01	.13522222E+01	.10166667E+01	.13428816E-02	.71978781E+04	.98755414E+03	.20886644E+03	.21246009E+03	9
4401	.53005133E+01	.27666667E+01	.16416667E+01	.39061049E-03	.58586195E+04	.17914512E+04	.25172945E+03	.91481658E+01	9
4501	.48000000E+01	-.18560000E+01	.28560000E+01	.32230552E-02	.57907005E+04	-.14362826E-02	.19580725E+02	.10585566E+03	9
4601	.48000000E+01	-.55000000E+00	.40000000E+00	.32221123E-02	.57897759E+04	-.10979414E+03	.36541468E+02	.10582518E+03	9
4701	.48866100E+01	.75000000E-01	.11750000E+01	.15960438E-02	.72775316E+04	-.61375291E+02	.19888093E+03	.25944941E+03	9
4801	.51348667E+01	.13400000E+01	.16000000E+01	.16717011E-02	.58659524E+04	.80625038E+03	.25494311E+03	.47482740E+02	9
4901	.54004400E+01	.27200000E+01	.33540000E+01	.39633494E-03	.58810831E+04	.18607646E+04	.82342758E+02	.79089577E+01	9
5001	.50000000E+01	-.14400000E+01	.62500000E+00	.32224466E-02	.57902277E+04	.44387093E-03	.29086904E+02	.10588623E+03	9
5101	.50000000E+01	-.58333333E+00	.13333333E+01	.32226405E-02	.57868033E+04	-.60571106E+02	.10072698E+03	.10582485E+03	9

Fig. 5-6 - Three-Dimensional One Line Output

ITERATION NUMBER 110 DTIME= .20000000E-05 TIME= .20000000E-04

NODE	X	Y	RHO	U	V	SOS	E	P	IB
		GAM	CS	PHIX	PHIY	QVEL	T	W	
576	.49500000E+01	.30118615E+01	.22178847E-02	.64653169E+04	.23531814E+04	.28940331E+04	.48093926E+08	.45460731E+03	4
		.12700022E+01	.99956909E+00	.19999988E+02	.0	.68802460E+04	.30507149E+04	.23773902E+01	
592	.51000000E+01	.30664570E+01	.21564125E-02	.65014648E+04	.23663381E+04	.28678963E+04	.47920193E+08	.43405957E+03	4
		.12700018E+01	.99997502E+00	.19999988E+02	.0	.69187138E+04	.29958579E+04	.24124700E+01	
608	.52500000E+01	.31210525E+01	.20948790E-02	.65386736E+04	.23798810E+04	.28399313E+04	.47729486E+08	.41349035E+03	4
		.12700014E+01	.99998082E+00	.19999988E+02	.0	.69583106E+04	.29377152E+04	.24501686E+01	
624	.54000000E+01	.31756480E+01	.20332886E-02	.65769320E+04	.23938059E+04	.28099376E+04	.47519461E+08	.39290113E+03	4
		.12700010E+01	.99998650E+00	.19999988E+02	.0	.69990243E+04	.28759880E+04	.24908113E+01	
640	.55500000E+01	.32302435E+01	.19716459E-02	.66162310E+04	.24081096E+04	.27776833E+04	.47287495E+08	.37229347E+03	4
		.12700006E+01	.99999208E+00	.19999988E+02	.0	.70408454E+04	.28103401E+04	.25347905E+01	
656	.57000000E+01	.32848390E+01	.19099464E-02	.66565420E+04	.24227816E+04	.27428964E+04	.47030439E+08	.35166664E+03	4
		.12700002E+01	.99999783E+00	.19999988E+02	.0	.70837435E+04	.27403872E+04	.25825778E+01	
672	.58500000E+01	.33394345E+01	.18482504E-02	.66979983E+04	.24378704E+04	.27052818E+04	.46746298E+08	.33103739E+03	4
		.12700000E+01	.10000000E+01	.19999988E+02	.0	.71278603E+04	.26657413E+04	.26347941E+01	
688	.60000000E+01	.33940300E+01	.17863383E-02	.67399056E+04	.24531234E+04	.26643150E+04	.46423659E+08	.31033166E+03	4
		.12700000E+01	.10000000E+01	.19999988E+02	.0	.71724572E+04	.25856167E+04	.26920455E+01	
673	.60000000E+01	.0	.13203870E-02	.72586152E+04	-.10591957E+03	.24601813E+04	.43986219E+08	.19555373E+03	8
		.12701771E+01	.99754511E+00	-.83601532E+00	.0	.72593880E+04	.22052462E+04	.29507532E+01	
674	.60000000E+01	.16970150E+00	.13550006E-02	.73896821E+04	.55647336E+02	.25260201E+04	.45913418E+08	.21159426E+03	8
		.12700013E+01	.99998219E+00	.43145256E+00	.0	.73898917E+04	.23241682E+04	.29255078E+01	
675	.60000000E+01	.33940300E+00	.14100619E-02	.73667496E+04	.19103629E+03	.25447721E+04	.46038162E+08	.22347376E+03	8
		.12700019E+01	.99997305E+00	.14854748E+01	.0	.73692262E+04	.23588060E+04	.28958295E+01	
676	.60000000E+01	.50910450E+00	.14637144E-02	.73393574E+04	.32100350E+03	.25608362E+04	.46109142E+08	.23491472E+03	8
		.12700027E+01	.99996312E+00	.25043652E+01	.0	.73463740E+04	.23886831E+04	.28687403E+01	
677	.60000000E+01	.67880600E+00	.15170245E-02	.73097729E+04	.44951265E+03	.25756047E+04	.46163201E+08	.24628695E+03	8
		.12700024E+01	.99996683E+00	.35189583E+01	.0	.73235812E+04	.24163128E+04	.28434415E+01	
678	.60000000E+01	.84850750E+00	.15698147E-02	.72785526E+04	.57682617E+03	.25895479E+04	.46211046E+08	.25762470E+03	8
		.12700000E+01	.10000000E+01	.45312270E+01	.0	.73013736E+04	.24425356E+04	.28195553E+01	
679	.60000000E+01	.10182090E+01	.16215457E-02	.72461355E+04	.70322237E+03	.26031553E+04	.46262581E+08	.26891843E+03	8
		.12700000E+01	.10000000E+01	.55430776E+01	.0	.72801787E+04	.24682727E+04	.27966748E+01	
680	.60000000E+01	.11879105E+01	.16687705E-02	.72130964E+04	.83240348E+03	.26183863E+04	.46354840E+08	.27999823E+03	8
		.12700000E+01	.10000000E+01	.65829099E+01	.0	.72609679E+04	.24972409E+04	.27730698E+01	
681	.60000000E+01	.13576120E+01	.17033431E-02	.71756522E+04	.95856578E+03	.26282518E+04	.46349378E+08	.28795676E+03	8
		.12700000E+01	.10000000E+01	.76088598E+01	.0	.72393946E+04	.25160943E+04	.27544525E+01	
682	.60000000E+01	.15273135E+01	.17391703E-02	.71366592E+04	.10795406E+04	.26446563E+04	.46445876E+08	.29769517E+03	8
		.12700000E+01	.10000000E+01	.86017458E+01	.0	.72178468E+04	.25476013E+04	.27292193E+01	
683	.60000000E+01	.16970150E+01	.17721976E-02	.70949515E+04	.12060148E+04	.26614074E+04	.46552833E+08	.30720344E+03	8
		.12700000E+01	.10000000E+01	.96470487E+01	.0	.71967220E+04	.25799763E+04	.27041038E+01	
684	.60000000E+01	.20364180E+01	.18032088E-02	.70241550E+04	.14621801E+04	.26760063E+04	.46622031E+08	.31601778E+03	8
		.12700000E+01	.10000000E+01	.11759021E+02	.0	.71747282E+04	.26083585E+04	.26811327E+01	
685	.60000000E+01	.23758210E+01	.17991606E-02	.69662178E+04	.17143324E+04	.26729879E+04	.46570145E+08	.31459741E+03	8
		.12700000E+01	.10000000E+01	.13825325E+02	.0	.71740592E+04	.26024774E+04	.26839101E+01	
686	.60000000E+01	.27152240E+01	.17924646E-02	.69005832E+04	.19592530E+04	.26679764E+04	.46486885E+08	.31225240E+03	8
		.12700000E+01	.10000000E+01	.15856607E+02	.0	.71733340E+04	.25927280E+04	.26886797E+01	
687	.60000000E+01	.30546270E+01	.17875394E-02	.68268516E+04	.21999929E+04	.26646264E+04	.46429364E+08	.31061291E+03	8
		.12700000E+01	.10000000E+01	.17461840E+02	.0	.71725778E+04	.25862212E+04	.26917761E+01	
688	.60000000E+01	.33940300E+01	.17863383E-02	.67399056E+04	.24531234E+04	.26643150E+04	.46423659E+08	.31033166E+03	4
		.12700000E+01	.10000000E+01	.19999988E+02	.0	.71724572E+04	.25856167E+04	.26920455E+01	

CP TIME(SEC)= 1.62 WALL TIME(SEC)= 5.92

Fig. 5-7 - Two-Dimensional Two Line Output

ITERATION NUMBER 5 DTIME= .10000000E-03 TIME= .50000000E-03

NODE	X / Z	Y / GAM	RHO / CS	U / PHIX	V / PHIY	W / QVEL	E / T	P / M	IB
53	.25000000E+01	.76429775E+00	.78884609E-01	.35474900E+03	.84662684E+01	.57089049E+01	.88907321E+06	.81017455E+03	9
	.57322332E+00	.14000000E+01	.10000000E+01	.13669570E+01	.92196997E+00	.35489593E+03	.33043906E+06	.52178467E+00	
54	.25000000E+01	.76429776E+00	.76761890E-01	.35521214E+03	.83953366E+01	.14338624E+02	.88030773E+06	.77976936E+03	9
	.85983498E+00	.14000000E+01	.10000000E+01	.13528159E+01	.23115675E+01	.35560053E+03	.32683274E+06	.52569713E+00	
55	.25000000E+01	.76429777E+00	.74811577E-01	.35495310E+03	.82932334E+01	.39425383E+02	.87219781E+06	.75187369E+03	4
	.11464466E+01	.14000000E+01	.10000000E+01	.13302552E+01	.63379834E+01	.35723219E+03	.32335615E+06	.53094068E+00	
56	.25000000E+01	.11464466E+01	.77582784E-01	.35407836E+03	.39328217E+02	.0	.88374620E+06	.79119981E+03	3
	.0	.14000000E+01	.10000000E+01	.63379823E+01	.0	.35625580E+03	.32811484E+06	.52563586E+00	
57	.25000000E+01	.11464466E+01	.77511721E-01	.35407552E+03	.39327904E+02	.53828946E+00	.88344655E+06	.79018720E+03	4
	.28661166E+00	.14000000E+01	.10000000E+01	.63379755E+01	.87104838E-01	.35625335E+03	.32799533E+06	.52572800E+00	
58	.25000000E+01	.11464466E+01	.77185737E-01	.35380789E+03	.39298181E+02	.55968567E+01	.88204220E+06	.78559348E+03	4
	.57322332E+00	.14000000E+01	.10000000E+01	.63371967E+01	.90628145E+00	.35602766E+03	.32746574E+06	.52581961E+00	
59	.25000000E+01	.11464466E+01	.75120751E-01	.35423395E+03	.39345507E+02	.14189466E+02	.87346629E+06	.75634482E+03	4
	.85983499E+00	.14000000E+01	.10000000E+01	.63329462E+01	.22938573E+01	.35669469E+03	.32394030E+06	.52966361E+00	
60	.25000000E+01	.11464466E+01	.73218873E-01	.35393995E+03	.39312855E+02	.39312855E+02	.86540462E+06	.72934169E+03	3
	.11464466E+01	.14000000E+01	.10000000E+01	.62995585E+01	.63379840E+01	.35827991E+03	.32048895E+06	.53487452E+00	
61	.37500000E+01	.0	.81170468E-01	.35463926E+03	.0	.0	.89837475E+06	.84312966E+03	3
	.0	.14000000E+01	.10000000E+01	.0	.0	.35463926E+03	.33419610E+06	.51846818E+00	
62	.37500000E+01	.0	.81101347E-01	.35461673E+03	.0	.44206410E+00	.89808368E+06	.84212617E+03	4
	.32716457E+00	.14000000E+01	.10000000E+01	.0	.71424701E-01	.35461701E+03	.33408283E+06	.51852353E+00	
63	.37500000E+01	.0	.80778037E-01	.35418118E+03	.0	.58122781E+01	.89667034E+06	.83748783E+03	4
	.65432914E+00	.14000000E+01	.10000000E+01	.0	.94016605E+00	.35422887E+03	.33357252E+06	.51835203E+00	
64	.37500000E+01	.0	.78122029E-01	.35345697E+03	.0	.14997645E+02	.88548104E+06	.79923946E+03	4
	.98149371E+00	.14000000E+01	.10000000E+01	.0	.24296779E+01	.35377501E+03	.32916106E+06	.52114540E+00	
65	.37500000E+01	.0	.75640927E-01	.35182408E+03	.0	.51057645E+02	.87490639E+06	.76333329E+03	3
	.13086583E+01	.14000000E+01	.10000000E+01	.0	.82572702E+01	.35550959E+03	.32468514E+06	.52729796E+00	
66	.37500000E+01	.43621943E+00	.81113997E-01	.35447400E+03	.31462328E+01	.43470700E-14	.89810119E+06	.84232132E+03	4
	.0	.14000000E+01	.10000000E+01	.50853131E+00	.70264326E-15	.35448796E+03	.33410813E+06	.51831520E+00	
67	.37500000E+01	.43621943E+00	.81044872E-01	.35445144E+03	.31477797E+01	.44159968E+00	.89780986E+06	.84131792E+03	9
	.32716458E+00	.14000000E+01	.10000000E+01	.50881331E+00	.71382938E-01	.35446569E+03	.33399476E+06	.51837060E+00	
68	.37500000E+01	.43621944E+00	.80721860E-01	.35401589E+03	.31461908E+01	.58133069E+01	.89639723E+06	.83668507E+03	9
	.65432916E+00	.14000000E+01	.10000000E+01	.50911392E+00	.94077139E+00	.35407759E+03	.33348470E+06	.51819887E+00	
69	.37500000E+01	.43621945E+00	.78068753E-01	.35329137E+03	.31610830E+01	.14991195E+02	.88521299E+06	.79848628E+03	9
	.98149373E+00	.14000000E+01	.10000000E+01	.51218080E+00	.24297714E+01	.35362342E+03	.32907529E+06	.52098997E+00	
70	.37500000E+01	.43621946E+00	.75590198E-01	.35166596E+03	.30580703E+01	.51034703E+02	.87464845E+06	.76262792E+03	4
	.13086583E+01	.14000000E+01	.10000000E+01	.49306399E+00	.82572708E+01	.35536297E+03	.32460281E+06	.52714734E+00	
71	.37500000E+01	.87243885E+00	.78966531E-01	.35411882E+03	.86104052E+01	.0	.88914233E+06	.81131785E+03	4
	.0	.14000000E+01	.10000000E+01	.13928734E+01	.0	.35422348E+03	.33056208E+06	.52069909E+00	
72	.37500000E+01	.87243887E+00	.78898295E-01	.35409633E+03	.86090853E+01	.44268531E+00	.88884809E+06	.81033589E+03	9
	.32716459E+00	.14000000E+01	.10000000E+01	.13927473E+01	.71630189E-01	.35420124E+03	.33044753E+06	.52075663E+00	
73	.37500000E+01	.87243888E+00	.78585116E-01	.35366000E+03	.86000174E+01	.58307318E+01	.88745475E+06	.80589247E+03	9
	.65432917E+00	.14000000E+01	.10000000E+01	.13928086E+01	.94454013E+00	.35381260E+03	.32994523E+06	.52058104E+00	
74	.37500000E+01	.87243890E+00	.75995473E-01	.35295853E+03	.84932837E+01	.14863869E+02	.87627337E+06	.76891808E+03	9
	.98149376E+00	.14000000E+01	.10000000E+01	.13772291E+01	.24114279E+01	.35337344E+03	.32553479E+06	.52344516E+00	
75	.37500000E+01	.87243892E+00	.73605994E-01	.35131765E+03	.83295358E+01	.50984159E+02	.86602048E+06	.73480081E+03	4
	.13086583E+01	.14000000E+01	.10000000E+01	.13441199E+01	.82572715E+01	.35509556E+03	.32118962E+06	.52954208E+00	
76	.37500000E+01	.13086583E+01	.76898237E-01	.35159825E+03	.51024872E+02	.0	.88036853E+06	.78132099E+03	3
	.0	.14000000E+01	.10000000E+01	.82572702E+01	.0	.35528139E+03	.32690244E+06	.52516934E+00	
77	.37500000E+01	.13086583E+01	.76834056E-01	.35157631E+03	.51021692E+02	.42918489E+00	.88008918E+06	.78040946E+03	4
	.32716459E+00	.14000000E+01	.10000000E+01	.82572646E+01	.69943479E-01	.35525949E+03	.32679381E+06	.52522423E+00	
78	.37500000E+01	.13086583E+01	.76534512E-01	.35115870E+03	.50961089E+02	.56714277E+01	.87873592E+06	.77620668E+03	4
	.65432919E+00	.14000000E+01	.10000000E+01	.82562093E+01	.92528143E+00	.35488256E+03	.32630604E+06	.52505896E+00	

