Computational investigation into using impinging jets with swirl to enhance the heat transfer in a solar cavity receiver

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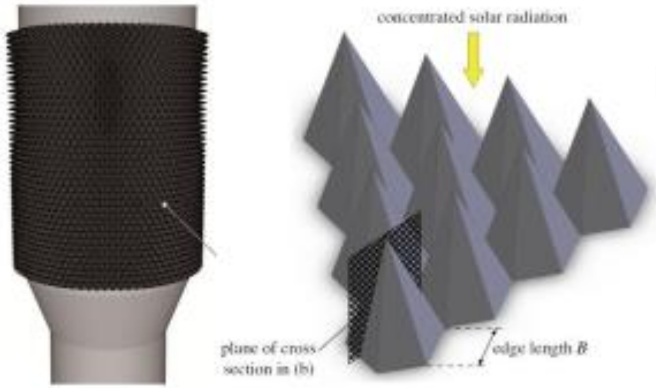
OUTLINE

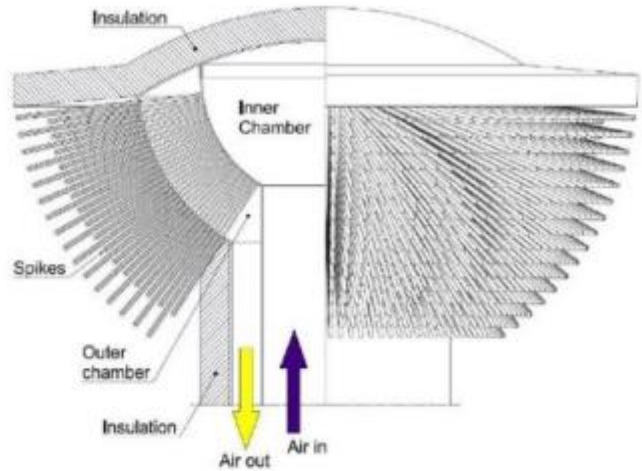
- Background
- Receiver designs
- Receiver overview
- Initial concept
- Improving the concept
- Swirling impinging jets
- Numerical modelling
- Conclusions

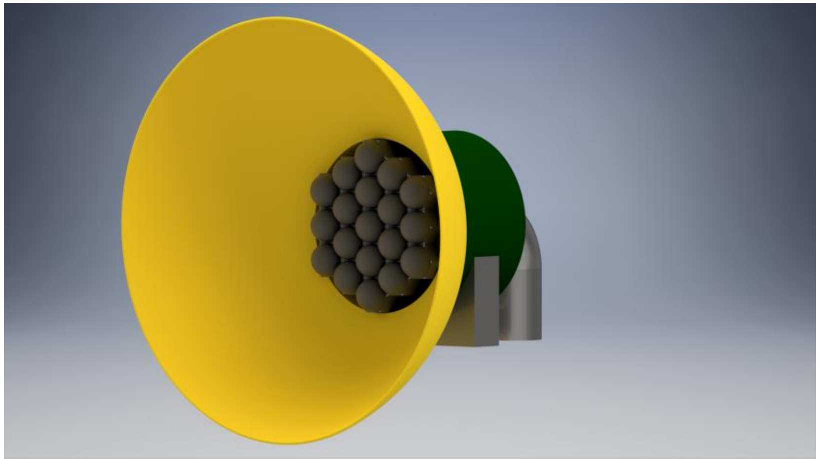
BACKGROUND

- Central tower receivers hold significant promise for improving CSP efficiencies
- There is a need for further research in this area
- Improving the receiver designs can lower the cost of the CSP Plant and make it competitive with coal
- The bottom line is the cost

