Introduction to flow visualization

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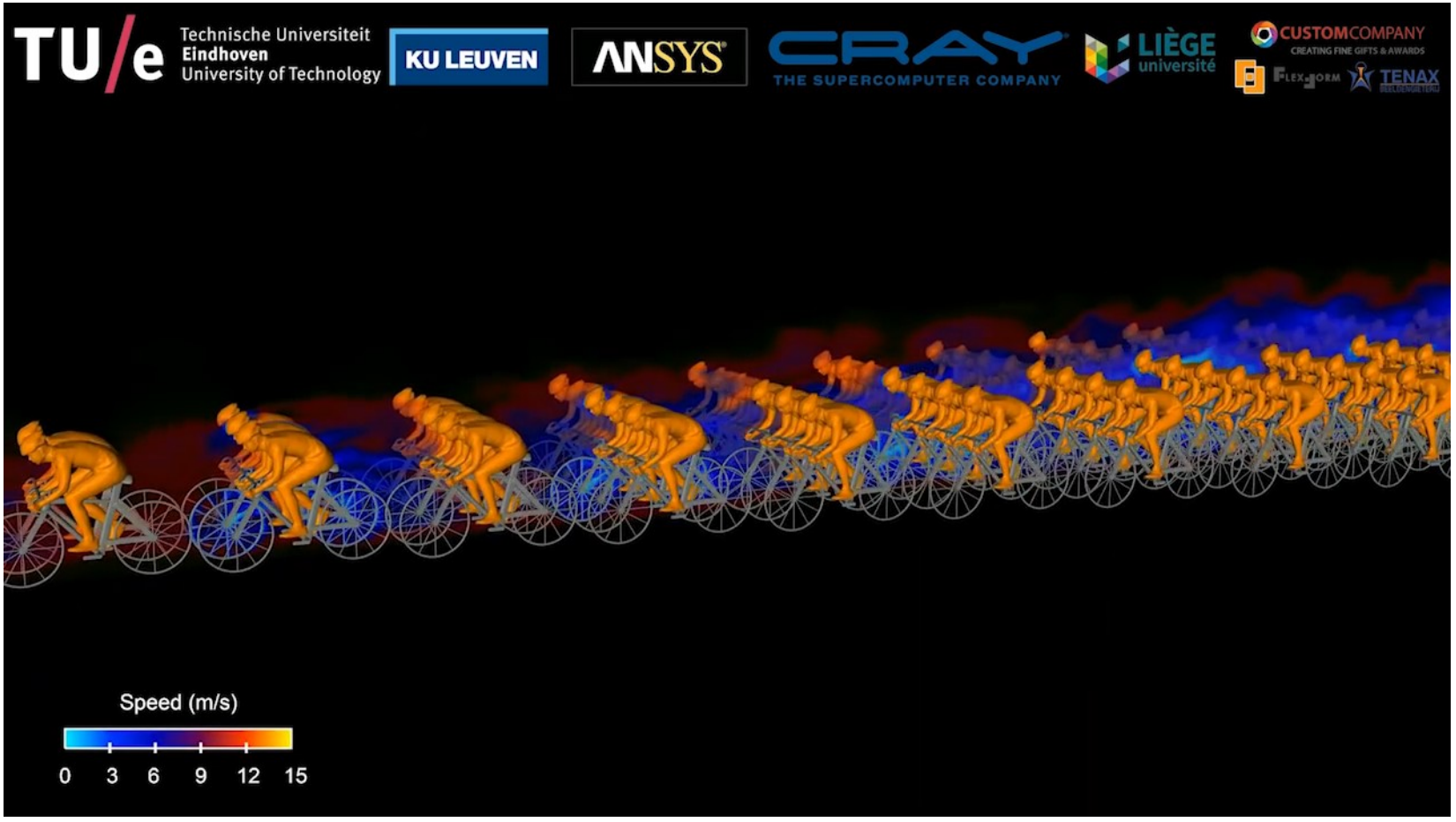
What is flow visualization?

- A classic topic within scientific visualization
- The depiction of vector quantities (as opposed to scalar quantities)
- Applications include automotive simulation, aerodynamics, turbomachinery, meteorology, oceanography, medical visualization, sports

https://www.youtube.com/watch?v=A05n32Bl0aY

Example



https://www.youtube.com/watch?v=kZBh-fpv2sY

Origins of flow data

flow simulation

- airplane- / ship- / car-design
- weather simulation (air-, sea-flows)
- medicine (blood flows, etc.)
- Simulation data is given as a set of samples on a grid
- Computational fluid dynamics (CFD)

flow measurement

- wind tunnels, water channels
- optical measurement techniques
- Vectors are measure using instrumental equipment, e.g. optical methods like particle image velocimetry

flow models

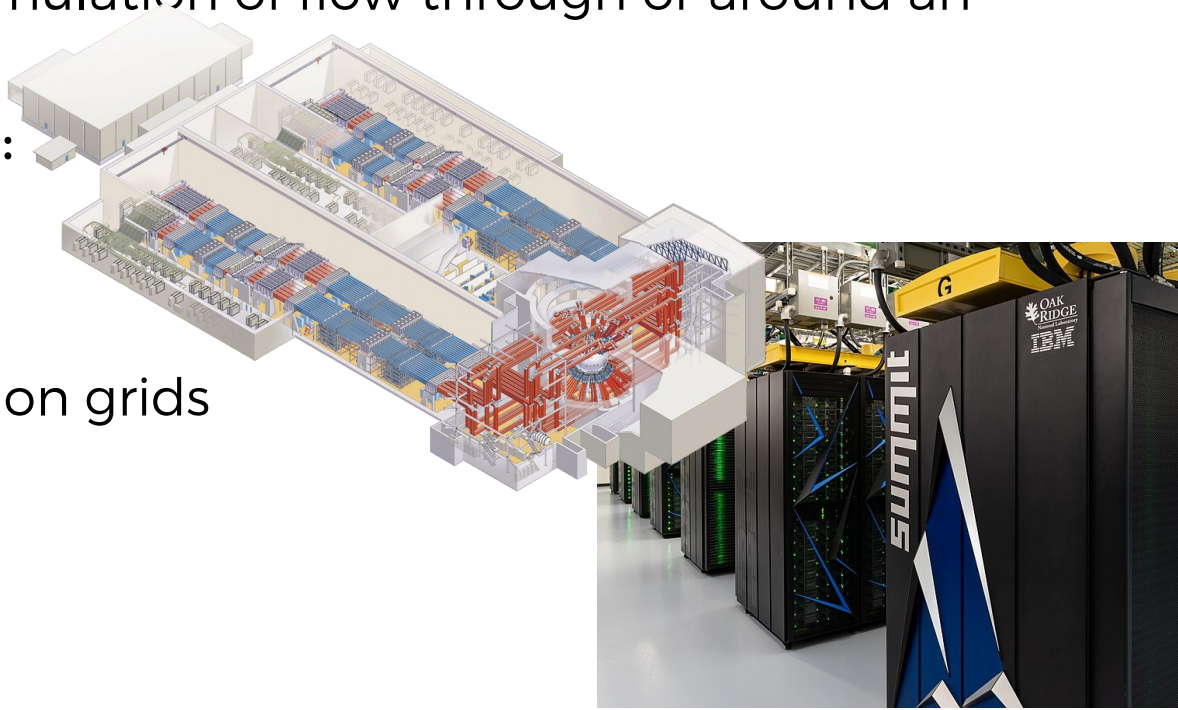
- differential equation systems (dynamic systems)
- Vectors are provided by an analytic formula, wherever needed

Computational fluid dynamics

- We often visualize Computational Fluid Dynamics (CFD) simulation data
- CFD is the discipline of predicting flow behavior, quantitatively
- data is (often) the result of a simulation of flow through or around an object of interest

some characteristics of CFD data:

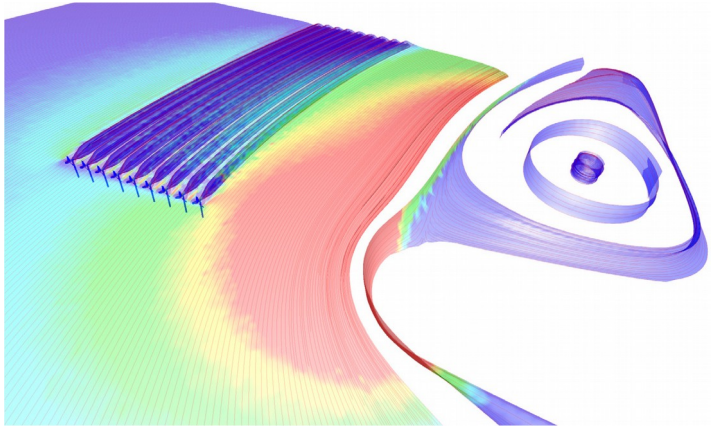
- large, often gigabytes
- unsteady, time-dependent
- unstructured, adaptive resolution grids
- smooth



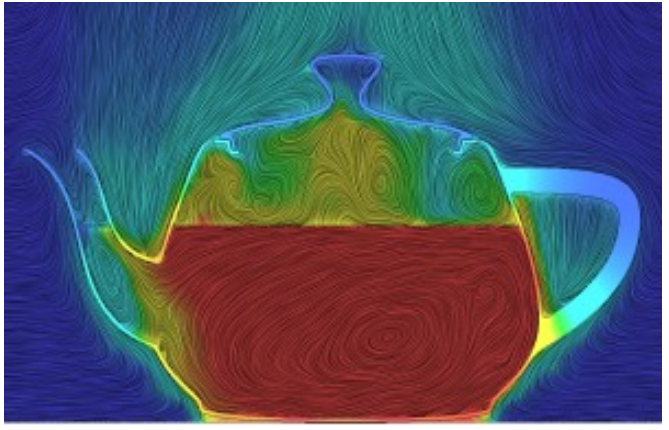
Tasks

- Find eddies
- How flows interfere with objects
- Forces over time
- Diffusion of one fluid into another

