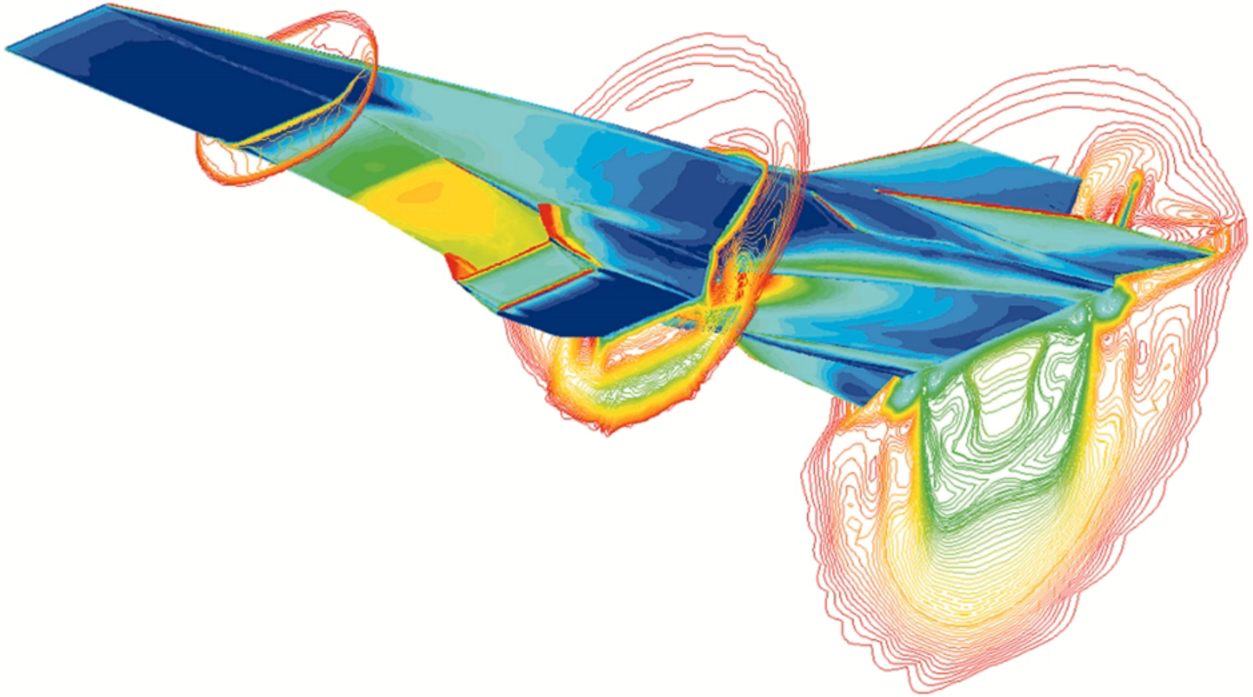
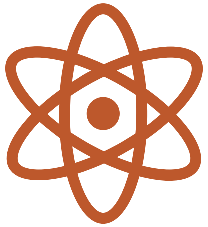
Course Map

