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 (LO₂) and liquid hydrogen (LH₂). The main objectives of the analysis 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 SVTG3D 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 LO₂ and LH₂ 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 LO₂ and LH₂ 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 LO₂ unit and 2.4E06 for LH₂ 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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LH₂ DISCONNECT VALVE

WATER FLIGHT

Re = 2.7E06  50E06

260 INLET BEND

FLOW

2.40 ± 0.250

0.750 ± 0.250

4.0 IN.
OBJECTIVES

- PREDICT
  - HYDRODYNAMIC STABILITY
  - PRESSURE DROP
  - CAVITATION
COMPUTATIONAL GRID

CODE : SVTG3D ( SONI ET AL. 1986 )
ORG  : SVERDRUP / AIR FORCE

LO2 DISCONNECT
FLOW SOLUTION DEVELOPMENT

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

- INTERNAL OBSTACLES
- TURBULENCE MODEL
- UNDER-RELAXATION

ANGLE CORRECTIONS

\[
\begin{align*}
\text{ET} : & \quad FA = (PA + 1) \text{ deg} \\
\text{ORB} : & \quad FA = (PA - 5) \text{ deg} \\
\text{LO}_2 : & \quad \begin{cases} 
PA = \text{PRELOAD ANGLE} \\
FA = \text{FLIGHT ANGLE}
\end{cases} \\
\text{LH}_2 : & \quad \text{NONE}
\end{align*}
\]
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

PITCHING MOMENT (lbf-ft)

NO. OF ITERATIONS
EFFECT OF FLOW RATE

STOP LOAD (lbf)

1600

800

FLOW RATE**2 (10**8 gpm**2)

LO₂
ET FLAPPER

CFD
DATA

MPL
RPL FPL
EFFECT OF FLAPPER ANGLE

PITCHING MOMENT (lbf-ft)

Re = 3.5E06
ORB : -8 deg
MIN
ET
AVG
MIN
ORB
AVG

ET FLAPPER ANGLE, deg

200
0
-200
SUMMARY

- ENHANCED 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