

Titles of all posts: Please make 1 sentence descriptions.

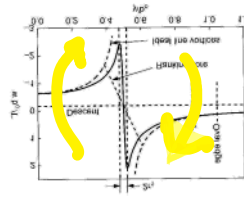
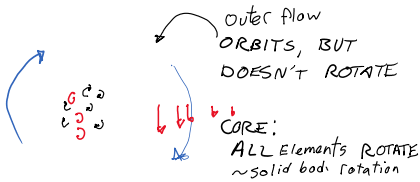
Resubmissions: Both on FV.org and Canvas

- Today:
- Vorticity
- Explosions: BLEVEs

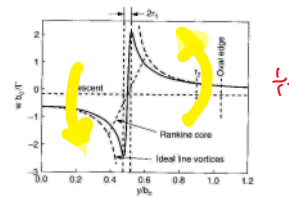
Vorticity = rotation of a fluid element around its own middle

Vortical fluid = fluid with vorticity

Vortex = Vortical fluid (vortex core), often surrounded by irrotational (non-vortical) fluid



McLean, Doug. *Understanding Aerodynamics Arguing from the Real Physics*. Chichester: Wiley-Blackwell, 2013.



<http://www.youtube.com/watch?v=loCLkcYEWD4>

2:28 - 6 min, vorticity in boundary layer, then irrotational flow around bathtub vortex.

<http://www.youtube.com/watch?v=JI0M1gVNhbw>

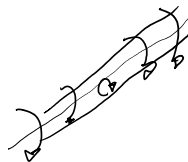
Parody of NCFMF

<http://mccabism.blogspot.com/2014/01/red-bulls-y250-and-batchelor-vortex.html>

Nice, short vortex model discussion.

Vortex and vorticity behaviors. Watch for them.

1. Vorticity is created only at boundaries



Math& physics references:

- Panton, Ronald L. *Incompressible Flow*. 3rd ed. Wiley, 2005. New edition will have FV image in it.
- Batchelor, G. K. *An Introduction to Fluid Dynamics*. Cambridge University Press, 2000.
- McLean, Doug. *Understanding Aerodynamics Arguing from the Real Physics*. Chichester: Wiley-Blackwell, 2013.

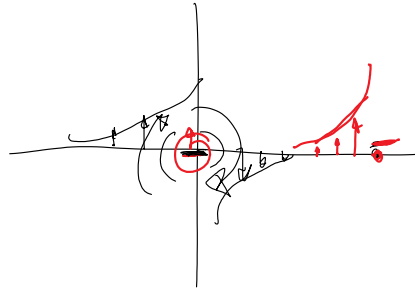
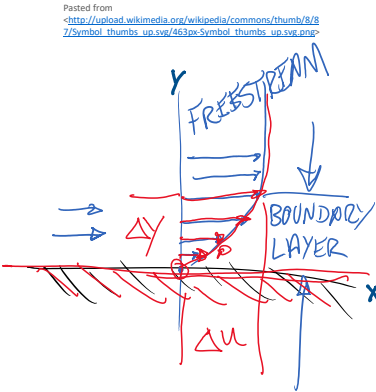
Use right-hand rule to keep track of vorticity



$$\text{vorticity} = \omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

$$\frac{du}{dy}$$

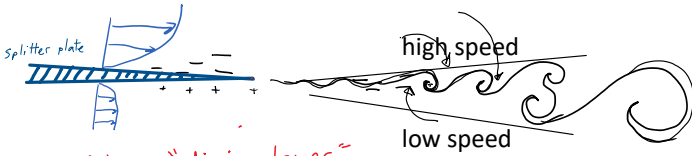
$$\frac{\Delta u}{\Delta y}$$



Boundary layer. Vorticity (negative)

