Preliminary investigation into two-way fluid structure interaction of heliostat wind loads

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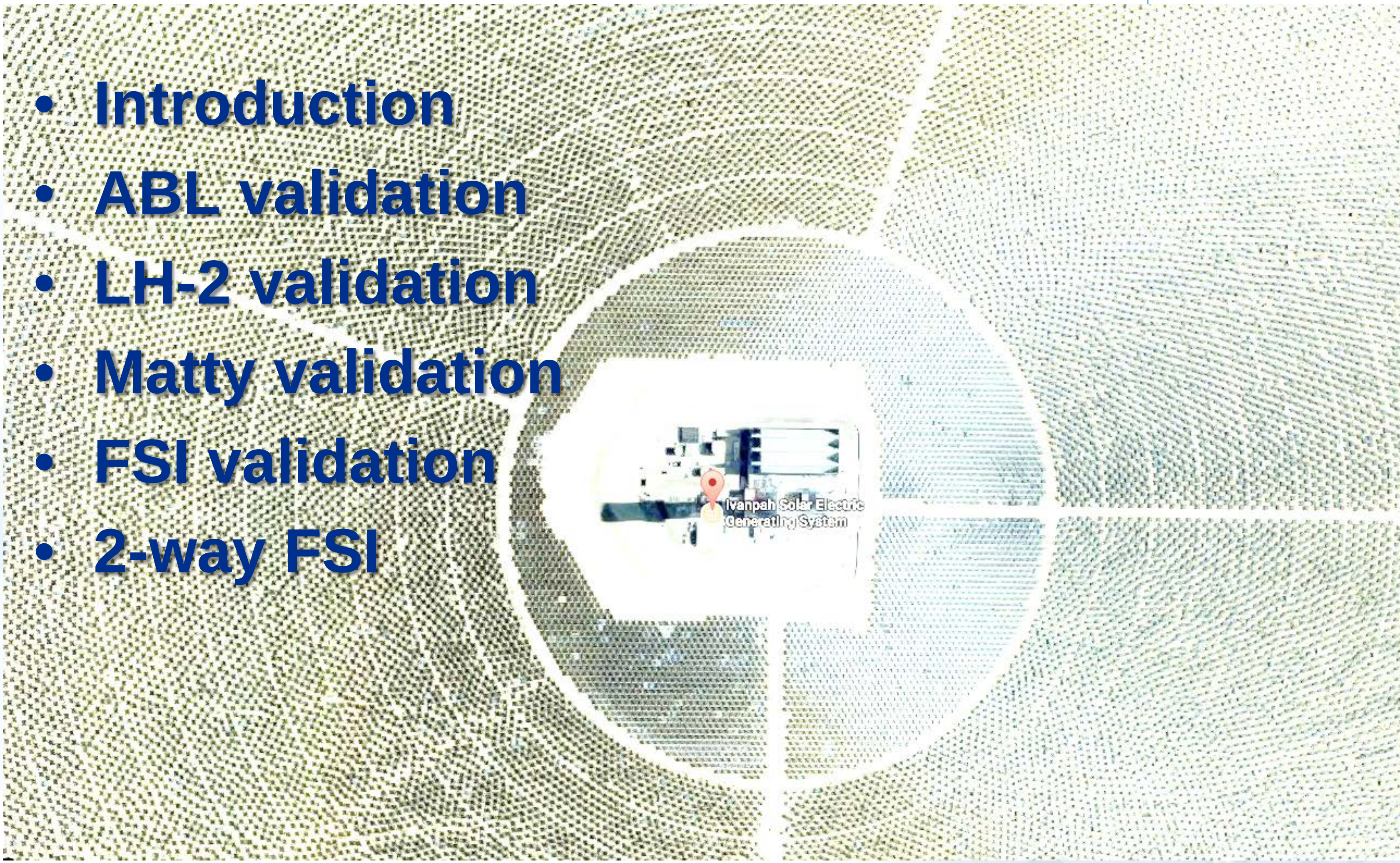
Outline

- Introduction
- ABL validation
- LH-2 validation
- Matty validation
- FSI validation
- 2-way FSI



Introduction

- Trends show shift to renewable energy sector, especially solar energy
- CSP technology has advantage of storing heat during times of no sun
- Central Receivers consist of an array of heliostats that reflect solar radiation to a central receiver
- Designs may differ significantly
- Cost-saving in heliostat design can be significant

