Investigation of Particle Flight under Aerodynamic Loads using Computational Fluid Dynamics

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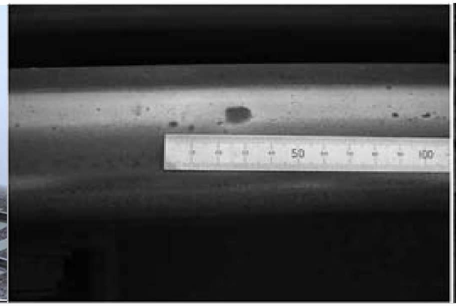
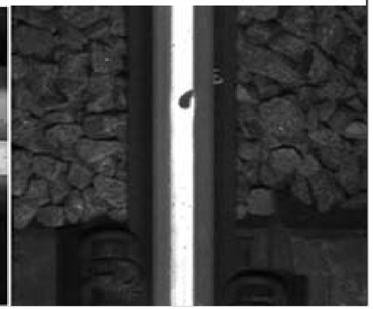
Industry Supervisors: Andrew McNaughton, Niall Fagan (HS2)

Outline

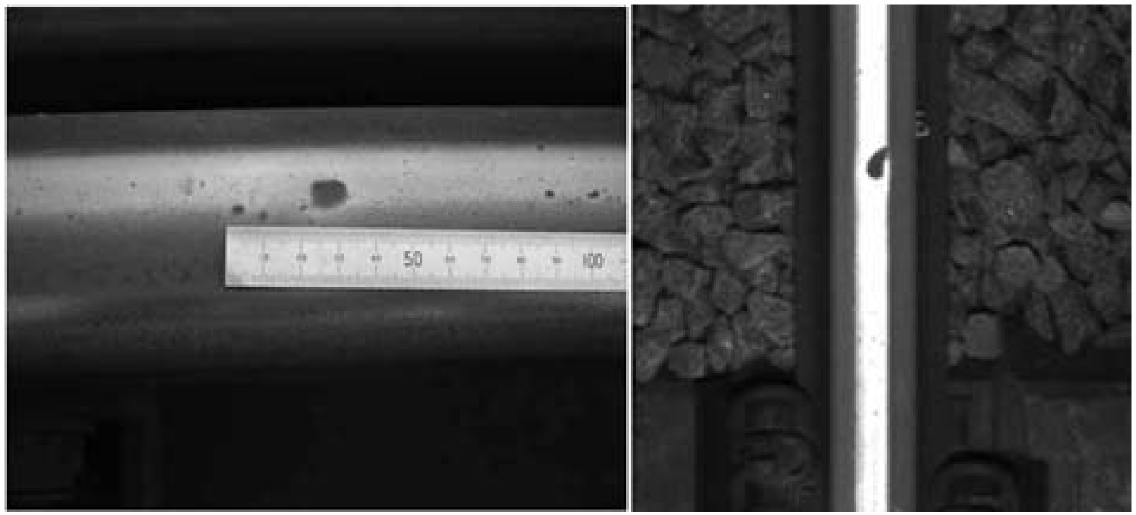
- Ballast flight.
- Research strategy and previous work.
- Effects of computational methods (URANS vs. DES).
- Effects of particle shape and orientation.
- Summary and future research.



Ballast Flight

- Ballast being displaced by Mechanical and **Aerodynamic forces**.
- Sufficient momentum can lead to ballast flight.
- Triggered by train speed.
- Critical velocity relates to sub-base.
- Results in structural damage and safety concerns.



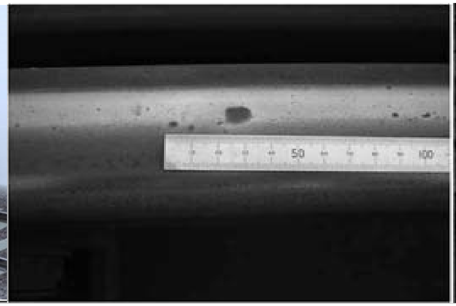
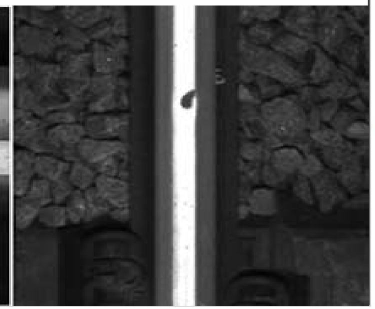
Quinn et al. (2009): *A full-scale experimental and modelling study of ballast flight under high-speed trains*.

Research Strategy

- Expand from previous studies on turbulent flow using CFD.
- Start with simple geometry, more towards more complex shapes.
- Expand towards the track and train segment.
- Validate results using experimental data.

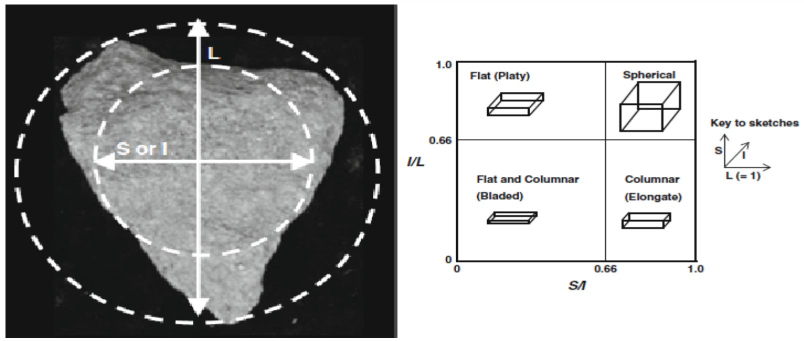
	Simple	**Complex**
Particle geometry	Cubes, Hemispheres.	Realistic ballast shapes & roughness.
Computational methods	URANS, DES.	LES, DNS.
Context	Single particles.	Bed of particles, train & track.
Airflow	Uniform free flow.	Boundary layer profile.



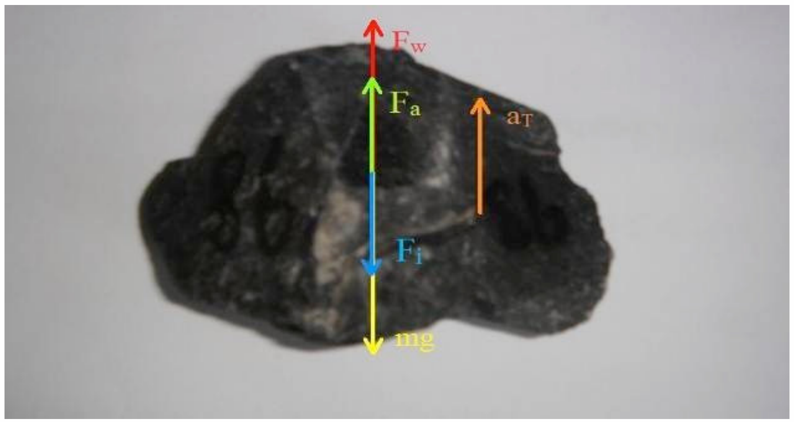



Previous Work

- Parameterise the ballast particles.
- Flow around flat surfaced and smooth geometries.
- Aerodynamics of ballast particles.



Le Pen et al. (2013) *Dependence of shape on particle size for a crushed rock on railway ballast*.

