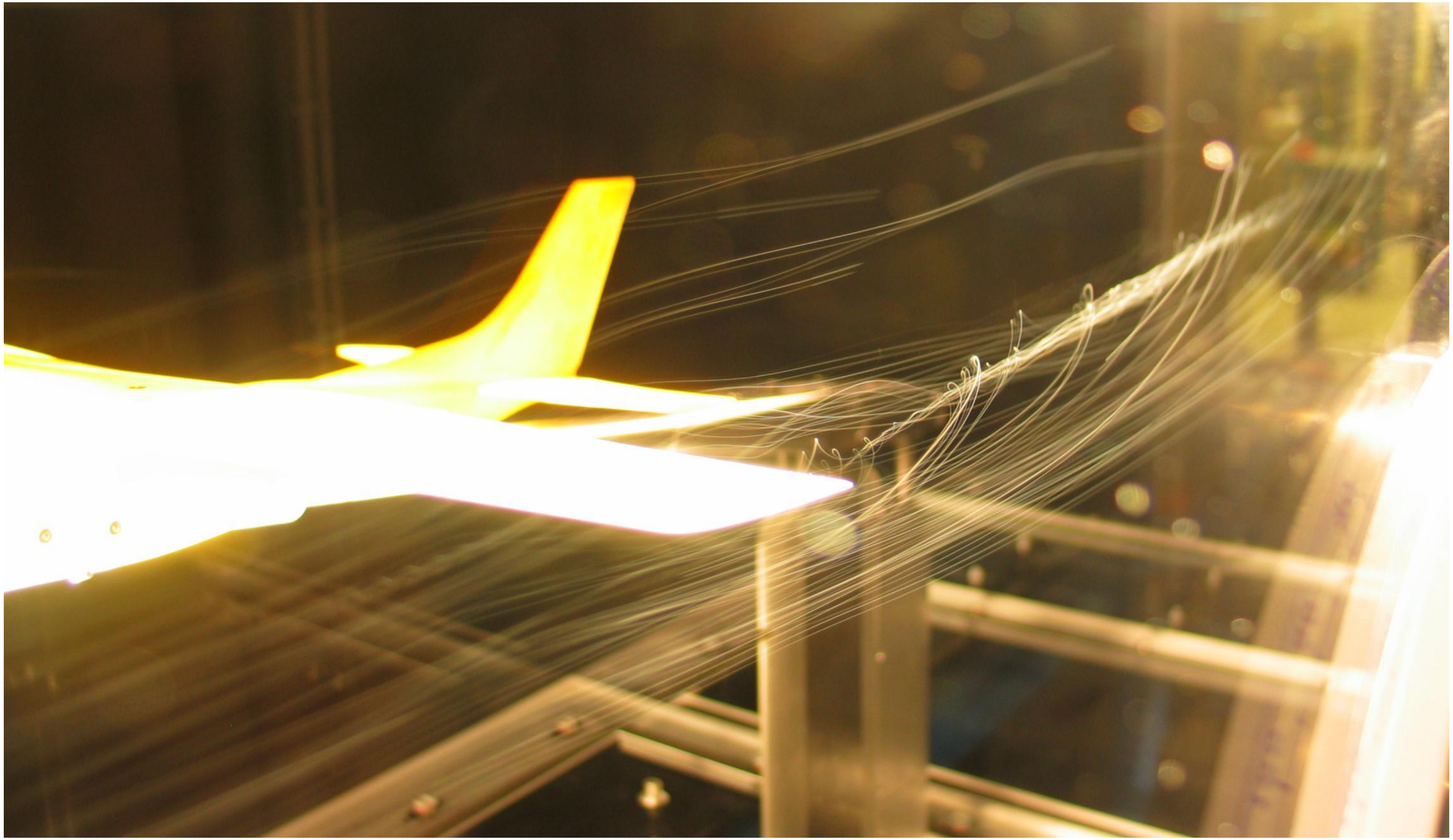
Visualization, DD2257

Prof. Dr. Tino Weinkauf

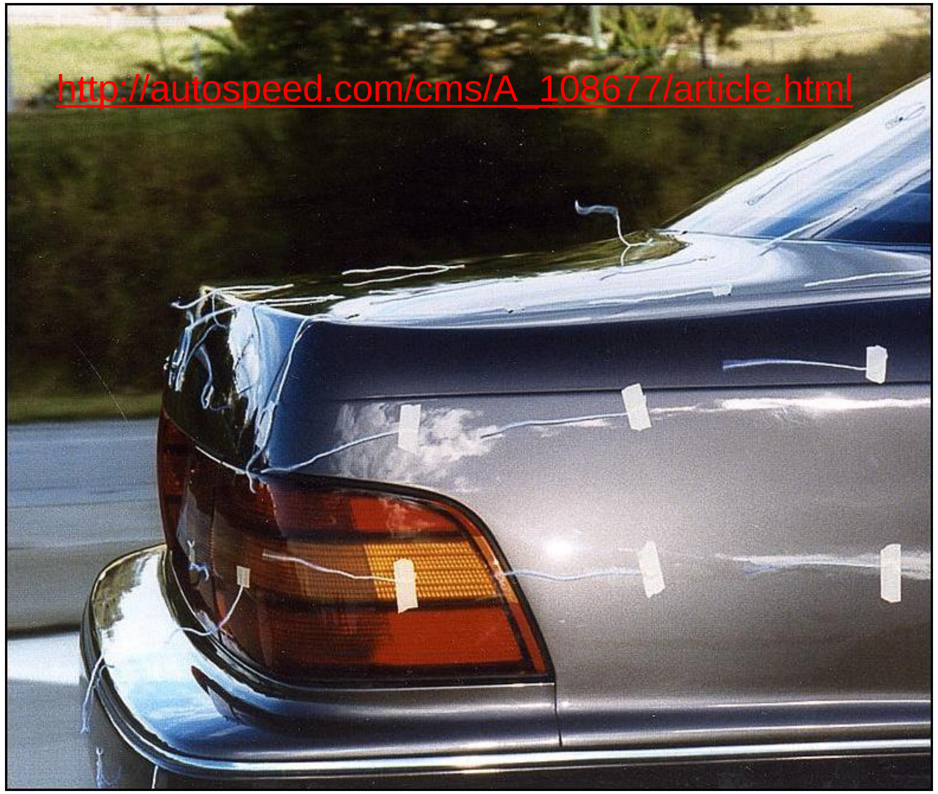
Vector Fields

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).

