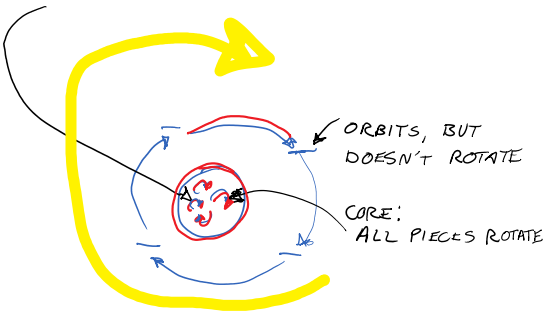
25.Vorticity
Friday, November 20, 2020 11:53 PM

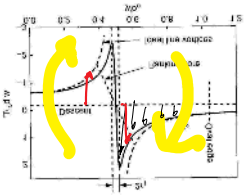
Titles of all posts: Please make 1 sentence descriptions
Resubmissions: Both on FV.org and Canvas
Equipment exchange this afternoon?

ME front desk W end of ME Hallway E.C. NW wing

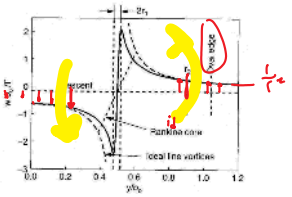
- Today:
- VORTICITY

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

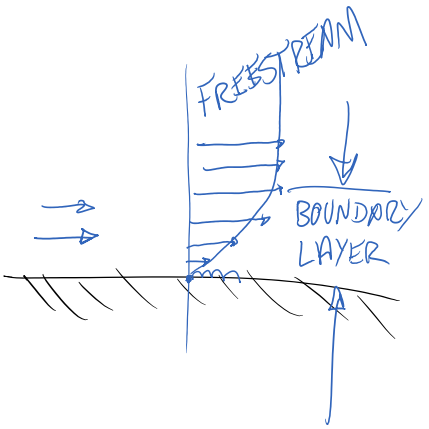




McLean, Doug. *Understanding Aerodynamics Arguing from the Real Physics*. Chichester: Wiley-Blackwell, 2013.

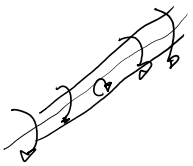


http://www.youtube.com/watch?v=loCLkcYEWD4 3:30 - 6 min, vorticity in boundary layer, then irrotational flow around bathtub vortex.
http://www.youtube.com/watch?v=JI0M1gVNhbw Parody of NCFMF
http://mccabism.blogspot.com/2014/01/red-bulls-y250-and-batchelor-vortex.html Nice, short vortex model discussion.



Vortex and vorticity behaviors. Watch for them.

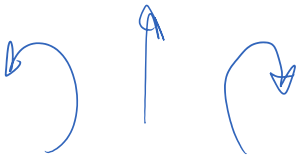
1. Vorticity is created only at boundaries



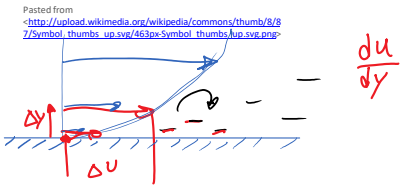
Math& physics references:

- 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.

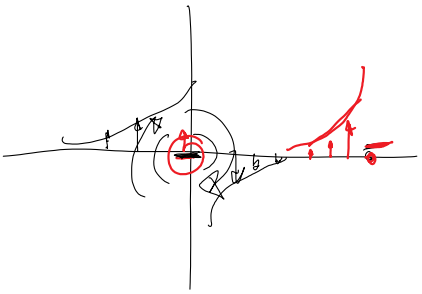
Use right-hand rule to keep track of vorticity



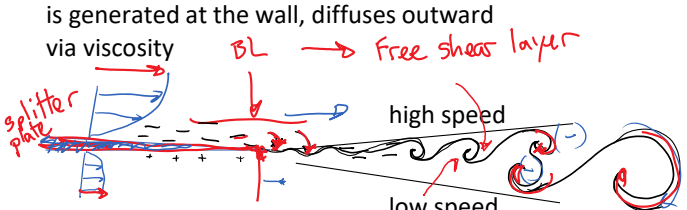
$\text{Vorticity} = \omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$

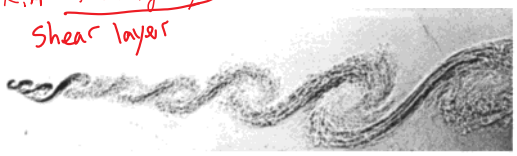


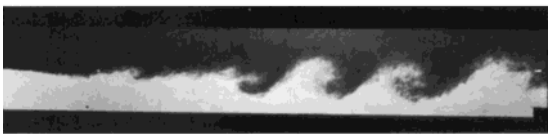
$\frac{du}{dy}$



Boundary layer. Vorticity (negative) is generated at the wall, diffuses outward via viscosity