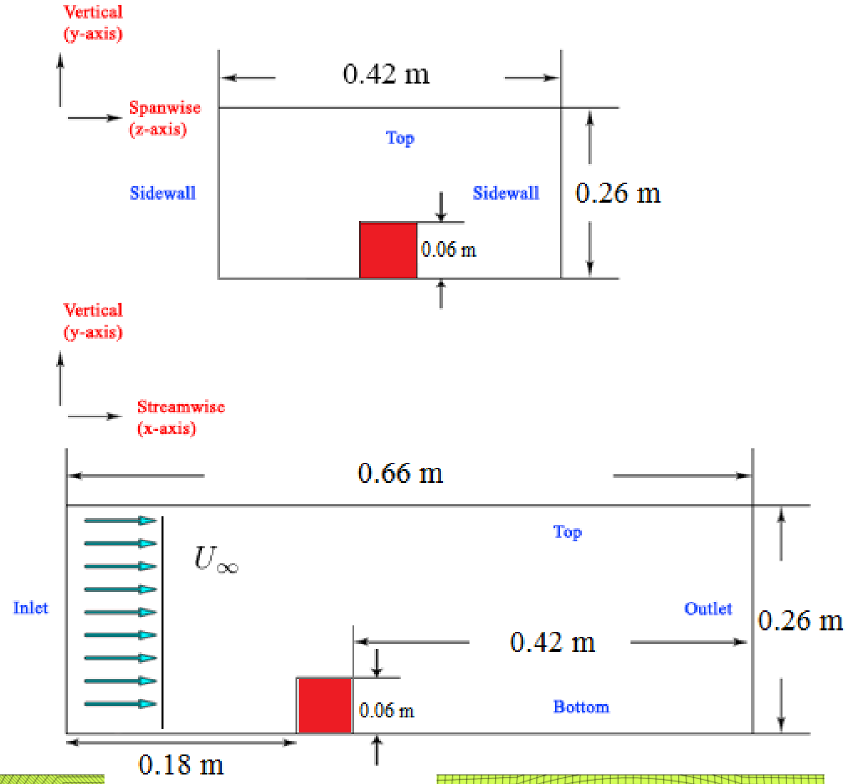


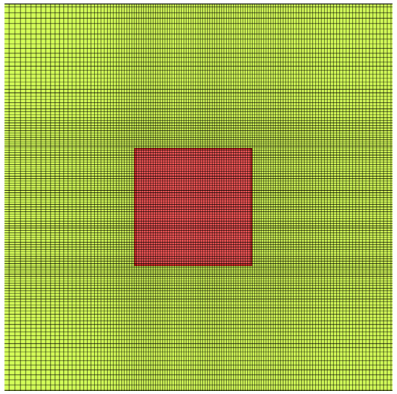
Jing et al. (2014) *Aerodynamic Characteristics of Individual Ballast Particle*.

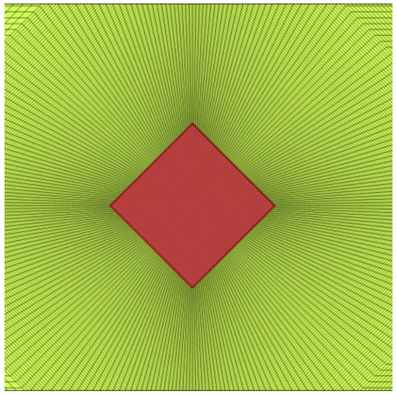
- Studies of ballast flight and HST aerodynamics.
- Mitigation strategies.

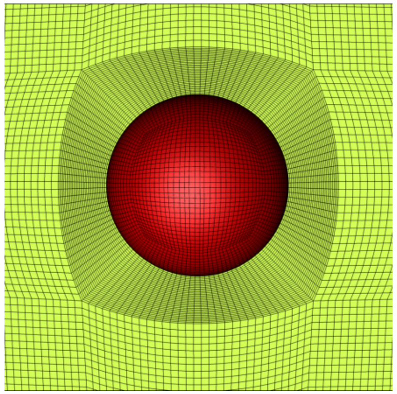
Computational Domain for URANS & DES

- Perform numerical simulations of a cube and a hemisphere referring to experimental data.
- Computational efficiency vs. accuracy.
- Study effects of particle position and orientation.
- Particle airborne.
- Validate and verify results.



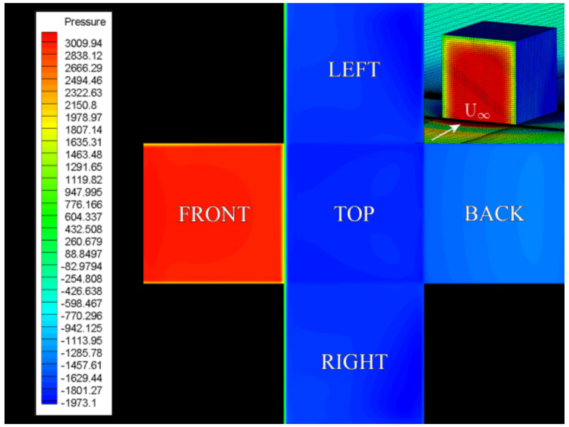






Results: Cubic particle (URANS vs DES)

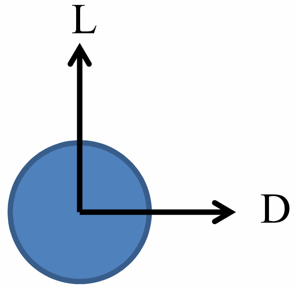
URANS



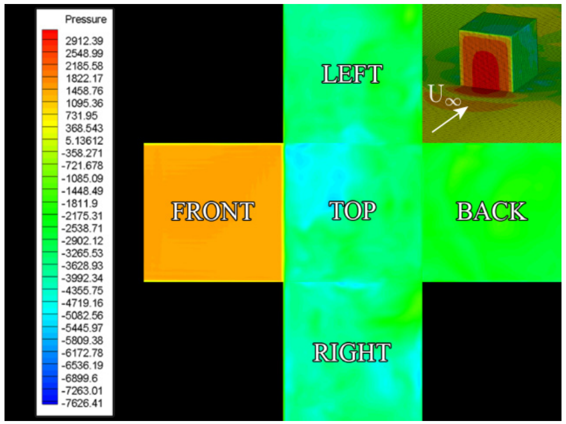
$$\overline{C_D} = 1.24757$$
$$C_{D_{RMS}} = 1.24886$$
$$\overline{C_L} = 0.64758$$
$$C_{L_{RMS}} = 0.66397$$

$$C_D = \frac{D}{\frac{1}{2}\rho U_\infty^2 A}$$

A: Projected Area



DES



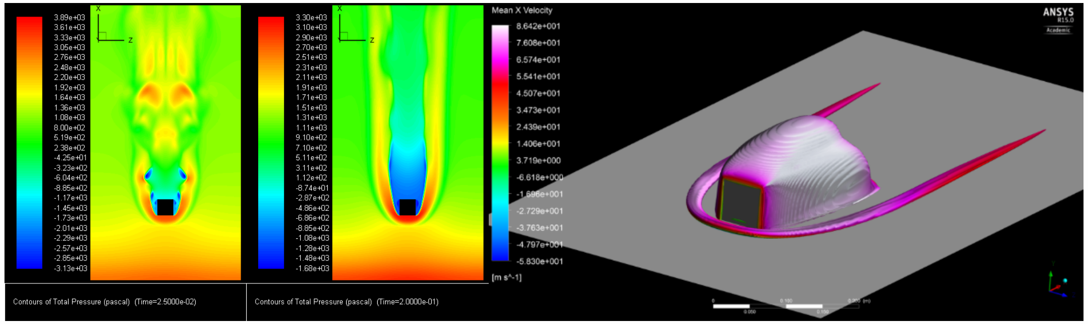
$$\overline{C_D} = 1.31983$$
$$C_{D_{RMS}} = 1.32056$$
$$\overline{C_L} = 0.68911$$
$$C_{L_{RMS}} = 0.69102$$

$$C_L = \frac{L}{\frac{1}{2}\rho U_\infty^2 A}$$

Results: Cubic particle (URANS vs DES)

URANS

- Quicker to implement.
- Resolves less turbulence.
- Energy of calculated flow dissipates rapidly.