Fig. 5-8 - Three-Dimensional Two Line Output

ITERATION NUMBER 110 DTIME= .38027585E-05 TIME= .38027585E-04

NODE	RHO	P	M	PHIX	PHIY	IM
160	.28123275E-02	.66749860E+03	.21069119E+01	.20000060E+02	.0	4
176	.27793581E-02	.65767513E+03	.21120307E+01	.20000060E+02	.0	4
192	.27524966E-02	.64902340E+03	.21128896E+01	.20000060E+02	.0	4
208	.27434544E-02	.64497086E+03	.21120939E+01	.20000060E+02	.0	4
224	.27470355E-02	.64441572E+03	.21110085E+01	.20000060E+02	.0	4
240	.27556845E-02	.64544085E+03	.21099083E+01	.20000060E+02	.0	4
256	.27656143E-02	.64704259E+03	.21088766E+01	.20000060E+02	.0	4
272	.27756236E-02	.64885436E+03	.21079632E+01	.20000060E+02	.0	4
288	.27849717E-02	.65070860E+03	.21071187E+01	.20000060E+02	.0	4
304	.27937461E-02	.65264834E+03	.21063374E+01	.20000060E+02	.0	4
320	.28023085E-02	.65470139E+03	.21056295E+01	.20000060E+02	.0	4
336	.28106337E-02	.65680507E+03	.21049371E+01	.20000060E+02	.0	4
352	.28190176E-02	.65899317E+03	.21045638E+01	.20000060E+02	.0	4
368	.28267760E-02	.66084771E+03	.21024000E+01	.20000060E+02	.0	4
384	.28419295E-02	.66527817E+03	.21025591E+01	.19999988E+02	.0	4
400	.28321636E-02	.66200266E+03	.21125290E+01	.19999988E+02	.0	4
416	.27445109E-02	.64977021E+03	.21282121E+01	.19999988E+02	.0	4
432	.27425825E-02	.63275160E+03	.21461152E+01	.19999988E+02	.0	4
448	.26859361E-02	.61402256E+03	.21653301E+01	.19999988E+02	.0	4
464	.26280370E-02	.59478979E+03	.21857656E+01	.19999988E+02	.0	4
480	.25697386E-02	.57539240E+03	.22074606E+01	.19999988E+02	.0	4
496	.25112187E-02	.55591187E+03	.22304870E+01	.19999988E+02	.0	4
512	.24525214E-02	.53636863E+03	.22549380E+01	.19999988E+02	.0	4
528	.23936649E-02	.51676992E+03	.22809237E+01	.19999988E+02	.0	4
544	.23346620E-02	.49712026E+03	.23085719E+01	.19999988E+02	.0	4
560	.22755235E-02	.47742343E+03	.23380311E+01	.19999988E+02	.0	4
576	.22162594E-02	.45768286E+03	.23694743E+01	.19999988E+02	.0	4
592	.21568787E-02	.43790170E+03	.24031045E+01	.19999988E+02	.0	4
608	.20973899E-02	.41808283E+03	.24391612E+01	.19999988E+02	.0	4
624	.20378004E-02	.39822882E+03	.24779289E+01	.19999988E+02	.0	4
640	.19781195E-02	.37834253E+03	.25197510E+01	.19999988E+02	.0	4
656	.19183359E-02	.35842325E+03	.25650149E+01	.19999988E+02	.0	4
672	.18585379E-02	.33848553E+03	.26143441E+01	.19999988E+02	.0	4
688	.17985145E-02	.31849355E+03	.26679564E+01	.19999988E+02	.0	4
673	.13292930E-02	.19032279E+03	.28413418E+01	-.20359783E+01	.0	8
674	.13576715E-02	.21157470E+03	.29194174E+01	-.28670647E+00	.0	8
675	.14281260E-02	.22749858E+03	.28890136E+01	.93390820E+00	.0	8
676	.14926889E-02	.24130736E+03	.28592904E+01	.19997900E+01	.0	8
677	.15552023E-02	.25479722E+03	.28321275E+01	.30365478E+01	.0	8
678	.16144579E-02	.26812411E+03	.28057672E+01	.40690191E+01	.0	8
679	.16684505E-02	.28108345E+03	.27789964E+01	.51121114E+01	.0	8
680	.17131431E-02	.29307126E+03	.27506997E+01	.62228854E+01	.0	8
681	.17405579E-02	.30077765E+03	.27279121E+01	.72792638E+01	.0	8
682	.17737481E-02	.31078916E+03	.27006090E+01	.82626226E+01	.0	8
683	.18030875E-02	.32013306E+03	.26749149E+01	.93487902E+01	.0	8
684	.18298921E-02	.32881438E+03	.26501411E+01	.11570132E+02	.0	8
685	.18230001E-02	.32643171E+03	.26543186E+01	.13708232E+02	.0	8
686	.18110097E-02	.32226516E+03	.26622240E+01	.15756165E+02	.0	8
687	.18015320E-02	.31920502E+03	.26673271E+01	.17764462E+02	.0	8
688	.17985145E-02	.31849355E+03	.26679564E+01	.19999988E+02	.0	4
689	.32230000E-02	.10580000E+03	.24996632E+01	.0	.0	0
690	.32230000E-02	.10580000E+03	.24996632E+01	.0	.0	0

Fig. 5-9 - Special Output Format

P — pressure

IB — node point type (see Section 4)

IOTYPE = 2: This will be called the "two-line" output and consists of the basic flow variables plus auxiliary calculations. Figures 5-7 and 5-8 are examples of a two-line output for two- and three-dimensional flow, respectively. In addition to the basic variables printed out for IOTYPE = 1, the following are given for IOTYPE = 2.

GAM — local value of the ratio of specific heats

CS — mass fraction of gas species number one

PHIX — flow angle in the x-y plane

PHIY — flow angle in the y-z plane

SOS — local sonic velocity

T — temperature

M — Mach number

If a two-gas code is being run, then IOTYPE = 2 will give a printout of the species continuity equation solution.

IOTYPE = 3: This will be called the "simplified output" option and consists of only auxiliary flow variables;

RHO — density

P — pressure

M — Mach number

PHIX — flow angle in x-y plane

PHIY — flow angle in y-z plane

IB — node point type

This option is generally useful for simple cases such as inviscid supersonic flow where only pressure and Mach number are wanted. It can also be used during the debugging stage to reduce the volume of numbers to be viewed. Figure 5-9 is an example of this type of output.

At the top of each new page, the current iteration number and time step are also printed. Following each flowfield iteration is a STAR run time printout. The CP time in seconds and the wall clock time in seconds is given. The values are the elapsed times since the last printout. For example, if output is requested every 10 iterations, and the CP time = 1.62 then each iteration is taking 0.162 sec on STAR.

The units for the output variables are the same as the input set of units. This is set by the user input value of IUNITS (see Section 5.4).

5.5.4 Error Messages

The current INTEG module has a few error diagnostic messages that are printed if the code detects an irregularity. This is not a complete set of possible errors, but have been found to be most common ones which occur. A brief description of these seven error messages follows.

1. TOO MANY OUTPUT NODES REQUESTED, MAXIMUM = NN

   This message indicates that the user has made an error on the node printout card type 12. The maximum number of nodes that can be printed is NN, the total number of nodes in a problem.

2. TIME ITERATION DID NOT CONVERGE

   This message is printed if the solution "blows-up" before ITMAX iterations are reached (see Section 7).

3. UNSTEADY DERIVATIVES GREATER THAN TOLERANCE

   The normalized sum of squares of the unsteady derivatives are monitored by the code. If any of the values goes up by more than 5 orders of magnitude, this message is printed. It usually means that the solution is about to "blow-up." The time step parameters, DTFAC, INCDT are a possible source of the trouble. The NDC coefficients should be checked and possibly adjusted. An error in the initial conditions can often cause this message.

4. INITIAL CONDITIONS INPUT FOR NODE NUMBER GREATER THAN NN

   A common error is the input of initial conditions data for a non-existent node number. If this error message is printed, the user should check the input cards type 10.

5. INVALID IOTYPE

   The value of IOTYPE, on the input card type 2, must be either 1, 2 or 3.

6. INVALID BOUNDARY CONDITION TYPE

   The INTEG module checks the boundary condition flags IB which are input from the GEOM module. All nodes must have IB values between 0 and 9. The user should check the GEOM module input data deck.

7. TWO-GAS CASE REQUESTED WITHOUT VISCOUS OPTION

   If a two-gas problem is being run, the INTEG module requires that the IVISC = 1 option is selected. This is done to ensure that the mixing coefficients for the equations are all consistent. The GIM formulation does not use an "inviscid slip-line" approach for shear flows and hence must use the viscous terms to mix a flow from two different streams. If ISPEC = 1, then the user must also set IVISC = 1.

Other possible error messages may be printed by the STAR system itself. The user should refer to their documentation for explanation of these diagnostics.

6. GRAPHICS MODULE GUIDE (GIMPLT)

6.1 USE OF THE MODULE

The GIMPLT module may be used to generate plots of the finite element grid, velocity vectors, and/or pressure, temperature, density and Mach number contours.

Portions of the flow field may be plotted separately to obtain enlarged views of certain regions, such as corner regions, throat sections, etc. These regions may be plotted to the same scale, if desired, so they can be placed together to form a large plot of the entire flow field.

The description of the region to be plotted including its node/element topology, view angle, etc., is defined by a "Plot Specification." Once these "Plot Specifications" are input, grid plots, velocity vector plots, and/or contour plots may be generated for any, or all, of the flowfield regions described by the set of "Plot Specifications."

Many of the input data parameters to the GIMPLT module have default values which are used if the input parameter field is left blank or set to zero. Most of these default values will be satisfactory in most cases, relieving the user of some data input.

The GIMPLT module may be executed following the INTEG module for generation of velocity vector, contour, and/or grid plots. If grid plots only are desired, the GIMPLT module may be executed following the GEOM module. When checking out a new model, it is recommended that plots of the grid be generated and examined before proceeding with INTEG executions.

The file requirements for the GIMPLT module are illustrated in Fig. 6-1.

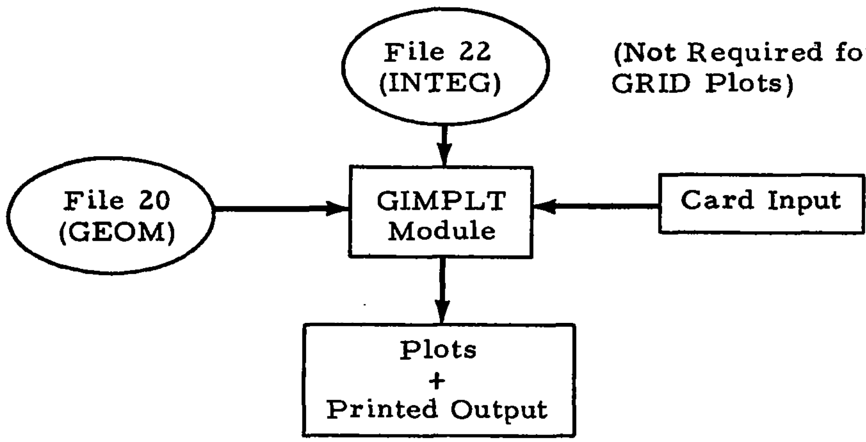


Fig. 6-1 - File Requirements for GIMPLT Module

The GIMPLT module resides on the STAR Access Station (CDC 6400 "Z" machine). Hence, all files needed must be available on the Access Station when executing the GIMPLT module. Since the GEOM and INTEG modules execute on STAR, files 20 and 22 must be transferred back to the Access Station via the TOAS command. See Section 3 of this report and/or the STAR Programming Manual for details.

Following the execution of the GIMPLT module, the system PLOT post-processor must be executed to obtain the actual plots. Several graphics devices are available at Langley. Refer to the Graphic Output System User's Guide for details.

6.2 INPUT CARD SUMMARY

This section presents a summary of the input cards and formats for the GIMPLT module. A detailed description of each input parameter, its options, and default values (where present) is given in the following

Section 6.3. After a user becomes familiar with the GIMPLT input parameters this input card summary can be used to quickly identify each card and its contents.

Three basic formats are used to input the data to the GIMPLT module:

ALPHANUMERIC	Axx
INTEGER	I5
DECIMAL	E10.0

Note that some fields are skipped for some card types as indicated by nX in the format description.

Card Type	Parameter List/Format
1	ITITLE(1), ITITLE(2) (2A40)
2	NX, ITERAD, ITRBLK, KDIM, ISP (5I5)
3	GAMMA, FACTOR, RK, PO, TO, RHOO (6E10.0)
Specs.	
S-1	NPLT, STITLE, IVIEW, ISYM, ITHET1, IAXIS1, ITHET2, IAXIS2, IXTABL, IYTABL, VFAC (I5, 5X, A20, 8I5, E10.0)
S-2	NTYPE, JO, IJUMP, JJUMP, NI, NJ, IPRNT (7I5)
Grid	
G-1	'GRID', IOPT, ICSCLE, NSPECS,(ISPEC(I), I = 1, NSPECS) (A4, 1X, I5, 25X, 2I5, 7I5)
G-2	(ISPEC(I), I = 8, NSPECS) if NSPECS > 7) (45X, 7I5)
VVEC	
V-1	'VVEC', IOPT, NITER, ICSCLE, NSPECS, (ISPEC(I), I = 1, NSPECS) (A4, IX, 2I5, 20X, 2I5, 7I5)

Card Type	Parameter List/Format
VVEC	
V-2	(ISPEC(I), I = 8, NSPECS) (if NSPECS > 7)
	(45X, 7I5)
I-1	(ITER(I), I = 1, NITER)
	(16I5)
Contours	
C-1	ITYPE, IOPT, NITER, NC, ITABLE, INCR, ICSCLE, NSPECS, ISPEC(I), I = 1, NSPECS)
	(A4, 1X, 5I5, 5X, 2I5, 7I5)
C-2	(ISPEC(I), I = 1, NSPECS) (if NSPECS > 7)
	(45X, 7I5)
I-1	(ITER(I), I = 1, NITER)
	(16I5)
L-1	(CVAL(I), I = 1, NC)
	(8E10.0)

6.3 DESCRIPTION OF INPUT DATA

This section presents a description of the input parameters listed in Section 6.2. Each parameter is identified as to its usage in the GIMPLT module with options of each shown.

Example plots are given for a few selected cases. All possible plot combinations cannot be illustrated due to large numbers of possibilities. The user can generate those options of interest for the example problems as a learning tool for understanding the GIMPLT module. Finally, certain restrictions which apply to GIMPLT on the STAR-100 system are given.

CARD TYPE 1 Format (2A40)

Problem Identification

ITITLE(1), ITITLE(2)

This problem identification title appears on contour and velocity vector plot frames as two lines of forty characters each. This title identification should be made consistent with the problem identification for the corresponding INTEG run which generated the flow field to be plotted.

CARD TYPE 2 Format (5I5)

Problem Size and Type Description

NX

The total number of nodal points in the model which is being plotted. NX must be consistent with the GEOM and INTEG runs which generated the grid and flow field.

ITERAD

The iteration number of the first set of flowfield information on the INTEG File 22 which is being used as input to the GIMPLT module. This parameter may be left blank if GRID plots only are being generated.

ITRBLK

The number of iterations per block on File 22. This corresponds to the iteration save increment ITSAVE used in the INTEG run which created File 22.

This parameter may be left blank if GRID plots only are being generated.

KDIM

The dimensionality of the problem.

KDIM = 2 for 2-D planar or axisymmetric

KDIM = 3 for 3-D

ISP

The two-gas flag used in INTEG.

ISP = 0 for single gas
= 1 for two gases

This parameter is needed to define File 22 content and may be left blank if GRID plots only are being generated.

CARD TYPE 3 Format (6E10.0)

Gas Constants and Reference Values

(This card may be left blank if contour plots are not being generated.)

GAMMA

The ratio of specific heats as input in the INTEG module.

FACTOR

This is a unit conversion factor.

Set FACTOR = 32.174 if IUNITS = 1 in INTEG
Set FACTOR = 1.0 if IUNITS = 2 in INTEG.

RK

The gas constant as input in INTEG.

PO, TO, RHOO

These are reference values which are used to normalize pressure, temperature and density, respectively, for contour plots. These may be stagnation values if desired. If contour plots of the unnormalized quantities are desired, PO, TO and RHOO may be set to 1.0.

A set of "Plot Specifications" follows. Each "Plot Specification" defines the node/element content of the plot, its orientation, view angle, etc. A description of the four-node elements which constitute the flowfield region represented by each plot specification is required. These element outlines always appear on GRID plots but normally do not appear on velocity vector or contour plots unless requested by the user.

A set of two-node line connectors is available to describe the outline of the flowfield region and/or any distinguishing features, such as centerlines, flow boundaries, etc. Once this library of "Plot Specification" is established, GRID plots, velocity vector, or contour plots may be generated for any or all of the flowfield region by selecting the proper "Plot Specification." The input data requirements for a single "Plot Specification" follow. The data for several "Plot Specifications" may be stacked. A card containing a -1 in Columns 4 and 5 terminates the "Plot Specification" data library.

CARD TYPE S-1 Format (I5, 5X, A20, 8I5, E10.0)

Plot Specification Labeling and View Angle Options

NPLT No Default

Plot specification identification number. NPLT may be any positive number less than or equal to 100. The plot specifications need not be identified in ascending order. NPLT = -1 terminates the plot specification data.

STITLE No Default

The plot specification title. This title will appear on grid plots identifying the plotted region, e.g., CORNER REGION.

IVIEW Default IVIEW = 3

The view axis which is normal to the plotted plane.

ISYM Default ISYM = 0

A symmetric reflection parameter. If ISYM $\neq$ 0, the plane normal to axis ISYM is a symmetry plane. The symmetric reflection about this plane is plotted. This parameter is normally left blank.

The next four parameters on this card, ITHET1, IAXIS1, ITHET2, IAXIS2 along with the view axis, IVIEW, are used to select a non-standard axis orientation on an oblique view angle.

ITHET1 Default ITHET1 = 0

Rotation in degrees about axis IAXIS1.

IAXIS1 No Default

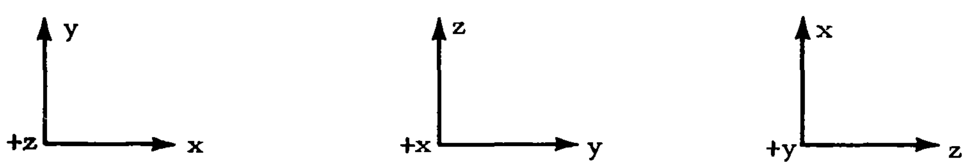
Axis about which first rotation is performed.

ITHET2 Default ITHET2 = 0

Rotation in degrees about axis IAXIS2.

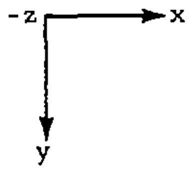
IAXIS2 No Default

Axis about which second rotation is performed. The standard view angle consists of the z-axis (3) directed toward the viewer (out of the paper) with the x and y axes directed to the right and top respectively, as illustrated below.

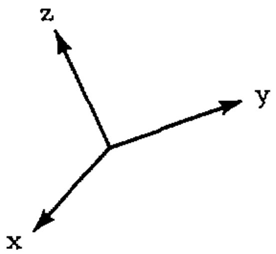


IVIEW = 3 (Standard) IVIEW = 1 IVIEW = 2

If a different axis orientation is desired, or if an oblique view angle is required, rotations may be performed by using the ITHET1, IAXIS1, ITHET2, and IAXIS2 parameters. Following are two examples.



IVIEW = 3
ITHET1 = 180
IAXIS1 = 1



IVIEW = 1
ITHET1 = 30 IAXIS1 = 2
ITHET2 = -30 IAXIS2 = 3

Note that the second rotation (ITHET2, IAXIS2) is performed about the rotated reference frame resulting from the first rotation.

