

Exit Survey is coming

One-sentence description needed on T3 post

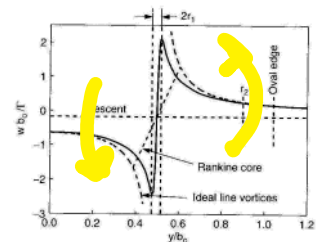
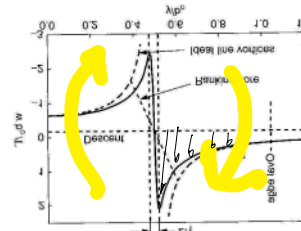
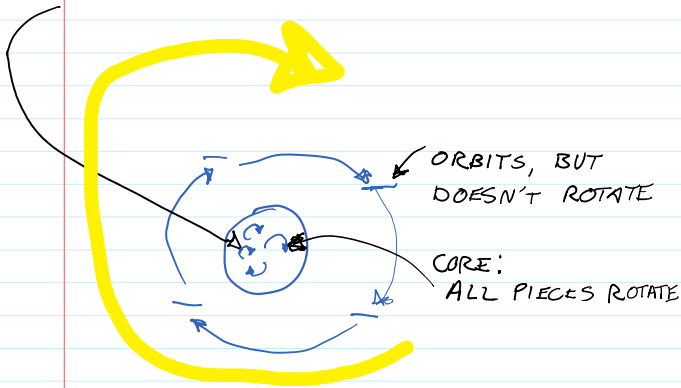
Resubmissions: Both on FV.org and Canvas

- Today: Finish T3 critique
- 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

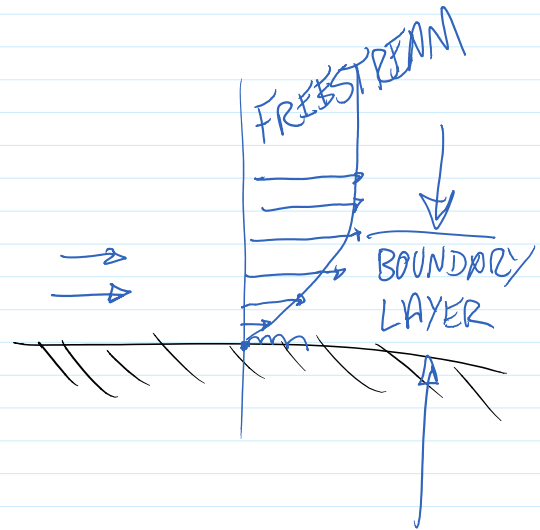


McLean, Doug. *Understanding Aerodynamics Arguing from the Real Physics*. Chichester: Wiley-Blackwell, 2013.

<http://www.youtube.com/watch?v=loCLkYEWD4> 3:30 - 6 min, vorticity in boundary layer, then irrotational flow around bathtub vortex.

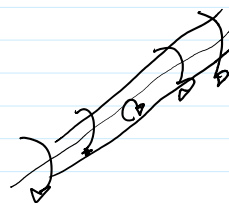
<http://www.youtube.com/watch?v=JIOM1gVNhbw> Parody of NCFMF

<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.



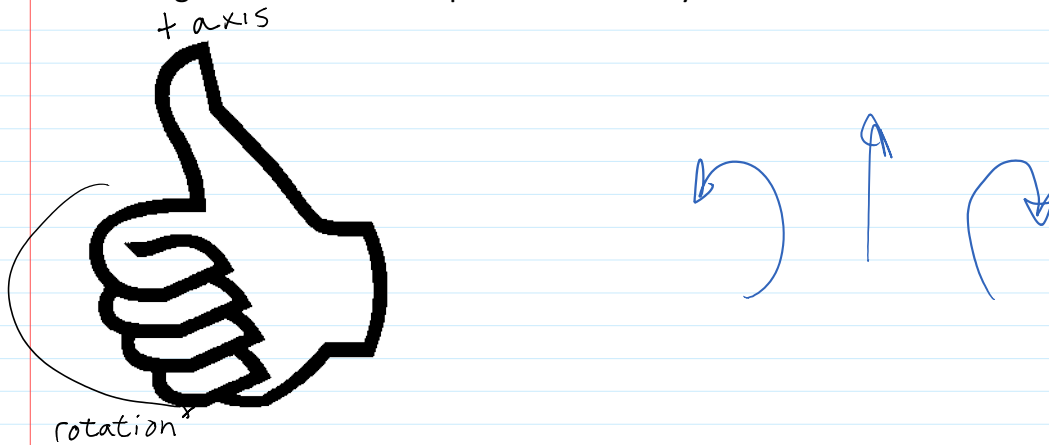
Math& physics references:

- Panton, Ronald L. *Incompressible Flow*. 3rd ed. Wiley, 2005. New edition will have

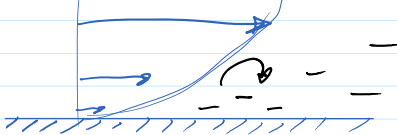
FV image in it.

- 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.

