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LAUNCH SERVICES PROGRAM

EXPERIMENTAL VALIDATION OF STAR CCM+ FOR LIQUID CONTAINER SLOSH DYNAMICS

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Agenda



- **Introduction**
- **Problem**
- **Background**
- **Experiment**
- **Star ccm+ CFD model**
- **Results**
- **Conclusion**



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Introduction



- **Launch Services Program**
 - Provide leadership, expertise and cost effective services in the commercial arena to satisfy agency wide (NASA) space transportation requirements and maximize the opportunity for mission success
 - Interface between launch service provider (commercial) and NASA spacecraft
 - Requires engineering success
- **Mission Analysis Division**
 - Verify and validate mission engineering/analysis
 - Conduct any analysis required by NASA's unique missions
 - Reduce technical risk to NASA missions



Problem



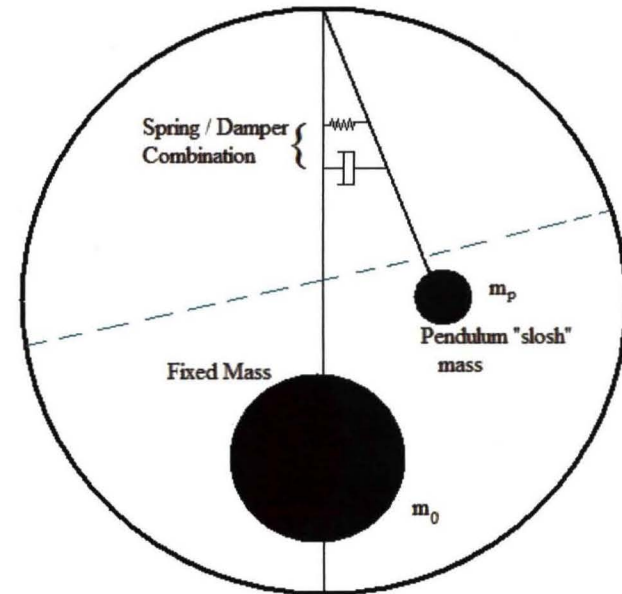
- **Fuel Slosh**
 - **Liquid propellants account for most of the mass on a launch vehicle**
 - **During flight, these liquids “slosh” back and forth within the tanks**
 - **This sloshing motion causes forces on the vehicle which must be accounted for in the flight software**
 - **Both frequency and damping rate for all liquid propellant tanks must be accurately predicted in order to create an efficient autopilot design**
 - **The idea is to keep the rocket flying straight!**
 - » **This will lead to engineering success**
- **Typical propellant tanks on NASA missions**
 - **2 on booster stage**
 - **2 on upper stage**
 - **1-16 tanks on payload**



Background



- **Guidance Navigation and Controls (GN&C) analyses use simplified mechanical analog models**
 - Spring mass system
 - Pendulum system
- **These simplified models require parameters as inputs**
 - Pendulum mass
 - Fixed mass
 - Pendulum length
 - Hinge point
 - Fixed mass location
- **These parameters vary as a function of fill level**