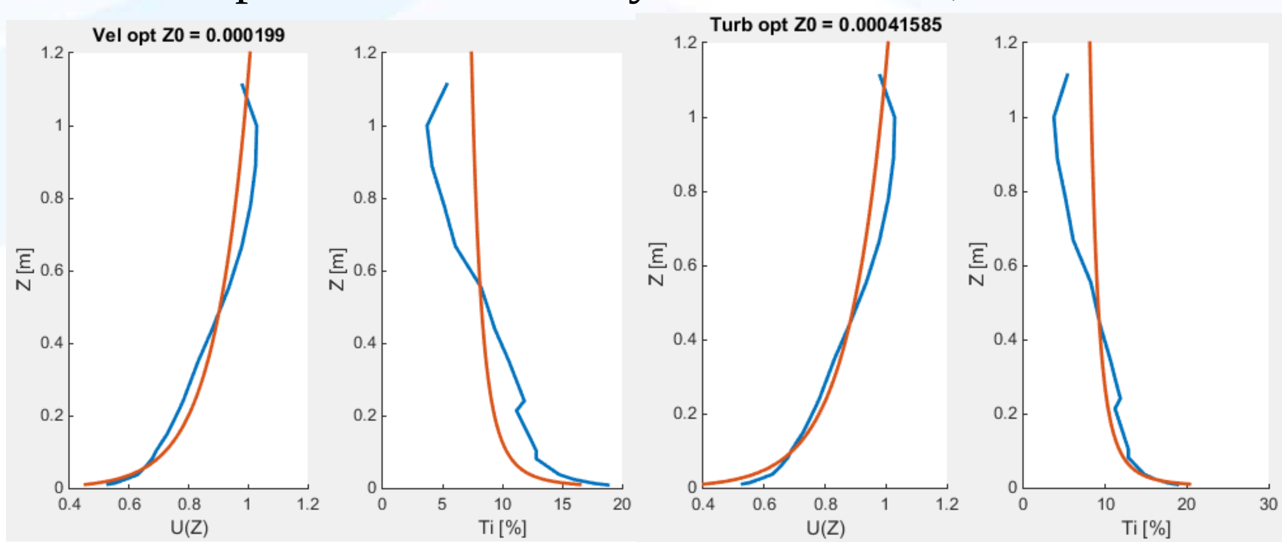
Peterka-ABL validation

- Characterize the Atmospheric Boundary Layer (ABL)
- Homogeneous- inlet, approach, incident profiles
  - Horizontally homogeneous
- High mesh near surface
- Roughness length < roughness height
- Log law profile, not a power law
- Equation used to match velocity profile (U(z)) using least-squares approach, similar equation used for Turbulence Intensity (TI)

$$Er(z_0) = \sum_{\eta=1}^{\xi}\left[U_\eta - U_{ref}\frac{\ln\left(\frac{z_\eta}{z_0}\right)}{\ln\left(\frac{z_{ref}}{z_0}\right)}\right]^2$$

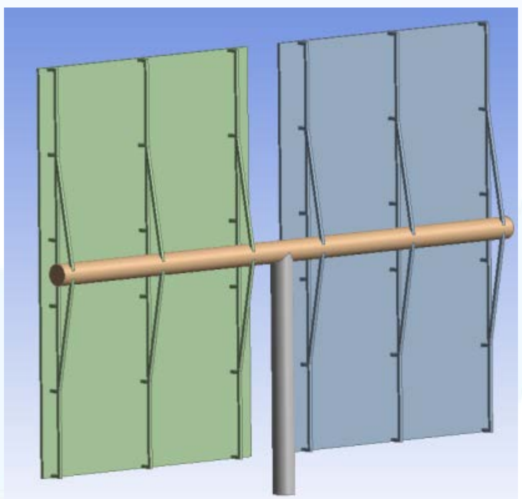
Peterka (1986)