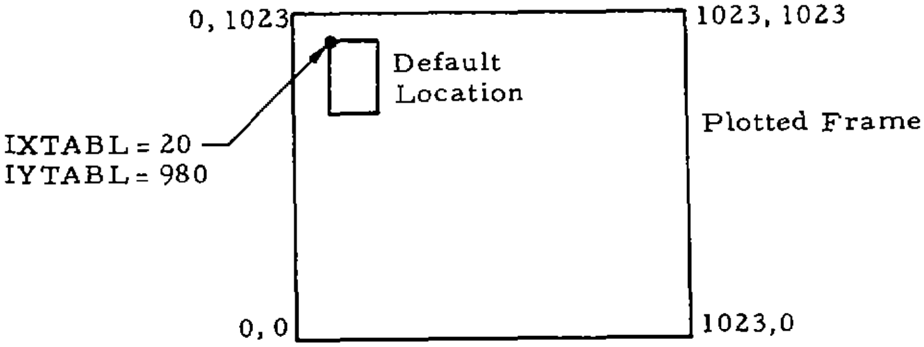
When creating contour plots, an option exists for labeling the contours and constructing a label ID table. (See discussion of contour plots later in this section.) This table is normally placed in the upper left-hand corner of the plot frame. The following parameters may be used to position the ID table elsewhere on the plotted frame.

<u>IXTABL</u> Default IXTABL = 20

X raster value for upper left-hand corner of label ID table.

IYTABL Default IYTABL = 980

Y raster value for upper left-hand corner of label ID table.



VFAC Default VFAC = 1.0

A length factor used to lengthen or shorten the vectors on velocity vector plots. (See discussion of velocity vector plots later in this section.)

Examples

VFAC = 2.0	doubles the length
VFAC = 0.5	halves the length

CARD TYPE S-2 Format (7I5)

Plot Specification Node/Element Content

Card type S-2 is used to specify the node/element content of a plot specification. Any number of cards of this type may be input to describe a single plot specification. The last card for a particular plot specification should be blank except for a -1 in Columns 9 and 10, which terminates the data for that plot specification.

NTYPE Default NTYPE = 0

Element generation control parameter.

NTYPE = 0	a single element is input
= 2	a network of two-node line connectors is generated
= 4	a network of 4-node elements is generated

JO No Default

For NTYPE = 2 or 4, JO is the starting node in the generated network. For NTYPE = 0, JO is the first connected node. JO = -1 terminates the sequence of card type S-2 input for a plot specification.

IJUMP No Default

For NTYPE = 2 or 4, IJUMP is the nodal increment in the i^{th} direction for the element network generation. For NTYPE = 0, this is the second connected node, i.e., node JO connects to node IJUMP.

JJUMP No Default

For NTYPE = 2 or 4, JJUMP is the nodal increment in the j^{th} direction. For NTYPE = 0, JJUMP is the third connecting node, i.e., node JJUMP is connected to node IJUMP.

NI Default NI = 1

For NTYPE = 2 or 4, NI is the number of elements generated in the i^{th} direction. For NTYPE = 0, NI is the fourth connecting node, i.e., node NI is connected to nodes JJUMP and JO.

NJ Default NJ = 1

For NTYPE = 4, NJ is the number of elements generated in the j^{th} direction. If NTYPE = 2, NJ is the number of lines of connecting nodes in the j^{th} direction. For NTYPE = 0, NJ is not used.

IPRNT Default IPRNT = 0

IPRNT = 0	no printout
= 1	nodal connections are printed for each element generated by this card

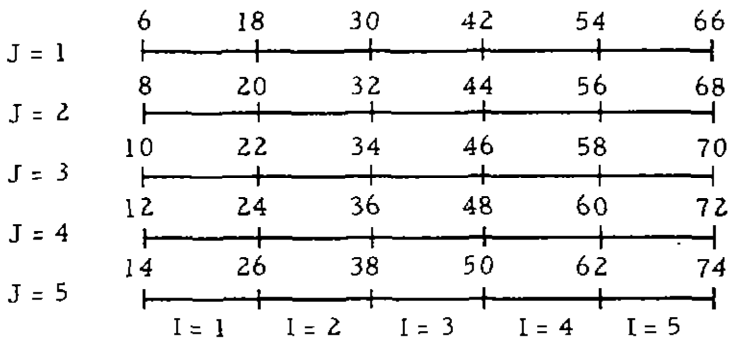
For NTYPE = 2, a network of 2-node line connectors are generated as illustrated below.

Where the 'origin' and 'terminus' of a line are connected to nodes J1 and J2, respectively. The program generated NI*NJ lines, as follows. For I = 1, through NI, and J = 1 through NJ.

$$J1 = JO + (J-1)*JJUMP + (I-1)*IJUMP$$

$$J2 = J1 + IJUMP$$

Example: NTYPE = 2, JO = 6, IJUMP = 12, JJUMP = 2, NI = 5, NJ = 5

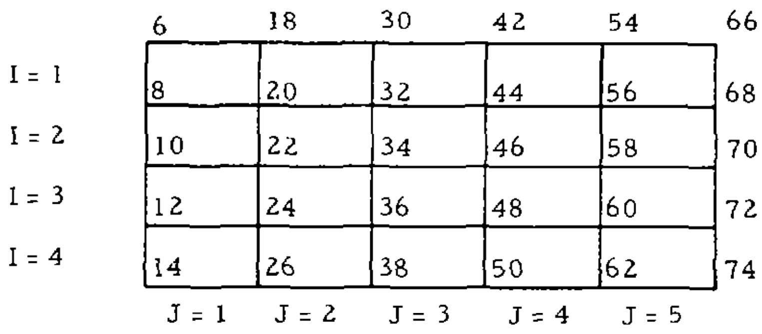


For NTYPE = 4, a network of 4-node elements are generated as illustrated below.

Where J1, J2, J3, and J4 are the nodes connected by the element, the program generates, for I = 1 through NI, and J = 1 through NJ.

$$J1 = JO + (I-1)*IJUMP + (J-1)*JJUMP$$
$$J2 = J1 + IJUMP$$
$$J3 = J2 + JJUMP$$
$$J4 = J3 - IJUMP = J1 + JJUMP$$

Example: NTYPE = 4, JO = 6, IJUMP = 2, JJUMP = 12, NI = 4, NJ = 5



The remaining data describes the content and form of:

- finite element grid plots,
- velocity vector plots, and
- P, T, ρ and Mach number contour plots.

Any number of finite element grid (GRID), velocity vector (VVEC), and/or contour (PRES, TEMP, DENS, MACH) definition decks may be included in any order.

A card containing STOP in Columns 1 through 4 (or a blank card) terminates the entire GIMPLT input data sequence.

CARD TYPE G-1 Format (A4, 1X, I5, 25X, 2I5, 7I5)

Grid Definition Card

GRID   No Default

The first entry on this card consists of the alphameric characters GRID in Columns 1 through 4. This field defines this card as a grid definition card, calling for grid plots to be generated.

IOPT   Default   IOPT = 0

Option parameter for optionally numbering the nodes and/or shading elements on grid plots.

IOPT = 0	no numbering or shading
= 1	nodes will be numbered
= 2	elements will be shaded
= 3	nodes numbered and elements shaded.

ICSCLE   Default   ICSCLE = 0

Constant scale parameter which permits plot specifications to be plotted to the same scale such that portions of a flow field appearing on separate plot specifications may be plotted on separate frames and placed together to form the complete flowfield grid.

ICSCLE = 0	all plot specifications are plotted to the maximum size on each frame
= 1	all plot specifications called for on this GRID card will be plotted to the same scale.

NSPECS   Default   NSPECS = 0

The number of specifications to be plotted as a result of this GRID card. If NSPECS is input as zero, or left blank, all plot specifications will be plotted. If NSPECS > 0, NSPECS values will be read on the remainder of this card and continuing on following card(s) if necessary.

ISPEC(I), I = 1, NSPECS)

List of plot specifications to be plotted as a result of this card. If NSPECS > 7, continue on subsequent card(s) starting in Columns 46 through 50.

CARD TYPE G-2 Format (45X, 7I5)

List of plot specifications is continued on cards of this type if NSPECS > 7.

CARD TYPE V-1 Format (A4, 1X, 2I5, 20X, 2I5, 7I5)

Velocity Vector Card

VVEC No Default

The first entry on this card consists of the alphameric characters VVEC in Columns 1 through 4. This field defines this card as a velocity vector parameter card, calling for velocity vector plots to be generated.

IOPT Default IOPT = 0

Option parameter for optionally superimposing the grid on velocity vector plots.

IOPT = 0 grid will not be superimposed
= 1 grid will be superimposed.

NITER Default NITER = 1

Number of iterations for which velocity vector plots are to be generated.

ICSCLE Default ICSCLE = 0

Constant scale parameter. Refer to GRID card for description.

NSPECS Default NSPECS = 0

The number of specifications to be plotted as a result of this VVEC card. If NSPECS is input as zero, or left blank, all plot specifications will be plotted. If NSPECS > 0, NSPECS values will be read on the remainder of this card and continuing on following card(s) if necessary.

(ISPEC(I), I = 1, NSPECS)

List of plot specifications to be plotted as a result of this card. If NSPECS > 7, continue on subsequent card(s) starting in Columns 46 through 50.

CARD TYPE V-2 Format (45X, 7I5)

List of plot specifications is continued on cards of this type if NSPECS > 7.

CARD TYPE I-1 Format (16I5)

(ITER(I), I = 1, NITER)

List of iteration numbers for which velocity vector plots are desired. If more than 16 iterations are desired, continue on subsequent cards of this type. If plots of initial conditions only are desired, NITER may be set to zero, or left blank, and Card I-1 omitted. Iteration 0 will be plotted automatically.

CARD TYPE C-1 Format (A4, 1X, 5I5, 5X, 2I5, 7I5)

Contour Plot Card

ITYPE — No Default

The first entry on this card identifies the type of contour plots desired. Four types of contour plots are permitted, identified by the following four-character alphameric names.

PRES — Pressure contours (P/PO)
TEMP — Temperature contours (T/TO)
DENS — Density contours (RHO/RHOO)
MACH — Mach number contours

IOPT — Default IOPT = 0

Option parameter for superimposing the grid on contour plots.

IOPT = 0 grid will not be superimposed
= 1 grid will be superimposed.

NITER — Default NITER = 1

Number of iterations for which contour plots are to be generated as a result of this card.

NC Default NC = -10

Number of contour values to be plotted as a result of this card. NC may be input as a positive or negative number. If NC is positive, the actual contour values are read in on card types L-1. If NC is negative, the contour levels are calculated automatically based on the maximum and minimum values for the flowfield variable for which contours are being plotted. The absolute value of NC must be less than or equal to 50.

ITABLE Default ITABLE = 0

This is a contour labeling flag. If ITABLE = 0, the contours are not labeled. If ITABLE ≠ 0, the contours are labeled and a table is constructed showing the actual contour values.

If ITABLE = 1, the table will be placed directly on the contour plot frame at raster locations IX, IY specified on card S-1.

If ITABLE = -1, the table will be placed on a separate frame at raster locations IX and IY. This is sometimes necessary if there is not enough room on the contour frame itself for the table.

INCR Default INCR = 7

This is a contour labeling increment controlling the labeling density on the contours. It is approximately the number of grid points between contour labels.

If the contours are labeled too often, increase INCR. If the contours are not labeled often enough, decrease INCR.

ICSCLE Default ICSCLE = 0

Constant scale parameter. Refer to GRID card for description.

NSPECS Default NSPECS = 0

The number of specifications to be plotted for this set of contours. If NSPECS is input as zero, or left blank, all plot specifications will be plotted. If NSPECS > 0, NSPECS values will be read on the remainder of this card and continuing on following card(s) if necessary.

(ISPEC(I), I = 1, NSPECS)

List of plot specifications to be plotted for this set of contours. If NSPECS > 7, continue on subsequent card(s) starting in Columns 46 through 50.

CARD TYPE C-2 Format (45X, 7I5)

List of plot specifications is continued on cards of this type if NSPECS > 7.

CARD TYPE I-1 Format (16I5)

(ITER(I), I = 1, NITER)

List of iteration numbers for which contour plots of this type are desired. If more than 16 iterations are desired, continue on subsequent cards of this type. If contour plots of initial conditions only are desired NITER may be set to zero or left blank, and Card I-1 omitted. Contour plots for iteration 0 will be generated automatically.

CARD TYPE L-1 Format (8E10.0)

(CVAL(I), I = 1, NC)

List of values for which contours will be plotted. IF NC was input as a negative number, omit this card. If NC is greater than 8, continue on subsequent cards of this type.

6.4 OUTPUT DESCRIPTION

Printed output from the GIMPLT module consists essentially of just an echo printout of the input parameters. When input parameters are left blank the default values will be printed out. Additional printout can be called for on card type S-2 by setting IPRNT = 1. This causes the nodal connections to be printed out for each element generated by that S-2 card. Otherwise, just the generation parameters as input will be printed. In addition, following the echo print of each GRID, velocity vector, and contour plot control parameters, a message is printed indicating the number of plot frames generated for that command.

The main output from the GIMPLT module are the plots. Figure 6-2 is an example of a GRID plot for a 121-node duct case. This figure shows the two types of plots, with and without nodal numbering. Figure 6-3 is examples of solution contours for the 121-node source flow expansion. Shown are velocity vectors and Mach contours at steady state (approximately 200 iterations).

Figure 6-4 is an example of a GRID plot for a converging-diverging nozzle. The model was only for half of the symmetric nozzle, but the GIMPLT module can plot the reflected half as shown. Figure 6-5 is a Mach contour plot for this nozzle problem showing the details of flow that can be resolved. Figure 6-6 is an example of a three-dimensional grid generated for an expanding duct. Many combinations of plot types can be obtained. These figures illustrate the type of capability available.

6.5 RESTRICTIONS

There is a limit to the size problem which can be plotted with the GIMPLT module in its present form. The GIMPLT module resides entirely on the 6400 "Z" machine which does not have the paging capability of the STAR.

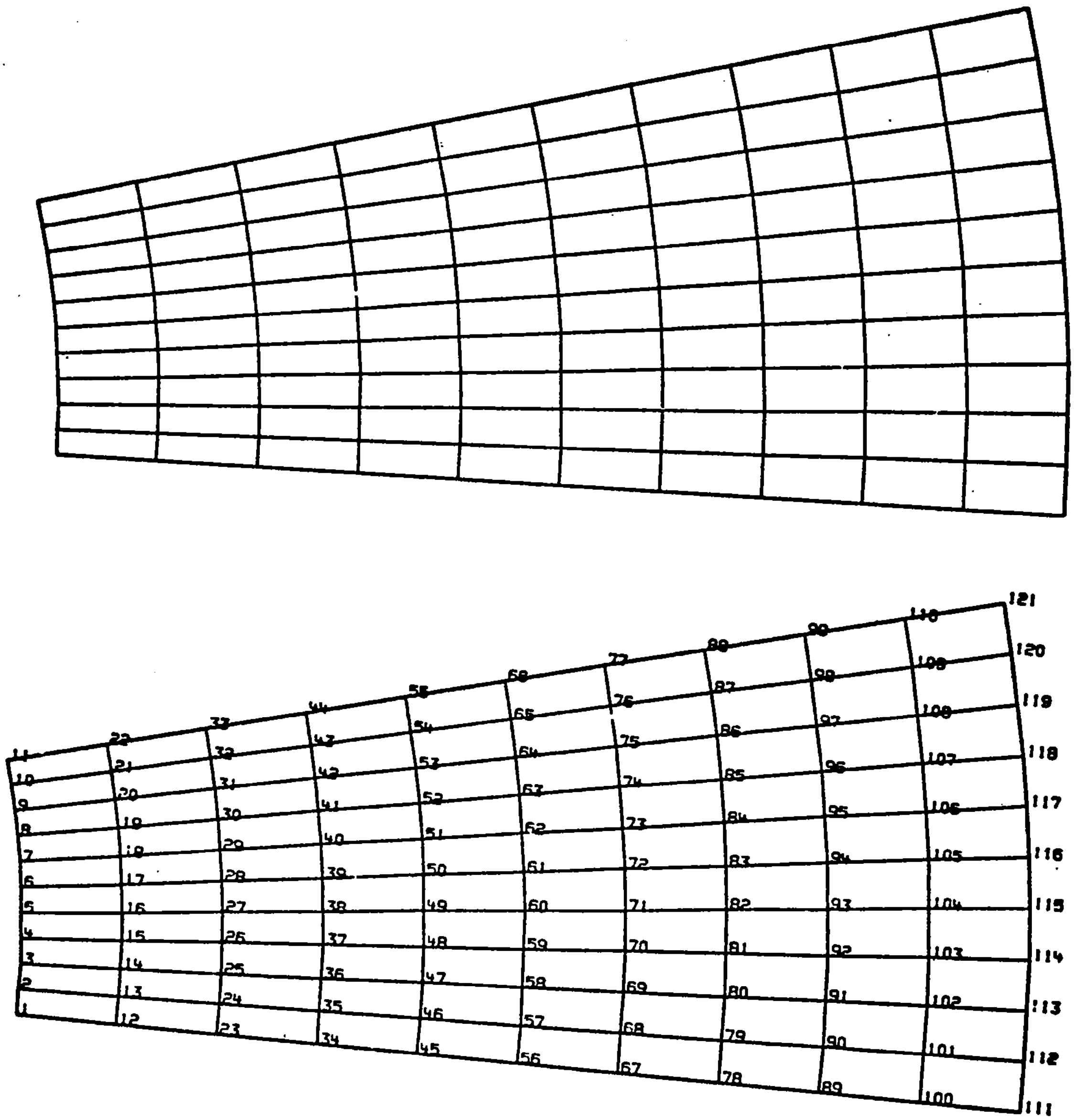
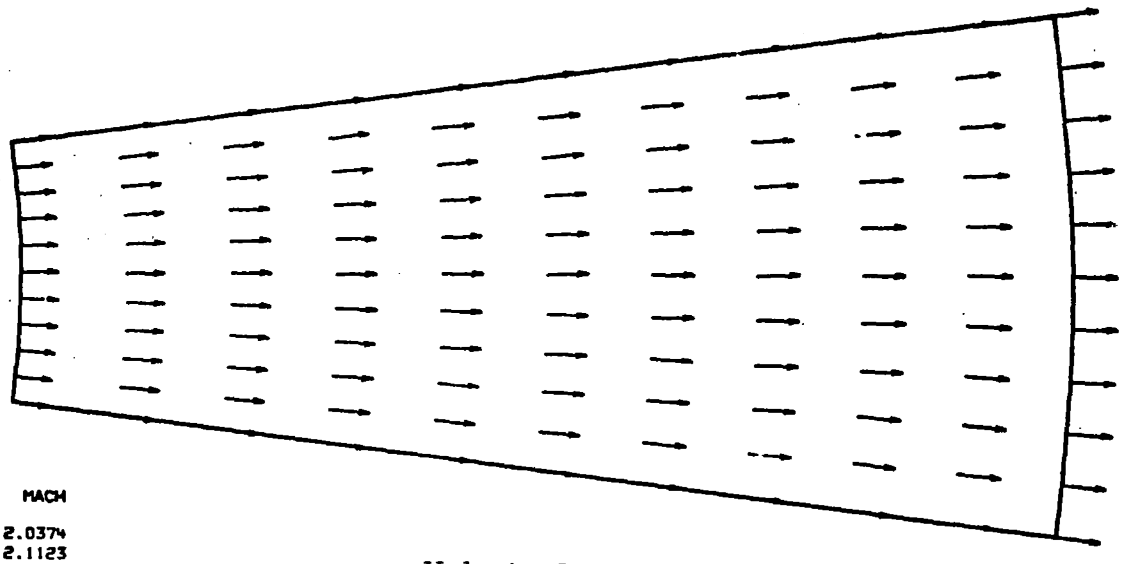
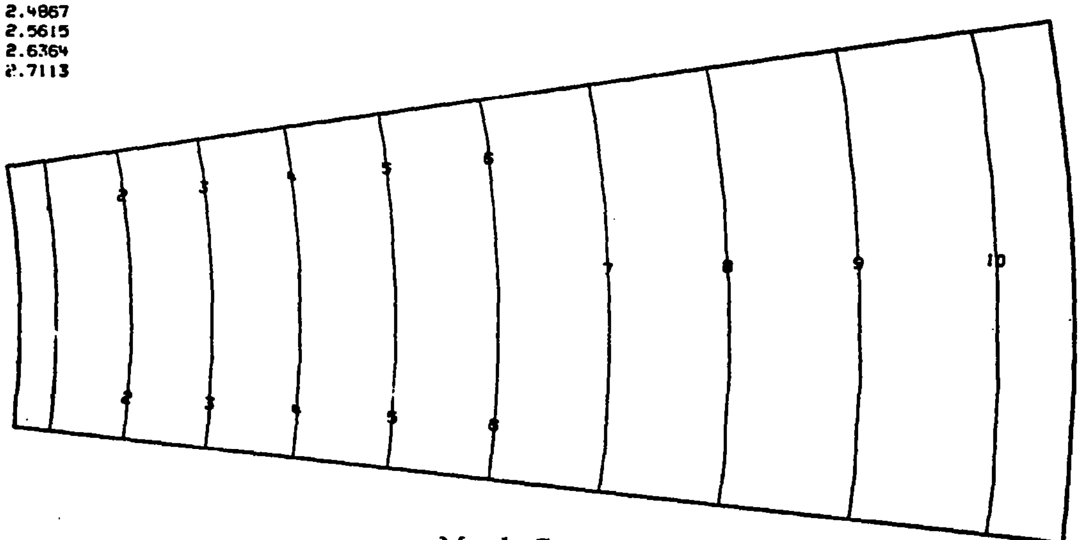