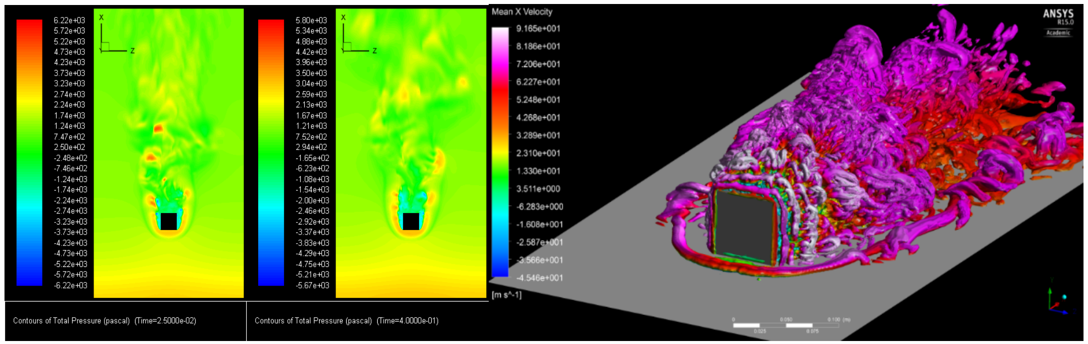


Total Pressure

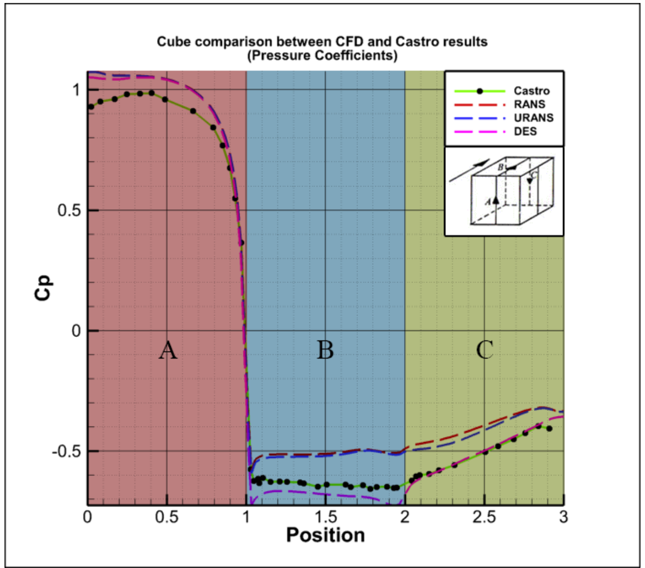
Q-Criterion = 325,000

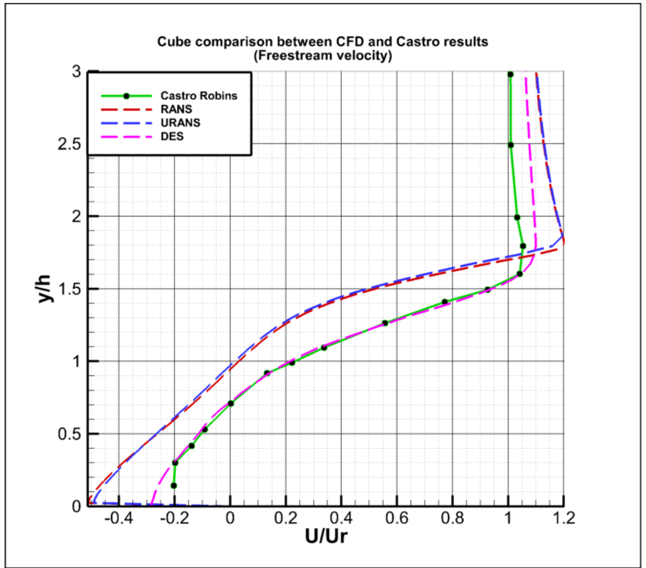
DES

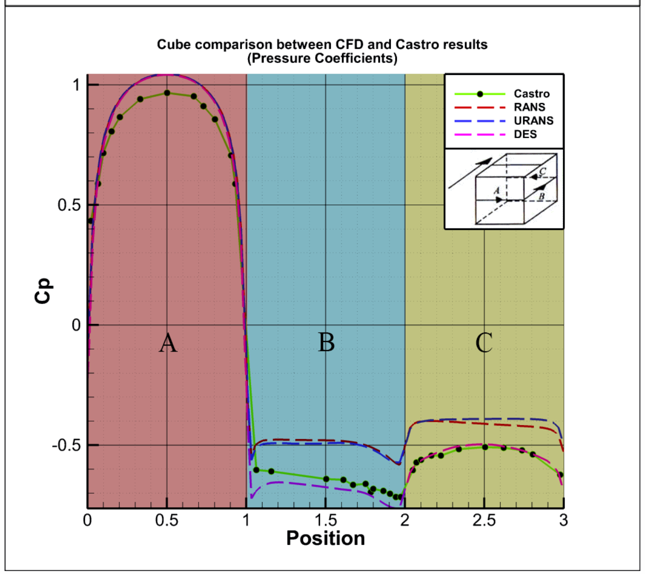
- More efficient than Large-Eddy Simulation model (LES).
- Useful for complex geometries.
- Requires refined grid.
- Longer to implement.

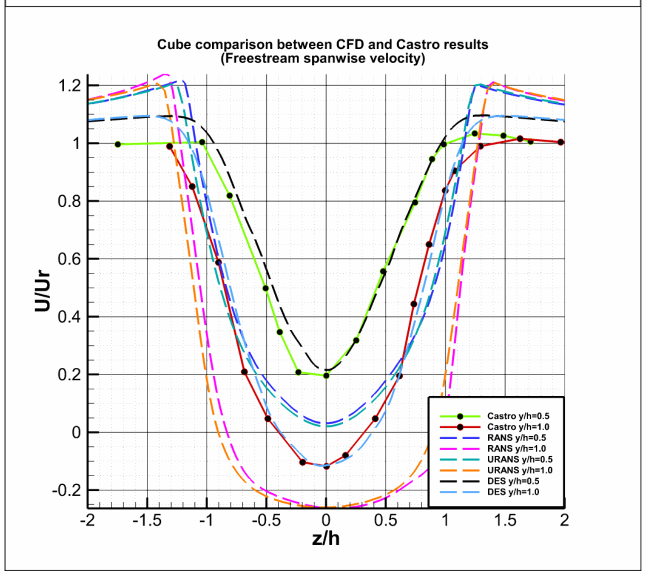


Results: Cubic particle (URANS vs DES)