Can optimize for velocity or turbulence, not both

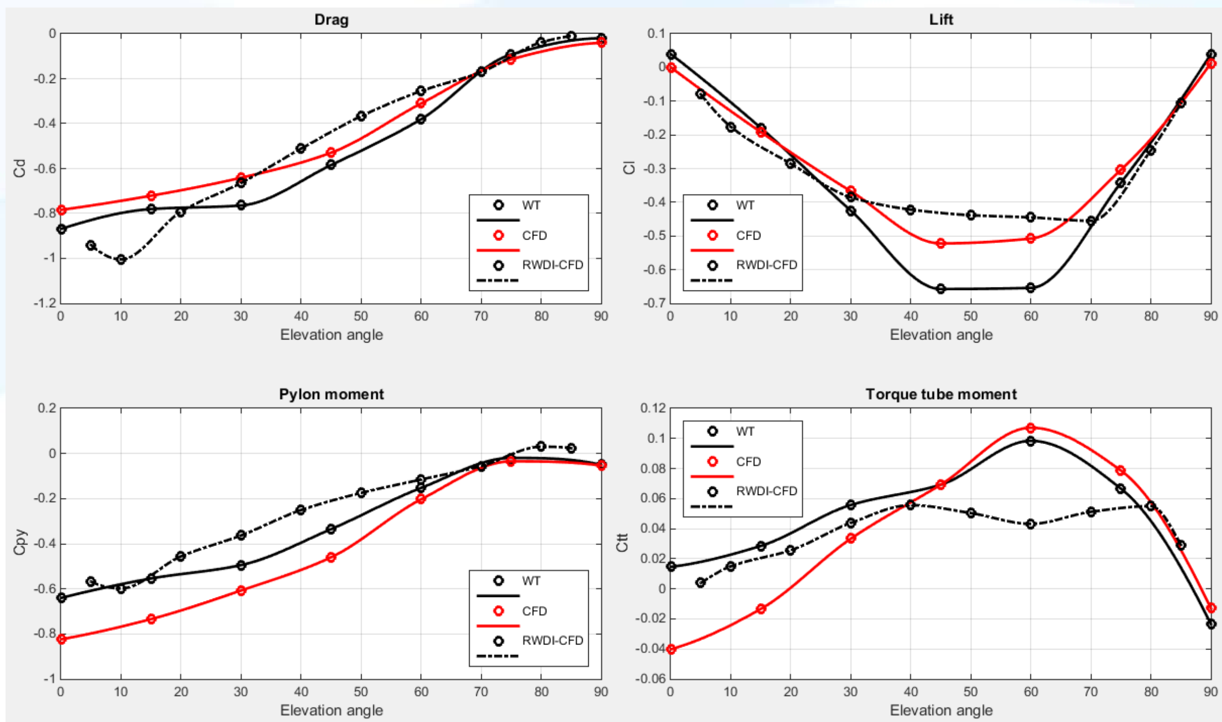


LH-2 steady-state validation using RWDI data

- The LH-2 heliostat is used in the Brightsource Ivanpah project
- 173 500 heliostats in three power plants
- Steady-state CFD validation done using RWDI experimental data (Huss, S (2011))
- Employed realizable k-ε (RKE) Reynolds Averaged Navier-Stokes (RANS)
- Better results than RWDI CFD for most elevation angles



WT=wind tunnel
CFD=current CFD



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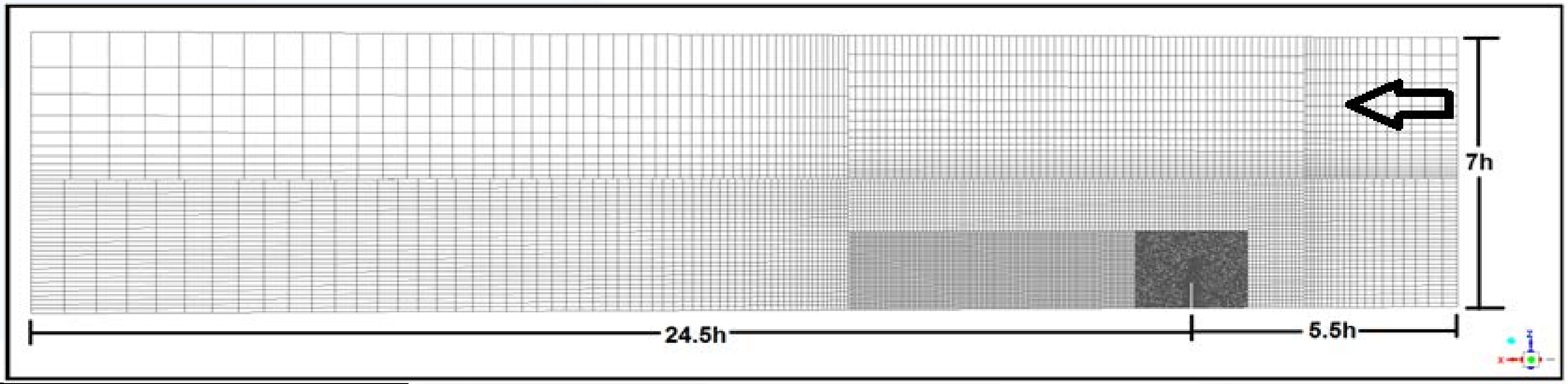
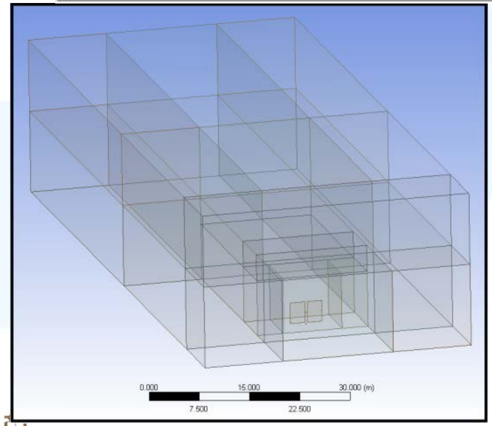
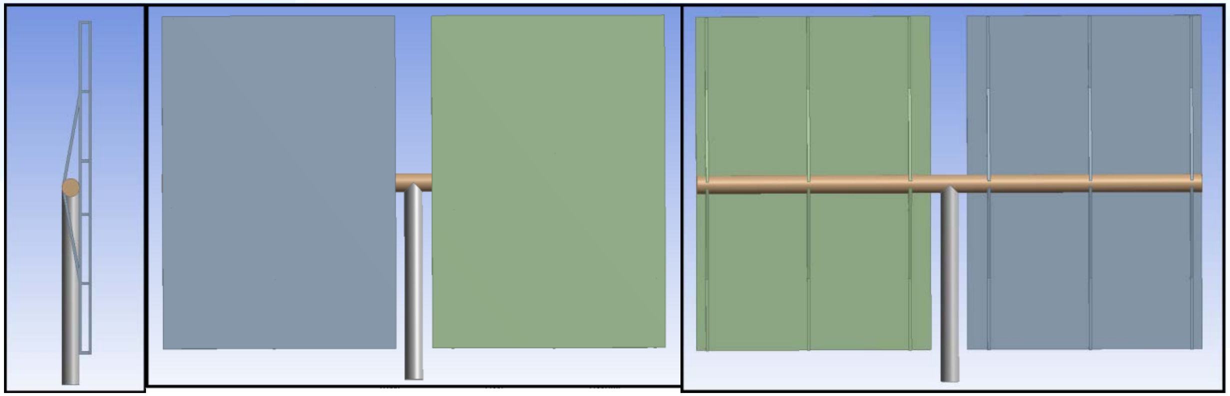
LH- 2 computational model

