King Abdullah University of
Science and Technology

KAUST

CS 247 – Scientific Visualization
Lecture 22: Volume Visualization, Pt. 9;
Vector / Flow Visualization, Pt. 1

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Reading Assignment #12 (until Apr 27)

Read (required):

- Data Visualization book
  - Chapter 6 (Vector Visualization)
    - Beginning (before 6.1)
    - Chapters 6.2, 6.3, 6.5
- More general vector field basics (the book is not very precise on the basics)

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

Read (optional):

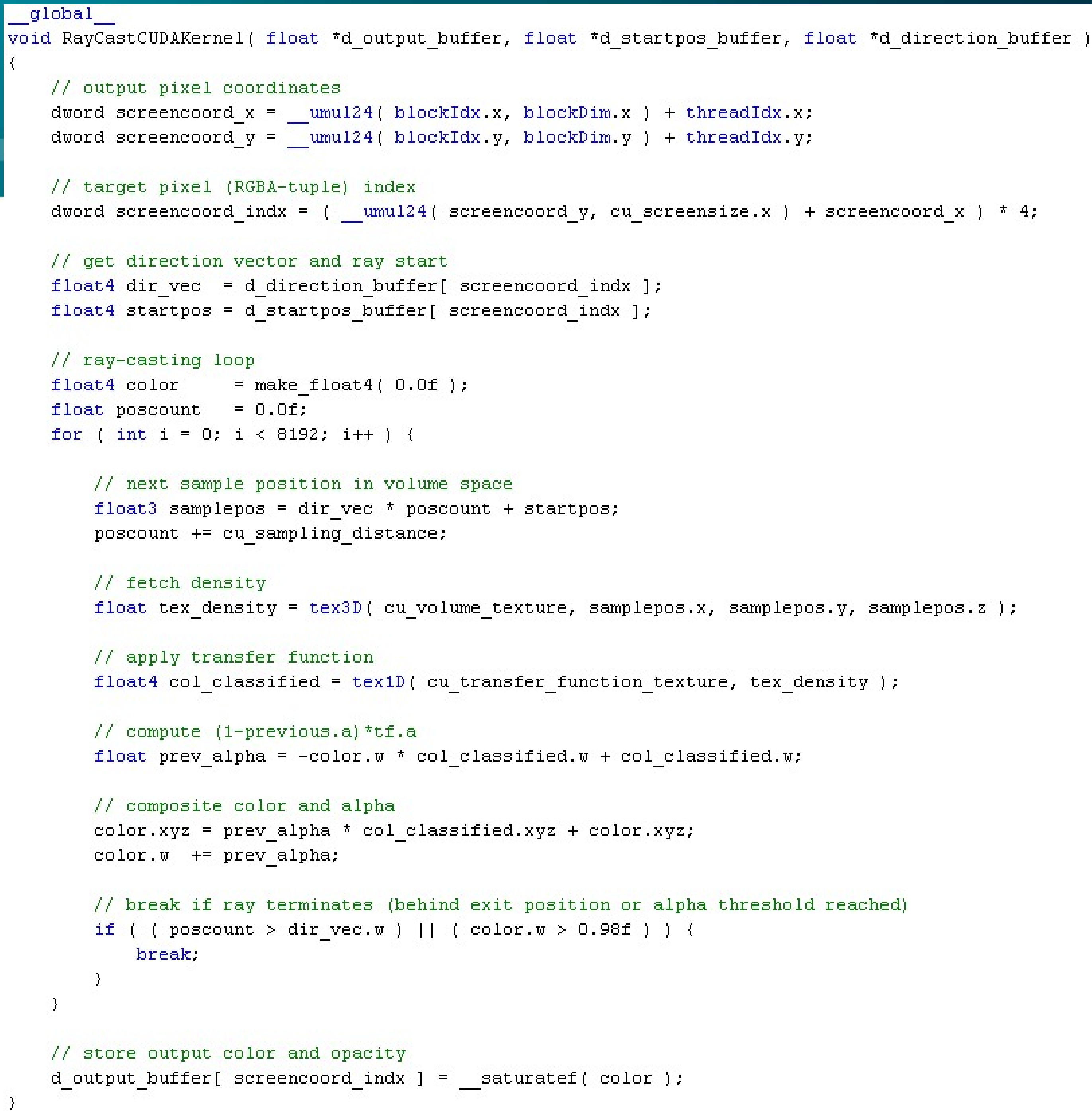
- Paper:
  Bruno Jobard and Wilfrid Lefer
  Creating Evenly-Spaced Streamlines of Arbitrary Density,

  http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.29.9498

Volume Rendering

CUDA Kernel

- Image-based ray setup
  - Ray start image
  - Direction image
- Ray-cast loop
  - Sample volume
  - Accumulate color and opacity
- Terminate
- Store output



```
__global__
void RayCastCUDAKernel( float *d_output_buffer, float *d_startpos_buffer, float *d_direction_buffer )
{
    // output pixel coordinates
    dword screencoord_x = __umul24( blockIdx.x, blockDim.x ) + threadIdx.x;
    dword screencoord_y = __umul24( blockIdx.y, blockDim.y ) + threadIdx.y;

    // target pixel (RGBA-tuple) index
    dword screencoord_indx = ( __umul24( screencoord_y, cu_screensize.x ) + screencoord_x ) * 4;

    // get direction vector and ray start
    float4 dir_vec  = d_direction_buffer[ screencoord_indx ];
    float4 startpos = d_startpos_buffer[ screencoord_indx ];

    // ray-casting loop
    float4 color     = make_float4( 0.0f );
    float poscount   = 0.0f;
    for ( int i = 0; i < 8192; i++ ) {

        // next sample position in volume space
        float3 samplepos = dir_vec * poscount + startpos;
        poscount += cu_sampling_distance;

        // fetch density
        float tex_density = tex3D( cu_volume_texture, samplepos.x, samplepos.y, samplepos.z );

        // apply transfer function
        float4 col_classified = tex1D( cu_transfer_function_texture, tex_density );

        // compute (1-previous.a)*tf.a
        float prev_alpha = -color.w * col_classified.w + col_classified.w;

        // composite color and alpha
        color.xyz = prev_alpha * col_classified.xyz + color.xyz;
        color.w  += prev_alpha;

        // break if ray terminates (behind exit position or alpha threshold reached)
        if ( ( poscount > dir_vec.w ) || ( color.w > 0.98f ) ) {
            break;
        }
    }

    // store output color and opacity
    d_output_buffer[ screencoord_indx ] = __saturatef( color );
}
```

Isosurface Ray-Casting

Isosurface Ray-Casting

Isosurfaces/Level Sets

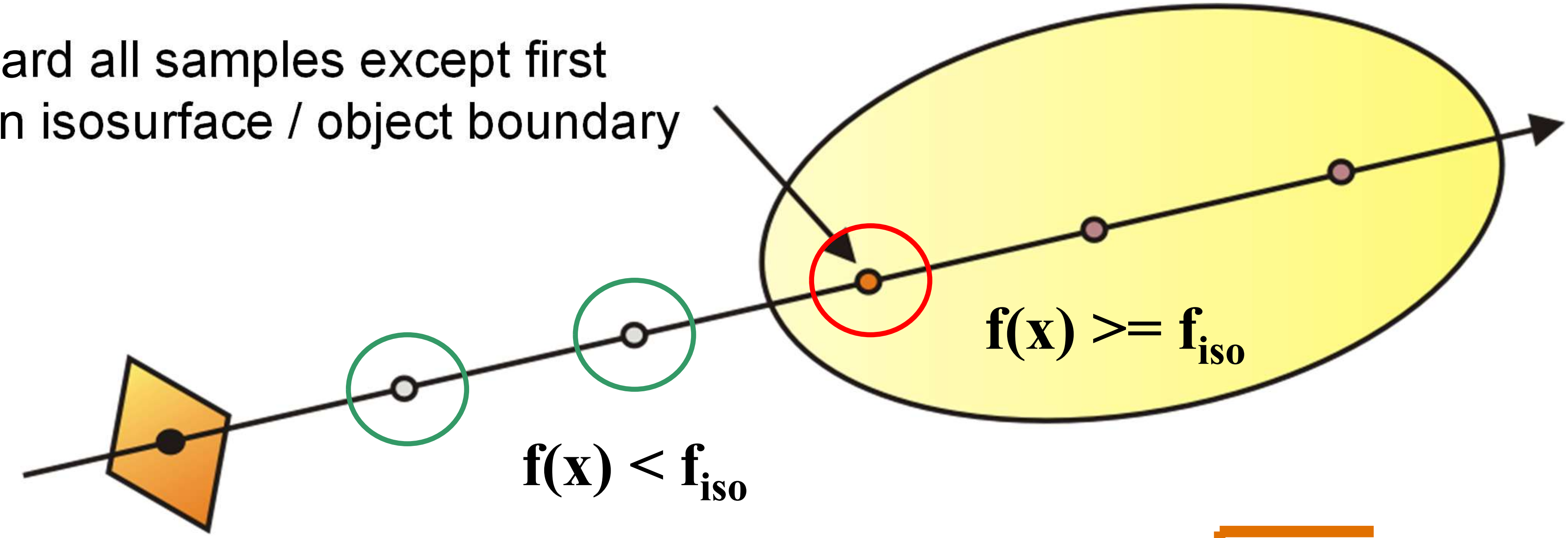
- Scanned data (fit signed distance function to points, ...)
- Signed distance fields
- CSG (constructive solid geometry) operations

..

