ME 747 Introduction to computational fluid dynamics

Lecture 1

Overviews of computational fluid dynamics

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Consulting time :	Make an appointment via E-mail

Contents

- แบบประเมินก่อนเรียน ME 747
- Outline of this course
- Overviews of computational fluid dynamics

แบบประเมินก่อนเรียน วก 747 Introduction to computational fluid dynamics

คะแนน	1. ความรู้จักเกี่ยวกับ CFD	2. การนำ CFD ไปใช้งานกับงานวิจัย	3. การเขียนหรือพัฒนาโปรแกรมด้วยตนเอง	4. Stability ของโปรแกรม	5. การเลือกใช้ Numerical scheme	6. Verify code and computational domain	7. Grid validation & discretization method	8. Initial and boundary conditions	9. ความรู้เกี่ยวกับ Fortran
4	☐ ใช้งานได้ดี	☐ การใช้ CFD เป็นงานหลักของงานวิจัย	☐ สามารถเขียนโปรแกรมและพัฒนาโปรแกรมได้ดี	☐ รู้จักและสามารถตรวจสอบรวมถึงแก้ไข stability ของโปรแกรม	☐ รู้จักและสามารถพัฒนา numerical scheme เป็นของตัวเองได้	☐ รู้จักดีและ verify ได้ดี	☐ รู้จักดีและตรวจสอบได้ดี	☐ รู้จักดีและกำหนดเองได้อย่างเหมาะสม	☐ รู้จักดีและเคยใช้กับงาน CFD
3	☐ รู้จักเป็นอย่างดีและใช้งานได้พอสมควร	☐ ใช้เพื่อเปรียบเทียบผลที่การทดลอง (การทดลองเป็นงานหลัก)	☐ สามารถสร้าง subroutine เพิ่มเติมจากโปรแกรมที่เคยมีอยู่แล้วแต่ไม่สามารถเขียนเองทั้งหมด	☐ รู้จักและสามารถตรวจสอบได้	☐ รู้จักดีและสามารถเลือกใช้งานได้	☐ รู้จักและ verify ได้บ้าง	☐ รู้จักและตรวจสอบได้บ้าง	☐ รู้จักและกำหนดเองได้บ้าง	☐ รู้จักและใช้งานได้คล่องแต่ไม่เคยใช้กับ CFD
2	☐ เคยเรียนมาแล้วแต่ไม่เคยใช้จริง	☐ ใช้บ้างเล็กน้อย	☐ สามารถแก้ไข subroutine ที่เคยมีอยู่แล้ว	☐ รู้จักบ้างและสามารถตรวจสอบได้เล็กน้อย	☐ รู้จักดีแต่ไม่รู้ว่าจะเลือกใช้อย่างไร	☐ รู้จักแต่ไม่รู้ว่าจะ verify อย่างไร	☐ รู้จักแต่ไม่รู้ว่าจะตรวจสอบอย่างไร	☐ รู้จักแต่ไม่รู้ว่าจะตรวจสอบอย่างไร	☐ รู้จักและเคยใช้มาบ้าง
1	☐ รู้จักเพียงเล็กน้อยและเคยใช้บ้างเล็กน้อย	☐ เกี่ยวข้องแต่ยังไม่เคยใช้	☐ สามารถแก้ไขโปรแกรมได้เล็กน้อย	☐ รู้จักบ้างแต่ไม่สามารถตรวจสอบ	☐ รู้จักเล็กน้อย	☐ รู้จักเล็กน้อย	☐ รู้จักเล็กน้อย	☐ รู้จักเล็กน้อย	☐ รู้จักเล็กน้อย
0	☐ ไม่รู้จักหรือไม่เคยใช้งานมาก่อน	☐ ไม่เกี่ยวข้องกับงานวิจัยที่ทำอยู่	☐ ไม่สามารถเขียนโปรแกรมเอง	☐ ไม่รู้จัก	☐ ไม่รู้จัก	☐ ไม่รู้จัก	☐ ไม่รู้จัก	☐ ไม่รู้จัก	☐ ไม่รู้จัก

Descriptions

- Dynamics of body moving through a fluid medium; numerical solution of ordinary differential equations.
- Inviscid and viscous fluid flows: numerical for solving elliptic partial differential equations, explicit and implicit methods for solving parabolic partial differential equations.
- Secondary flows and flow instabilities: upwind differencing and artificial viscosity.
- Discretization methods.
- Initial and boundary condition treatments.
- Fortran programming.

Objectives

- Describe the physical significance of each term in the governing equations for CFD.
- Construct computer code to solve the CFD problem with Fortran programming
- Quantify and analyze the numerical error in solution of the CFD partial differential equations
- Develop finite difference discretized forms of the CFD equations.
- Formulate explicit & implicit algorithms for solving the Euler Equation & Navier-Stokes Equations.
- Demonstrate verification strategies for evaluating CFD code.

