Asymmetric Vortex Interactions in the Presence of Background Shear

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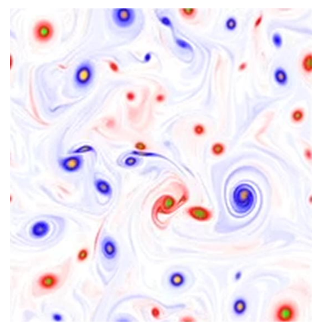
Introduction



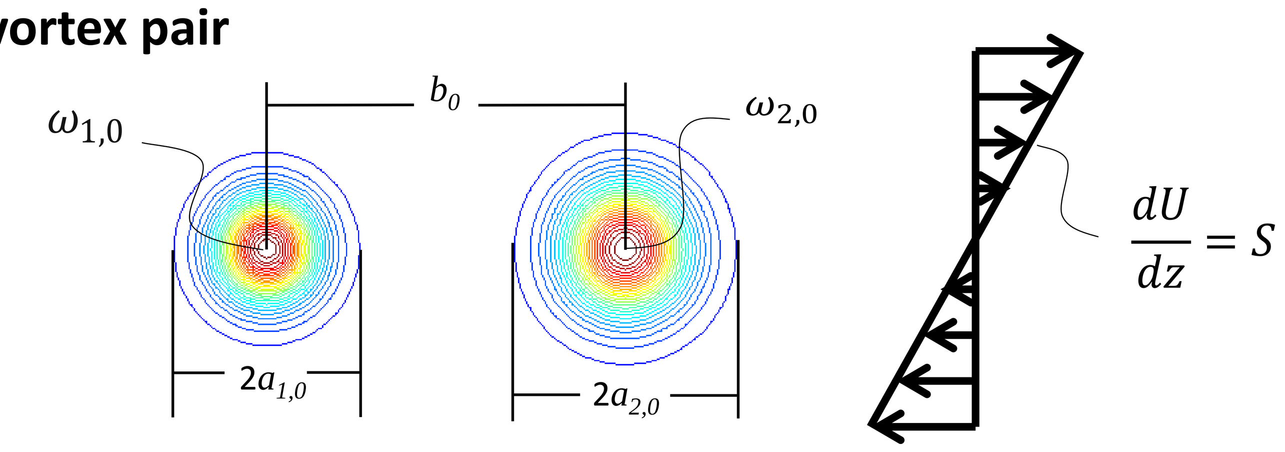
Studying fundamental vortex interactions aids understanding of more complex flows such as 2D turbulence

Most previous work has focused on isolated, symmetric vortex pairs

In order to better model vortices in turbulence, effects of asymmetry and distant vortices must be considered

Objective: characterize interactions of viscous unequal vortices in background shear

Approach: 2D numerical simulation of a co-rotating vortex pair



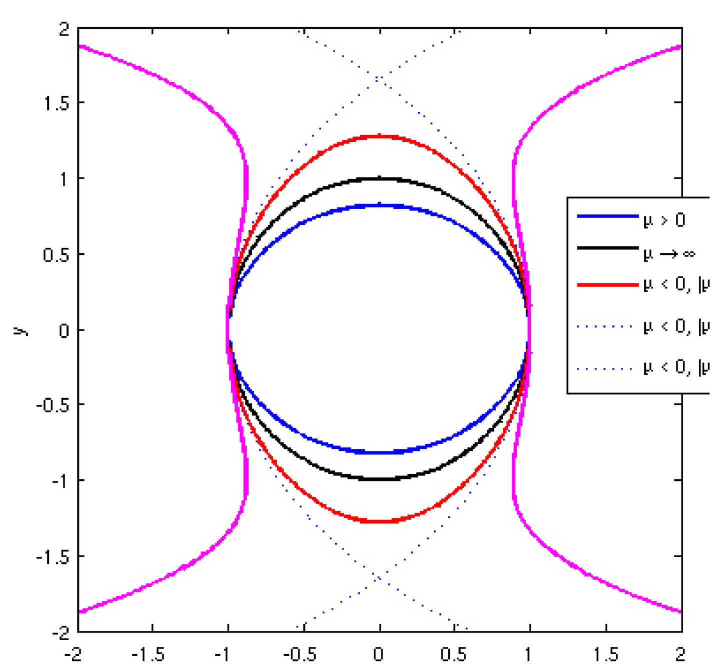
Flow Parameters:

Aspect Ratio:	$a_{2,0}/b_0 = 0.157$	**Reynolds Number:**	$Re = \frac{\pi a_{2,0}^2 \omega_{2,0}}{\nu} = 5000$
Radius Ratio:	$a_{1,0}^2 / a_{2,0}^2$	**Peak Vorticity Ratio:**	$\omega_{1,0}/\omega_{2,0} = 1$
Shear Ratio:	$\chi = \frac{\omega_{2,0}}{S}$		

Point Vortices in Shear

Trajectories of two equal point vortices in uniform shear can be computed for different strengths and shear, i.e. $\Gamma/b_0^2 S$

Let $\mu \equiv \frac{\Gamma}{b_0^2 S}$



Based on the method described in Kimura and Hasimoto, JPSJ, 1985 and Trieling et al., Phys. Fluids, 2010

Favorable Shear ($\mu > 0$): Closed circuit with minimum b(t) at $\pm\frac{\pi}{2}$

No Shear ($\mu \to \infty$): Circular orbit

Adverse Shear ($\mu < 0$):

- $|\mu| < |\mu_c|$: Closed circuit with maximum b(t) at ±
- $|\mu| > |\mu_c|$: Separative motion

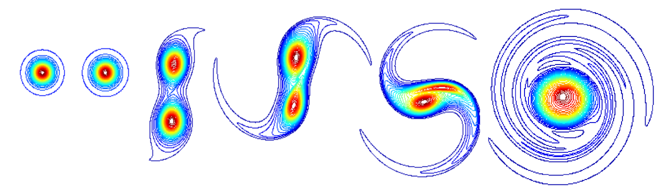
Viscous Vortex Pairs Without Shear

(Brandt and Nomura, JFM, 2010)

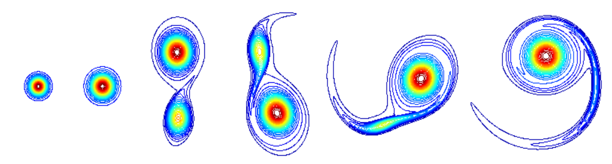
Symmetric pairs will eventually merge since viscous core growth a(b) will cause attainment of **critical merging distance $(b/a)_c$**

Asymmetric interactions depend on relative timing of detrainment and destruction

If both vortex cores detrain, **partial merger** results $\left(\frac{a_{10}}{a_{20}}\right)^2 = 0.9$



If one core detrains sufficiently earlier than the other, it can be **strained out** and destroyed – no merger occurs $\left(\frac{a_{10}}{a_{20}}\right)^2 = 0.56$



Preliminary analysis suggests that if the strain rate parameter of vortex *i*, reaches a critical value of about 0.247 ± 0.007, detrainment of vortex *i* begins

Strain Rate Parameter

$$\gamma_i = \left(\frac{\text{Normalized Strain at CH}}{\text{Normalized Peak Vorticity of Vortex } i}\right)^{\frac{1}{2}}$$

For symmetric vortices, the critical strain rate parameter γ_c is directly related to $(b/a)_c$

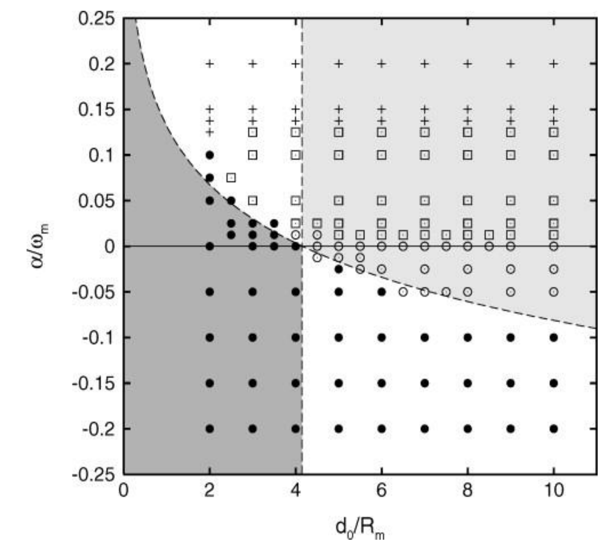
Inviscid , Symmetric Vortex Pairs in Shear