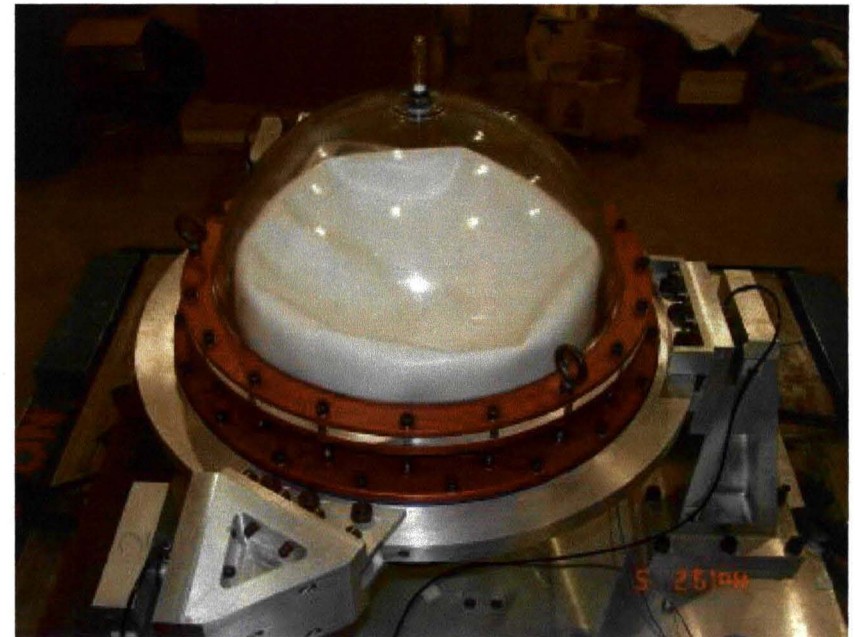


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Background



- **How to derive these parameters**
 - **Experimental data**
 - » **Expensive**
 - » **Time consuming**
 - » **Lots of data reduction necessary**
 - **CFD**
 - » **Quick**
 - » **Inexpensive**
 - » **Simple**
 - **Analytical Methods**
 - » **Very easy to apply**
 - » **Only valid with simple geometry**
- **CFD must first be validated**
 - **Producing engineering success**



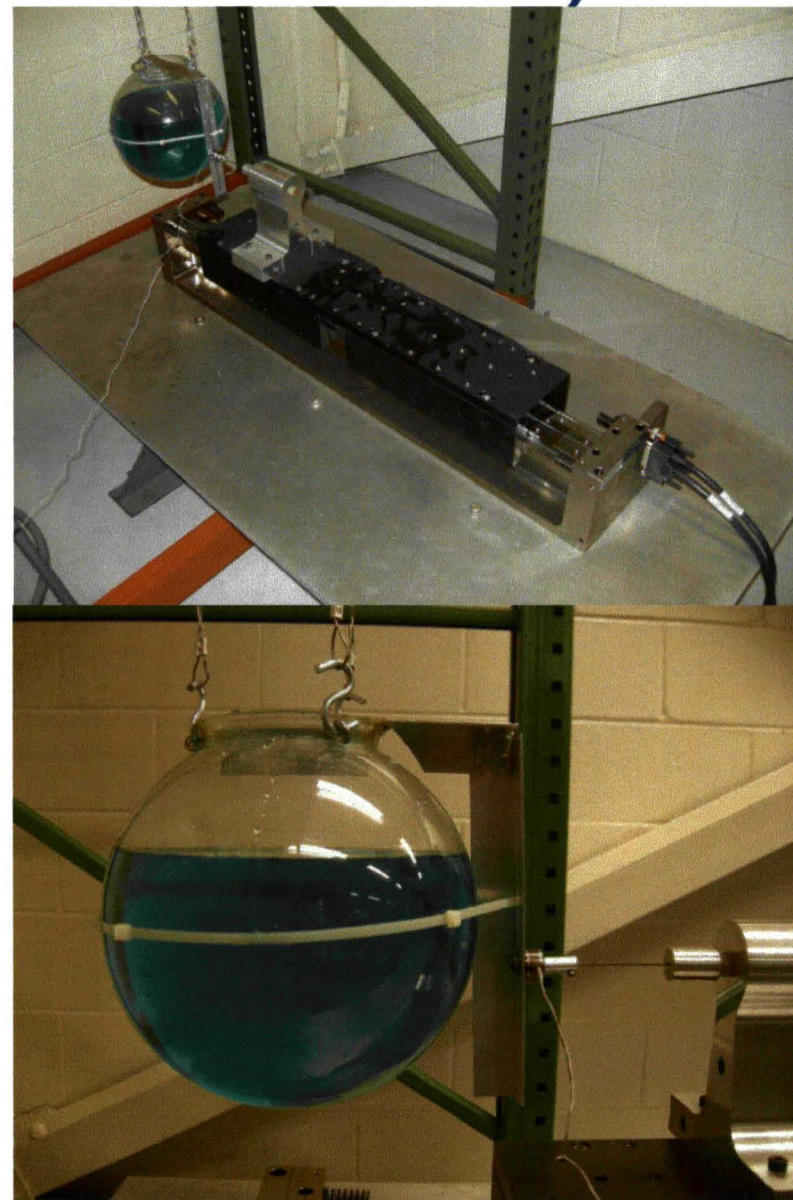
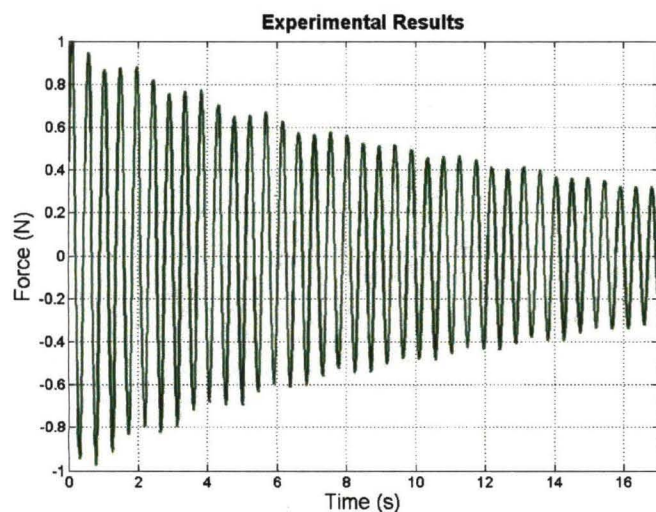


