11.Vorticity

Monday, March 05, 2012
11:53 PM

- Today: VORTICITY

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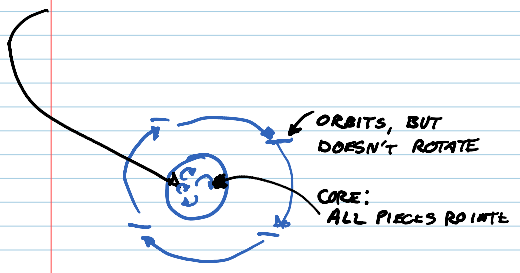
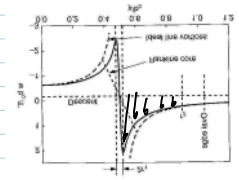
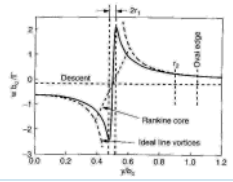
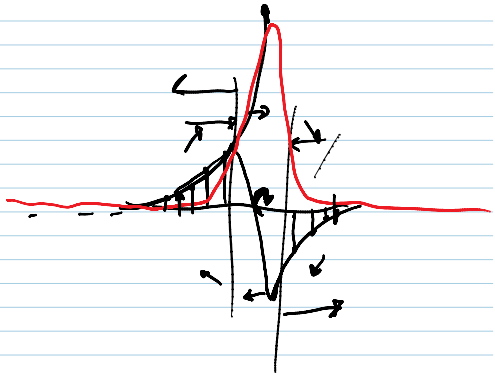
Vorticity = rotation of a fluid element around its own middle
Vortical fluid = fluid with vorticity
Vortex = Vortical fluid (vortex core), often surrounded by irrotational (non-vortical) fluid





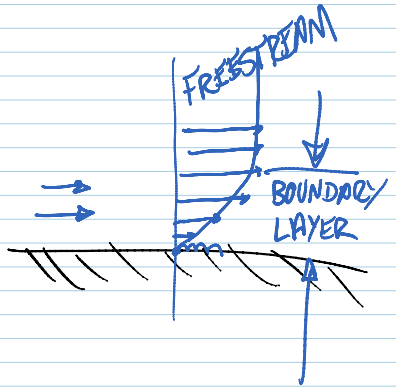
McLean, Doug. *Understanding Aerodynamics Arguing from the Real Physics*. Chichester: Wiley-Blackwell, 2013.





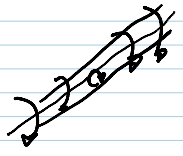
http://www.youtube.com/watch?v=loCLkcYEWD4 3:30 - 6 min, vorticity in boundary layer, then irrotational flow around bathtub vortex.
http://www.youtube.com/watch?v=JI0M1gVNhbw Parody of NCFMF

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.

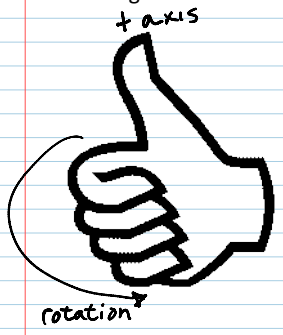
1. Vorticity is created only at boundaries
2. Vortex lines (along the vortex axis) must end at a surface, or form a loop. Can't end in the middle of a fluid.
3. Viscosity makes vorticity diffuse, spread. Will eventually make a vortex die.

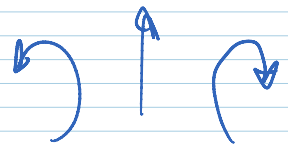


Math& physics references:

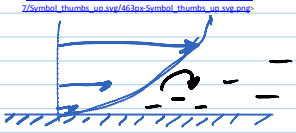
- Panton, Ronald L. *Incompressible Flow*. 3rd ed. Wiley, 2005. New edition will have FV image in it.
- Batchelor, G. K. *An Introduction to Fluid Dynamics*. Cambridge University Press, 2000.
- McLean, Doug. *Understanding Aerodynamics Arguing from the Real Physics*. Chichester: Wiley-Blackwell, 2013.

Use right-hand rule to keep track of vorticity

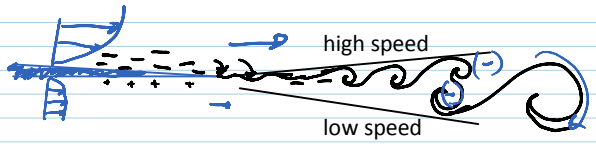




Pasted from <http://upload.wikimedia.org/wikipedia/commons/thumb/8/87/Symbol_thumbs_up.svg/463px-Symbol_thumbs_up.svg.png>



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

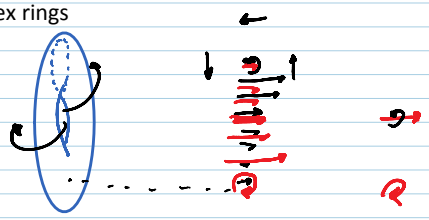


Shear layer. Vortex sheet is unstable, rolls up into vortexes (Kelvin-Helmholtz instability), which then pair and form larger vortexes. This is how shear layers grow. *Hydrodynamic stability theory* can predict initial roll-up frequency, spacing.