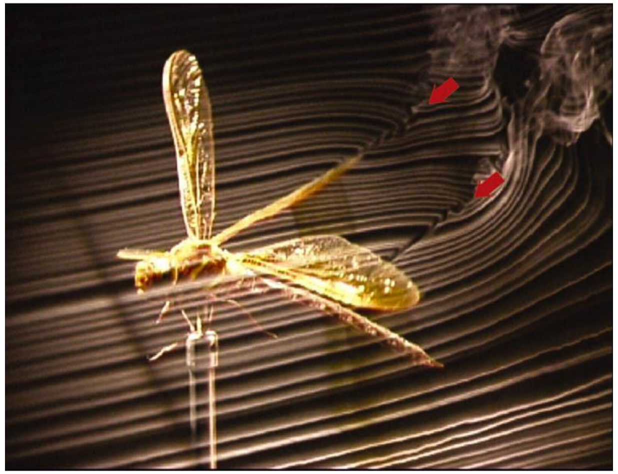

http://autospeed.com/cms/A_108677/article.html


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

wool tufts

smoke injection

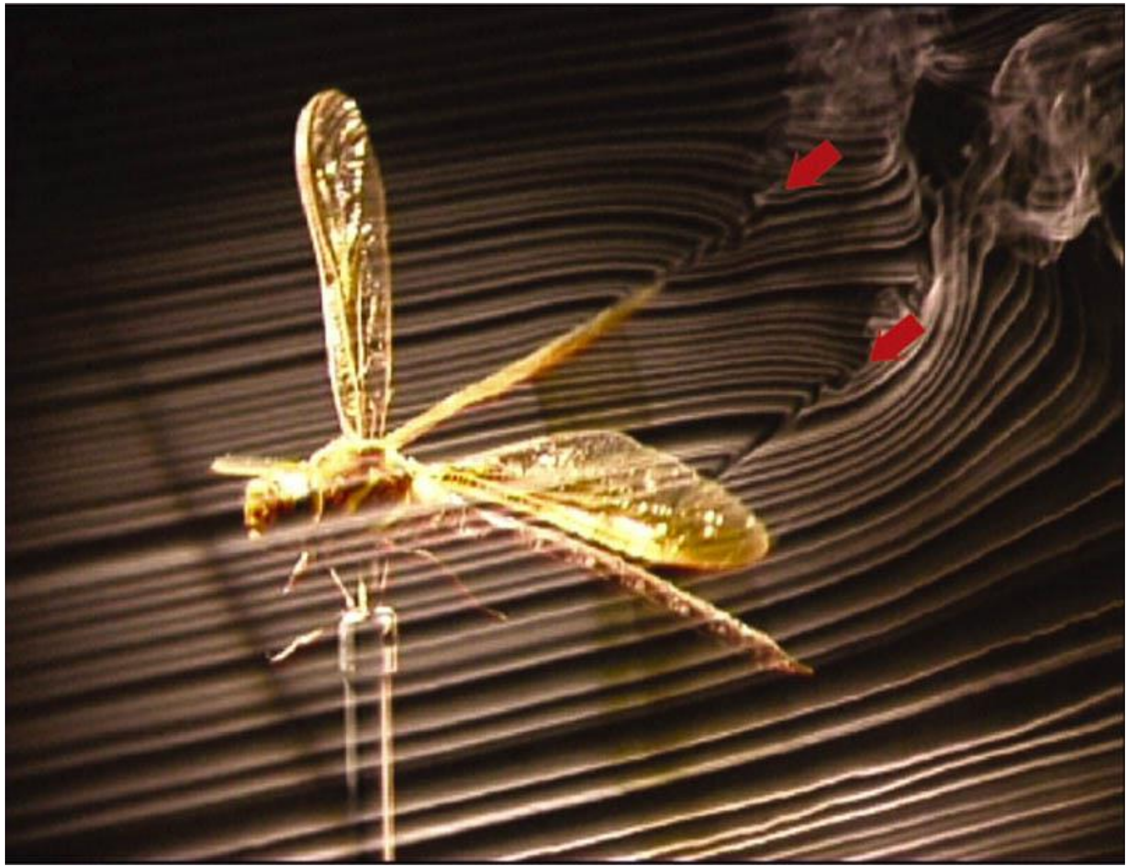
http://autospeed.com/cms/A_108677/article.html smoke nozzles



[NASA, J. Exp. Biol.]