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Experiment



- Carried out at Embry-Riddle Aeronautical University
- Simplified case
 - 8 inch diameter sphere
 - Water
 - 60% fill level
 - Linear excitation
 - Step impulse and hold
 - No breaking waves



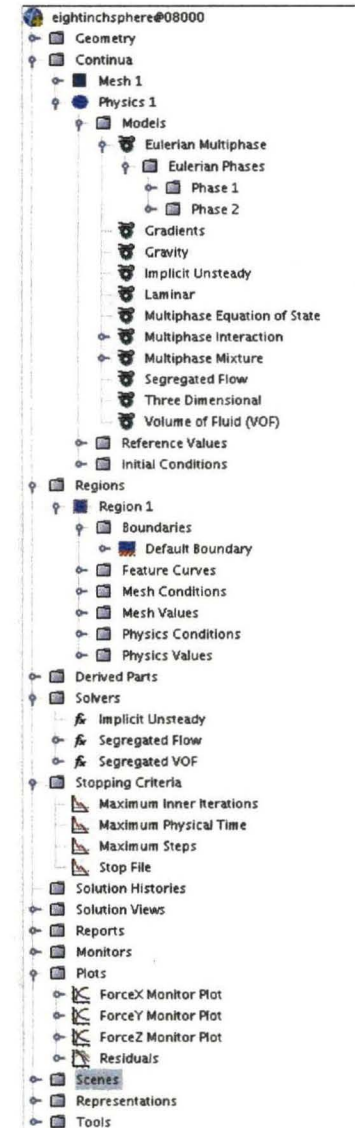


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Star-CCM+ Model



- Same geometry was modeled using Star-CCM+
 - Volume of Fluid (VOF)
 - » Phase 1 = water
 - » Phase 2 = air
 - Implicit unsteady
 - » 2nd order Time
 - » Timestep 0.0025 s
 - » Total time 20 s
 - Gravity
 - » 1g
 - Constant density (incompressible)
 - » 997.561 kg/m³ – water
 - » 1.18415 kg/m³ - air
 - Three dimensional





