The Study of Slosh Phenomenon in Satellite Propellant Tank

陳秋富、楊安石

E-mail: 9511385@mail.dyu.edu.tw

ABSTRACT

The surface-tension type propellant tank is generally adopted in the baseline design of 500-kg class satellites. For this specific type of propellant tank, there is no diaphragm to physically separate the liquid hydrazine (N2H4) from the pressurant gas (typically N2 or He). In response to different mission requirements, the change of satellite attitude configurations could lead to the excitation of the time-dependent liquid sloshing flows inside the tank. Those sloshing waves along the liquid-gas interface can further induce considerable fluctuations of fluid stress and its disturbance moment exerted on the inner walls of the tank. In addition, under the situations of large-amplitude sloshing waves and some particular attitude modes, the pressurant gas bubble can be settled over the tank outlet prior to thruster restart, likely causing the gas entrainment into the propellant supply line with the worst consequence of the degradation or even failure for the propulsive performance. The objective of this research is to set up a free-falling tower to observe dynamical behavior of liquid-gas interfaces and the distributions of liquid in a transparent sphere under low-gravity environments. Theoretically, the time-dependent interfacial transport behavior has been formulated using the conservation equations of mass and momentum in conjunction with the VOF-PLIC (Volume of Fluid-Piecewise Linear Interface Construction) method. The CFS (Continuum Surface Force) model was adopted to treat the surface tension effect on the liquid-gas interface movement. Numerical calculations were performed using the SIMPLEC (Semi-Implicit Method for Pressure-Linked Equations Consistent) scheme. The predictions are in reasonable agreement the experiment showing the validity of the present theoretical model. For ROCSAT-2 propellant tank, various effects including liquid filled ratio, gravity level, surface tension, and contact angle on the spatial distribution of the gas bubble shape also has been examined detail.

Keywords : satellite, micro-gravity, fuel tank, hydrazine, liquid-gas interface, sloshing

Table of Contents

REFERENCES

[1] " Request for Proposal for the ROCSAT-2 Spacecraft, " Document No.ROCSAT-2. PO.87.015, National Space Program Office, Hsinchu, Taiwan, October 15, 1998 [2] Propulsion Module Requirement Specification for ROCSAT-2 Bus, Astrium Report No ROC2.SP.0003.MMS-T, Toulouse, France, 2000.

[3] ROCSAT-2 Sloshing Analysis Report, Astrium Report No ROC2.TN.0048. MMS-T, Toulouse, France, 2000.

[4] ROCSAT-2 Propulsion Module PDR Data Package, Astrium Report No ROC2- RIBRE-TN-0001, Toulouse, France, 2000 [5] Huzel, D. K. and Huang, D. H., " Modern Engineering for Design of Liquid Propellant Rocket Engines, " Vol.174, Progress in Astronautics and Aeronautics, AIAA, 1992.

[6] NASA Office of Aeronautics and Space Technology, Technology for Future NASA Missions: Civil Space Technology Initiative and Pathfinder, NASA CP-3016. NASA, Washington, D. C., 1988.

[7] Chandrasekhar, F. R. S., " The Stability of a Rotating Liquid Drop, " Proceedings of the Royal Society of London, Ser. A, Vol. 286, pp. 1-26, 1965.

[8] Leslie, F. W., " Measurement of Rotating Bubble Shapes in a Low- gravity Environment, " Journal Fluid Mechanics, Vol. 161, pp. 269-279, 1985.

