Study of the Interaction of Vortex Tubes with Suspended Dust Particles

Abd Awale, Aerospace Engineering
Mentor: Dr. Mohamed Houssem Kasbaoui, Assistant Professor
School for Engineering of Matter, Transport and Energy

Abstract

Vortex stability is a key area of interest. Vortical flows over aircraft wings at high angle of attack can enable the aircraft to perform maneuvers that are impossible otherwise. On the downside, vortices shed by aircrafts, the so-called wingtip vortices, are one of the main factors in limiting airport efficiency and induce contrail cirrus that persist for long durations in our atmosphere.(refer Figure 2) The research team proposed to investigate dispersing dust particles as a mechanism to increase the decay rate. The research goal was to investigate the role of Stokes number (a measure of particle inertia) on the decay rate of the vorticity while keeping the Reynolds number (a measure of non-linear convective effects) constant.This study found that

- particles with Stokes number (St) of .6 dissipate 40% of the vorticity after 3 seconds while St=8 only dissipates 20 % vorticity within the same time.
- Smaller particles have a more lasting effect than larger particles and dissipate the vorticity rapidly.
- Conversely, based on the volume fraction and the particle number density, large particles are shown to be quickly thrown outwardly in comparison to smaller particles.

Methodology

- Setup and conduct a suite of simulations on ASU's supercomputer AGAVE
- Vary the Stokes number (St) while keeping the Reynolds (Re) number and Volume Fraction constant while measure the decay rate
- Run NGA to solve governing equations, the Incompressible Navier-Stokes equation
- Extract data from simulations using big data methods: parallel and scalable rendering software VisIt, and a Fortran-MPI post-processing toolkit.

	Case 1	Case 2	Case 3	Case 4	Case 5
dp	10 μm	80 μm	180 μm	230 μm	300 μm
N Particles	1.8e6	28124	5552	3400	2000
		Non-Dimensional Numbers			
Re	5000	5000	5000	5000	5000
St	0.009	0.592	3	4.98	8.33
φ_p	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
M	0.83	0.83	0.83	0.83	0.83
$\mathcal{A}$	.04	.04	.04	.04	.04

