THREE-DIMENSIONAL UNSTRUCTURED GRID METHOD APPLIED TO TURBOMACHINERY

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OBJECTIVES

- To develop a three-dimensional flow solver based on unstructured tetrahedral meshes for turbomachinery flows.

- To validate the solver through comparisons with experimental data.

- To apply the solver for better understanding of the flow through turbomachinery geometries and design improvement.

APPROACH

- Existing external flow solver/grid generator *(USM3D/VGRID)* has been extensively modified for internal flows.

- Three–dimensional, finite-volume solver based on Roe's flux-difference splitting and explicit Runge-Kutta time stepping.

- Three–dimensional unstructured tetrahedral mesh generation using an advancing-front technique.

GOVERNING EQUATIONS

The governing equations are cast in body-fixed coordinate system which may rotate with an angular velocity Ω about the x-axis :

$$\frac{\partial}{\partial t}\iiint_{\Omega} Q\, dV + \iint_{\partial\Omega} F(Q)\cdot\hat{n}\, dS = R$$

$$Q = \begin{Bmatrix} \rho \\ \rho u^* \\ \rho v^* \\ \rho w^* \\ e_o \end{Bmatrix}, F(Q)\cdot\hat{n} = \begin{Bmatrix} \rho\bar{u} \\ \rho u^*\bar{u} + p\hat{n}_x \\ \rho v^*\bar{u} + p\hat{n}_y \\ \rho w^*\bar{u} + p\hat{n}_z \\ e_o\bar{u} + pu_n \end{Bmatrix}, R = V \begin{Bmatrix} 0 \\ 0 \\ \Omega\rho w^* \\ -\Omega\rho v^* \\ 0 \end{Bmatrix}$$

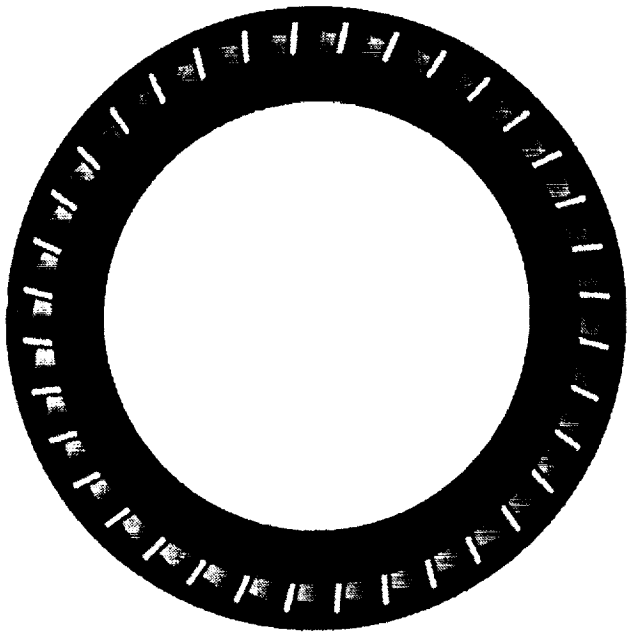
BOUNDARY CONDITIONS

- **Flow tangency condition is imposed on solid surfaces.**
- **Periodic flow condition is imposed between the blades.**
- **At the inflow boundary, total pressure, total temperature, and the flow angle are specified.**
- **At the exit plane, the static pressure is prescribed.**

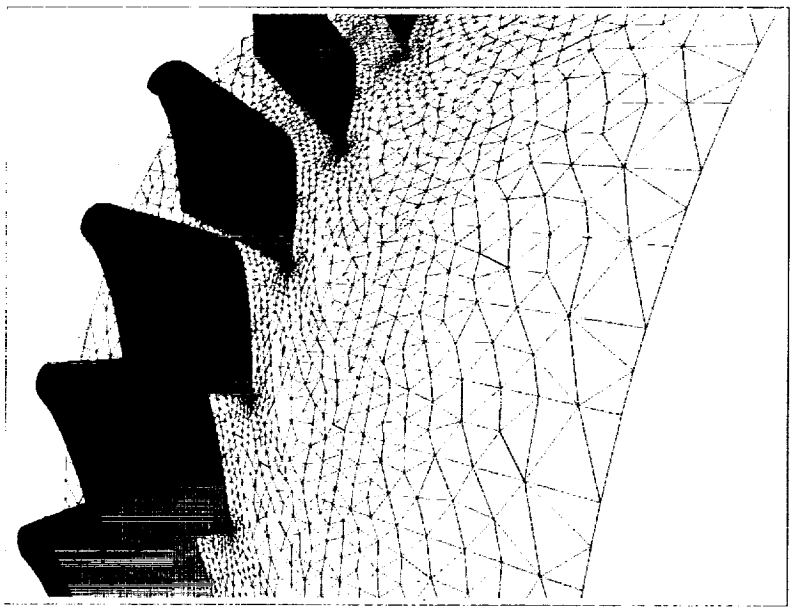
MESH GENERATION

VGRID has been modified to enforce grid periodicity of the surface mesh on the periodic boundaries.

