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A User Guide for the EMTAC-MZ CFD Code

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SUMMARY

The Euler Marching Technique for Accurate Computation (EMTAC) code was developed by Chakravarthy and Szema as part of a NASA-Langley Research Center Contract (NAS1-15820). The main objective of the present contract (NAS1-17492) is to include the multi-zone capability to solve the flow over very complex configurations (EMTAC-MZ). The combined mode of space marching and three-dimensional approximate factorization is also incorporate into this code which gives a very efficient way to calculate pure subsonic flow. Numerical results are obtained for several realistic fighter configurations, F-14, and Shuttle Orbiter with external tank and solid rocket boosters. Solutions are in good agreement with available experimental data. The computer time is very reasonable, it takes approximately 200 s CPU time for the analysis of a typical fighter-like configuration with an average marching plane grid (60×25) for the supersonic case and 2 hrs for the F-14 subsonic case on the CRAY-XMP computer.

The basic methodology and some results of the EMTAC-MZ code have been described in several AIAA papers which are given in the references.

1.0 INTRODUCTION

The computer code Euler Marching Technique for Accurate Computation (EMTAC) based on solving the unsteady Euler equations has been developed at Rockwell Science Center under a NASA-Langley Research Center Contract (NASA-15820). This code applies a unified approach which can operate in both time- and space-marching modes. In the time-marching mode, this code can be used to reach a time-asymptotic steady state flow. The space-marching mode is a specialization of the Gauss-Seidel relaxation method. The basic relaxation method can be used for both time- and space-marching. The time-marching mode using Gauss-Seidel relaxation could include forward sweeps only, backward sweeps only, or both. This mode of operation will be referred to as the space-relaxation mode, which is further specialized to the space-marching mode by setting the time step to be "infinitely large." The large time step makes the transient terms of the discretized unsteady equations vanish. This infinitely large time step and space-marching mode is used for supersonic flow. In regions of subsonic flow, a finite time step and a relaxation and/or approximate factorization method are used and the steady state is approached asymptotically. A finite volume implementation of high accuracy (up to third order) TVD discretizations is used, and thus the method is more accurate and reliable than other Euler space- and time-marching techniques based on central difference approximations.

The main objective of this contract (NAS1-17492) is to develop a multi-zone technique that has the capability of dealing with very complex configurations (both internal and external flow calculations) and can easily handle the combined yaw and angle of attack cases. Because of the unified approach, the EMTAC-MZ code can efficiently solve flow problems across the Mach number range.

2.0 METHOD

The method of EMTAC-MZ code is described in detail in Ref. 2 and a copy of that paper is included in the Appendix.

Some of the salient feature of method are:

- Efficient space-marching and three-dimension approximate factorization technique based on unsteady Euler equations.
- Finite volume upwind-biased scheme (modified Roe's approximate Riemann solver)
- High accuracy TVD formulation (up to third order)
- Approximate factorization in cross plane; forwarding marching for purely supersonic regions; Gauss-Seidel relaxation in marching direction and/or three-dimension approximate factorization for subsonic regions.
- Multi-zone technique to handle wake flow, nacelle region and very complex configuations.
- Can efficiently solve flow problems across the Mach number range (subsonic to hypersonic) under perfect gas assumption.
- This multi-zone technique can accommodate up to ten computational zones with proper flux balancing treatment at zonal boundaries.
- For the pure supersonic flow region, space marching method should be used.
- For the supersonic flow with subsonic pocket, use space marching method in the supersonic region and in the subsonic region, use one space marching sweep followed by time relaxation method.
- A completr subsonic flow region is treated in the same way as subsonic pocket region.

3.0 CODE STRUCTURE

The EMTAC-MZ code is written in the FORTRAN 77 language. The program consists of a main routine (UALLOC) which sets the memory storage parameters and then calls subroutine MDRIVE which in turn calls several subroutines. A brief description of the code along with input instructions needed to execute the code are given in this section.

Subroutine MDRIVE

Subroutine MDRIVE coordinates the entire operation. A flowchart and subroutines describing the various operations performed by the MDRIVE subroutine are given in Figs. 1 and 2. The MDRIVE subroutine sets up the initial (known) data plane and the body-fitted grid system and performs the marching procedure to advance the solution. The various read and write tapes used in the calculation are listed below:

5	-	Input data
6	-	Output data
1n	-	Read in restart data created in a previous run on unit 2n
2n	-	Write out restart data
5n	-	Read in multiple sweep restart data generated on unit 8n or 9n of a previous run.
7n	-	Older style plot file, containing 4 grid planes and 5 Q planes. The third grid plane is the axial location of the last station.
8n,9n	-	Complete grid and flowfield data written out when MDISKC = TRUE. This data is used for multiple sweep interations, when NTSTEP . GT. 1; SMAFCB = .FALSE.; MDISKC = .TRUE. The first iteration writes to unit 8n, the second interation writes to unit 9n, the third iteration writes to unit 8n and so on.
11n	-	Read in first five planes of flowfield and four planes of grid data from a previous approximate factorization run generated on unit 21n.

12n - Read in the complete flowfield and grid from a previous combined space marching and approximate factorization run generated on unit 22n.

13n - Read in last five planes of flowfield and four planes of grid data from a previous approximate factorization run generated on unit 23n.

21n - Write out the first five planes of flowfield and four planes of grid data for the approximate factorization run.

22n - Write out all of the flowfield and grid for the approximate factorization run.

23n - Write out the last five planes of flowfield and four planes of grid data for the approximate factorization run, where 2n means unit 21 of zone 1, unit 22 for zone 2, unit 23 for zone 3 and so on.

For all the above tape numbers, n is the zone number designation. For example, the restart data for zone 1 is written out to unit 21, the restart data for zone 2 is written out for unit 22, and so on.

Subroutine IAFIMP

The factored implicit scheme for the governing Euler equations can be written as

$$[I + \frac{1}{V} \hat{A}^{-1} \{B^{+}_{k-1/2}\Delta_{k-1/2} + B^{-}_{k+1/2}\Delta_{k+1/2}\}]$$

$$[I + \frac{1}{V} \hat{A}^{-1} \{C^{+}_{l-1/2}\Delta_{l-1/2} + C^{-}_{l+1/2}\Delta_{l+1/2}\}]\Delta^{s} q$$

$$= \frac{1}{V} \hat{A}^{-1} [\text{Right Hand Side}]$$

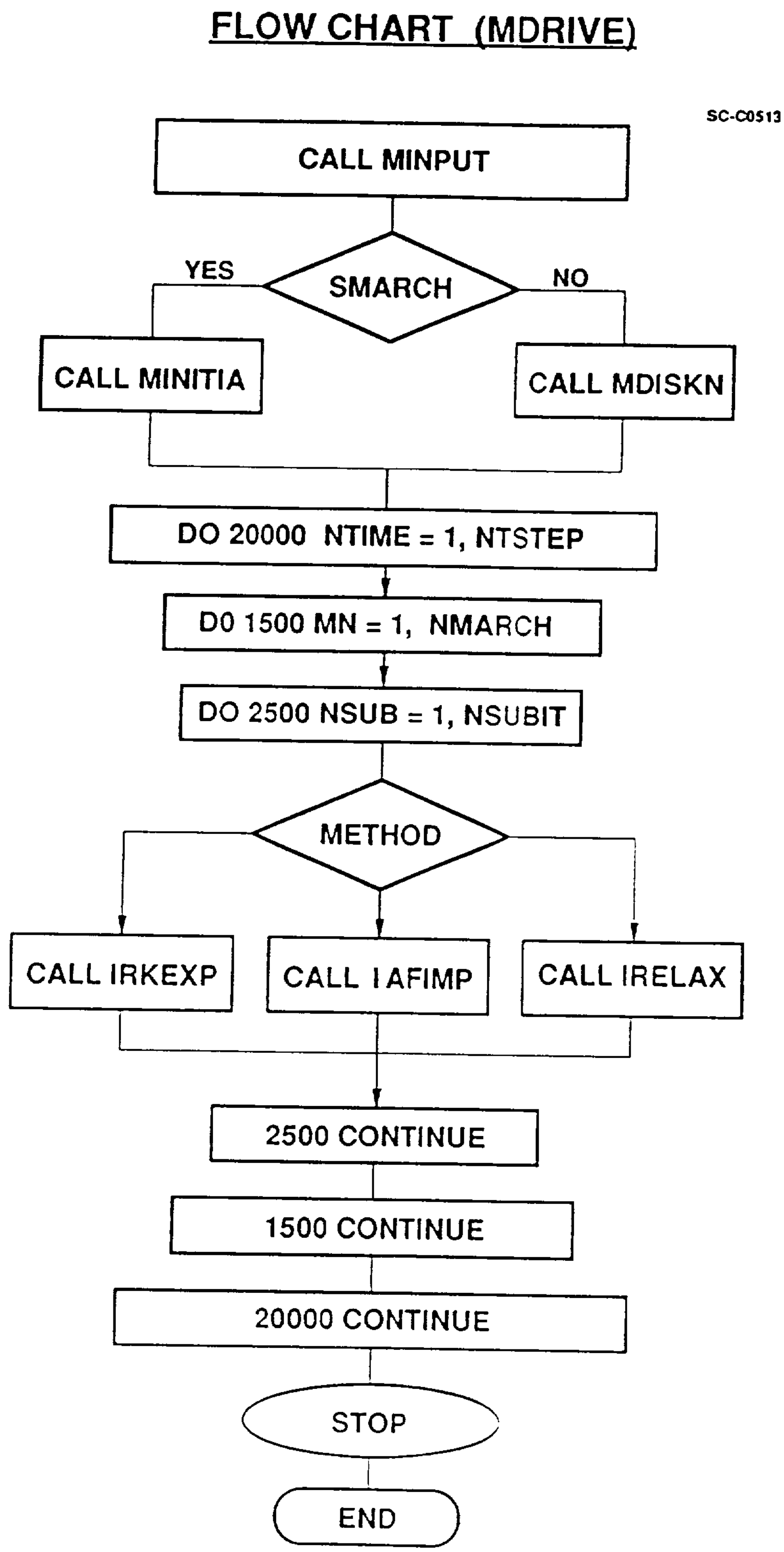


Fig. 1 Flow chart for EMTAC-MZ code.

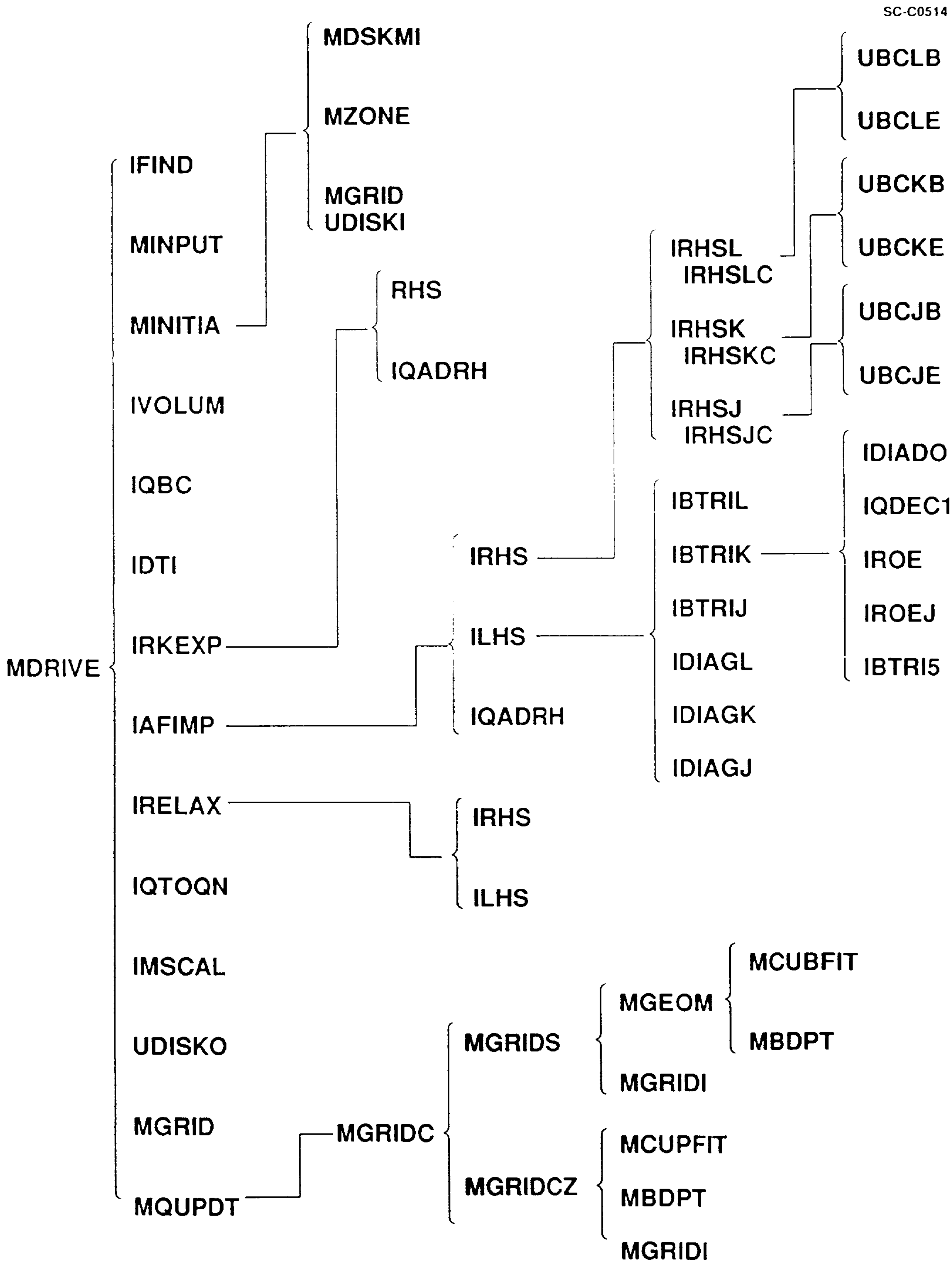


Fig. 2 Flow chart for EMTAC-MZ code.

The subroutine IAPFAC calls Subroutines ILHS (left hand side) and IRHS (right hand side) to calculate the solution by using the approximate factorization method.

Subroutine IROE

The numerical flux at cell surface m + 1/2 is given as

$$h_{m+1/2} = \frac{1}{2}\,[f(Q_{m+1},\ N_{m+1/2}) + f(Q_m,N_{m+1/2})]$$

$$- \frac{1}{2}\,[\sum_{1} (\lambda^{i+}_{m+1/2} - \lambda^{i-}_{m+1/2})\ \alpha^{i}_{2} r^{i}_{m+1/2}]$$

$$= f(Q_m,N_{m+1/2}) + \sum_{i} \lambda^{i-}_{m+1/2}\ \alpha^{i}_{2} r^{i}_{m+1/2}$$

$$= f(A_{m+1},N_{m+1/2}) - \sum_{i} \lambda^{i+}_{m+1/2}\ \alpha^{i}_{1} r^{i}_{m+1/2}$$

where $\alpha_i = \ell_i dQ$.