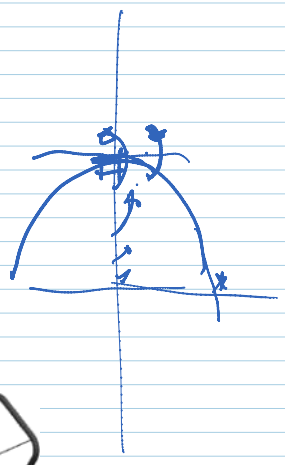
Ref: Drazin, P. G., and W. H. Reid. *Hydrodynamic Stability*. 2nd ed. Cambridge University Press, 2004.

4. Like-sign vortexes pair, unlike vortexes cancel.

Vortex rings

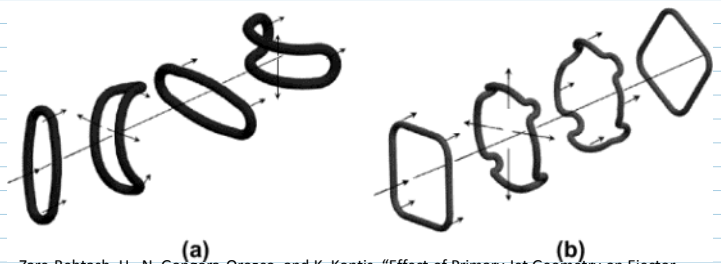


Self-induction: each part of the ring tries to get the rest of the ring to rotate around it. Net result: every part of the ring moves forward the same.



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.

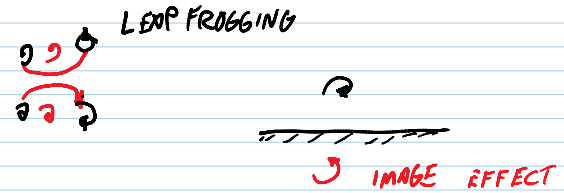


Zara Bashtach, H. N. Gonzalez Orozco, and K. Kontis, "Effect of Primary Jet Geometry on Ejector

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.

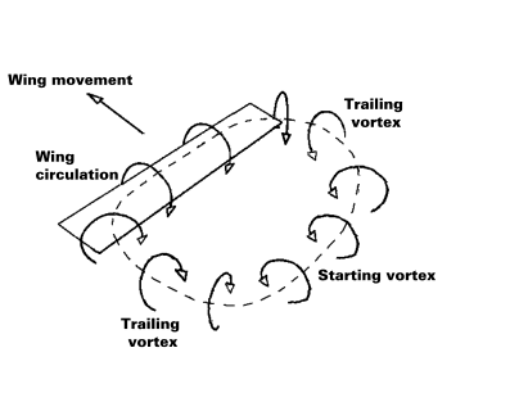
Other interesting vortex ring behaviors:



http://www.youtube.com/watch?v=j3wJal_AggY
Very short and fast example

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

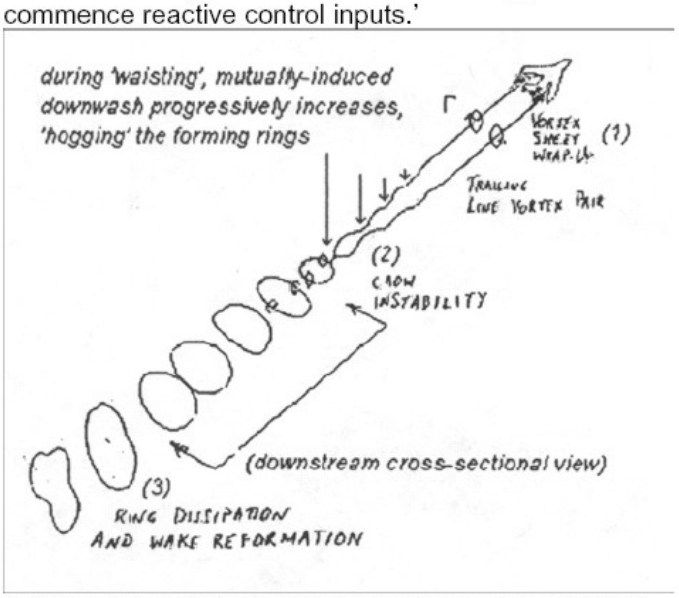
Contrails are long parallel vortexes. Loop forms starting with takeoff, ends on landing



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

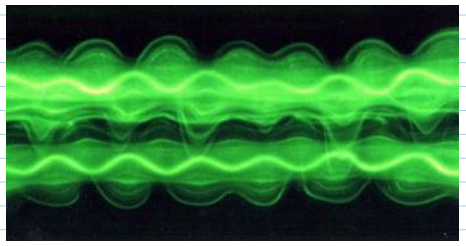
Crow instability

http://upload.wikimedia.org/wikipedia/commons/thumb/0/05/Contrail_with_crow_instability.jpg/200px-Contrail_with_crow_instability.jpg

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

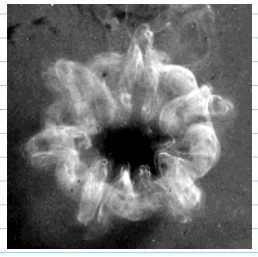
Persistent spreading contrail

Crow (1970) and Widnall et al



Crow (1970) and Widnall et al (1974)

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



Widnall instability

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.