- Block-structured mesh of domain before adaption with roughly 4.7mil cells



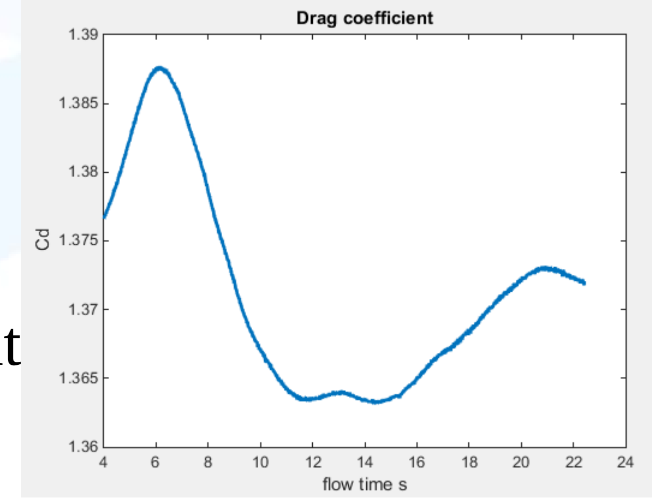


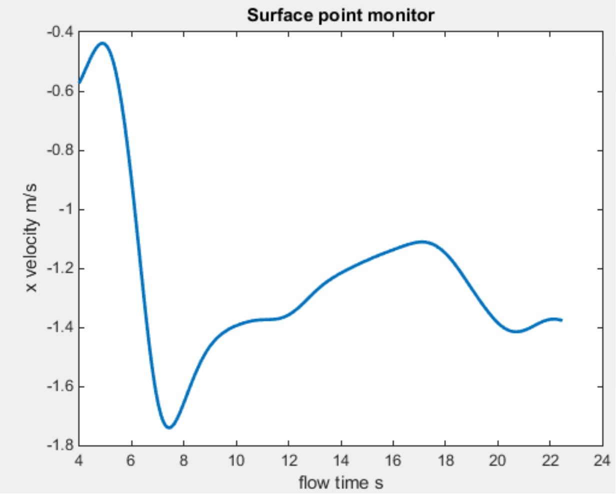


LH-2 Transient simulation

- Unsteady RANS (URANS) in attempt to capture vortex shedding
- A regional mesh adaption in ANSYS Fluent
- Mesh of roughly 8 million cells
- k-ω SST model was used instead of the more accurate RKE
- Run at the CHPC using 192 cores, 30 hours