The right eigenvector (r), left eigenvector (ℓ), and parameter α are calculated in this subroutine.

Subroutines UBCLB, UBCLE, UBCKB, UBCKE

UBCLB: Apply boundary conditions at L = 1.
UBCLE: Apply boundary conditions at : LGRD (END OF L).
UBCKB: Apply boundary conditions at K = 1.
UBCKE: Apply boundary conditions at K = KGRD (end of K).

Subroutine MGEOM (N9, KMAX, NZ)

N9 = 0, geometry data at X_1 and X_2 are read in
   > 0, geometry data at X_1 is updated and X_2 is read in

Subroutine MGEOM sets up the body grid points from a prescribed geometry shape. From the input geometry points, a key point system is established using cubic splines. These key points are then joined from one prescribed geometry station to the next to provide the geometry at any intermediate marching plane.[12]

Subroutine MGRID

Once the boundary points for each zone are obtained at a marching plane from MGEOM, subroutine MGRID sets up the entire crossflow plane grid using an ellioptic grid solver that satisfies certain grid constraints.

Subroutine MFORCE (.,.,.,.,KFG,.,.,.)

At the end of each marching plane calculation, this subroutine computes the axial force, PX, vertical force, PY, and the side force, PZ, by integrating the pressure force acting on an elemental area, dA.

KFG = 0, conical or blunt body nose force calculation
= 1, rest of the body force calculation

The program also prints the force coefficients, C_L and C_D, information based on a prescribed reference area, and moment coefficients, C_M, about a given reference point (X_0, Y_0).

Header Data

A typical analysis of a comlete configuration requries several regions of marching calculations for a complete analysis. Each region calculation has a different set of header instructions for describing grid parameters, wake information if pertinent, restart directions, and number of mesh points for each patch of the region. A sample input is given in Appendix 2, and a brief description of each variable in this section.

Symbol	Format	Description
NZONES	I5	Number of zones ($1 \le NZONES \le 10$)
NTSTEP	I5	Number of multiple relaxation sweeps/ approximate factorization steps for the current run. If SMARCH.EQ. . TRUE., then one space marching sweep will occur followed by NTSTEP multiple relaxation sweeps/approximate factorization steps. Use 1 for space marching.
NSTORE	I5	The interval in multiple relaxation sweeps/ approximate factorization steps at which restart solution (flowfield) is stored on disk. Input NSTORE . GT. 0 for all types of runs.
NPRTT	I5	The interval in multiple relaxation sweeps/ approximate factorization steps at which the flowfield solution printout occurs. Input 0 to avoid intermediate printout.
ISTART	I5	Not used. Input 0.
ITSTEP		-1: Variable time steps (X,Y,Z). The delta time step for a cross-sectional plane of cells is calculated individually for each cell based on the cell's dimension. +1: Constant time steps. All cells within a cross-sectional plane have a constant delta time. The delta time step used is the smallest time step calculated from any one of the cells in the plane.

		Normally use 1 for space marching, with and/or without multiple relaxation sweeps. The solution converges in a non-accurate time sense for ITSTEP=-1.
NMARCH	I5	Maximum number of space marching steps for the current run. The input value of NMARCH includes the number of interations for the conical starting solution, MCONE, if any.
NDISKM	I5	Intervals in number of space marching steps at which restart information is stored on disk. If NDISKM = 0, the restart is stored after initialization and when program execution stops. For NDISKM .GT. 0, the restart information is overwritten on disk every NDISKM step. Currently, this option does not work. The restart information is written to disk on unit 2n at the successful termination of the run. No data is saved if the run terminates abnormally.
NPRTM	I5	The interval in the number of space marching steps at which the flowfield boundary solution printout occurs. The plot dataset information is written to disk on unit 7n at the same time as the flowfield printout occurs.
MCONE	I5	Number of interations (steps) for the conical starting solution.
LDACCU	I5	Spatial differencing accuracy in L direction. = 1 implies first order accuracy .NE. 1 implies higher order accuracy Normally use 2.

KDACCU	I5	Spatial differencing accuracy in J direction. = 1 implies first order accuracy .NE. 1 implies higher order accuracy Normally use 2.
NSUBIT	I5	Number of global iterations of the flow solver per marching step. NSUBIT is the number of global passes in the outer loop of the flow solver. For each zone, NRELAX(i) (i is zone number) is the number of passes in the inner loop (i.e., inside the zone) of the flow solver. Information is passed between zones on each global relaxation step. For a single zone case typically set NUBIT to 2 and set NRELAX(i) to 1. For a multiple zone case, set NSUBIT to at least 2 and no more than 4 to communicate information between zones and set NRELAX(i) to 2.
NITER	I5	Number of interations to generate the marching grid using an elliptic grid solver. Usually set to 30. If the grid routine fails, set this to 0 to analyze the geometry and the grid generated before grid relaxation (this is for degugging purposes). Set NITER back to 30 for flow field analysis. When NITER is set to 0, the grid is generated using transfinite interpolation. See note 8 in Appendix 1.

IFPBAC	I5	= 0: for no conditions specified on downstream face of zone. = 1: pressure must be specified on downstream fact of zone. This parameter is used only when subsonic flow is expected in front of downstream face of zone and when either multiple sweeps or approximate factorization is used so that the effect of the downstream pressure bundary condition can propagate upstream. Used in conjunction with PBAC. This option is typically used to simulate the engine compressor face in an inlet.
NEWCFL	I5	Number of time steps for which the time step is a constant. Use 1. Input is ignored for space marching. Currently not implemented.
NEWDTI	I5	Number of time steps after which time step is recomputed. Use 1. Input is ignored for space marching. Currently not implemented.
ISONIC	I5	Treatment of sonic point. = 0 No special sonic point treatment is desired = 1 Extra dissipation needed at sonic rarefaction = 2 Extra dissipation needed at sonic rarefaction and sonic compression. These options are used in the Riemann solver. A value of 0 should usually be input. A value of 1 is available for testing. The value of 2 is possibly necessary when dealing with very high

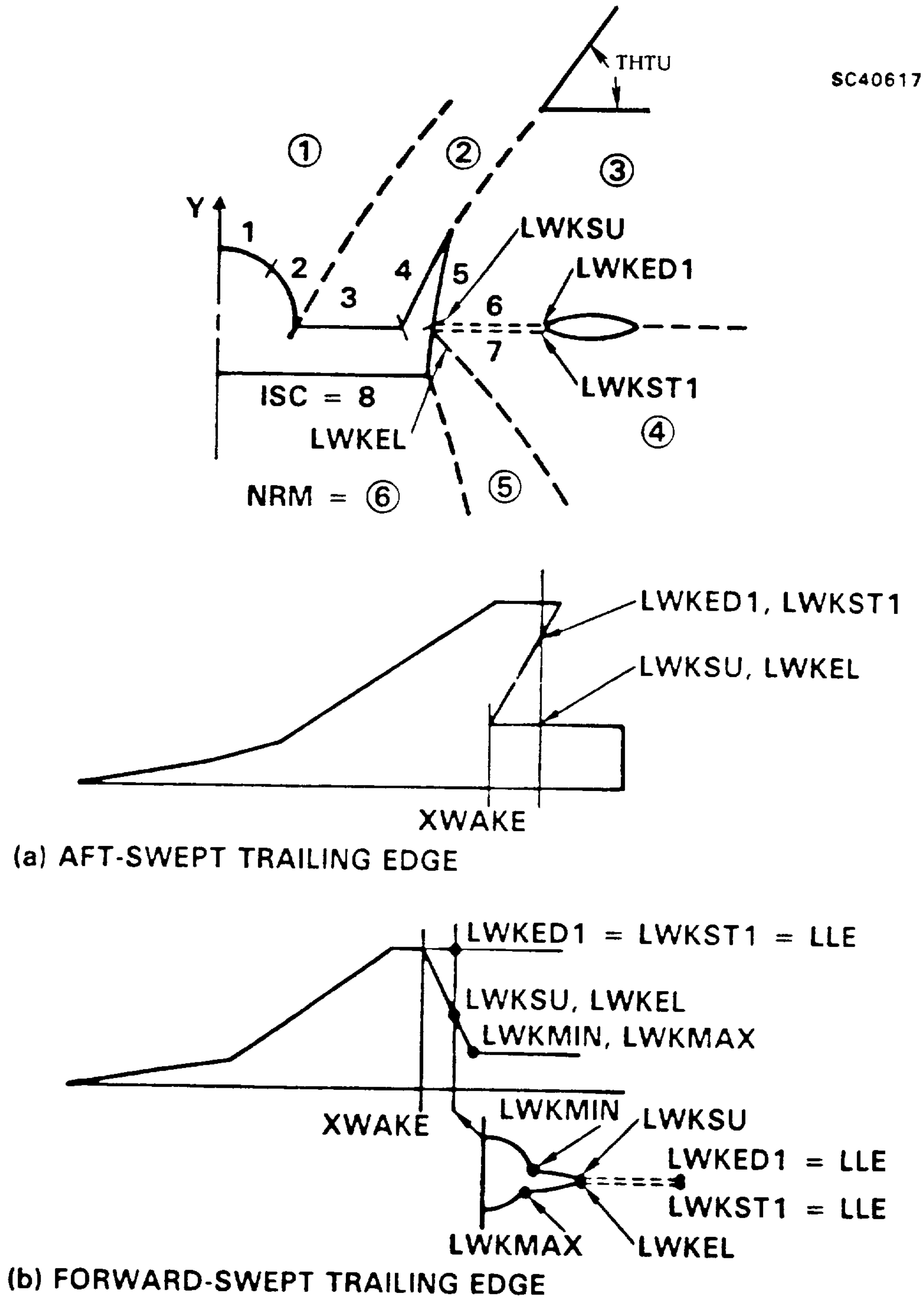


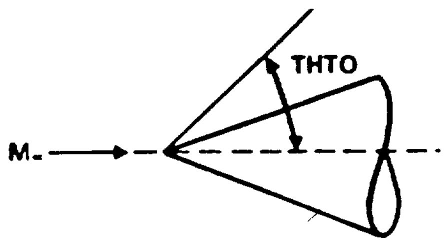
Fig. 3 Cross section patches and nomenclature.

		strength shocks (Normal Mach number of 10 and above).
NRM	I5	Number of grid regions in the first zone. A grid region is used to control the generation of the grid. A grid region is bounded by straight lines going from the INU point on the surface to the INU point on the outer boundary at an angle of THTU. The upper and lower centerlines are also grid region boundaries for symmetrical configurations (separated by dashed lines in Fig. 3).
NBDTOT	I5	The number of bodies. Bodies are used for force and moment accounting only.
LWKSU	I5	L value of starting point on the upper surface of a patch containing the wake. The ending L value of the wake on the upper surface is determined by an equation hardwired in the code. See wake treatment section.
LWKEL	I5	L value of ending point on the lower surface of a patch containing the wake. The beginning L value of the wake on the lower surface is determined by an equation hardwired in the code.
NXXX1	I5	Not used.

CFLNEW	F10.5	Starting CFL number. For supersonic flow, use 500-1000. If high flowfield gradients are expected, lower to 50. Use CFLINC to gradually increase.
CFLMIN	F10.5	Minimum CFL number (starting from time step 2 onwards) Delta T at time step 1 = 0.1E-04) For supersonic flow, use 500-1000. If high flowfield gradients are expected, lower to 50.
CFLMAX	F10.5	Maximum CFL number to be used at any time step. For supersonic flow, use 500-1000. If high flowfield gradients are expected, lower to 100.
CFLINC	F10.5	The ratio of the CFL number at the next step to the CFL number at the current step. This ratio is used if the CFL number is increasing.
CFLDEC	F10.5	The ratio of the CFL number at the next step to the CFL number at the current step. This ratio is used if the CFL number is decreasing.
DXIN	F10.5	Starting step size for space marching. If DXIN is set to less than DXMAX, then during the marching calculation, the step size will be slowed increased to DXMAX
DXMIN	F10.5	Minimum step size for space marching.
DXMAX	F10.5	Maximum step size for space marching. (DXMAX and DXMIN depend on the complexity of the geometry.

		Suggested values: DXMAX = total length/400 DXMIN = DXMAX/2 If DXMIN is set equal to DZMAX, then constant step size is used.)
XSTART	F10.5	Starting axial location for space marching. For MDSKIN = .FALSE. this is the plane of the conical starting solution. The code will generate grid planes at XSTART-DXIN and XSTART-2*DXIN. The input geometry should start before XSTART-2*DXIN. For MDSKIN = .TRUE., this input is ignored, and the starting plane is read from the restart file. The term axial location efers to the X coordinate of the downstream face of the computatinal cell.
XEND	F10.5	Ending X location. The code will stop if the next axial location is greater than XEND. The code will generate grid planes at XEND+DX and XEND+2*DX. The input geometry should end after XEND+2*DX. The term axial location refers to the X coordinate of the downstream face of the computational cell. XEND is ignored if the code stops because the number of steps equals NMARCH.
FSMACH	F10.5	Free stream Mach number.
ALFA	F10.5	Angle of incidence (degrees).
BETA	F10.5	Angle of yaw (degrees).

THTO	F10.5	Angle of outer boundary (degrees). This angle must be larger than the bow shock wave in order for the code to capture the bow shock. Often the best way to choose this value is to calculate the bow shock wave angle (assuming conical flow) and add ten degrees.



GAM	F10.5	Ratio of specific heats (1.4 for air).
SCHEME	F10.5	Input parameter to pick particular TVD scheme. This paramter is used only when LDACCU, or KDACCU, or JDACCU is not equal to 1. = 1/3 for third order accurate scheme. = -1. for fully upwind 2nd order scheme. = 0. for Fromm's 2nd ordere scheme. = 1/2 for low truncation error 2nd order scheme. Normally use -1.
CMPRES	F10.5	Compression factor for clipping. Choose in the range: 1. .LT. CMPRES .LE. (3-SCHEME)/(1-SCHEME) Normally CMPRES = (3-SCHEME)/(1-SCHEME). If negative value is input, default (above is chosen).
DISSIP	F10.5	Parameter defining background dissipation. Normally DISSIP = 0 This option is provided only for testing the role of background dissipation used by central difference method.

PBAC	F10.5	Specified value of pressure on the downstream face of a zone. Used only if IFPBAC = 1. (see note 8 in Appendix 1)
AO	F10.5	Not used.
BO	F10.5	Not used.
CO	F10.5	Not used.
CHL	F10.5	Inverse of geometry scale factor. All input geometry will be divided by CHL. If CHL equals overall length, then all geometry will be nondimensionalized by overall length. If CHL equals 1, then input geometry will be used as is.
XSHIFT	F10.5	Axial geometry shift. This value is added to all input x coordinates. The x coordinate of the apex of the nose of the configuration must be shifted so that it is at 0.0. This is required because the outer boundary is a cone with its apex at X = 0.0.
YSHIFT	F10.5	Vertical geometry shift. This value is added to all input y coordinates. The y coordinate of the nose of the configuration must be shifted so that it is at 0.0. This is required because the outer boundary is a cone with its apex at Y = 0.0.
XWAKE	F10.5	Wake starting location in the axial (X) direction.

