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The use of CFD for heliostat wind load analysis

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Introduction: Why CFD?

- Heliostat field can make up to 40% of central receiver plant's cost
- Cost reduction in development of heliostats could have major cost saving implications
- Can be achieved by designing heliostats based on wind loads and to not overdesign them
- Wind loads traditionally acquired through wind tunnel testing
- Wind tunnel testing can be time consuming and expensive, with CFD providing an alternative method to determine wind loads

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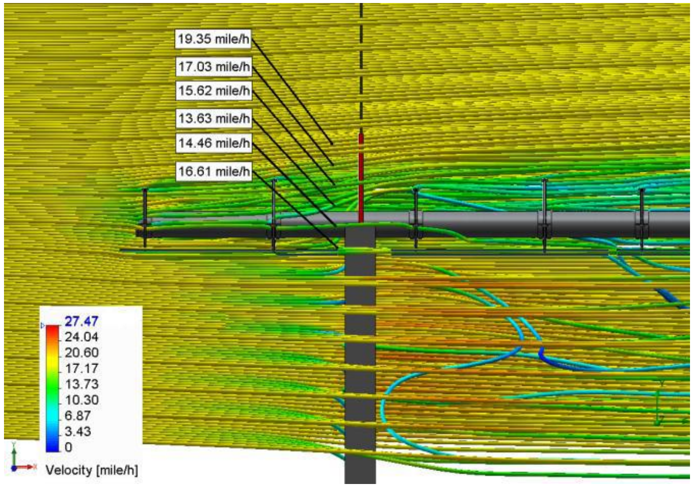
Past CFD work

- To my knowledge, only 2 previous numerical studies on full 3-D heliostats
- Sment and Ho investigated velocity profiles above a heliostat predicted by CFD with comparison to full scale field measurements
- Wu and Wang looked at load and moment coefficients with comparison to experimental results, concluding that CFD would be a useful tool in this area



Simulations from Sment and Ho

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CFD Methods Chosen

- RANS modelling methods chosen for this study due to it being essentially a first study; simple approach desired
- Three turbulence models of interest were RNG-k-ε, Realisable-k-ε and SST-k-ω
- Complete analysis including mesh independency and strong possibility of transient analysis with all three models not viable in time available
- Single model to be chosen to move forward with for complete analysis
- Selection of model based on simulation of flat plate perpendicular to the flow in two orientations (next slide)
- Geometry very similar to a heliostat with reported results for drag and velocity fluctuations in the wake makes for an ideal test case

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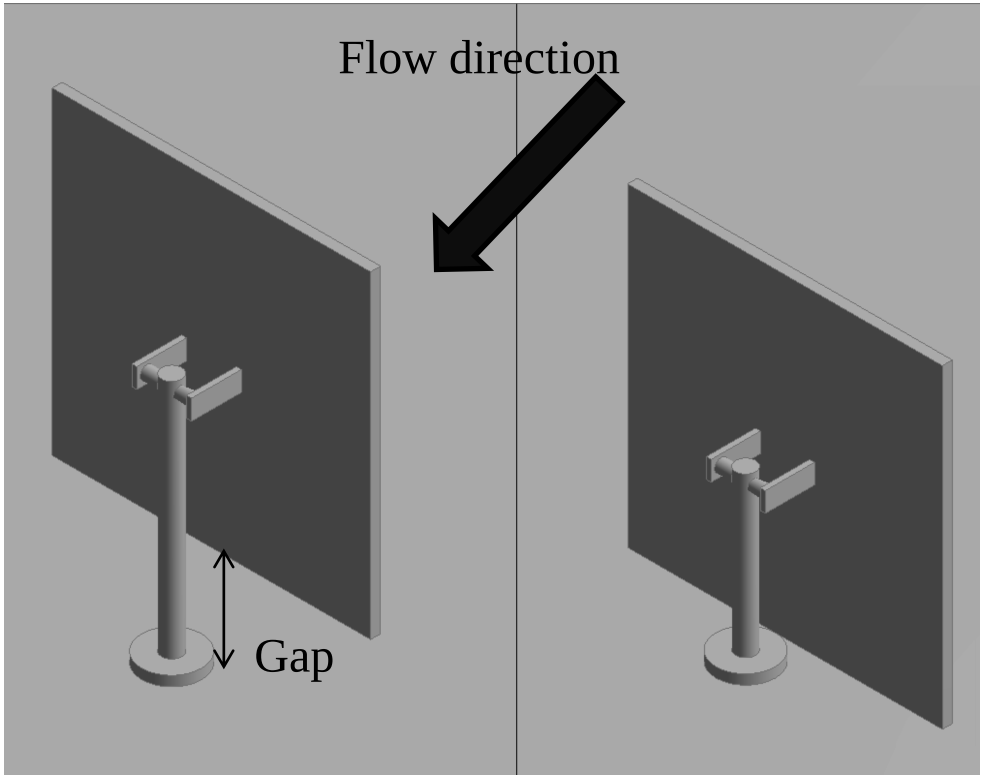
Flat Plate Orientations