Fig. 6-2 - Example Grid Plots for 121 Node Duct Problem



Velocity Vectors

ID	MACH
1	2.0374
2	2.1123
3	2.1872
4	2.2621
5	2.3369
6	2.4118
7	2.4867
8	2.5615
9	2.6364
10	2.7113



Mach Contours

Fig.6-3 - Example Flow Plots for 121-Node Duct Problem

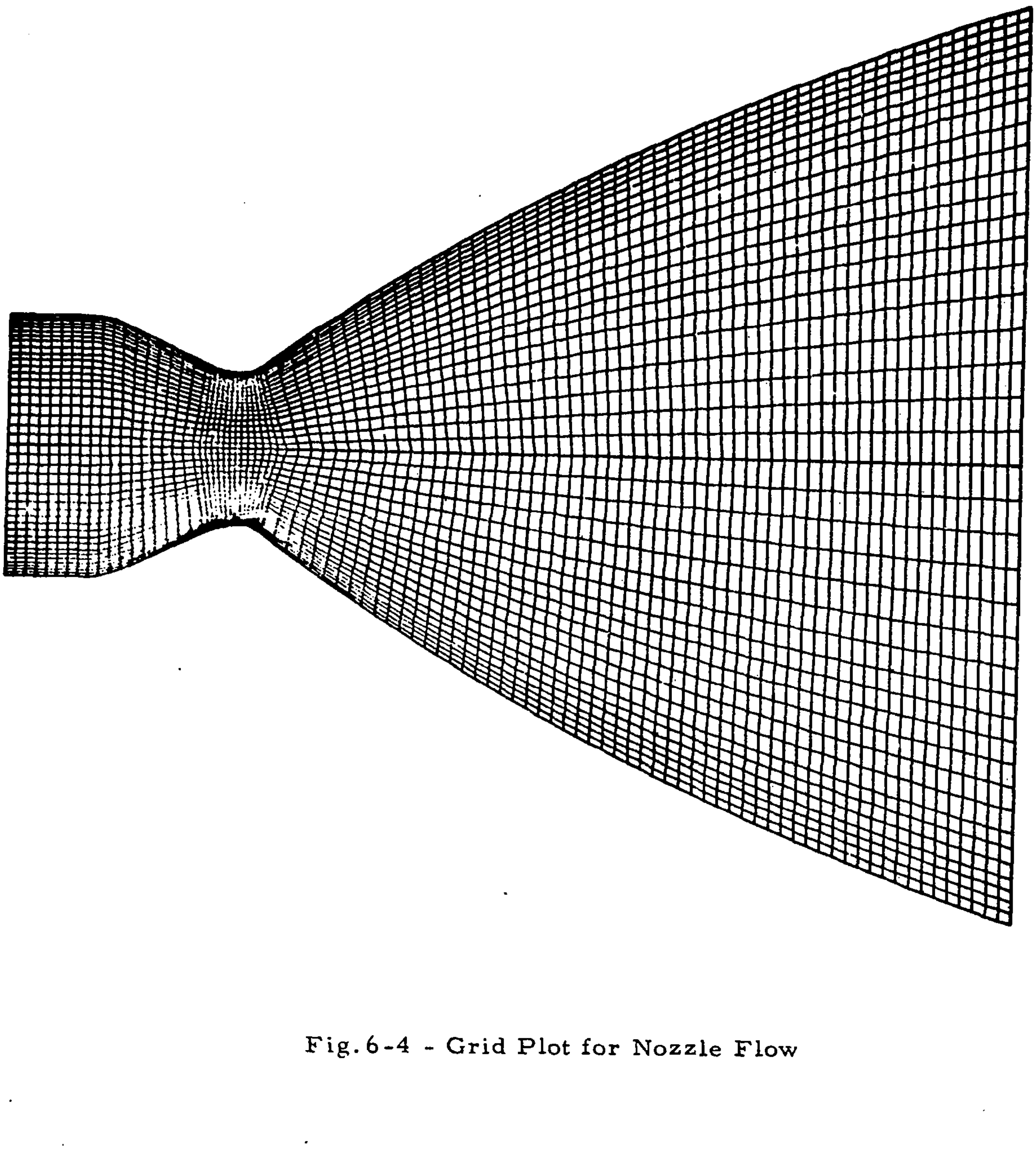


Fig. 6-4 - Grid Plot for Nozzle Flow

ID	MACH
1	.3000
2	.4000
3	.6000
4	.8000
5	1.0000
6	1.2000
7	1.4000
8	1.6000
9	1.8000
10	2.0000
11	2.3000
12	2.4000
13	2.5000
14	2.6000
15	2.7000
16	2.8000
17	2.9000
18	3.0000
19	3.1000
20	3.2000
21	3.3000
22	3.4000
23	3.5000
24	3.6000
25	3.7000

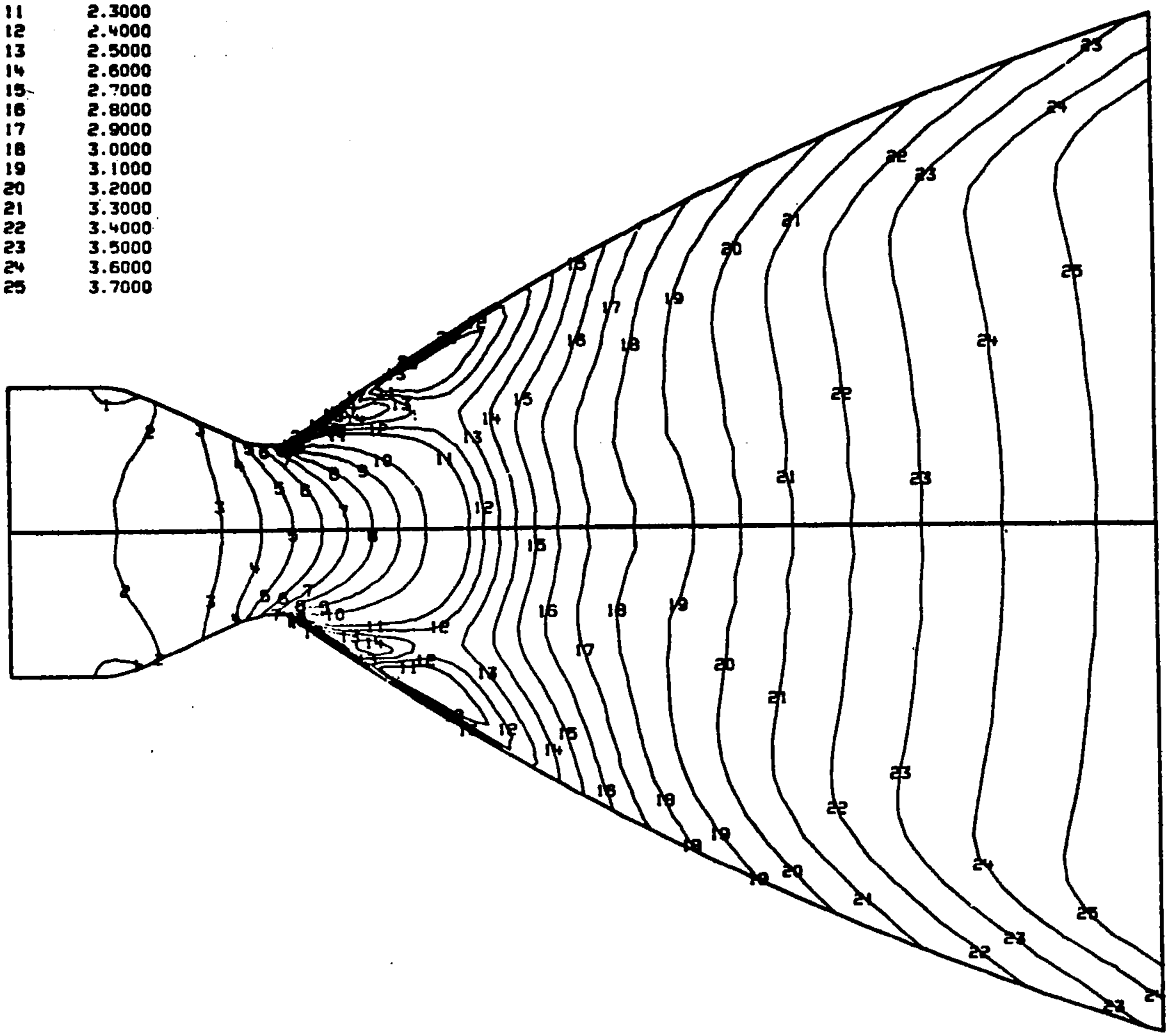


Fig. 6-5 - Example Mach Contours for Inviscid Nozzle Flow

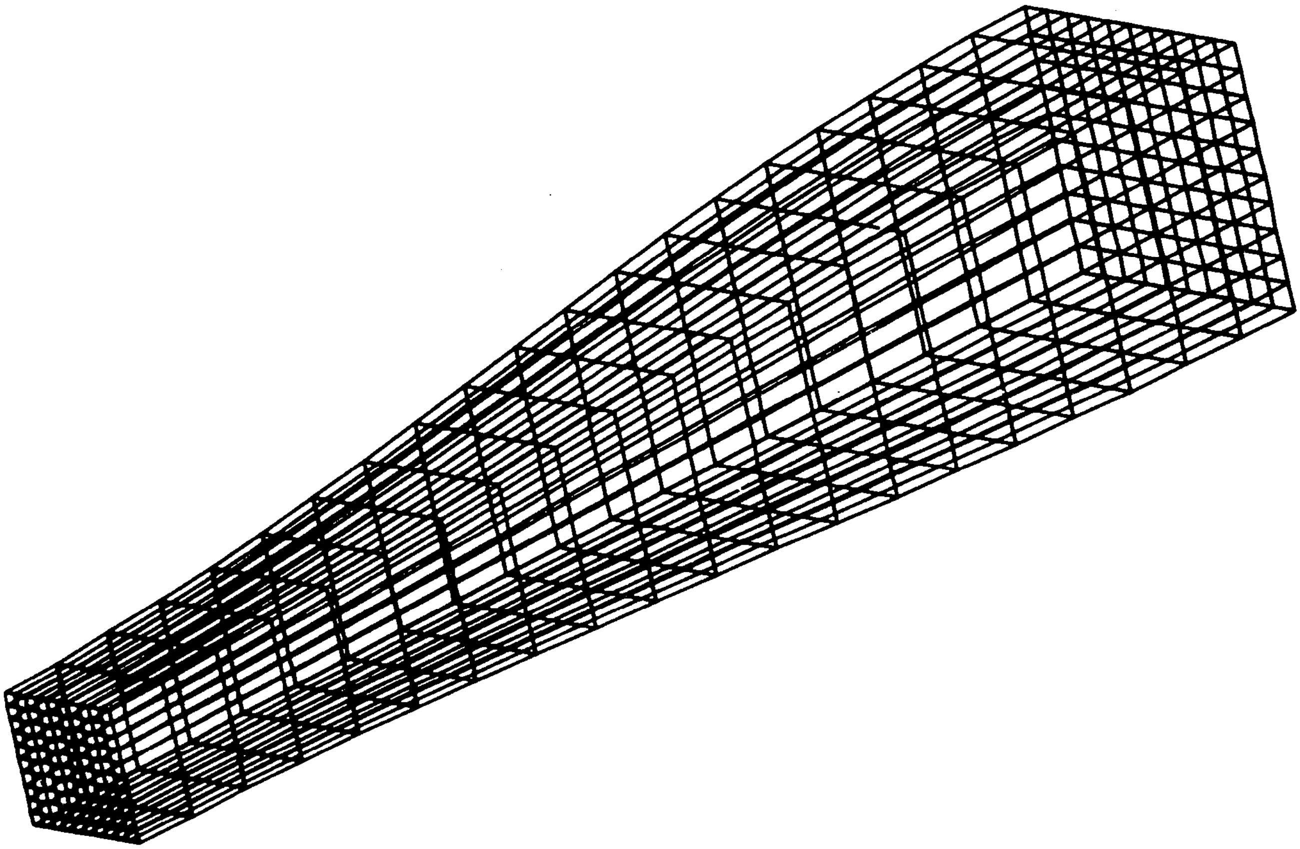


Fig. 6-6 - Three-Dimensional Grid for an Expanding Duct

The total core requirements for plotting including the program storage, system library, and all data arrays are given by the following formula:

$$KFL_{10} = KMAX_{10} + 16000_{10}$$

where

$$KMAX_{10} = 5040_{10} + 8*NX \qquad (NX = \text{number of nodes})$$

KMAX is the dimension of the array "A" in the GIMPLT MAIN program which is normally set to 15000 and must be changed to plot a larger model. KMAX is also a program variable which must be set in the MAIN program.

For KMAX = 15000, the maximum number of nodes in a model to be plotted is

$$NX = \frac{15000 - 5040}{8} = 1245$$

The field length requirement for KMAX = 15000 is

$$\begin{aligned} KFL_{10} &= 15000_{10} + 16000_{10} \\ &= 31000_{10} \\ &= 74430_{8} \end{aligned}$$

The CM parameter on the JOB card must be at least as large as KFL_8. A field length of 200000_8 (65536_{10}) would permit the following.

$$KMAX_{10} = 65536_{10} - 16000_{10} = 49536$$

$$NX = \frac{49536 - 5040}{8} = 5562 \text{ nodes.}$$

7. USING THE GIM/STAR CODE

The GIM/STAR code described herein is operational on the STAR-100 system at NASA-Langley. A number of example cases have been successfully computed by Lockheed-Huntsville through a remote batch terminal. As with any large fluid dynamics code, the GIM-ON-STAR version may experience problems for some flow cases. It is recommended that the user contact the orginators at Lockheed-Huntsville to discuss any such problems which may arise. The following subsections summarize a number of items that should prove useful in running the code on the STAR system.

7.1 SETUP PROCEDURE

A first step, that we have found useful before setting up a problem on GIM, is to have an open discussion of the case with people knowledgeable in that type of flow. Major problem areas can be isolated, the type of flow patterns expected can be identified and modeling techniques discussed. The next step is to set up a geometry model of the flow domain, decide on the number of grid points needed and run the GEOM module. Execution of the GIMPLT module should be made next, if the grid is relatively complex. A plot of the grid, especially for three dimensions, is often times the only way to get it right. We usually require more than one try to get the nodal distribution into the code properly.

The next step is to set up the INTEG module input deck. Selection of appropriate initial conditions is critical for converging a case in a reasonable amount of run time. It is usually a good idea to plot contours of the initial conditions and to check iteration zero before making a long run. Always make a short run (10 iterations or so) and check the unsteady derivative printout, time step and spot check a few critical nodes. We have found that the most efficient way to run a case is to use the "RSTART" option. Run a few hundred iterations and save File 22. Check the flow field, either by printout or plots and restart the case running a few hundred more. As the problem converges to steady state the unsteady derivatives should go down several orders of magnitude and then stop changing.

The final step is to execute the GIMPLT module to give the desired flow field contour maps. This sometimes requires several runs to get the exact pictures that you want. An additional item that we ususally do after a case has converged, is to run INTEG for a "dummy restart" case and simply printout the entire flow field of nodes. This will provide a permanent record for the files of the complete problem.

The following discussion describes some of the procedures that we have found useful in making the code work.