XXX02	F10.5	Not used.
XXX03	F10.5	Not used.
XXX04	F10.5	Not used.
OMEGA	F10.5	Overrelaxation parameter for grid generation. Suggested value: 1.0 (for vectorized code)
XXX1	F10.5	Not used.
XXX2	F10.5	Not used.
XXX3	F10.5	Not used.
SMARCH	3X,L3	.TRUE. Run code in space marching mode as the initial sweep. .FALSE. Run code in multiple relaxation sweeps or approximate factorization mode without initial space marching sweep. The .FALSE. option is used to continue further interations on a previous multiple relaxation sweep or approximate factorization run.
MJBGED	3X,L3	Used for restarting an approximate factorization run. .TRUE. Read in beginning and ending chunks (4 grid planes) JBCGB and JBCED from units 11n and 13n. .FALSE. Do not read in beginning and ending chunks from units 11n and 13n.

DISKIN	3X,L3	Used for either multiple sweep or approximate factorization mode. .TRUE. Stored solution is to be read in from disk. For a multiple relaxation sweep run, the old solution is read in on unit 5n. For an approximate factorization run, the old solution is read in from units 21n, 22n, and 23n. .FALSE. Start the calculation with the flowfield initialized to freestream.
MDSKIN	3X,L3	Used for space marching mode. .TRUE. Read in restart solution (initial 3 grid planes of data) from disk. .FALSE. Code generates a conical starting solution at X = XSTART. This flag is also used for the initial space marching sweep of a multiple sweep or approximate factorization case, i.e., SMARCH = .TRUE.
SMAFCB	3X,L3	This flag is used in either of two cases: if NTSTEP .GT. 1 and SMARCH is .TRUE. or if SMARCH is .FALSE. .TRUE. Code uses approximate factorization. .FALSE. Code uses multiple relaxation sweeps.
TAPE8W	3X,L3	Not used.
FORCE	3X,L3	.TRUE. Compute aerodynamic forces and moments for all bodies. .FALSE. Do not do force and moment accounting.

MDISKC	3X,L3	Used for space marching or multiple relaxation sweep mode run. .TRUE. Save each cross section solution on disk for (subsonic) iteration. The flowfield is saved on units 8n and 9n alternatively. To get a complete flowfield on the file, the run must end on NMARCH steps, not on XEND coordinate. MDISKC must be set true for any multiple relaxation sweep run. For a space marching run, MDISKC could be set to .TRUE. to save all of the flowfield for later postprocessing or to be used as a restart for a later multiple relaxation sweep run. .FALSE. Do not save each cross sectional flowfield on disk.
IREAD	3X,L3	.TRUE. Read configuration gemetry form the last section of the input data in the format described in the section titled, "Geometry Input Data" .FALSE. Analytically describe the configuration geometry. The user must modify SUBROUTINE GRID to define the geometry.
MYAW	3X,L3	.TRUE. Yaw calculation. .FALSE. Symmetrical calculation. No change in input gemoetry is required.

Repeat the following two lines of input, NBDTOT number of times.

XMO(i), YMO(i)	*	The x (longitudinal) and y (vertical) origin of the force and moment coordinate system for the i'th body.

		Real constants. (In the coordinate system, adjusted for CHL XSHIFT and YSHIFT.)
AAA(i), ALL(i)	*	The reference area and length for the i'th body. Real constants.

Repeat the following fifteen lines of input, NZONES number of times.

title	*	Any description you want. Typically ZONE n. Not used in the program.
LGRDNZ(i),KGRIDNZ(i), JGRDNZ(i)	*	Number f grid points in the L, K, and J directions for the i'th zone. Note that for space marching JGRDNZ should be set to four. The maximum value of KGRD is 30, although 29 is recommended because of a bug in the creation of TAPE8n. LGRDNZ(1) is ignored and the number used is calculated by the input NPT(i). Integer constants.
LBST(i)	*	Starting checking point for respace. This is the starting value of the grid indice in the L direction for the previus run that is being used for the restart. The grid cells withan L indice of LBSTor greater will be used for interpolation to the new (respaced) grid. This input is primarily used when the run switches from one zone to multiple zones. For any zone on the upper part of the configuration, set LBST to 2. For any zone on the lower part of the configuration set LBST to the L grid indice (of the previous run) that is the maximum half breadth of the configuration. Integer constant.

MJBG(i)	*	Used if MJBGED = .TRUE. = 1 Read front 4 planes of approximate factorization restart data from unit 11n. This option is used if there is subsonic flow that crosses the chunk boundary (i.e., subsonic flow in any of the first four planes of data for this chunk) = 0 Do not read first 4 planes of restart data from unit 11n. This option is used if the flow is fully supersonic at the front of this chunk. Integer constant.
MJED(i)	*	Used if MJBGED = .TRUE. = 1 Read last 4 planes of approximate factorization restrt data from unit 13n. This option is used if there is subsonic flow that crosses the chunk boundary (i.e., subsonic flow in any of the last four planes of data for this chunk. = 0 Do not read last 4 planes of restart data from unit 13n. This option is used if the flow is fully supersonic at the end of this chunk. Integer constant.
METHOD(i)	*	Definition of solution method of i'th zone. The code should automatically use the correct value of METHOD. Use 22 for space marching. Code will automatically change to approximate factorization after first marching solution (see SMAFCB).

NRELAX(i)	*	Number of relaxation subiterations within this zone. Normally set to 2 (or 3 for complex flowfields). Read the instruction for NSUBIT for the interaction between NRELAX and NSUBIT. Integer constant.
MOPRHS(j,i), j=1,3	*	Option on right hand side. The code should automatically use the correct value of MOPRHS. Use +1, +1, -1 for space marching. Integer constant.
MOPLHS(j,i), j=1,3	*	Option on left hand side. The code should automatically use the correct value of MOPLHS. Use 13,23,0 for space marching. Integer constant.
MSDPH(i)	*	For zone 1; number of patches. For zones 2 through NZONES; number of sides (always 4) Integer constant.
MBCTYP(j,i), j=1,MSDPH	*	Boundary condition type on each patch of zone 1 or each side of zone 2 through NZONES. = 0 Zero flux through face. Typically used when the patch or side has collapsed to zero length. = 1 Reflection boundary conditin. Typically used when the patch or side is on the centerline and is a plane of symmetry. = 2 Zonal boundary condition (All Q's known).

	This boundary condition is used when the patch or side abuts another patch or side. Flow is free to pass through the boundary between zones. = 3 Solid wall boundary condition. Integer constant.
MBDZR(j,i),j=1,MSDPH *	The body number that each patch of zone 1 or side of zones 2 through NZONES is part of. This is used for force and moment calculation. Use 0 for any patch or side that is not part of a body. Integer constants.
NZOCNT(j,i),j=1,MSDPH *	The zone number that the patch from zone 1 or side from zones 2 through NZONES is connected to. Use zero for no connection. Integer constant. (See Appendix 2)
NPHCNT(j,i),j=1,MSDPH *	The side or patch number corresponding to NZOCNT. Integer constant. (See Appendix 2)
NDRCNT(j,i),j=1,MSDPH *	Abutting Grid direction indicator. = 0 The grid direction (either L or K) on abutting patches or sides increases in the same direction. = 1 The grid direction (either L or K) increases in the opposite direction. This input is ignored if there is no abutment. (Use 0). Integer constant. (See Appendix 2)

Do the following four lines of input only once.

THHTU(i), i=1, BRM-1 * — The polar angle (degrees) for each grid region terminal point. Input only for zone 1. Integer constant.

INU(i), i=1, NMR-1 * — Grid region terminal points. These values are the surface grid K=1 values where the grid region boundaries intersect the zone 1 inner boundary. Note that the first and last L points are not input as INU(i). See Fig. 3. The values input are L=L+1 for compatibility with the older SIMP code. Integer constant.

ISC * — Number of patches that define the inner surface of zone 1. Integer constant.

NPT(i), i=1,ISC * — Number of surface grid points to be generated for each patch on the inner surface of zone 1. Integer constant.

ND(i), i=1, ISC * — Mesh spacing parameter for each patch of zone 1.
= 0 Equal point spacing.
= 1 Cluster points near beginning of patch.
= 2 Cluster points near end of patch.
Integer constant.

Repeat the following line once for each zone from zone 2 to zone NZONES.

NDA(i), i=1, 4 * — Mesh spacing parameter for each of the four sides of zones 2 through NZONES.
= 0 Equal point spacing.

= 1 Cluster points near beginning of side.
= 2 Cluster points near each side.
Integer constant.

Wake Treatment

Behind the trailing edge of a lifting surface, a wake cut is introduced (see Fig. 3). The treatment of wake cut within the code requires the knowledge of starting and ending L index values of the upper wake cut and the lower one. Depending on the sweep of the trailing edge, the wake cut is appropriately modeled. This is illustrated in Fig. 3. The user has to define the shape of the trailing edge and also the starting x value in Subroutine MGRID where the wake begins to appear in the cross-sectional geometry (XWAKE). The wake cut is part of a patch which contains the wing also as illustrated in Fig. 3. As marching proceeds along the axial direction, the extent of the wake cut grows within that patch. The nomenclature for the starting and ending points of the wake cut are also indicated in Fig. 3. The number of points in the patch containing the wake cut is not allowed to change during the calculation. Thus, while exercising the respace option in the region containing the wake, the user has to ensure that the number of points in the wake patch (usually there are two wake patches; one corresponding to the upper cut and one for the lower cut) is not altered.

The shape of the trailing edge is provided by the user using the update option. The hardwired equations in the source code determine LWKEU, the L value at the outer edge of the upper surface wake patch and LWKSL, the L value at the outer edge of the lower surface is found in subroutine MGRIDC. The specific code is:

```
C...
C.........CALCULATE WAKE ENDING POINT.............
C...
      XLO = XLOC
      IF (XLOC.GE.XWAKE) THEN
```

```
C...
          AA = -15.65
          BB = -8288.98
          ZWK = AA*XLOC-BB
C
```

The variable ZWK is the spanwise coordinate of the outer edge of the wake. To change the line to your configuration, use UPDATE to change the constant AA and BB as follows:

```
*D MGRIDC.69,MGRIDC.70
          AA = -10.
          BB = -6000.
```

If the trailing edge of the configuration is not a straight line, a new equation for ZWK is necessary.

Geometry Data

The cross-sectional geometry of a typical aircraft changes considerably in the axial direction due to emergence of various components such as canopy, wing, nacelle, and tail, etc. The marching computation, as it sweeps along the marching direction ξ, has to account for this geometry variation to set up the proper body-fitted corrdinate system to aid in the application of body boundary conditions. To treat complex geometry cross sections, zones and patches are introduced to define the geometry cross-section, as indicated in Fig. 4. A configuration is defined by several regions of cross sections. The number of zones and patches defining a section is constant for a given region (Fig. 4). The geometry treatment for a single zone and multi-zone are different and is described in the following:

For a single zone case, only the body surface (side 3 in Fig. 4) is prescribed at discrete points in a crossplane (x = constant plane) at various axial locations (i.e., there is no change is geometry input data between EMTAC and EMTAC-MZ code).

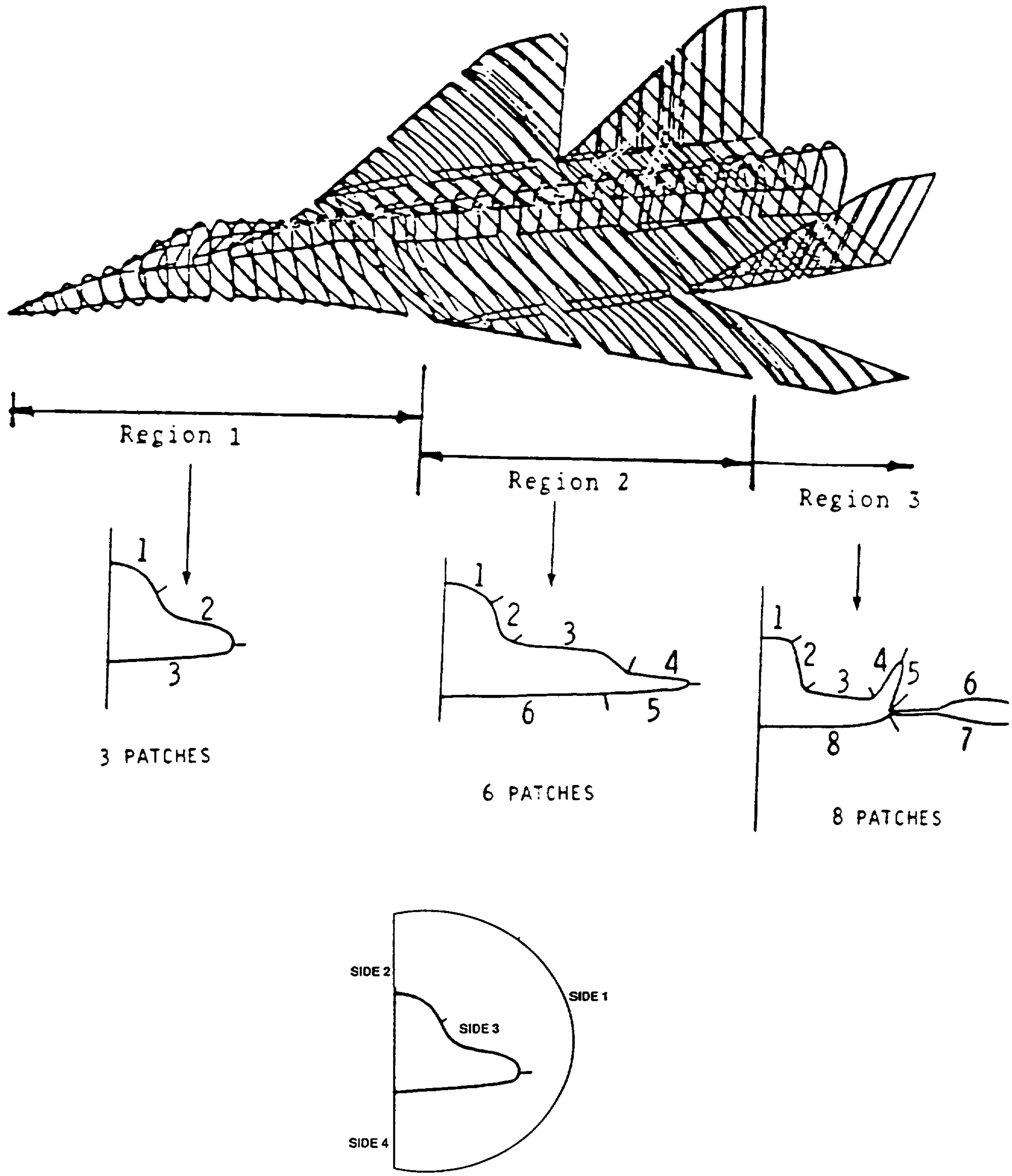


Fig. 4 Sample problem for single zone.