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

Smoke injection

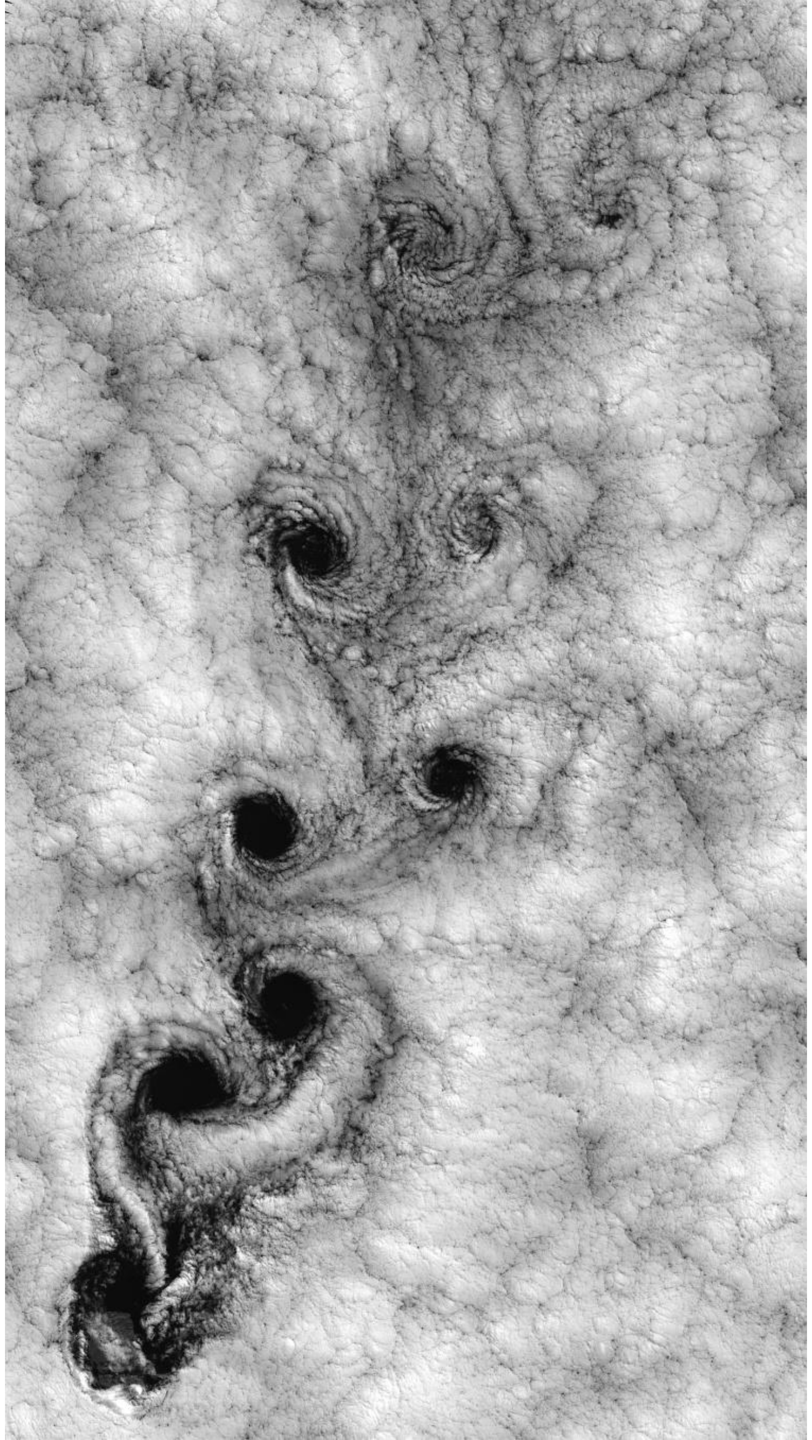


A. L. R. Thomas, G. K. Taylor, R. B. Srygley, R. L. Nudds, and R. J. Bomphrey. Dragonfly flight: free-flight and tethered flow visualizations reveal a diverse array of unsteady lift-generating mechanisms, controlled primarily via angle of attack. J Exp Biol, 207(24):4299–4323, 2004.

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

Smoke injection

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



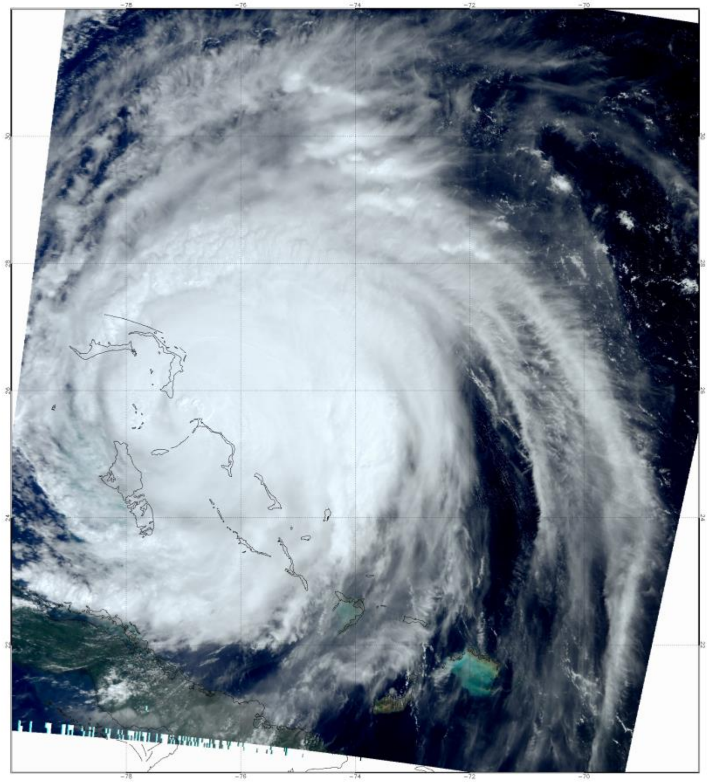
Clouds (satellite image)

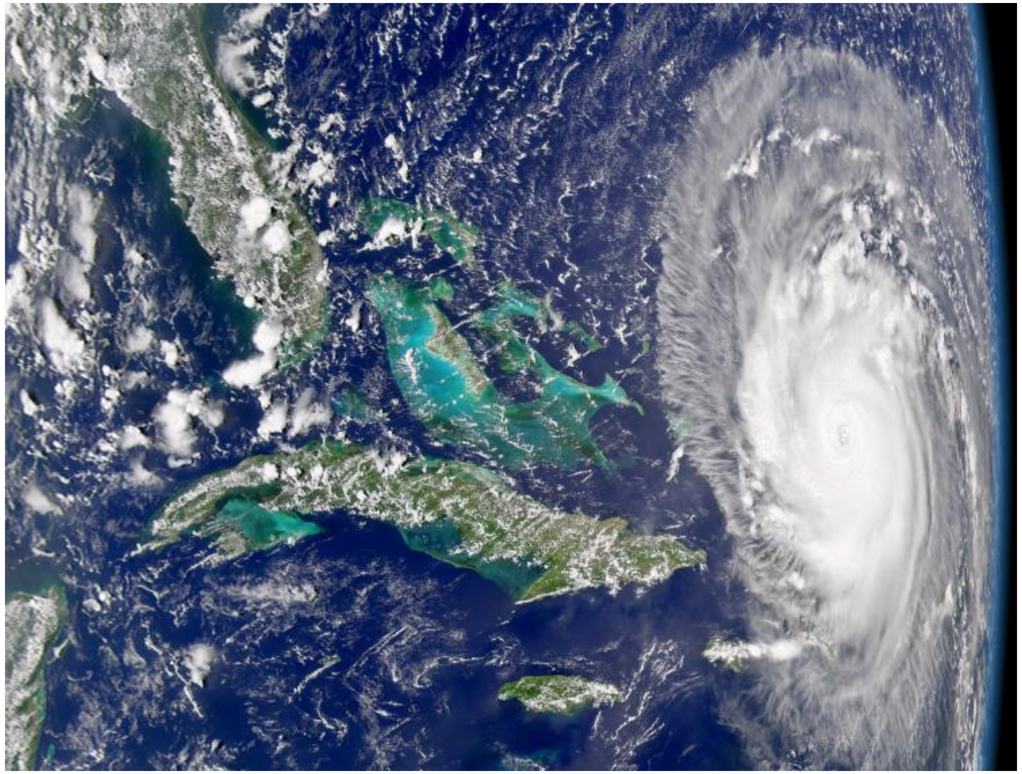
Juan Fernandez Islands

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

Clouds (satellite image)

