Introduction to Multi-physics Modelling

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Computational Modelling of multi-physics processes - What is it?

- **Computational Modelling is :**
  - "The application of numerical approximation methods and computers to the solution of problems in Engineering and Applied Sciences" - O. Zienkiewicz

- **Computational modelling can be used to predict a number of physical phenomena including:**
  - Fluid Flow
  - Heat Transfer
  - Solid mechanics
  - Electromagnetics
  - Etc

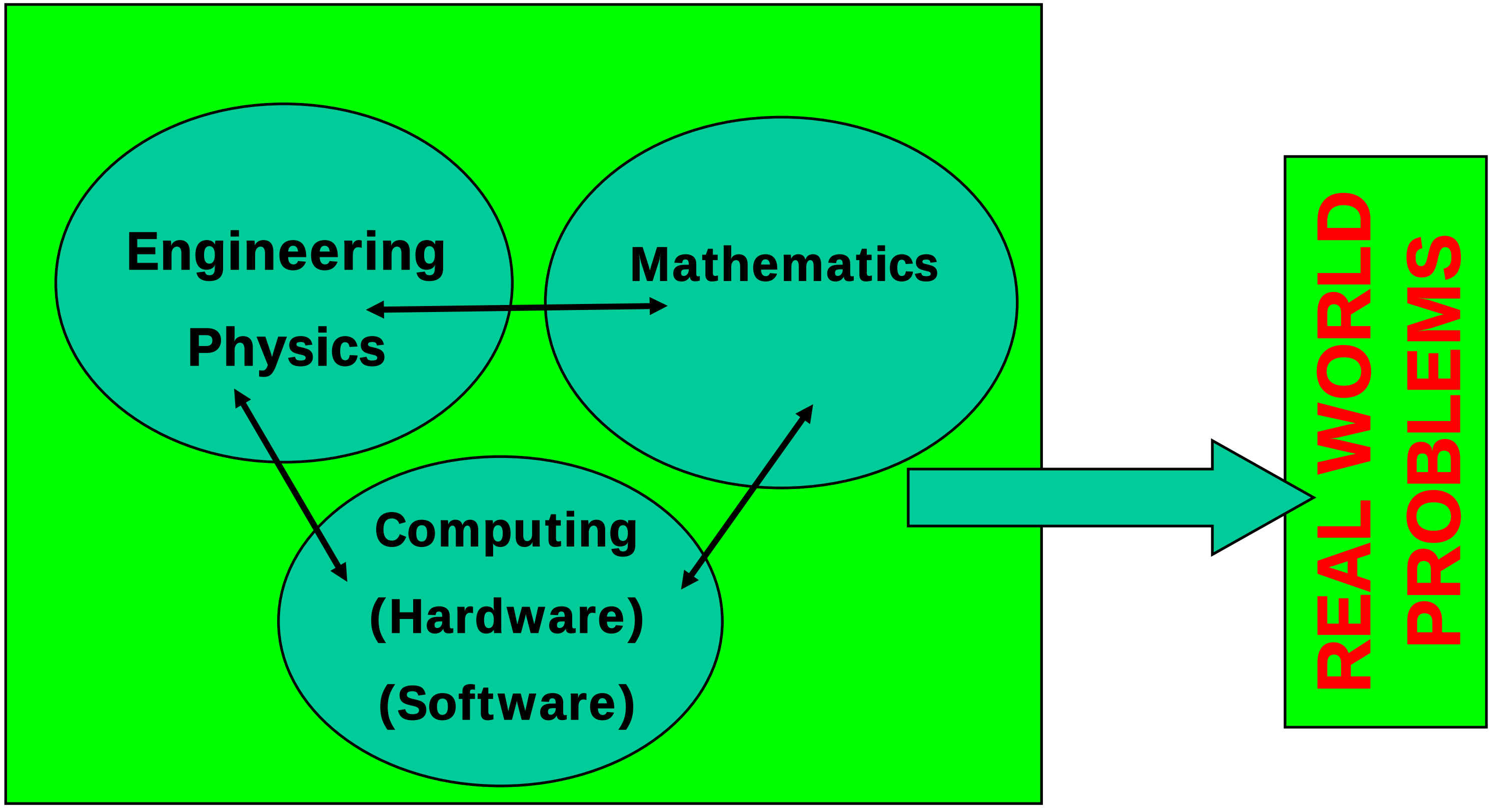
- **Multi-physics involves some or all of the above simultaneously**

Computational Modelling – What is it?

- **Simulating real-world phenomena on a computer involves:**
  - understanding the governing physics.
  - formulating the problem in terms of mathematics.
  - writing computer software that solves the mathematical equations.
  - running the computer program
  - viewing (& analyzing) the results.
- **Generally most real-world problems require solution to thousands of equations.**
- **Many commercial software tools now available.**

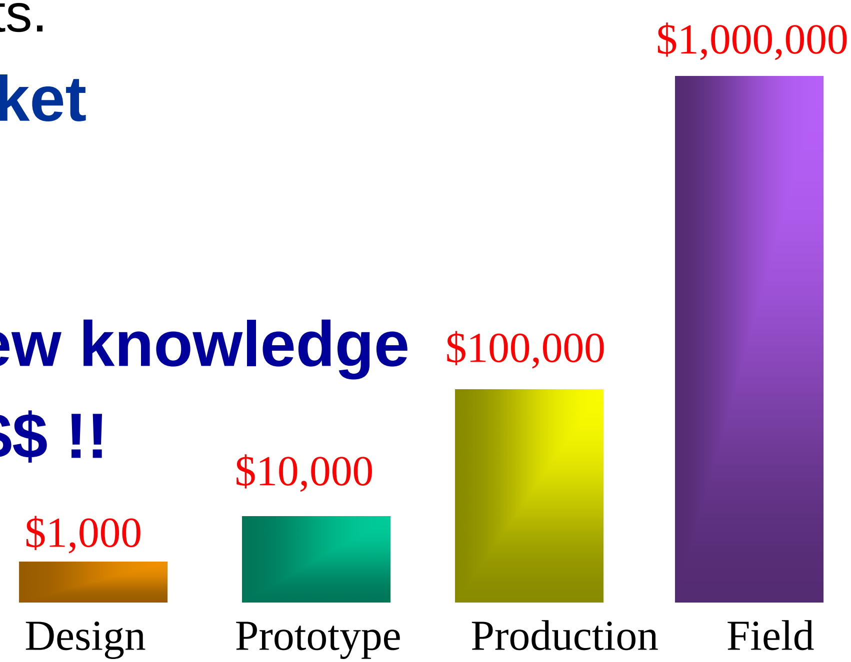
Computational Modelling - What is it?