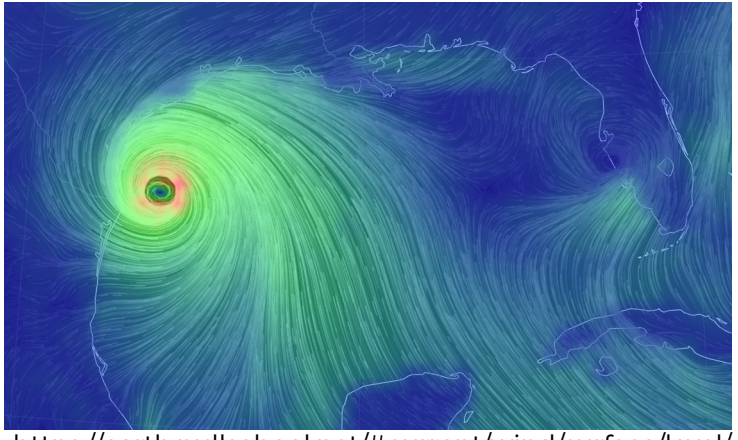
Tasks



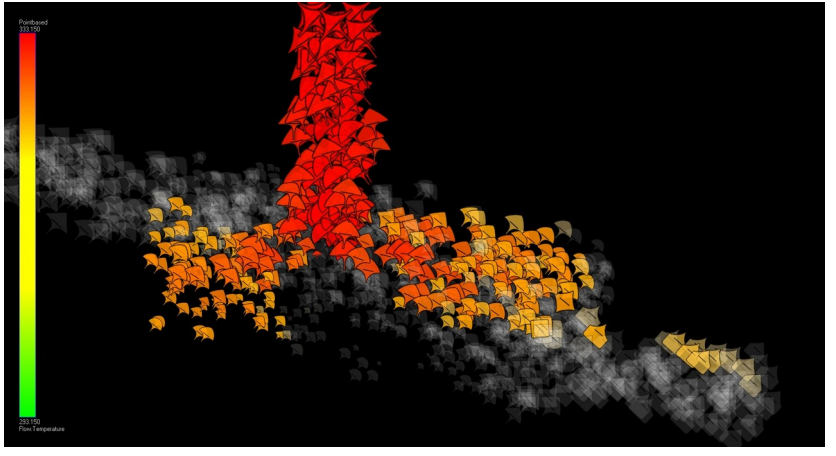
Edmunds et al., “Aspects of Tidal Stream Turbine Modelling in the Natural Environment Using a Coupled BEM–CFD Model.”



https://blog.pointwise.com/2015/07/10/this-week-in-cfd-204/



https://earth.nullschool.net/#current/wind/surface/level/



http://ii.uib.no/vis_old/teaching/vis-project/2008-fall/lie/index.html

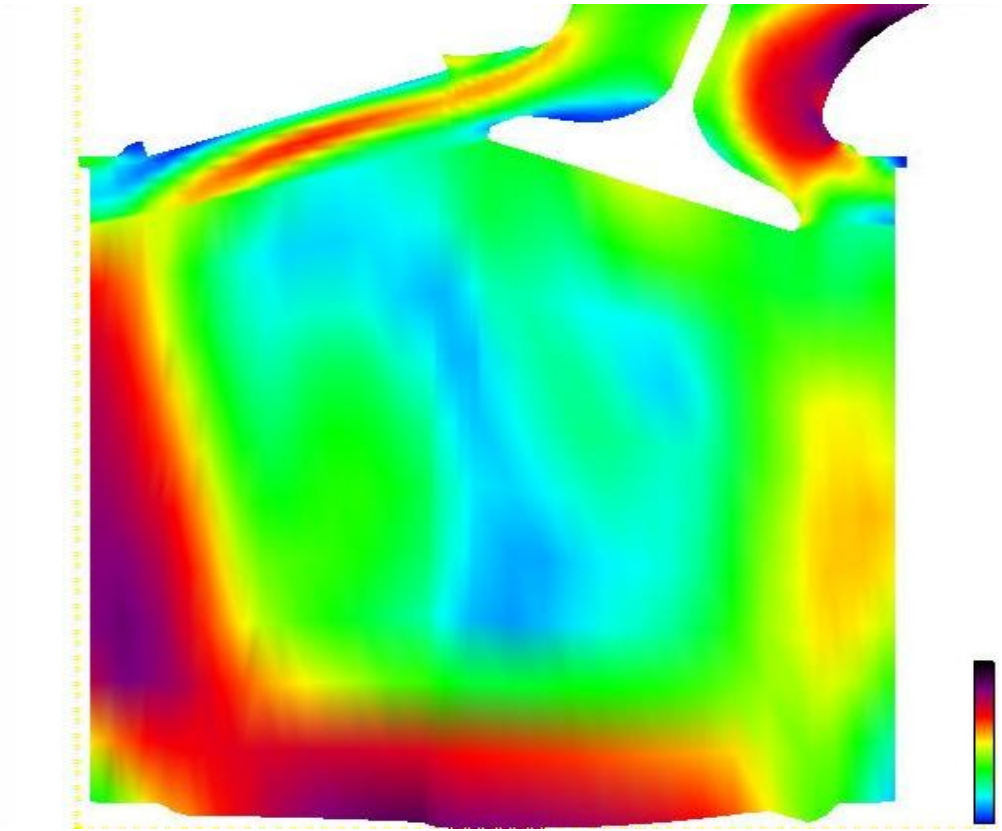
Challenges

- effectively visualize both magnitude + direction, often simultaneously
- large data sets
- time-dependent data
- What should be visualized? (data filtering/feature extraction)

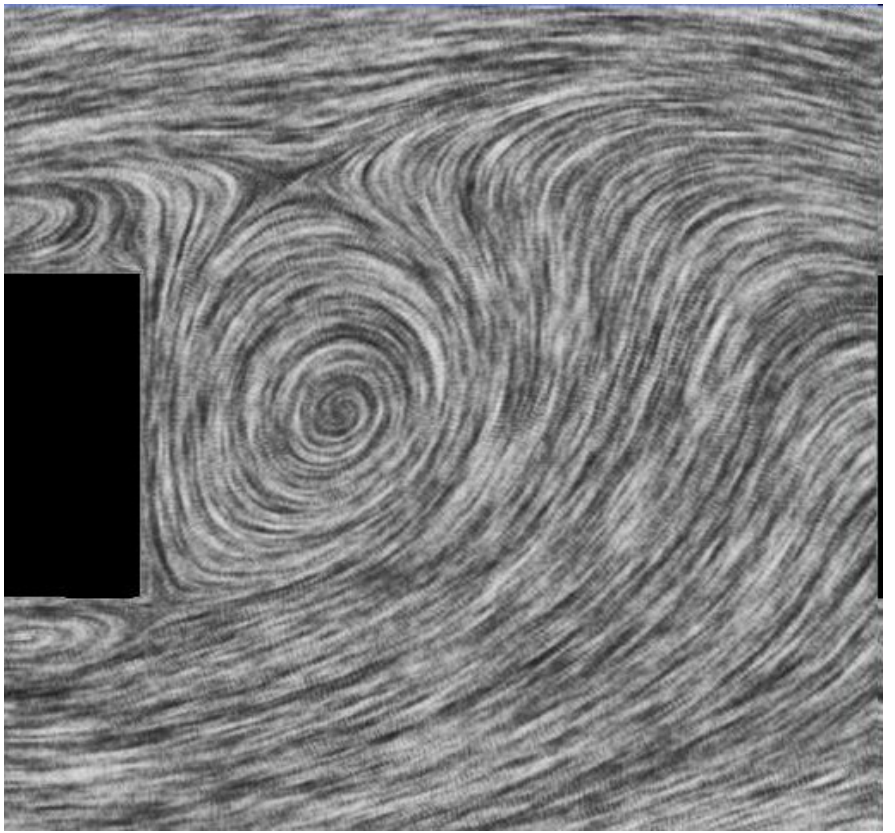
Challenges

Challenge: to effectively visualize both *magnitude + direction* often simultaneously