Drag of heliostat
and velocity
in wake of heliostat

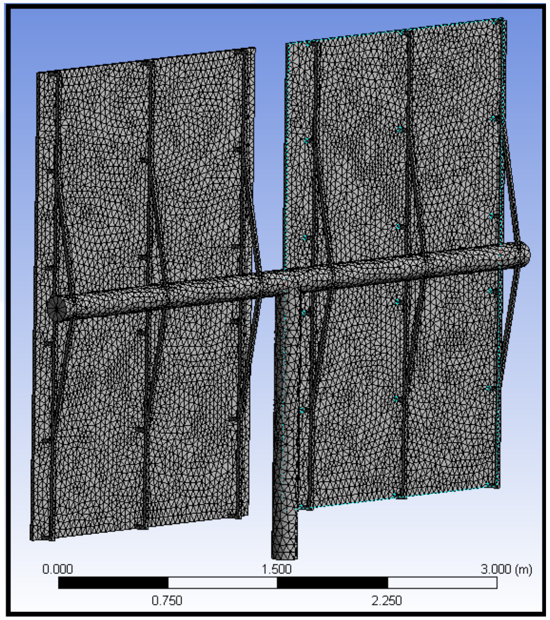




LH-2 Modal analysis

- A structural modal analysis was performed
- Possible resonance failure of the heliostat is investigated
- Matty (1979) predicted the vortex frequency could be roughly 1.4Hz to 2Hz for a velocity of 45m/s for a square-plate heliostat
- Vortex shedding may therefore excite the natural frequencies
- Case for 2-way fluid structure interaction

ANSYS Mechanical model



Mode	Freq [Hz]
1	1.8294
2	2.1829
3	2.6907
4	5.4507
5	6.0299
6	6.2795
7	7.4327
8	12.627
9	17.216
10	17.783

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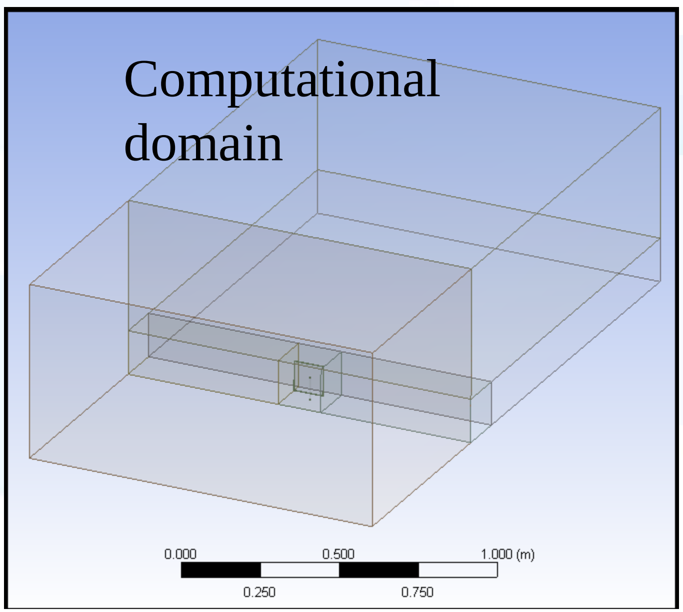
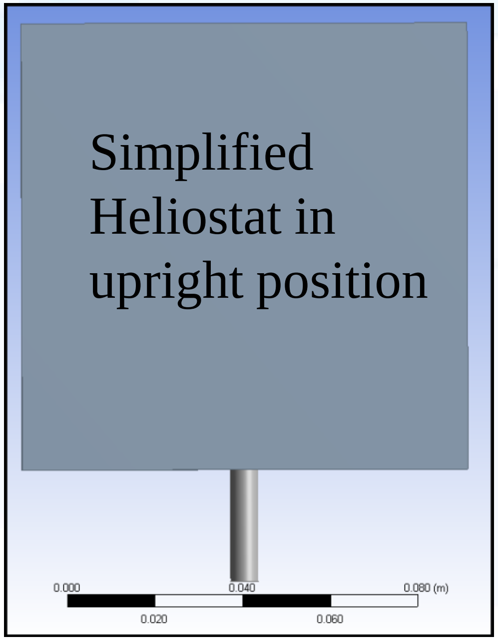
Matty Validation

- Matty (1979) is used as an additional transient validation case for the URANS simulations
- Reynolds number of around 150 000
- k-ω SST used instead of RKE
- Cell count of 2.5mil adapted up to about 10 million cells
- Run on the CHPC with 192 cores