Two orientations: Gap at lower edge of plate (left) and ground mounted (right)

Flat Plate Simulation

- These simulations used same mesh and settings across all models to isolate effect of just turbulence model
- Mesh independency also achieved with each model to ensure results only affect by modelling techniques
- First result investigated was drag coefficient:

	Realisable-k-ε	RNG-k-ε	SST-k-ω
Simulation	1.13	1.11	1.17
Experimental	1.14	1.14	1.14
Error	-0.87 %	-2.63 %	2.63 %

- Results show that the Realisable-k-ε model predicts the drag the closest whilst the other two models show similar accuracy to each other

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Flat Plate Simulation

- Second result to look at is frequency of velocity fluctuations in the wake:

	Realisable-k-ε	RNG-k-ε	SST-k-ω	Experimental
Ground mounted	0 Hz	30.91 Hz	41.24 Hz	25 Hz
Plate with a gap	0 Hz	0 Hz	17.85 Hz	31.44 Hz

- Realisable shows no fluctuations and RNG only shows fluctuations for ground mounted plate
- SST less accurate for ground mounted case than RNG, however does show fluctuations for second orientation
- Since SST shows fluctuations for both cases it may appear to be the most appropriate model moving forwards, however this was not the case

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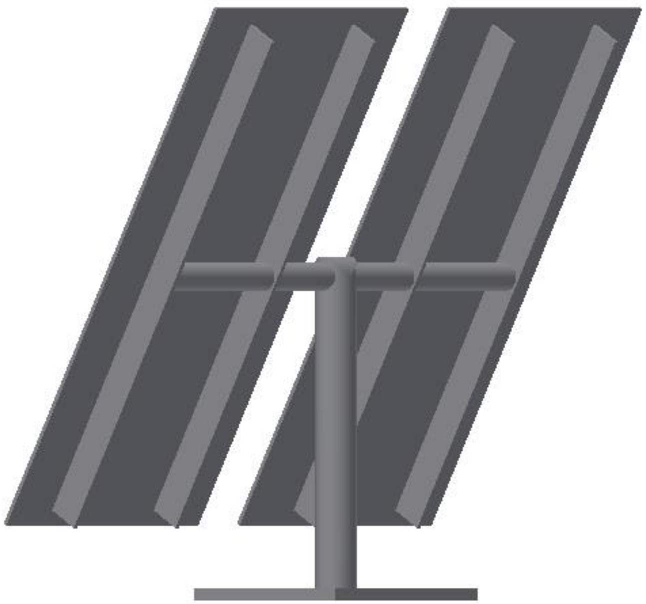
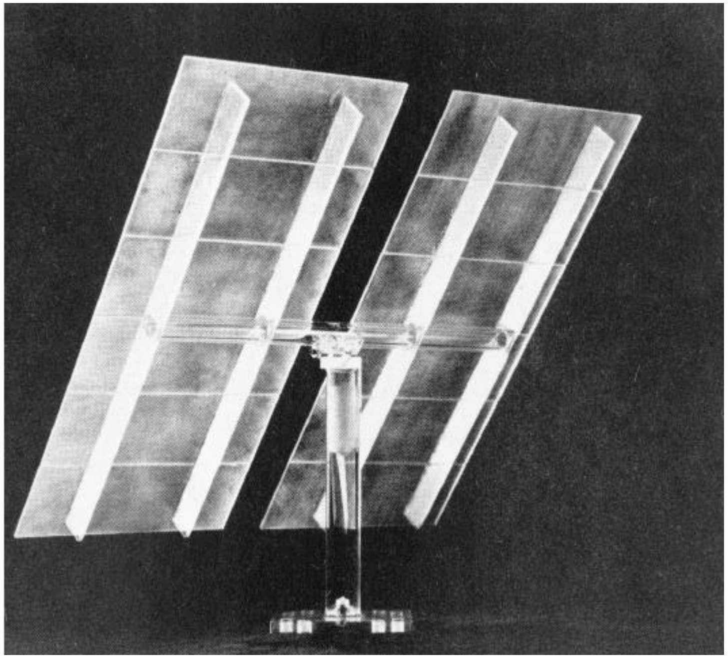
Model Selection

