Preliminary Simulations of the Ullage Dynamics in Microgravity during the Jet Mixing Portion of Tank Pressure Control Experiments

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Tank Pressure Control Experiment (TPCE)
- Get-Away Special experiment flown on the Space Shuttle in 1991

Objectives

- characterize the dynamics of jet induced mixing processes in microgravity

- provide data to validate CFD models of jet mixing in microgravity

Our objective as part of the e-Cryo program is to evaluate current cryogenic fluid capabilities to support NASA efforts and to identify areas requiring further development
TPCE hardware

- clear acrylic tank for optical access
- 83% fill with Freon (r-113)
- embedded jet nozzle
- two electrical heaters
- liquid acquisition device (LAD) to recirculate fluid

- video cameras were used to record ullage interface (limited to 2 mins of heating 4 min mixing)
- temperatures and pressures in the tank were recorded
- cartesian grid placed behind the tank
The results of 38 tests were reported with jet flow rates ranging from 0.38 to 3.35 L/min. The jet Weber number used to characterize the TPCE tests was adopted from previous testing by Aydelott:\(^3\):

\[
\text{We}_j = \frac{r_1 V_o^2 R_o^2}{s D_j}
\]

where

- \(D_j\) - is the diameter of the jet at the interface
- \(R_o\) - is the radius of the liquid jet at the nozzle outlet
- \(V_o\) - is the velocity of the liquid jet at nozzle outlet
- \(r_1\) - is the density of the liquid jet
- \(s\) - is the surface tension at the interface
- \(x\) - is the distance from jet nozzle outlet to liquid/vapor interface

and

\[
D_j = 2R_o + 0.24x \quad \text{(for } x < 12.4 \text{ R}_o\text{)}
\]

\[
= 0.22R_o + 0.38x \quad \text{(for } x > 12.4 \text{ R}_o\text{)}
\]

Nonpenetrating – jet doesn’t penetrate the ullage

Asymmetric – jet forces ullage to one side of tank

Penetrating – jet penetrates and flows behind the ullage

Figure 43: Flow Pattern versus Flow Rate and $We_j$

Figure from
FLOW-3D

- multi-physics, multi-dimensional, transient, CFD code
- uses fractional area/volumes (FAVOR) for geometry definition (no arbitrary body fitted grid)
- volume of fluid (VOF) for fluid interfaces
- variety of surface tracking algorithms (split Lagrangian)
- 2nd order advection
- implicit surface tension
- turbulence models (k-ε used)
- 5° contact angle
- thermophysical properties for Freon r113 from NIST
95 cells in the x and y directions

135 cells in the z direction (along jet axis)

742,000 active cells

Clustered around the jet

grid details above the top heater and grid resolution of the jet (6 cells)
Run 11  \( \text{We}_j - .71 \)  Non-penetrating

t= 20 s  

t= 55 s  

t= 90 s


t= 101 s  

t= 180 s  

t= 261 s
Run 15  \( W_{ej} = 4.74 \)  Asymmetric

- \( t = 20 \text{ s} \)
- \( t = 25 \text{ s} \)
- \( t = 71 \text{ s} \)
- \( t = 104 \text{ s} \)
- \( t = 173 \text{ s} \)
- \( t = 203 \text{ s} \)
Run 13  \( \text{We}_j - 15.5 \)  Penetrating
Run 4 – Comparison of simulation to experimental ullage protuberance.
Transit of ullage protuberance digitized from video images
Qualitatively able to capture ullage dynamics for a range of jet Weber numbers

- quantitative comparisons remain an issue (ray tracing?)

Future work

include heating portion of test

use multiblock capability to refine jet

add acceleration(s) to simulations