



**COMPUTATIONAL ISSUES ASSOCIATED WITH
TEMPORALLY DEFORMING GEOMETRIES
SUCH AS THRUST VECTORING NOZZLES**

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COMPUTATIONAL ISSUES ASSOCIATED WITH TEMPORALLY DEFORMING GEOMETRIES SUCH AS THRUST VECTORING NOZZLES

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ABSTRACT

During the past decade Computational Simulation of fluid flow around complex configurations has progressed significantly and many notable successes have been reported, however unsteady time-dependent solutions are not easily obtainable. The present effort involves unsteady time dependent simulation of temporally deforming geometries. Grid generation for a complex configuration can be a time consuming process and temporally varying geometries necessitate the regeneration of such a grid for every time step. Traditional grid generation techniques have been tried and demonstrated to be inadequate to such simulations. NURBS based techniques provide a compact and accurate representation of the geometry. This definition can be coupled with a distribution mesh for a user defined spacing. The present method greatly reduces cpu requirements for time dependent remeshing, facilitating the simulation of more complex unsteady problems. A Thrust Vectoring Nozzle has been chosen to demonstrate the capability as it is of current interest in aerospace industry for better maneuverability of fighter aircraft in close combat and in post stall regimes. This current effort is the first step towards multidisciplinary design optimization which involves coupling the aerodynamic heat transfer and structural analysis techniques. Applications include simulation of temporally deforming bodies and areoelastic problems.

A NURBS based volume grid generation technique is used for remeshing at each timestep. Remeshing is easily accomplished by varying the control points and time dependent motion is contained in the motion of the control points. Timestep controls the movement of control points. Great flexibility in geometric definition is achieved. The grid generation code is successfully coupled with UBIFLOW and INS3d which are compressible and incompressible flow solvers respectively.

Various geometries such as converging diverging nozzle, duct and thrust vectoring nozzle have been simulated and will be presented.



OBJECTIVE:

The objective of this work is to develop a capability for CFD simulation of temporally deforming geometries such as thrust vectoring nozzles.

- 1. Efficient grid generation system.**
- 2. Flow solver that can handle moving geometries.**



MOTIVATION:

- 1. Biomedical flows (heart valve, blood flow in arteries or veins).**
- 2. Flapping of wing, helicopter rotor.**
- 3. Thrust vectoring.**
- 4. Wear and deformation on bodies, molding.**
- 5. Coupling with finite element for structural analysis for design optimisation.**



DESIRED FEATURES:

- 1. Good control over mesh point spacing.**
- 2. Grid quality.**
- 3. Grid generation must be user independent.**
- 4. Geometric fidelity.**
- 5. Consume moderate CPU time.**
- 6. Handle severe deflections.**
- 7. Flowsolver that can handle moving boundaries.**



OVERVIEW OF STUDY :

- 1. Approach.**
- 2. Grid generation.**
- 3. Why NURBS?**
- 4. Flow solver.**
- 5. Why thrust vectoring ?**
- 6. Ongoing research**
- 7. Results.**

PRETTY PICTURES IN BETWEEN

and ???????



APPROACH:

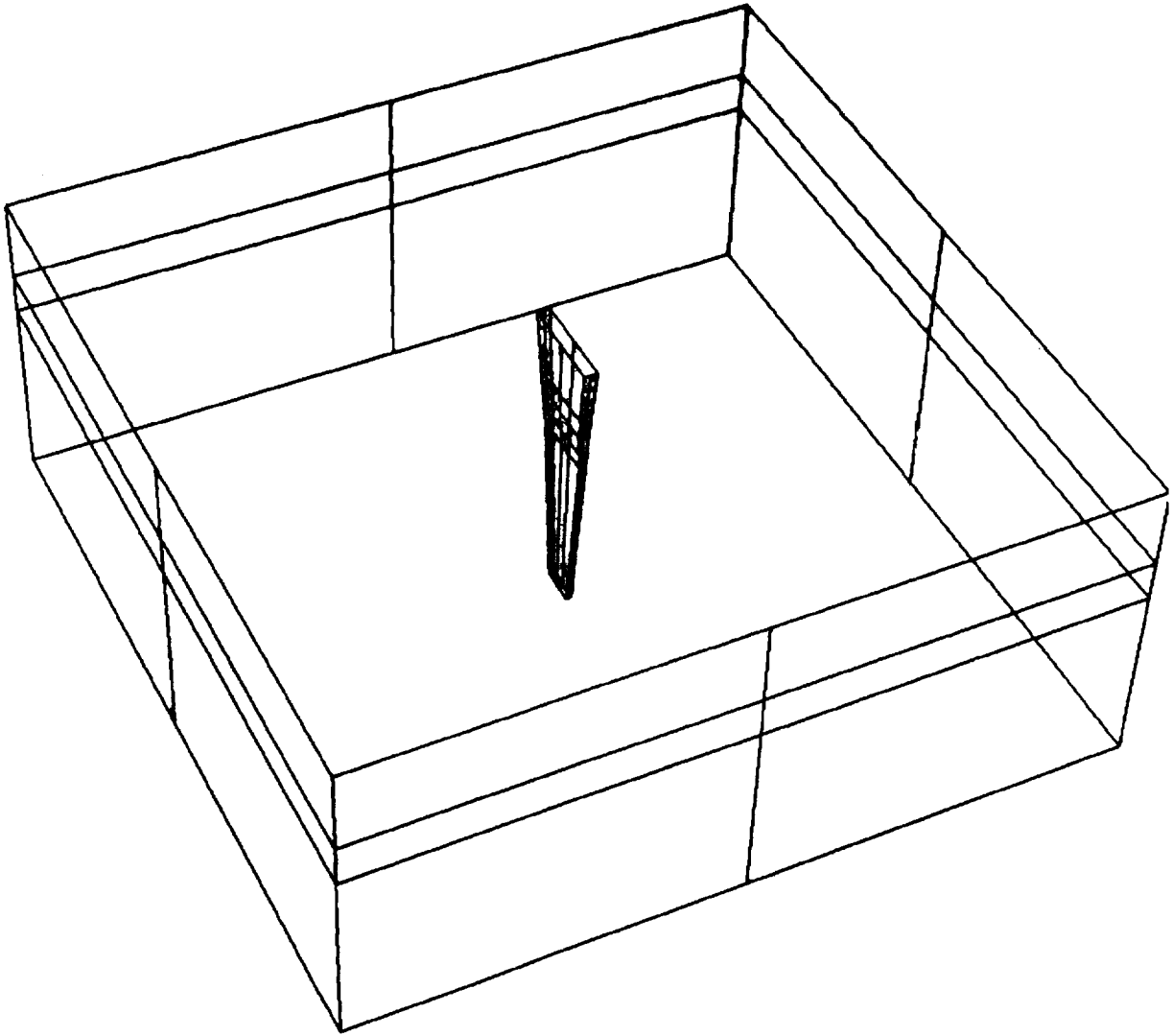
- 1. Grid Generation is discretised representation of volume in interest.**
- 2. Temporally deforming bodies require remeshing every time – step.**
- 3. TFI and Elliptic Grid Generation techniques have been found to be inadequate.**
- 4. NURBS based volume grid generation techniques are well suited for temporally varying geometries.**