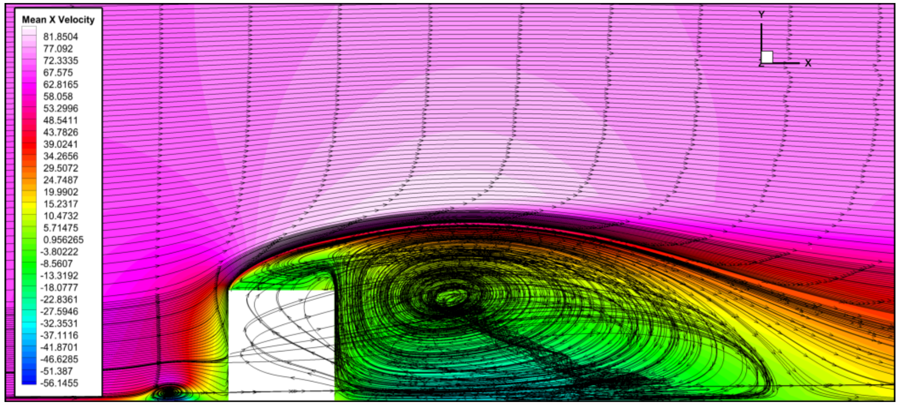


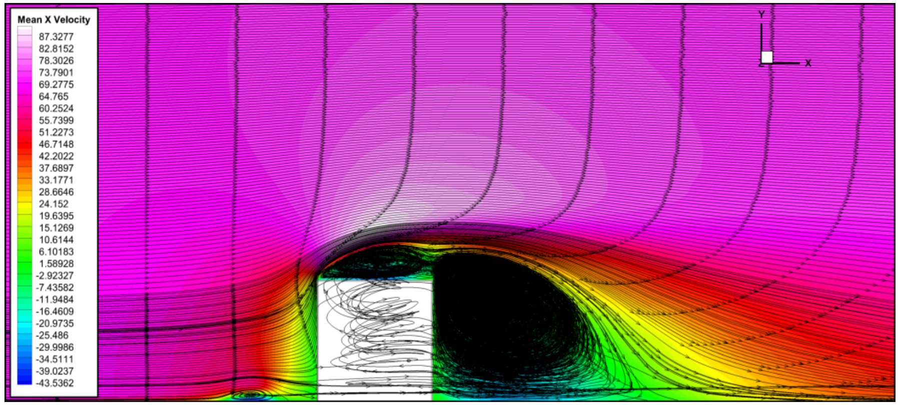


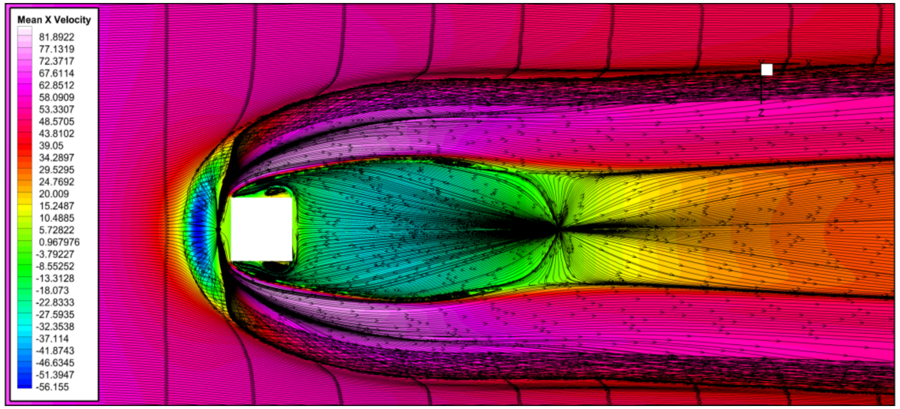


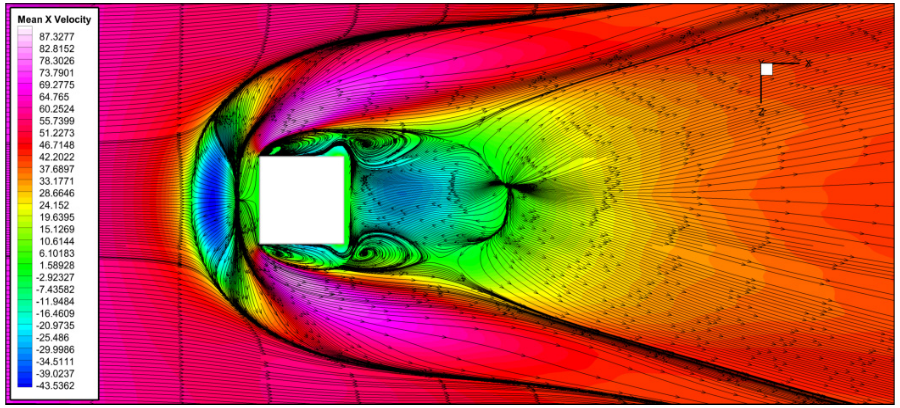
Results: Cubic particle (URANS vs DES)

URANS	DES



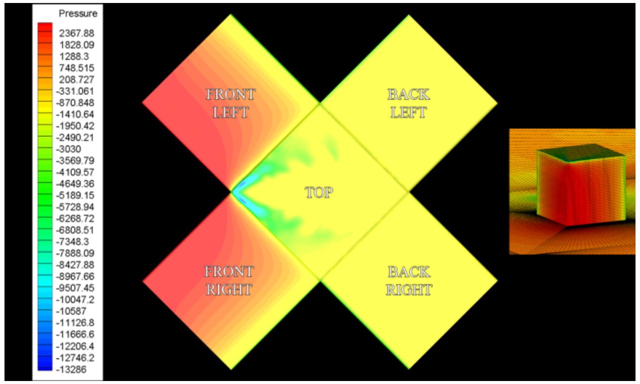






Results: Cubic particle at 45 degrees (DES)

DES



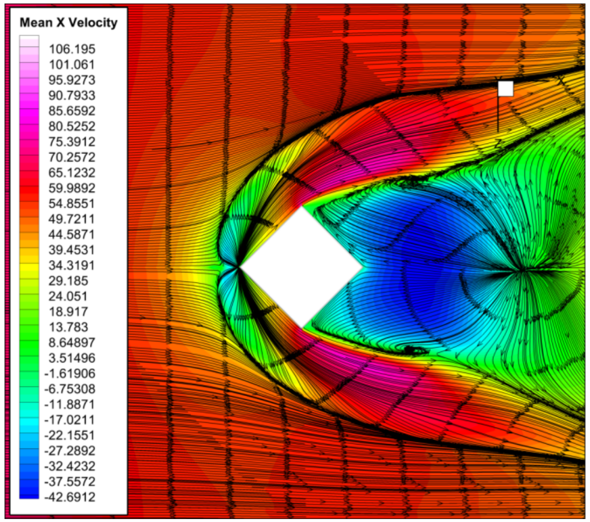
Cube 45 degrees

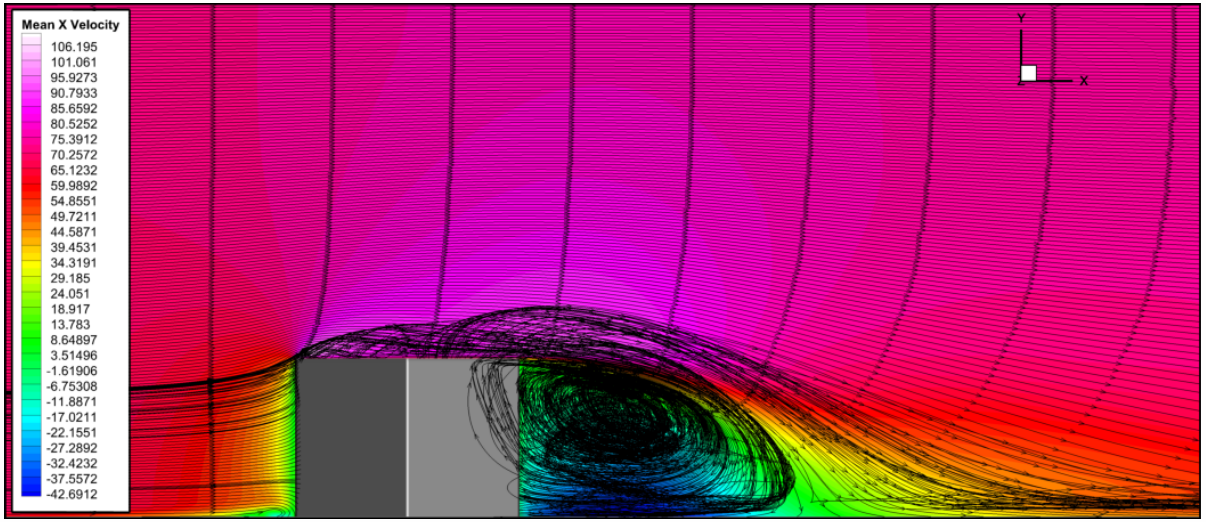
$\overline{C_D} = 0.99253$

$C_{D_{RMS}} = 0.99394$

$\overline{C_L} = 0.64417$

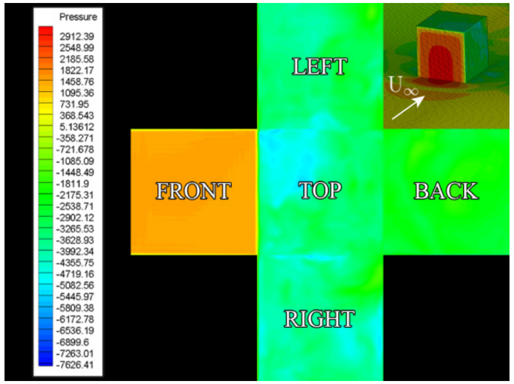
$C_{L_{RMS}} = 0.64446$





Results: Cubic particle at 45 degrees vs. 90 degrees (DES)

