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

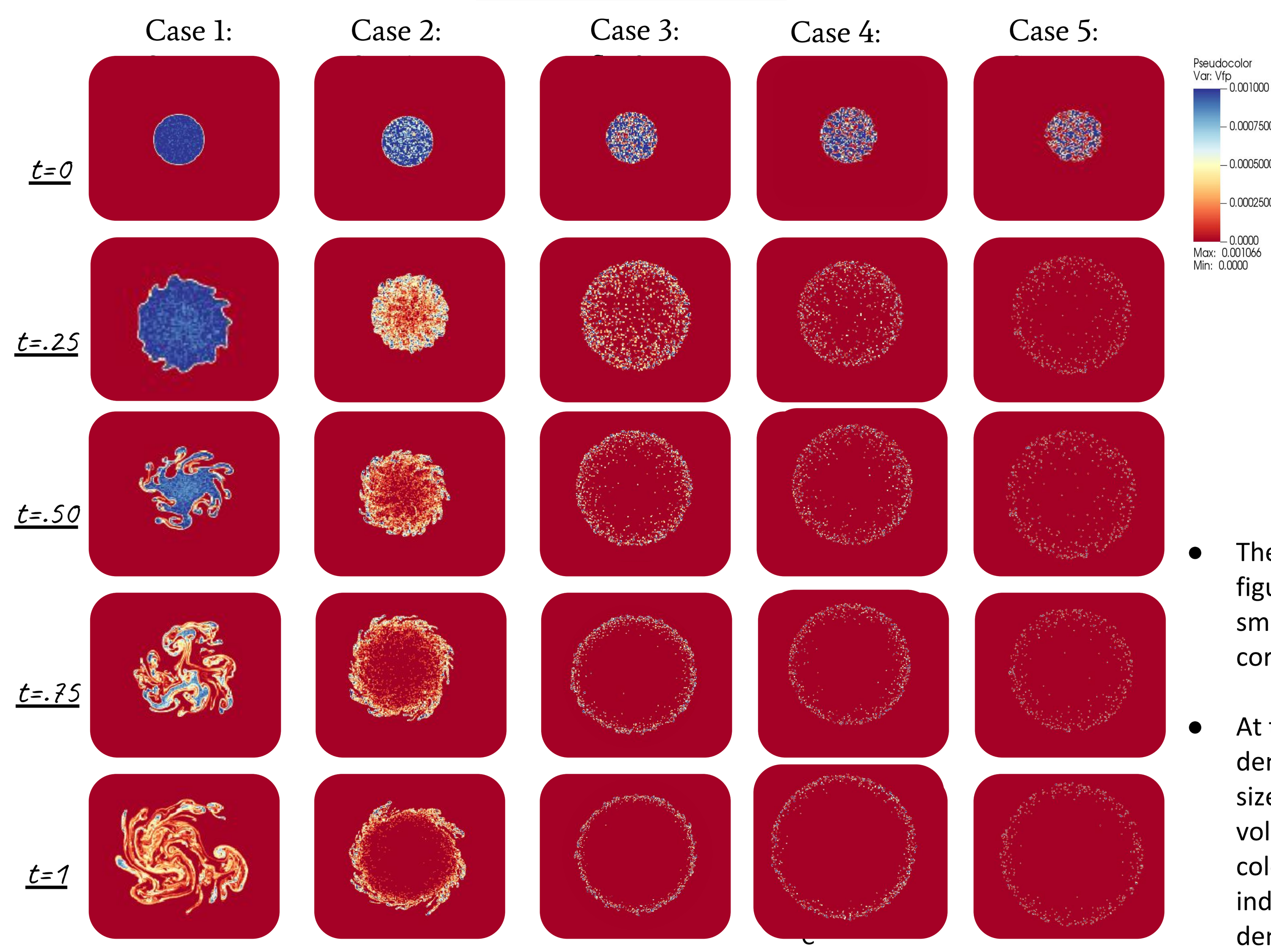


Figure 2: Wake Turbulence

