N91-10876

COMPUTATIONAL FLUID DYNAMICS ANALYSIS OF SPACE SHUTTLE MAIN PROPULSION FEED LINE 17-INCH DISCONNECT VALVES

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ABSTRACT

A steady incompressible three-dimensional (3-D) viscous flow analysis has been conducted for the Space Shuttle Main Propulsion External Tank (ET)/Orbiter (ORB) propellant feed line quick separable 17-inch disconnect flapper valves for liquid oxygen (LO_2) and liquid hydrogen (LH_2). The main objectives of the analyis were to predict and correlate the hydrodynamic stability of the flappers and pressure drop with available water test data.

Computational Fluid Dynamics (CFD) computer codes were procured at no cost from the public domain, and were modified and extended to carry out the disconnect flow analysis. The grid generator codes SVTGD3D and INGRID, developed by Sverdrup Technology Inc., were obtained from Arnold Air Force Station, Tennessee. NASA Ames Research Center supplied the flow solution code INS3D, and the color graphics code PLOT3D. A driver routine was developed to automate the grid generation process. Components such as pipes, elbows and flappers can be generated with simple commands, and flapper angles can be varied easily. The flow solver INS3D code was modified to treat interior flappers, and other interfacing routines were developed, which include a turbulence model, a force/moment routine, a time-step routine, and initial and boundary conditions. In particular, an under-relaxation scheme was implemented to enhance the solution stability.

Major physical assumptions and simplifications made in the analysis include the neglect of linkages (drive/follower arms), slightly reduced flapper diameter, and smooth solid surfaces. A grid size of 54x21x25 was employed for both the LO_2 and LH_2 units. Mixing length theory applied to turbulent shear flow in pipes formed the basis for the simple turbulence model.

Results of the analysis are presented for LO_2 and LH_2 disconnects. The predicted stop loads, hydrodynamic stability boundaries of the ET and orbiter flappers, and pressure drop across the valve compare well with the water test data, covering a tube Reynolds number of 3.5E06 for LO_2 unit and 2.4E06 for LH_2 unit. The ability to predict the valve performance and flapper stability over a wide range of flow rates and flapper angle combinations demonstrates the validity of the CFD model.

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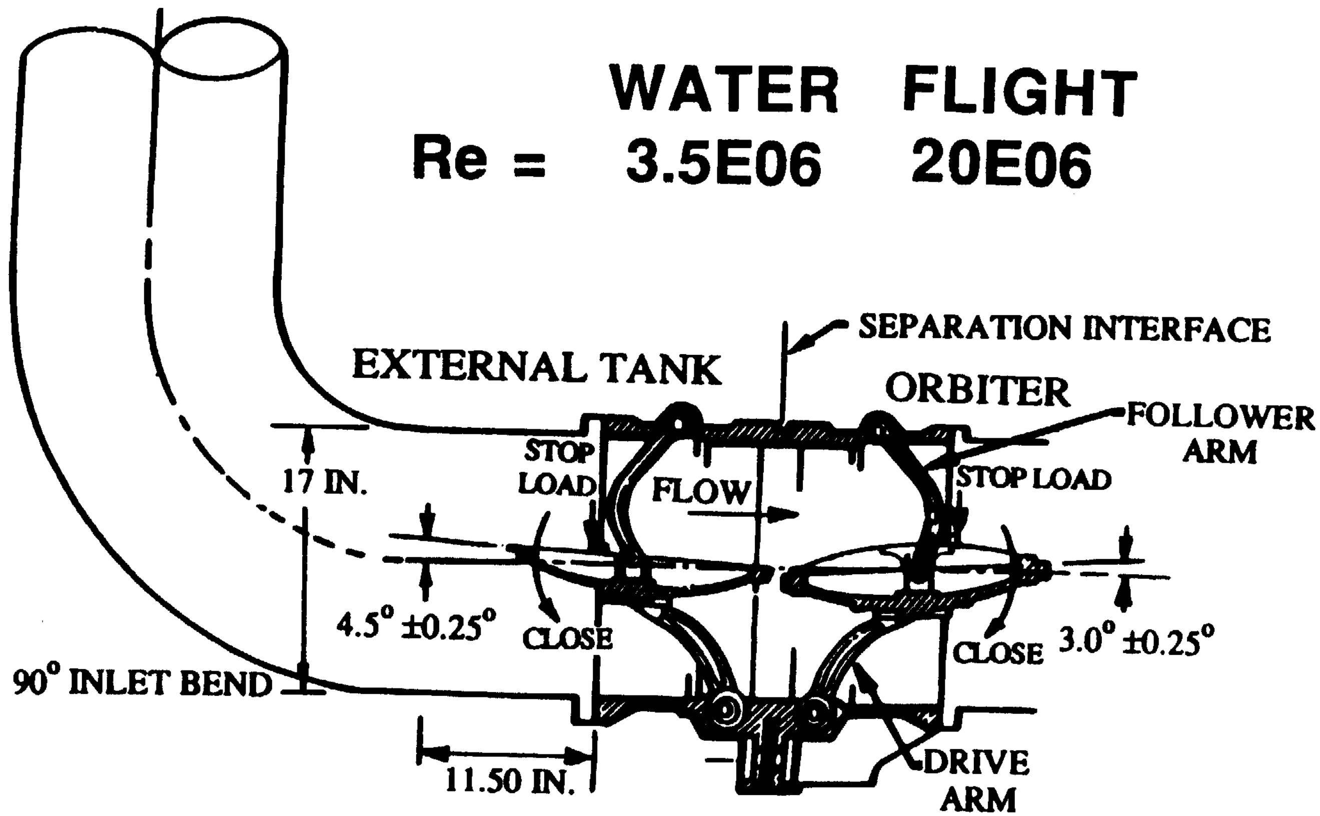
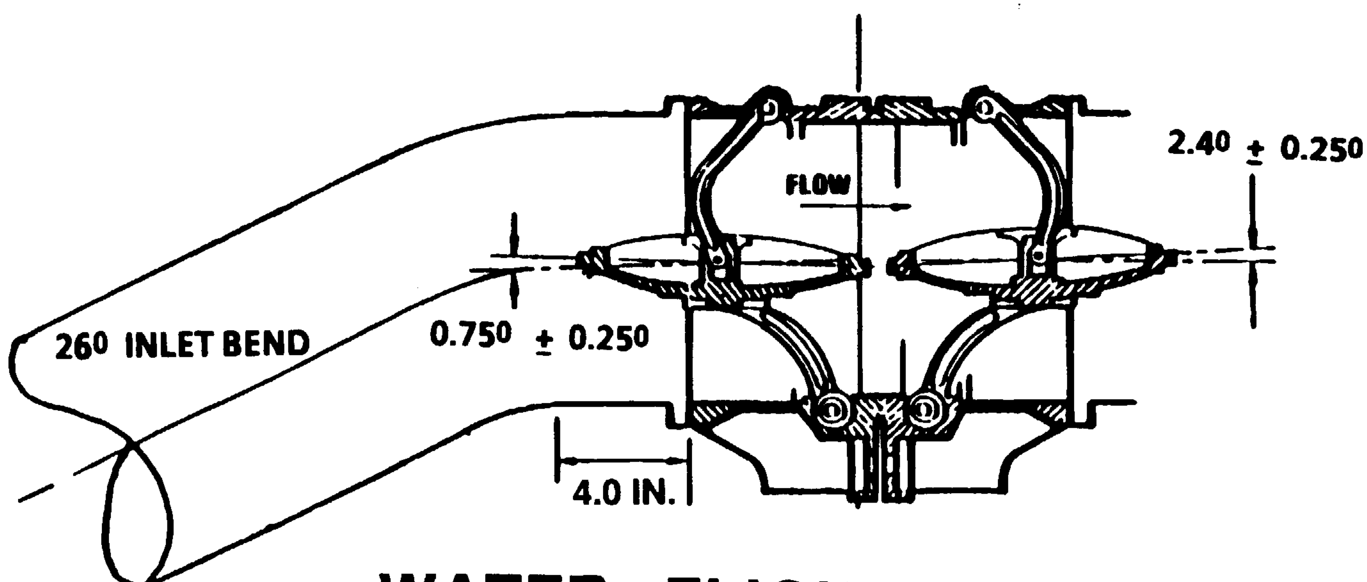
LO_2 DISCONNECT VALVE