- Computational Modelling Research - Interdisciplinary



Why use Computational Modelling?

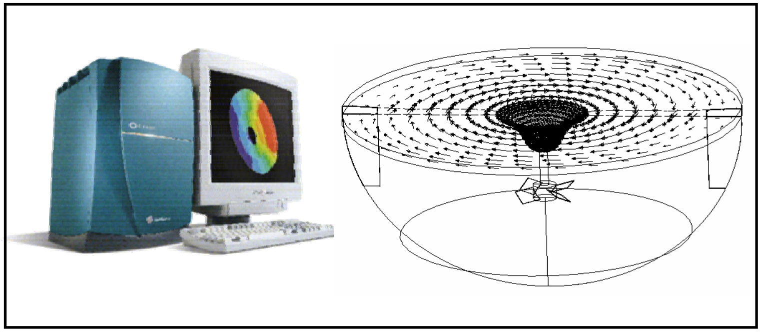
- **Cost of Quality**
  - warranty liabilities due to field failures;
  - redesign; rework; and scrap costs.
- **Lateness of product to market**
  - First two manufactures to market lock up 80% of business
- **Modelling helps generate new knowledge**
- **Modelling upfront saves $$$$!!**



Modelling – real world interaction

- Compliments Experimentation
- Validation should always be undertaken when possible

Refining Process



Computational Modelling

Water Modelling

Governing Physics

- **Materials Processing**
  - Fluid Flow + Free surface
  - Chemical Reactions
  - Electromagnetic Fields
  - Heat Transfer
  - Solidification
  - Stress
- **Many processes governed by interactions of the above**
  - Multi-physics
- **Multi-scale - 0.1μ - 1m**

Casting

Refining

Governing Equations

- **The governing equations can be expressed in a standard form:**

$$\frac{\partial}{\partial t}(\rho A \phi) + \nabla.Q = \nabla.(\Gamma \nabla \phi) + S$$

	ϕ	A	Γ_ϕ	S	Q
Continuity	1	1	0	S_{mass}	$\rho \underline{v}$
Momentum	$\underline{v}$	1	Γ_v	$(S + \underline{J} x \underline{B} - \nabla P)$	$\rho \underline{v.v}$
Heat transfer	h	1	k/c	S_h	$\rho \underline{v} h$
Electromagnetism	$\underline{B}$	1	η	$(\underline{B}\nabla)\underline{v}$	$\underline{u.B}$
Solid Mechanics	$\underline{u}$	$\partial / \partial t$	μ	$\rho \underline{f}_b$	$\mu(grad\ \underline{u})^T + \lambda(div\,\underline{u} - (2\mu + 3\lambda)\alpha T)\underline{I}$

Steps In Computational Modelling

- **CAD generates geometry**
- **CAD captures 'patches'**
- **CAD domain meshed**
- **Number of methods used to discretise equations**
  - Finite Difference
  - Finite Element
  - Finite Volume
- **Graphically based software tools for results analysis & visualisation.**
- **'patches' – are points, surfaces or volumes**