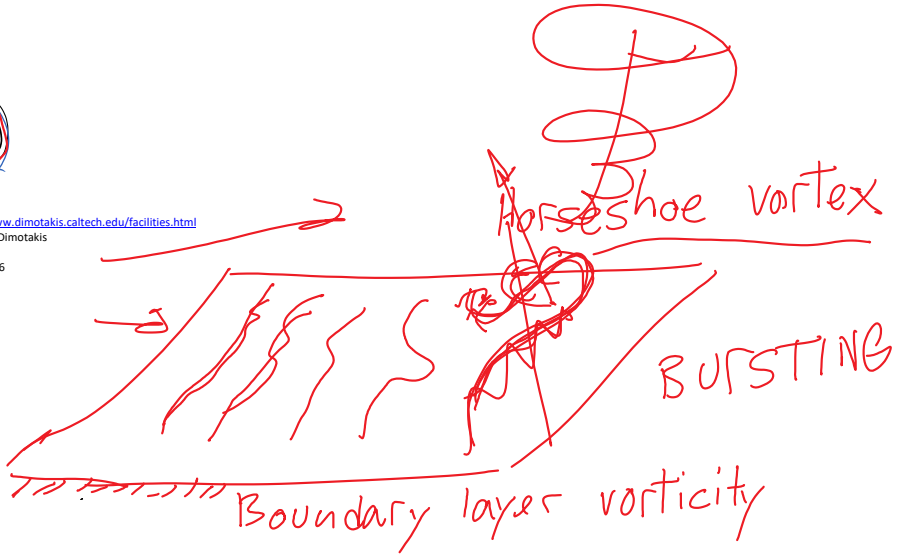




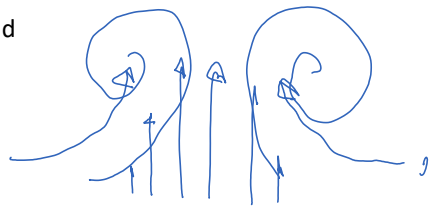


https://www.researchgate.net/figure/Turbulent-shear-layer-a-Gas-layer-shadowgraph-upper-stream-nitrogen-U-1000_fig1_231893459

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

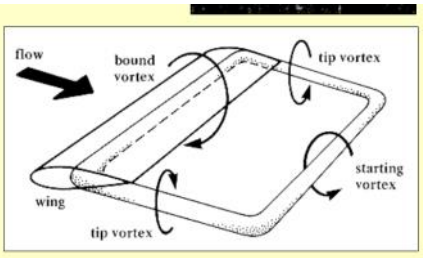


Shear layer. Vortex sheet is unstable, rolls up into vortexes (Kelvin-Helmholtz instability), which then pair and form larger vortexes. This is how shear layers grow. *Hydrodynamic stability theory* can predict initial roll-up frequency, spacing.

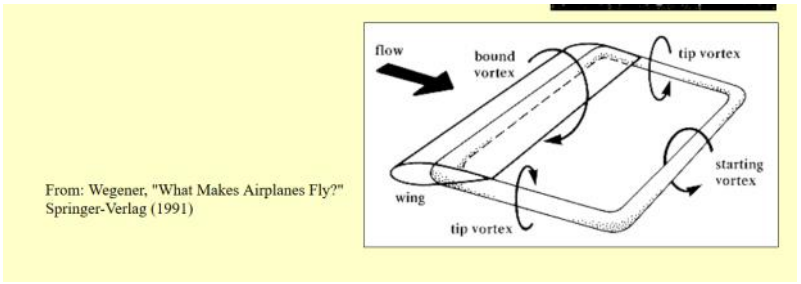


Ref: Drazin, P. G., and W. H. Reid. *Hydrodynamic Stability*. 2nd ed. Cambridge University Press, 2004.

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.

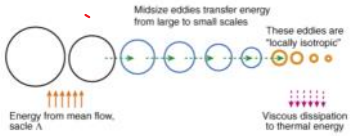


From: Wegener, "What Makes Airplanes Fly?" Springer-Verlag (1991)



From: Wegener, "What Makes Airplanes Fly?" Springer-Verlag (1991)

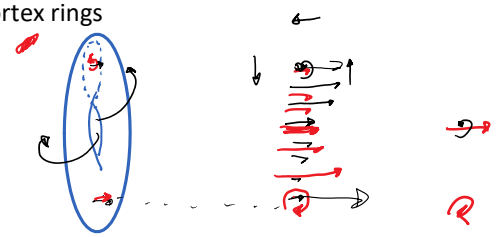
3. Viscosity makes vorticity diffuse, spread. Will eventually make a vortex die.



