SloshSAT

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Liquid Slosh

- Forces produced by liquid fuel slosh can cause dramatic wobble during flight leading to control issues which may lead to failure of the mission.

- Years of research into fuel slosh has yielded computationally intensive models.

- This research begins with a simplified mathematical model which predicts the velocity profile of the fluid along a single axis. This model will be tested with an apparatus placed on the central axis of a two-stage Improved Terrier-Orion Sounding Rocket to be launched in June of 2010.

- If our experiment is successful, it may be possible in the future to generate a more comprehensive model.

Current Solutions

Passive Attenuation

- A modeling system that accounts for both the motion of the spacecraft and the liquid fuel simultaneously is most ideal.

- This is very difficult as one can not control or measure the position or orientation of the fuel aboard the spacecraft accurately. **It is only possible to measure the effects of the fuel slosh on the total system**.

- As a result, many passive ways have been developed to dissipate the energy of the fuel sloshing:
  - Baffles,
  - Slosh absorbers,
  - Breaking a large tank into a smaller one

- However, these methods add weight and therefore increase launch costs.

Traditional Modeling Methods

- Numerous analytical models have been used to describe the motion of fluids. The most accurate description of liquid motions requires use of the Navier-Stokes equations.

- These formulas, however, are not practical for control implementations as they are highly dependent on boundary conditions and are computationally intensive.

- Additional models have been suggested including
  - (Single and multi) mass-spring-damper
  - Pendulum liquid slug,
  - CFD/FEA models. (explain)

Mathematical Model

• Our mathematical model will predict the movement of the fluid along the central axis. The spin of the rocket will produce a net force which will tend toward zero in the x- and y- plane.

• To build the most general model, we look at the acceleration of a small volume element of the fluid:

$$\frac{dv}{dt} = \frac{\partial v}{\partial t} + v \cdot \nabla v$$

• Our project focuses on forces and our payload will collect acceleration data.

$$F = \lambda dV \frac{dv}{dt} = \lambda g dV - \nabla \mathrm{p} \mathrm{dV}$$

$$where \begin{cases} \lambda = volume\ density \\ p = pressuure \\ dV = volume\ element \\ g = acceleration\ due\ to\ gravity \end{cases}$$

Mathematical Model

- From the equations, we have too many variables to solve. The additional equations are continuity equations derived from conservation of mass considerations as well as an equation that relates a small change in a fluid element's density to the resulting change in the pressure on that element through the bulk modulus.

$$\frac{d\lambda}{dt} + \nabla \cdot (\lambda v) = 0$$

$$p' = BM\frac{\lambda'}{\lambda_0} \qquad where \begin{cases} p' = small\ change\ in\ pressure \\ \lambda' = small\ change\ in\ density \\ \lambda_0 = equilibrium\ density \end{cases}$$

Mathematical Model

- Combining these equations gives the final expression for the fluid motion in the form of a wave equation in the z-direction:

$$\frac{c^2}{g}\frac{\partial^2 v}{\partial z^2} - \frac{\partial v}{\partial z} = \frac{1}{g}\frac{\partial^2 v}{\partial t^2} \quad \textit{where } c = \textit{speed of the wave in the fluid}$$

- The solutions to this equation for which time and space separable (which does not include any driving forces):

$$v(z,t) = e^{-gz/2c^2}\left[\Psi_{-}\cos\left(\sqrt{\frac{\alpha g}{c^2} - \frac{g^2}{c^4}}\,z + \alpha g t - \frac{\pi}{4}\right) + \Psi_{+}\cos\left(\sqrt{\frac{\alpha g}{c^2} - \frac{g^2}{c^4}}\,z - \alpha g t - \frac{\pi}{4}\right)\right]$$

- This equation represents the velocity profile of the fluid which takes the form of bi-directional traveling waves within the liquid. Boundary conditions and driving forces are needed to complete the model.

Expected Results

- If the canister and fluid behave as expected, the data we collect will yield a solution to the equation shown on the previous slide.
- Comparison of the data from the canisters movement with a control output will reveal if the system behaves in the manner that the model predicts.

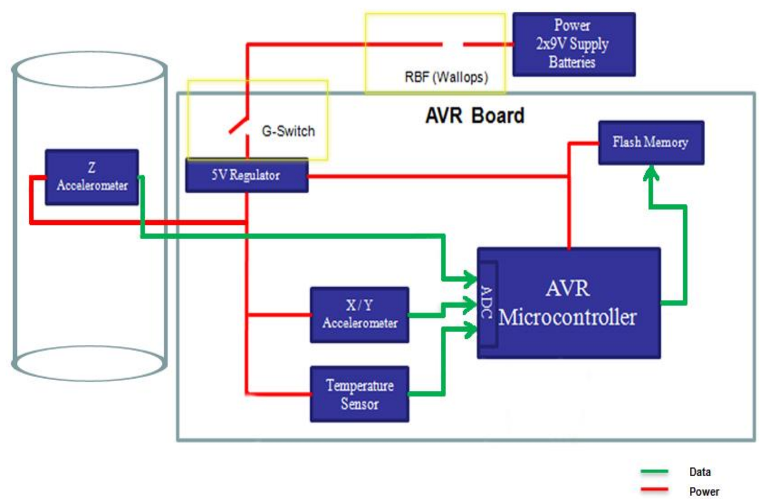
Experiment Description

- A cylinder partially filled with Galden© will be constrained by an outer container so that it may only move along the central axis throughout the duration of the flight.

- The reason that we are using Galden© is for safety.

- The acceleration of the liquid cylinder will be recorded and these data will be combined with NASA rocket acceleration data and analyzed on the ground.

- The data collection electronics are the same as those designed by NASA for the Wallops RockOn! Workshop attended by UNC students in 2008.



Requirements Matrix

Requirement	Method	Status
The payload shall not weigh more than 3 kg .	Design	
The payload shall not be more than tall 4.75”.	Design	
The payload center of gravity (CG) shall be within 1”^{3} of the geometric center.	Design, Analysis	
The payload shall follow the no-volt requirement.	Design	
The payload shall be self contained.	Design	
The liquid shall not escape the redundant containment system.	Design, Test	
The liquid shall not be conductive, corrosive, or flammable.	Design, Test	

Conclusions

The project is scheduled to launch on June 24, 2010 from Wallops Flight Facility.

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