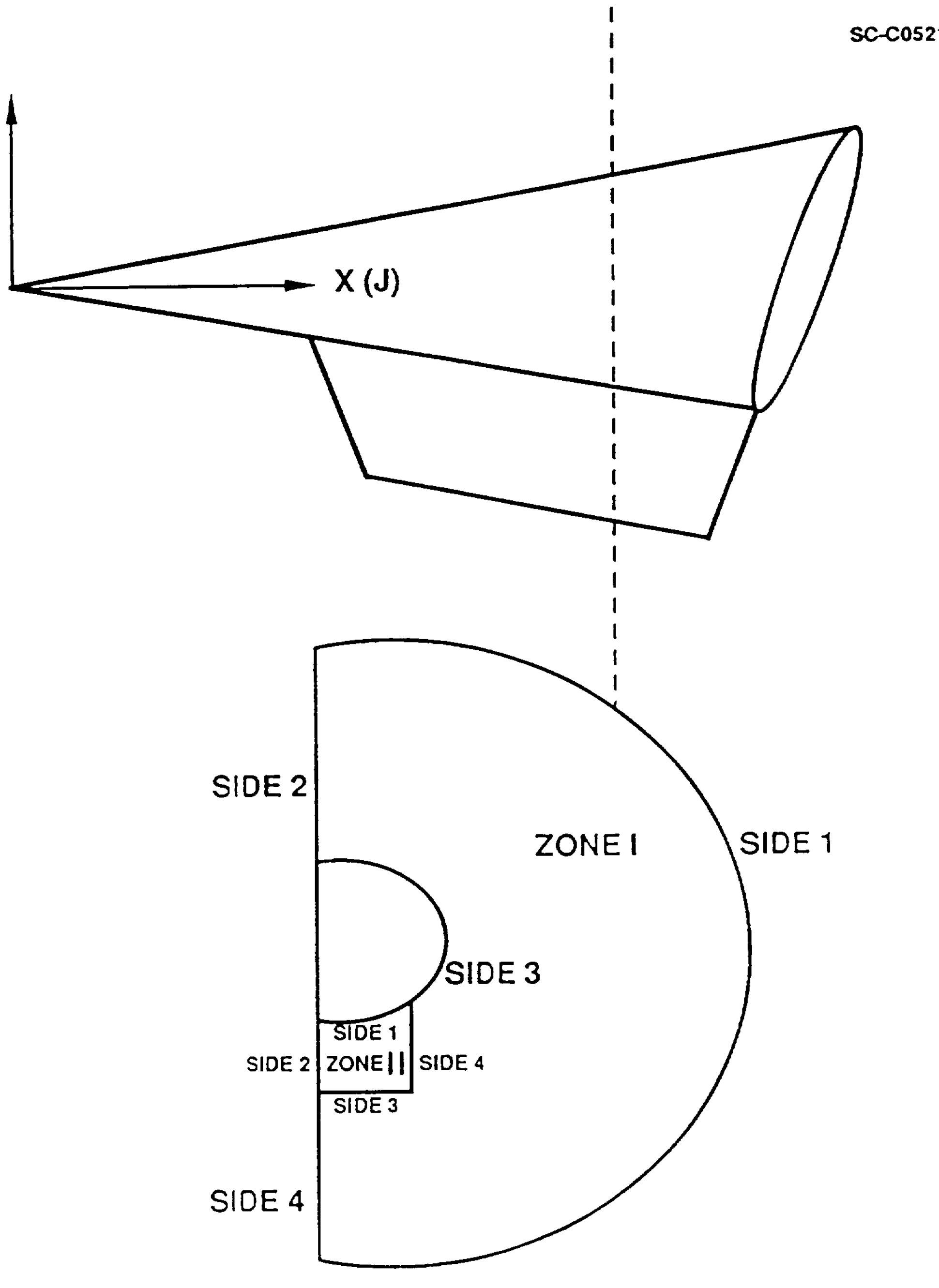


Fig. 5 Sample problem for multi-zone.

For multi-zone cases, first an outer zone (zone 1) is generated in the same way as in the case of single zone, then the inner zones (zone 2, 3, etc.) are determined by prescribing four sides (Fig. 5). The geometry input data for first zone are exactly the same as single zone, and four side discrete points have to be supplied to form the rest of the zones. Except the first zone, only one patch for each side is allowed and the L,K coordinates of all the zones have to be aligned (grid lines have to be continuous across a zonal boundary).

A complete computation over a configuration such as the one in Fig. 4 is usually done in segments rather than in one shot. The calculation starts from the nose and proceeds along ξ. Even within a region (defined by the same number of patches), the calculation might be done in segments using the restart option in the code. Restart is used any time the calculation is halted and then continued with another run that picks up where the previous run left off. Pure restart is performed only when there is no alteration to the number of points along η and along ξ, and no change in the number of grid points per patch between the previus run and the current restartrun. If there is any alteration to the total zone numbers of the grid structure, the restart run will automatically perform a respace operation to interpolate the solution from the previous solution grid to the current grid. Respace is used whenever the following situations are encountered:

1. Total zone number is increased.
2. Number of patches defining the cross section at first zone is changed. This situation occurs when the cross-sectional geometry becomes more complex. This is illustrated in Fig. 4.
3. Number of KGRD (KGRD = KMAX-1) and/or LGRD (LGRD = LMAX-1) points in each zone is changed (even if the number of patches defining the cross section is kept the same as before). This situation often occurs for cases where a patch length is increasing with ξ. For example, a swept wing is very small when it first appears in the cross section of the geometry and ony requires a few grid points for accurate computation of the flow field. However, as the analysis is continued in the ξ direction, the wing patches grow and will require more points for accurate flow field analysis.

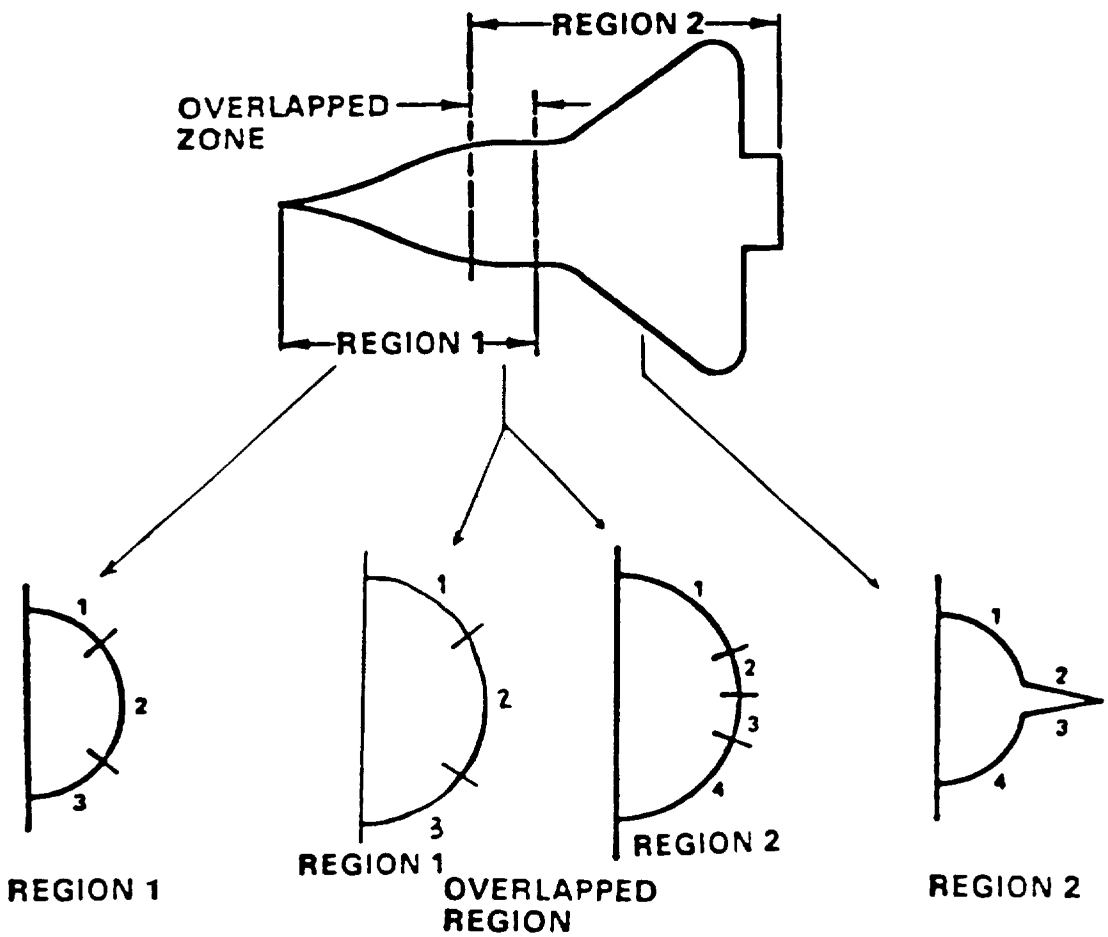


Fig. 6 Cross section patches in overlap region.

4. Number of grid points per patch is changed (even if KGRD is kept the same as before).

Any time a respace is required, the code must be stopped. The code will automatically do a respace if KGRD or LGRD is different from the previus values of KGRD and LGRD for each zone.

One may be able to compute the entire configuration using the same number of zones and patches and same KGRD and LGRD values for each zone throughout to avoid the respace requirement. This will mean even in the forebody region of a configuration, where the cross-sectional geometry is ususally simple, more grid points and more patches are to be used than necessary to adequately resolve the flow field. Use of the same number of patches and grid points for throughout the length of the configuration is generally not recommended. Ths can substantially increase the total execution time.

Transitioning from one region to the next (number of patches and/or zone is changed) requires an overlapped region, as illustrated in Fig. 6, to allow for increased or decreased number of patches in the next region. The extent of this overlapped region must be sufficient to include at least the final three marching data planes of the prior region. In the overlapped region, the data from the previus region is interpolated onto the grids of the new region. For the example in Fig. 4, the results from the 4-patch region are interpolated onto a six-patch region in zone 1 grid at the same x location. This is required in order to continue marching along the body with the new patch definition.

Figure 6 illustrates how to transition from a fuselage computation to a wing-fuselage computation in first zone. First, the calculation is performed for the fuselage section denoted by REGION1 which ends just prior to the starting point of the wing. This calculation might involve, say, three patches. Then, to introduce the wing, four patch representation is used in REGION2. In the overlapped region, the fuselage which is defined using a four patch representation in REGION1 is represented by a four patch representation as part of REGION2. The second and third patch locations on the fuselage in REGION2 within the overlapped zone are chosen in the vicinity of where the leading edge of the wing is expected to emerge from the fuselage.

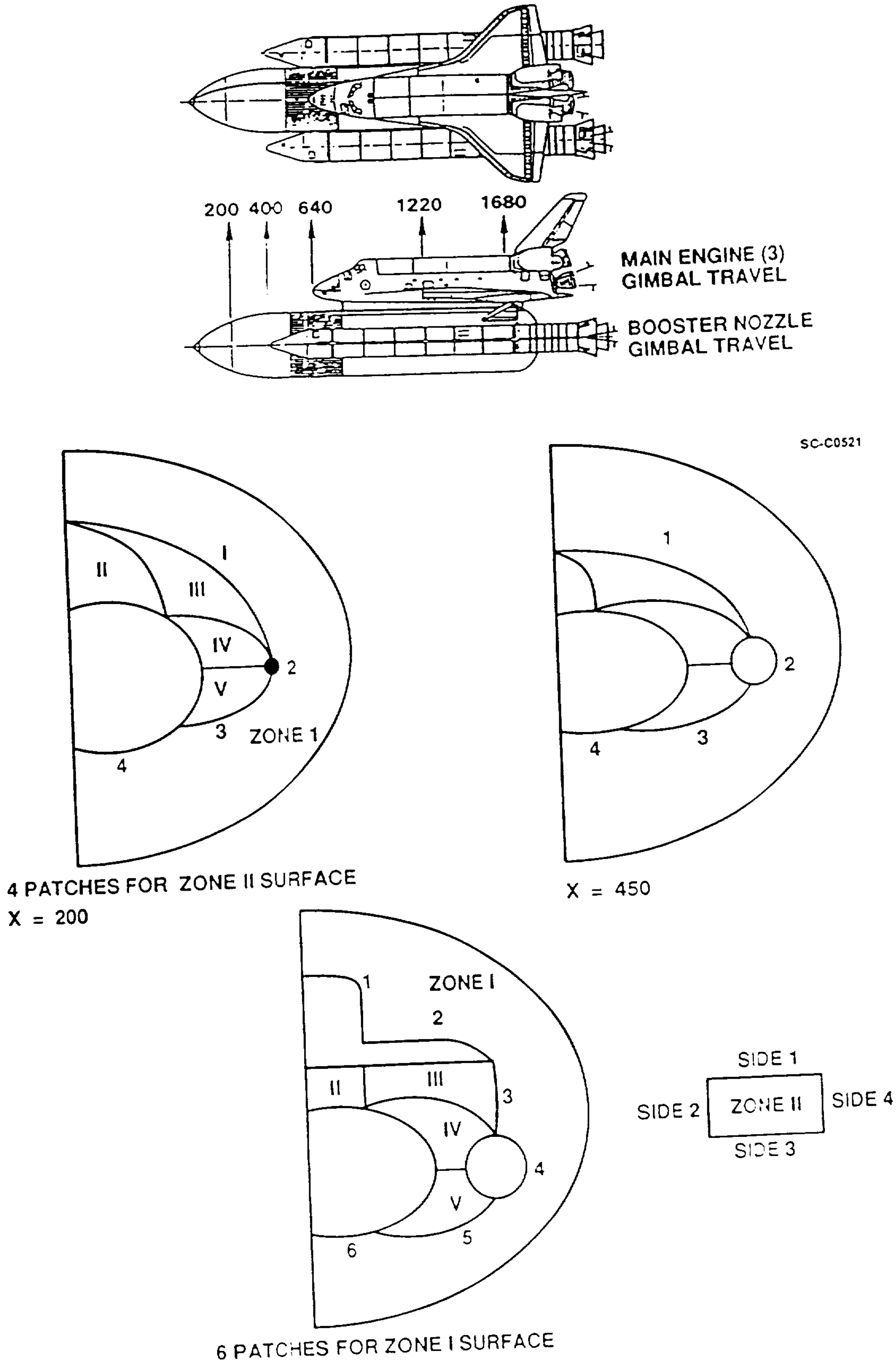


Fig. 7 Multi-zone of Space Shuttle with ET and SRBS.