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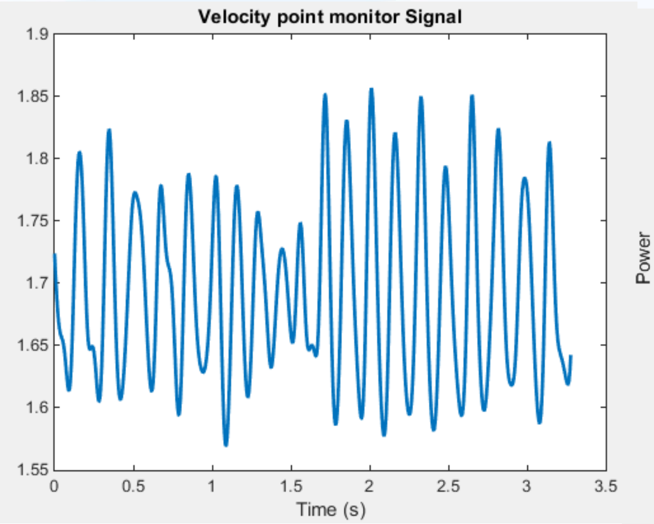
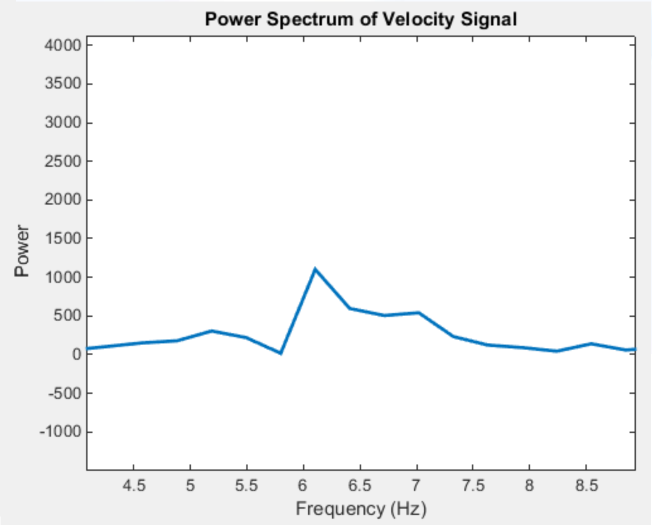
Matty Validation (cont.)

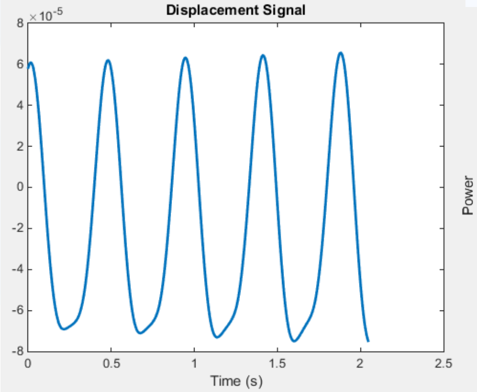
- Run for 10sec (25 domain flow-throughs)
- Transient behaviour found in drag and velocity point monitors
- The FFT shows a dominating frequency of 6.1Hz ,within 17.3% of the 7.38Hz Matty experiments
- 2-way FSI may be plausible with URANS
- Scaled up in ANSYS Fluent to simulate the LH-2 Re of 2.5million: no transient behaviour observed
- Vortex shedding may not be attainable with URANS for this geometry and Re number

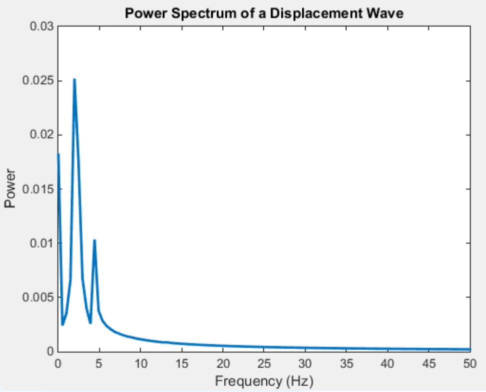


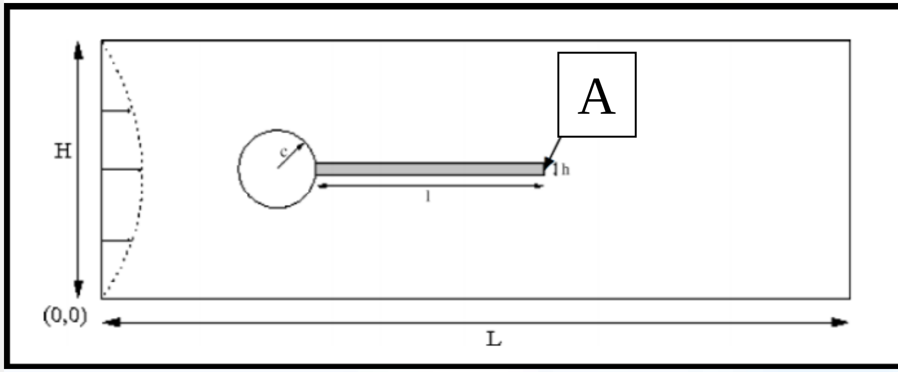


FSI Validation test case

- 2-way FSI validation using ANSYS WorkBench system coupling
- 2-D fixed sphere, slightly off centre, flexible beam attached to the rear as seen below (T Dunne and R Rannacher (2006))
- FSI on 3-D geometry so 1-cell thick domain was used
- Beam displacement at point A as well as FFT available