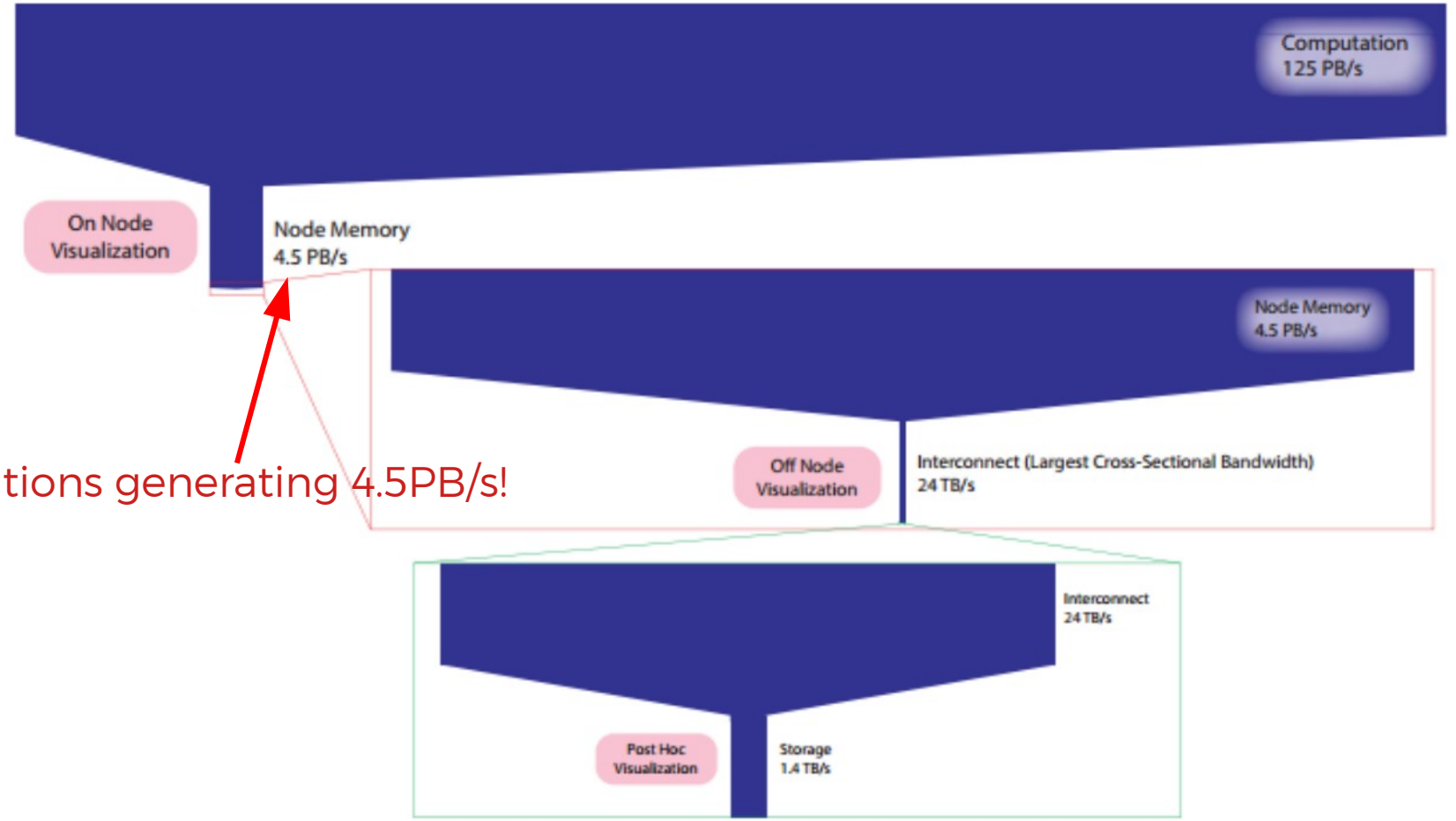
Magnitude only



Direction only



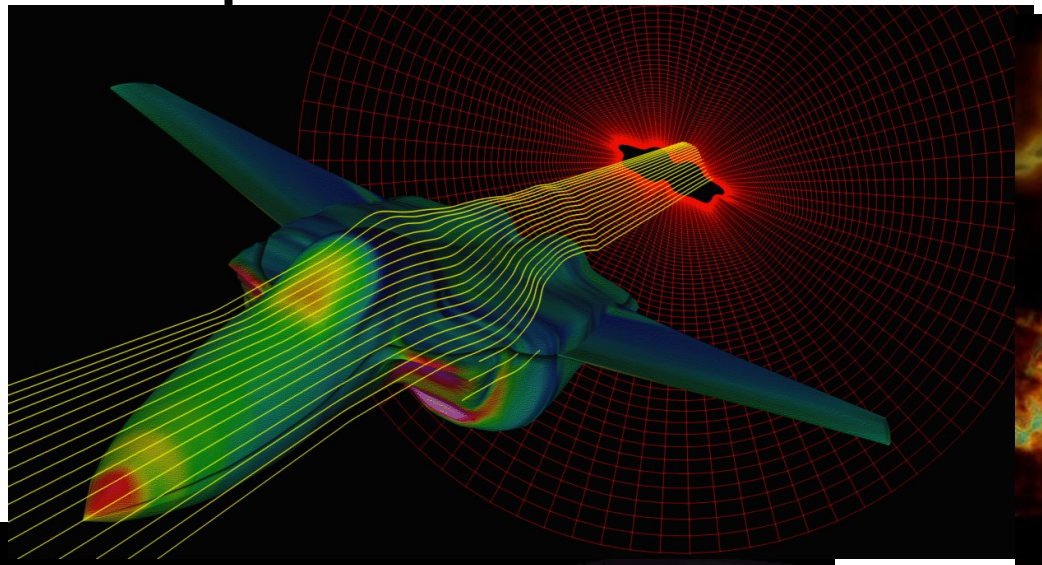
Large datasets

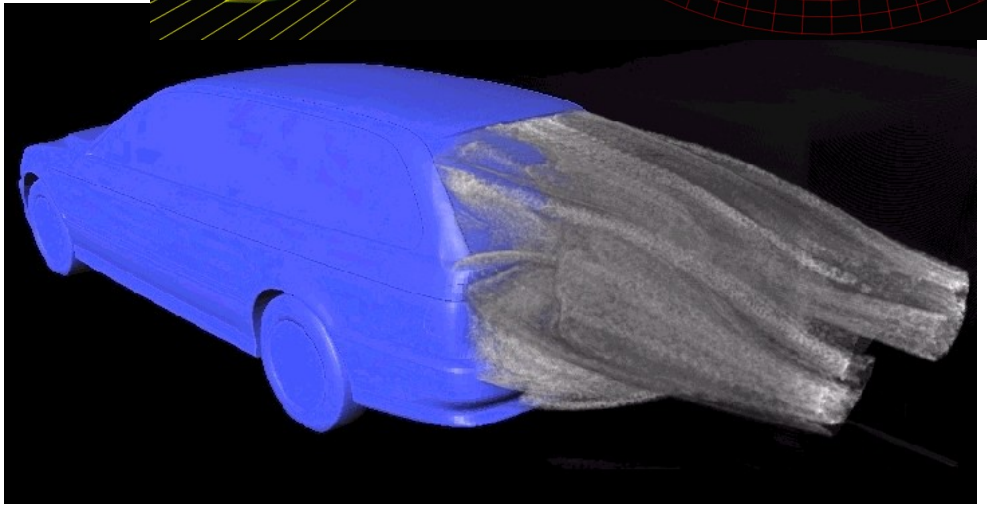


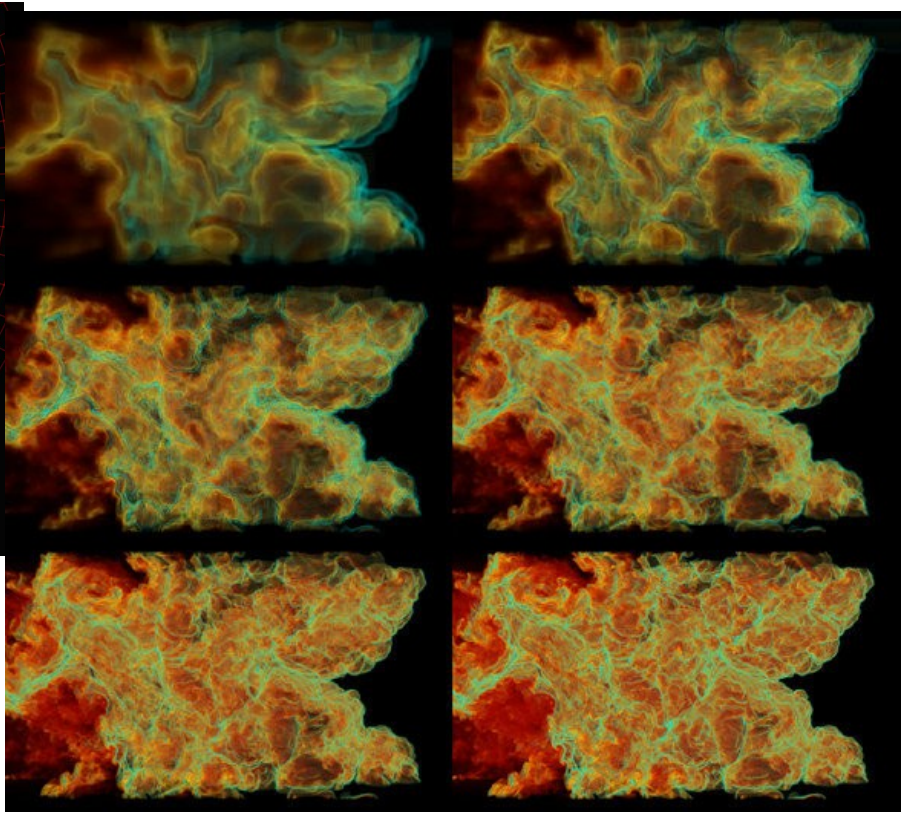
Simulations generating 4.5PB/s!

Bauer et al., "In Situ Methods, Infrastructures, and Applications on High Performance Computing Platforms."