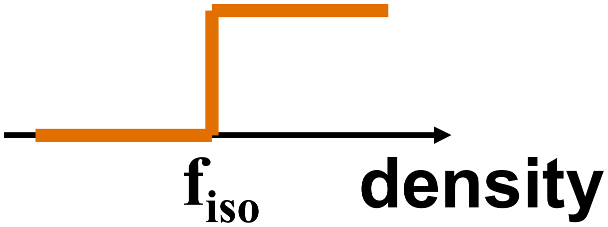
Isosurface Ray-Casting

Opaque isosurfaces:
only one sample contributes per ray/pixel

Discard all samples except first
hit on isosurface / object boundary



Threshold transfer function / alpha test

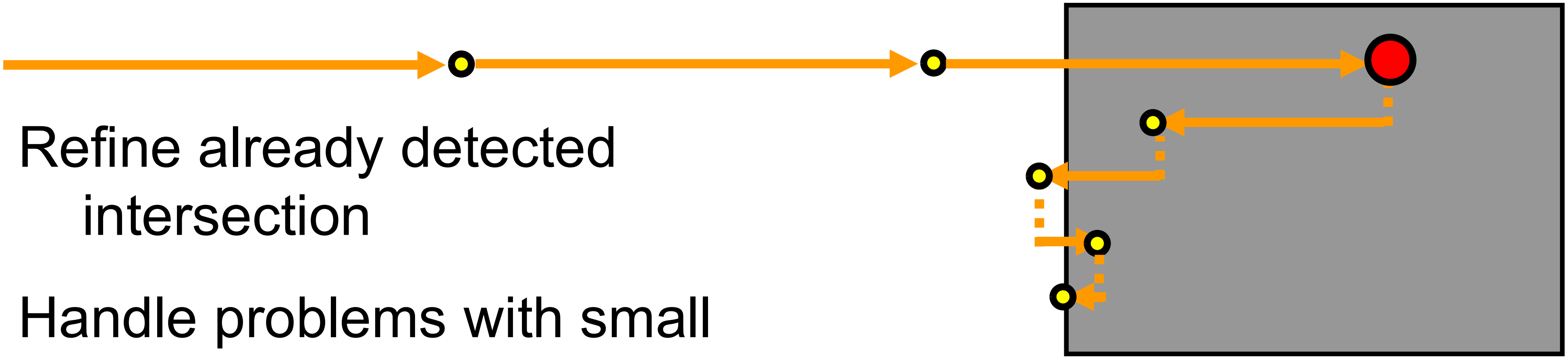


First hit ray casting

Intersection Refinement (1)

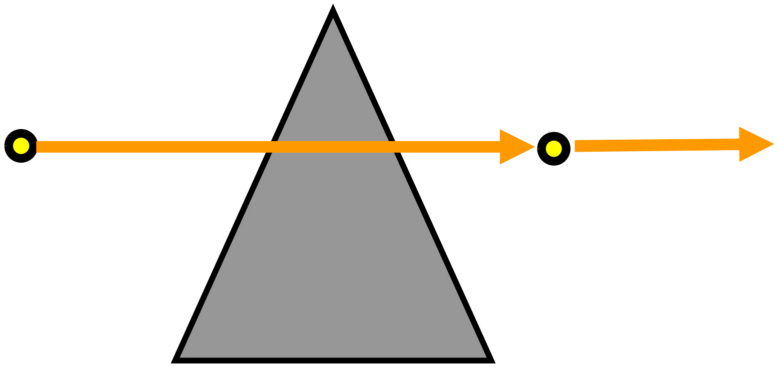
Fixed number of bisection / binary search steps

Virtually no impact on performance

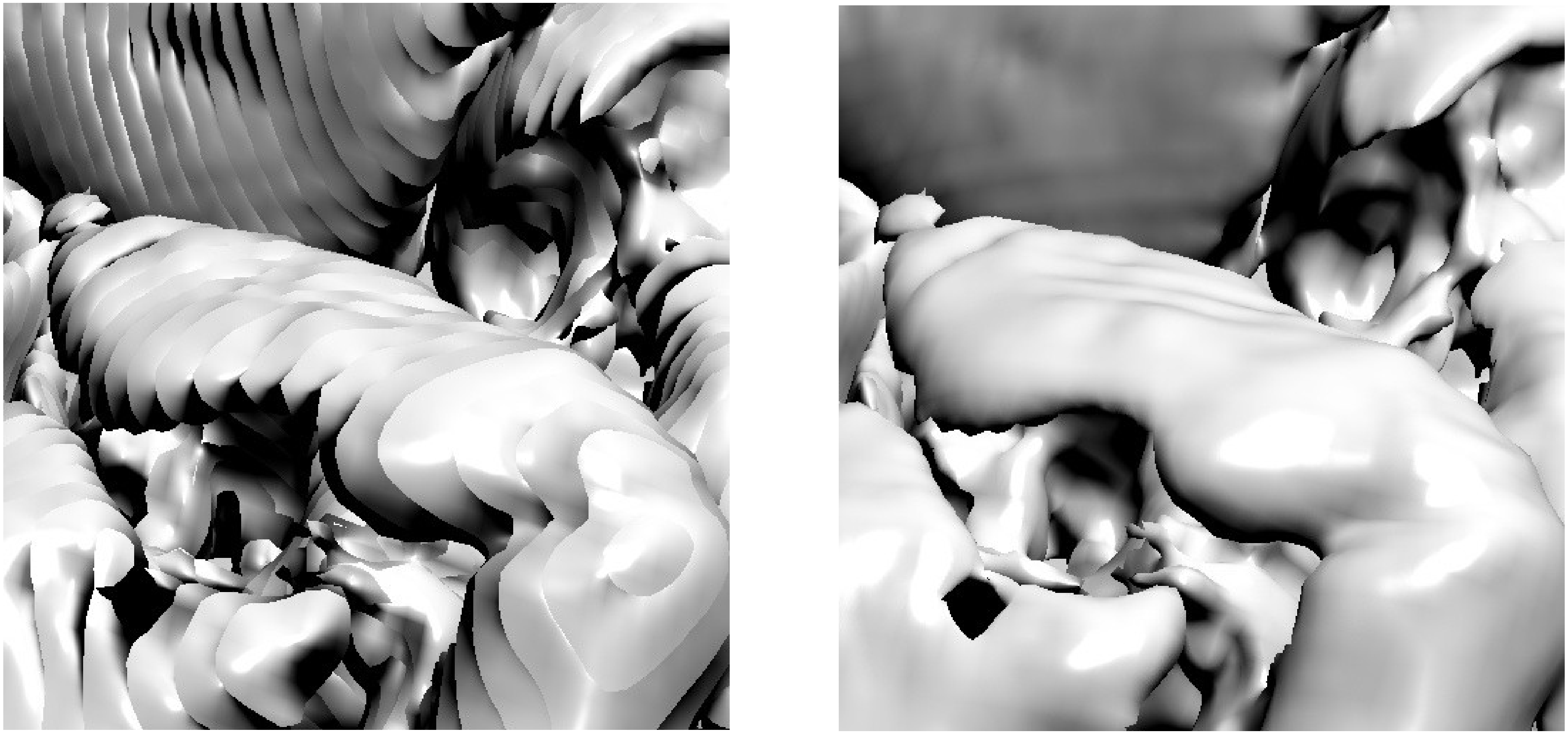


Refine already detected intersection

Handle problems with small features / at silhouettes with adaptive sampling



Intersection Refinement (2)



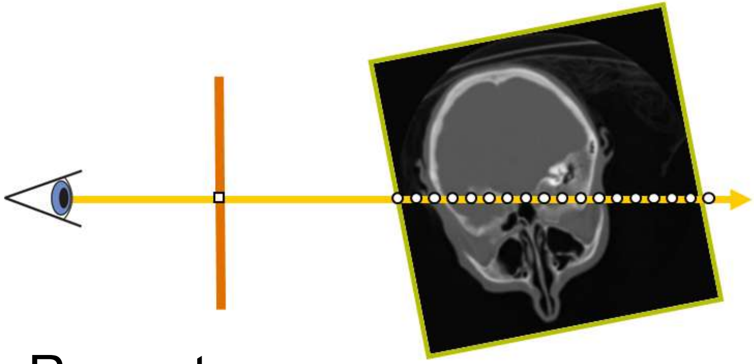
without refinement

with refinement

sampling distance 5 voxels (no adaptive sampling)

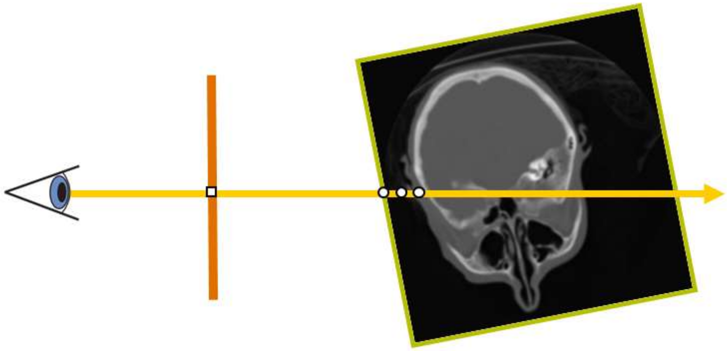
Ray-Casting vs. Isosurface Ray-Casting

Ray-Casting



```
Ray setup
Loop over ray
    Sample scalar field
    Classification
    Shading
    Compositing
```

Isosurface Ray-Casting



```
Ray setup
Loop over ray
    Sample scalar field
    if  value >= isoValue (i.e., first hit)
        break out of the loop
[Refine first hit location] (optional)
Shading
(Compositing not needed)
```