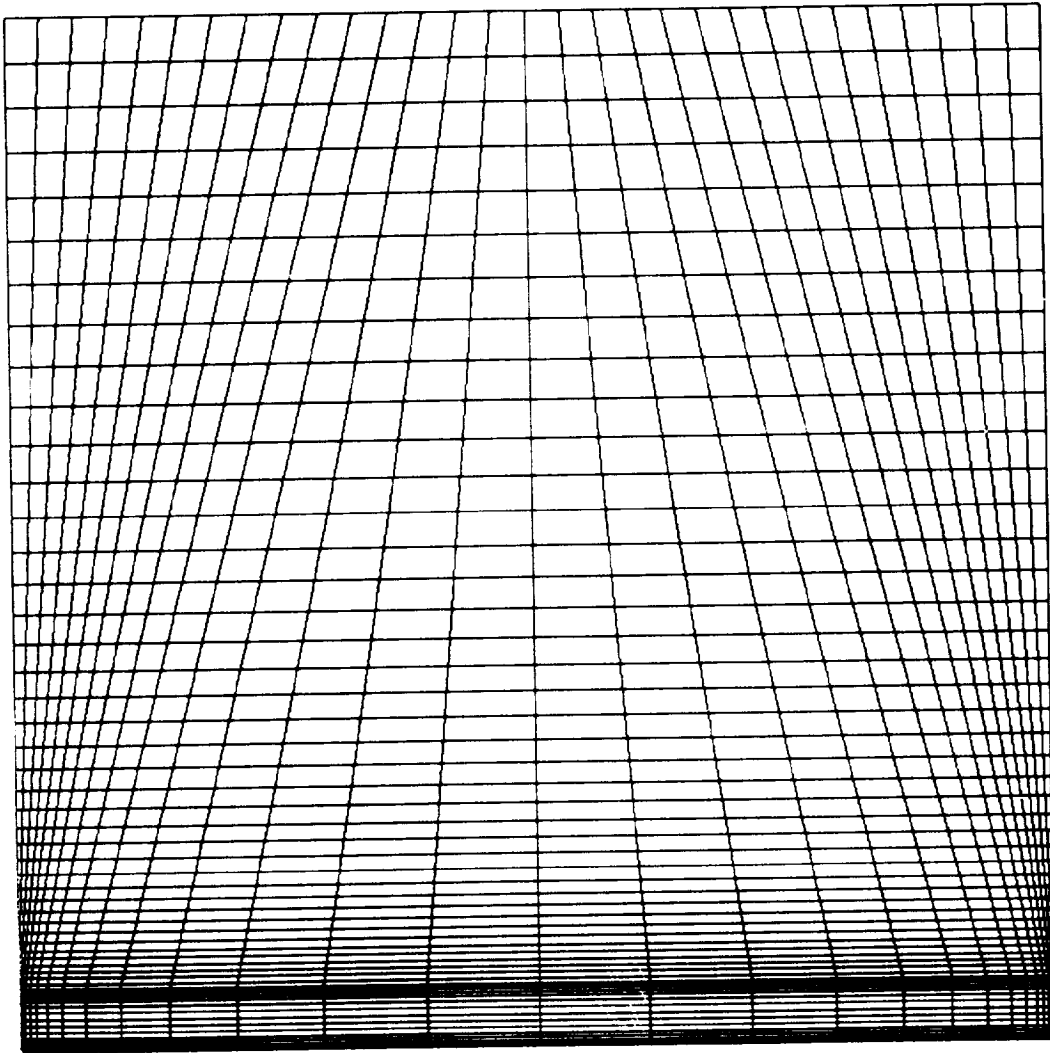
NURBS based volume grid generation (YU Method):

- 1. SIGNIFICANT FEATURE IS THAT IT ONLY REQUIRES THE CONTROL POINTS, WEIGHTS AND DISTRIBUTION MESH.**
- 2. REDUCES CPU REQUIREMENT.**
- 3. REMESHING IS EASILY DONE.**
- 4. CONTROL POINTS AND THE ORDER DEFINE THE GEOMETRY.**
- 5. USER DEFINED SPACING IS ACCOMPLISHED THROUGH USE OF DISTRIBUTION MESH.**