Examples

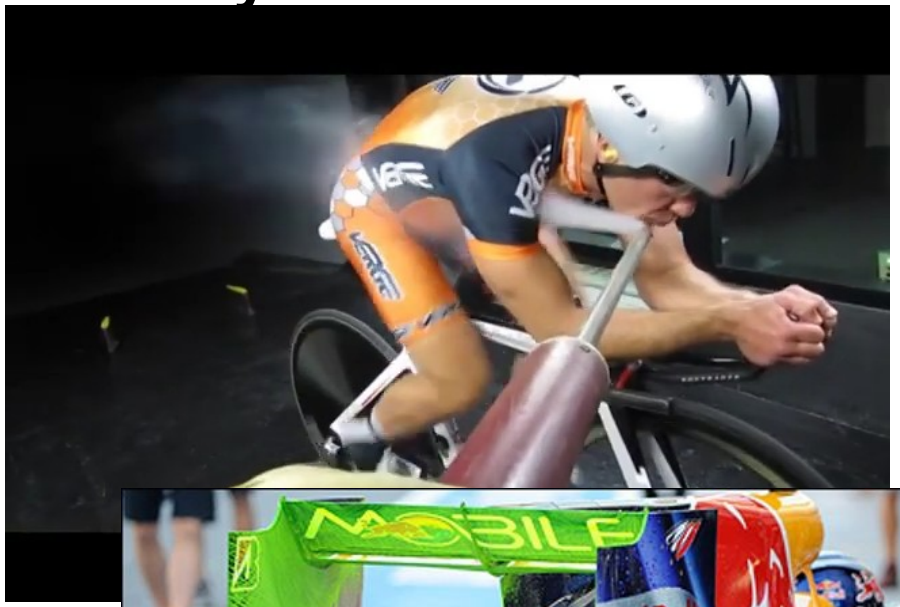


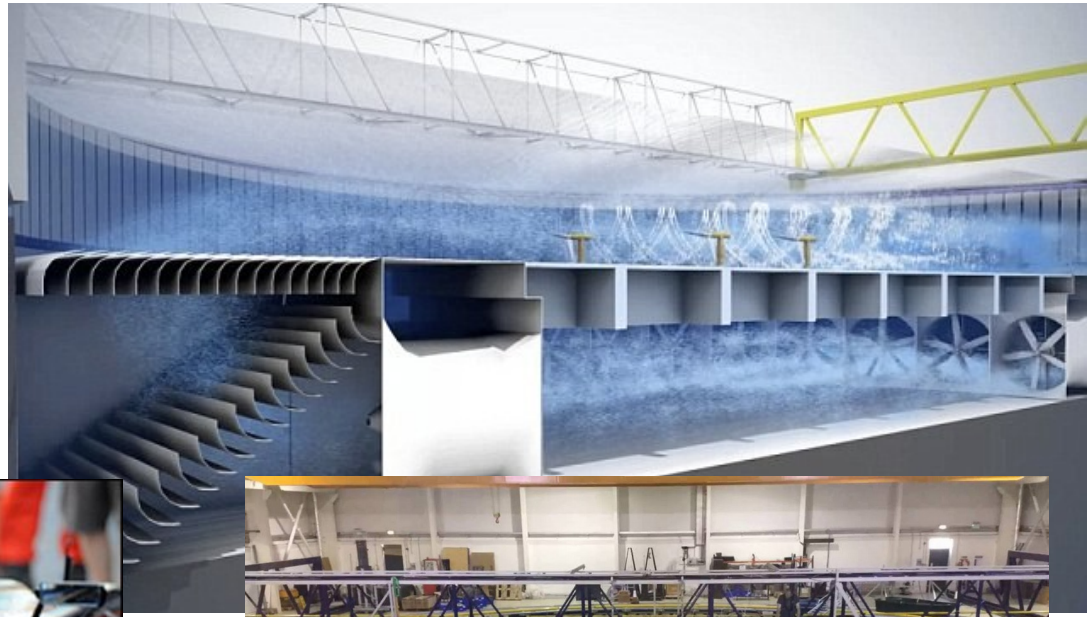


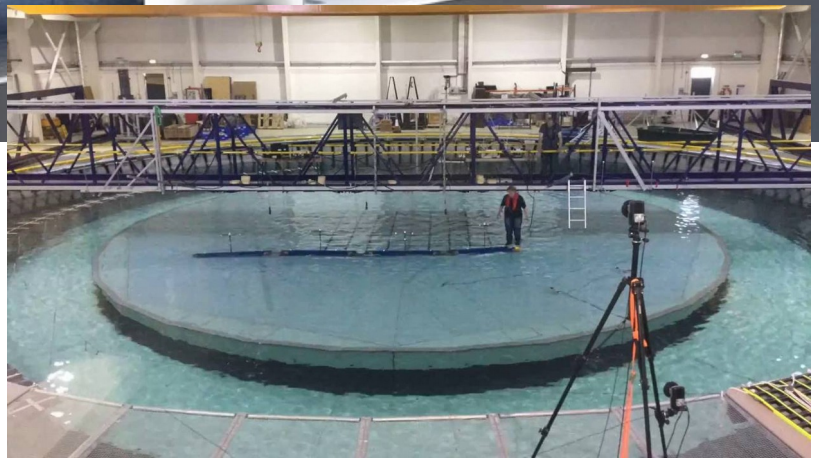


Bauer et al., “In Situ Methods, Infrastructures, and Applications on High Performance Computing Platforms.”

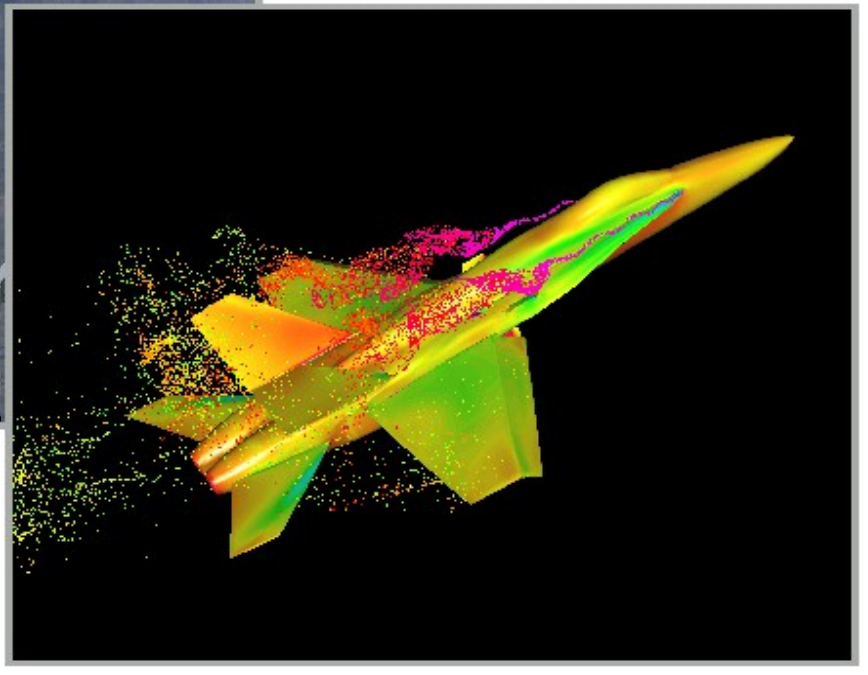
Why flow visualization?







Why flow visualization?



Types of flow

Steady (time-independent) flows:

- flow itself constant over time
- v(x), e.g., laminar flows
- simpler case for visualization

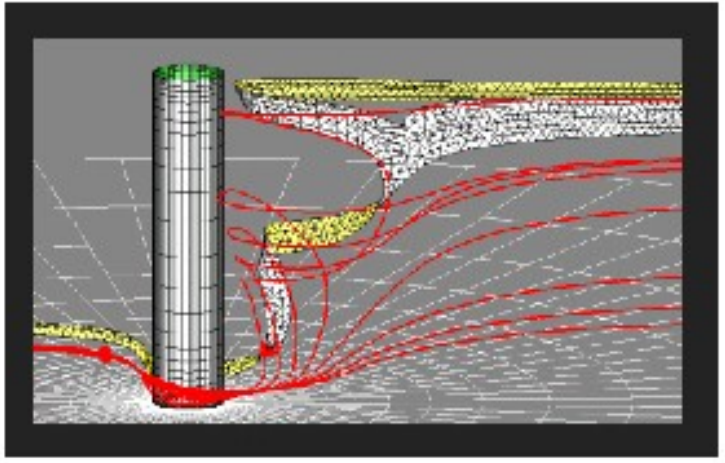
Time-dependent (unsteady) flows:

- flow itself changes over time
- v(x,t), e.g., turbulent flow
- often has moving objects
- more complex case

Steady state flow data

Data set name and year	Number of vertices	Size (MB)
McDonnell Douglas MD−80 '89	230,000	13
McDonnell Douglas F/A−18 '91	900,000	32
Space shuttle launch vehicle '90	1,000,000	34
Space shuttle launch vehicle '93	6,000,000	216
Space shuttle launch vehicle '96	30,000,000	1,080
Advanced subsonic transport '98	60,000,000	2,160
Army UH−60 Blackhawk '99	100,000,000	~4,000

Steady state flow vis



Single Zone
100K Nodes
4 MB

(1985)

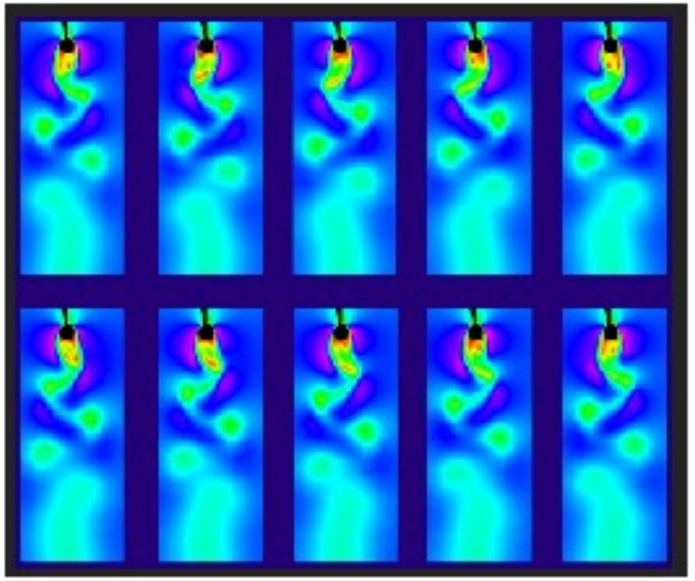
128 Zones
30M Nodes
1080 MB

(1996)

Unsteady flow data

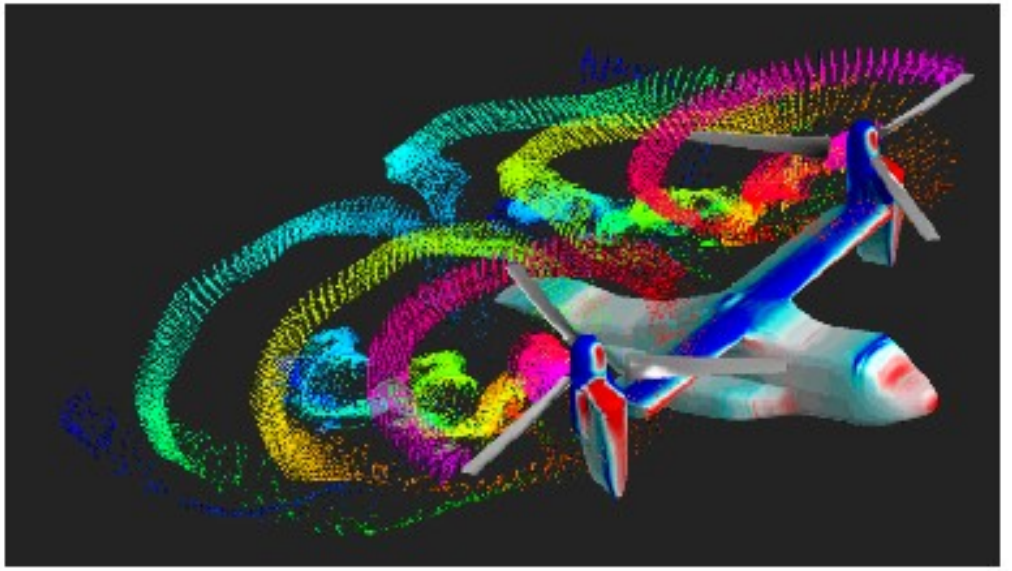
Data set name and year	# vertices	# time steps	size (MB)
Tapered Cylinder '90	131,000	400	1,050
McDonnell Douglas F/A−18 '92	1,200,000	400	12,800
Descending Delta Wing '93	900,000	1,800	64,800
Bell−Boeing V−22 tiltrotor '93	1,300,000	1,450	140,000
Bell−Boeing V−22 tiltrotor '98	10,000,000	1,450	600,000

