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CFD Analysis of Turbopump Volutes

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Workshop for Computational Fluid Dynamic
Applications in Rocket Propulsion

April 20-22, 1993
NASA Marshall Space Flight Center

Abstract

An effort is underway to develop a procedure for the regular use of CFD analysis in the design of turbopump volutes. Airflow data to be taken at NASA Marshall will be used to validate the CFD code and overall procedure. Initial focus has been on preprocessing (geometry creation, translation, and grid generation). Volute geometries have been acquired electronically and imported into the CATIA CAD system and RAGGS (Rockwell Automated Grid Generation System) via the IGES standard. An initial grid topology has been identified and grids have been constructed for turbine inlet and discharge volutes. For CFD analysis of volutes to be used regularly, a procedure must be defined to meet engineering design needs in a timely manner. Thus, a compromise must be established between making geometric approximations, the selection of grid topologies, and possible CFD code enhancements. While the initial grid developed approximated the volute tongue with a zero thickness, final computations should more accurately account for the geometry in this region. Additionally, grid topologies will be explored to minimize skewness and high aspect ratio cells that can affect solution accuracy and slow code convergence. Finally, as appropriate, code modifications will be made to allow for new grid topologies in an effort to expedite the overall CFD analysis process.

CFD ANALYSIS OF TURBOPUMP VOLUTES

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TASK OBJECTIVES

- **DEVELOP CFD ANALYSIS PROCEDURE FOR REGULAR USE IN ENGINEERING DESIGN**

- **VALIDATE CFD CODE AND PROCEDURE WITH MSFC TURBINE AIRFLOW DATA**

- **PERFORM CFD ANALYSIS IN SUPPORT OF VOLUTE DESIGNS FOR ROCKET ENGINE TURBINES**
  - EMPHASIS ON GAS GENERATOR OXIDIZER TURBINE (GGOT) DESIGN OF TURBINE TECHNOLOGY TEAM
  - DESIGN AND OFF-DESIGN CONDITIONS

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INITIAL FOCUS ON DEVELOPMENT OF PROCEDURE

- **AUTOMATE PREPROCESSING**
  - GEOMETRY CREATION AND TRANSLATION
  - GRID GENERATION
- **MODIFY/UPGRADE REACT CFD CODE AS NEEDED**
- **DEMONSTRATE PROCEDURE ON TURBINE INLET AND DISCHARGE VOLUTES**

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PREPROCESSING PROCEDURE ESTABLISHED

- GEOMETRY ACQUIRED ELECTRONICALLY
- TRANSLATION VIA IGES INTO CATIA AND RAGGS
- INITIAL GRID TOPOLOGY IDENTIFIED
- INITIAL INLET AND DISCHARGE GRIDS DEVELOPED

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ELECTRONIC DESIGN & GRID GENERATION TOOLS

- **CAD/CAM**
  - UNIGRAPHICS (UG) USED AT P&W
  - CATIA USED AT ROCKETDYNE
- **IGES TRANSLATOR**
  - GRAPHICS EXCHANGE STANDARD FORMAT
  - COMMON TO MOST ADVANCED GEOMETRY AND GRID GENERATION SYSTEMS
- **ROCKWELL AUTOMATED GRID GENERATION SYSTEM (RAGGS)**
  - FAMILY OF CODES FOR SURFACE DEFINITION, GRID GENERATION, AND POSTPROCESSING
  - INTERACTIVE USER INTERFACE
  - ACCEPTS IGES GEOMETRY FILES

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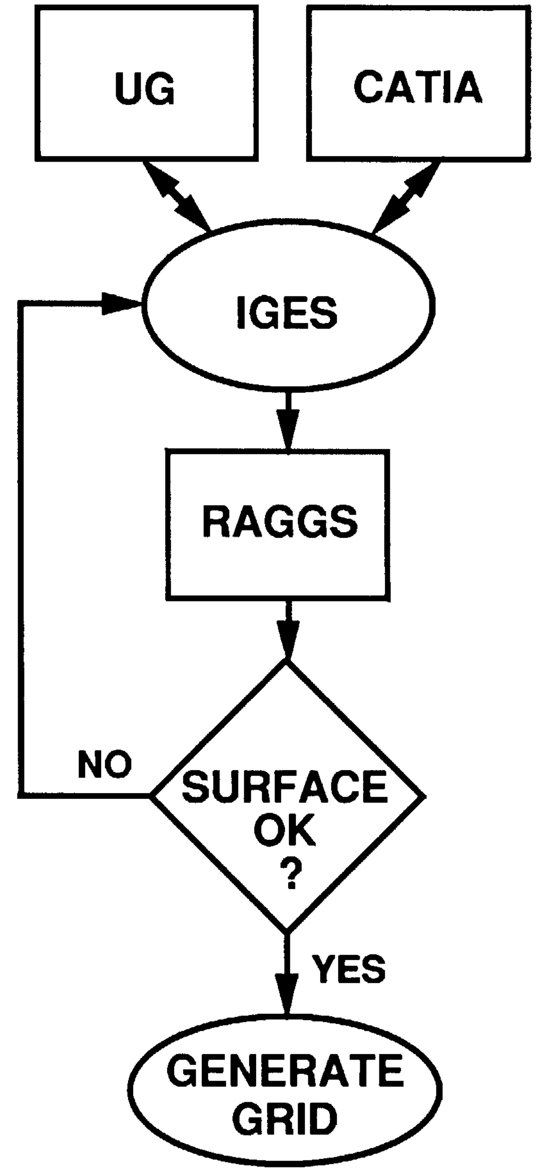
EXTENSIVE TRANSLATION/VERIFICATION REQUIRED