[9] Hung, R. J. and Leslie, F. W., “ Bubble Shapes in a Liquid-Filled Rotating Container Under Low Gravity, ” Journal of Spacecraft, Vol. 25, No. 1, pp. 70-74, 1988.
[10] Hung, R. J., Tsao, Y. D, Hong, B. B., and Leslie, F. W., “ Bubble Dehaviors in a Slowly Rotating Helium Dewar in Gravity Probe-B Spacecraft Experiment, ” Journal of Spacecraft and Rockets, Vol. 26, No. 3, pp. 167-172, 1989.
[11] Hung, R. J., Tsao, Y. D, Hong, B. B., and Leslie, F. W., “ Axisymmetric Bubble Profiles in a Slowly Rotating Helium Dewar Under Low and Microgravity Environments, ” Acta Astronautica, Vol. 19, May, pp. 411-426, 1989.
[12] Hung, R. J., Lee, C. C., and Leslie, F. W. “ Response of Gravity Level Fluctuations on the Gravity Probe-B Spacecraft Propellant System, ” Journal Propulsion Power, Vol. 7, pp. 556-564, 1991.
[13] Hung, R. J., Lee, C. C., and Leslie, F. W. “ Spacecraft Dynamical Distribution of Fluid Stresses Activated by Gravity-Jitter-Induced Slosh Wave, ” Journal Guidance, Control Dynamics, Vol. 15, No. 4, pp. 817-824, 1992.
[14] Hung, R. J. and Pan, H. L., “ Gravity Gradient or Gravity Jitter Induced Viscous Stress and Moment Fluctuations in Microgravity, ” Fluid Dynamics Research, Vol. 14, pp. 29-51, 1994.
[15] Hung, R. J. and Long, Y. T., “ Response of Lateral Impulse on Liquid Helium Sloshing with Baffle Effect in Mircrgravity, ” Journal Mechanical Engineering Science, Vol. 38, pp. 951-965, 1996.
[16] Welch, J .E., Harlow, F.H., Shannon, J.P., Daly, B.J., “ The MAC Method: A Computing Technique for Solving Viscous Incompressible, Transient Fluid Flow Problems Involving Free Surface, ” Report LA-3425, Los Alamos Scientific Report, CA, USA.
[17] Hirt, C. W. and Nichols, B. D., “ Volume of fluid (VOF) method for the dynamics of free boundaries, ” Journal Computational Physics, Vol. 39, pp. 201-225, 1981.
[18] DeBar, R., “ Fundamentals of the KRAKEN Code, ” Technical Report UCIR-760, LLNL, 1974.
[19] Ashgriz, N., and Poo, J. Y., Journal of Computational Physics Vol. 93, pp. 449, 1991.
[20] Youngs, D. L., “ Time-Dependent Multi-Material Flow with Large Fluid Distortion, ” Morton, K.W., and Baines, M.J., editor, Numerical Methods for Fluid Dynamics, pp. 273-285, 1982.
[21] Pilliod, J. E., and Puckett, E. G.. “ Second Order Volume-of-Fluid Interface Tracking Algorithms. ” Unpublished manuscript, to be submitted to Journal Computational Physics , 1996.
[22] Noh, W. F., and Woodward, P. R., “ SLIC (Simple Line Interface Method), ” In A.I. Van de Vooren and Zandbergen, P. J., editors, Lecture Notes in Physics Vol. 59, pp. 330-340, 1976.
[23] Van Doormaal, J. P., and Raithby, G. D., “ Enhancements of The SIMPLE Method for Predicting Incompressible Fluid Flows, ” Numerical Heat Transfer, Vol. 7, pp. 147-163, 1984.
[24] Kothe, D. B., Rider, W. J., Mosso, S. J., Brock, J. S., Hochstein, J. I., “ Volume Tracking of Interfaces Having Surface Tension in Two and Three Dimensions, ” Technical Report AIAA 96-0859, [Presented at the 34th Aerospace Sciences Meeting and Exhibit, Reno, NV, Jan, 15-18, 1996..
[25] Suhas V. Patankar, “ Numerical Heat Transfer and Fluid Flow, ” Hemisphere Publishing Corporation, New York, 1983.
[26] Parker, B. J., and Youngs, D. L., “ Two and Three Dimensional Eulerian Simulation of Fluid Flow with Material Interfaces, ” Technical Report AWE 01/92, Atomic Weapons Establishment (1992). Presented at the Third Zababakhin Scientific Talks, Kyshitm, Russia, 1992.
[27] Dukowicz, J. K. “ Efficient Volume Computation For Three-Dimensional Hexahedral Cells. ” Journal Computational Physics, Vol. 74, pp. 493-496, 1988.
[28] Zemach, C. “ Notes on the Volume of a Ruled Hexahedron Behind a Truncating Plane. ” Unpublished Manuscript, Los Alamos National Laboratory, 1993.
[29] Brackbill, J. U., Kothe, D. B., and Zemach, C. “ A Continuum Method for Modeling Surface Tension, ” Journal Computational Physics, Vol. 100, pp. 335-354, 1998.