Unsteady flow data



Single Zone
128K Nodes
1 GB

(1990)



25 Zones (9 Moving)
2.8M Nodes
300 GB

(1996)

Flow vis taxonomy

analogous to indirect (vs. direct) volume visualization

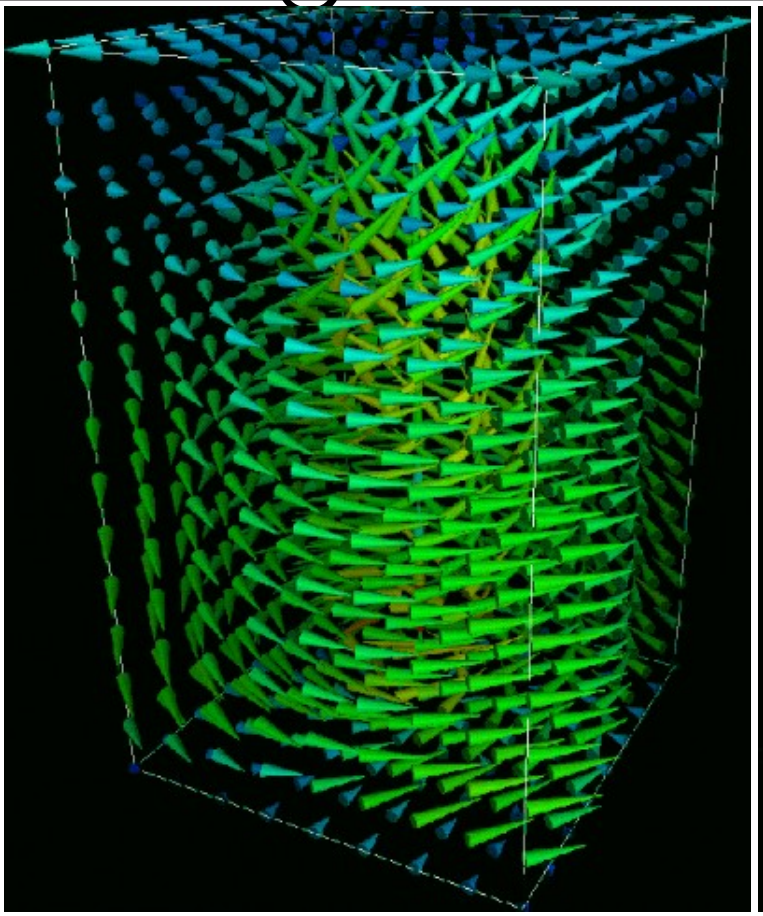
Direct flow visualization:

- overview of current state of flow
- visualization with vectors popular
- arrows, icons, glyph techniques

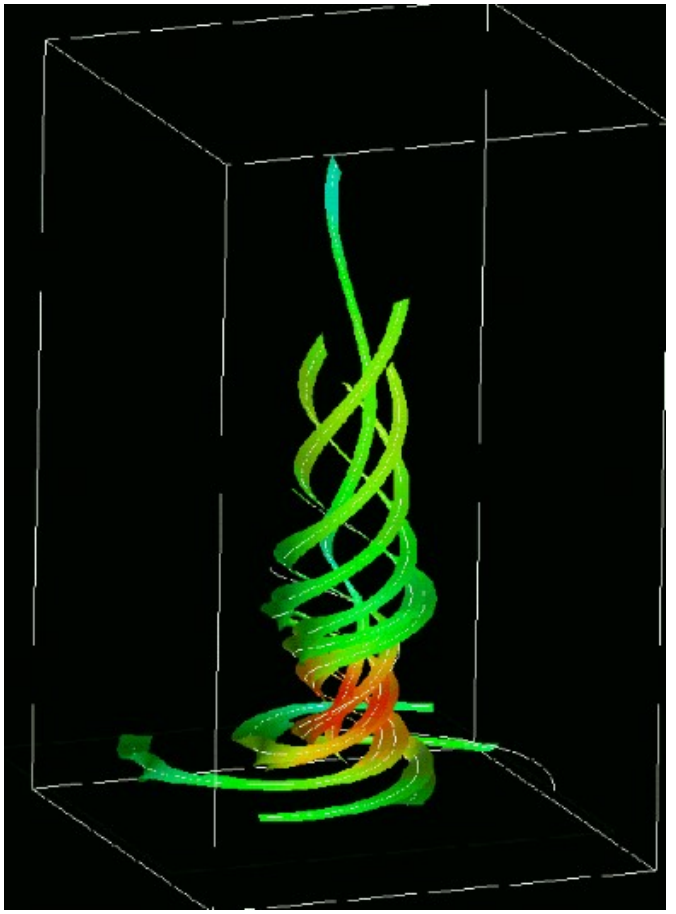
Geometric flow visualization:

- use of intermediate objects, e.g., after vector field integration over time
- visualization of development over time
- streamlines, stream surfaces

Direct vs geometric flow vis



Direct



Geometric

Further classification

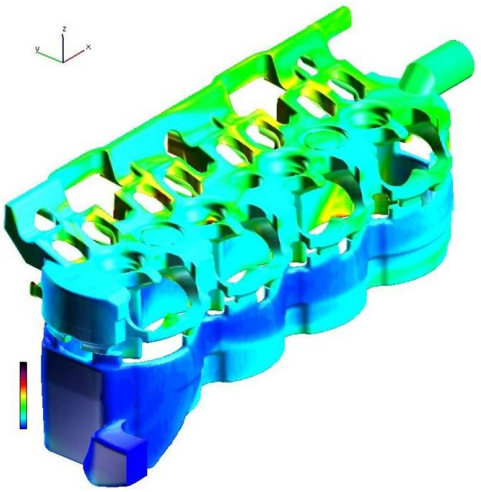
direct: overview of vector field, minimal computation, e.g. glyphs, color mapping

texture-based: covers domain with a convolved texture, e.g., Spot Noise, LIC, ISA, IBFV(S)

geometric: a discrete object(s) whose geometry reflects flow characteristics, e.g. streamlines

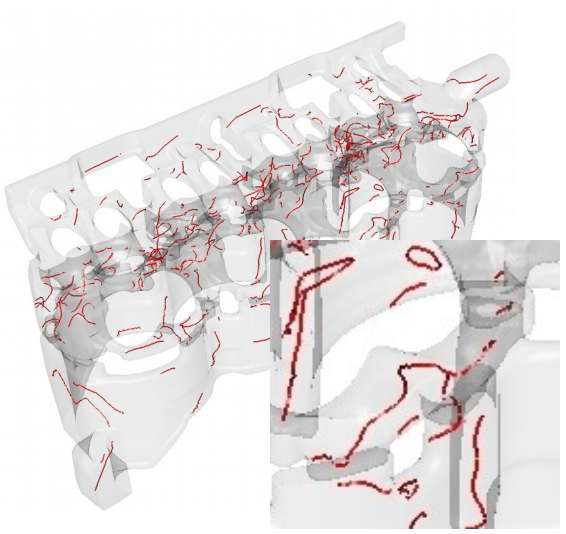
feature-based: both automatic and interactive feature-based techniques, e.g. flow topology

Further classification



Direct

Texture-based



Feature-based

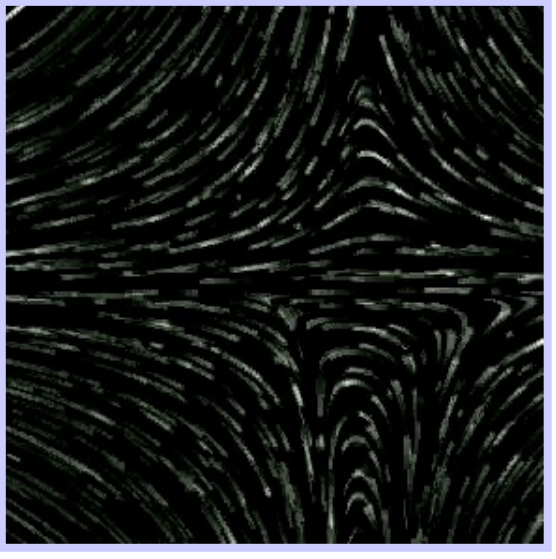
Geometric

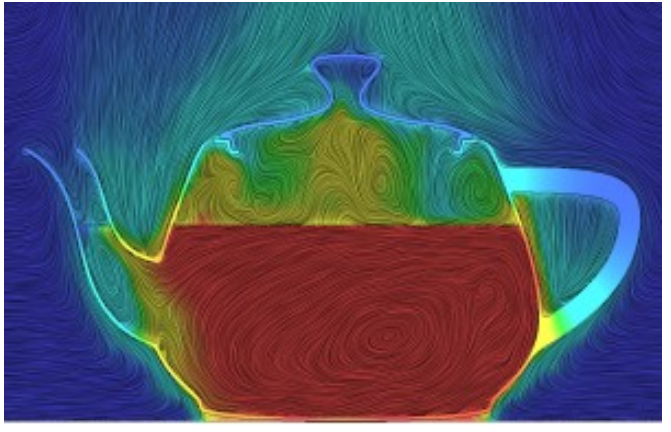
Dimensionality

Dimensions of visualization, not dataset

2D flow visualization

- models, flow layers (2D section through 3D)





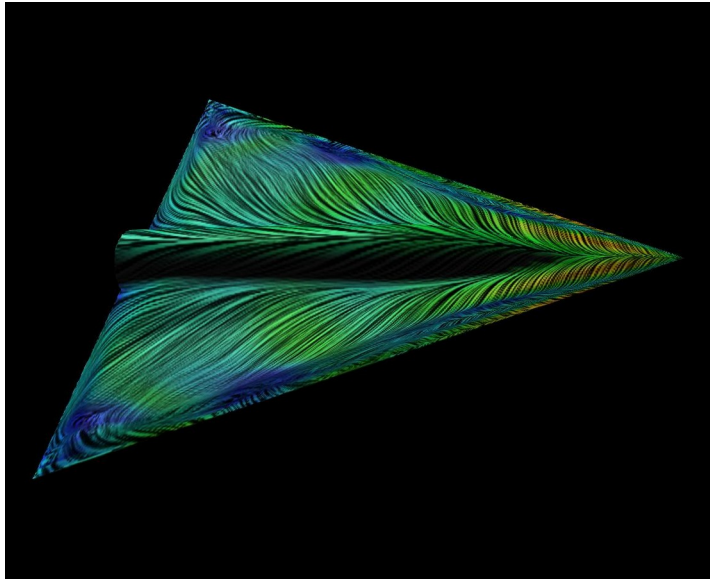
https://blog.pointwise.com/2015/07/10/this-week-in-cfd-204/

