

ORIGINAL CONTAINS  
COLOR ILLUSTRATIONS

N91-10861

**NAVIER-STOKES SOLUTIONS FOR FLOWS  
RELATED TO STORE SEPARATION**

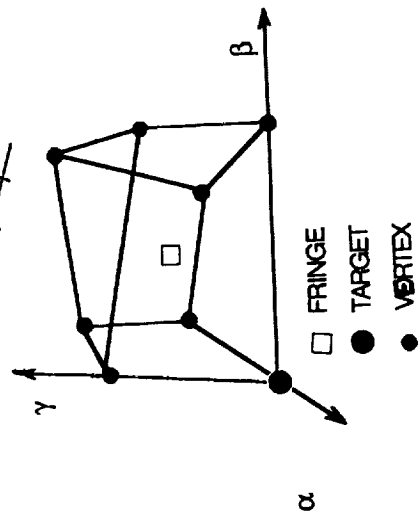
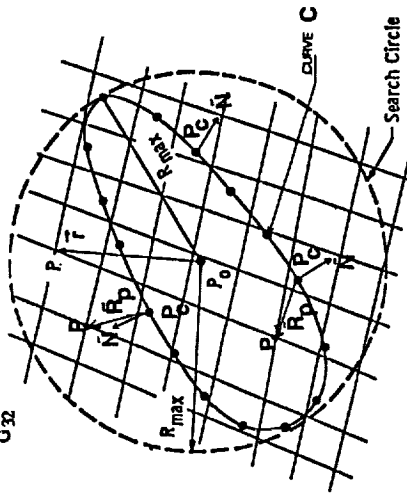
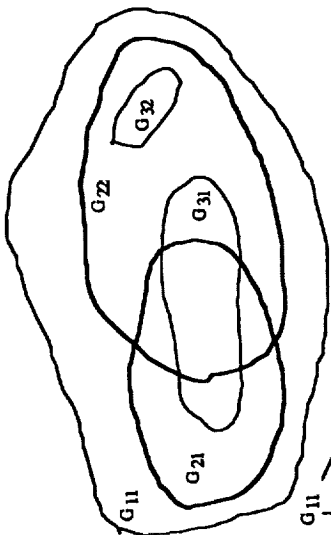
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The objective is developing CFD capabilities to obtain solutions for viscous flows about generic configurations of internally and externally carried stores. The emphasis is placed on the supersonic flow regime with extensions being made to the transonic regime. The project is broken into four steps : (A) Cavity flows for internal carriage configurations; (B) High angle of attack flows, which may be experienced during the separation of the stores; (C) Flows about a body near a flat plate for external carriage configurations; (D) Flows about a body inside or in the proximity of a cavity. Three dimensional unsteady cavity flow solutions are obtained by an explicit, MacCormack algorithm, EMCAV3, for open, close, and transitional cavities. High angle of attack flows past cylinders are solved by an implicit, upwind algorithm. All the results compare favorably with the experimental data. For flows about multiple body configurations, the Chimera embedding scheme is modified for finite-volume and multigrid algorithms, MaGGiE. Then a finite volume, implicit, upwind, multigrid Navier-Stokes solver which uses on overlapped/embedded and zonal grids, VUMXZ3, is developed from the CFL3D code. Supersonic flows past a cylinder near a flat plate are computed using this code. The results are compared with the experimental data. Currently the VUMXZ3 code is being modified to accomplish step (D) of this project. Wind tunnel experiments are also being conducted for validation purposes.

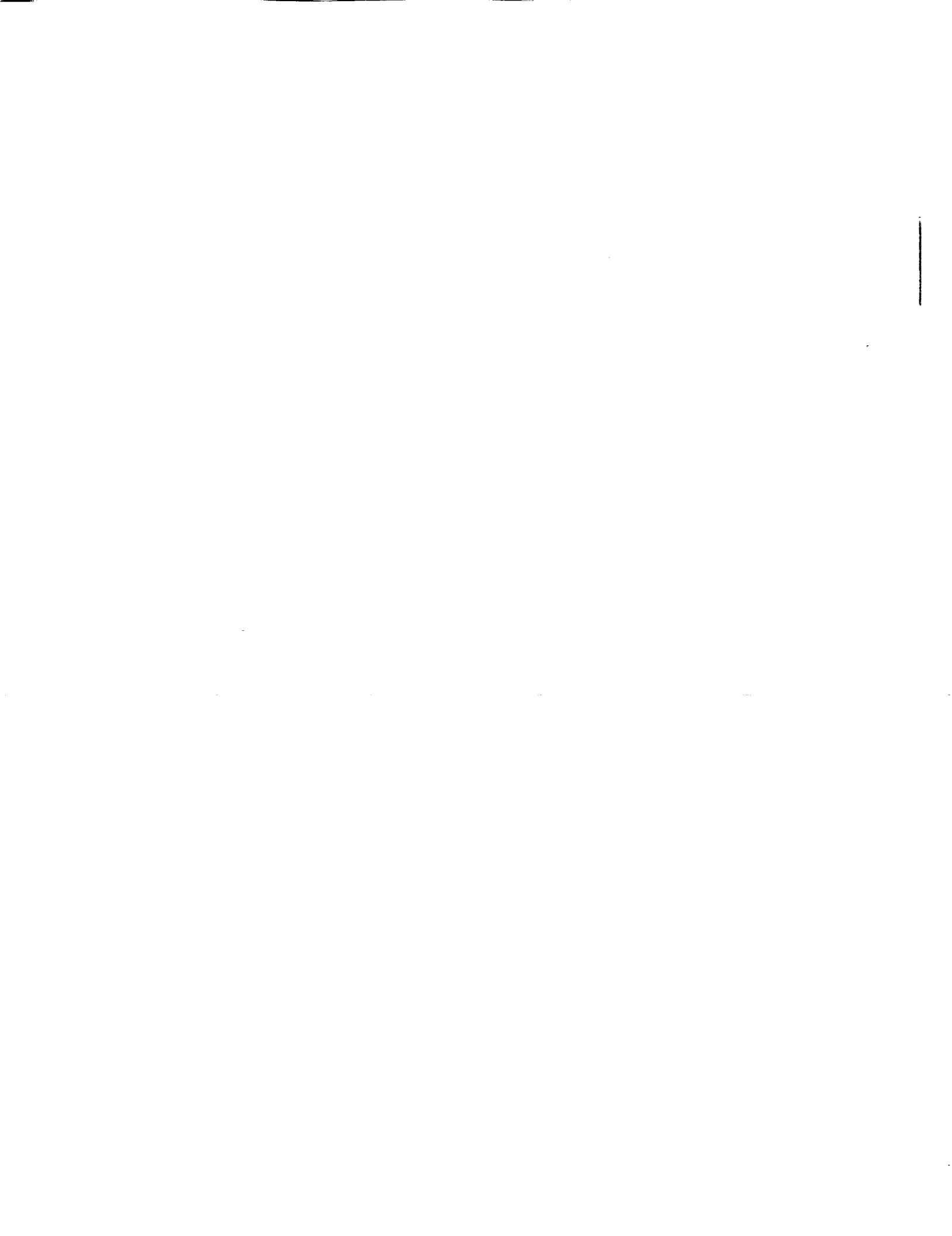
## ATTRIBUTES OF MAGGIE CODE

- SUBDOMAIN GRIDS GENERATED SEPARATELY AND INDEPENDENTLY.
- DISTANCE BETWEEN CELL CENTERS USED FOR INTERPOLATIONS.
- REGIONS OF A FINE LEVEL GRID COMMON TO OTHERS REMOVED (HOLES).
- REGIONS OF A COARSE LEVEL GRID OVERLAPPING SOLID SURFACES REMOVED (ILLEGAL ZONES).
- EDGES OF HOLES OR ILLEGAL ZONES ARE INTERGRID BOUNDARIES.
- 3-D VECTOR OPERATIONS TO LOCATE CELLS IN A HOLE OR AN ILLEGAL ZONE.
- CELLS OF OUTER BOUNDARY OF OVERLAP REGIONS (FRINGE CELL).
- IMMEDIATE-NEIGHBOR CELLS OF A HOLE OR AN ILLEGAL-ZONE CELL (FRINGE CELL).
- **INFORMATION HEXAHEDRONS** AROUND FRINGE CELLS FORMED.
- CELLS IN A HOLE BUT NOT IN AN ILLEGAL ZONE UPDATED FROM FINE LEVEL EQUAL COARSE LEVEL OF OTHER GRIDS
- COEFFICIENTS FOR TRILINEAR INTERPOLATIONS.
- VECTORIZED DATA STRUCTURES AS PREPROCESSOR FOR VUMXZ3
- DEVELOPED FROM CHIMERA.
- CHARACTERISTIC INTERGRID BOUNDARY CONDITIONS.



