EXPERIMENTAL VALIDATION OF STAR CCM+ FOR LIQUID CONTAINER SLOSH DYNAMICS

Brandon Marsell

a.i. solutions, Launch Services Program, Kennedy Space Center, FL

Agenda

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

Introduction

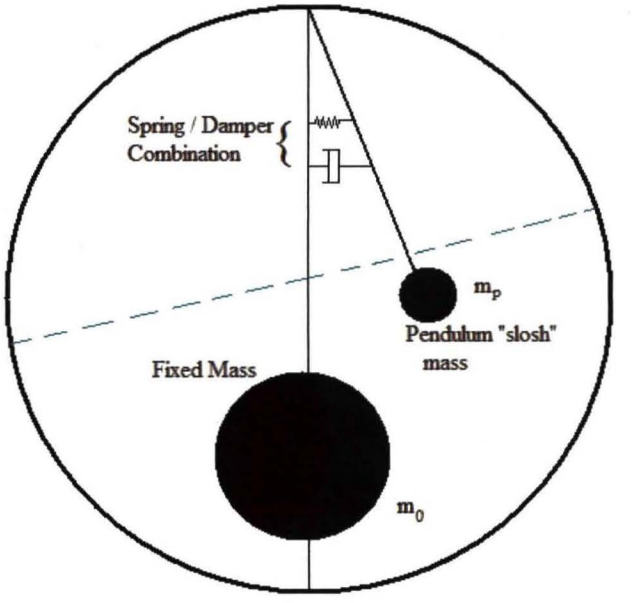
- **Launch Services Program**
  - **Provide leadership, expertise and cost effective services in the commercial arena to satisfy agency wide (NASA) space transportation requirements and maximize the opportunity for mission success**
  - **Interface between launch service provider (commercial) and NASA 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