Build Geometry

Specify patches for bdy conditions & vol loads

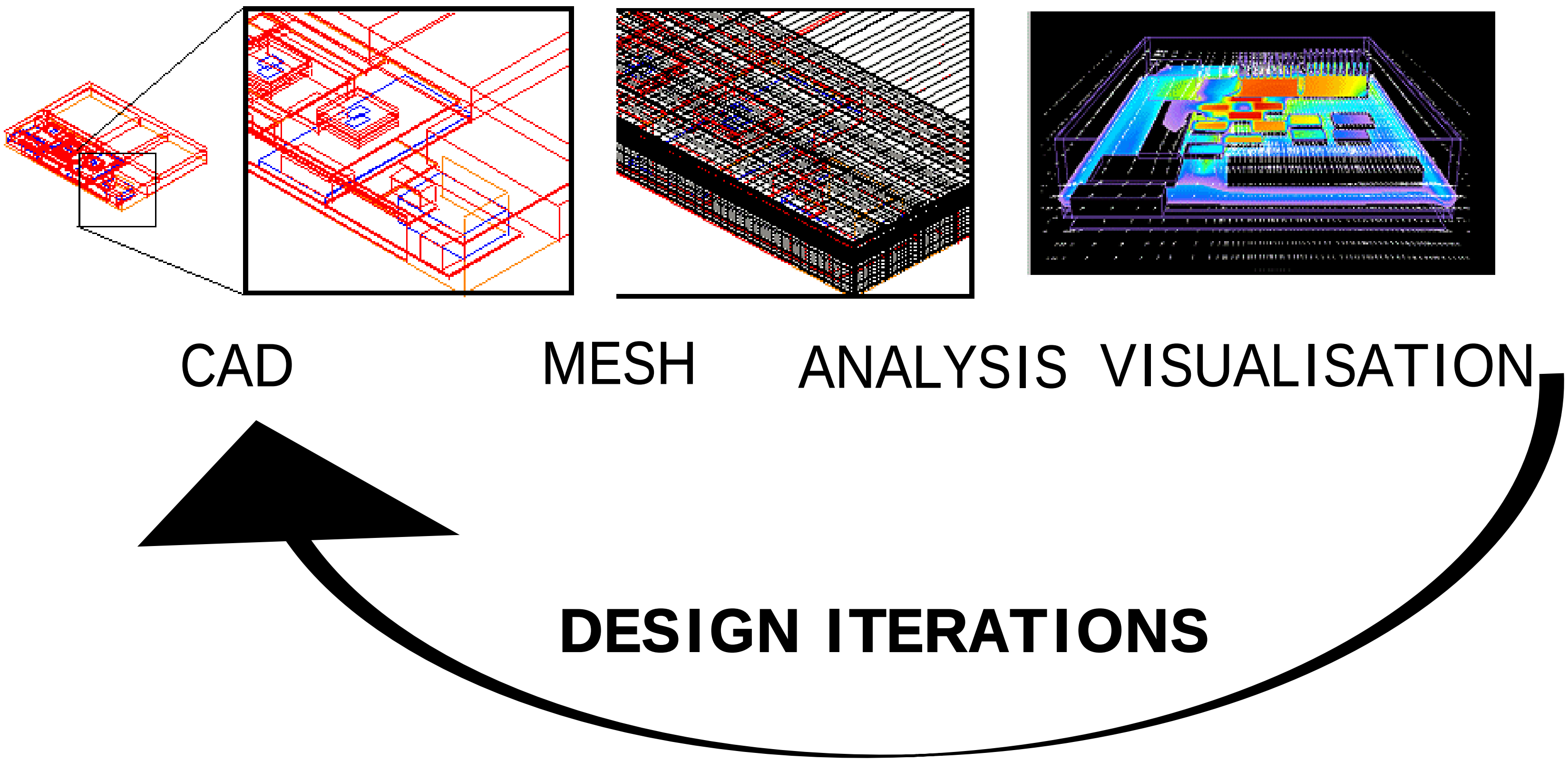
Mesh the Geometry

Specify & Solve governing equations

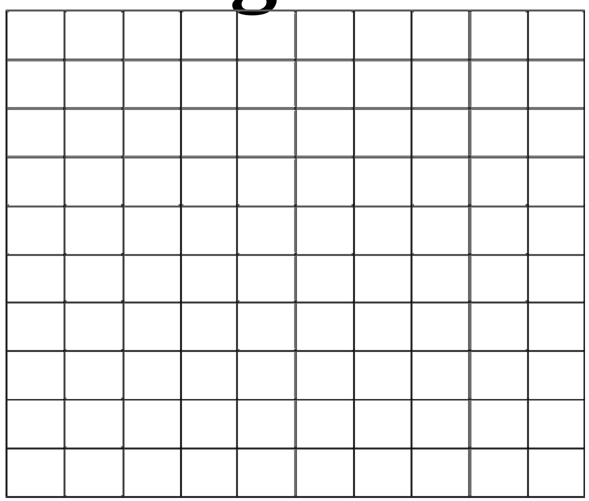
Visualise / analyse the results

Steps in Computational Simulation

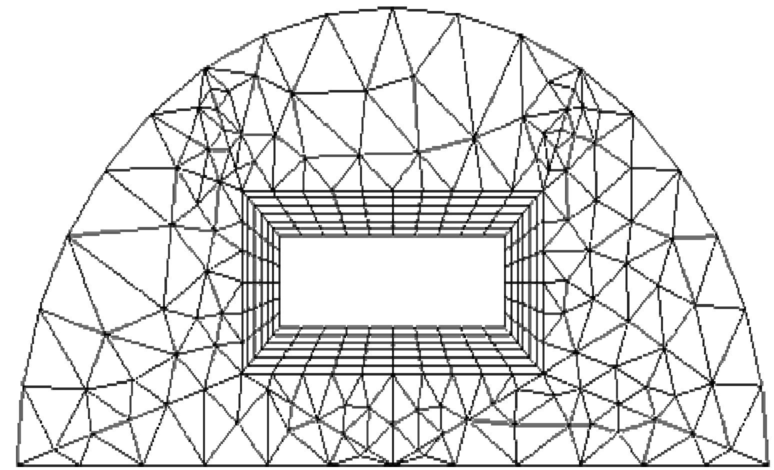
- **CAD – MESHING – ANALYSIS - VISUALISATION**



Meshing – Structured and Unstructured



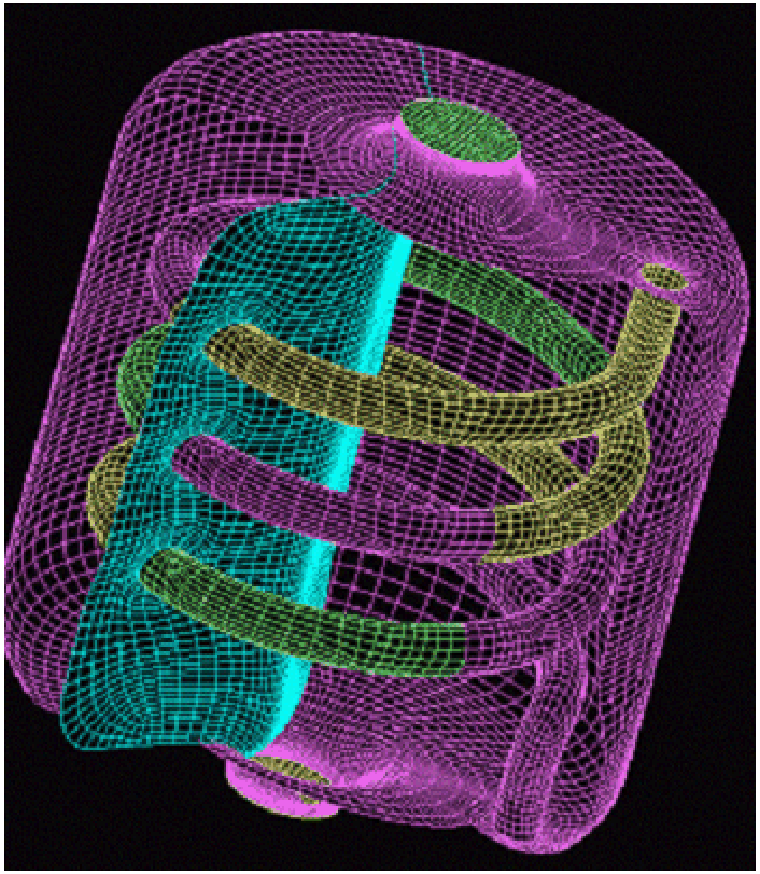
- **Data referenced using I,J grid lines**
- **Allows line-line solvers.**
  - Low in-core memory requirement
- **Poor on complex shapes.**
  - Use BFC or Block-Structured



- **Good for complex geometry**
- **Topology representation**
  - Points - Faces - Elements
- **Mix element types.**
- **Requires whole field solvers.**
  - Large memory needed