- 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

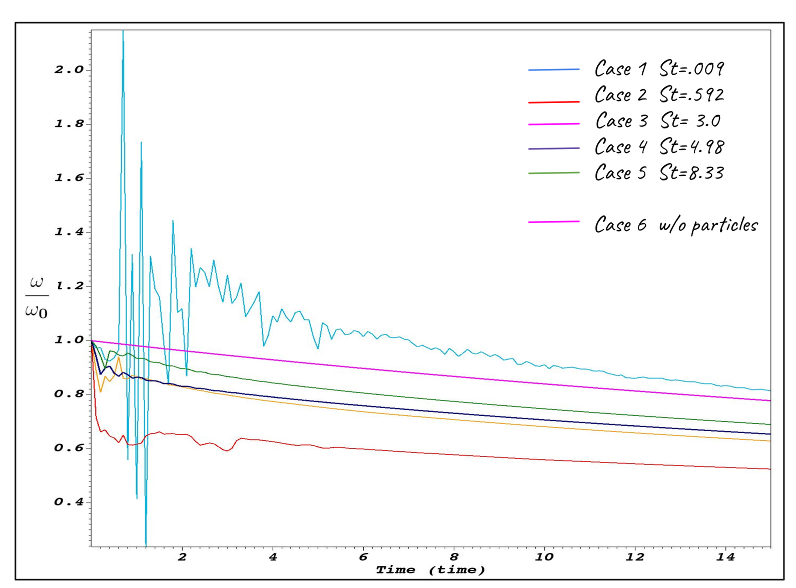
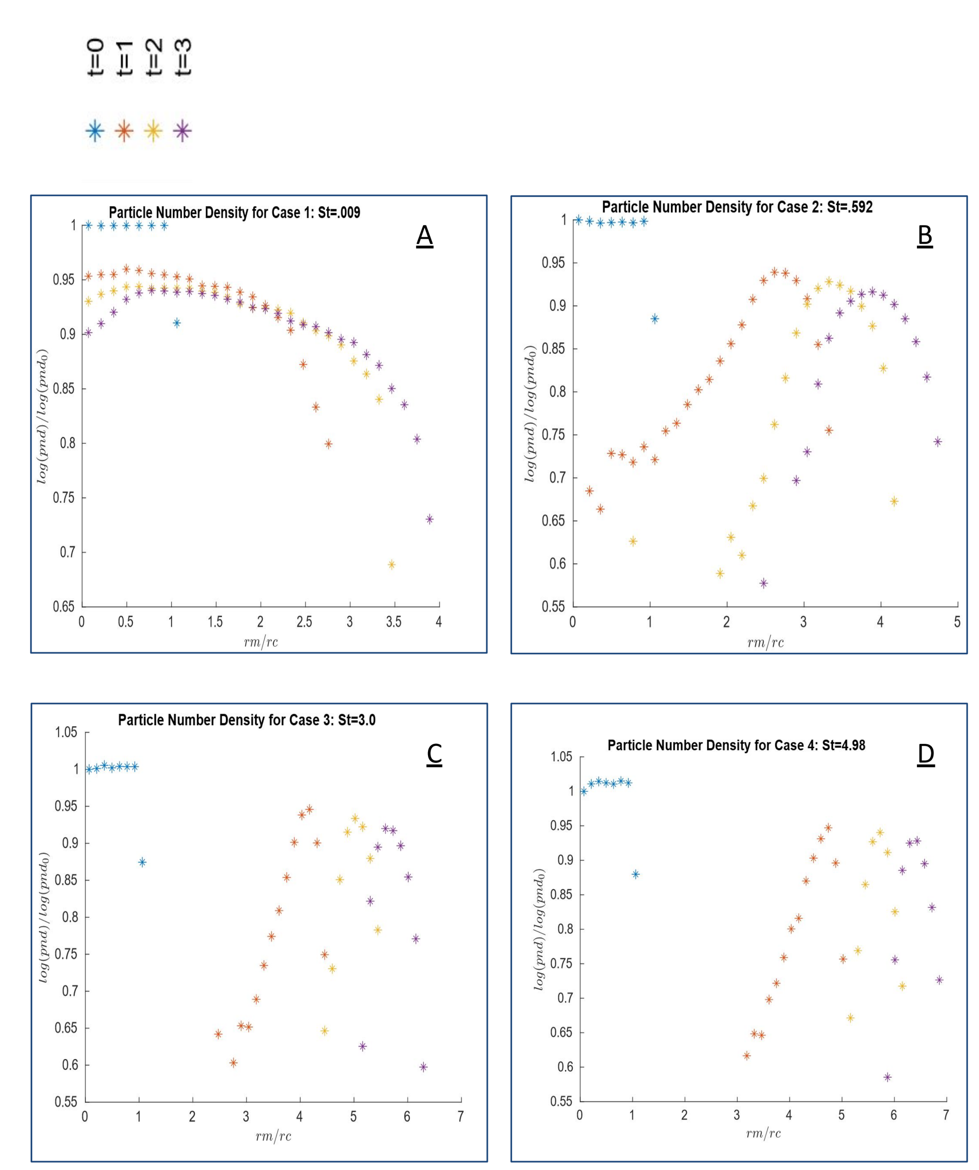