Star-CCM+ Model

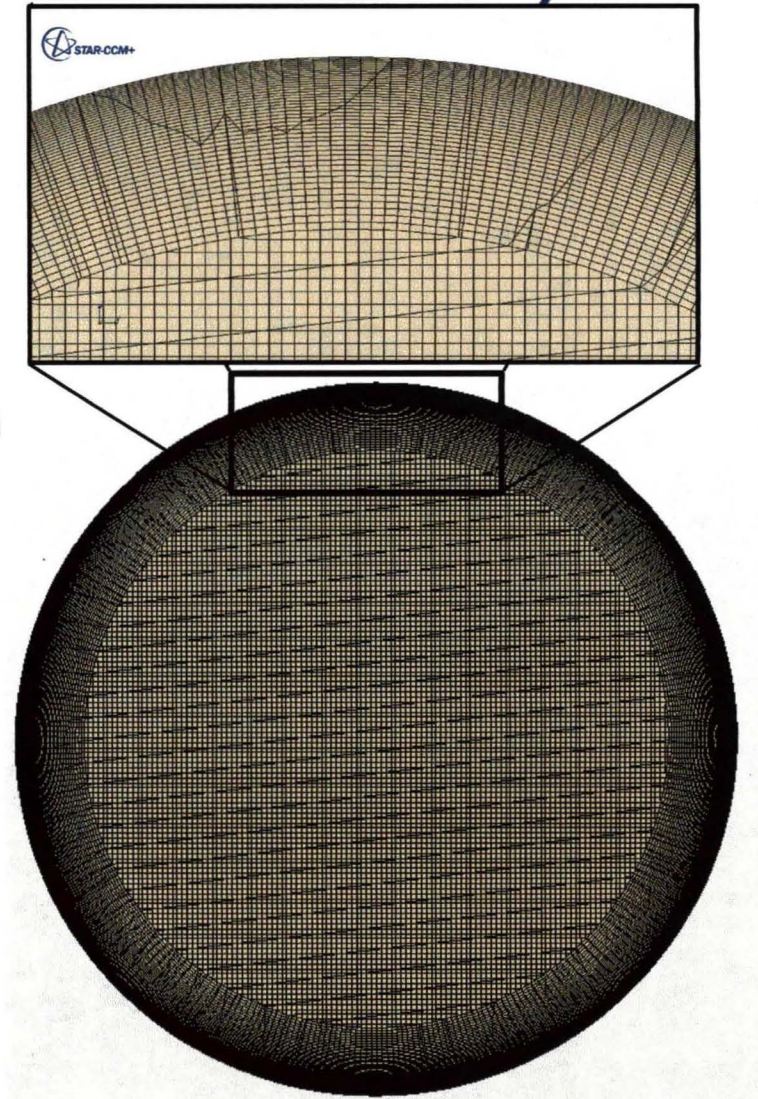


- **Mesh**

- **Used simple (new shape part) sphere**
- **Surface remesher**
- **Trimmer Mesh**
 - » **Works well with VOF formulation**
 - » **Need high resolution throughout domain**
- **Prism layer mesher for accurate viscous damping**
- **3.1 M cells**