is generated at the wall, diffuses outward via viscosity

Free shear layer



A.K.A "Mixing layer" or Shear layer

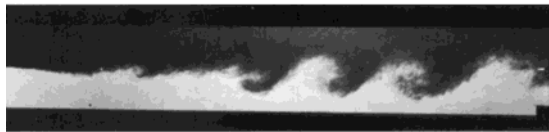
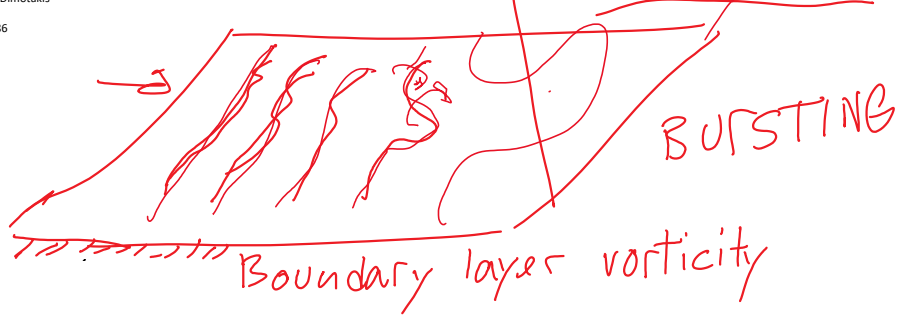
high speed
low speed



(a)

<https://www.dimotakis.caltech.edu/facilities.html>
Prof. Paul Dimotakis
Cal Tech
AIAA J 1986

horseshoe vortex

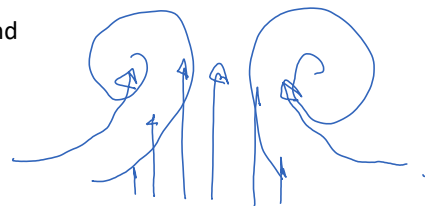


(b)

https://www.researchgate.net/figure/Turbulent-shear-layer-a-Gas-layer-shadowgraph-upper-stream-nitrogen-U-1000_fig1_231893459

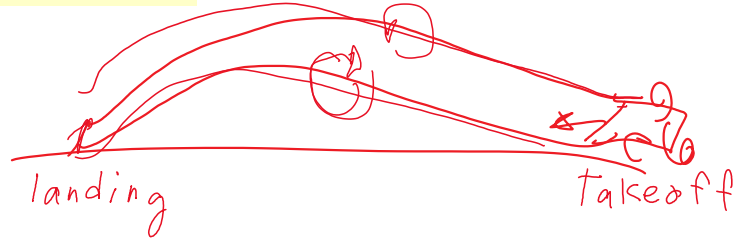
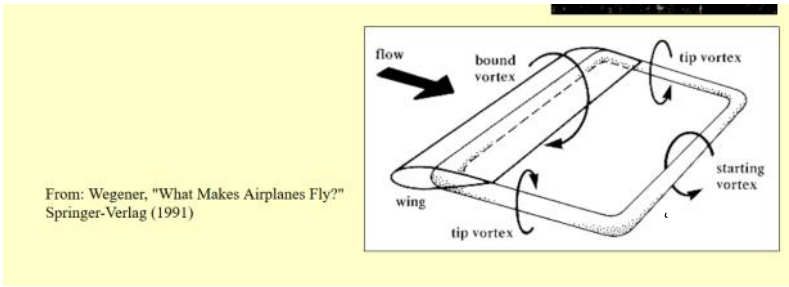
Shear layer. Vortex sheet is unstable, rolls up into vortices (Kelvin-Helmholtz instability), which then pair and form larger vortices. This is how shear layers grow. *Hydrodynamic stability theory* can predict initial roll-up frequency, spacing.

Ref: Drazin, P. G., and W. H. Reid. *Hydrodynamic Stability*. 2nd ed. Cambridge University Press, 2004.

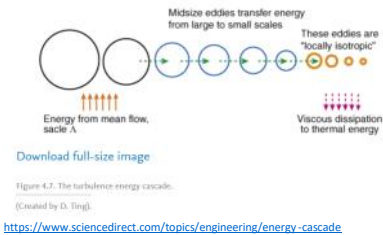


2. Vortex lines (along the vortex axis) must end at a surface, or form a loop. Can't end in the

middle of a fluid.



