Automated Method for Estimating Nutation Time Constant Model Parameters for Spacecraft Spinning on Axis

Spacecraft Nutation Models

Calculating an accurate nutation time constant (NTC), or nutation rate of growth, for a spinning upper stage is important for ensuring mission success. Spacecraft nutation, or wobble, is caused by energy dissipation anywhere in the system. Propellant slosh in the spacecraft fuel tanks is the primary source for this dissipation and, if it is in a state of resonance, the NTC can become short enough to violate mission constraints. The Spinning Slosh Test Rig (SSTR), developed by NASA and Southwest Research Institute (SwRI), is a forced-motion spin table where fluid dynamic effects in full-scale fuel tanks can be tested in order to obtain key parameters used to calculate the NTC. We accomplish this by independently varying nutation frequency versus the spin rate and measuring force and torque responses on the tank. This method was used to predict parameters for the Genesis, Contour, and Stereo missions, whose tanks were mounted outboard from the spin axis. These parameters are incorporated into a mathematical model that uses mechanical analogs, such as pendulums and rotors, to simulate the force and torque resonances associated with fluid slosh.

Most recently, the SSTR was modified to simulate the on-axis spin motions of the centerline-mounted tanks used in the Pluto New Horizons (PNH) and Deep Impact (DI) spacecraft (Figures 1 and 2). We varied diaphragm shapes (Figure 3), nutation frequencies (ratio of upper-motor to total revolutions per minute [RPM]), and fill levels at a constant spin rate of nearly 60.5 RPM to examine how the various force and torque activity would influence the mechanical analog parameters. Data was recorded while each fill level/diaphragm shape combination underwent a nutation sweep where specific nutation frequencies ranged from 10 to 90 percent of the total spin rate. After testing, it was determined that the pendulum analog parameters could be set to zero because very little resonance activity was observed in the force response along the tank wall, leaving the rotor analog available to be the sole influencer of the torque response. These ideal, or massless, rotors have inertia only about their primary axis of spin. Their associated parameters include inertia and spring/damping constants.

The current method for identifying model parameters involves laboriously hand-deriving equations of motion for both the SSTR and mechanical analogs and, by trial and error,

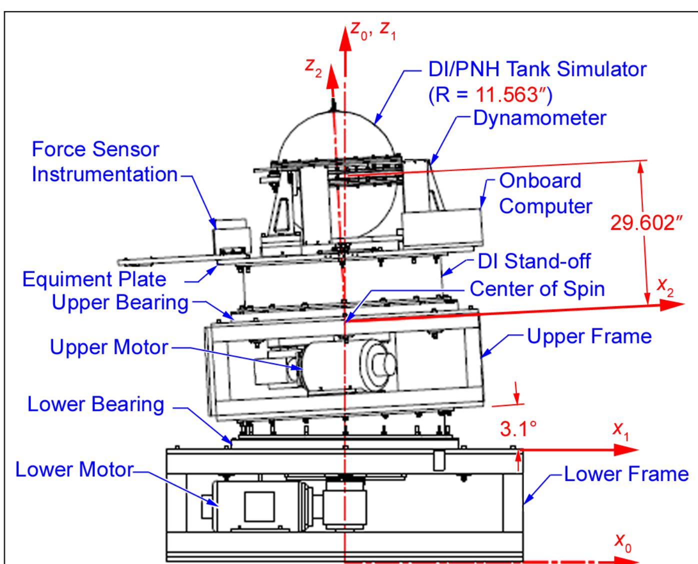

Figure 1. DI configuration (with stand-off).

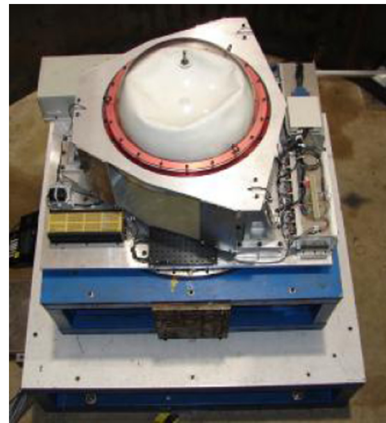

Figure 2. PNH configuration (without stand-off).

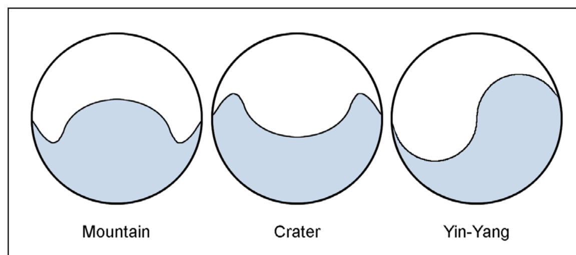

Figure 3. Diaphragm shapes tested by SwRI.