Figure 1: Simulation Table

Results/Analysis

Volume Particle Fraction

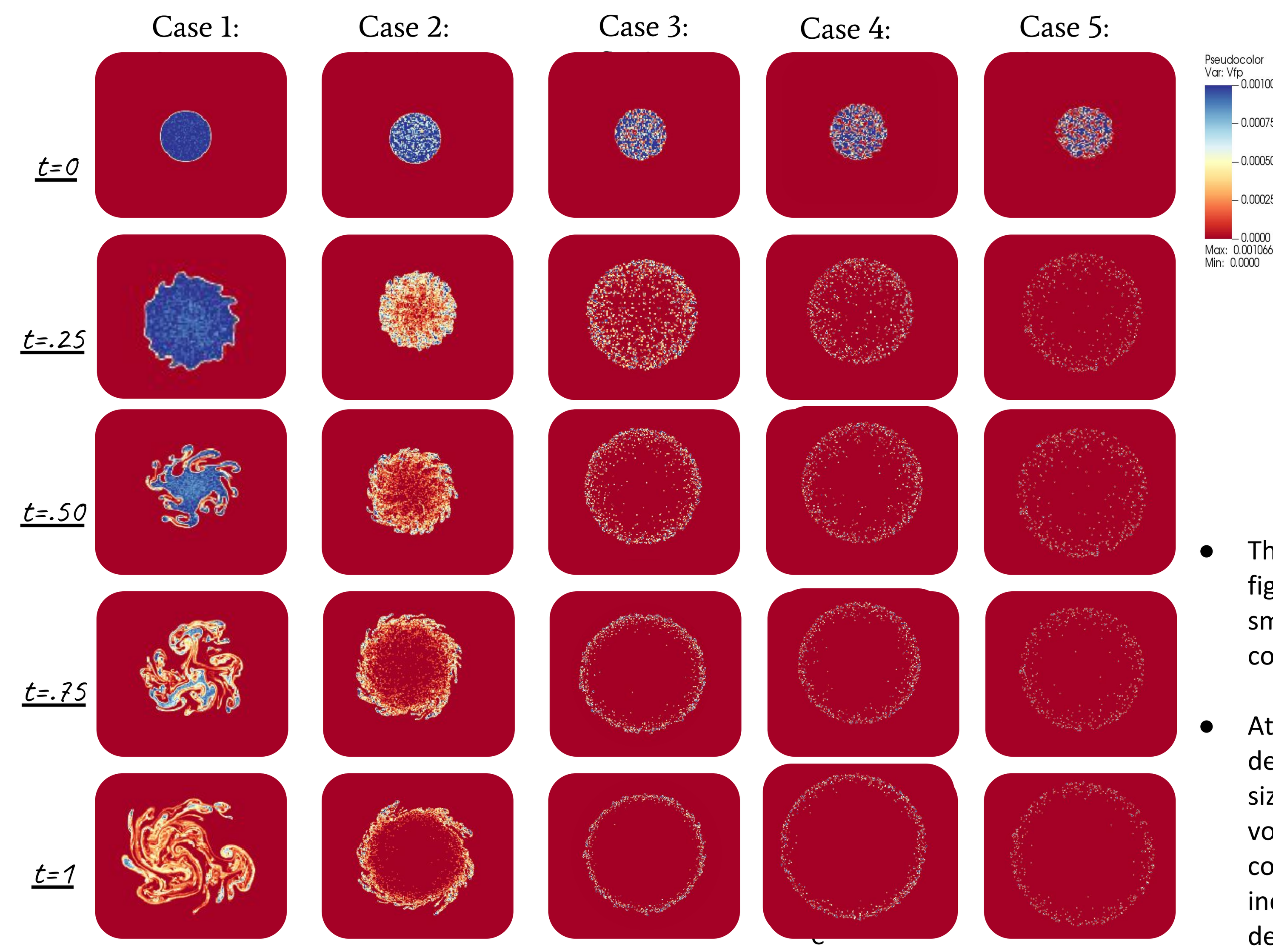
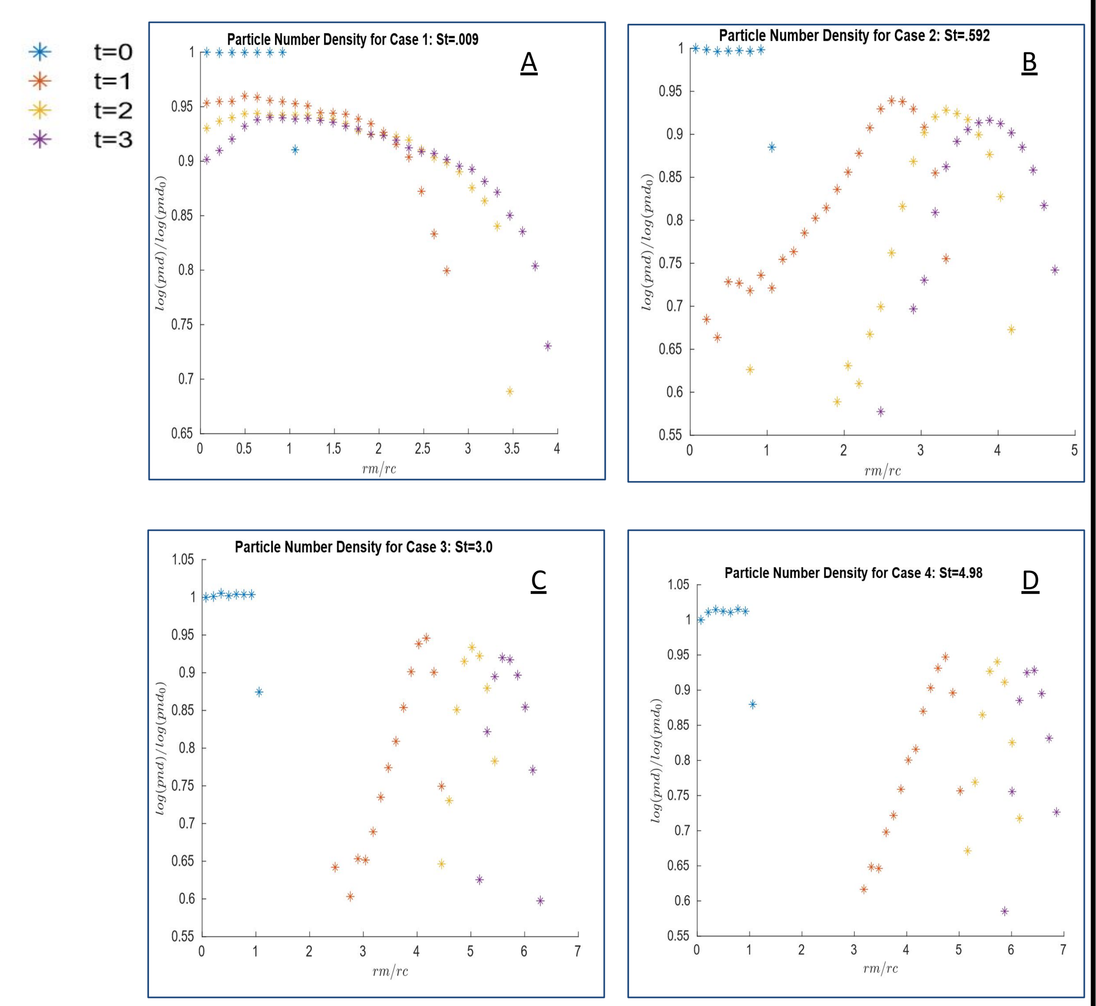