Vector / Flow Visualization

Online Demos and Info

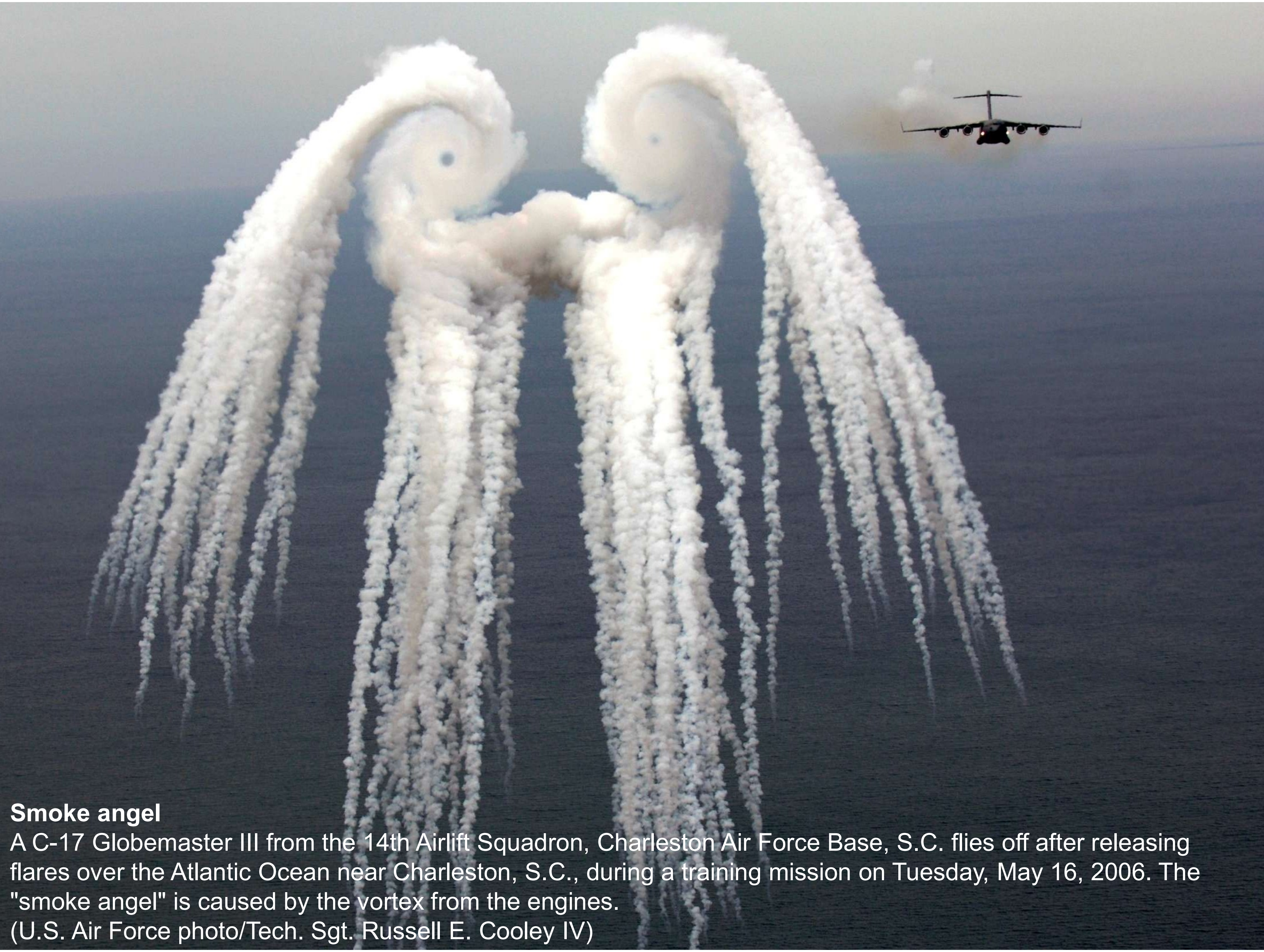
Numerical ODE integration methods (Euler vs. Runge Kutta, etc.)

https://demonstrations.wolfram.com/NumericalMethodsForDifferentialEquations/

Flow visualization concepts

https://www3.nd.edu/~cwang11/flowvis.html

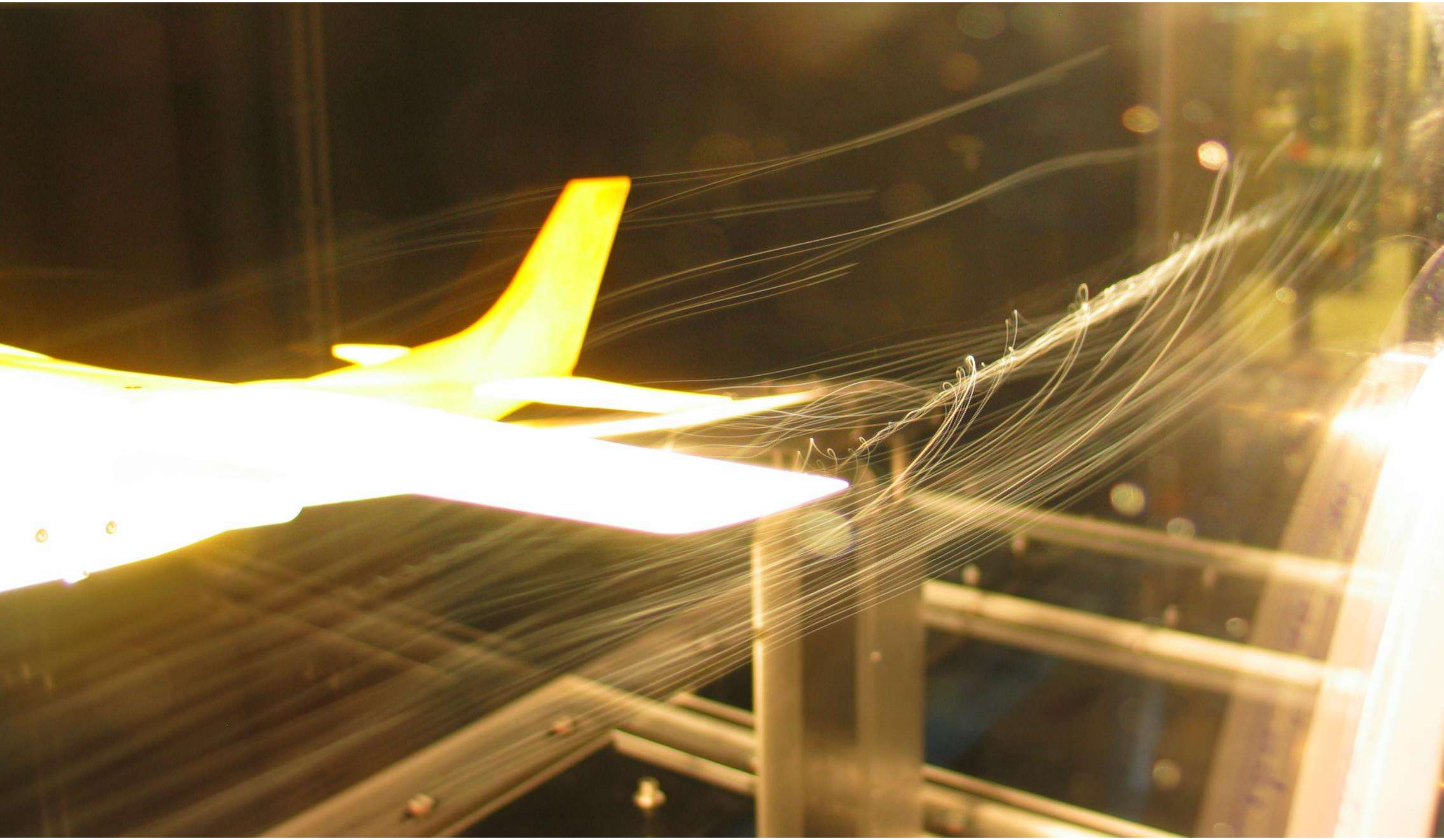
Vector Fields: Motivation



Smoke angel

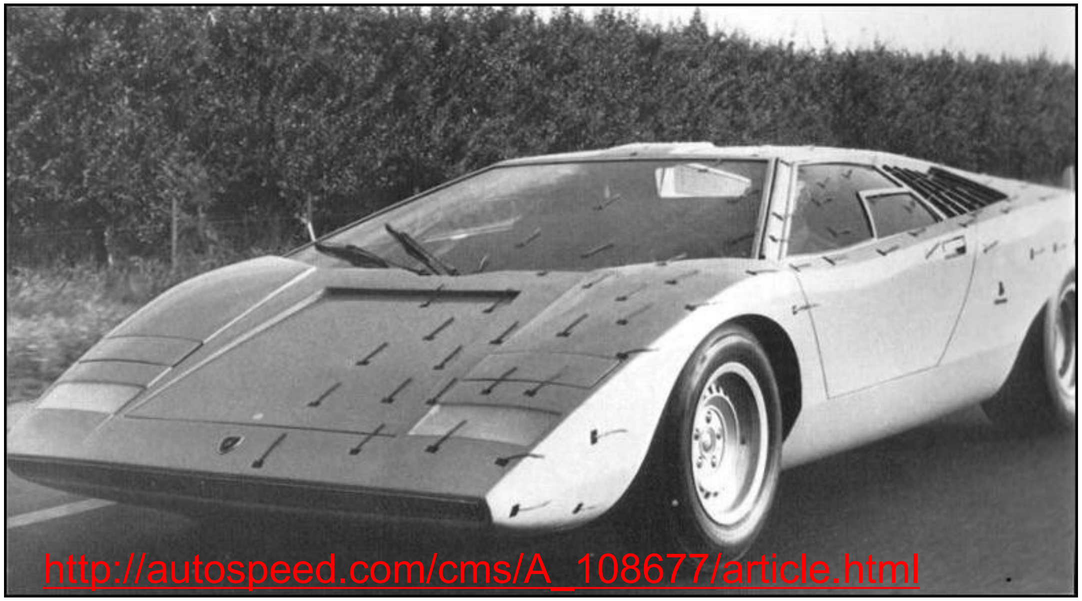
A C-17 Globemaster III from the 14th Airlift Squadron, Charleston Air Force Base, S.C. flies off after releasing flares over the Atlantic Ocean near Charleston, S.C., during a training mission on Tuesday, May 16, 2006. The "smoke angel" is caused by the vortex from the engines.