7.2 GRID SELECTION

The choice of mesh sizes for the problems that can be solved with GIM is dictated primarily by the truncation error of the difference equations and, in some cases, by the stability criteria. The only way in which a final mesh size may be chosen with complete confidence is to run the problem with successively smaller mesh sizes until little or no change is observed in the results. Such a procedure may be impractical from the standpoint of computer time required, and in this case an alternative, although somewhat less desirable, solution is to run the problem for three mesh sizes and then extrapolate to zero mesh size. This method will not produce satisfactory results if the mesh sizes chosen are not fairly close to the size required to give a reasonable solution.

No quantitative statements can be made about the choice of mesh sizes for general domains. Smaller mesh sizes are usually required in regions of more rapidly changing velocity and pressure. This means that a fine mesh is required close to the wall in boundary layer problems, as well as close to leading edges. In the region close to a wall, or in the mixing region of streams of different velocities, it is usually desirable to employ a finer mesh size than that needed far out in the free stream where flow gradients are less steep.

In general, the use of different mesh sizes in the same flow field does not significantly change the GIM method of solution. This is true since a special form of the difference equations is used at the point of mesh size change. GIM uses "general interpolation" functions to account for mesh size changes. Whenever possible, the use of a grid with rapidly changing mesh size should be avoided. It is better to stretch the mesh and have uniformily changing mesh size rather than abrupt changes.

7.3 INITIAL CONDITIONS

If only a steady state solution is to be computed, the initial conditions, theoretically, do not effect the results. In practice there are three primary ways that initial conditions effect a GIM code run.

1. Convergence to steady state can be done with much less computer time if the initial conditions are chosen as close as possible to the expected solution.
2. Improper initial conditions, such as violating the ideal gas law, mass conservation, etc., can cause spurious behavior of the relaxation solution.
3. Sharp discontinuities in the initial conditions, such as a "sharp" shock can cause early instabilities to set up and ultimately diverge the solution.

Thus the user should take special precautions to start a problem as best he can. In the GIM/STAR code, a special input option called USERIP is provided which will allow a user to set up initial conditions for special circumstances. We recommend using this option and did so in both the two-dimensional and three-dimensional Scramjet example cases. Another alternative is to start with the sharp discontinuities and use a very small time step until the discontinuity gets washed out and then switch to a realistic step size.

7.4 DIFFERENCE OPERATORS

One of the advantages of the GIM formulation is the flexibility of the finite difference algorithm. We have experimented somewhat with various algorithms and have found that for explicit calculations, the two-step MacCormack scheme works best for a wide range of flows. If the user has any doubt about the choice of scheme, we recommend this MacCormack-type algorithm in this fully elliptic, explicit version of the GIM code.

For certain cases, a choice of two steps in the MacCormack algorithm must be made. For most applications to flows with shock waves, we have found that "forward-forward-(forward)" and "backward-backward-(backward)" operators work best. For supersonic, inviscid flows without shocks, we have had some success with "backward-forward-(forward)" for step 1 and "backward-backward-(backward)" for step 2. This scheme always differences "backward" into the supersonic flow and does not allow the downstream side to cause any influence (as physically it does not).

A simple one-sided, one-step, Euler scheme has also worked well for certain subsonic flows. The truncation error is of first order and generally is unacceptable for flows with any appreciable gradients. It is suggested that the beginning user print out selected nodal analogs in the GEOM module and check them to see that the desired scheme has indeed been input properly.

7.5 CONVERGING A CASE

A definite well formulated and programmable criteria for determining when a Navier-Stokes solution has converged is not known to these authors. Consequently, in the GIM/STAR code we have left some of this burden on the user. We have, however, provided some assistance in making these decisions. The code prints out the "sum of squares of the unsteady derivatives" at each iteration as explained in Section 5.5. The user should monitor these quantities. Theoretically, they should go to zero as actual steady state is reached. Due to finite discretization of a problem, this will of course not be true. As steady state is approached, the "sums square" should go down. Based on our experience, they should go down several orders of magnitude and then stop changing significantly. If the solution is going unstable, these "sums square" will begin to increase in value. The code is currently set to stop the calculation if any of the values go up by five orders of magnitude.

Another technique that we commonly use is to plot contours at selected iterations and overlay the plots on a light table. Significant changes can be detected and the solution iterated for more steps. If the contours exhibit no change for approximately 100 steps or so, we generally stop the calculation. A careful look at the full printout of the flow field can then be made to detect any special area of flow which may not have settled out. Any other technique known by the user can, of course, be applied to the GIM solution as with any finite difference code.

7.6 ESTIMATING RUN TIME

A definite formula for run times of the GIM/STAR code has not been established at this time. The CDC 7600 version has such a formula, but due to the vectorization on STAR, this formula no longer applies. The following tables gives the CP times for the GEOM and INTEG modules for the two example problems which were computed on STAR.

Config.	Nodes	GEOM CP (sec)	INTEG CP (sec for 100 steps)
2-D Scramjet	940	27	10
3-D Scramjet	7904	1009	124

Several notes should be made about this table. For the two-dimensional Scramjet problem, the INTEG module converged in $\sim$ 1000 steps which required about 100 seconds of CP time, compared to 27 sec total for the GEOM module. If a number of parametric cases were to be run, then the GEOM module time would be insignificant compared to the INTEG times. For larger three-dimensional cases, such as the 7904-node Scramjet, the run time would be essentially comparable among the two modules, for one case. Still a 1000 sec job on STAR is not insignificant as with the smaller problems.

The actual CRU time of a run is even more difficult to estimate. For problems which require very few large page faults, the CRU "time" of a GIM/STAR run is essentially all CP time. However, for problems such as the 7094-node Scramjet cases, the large page faulting on STAR does cause the CRU time to be significantly higher than the CP. At this writing, no definitive criteria have been established to relate the run time (cost) with the CP seconds. It depends largely, perhaps nonlinearly, on the way the grid is constructed, and the manner in which the LOAD card is arranged. Our recommendation at this time is to make a short INTEG run on the problem and determine the number of large page faults. Extrapolation can then perhaps yield a run time estimate for the particular case.

7.7 TROUBLESHOOTING

If a GIM/STAR code run "bombs," there are a number of items which should be checked early in the debugging stages. Among these are:

- Check the dynamic dimension inputs to ensure that the code has been properly compiled.
- Check the grid plot for proper connectivity and distribution of points.
- Analyze the nodal analogs to ensure that the finite difference scheme is a "good" one.
- Hand calculate a time step at a selected set of nodes to ensure that violation of the CFL is not being inadvertently done in the INTEG module.

- Increase the NDC coefficients if the INTEG solution appears to be slowly blowing-up. They can be reduced again after the solution has settled down. Nominal values of the NDC coefficients are ~ 0.1 to 0.5. We have used values as high as 1.5 to stabilize a troublesome case.
- Double check the initial conditions for violation of the physics of the problem and for existence of unusually sharp gradients.
- Check that the boundary conditions, flags and values, are correct as the user intended.

During the initial usage of GIM/STAR, version SE-1, problems may occur which are not covered in this manual. If this happens, please call the authors* to discuss a particular set of difficulties.

*(205) 837-1800.

8. EXAMPLE PROBLEMS

Five example data setups are presented in this section to illustrate the input formats described in this report. Full details of each case are not given since the purpose here is to show the user the proper way to input the cards. The input guides (Sections 4, 5 and 6) should be consulted while reading this section.

The five cases consist of:

1. Supersonic Source Flow (2-D)
2. Nozzle Flow (2-D)
3. Scramjet Shear Layer Flow (2-D)
4. Scramjet Shear Layer Flow (3-D)
5. Internal Duct Flow (3-D)

Each of these cases is now described briefly followed by a listing of the input cards for each module of GIM/STAR.

8.1 SUPERSONIC SOURCE FLOW

This simple two-dimensional supersonic source flow case is used to test the code on new installations. It may prove useful for the beginning user of GIM to follow this simple example as a first case. The configuration is shown in Fig. 8-1a and consists of a 15 deg expansion in a planar duct. Source-like circular arcs are used as grids to render the flow effectively one-dimensional. Figure 8-1b shows the input data cards for DYNMAT, GEOM and DYNDIM modules. Figure 8-1c gives the input cards for INTEG and GIMPLT modules.

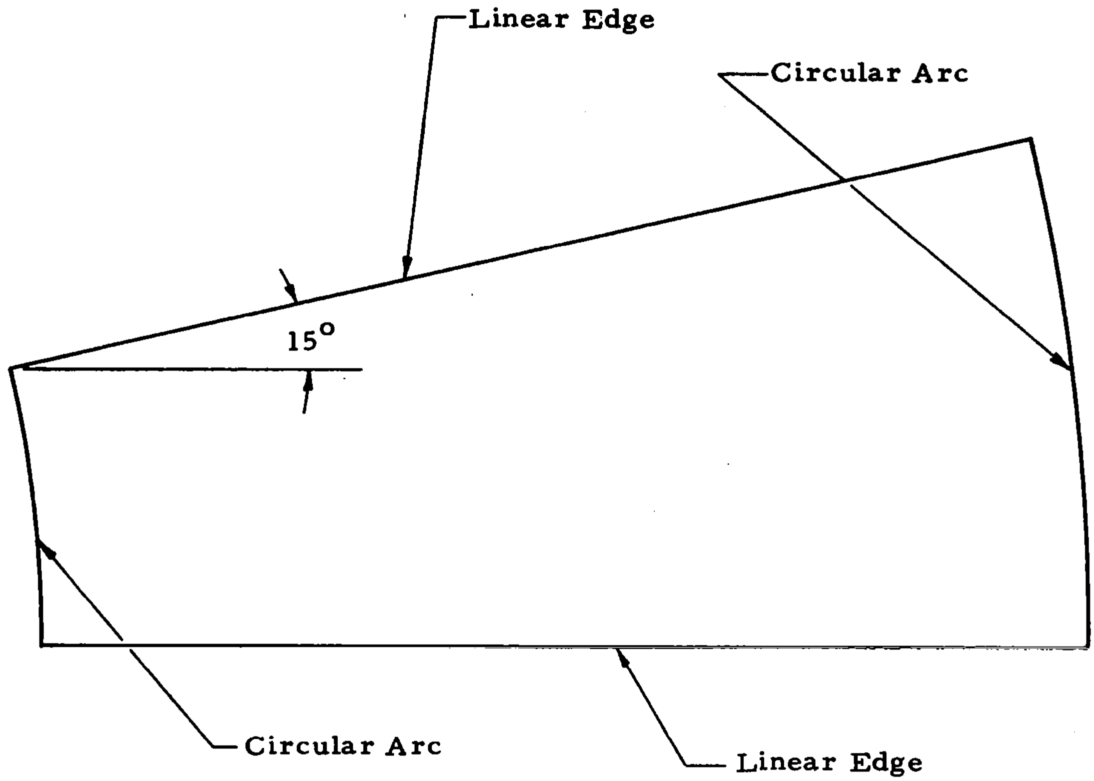


Fig. 8-1a - Configuration for Two-Dimensional Source Flow Check Out Problem

```
****  SUPERSONIC SOURCE FLOW  TWO DIMENSIONAL  PLANAR  ****


      **  DYNMAT INPUT  **

  121     2


      **  GEOM INPUT  **

     2-D SOURCE FLOW CASE
    1     2     2     0     0
    0     0     1
  1.0      1.00000E-8 1.000E-16 1.0000E-8 1.000E-16 1.0000E-8  1.0      1.00000E-8
    1
    1     2     1     2
    4     8     4     0                 1
   11    11     0     0     0
  0.0     0.0          0.0        0.0
  0.0     0.0          0.0        0.0
 0.5        0.0        0.0        0.0        0.0
  1.0     0.0          0.0        0.0        0.0
 0.96593  0.25882      0.0       15.0       0.0
 0.48296  0.12941      0.0       15.0       0.0
   11     1     0     0
    1     1   121
   -1


      **  DYNDIM INPUT  **

  121     2     0     0
```

Fig. 8-1b - Supersonic Source Flow Example Case (DYNMAT, GEOM, DYNDIM)

```
****  SUPERSONIC SOURCE FLOW  TWO DIMENSIONAL  PLANAR  ****


      **  INTEG INPUT  **

 1     2-D SOURCE FLOW CASE
    2    2   200   200   200     0    -3     2     0     0     0     0
  121   11    11    11     1     0     0     0
 0.5000E-2    1.0            1
  0.0       0.0       1.4       0.0       0.0       0.0       0.0       1.0
  0.0       0.0       0.0       0.0
 1.0        1.0       1.0          0   0.0       0.0
    1    1   121     1     0
  1.4       2.0       0.0       0.0       1.0       1.0
   -1
    1    1   121
   -1
-1        END OF RUN


      **  GIMPLT INPUT  **

    2-D SOURCE FLOW CASE
  121    0   200     2     0
  1.4       1.0       1.0       1.0       1.0       1.0
    1      121-NODE SOURCE FLOW    3     0     0     1     0     2     0     0   1.0
    4    1     1    11    10    10     0
    2    1     1   110    10     2     0
    0    1   111     0     0     0     0
    0   11   121     0     0     0     0
        -1
   -1
GRID      0     0     0
GRID      1     0     0
VVEC      0     2     0
    0   200
PRES      0     2   -10     1
    0   200
MACH      0     2   -10     1
    0   200
STOP
```

Fig. 8-1c - Supersonic Source Flow Example Case (INTEG, GIMPLT)

8.2 NOZZLE FLOW CASE

Next in the degree of complexity for internal flow is a transonic/supersonic flow in a converging-diverging nozzle. Figure 8-2a is a sketch of the Space Shuttle Main Engine (SSME) nozzle contour used in the example calculations. The engine has been scaled down here for example only. The throat radius is 5×10^{-3} cm. The equation shown on this figure is the wall contour used in GEOM to generate the nozzle geometry. Figure 8-2b is an input set-up for DYNMAT, GEOM and DYNDIM for this nozzle contour. Figure 8-2c shows the corresponding INTEG module data set-up. The GIMPLT module input is given in Fig. 8-2d to plot a grid and pressure/Mach contours from an INTEG calculation.

8.3 TWO-DIMENSIONAL SCRAMJET SIMULATION

The flow field analyzed involved mixing the exhaust from a two-dimensional Scramjet afterbody nozzle with freestream. The problem configuration and the flow properties of the two flow streams are shown in Fig. 8-3a. The flow streams have different values for the ratio of specific heats γ. Details of this problem are given in Ref. 1. Figure 8-3b shows the input cards for the DYNMAT, GEOM, and DYNDIM modules. This case is initialized in the INTEG module using the USERIP subroutine explained in Section 5. Figure 8-3c is a FORTRAN listing of this subroutine for the 2-D Scramjet problem. The INTEG input cards are given in Fig. 8-3d for the USERIP optional input. The GIMPLT module input cards are given in Fig. 8-3e. Finally, Fig. 8-3f is an example INTEG data deck for the RSTART optional input. It is this type of data deck that can be used to converge a case to steady state.

8.4 THREE-DIMENSIONAL SCRAMJET SIMULATION

A three-dimensional shear layer, resulting from the interaction of a nozzle exhaust stream with the free stream, both beneath and beside the nozzle, was computed using the GIM code. The configuration, shown in Fig. 8-4a consists of a rectangular nozzle suspended below a body or wing.

$$R/R_T = 1.97893 - 0.77040726 * (Z - 0.235910) - 33.525936 + [102.18460 * (Z - 0.235910) + 1123.9917]^{1/2}$$

$R_T = 5 \times 10^{-3}$ cm

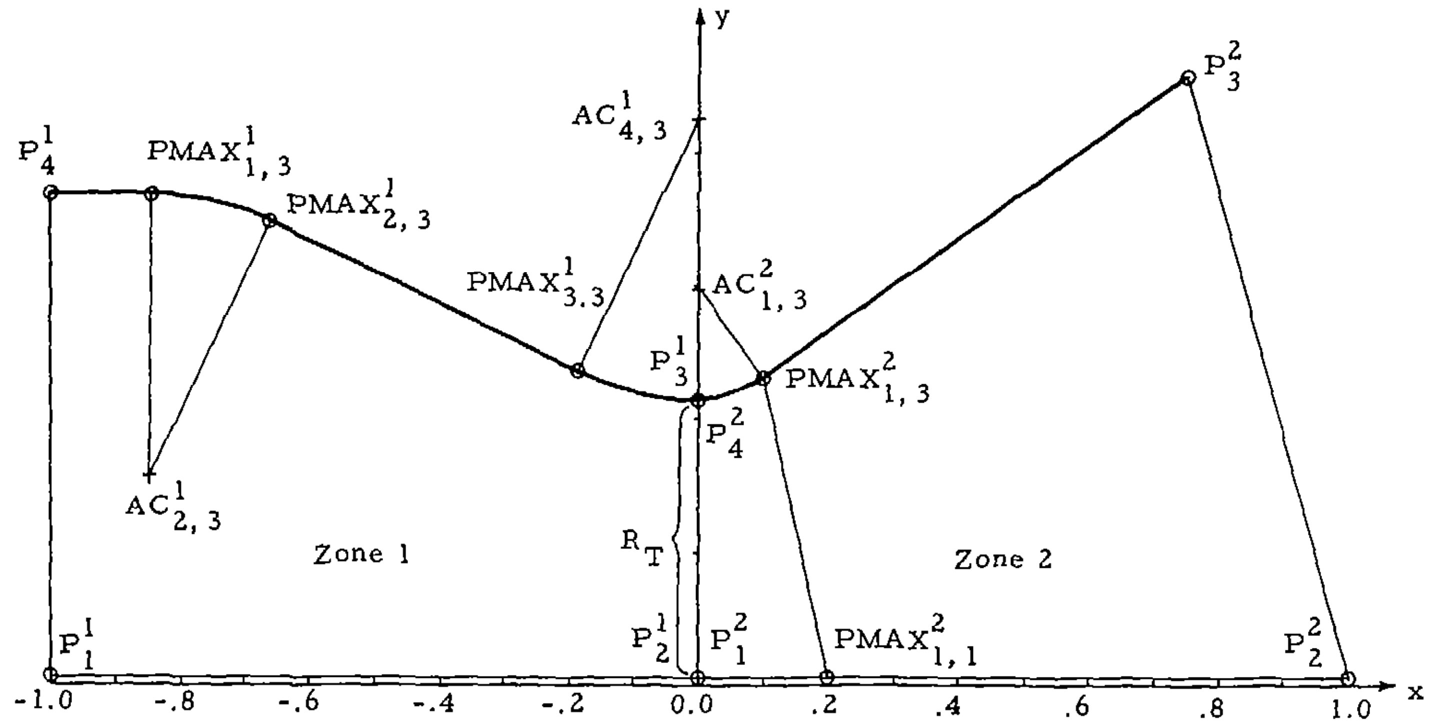


Fig. 8-2a - Nozzle Contour Used in Example Case (SSME Scaled Down)

```
****  FLOW IN A TWO DIMENSIONAL NOZZLE  ****

      **  DYNMAT INPUT

 1932    2

      **  GEOM INPUT  **

  TWO DIMENSIONAL NOZZLE EXAMPLE CASE
    1    2    2    0    0
    0    0    1
1.0          1.00E-08   1.0E-16   1.0E-08   1.0E-16   1.0E-08   1.0       1.0E-08
    2
  111    1 1212    1
    4    9    4    0    0    0    1
   27   21    0    0   21    0
0.0       0.075     0.15      0.225     0.30      0.375     0.44      0.50
0.55      0.60      0.65      0.70      0.75      0.80      0.833     0.867
0.90      0.925     0.95      0.975     1.0
-9.8414E-3 3.6050E-3  0.0     0.0
0.0        1.0000E-2 0.0      0.0
 -1.500E-2  0.0       0.0       0.0
-9.8414E-3  0.0     0.0       0.0       0.0       0.3
 -3.000E-3  0.0     0.0       0.0       0.0       0.70
0.0         0.0     0.0       0.0       0.0
0.0       5.00000E-3  0.0     0.0       0.0
-9.8414E-3 8.6050E-3  0.0     0.0       0.0       .3
-7.6950E-3 8.1210E-3 0.0      -25.417   0.0       0.42
-2.1460E-3 5.4839E-3 0.0      -25.417   0.0       0.70
-1.5000E-2 8.6050E-3  0.0     0.0       0.0
   11    1   27    1
    4    8    4    9    0    0    1
   66   21    0    0   21    0
  0.0      6.96000E-3  0.0     0.0
5.0000E-03.23591    102.1846  1123.9917 -.77040726-32.447655
2.80000E-3  0.0     0.0       0.0       0.0       .09
 5.0000E-2  0.0     0.0       0.0       0.0
 5.0000E-2 3.0463E-2 0.0      18.716    0.0
1.17950E-3 5.3946E-3  0.0     37.0      0.0       .09
   21    1    0    0
    1    1  100
   -1

       **  DYNDIM INPUT  **
 1932    2    0    0
```