DES



Cube 45 degrees

$\overline{C_D} = 0.99253$

$C_{D_{RMS}} = 0.99394$

$\overline{C_L} = 0.64417$

$C_{L_{RMS}} = 0.64446$

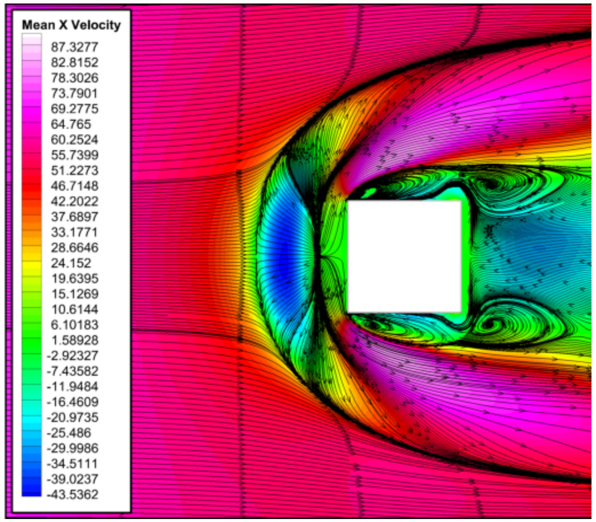
Cube 90 degrees

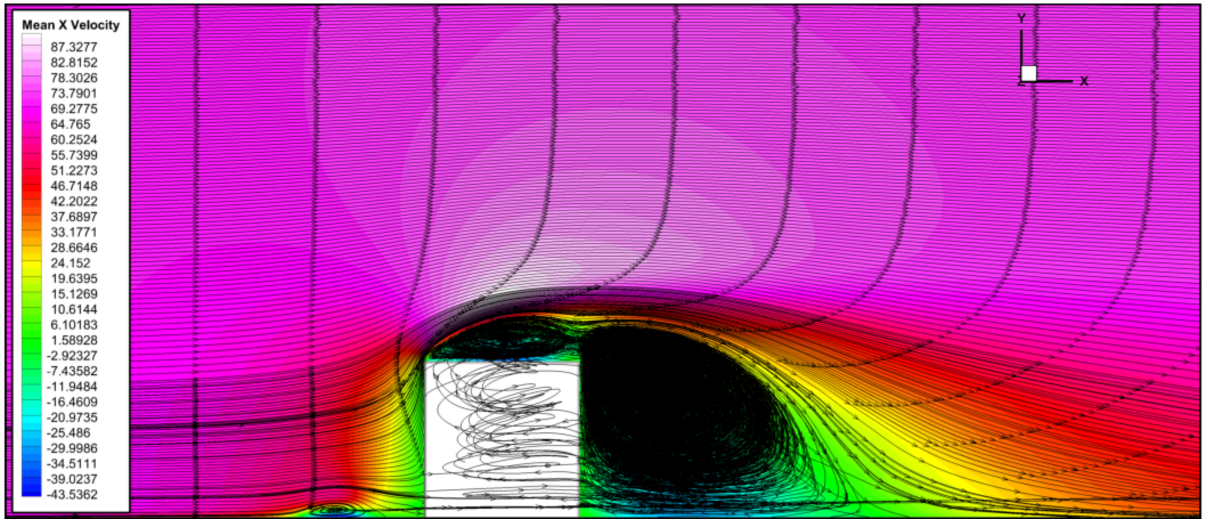
$\overline{C_D} = 1.31983$

$C_{D_{RMS}} = 1.32056$

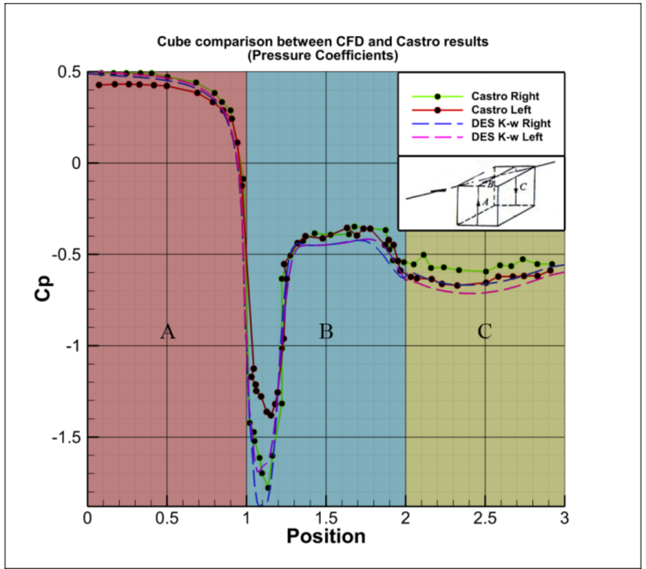
$\overline{C_L} = 0.68911$

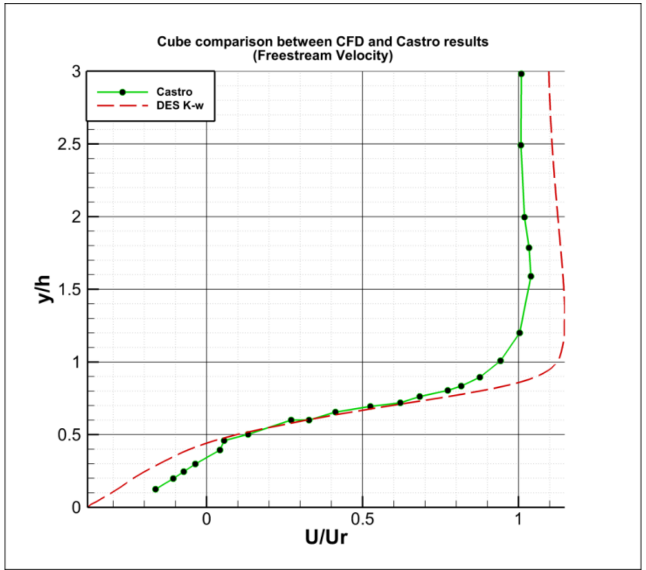
$C_{L_{RMS}} = 0.69102$

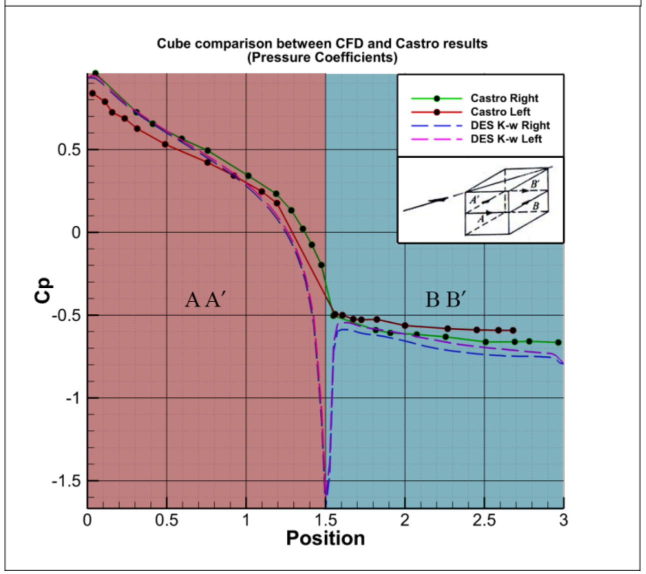


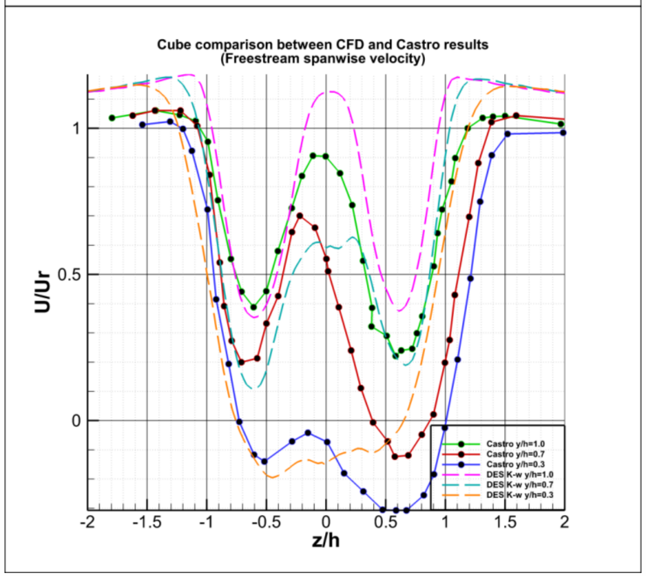


Results: Cubic particle at 45 degrees (DES)

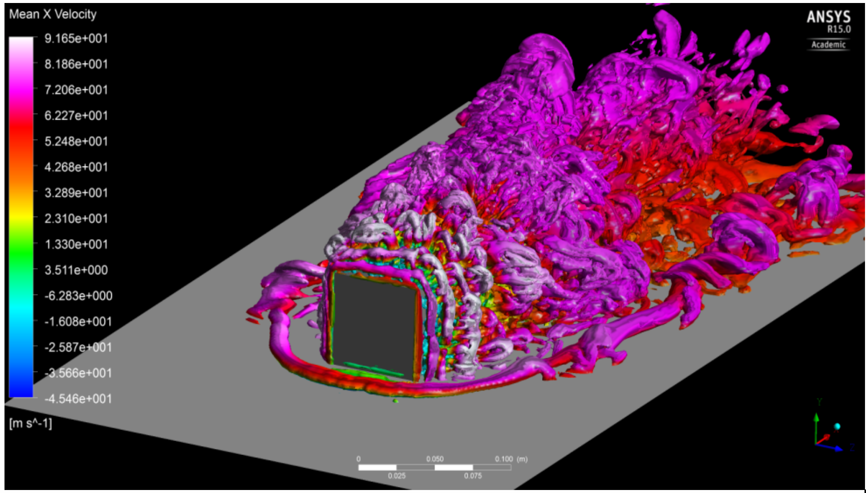








Results: Cubic particle at 45 degrees (DES)