(U.S. Air Force photo/Tech. Sgt. Russell E. Cooley IV)



A wind tunnel model of a Cessna 182 showing a wingtip vortex.
Tested in the RPI (Rensselaer Polytechnic Institute) Subsonic Wind Tunnel.
By Ben FrantzDale (2007).

Flow Visualization: Problems and Concepts



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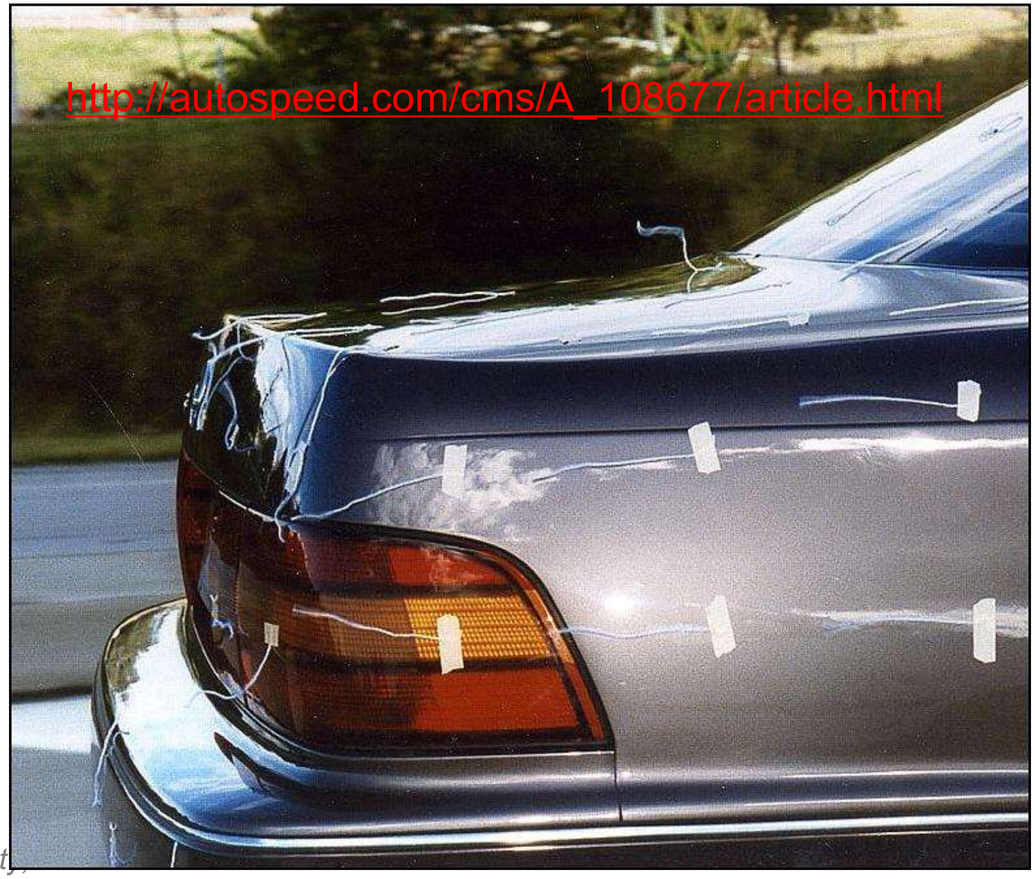
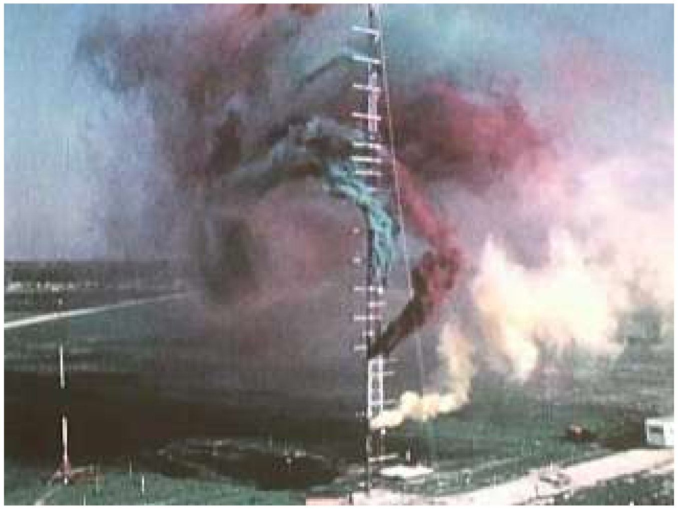
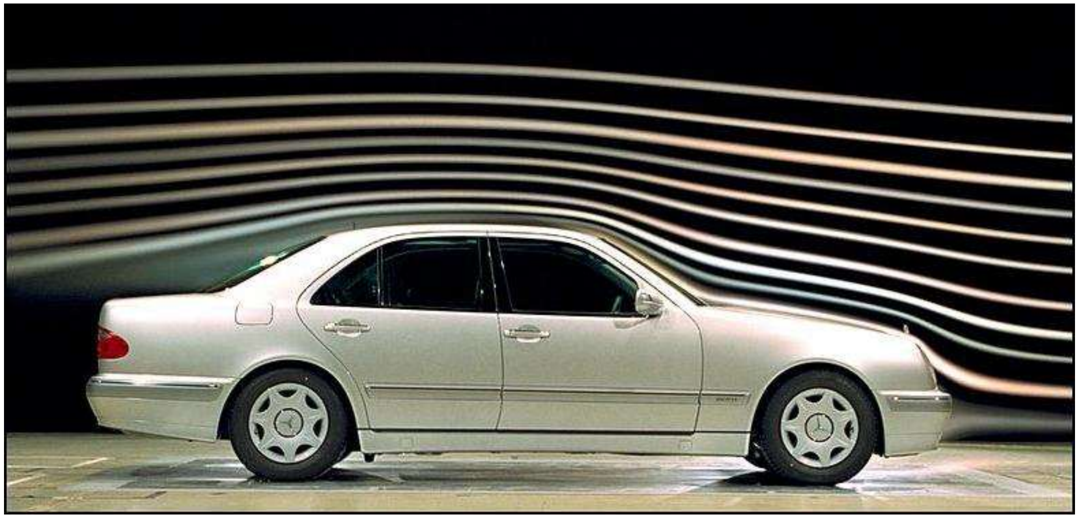