### ATTRIBUTES OF VUMXZ3 CODE

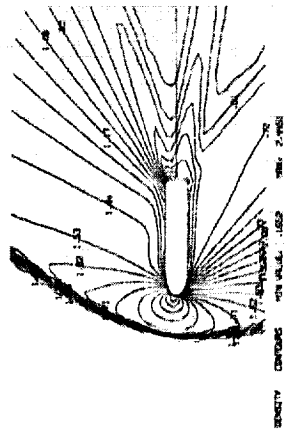
- DEVELOPED FROM CFL3D CODE, HENCE INCLUDES ALL CFL3D ATTRIBUTES.
- ALL BUT CROSS-DERIVATIVE VISCOUS TERMS.
- BALDWIN-LOMAX TURBULENCE MODEL MODIFIED FOR VORTICAL FLOWS, MULTIPLE-WALLS, AND TURBULENT MEMORY RELAXATION FOR WAKES AND SHEAR LAYERS.
- BLOCK OR DIAGONAL INVERSIONS ACCOMMODATE HOLES AND ILLEGAL ZONES FOR OVERLAPPED GRIDS.
- AVOIDS INFORMATION POLLUTION NEAR HOLES OR ILLEGAL ZONES FOR HIGHER ORDER SCHEMES.
- NULLIFIES WEIGHT OF CONTRIBUTIONS FROM ILLEGAL ZONES DURING 3-D MULTIGRID PROLONGATION.
- INTERGRID INFORMATION EXCHANGED BY TRILINEAR INTERPOLATIONS COUPLED WITH CHARACTERISTIC BOUNDARY CONDITIONS.
- COMBINED ZONAL AND OVERLAPPED EMBEDDING.
- DEMONSTRATIVE CASES :
  - SUPERSONIC FLOW PAST A BLUNT-NOSE CYLINDER (L/D=6.7)
    - AT 32° -ANGLE OF ATTACK ON SINGLE C-O GRID.
    - C-O GRID EMBEDDED IN CARTESIAN GRID.
    - C-O GRID PATCHED TO H-O GRID.
  - SUPERSONIC FLOW PAST AN OGIVE-NOSE CYLINDER (L/D=18) NEAR FLAT PLATE.



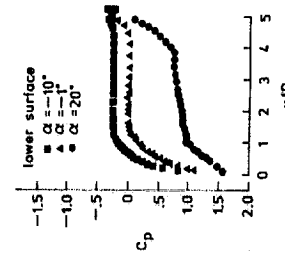
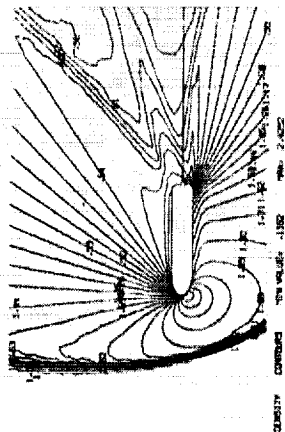
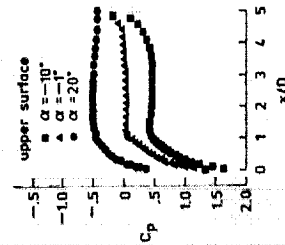
EFFECTS OF SHAPE AND INCIDENCE ON FLOW PAST A CYLINDRICAL SECTION

$M_\infty = 1.6$   $Re_{x/c} = 2 \times 10^6$  / ft

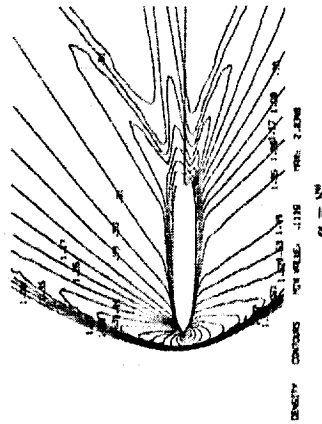
DENSITY



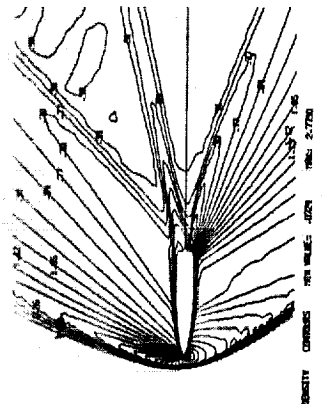
$C_p$



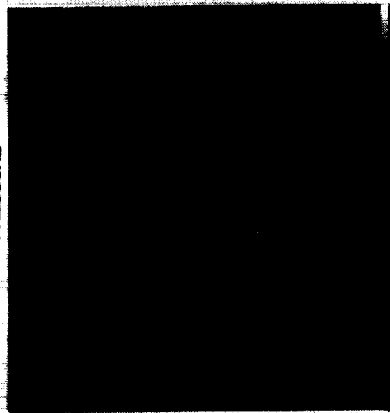
DENSITY



HEMISPHERICAL-NOSE CYLINDER



PRESSURE



SECANT-OGIVE-NOSE-BOAT-TAIL CYLINDER

BLUNT-NOSE CYLINDER

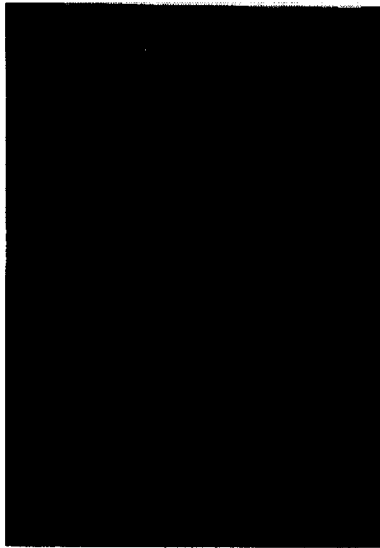
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# EMBEDDED GRIDS FOR BLUNT-NOSE-CYLINDER WITH STING