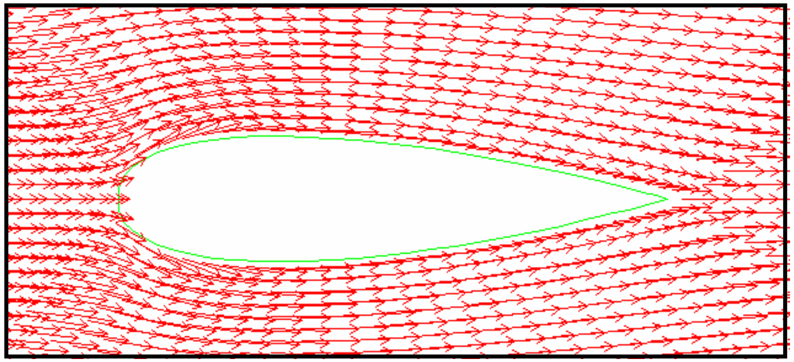
CAD + Meshing Software

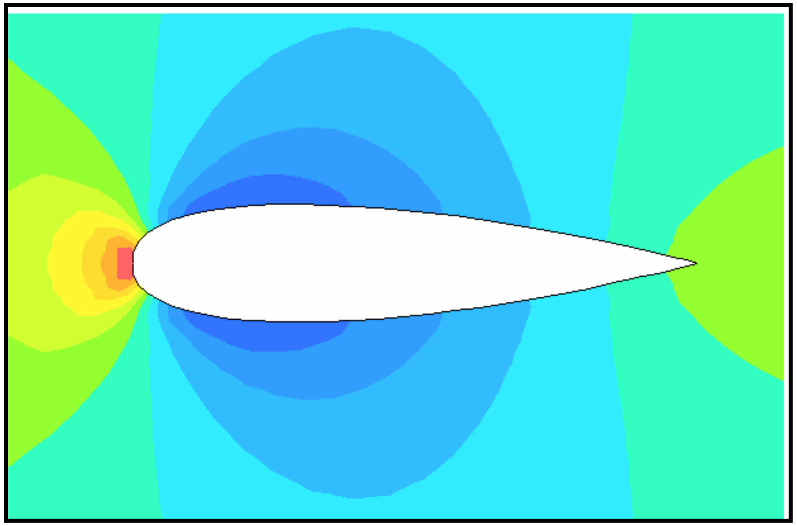
- **PRO/ENGINEER**
  - http://www.ptc.com/
- **CATIA**
  - http://www.catia.com/
- **Mentor Graphics**
  - http://www.mentor.com/
- **FEMSYS**
  - http://www.femsys.co.uk/
- **GRIDPRO**
  - http://www.gridpro.com/



Computational Fluid Dynamics - CFD

- **Started in early late 60's early 70's**
- **Based on Finite Difference/Volume Methods**
- **Simulations now include**
  - Turbulence
  - Free surface Flows
  - Heat Transfer + Solidification
  - Chemical Reactions
- **Early work based on structured grids**
- **Unstructured Meshes now used**
- **FE Methods also used.**





Computational Fluid Dynamics

$$\frac{\partial \rho\phi}{\partial t} + div(\rho \underline{u}\phi - \Gamma_\phi \nabla \phi) = S_\phi$$

Typically

- **Used Finite Volume Method**
- **Eulerian Approach (Fluid moves through a static mesh)**
- **Highly non-linear**

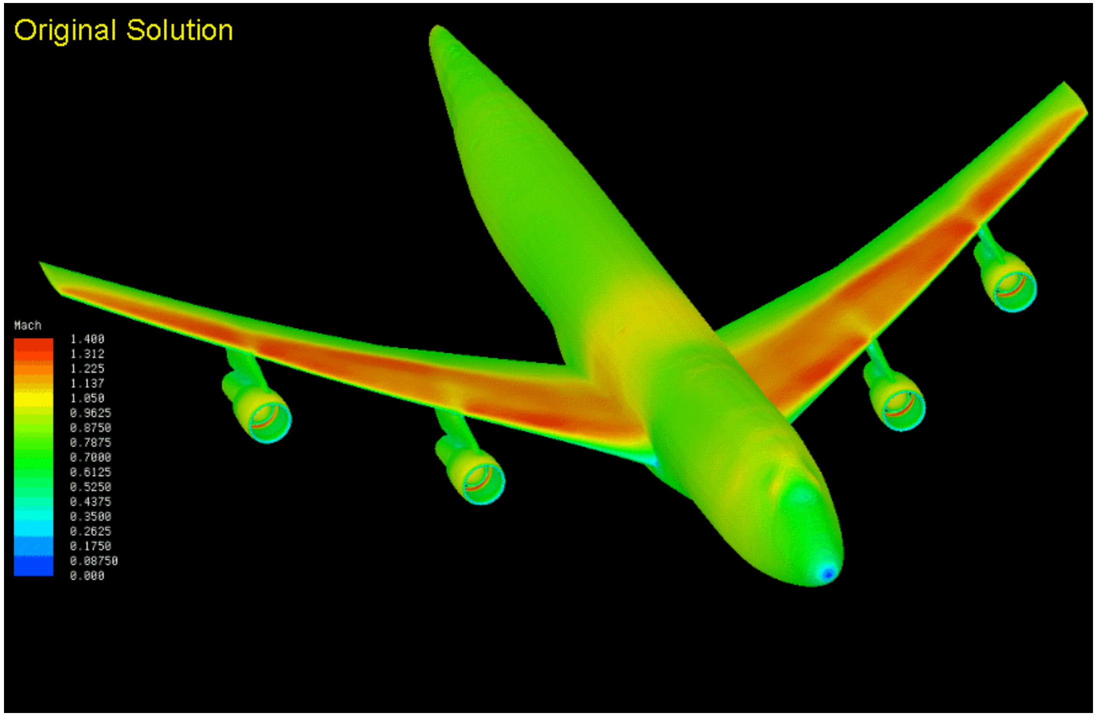
Fluid Flow

$$\frac{\partial \rho u_x}{\partial t} + div(\rho \underline{u} u_x - \mu \nabla u_x) = -\frac{\partial p}{\partial x} + \rho g$$

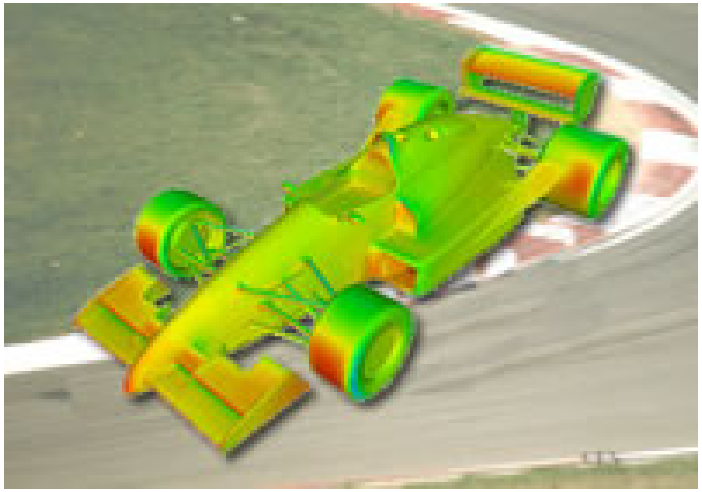
$$\frac{\partial \rho}{\partial t} + div(\rho \underline{u}) = S_m$$

- **Navier-Stokes equation**
- **Newtonian fluid**
- **SIMPLE type algorithm resolve pressure**
- **Staggered – Multi-block - Cartesian or cylindrical polars**