- Realisable model actually chosen moving forward for a few reasons
- One major factor is dataset from Peterka and associates, used to validate CFD results, does not contain transient data meaning transient data from CFD cannot be validated
- Transient simulations also require undesirable amounts of time to obtain results that cannot be full validated
- Since Realisable model produced most accurate drag coefficient and considering only time-averaged load coefficients are available for validation, Realisable was chosen to move forward

Heliostat Simulation

- Once Realisable model chosen to move forward, simulations for heliostat based on Peterka *et al.* were conducted





Geometry used in CFD (left) and experimental geometry from Peterka *et al.* (right)

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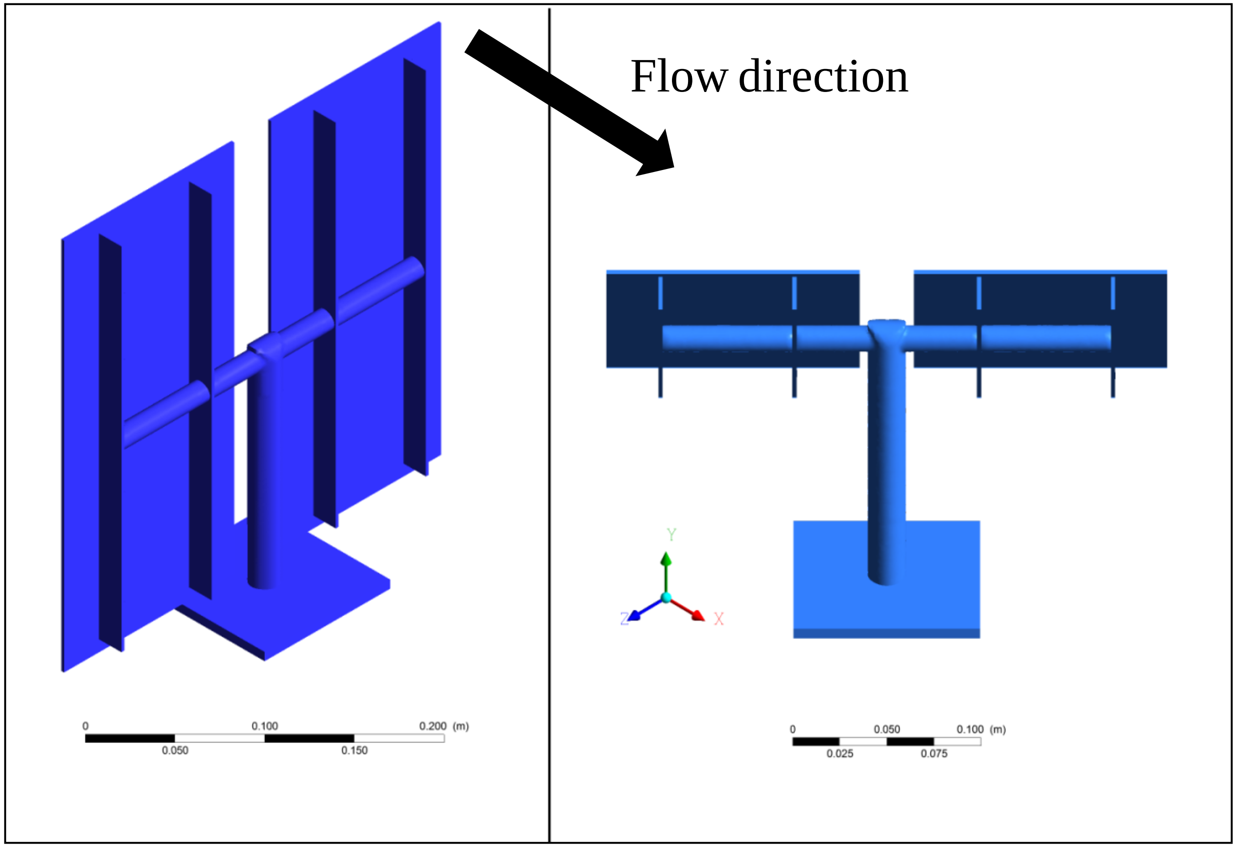
Heliostat Simulation