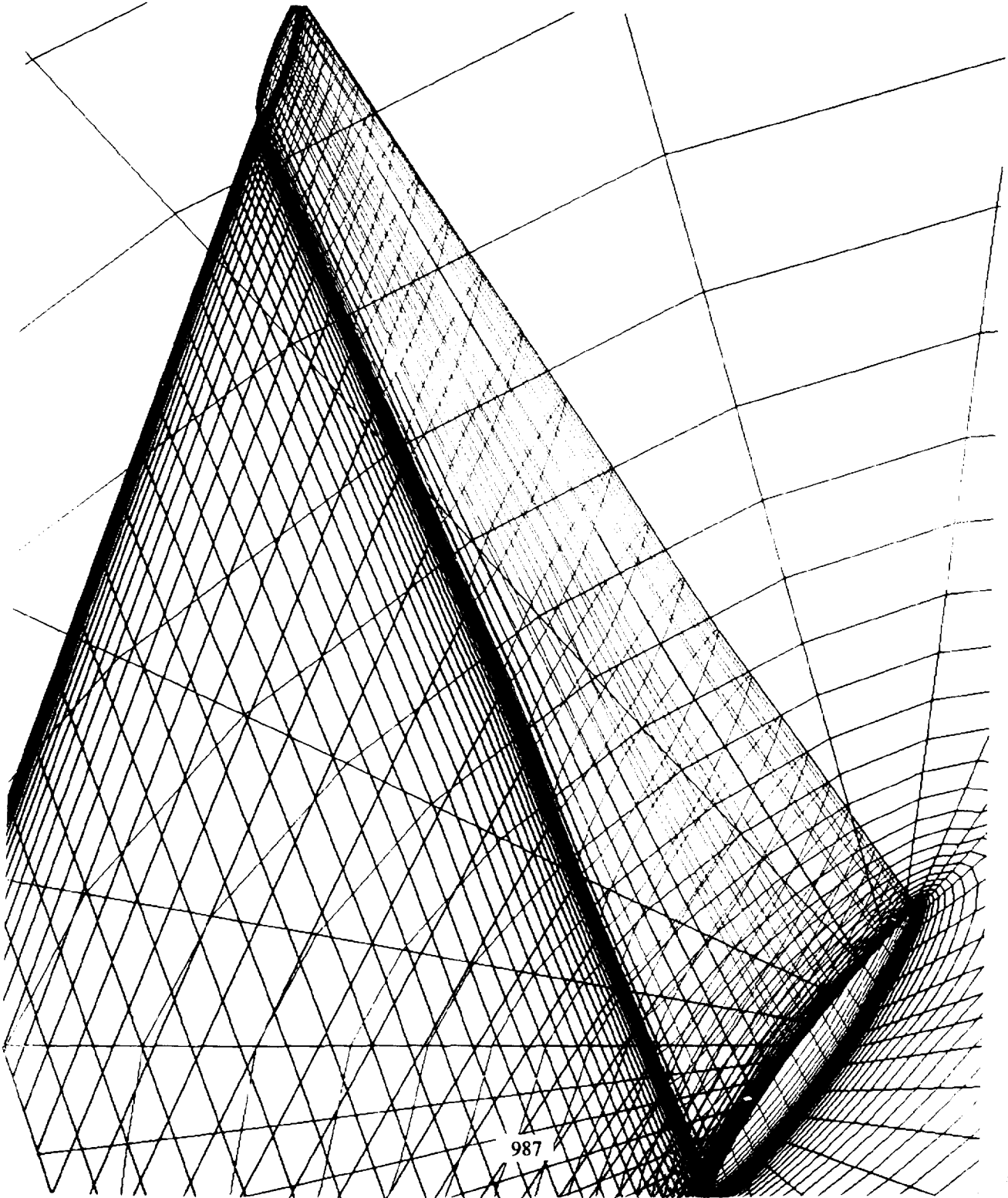
CONTROL POINTS FOR AIRCRAFT WING (4 x 2 x 9)



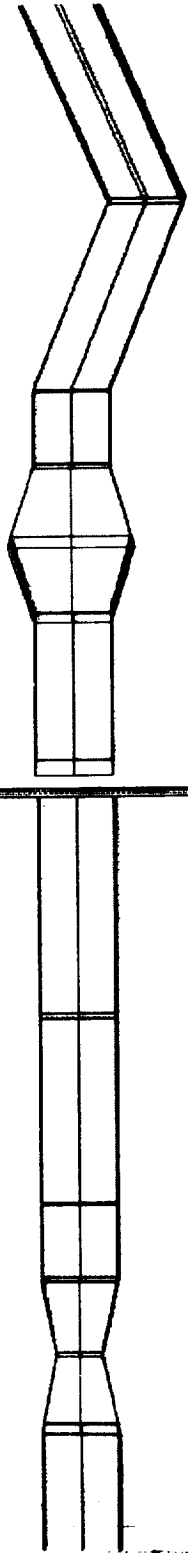
Distribution Mesh



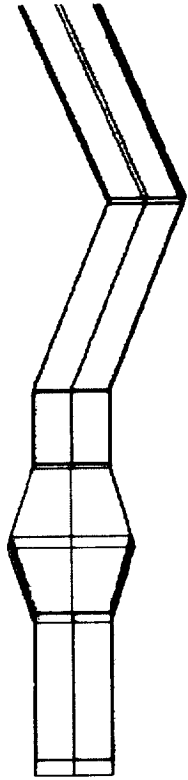
wing generated with control points and distribution mesh