Lecture schedule

Session	Topics
1	**1.Overviews of computational fluid dynamics** **-** Overviews and importance of heat transfer in real applications
2 - 3	**2. Introduction to Fortran programming** - Basic commands in Fortran programming
4	**3. Overviews of governing equations for flow and heat transfer** -Elliptic, Parabolic and Hyperbolic equations
5	**4. Introduction to numerical methods** - Finite different method, Finite volume method, Finite element method, etc.
6 – 7	**5. Introduction to solve engineering problems with finite-different method** - Taylor series expansion, Approximation of the second derivative, Initial condition and Boundary conditions

Lecture schedule

8 - 9	**6. Basics of discretization methods** -Principle of discretization method, Truncation error, Round-off and Discretization errors, Convergence for marching problems, Stability analysis, Von Neumann analysis
10 - 12	**7. Application of numerical methods to selected model equations** - Wave and Heat equations, Euler explicit and implicit methods, Second-order upwind method, Second central different method
13 – 14	**8. Application of numerical methods to selected model equations (Continue)** - Laplace's and Burges equations - Adam-Bashforth and Crank-Nicolson methods - Solve the matrices with ADI, SOR methods, and etc.
15 - 16	**9. Numerical techniques to solve fluid flow problems**

Material sources

❑ Materials

Lecture note provided via homepage (www.engr.tu.ac.th/~cchainar)

❑ References

- Numerical recipes (www.nr.com/oldverswitcher.html)
- Joel H. Ferziger (1981). Numerical methods for engineering application. John Wiley & Sons.
- John C. Tannehill, Dale A. Anderson, and Richard H. Pletcher (1997). Computational fluid mechanics and heat transfer. Taylor & Francis.
- John D. Anderson, JR. (1995). Computational fluid dynamics: The basics with applications. McGraw-Hill.

Score

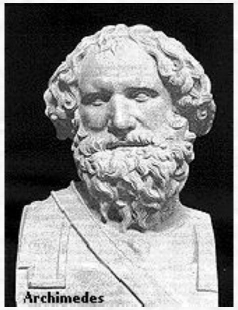
Attendance and Quiz	10%
Project I	20%
Project II	20%
Assignment	30%
Final examination	20%
Total	100%

Evaluations

	A	≥ 80
75 ≤	**A -**	< 80
70 ≤	**B +**	< 75
65 ≤	**B**	< 70
60 ≤	**B -**	< 65
55 ≤	**C+**	< 60
50 ≤	**C**	< 55
45 ≤	**D**	< 50
45 >	**F**	

History

Faces of Fluid Mechanics



Archimedes

(C. 287-212 BC)

Newton

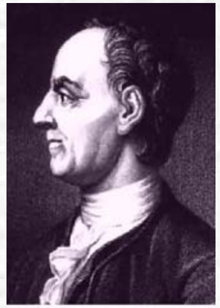
(1642-1727)

Leibniz

(1646-1716)

Bernoulli

(1667-1748)



Euler

(1707-1783)

Navier

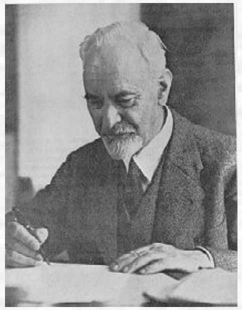
(1785-1836)

Stokes

(1819-1903)

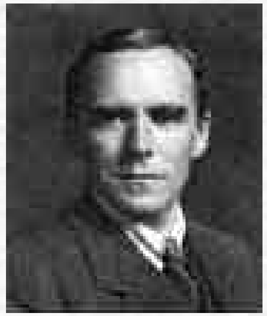
Reynolds

(1842-1912)



Prandtl

(1875-1953)



Taylor

(1886-1975)

Significance

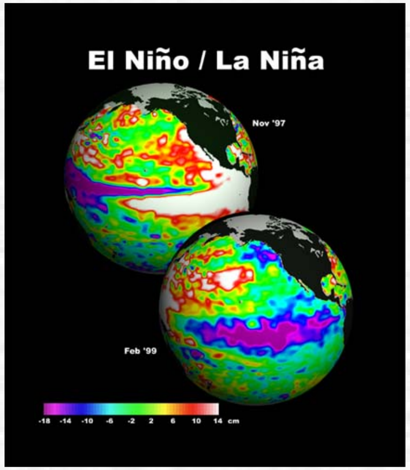
- Fluids omnipresent
  - Weather & climate
  - Vehicles: automobiles, trains, ships, and planes, etc.
  - Environment
  - Physiology and medicine
  - Sports & recreation
  - Many other examples!