(Trieling et al., Phys. Fluids, 2010)

Simulations of inviscid Lamb vortices in background shear identified four interaction regimes:

I. Separation with elongation (+)
II. Separation without elongation (□)
III. Periodic motion (○)
IV. Merger (●)

Regime boundary between merger and no merger predicted well by point vortex trajectories and $(b/a)_c$ for non-sheared vortices



Regime diagram for Lamb vortices in shear. Reproduction of Fig. 9 from Trieling et al. 2010

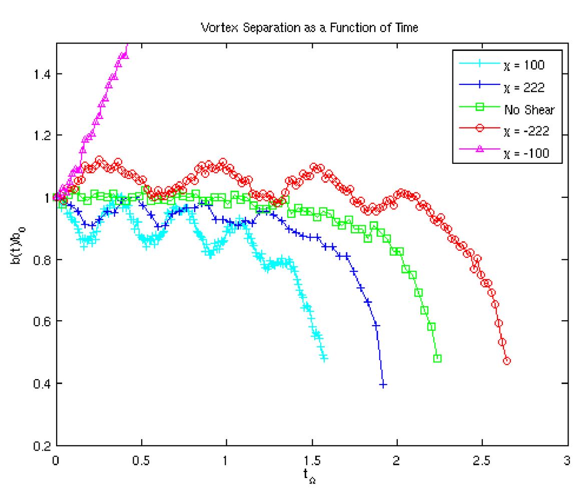
Viscous Vortex Pairs in Shear

During viscous phase (a(t) increasing), as vortices rotate, separation b(t) varies as described by point vortex pair in shear

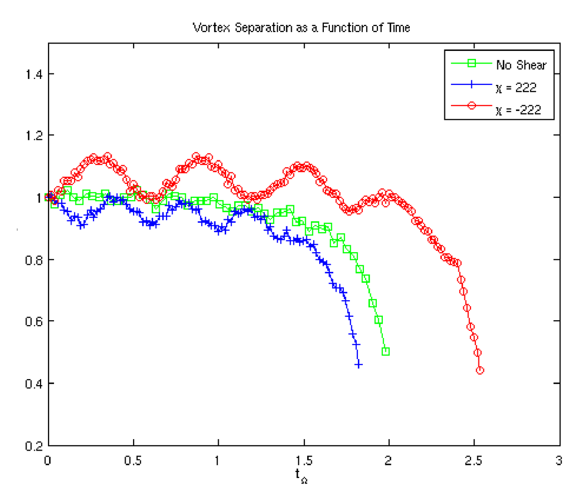
For **favorable/adverse (weak)** shear, this effectively **increases/reduces** the time to **start of detrainment** for one or both cores