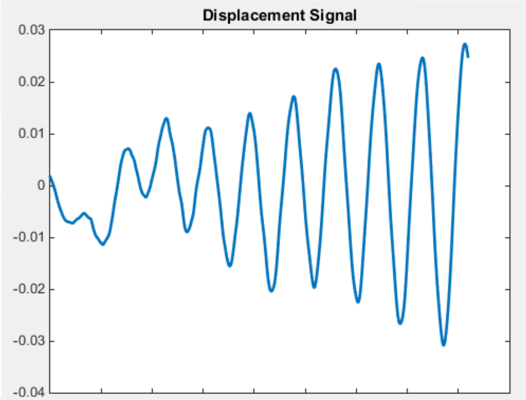


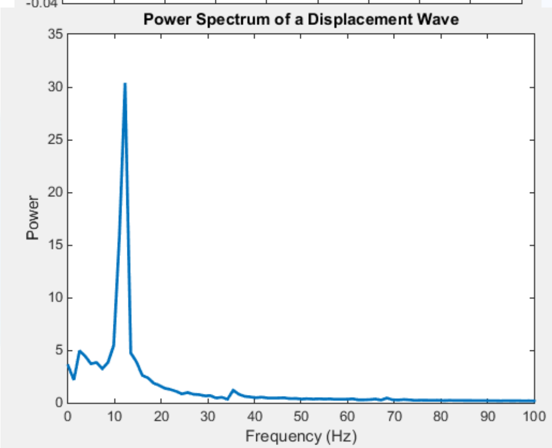


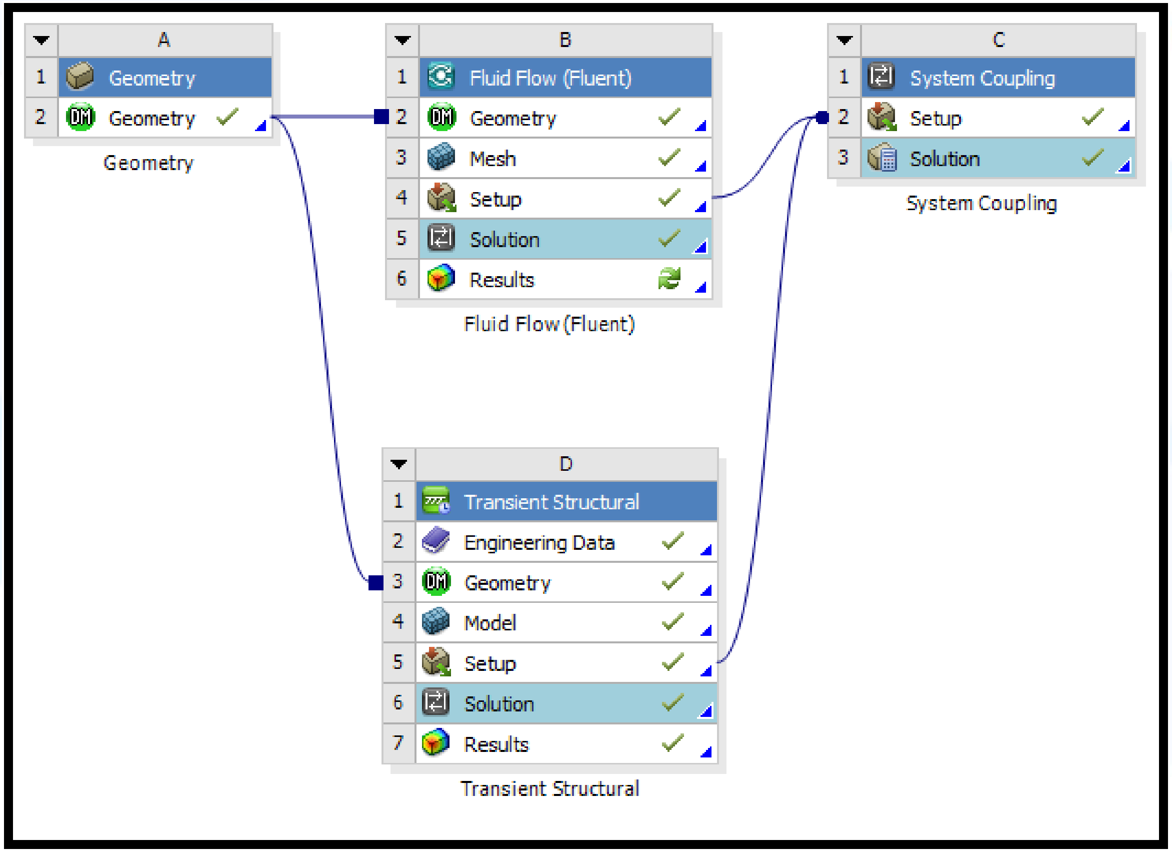
- Oscillation of beam obtained as 1.953Hz (exactly the same benchmark)
- Lift coefficient oscillation obtained as 4.4Hz (benchmark is given as 4.99Hz)
- Successful validation for laminar case

FSI Validation (cont.)

