change in the main body acceleration. The step change in acceleration excites the sloshing mass motion which, when coupled with the main body decreased inertia ratio, produces an unstable oscillation.

Figure 3 shows telemetered flight data from a previous mission. The pitch and yaw rate gyro data show approximately equal amplitude with 90-deg phase shift, indicating a coning response. Comparison of Figs. 2 and 3 shows that the growth of the coning motion is substantially different, indicating that sloshing mass motion is not the mechanism causing the anomaly.

Conclusions and Recommendations

This study has shown that powered flight of a spacecraft carrying fluid stores within the main rigid body can be a source of dynamic instability.

The major conclusions and recommendations drawn from this study are:

1) Explicit dynamic response equations for this complex system were derived using both Kane's method and Lagrange's equation, with the fluid modeled as an equivalent spherical pendulum.

2) Sloshing fluid stores are not the source of dynamic instability seen in the launchings of STAR 48 rocket-motor-equipped spacecraft that carried the fluid stores.

Acknowledgments

This study was completed under partial support of Contract AFOSR-86-0080 and Subcontract 83RIP33, U.S. Air Force. The authors wish to acknowledge the support of Iowa State University in accomplishing the lengthy digital computer simulation required in this study.

References

[1]Sumner, I. E., "Experimentally Determined Pendulum Analogy of Liquid Sloshing in Spherical and Oblate-Spherical Tanks," NASA TN D-1991, Dec. 1963.

[2]Sumner, I. E. and Stofan, A. J., "An Experimental Investigation of the Viscous Damping of Liquid Sloshing in Spherical Tanks," NASA TN D-1991, Dec. 1963.

[3]Sayar, B. A. and Baumgarten, J. R., "Linear and Nonlinear Analysis of Fluid Slosh Dampers," *AIAA Journal*, Vol. 20, Nov. 1982, pp. 1534–1538.

[4]Michelini, R. C., Lucifredi, A., and Dini, D., "The Dynamics of a Non-Rigid Spinning Satellite Containing Oscillating Liquids," *Proceedings of the Third International Conference on Automatic Control in Space*, France, 1970.

[5]Hill, D. E., "Dynamics and Control of Spin-Stabilized Spacecraft with Sloshing Fluid Stores," Thesis, Iowa State Univ., Ames, IA, 1985.

[6]Kane, T. R., *Dynamics*, Stanford Univ. Press, Stanford, CA, 1972.

[7]Kane, T. R., Likins, P. W., and Levinson, D. A., *Spacecraft Dynamics*. McGraw-Hill, New York, 1983.

Book Announcements

NELSON, R. C., ***Flight Stability and Automatic Control,*** McGraw-Hill, New York, 1988, 284 pages.

Purpose: This book is designed for a course in airplane stability and control at the undergraduate level. It covers the basic topics of static and dynamic stability, aircraft equations of motion, aerodynamic modeling, and automatic control.

Contents: Static stability and control; aircraft equations of motion; longitudinal motion (stick fixed); lateral motion (stick fixed); response to control or atmospheric inputs; automatic control-application of conventional as well as modern control theory.

WHITFORD, R., ***Design For Air Combat,*** Jane's Publishing, London, 1987, 224 pages.

Purpose: This book is concerned with the design of the modern combat aircraft, dealing with the shapes of such aircraft and their aerodynamic rationale. It includes the design features found on the exciting breed of aircraft that appeared in the 1970's, as well as those likely to enter service in the 1990's.

Contents: Wing design; air intakes; fuselage design; tailplanes; fins; exhaust nozzles and aft-body shape.

GREENBERG, M. D., ***Advanced Engineering Mathematics,*** Prentice-Hall, Englewood Cliffs, NJ, 1988, 946 pages.

Purpose: This book is intended primarily as a text for a single- or multi-semester course in applied mathematics for students in engineering and science. It is also useful for reference.

Contents: Linear algebra; multivariable calculus and field theory; Fourier series; Fourier and Laplace transforms; partial differential equations; complex variable theory.

GREENWOOD, D. T., ***Principles of Dynamics,*** 2nd ed., Prentice-Hall, Englewood Cliffs, NJ, 1988, 552 pages.

Purpose: This book is a senior-level text in dynamics of particles and rigid bodies.

Contents: Kinematics and dynamics of a particle; dynamics of a system of particles; orbital motion; Lagrange's equation; kinematics of rigid body motion; dynamics of a rigid body; vibration theory.

THOMSON, W. T., ***Theory of Vibration With Applications,*** 3rd ed., Prentice-Hall, Englewood Cliffs, NJ, 1988, 467 pages.

Purpose: This book is a senior-level text in mechanical vibrations. It includes newer material and a modern treatment of the subject matter.

Contents: Oscillatory motion; free, harmonically excited, and transient vibration; vibrating systems; Lagrange's equation; normal modes; mode summation procedures; finite element method; approximate numerical methods; numerical procedures for lumped mass systems; random vibrations; nonlinear vibrations.

FLIESS, M. and **HAZEWINKEL, M.** (Eds.), ***Algebraic and Geometric Methods in Nonlinear Control Theory,*** D. Reidel Publishing Co., Boston, MA, 1986, 642 pages.

Purpose: This volume is the proceedings of a conference on nonlinear system theory held in Paris in June of 1985.

Contents: Controllability, observability, realization, and other structural properties; feedback synthesis and linearization techniques; optimal control; discrete-time systems; various other theoretical aspects; applications.