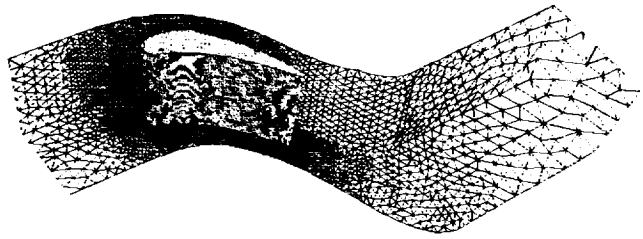
- The same surface patches are defined on the periodic boundaries from the definition of computational domain.
- The corresponding boundary lines on the periodic surfaces are divided into same segments.
- One periodic boundary surface is meshed and the surface triangles are replaced on the other surface with proper connectivity.



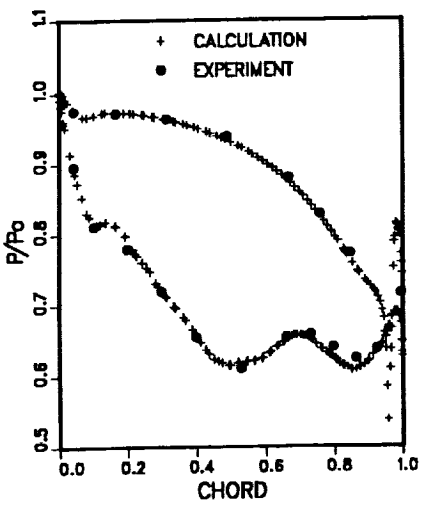
Turbine Stator Annular Cascade



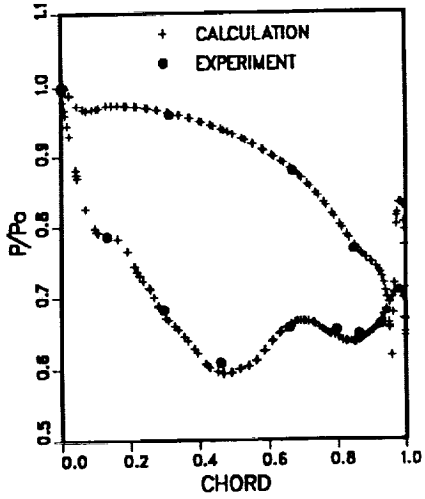
Close–Up View of Blade and Hub Surface Triangulation