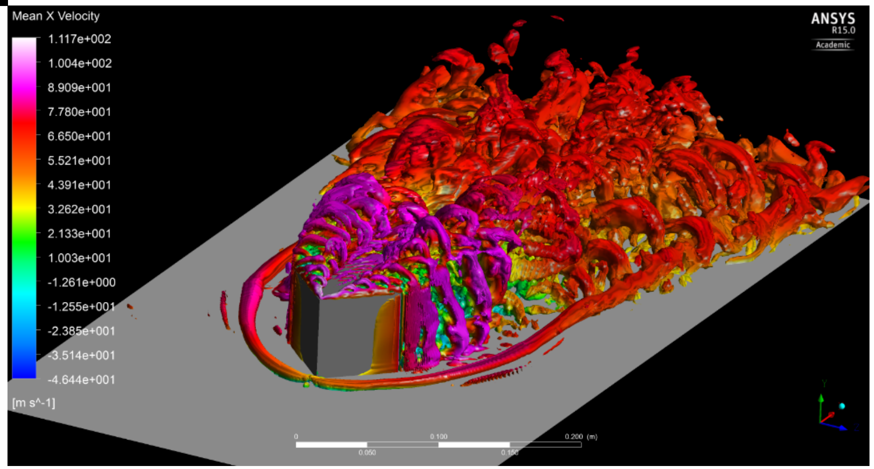


90 degree cube

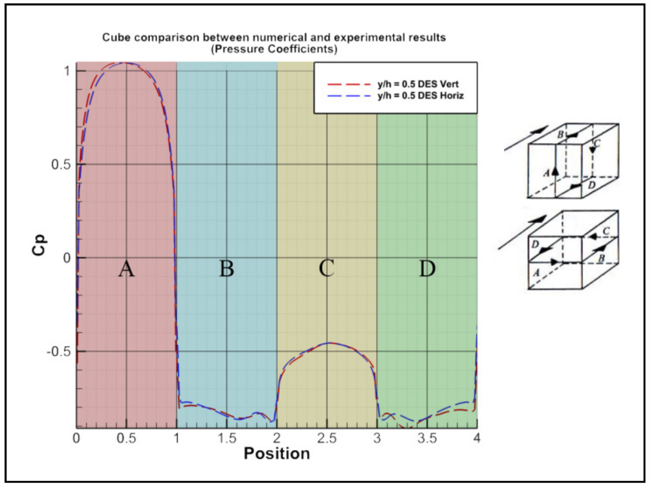
DES $(k - \omega)$ model

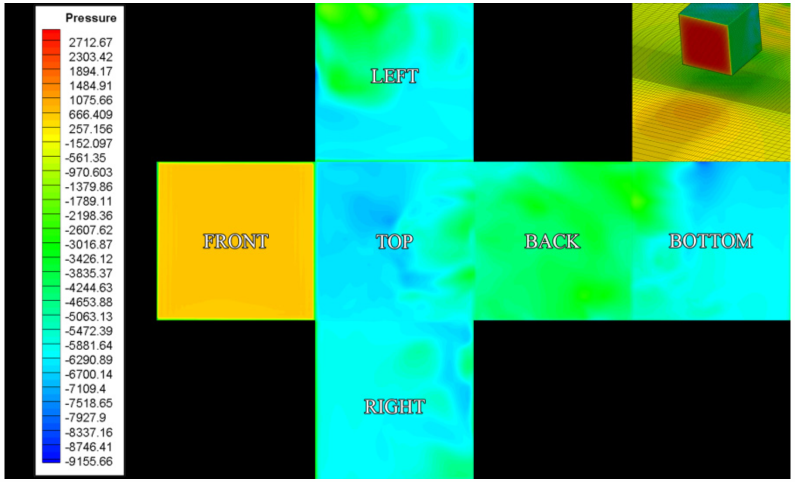
45 degree cube

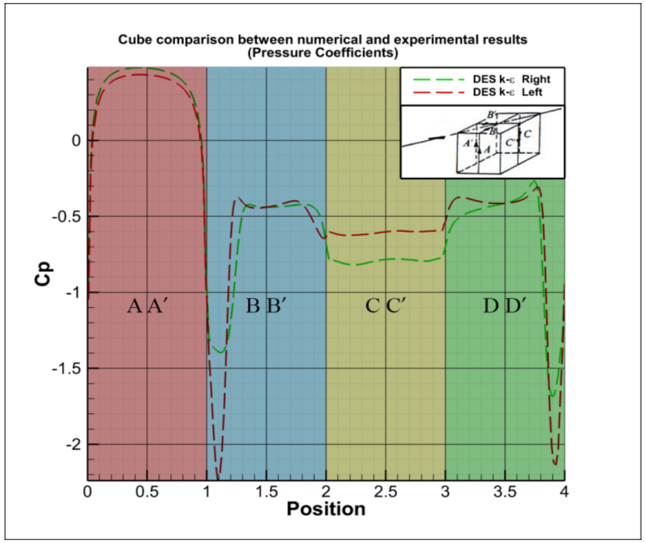
DES $(k - \omega)$ model

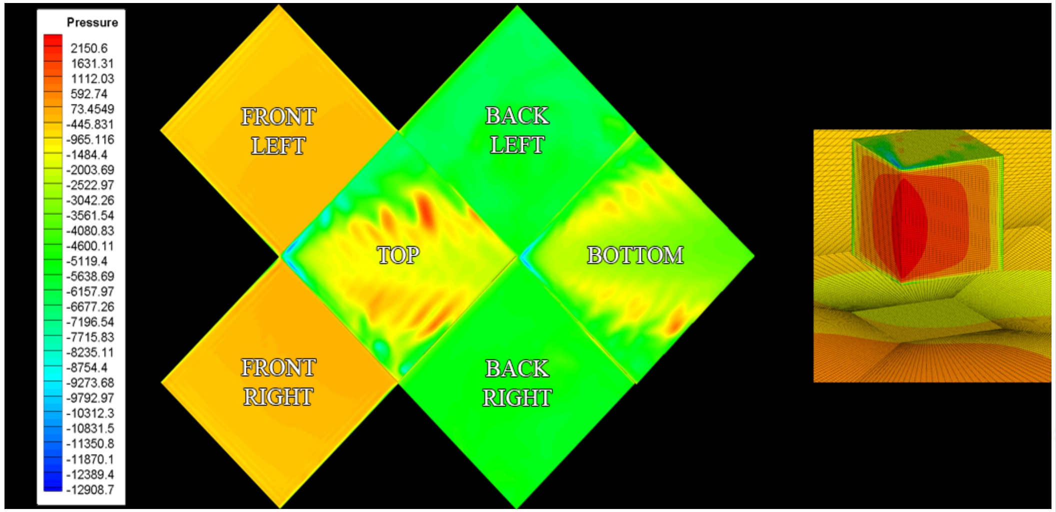


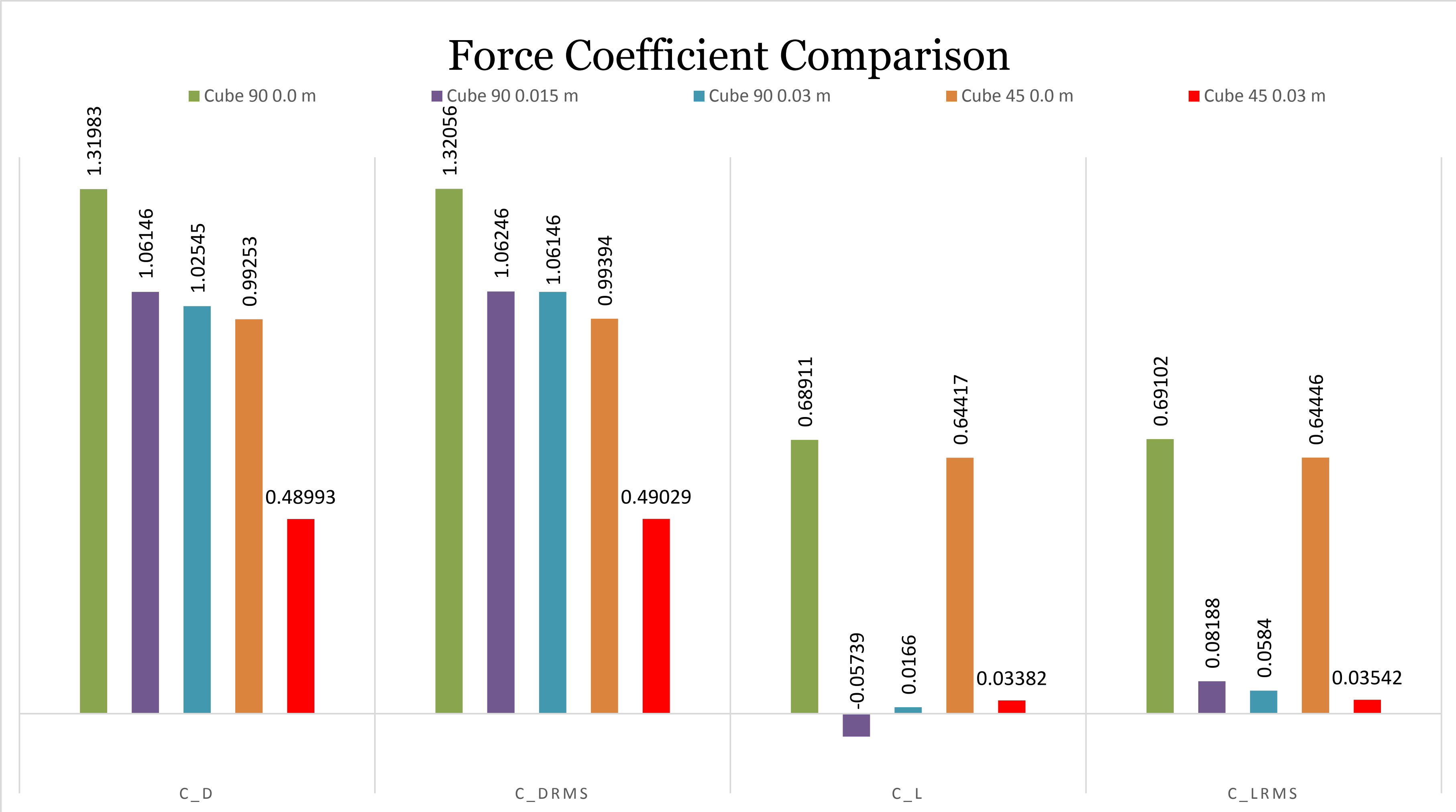
Results: Cubic particle above ground (DES)