For the multi-zone case of space shuttle with external tank and solid rocket booster (Fig. 7), the first cross section has four patches and the last has six patches in zone I. Zero length patches are permissible. For the subzones (zone II-V), all four sides have to be prescribed and only one patch is allowed on each side. Sides 1, 2, 3, and 4 are corresponding to K = KGRD, L = 2, K = 1, and L = LGRD, respectively.

The format for a typical station is shown below. The group of cards is repeated for each station of a region. The last point of each patch (except for the last patch of a station) should have the same coordinates as the first point of the next patch.

Geometry Input Data

Card No.	Format	Field	Name	Description
The group of cards, A1 through A4, is repeated for each input cross section.				
A1	F15.6,I5	1	X1	The axial (X) coordinate of this station.
		2	ISC1	The number of patches (for zone 1) for this section.
The group of cards, A2 through A4, is repeated NZONES times per cross section.				
A2	5A4	1	title	Dummy title, not used by code. Typically, 'ZONE i' Card A2 is only used if NZONES .GT. 1.
A3	2I5	1	ITH	Patch (for zone 1) or side (for zones 2 through NZONES) number.
		2	IPT	Number of input geometry points. (2 .GE. IPT .LE. 30)
The A4 card is repeated IPT times.				
A4	2F15.6	1	YK	Vertical location of input geometry points (positive upwards). Points start at top centerline.
		1	ZK	Spanwise location of input geometry point (positive outwards).

4.0 CONCLUSIONS

A unified computer code EMTAC-MZ has been developed and can be applied to efficiently solve the unsteady Euler equations for three-dimension inviscid flows across the Mach number range. The multi-zone technique is used to treat very complex geometries and combined yaw and angle of attack cass. The geometry setup for single zone cases are exactly the same as SIMP and EMTAC code. Numerical results are obtained for several realistic fighter configurations and mated Shuttle Orbiter with external tank and solid rocket boosters. Solutions are in very good agreement with available experimental data.

5.0 REFERENCES

1. K.-Y. Szema, S. Chakravarthy, and V. Shankar, "Supersonic Flow Computations Over Aerospace Configuration Using an Euler Marching Solver," NASA Contract Report 4085, July 1987.

2. S. Chakravarthy and K.-Y. Szema, "Euler Solver for Three-Dimensional Superesonic Flow with Subsonic Pockets," Journal of Aircraft 24, 73 (1987); S. Chakravarthy and K.-Y. Szema, "Advances in Finite Difference Techniques for Computational Fluid Dynamics," State-of-the-Art Surveys on Computational Mechanics, ASME, 1989, pp. 1-47.

3. K.-Y. Szema, S.R. Chakravarthy, D. Pan, B.L. Bihari, W.T. Riba, V.M. Akday and H.S. Dresser, "The Application of Unified Marching Technique for Flow Over Complex Three-Dimensional Configuration Across the Mach Number Range," AIAA Paper No. 88-0276, Jan. 1988.

4. K.-Y. Szema, S.R. Chakravarthy and B.L. Bihari, "F-14 Flow Field Simulation," AIAA Paper No. 89-0642, Jan. 1989.

APPENDIX 1

There are a few notes which may help the user in running EMTAC-MZ easier which are given in this Appendix:

1. The code when run in space marching mode stops based on one of three conditions:
   a. The number of space marching steps for this run equals NMARCH.
   b. The next step would exceed the x coordinate of XEND.
   c. There is no more input geometry that has the input number of patches, ISC in zone 1.

2. The geometry used in the code calculations and code printouts has had XSHIFT added to the input axial (X) coordinates and YSHIFT added to the input vertical (y) coordinates. Note that the input values, XSTART, XEND, and XWAKE are in the transformed (shifted) coordinate system.

3. The coordinate system for the code is right handed. X is positive aft along the vehicle in the horizontal plane. Z is positive out the wing in the horizontal plane. Y is vertical, positive upwards.

4. Grid directions. See Fig. 5.

   For zone 1:

   J Increasing as you go aft in the axial (X) direction.

   K Normal to the inner input surface (body). K = 1 is inner surface. K = KGRDNZ(1) is outer conical boundary.

   L Circumferential direction around the inner surface. L = 1 is the top centerline. L = LGRDNZ(1) is the lower centerline.

   For zone 2 through NZONES:

   J Increasing as you go aft in the axial (X) direction.

   K Increasing as you go from side 3 to side 1. K = 1 on side 3. K = KGRDNZ(i) on side 1.

L Increasing as you go from side 2 to side 4. L = 1 on side 2.
L = LGRDNZ(i) on side 4.

A restriction in the code is that the J, K, and L directions of the grid must form a right hand rule.

5. Some notes about a space marching restart where the DX values are changing. If you do a restart with a new value of DX, the first two steps of the run will use the old DX value.

6. You must restart the code if you change anything having to do with gridding. The code will interpolate the flowfield data to the new grid locations only if you change the total number of points on the zone 1 boundary (in either L or K direction), change the number of points on any patch in zone 2 through n, or change the number of zones. Therefore, if you change any gridding parameter, you must do one of the above three things in order to get the new flowfield data at the proper location.

7. There are two methods of doing a grid alone run, i.e., generating a grid without solving for the flowfield:
   a. To generate a grid for a specific axial location, set
      XSTART = xxx.xx
      NMARCH = 0

      This will generate a plot file on unit 7n for each zone. The requested axial location will be the third grid station in the plot file. The flowfield data in this file will be zeroed out.
   b. To generate the grid for every marching station, set
      NSUBIT = 0
      NMARCH = n
      MDISKC = .TRUE.

This will generate a file on unit 8n for each zone that contains all of the grid. The flowfield data in the file will be zeroed out. An alternative method to generate the grid on unit 22n is to set

```
NSUBIT = 0
NMARCH = n
SMAFCB = .TRUE.
MDISKC = .TRUE.
NTSTEP = 2.
```

Again, the flowfield data will be zeroed out.

8. The following hardwired code modifications are required to use the downstream face pressure boundary condition (IFPBAC = 1 and PBAC = pressure: P/P_∞

   a. For setting the pressure on the downstream face of zone 1, use UPDATE to modify routine UBCJE

```
* D UBCJE.114,UBCJE.115
        NPGIV = 1
        IF (MTOTL.EQ.nn.AND.NPGIV.EQ.1)THEN
```

   where nn equals the total step count where boundary condition is to be applied.

   b. For setting the pressure on the downstream face of any zone 2 through 5, use UPDATE to modify routine UBCJE

```
* D UBCJE.158
        NPGIV = 1
        IF
        (MTOTL.EQ.nn.AND.NPGIV.EQ.1.AND.INZONE.EQ.n)THE
        N.
```

where nn equals the total step count where boundary condition is to be applied and n is the zone for which the downstream face pressure boundary condition is to be applied.

WARNING: The UBCJE routine appears to support only 5 zones.

9. Some notes on combined space marching and multiple sweep relaxation runs:

   a. You cannot start off the run with a grid/flowfield reinterpolation. See note 7 for the conditions under which a flowfield reinterplation coccurs.
   b. You must end the run on NMARCH steps, not on an XEND coordinate.
   c. The EMTAC-MZ code is like the EDMTAC code, you must have constant X step size if you do both forward and backward sweeps.
   d. The EMTAC-MZ code is hardwired in subroutine MDRIVE to do NTBAC number.

10. Some notes on grid generation. In certain instances, it may be better to use a value of NITER = 0 to get a transfinite interpolation grid instead of NITER = 30 to get a converged eliptic grid. The first case is in the local area just off the surface of a concave wall. Elliptic gridders tend to stretch grid cells normal to a concave wall too much. These elongated cells may lead to poor convergence. The second case is for a symmetrical cross section with respect to the Z axis. The elliptic gridder generates a slightly nonsymmetric grid, whereas the transfinite interpolation grid is symmetric.

    The EMATCMZ flow is robust enough that it will tolerate the nonsmooth grids generated by a transfinite interpolation procedure.

APPENDIX 2

A sample input of AVSTOL-3 configuration at $M_\infty = 1.5$ and $\alpha = 3.0°$ is given in each cross section are used in this calculation. The results are presented in detail in Ref. 3, which is included in Appendix 3.

02	NZONES I5	NO. OF ZONE.
01	NTSETP	NO. OF TIME MARCHING STEP (GLOB ITER).
10	NSTORE	RESTART SOLUTION FOR TIME MARCHING.
10	NPRTT	OUTPUT SOLUTION FOR TIME MARCHING.
0	ISTART	TIME MARCH RESTART.
1	ITSTEP	-:VAR. TM STEP.(X,Y,Z), +:CST. TM STEP.
50	NMARCH	NO. OF SPACE MARCHING STEP.
10	NDISKM	RESTART SOLUTION FOR SPACE MARCHING.
20	NPRTM	OUTPUT SOLUTION FOR SPACE MARCHING.
50	MCONE	NO. OF ITERATIONS FOR CONICAL SOLUTION.
02	LDACCU	L-DIR. ACCURACY. 1:1ST ORDER.
02	KDACCU	K-DIR. ACCURACY.
01	JDACCU	J-DIR. ACCURACY.
02	NSUBIT	NO. OF INTERNAL ITERATION.
30	NITERI	NO. OF ITERATION FOR GRID.
1	IFPBAC	0: NO CONDITION SPEC, 1:BACK P MUST BE GIVEN.
05	NEWCFL	NO. OF TIME STEP FOR WHICH TIME STEP=C.
01	NEWDTI	NO. OF TIME STEP AFTER THAT A NEW TIME STEP.
00	SONIC	0:NO SPECIAL SONIC TREATMENT, 1:MOREMDISSIP.
2	NRM	NO. OF REGION TO GENERATE GRID.
1	NBDTOT	NO. OF BODY. (FOR FORCE CALCULATION.)
14	LWKSU	WAKE STARTING POINT.
27	LWKEL	WAKE ENDING POINT.
1	NXXXXX	NOT USED.
500.0	CFLNEW F30.5	CFL NUMBER.
500.0	CFLMIN	MINIMUM CFL NO.
500.0	CFLMAX	MAXIMUM CFL NO.
1.20	CFLINC	CFL SHOULD FLINC*CFL
0.95	CFLDEC	CFL SHOLLD > CFLDEC*CFL
001.5	DXIN	STEP SIZE FOR SPACE MARCHING.
001.5	DXMIN	MIN. STEP SIZE FOR SPACE MARCHING.
01.5	DXMAX	MAX. STEP SIZE FOR SPACE MARCHING.
15.00	XSTAT	STARTING X LOCATION FOR SPACE MARCHING.
139.00	XEND	ENDING X LOCATION FOR SPACE MARCHING.
1.50	FSMACH	FREE STREAM MACH NO.
03.00	ALFA	ANGLE OF ATTACK.
0.00	BETA	ANGLE OF YAW.
65.0	THTO	OUTER BOUNDARY ANGLE.
1.4	GAM	RATIO OF SPECIFIC HEAT.
-1.00	SCHEME	0.33:3ND, -1.:2ND,I0.5:LOW TR. 2ND
1.0	COMPRES	(3-SCHEME)/(1-SCHEME)
00.	DISSIPS	DEFINING BACKGROUND DISSIPATION.
1.01	PBAC	SPECIFIED BACKTPRESSURE.TREAM)
27.00	AO	NOT USED.
90.0	BO	NOT USED.
-25.0	CO	NOT USED.
001.	CHL	CHARACTERISTIC LENGTH
000.0	XSHIFT	AXIAL COORDINATE SHIFT.
000.0	YSHIFT	Y-AXI COORDINATE SHIFT.
9999.0	XWAKE	STARTING X WAKE LOCATION.
000.0	XXX02	NOT USED.
000.0	XXX03	NOT USED.
000.0	XXX04	NOT USED.
0.80	OMEGA	RELAXIATION FACTOR.

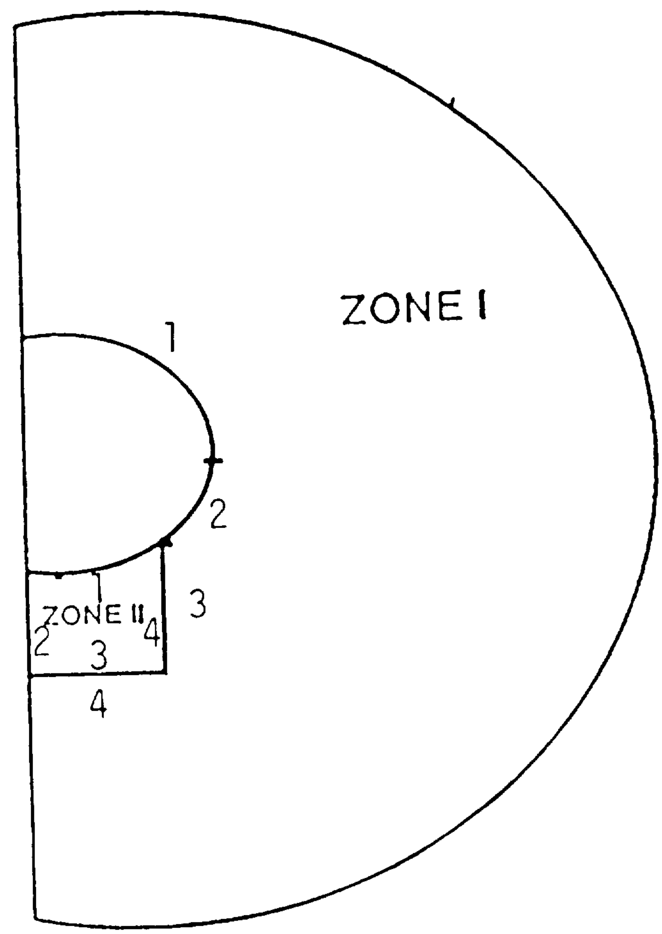


Fig. A1. Zone and patch number for AVSTOL-3.

```
      0.000    XXX1              NOT USED.
      0.000    XXX2              NOT USED.
      0.000    XXX3              NOT USED.
        T      SMARCH      L3   SPACE MARCHING
        F      MJBGED            READ IN JBCBG & JBCED DATA FROM UNIT 110&130.
        F      DISKIN            RESTART DATA FROM DISK ( TIME M. MODE )
        F      MDSKIN            RESTART DATA FROM DISK.(SPACE M. MODE )
        F      SMTMCB            COMBINE SPACE AND TIME MARCHING.
        F      TAPE8W            NOT USED.
        F      FORCE             DO FORCE CALCULATION
        F      MDISKC            SAVE EACH CROSS-SEC. SOLU. FOR SUBSONIC ITER.
        T      IREAD             INPUT GEOMETRY DATA
        F      MYAW              YAW CALCULATION
     0.0, 0.0                    XM0,YM0 (REF. X&Y FOR PITCH MOMENT) ** BODY
   100.0,  100.000               AAA,ALL (REF. AREA & LENGTH)        **   1
 ****** ZONE 1 ******
 20,20,4      L,K,J    *        LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
     02,      LBST     *        STARTING CHECKING POINT FOR RESPACEING.
     00       MJBG     *        IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
     00       MJED     *        IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
     22,      METHOD   *        EXPLIC OR APPFAC.
     01,      NRELAX   *        NO. OF RELAX. SUBERATIONS
 +1,+1,-1     MOPRHS            OPTION ON R.H.S.
 13,23,0      MOPLHS            OPTION ON L.H.S.
 04           MSDPH             HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
 3,3,2,2      MBCTYP 0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WALL
 1,1,1,1      MBDZR  FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #)
 0,0,2,2      NZOCNT EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
 0,0,4,3      NPHCNT ..........................SIDE. ..........
 0,0,1,1      NDRCNT DIRECTION (0:SAME DIR,1:OPSIT-DIR)
 ****** ZONE 2 ******
 09,09,04     L,K,J    *        LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
     02,      LBST     *        STARTING CHECKING POINT FOR RESPACEING.
     00       MJBG     *        IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
     00       MJED     *        IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
     22,      METHOD   *        EXPLIC OR APPFAC.
     01,      NRELAX   *        NO. OF RELAX. SUBERATIONS
 +1,+1,-1     MOPRHS            OPTION ON R.H.S.
 13,23,0      MOPLHS            OPTION ON L.H.S.
 04           MSDPH             HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
 3,1,2,2      MBCTYP            0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WA
 0,1,0,0      MBDZR             FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #
 0,0,1,1      NZOCNT            EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
 0,0,4,3      NPHCNT            ...................SIDE. ..........
 0,0,1,1      NDRCNT            DIRECTION (0:SAME DIR,1:OPSIT-DIR)
    17                             INU 5I5 GRID SECTION LINE
    00.0                           ANGLE
    04        ISC                  NO. OF PATCH. (GEOMETRY)
    08   12    09     09           POINTS PER PATCHS
    00   00    00     00           ND FOR ZONE 1
    00   00    00     00           ND FOR ZONE 2
```