- Simulations conducted to reproduce similar upstream turbulence and velocity profiles for a heliostat on two orientations.



Oriented perpendicular to the flow (left) and at 45° to both the ground and flow (right)

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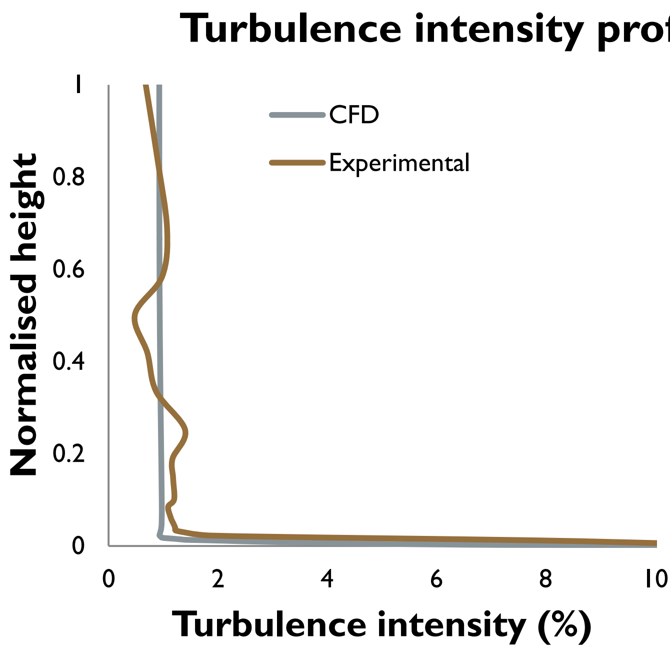
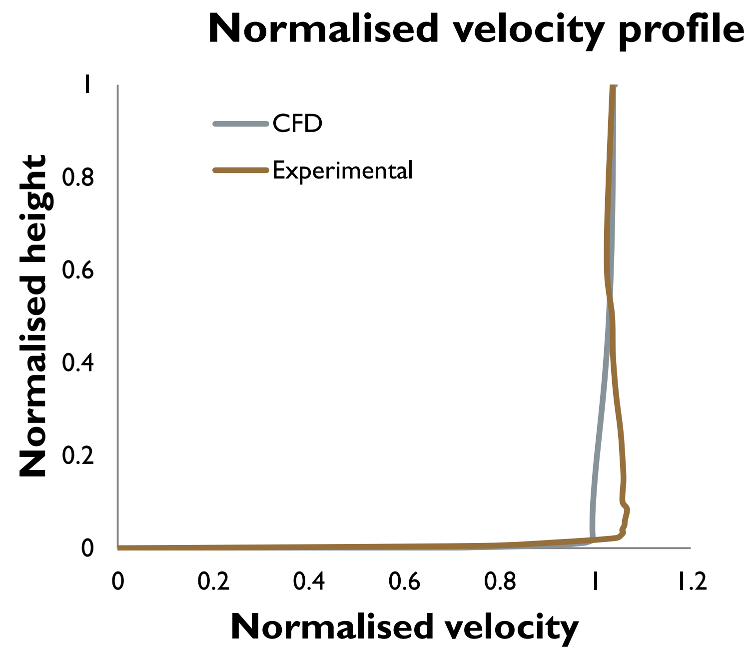
Heliostat Simulation

- First look at the upstream velocity and turbulence profiles produced compared to experimental profiles:





- Turbulence matches well whereas velocity can be seen to show some inaccuracy near the ground

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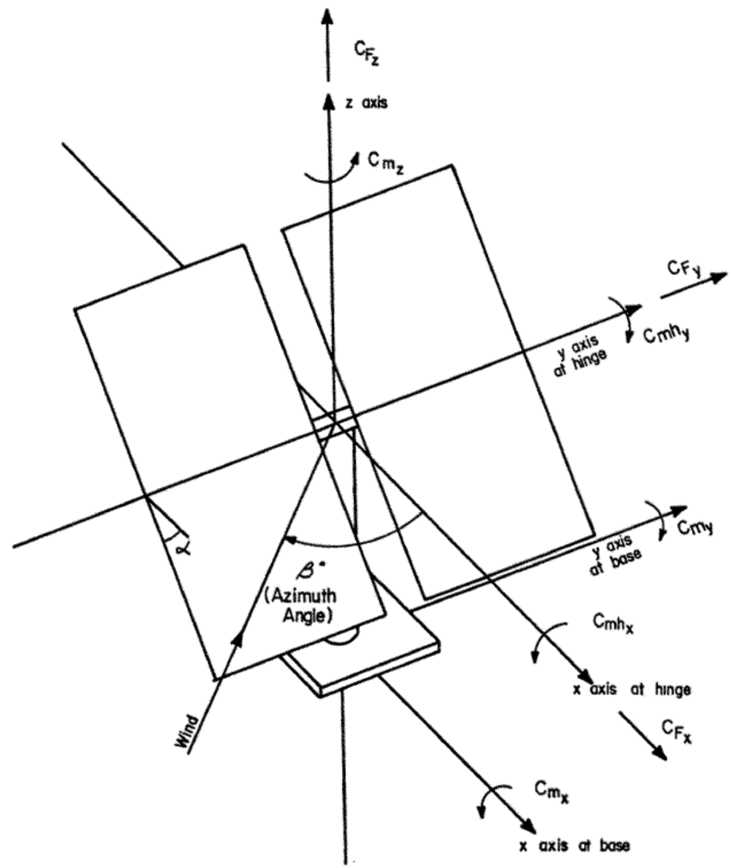
Heliostat Simulation

- Results of concern are various load and moment coefficients such as C_{F_X} (drag) and C_{m_y} (overturning moment):



Various load and moment coefficients from Peterka *et al.*

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Heliostat simulation

- For perpendicular orientation, only the drag and overturning moment about base are considered as other reported coefficients are small and thus can be sensitive to measurement errors making the CFD results appear inaccurate

	C_{F_x} (Drag)	$C_{m_{y_{base}}}$ (Overturning moment about base)
CFD	-1.265	-0.647
Experimental	-1.171	-0.635
Error	8.02 %	1.89 %

- At this orientation, it can be seen that values are slightly over predicted, yet are still quite accurate
- Overturning difference likely due to difference in velocity profile

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Heliostat simulation

- For the angled orientation, again only some coefficients are considered:

	C_{F_x} (Drag)	C_{F_z} (Lift)	$C_{m_{y_{base}}}$ (Overturning moment about base)
CFD	-0.724	-0.690	-0.387
Experimental	-0.556	-0.672	-0.208
Error	-23.20 %	-2.6 %	-46.25 %

- Drag prediction accuracy decreased whilst lift prediction is quite accurate
- Moment prediction inaccurate with likely cause again being the differing velocity profile
- Other cause of inaccuracies could be the geometric simplifications affecting the flow field
- Could be RANS cannot accurately predict complex flow features associated with bluff body flows

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Conclusions

- CFD can potentially be used to estimate basic loading coefficients
- RANS modelling techniques not appropriate to capture all relevant information required for a complete heliostat design
- Even with inaccuracies predicted from CFD, it can still be useful in comparing heliostat designs early in the process

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Current and Future Work

- Involved in post-processing of PIV data acquired with Danica Bezuidenhout for a heliostat with a simpler geometry than Peterka *et al.*
- Simulations conducted with partial lower atmospheric boundary lower turbulence and velocity profiles
- If computing power allows, LES or hybrid RANS-LES models would be the most appropriate to model flow over a heliostat

Acknowledgements:

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