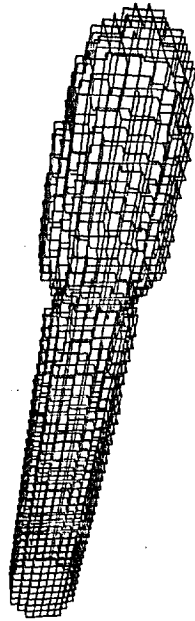
C-O GRID : 73x65x57

CARTESIAN GRID : 81x73x73

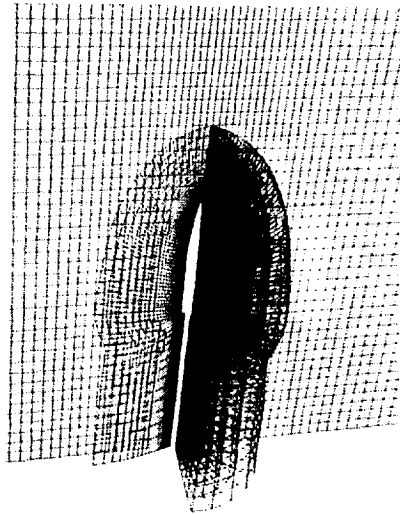


cartesian grid with hole

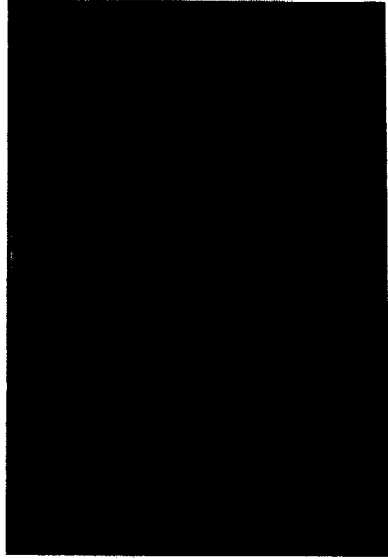
DATE 1  
TIME 1  
DATE 2  
TIME 2



hole boundary cells



overlap of c-o with cartesian



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1. The first part of the document is a list of names and titles.

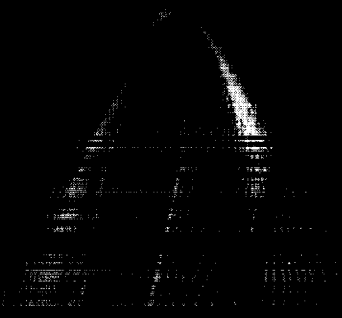
2. The second part is a list of dates.



MACH CONTOURS OF FLOW (M=1.6, RE=2E6/FT) PAST OGIVE-NOSE CYLINDER (L/D=6.7, alpha=32)

THECH NUMBER

01181349  
01181349  
01181349  
01181349



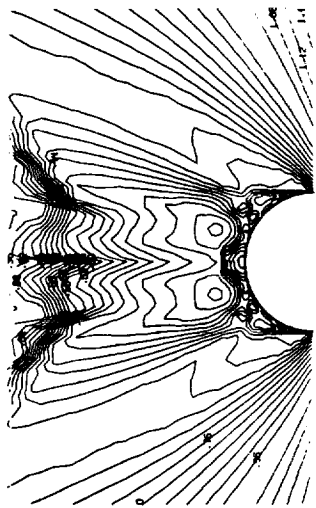
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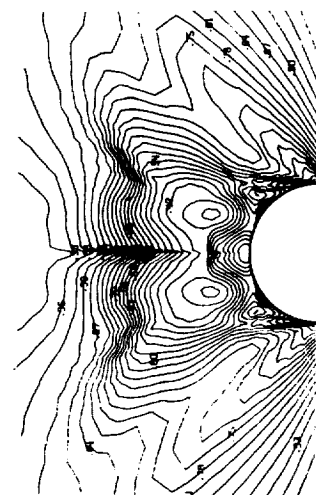
1

CROSSFLOW DENSITY CONTOURS OF FLOW PAST A BLUNT-NOSE-CYLINDER

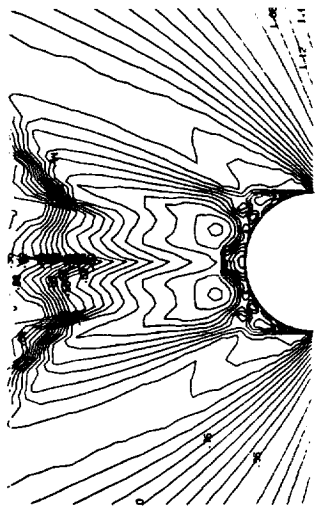
$M_\infty = 1.6$   $Re_\infty = 2 \times 10^6$  / ft



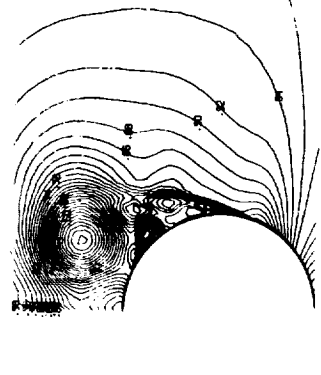
DENSITY CONTOURS  
MIN VALUE: .985  
MAX VALUE: 1.020  
 $\alpha = 12^\circ$



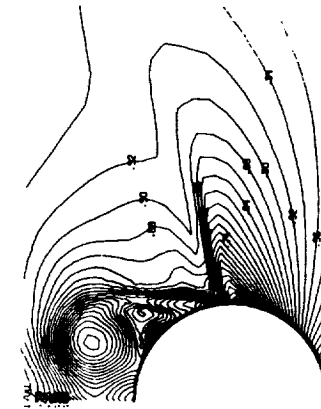
DENSITY CONTOURS  
MIN VALUE: .985  
MAX VALUE: 1.020  
 $\alpha = 32^\circ$