Weather & Climate

Tornadoes

Thunderstorm

Global Climate



Hurricanes

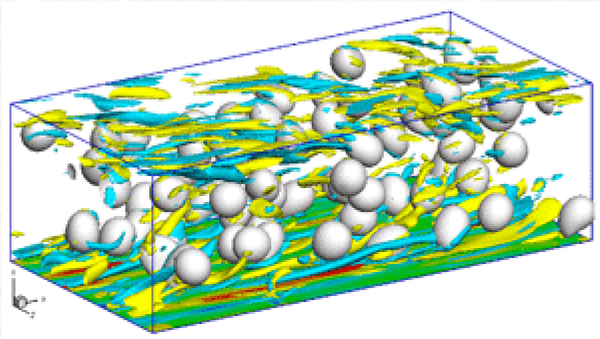
Vehicles

Aircraft

Surface ships

High-speed rail

Submarines



Environment

Air pollution

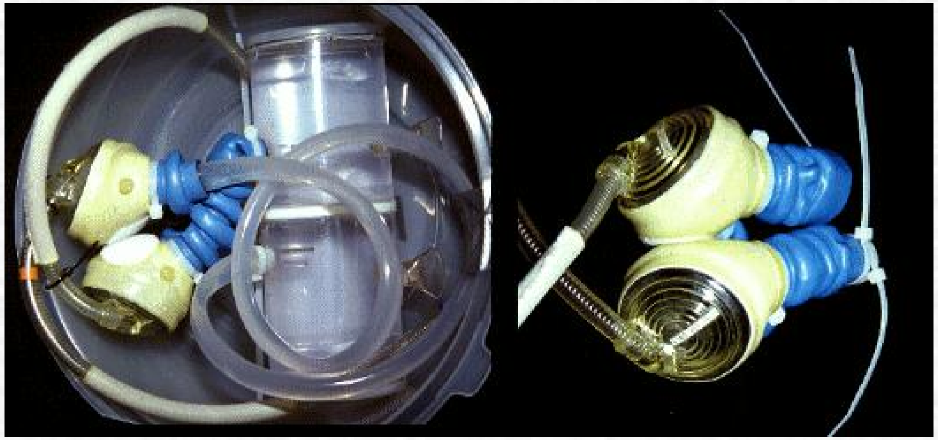
River hydraulics

Physiology and Medicine

Blood pump

A BVS blood pump

Ventricular assist device



Sports

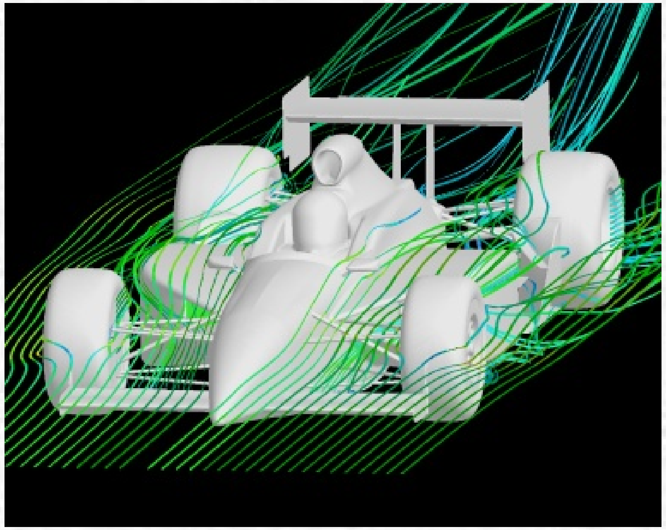
Water sports

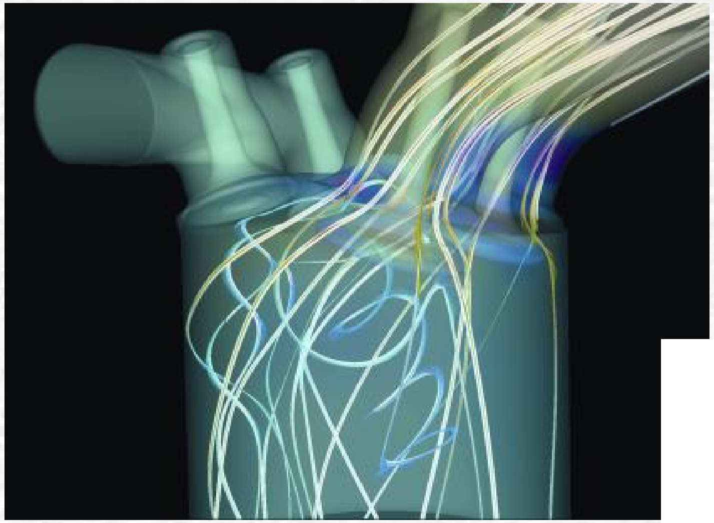
Cycling

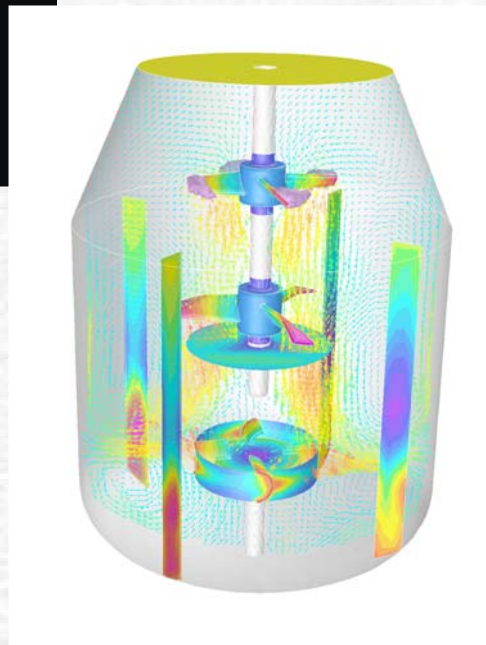
Offshore racing

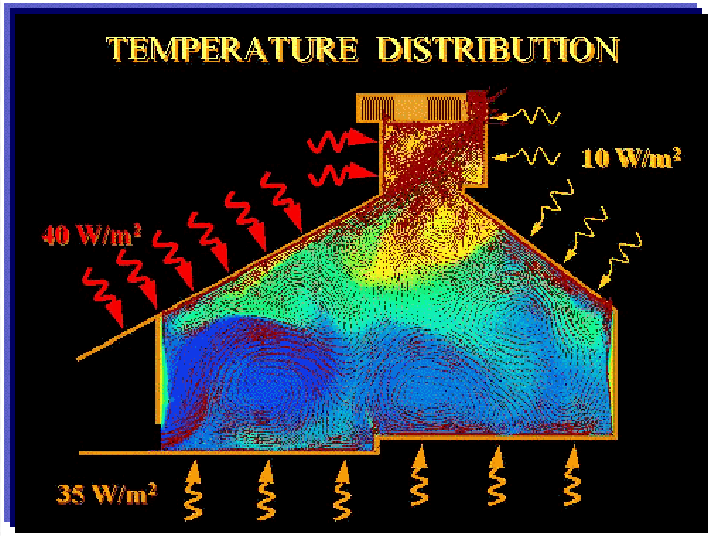
Auto racing

Surfing








TEMPERATURE DISTRIBUTION
10 W/m²
40 W/m²
35 W/m²

Applications of CFD

Example of industrial application