Surface Triangulation of Computational Domain

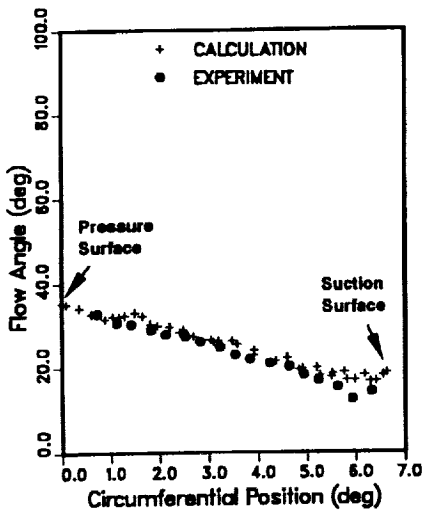


50.0% Span

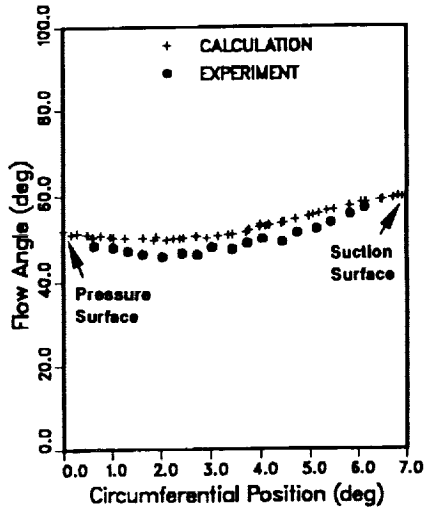


86.7% Span

Static Pressure Distribution on the Blade

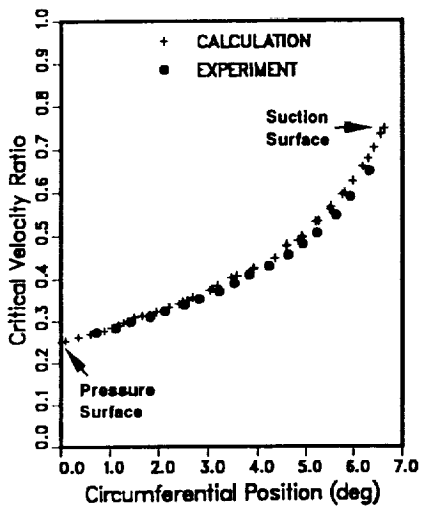


30% Axial Chord

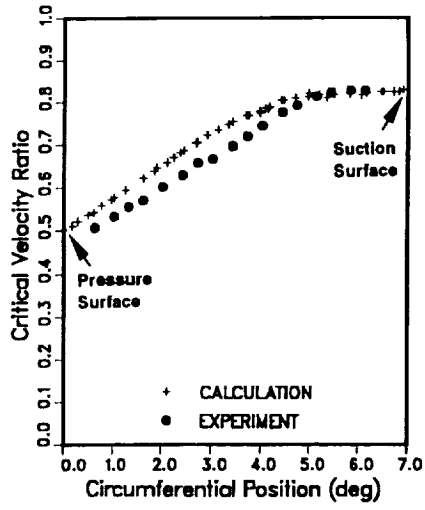


70% Axial Chord

Flow Angle at 50% Span

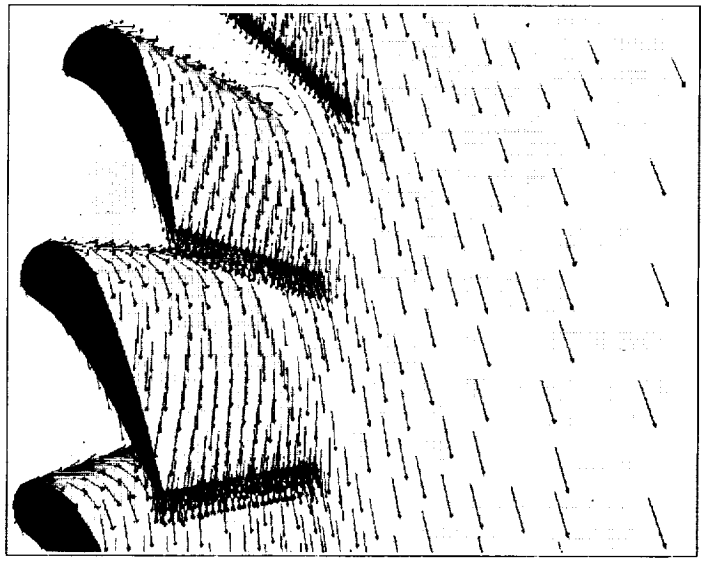