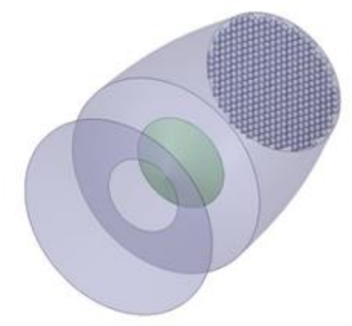
RECEIVER DESIGNS

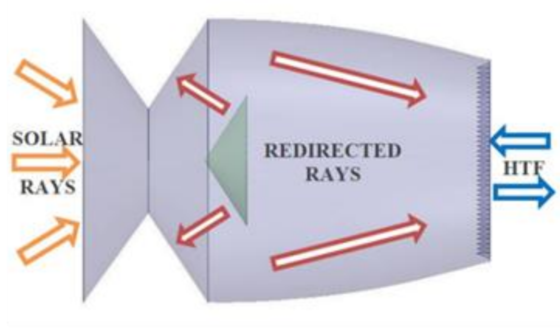


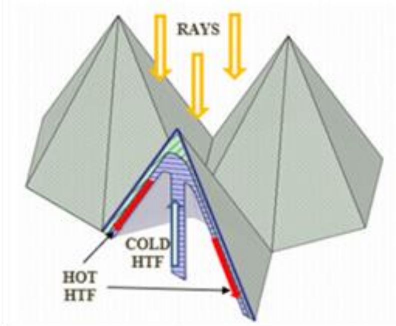


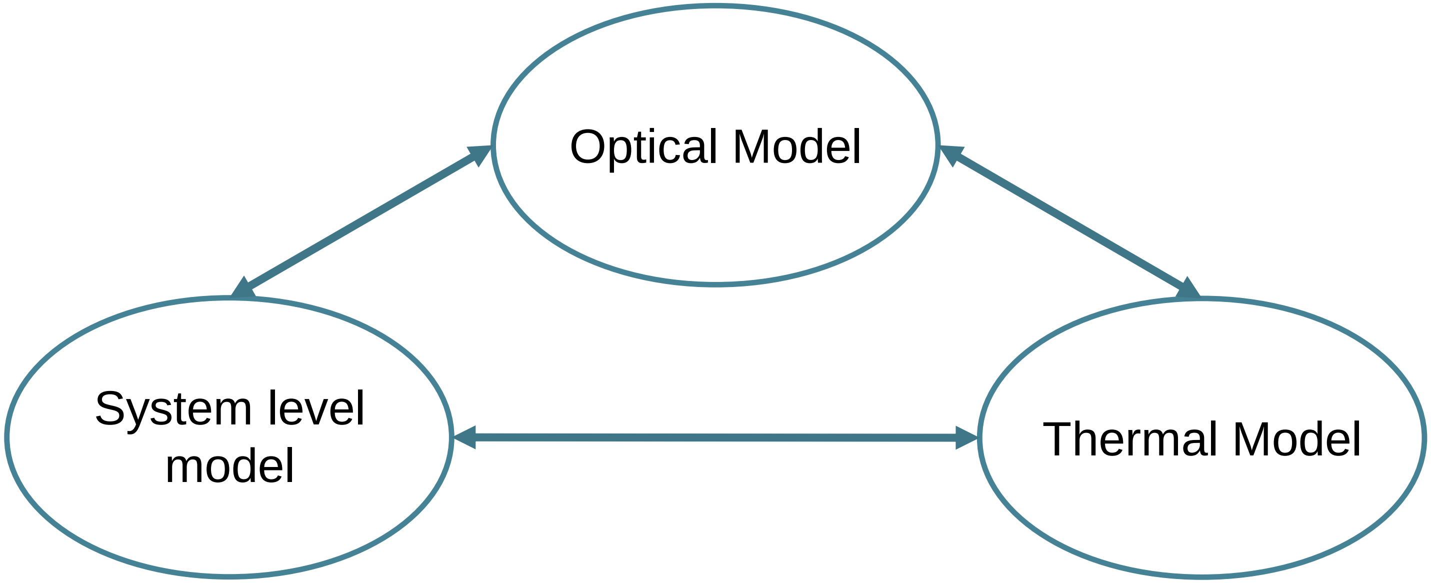


RECEIVER MODEL



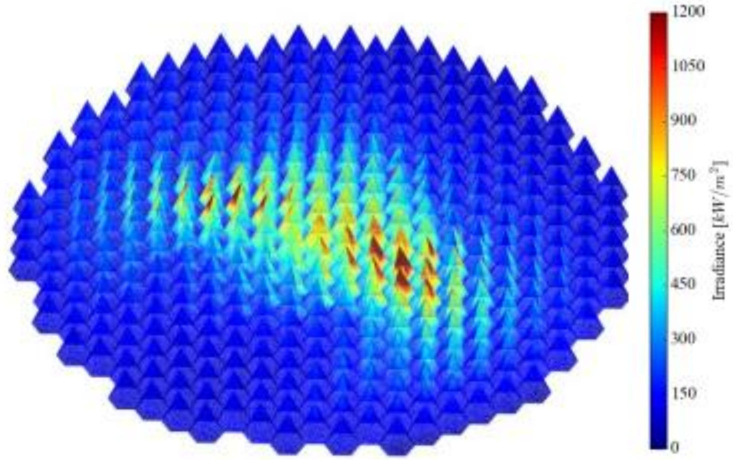


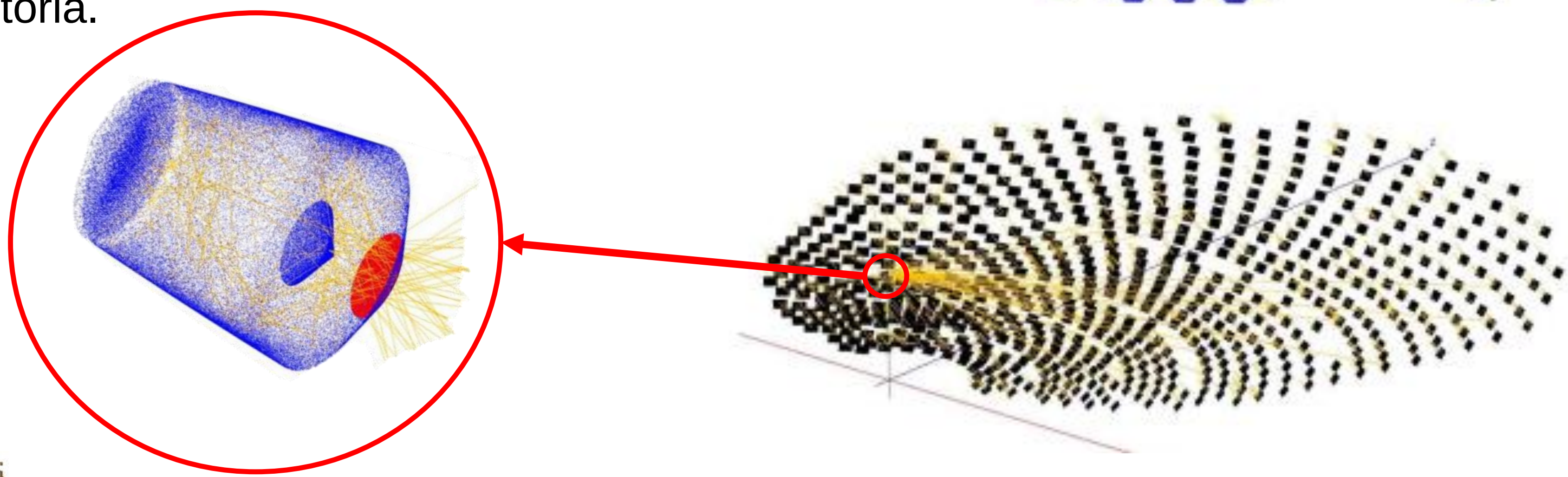




OPTICAL MODELLING

- Sunlight reflections are modelled using SolTrace (Monte-Carlo ray tracing).
- The solar model was developed by Mr. M Slootweg at the University of Pretoria.

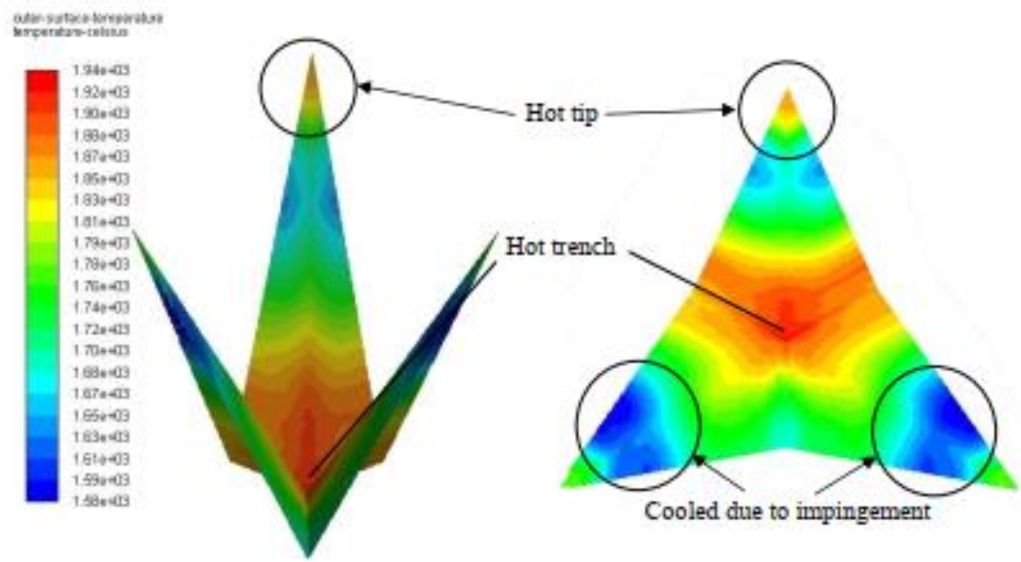




INITIAL PERFORMANCE

From the initial proposed design by Mr. M Slootweg:

- Field to aperture efficiency: 86%
- Aperture capture efficiency: 90%
- Aperture to absorber efficiency: 79%
- Thermal efficiency: 88.5%
- System efficiency: 54.1%
- Receiver efficiency: 69.9%



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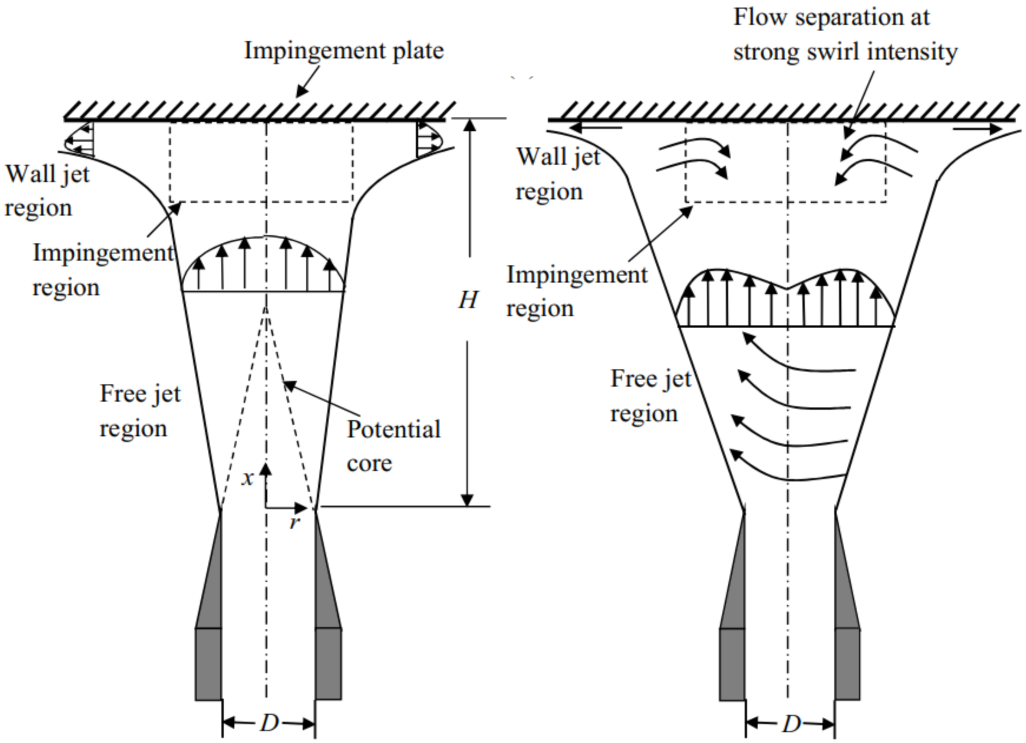
LIMITATIONS

- The previous work does not provide an optimized geometry
- The outer surface temperatures are higher than the melting temperature of steel and must be reduced
- The optical concentration mechanism is not optimal for the investigation (improvements are suggested)
- No internal fins used, but may be required
- The practical implementation of the design must be considered
- Operation of the design must be considered
- The design has a high pressure drop and low outlet temperature of

SWIRL HEAT TRANSFER

- Enhance heat transfer by up to 30%
- Still relatively underdeveloped and not adequately investigated
- Swirl generation methods – Geometric and aerodynamic
- Numerical modelling – 2D axi-symmetric, 3D RANS, and LES



Conventional non-swirling jet

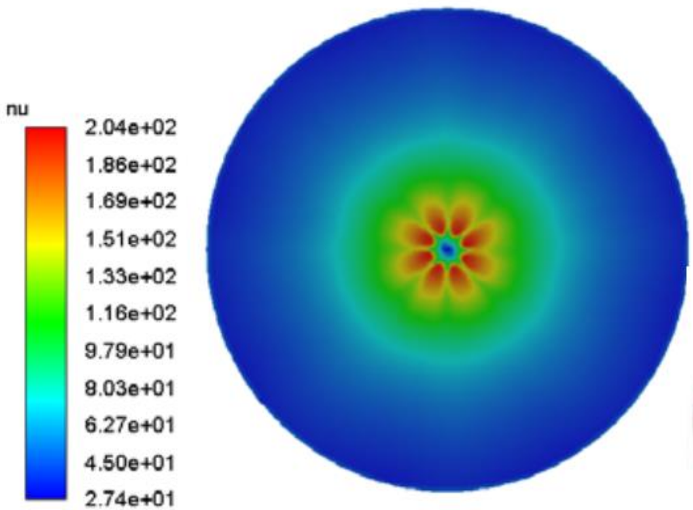
Swirling jet

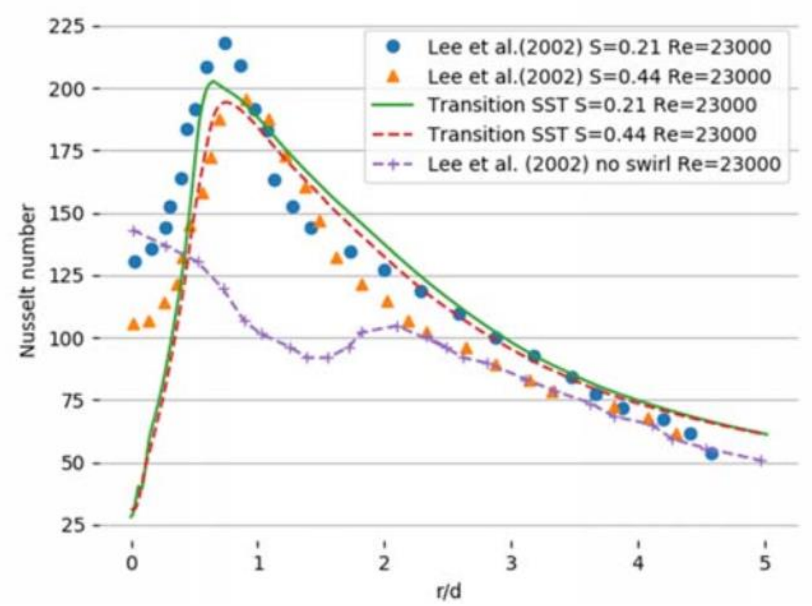
SWIRL HEAT TRANSFER PARAMETERS

Non-dimensional parameter	Description
H/d	Nozzle height to impingement surface
r/d	Radial position from the centre of the jet
d/D	Impingement surface curvature
Nu	Nusselt number
Re	Reynolds number
S	Swirl number