DENSITY CONTOURS  
MIN VALUE: .985  
MAX VALUE: 1.020  
 $\alpha = 44^\circ$

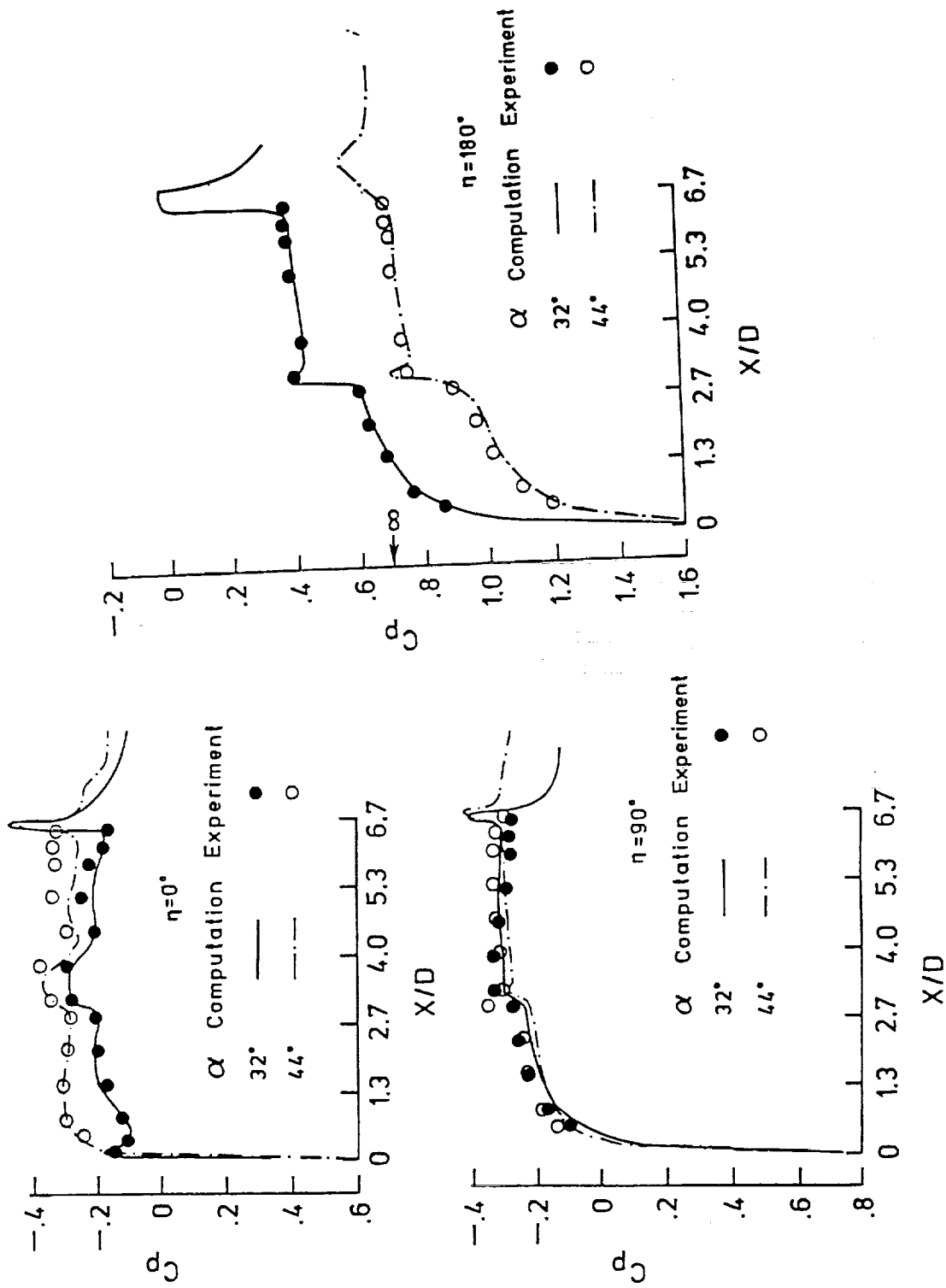


DENSITY CONTOURS  
MIN VALUE: .985  
MAX VALUE: 1.020  
LAMINAR  
 $\alpha = 20^\circ$



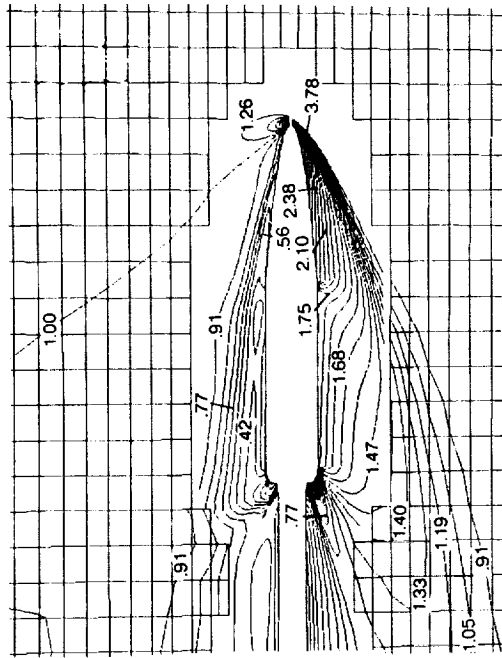
DENSITY CONTOURS  
MIN VALUE: .985  
MAX VALUE: 1.020  
TURBULENT  
 $\alpha = 20^\circ$

FLOW PAST A BLUNT-NOSE CYLINDER (L/D=6.7, M=1.6, Re=2E6/FT)  $\eta=0$  LEESIDE,  $\eta=180$  WINDSIDE

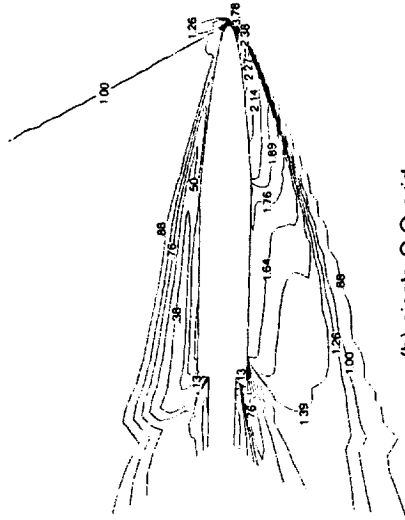


PRESSURE CONTOURS ON THE SYMMETRY PLANES OF BLUNT-NOSE-CYLINDER

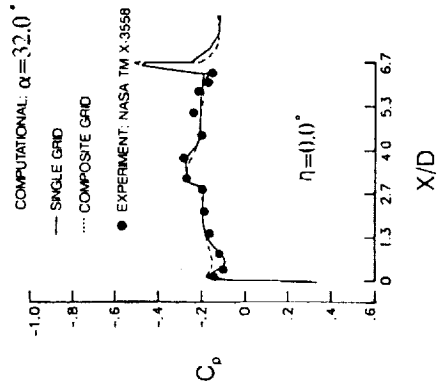
$M_\infty = 1.6$     $Re_\infty = 2 \times 10^6 / ft$     $\alpha = 32^\circ$



(a) composite grid



(b) single C-O grid



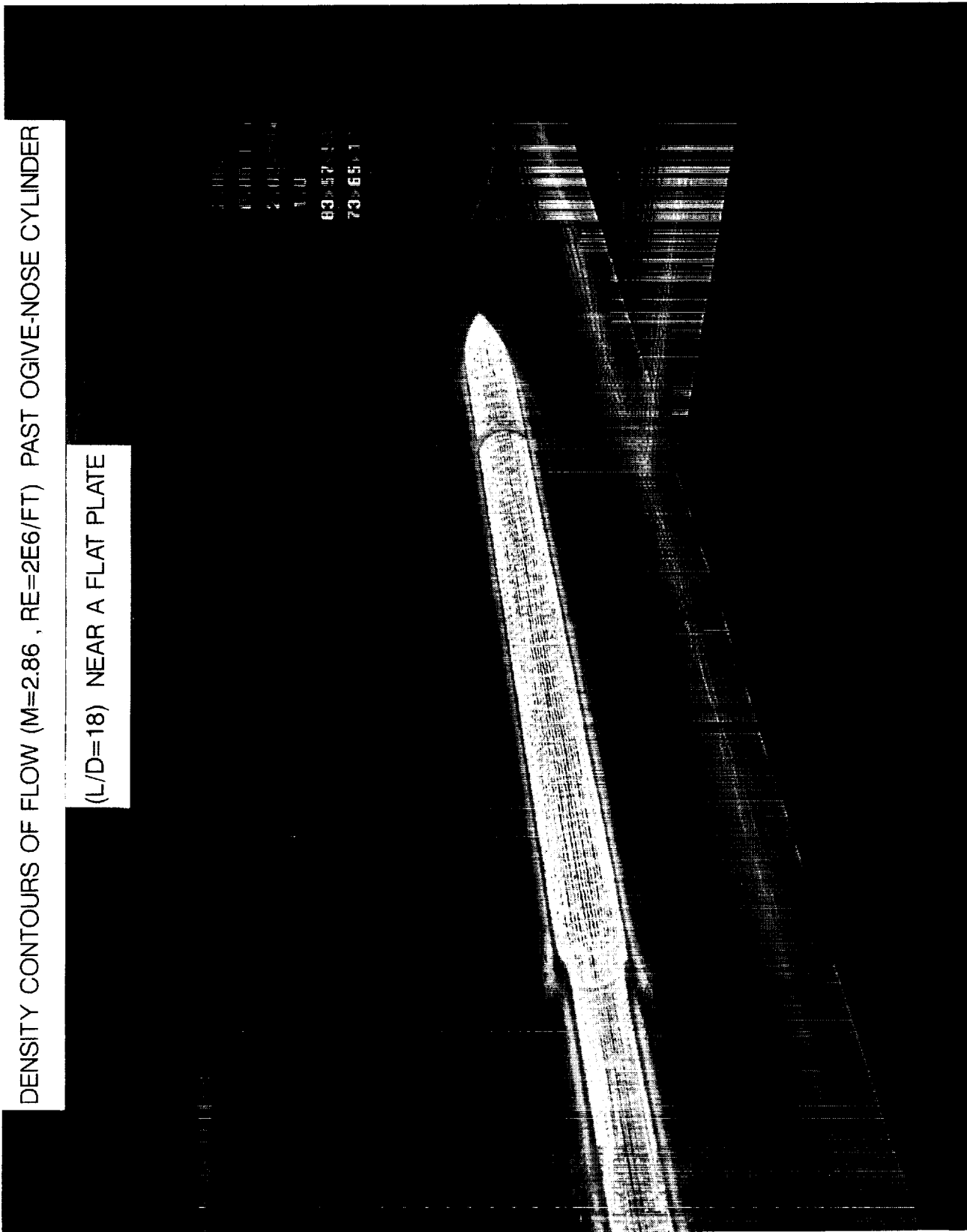
(c) Cp on leeside



DENSITY CONTOURS OF FLOW (M=2.86 , RE=2E6/FT) PAST OGIVE-NOSE CYLINDER

(L/D=18) NEAR A FLAT PLATE

03-57-10  
73-65-11



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1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is crucial for ensuring transparency and accountability in the organization's operations.