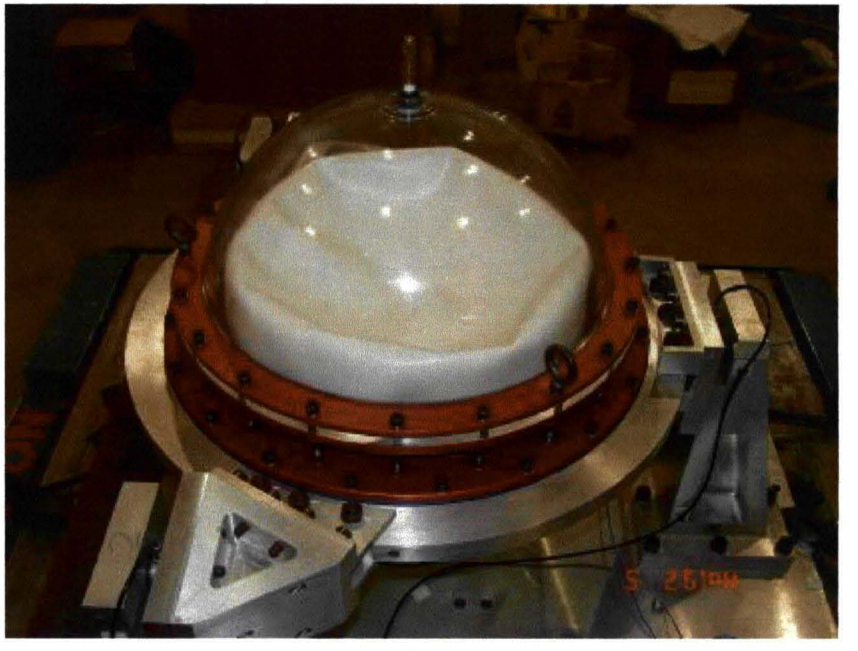
Background

- 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



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

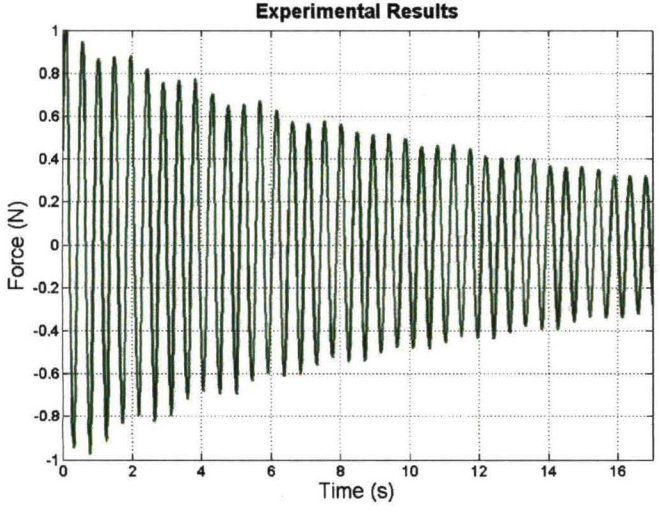


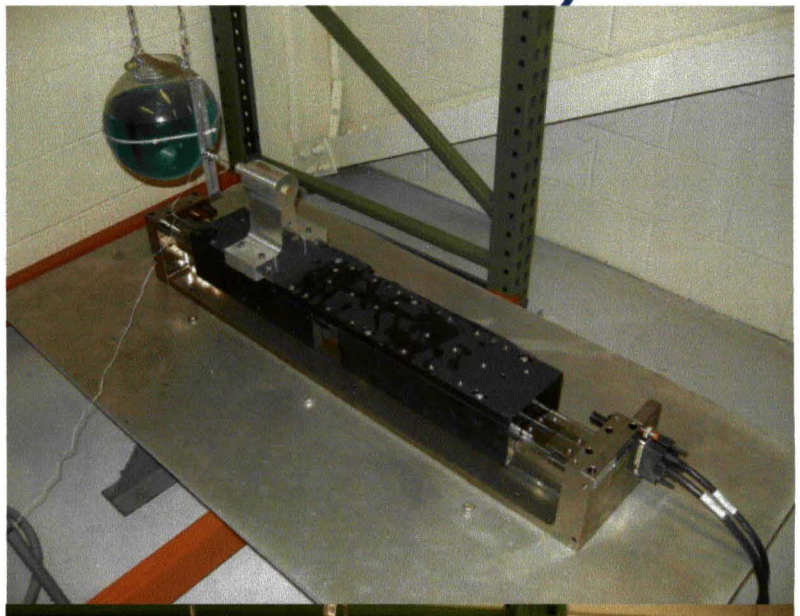
JOHN F. KENNEDY SPACE CENTER

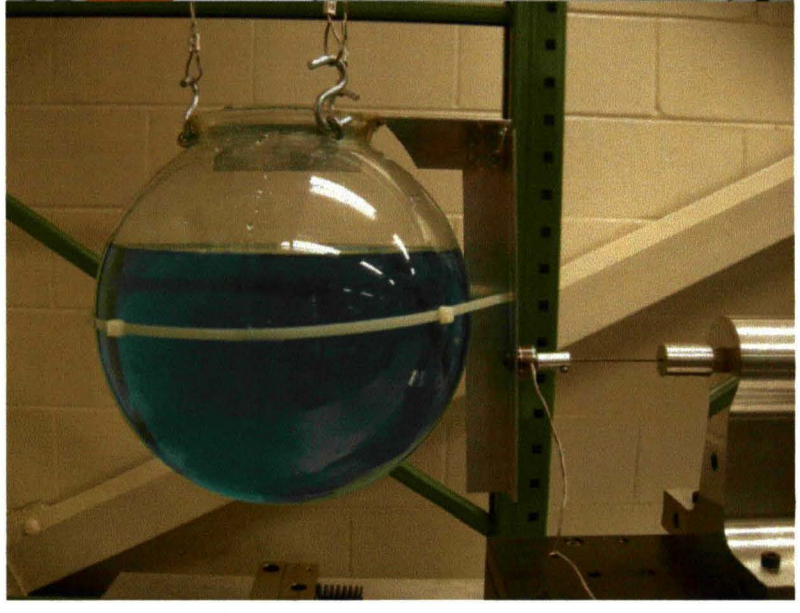
Experiment