Fluid Flow



Original Solution
Mach
1.400
1.312
1.225
1.137
1.050
0.9625
0.8750
0.7875
0.7000
0.6125
0.5250
0.4375
0.3500
0.2625
0.1750
0.08750
0.000



Turbulence

- **Solved variables contain a**
  - time averaged component
  - fluctuating component
- **Turbulence models the effects of the fluctuating component**
- **Effects other equations by affecting the diffusion coefficient**
- **Many turbulence models**
- **k-e most commonly used**

Turbulence

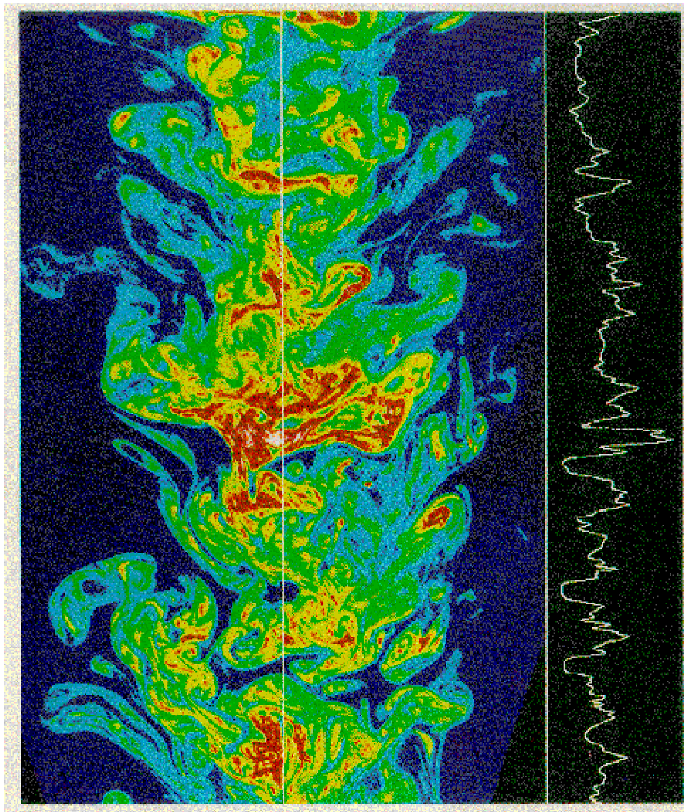
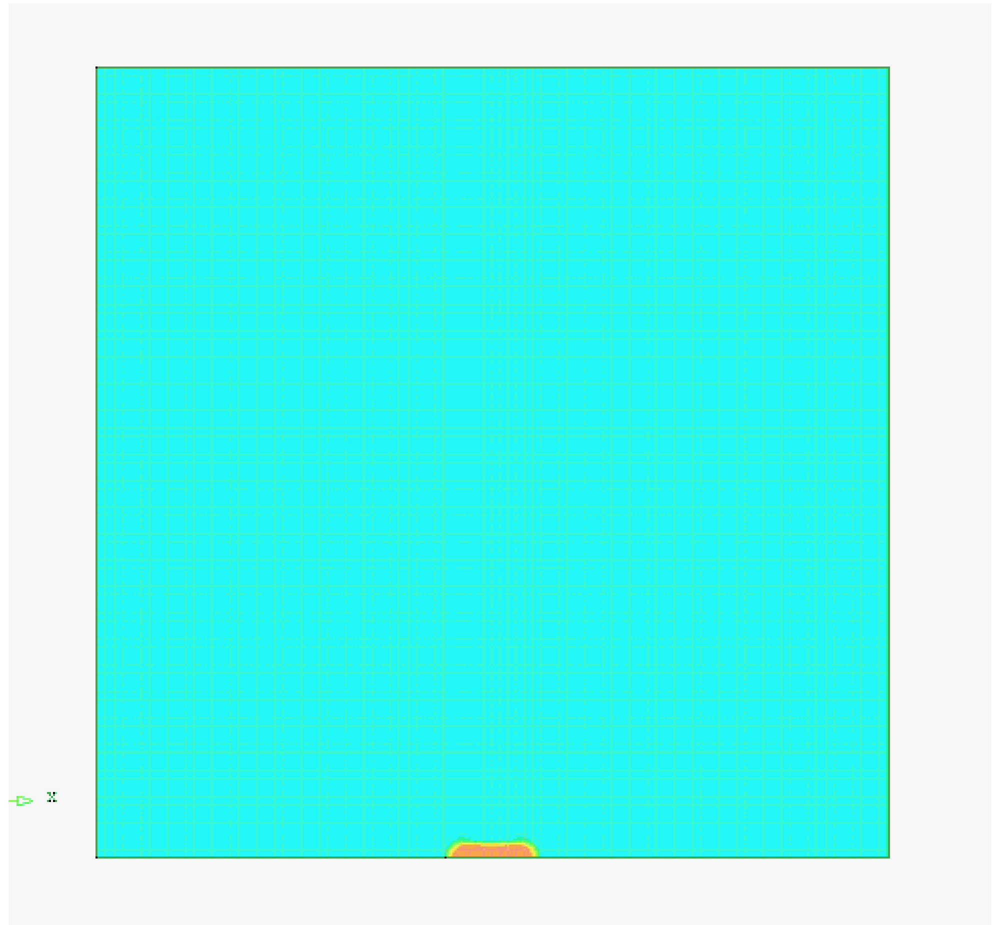
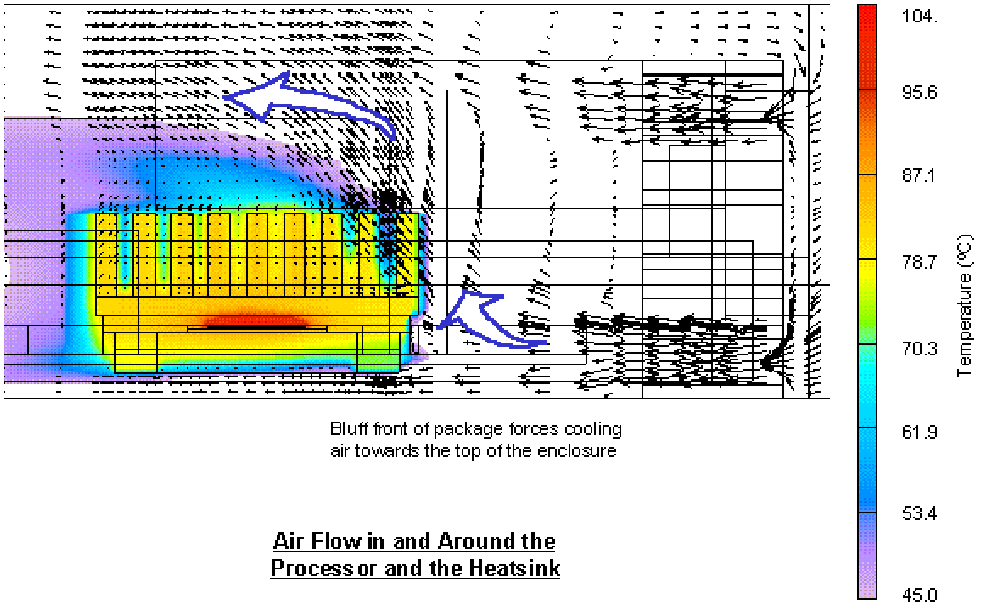