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





Real-World Sources of Flow Data

point sensors

optical methods

particle image velocimetry

particle image velocimetry

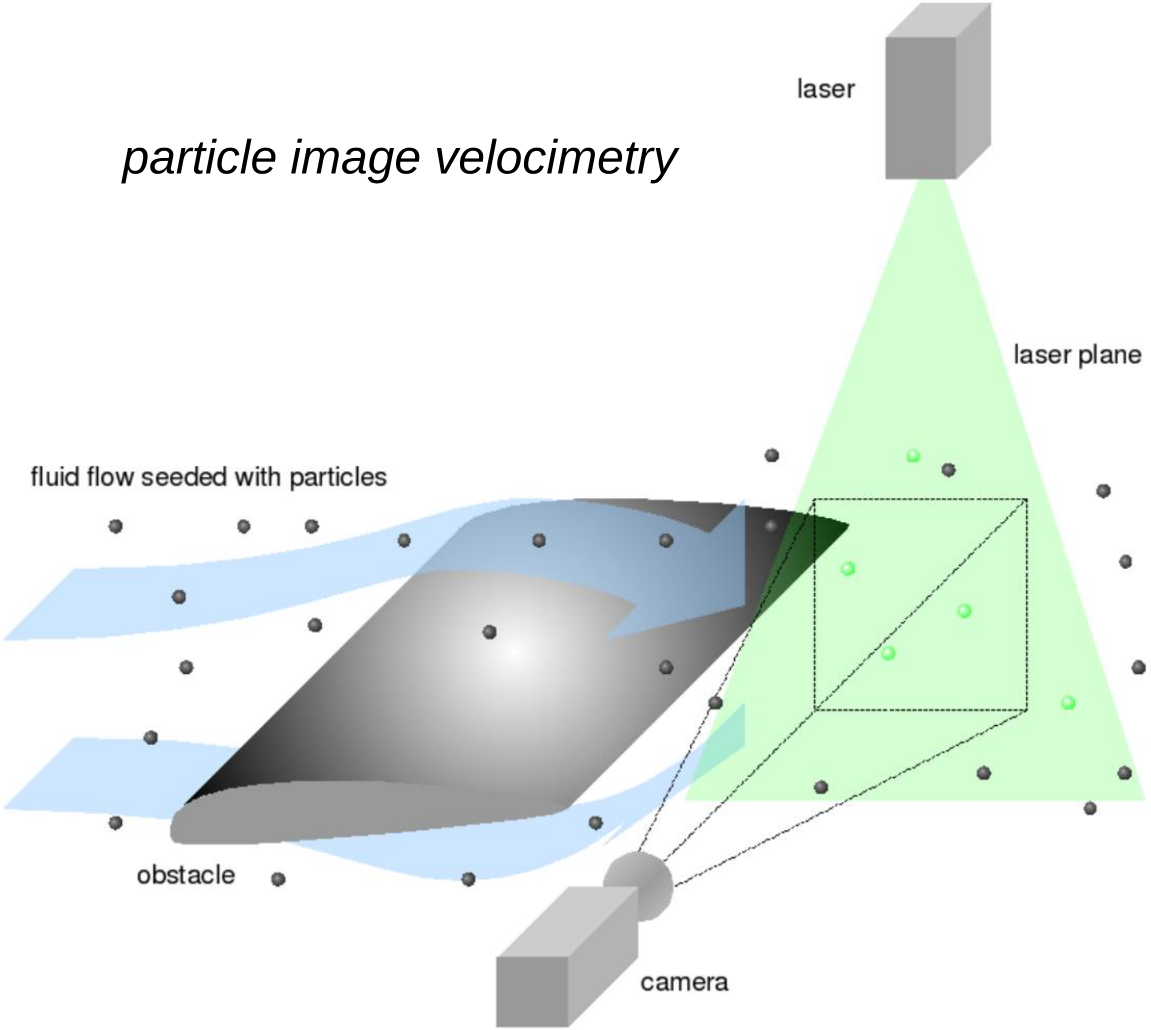


image from Florian Becker, PhD thesis, Heidelberg University, 2009

Simulation of Flow Data

Navier–Stokes equations

$$\rho\dot{\vec{v}} = \rho\left(\frac{\partial\vec{v}}{\partial t} + (\vec{v}\cdot\nabla)\vec{v}\right) = -\nabla p + \mu\Delta\vec{v} + (\lambda+\mu)\nabla(\nabla\cdot\vec{v}) + \vec{f}$$

Simulation of Flow Data

high computational costs

example:

flow simulation around airplane

1 second fully resolved flight
computed on KTH's Beskow

computation time: 500 years

data size: 100 petabyte

Beskow

vector field

$$\mathbf{v} : \mathbb{E}^n \to \mathbb{R}^m$$

$$\mathbf{v}(\mathbf{x}) = \begin{pmatrix} c_1(\mathbf{x}) \\ \vdots \\ c_m(\mathbf{x}) \end{pmatrix}$$

$\text{with } \mathbf{x} \in \mathbb{E}^n$

$$\mathbf{v}(x, y) = \begin{pmatrix} u(x, y) \\ v(x, y) \end{pmatrix}$$

2D vector field

vector field

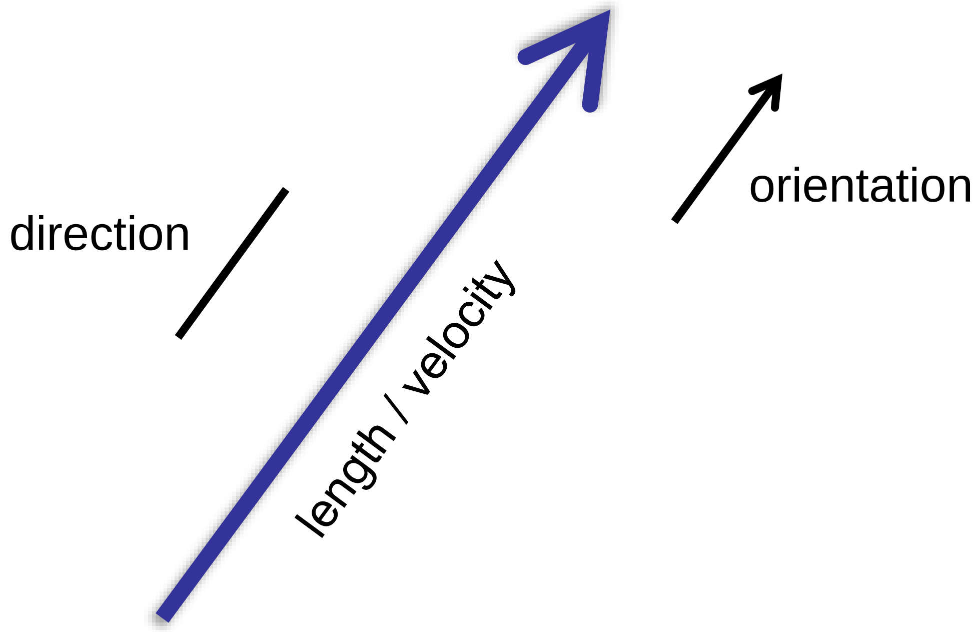
$$\mathbf{v} : \mathbb{E}^n \to \mathbb{R}^m$$

$$\mathbf{v}(\mathbf{x}) = \begin{pmatrix} c_1(\mathbf{x}) \\ \vdots \\ c_m(\mathbf{x}) \end{pmatrix}$$

with $\mathbf{x} \in \mathbb{E}^n$

$$\mathbf{v}(x, y) = \begin{pmatrix} 2x - y \\ 2y \end{pmatrix}$$

2D vector field



information encoded in a vector

vector field visualization method:
which of these aspects are shown?