Dimensionality

Dimensions of visualization, not dataset

Visualization of flows on surfaces (2.5D)

- 3D flows around obstacles
- boundary flows on surfaces (locally 2D)

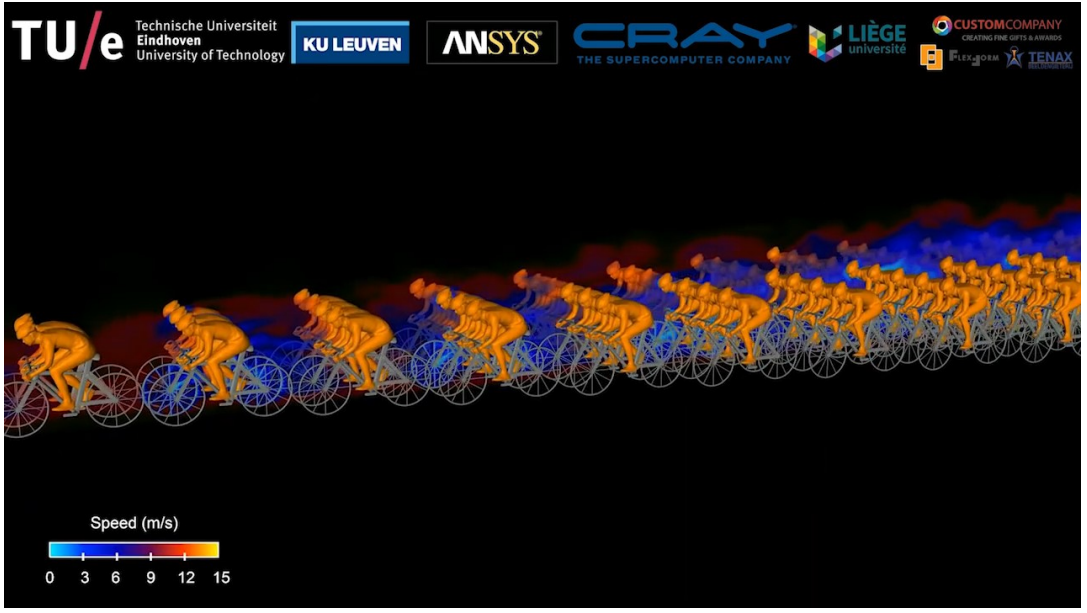


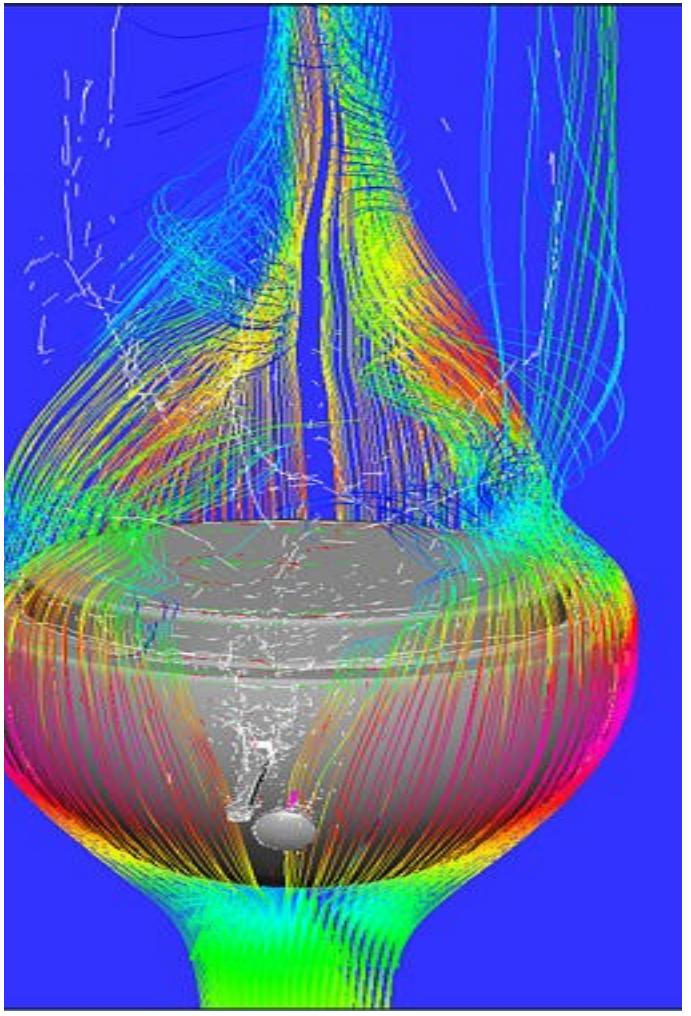
Dimensionality

Dimensions of visualization, not dataset

3D flow visualization

- simulations, 3D models

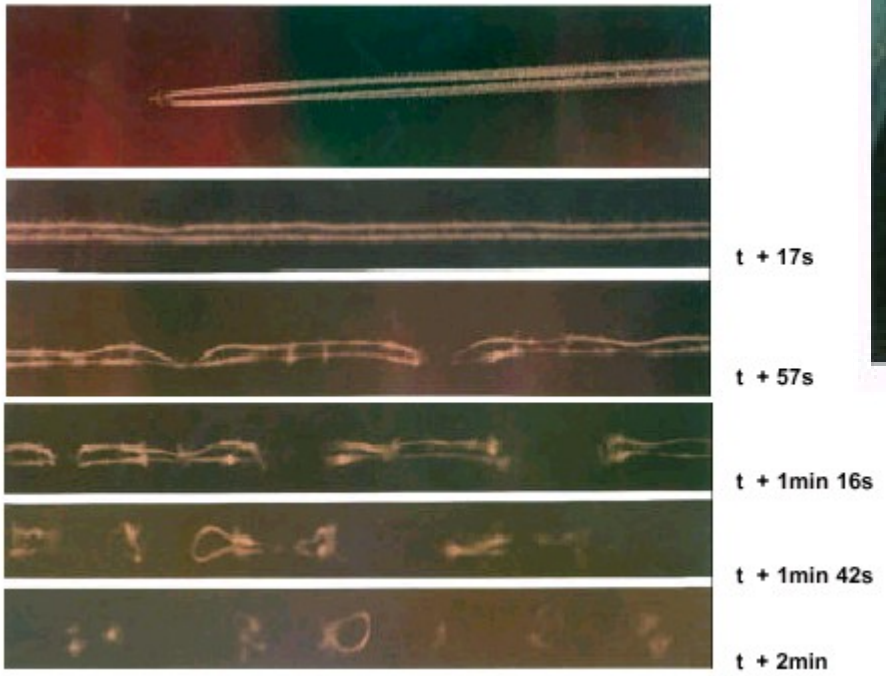


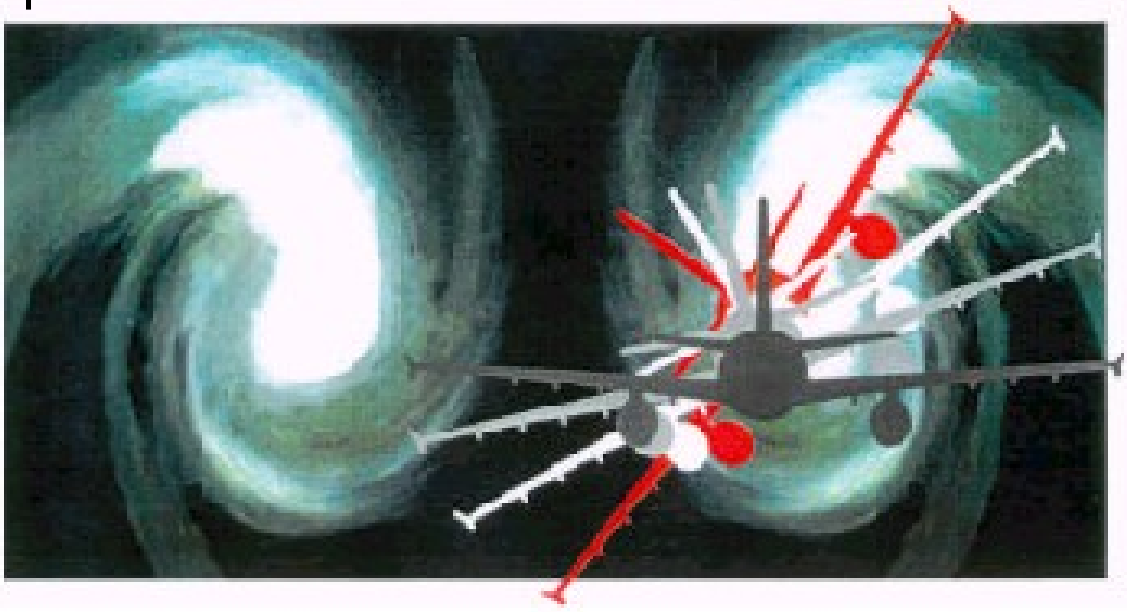


Full example

Airplane example

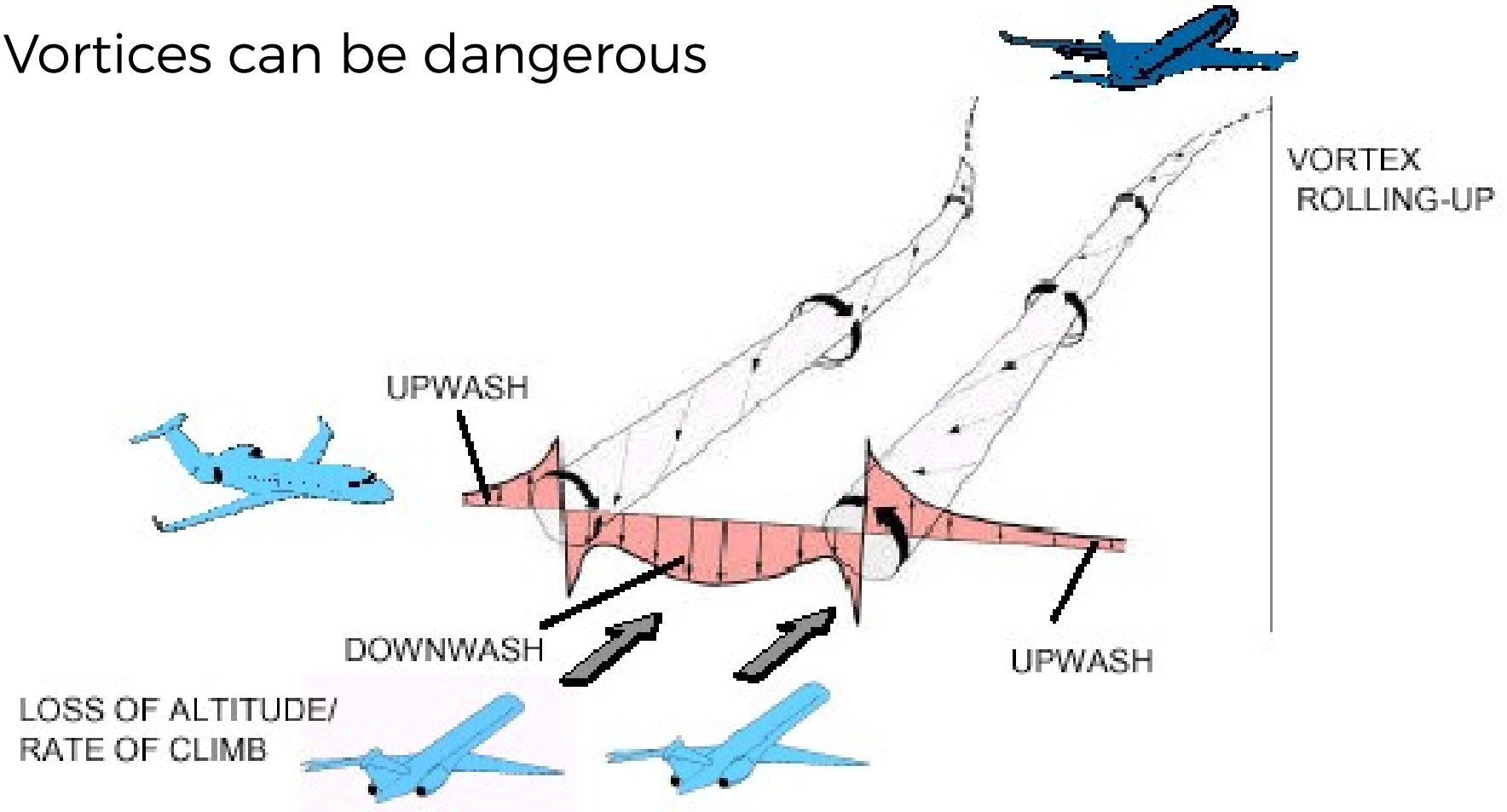
Problem: vortices behind airplanes





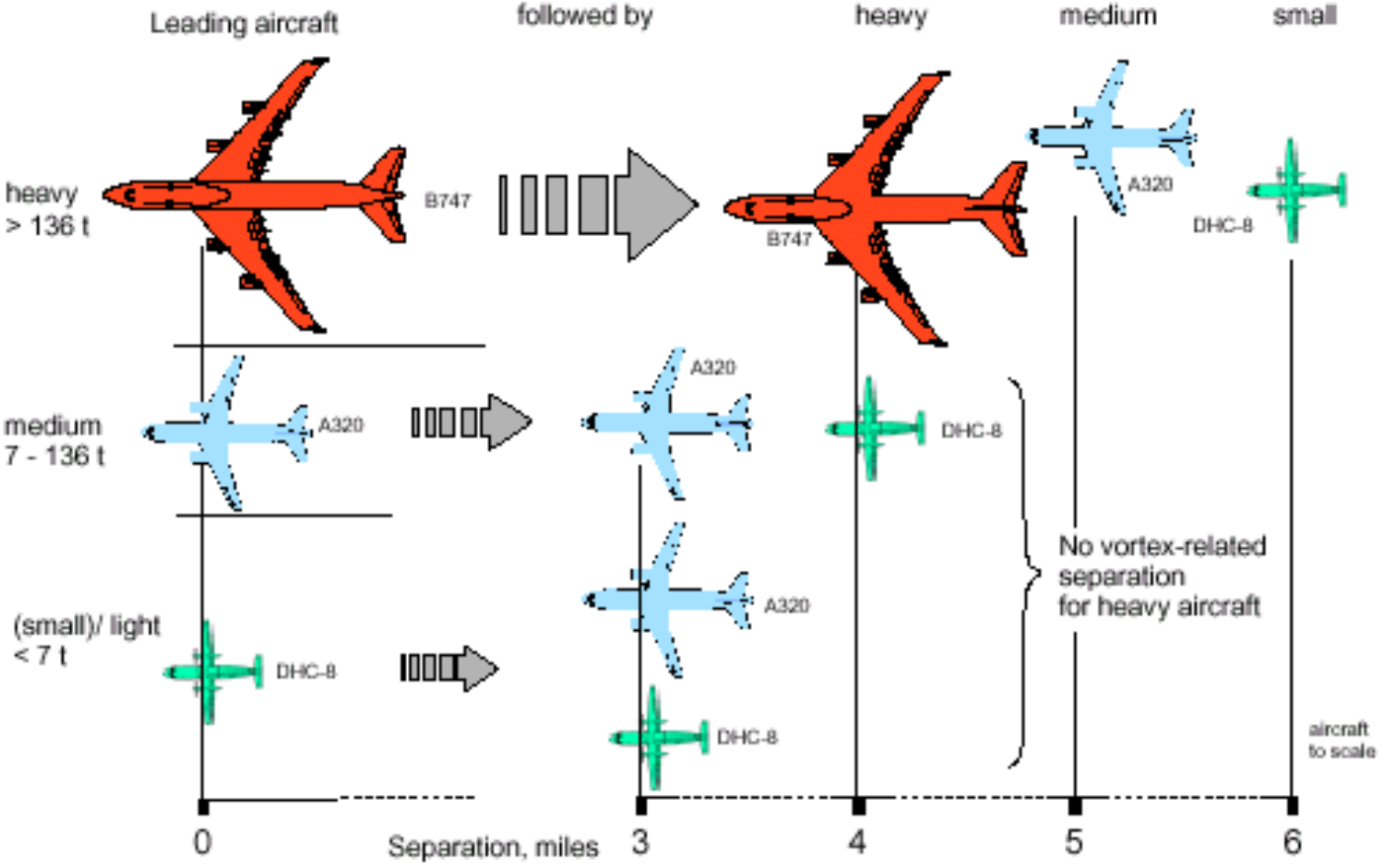
Airplane example

Vortices can be dangerous



Airplane example

Planes need to keep distance



Airplane example

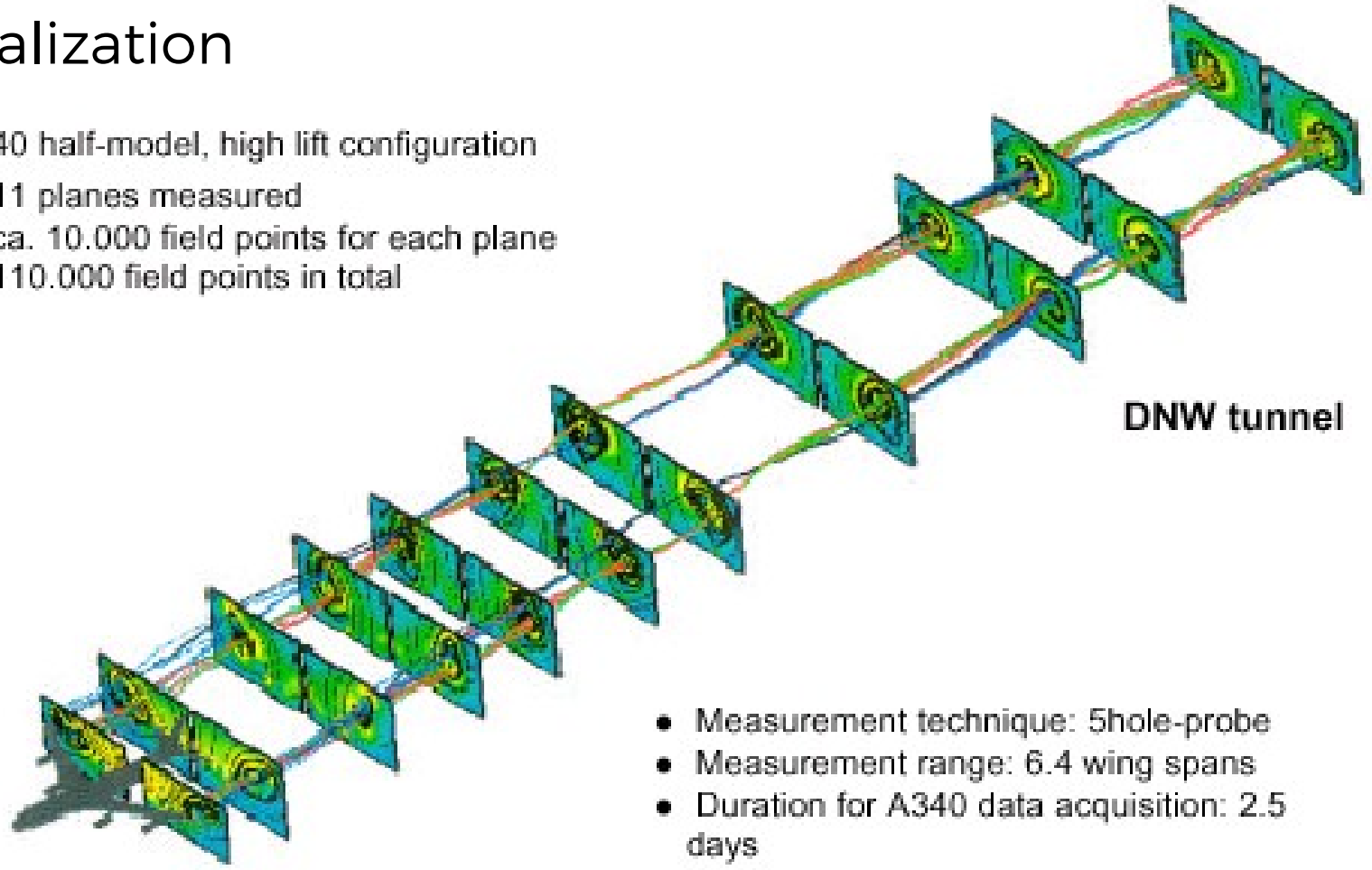
Run wind tunnel experiments

Airplane example

Visualization

A340 half-model, high lift configuration

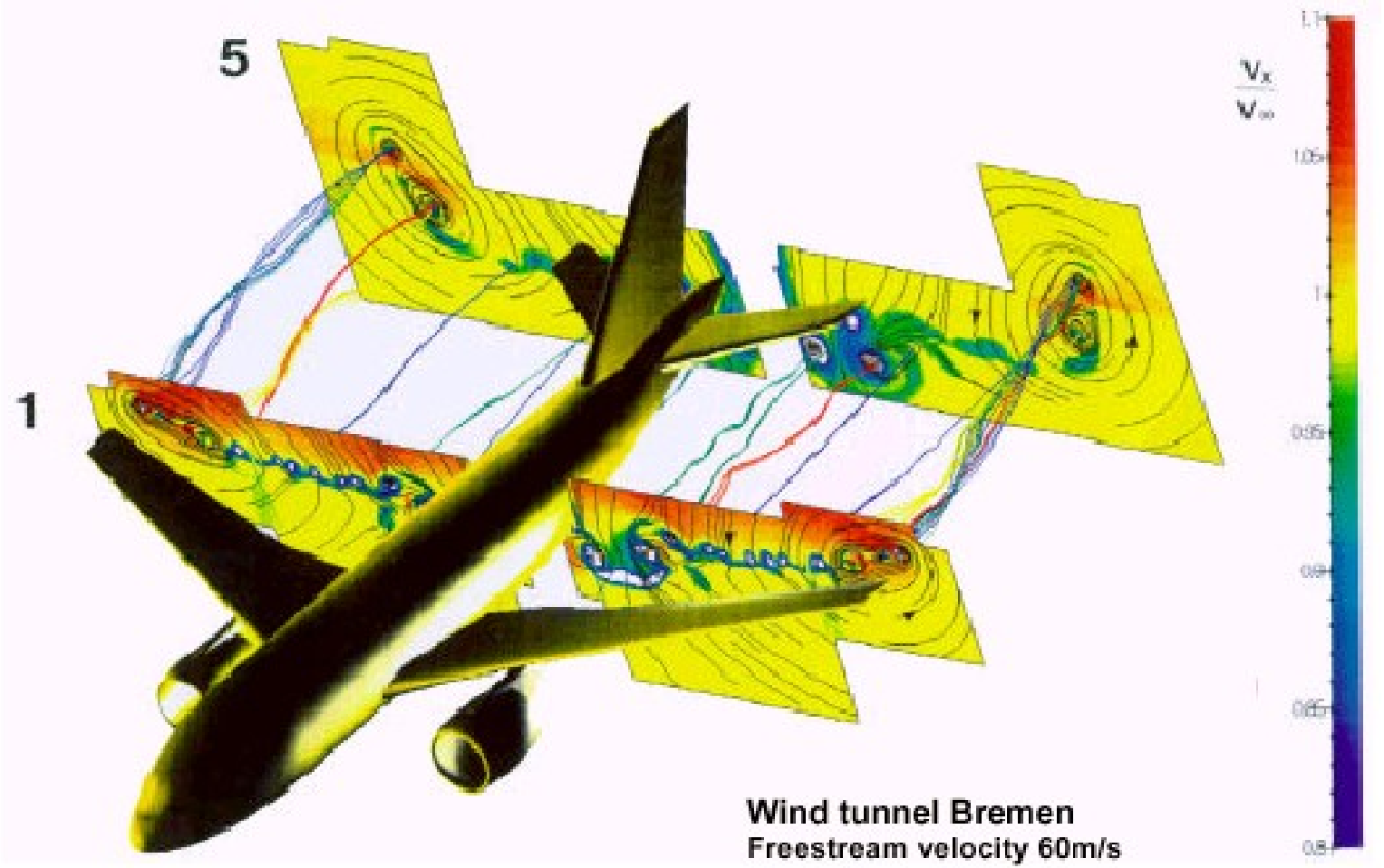
- 11 planes measured
- ca. 10.000 field points for each plane
- 110.000 field points in total



DNW tunnel