https://www.sciencedirect.com/topics/engineering/energy-cascade

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

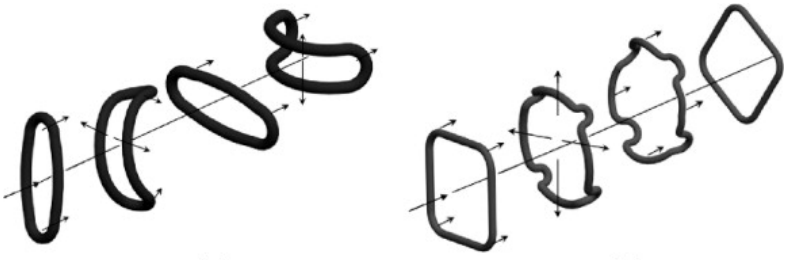
Vortex rings



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

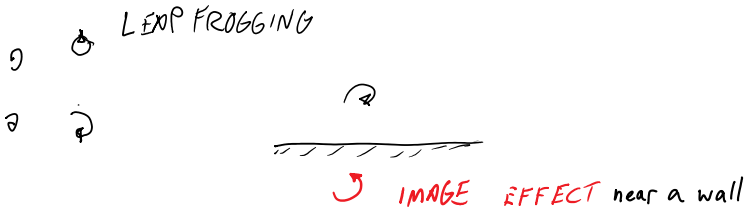
Elliptic rings: high curvature parts move ahead, increasing curvature on the straighter parts, which then speed up.



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.

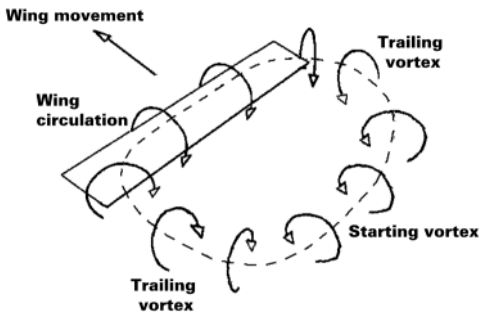
Other interesting vortex ring behaviors:



https://www.youtube.com/watch?v=DLozDMTWNRk
Very short and fast example

http://www.youtube.com/watch?v=mHyTOcfF99o Extraordinary vortex rings. Leapfrogging doesn't show net motion. Has dolphins.

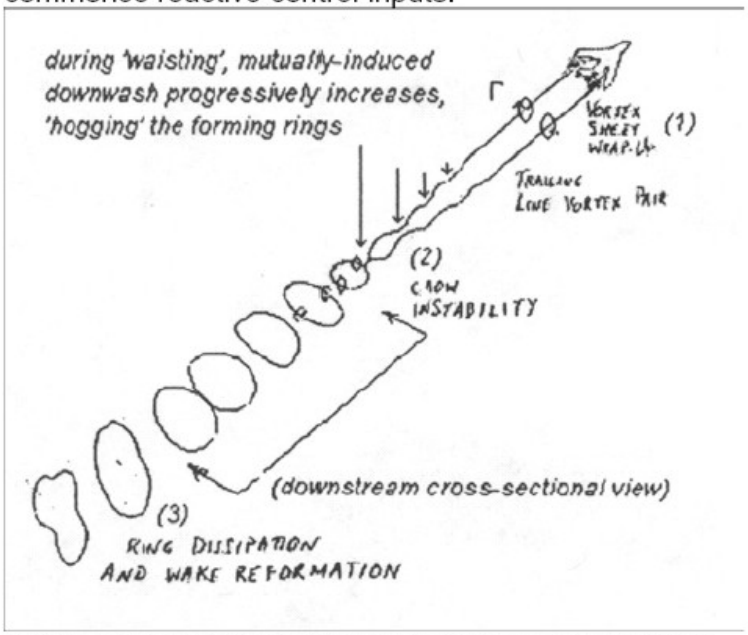
Contrails are long parallel vortex pairs. Loop forms starting with takeoff, ends on landing



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*

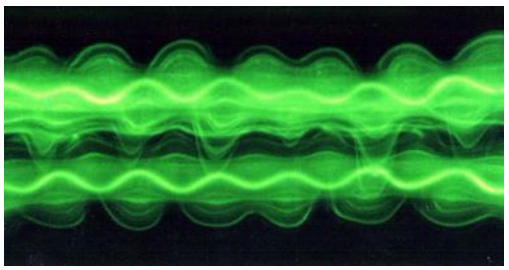
http://www.iasa-intl.com/folders/the068event/587crows-1_files/crowinstab-1.jpg

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

Here 2020

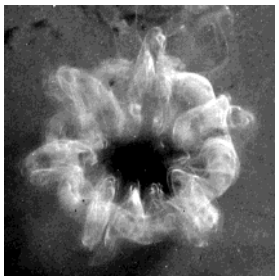
http://science-edu.larc.nasa.gov/contrail-edu/science.php

Persistent spreading contrail



Crow (1970) and Widnall et al (1974)

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



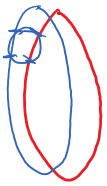
Widnall instability, loops on a vortex ring

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=fTlW1zucWn8&list=UUj7HhOlDAW1fmoXhhPtnTEw&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=UM0jtD_OWLU&feature=youtube_gdata_player.