http://autospeed.com/cms/A_108677/article.html

wool tufts

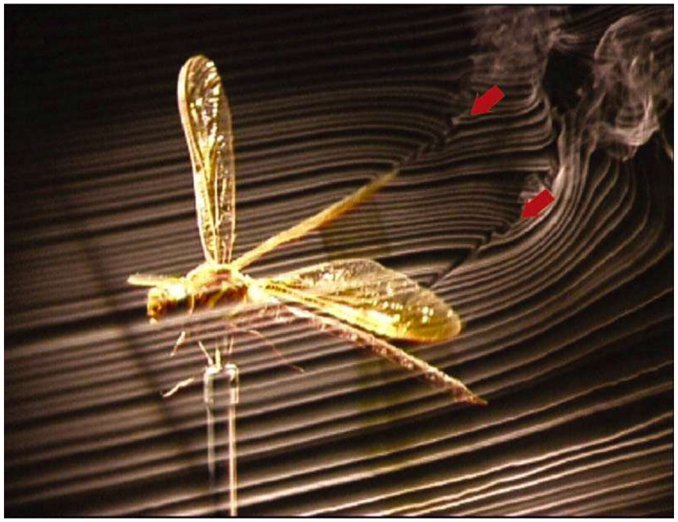


smoke injection

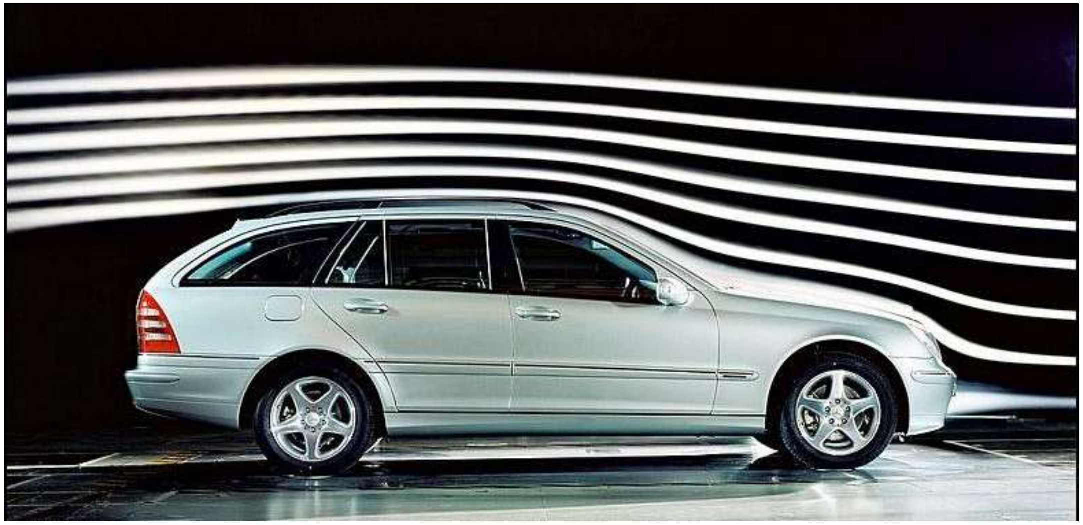


http://autospeed.com/cms/A_108677/article.html

smoke nozzles



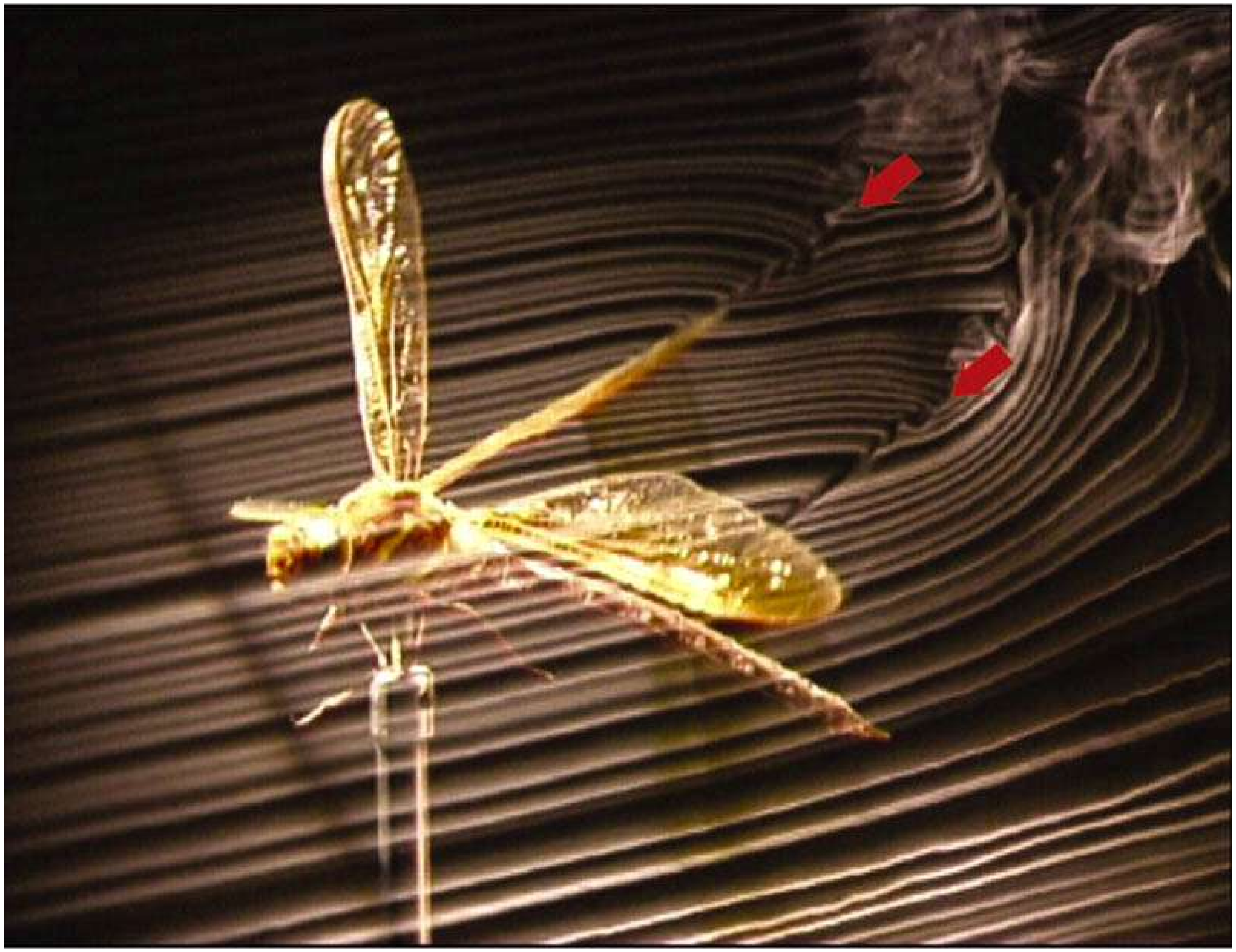
[NASA, J. Exp. Biol.]



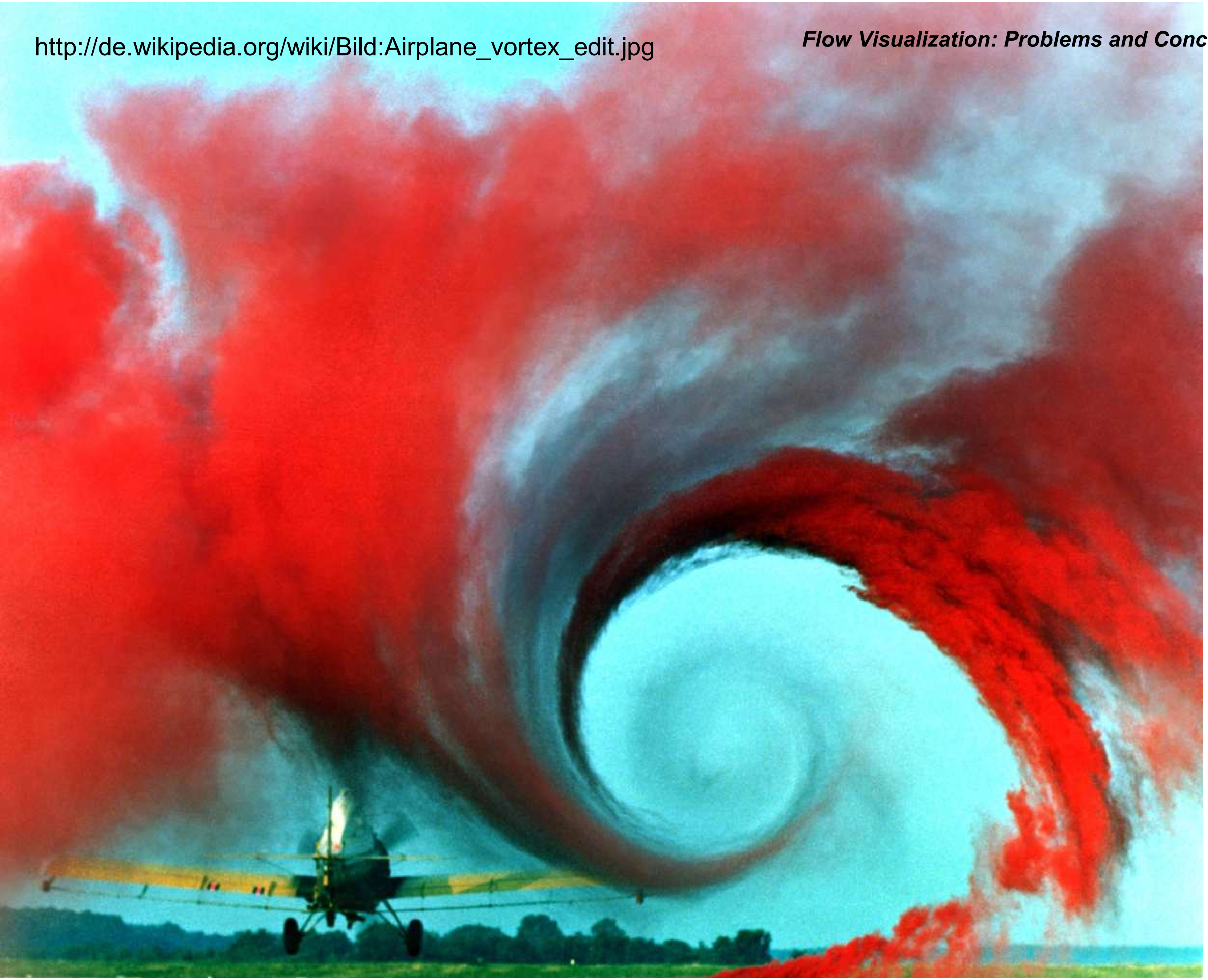
http://autospeed.com/cms/A_108677/article.html