	WATER	FLIGHT
Re =	3.5E06	20E06



LH_2 DISCONNECT VALVE



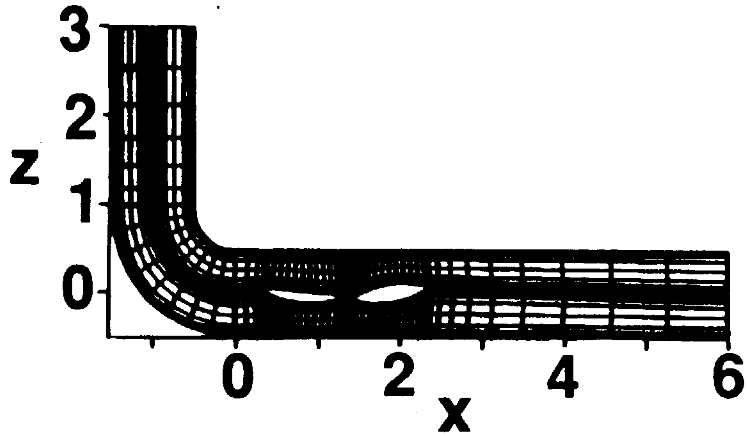
	WATER	FLIGHT
Re =	2.7E06	50E06

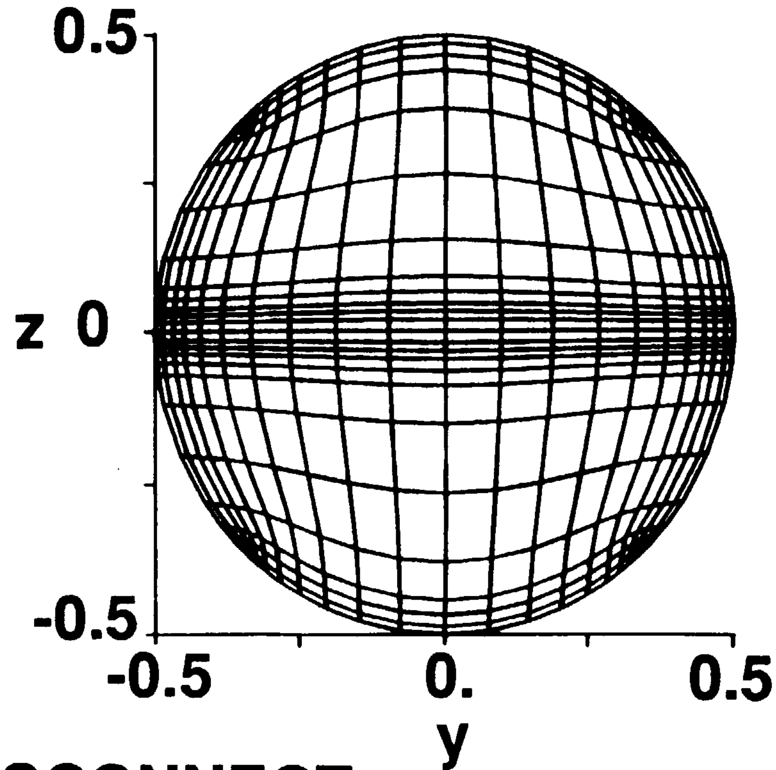
OBJECTIVES

- PREDICT
  - HYDRODYNAMIC STABILITY
  - PRESSURE DROP
  - CAVITATION

COMPUTATIONAL GRID

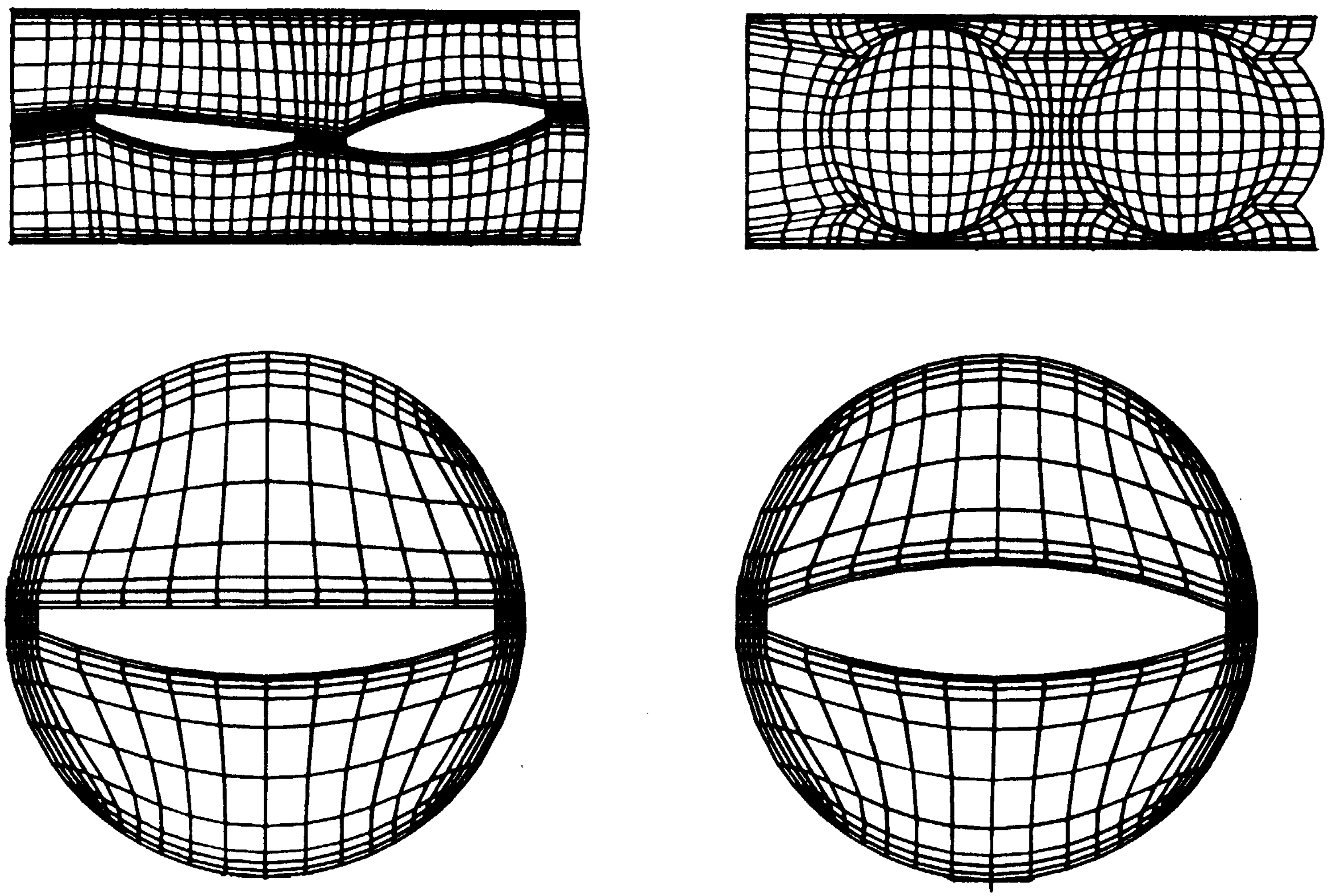
CODE : SVTGD3D (SONI ET AL. 1986)
ORG : SVERDRUP / AIR FORCE