02	NZONES	I5	NO. OF ZONE.
01	NTSETP		NO. OF TIME MARCHING STEP (GLOB ITER).
10	NSTORE		RESTART SOLUTION FOR TIME MARCHING.
10	NPRTT		OUTPUT SOLUTION FOR TIME MARCHING.
0	ISTART		TIME MARCH RESTART.
1	ITSTEP		-:VAR. TM STEP.(X,Y,Z), +:CST. TM STEP.
100	NMARCH		NO. OF SPACE MARCHING STEP.
10	NDISKM		RESTART SOLUTION FOR SPACE MARCHING.
20	NPRTM		OUTPUT SOLUTION FOR SPACE MARCHING.
50	MCONE		NO. OF ITERATIONS FOR CONICAL SOLUTION.
02	LDACCU		L-DIR. ACCURACY. 1:1ST ORDER.
02	KDACCU		K-DIR. ACCURACY.
01	JDACCU		J-DIR. ACCURACY.
02	NSUBIT		NO. OF INTERNAL ITERATION.
30	NITERI		NO. OF ITERATION FOR GRID.
1	IFPBAC		0: NO CONDITION SPEC, 1:BACK P MUST BE GIVEN.
05	NEWCFL		NO. OF TIME STEP FOR WHICH TIME STEP=C.
01	NEWDTI		NO. OF TIME STEP AFTER THAT A NEW TIME STEP.
00	SONIC		0:NO SPECIAL SONIC TREATMENT, 1:MOREMDISSIP.
2	NRM		NO. OF REGION TO GENERATE GRID.
1	NBDTOT		NO. OF BODY. (FOR FORCE CALCULATION.)
14	LWKSU		WAKE STARTING POINT.
27	LWKEL		WAKE ENDING POINT.
1	NXXXXX		NOT USED.
020.0	CFLNEW	F30.5	CFL NUMBER.
020.0	CFLMIN		MINIMUM CFL NO.
500.0	CFLMAX		MAXIMUM CFL NO.
1.50	CFLINC		CFL SHOULD FLINC*CFL
0.95	CFLDEC		CFL SHOLLD > CFLDEC*CFL
001.0	DXIN		STEP SIZE FOR SPACE MARCHING.
001.0	DXMIN		MIN. STEP SIZE FOR SPACE MARCHING.
01.2	DXMAX		MAX. STEP SIZE FOR SPACE MARCHING.
140.00	XSTAT		STARTING X LOCATION FOR SPACE MARCHING.
215.00	XEND		ENDING X LOCATION FOR SPACE MARCHING.
1.50	FSMACH		FREE STREAM MACH NO.
03.00	ALFA		ANGLE OF ATTACK.
0.00	BETA		ANGLE OF YAW.
65.0	THTO		OUTER BOUNDARY ANGLE.
1.4	GAM		RATIO OF SPECIFIC HEAT.
-1.00	SCHEME		0.33:3ND, -1.:2ND,I0.5:LOW TR. 2ND
1.0	COMPRES		(3-SCHEME)/(1-SCHEME)
00.	DISSIPS		DEFINING BACKGROUND DISSIPATION.
1.01	PBAC		SPECIFIED BACKTPRESSURE.TREAM)
27.00	AO		NOT USED.
90.0	BO		NOT USED.
-25.0	CO		NOT USED.
001.	CHL		CHARACTERISTIC LENGTH
000.0	XSHIFT		AXIAL COORDINATE SHIFT.
000.0	YSHIFT		Y-AXI COORDINATE SHIFT.
9999.0	XWAKE		STARTING X WAKE LOCATION.
000.0	XXX02		NOT USED.
000.0	XXX03		NOT USED.
000.0	XXX04		NOT USED.
0.80	OMEGA		RELAXIATION FACTOR.

```
    0.000    XXX1              NOT USED.
    0.000    XXX2              NOT USED.
    0.000    XXX3              NOT USED.
     T       SMARCH      L3    SPACE MARCHING
     F       MJBGED            READ IN JBCBG & JBCED DATA FROM UNIT 110&130.
     F       DISKIN            RESTART DATA FROM DISK ( TIME M. MODE )
     T       MDSKIN            RESTART DATA FROM DISK.(SPACE M. MODE )
     F       SMTMCB            COMBINE SPACE AND TIME MARCHING.
     F       TAPE8W            NOT USED.
     F       FORCE             DO FORCE CALCULATION
     F       MDISKC            SAVE EACH CROSS-SEC. SOLU. FOR SUBSONIC ITER.
     T       IREAD             INPUT GEOMETRY DATA
     F       MYAW              YAW CALCULATION
   0.0, 0.0                    XM0,YM0 (REF. X&Y FOR PITCH MOMENT) ** BODY
  100.0,  100.000              AAA,ALL (REF. AREA & LENGTH)        **   1
****** ZONE 1 ******
20,20,4     L,K,J    *         LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST     *         STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG     *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED     *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD   *         EXPLIC OR APPFAC.
    01,     NRELAX   *         NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS             OPTION ON R.H.S.
13,23,0     MOPLHS             OPTION ON L.H.S.
05          MSDPH              HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,3,3,3,3     MBCTYP 0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WALL
1,1,1,1,1     MBDZR  FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #)
0,0,0,0,0     NZOCNT EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,0,0,0     NPHCNT ..........................SIDE. ..........
0,0,0,0,0     NDRCNT DIRECTION (0:SAME DIR,1:OPSIT-DIR)
****** ZONE 2 ******
09,09,04    L,K,J    *         LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST     *         STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG     *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED     *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD   *         EXPLIC OR APPFAC.
    01,     NRELAX   *         NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS             OPTION ON R.H.S.
13,23,0     MOPLHS             OPTION ON L.H.S.
04          MSDPH              HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,1,3,3     MBCTYP             0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WA
0,1,0,0     MBDZR              FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #
0,0,0,0     NZOCNT             EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,0,0     NPHCNT             ....................SIDE. ..........
0,0,0,0     NDRCNT             DIRECTION (0:SAME DIR,1:OPSIT-DIR)
   18                            INU 5I5 GRID SECTION LINE
   00.0                          ANGLE
   05       ISC                  NO. OF PATCH. (GEOMETRY)
   10   12   08   09   09            POINTS PER PATCHS
   00   00   00   00   00            ND FOR ZONE 1
   00   00   00   00   00            ND FOR ZONE 2
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 02      NZONES   I5     NO. OF ZONE.
 01      NTSETP          NO. OF TIME MARCHING STEP (GLOB ITER).
 10      NSTORE          RESTART SOLUTION FOR TIME MARCHING.
 10      NPRTT           OUTPUT SOLUTION FOR TIME MARCHING.
  0      ISTART          TIME MARCH RESTART.
  1      ITSTEP          -:VAR. TM STEP.(X,Y,Z), +:CST. TM STEP.
100      NMARCH          NO. OF SPACE MARCHING STEP.
 10      NDISKM          RESTART SOLUTION FOR SPACE MARCHING.
 20      NPRTM           OUTPUT SOLUTION FOR SPACE MARCHING.
 50      MCONE           NO. OF ITERATIONS FOR CONICAL SOLUTION.
 02      LDACCU          L-DIR. ACCURACY. 1:1ST ORDER.
 02      KDACCU          K-DIR. ACCURACY.
 01      JDACCU          J-DIR. ACCURACY.
 02      NSUBIT          NO. OF INTERNAL ITERATION.
 30      NITERI          NO. OF ITERATION FOR GRID.
  1      IFPBAC          0: NO CONDITION SPEC, 1:BACK P MUST BE GIVEN.
 05      NEWCFL          NO. OF TIME STEP FOR WHICH TIME STEP=C.
 01      NEWDTI          NO. OF TIME STEP AFTER THAT A NEW TIME STEP.
 00      SONIC           0:NO SPECIAL SONIC TREATMENT, 1:MOREMDISSIP.
  2      NRM             NO. OF REGION TO GENERATE GRID.
  1      NBDTOT          NO. OF BODY. (FOR FORCE CALCULATION.)
 14      LWKSU           WAKE STARTING POINT.
 27      LWKEL           WAKE ENDING POINT.
  1      NXXXXX          NOT USED.
100.0    CFLNEW F30.5    CFL NUMBER.
100.0    CFLMIN          MINIMUM CFL NO.
500.0    CFLMAX          MAXIMUM CFL NO.
  1.50   CFLINC          CFL SHOULD FLINC*CFL
 0.95    CFLDEC          CFL SHOLLD > CFLDEC*CFL
001.0    DXIN            STEP SIZE FOR SPACE MARCHING.
001.0    DXMIN           MIN. STEP SIZE FOR SPACE MARCHING.
 01.2    DXMAX           MAX. STEP SIZE FOR SPACE MARCHING.
215.00   XSTAT           STARTING X LOCATION FOR SPACE MARCHING.
270.00   XEND            ENDING   X LOCATION FOR SPACE MARCHING.
 1.50    FSMACH          FREE STREAM MACH NO.
 03.00   ALFA            ANGLE OF ATTACK.
  0.00   BETA            ANGLE OF YAW.
 65.0    THTO            OUTER BOUNDARY ANGLE.
  1.4    GAM             RATIO OF SPECIFIC HEAT.
 -1.00   SCHEME          0.33:3ND, -1.:2ND,I0.5:LOW TR. 2ND
  1.0    COMPRES         (3-SCHEME)/(1-SCHEME)
 00.     DISSIPS         DEFINING BACKGROUND DISSIPATION.
 1.01    PBAC            SPECIFIED BACKTPRESSURE.TREAM)
   27.00 AO              NOT USED.
   90.0  BO              NOT USED.
  -25.0  CO              NOT USED.
  001.   CHL             CHARACTERISTIC LENGTH
000.0    XSHIFT          AXIAL COORDINATE SHIFT.
000.0    YSHIFT          Y-AXI COORDINATE SHIFT.
9999.0   XWAKE           STARTING X WAKE LOCATION.
000.0    XXX02           NOT USED.
000.0    XXX03           NOT USED.
000.0    XXX04           NOT USED.
  0.80   OMEGA           RELAXIATION FACTOR.
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   0.000    XXX1                NOT USED.
   0.000    XXX2                NOT USED.
   0.000    XXX3                NOT USED.
    T       SMARCH     L3       SPACE MARCHING
    F       MJBGED              READ IN JBCBG & JBCED DATA FROM UNIT 110&130.
    F       DISKIN              RESTART DATA FROM DISK ( TIME M. MODE )
    T       MDSKIN              RESTART DATA FROM DISK.(SPACE M. MODE )
    F       SMTMCB              COMBINE SPACE AND TIME MARCHING.
    F       TAPE8W              NOT USED.
    F       FORCE               DO FORCE CALCULATION
    F       MDISKC              SAVE EACH CROSS-SEC. SOLU. FOR SUBSONIC ITER.
    T       IREAD               INPUT GEOMETRY DATA
    F       MYAW                YAW CALCULATION
   0.0, 0.0                     XM0,YM0 (REF. X&Y FOR PITCH MOMENT) ** BODY
  100.0,  100.000               AAA,ALL (REF. AREA & LENGTH)        **   1
****** ZONE 1 ******
20,20,4     L,K,J     *         LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST      *         STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG      *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED      *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD    *         EXPLIC OR APPFAC.
    01,     NRELAX    *         NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS              OPTION ON R.H.S.
13,23,0     MOPLHS              OPTION ON L.H.S.
07          MSDPH               HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,3,3,3,3,3,3     MBCTYP 0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WAL
1,1,1,1,1,1,1     MBDZR  FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #)
0,0,0,0,0,0,0     NZOCNT EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,0,0,0,0,0     NPHCNT ..........................SIDE. ..........
0,0,0,0,0,0,0     NDRCNT DIRECTION (0:SAME DIR,1:OPSIT-DIR)
****** ZONE 2 ******
09,09,04    L,K,J     *         LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST      *         STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG      *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED      *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD    *         EXPLIC OR APPFAC.
    01,     NRELAX    *         NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS              OPTION ON R.H.S.
13,23,0     MOPLHS              OPTION ON L.H.S.
04          MSDPH               HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,1,3,3     MBCTYP              0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WA
0,1,0,0     MBDZR               FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #
0,0,0,0     NZOCNT              EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,0,0     NPHCNT              ...................SIDE. ..........
0,0,0,0     NDRCNT              DIRECTION (0:SAME DIR,1:OPSIT-DIR)
   27                              INU 5I5 GRID SECTION LINE
   00.0                            ANGLE
   07      ISC                     NO. OF PATCH. (GEOMETRY)
   10   12   06   06   09   09   09        POINTS PER PATCHS
   00   00   00   00   00   00   00     ND FOR ZONE 1
   00   00   00   00   00   00   00     ND FOR ZONE 2
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  02       NZONES   I5     NO. OF ZONE.
  01       NTSETP          NO. OF TIME MARCHING STEP (GLOB ITER).
  10       NSTORE          RESTART SOLUTION FOR TIME MARCHING.
  10       NPRTT           OUTPUT SOLUTION FOR TIME MARCHING.
   0       ISTART          TIME MARCH RESTART.
   1       ITSTEP          -:VAR. TM STEP.(X,Y,Z), +:CST. TM STEP.
 060       NMARCH          NO. OF SPACE MARCHING STEP.
  10       NDISKM          RESTART SOLUTION FOR SPACE MARCHING.
  20       NPRTM           OUTPUT SOLUTION FOR SPACE MARCHING.
  50       MCONE           NO. OF ITERATIONS FOR CONICAL SOLUTION.
  02       LDACCU          L-DIR. ACCURACY. 1:1ST ORDER.
  02       KDACCU          K-DIR. ACCURACY.
  01       JDACCU          J-DIR. ACCURACY.
  02       NSUBIT          NO. OF INTERNAL ITERATION.
  30       NITERI          NO. OF ITERATION FOR GRID.
   1       IFPBAC          0: NO CONDITION SPEC, 1:BACK P MUST BE GIVEN.
  05       NEWCFL          NO. OF TIME STEP FOR WHICH TIME STEP=C.
  01       NEWDTI          NO. OF TIME STEP AFTER THAT A NEW TIME STEP.
  00       SONIC           0:NO SPECIAL SONIC TREATMENT, 1:MOREMDISSIP.
   2       NRM             NO. OF REGION TO GENERATE GRID.
   1       NBDTOT          NO. OF BODY. (FOR FORCE CALCULATION.)
  14       LWKSU           WAKE STARTING POINT.
  27       LWKEL           WAKE ENDING POINT.
   1       NXXXXX          NOT USED.
 100.0    CFLNEW F30.5    CFL NUMBER.
 100.0    CFLMIN          MINIMUM CFL NO.
 500.0    CFLMAX          MAXIMUM CFL NO.
  1.50     CFLINC          CFL SHOULD FLINC*CFL
  0.95     CFLDEC          CFL SHOLLD > CFLDEC*CFL
 001.5     DXIN            STEP SIZE FOR SPACE MARCHING.
 001.5     DXMIN           MIN. STEP SIZE FOR SPACE MARCHING.
  01.5     DXMAX           MAX. STEP SIZE FOR SPACE MARCHING.
270.00     XSTAT           STARTING X LOCATION FOR SPACE MARCHING.
399.00     XEND            ENDING   X LOCATION FOR SPACE MARCHING.
  1.50     FSMACH          FREE STREAM MACH NO.
  03.00    ALFA            ANGLE OF ATTACK.