smoke nozzles

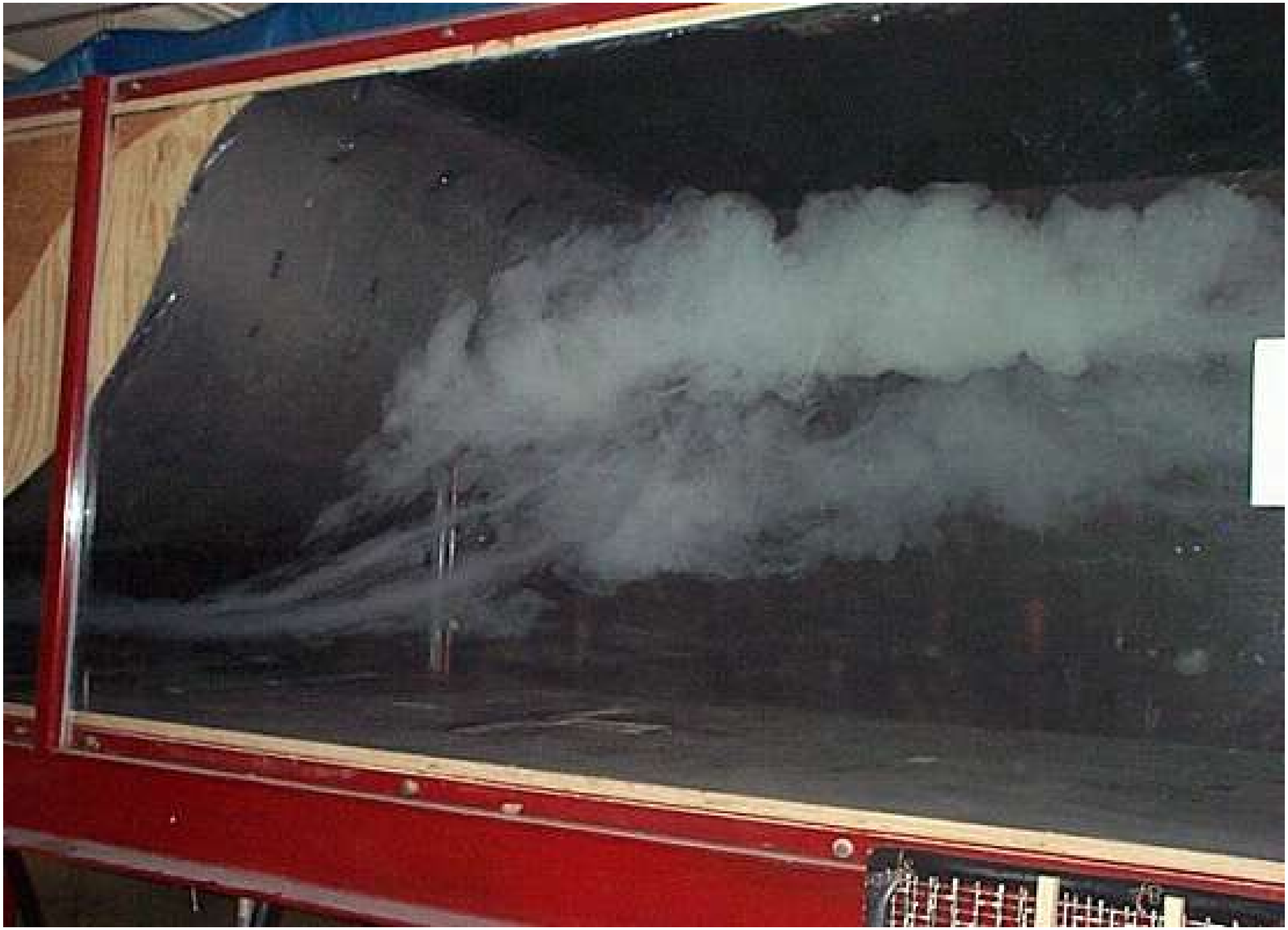
Smoke injection



A. L. R. Thomas, G. K. Taylor, R. B. Srygley, R. L. Nudds, and R. J. Bomphrey. Dragonfly flight: free-flight and tethered flow visualizations reveal a diverse array of unsteady lift-generating mechanisms, controlled primarily via angle of attack. J Exp Biol, 207(24):4299–4323, 2004.

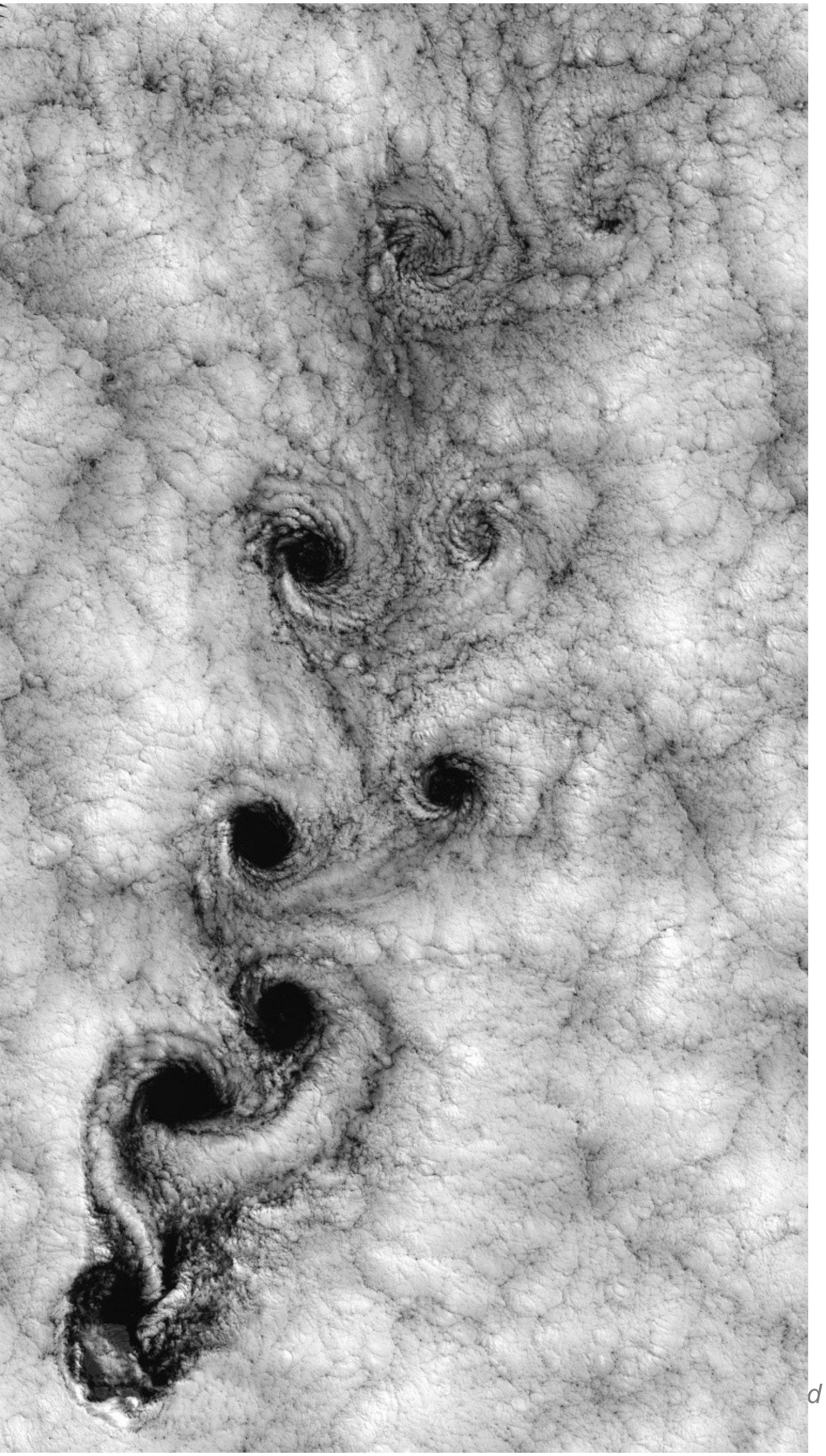


http://de.wikipedia.org/wiki/Bild:Airplane_vortex_edit.jpg



Smoke injection

http://www-me.ccny.cuny.edu/research/aerolab/facilities/images/wt2.jpg



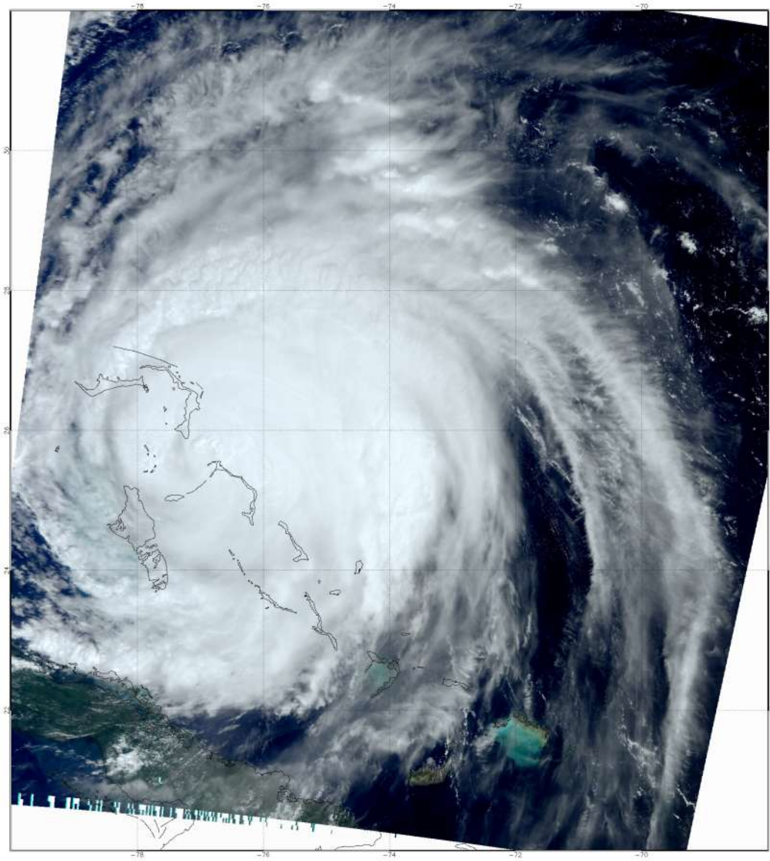
Clouds (satellite image)