30% Axial Chord



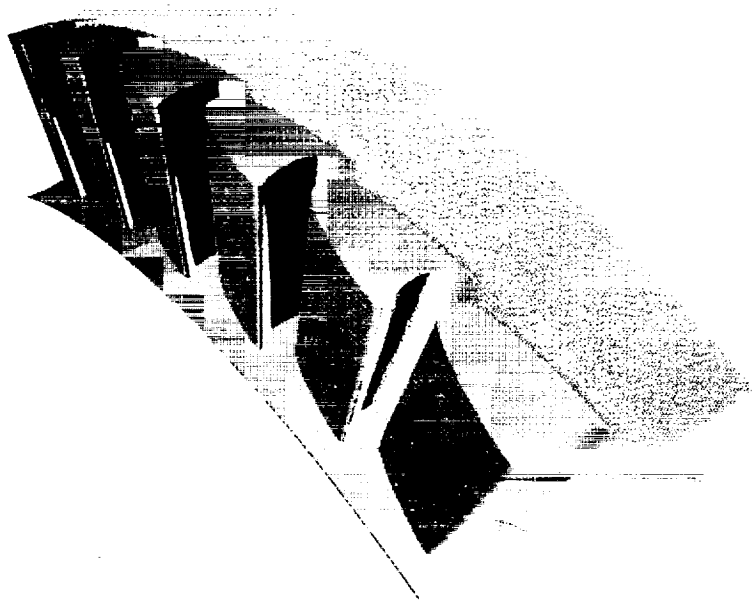
70% Axial Chord

Critical Velocity Ratio at 50% Span

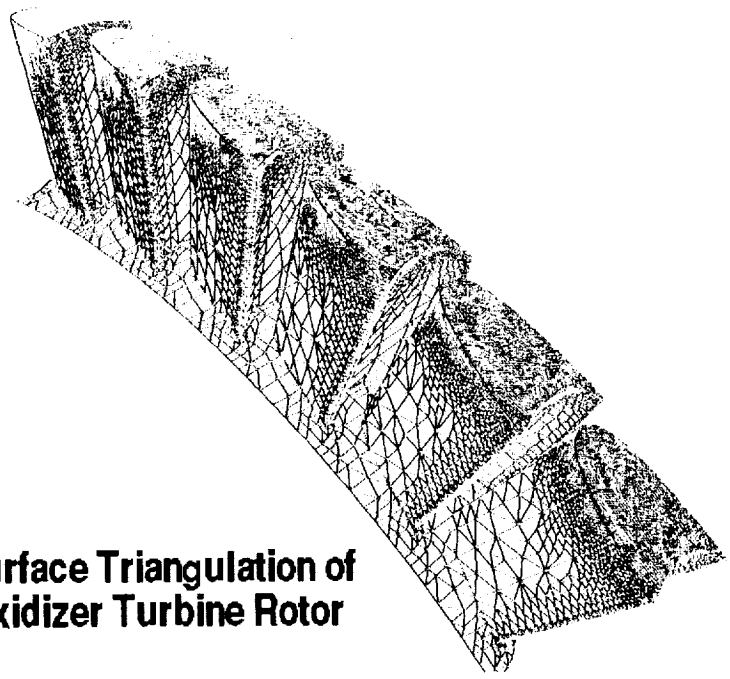


Velocity Vectors on the Blade and Hub Surfaces

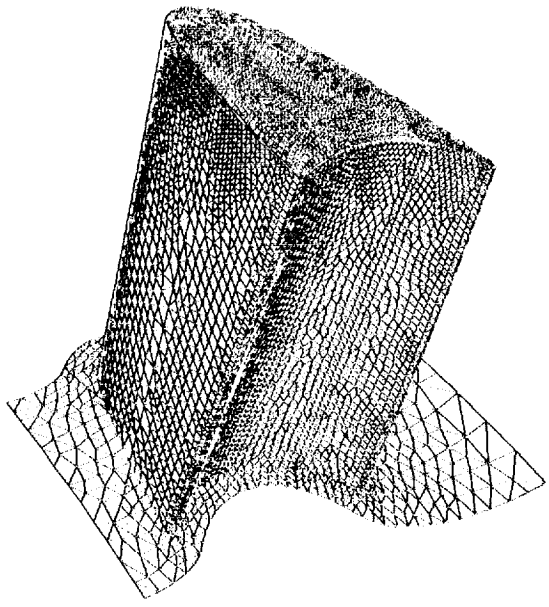
Mach Number Contour on the Blade and Hub Surfaces



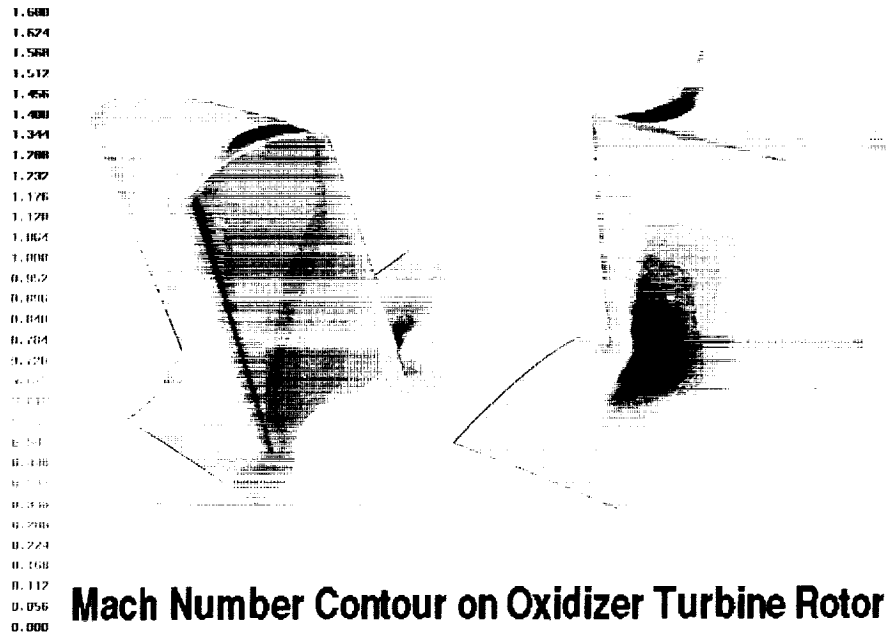
Advanced Gas Generator Oxidizer Turbine Rotor