NASA's cryogenic wind tunnel simulates flight conditions for scale models--a critical tool in designing airplanes.

Application in teaching

Fluid dynamics laboratory

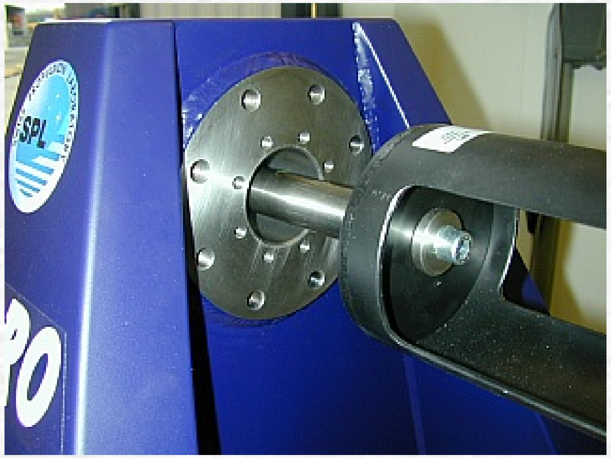
Full and model scale

- Scales: model, and full-scale
- Selection of the model scale: governed by dimensional analysis and similarity

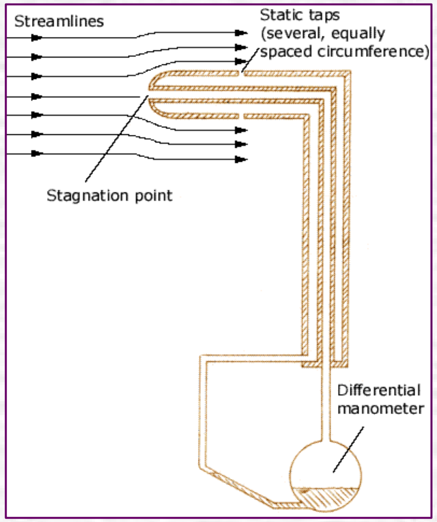
Measurement systems

- **Instrumentation**
  - Load cell to measure forces and moments
  - Pressure transducers
  - Pitot tubes
  - Hotwire anemometry
  - PIV, LDV
- **Data acquisition**
  - Serial port devices
  - Desktop PC's
  - Plug-in data acquisition boards
  - Data Acquisition software - Labview
- **Data analysis and data reduction**
  - Data reduction equations
  - Spectral analysis