vector field

$$\mathbf{v} : \mathbb{E}^n \rightarrow \mathbb{R}^m$$

tensor field

$$\mathbf{T} : \mathbb{E}^n \rightarrow \mathbb{R}^{m \times b}$$

$$\begin{pmatrix} c_1(\mathbf{x}) \\ \vdots \end{pmatrix}$$

The first derivative of a vector field is a tensor field called **Jacobian**. It consists of the partial derivatives of $\mathbf{v}(\mathbf{x})$ for each dimension of the observation space.

$$\mathbf{T}(\mathbf{x}) = \begin{pmatrix} c_{11}(\mathbf{x}) & \dots & c_{1b}(\mathbf{x}) \\ \vdots & & \vdots \\ c_{m1}(\mathbf{x}) & \dots & c_{mb}(\mathbf{x}) \end{pmatrix}$$

with $\mathbf{x} \in \mathbb{E}^n$

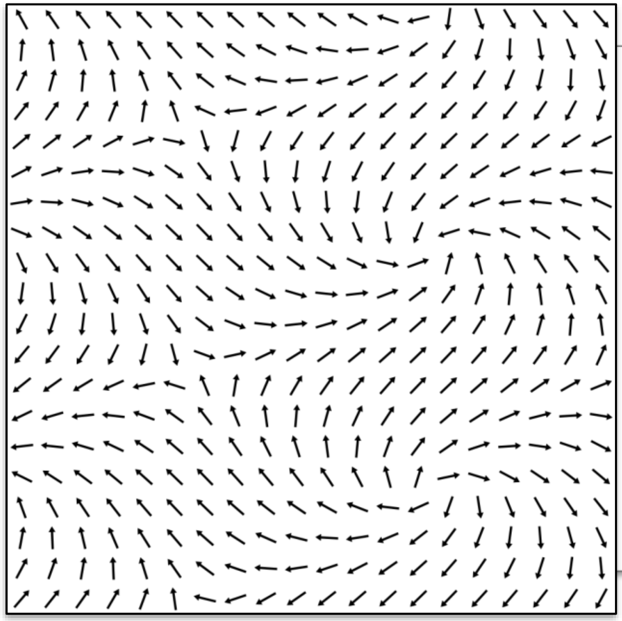
$$\mathbf{v}(x, y) = \begin{pmatrix} u(x, y) \\ v(x, y) \end{pmatrix}$$

2D vector field

$$\nabla \mathbf{v}(x, y) = \begin{pmatrix} u_x & u_y \\ v_x & v_y \end{pmatrix}$$