Figure 2: Wake Turbulence

- The Volume Particle Fraction figure to the left shows that smaller particles retain near the core longer than larger particles
- At the initial state, the particle density is adjusted with particle size because of the fixed volume. The smaller particles colors are more concentrated indicating a large particle density while larger particles seem to be faded.

- The figures A-D show how quickly particles are thrown outwardly. Larger particles are thrown outwardly faster than smaller particles
- At t=1s, St-.009 (Figure A) contains 95% of the particles while case 2 (Figure B) contains 75%. However, case 3 and 4(Figure C-D) contain 0% particles at the core after one second.
- Figure 3 below for Cases 2-5 show that the vorticity decreased faster compared to the Single Phase.
- Case 6, is the Single Phase Flow meaning it does not contain any dilute particles
- However, Case 1 indicates that the vorticity increases. Which requires further investigation



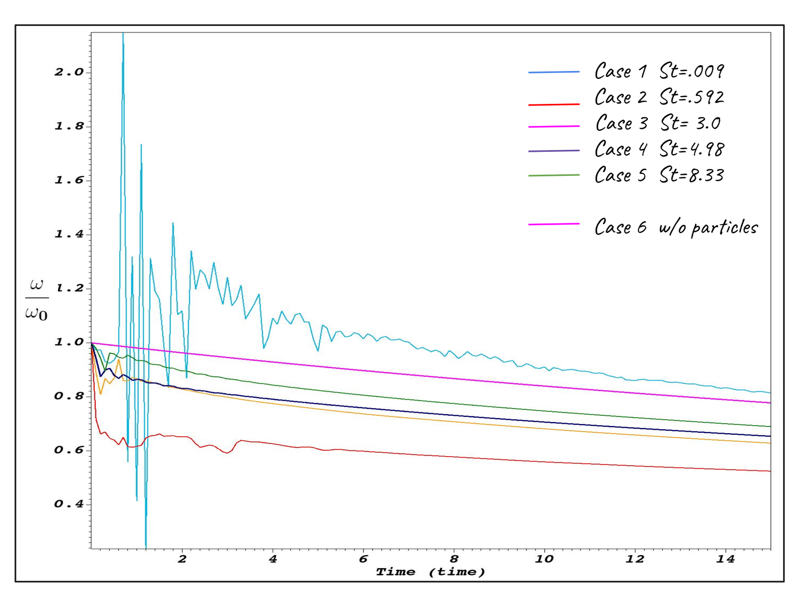


Figure 3: Vorticity at the core

Conclusion

The data collected from high-performing computing and images generated by the parallel and scalable rendering software Visit suggests that

- As particles size increase the quicker the particles are thrown outwardly as indicated in the particle number density over time.
- However, smaller particles have a more lasting effect and quickly dissipates the vortex. This can be observed in how the strength of the vorticity (ω) decreases.

Future Works and Limitations

- Experimenting with additional ways of disturbing a vortex tube using axial perturbation and observing the effects of three-dimensionality
- Observing a smaller regime of Stokes number and varying Reynolds Number
- Study the effects of polydispersity

Acknowledgements

I would like to take the time to express my sincere gratitude and appreciation to Dr Mohamed Houssem Kasbaoui and Shuai Shuai for the extensive guidance and assistance. It would have been impossible for me to finish this project without their continuous support.

Works Cited

[1] Paoli, R., & Shariff, K. (2016). Contrail Modeling and Simulation. Annual Review of Fluid Mechanics, 48(1), 393–427. doi: 10.1146/annurev-fluid-010814-013619

[2]Hu, X., & Zhang, G. (2018). Investigation of Lamb–Oseen Vortex Evolution and Decay in Ground Proximity With Obstacle. Journal of Fluids Engineering, 141(1). doi: 10.1115/1.4040441

FURI

Ira A. Fulton Schools of Engineering
Arizona State University