- **Boundary Condition**

- **1 region**
 - » **Walls**
 - » **No-slip**



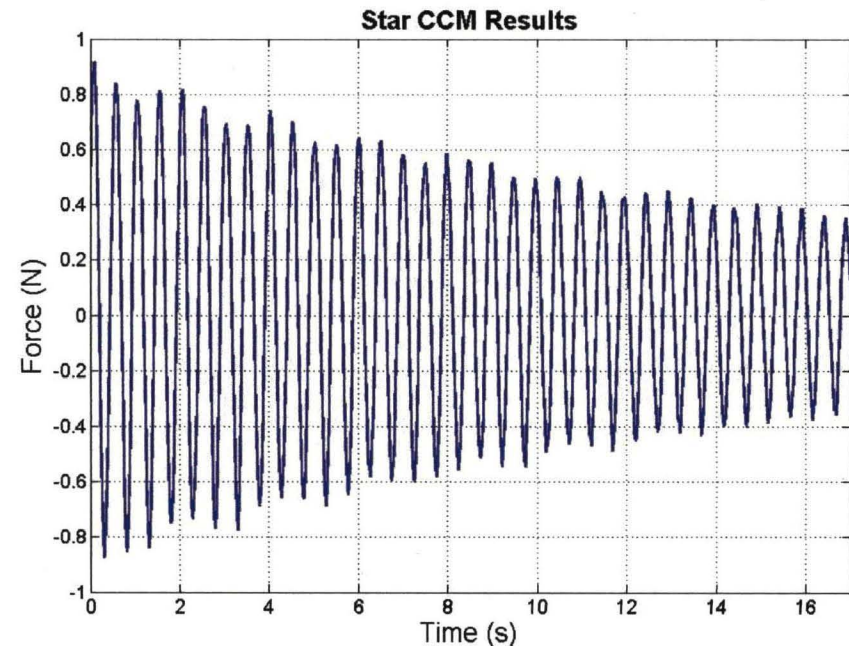


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Star-CCM+ Model



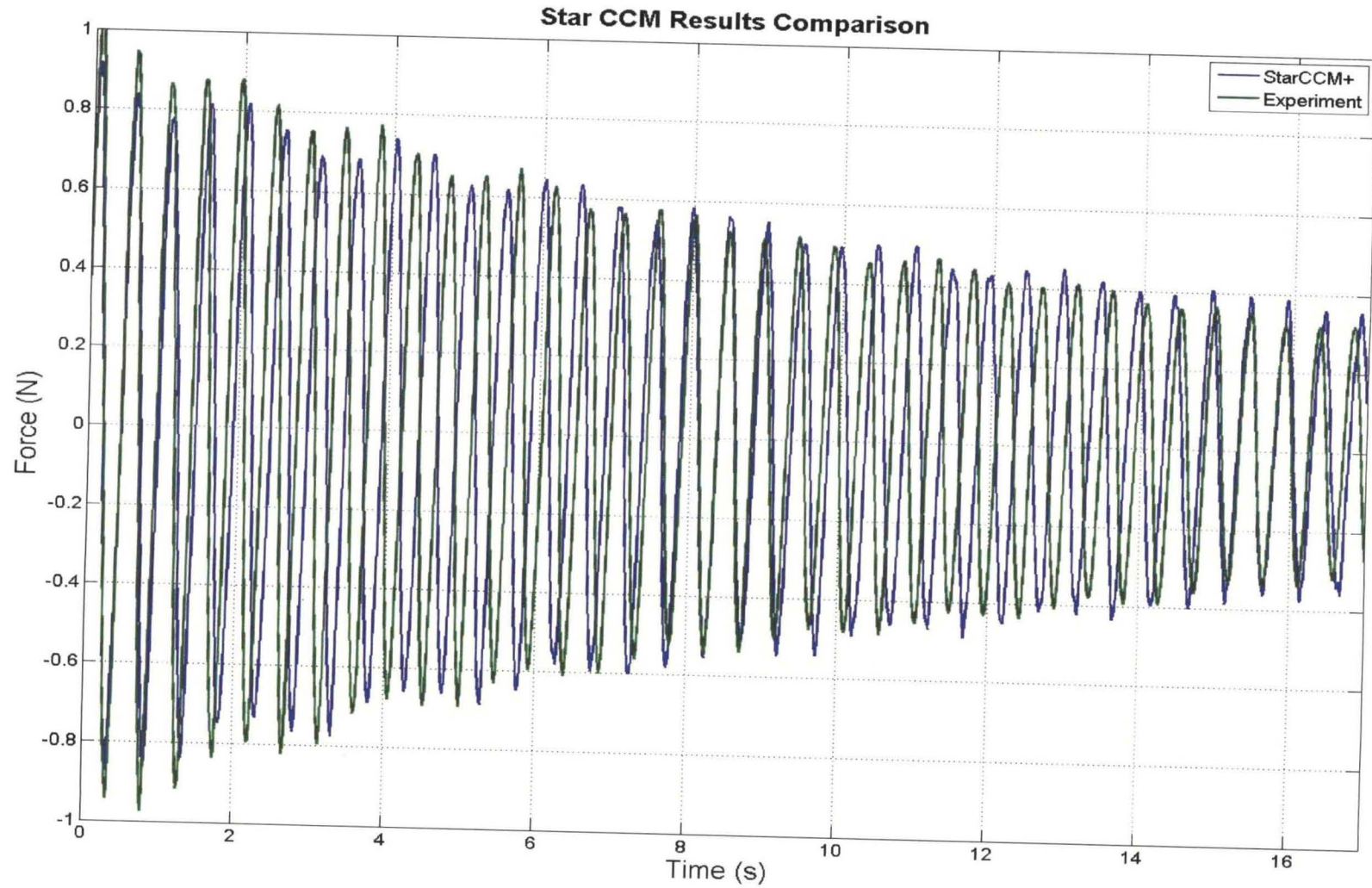
- **Stopping Criteria**
 - **Maximum inner iterations = 10**
 - » **Reduced residual by at least 2 orders of magnitude**
 - **Maximum physical time = 20 s**
 - **Maximum steps disabled**
- **Reports/monitors/plots**
 - **Fluid forces on tank walls**
 - » **Pressure and viscous**
 - » **X, Y, Z direction**
 - » **Plot every time step**
- **Initial condition**
 - **Fluid velocity = 0.065 m/s**