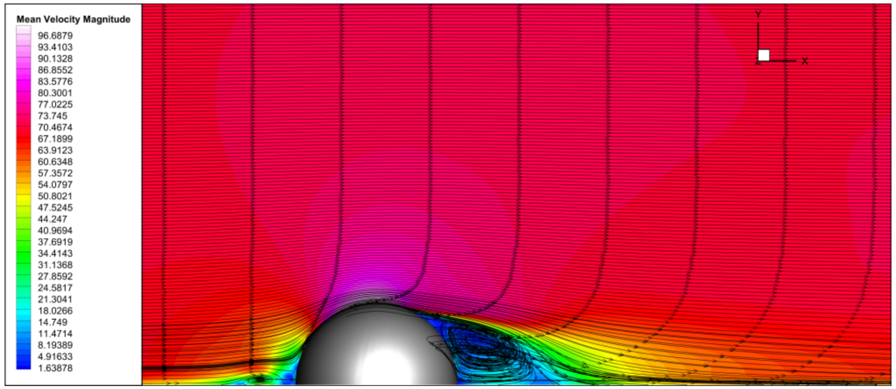


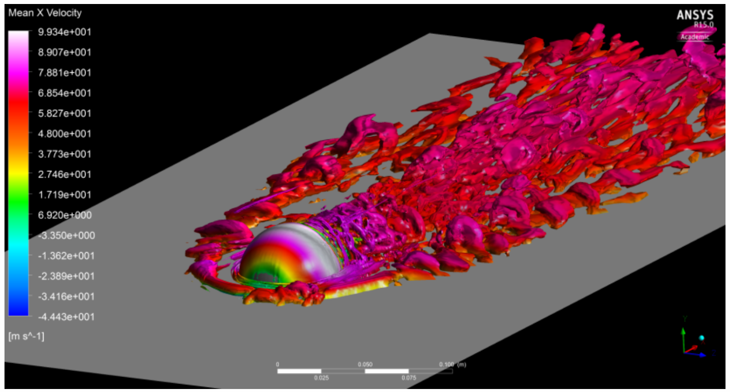
- Lift and drag coefficients decreases as height increases.
- The 45 degree case has a lower lift and drag coefficient than 90 degree case.
- Force coefficients is dependent on its orientation and position as well as the effect of train speed.

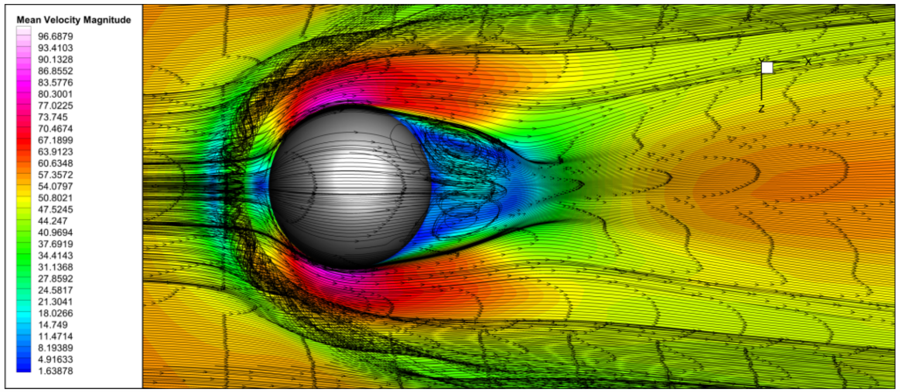
Results: Hemisphere with DES

Hemisphere

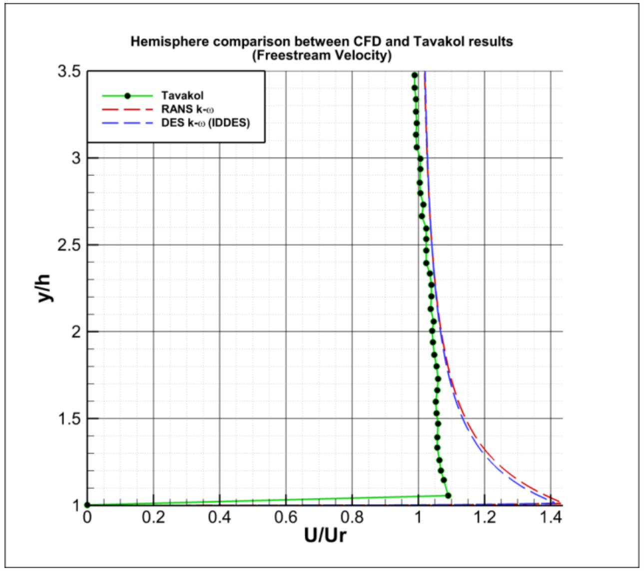
$$\overline{C_D} = 0.12860$$
$$C_{D_{RMS}} = 0.12929$$
$$\overline{C_L} = 0.48168$$
$$C_{L_{RMS}} = 0.48361$$