Juan Fernandez Islands

http://de.wikipedia.org/wiki/Bild:Vortex-street-1.jpg

Clouds (satellite image)

http://daac.gsfc.nasa.gov/gallery/frances/



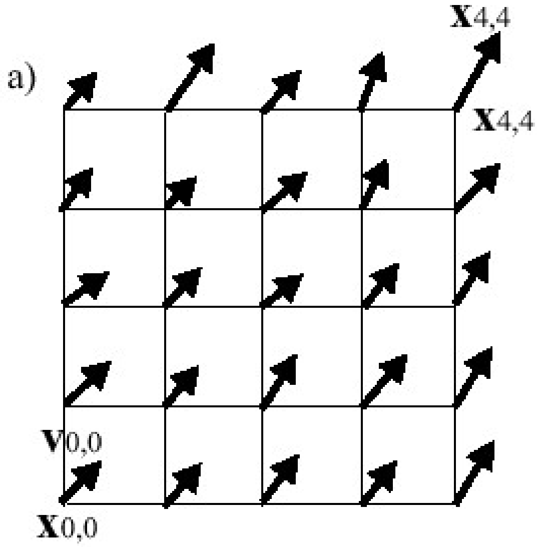
- **Vortex/ Vortex core lines**
  - There is no exact definition of vortices
  - capturing some swirling behavior

Vector Fields

Each vector is usually thought of as a velocity vector

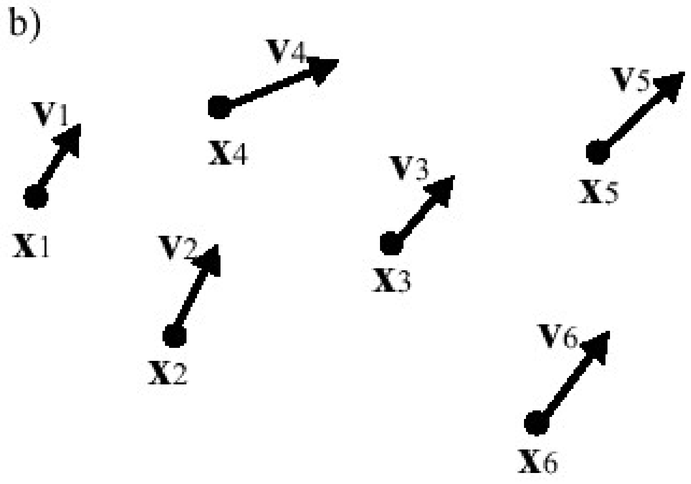
- Example for actual velocity: fluid flow
- But also force fields, etc. (e.g., electrostatic field)

Eulerian specification:



vectors given at grid points
(grid points do not move)

Lagrangian specification:

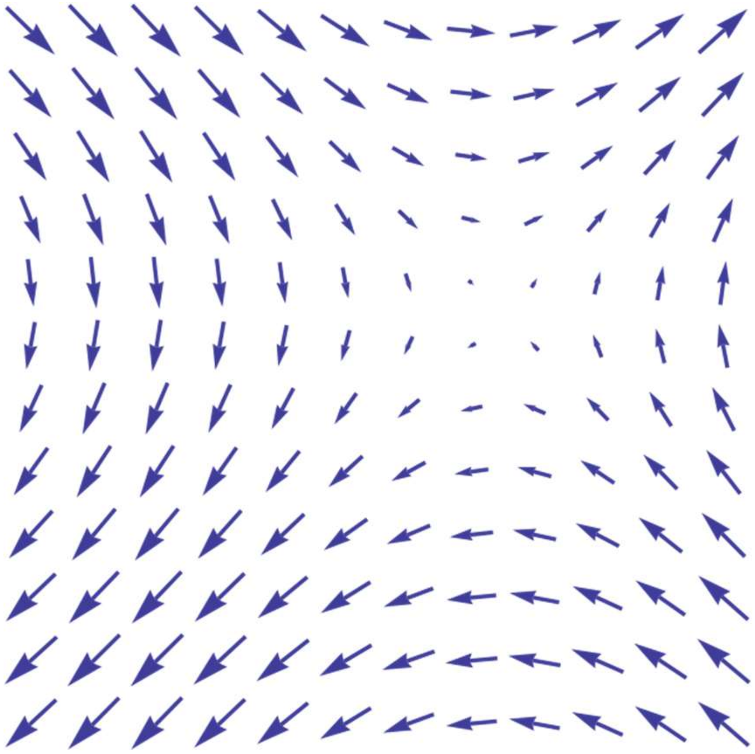


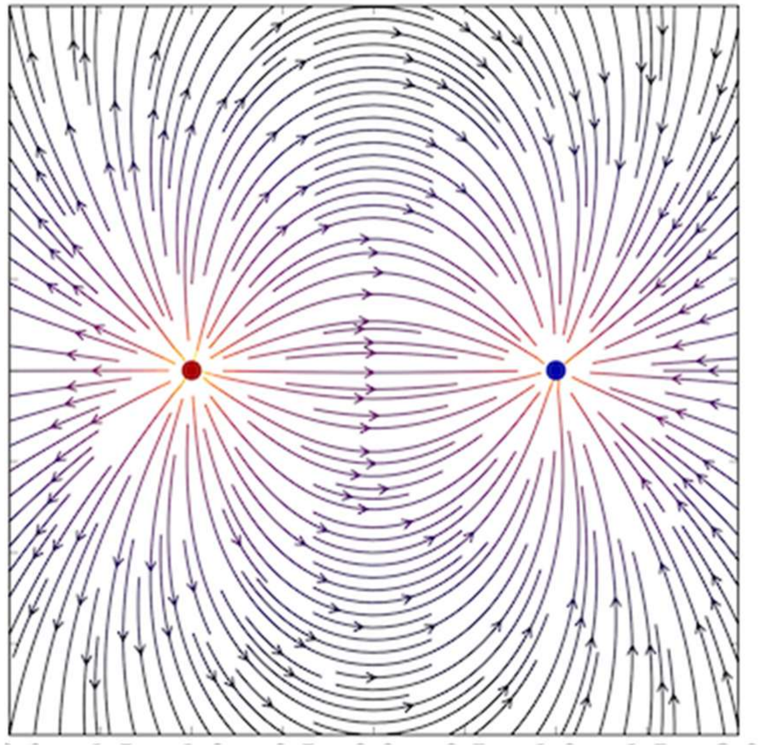
vectors given at particle positions
(particle positions do move)

Vector Fields

Each vector is usually thought of as a velocity vector

- Example for actual velocity: fluid flow
- But also force fields, etc. (e.g., electrostatic field)