LO_2 DISCONNECT

COMPUTATIONAL GRID
LO_2 DISCONNECT



FLOW SOLUTION DEVELOPMENT

CODE : INS3D (KWAK ET AL. , 1985)
ORG : NASA AMES

- INTERNAL OBSTACLES
- TURBULENCE MODEL
- UNDER-RELAXATION

ANGLE CORRECTIONS

LO_2:
- ET : FA = (PA+1) deg
- ORB : FA = (PA-5) deg
- PA = PRELOAD ANGLE
- FA = FLIGHT ANGLE

LH_2: NONE

UNDER-RELAXATION

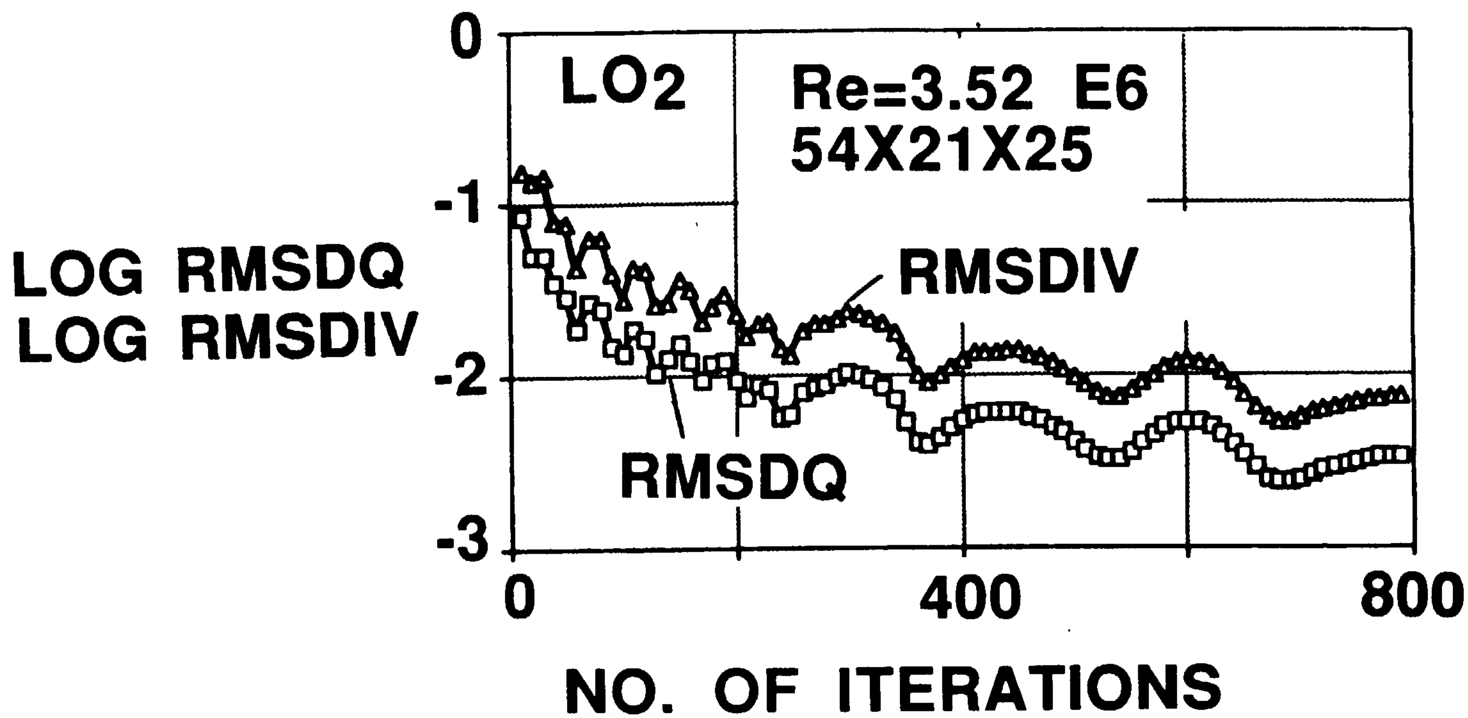
- ENHANCED STABILITY

$$Q_i^{n+1} = Q_i^{n} + \alpha_r \, \Delta Q_i^{n}$$

$$Q_i = [\, p, u, v, w \,]^T$$