Figure 23 The result of applying a conformal mapping to the jet shown in Figure 3. Th map, due to Everson et al (1990), corrects for the growth of the jet by coverting a wedge int a slot. The downstream decay of the mean concentration has been normalized using similarit considerations. The signal to the right corresponds to the vertical line cut shown in the jet.



Commercial Software – CFD

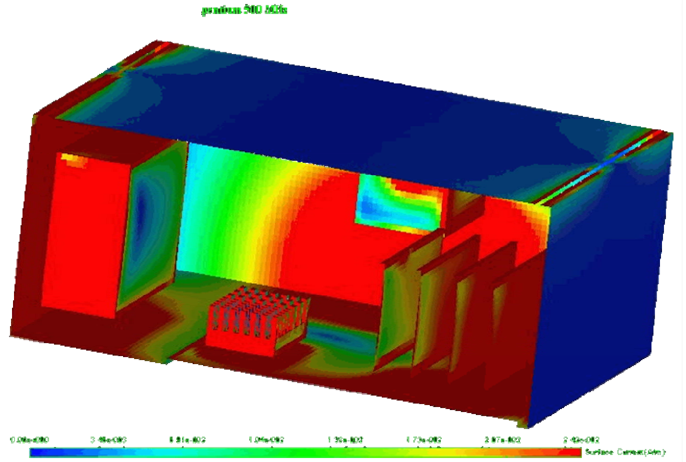
- **Resources at : http://www.cfd-online.com/**
- **FLUENT**
  - http://www.fluent.com/
- **PHOENICS**
  - http://www.cham.co.uk/
- **STAR-CD**
  - http://www.cdadapco.com
- **PHYSICA**
  - http://www.multi-physics.com
- **CFX**
  - http://www.annsys.com/cfx



Air Flow in and Around the
Processor and the Heatsink

Computational Electromagnetics

- **Solution to Maxwells equations**
- **Low Frequency (10-100KHz)**
  - Time dependence importance
- **High Frequency (>1MHz)**
  - Frequency domain
- **Number of methods used**
  - Finite Difference
  - Transmission Line Methods
  - Finite Element Methods



Surface currents
at 482MHz

MHD Equations

- **Assume I have the NS equations, etc then ADD**
- **For example a simple derivative form of the Maxwell's Equations**

$$\nabla \cdot (\sigma \nabla \phi) = \nabla \cdot (\mathbf{u} \times \mathbf{B}) + S_{\phi}$$

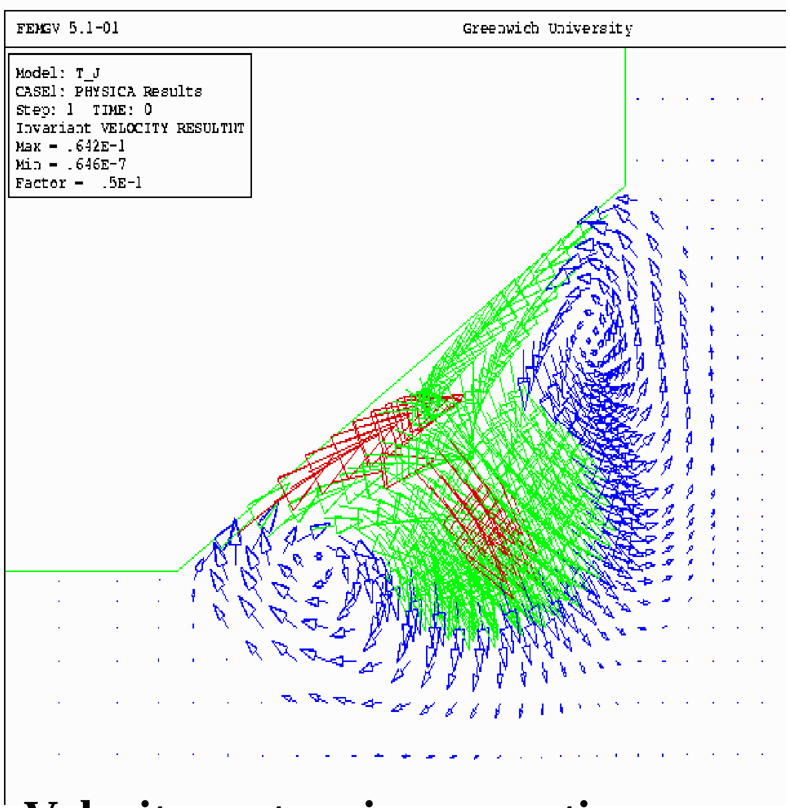
$$\mathbf{E} = -\nabla \phi \text{ and } \boldsymbol{J} = \sigma_e \boldsymbol{E} \,.$$

- **B from the Biot – Savart Law**
  - e.g. B = (m I/4p)   dl x r / |r|3
- **Lorentz force: J x B**

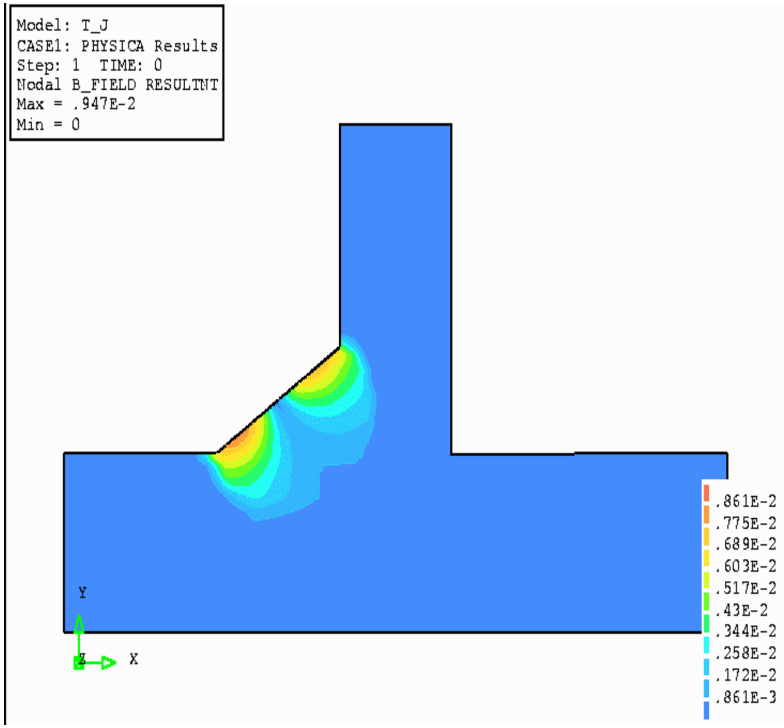
  add to the NS momentum equations
  - Extra source term in heat equation due to magnetic field | J |2 / s