Figure 3: Vorticity at the core



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 (ɯ) 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

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[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

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Ira A. Fulton Schools of Engineering
Arizona State University

Study of the Effects of Polydispersity on Vortex Tubes

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

Abstract

This study explores polydispersity as a method of mitigating vortical flows. A cluster of particles with ranging sizes will be dispersed in the core of a vortex to observe the rate of dissipation and vortex evolution. One main motivation for this study is that vortices affect airport efficiency and persist in the atmosphere in the form of contrails. Despite this, currently, there is not an effective way to destabilize them. The research hopes to determine the best configuration of particle sizes that will efficiently dissipate a vortex, and analyze subtle interaction in multiphase flow. The experiment will utilize massive parallel simulations to solve nonlinear governing equations.

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.

Particle Class 1 has a Diameter(dp= 80 μm)

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

Figure 1: Simulation Table

Results/Analysis

- The vorticity over time for a monodispersity can be observed in figure 1. A it shows how the vorticity decreases over time and by decreasing the Stokes number the vorticity is dissipated more quickly. With the exception of Stokes number less than .01 it appears to increase the vorticity. It is important to note that, case 2 Stokes number 0.592 performs the best and dissipates 40% of the vorticity after 3 seconds while the largest Stokes number St=8 only dissipates 20% of the vorticity.

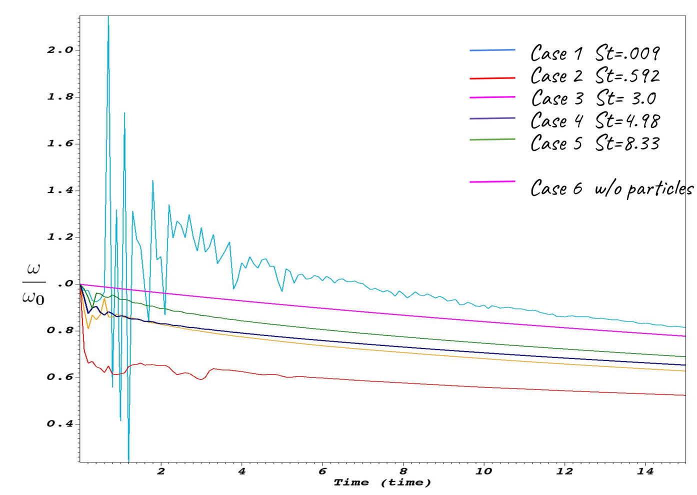
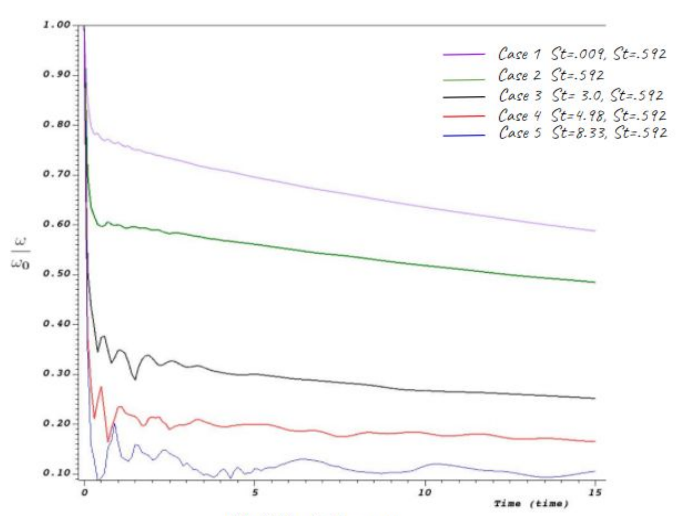
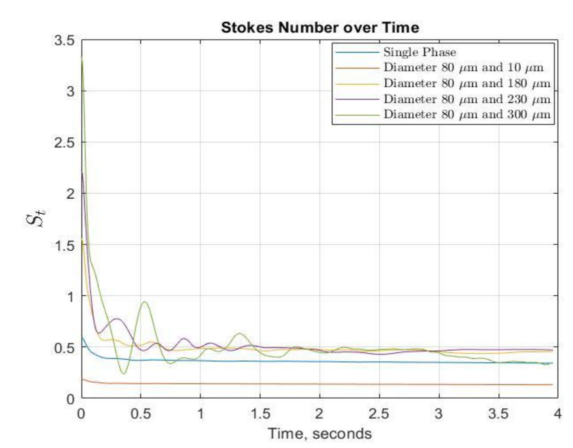
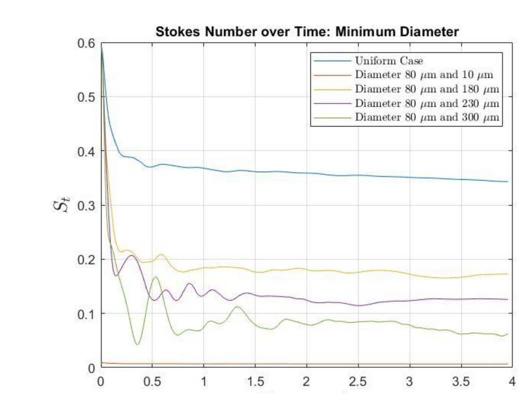


