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:\(^1\):

\[
\text{\( We_j = r_1 V_o^2 R_o^2 / (s D_j) \)}
\]

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

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

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

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 Wej
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)

$2^{\text{nd}}$ order advection

implicit surface tension

turbulence models ($k-\epsilon$ used)

$5^\circ$ 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  \( W_{e_j} - .71 \)  Non-penetrating

t= 20 s  

t= 55 s  

t= 90 s  

t= 101 s  

t= 180 s  

t= 261 s
Run 15  $We_j = 4.74$  Asymmetric

t= 20 s  t= 25 s  t= 71 s  


t= 104 s  t= 173 s  t= 203 s
Run 13  We$_j$ – 15.5  Penetrating

t= 20s  t= 23s  t= 25s

t= 27 s  t= 53 s  t= 116 s
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