2. The second part of the document outlines the various methods and tools used to collect and analyze data. It highlights the need for consistent data collection procedures and the use of advanced analytical techniques to derive meaningful insights from the data.

3. The third part of the document focuses on the role of technology in data management and analysis. It discusses how modern software solutions can streamline data collection, storage, and processing, thereby improving efficiency and accuracy.

4. The fourth part of the document addresses the challenges associated with data management, such as data quality, security, and privacy. It provides strategies to mitigate these risks and ensure that the data remains reliable and secure throughout its lifecycle.

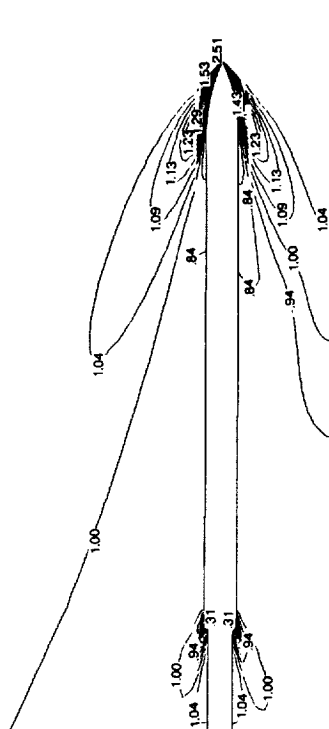
5. The fifth part of the document concludes by summarizing the key findings and recommendations. It stresses the importance of a data-driven approach in decision-making and the need for continuous monitoring and improvement of the data management process.



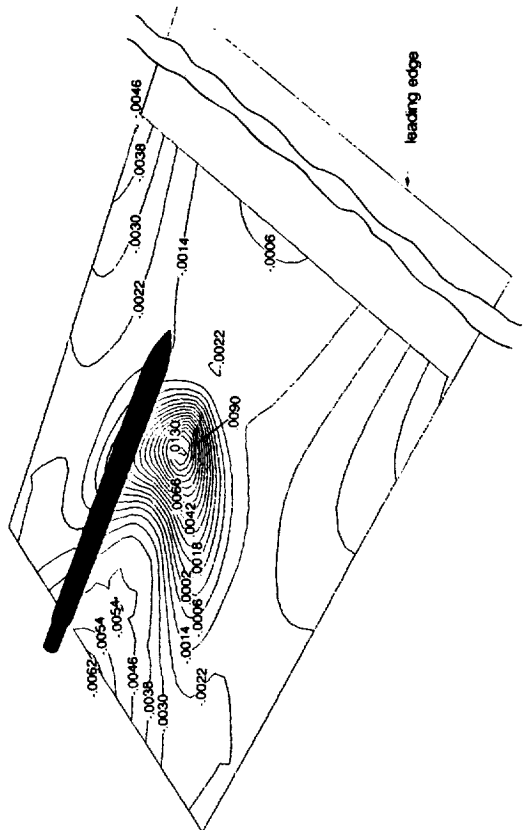
FLOW OVER OGIVE-NOSE-CYLINDER NEAR FLAT PLATE

$M_\infty = 2.86$   $Re_\infty = 2 \times 10^6 / ft$   $\alpha = 0^\circ$

Pressure Contours on the Symmetry Plane of ONC



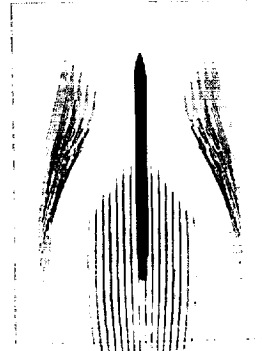
Pressure Coefficient Contours on the surface of the flat plate