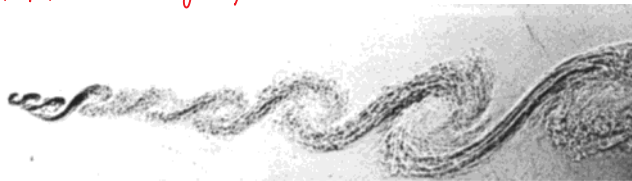
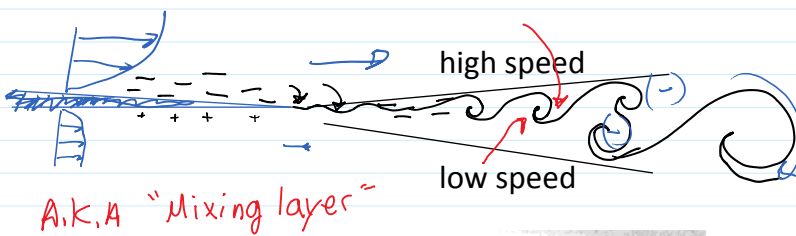
Use right-hand rule to keep track of vorticity



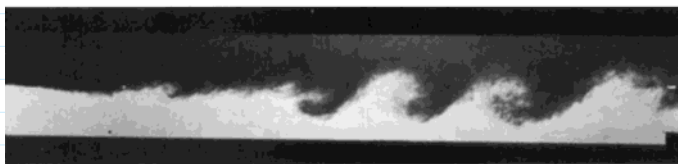
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<http://upload.wikimedia.org/wikipedia/commons/thumb/8/87/Symbol_thumbs_up.svg/463px-Symbol_thumbs_up.svg.png>



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



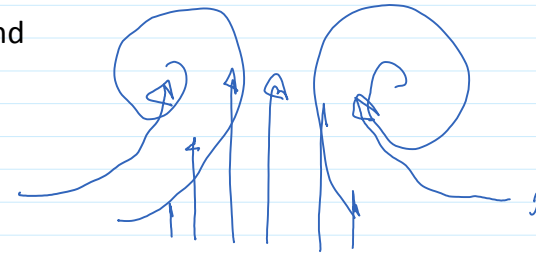
(a)



(b)

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

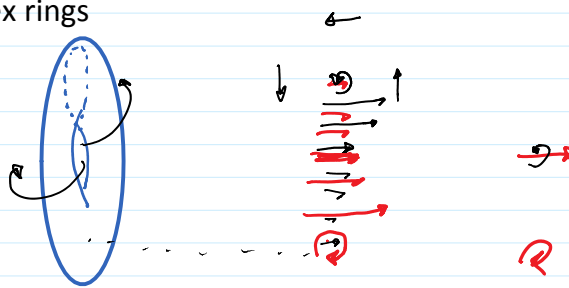
Shear layer. Vortex sheet is unstable, rolls up into vortices (Kelvin-Helmholtz instability), which then pair and form larger vortices. This is how shear layers grow. *Hydrodynamic stability theory* can predict initial roll-up frequency, spacing.



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

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

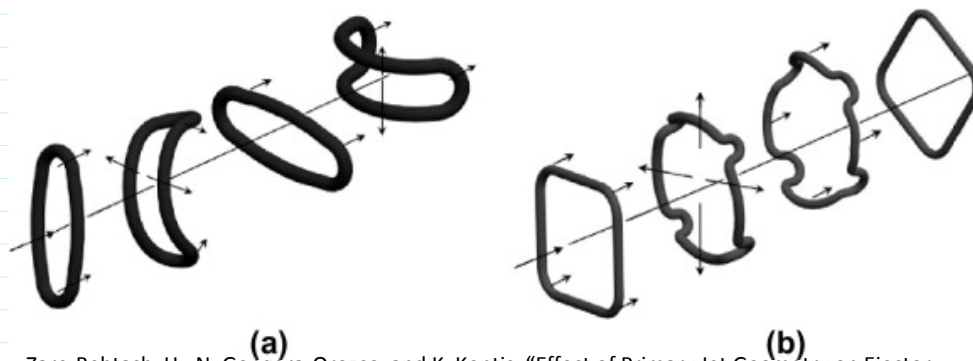
Vortex rings



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:

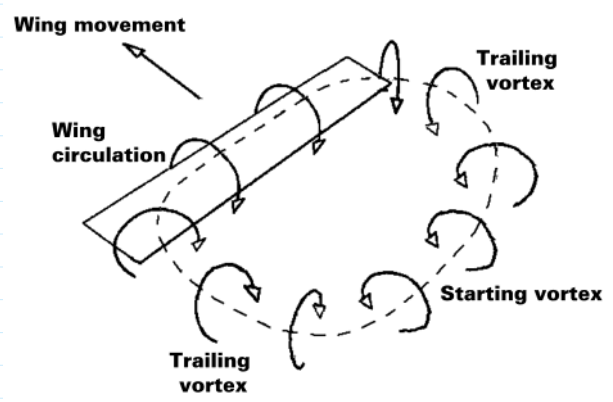


<https://www.youtube.com/watch?v=DLozDMTWNrk>

Very short and fast example

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

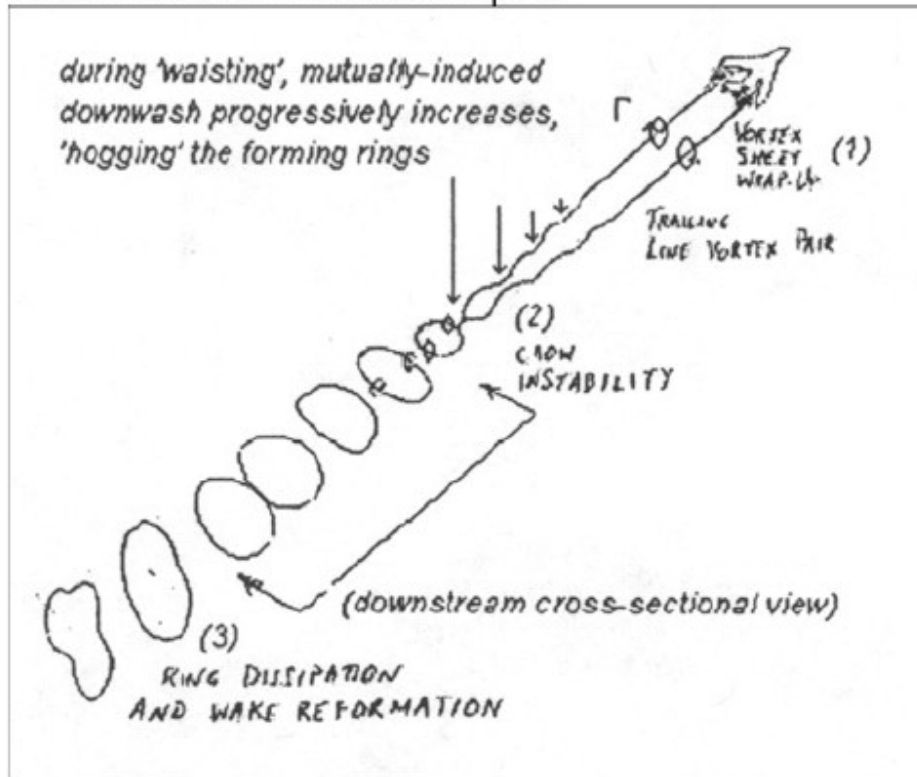
Contraails are long parallel vortex pairs. Loop forms starting with takeoff, ends on landing



<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



Crow instability

<http://upload.wikimedia.org/wikipedia/commo>

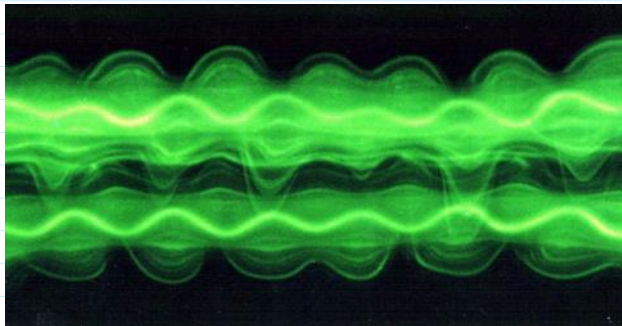
[ns/thumb/0/05/Contrail with crow instability.
jpg/200px-Contrail with crow instability.jpg](https://www.nasa.gov/images/content/105487main_05Contrail_with_crow_instability.jpg/200px-Contrail_with_crow_instability.jpg)

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



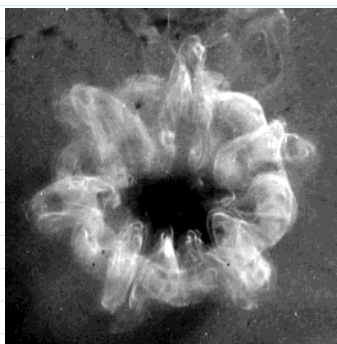
[http://science-
edu.larc.nasa.gov/contrail
-edu/science.php](http://science-edu.larc.nasa.gov/contrail-edu/science.php)

Persistent spreading
contrail



Crow (1970) and Widnall et al
(1974)

[http://www.efluids.com/efluids/gallery/gallery
_pages/pair_instability_page.jsp](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

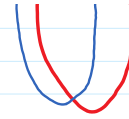
[http://iopscience.iop.org/1873-7005/44/1/015501/arti
cle](http://iopscience.iop.org/1873-7005/44/1/015501/article) Collision of vortex ring and granular layer

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

[http://www.youtube.com/watch?v=fTIW1zucWn8
&list=UUj7HhOIDAW1fmoXhhPtnTEw&feature=c4-
...](http://www.youtube.com/watch?v=fTIW1zucWn8&list=UUj7HhOIDAW1fmoXhhPtnTEw&feature=c4-)



<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=UM0jtD_OWLU&feature=youtube_gdata_player.