LAUNCH SERVICES PROGRAM

- **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**

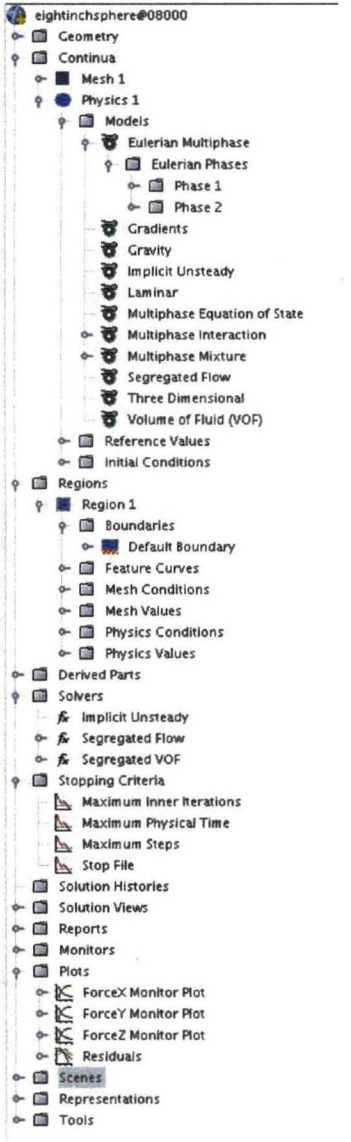






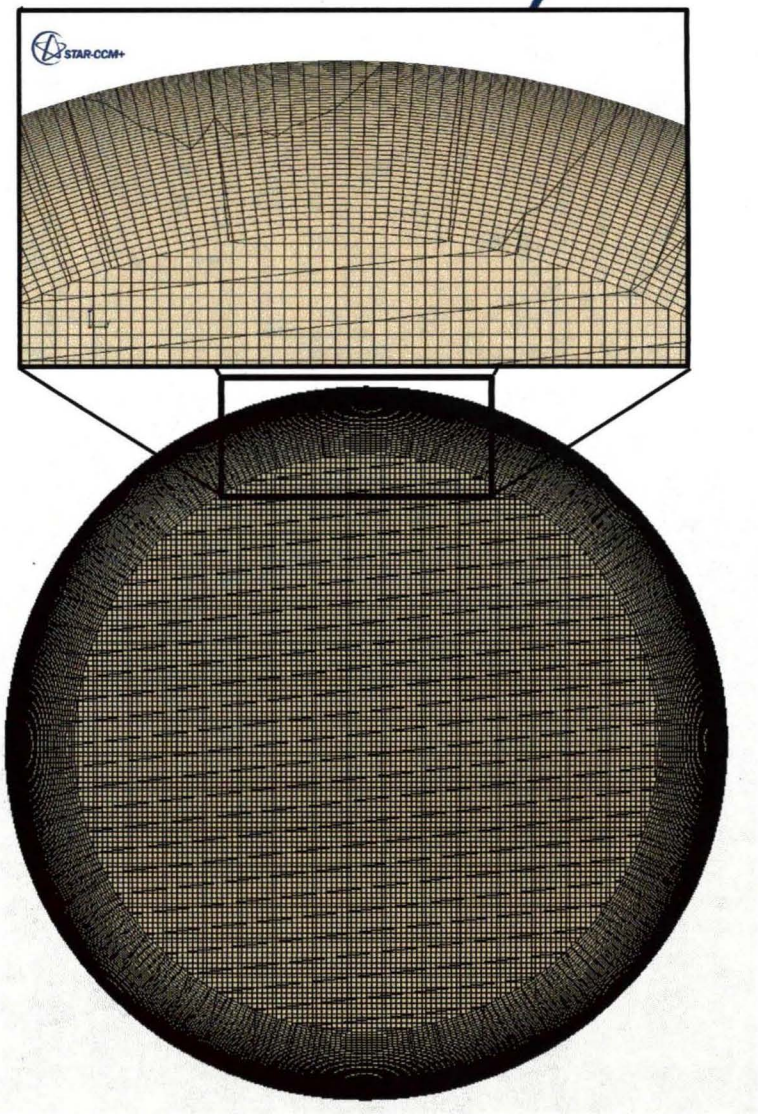
Star-CCM+ Model

- **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/m^3 – water**
    - » **1.18415 kg/m^3 - air**
  - **Three dimensional**