Fig. 8-2b - Two-Dimensional Nozzle Example Case (DYNMAT, GEOM, DYNDIM)

```
      **   INTEG INPUT   **

 2  TWO DIMENSIONAL NOZZLE EXAMPLE CASE
    2     2    50    50    50     0    -2     2     0     1     0     0
 1932    92    21    21     1     0     0     0
  .5000E-9   1.0        100
 0.0        0.0        1.5354     0.0        0.0        0.0        0.0        2.02850E+7
  .2        -.67       .2         0.0
1.62450E-4 1.0130E+6 5.0000E-3   20   0.0        0.0
    1     1    21     1     1
   22     1    21     1     1
   43     1    21     1     1
   64     1    21     1     1
   85     1    21     1     1
  106     1    21     1     1
  127     1    21     1     1
  148     1    21     1     1
  169     1    21     1     1
  190     1    21     1     1
  211     1    21     1     1
  232     1    21     1     1
  253     1    21     1     1
  274     1    21     1     1
  295     1    21     1     1
  316     1    21     1     1
  337     1    21     1     1
  358     1    21     1     1
  379     1    21     1     1
  400     1    21     1     1
  421     1    21     1     1
  442     1    21     1     1
  463     1    21     1     1
  484     1    21     1     1
  505     1    21     1     1
  526     1    21     1     1
  547     1    21     1     1
  568     1    21     1     1
  589     1    21     1     1
  610     1    21     1     1
  631     1    21     1     1
  652     1    21     1     1
  673     1    21     1     1
  694     1    21     1     1
  715     1    21     1     1
  736     1    21     1     1
  757     1    21     1     1
  778     1    21     1     1
  799     1    21     1     1
  820     1    21     1     1
  841     1    21     1     1
  862     1    21     1     1
  883     1    21     1     1
  904     1    21     1     1
  925     1    21     1     1
  946     1    21     1     1
  967     1    21     1     1
```

Fig. 8-2c - Two-Dimensional Nozzle Example Case (INTEG)

988	1	21	1	1
1009	1	21	1	1
1030	1	21	1	1
1051	1	21	1	1
1072	1	21	1	1
1093	1	21	1	1
1114	1	21	1	1
1135	1	21	1	1
1156	1	21	1	1
1177	1	21	1	1
1198	1	21	1	1
1219	1	21	1	1
1240	1	21	1	1
1261	1	21	1	1
1282	1	21	1	1
1303	1	21	1	1
1324	1	21	1	1
1345	1	21	1	1
1366	1	21	1	1
1387	1	21	1	1
1408	1	21	1	1
1429	1	21	1	1
1450	1	21	1	1
1471	1	21	1	1
1492	1	21	1	1
1513	1	21	1	1
1534	1	21	1	1
1555	1	21	1	1
1576	1	21	1	1
1597	1	21	1	1
1618	1	21	1	1
1639	1	21	1	1
1660	1	21	1	1
1681	1	21	1	1
1702	1	21	1	1
1723	1	21	1	1
1744	1	21	1	1
1765	1	21	1	1
1786	1	21	1	1
1807	1	21	1	1
1828	1	21	1	1
1849	1	21	1	1
1870	1	21	1	1
1891	1	21	1	1
1912	1	21	1	1
-1				
1	1	1932		
-1				
-2	END OF RUN			

Fig. 8-2c (Concluded)

```
      **   GIMPLT INPUT   **

  TWO DIMENSIONAL NOZZLE EXAMPLE CASE
 1932     0    50     2     0
     1.535         1.0 2.0785E+7 1.0130E+6 1.0        1.0
    1      THROAT REGION                                                      .50
    4     1     1    21    20    45
    2     1    21    20    45     2
          1    21
        -1
    2      AFT END REGION                                                     .50
    4   946     1    21    20    46
    2   946    21    20    46     2
      1912 1932
        -1
    3       COMPLETE NOZZLE                 2                                 0.30
    4     1     1    21    20    91
    2     1    21    20    91     2
          1    21
      1912 1932
        -1
   -1
GRID      0                                 1     2     1     2
GRID      0                                 0     1     3
GRID
PRES      0     1    24    -1    17         0     1     3
   50
 .0115     0.0125     0.015     0.0175     0.02     0.025     0.03     0.035
 .04        .045       .05       .06        .07     0.08       .1       .2
  0.3       0.4       0.5       0.6        0.7      0.8       .85      .90
MACH      0     1    26    -1    17         0     1     3
   50
  .3        .4         .6        .8        1.0       1.2       1.4      1.6
 1.8       2.0        2.3       2.4        2.5       2.6       2.7      2.8
 2.9       3.0        3.1       3.2        3.3       3.4       3.5      3.6
 3.7       3.8
VVEC      0     1                           0     1     3
   50
VVEC      0     1                           1     2     1     2
   50
MACH      1     1     0     1    17         0     1     3
   50
PRES      1     1     0     1    17         0     1     3
   50
STOP
```

Fig. 8-2d - Two-Dimensional Nozzle Example Case (GIMPLT)

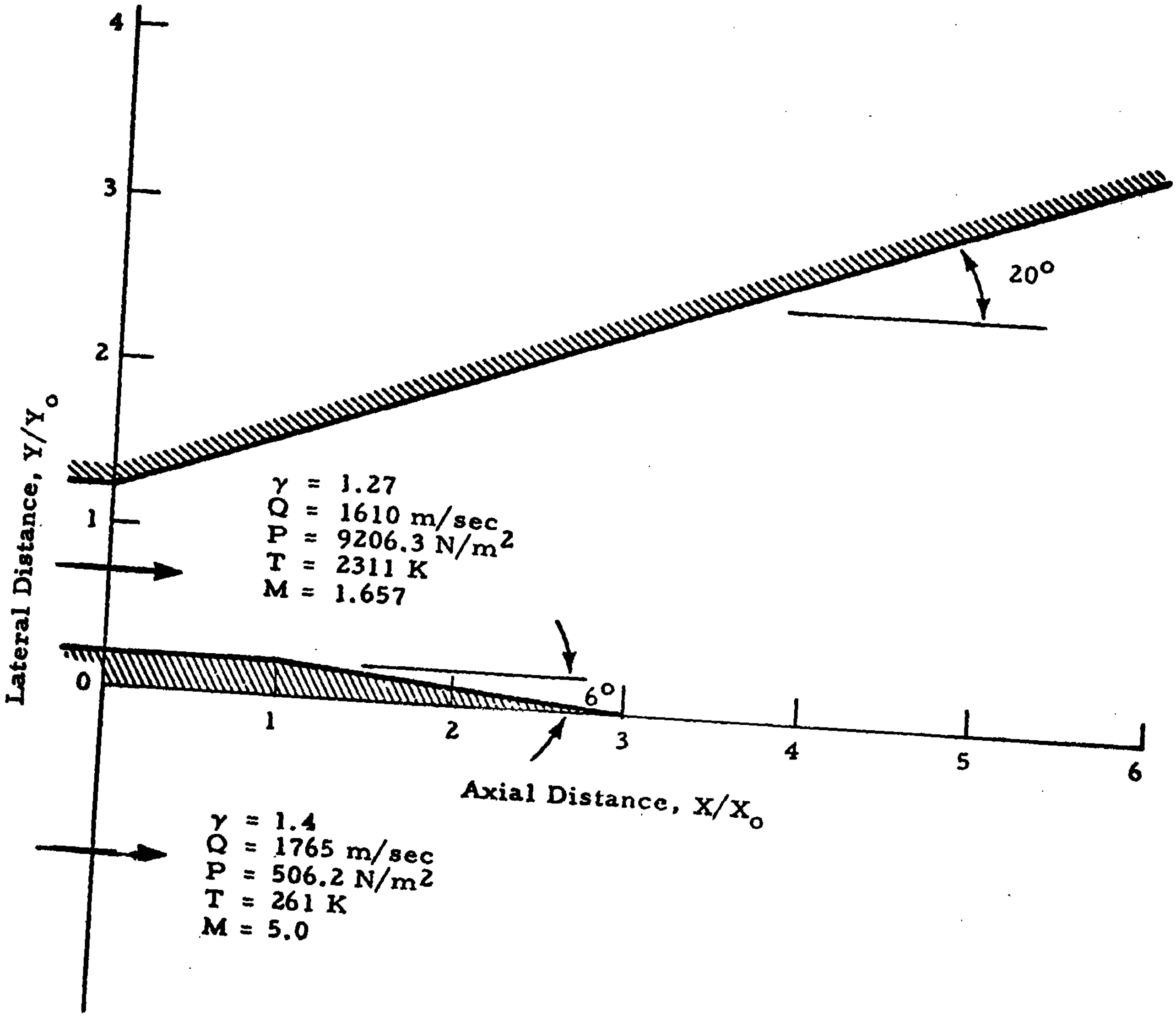


Fig. 8-3a - Two-Dimensional Shear Flow Configuration

** DYNMAT INPUT **

```
940     2
```

** GEOM INPUT **

```
  TWO DIMENSIONAL SCRAMJET CASE
    2     2     2     0     1
    0     0     1
1.0           1.0E-08    1.0E-16    1.0E-08    1.0E-16    1.0E-08    1.0         1.0E-08
    2
  111     1     1    11
   24     9     4     0     0     0     1
   23    16     0     0    16     0
0.0         0.05        0.10        0.15        0.20        0.25        0.30        0.35
0.40        0.45        0.50        0.60        0.70        0.80        0.90        1.0
0.2         0.21021     0.0         0.0         0.0
1.0         0.21021     0.0         0.0         0.0         0.363636
1.2         0.18918     0.0         -6.0        0.0         0.454545
3.0         0.0         0.0         -6.0        0.0
3.0         2.30212     0.0         20.0        0.0
0.2         1.283       0.0         20.0        0.0
0.2         1.0         0.0         0.0         0.0         0.4
    1     1     1     1
   29     8     4     9     0     0     1
   21    16     0     0    16     0
6.0         0.0         0.0         0.0         0.0
6.0         3.39403     0.0         20.0        0.0
    1
    1     1     1     1
    8     8    19     0     0     0     1
   21    13     0     0    13     0
0.0         0.15        0.30        0.4         0.5         0.565       0.625       0.6875
0.75        0.8125      0.875       0.9375      1.0
3.0         -2.0        0.0         0.0         0.0
6.0         -2.0        0.0         0.0         0.0
6.0         0.0         0.0         0.0         0.0
3.0         0.0         0.0         0.0         0.0
   16     1     0     1
    1     1   100
   -1
```

** DYNDIM INPUT **

```
940     2     1   318
```

Fig. 8-3b - Two-Dimensional Scramjet Case (DYNMAT, GEOM, DYNDIM)

```
****  UPDATE MOD TO USE 'USERIP' SUBROUTINE  ****
  **  TWO DIMENSIONAL SCRAMJET CASE **

*IDENT  USERIP
*D  PAGE2.142
C
C      **  USER ROUTINE TO INPUT 2-D SCRAMJET CASE   **
C
      DIMENSION AP(10,4),JMAX(4),AETA(10,4),DAT(4,10),PE(4),PP(4)
      READ(5,580) (JMAX(J),J=1,4),JNUM
  580 FORMAT(5I5)
      DO 550 J=1,4
      JMX=JMAX(J)
      READ(5,590) (AP(JJ,J),JJ=1,JMX)
      READ(5,590) (AETA(JJ,J),JJ=1,JMX)
  550 CONTINUE
  590 FORMAT(8E10.4)
      DO 560 J=1,JNUM
      READ(5,595) (DAT(JJ,J),JJ=1,4)
  560 CONTINUE
  595 FORMAT(4E10.4)
      XLINE=0.0
      PP(1)=AP(1,1)
      PP(2)=AP(1,4)
      PP(3)=AP(JMAX(4),4)
      PP(4)=AP(JMAX(3),3)
      DO 800 I=1,NTOT
      WI=0.0
      ITAN=0
      IF(I.LT.689) GO TO 600
C      **  FREE STREAM CONDITIONS   **
      RI=0.003223
      UI=5791.0
      VI=0.0
      PI=105.8
      CSI=0.0
      GO TO 700
  600 CONTINUE
      II=I/16
      II=I-II*16
      IF(II.EQ.1) XLINE=XLINE+1.0
      IF(II.EQ.0) II=16
      ETA=(XLINE-1.0)/42.0
      YI=II
      EPS=(YI-1.0)/15.0
      CHI=ETA
      DO 620 J=1,4
      IF(J.GT.2) CHI=EPS
      IF(CHI.GT.1.0) CHI=1.0
      JMX=JMAX(J)
      DO 610 L=2,JMX
      L2=L
      IF(CHI.LE.AETA(L,J)) GO TO 615
  610 CONTINUE
  615 CONTINUE
      L1=L2-1
      PSI=(CHI-AETA(L1,J))/(AETA(L2,J)-AETA(L1,J))
      PE(J)=AP(L1,J)+PSI*(AP(L2,J)-AP(L1,J))
```

Fig. 8-3c - Two-Dimensional Scramjet Case (INTEG Input by USERIP)

```
  620 CONTINUE
      EPS1=1.0-EPS
      PI=(1.0-ETA)*(PE(3)-EPS1*PP(1)-EPS*PP(4))+ETA*(PE(4)-EPS1*PP(2)
     $-EPS*PP(3))+EPS1*PE(1)+EPS*PE(2)
      DO 650 J=2,JNUM
      JJ=J
      IF(PI.LE.DAT(4,J)) GO TO 660
  650 CONTINUE
  660 CONTINUE
      J1=JJ-1
      RRR=(PI-DAT(4,J1))/(DAT(4,JJ)-DAT(4,J1))
      RI=DAT(1,J1)+RRR*(DAT(1,JJ)-DAT(1,J1))
      UI=DAT(2,J1)+RRR*(DAT(2,JJ)-DAT(2,J1))
      VI=DAT(3,J1)+RRR*(DAT(3,JJ)-DAT(3,J1))
      QI=SQRT(UI**2+VI**2)
      CSI=1.0
      IF(XLINE.GT.1.0) ITAN=1
      IF(EPS.GE.1.0) ITAN=1
      IF(EPS.LE.0.0) ITAN=1
  700 CONTINUE
C     **  CHECK FOR TANGENCY  **
      IF(ITAN .EQ. 0) GO TO 15
      THXY=THETA(I)/57.29578
      THXZ=0.0
      CALL TANGNT(QI,THXY,THXZ,UI,VI,WI)
 15   CONTINUE
C     **  STORE INITIAL CONDITIONS  **
      RHO(I)=RI
      UVEL(I)=UI
      VVEL(I)=VI
      P(I)=PI*FACTOR
      QVEL=SQRT(UI**2+VI**2)
      IF(ISPEC .EQ. 0) GO TO 18
      CS(I)=CSI
      RLOC=RGAS1*CS(I)+RGAS2*(1.0-CS(I))
      CVM(I)=CV1*CS(I)+CV2*(1.0-CS(I))
      GAML1(I)=RLOC/CVM(I)
      GAM1=GAML1(I)
 18   CONTINUE
      ENER(I)=P(I)/(GAM1*RHO(I)) + 0.5*QVEL**2
 800  CONTINUE
C     **  RETURN TO REGULAR OPERATION  **
      IRTN=1
```

Fig. 8-3c (Concluded)

```
        **   INTEG INPUT USING USERIP   **

  3  TWO DIMENSIONAL SCRAMJET SIMULATION   *TWO GAS*   *SHARP CORNER*
     2    2 1000 1000   200      0    -2     1     0     1     0     1
   940    43    16    16     1     1     0     1
   .2000E-5    1.0        1000
  1.0000E-3    0.0        1.27       1.4        23.0        28.0        -1.0         0.0
   .5        -.67         .5         0.0
   129     2   145   146     0     0     0 -6.0
   129-9.8544914 1.2047769
   130-.02186598-.01242926
   1455.8312419 -10.918867
   1461.0431156 9.7265189
   129.021809047.012247726
   130-9.7740653 1.1653537
   145-.9543836 -9.7370468
   14610.70664   8.5594455
  1.0         1.0         1.0              0   0.0        0.0
     1     1   940     0     3
     4     3     9     3    10
1923.0      1923.0      300.0       200.0
0.0         0.19        0.5238      1.0
707.55      707.55      300.0
0.0         0.5476      1.0
1923.0      1923.0      1746.0      1557.5      1327.7      1235.2      1038.0      860.7
707.55
0.0         0.4667      0.5333      0.7063      0.7891      0.8128      0.8667      0.9191
1.0
200.0       300.0       300.0
0.0         0.733       1.0
0.001302    7309.0      1227.1      200.0
0.001769    7126.4      749.0       300.0
0.002984    6111.3      2224.2      707.55
0.003870    5994.0      1872.8      860.7
0.004656    6020.8      1437.0      1038.0
0.005432    5950.0      1003.9      1235.2
0.005773    5884.0      825.0       1327.7
0.006575    5671.0      445.6       1557.5
0.007195    5468.5      180.2       1746.0
0.007771    5269.0      0.0         1923.0
    -1
     1     1   940
    -1
-3          END OF RUN
```