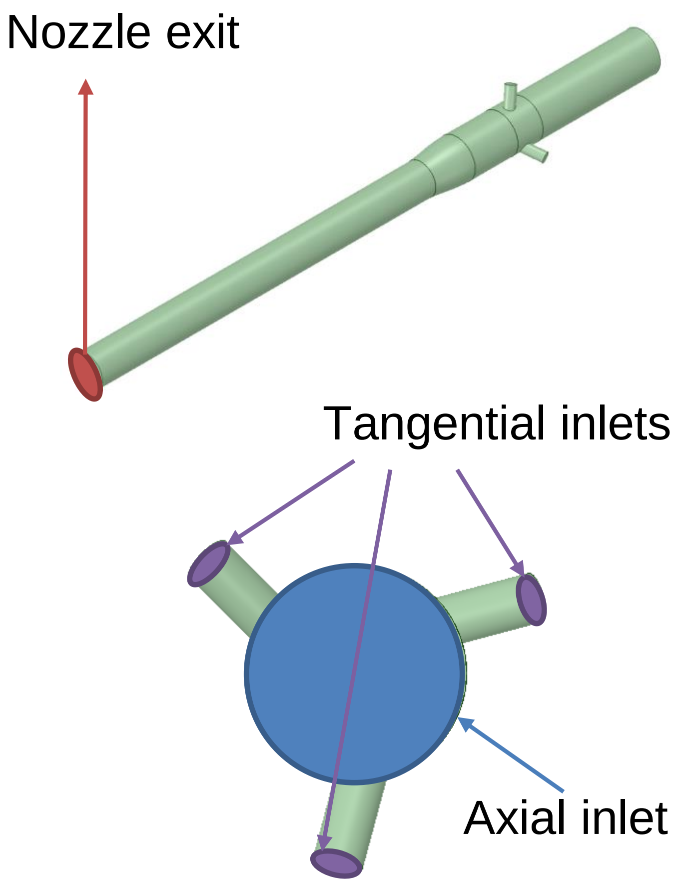
GEOMETRIC SWIRL

3D RANS simulation of geometric swirl generator

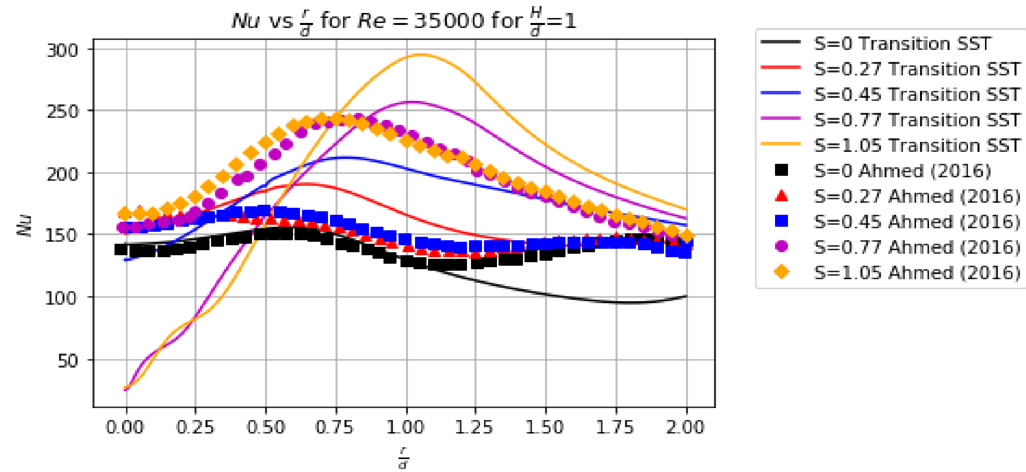


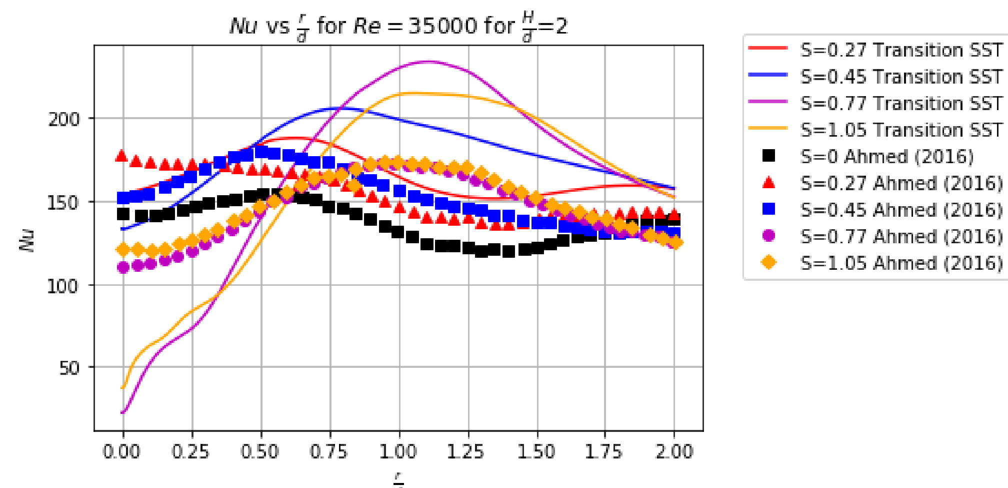