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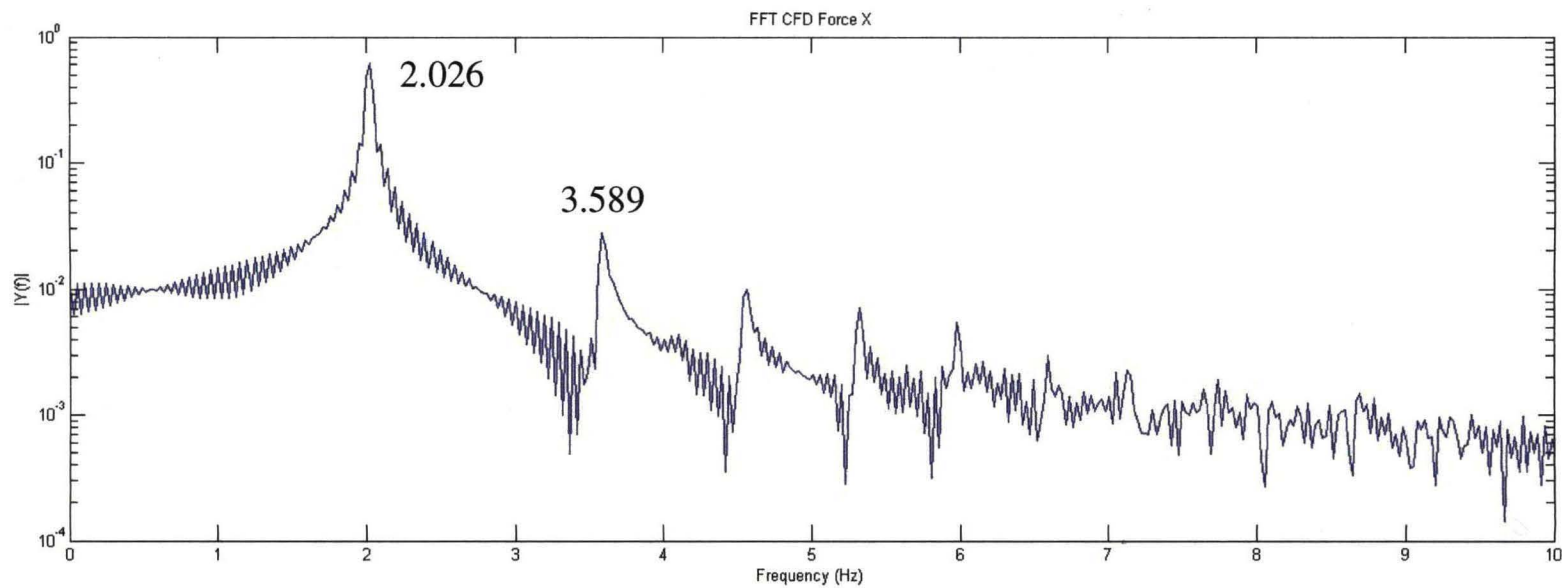
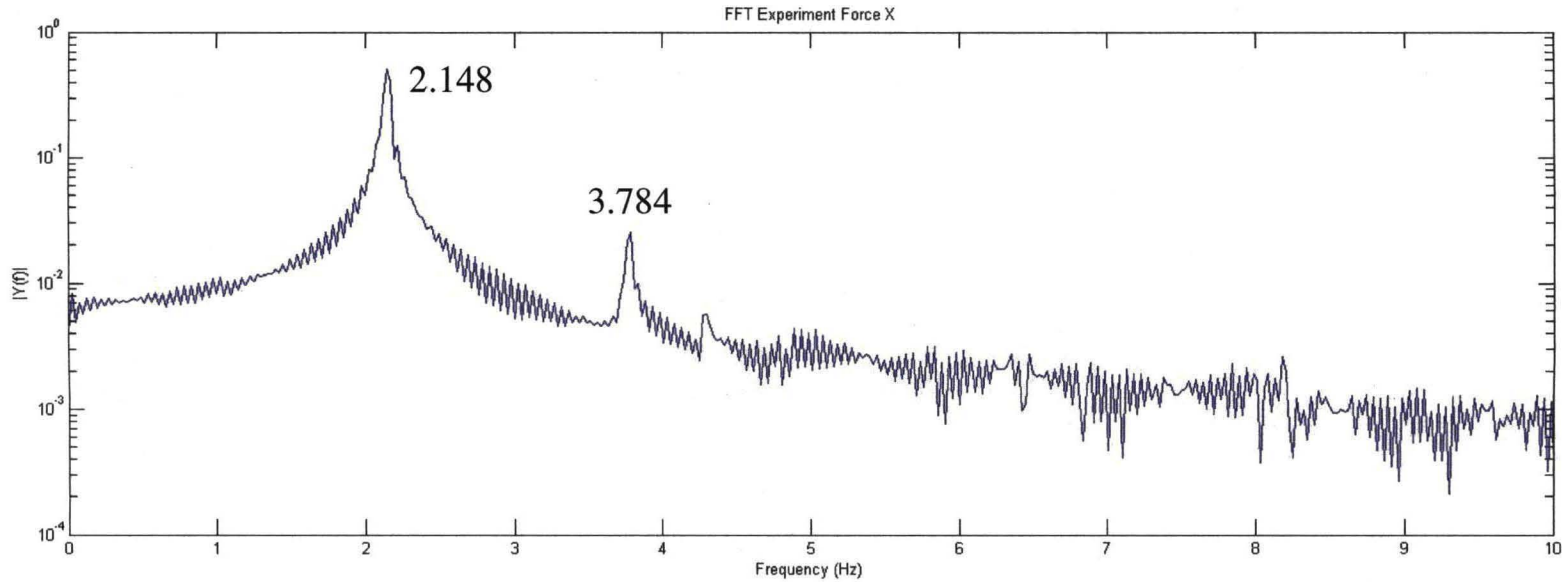
Results