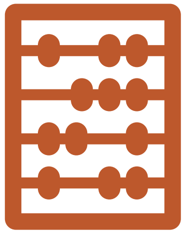
SEBASTIAN THOMAS



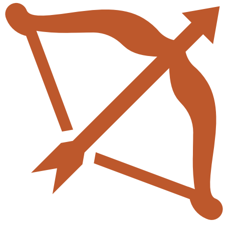
Pre-requisites



Newton’s Laws of Motion

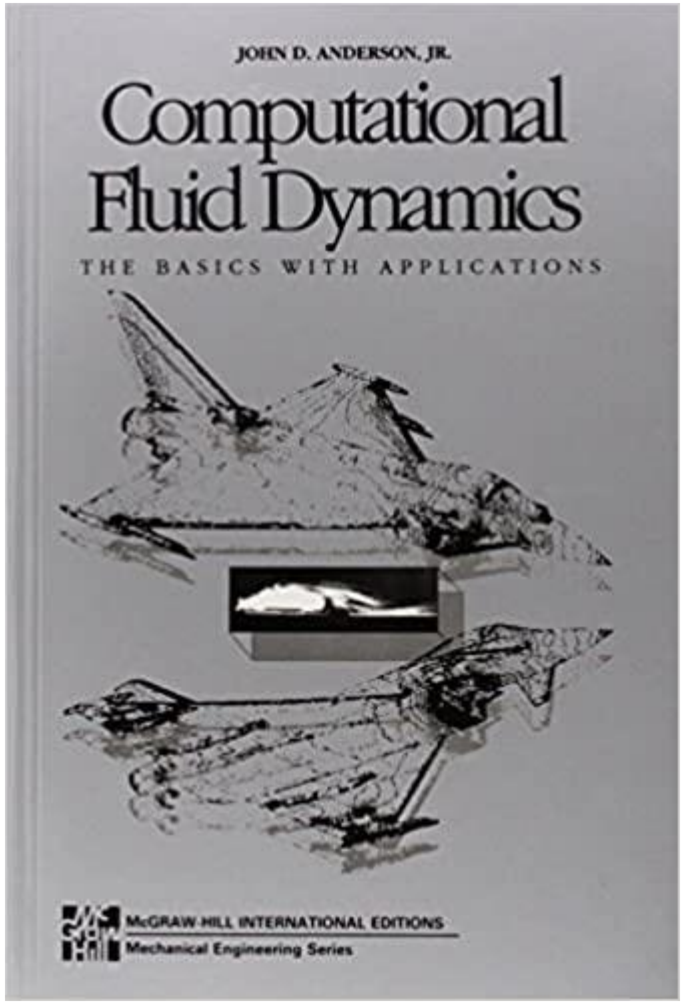


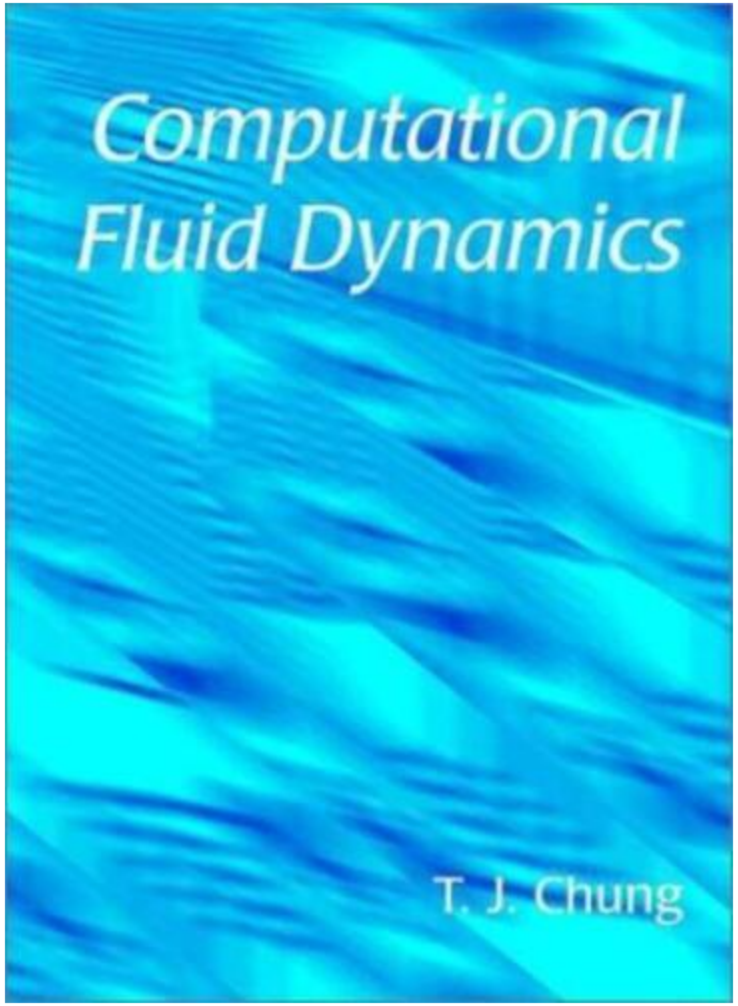
Basic Calculus

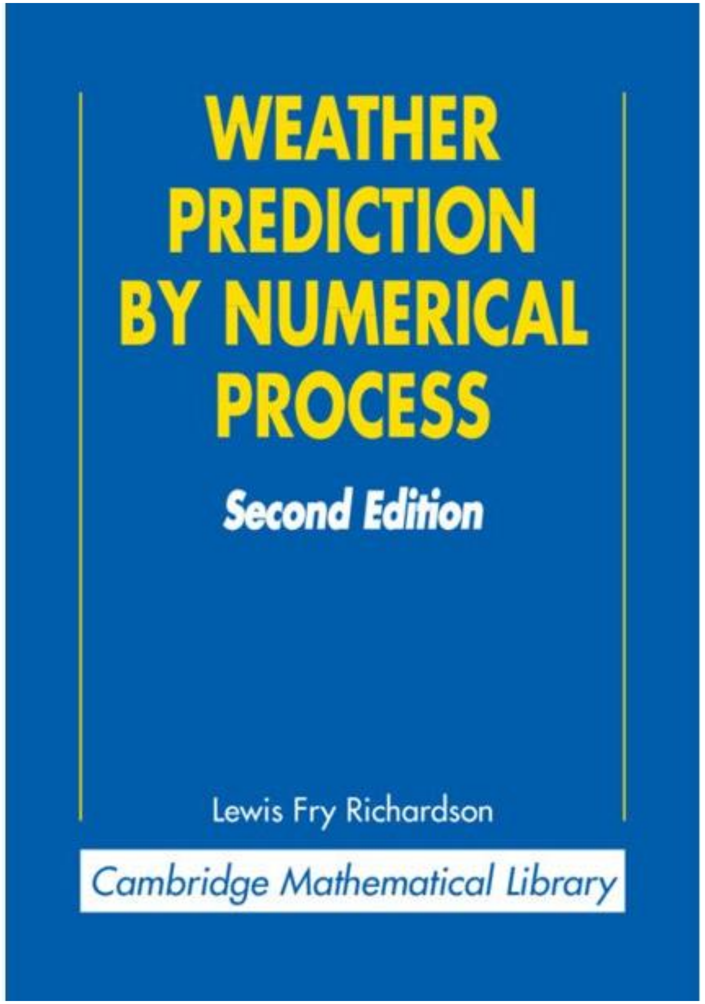


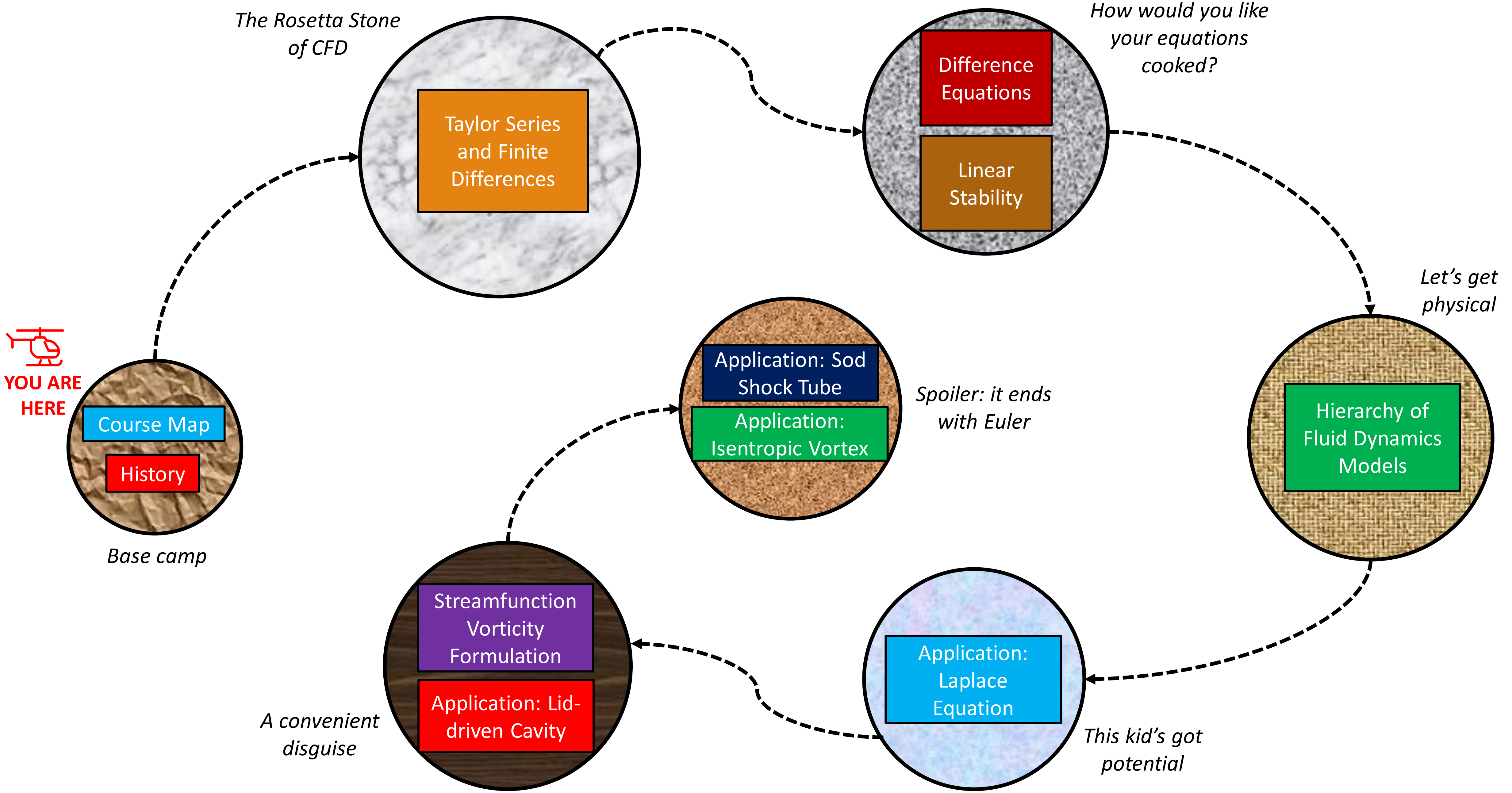
Vector Algebra

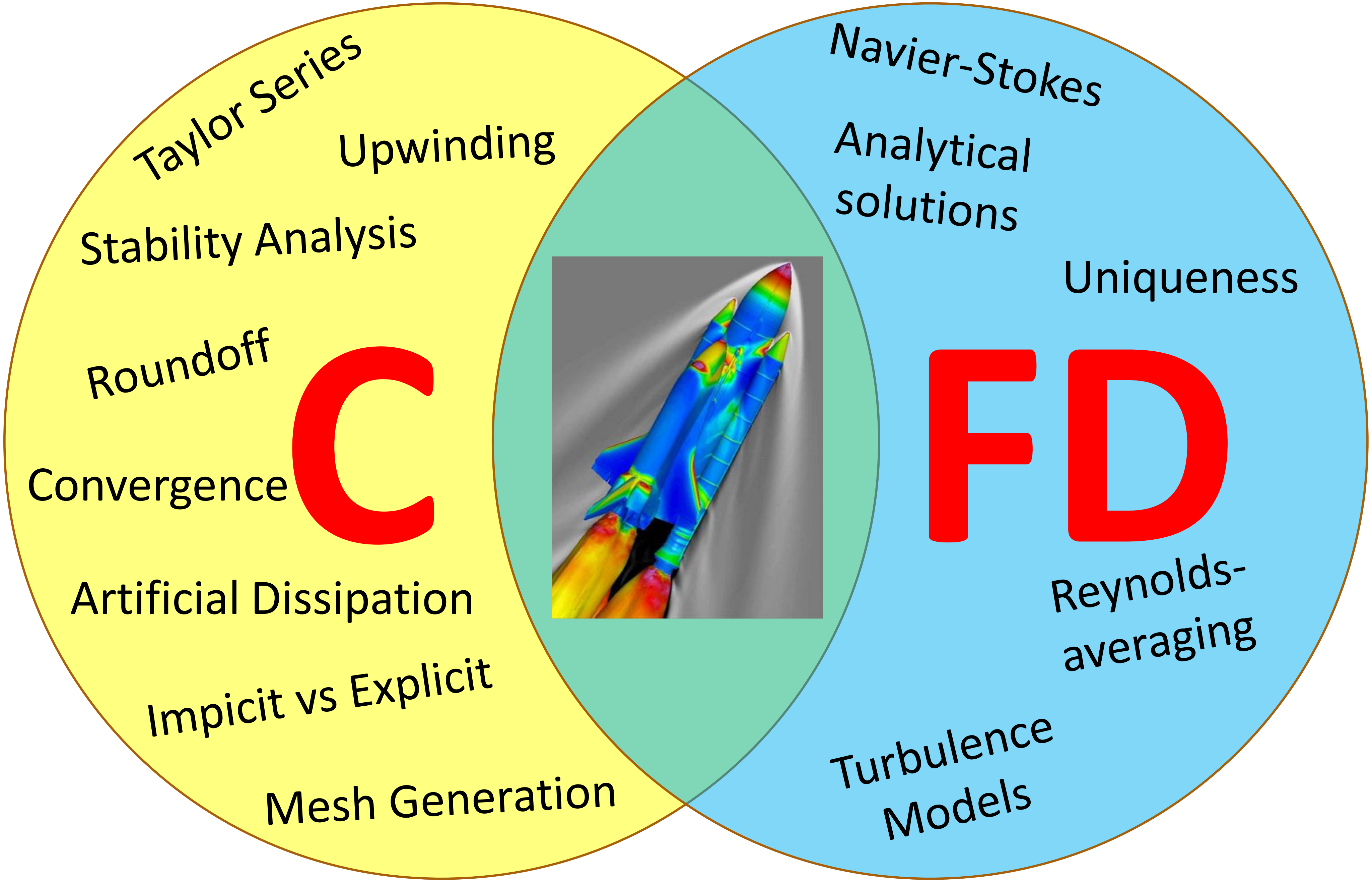
References

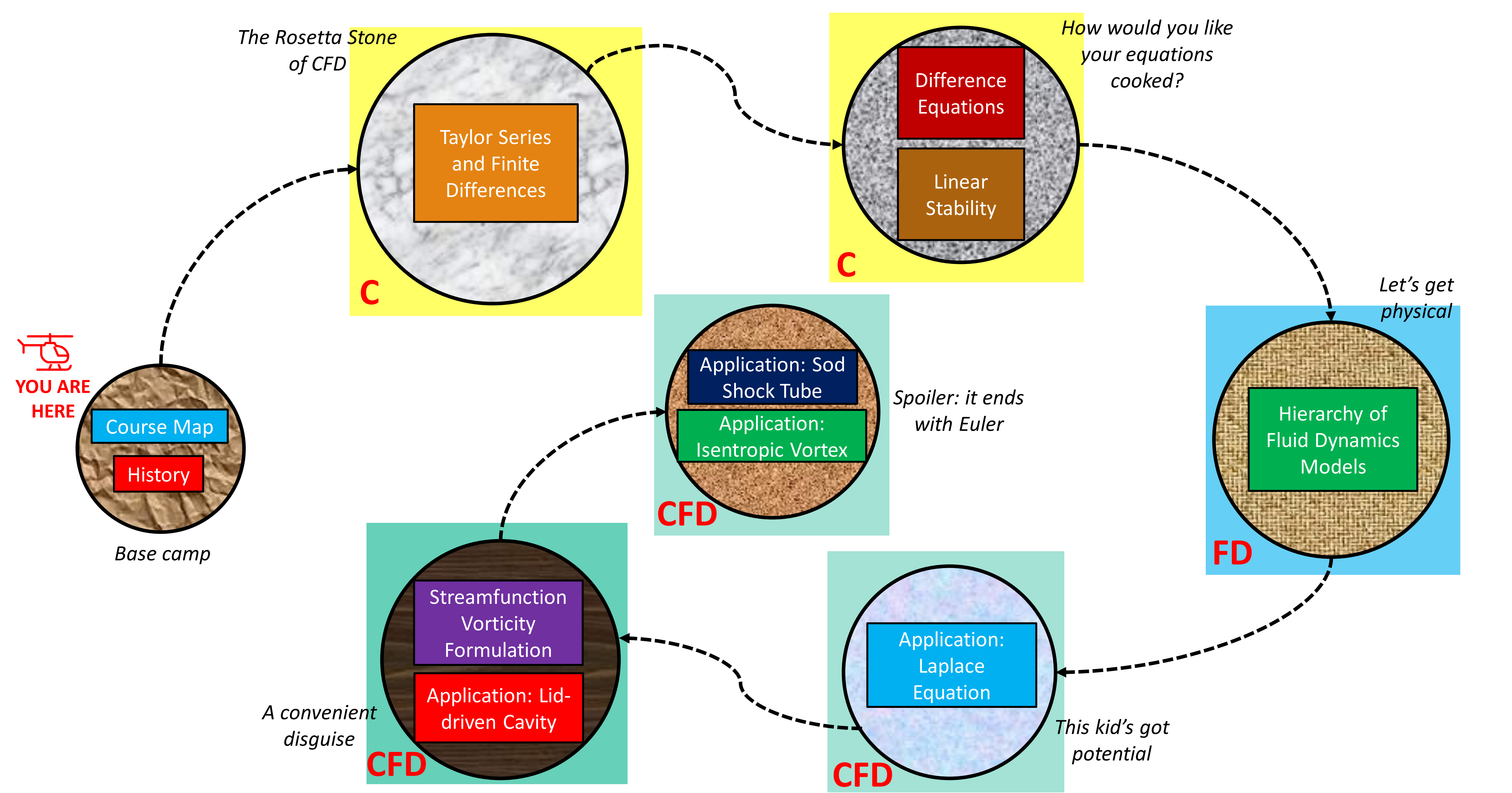

JOHN D. ANDERSON, JR.
Computational Fluid Dynamics
THE BASICS WITH APPLICATIONS
McGRAW-HILL INTERNATIONAL EDITIONS
Mechanical Engineering Series


Computational Fluid Dynamics
T. J. Chung


WEATHER PREDICTION BY NUMERICAL PROCESS
Second Edition
Lewis Fry Richardson
Cambridge Mathematical Library


YOU ARE HERE
Course Map
History
Base camp
The Rosetta Stone of CFD
Taylor Series and Finite Differences
Difference Equations
Linear Stability
How would you like your equations cooked?
Let's get physical
Hierarchy of Fluid Dynamics Models
Application: Laplace Equation
This kid's got potential
Streamfunction Vorticity Formulation
Application: Lid-driven Cavity
A convenient disguise
Application: Sod Shock Tube
Application: Isentropic Vortex
Spoiler: it ends with Euler


Taylor Series
Upwinding
Stability Analysis
Roundoff
Convergence
C
Artificial Dissipation
Impicit vs Explicit
Mesh Generation
Navier-Stokes
Analytical solutions
Uniqueness
FD
Reynolds-averaging
Turbulence Models


The Rosetta Stone of CFD
Taylor Series and Finite Differences
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Application: Isentropic Vortex
CFD
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CFD
Application: Laplace Equation
This kid's got potential
CFD

What this Course DOES NOT Have

- Exhaustive Intro to Fluid Dynamics/Thermodynamics
- Grid generation
- RANS / Turbulence modeling
- LES / DES