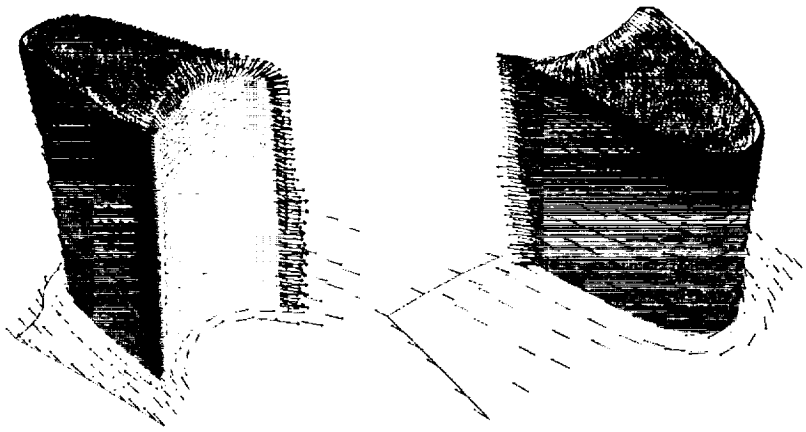
Surface Triangulation of
Oxidizer Turbine Rotor



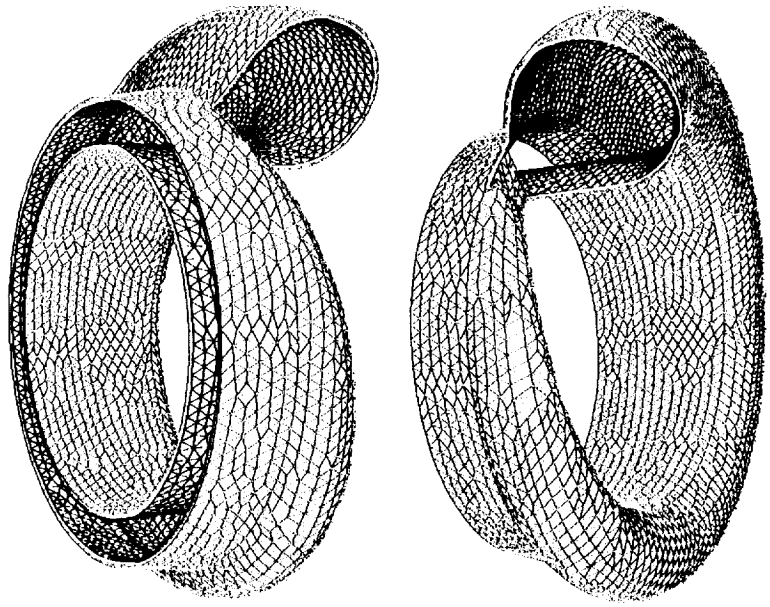
Surface Triangulation of Oxidizer Turbine Rotor



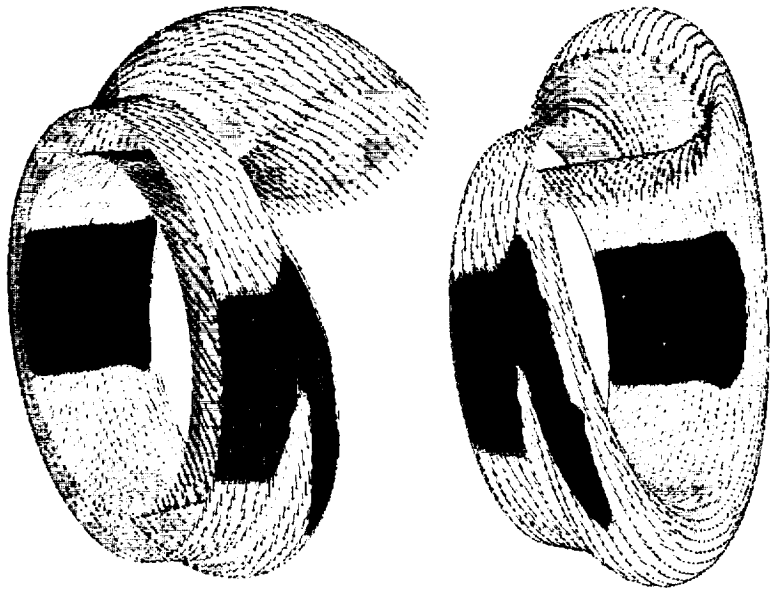
Mach Number Contour on Oxidizer Turbine Rotor