AERO-DYNAMIC SWIRL



2D axi-symmetric swirl





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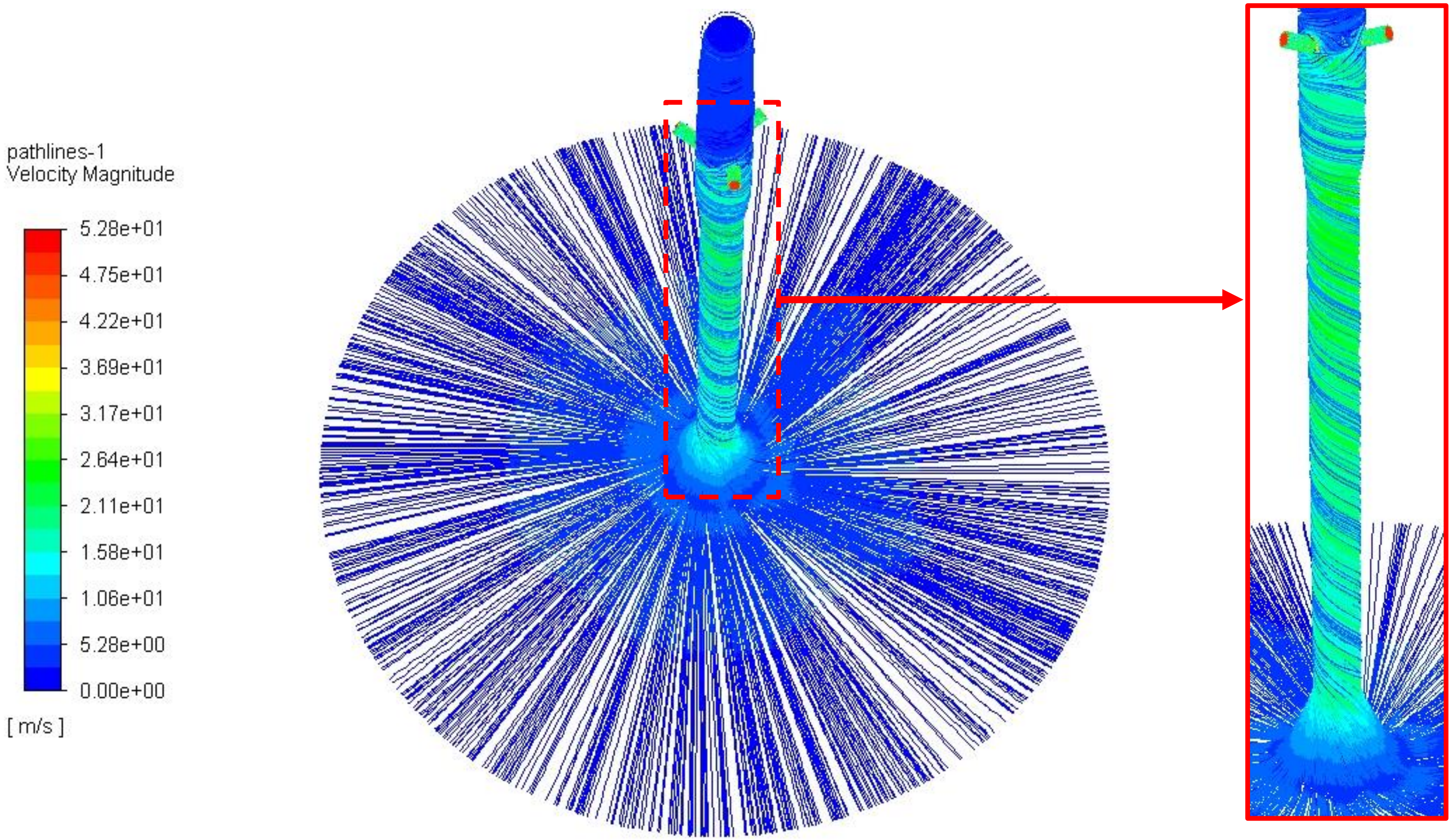
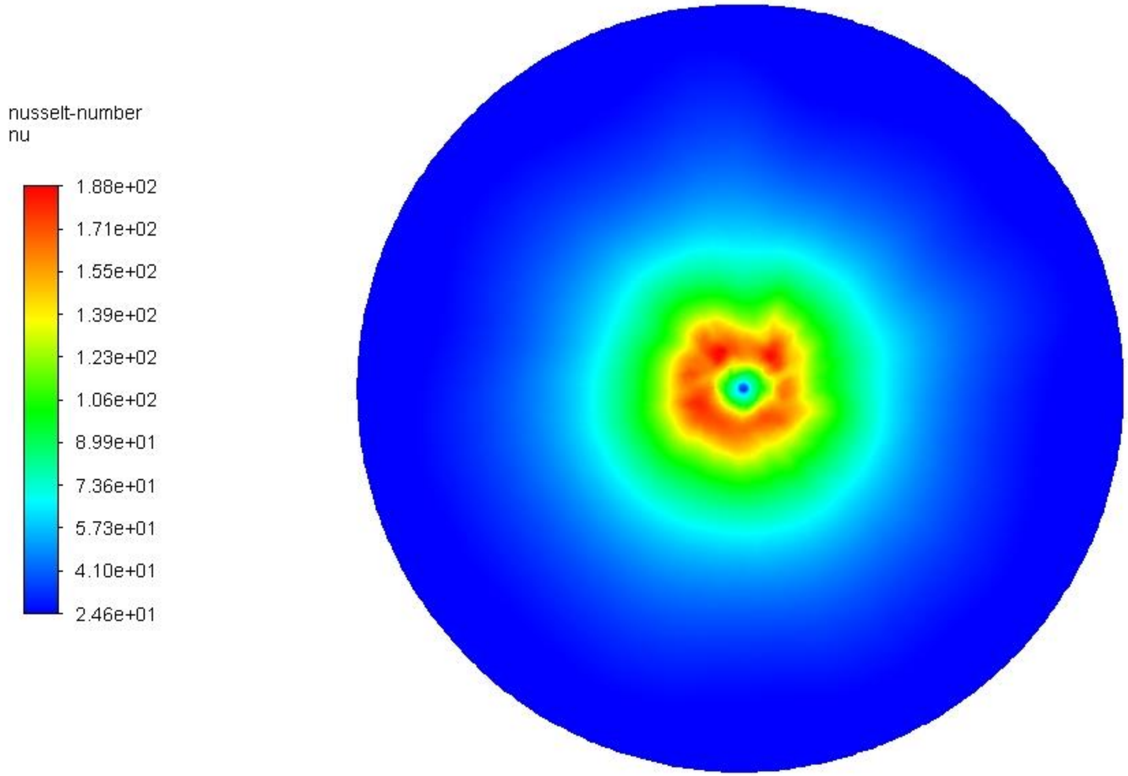
3D RANS SWIRL GENERATOR