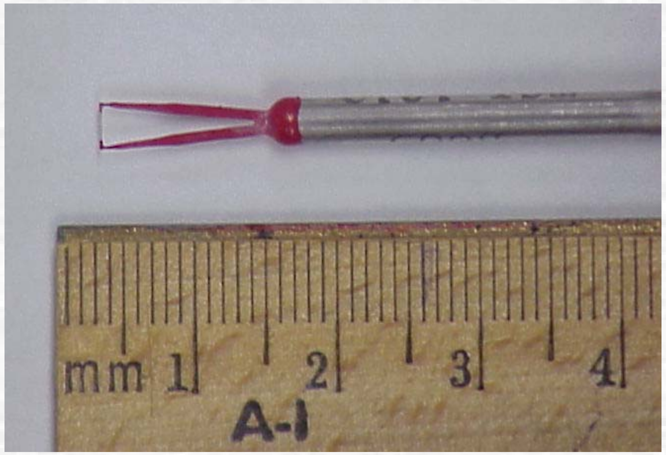
Instrumentation



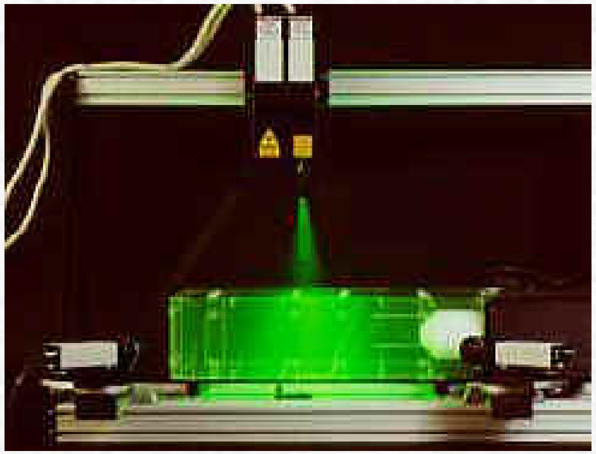
Load cell



Pitot tube



Hotwire

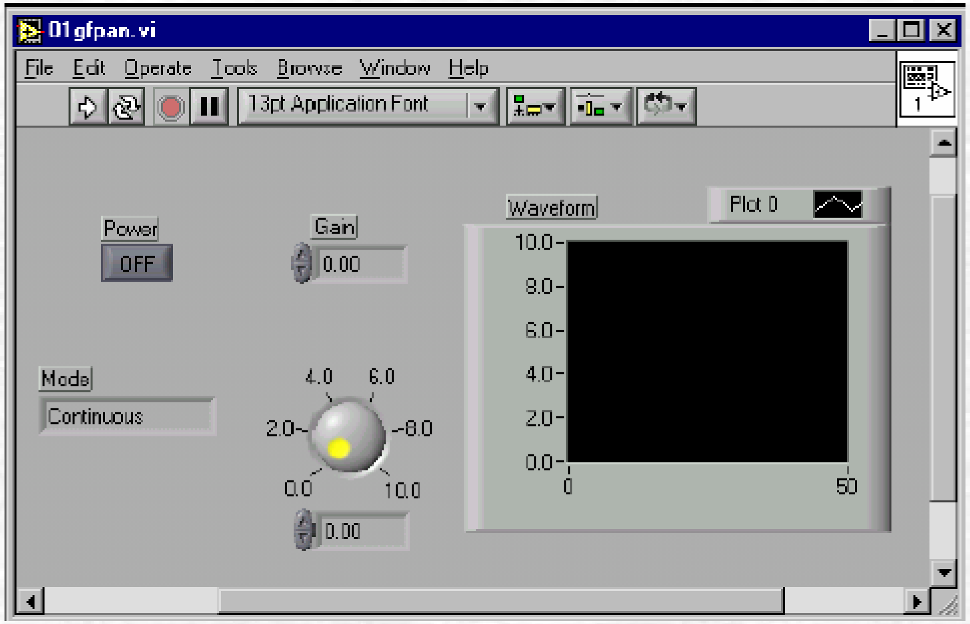


3D - PIV

Data acquisition system

Hardware

Software - Labview



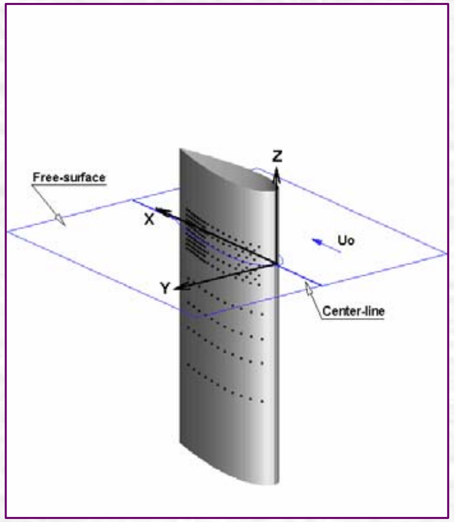
Spectral analysis

Aim: To analyze the natural unsteadiness of the separated flow, around a surface piercing strut, using FFT.

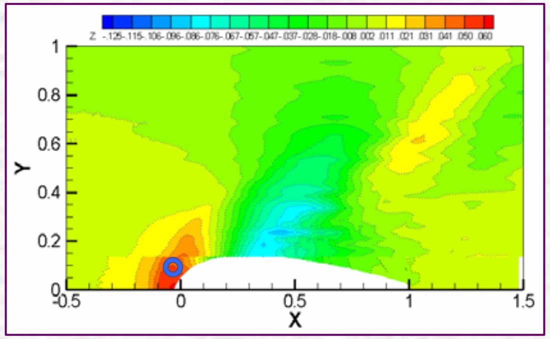
FFT: ***Converts a function from amplitude as function of time to amplitude as function of frequency***

$$x(t) = a_0 + \sum_{k=1}^{\infty}\left(a_k \cos\left(2\pi k f_0 t\right) + b_k \sin\left(2\pi k f_0 t\right)\right)$$