Skin Friction Patterns near the flat plate surface



(a) two cells above the surface



(b) one cell above the surface

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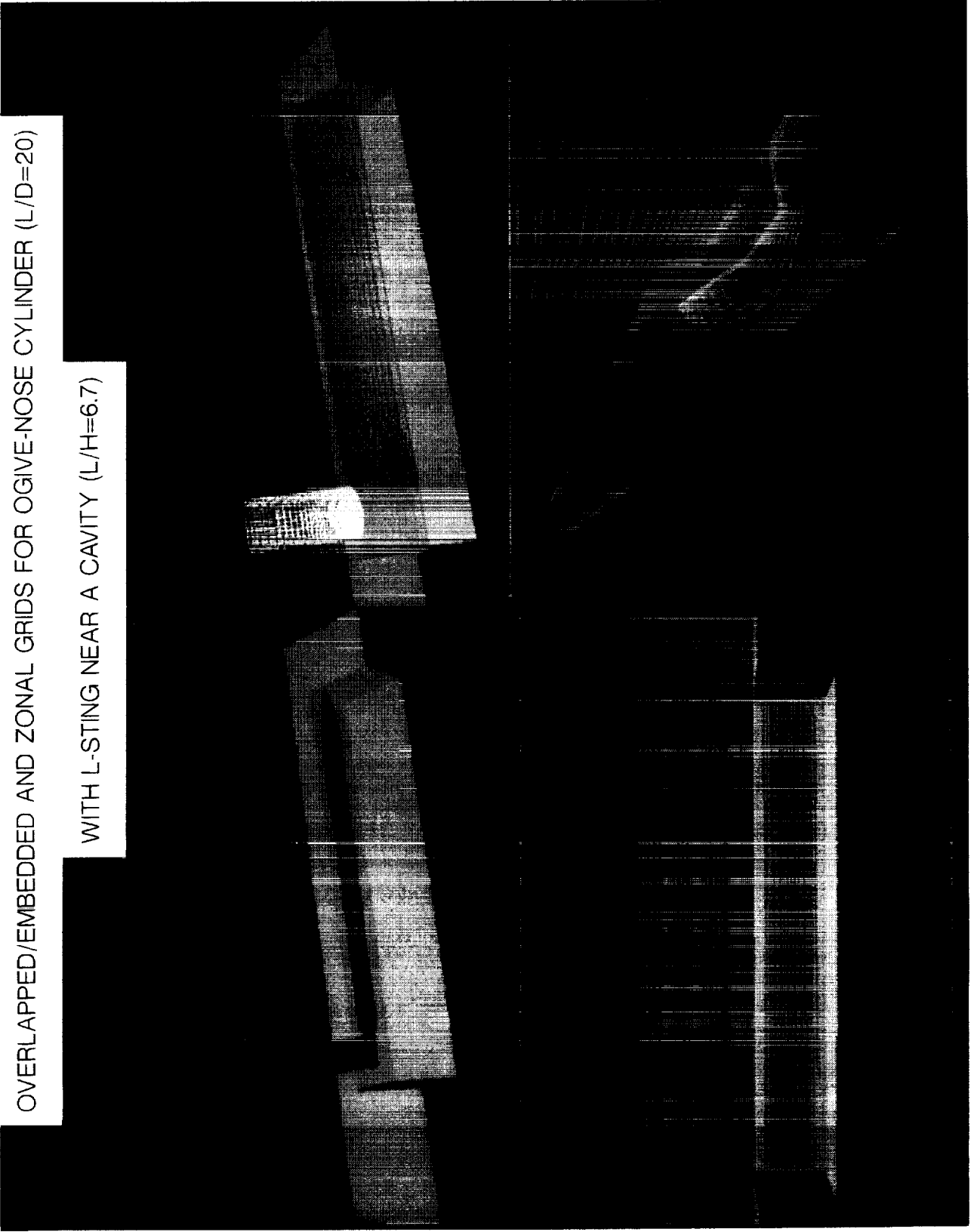
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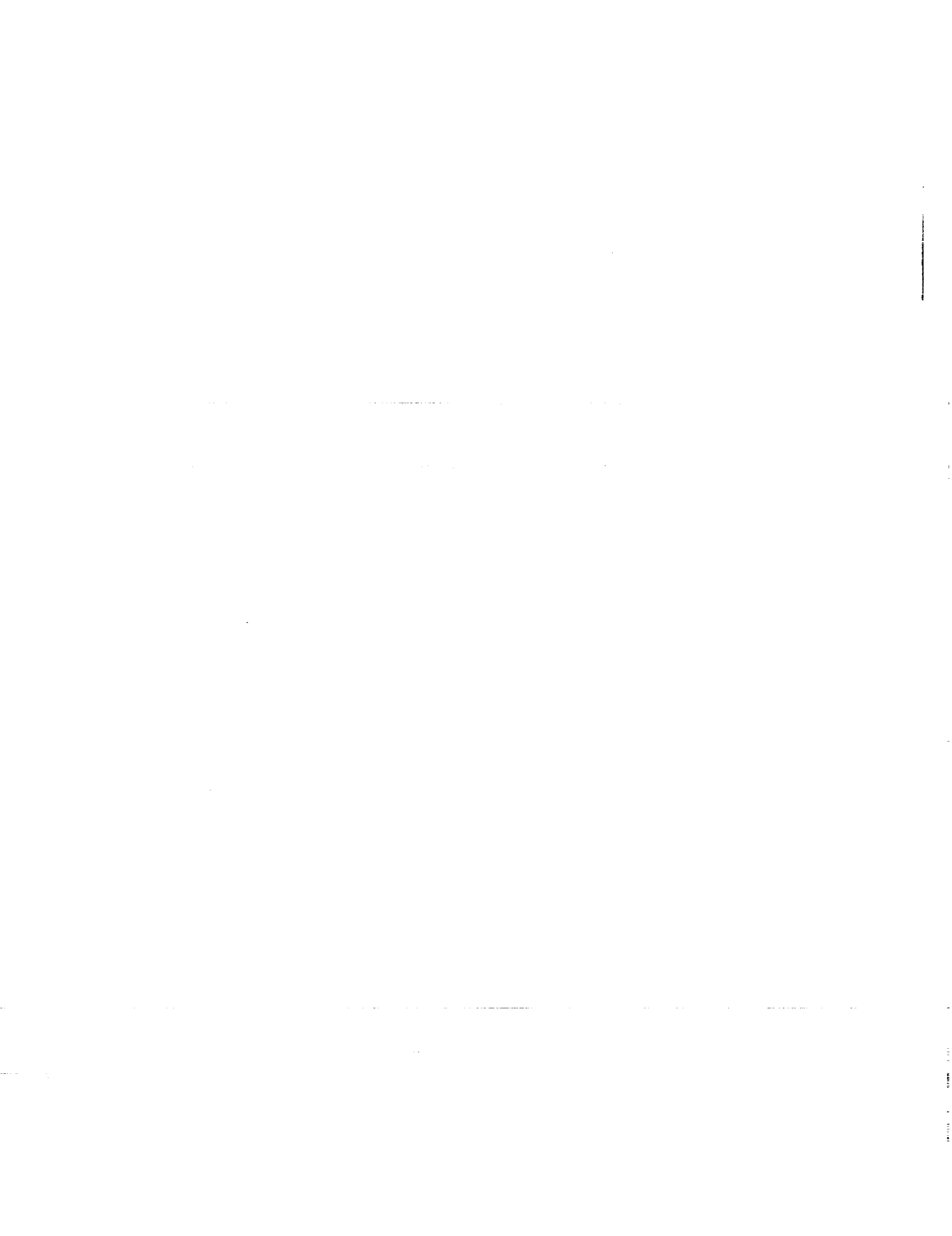
OVERLAPPED/EMBEDDED AND ZONAL GRIDS FOR OGIVE-NOSE CYLINDER (L/D=20)

WITH L-STING NEAR A CAVITY (L/H=6.7)



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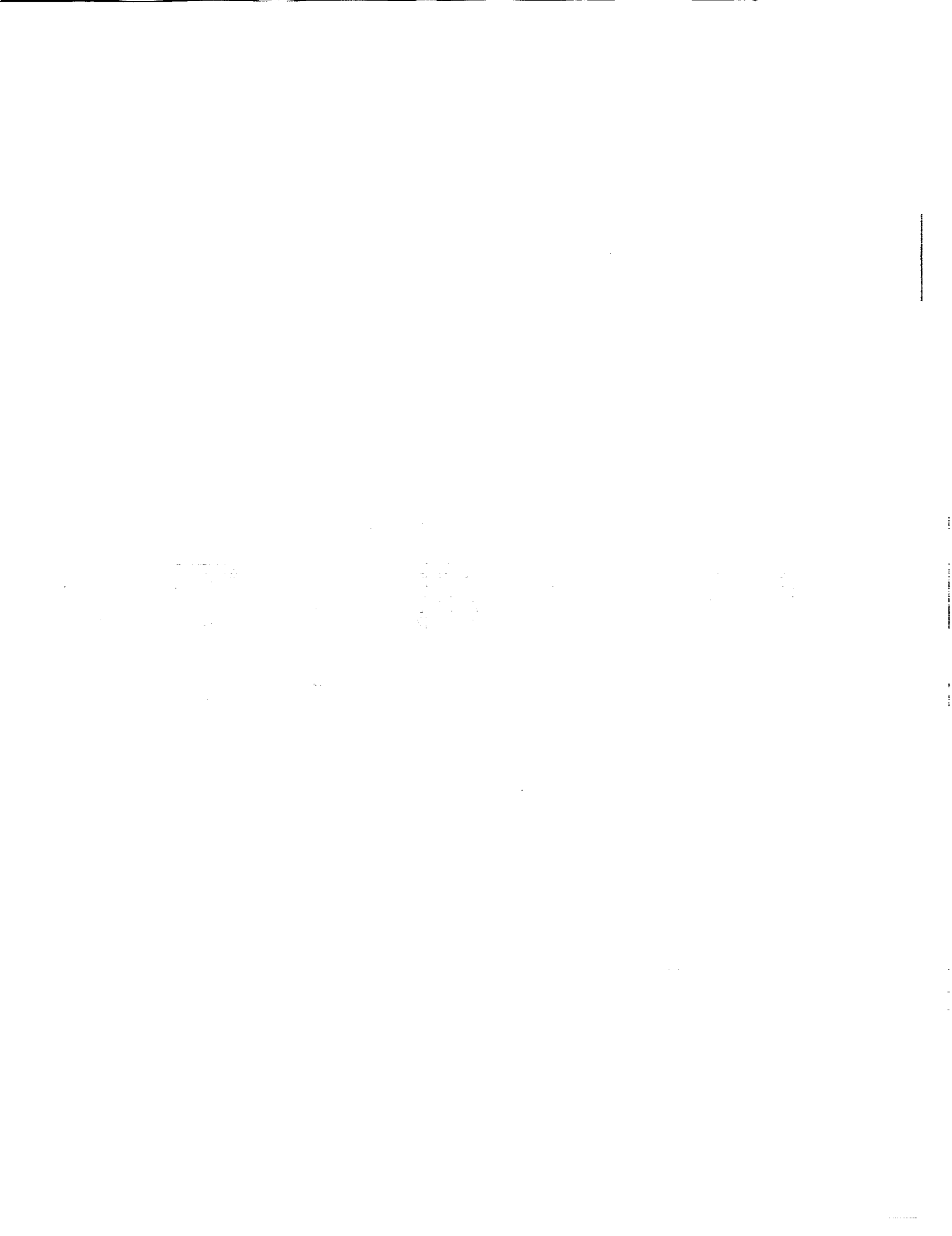