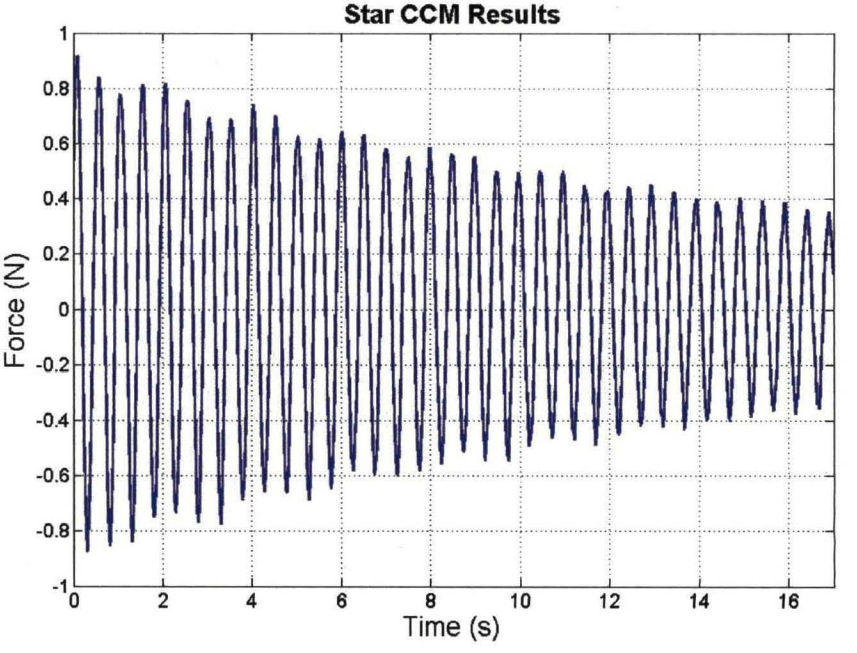
Star-CCM+ Model

- **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**

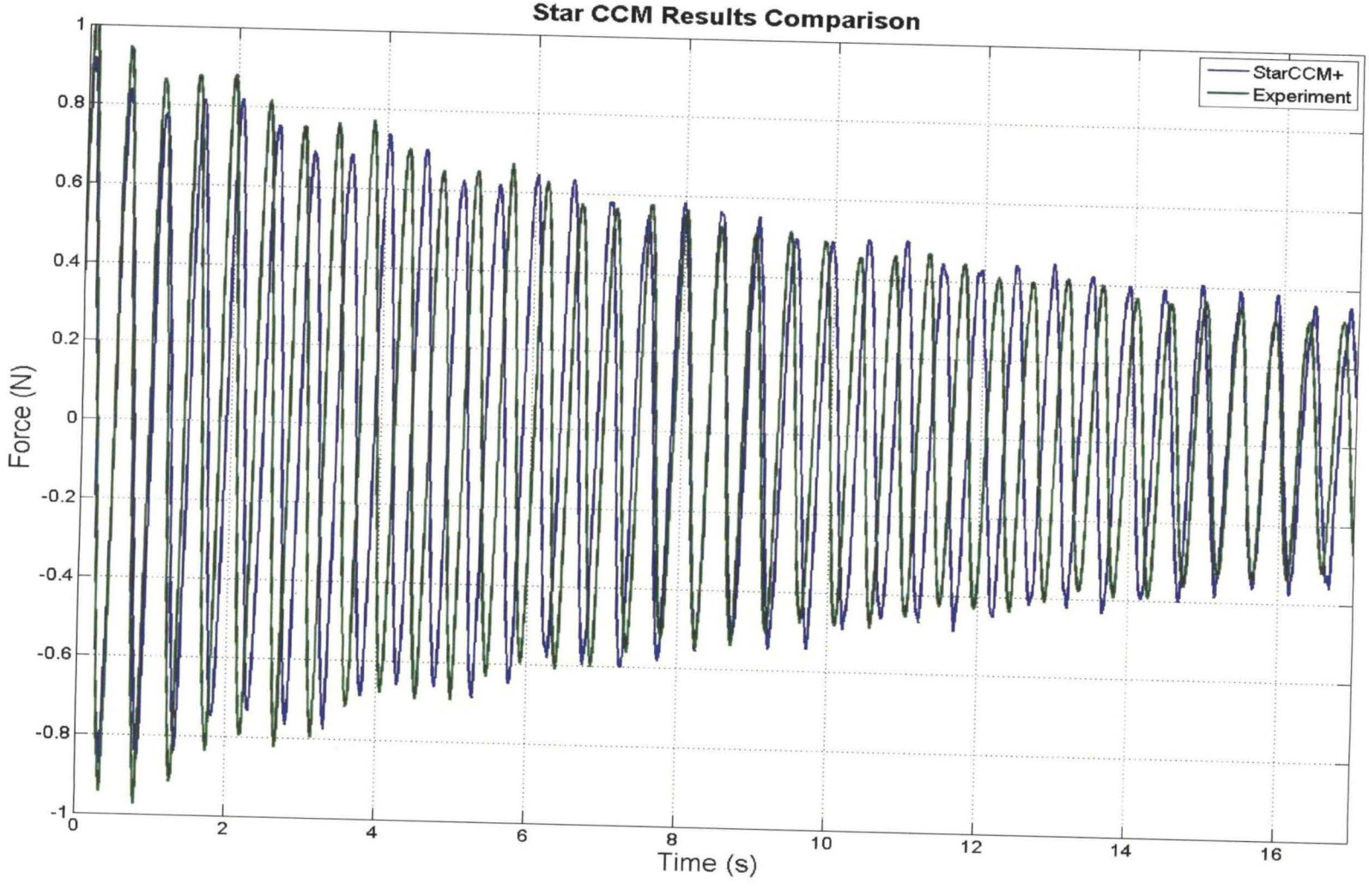


Star-CCM+ Model

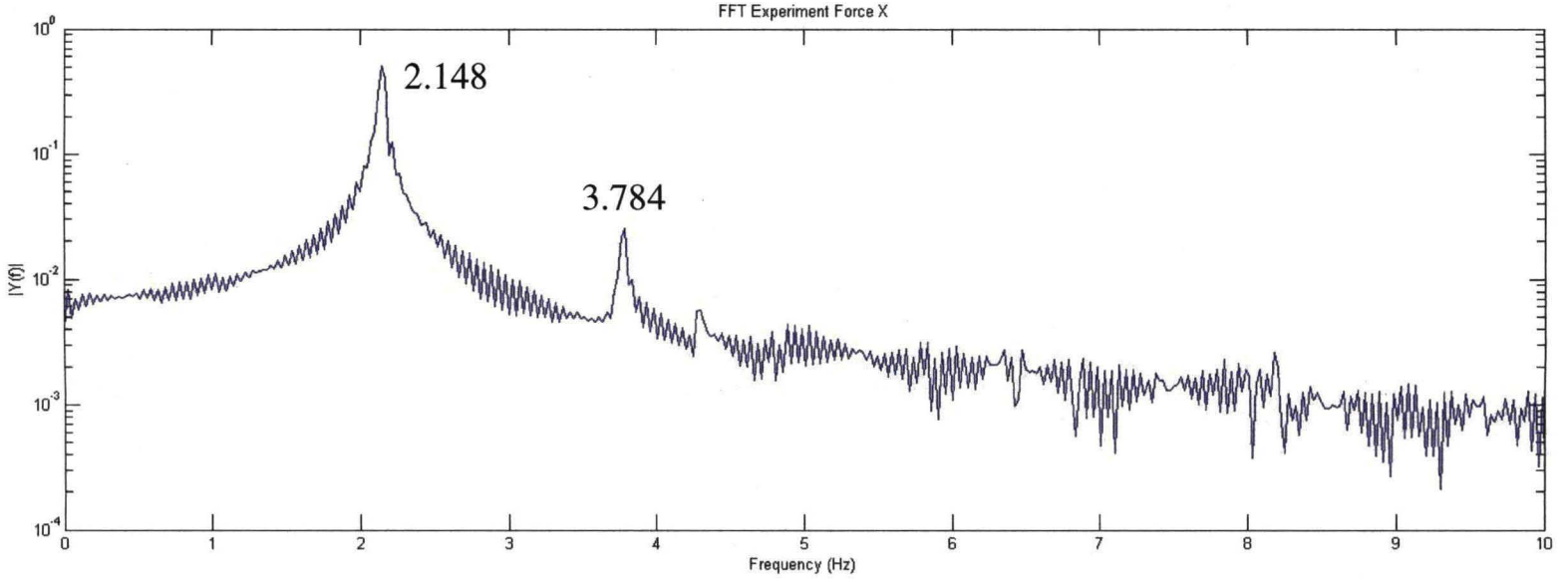
- **Stopping Criteria**
  - **Maximum inner iterations = 10**
    - » **Reduced residual by at least 2 orders of magnitude**
  - **Maximum physical time = 20 s**
  - **Maximum steps disabled**
- **Reports/monitors/plots**
  - **Fluid forces on tank walls**
    - » **Pressure and viscous**
    - » **X,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