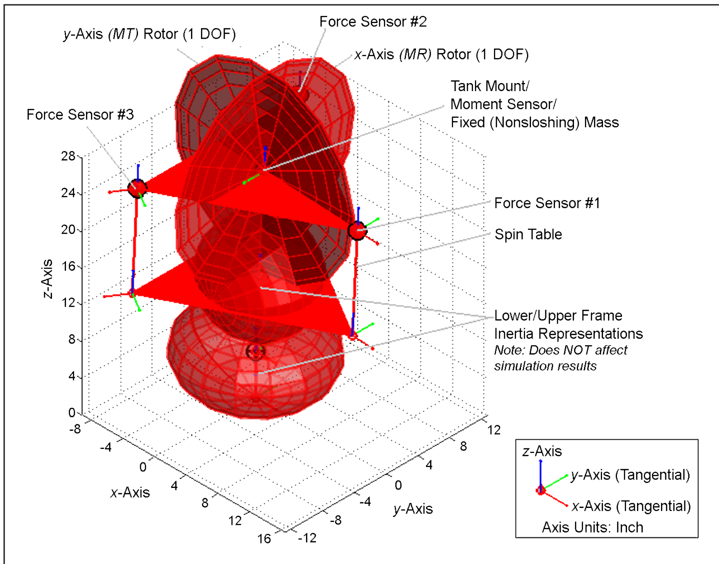

Figure 4. Overall layout of on-axis SSTR SimMechanics model.

comparing their results with experimental results. A strong desire exists to automate this method so different analogs can be tested quickly and the results can be compared with measured data.

The method presented accomplishes this task by using a MATLAB Simulink/SimMechanics-based simulation where the parameters are identified by the Parameter Estimation tool. Simulink Parameter Estimation provides a graphical interface where several optimization algorithms can be selected. The simulation incorporates the same slosh analog used by SwRI, two torque rotors about the radial (x) and tangential (y) axes (Figure 4), allowing direct comparisons between the hand-derived and automated methods. Six sets of measured data can be supplied to the simulation for parameter estimation. These include forces (*Fx*/*Fy*) along the tank wall and torques (*MR*/*MT*) resolved to the tank center of gravity (CG) (Figure 5), as well as the angular velocities of the tank CG ($\Omega x/\Omega y$) about each axis. Each nutation sweep test, usually consisting of 9 to 11 individual nutation frequencies, is supplied to the Estimator, where its multiple dataset estimation feature can be used. Estimating to the entire set of measured data allows the rotor parameters to be optimized for reproduction of the torque resonance response over the entire range of tested nutation frequencies (Figure 6).

Current research efforts focus on identifying and recording the differences between the hand-derived and SimMechanics methods, such as the effects of larger rotor inertias. Once complete, the same SimMechanics analog used in the SSTR model will be incorporated into

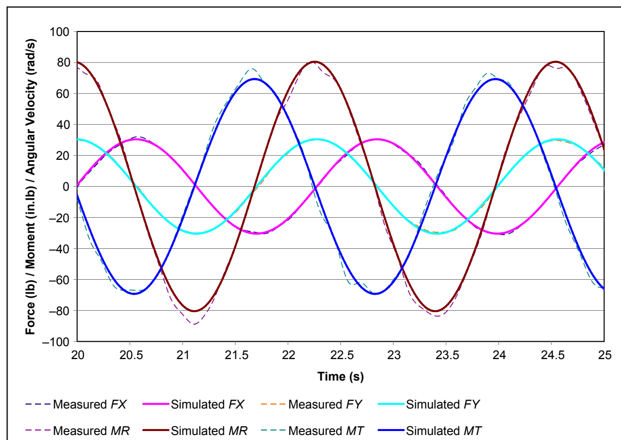

Figure 5. Comparison between measured and simulation data at a nutation rate of 0.44 for typical PNH test (upper-motor RPM = 26.26, lower-motor RPM = 34.30).

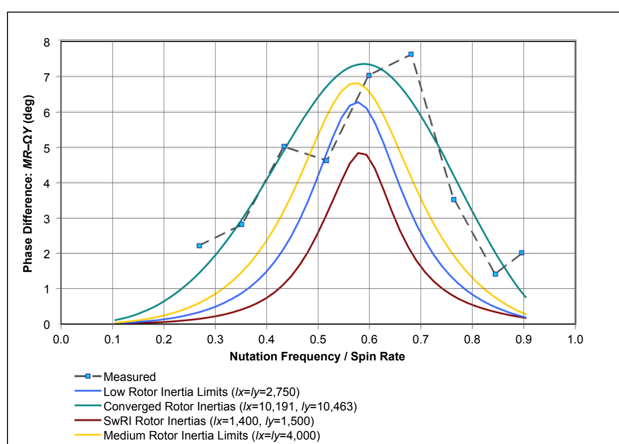

Figure 6. MT-to-ΩY phase comparison using various estimated parameters (inertia unit: lb.in²).

a compatible spacecraft model where the NTC can be calculated and compared with flight data. This proven process will be a valuable tool for quickly examining both traditional and novel mechanical fuel slosh analogs and for allowing spacecraft designers to build accurate slosh models early in the design phase, when potential NTC violations can be avoided.

Contacts: James E. Sudermann <James.E.Sudermann@nasa.gov>, NASA-KSC, (321) 867-8447; and Keith L. Schlee <Keith.L.Schlee@nasa.gov>, Analex Corporation, (321) 867-4186

Participating Organization: Southwest Research Institute (Dr. Steve Green and Russell C. Burkey)