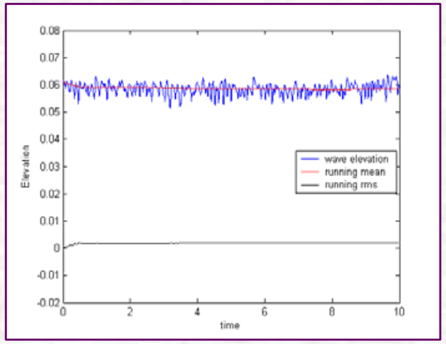
Fast Fourier Transform



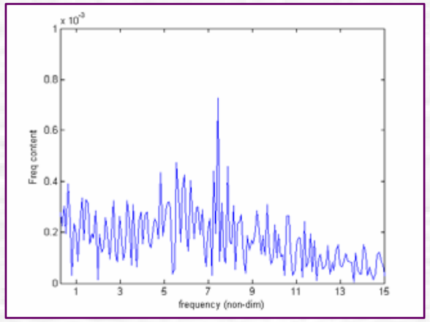
Surface piercing strut



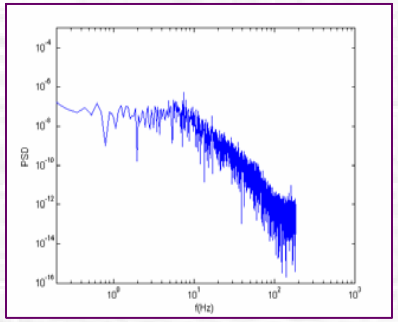
Free-surface wave elevation contours



Time history of wave elevation

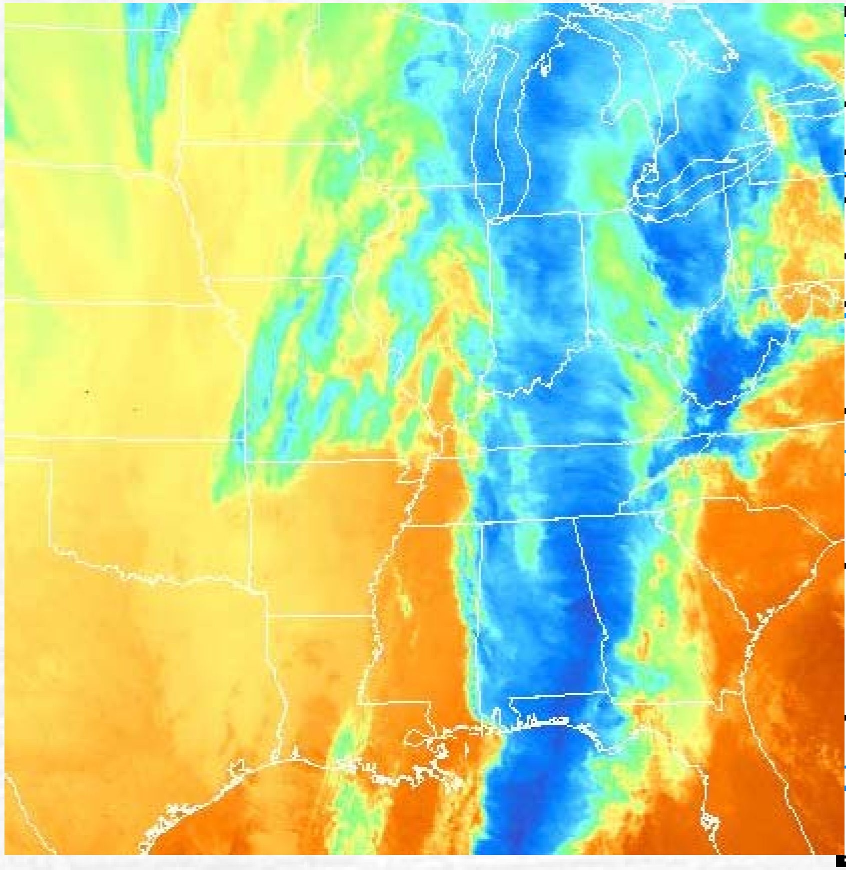


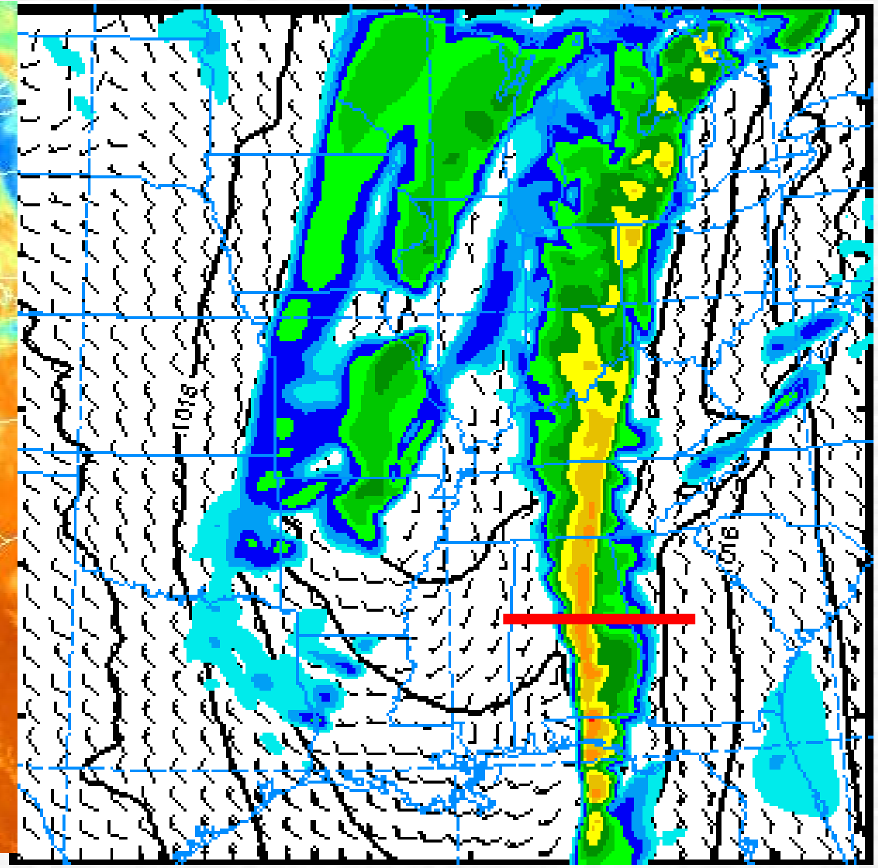
FFT of wave elevation



Power spectral density of wave elevation

Simulation of an Convective Squall Line in Atmosphere





Infrared Imagery Showing Squall Line at 12 UTC January 23, 1999.