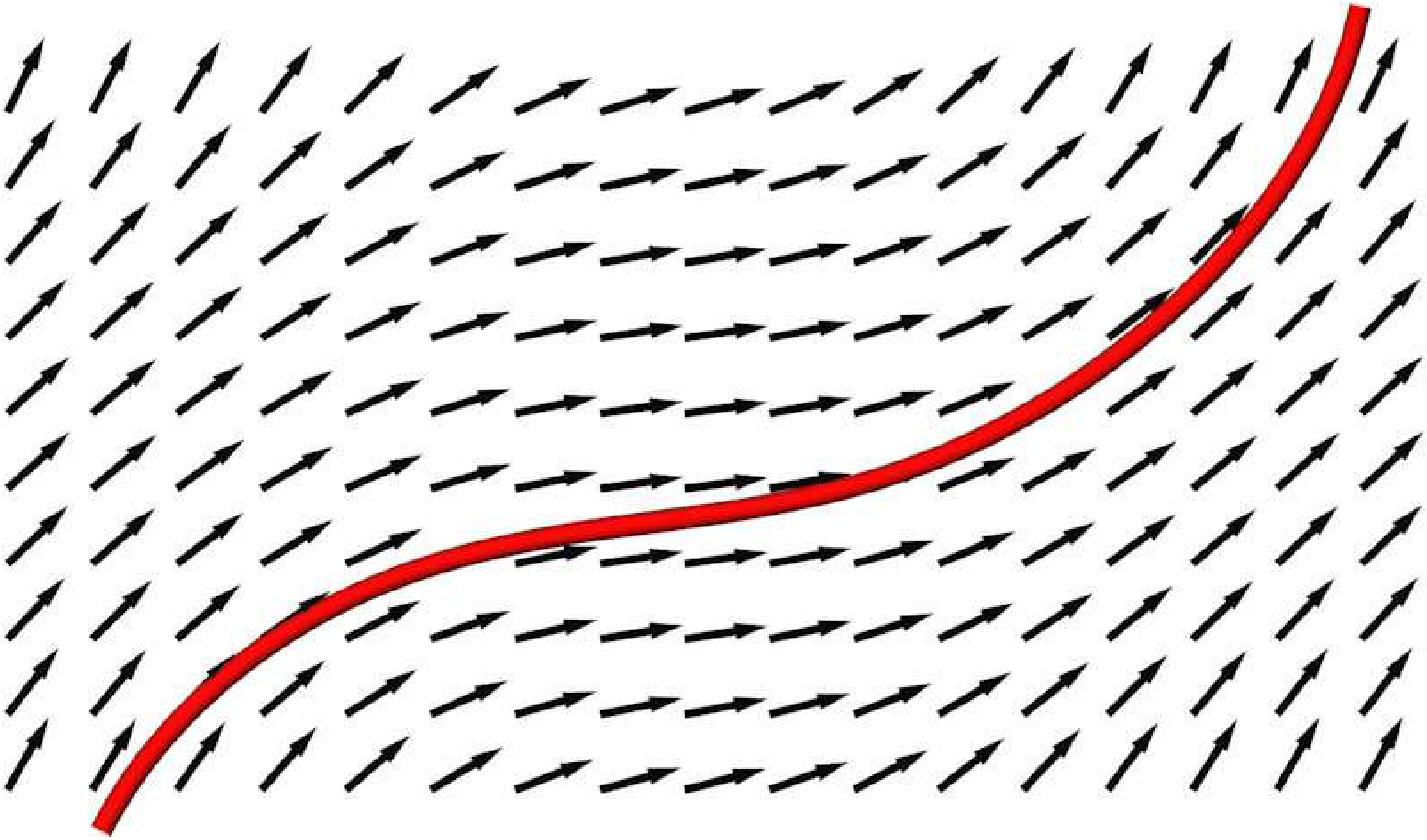




images from wikipedia

Integral Curves / Stream Objects

Integrating velocity over time yields spatial motion

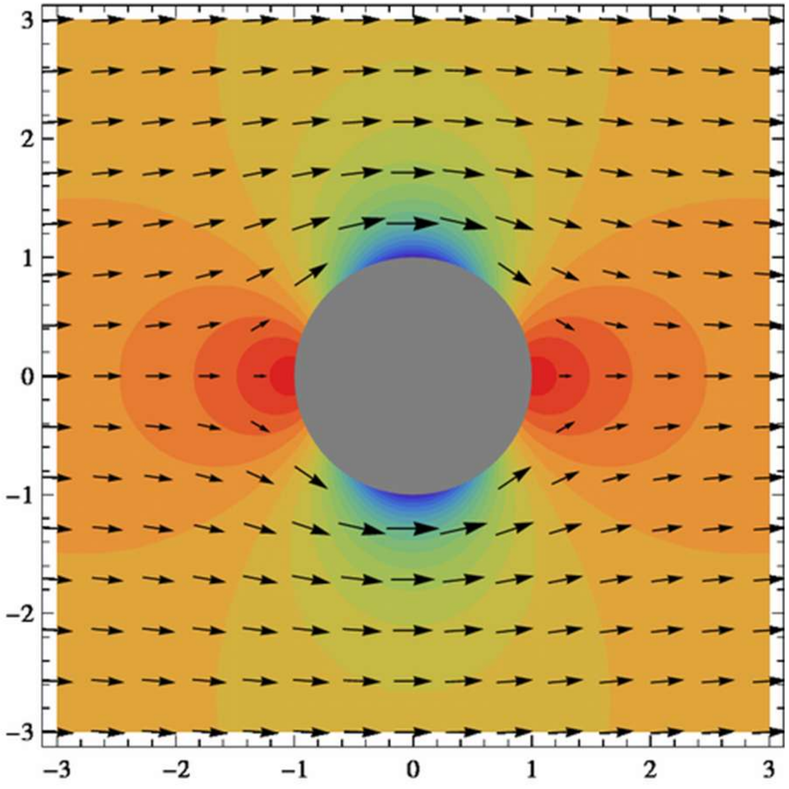


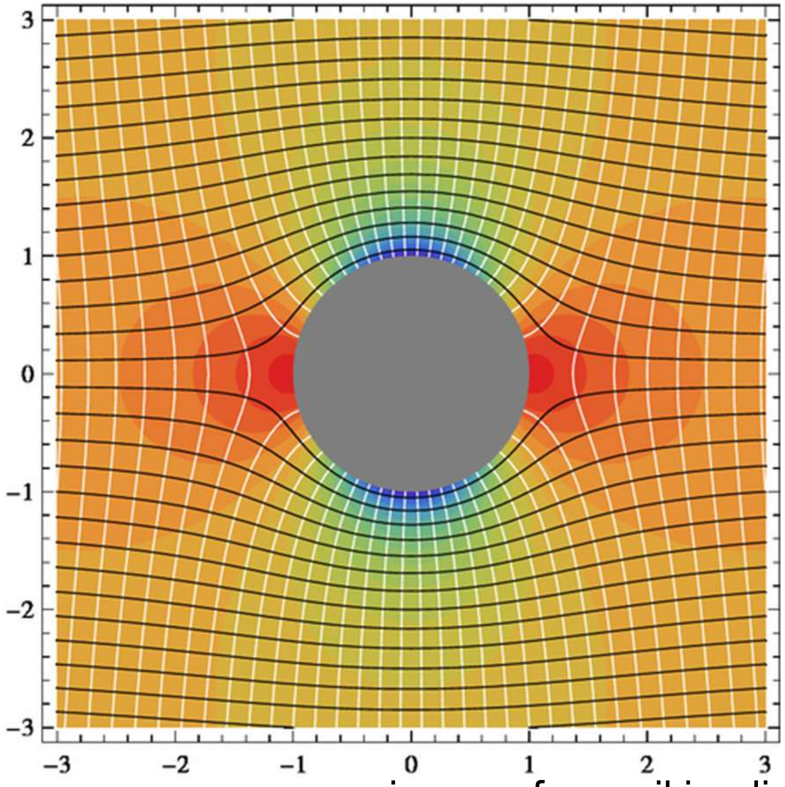
Flow Field Example (1)

Potential flow around a circular cylinder

`https://en.wikipedia.org/wiki/Potential_flow_around_a_circular_cylinder`

Inviscid, incompressible flow that is irrotational (curl-free) and can be modeled as the gradient of a scalar function called the (scalar) velocity potential





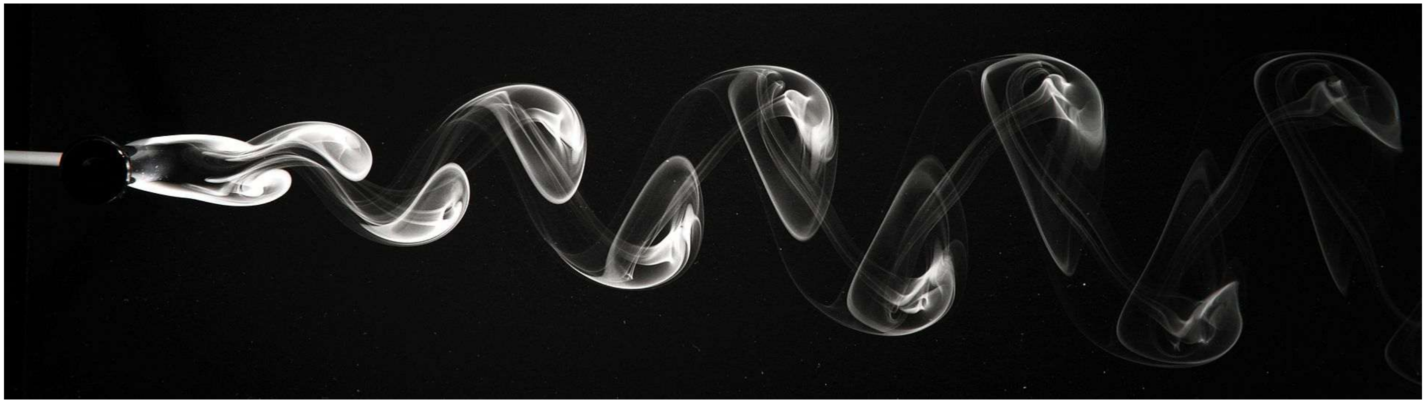
images from wikipedia

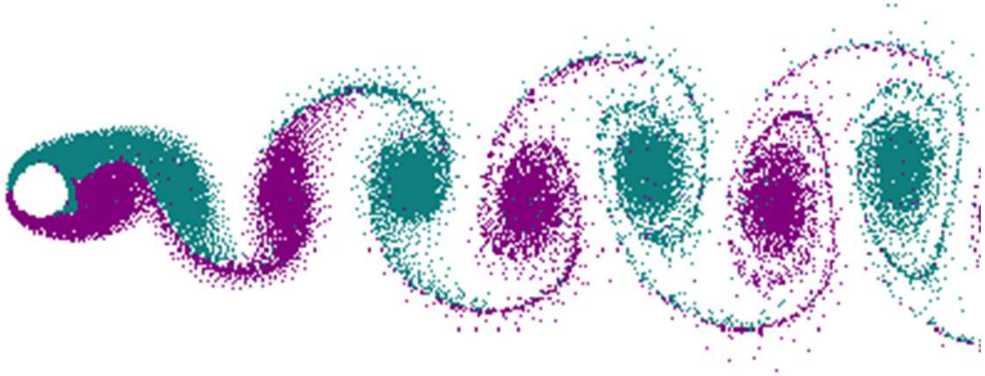
Flow Field Example (2)

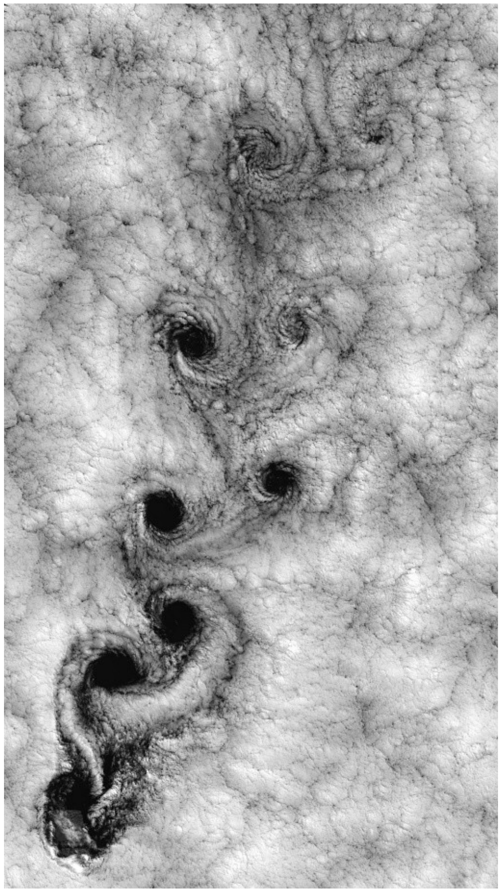
Depending on Reynolds number, turbulence will develop

Example: von Kármán vortex street: vortex shedding

`https://en.wikipedia.org/wiki/Karman_vortex_street`







images from wikipedia

Thank you.

Thanks for material

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- Philipp Muigg
- Christof Rezk-Salama