- **UG IGES FILE TRANSLATED DIRECTLY TO RAGGS**
  - FILE READ SUCCESSFULLY
  - EXCESSIVE NUMBER OF PATCHES (OVER 7,000)

- **UG IGES FILE TRANSLATED TO CATIA**
  - NUMBER OF SURFACE PATCHES REDUCED
  - SURFACE ACCURACY CHECKED
  - APPROXIMATELY 340 SURFACE PATCHES USED



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VARIETY OF TRANSLATION ISSUES ENCOUNTERED

ISSUE	SOLUTION
7249 IGES PATCHES • EXCESSIVE MEMORY REQUIREMENTS • SLOW SYSTEM RESPONSE	• INCREASED RAGGS MEMORY ALLOCATION • REDUCED NUMBER OF PATCHES VIA CATIA UTILITY
SURFACE ACCURACY INADEQUATE DUE TO PATCH NUMBER REDUCTION	ESTABLISHED BALANCE BETWEEN REDUCED NUMBER OF SURFACE PATCHES AND ACCURACY OF SURFACE

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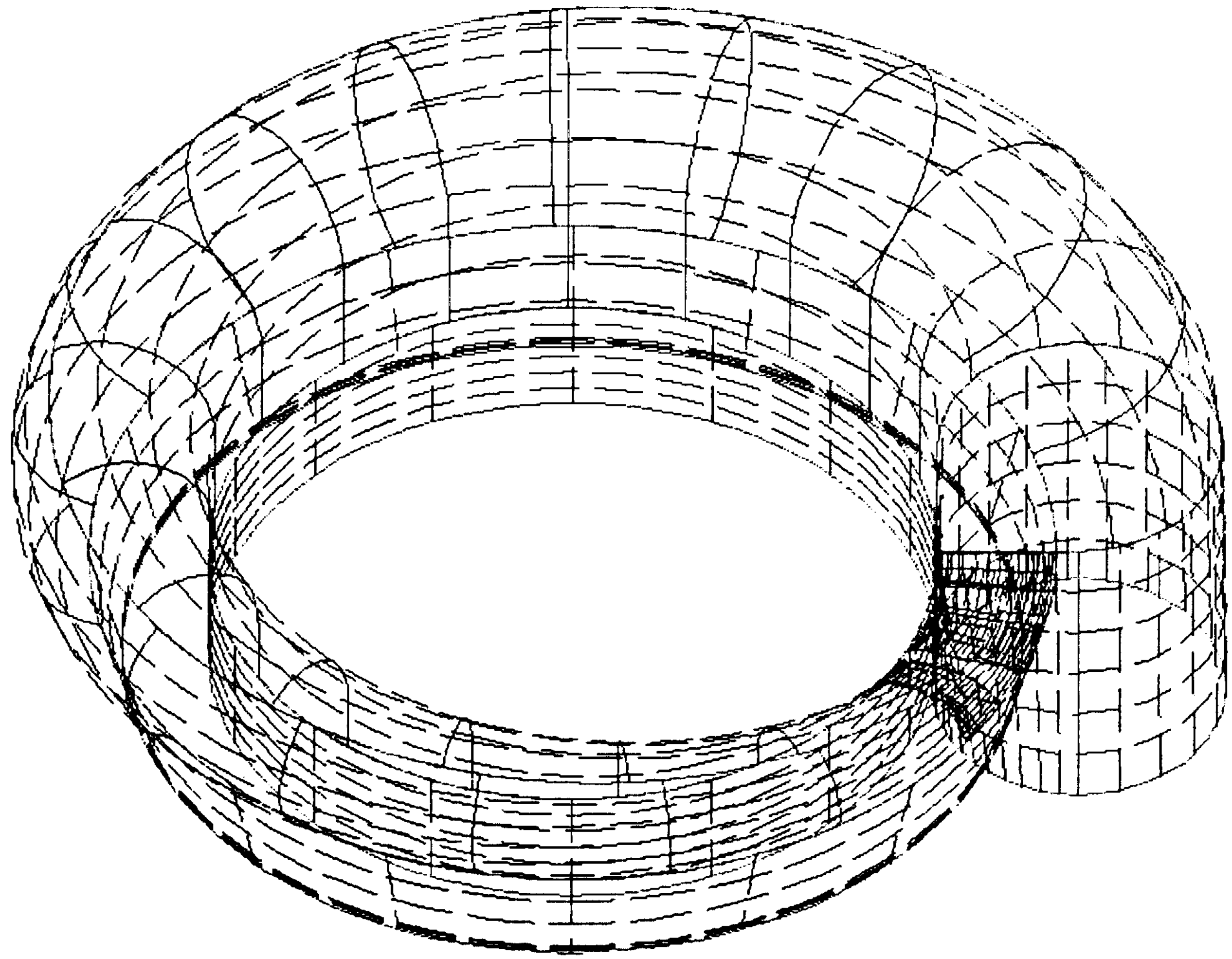
VOLUTE GEOMETRY TRANSLATED TO CATIA