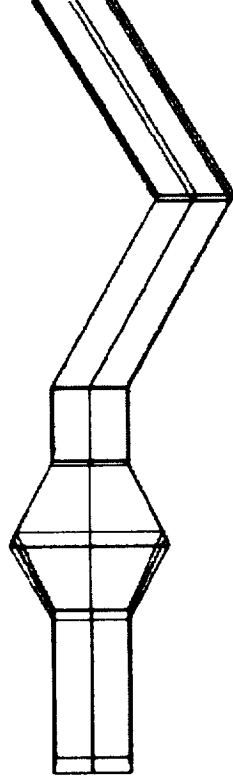
Initial control points



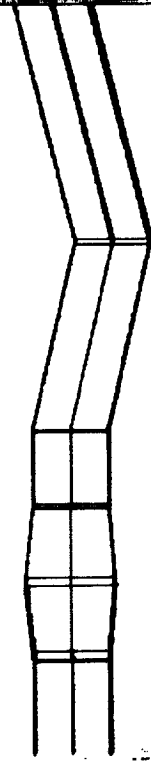
100 iterations



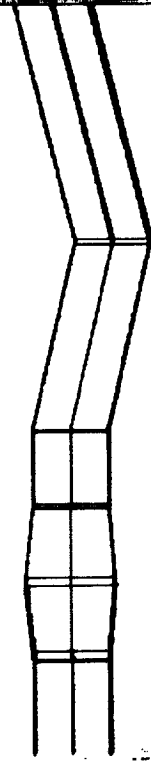
150 iterations



50 iterations



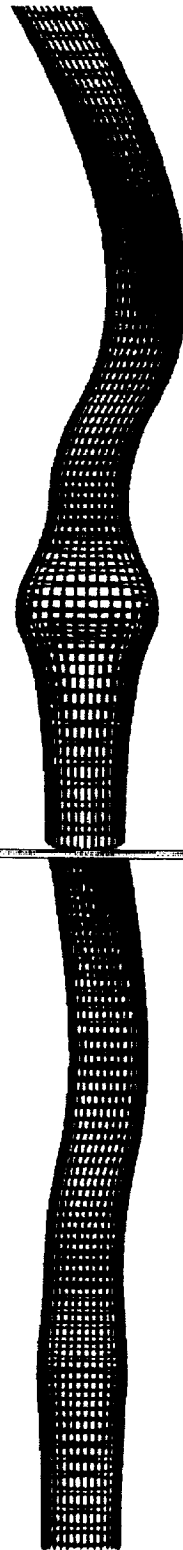
988



100 iter

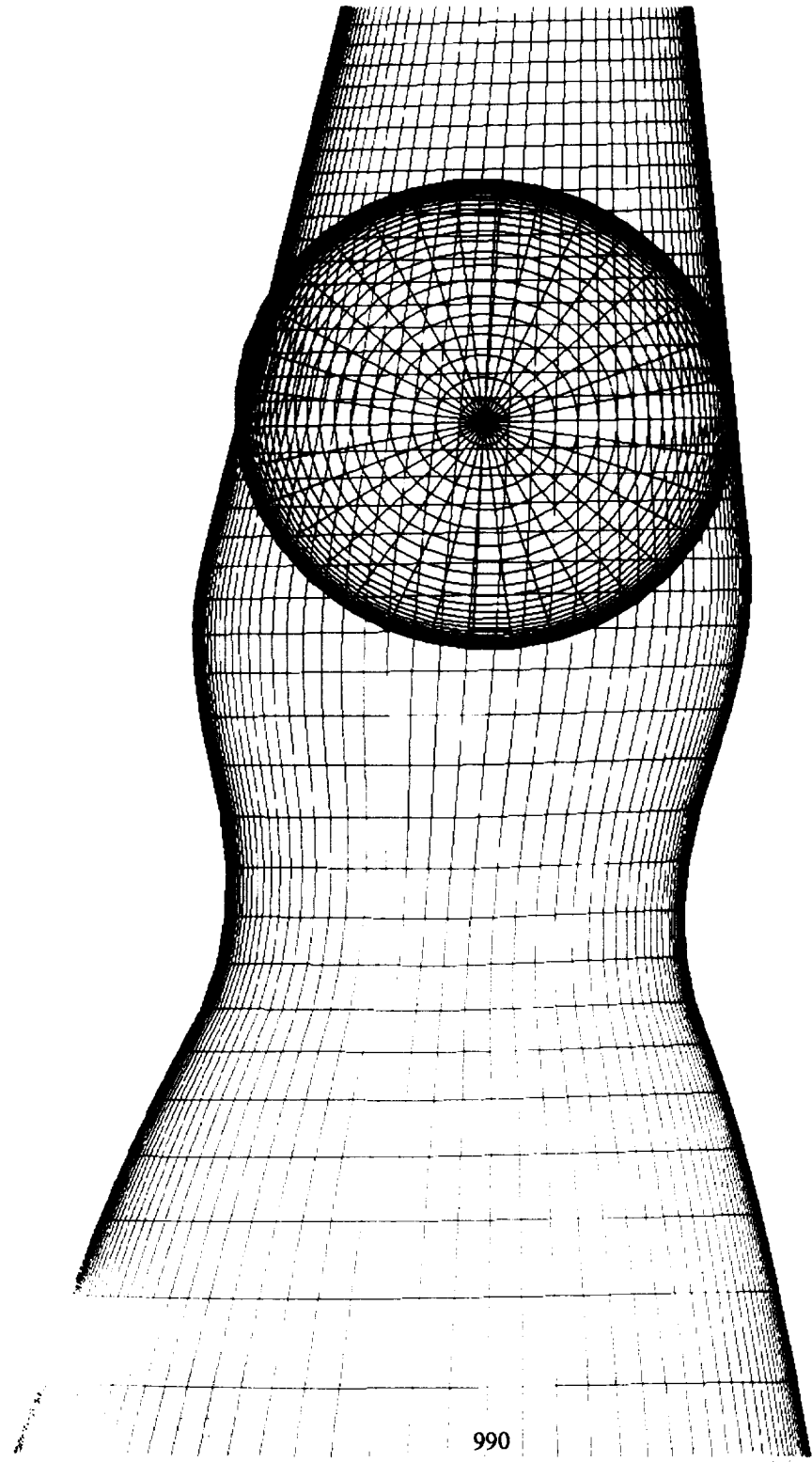


150 iter



Initial grid

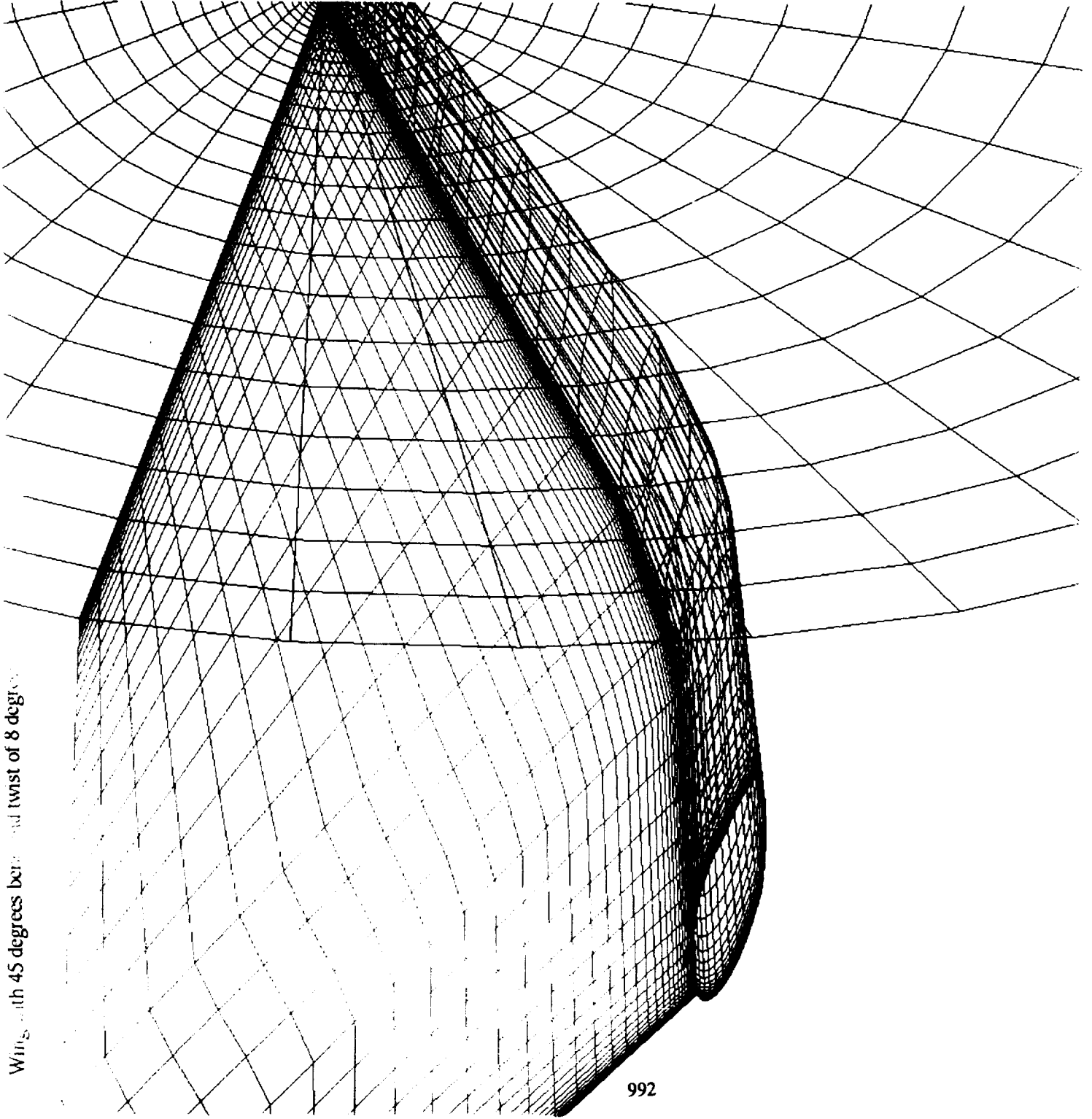
50 iter





- 6. TIME DEPENDENT MOTION IS ACCOMPLISHED BY MOVING THE CONTROL POINTS OR BY INTERPOLATION .**
- 7. THE AMOUNT OF MOVEMENT IS CONTROLLED BY THE TIME STEP.**
- 8. FLEXIBILITY IN GEOMETRIC DEFINITION**
- 9. ADAPTATION CAN BE EASILY ACHIEVED BY ADAPTING THE DISTRIBUTION MESH.**

Wings with 45 degrees bend and twist of 8 degrees





FLOW SOLVER:

- **Grid generation code is coupled with**