For **strongly adverse** shear, vortices **separate or are destroyed**

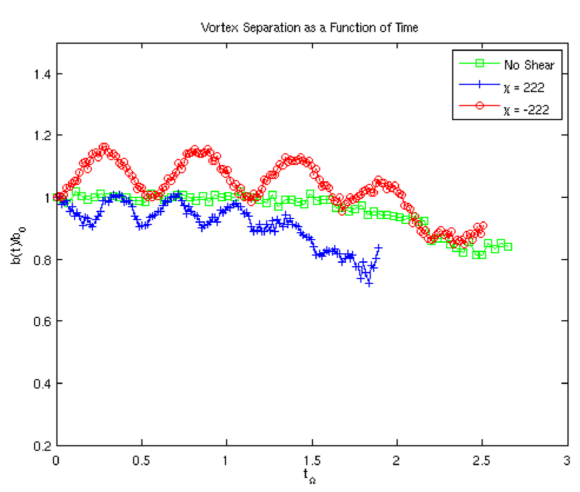
$(r_1/r_2)^2 = 1.0$



$(r_1/r_2)^2 = 0.9$

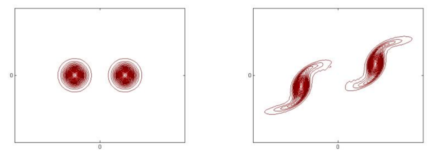


$(r_1/r_2)^2 = 0.7$



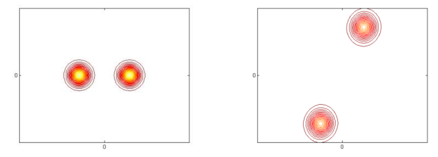
Observed Interaction Regimes

Separation With Elongation:



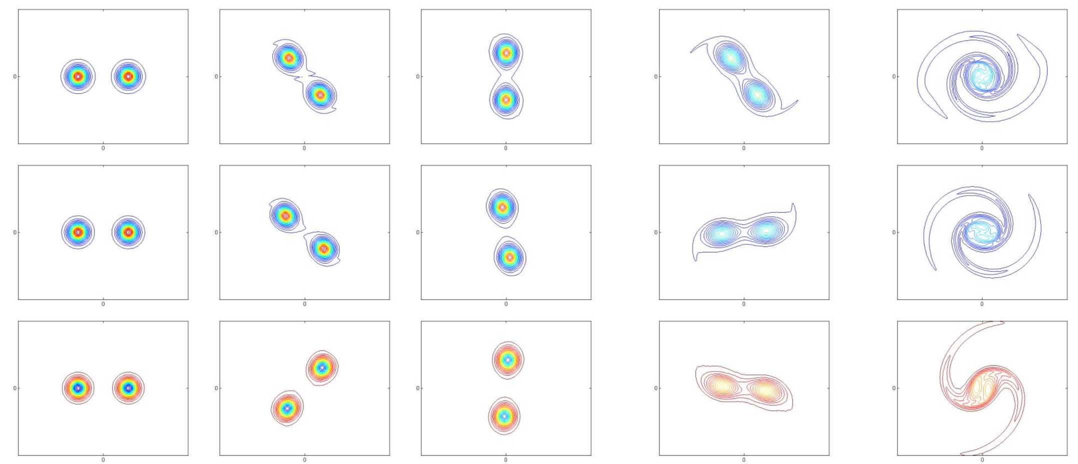
X = -10, $(r_1/r_2)^2 = 1$

Separation Without Elongation:



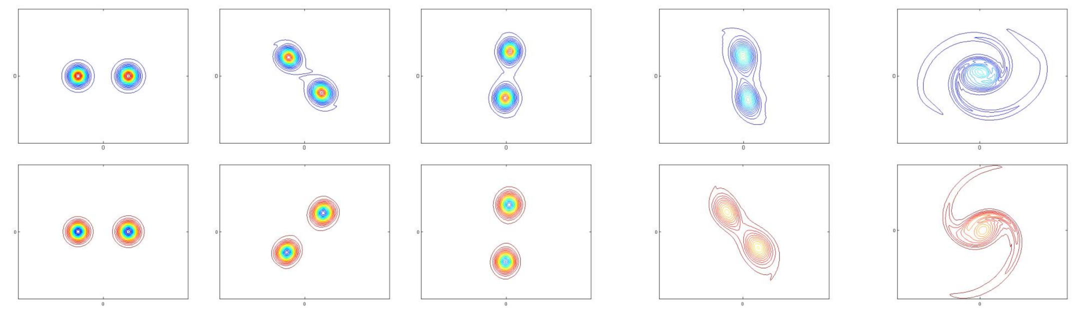
X = -100, $(r_1/r_2)^2 = 1$

Merger: (Symmetric Pair)