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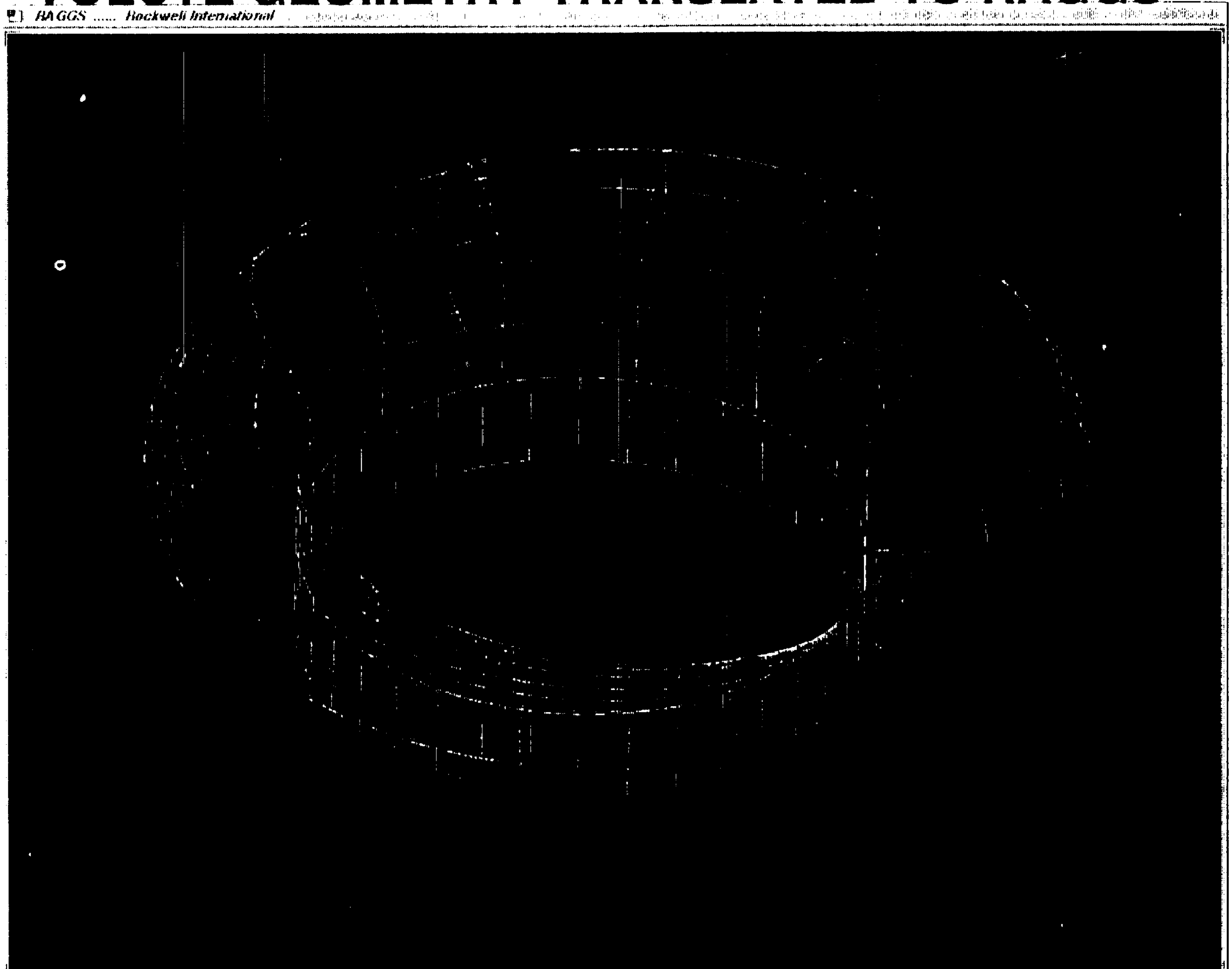
VOLUTE GEOMETRY TRANSLATED TO RAGGS



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RAGGS REPRESENTATION OF VOLUTE SURFACES

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THREE ZONE GRID DEVELOPED

REGION	ZONE	COLOR	GRID POINTS
INLET	1	RED	50 X 31 X 31 = 48,050
TAPERED MANIFOLD	2	YELLOW	95 X 31 X 31 = 91,295
ANNULAR DISCHARGE	3	MAGENTA	100 X 31 X 31 = 155,000