ATTRIBUTES OF EMCAV3

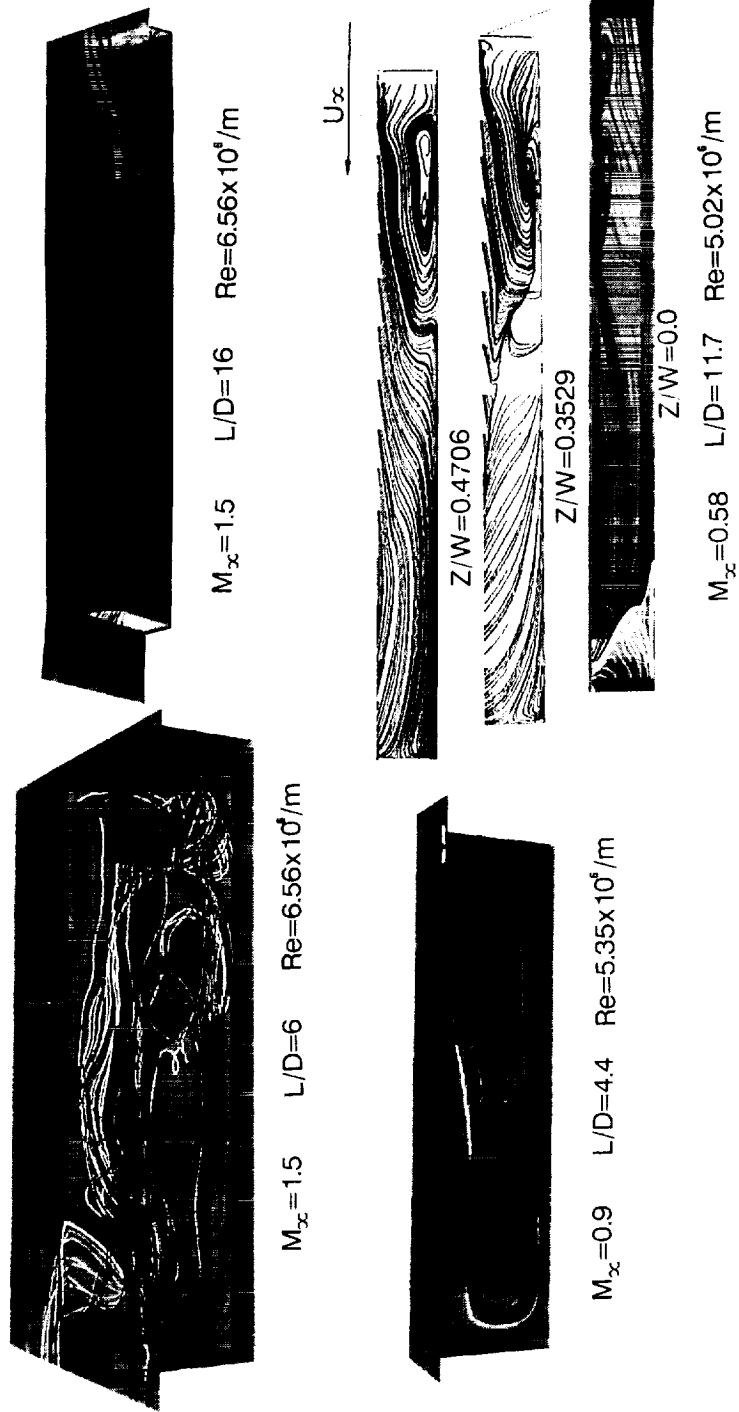
- 3-D REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS FOR UNSTEADY COMPRESSIBLE FLOW.
- EXPLICIT, UNSPLIT, PREDICTOR-CORRECTOR TIME INTEGRATION (MACCORMACK).
- FINITE DIFFERENCE SPATIAL DISCRETIZATION.
- SECOND ORDER ACCURATE IN TIME AND SPACE.
- VECTORIZED DATA STRUCTURE.
- DEVELOPED FROM SCRM32.
- ALGEBRAIC GRID GENERATOR.
- BALDWIN-LOMAX TURBULENCE MODEL MODIFIED FOR
 

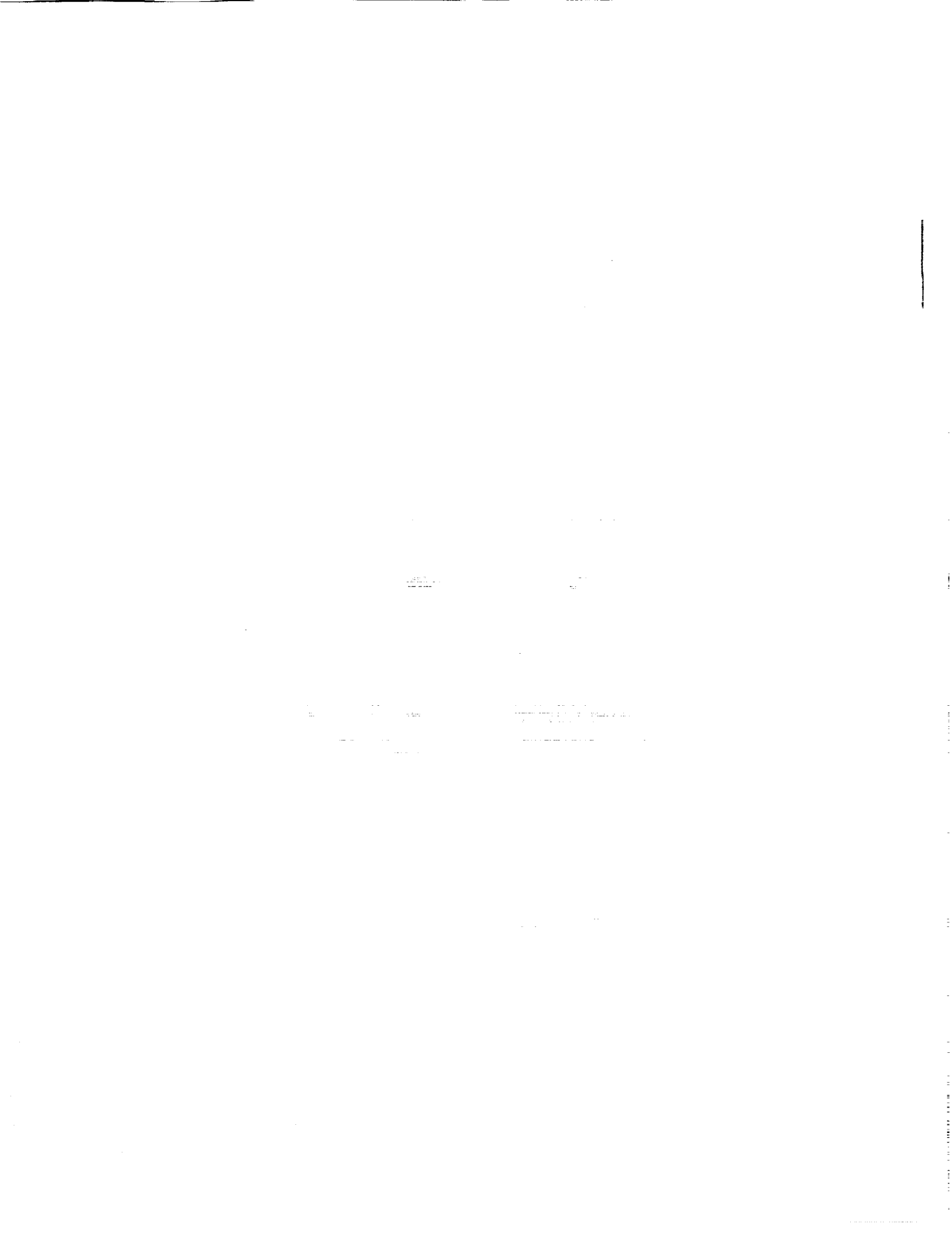
VORTICAL FLOWS.
MULTIPLE WALLS.
TURBULENT MEMORY RELAXATION FOR SHEAR LAYER.
- IMPLICIT MARCHING SOLUTION FOR 2-D COMPRESSIBLE BOUNDARY LAYER PROFILE.
- FOURIER TIME SERIES ANALYSIS FOR CAVITY ACOUSTICS.
- DEMONSTRATIVE CASES
 