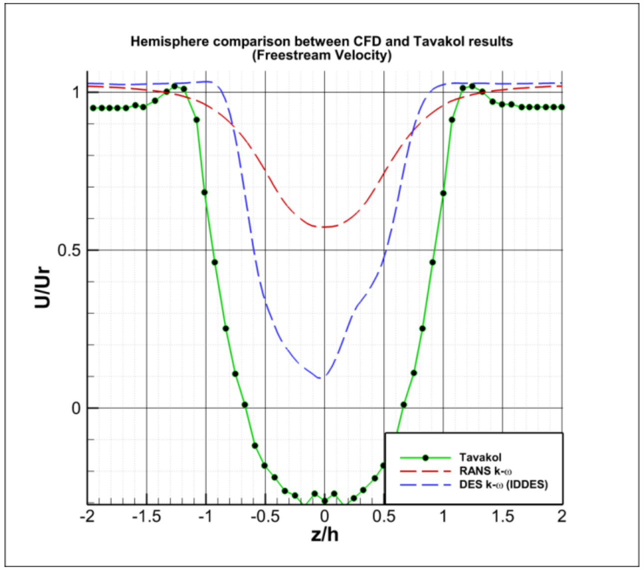


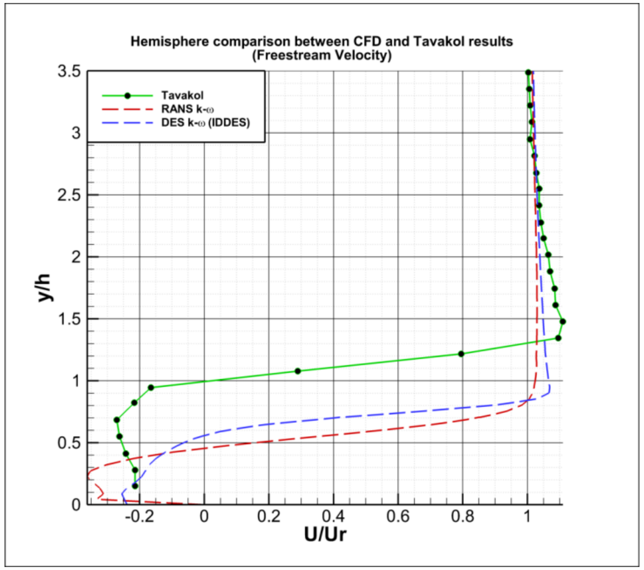


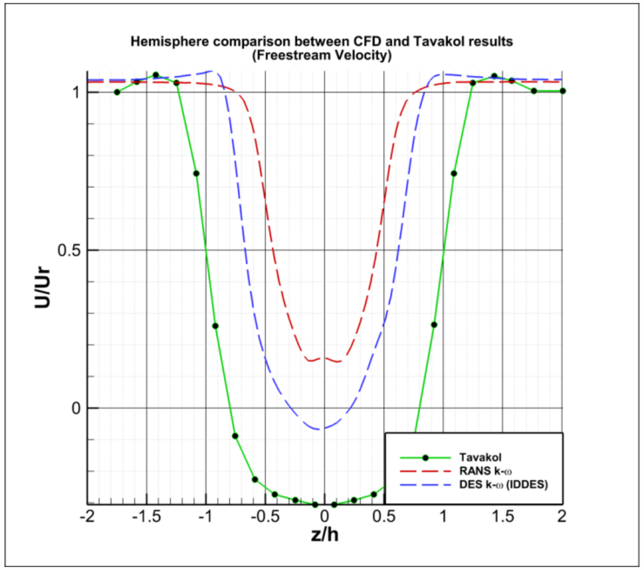


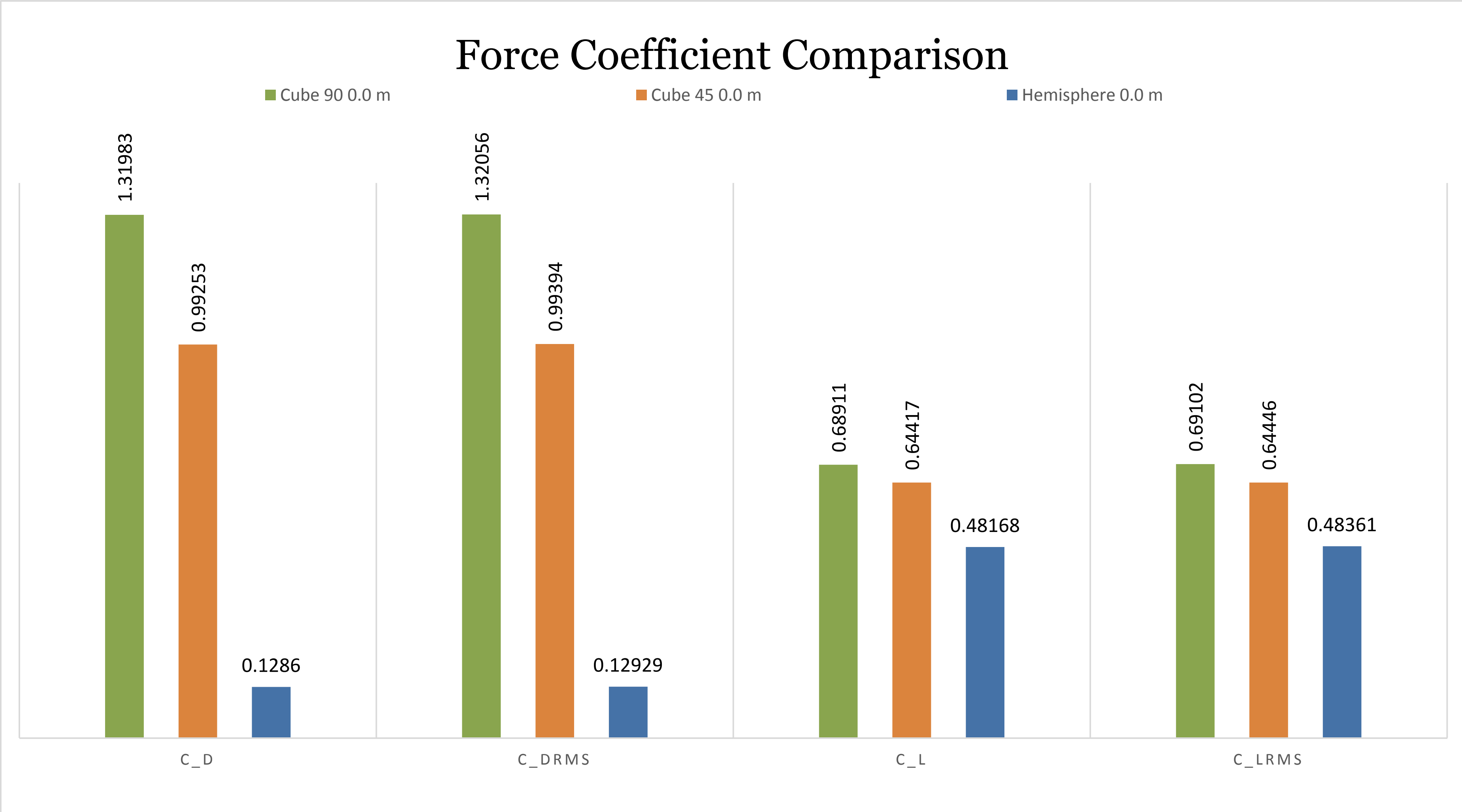
Results: Hemisphere with DES







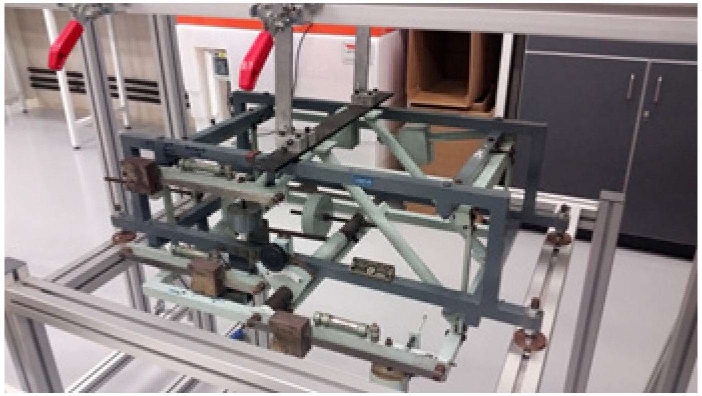




- Hemisphere has less lift and drag coefficient than the cube.
- Force coefficients is also dependent on the smoothness of geometry.

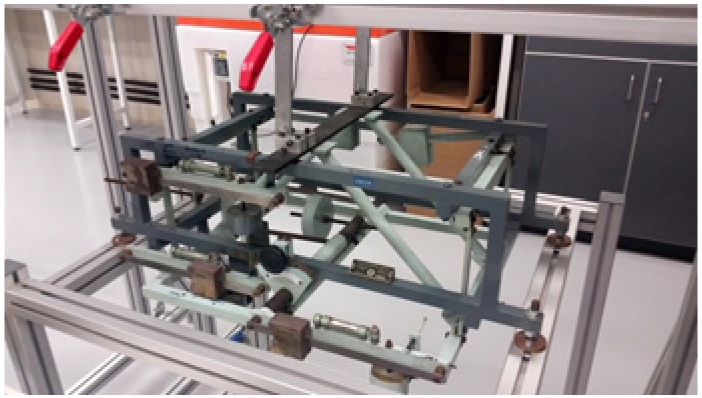
Summarised conclusions

- DES provides better results.
- Orientation, position and geometry can determine ballast flight occurrence.
- Flow structure is dependent on geometry.
- Force coefficients are greater on flat faced geometries than curved geometries.



Future work

- Work towards more complex problems using CFD.
- Resolve additional turbulence using LES.
- Generate scaled models of particles for Wind Tunnel testing.




ANY
QUESTIONS
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References

1) Castro I.P. & Robins A.G. (1977). The flow around a surface-mounted cube in uniform and turbulent streams, Journal of Fluid Mechanics, vol. 79, part 2.
2) Quinn A.D., Hayward M., Baker C.J., Schmid F., Priest J.A. & Powrie W. (2009). A full-scale experimental and modelling study of ballast flight under high-speed trains, IMechE Journal. vol. 224, part F.
3) Jing G.Q., Liu G.X., Lin J., Martinez J. & Yin C.T. (2014). Aerodynamic Characteristics of Individual Ballast Particle by Wind Tunnel Tests, Journal of Engineering Science and Technology, review 7, pp. 137-142.
4) Pen L.M.L., Powrie W., Zervos A., Ahmed S., Aingaran A. (2013) Dependence of shape on particle size for a crushed rock railway ballast, Granular Matter, Vol. 15, No. 6.