Fig. 8-3d - Two-Dimensional Scramjet Case (INTEG)

```
**   GIMPLT INPUT   **

TWO DIMENSIONAL SCRAMJET SIMULATION
940    0  200    2    0
   1.27    32.174        1895. 1.0         1.0         1.0
   1       SCRAMJET REGION
   4    1     1    16    15    22
       -1
   2       SCRAMJET REGION
   4  353     1    16    15    20
       -1
   3       SCRAMJET REGION
   4  689     1    12    11    20
      700   712   369   353
      712   724   385   369
      724   736   401   385
      736   748   417   401
      748   760   433   417
      760   772   449   433
      772   784   465   449
      784   796   481   465
      796   808   497   481
      808   820   513   497
      820   832   529   513
      832   844   545   529
      844   856   561   545
      856   868   577   561
      868   880   593   577
      880   892   609   593
      892   904   625   609
      904   916   641   625
      916   928   657   641
      928   940   673   657
       -1
   4       SCRAMJET REGION
   4    1     1    16    15    42
   4  689     1    12    11    20
      700   712   369   353
      712   724   385   369
      724   736   401   385
      736   748   417   401
      748   760   433   417
      760   772   449   433
      772   784   465   449
      784   796   481   465
      796   808   497   481
      808   820   513   497
      820   832   529   513
      832   844   545   529
      844   856   561   545
      856   868   577   561
      868   880   593   577
```

Fig. 8-3e - Two-Dimensional Scramjet Case (GIMPLT)

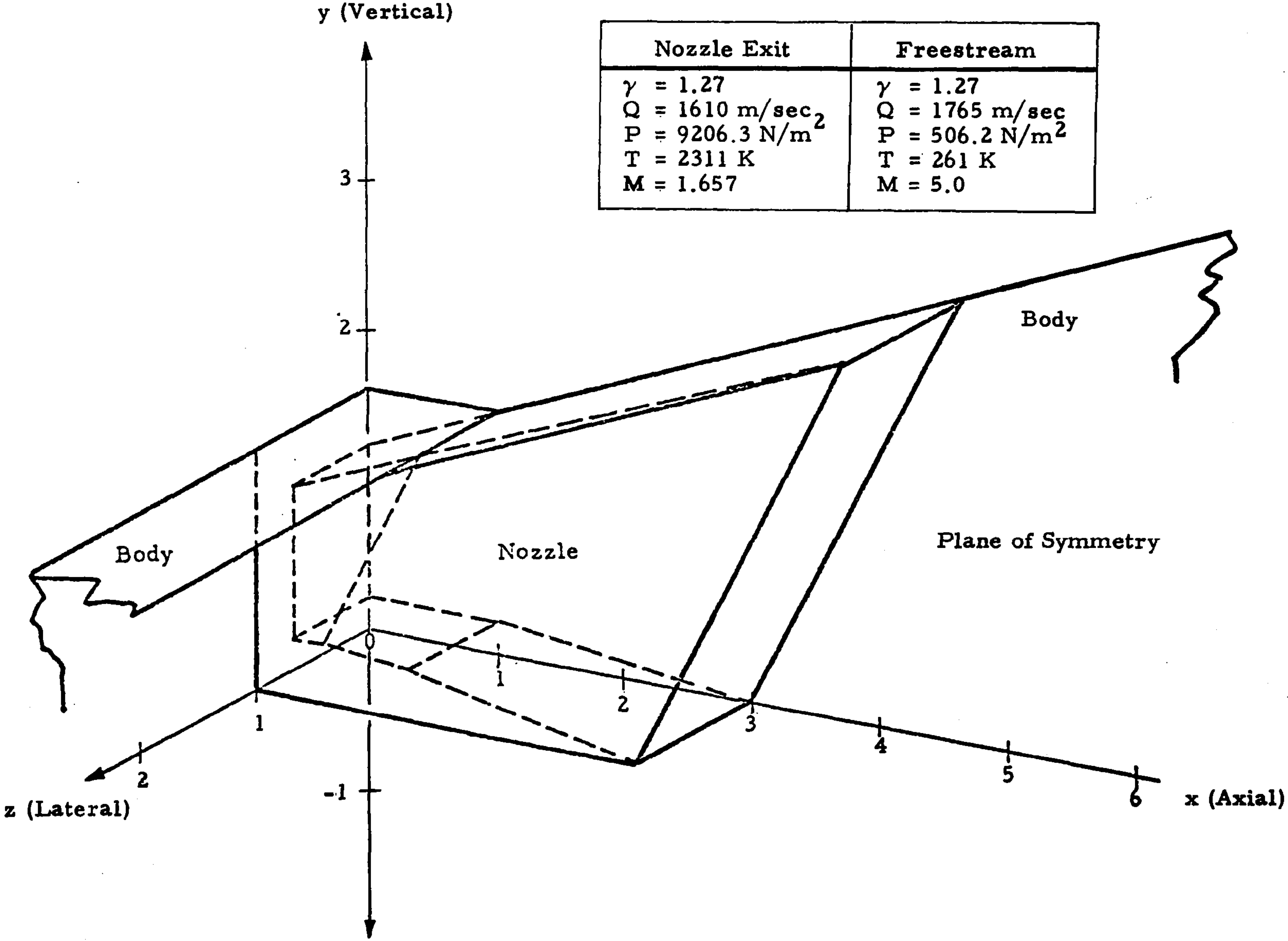
```
          880   892   609   593
          892   904   625   609
          904   916   641   625
          916   928   657   641
          928   940   673   657
            1    16
           16   688
          688   929
          689   929
          353   689
            1   129
          129   353
           -1
     -1
GRID        0
GRID        1                                            1     1
PRES        0     1     24     -1      7          0      1     4
 1000
         106.        125.        150.        200.        250.        270.        285.        300.
         325.        350.        400.        450.        500.        550.        600.        650.
         700.        800.        900.       1100.       1300.       1500.       1700.       1900.
MACH        0     1     22     -1      7          0      1     4
 1000
          1.8         2.0         2.1         2.2         2.3         2.4         2.5         2.6
          2.7         2.8         2.9         3.0         3.2         3.4         3.6         3.8
          4.0         4.2         4.4         4.6         4.8         4.9
STOP
```

Fig. 8-3e (Concluded)

```
        **   INTEG INPUT FOR RESTART CASE   **

  3  EXAMPLE RESTART OF 2-D SCRAMJET CASE
     2     2   200   200     0     6     2     1  1000      1      0      1
   940    43    16    16     1     1     0     1
   .2000E-5  1.0         1000
  1.0000E-3 0.0          1.27       1.4        23.        28.        -1.0       0.0
   .5        -.67        .5         0.0
   129     2   145   146     0     0     0 -6.0
   129-9.8544914 1.2047769
   130-.02186598-.01242926
   1458.8312419 -10.918867
   1461.0431156 9.7265189
   129.021809047.012247726
   130-9.7740653 1.1653537
   145-.9543836 -9.7370468
   14610.70664  8.5594455
    -1
     1    16    43
    16    16    43
   673     1    16
   689     1    12
    -1
 -3  END OF FIRST SCRAMJET RESTART
```

Fig. 8-3f - Two-Dimensional Scramjet Case (RSTART)



Nozzle Exit	Freestream
γ = 1.27	γ = 1.27
Q = 1610 m/sec	Q = 1765 m/sec
P = 9206.3 N/m^2	P = 506.2 N/m^2
T = 2311 K	T = 261 K
M = 1.657	M = 5.0

Fig. 8-4a - Three-Dimensional Scramjet Configuration

```
****   THREE DIMENSIONAL SCRAMJET EXAMPLE CASE   ****

       **  DYNMAT INPUT  **

 7934     3

       **  GEOM INPUT  **

  THREE DIMENSIONAL SCRAMJET SIMULATION - SHEAR LAYER REGION
    1     3     2     0     0
    0     0     9
  1.0        1.0000E-6 1.000E-12  1.000E-6  1.000E-6  1.00E-12 1.000E-16  1.00E-12
  1.00E-16  1.00E-12  1.000E-6  1.00E-12  1.00E-12  1.000E-6   1.0      1.0000E-6
    1
    1 1111     111111   11  111  111    11    1 1111    111111
    1     1     1     1     1     1
    4     8     6     4     0     6     1
   16    26    19     0    26    19
0.0       0.056     0.104     0.144     0.172     0.186     0.20      0.25
0.30      0.35      0.40      0.45      0.50      0.55      0.60      0.615
0.635     0.665     0.695     0.725     0.750     0.770     0.790     0.810
0.825     1.0
0.0       0.05      0.1       0.15      0.2       0.25      0.3       0.35
0.4       0.45      0.5       0.55      0.6       0.624     0.656     0.712
0.792     0.888     1.0
3.0       -3.0      0.0       0.0       0.0
6.0       -3.0      0.0       0.0       0.0
6.0       -1.0      0.0       0.0       0.0       0.2
6.0       0.0       0.0       0.0       0.0       0.6
6.0       3.0       0.0       18.0      0.0       0.825
6.0       3.39403   0.0       20.0      0.0
4.68274   2.91459   0.0       20.0      0.0
3.0       -0.50     0.0       0.0       0.0       0.2
3.0       0.0       0.0       -6.0      0.0       0.4
3.2887    0.5       0.0       0.0       0.0       0.6
4.5877    2.75      0.0       19.3      0.0       0.825
3.0       -3.0      1.5       0.0       0.0       0.6
3.0       -3.0      4.0       0.0       0.0
6.0       -3.0      1.0       0.0       0.0       0.2
6.0       -3.0      2.0       0.0       0.0       0.6
6.0       -3.0      4.0       0.0       0.0
6.0       3.39403   1.0       20.0      4.0       0.2
6.0       3.39403   2.0       20.0      6.0       0.6
6.0       3.39403   4.0       20.0      0.0
4.68274   2.91459   1.5       20.0      0.0       0.6
4.68274   2.91459   4.0       20.0      0.0
6.0       -1.0      4.0       0.0       0.0       0.2
6.0       0.0       4.0       0.0       0.0       0.6
6.0       3.0       4.0       18.0      0.0       0.825
3.0       -0.50     4.0       0.0       0.0       0.2
3.0       0.0       4.0       0.0       0.0       0.4
3.2887    0.5       4.0       0.0       0.0       0.6
4.5877    2.75      4.0       19.3      0.0       0.825
   494   19     1     1
     1    1   100
    -1
```

Fig. 8-4b - Three-Dimensional Scramjet Case (DYNMAT, GEOM)

```
****   UPDATE MOD TO USE 'USERIP' SUBROUTINE   ****
       * THREE DIMENSIONAL SCRAMJET CASE *

*IDENT  USERIP
*D  PAGE2.142
C
C      **  SPECIAL -USERIP- FOR 3-D SCRAMJET CASE   **
C
       DIMENSION PANG(10),DAT(5,10)
       DIMENSION DAH(5,144)
       READ(5,590) XC,YC
       READ(5,580) JNUM
       DO 560 J=1,JNUM
       READ(5,590) PANG(J),(DAT(JJ,J),JJ=1,5)
  560  CONTINUE
  580  FORMAT(I5)
  590  FORMAT(6E10.4)
       I=1
       INC=1
       NTOT=494
       DO 400 K=1,16
       ITAN=1
       IF(K.EQ.1) ITAN=0
       DO 295 M=1,NTOT
       II=M/494
       II=M-II*494
       IF(II.EQ.0) II=494
       IIMAX=191
       JJ=1
       IF(II.LT.IIMAX) GO TO 600
       III=II/19
       III=II-III*19
       IF(III.EQ.0) III=19
       IIIMX=10
       IF(III.LT.IIIMX) GO TO 730
       ARG=(Y(I)-YC)/(X(I)-XC)
       ANG=ATAN(ARG)*57.295
       JJ=1
       IF(ANG.LE.PANG(1)) GO TO 600
       JJ=JNUM
       IF(ANG.LT.PANG(JNUM)) GO TO 650
  600  CONTINUE
       RI=DAT(1,JJ)
       UI=DAT(2,JJ)
       VI=DAT(3,JJ)
       WI=DAT(4,JJ)
       PI=DAT(5,JJ)
       GO TO 750
  650  CONTINUE
       DO 700 J=2,JNUM
       JJ=J
       IF(ANG.GT.PANG(J)) GO TO 700
       J1=JJ-1
       RRR=(ANG-PANG(J1))/(PANG(JJ)-PANG(J1))
       RI=DAT(1,J1)+RRR*(DAT(1,JJ)-DAT(1,J1))
       UI=DAT(2,J1)+RRR*(DAT(2,JJ)-DAT(2,J1))
       VI=DAT(3,J1)+RRR*(DAT(3,JJ)-DAT(3,J1))
```

Fig. 8-4c - Three-Dimensional Scramjet Case (USERIP)

```
      WI=DAT(4,J1)+RRR*(DAT(4,JJ)-DAT(4,J1))
      PI=DAT(5,J1)+RRR*(DAT(5,JJ)-DAT(5,J1))
      GO TO 720
  700 CONTINUE
  720 CONTINUE
      GO TO 750
  730 CONTINUE
      LL=(II-190)/19
      L=LL*9+III
      IF(K.GT.1) GO TO 735
      READ(5,590) (DAN(J,L),J=1,5)
  735 CONTINUE
      RI=DAN(1,L)
      UI=DAN(2,L)
      VI=DAN(3,L)
      WI=DAN(4,L)
      PI=DAN(5,L)
  750 CONTINUE
      QI=SQRT(UI*UI+VI*VI+WI*WI)
      IF(ITAN .EQ. 0) GO TO 294
      THXY=THETA(I)/57.29578
      THXZ=PHI(I)/57.29578
      CALL TANGNT(QI,THXY,THXZ,UI,VI,WI)
 294  CONTINUE
      RHO(I)=RI
      UVEL(I)=UI
      VVEL(I)=VI
      WVEL(I)=WI
      QVEL=SQRT(UI**2+VI**2+WI**2)
      P(I)=FACTOR*PI
      ENER(I)=P(I)/(GAM1*RHO(I)) + 0.5*QVEL**2
      I=I+INC
 295  CONTINUE
 400  CONTINUE
      IRTN=1
C     **  RETURN TO NORMAL OPERATION  **
```

Fig. 8-4c (Concluded)

```
     **  DYNDIM INPUT  **

 7904     3     0 2353

      **  INTEG INPUT USING 'USERIP' SUBROUTINE  **

 4  THREE DIMENSIONAL SCRAMJET SIMULATION - SHEAR LAYER REGION
    3    2    10    10    0    0    2    1    0    1    0    0
 7904   16   494    26   19   19    1    0
  .4000E-5   1.0      100
 1.0000E-4  0.0      1.4       0.0       0.0       0.0       0.0       2070.
 .5         -.67     .5        0.0
 1.0        1.0      1.0       0   1.0     1.0
    1    1   494    1    3
1.0         1.57418
   10
-11.537     0.003223  5791.0   0.0       0.0       105.8
-10.380     0.002952  5810.0   99.3      0.0       94.6
-8.963      0.002646  5831.0   222.0     0.0       82.3
-7.032      0.002271  5855.0   391.0     0.0       67.8
-4.636      0.001867  5876.0   603.0     0.0       52.9
-1.839      0.001473  5891.0   853.0     0.0       39.2
1.290       0.001117  5892.0   1137.0    0.0       27.5
4.672       0.000816  5875.0   1445.0    0.0       18.5
8.219       0.000575  5839.0   1770.0    0.0       11.8
11.848      0.000394  5780.0   2104.0    0.0       7.34
 .1738E-02 .7149E+04-.7514E+030.            .2943E+03
 .1745E-02 .7150E+04-.7515E+03 .1214E+03 .2956E+03
 .1755E-02 .7143E+04-.7508E+03 .2458E+03 .2976E+03
 .1769E-02 .7127E+04-.7491E+03 .3686E+03 .3005E+03
 .1782E-02 .7101E+04-.7464E+03 .4906E+03 .3033E+03
 .1791E-02 .7067E+04-.7427E+03 .6123E+03 .3054E+03
 .1791E-02 .7022E+04-.7380E+03 .7320E+03 .3059E+03
 .1787E-02 .6958E+04-.7324E+03 .8504E+03 .3053E+03
 .1767E-02 .6897E+04-.7249E+03 .9577E+03 .3019E+03
 .1689E-02 .7255E+04-.4747E+03-.2850E-11 .2812E+03
 .1696E-02 .7256E+04-.4746E+03 .1179E+03 .2825E+03
 .1705E-02 .7248E+04-.4734E+03 .2395E+03 .2842E+03
 .1718E-02 .7233E+04-.4711E+03 .3602E+03 .2868E+03
 .1729E-02 .7207E+04-.4676E+03 .4814E+03 .2893E+03
 .1737E-02 .7172E+04-.4632E+03 .6031E+03 .2911E+03
 .1737E-02 .7126E+04-.4579E+03 .7231E+03 .2914E+03
 .1732E-02 .7071E+04-.4517E+03 .8421E+03 .2908E+03
 .1712E-02 .6998E+04-.4446E+03 .9503E+03 .2875E+03
 .1623E-02 .7316E+04-.2021E+03-.3317E-11 .2664E+03
 .1629E-02 .7316E+04-.2020E+03 .1144E+03 .2676E+03
 .1638E-02 .7308E+04-.2011E+03 .2328E+03 .2692E+03
 .1650E-02 .7293E+04-.1992E+03 .3511E+03 .2717E+03
 .1661E-02 .7267E+04-.1964E+03 .4707E+03 .2740E+03
 .1669E-02 .723[illegible]E+04-.1928E+03 .5913E+03 .2758E+03
 .1669E-02 .7187E+04-.1883E+03 .7109E+03 .2762E+03
 .1665E-02 .7132E+04-.1830E+03 .8298E+03 .2758E+03
 .1647E-02 .7058E+04-.1775E+03 .9387E+03 .2729E+03
 .1552E-02 .7360E+04 .5988E+02-.3217E-11 .2515E+03
 .1558E-02 .7359E+04 .5983E+02 .1111E+03 .2525E+03
 .1566E-02 .7351E+04 .6033E+02 .2264E+03 .2541E+03
 .1578E-02 .7335E+04 .6164E+02 .3422E+03 .2564E+03
 .1588E-02 .7310E+04 .6376E+02 .4600E+03 .2586E+03
```