<table border="1"> <tr><td>2-D</td></tr> <tr><td>3-D</td></tr> </table>	2-D	3-D	SUBSONIC TRANSONIC SUPERSONIC	FLOWS AT <table border="1" style="display: inline-table; vertical-align: middle;"> <tr><td>0°</td></tr> <tr><td>45°</td></tr> </table>	0°	45°	YAW PAST	<table border="1"> <tr><td>DEEP</td></tr> <tr><td>TRANSITIONAL</td></tr> <tr><td>SHALLOW</td></tr> </table>	DEEP	TRANSITIONAL	SHALLOW	CAVITIES.
	2-D											
3-D												
0°												
45°												
DEEP												
TRANSITIONAL												
SHALLOW												



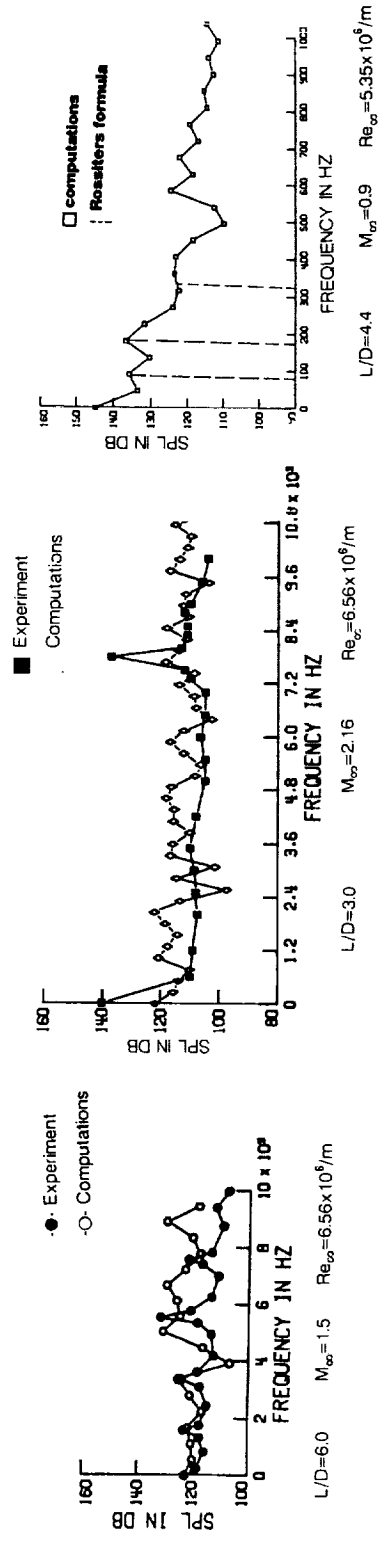
# INSTANTANEOUS STREAMLINES OF FLOW PAST RECTANGULAR CAVITIES



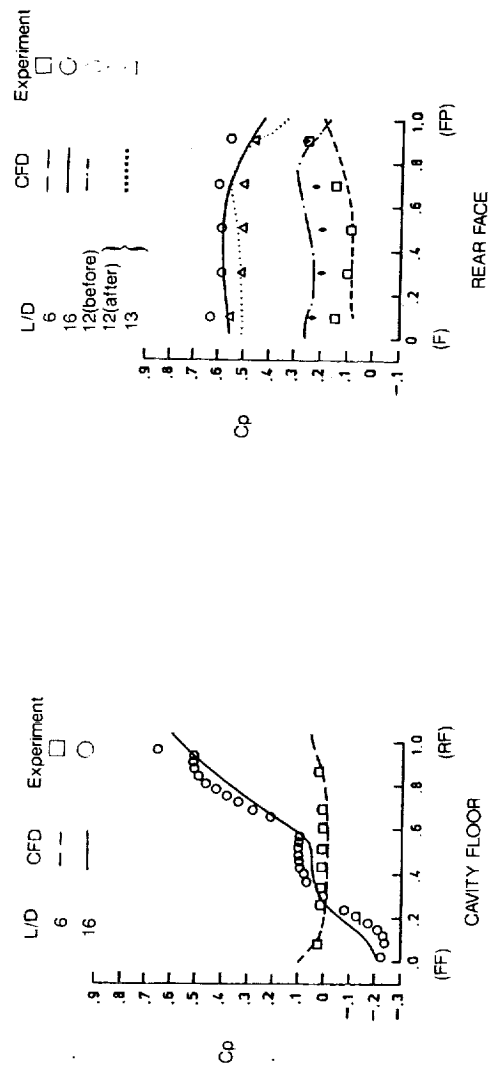




FREQUENCY SPECTRA OF SOUND PRESSURE LEVEL ON THE CAVITY FLOOR



Cp FOR  $M_{\infty}=1.5$   $Re_{\infty}=6.56 \times 10^6/m$  FLOW



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## **CONCLUSIONS**

- 3-D CFD CAPABILITIES FOR UNSTEADY CAVITY FLOWS.
- TIME-AVERAGED AND TIME SERIES ANALYSES OF CAVITY FLOWS :
  - EFFECTS OF LENGTH-TO DEPTH, FLOW REGIMES, YAW ANGLES.
- 2-D ANALYSES OF FLOWS PAST VARIOUS CYLINDRICAL SECTIONS AT VARIOUS ANGLES OF ATTACK.
- 3-D ANALYSES OF LAMINAR AND TURBULENT FLOWS PAST A BODY OF REVOLUTION AT VARIOUS ANGLES OF ATTACK.
- 3-D CFD CAPABILITIES DEVELOPED FOR VISCOUS FLOWS ABOUT COMPLEX AND/OR MULTICOMPONENT CONFIGURATIONS.
- COMBINED ADVANTAGES : GEOMETRICALLY CONSERVATIVE, MINIMALLY DISSIPATIVE
  - : NUMERICALLY AND COMPUTATIONALLY EFFICIENT.
  - : FLEXIBILITY IN BODY GEOMETRIES AND GRID TOPOLOGIES.
- FLUX CONSERVATION ACROSS INTERGRID BOUNDARIES NEED FURTHER STUDY.
- ANALYSES OF AERODYNAMIC INTERFERENCE OF A STORE NEAR A FLAT PLATE (EXTERNAL CARRIAGE).
- WORK-IN-PROGRESS : CFD SOLUTIONS FOR FLOWS PAST AN OGIVE-NOSE-CYLINDER WITH L-SHAPE STING NEAR A CAVITY AND CODE VALIDATION WIND TUNNEL EXPERIMENTS.