SPACING AT WALL < 0.02" TO MAINTAIN Y + $\leq$ 1,000

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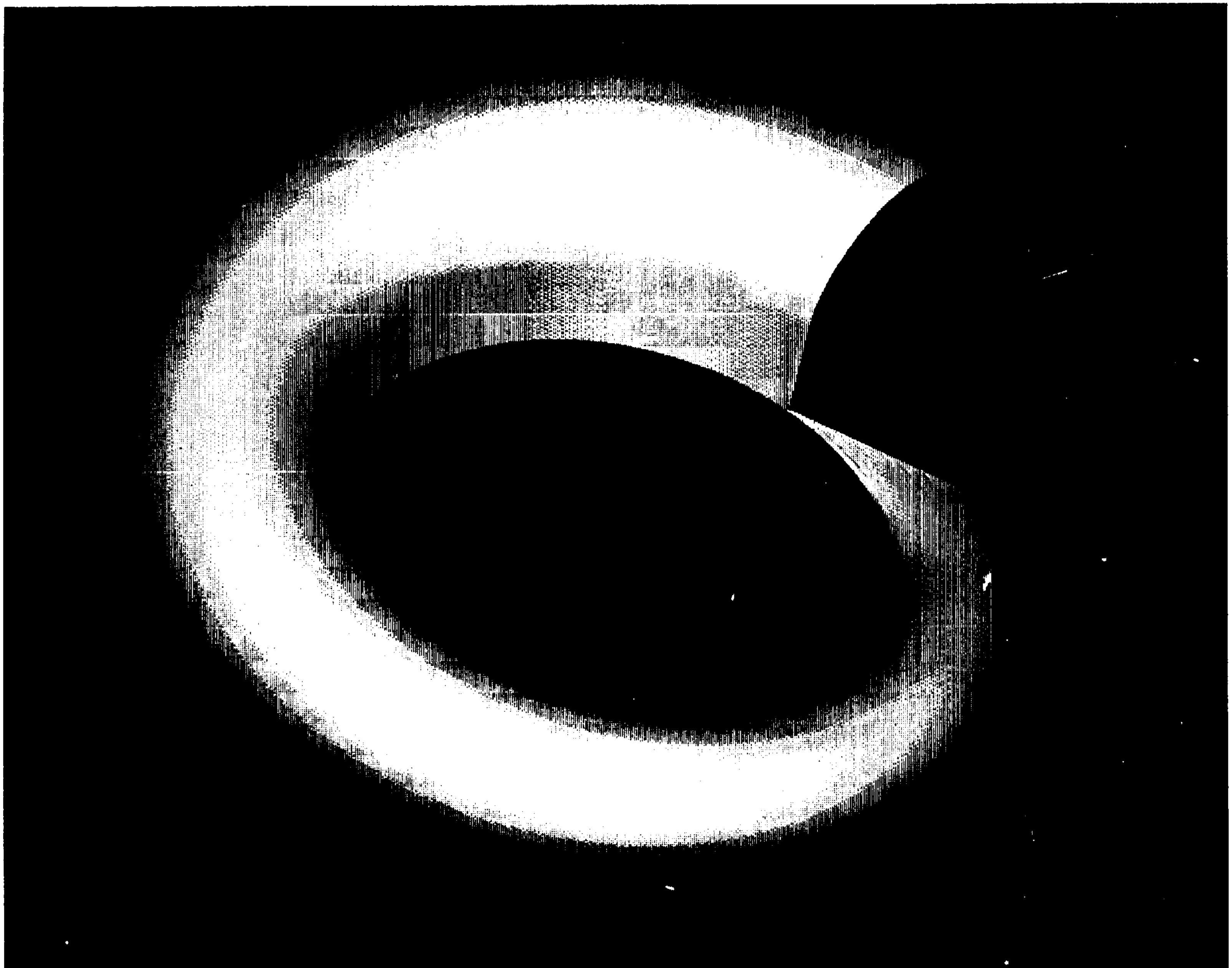
THREE-ZONE VOLUTE TOPOLOGY