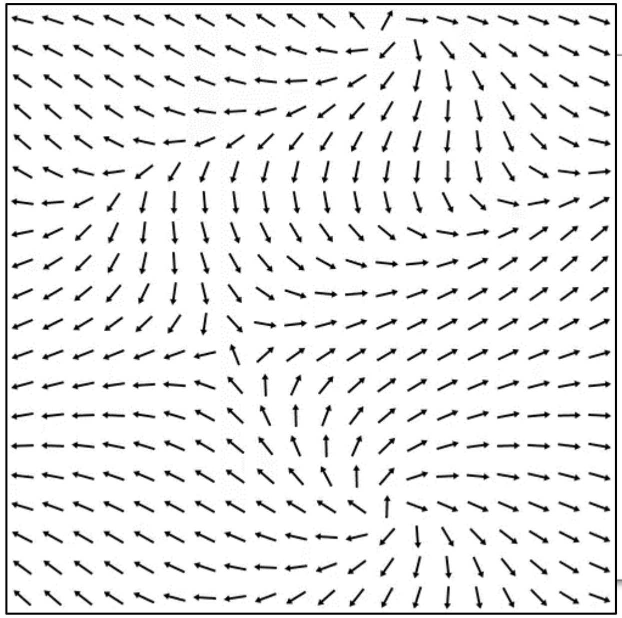
Jacobian

$\mathbf{v}: \mathrm{E}^n \to \mathbb{R}^n$



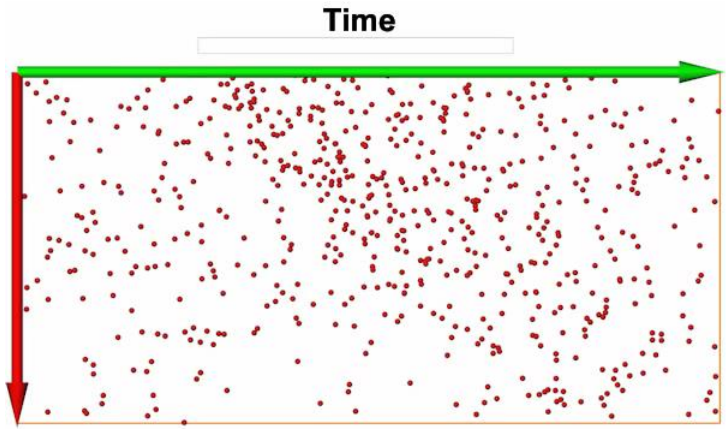
Steady Vector Fields

$\mathbf{v}: \mathrm{E}^{n+1} \to \mathbb{R}^n$

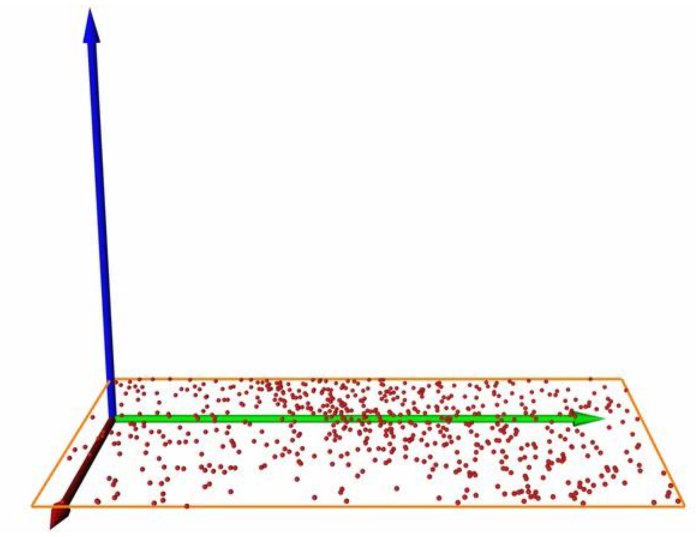


Unsteady Vector Fields

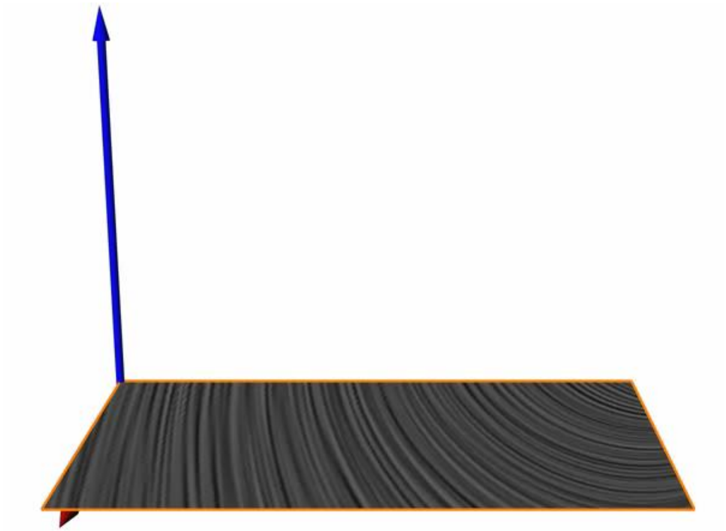
- time-dependent



2D time-dependent vector field
particle visualization



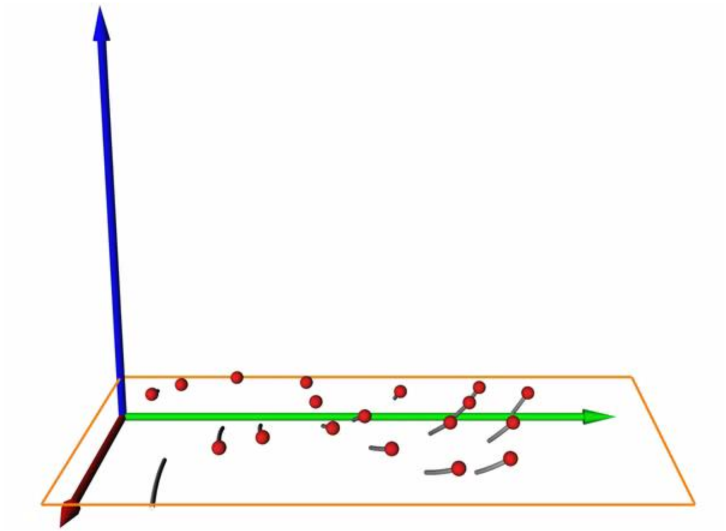
2D time-dependent vector field
particle visualization
space-time diagram



stream lines

curve tangential to the vector field
in each point for a **fixed time**

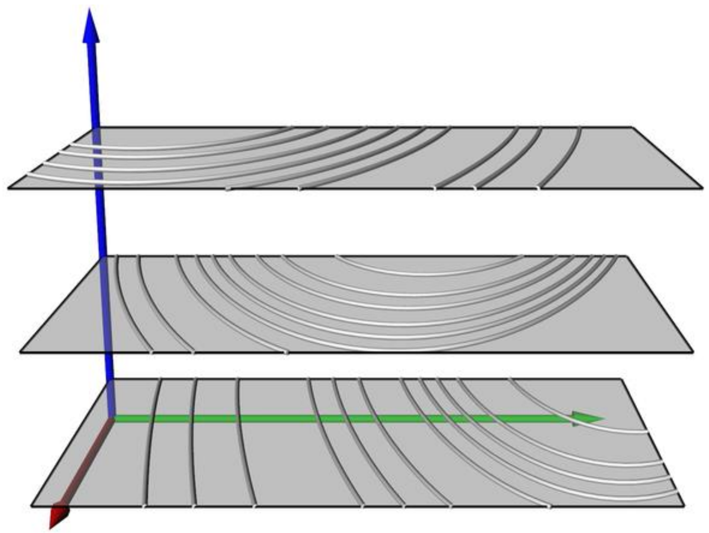
describes motion of a massless particle
in a **steady** flow field