**UBIFLOW
INS3D**

- **Time metrics are calculated as**

$$\mathbf{dxdt}(i,j,k) = (x(i,j,k) - x0(i,j,k))/dt$$

$$\mathbf{dydt}(i,j,k) = (y(i,j,k) - y0(i,j,k))/dt$$

$$\mathbf{dzdt}(i,j,k) = (z(i,j,k) - z0(i,j,k))/dt$$

UBIFLOW calculates the time metrics

Time metrics have to be calculated in grid code in INS3D



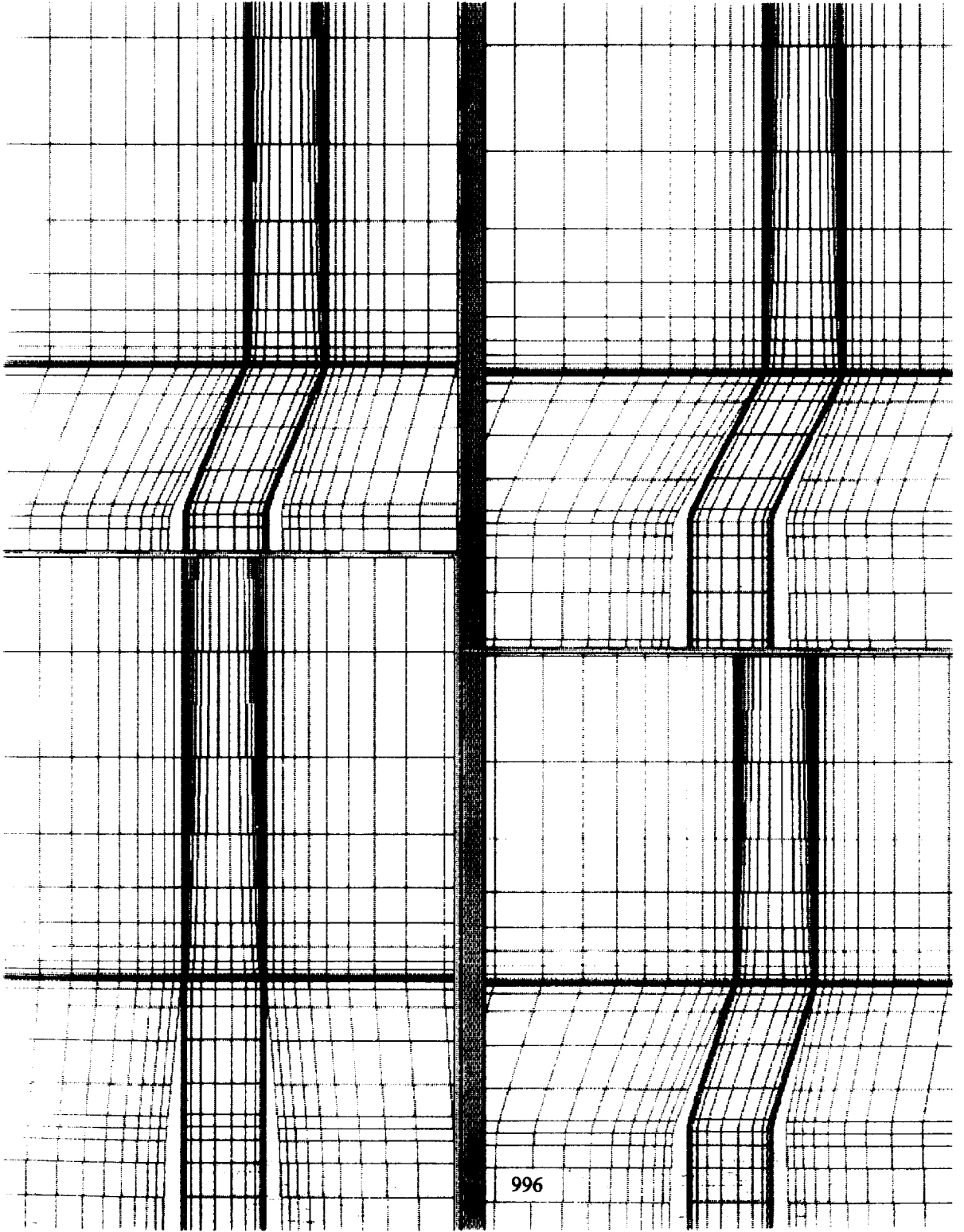
- **UBIFLOW (Whitfield and Arabshasi) :**
- **Multiblock compressible Navier – Stokes solver**
- **Cell centered finite volume scheme.**
- **Flux difference splitting on the RHS and upwind difference using flux splitting on LHS.**
- **Accounts for the block boundary movement.**
- **INS3D is a incompressible Navier – Stokes solver and both can solve unsteady and time varying flow.**



THRUST VECTORING:

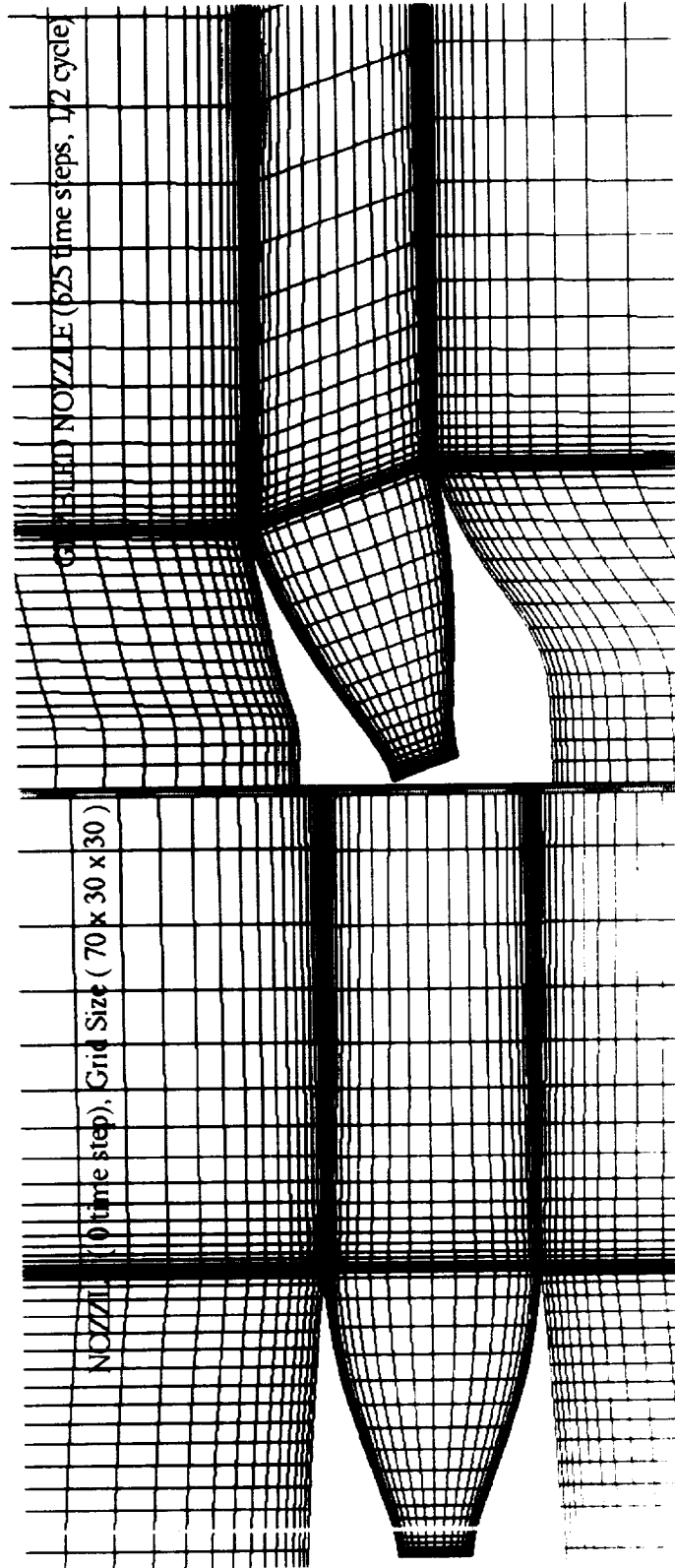
- 1. Reasonably complex problem.**
- 2. Increase performance.**
- 3. Shrink high drag, radar reflecting horizontal and vertical tail.**
- 4. Better maneuverability in high angle of attack and low speed.**
- 5. Reduce landing and take-off distances.**
- 6. Greater payload capability for air – to ground mission aircraft.**
- 7. Reduce over the deck wind speed requirements for aircraft operating on aircraft carriers.**

Grid at time steps of 0, 273, 363, 423($\frac{1}{2}$ cycle)

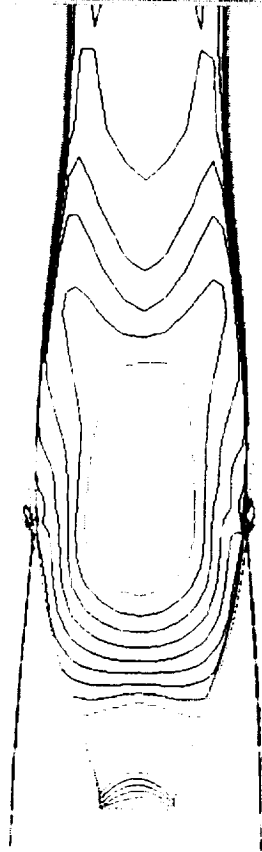


Pressure Distribution for timesteps of 0, 273, 363, 423





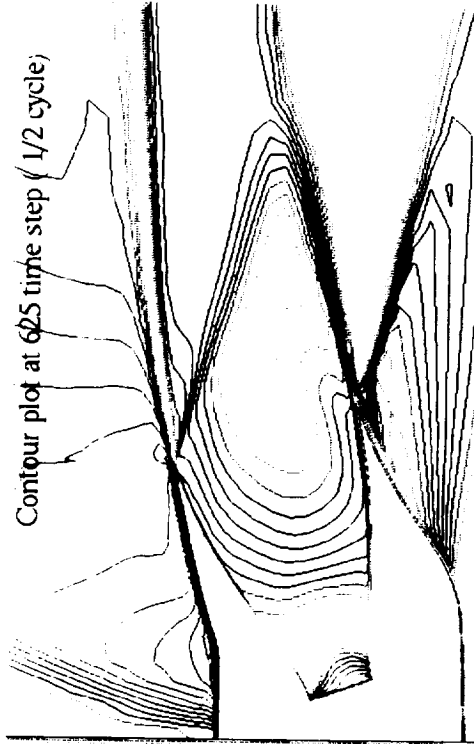
Contour Plot at zero time step



Mach Number

0.000 0.596 1.193 1.789 2.385 2.982

Contour plot at 625 time step (1/2 cycle)