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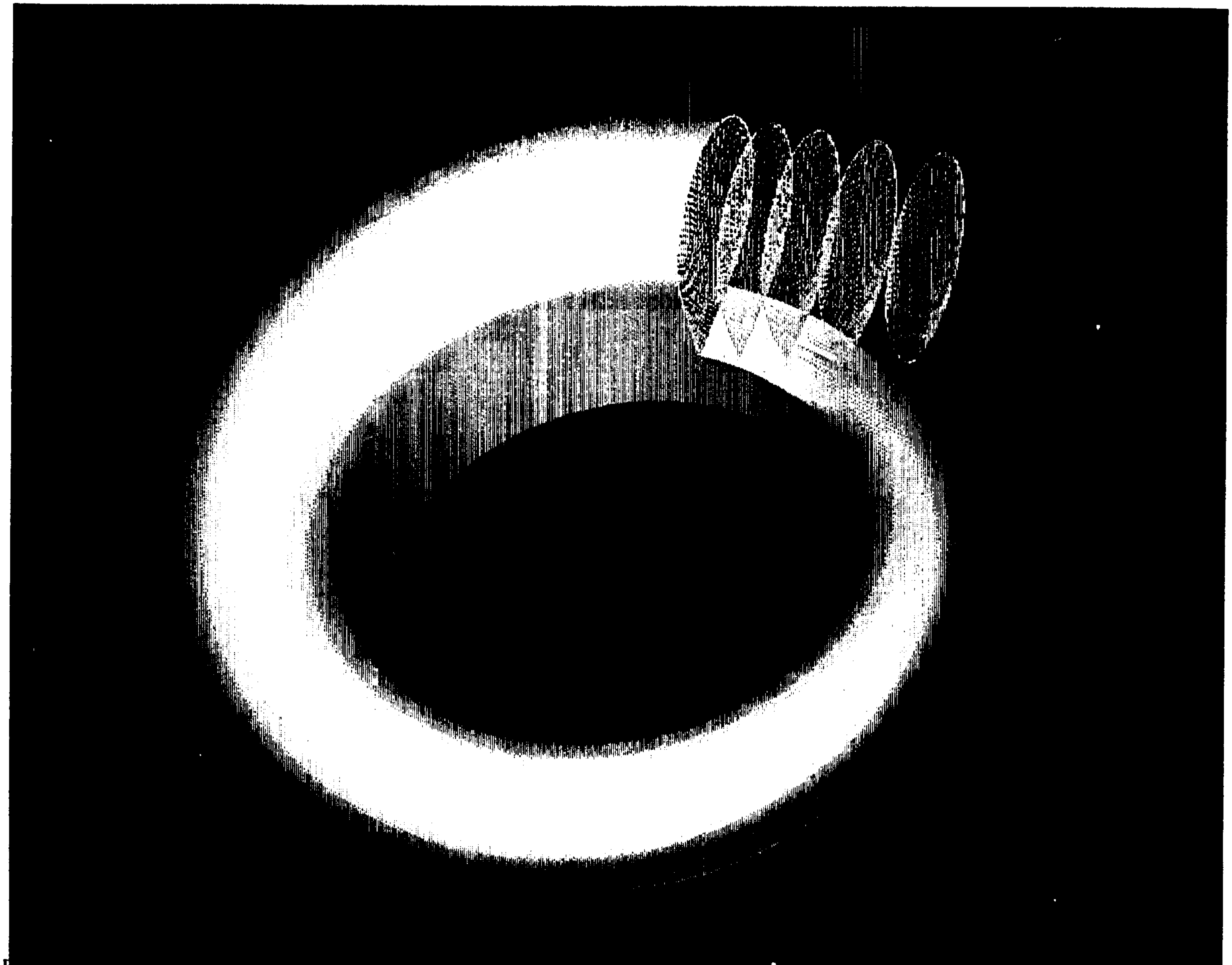
ZONE 1 – INLET GRID



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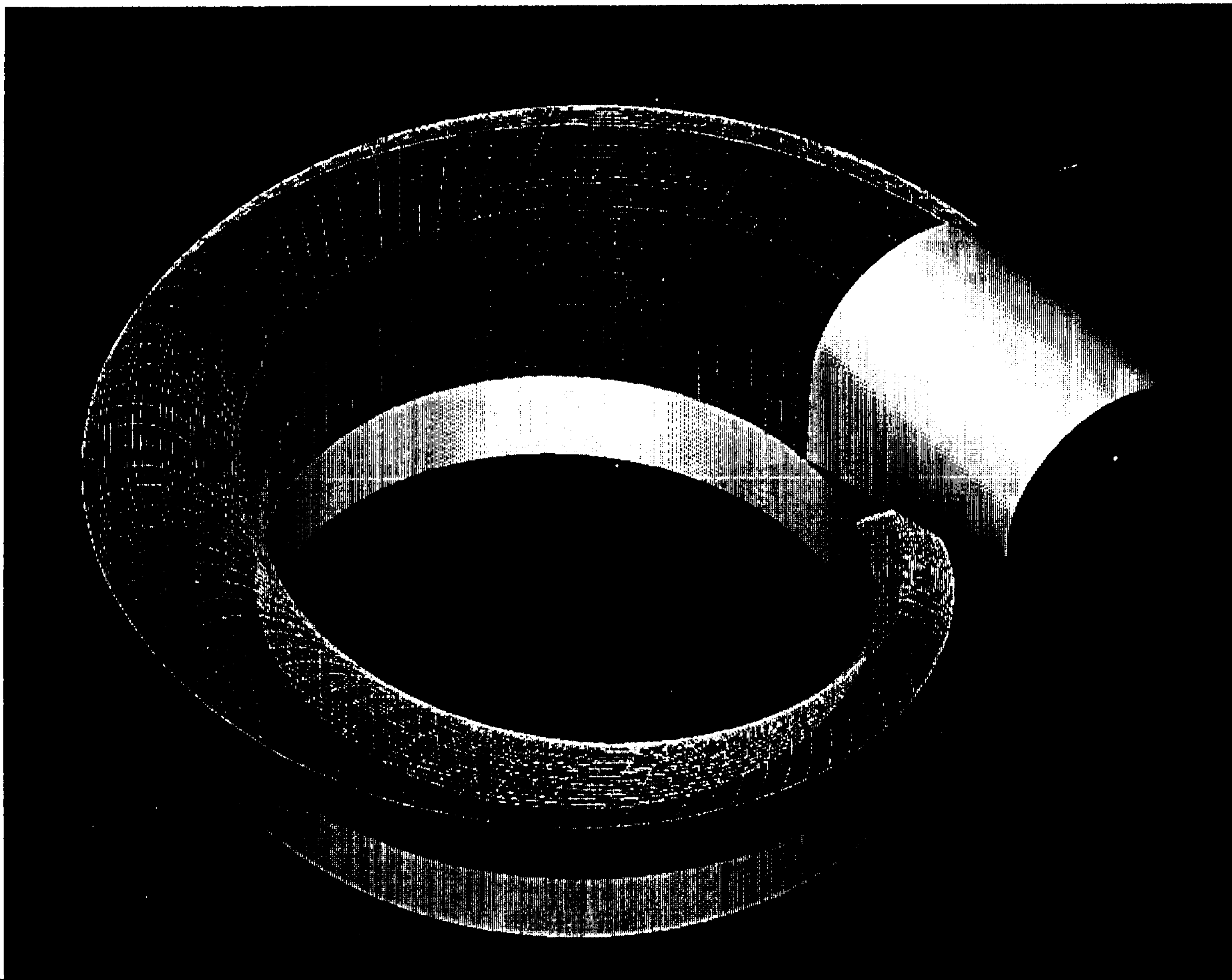
ZONE 2 – TAPERED MANIFOLD