ARPS 48 h Forecast at 6 km Resolution Shown are the Composite Reflectivity and Mean Sea-level Pressure.

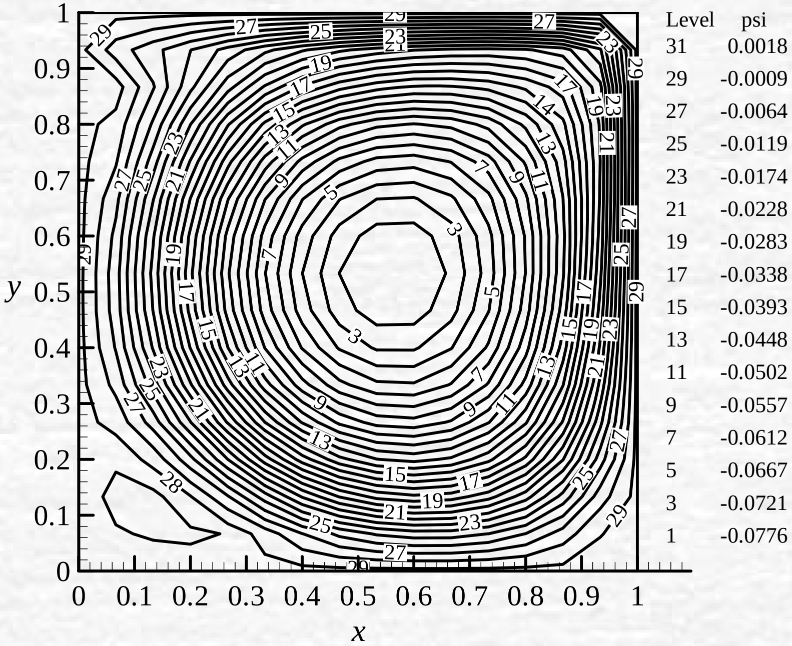
Computational Fluid Dynamics

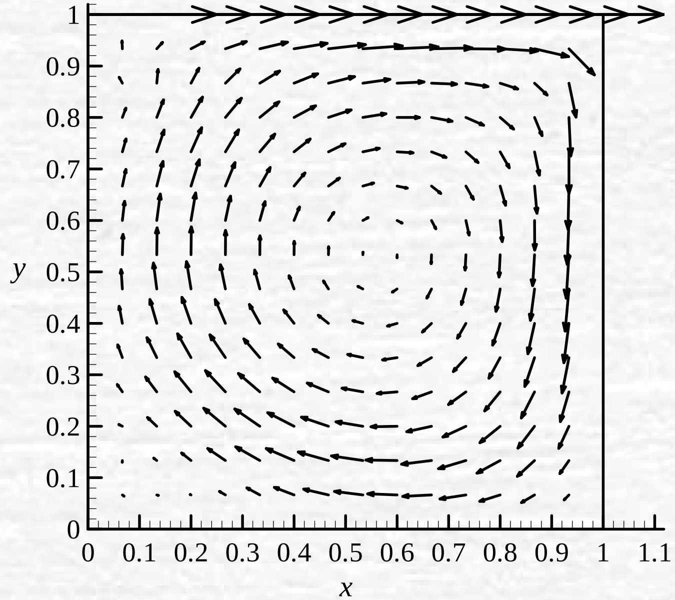
- CFD is use of computational methods for solving fluid engineering systems, including modeling (mathematical & Physics) and numerical methods (solvers, finite differences, and grid generations, etc.).
- Rapid growth in CFD technology since advent of computer