$$\alpha_r = \text{RELAXATION FACTOR}$$

CONVERGENCE HISTORY



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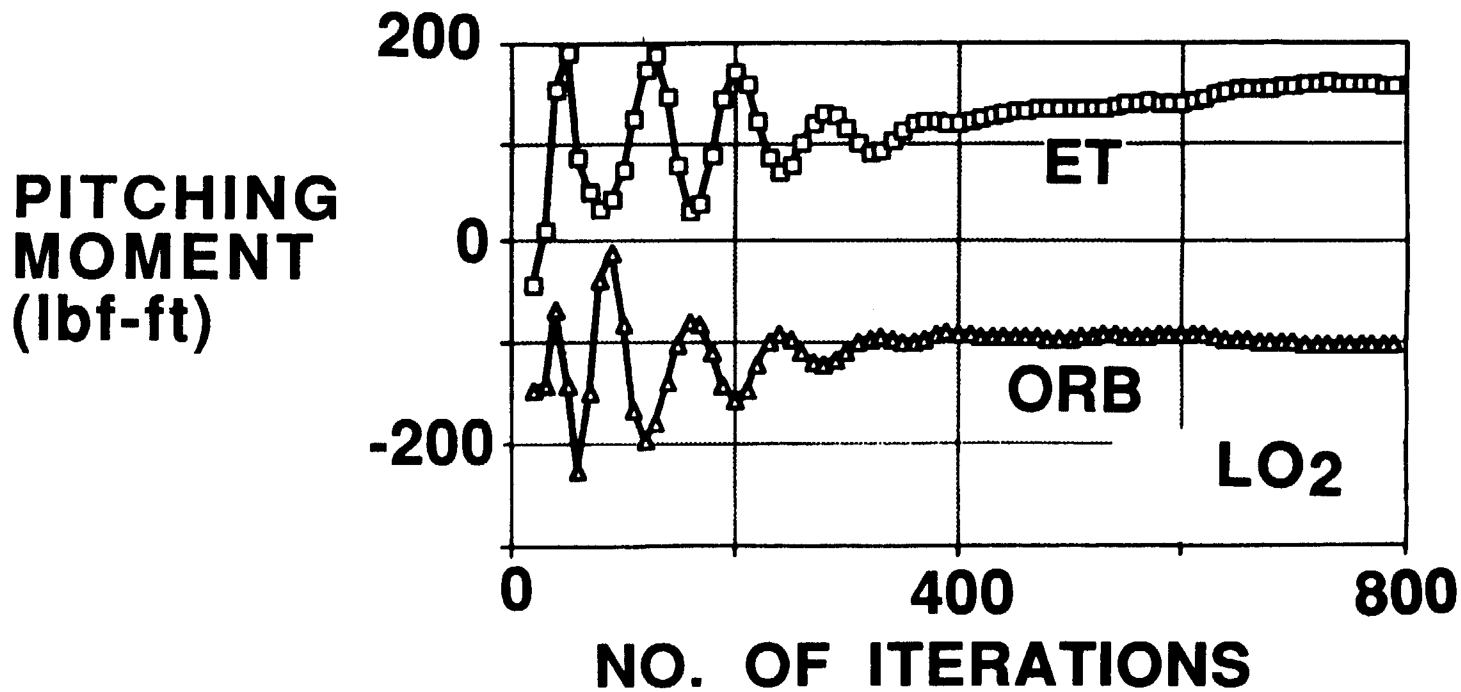
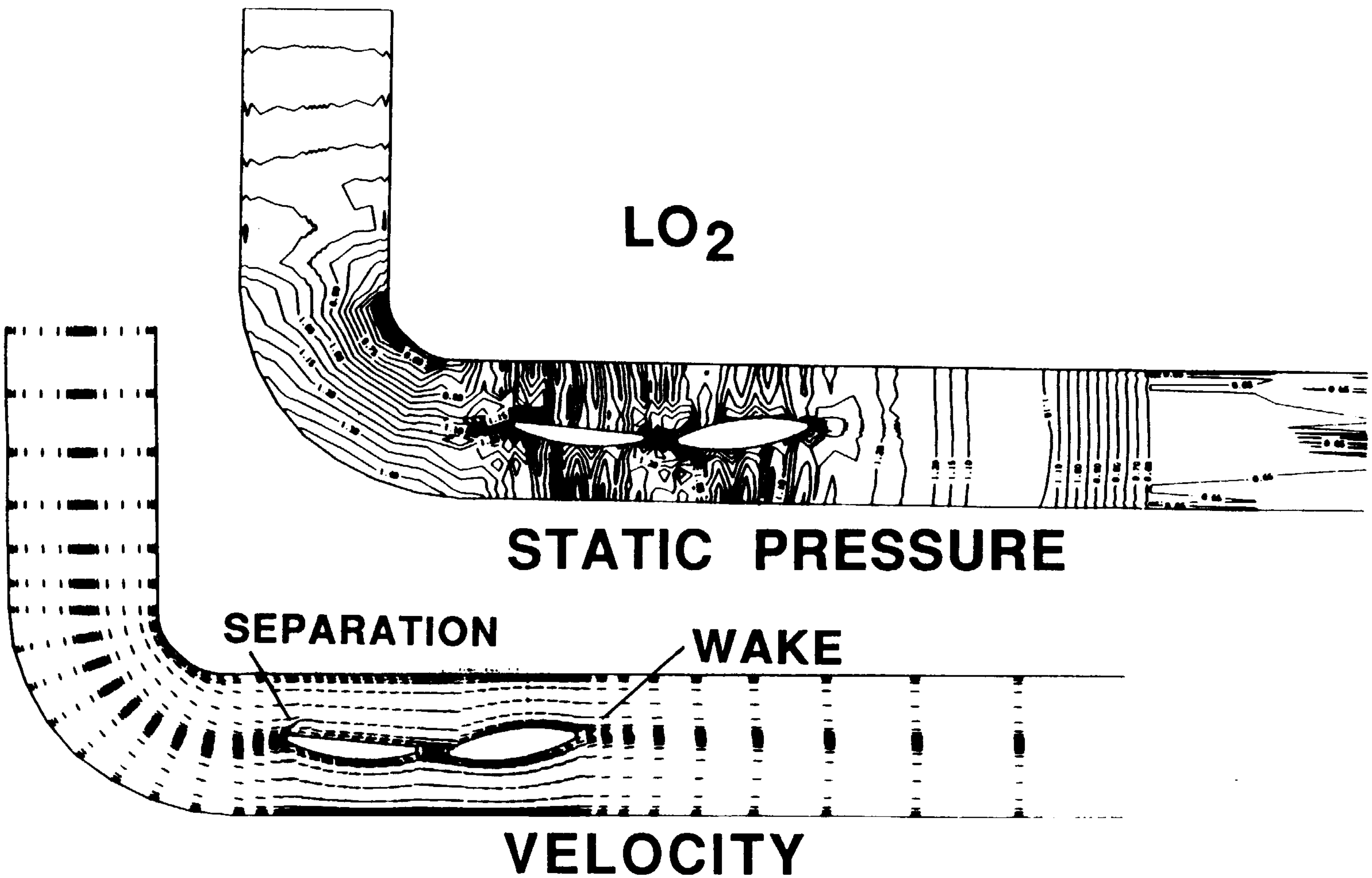
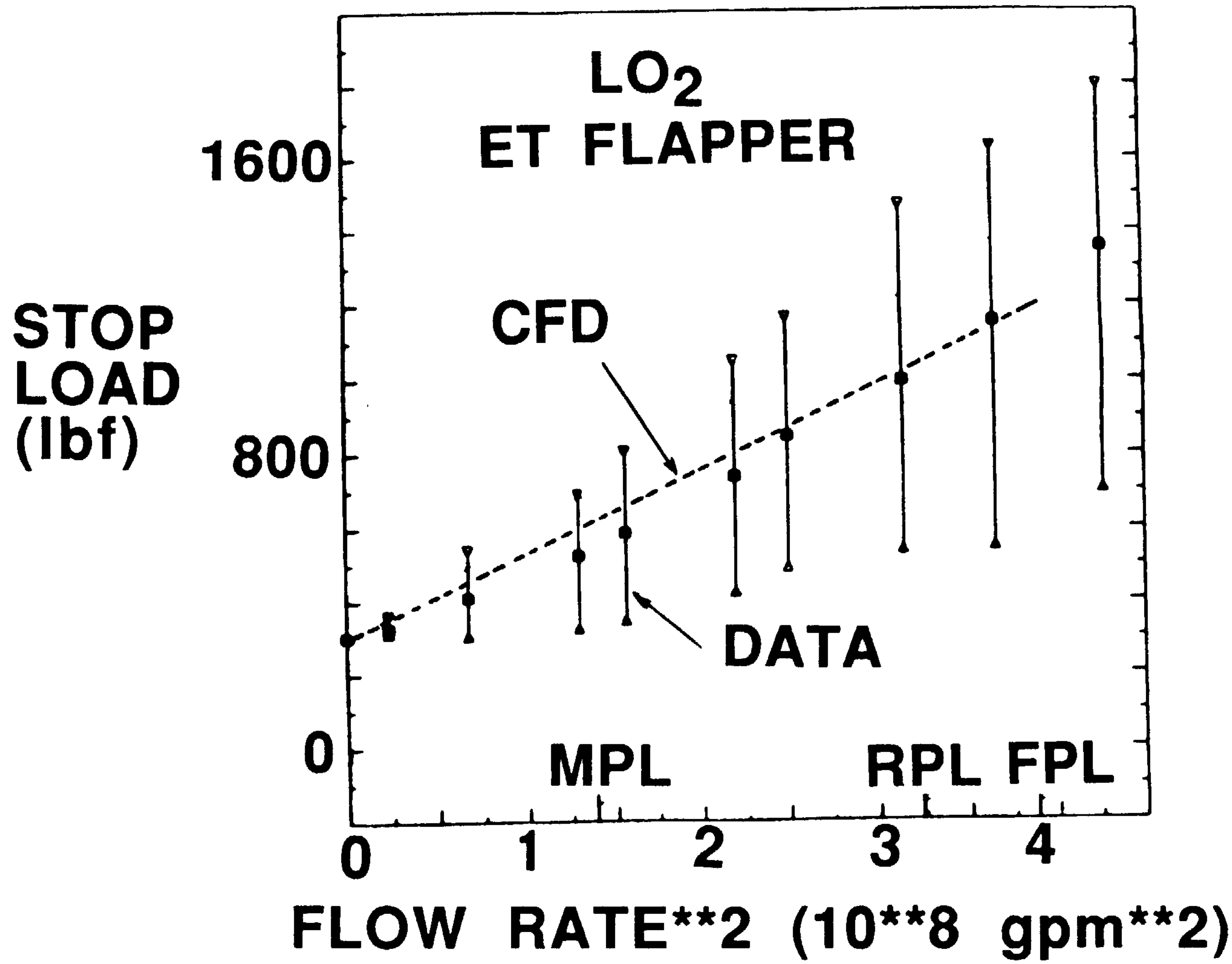