  and include both in the CFD solution loop

Weld Pool Dynamics



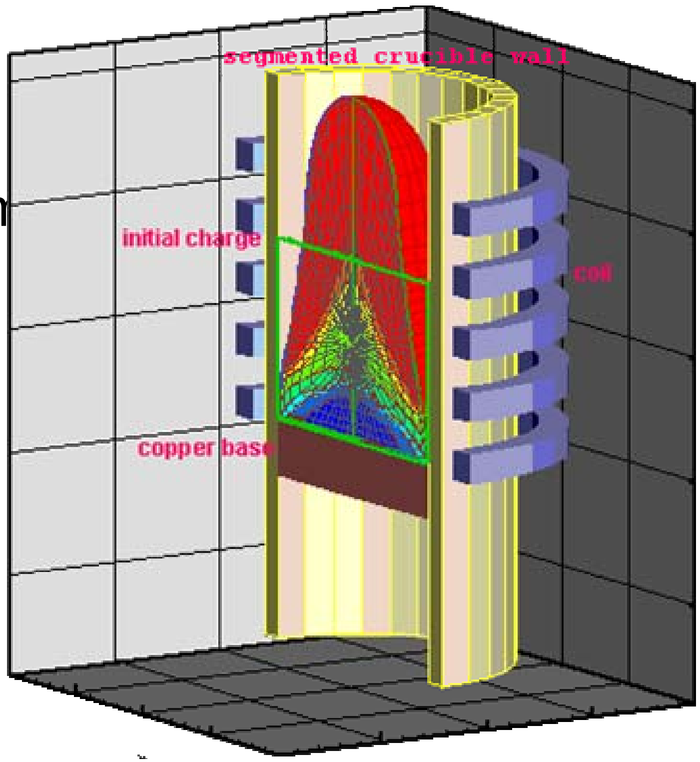
Velocity vectors in crossection



Lorentz force distribution in the weld-pool

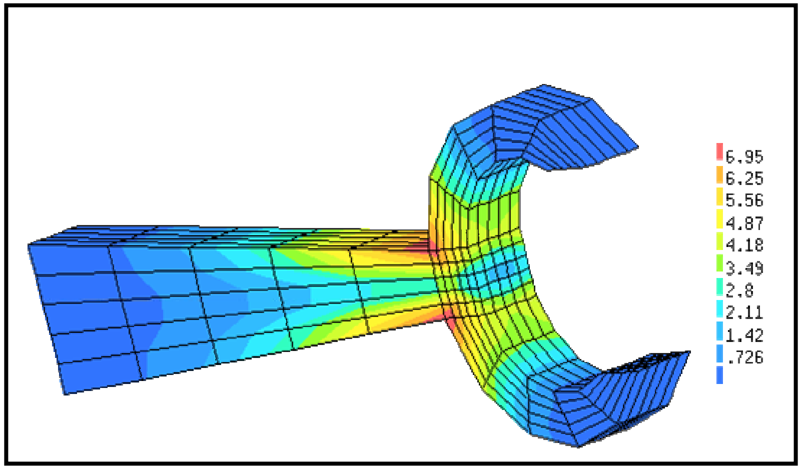
Commercial Software - Electromagnetics

- **General resource : http://emlib.jpl.nasa.gov/**
- **Vector Fields**
  - http://www.vectorfields.com/
- **ANSYS/EMAG**
  - http://www.ansys.com/products/emag.htm
- **Microstripes**
  - http://www.flomerics.com/
  - Close links to Flotherm
- **FLO/EMC**
  - For Electronic enclosures
  - http://www.flomerics.com/



Computational Solid Mechanics

- **Early work : Finite Difference**
  - Simple shapes.
- **Finite Elements introduced in late 50's**
  - Restricted to linear problems
  - Structural elements (beams, Trusses)
- **Continuum elements introduced mid 60's**
- **Plasticity included in early 70's**
- **Finite Volume Methods now also being used (early 90's)**



Solid Mechanics

$$\frac{\partial}{\partial t}\left(\rho \frac{\partial u_i}{\partial t}\right) = \frac{\partial \sigma_{ij}}{\partial x_j}$$

$$\sigma_{ij} = 2\mu\varepsilon_{ij}^{el} + \lambda\varepsilon_{kk}^{el}\delta_{ij}$$

$$\varepsilon_{ij}^{el} = \varepsilon_{ij}^{tot} - \varepsilon_{ij}^{th}$$

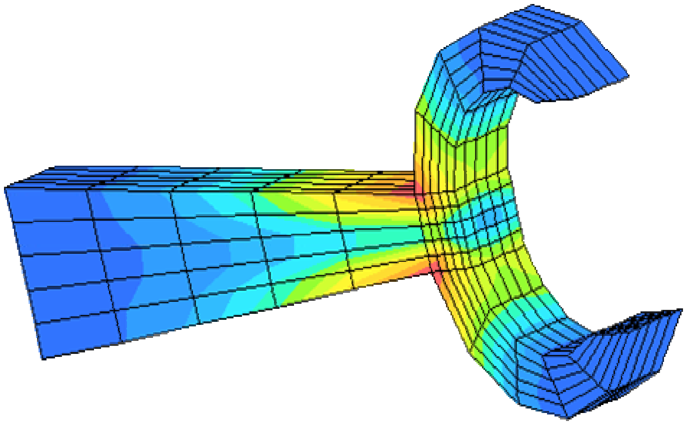
$$\varepsilon_{ij}^{tot} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