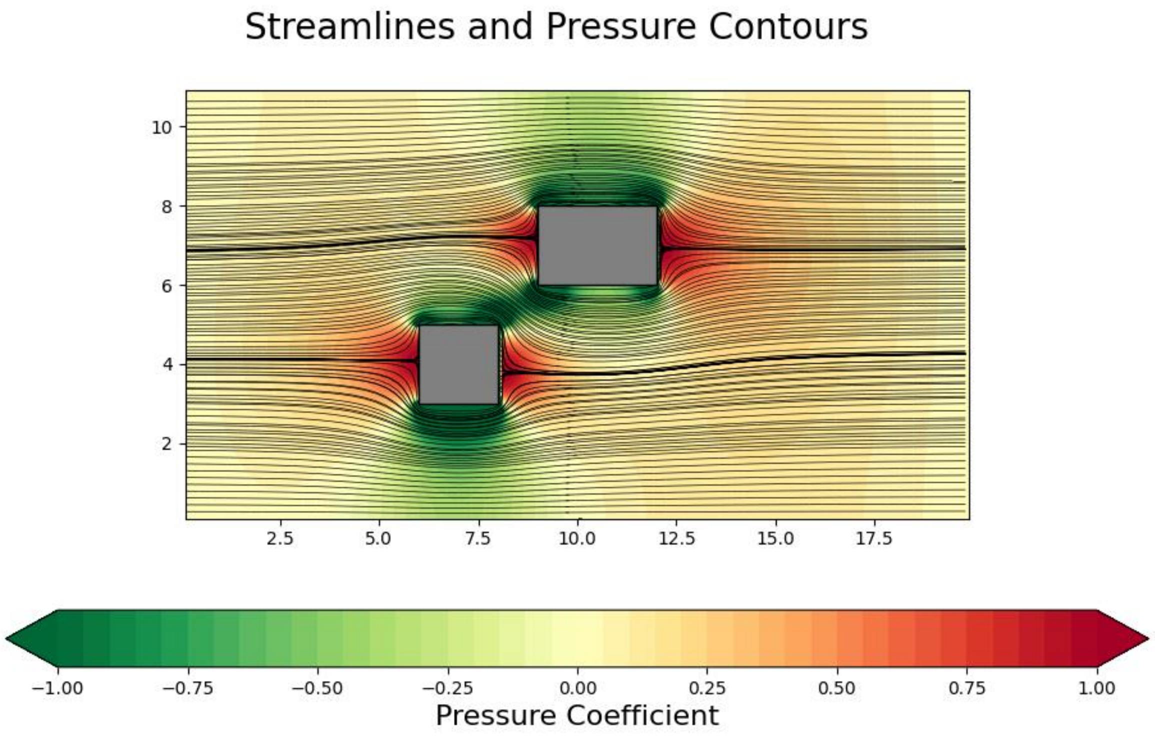
Mission Statement

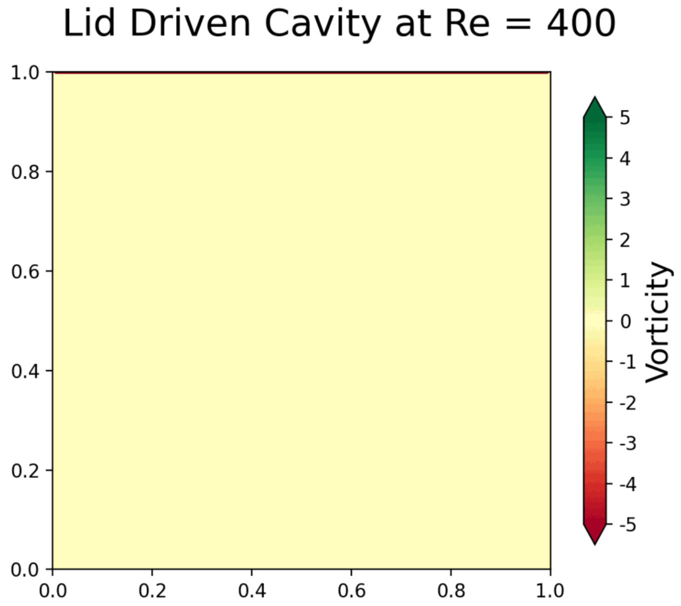
<u>Equip the student with the means to:</u>

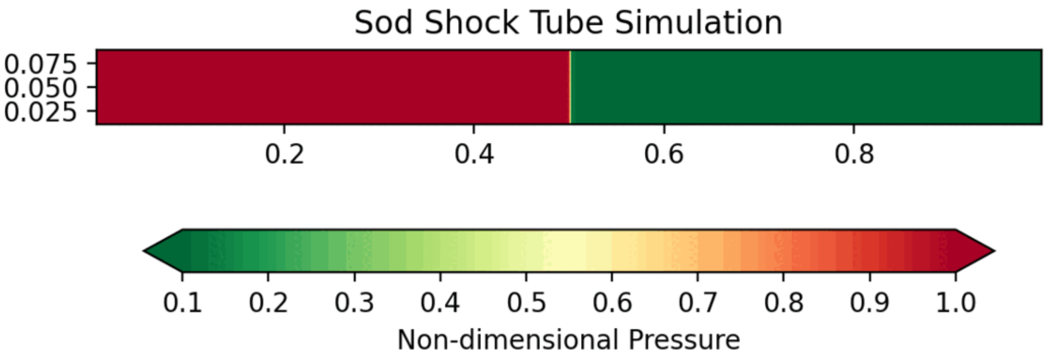
(1) Navigate the "*fidelity-ladder*" of the Navier-Stokes equations to find a suitable model

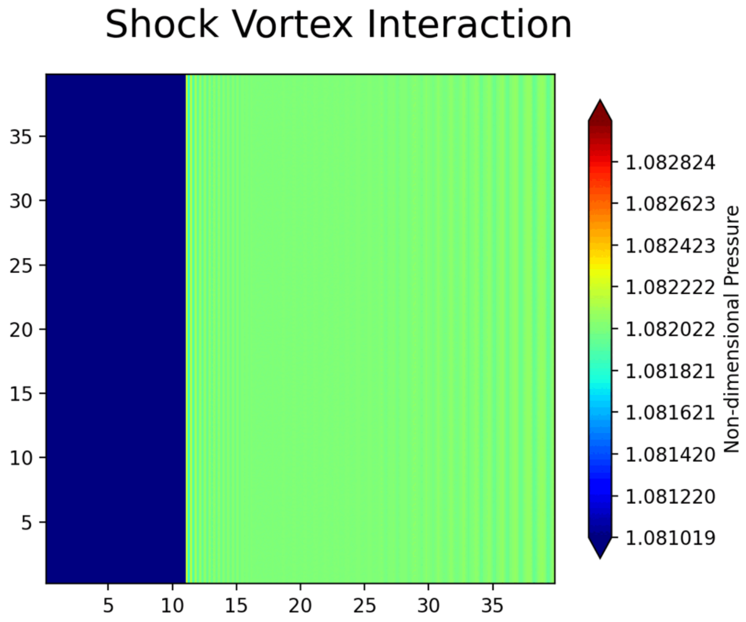
(2) Tailor a *finite-difference* scheme with a desired level of *accuracy* and *stability* (and be able to predict how it will behave before writing a single line of code)

(3) Write/extend/run/validate a CFD solver in two spatial dimensions or more


Streamlines and Pressure Contours
−1.00 −0.75 −0.50 −0.25 0.00 0.25 0.50 0.75 1.00
Pressure Coefficient


Lid Driven Cavity at Re = 400
Vorticity


Sod Shock Tube Simulation
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Non-dimensional Pressure


Shock Vortex Interaction
Non-dimensional Pressure

Alternatives

‘Computational Fluid Dynamics Fundamentals Course’ – Dr. Aidan Wimshurst (Udemy)