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Results Frequency





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Results Frequency



- **difference roughly 5%**
- **Very sensitive to fill level**
 - Experiment was filled using fluid volume
 - CFD initialized using fill level converted from volume
 - Frequency content in “stinger”?

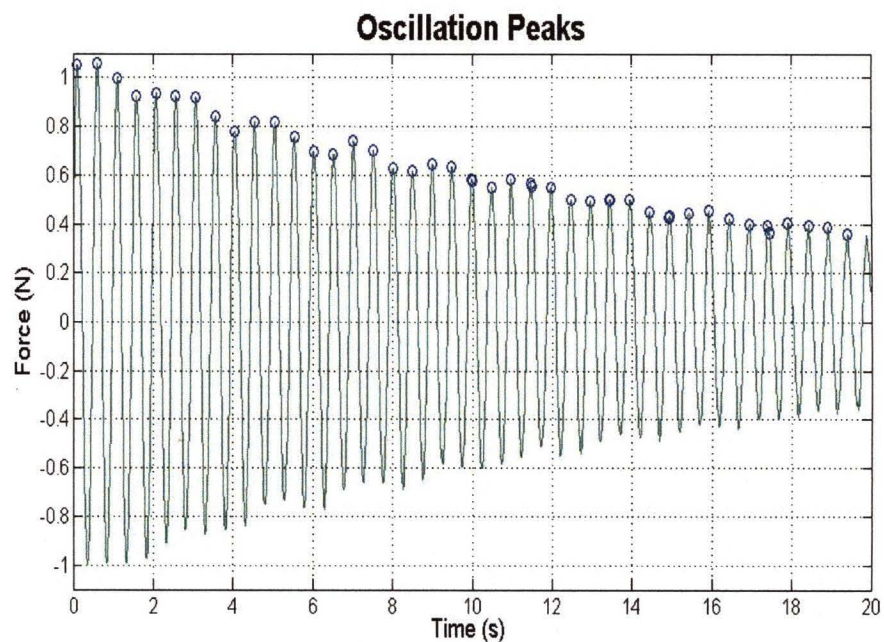


Damping Ratio



- **Logarithmic decrement Δ**
 - $\Delta = \ln(\text{peak oscillation} / \text{peak one cycle later})$
- **Damping ratio γ**
 - $\gamma = \Delta / 2\pi$
 - 2.9% difference
 - **Very difficult to calculate properly**

	Damping Ratio
Experiment	0.004002
Star ccm+	0.003887





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Conclusion



- **Star-CCM+ validated for low amplitude, simple geometry slosh modeling**
- **Both frequency and damping rate match fairly well**
 - Frequency off a bit more than desired but that could be caused by inaccurate fill procedures during experimental testing
 - Further research will be carried out to investigate the causes
- **Increases LSP confidence in this method for slosh calculations**
- **Will add to LSP's engineering success!**