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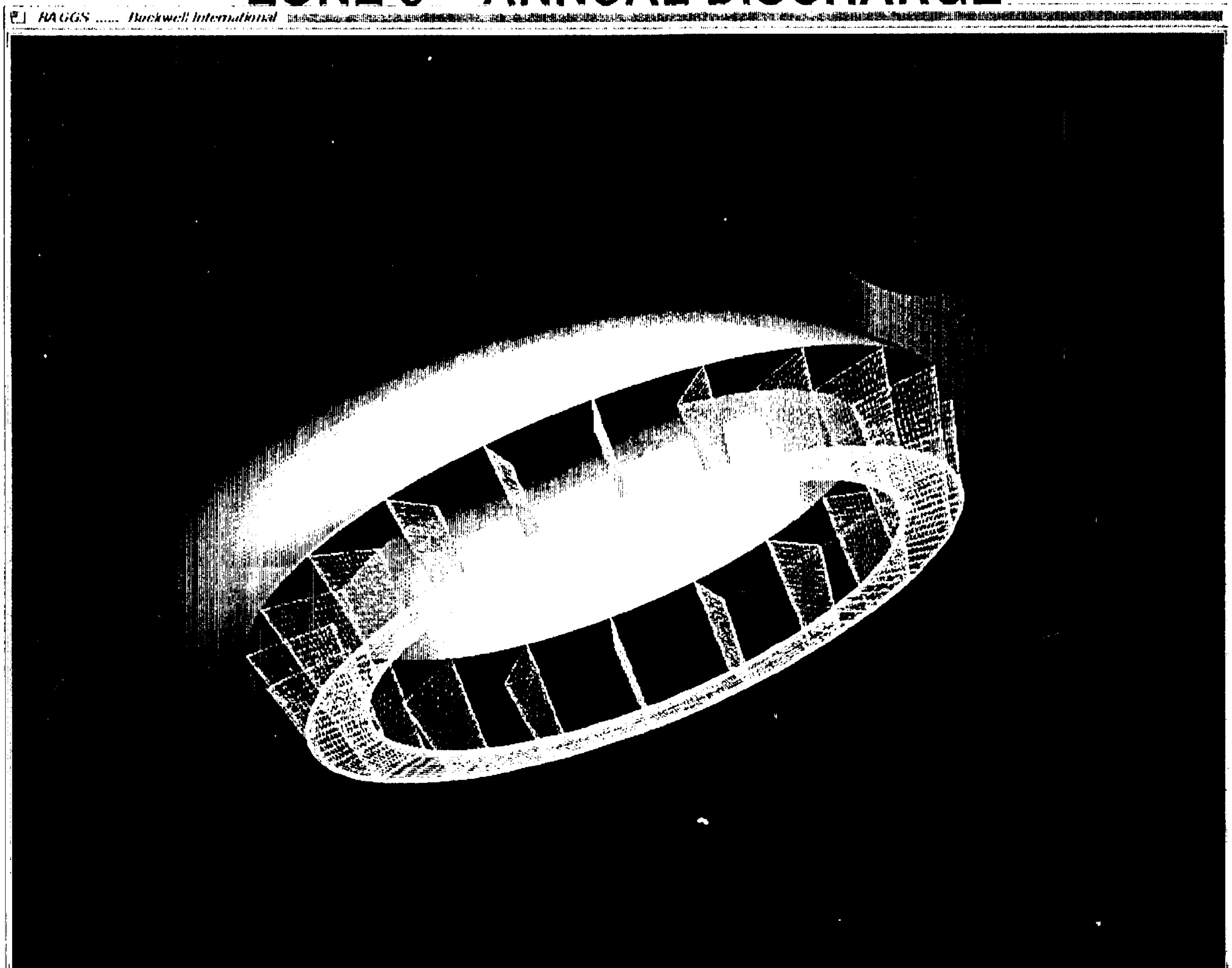
ZONE 3 – ANNUAL DISCHARGE



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SAME TOPOLOGY USED FOR EXIT VOLUTE

ZONE	COLOR	REGION	GRID POINTS
1	RED	ANNULAR INLET	49 x 31 x 99 = 150,381
2	GREEN	MANIFOLD	31 x 31 x 95 = 91,295
3	MAGENTA	DISCHARGE	31 x 31 x 49 = 47,089
			TOTAL = 288,765