Mach Number

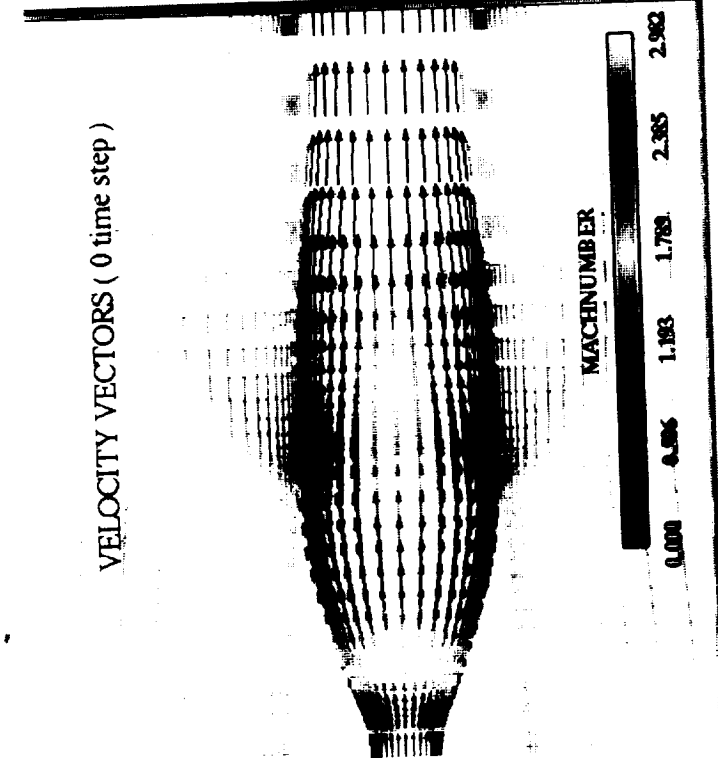
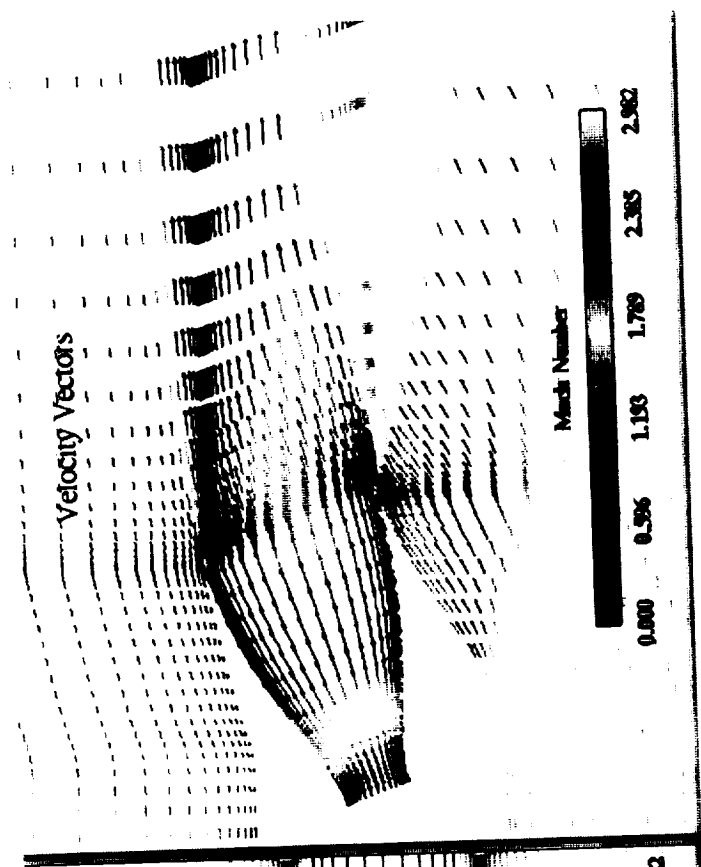
0.000 0.596 1.193 1.789 2.385 2.98