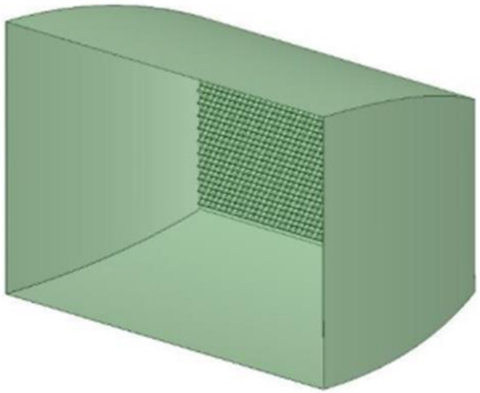
3D STEADY RANS

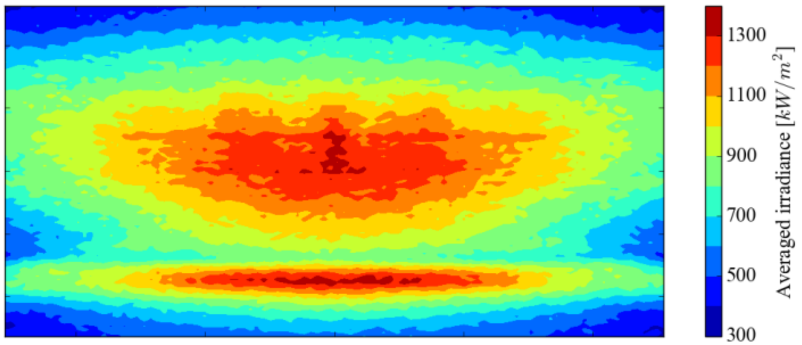
Nusselt number distribution on flat plate for S=1.05



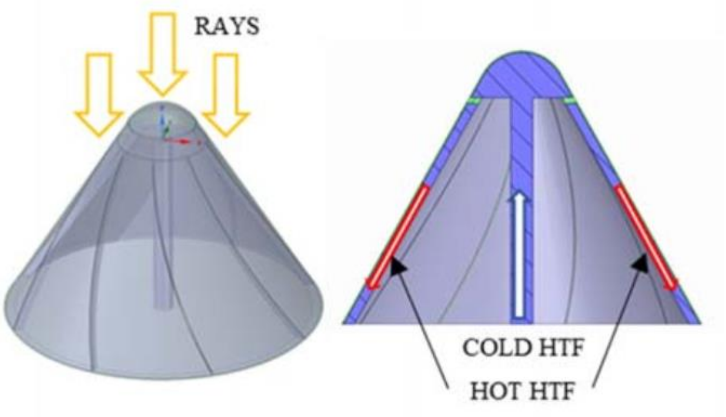
PROPOSED CONCEPT

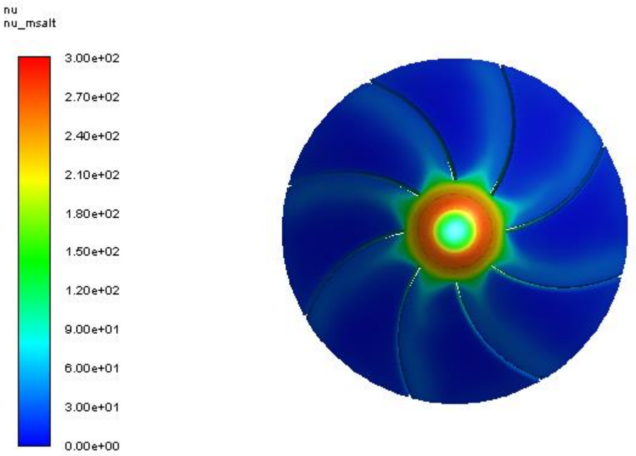
Optical design





Receiver design





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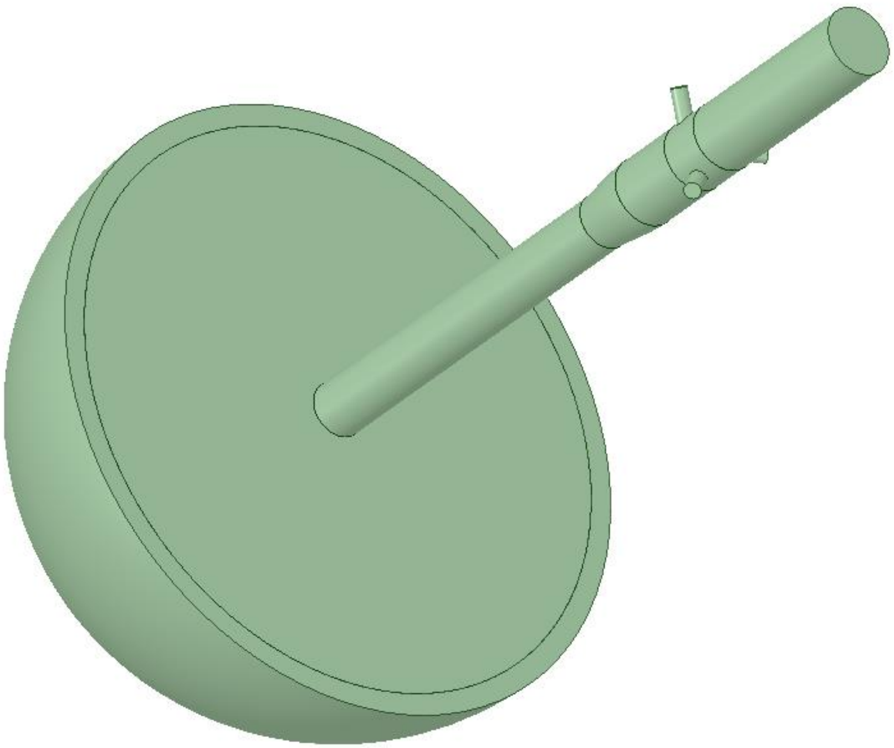
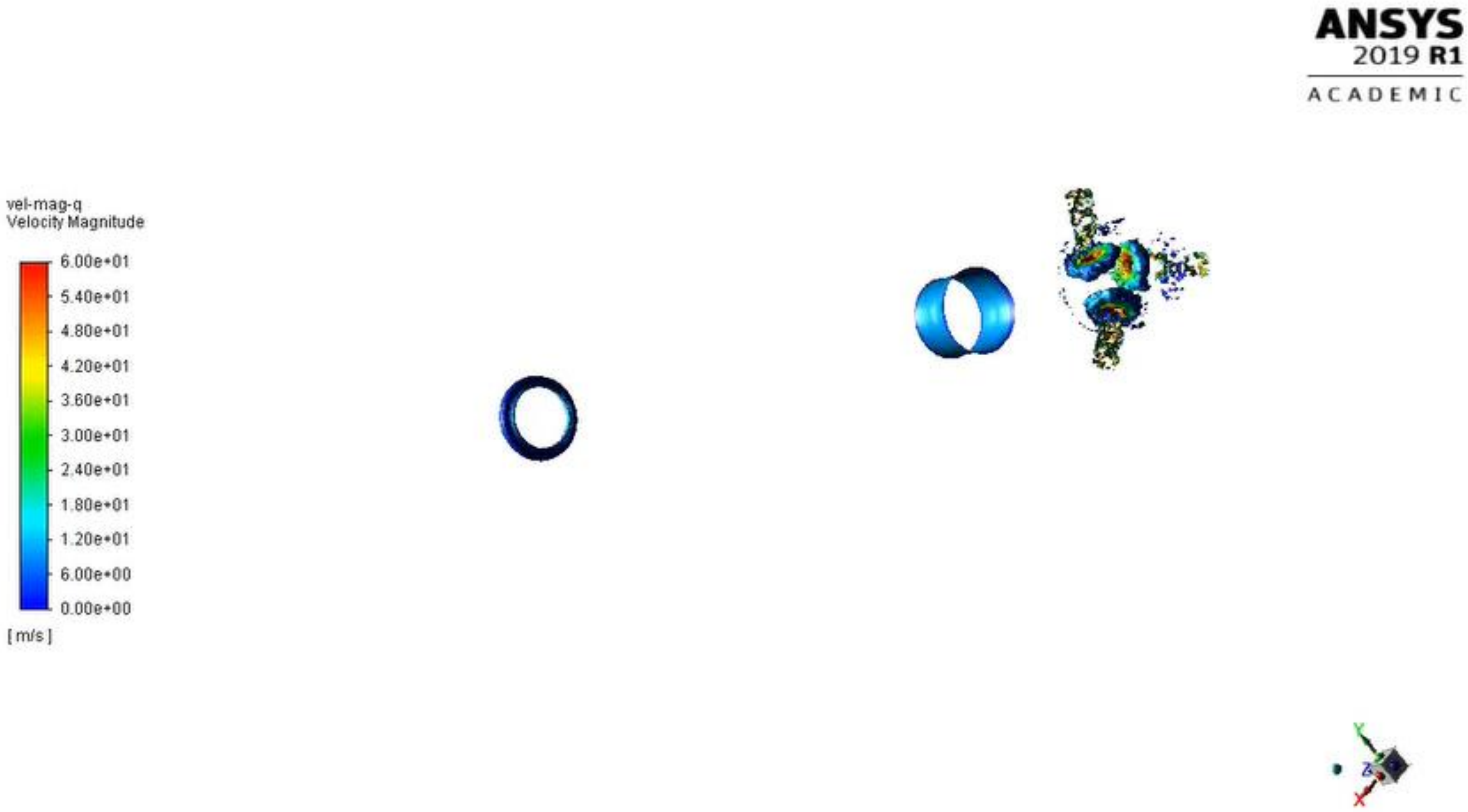
LARGE EDDY SIMULATIONS