- Turbulent LES FSI validation was carried out by Breuer,M (2010) on the same case
- Fluid density 1000 times smaller the FFT finds a Strouhal number 0.175 which is the same as the rigid body case



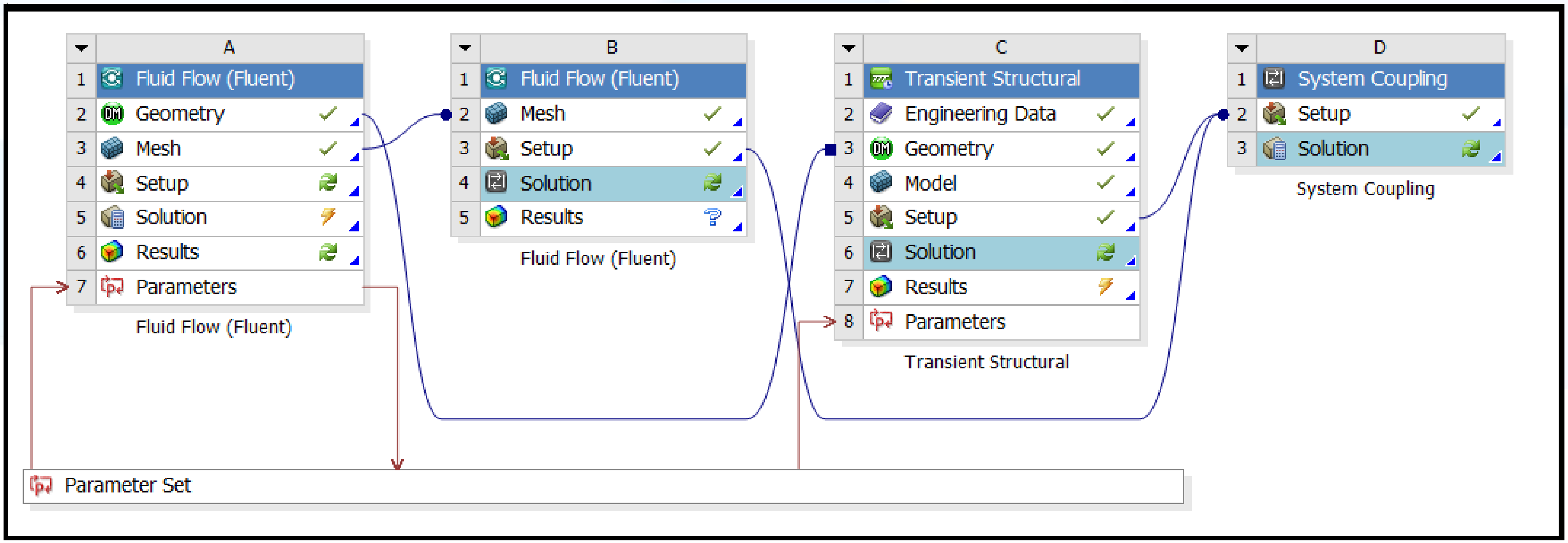




Implementation in ANSYS WB

LH-2 2-way FSI (in progress)

- 1-way FSI as well as static data transfers between CFD and Mechanical models have been conducted in the ANSYS environment
- 2-way FSI using URANS with ANSYS system coupling has been performed on various fluid mesh sizes ranging from 1 to 10 mil
- The ANSYS WorkBench setup is seen below for full 2-way FSI of the LH-2 heliostat



LH-2 2-way FSI (cont.)

- Preliminary results for the smaller mesh cases show no transient behaviour in the fluid flow and decaying transient behaviour from the structure due to the initial displacement.
- Smaller cases run on 8 cores for 5 days
- 10 million cell case run on 16 cores for 5 days for 18% completion only
- System coupling seems to be buggy and very computationally intensive (even for URANS)
- Not computationally realistic to use Scale-Resolving Simulation (SRS) CFD (e.g., DES, ELES)
- ANSYS WB graphical environment not currently available at the CHPC

Future work

- 2-D vortex shedding URANS simulations to establish shedding frequencies cheaply
- 2-D 2-way FSI simulations provided the CFD is successful
- High fidelity Scale Resolving Simulation of the LH-2 using SAS, DES or ELES.
- External data import 1-way FSI using the SRS CFD data
- Relatively cheap structural optimisation of the LH-2 using the same SRS data

Thank You