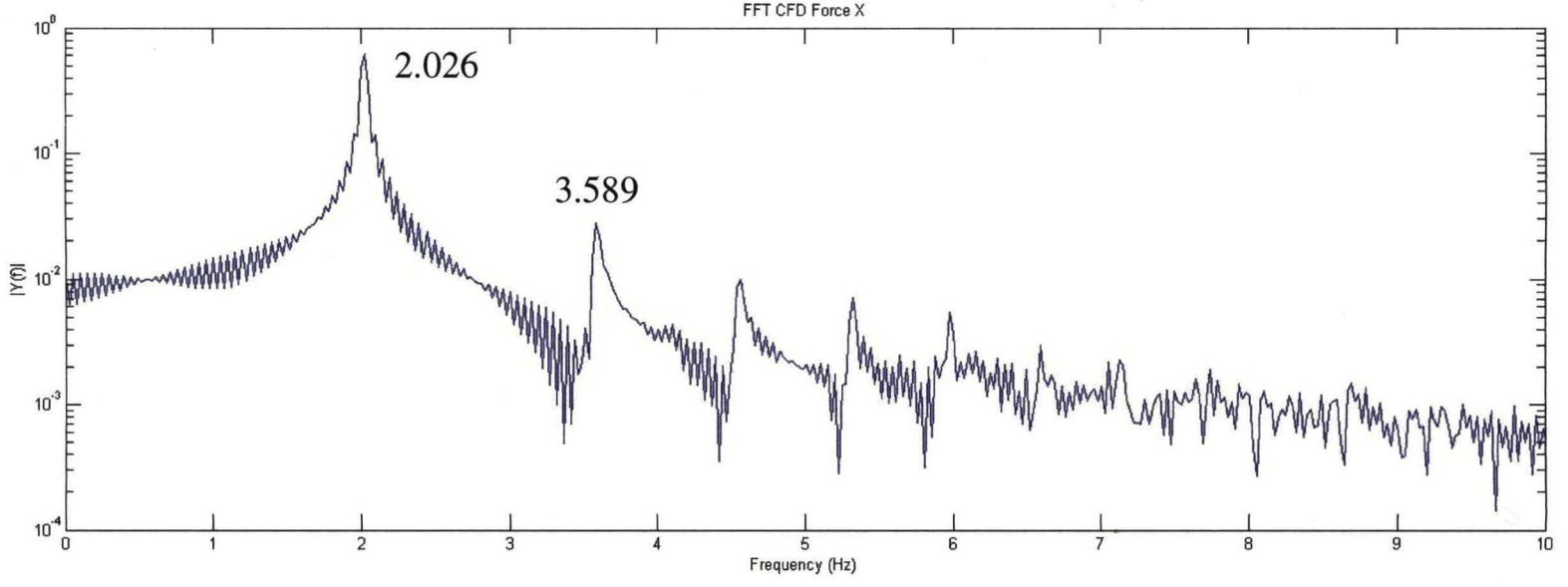


Results


Star CCM Results Comparison
StarCCM+
Experiment
Force (N)
Time (s)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
2
4
6
8
10
12
14
16

Results Frequency





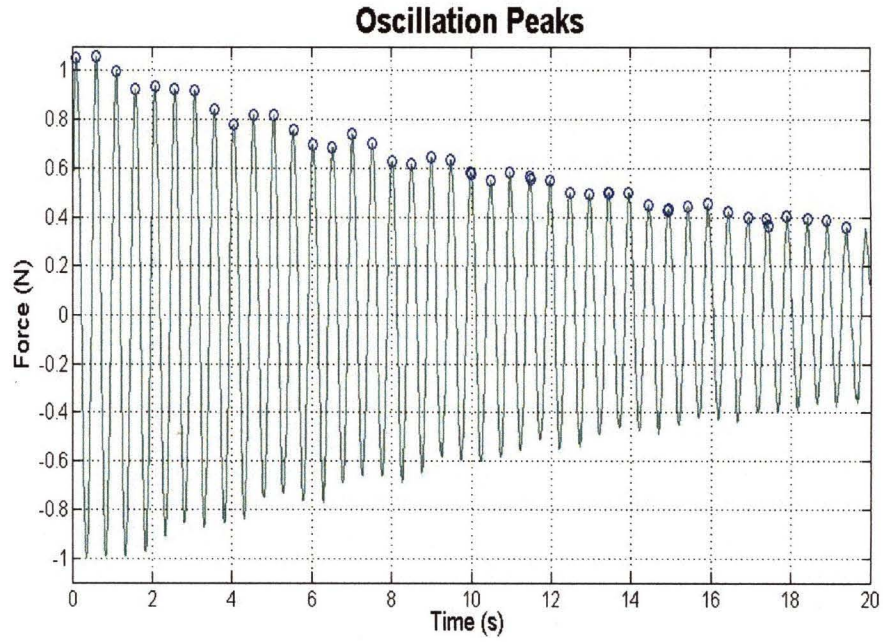
Results Frequency

- 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**
  - **Δ=ln(peak oscillation / peak one cycle later)**
- **Damping ratio γ**
  - **γ= Δ/2π**
  - **2.9% difference**
  - **Very difficult to calculate properly**

	Damping Ratio
Experiment	0.004002
Star ccm+	0.003887



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!