- LES has shown excellent prediction of jet impingement
- Currently under further investigation for a 20 million cell mesh with 1×10^{-6} time step
- The LES investigation covers flat and curved impingement surfaces
- Finally a LES Simulation will be conducted for the receiver



LARGE EDDY SIMULATION



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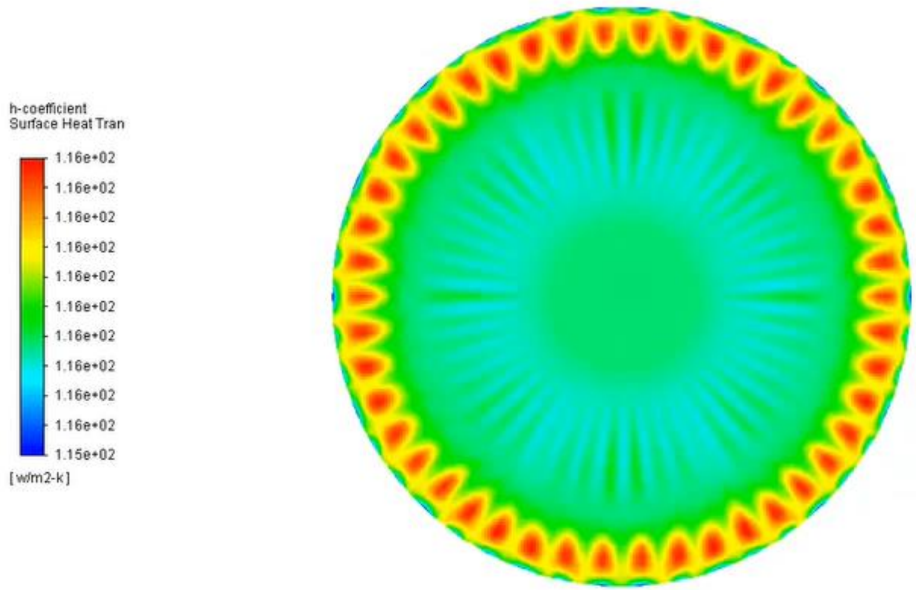
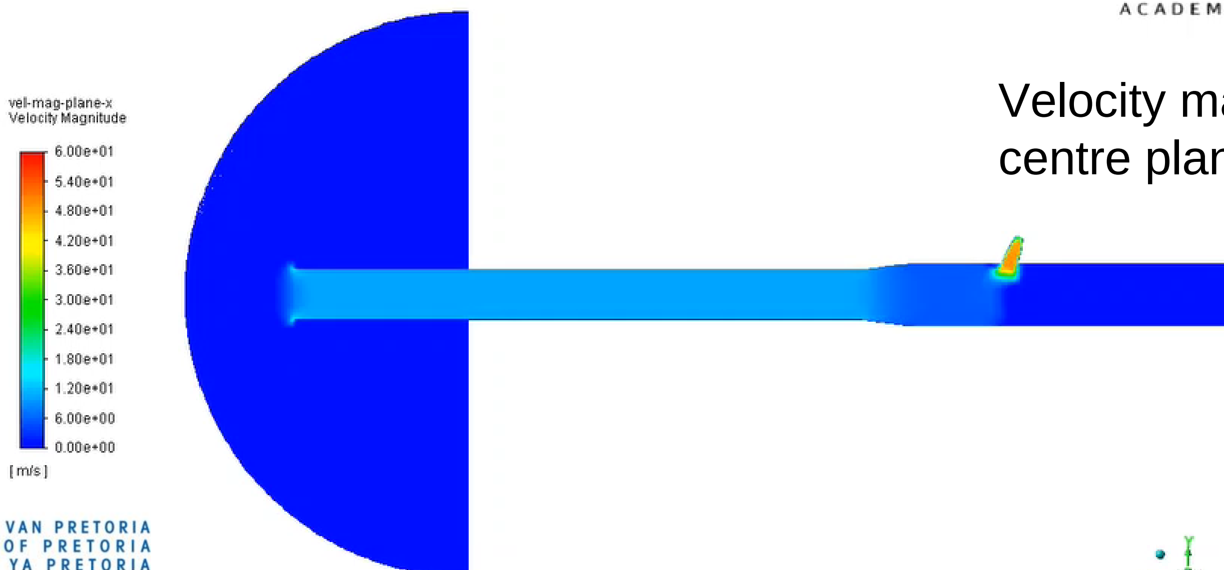