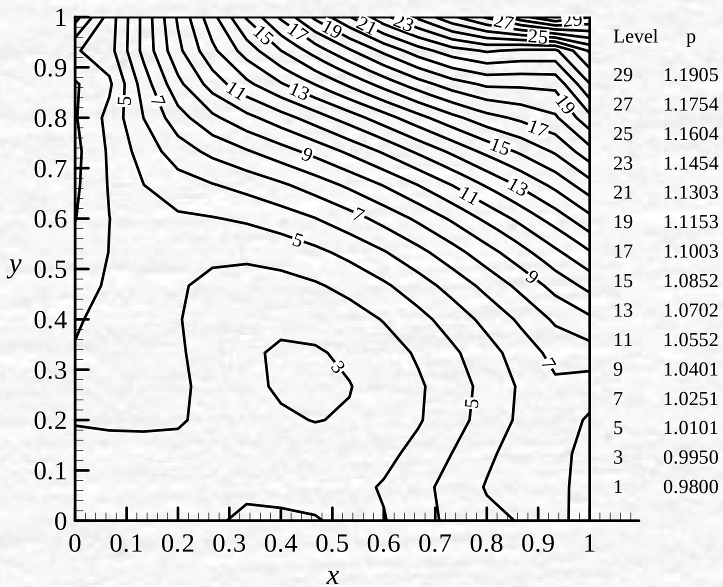
Modeling

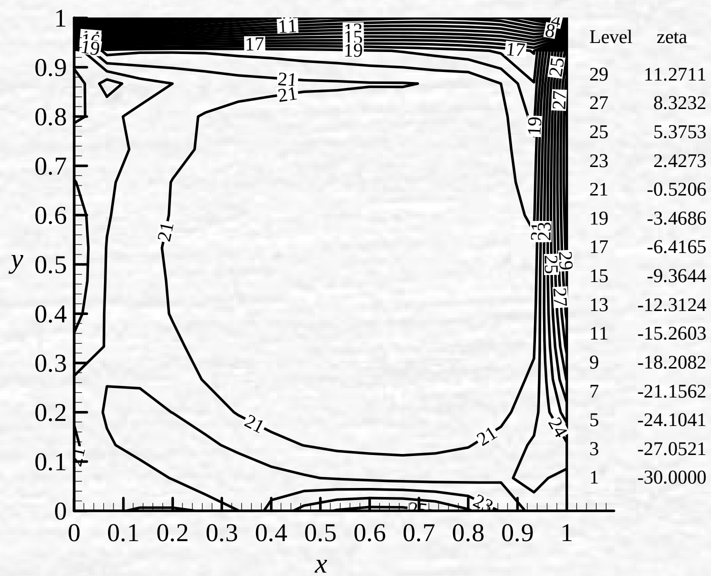
- Mathematical physics problem formulation of fluid engineering system
- Governing equations: Navier-Stokes equations (momentum), continuity equation, pressure Poisson equation, energy equation, ideal gas law, combustions (chemical reaction equation), multi-phase flows(e.g. Rayleigh equation), and turbulent models (RANS, LES, DES).
- Coordinates: Cartesian, cylindrical and spherical coordinates result in different form of governing equations
- Initial conditions(initial guess of the solution) and Boundary Conditions (no-slip wall, free-surface, zero-gradient, symmetry, velocity/pressure inlet/outlet)
- Flow conditions: Geometry approximation, domain, Reynolds Number, and Mach Number, etc.

Example (lid-driven cavity, sample results)









Why CFD

- Analytical solutions exist only for a handful of typically boring problems
- Can control numerical experiments and perform sensitivity studies, some in very ideaized settings.
- Can study something that is not directly observable (black holes).
- Computer solutions provide a more complete sets of data in time and space
- We can perform realistic experiments on phenomena that are not possible to reproduce in reality, e.g., the weather
- Much cheaper than laboratory experiments
- Much more flexible – each change of configurations, parameters
- We can now use computers to DISCOVER new things (drugs, sub-atomic particles, storm dynamics) much quicker

Difficulties with CFD

PDE's are not well-suited for solution on computers - must approximate a continuous system by a discrete one. One must keep in mind that the governing equations themselves are approximations

- Most physically important problems are highly nonlinear - advantage of models is that you can examine the relative contribution of each term. But, how will you then know if the solution is correct? Validation?!
- It is impossible to represent all relevant scales in a given problem - there is strong coupling in atmospheric flows and most CFD problems. ENERGY TRANSFERS. (Transparency)
- Most of the numerical techniques we use are inherently unstable - often we have to beat down the instability with a hammer, resulting in degraded solutions. We must deal with physical and computational instabilities.

POSITIVE OUTLOOK

- New schemes / algorithms
- Bigger and faster computers
- Faster network access
- Better Desktop computers
- Better programming tools and environment
- Better understanding of dynamics / predictabilities
- etc.