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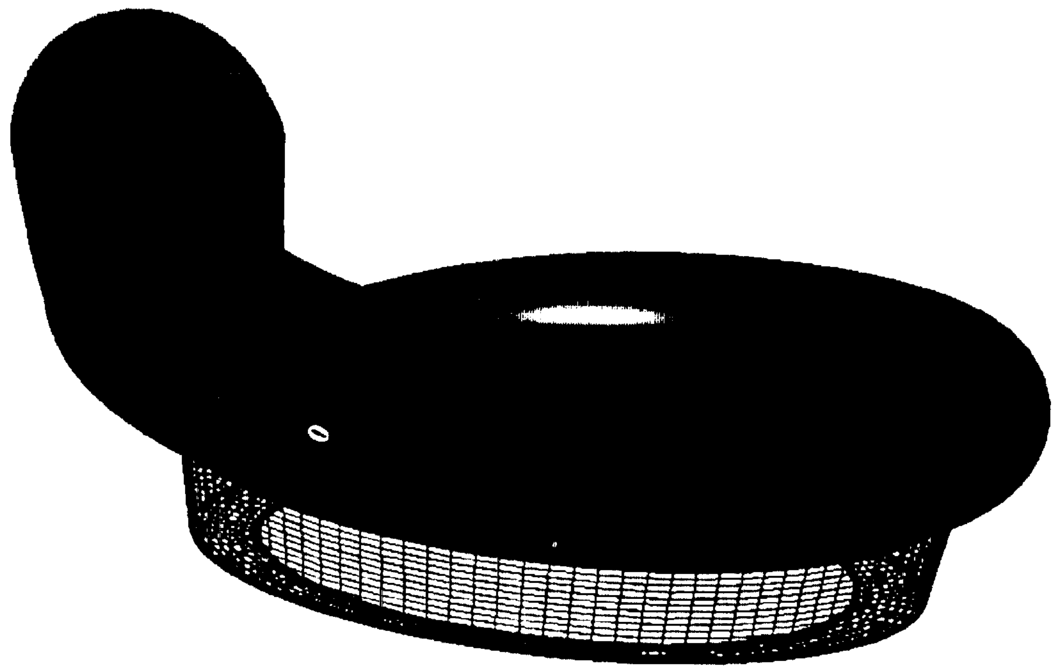
EXIT VOLUTE ZONE 1

ANNULAR INLET



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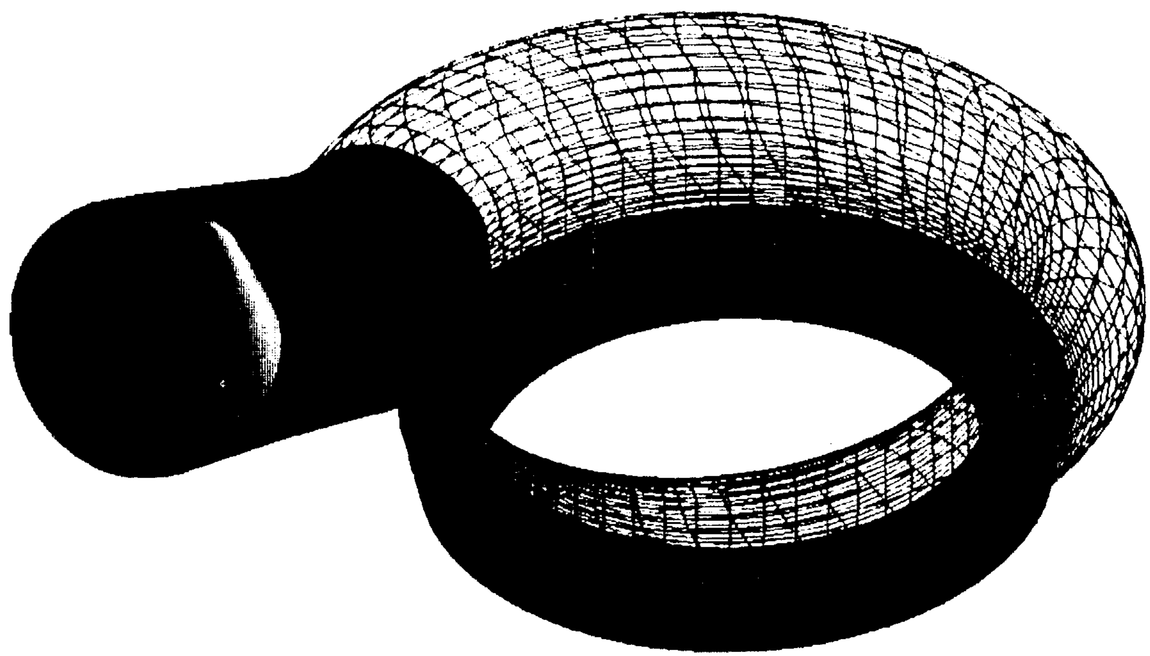
EXIT VOLUTE ZONE 2

