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

Max Kandula* and Daniel Pearce**
Lockheed Engineering and Sciences Company
Houston, Texas

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 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 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.

* Advanced Systems Engineering Specialist
** Engineer
**LO$_2$ DISCONNECT VALVE**

Re = \(3.5 \times 10^6\) \(20 \times 10^6\)

**Diagram Details:**
- **External Tank** connected to the valve with a 90° inlet bend.
- **Orbiter** and **follower arm** indicated with respective flow and stop load details.
- **Separation interface** marked between the tank and the orbiter.
- **Drive arm** designated for actuation.
LH$_2$ DISCONNECT VALVE

260 INLET BEND

0.750 ± 0.250

4.0 IN.

FLOW

2.40 ± 0.250

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
FLOW SOLUTION DEVELOPMENT

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

• INTERNAL OBSTACLES
• TURBULENCE MODEL
• UNDER-RELAXATION

ANGLE CORRECTIONS

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

LOG RMSDQ
LOG RMSDIV

LO₂
Re = 3.52 E6
54X21X25

RMSDIV
RMSDQ

NO. OF ITERATIONS
EFFECT OF FLOW RATE

STOP LOAD (lbf)

FLOW RATE**2 (10**8 gpm**2)
EFFECT OF FLAPPER ANGLE

PITCHING MOMENT (lbf·ft)

ET FLAPPER ANGLE, deg

Re = 3.5E06
ORB : -8 deg

AVG
MIN
ET
ORB
LO₂

-200
0
200

-6
-2
2
6
STABILITY BOUNDARIES
LO₂ DISCONNECT

ORBITER FLAPPER ANGLE, deg

ET FLAPPER ANGLE, deg

DATA

CFD

PRELOAD ANGLES

Test
△ Both flappers stable
△ ET flapper unstable
- Stability boundary
□ Flight envelope
CFD
□ ET flapper stable
■ ET flapper unstable
○ Orb. flapper stable
● Orb. flapper unstable
— Stability boundary
SUMMARY

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