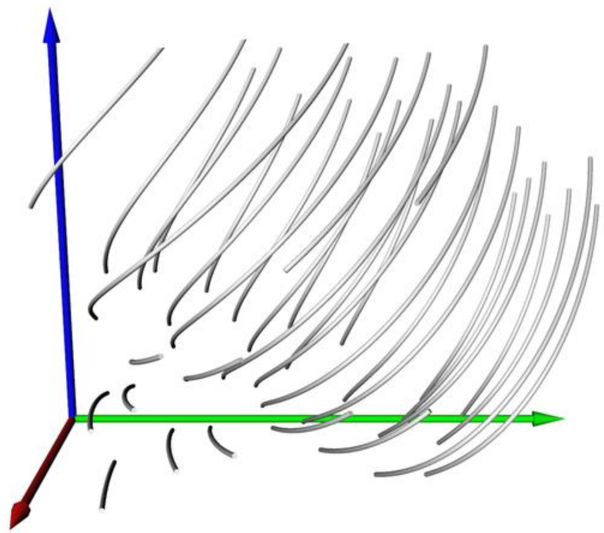
path lines

curve tangential to the vector field
in each point **over time**

describes motion of a massless particle
in an **unsteady** flow field

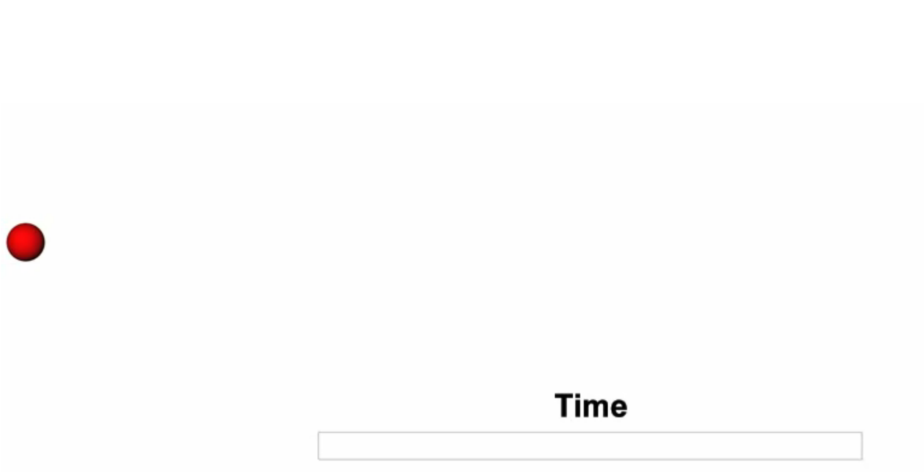


stream lines

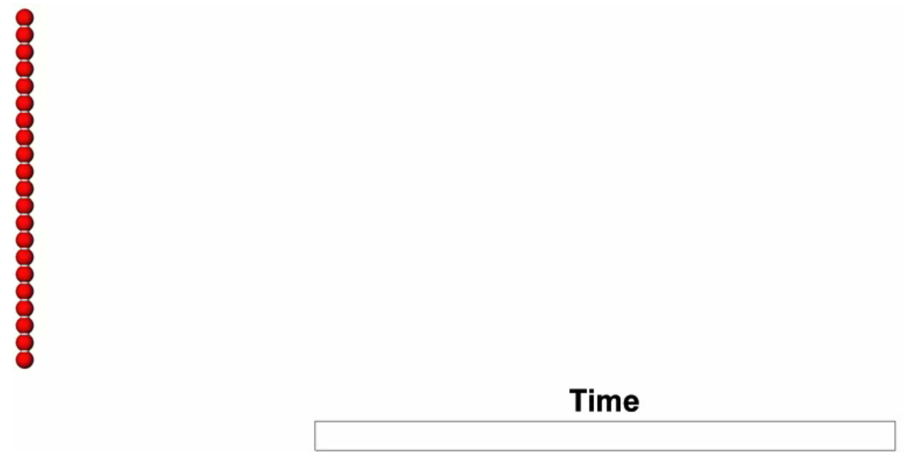


path lines

streak lines



time lines



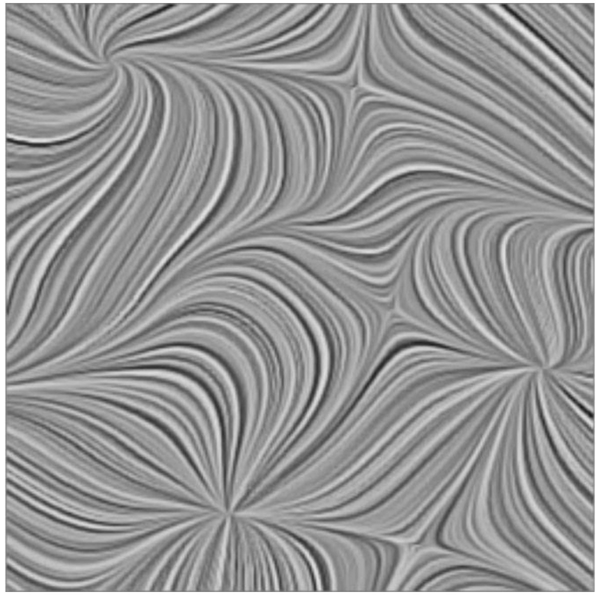
location of all particles set out at a fixed point at different times

location of all particles set out on a certain line at a fixed time

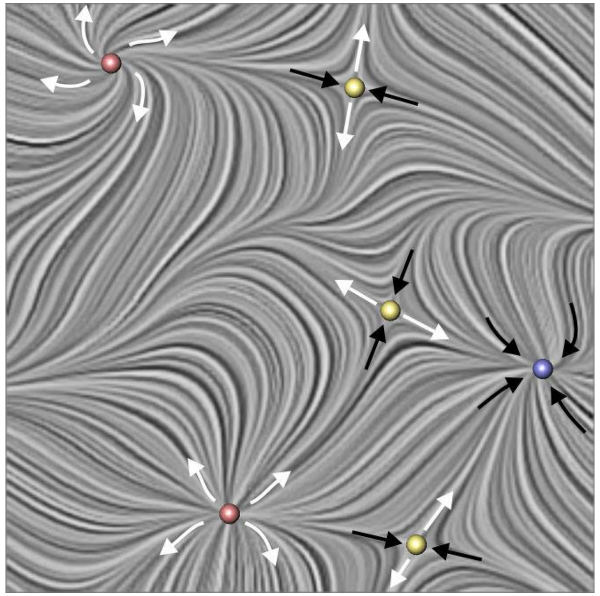
Topological Structures

steady 2D vector field

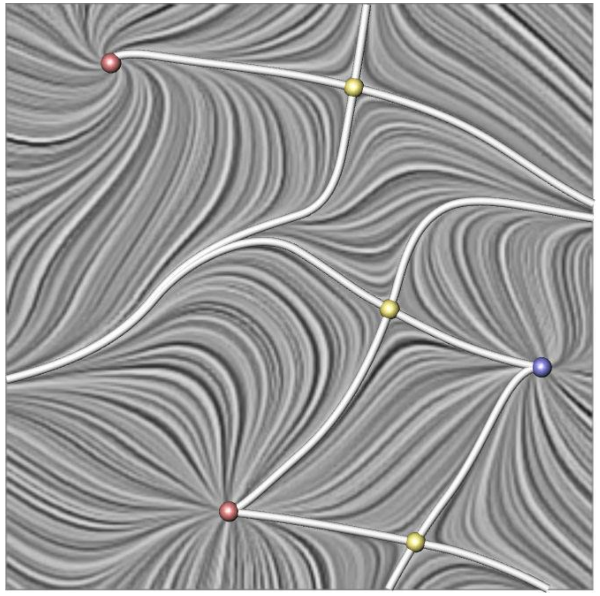
$$\mathbf{v} = \begin{pmatrix} u \\ v \end{pmatrix}$$