MIT OpenCourseWare

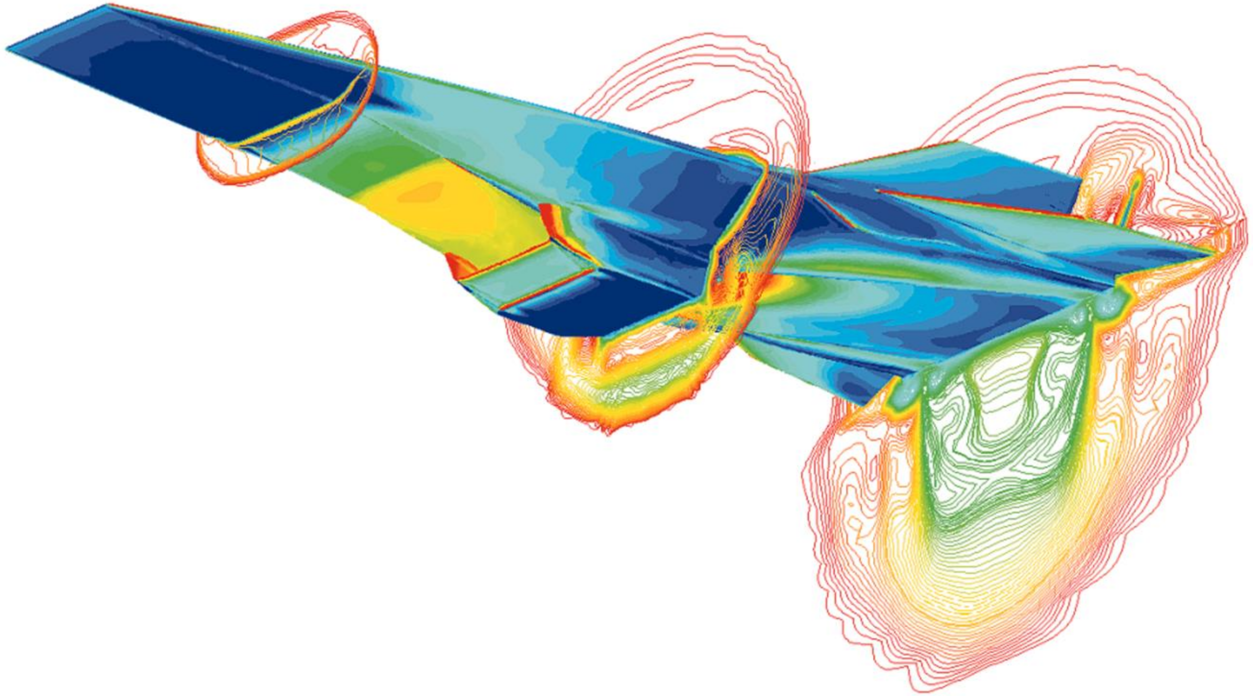
Youtube

Contact Info

Direct questions and feedback to *sthomas2@umd.edu*

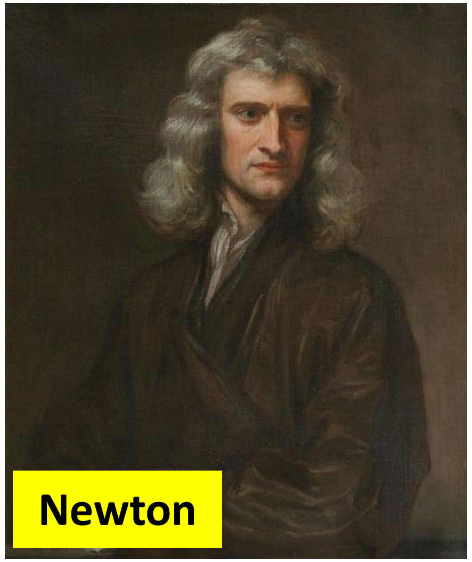
A (*very*) Brief History of CFD

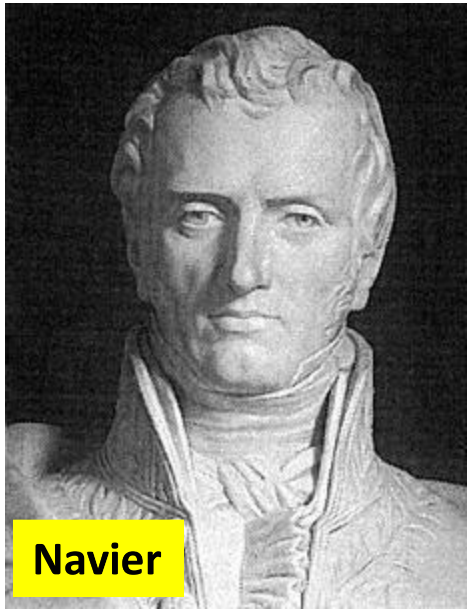
SEBASTIAN THOMAS

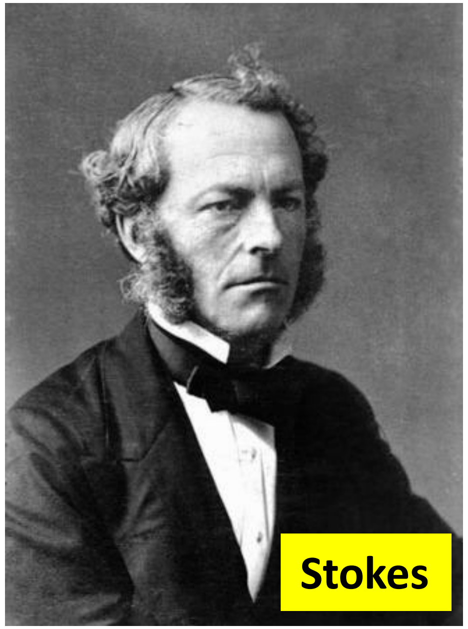


The “FD”

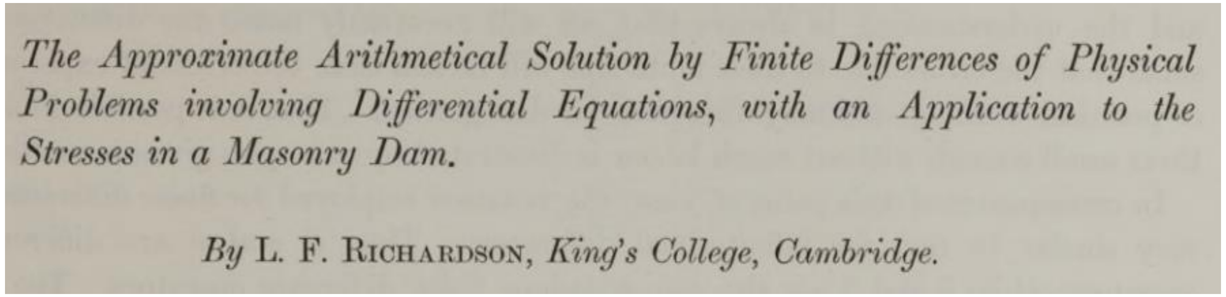
- Fluid dynamical equations assembled over two centuries
- Euler applied Newton’s conservation of momentum law to “*perfect*” fluids
- Navier, Stokes extend Euler’s equation to “*viscous*” fluids







The "C"



The Approximate Arithmetical Solution by Finite Differences of Physical Problems involving Differential Equations, with an Application to the Stresses in a Masonry Dam.

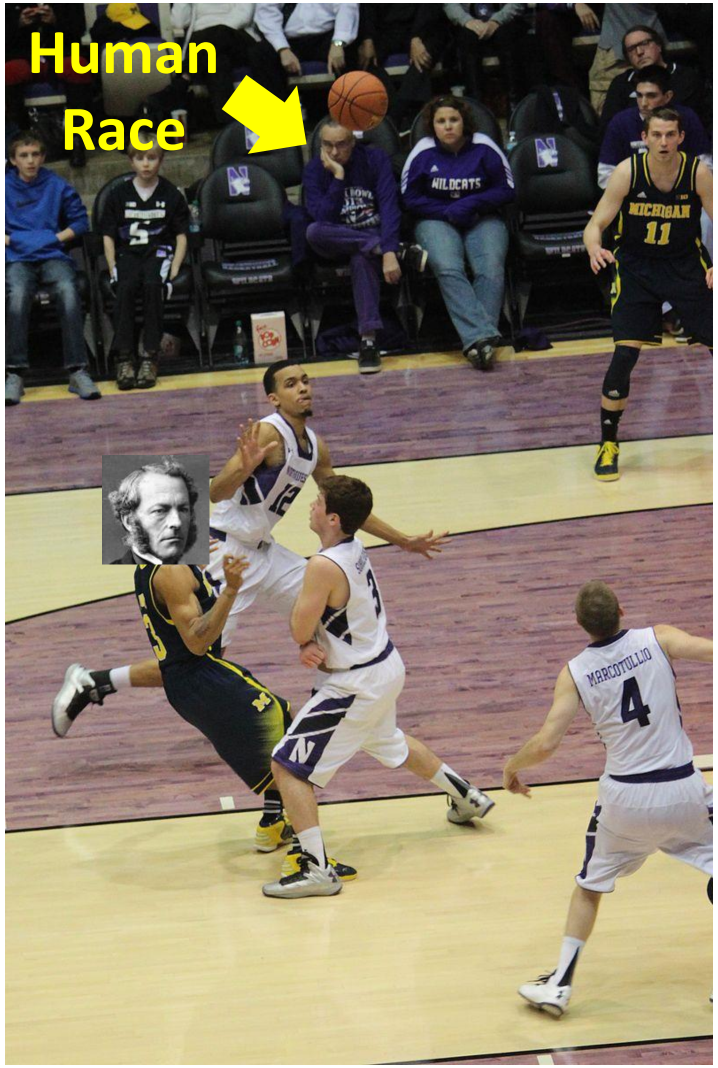
By L. F. Richardson, *King's College, Cambridge.*

- Richardson used 'finite differences' to compute stresses in a masonry dam (1910)

- Realized that this technique could work in meteorology too

- Completed calculation of a single day's weather *while transporting injured soldiers during the Battle of Champagne*

Stokes completes assembly of fluid dynamical equations



Seventy years go by

Richardson attempts the first weather forecast using a finite-difference approximation of the equations