   0.00    BETA            ANGLE OF YAW.
  65.0     THTO            OUTER BOUNDARY ANGLE.
   1.4     GAM             RATIO OF SPECIFIC HEAT.
 -1.00     SCHEME          0.33:3ND, -1.:2ND,I0.5:LOW TR. 2ND
  1.0      COMPRES         (3-SCHEME)/(1-SCHEME)
  00.      DISSIPS         DEFINING BACKGROUND DISSIPATION.
  1.01     PBAC            SPECIFIED BACKTPRESSURE.TREAM)
   27.00   AO              NOT USED.
    90.0   BO              NOT USED.
  -25.0    CO              NOT USED.
  001.     CHL             CHARACTERISTIC LENGTH
 000.0     XSHIFT          AXIAL COORDINATE SHIFT.
 000.0     YSHIFT          Y-AXI COORDINATE SHIFT.
 9999.0    XWAKE           STARTING X WAKE LOCATION.
 000.0     XXX02           NOT USED.
 000.0     XXX03           NOT USED.
 000.0     XXX04           NOT USED.
  0.80     OMEGA           RELAXIATION FACTOR.
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   0.000    XXX1               NOT USED.
   0.000    XXX2               NOT USED.
   0.000    XXX3               NOT USED.
    T       SMARCH     L3  SPACE MARCHING
    F       MJBGED         READ IN JBCBG & JBCED DATA FROM UNIT 110&130.
    F       DISKIN         RESTART DATA FROM DISK ( TIME M. MODE )
    T       MDSKIN         RESTART DATA FROM DISK.(SPACE M. MODE )
    F       SMTMCB         COMBINE SPACE AND TIME MARCHING.
    F       TAPE8W         NOT USED.
    F       FORCE          DO FORCE CALCULATION
    F       MDISKC         SAVE EACH CROSS-SEC. SOLU. FOR SUBSONIC ITER.
    T       IREAD          INPUT GEOMETRY DATA
    F       MYAW           YAW CALCULATION
   0.0, 0.0                XMO,YMO (REF. X&Y FOR PITCH MOMENT) ** BODY
  100.0,  100.000          AAA,ALL (REF. AREA & LENGTH)        **   1
****** ZONE 1 ******
20,20,4     L,K,J    *     LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST     *     STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG     *     IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED     *     IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD   *     EXPLIC OR APPFAC.
    01,     NRELAX   *     NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS         OPTION ON R.H.S.
13,23,0     MOPLHS         OPTION ON L.H.S.
07          MSDPH          HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,3,3,3,3,3,3     MBCTYP 0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WAL
1,1,1,1,1,1,1     MBDZR  FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #)
0,0,0,0,0,0,0     NZOCNT EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,0,0,0,0,0     NPHCNT ..........................SIDE. ..........
0,0,0,0,0,0,0     NDRCNT DIRECTION (0:SAME DIR,1:OPSIT-DIR)
****** ZONE 2 ******
09,09,04    L,K,J    *     LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST     *     STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG     *     IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED     *     IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD   *     EXPLIC OR APPFAC.
    01,     NRELAX   *     NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS         OPTION ON R.H.S.
13,23,0     MOPLHS         OPTION ON L.H.S.
04          MSDPH          HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,1,3,3     MBCTYP         0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WA
0,1,0,0     MBDZR          FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #
0,0,0,0     NZOCNT         EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,0,0     NPHCNT         ....................SIDE. ..........
0,0,0,0     NDRCNT         DIRECTION (0:SAME DIR,1:OPSIT-DIR)
   33                      INU 5I5 GRID SECTION LINE
   00.0                     ANGLE
   07      ISC              NO. OF PATCH. (GEOMETRY)
   10  12   12   12   09   09   09        POINTS PER PATCHS
   00  00   00   00   00   00   00     ND FOR ZONE 1
   00  00   00   00   00   00   00     ND FOR ZONE 2
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   02      NZONES   I5    NO. OF ZONE.
   01      NTSETP         NO. OF TIME MARCHING STEP (GLOB ITER).
   10      NSTORE         RESTART SOLUTION FOR TIME MARCHING.
   10      NPRTT          OUTPUT SOLUTION FOR TIME MARCHING.
    0      ISTART         TIME MARCH RESTART.
    1      ITSTEP         -:VAR. TM STEP.(X,Y,Z), +:CST. TM STEP.
  050      NMARCH         NO. OF SPACE MARCHING STEP.
   10      NDISKM         RESTART SOLUTION FOR SPACE MARCHING.
   20      NPRTM          OUTPUT SOLUTION FOR SPACE MARCHING.
   50      MCONE          NO. OF ITERATIONS FOR CONICAL SOLUTION.
   02      LDACCU         L-DIR. ACCURACY. 1:1ST ORDER.
   02      KDACCU         K-DIR. ACCURACY.
   01      JDACCU         J-DIR. ACCURACY.
   02      NSUBIT         NO. OF INTERNAL ITERATION.
   30      NITERI         NO. OF ITERATION FOR GRID.
    1      IFPBAC         0: NO CONDITION SPEC, 1:BACK P MUST BE GIVEN.
   05      NEWCFL         NO. OF TIME STEP FOR WHICH TIME STEP=C.
   01      NEWDTI         NO. OF TIME STEP AFTER THAT A NEW TIME STEP.
   00      SONIC          0:NO SPECIAL SONIC TREATMENT, 1:MOREMDISSIP.
    2      NRM            NO. OF REGION TO GENERATE GRID.
    1      NBDTOT         NO. OF BODY. (FOR FORCE CALCULATION.)
   14      LWKSU          WAKE STARTING POINT.
   27      LWKEL          WAKE ENDING POINT.
    1      NXXXXX         NOT USED.
 500.0      CFLNEW F30.5   CFL NUMBER.
 500.0      CFLMIN         MINIMUM CFL NO.
 500.0     CFLMAX         MAXIMUM CFL NO.
   1.50    CFLINC         CFL SHOULD FLINC*CFL
  0.95     CFLDEC         CFL SHOLLD > CFLDEC*CFL
 001.0     DXIN           STEP SIZE FOR SPACE MARCHING.
 001.0     DXMIN          MIN. STEP SIZE FOR SPACE MARCHING.
  01.0     DXMAX          MAX. STEP SIZE FOR SPACE MARCHING.
400.00     XSTAT          STARTING X LOCATION FOR SPACE MARCHING.
505.00     XEND           ENDING   X LOCATION FOR SPACE MARCHING.
  1.50     FSMACH         FREE STREAM MACH NO.
 03.00     ALFA           ANGLE OF ATTACK.
  0.00     BETA           ANGLE OF YAW.
  65.0     THTO           OUTER BOUNDARY ANGLE.
   1.4     GAM            RATIO OF SPECIFIC HEAT.
 -1.00     SCHEME         0.33:3ND, -1.:2ND,I0.5:LOW TR. 2ND
   1.0     COMPRES        (3-SCHEME)/(1-SCHEME)
  00.      DISSIPS        DEFINING BACKGROUND DISSIPATION.
  1.01     PBAC           SPECIFIED BACKTPRESSURE.TREAM)
    27.00  AO             NOT USED.
     90.0  BO             NOT USED.
    -25.0  CO             NOT USED.
   001.    CHL            CHARACTERISTIC LENGTH
 000.0     XSHIFT         AXIAL COORDINATE SHIFT.
 000.0     YSHIFT         Y-AXI COORDINATE SHIFT.
 9999.0    XWAKE          STARTING X WAKE LOCATION.
 000.0     XXX02          NOT USED.
 000.0     XXX03          NOT USED.
 000.0     XXX04          NOT USED.
   0.80    OMEGA          RELAXIATION FACTOR.
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```
   0.000    XXX1                NOT USED.
   0.000    XXX2                NOT USED.
   0.000    XXX3                NOT USED.
    T       SMARCH      L3      SPACE MARCHING
    F       MJBGED              READ IN JBCBG & JBCED DATA FROM UNIT 110&130.
    F       DISKIN              RESTART DATA FROM DISK ( TIME M. MODE )
    T       MDSKIN              RESTART DATA FROM DISK.(SPACE M. MODE )
    F       SMTMCB              COMBINE SPACE AND TIME MARCHING.
    F       TAPE8W              NOT USED.
    F       FORCE               DO FORCE CALCULATION
    F       MDISKC              SAVE EACH CROSS-SEC. SOLU. FOR SUBSONIC ITER.
    T       IREAD               INPUT GEOMETRY DATA
    F       MYAW                YAW CALCULATION
   0.0, 0.0                     XM0,YM0 (REF. X&Y FOR PITCH MOMENT) ** BODY
  100.0,  100.000               AAA,ALL (REF. AREA & LENGTH)         **   1
****** ZONE 1 ******
20,20,4     L,K,J    *          LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST     *          STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG     *          IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED     *          IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD   *          EXPLIC OR APPFAC.
    01,     NRELAX   *          NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS              OPTION ON R.H.S.
13,23,0     MOPLHS              OPTION ON L.H.S.
07          MSDPH               HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,3,3,3,3,2,2      MBCTYP 0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WAL
1,1,1,1,1,1,1      MBDZR  FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #)
0,0,0,0,0,2,2      NZOCNT EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,0,0,0,4,3      NPHCNT ...........................SIDE. ..........
0,0,0,0,0,1,1      NDRCNT DIRECTION (0:SAME DIR,1:OPSIT-DIR)
****** ZONE 2 ******
09,09,04    L,K,J    *          LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST     *          STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG     *          IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED     *          IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD   *          EXPLIC OR APPFAC.
    01,     NRELAX   *          NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS              OPTION ON R.H.S.
13,23,0     MOPLHS              OPTION ON L.H.S.
04          MSDPH               HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,1,2,2     MBCTYP              0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WA
0,1,0,0     MBDZR               FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #
0,0,1,1     NZOCNT              EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,7,6     NPHCNT              ....................SIDE. ..........
0,0,1,1     NDRCNT              DIRECTION (0:SAME DIR,1:OPSIT-DIR)
   32                           INU 5I5 GRID SECTION LINE
   00.0                           ANGLE
   07       ISC                   NO. OF PATCH. (GEOMETRY)
   10  11   12   12   09   09   09     POINTS PER PATCHS
   00  00   00   00   00   00   00     ND FOR ZONE 1
   00  00   00   00   00   00   00     ND FOR ZONE 2
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  02       NZONES  I5    NO. OF ZONE.
  01       NTSETP        NO. OF TIME MARCHING STEP (GLOB ITER).
  10       NSTORE        RESTART SOLUTION FOR TIME MARCHING.
  10       NPRTT         OUTPUT SOLUTION FOR TIME MARCHING.
   0       ISTART        TIME MARCH RESTART.
   1       ITSTEP        -:VAR. TM STEP.(X,Y,Z), +:CST. TM STEP.
 050      NMARCH        NO. OF SPACE MARCHING STEP.
  10       NDISKM        RESTART SOLUTION FOR SPACE MARCHING.
  20       NPRTM         OUTPUT SOLUTION FOR SPACE MARCHING.
  50       MCONE         NO. OF ITERATIONS FOR CONICAL SOLUTION.
  02       LDACCU        L-DIR. ACCURACY. 1:1ST ORDER.
  02       KDACCU        K-DIR. ACCURACY.
  01       JDACCU        J-DIR. ACCURACY.
  04       NSUBIT        NO. OF INTERNAL ITERATION.
  20       NITERI        NO. OF ITERATION FOR GRID.
   1       IFPBAC        0: NO CONDITION SPEC, 1:BACK P MUST BE GIVEN.
  05       NEWCFL        NO. OF TIME STEP FOR WHICH TIME STEP=C.
  01       NEWDTI        NO. OF TIME STEP AFTER THAT A NEW TIME STEP.
  00       SONIC         0:NO SPECIAL SONIC TREATMENT, 1:MOREMDISSIP.
   2       NRM           NO. OF REGION TO GENERATE GRID.
   1       NBDTOT        NO. OF BODY. (FOR FORCE CALCULATION.)
  14       LWKSU         WAKE STARTING POINT.
  27       LWKEL         WAKE ENDING POINT.
   1       NXXXXX        NOT USED.
 100.0      CFLNEW F30.5  CFL NUMBER.
 100.0      CFLMIN        MINIMUM CFL NO.
 500.0     CFLMAX        MAXIMUM CFL NO.
   1.50    CFLINC        CFL SHOULD FLINC*CFL
  0.95     CFLDEC        CFL SHOLLD > CFLDEC*CFL
 001.0     DXIN          STEP SIZE FOR SPACE MARCHING.
 001.0     DXMIN         MIN. STEP SIZE FOR SPACE MARCHING.
  01.0     DXMAX         MAX. STEP SIZE FOR SPACE MARCHING.
510.00     XSTAT         STARTING X LOCATION FOR SPACE MARCHING.
540.00     XEND          ENDING   X LOCATION FOR SPACE MARCHING.
  1.50     FSMACH        FREE STREAM MACH NO.
  03.00    ALFA          ANGLE OF ATTACK.
   0.00    BETA          ANGLE OF YAW.
  65.0     THTO          OUTER BOUNDARY ANGLE.
   1.4     GAM           RATIO OF SPECIFIC HEAT.
 -1.00     SCHEME        0.33:3ND, -1.:2ND,I0.5:LOW TR. 2ND
  1.0      COMPRES       (3-SCHEME)/(1-SCHEME)
 00.       DISSIPS       DEFINING BACKGROUND DISSIPATION.
 1.01      PBAC          SPECIFIED BACKTPRESSURE.TREAM)
   27.00   AO            NOT USED.
   90.0    BO            NOT USED.
  -25.0    CO            NOT USED.
  001.     CHL           CHARACTERISTIC LENGTH
 000.0     XSHIFT        AXIAL COORDINATE SHIFT.
 000.0     YSHIFT        Y-AXI COORDINATE SHIFT.
 9999.0    XWAKE         STARTING X WAKE LOCATION.
 000.0     XXX02         NOT USED.
 000.0     XXX03         NOT USED.
 000.0     XXX04         NOT USED.
   0.80    OMEGA         RELAXIATION FACTOR.
```

```
   0.000    XXX1               NOT USED.
   0.000    XXX2               NOT USED.
   0.000    XXX3               NOT USED.
    T       SMARCH      L3     SPACE MARCHING
    F       MJBGED             READ IN JBCBG & JBCED DATA FROM UNIT 110&130.
    F       DISKIN             RESTART DATA FROM DISK ( TIME M. MODE )