- Measurement technique: 5hole-probe
- Measurement range: 6.4 wing spans
- Duration for A340 data acquisition: 2.5 days

Airplane example

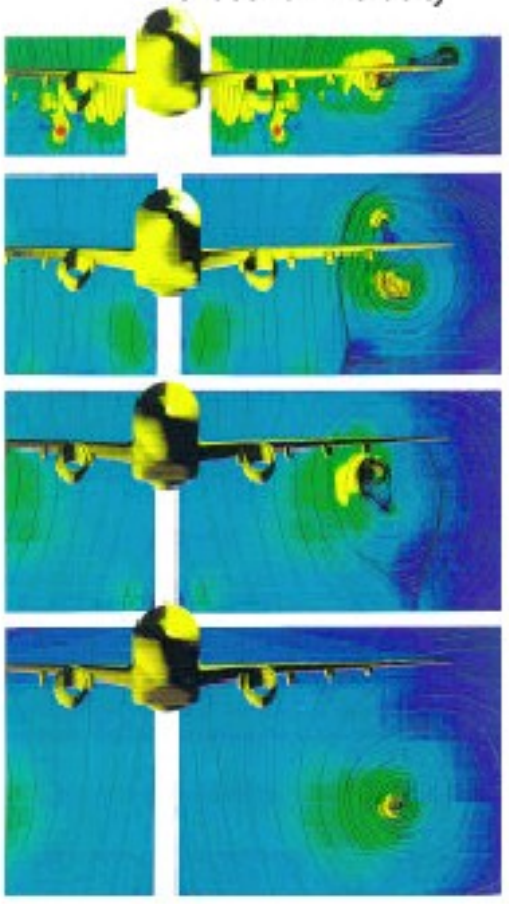


Airplane example

DNW tunnel
Freestream velocity 60m/s

Crossflow velocity

Vorticity

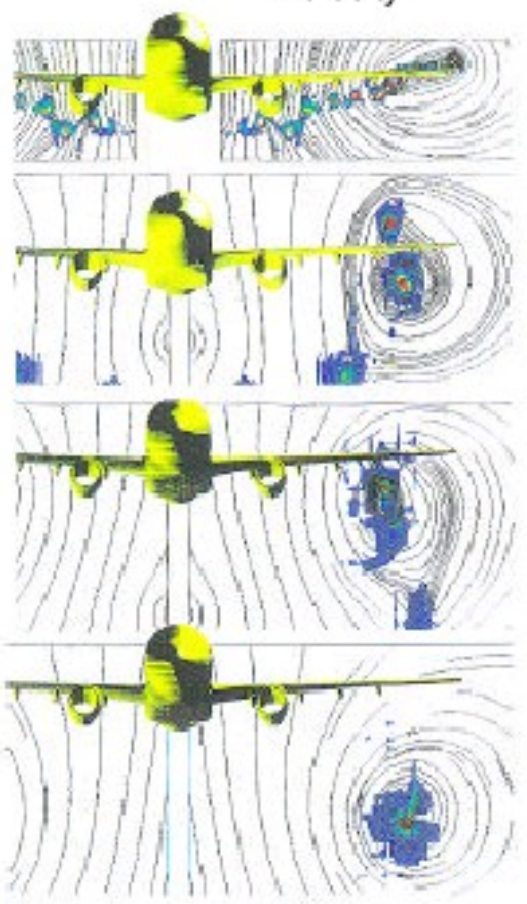


Surveying plane 1
0.03 wing spans behind wing tip

Surveying plane 9
1 wing spans behind wing

Surveying plane 12
2.5 wing spans behind wing

Surveying plane 17
6.8 wing spans behind wing



Conclusion

Summary

- Data is a set of vectors in 3D + time
- Visualization to see key aspects of flow
- Steady vs unsteady flow
- Direct vs geometric flow visualization

Reading/acknowledgements

Data Visualization: Principles and Practice, Chapter 6-Vector Visualization by A. Telea, AK Peters Ltd., 2008

Interactive Data Visualization: Foundations, Techniques, and Applications, Chapter 5-Visualization Techniques for Spatial Data, by M. Ward et al., AK Peters, Ltd., 2010

For material used in this lecture:

Robert S. Laramee

Hans-Georg Pagendarm

Roger Crawfis

Lloyd Treinish

David Kenwright

Terry Hewitt

Helwig Hauser

More videos

- Introduction to Vector: https://www.youtube.com/watch?v=A05n32Bl0aY
- Aerodynamics in British cycling: https://www.youtube.com/watch?v=BSnPqvsFpJM
- CFD for pelotons: https://www.youtube.com/watch?v=kZBh-fpv2sY
- Flow visualization through the years: https://www.youtube.com/watch?v=-GMg536L4PU

References

- Edmunds, M., R. Malki, A. J. Williams, I. Masters, and T. N. Croft. “Aspects of Tidal Stream Turbine Modelling in the Natural Environment Using a Coupled BEM–CFD Model.” International Journal of Marine Energy 7 (September 1, 2014): 20–42. https://doi.org/10.1016/j.ijome.2014.07.001.
- Bauer, A. C., H. Abbasi, J. Ahrens, H. Childs, B. Geveci, S. Klasky, K. Moreland, et al. “In Situ Methods, Infrastructures, and Applications on High Performance Computing Platforms.” Computer Graphics Forum 35, no. 3 (2016): 577–97. https://doi.org/10.1111/cgf.12930.