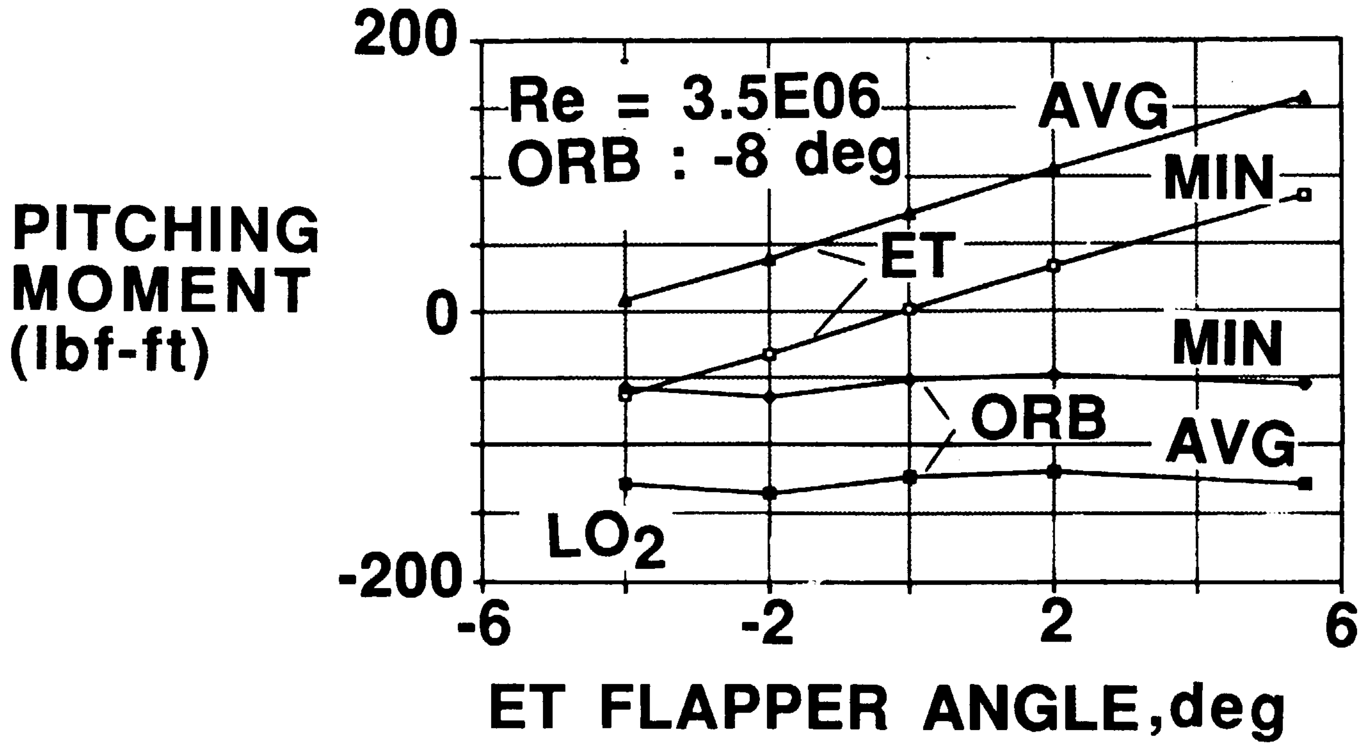
FLOW FIELD



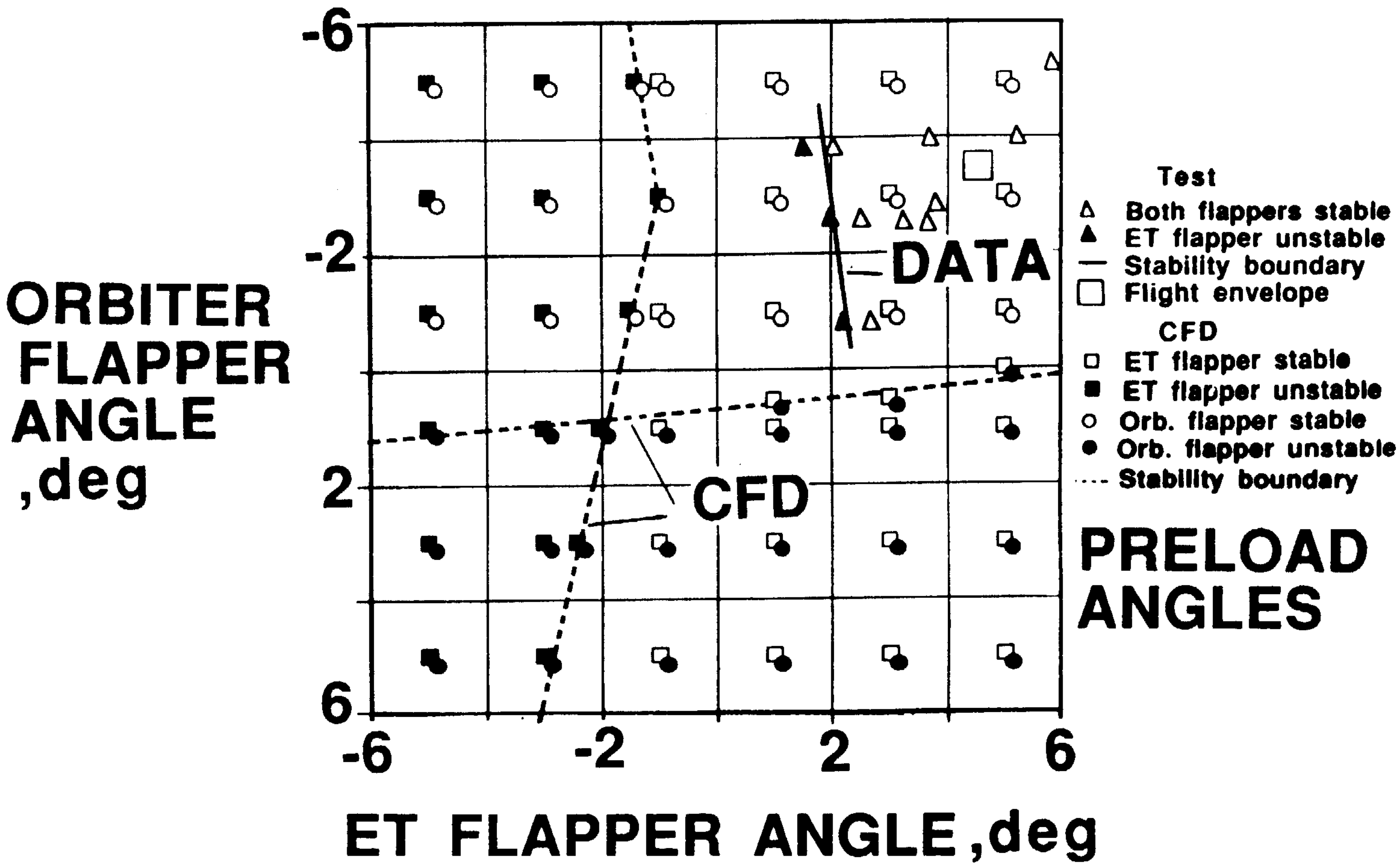
EFFECT OF FLOW RATE



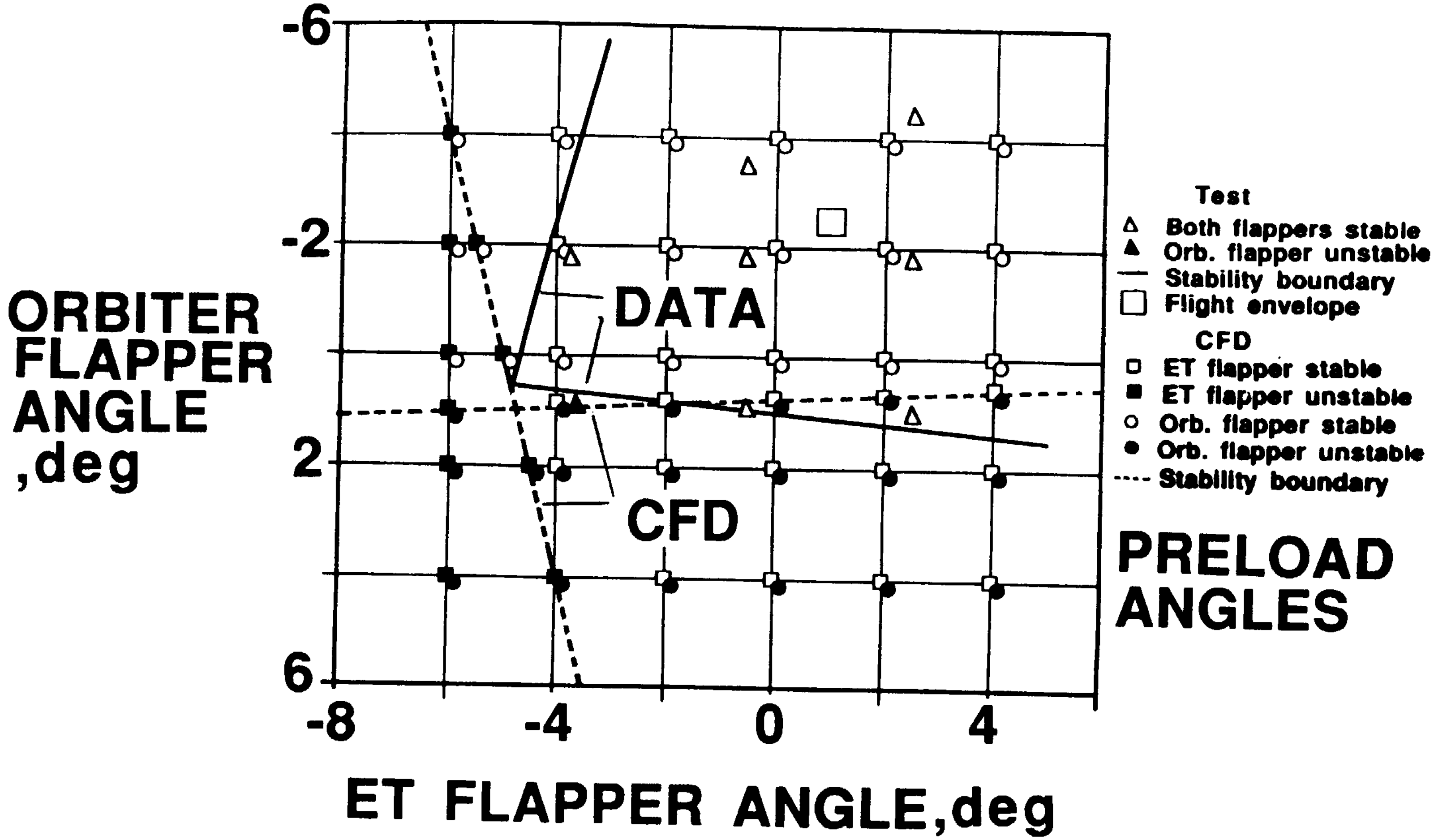
EFFECT OF FLAPPER ANGLE



STABILITY BOUNDARIES
LO_2 DISCONNECT



STABILITY BOUNDARIES
LH_2 DISCONNECT



SUMMARY

- ENHACED THE STABILITY OF INS3D
- VALIDATED THE CODE WITH DATA
  - INTERNAL FLOW
  - INTERNAL OBSTACLES
  - HIGH REYNOLDS NUMBER (3.5E06)
- PREDICTED FLAPPER STABILITY
- ASSISTED IN THE VALVE REDESIGN
  - LATCH BETWEEN FLAPPERS