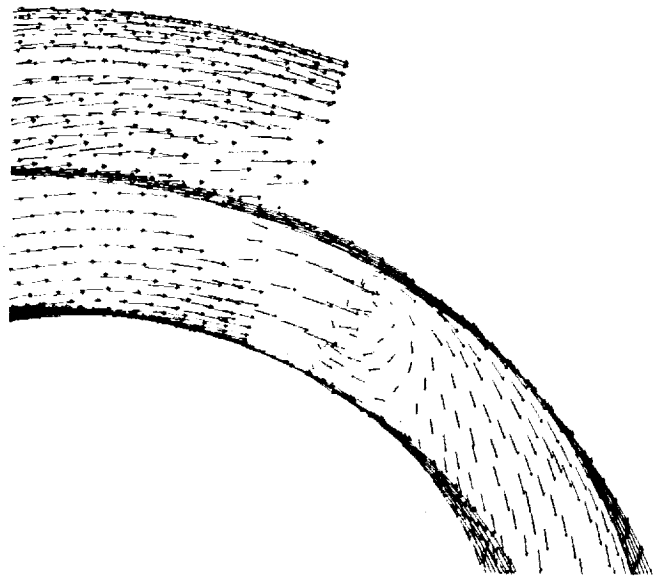
Velocity Vectors on Oxidizer Turbine Rotor



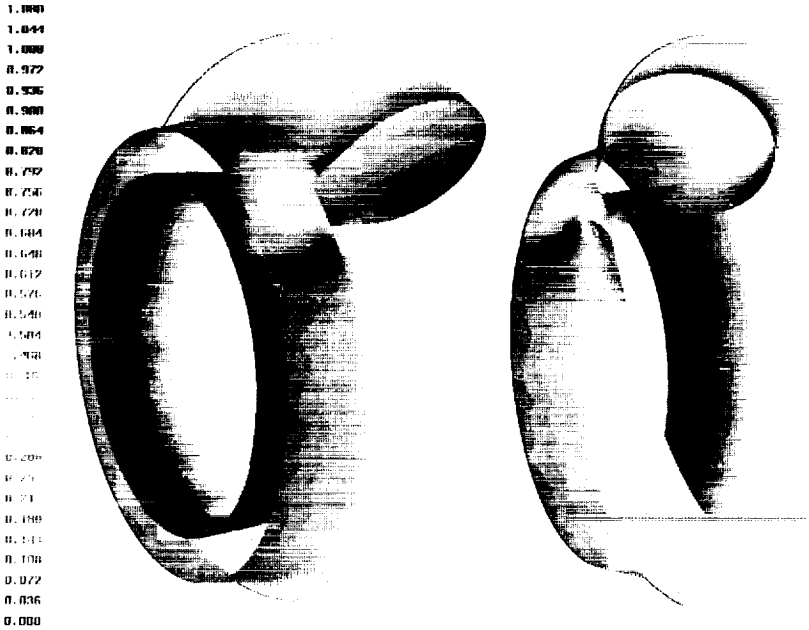
Surface Triangulation of Oxidizer Turbine Volute



Velocity Vectors on Oxidizer Turbine Volute



Velocity Vectors on Oxidizer Turbine Volute



Mach Number Contour on Oxidizer Turbine Volute

CONCLUDING REMARKS

- **A three-dimensional unstructured grid Euler solver has been developed for turbomachinery flows based on an existing external flow solver *USM3D*.**

- **Good correlation with experimental data has been observed both on the blade surface and in the flow passage between the blades.**

- **Applications are successfully made to calculate flows through various turbomachinery geometries.**

FUTURE WORKS

- **Solution-adaptive grid generation.**

- **Add viscous terms for the solver.**

- **Add adequate turbulence model.**