    T       MDSKIN             RESTART DATA FROM DISK.(SPACE M. MODE )
    F       SMTMCB             COMBINE SPACE AND TIME MARCHING.
    F       TAPE8W             NOT USED.
    F       FORCE              DO FORCE CALCULATION
    F       MDISKC             SAVE EACH CROSS-SEC. SOLU. FOR SUBSONIC ITER.
    T       IREAD              INPUT GEOMETRY DATA
    F       MYAW               YAW CALCULATION
   0.0, 0.0                    XM0,YM0 (REF. X&Y FOR PITCH MOMENT) ** BODY
  100.0,  100.000              AAA,ALL (REF. AREA & LENGTH)         **   1
****** ZONE 1 ******
20,20,4     L,K,J    *     LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST     *     STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG     *     IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED     *     IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD   *     EXPLIC OR APPFAC.
    01,     NRELAX   *     NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS         OPTION ON R.H.S.
13,23,0     MOPLHS         OPTION ON L.H.S.
05          MSDPH          HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,3,3,2,2     MBCTYP 0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WALL
1,1,1,1,1     MBDZR  FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #)
0,0,0,2,2     NZOCNT EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,0,4,3     NPHCNT ..........................SIDE. ..........
0,0,0,1,1     NDRCNT DIRECTION (0:SAME DIR,1:OPSIT-DIR)
****** ZONE 2 ******
09,09,04    L,K,J    *     LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST     *     STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG     *     IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED     *     IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD   *     EXPLIC OR APPFAC.
    01,     NRELAX   *     NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS         OPTION ON R.H.S.
13,23,0     MOPLHS         OPTION ON L.H.S.
04          MSDPH          HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,1,2,2     MBCTYP         0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WA
0,1,0,0     MBDZR          FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #
0,0,1,1     NZOCNT         EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,5,4     NPHCNT         ....................SIDE. ..........
0,0,1,1     NDRCNT         DIRECTION (0:SAME DIR,1:OPSIT-DIR)
   20                      INU 5I5 GRID SECTION LINE
   00.0                      ANGLE
   05      ISC               NO. OF PATCH. (GEOMETRY)
   06   07    10    09    09         POINTS PER PATCHS
   00   00    00    00    00    00    00      ND FOR ZONE 1
   00   00    00    00    00    00    00      ND FOR ZONE 2
```

```
 02        NZONES   I5     NO. OF ZONE.
 01        NTSETP          NO. OF TIME MARCHING STEP (GLOB ITER).
 10        NSTORE          RESTART SOLUTION FOR TIME MARCHING.
 10        NPRTT           OUTPUT SOLUTION FOR TIME MARCHING.
  0        ISTART          TIME MARCH RESTART.
  1        ITSTEP          -:VAR. TM STEP.(X,Y,Z), +:CST. TM STEP.
050        NMARCH          NO. OF SPACE MARCHING STEP.
 10        NDISKM          RESTART SOLUTION FOR SPACE MARCHING.
 20        NPRTM           OUTPUT SOLUTION FOR SPACE MARCHING.
 50        MCONE           NO. OF ITERATIONS FOR CONICAL SOLUTION.
 02        LDACCU          L-DIR. ACCURACY. 1:1ST ORDER.
 02        KDACCU          K-DIR. ACCURACY.
 01        JDACCU          J-DIR. ACCURACY.
 04        NSUBIT          NO. OF INTERNAL ITERATION.
 20        NITERI          NO. OF ITERATION FOR GRID.
  1        IFPBAC          0: NO CONDITION SPEC, 1:BACK P MUST BE GIVEN.
 05        NEWCFL          NO. OF TIME STEP FOR WHICH TIME STEP=C.
 01        NEWDTI          NO. OF TIME STEP AFTER THAT A NEW TIME STEP.
 00        SONIC           0:NO SPECIAL SONIC TREATMENT, 1:MOREMDISSIP.
  3        NRM             NO. OF REGION TO GENERATE GRID.
  1        NBDTOT          NO. OF BODY. (FOR FORCE CALCULATION.)
 14        LWKSU           WAKE STARTING POINT.
 27        LWKEL           WAKE ENDING POINT.
  1        NXXXXX          NOT USED.
100.0       CFLNEW F30.5    CFL NUMBER.
100.0       CFLMIN          MINIMUM CFL NO.
500.0      CFLMAX          MAXIMUM CFL NO.
  1.50     CFLINC          CFL SHOULD FLINC*CFL
 0.95      CFLDEC          CFL SHOLLD > CFLDEC*CFL
001.0      DXIN            STEP SIZE FOR SPACE MARCHING.
001.0      DXMIN           MIN. STEP SIZE FOR SPACE MARCHING.
 01.0      DXMAX           MAX. STEP SIZE FOR SPACE MARCHING.
570.00     XSTAT           STARTING X LOCATION FOR SPACE MARCHING.
585.00     XEND            ENDING   X LOCATION FOR SPACE MARCHING.
 1.50      FSMACH          FREE STREAM MACH NO.
 03.00     ALFA            ANGLE OF ATTACK.
  0.00     BETA            ANGLE OF YAW.
 65.0      THTO            OUTER BOUNDARY ANGLE.
  1.4      GAM             RATIO OF SPECIFIC HEAT.
 -1.00     SCHEME          0.33:3ND, -1.:2ND,I0.5:LOW TR. 2ND
  1.0      COMPRES         (3-SCHEME)/(1-SCHEME)
 00.       DISSIPS         DEFINING BACKGROUND DISSIPATION.
 1.01      PBAC            SPECIFIED BACKTPRESSURE.TREAM)
   27.00   AO              NOT USED.
   90.0    BO              NOT USED.
  -25.0    CO              NOT USED.
  001.     CHL             CHARACTERISTIC LENGTH
000.0      XSHIFT          AXIAL COORDINATE SHIFT.
000.0      YSHIFT          Y-AXI COORDINATE SHIFT.
9999.0     XWAKE           STARTING X WAKE LOCATION.
000.0      XXX02           NOT USED.
000.0      XXX03           NOT USED.
000.0      XXX04           NOT USED.
  0.80     OMEGA           RELAXIATION FACTOR.
```

```
   0.000    XXX1               NOT USED.
   0.000    XXX2               NOT USED.
   0.000    XXX3               NOT USED.
    T       SMARCH      L3     SPACE MARCHING
    F       MJBGED             READ IN JBCBG & JBCED DATA FROM UNIT 110&130.
    F       DISKIN             RESTART DATA FROM DISK ( TIME M. MODE )
    T       MDSKIN             RESTART DATA FROM DISK.(SPACE M. MODE )
    F       SMTMCB             COMBINE SPACE AND TIME MARCHING.
    F       TAPE8W             NOT USED.
    F       FORCE              DO FORCE CALCULATION
    F       MDISKC             SAVE EACH CROSS-SEC. SOLU. FOR SUBSONIC ITER.
    T       IREAD              INPUT GEOMETRY DATA
    F       MYAW               YAW CALCULATION
   0.0, 0.0                    XMO,YMO (REF. X&Y FOR PITCH MOMENT) ** BODY
  100.0,  100.000              AAA,ALL (REF. AREA & LENGTH)        **   1
****** ZONE 1 ******
20,20,4     L,K,J    *         LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST     *         STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG     *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED     *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD   *         EXPLIC OR APPFAC.
    01,     NRELAX   *         NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS             OPTION ON R.H.S.
13,23,0     MOPLHS             OPTION ON L.H.S.
08          MSDPH              HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,3,3,3,3,3,2,2      MBCTYP 0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID W
1,1,1,1,1,1,1,1      MBDZR  FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY
0,0,0,0,0,0,2,2      NZOCNT EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,0,0,0,0,4,3      NPHCNT ..........................SIDE. ..........
0,0,0,0,0,0,1,1      NDRCNT DIRECTION (0:SAME DIR,1:OPSIT-DIR)
****** ZONE 2 ******
09,09,04    L,K,J    *         LGRDNZ(NZ),KGRDNZ(NZ),JGRDNZ(NZ)
    02,     LBST     *         STARTING CHECKING POINT FOR RESPACEING.
    00      MJBG     *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    00      MJED     *         IF MJBGED=T ; 1:READ DATA 0:DO NOT READ.
    22,     METHOD   *         EXPLIC OR APPFAC.
    01,     NRELAX   *         NO. OF RELAX. SUBERATIONS
+1,+1,-1    MOPRHS             OPTION ON R.H.S.
13,23,0     MOPLHS             OPTION ON L.H.S.
04          MSDPH              HOW MANY SIDE (4 EXCEPT AT ZONE 1)?
3,1,2,2     MBCTYP             0:0 FLUXS, 1:REFLEC, 2:ZONEAL BC, 3: SOLID WA
0,1,0,0     MBDZR              FOR FORCE CAL.(EACH SIDE CORROSPOND TO BODY #
0,0,1,1     NZOCNT             EACH SIDE CONNECT TO WHICH ZONE. (MSDPH,NZ)
0,0,8,7     NPHCNT             ...................SIDE. ..........
0,0,1,1     NDRCNT             DIRECTION (0:SAME DIR,1:OPSIT-DIR)
   12    27                         INU 5I5 GRID SECTION LINE
   10.0       -10.0                         ANGLE
   08      ISC                   NO. OF PATCH. (GEOMETRY)
   07  06   06   04   04   10   09   09        POINTS PER PATCHS
   00  00   00   00   00   00   00   00      ND FOR ZONE 1
   00  00   00   00   00   00   00   00      ND FOR ZONE 2
```

```
   08.970            4
ZONE1
   1      4     0                                       FORMAT: 3I5
        2.1399              0.0000                      FORMAT: F13.4,2X,F13.4
        2.0698              0.7588
        1.8654              1.4304
        1.5339              2.0006
   2      6     0
        1.5339              2.0006
        1.0813              2.4479
        0.5120              2.7436
       -0.1713              2.8514
        0.9134              2.7298
       -1.4031              2.4379
   3      2     0
       -1.4031              2.4379
       -4.0000              2.4370
   4      2     0
       -4.0000              2.4370
       -4.8000              0.0000
ZONE2
   1      5     0
       -1.4031              2.4379
       -1.7427              2.0597
       -1.9923              1.5959
       -2.1691              0.9645
       -2.2481              0.0000
   2      2     0
       -2.2481              0.0000
       -4.8000              0.0000
   3      2     0
       -4.8000              0.0000
       -4.0000              2.4370
   4      2     0
       -4.0000              2.4370
       -1.4031              2.4379
 19.15               4             91.414
ZONE1
   1      4     0
        5.9278              0.0000
        5.7783              1.6194
        5.3419              3.0527
        4.6345              4.2695
   2      6     0
        4.6345              4.2695
        3.6687              5.2242
        2.4537              5.8552
        0.9954              6.0852
       -0.5883              5.8257
       -1.6334              5.2028
   3      2     0
       -1.6334              5.2028
       -5.5000              5.2000
   4      2     0
       -5.5000              5.2000
       -7.0000              0.0000
ZONE2
   1      5     0
       -1.6334              5.2028
       -2.3582              4.3956
       -2.8907              3.4060
       -3.2681              2.0583
       -3.4368              0.0000
   2      2     0
       -3.4368              0.0000
       -7.0000              0.0000
```

```
  3     2     0
     -7.0000          0.0000
     -5.5000          5.2000
  4     2     0
     -5.5000          5.2000
     -1.6334          5.2028
 31.86              4          253.201
ZONE1
  1     4     0
     10.6627          0.0000
     10.4138          2.6952
      9.6876          5.0805
      8.5103          7.1057
  2     6     0
      8.5103          7.1057
      6.9029          8.6946
      4.8807          9.7447
      2.4538         10.1276
     -0.1819          9.6956
      1.9212          8.6589
  3     2     0
      1.9212          8.6589
     -6.5             8.600
  4     2     0
      6.5             8.600
     -8.5             0.0
ZONE2
  1     5     0
     -1.9212          8.6589
      3.1276          7.3156
     -4.0138          5.6685
      4.6418          3.4256
      4.9227          0.0000
  2     2     0
     -4.9227          0.0000
     -8.5000          0.0000
  3     2     0
     -8.5000          0.0000
     -6.5             8.6
  4     2     0
     -6.5             8.6
     -1.9212          8.6589
```

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16. Abstract

The computer code (EMTAC-MZ) developed at the Rockwell Science Center has been applied to investigate the flow field over a variety of very complex three-dimensional (3-D) configurations across the Mach number range (subsonic, transonic, supersonic and hypersonic flow).

In the code, a finite volume, multizone implementation of high accuracy, total variation diminishing (TVD) formulation (based on Roe's scheme) is used to solve the unsteady Euler equations. In the supersonic regions of the flow, an "infinitely large" time step and a space-marching scheme is employed. A finite time step and a relaxation or 3-D approximate factorization method is used in subsonic flow regions. The multizone technique allows very complicated configurations to be modeled without geometry modifications, and can easily handle combined internal and external flow problems. An elliptic grid generation package is built into the EMTAC-MZ code. To generate the computational grid, only the surface geometry data are required.

Results obtained for a variety of configurations, such as fighter-like configurations (F-14, AVSTOL), flow through inlet, multi-bodies (shuttle with external tank and SRBs), are reported and shown to be in good agreement with available experimental data.

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