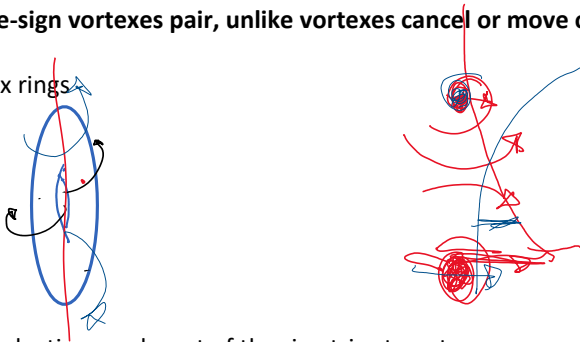
3. Viscosity makes vorticity diffuse, spread. Will eventually make a vortex die.



Kolmogorov scale

4. Like-sign vortices pair, unlike vortices cancel or move off together.

Vortex rings

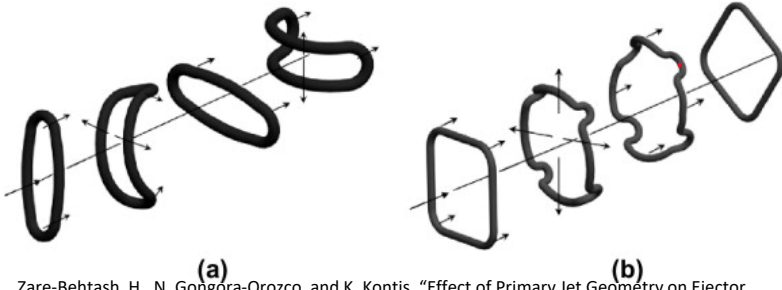


Self-induction: each part of the ring tries to get the rest of the ring to rotate around it. Net result: every part of the ring moves forward the same.

Strength of the self induction goes up as ring curvature tightens: small rings go faster

Elliptic rings: high curvature parts move ahead, increasing

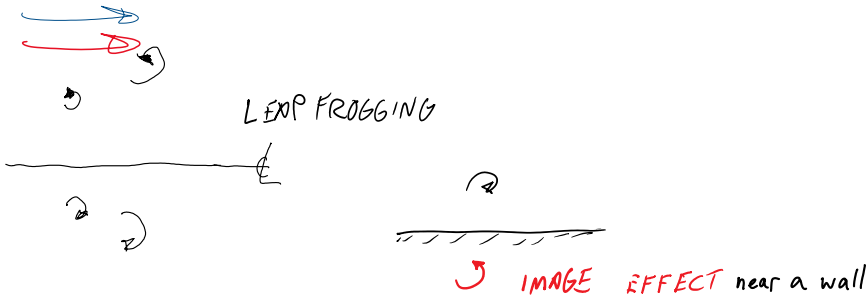
curvature on the straighter parts, which then speed up.



Zare-Behtash, H., N. Gongora-Orozco, and K. Kontis. "Effect of Primary Jet Geometry on Ejector Performance: A Cold-flow Investigation." *International Journal of Heat and Fluid Flow* 32, no. 3 (June 2011): 596–607. doi:10.1016/j.ijheatfluidflow.2011.02.013.

Major axis becomes the minor = axis switching.
Up to 7 switches have been seen.

Other interesting vortex ring behaviors:

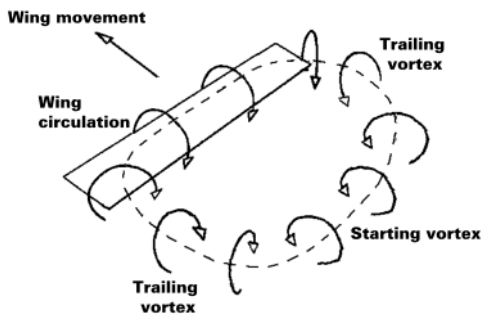


<https://www.youtube.com/watch?v=DLozDMTWNRk>

Very short and fast example

<https://www.youtube.com/watch?v=EISHbRxgi-8> Extraordinary vortex rings. Leapfrogging doesn't show net motion. Has dolphins.