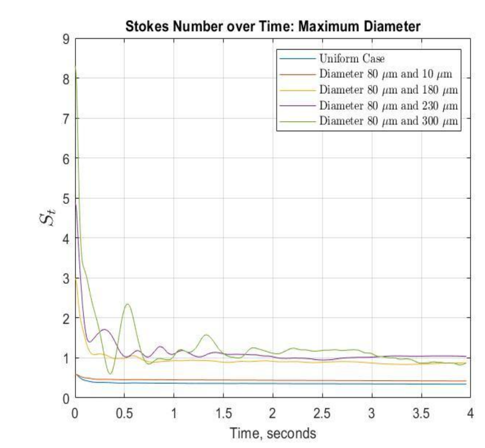
Figure 3: Vorticity at the core



Vorticity at the core

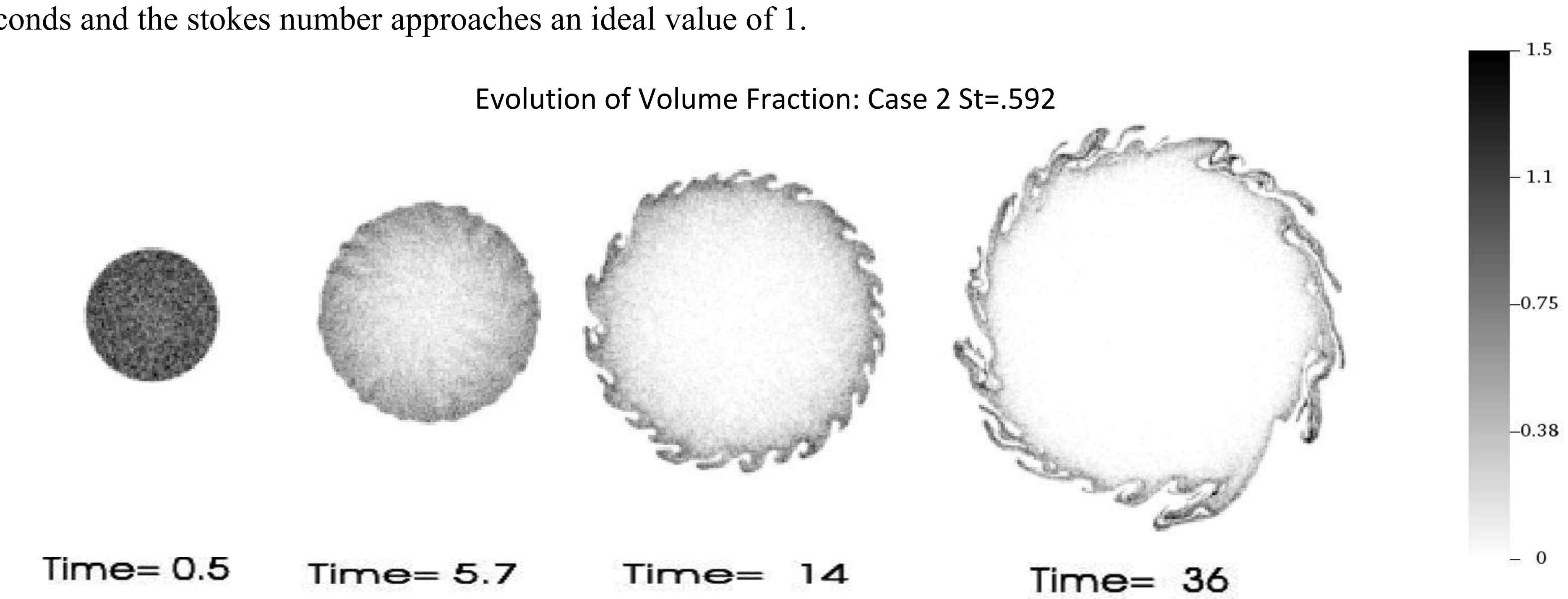






- The Stokes number is calculated as the particle response time over the fluid response time. The fluid response time is found by two over the vorticity.
- The minimum diameter used is the smallest diameter between the two classes of particles. The effects of smaller particles are shown in Figure 2.B; It appears that smaller particles have an effect initially for times between 0 to .5 seconds. On the other hand, observing Figure 2.C it showcases how larger particles have a dominant effect after .5 seconds and the stokes number approaches an ideal value of 1.

Evolution of Volume Fraction: Case 2 St=.592



Conclusion

- The data suggest that polydispersity alters the flow of the fluid such that it changes the time scale. In the earlier stages of the flow the smaller Stokes number have an effect over the larger classes of particles as can be seen in how the plots all collapse in one region and appear to be linear.