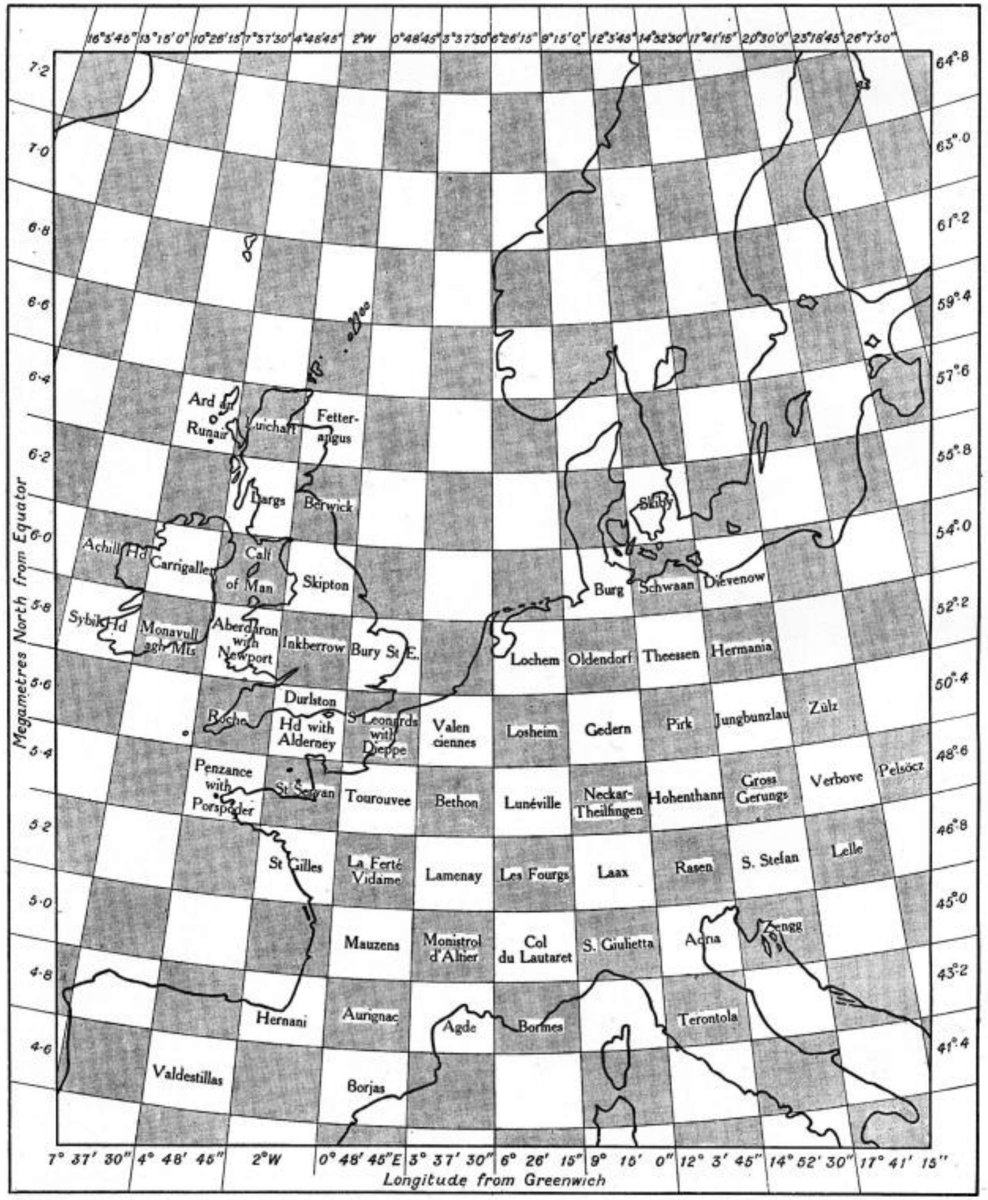
- Richardson divided the global atmosphere into 12000 cells

- Each cell spanned 200 km in north-south direction, 3° in east-west direction and 1/5th the vertical span of the atmosphere

- He initialized his atmosphere to conditions observed on May 10th 1910

- He advanced the state of his atmosphere 6 hours at a time, by solving his finite-difference approximation of the fluid dynamical equations

- His computational result was… ***UNDERWHELMING***



Richardson's grid

"The rate of rise of surface pressure, is found [...] as 145 millibars in 6 hours, whereas observations show that the barometer was nearly steady. This glaring error is examined in detail below [...] and is traced to errors in the representation of the initial wind."

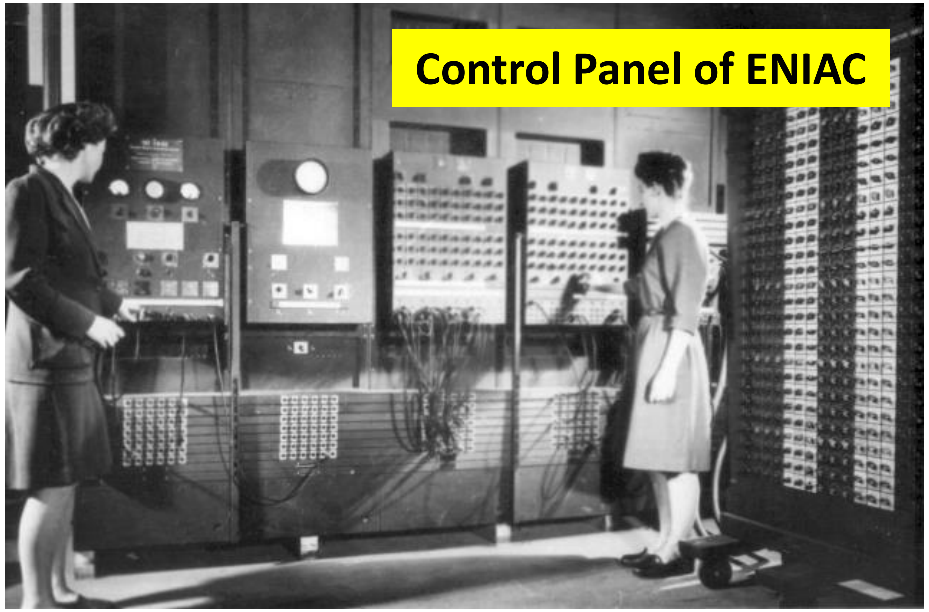
- L.F.Richardson (Weather Prediction by Numerical Process)

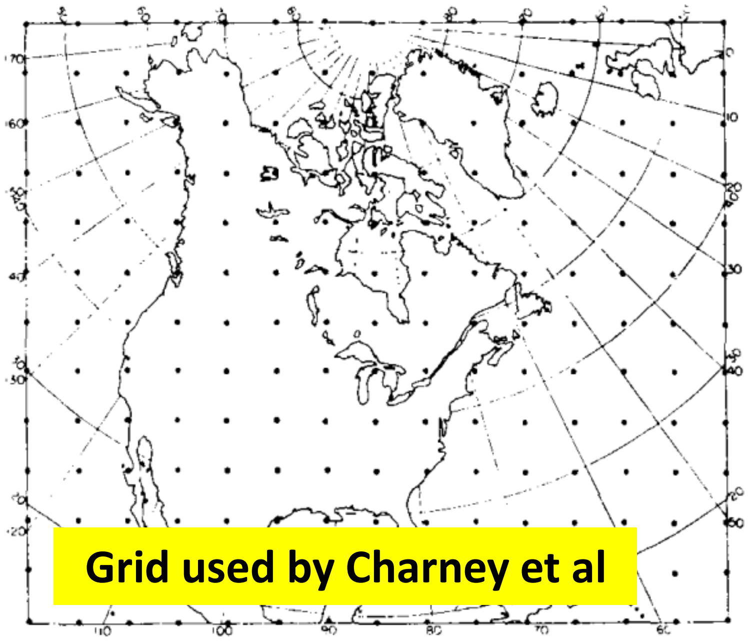
The Juggernaut Rolls On

- By the 1940s, Richardson's slide rule and paper was replaced by vacuum tubes and punch cards

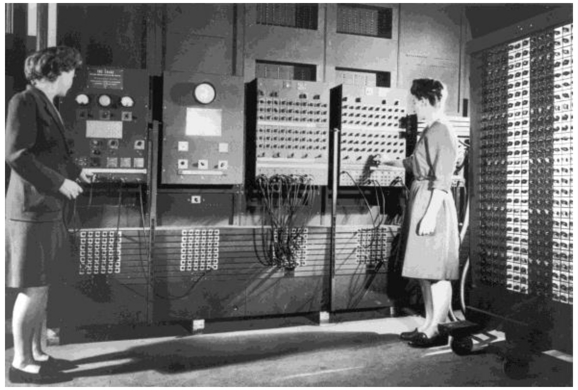
- First computer-based weather prediction performed in 1950 (Charney, Von Neumann)

- As compute power grows over the next fifty years, increasingly complicated solution methodologies are introduced and tested on increasingly complex applications