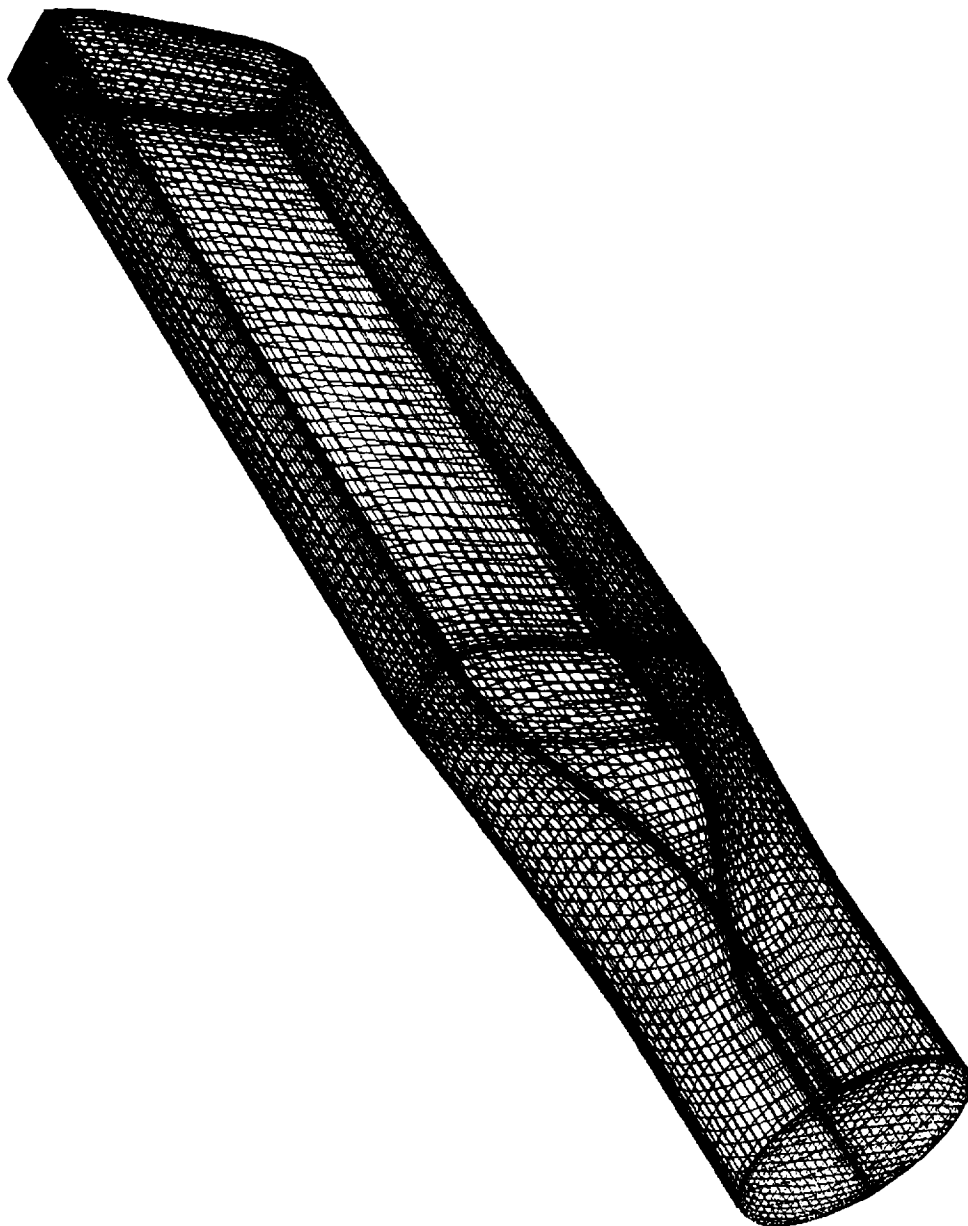
Mach

0.000 0.596 1.193 1.789 2.385 2.982



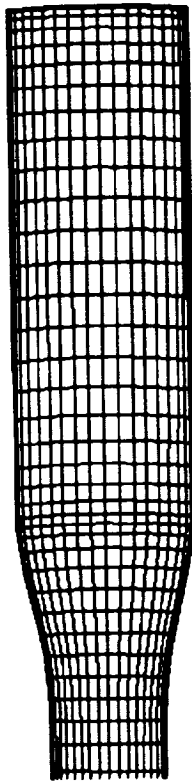


Circular to Rectangular Transition Duct



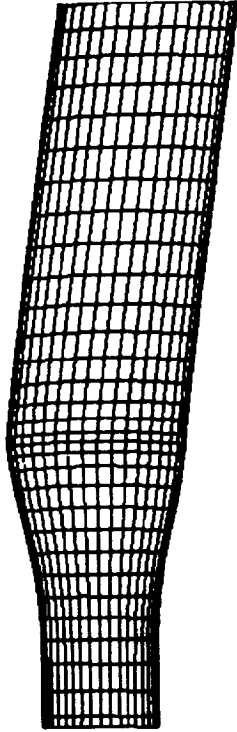
RECTANGULAR TO RECTANGULAR TRANSITION DUCT (0 timestep)

grid size (100 x 50 x 50) k = 25 plane



Thrust Vectoring (70 timestep)

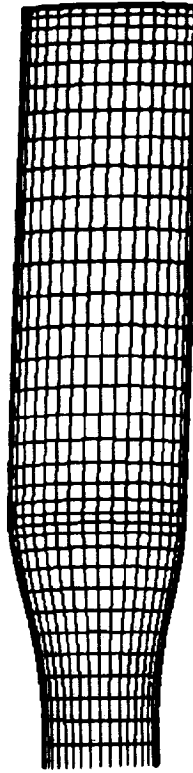
grid size (100 x 50 x 50) k = 25 plane



1002

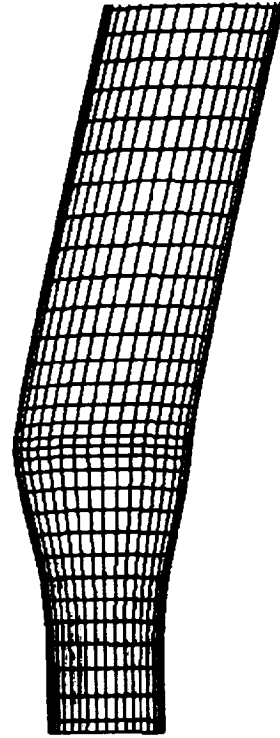
Thrust Vectoring (30 timestep)

grid size (100 x 50 x 50) k = 25 plane

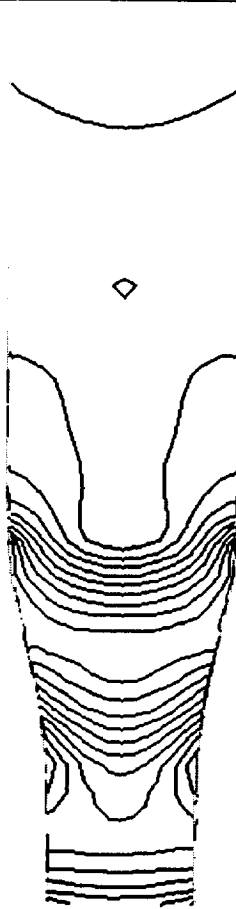


Thrust Vectoring (150 timestep)

grid size (100 x 50 x 50) k = 25 plane



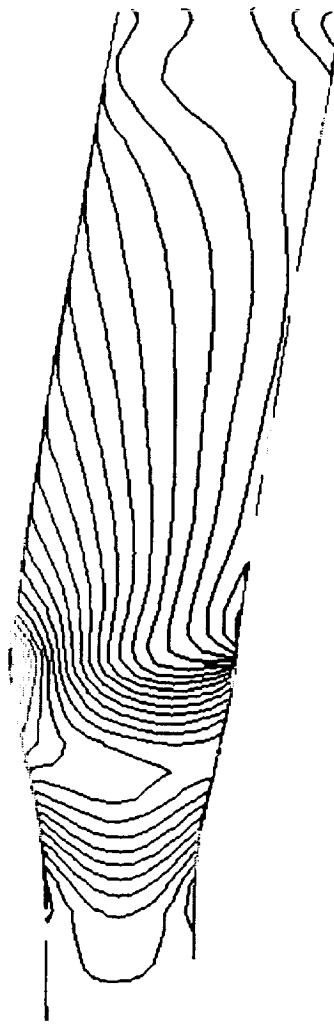
Circular to rectangular transition duct
0 timestep



Pressure

0.319 0.351 0.383 0.415 0.447 0.479

THRUST VECTORING (150 timesteps)



PRESSURE

0.000 0.096 0.192 0.288 0.383 0.479



ONGOING REASERCH:

**Adaption on the distribution mesh and link it with the moving grid
code**



RESULTS:

- 1. CPU of 2.1 secs / iteration for a grid size of 60*40*35 on a onyx 150 MHz processor**
- 2. Memory of the moving grid code is 1.8 Megs**
- 3. Linked with flowsolver it does not consume any memory.**
- 4. Flow solver consumes 75 secs of CPU per / iteration.**
- 5. Adaption is easy to perform as it is on the distribution mesh.**
- 6. Linked successfully to UBIFLOW and INS3D.**
- 7. Converging –diverging , 2– D and axisymmetric thrust vectoring nozzle have been successfully simulated.**