- In contrast to the monodispersed particles, polydisperse particles with larger classes of particles mixed with smaller particles have a more lasting effect in dissipating the vortex. Larger particles alter the flow fluid rather than being quickly thrown out as observed in the monodisperse case. .
- Polydispersity seems to be the most effective method in midgiating vortical flows and can be delivered by a spray.

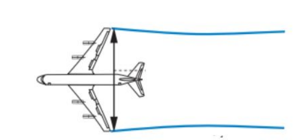
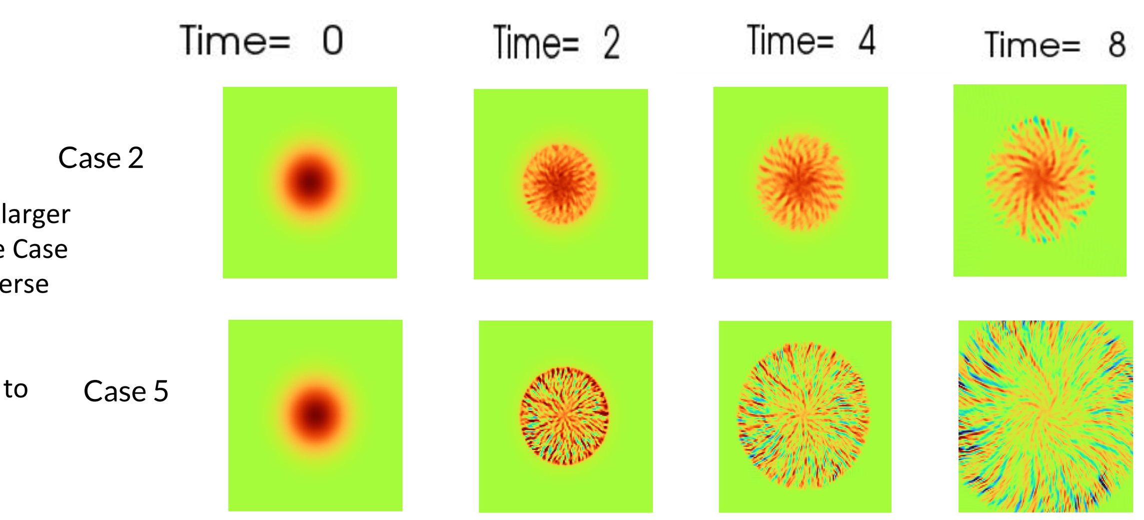


Figure 2: Wake Turbulence

- Case 5 is the polydisperse particles with larger particles while Case 2 is monodisperse particles.
- Polydisperse particles start to dissipate



Evolution of Vorticity over Dimensionless Time

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

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