Fig. 8-4d - Three-Dimensional Scramjet Case (INTEG)

.1596E-02	.7276E+04	.6672E+02	.5794E+03	.2608E+03
.1596E-02	.7230E+04	.7045E+02	.6982E+03	.2607E+03
.1592E-02	.7175E+04	.7505E+02	.8166E+03	.2604E+03
.1575E-02	.7100E+04	.7932E+02	.9254E+03	.2577E+03
.1485E-02	.7395E+04	.3161E+03	-.3025E-11	.2376E+03
.1491E-02	.7393E+04	.3159E+03	.1078E+03	.2388E+03
.1496E-02	.7385E+04	.3159E+03	.2201E+03	.2401E+03
.1510E-02	.7369E+04	.3165E+03	.3335E+03	.2422E+03
.1520E-02	.7344E+04	.3178E+03	.4494E+03	.2443E+03
.1527E-02	.7309E+04	.3200E+03	.5675E+03	.2456E+03
.1527E-02	.7263E+04	.3227E+03	.6854E+03	.2463E+03
.1524E-02	.7208E+04	.3263E+03	.8031E+03	.2460E+03
.1507E-02	.7133E+04	.3290E+03	.9115E+03	.2436E+03
.1402E-02	.7406E+04	.6028E+03	-.3299E-11	.2214E+03
.1408E-02	.7404E+04	.6022E+03	.1034E+03	.2223E+03
.1415E-02	.7395E+04	.6016E+03	.2116E+03	.2236E+03
.1425E-02	.7380E+04	.6014E+03	.3216E+03	.2256E+03
.1435E-02	.7355E+04	.6019E+03	.4350E+03	.2275E+03
.1441E-02	.7321E+04	.6030E+03	.5513E+03	.2289E+03
.1441E-02	.7275E+04	.6048E+03	.6679E+03	.2293E+03
.1436E-02	.7220E+04	.6074E+03	.7847E+03	.2290E+03
.1423E-02	.7145E+04	.6085E+03	.8926E+03	.2269E+03
.1336E-02	.740[illegible]E+04	.9257E+03	-.2821E-11	.2082E+03
.1341E-02	.7403E+04	.9249E+03	.9742E+02	.2091E+03
.1347E-02	.7394E+04	.9239E+03	.2001E+03	.2102E+03
.1357E-02	.7379E+04	.9234E+03	.3057E+03	.2120E+03
.1365E-02	.7355E+04	.9235E+03	.4160E+03	.2136E+03
.1370E-02	.7321E+04	.9243E+03	.5302E+03	.2147E+03
.1369E-02	.7276E+04	.9256E+03	.6456E+03	.2149E+03
.1365E-02	.7221E+04	.9275E+03	.7616E+03	.2145E+03
.1349E-02	.7146E+04	.9270E+03	.8699E+03	.2123E+03
.1301E-02	.7311E+04	.1227E+04	-.2158E-11	.2023E+03
.1304E-02	.7306E+04	.1227E+04	.8967E+02	.2029E+03
.1309E-02	.7298E+04	.1226E+04	.1848E+03	.2037E+03
.1315E-02	.7283E+04	.1227E+04	.2846E+03	.2050E+03
.1320E-02	.7261E+04	.1228E+04	.3907E+03	.2060E+03
.1322E-02	.7226E+04	.1230E+04	.5021E+03	.2065E+03
.1318E-02	.7184E+04	.1232E+04	.6155E+03	.2062E+03
.1311E-02	.7129E+04	.1234E+04	.7299E+03	.2053E+03
.1295E-02	.7055E+04	.1232E+04	.8364E+03	.2029E+03
.1337E-02	.7246E+04	.1402E+04	-.1861E-11	.2094E+03
.1339E-02	.7240E+04	.1403E+04	.8749E+02	.2098E+03
.1343E-02	.7231E+04	.1403E+04	.1797E+03	.2103E+03
.1347E-02	.7216E+04	.1404E+04	.2771E+03	.2112E+03
.1349E-02	.7192E+04	.1405E+04	.3808E+03	.2118E+03
.1348E-02	.7158E+04	.1406E+04	.4896E+03	.2119E+03
.1343E-02	.7112E+04	.1406E+04	.6004E+03	.2113E+03
.1334E-02	.7055E+04	.1406E+04	.7118E+03	.2102E+03
.1316E-02	.6979E+04	.1402E+04	.8153E+03	.2076E+03
.1317E-02	.7197E+04	.1627E+04	-.3009E-11	.2053E+03
.1320E-02	.7190E+04	.1627E+04	.8350E+02	.2058E+03
.1323E-02	.7180E+04	.1626E+04	.1721E+03	.2064E+03
.1328E-02	.7164E+04	.1623E+04	.2661E+03	.2074E+03
.1331E-02	.7139E+04	.1619E+04	.3667E+03	.2082E+03
.1331E-02	.7102E+04	.1615E+04	.4728E+03	.2086E+03
.1327E-02	.7053E+04	.1610E+04	.5814E+03	.2083E+03
.1319E-02	.6992E+04	.1604E+04	.6909E+03	.2075E+03
.1302E-02	.6912E+04	.1594E+04	.7937E+03	.2054E+03

Fig. 8-4d (Continued)

.1278E-02	.7201E+04	.1856E+04	-.3632E-11	.1970E+03
.1282E-02	.7194E+04	.1853E+04	.7497E+02	.1976E+03
.1286E-02	.7183E+04	.1849E+04	.1572E+03	.1984E+03
.1292E-02	.7167E+04	.1841E+04	.2467E+03	.1997E+03
.1297E-02	.7141E+04	.1832E+04	.3450E+03	.2007E+03
.1298E-02	.7103E+04	.1821E+04	.4508E+03	.2014E+03
.1295E-02	.7052E+04	.1810E+04	.5607E+03	.2014E+03
.1288E-02	.6987E+04	.1798E+04	.6726E+03	.2008E+03
.1272E-02	.6902E+04	.1780E+04	.7800E+03	.1991E+03
.1244E-02	.7197E+04	.2030E+04	-.4061E-11	.1900E+03
.1247E-02	.7189E+04	.2026E+04	.6623E+02	.1906E+03
.1251E-02	.7179E+04	.2020E+04	.1417E+03	.1913E+03
.1257E-02	.7165E+04	.2012E+04	.2268E+03	.1924E+03
.1261E-02	.7140E+04	.2000E+04	.3233E+03	.1933E+03
.1262E-02	.7103E+04	.1986E+04	.4295E+03	.1936E+03
.1258E-02	.7051E+04	.1973E+04	.5416E+03	.1937E+03
.1250E-02	.6984E+04	.1957E+04	.6564E+03	.1931E+03
.1236E-02	.6897E+04	.1933E+04	.7679E+03	.1916E+03
.1217E-02	.7199E+04	.2193E+04	-.3220E-11	.1842E+03
.1219E-02	.7191E+04	.2189E+04	.5931E+02	.1846E+03
.1220E-02	.7182E+04	.2184E+04	.1290E+03	.1848E+03
.1223E-02	.7168E+04	.2176E+04	.2101E+03	.1853E+03
.1224E-02	.7145E+04	.2166E+04	.3051E+03	.1856E+03
.1222E-02	.7109E+04	.2153E+04	.4115E+03	.1856E+03
.1217E-02	.7057E+04	.2138E+04	.5254E+03	.1852E+03
.1208E-02	.6988E+04	.2119E+04	.6425E+03	.1844E+03
.1194E-02	.6901E+04	.2091E+04	.7566E+03	.1831E+03
.1187E-02	.7196E+04	.2355E+04	-.1431E-11	.1779E+03
.1187E-02	.7188E+04	.2351E+04	.5624E+02	.1780E+03
.1185E-02	.7177E+04	.2347E+04	.1224E+03	.1776E+03
.1183E-02	.7164E+04	.2342E+04	.2007E+03	.1773E+03
.1180E-02	.7140E+04	.2334E+04	.2939E+03	.1767E+03
.1174E-02	.7104E+04	.2323E+04	.3992E+03	.1760E+03
.1166E-02	.7053E+04	.2307E+04	.5131E+03	.1752E+03
.1156E-02	[illegible]	.2265E+04	.6305E+03	.1741E+03
.1142E-02	.6895E+04	[illegible]	.7437E+03	.1728E+03
.1163E-02	.7195E+04	.2479E+04	-.1007E-11	.1727E+03
.1162E-02	.7185E+04	.2475E+04	.5613E+02	.1726E+03
.1157E-02	.7173E+04	.2472E+04	.1210E+03	.1717E+03
.1152E-02	.7158E+04	.2468E+04	.1976E+03	.1708E+03
.1145E-02	.7134E+04	.2461E+04	.2894E+03	.1697E+03
.1136E-02	.7097E+04	.2450E+04	.3933E+03	.1685E+03
.1127E-02	.7045E+04	.2434E+04	.5061E+03	.1674E+03
.1116E-02	.6975E+04	.2411E+04	.6226E+03	.1662E+03
.1102E-02	.6886E+04	.2379E+04	.7332E+03	.1648E+03
.1130E-02	.7186E+04	.2616E+04	0.	.1660E+03
.1128E-02	.7174E+04	.2611E+04	.5719E+02	.1655E+03
.1120E-02	.7160E+04	.2606E+04	.1215E+03	.1642E+03
.1111E-02	.7143E+04	.2600E+04	.1969E+03	.1626E+03
.1100E-02	.7117E+04	.2590E+04	.2865E+03	.1609E+03
.1088E-02	.7078E+04	.2576E+04	.3881E+03	.1591E+03
.1076E-02	.7025E+04	.2557E+04	.4986E+03	.1576E+03
.1064E-02	.6954E+04	.2531E+04	.6136E+03	.1563E+03
.1050E-02	.6864E+04	.2496E+04	.7215E+03	.1548E+03

-1

191 494 16

-1

-4 END OF 3-D SCRAMJET COLD START DATA

Fig. 8-4d (Concluded)

Referring to this figure, the nozzle has a sharp 20 deg upward turn at $X = 0$, a sharp 6 deg turn downward at $X = X_o$, and a sharp 6 deg turn outward along the dashed line located on the sidewall. The rectangular nozzle exit plane is inclined 30 deg from vertical. The body has a sharp 20 deg turn upward at $X = X_o$.

The problem was analyzed in three parts: (1) the nozzle; (2) the external flow upstream of the nozzle exit, and (3) the entire flow downstream of the exit plane. The nozzle flow field, which is three-dimensional, was computed using the GIM code. It was computed using 2160 nodes and required 570 iterations to relax to the steady solution. The external flow was computed using a Prandtl-Meyer expansion at the 20 deg sharp turn. The nozzle exit plane conditions and the freestream expansion were used as input boundary conditions for the downstream shear layer region. Details are given in Ref. 1.

The shear layer region is analyzed using 7904 nodes in the GIM code. Figure 8-4b shows the input cards for DYNMAT and GEOM modules for the shear layer region. Again the USERIP option of input to the INTEG module was used. A FORTRAN listing of this code is given in Fig. 8-4c for the three-dimensional Scramjet case. The input to INTEG corresponding to this code is shown in Fig. 8-4d for the DYNDIM and INTEG modules.

8.5 THREE-DIMENSIONAL DUCT EXAMPLE CASE

Next we consider three-dimensional inviscid flow in a square duct as shown in Fig. 8-5a. The first 10 X_o consists of an expansion region with the final 10 X_o being a constant area section. The three-dimensional GEOM and DYNMAT deck setups are shown in Fig. 8-5b. An example GIMPLT deck is shown in Fig. 8-5c. This case is shown as an example of a three-dimensional plot setup only; thus the INTEG module is not needed for this illustration.

$$(z, y) = 1.5 - 0.5 \sin\left(\frac{\pi}{2} + \frac{\pi x}{10}\right), \ x \leq 10$$

$$(z, y) = 2, \ x > 10$$

(All units dimensionless)

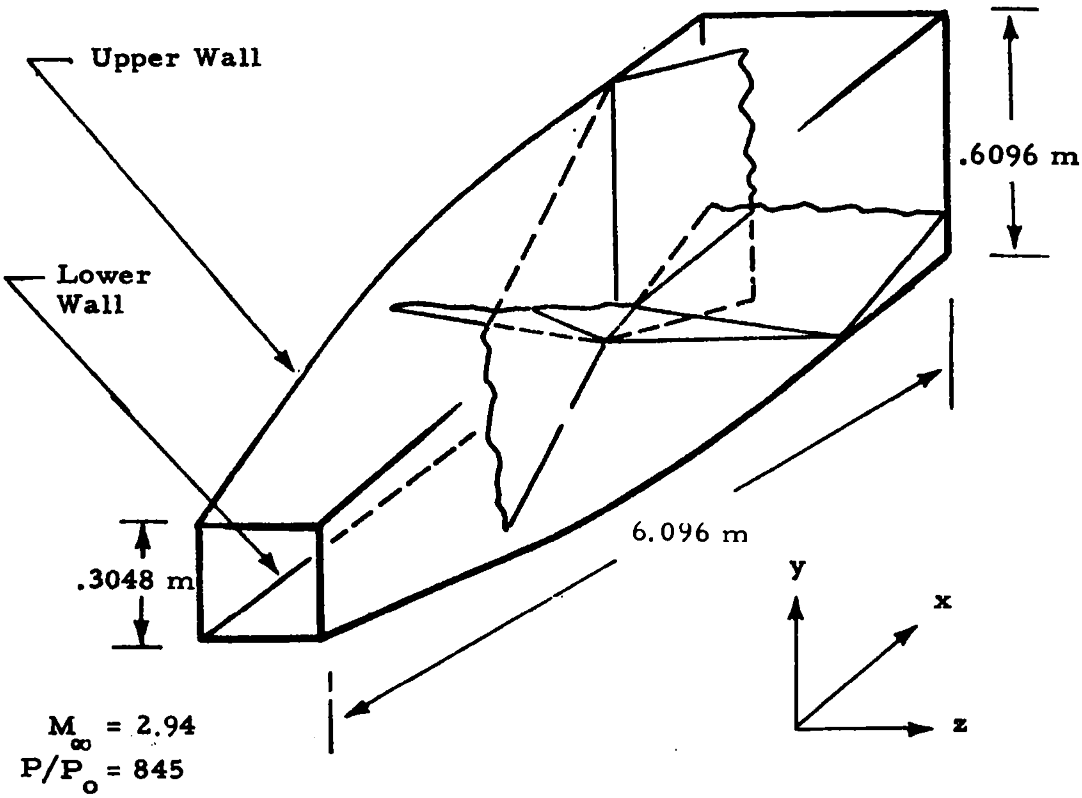


Fig. 8-5a - Three-Dimensional Duct Configuration

```
****   THREE DIMENSIONAL DUCT CASE   ****


      **   DYNMAT INPUT   **

 4961       3


       **   GEOM INPUT   **

          THREE DIMENSIONAL DUCT
    1      3      2      0      0
    0      0    100
 1.0        1.00000E-8 1.000E-12 1.0000E-8 1.0000E-8 1.000E-12 1.000E-16 1.000E-12
 1.000E-16 1.000E-12 1.0000E-8 1.000E-12 1.000E-12 1.0000E-8  1.0       1.00000E-8
    1
    1      1     51      1      1      1      1      1     51      1     51      1
    1      1      1      1      1      1
    4      4      4      4      0      8      1
   41     11     11      0      0      0
0.0        0.0        0.0        -0.5       0.0        .31415927 1.5707963
0.0        0.0        0.0        -0.5       0.0        .31415927 1.5707963
0.0        0.0        0.0        -0.707107  0.0        .31415927 1.5707963
0.0        0.0        0.0        0.0        0.0
20.0       0.0        0.0        0.0        0.0
20.0       2.0        0.0        0.0        0.0
10.0       2.0        0.0        0.0        0.0        0.5
0.0        1.0        0.0        0.0        0.0
0.0        0.0        1.0        0.0        0.0
20.0       0.0        2.0        0.0        0.0
20.0       2.0        2.0        0.0        0.0
0.0        1.0        1.0        0.0        0.0
10.0       0.0        2.0        0.0        0.0        0.5
10.0       2.0        2.0        0.0        0.0        0.5
  121     11      1      0
    1      1    100
   -1
```

Fig. 8-5b - Three-Dimensional Duct Case (DYNMAT, GEOM)

```
    **   GIMPLT INPUT   **

 THREE DIMENSIONAL DUCT
4961    0    0    3    0
1.4        1.0        1.0          1.0        1.0        1.0
   1       ENTIRE EXTERIOR SURF    3     0    45     2    30     3
   4     1     1    11    10    10
   4  4841     1    11    10    10
   4     1    11   121    10    40
   4    11    11   121    10    40
   4     1     1   121    10    40
   4   111     1   121    10    40
        -1
   2       ENTIRE EXTERIOR SURF    3     0    30     2    30     3
   4     1     1    11    10    10
   4  4841     1    11    10    10
   4     1    11   121    10    40
   4    11    11   121    10    40
   4     1     1   121    10    40
   4   111     1   121    10    40
        -1
   3       HALF DUCT               3     0    45     2    30     3
   4     1     1    11    10    10
   4  2421     1    11    10    10
   4     1    11   121    10    20
   4    11    11   121    10    20
   4     1     1   121    10    20
   4   111     1   121    10    20
        -1
   4       HALF DUCT               3     0    30     2    30     3
   4     1     1    11    10    10
   4  2421     1    11    10    10
   4     1    11   121    10    20
   4    11    11   121    10    20
   4     1     1   121    10    20
   4   111     1   121    10    20
        -1
  -1
GRID
STOP
```

Fig. 8-5c - Three-Dimensional Duct Case (GIMPLT)

9. REFERENCES

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16. Abstract

The General Interpolants Method (GIM) is a 3-D, time-dependent, hybrid procedure for generating numerical analogs of the conservation laws. The Navier-Stokes equations written for an Eulerian system are considered. GIM code was originally developed for a CDC 7600 computer system. The purpose of this work was the conversion of the GIM code to the STAR-100 computer at NASA-Langley Research Center. "GIM-ON-STAR" has demonstrated a CPU speed ratio of 5:1 to the CDC 7600 for a 2-D nozzle problem with 2000 nodes. This report documents the implementation of GIM-ON-STAR and also serves as a user's manual for the GIM/STAR code.

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