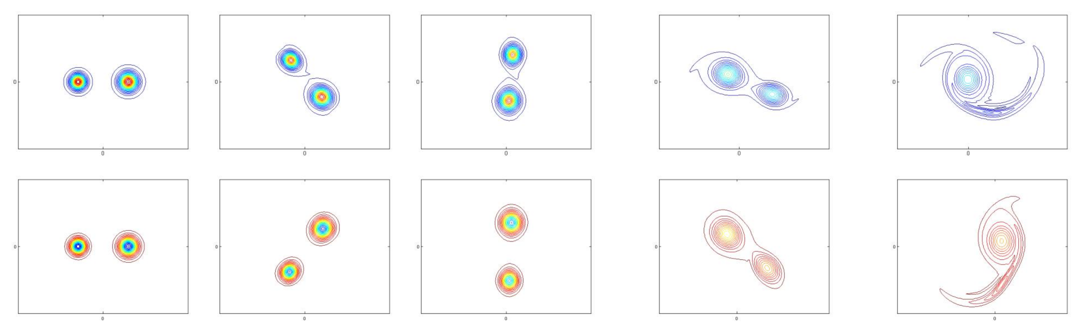
X = 222,
X →∞ (No Shear)
X = -222

Merger: (Asymmetric Pair)



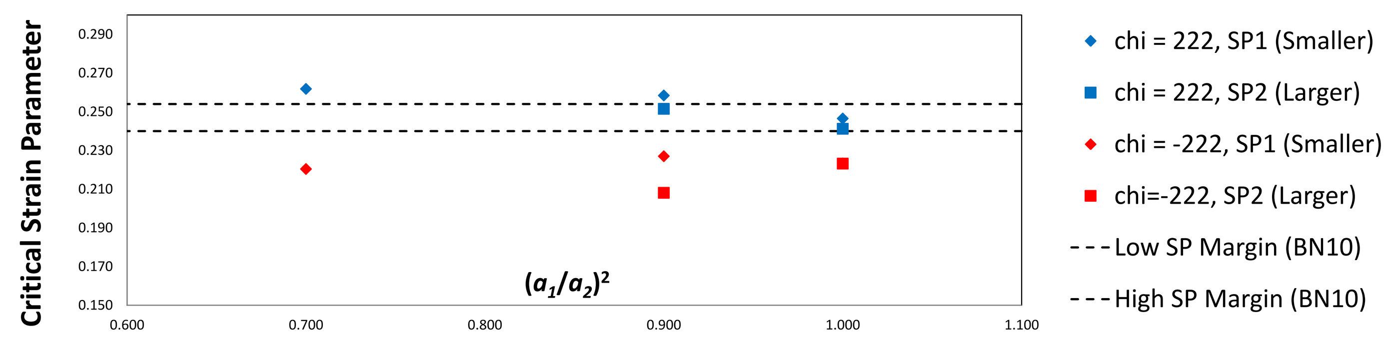
X = 222, $(r_1/r_2)^2 = 0.9$
X = -222, $(r_1/r_2)^2 = 0.9$

Straining Out:



X = 222, $(r_1/r_2)^2 = 0.7$
X = -222, $(r_1/r_2)^2 = 0.7$

Strain Rate Parameter



Summary

- Viscous vortex interactions develop in time due to effects of diffusion (**a(*t*)**) and shear (**b(*t*)**)
- For **symmetric pairs**, **cooperative/adverse** shear may **accelerate/delay** eventual **merger**
- For **asymmetric pairs**, shear may **accelerate/delay detrainment** process. This could potentially result in different outcomes
- Preliminary results indicate that γ_c does not accurately characterize the start of the detrainment process , but must be modified to account for shear
- **Future work:** extend the vortex pair parameter range and investigate physical mechanisms more deeply

References

1. Brandt, L. K., & Nomura, K. K. (2010). Characterization of the interactions of two unequal co-rotating vortices. *Journal of Fluid Mechanics*, *646*, 233.
2. Trieling, R. R., Dam, C. E. C., & van Heijst, G. J. F. (2010). Dynamics of two identical vortices in linear shear. *Physics of Fluids*, *22*, 117104.
3. Flow, S. S. (1985). Motion of two identical point vortices in a simple shear flow. *Journal of the Physical Society of Japan*, *54*(11), 4069-4072.