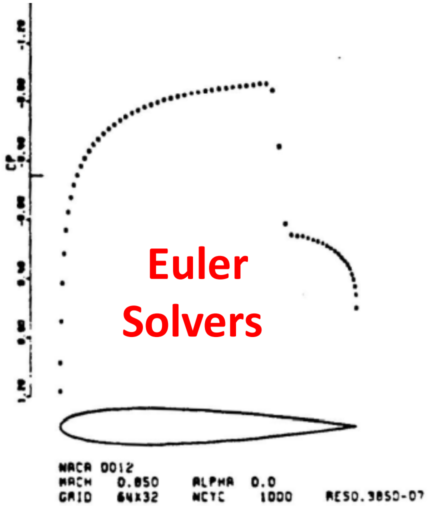


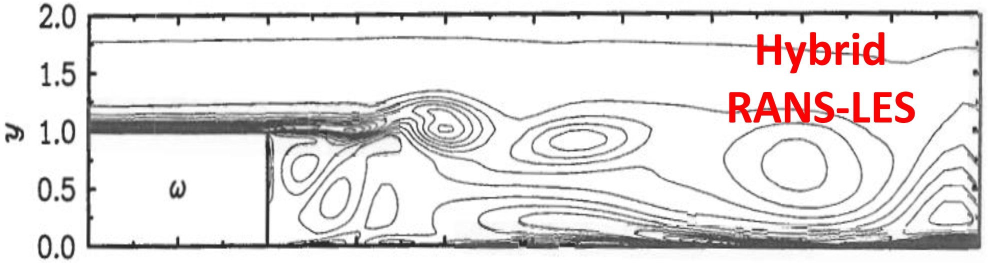


Barotropic Vorticity Solver

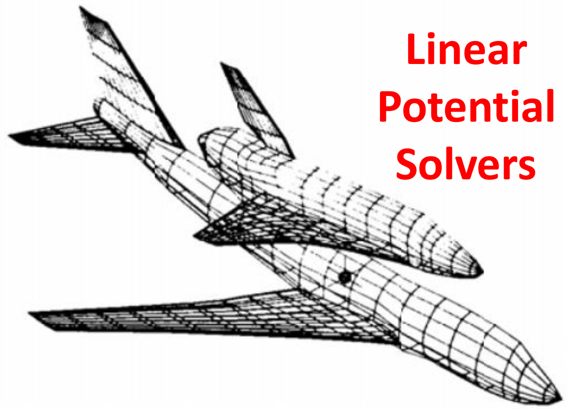


LES

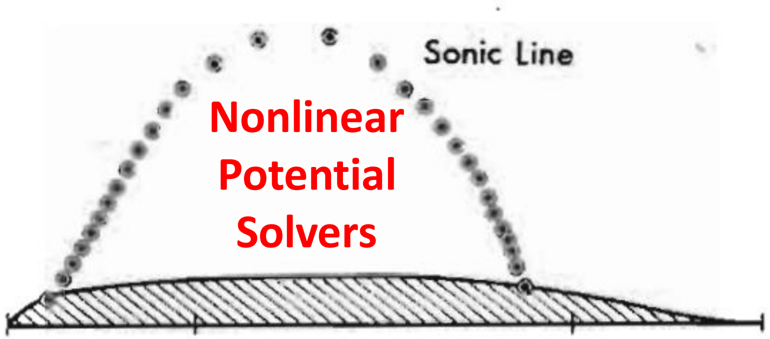


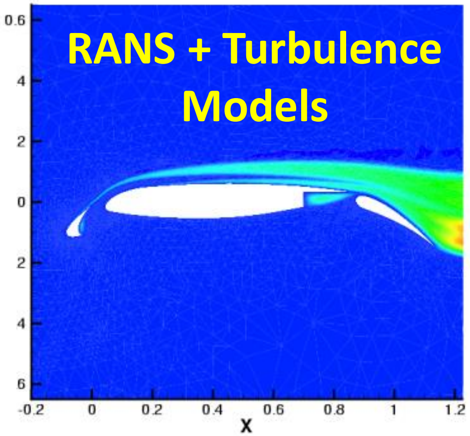


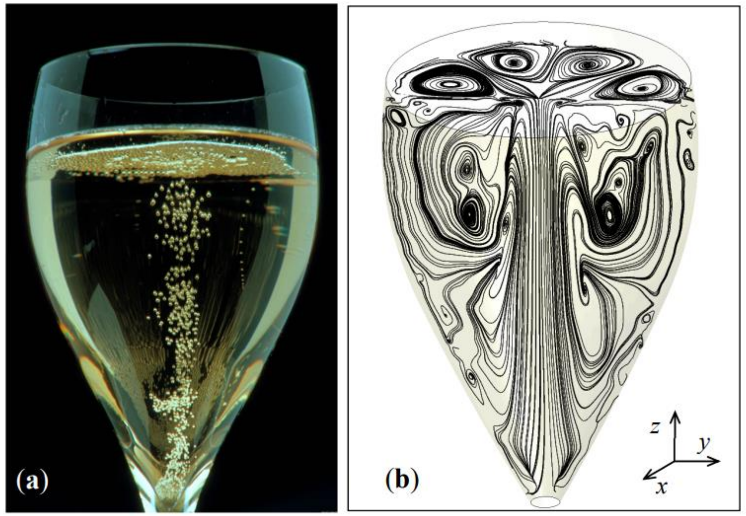
1950 1960 1970 1980 1990 2000 2010 2020

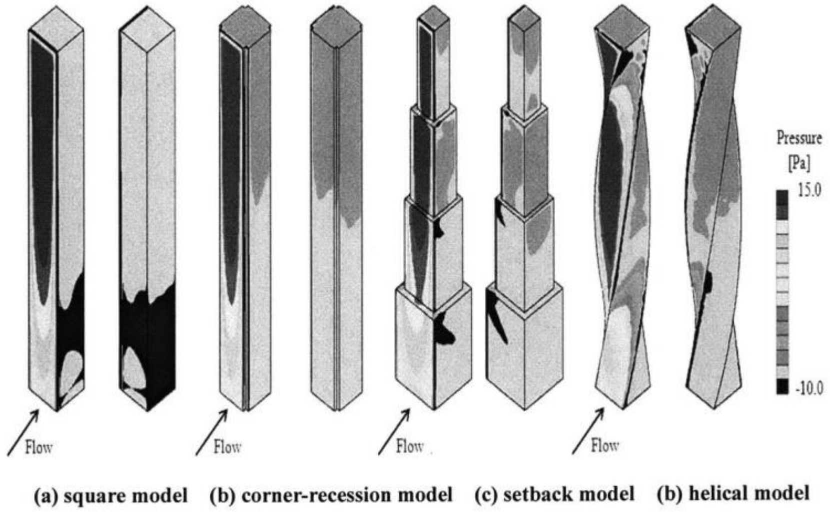


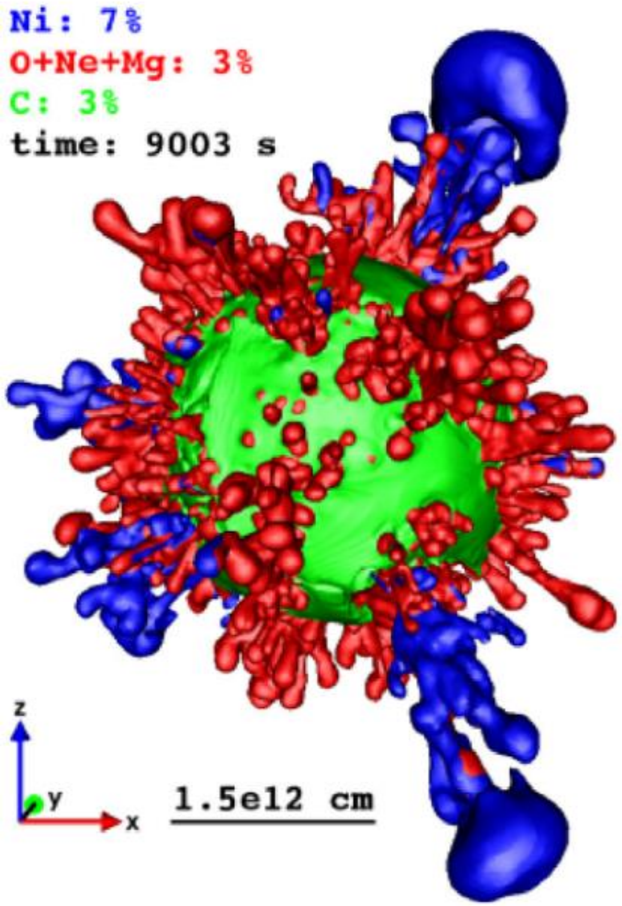
Linear
Potential
Solvers

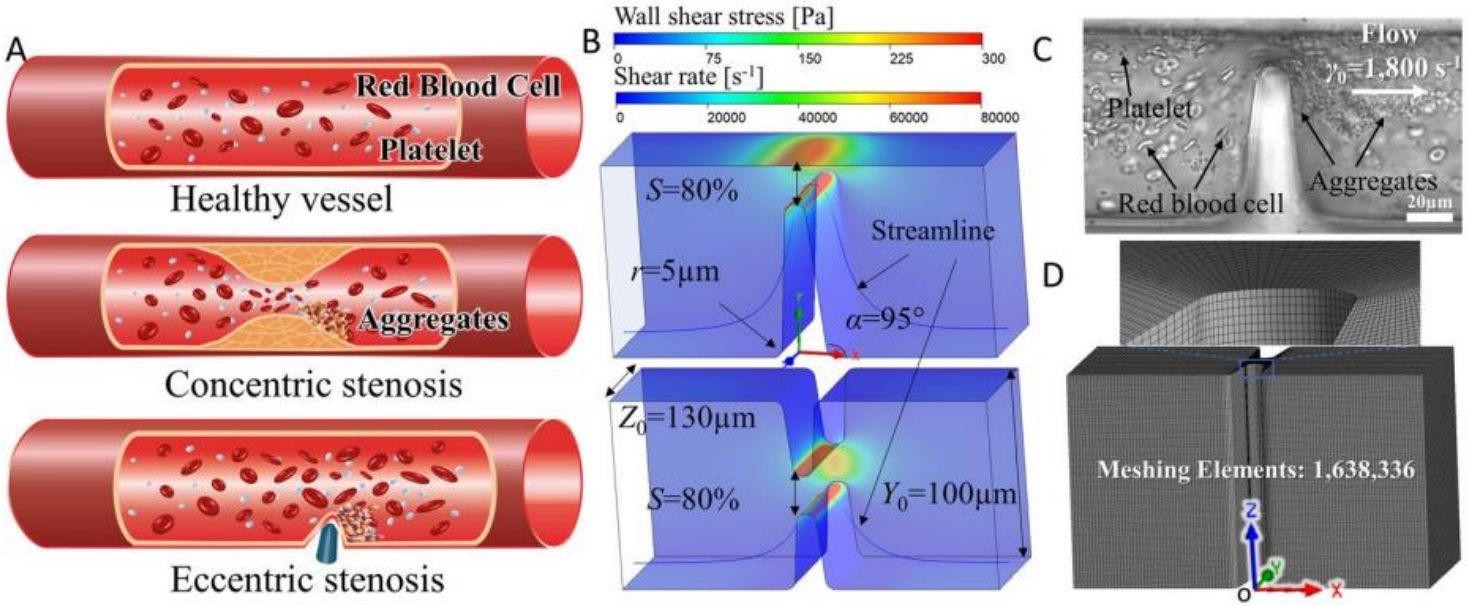


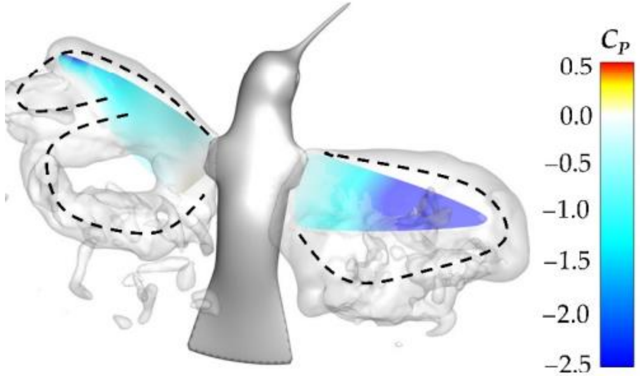


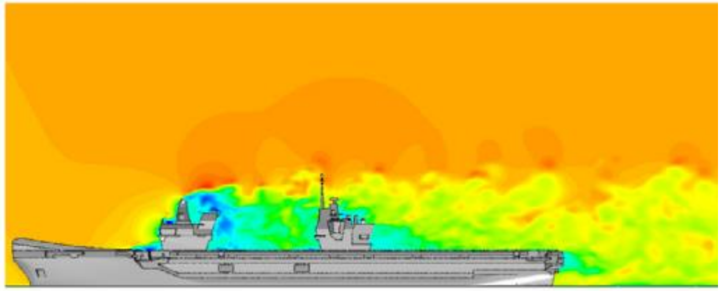

(a)
(b)
z
y
x

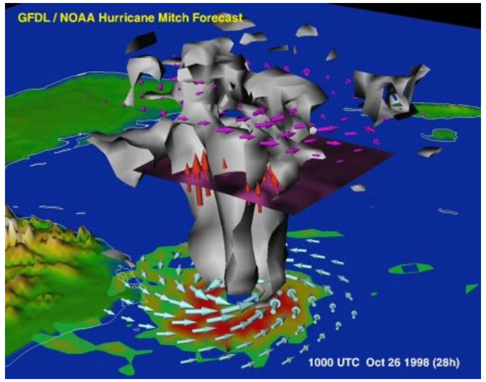

Pressure
[Pa]
15.0
-10.0
Flow
Flow
Flow
Flow
(a) square model
(b) corner-recession model
(c) setback model
(b) helical model