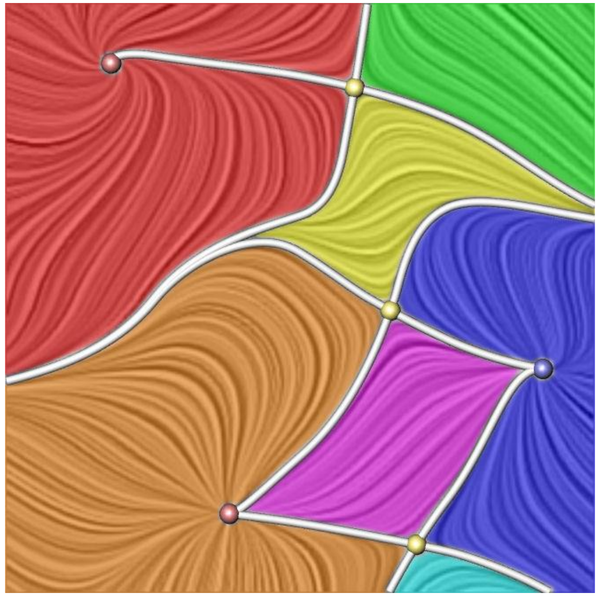
stream lines



critical points



separation lines

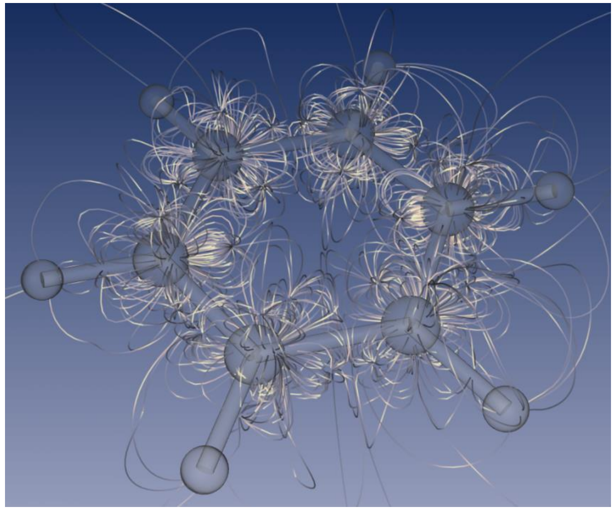


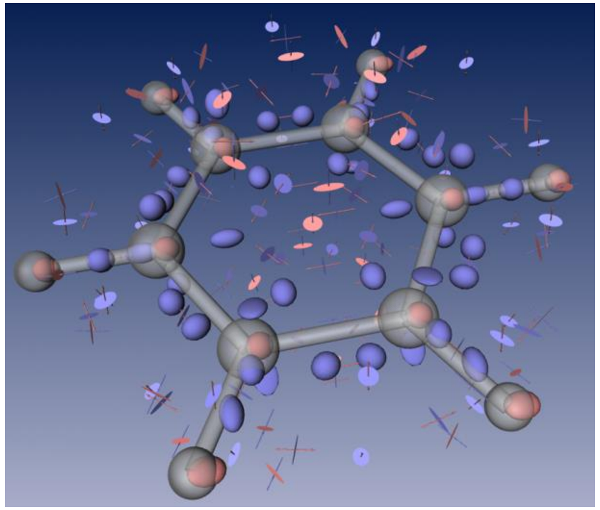
sectors of different flow behavior

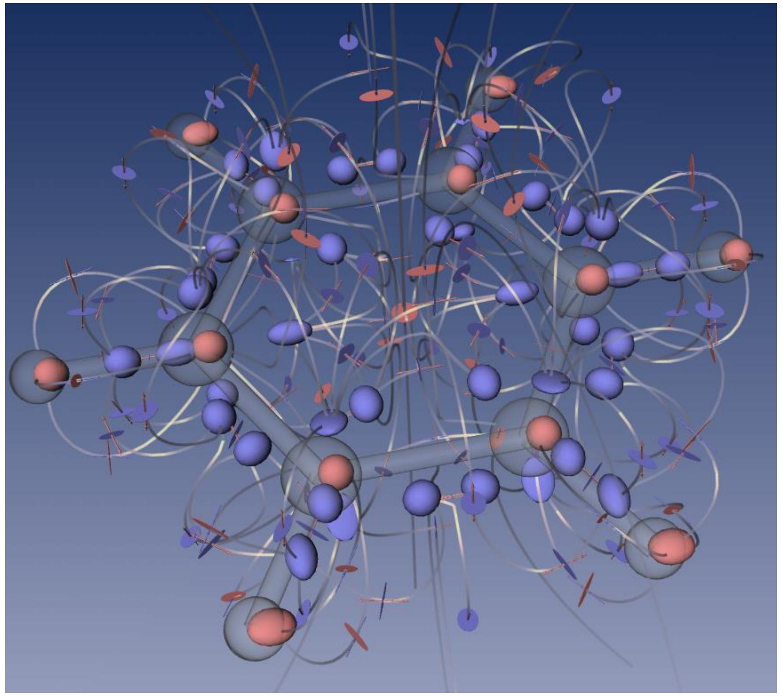
Topological Structures

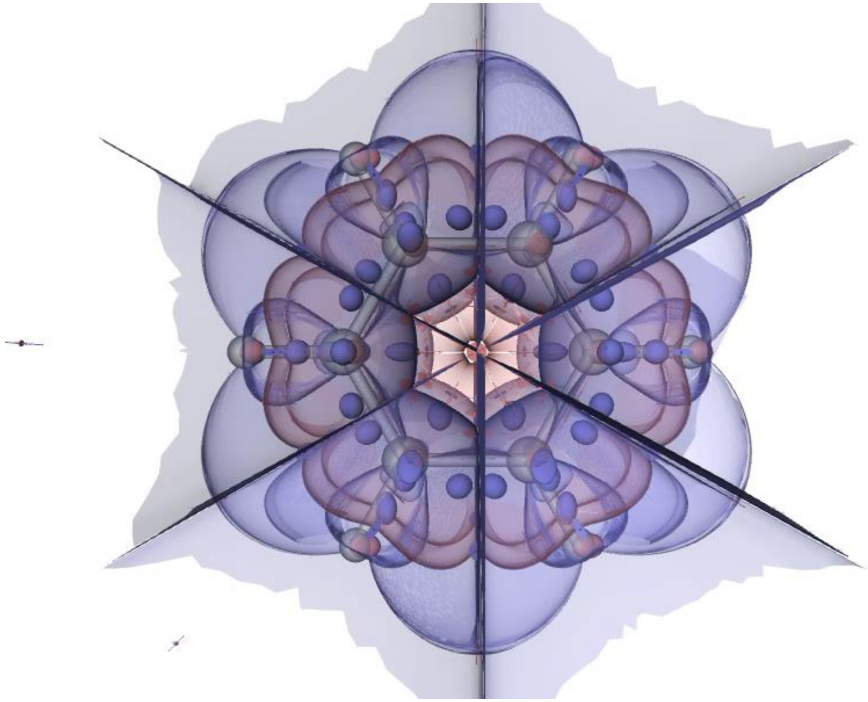
steady 3D vector field

$$\mathbf{v} = \begin{pmatrix} u \\ v \\ w \end{pmatrix}$$


stream lines


critical points


separation lines


separation surfaces

Direct	Integration		Features		
arrow plots	Geometry-based	Image-based: LIC, Spot Noise, IBFV	Derived Quantities	Topology	Vortex Structures