MANIFOLD



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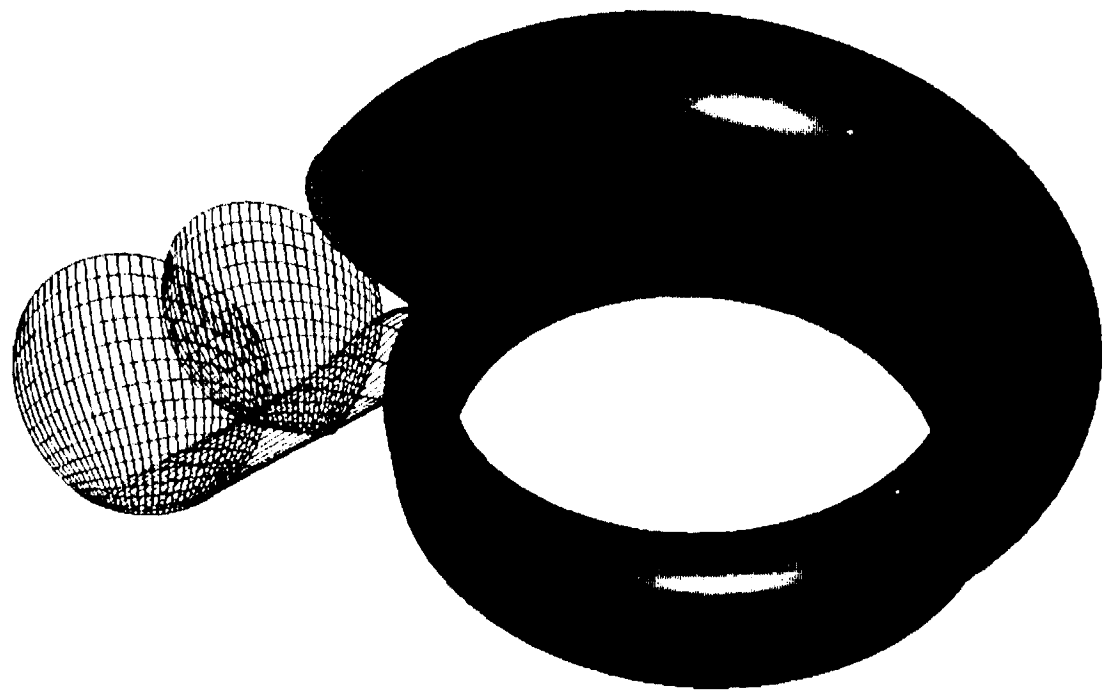
EXIT VOLUTE ZONE 3

DISCHARGE



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DESIGN PROCEDURE MUST MEET ENGINEERING ACCURACY, CYCLE TIME REQUIREMENTS

- **GEOMETRIC APPROXIMATIONS**
  - MAINTAIN ACCURACY IN CRITICAL AREAS
  - SIMPLIFY GRID GENERATION REQUIREMENTS
- **GRID TOPOLOGIES**
  - SATISFY CODE REQUIREMENTS
    - ASPECT RATIO
    - ORTHOGONALITY
    - ZONAL CONNECTIVITY
  - SIMPLIFY GRID GENERATION
  - GRID COINCIDENT WITH SURFACES AND REGIONS OF INTEREST
- **CODE ENHANCEMENTS AS NEEDED TO IMPROVE OVERALL PROCEDURE**

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GEOMETRIC APPROXIMATIONS

- **START WITH COMPLETE DESCRIPTION AS TRANSLATED FROM CAD SYSTEM**
- **TONGUE AREA CONSIDERED CRITICAL**
  - INITIAL APPROXIMATIONS CONSIDERED INADEQUATE
    - ZERO THICKNESS
    - ALTERED MANIFOLD GEOMETRY
  - RESTORE ORIGINAL GEOMETRY
- **MANIFOLD-ANNULUS ACCURACY LESS CRITICAL**
  - CONSIDER "FILLET" INSTEAD OF SHARP CORNER
  - GRID "SMEARING" POSSIBLE WITH SOME TOPOLOGIES

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GRID TOPOLOGY / CODE MODIFICATION

- **THREE-ZONE TOPOLOGY VERY NATURAL**
  - FOLLOWS GEOMETRY EXACTLY
  - SIMPLY CONNECTED ZONES
  - FORCES HIGH DEGREE OF SKEWED, HIGH ASPECT CELLS AT TAPERED END OF MANIFOLD

- **ALTERNATE TOPOLOGIES CONSIDERED**
  - PRIMARY GOAL TO MINIMIZE SKEWNESS
  - MAY "BLUR" GEOMETRY IN NONCRITICAL REGION
  - MAY REQUIRE ADDITIONAL LOGIC FOR ZONAL CONNECTIVITY
    - ALTERNATE GRID LINES REMOVED
    - ARBITRARY GRIDS

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SUMMARY

- **SIGNIFICANT AUTOMATION OF PREPROCESSING**
  - CAD GEOMETRY USED DIRECTLY
  - AUTOMATED GRID GENERATION SYSTEM (RAGGS) SUCCESSFULLY APPLIED
  - SIGNIFICANT REDUCTION IN CYCLE TIME
  - INITIAL INLET AND EXIT VOLUTE GRIDS GENERATED

- **PROCEDURE BEING DEFINED TO ALLOW FOR PRODUCTIVE USE OF CFD IN DESIGN CYCLE — BEST COMPROMISE OF:**
  - GEOMETRIC APPROXIMATION
  - GRID TOPOLOGY
  - CODE ENHANCEMENTS

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