Heat transfer coefficient on concave surface



Velocity magnitude on centre plane

NUMERICAL MODELS

Model	Applicability
2D axi-symmetric swirl	• Fails to adequately predict the stagnation point Nu • Reasonable estimate of average heat transfer • Predicts the location of peak Nu reasonable well • Possible use for fundamental optimization
3D Steady RANS	• Fails to adequately predict the stagnation point Nu • Provides far better predictions of Nu distribution • Predicts geometric generated swirl very well • Can be used for optimization of internal flow geometry
LES	Based on preliminary investigation: • Predicts Nu distribution well for geometric and aerodynamic generated swirl • Predicts the stagnation point Nu far better • Possibly the only method of predicting high swirl flows accurately, due to unsteady vortices

Conclusion

- The applicability of swirling impinging jets shows great promise
- RANS models do not show the best accuracy however they can be useful tools for optimization and general purposes
- LES simulations show the best accuracy at a significantly higher computational cost

FUTURE WORK

- Further investigations using LES.
- Optimization of swirl cone geometry.
- Practical implementation of the proposed design.
- The drainage considerations.
- Investigation of alternative heat transfer fluids.
- Ray tracing for accurate heat source modelling.

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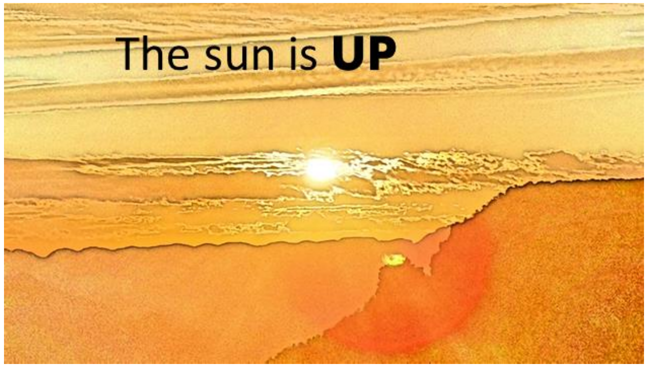

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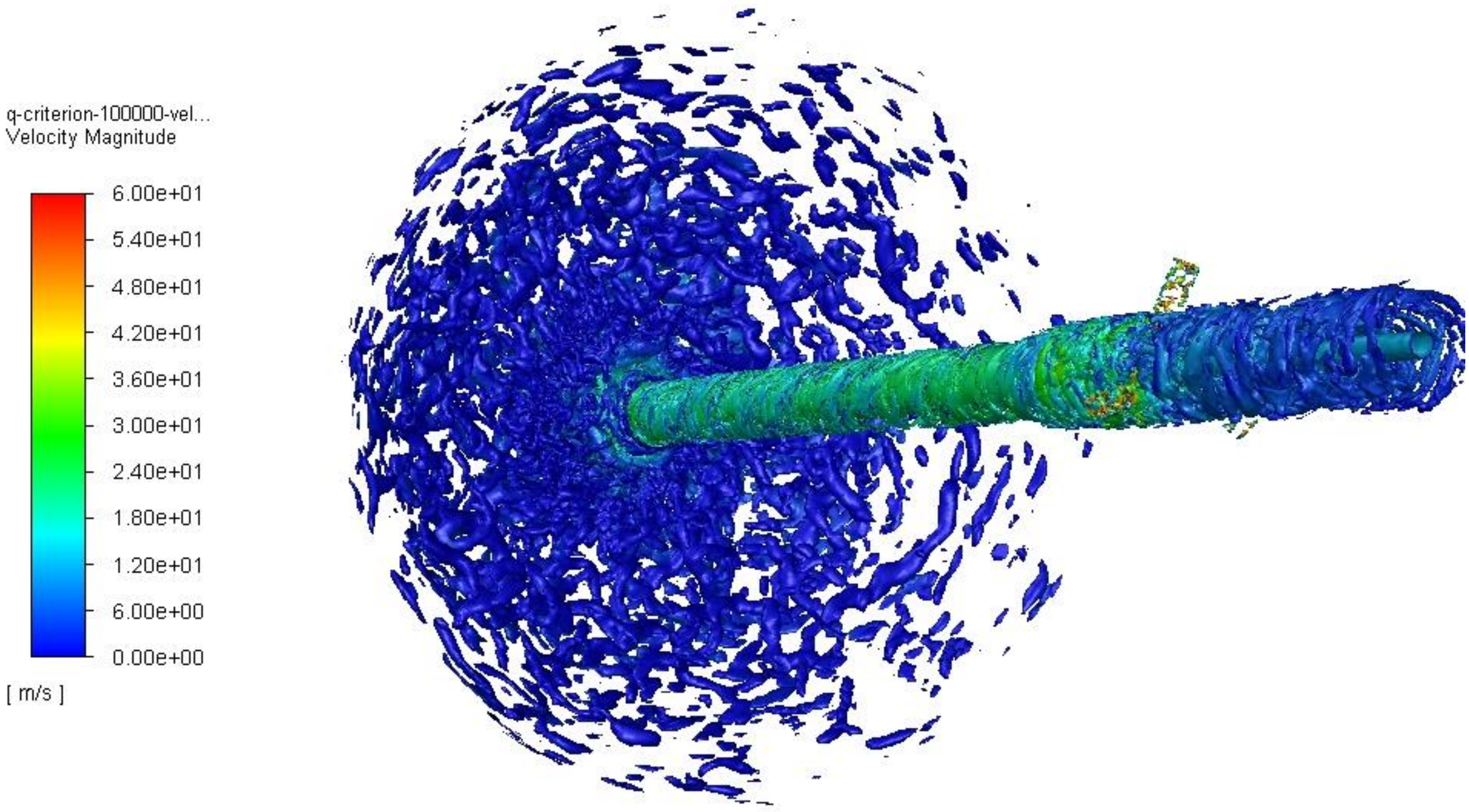
Questions?



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