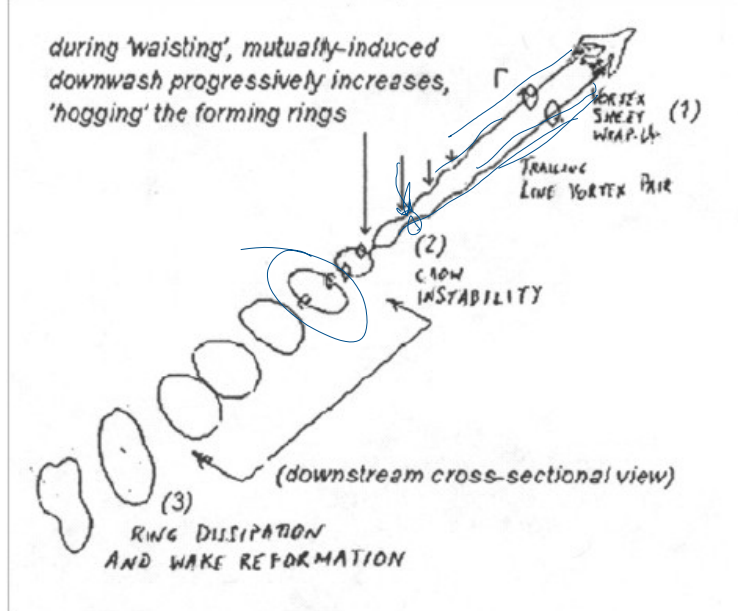
Contrails are long parallel vortex pairs. Loop forms starting with takeoff, ends on landing



<http://www.regenpress.com/>

The Crow Instability Process

'An instant flurry would likely be the GO trigger to commence reactive control inputs.'



A trailing pair of wake vortices can merge into a series of vortex segments inclined more or less vertically. Hence, upon climb-out, a following aircraft at two-minute takeoff separation could encounter a preceding wake which is not a stable vortex pair, but which is in a state of breakdown or transition. Source: Brown, in NTSB Docket No. SA-522, Exhibit 2-X, Aug. 2002

http://www.iasa-intl.com/folders/the068event/587crows-1_files/crowinstab-1.jpg



<http://www.images.bizhertzberg.com/CloudAnimation1920.gif>

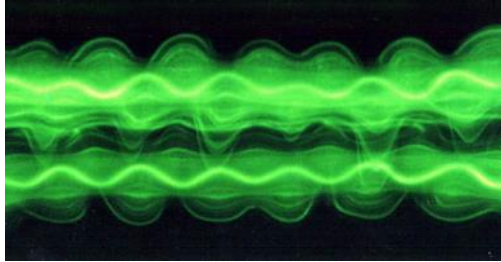
[Crow Instability Explained | Aero Fundamentals #65 |](#)





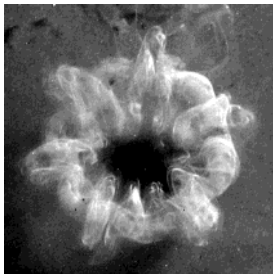
<http://science-edu.larc.nasa.gov/contrail-edu/science.php>

Persistent spreading contrail



Crow (1970) and Widnall et al (1974)

http://www.efluids.com/efluids/gallery/gallery_pages/pair_instability_page.jsp



Widnall instability, loops on a vortex ring

https://en.wikipedia.org/wiki/Sheila_Widnall



MIT aerospace professor. Secretary of the Air Force, 1993 - 1997

<http://iopscience.iop.org/1873-7005/44/1/015501/article> Collision of vortex ring and granular layer

<http://www.flamingtornado.com/> Fire art by Nate Smith

<http://www.youtube.com/watch?v=fTIW1zucWn8&list=UUj7HhOIDAW1fmoXhhPtnTEw&feature=c4-overview>

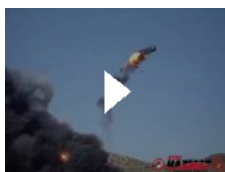


BLEVE: Boiling Liquid Expanding Vapor Explosion

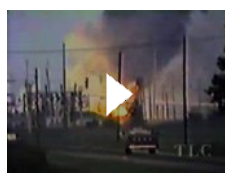
BLEVE (Boiling Liquid Expanding Vapor Explosion) Demonstration - How It Happens Training Video, 2009.

http://www.youtube.com/watch?v=UM0jtDOWL&feature=youtu_gdata_player.

[BLEVE of a tank car \(unknown place\)](#)



[Train Car Explosion Bleve](#)



Tank flew 3/4 mile

[BLEVE Explosion of 100 LB Propane Tank](#)