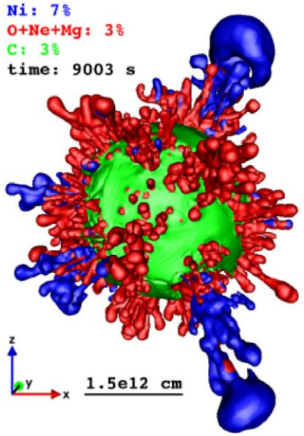

Ni: 7%
O+Ne+Mg: 3%
C: 3%
time: 9003 s
z
y
x
1.5e12 cm

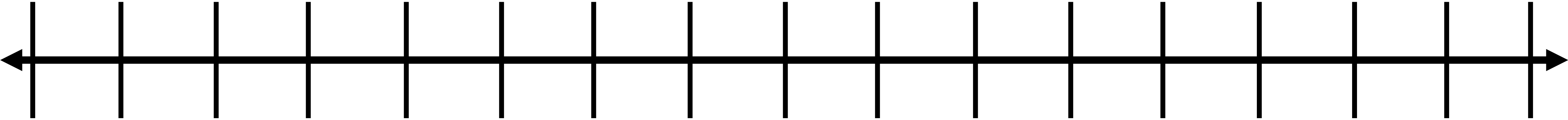

A
Red Blood Cell
Platelet
Healthy vessel
Aggregates
Concentric stenosis
Eccentric stenosis
B
Wall shear stress [Pa]
0
75
150
225
300
Shear rate [s-1]
0
20000
40000
60000
80000
S=80%
r=5μm
Streamline
α=95°
Z0=130μm
S=80%
Y0=100μm
C
Flow
γ0=1,800 s-1
Platelet
Aggregates
Red blood cell
20μm
D
Meshing Elements: 1,638,336
Z
Y
X
O



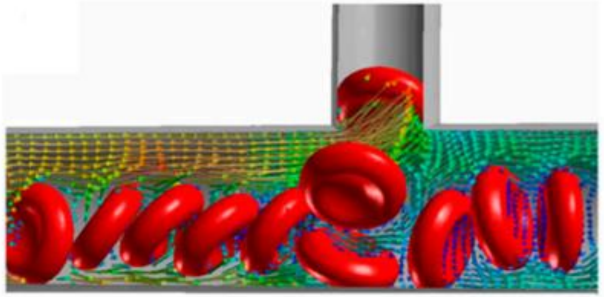


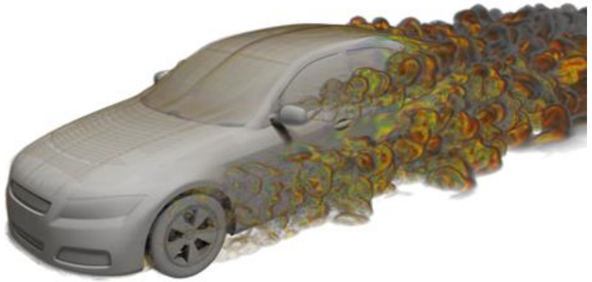


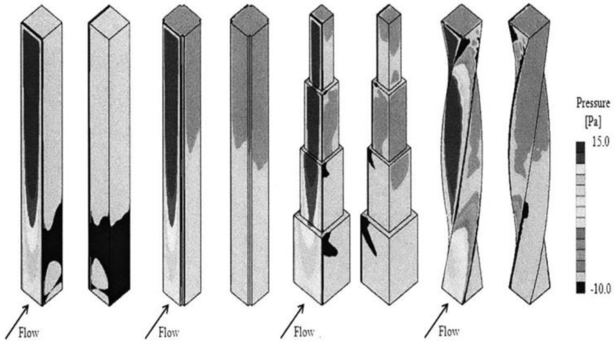




10^{-5}m 10^{-3}m 10^{-1}m 10^{1}m 10^{3}m 10^{5}m 10^{7}m 10^{10}m







(a) square model (b) corner-recession model (c) setback model (b) helical model