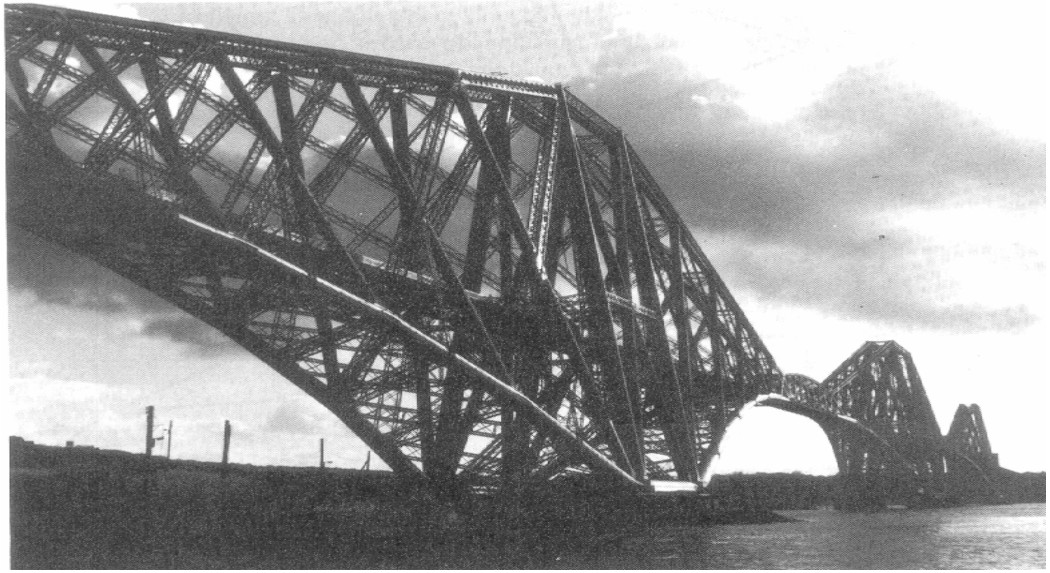
$$\varepsilon_{ij}^{th} = \alpha \Delta T \delta_{ij}$$

Typically

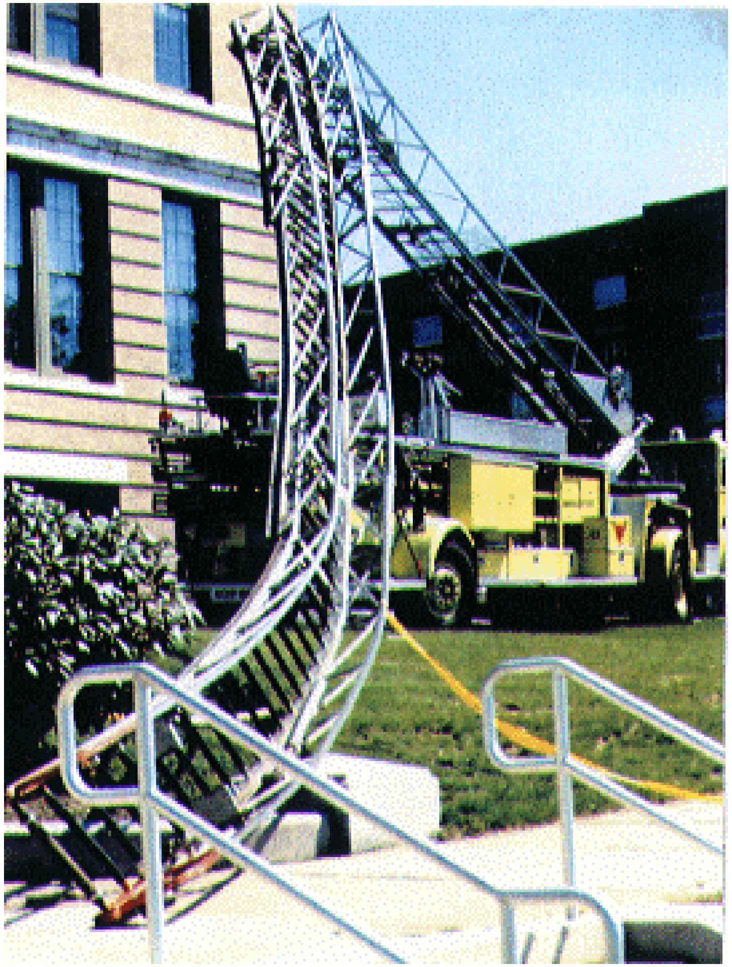
- **Uses the Finite Element Method**
- **Lagrangian Approach (Mesh moves with material)**
- **Elastic material => linear,**
- **Plasticity => some non-linearity**

Stress - Displacement





Fatigue



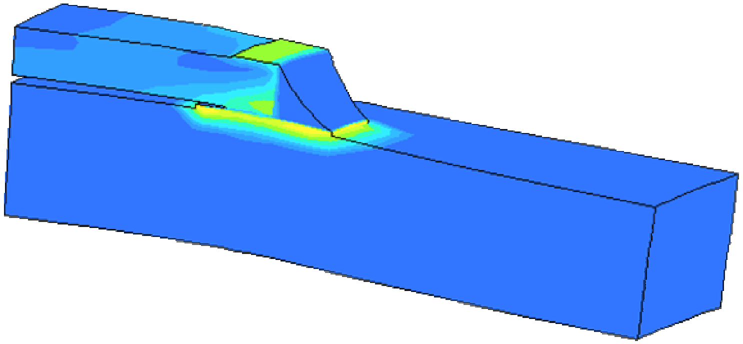
Commercial Software – Stress Analysis

Resources at :

http://www.engr.usask.ca/~macphed/finite/fe_resources/fe_resources.html

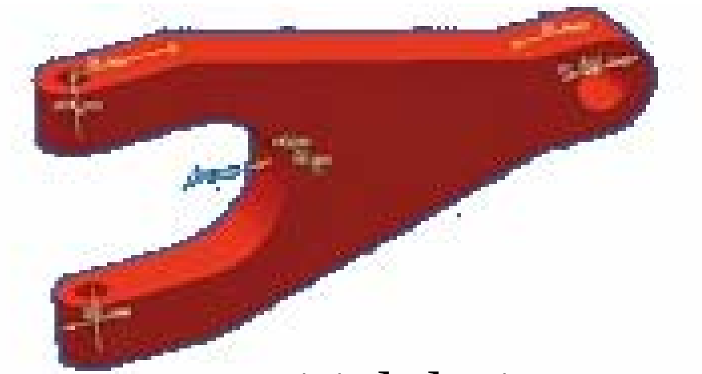
- **ANSYS**
  - http://www.ansys.com/
- **MARC**
  - http://www.marc.com/
- **NASTRAN**
  - http://www.mscsoftware.com/
- **ABAQUS**

  - http://www.abaqus.com

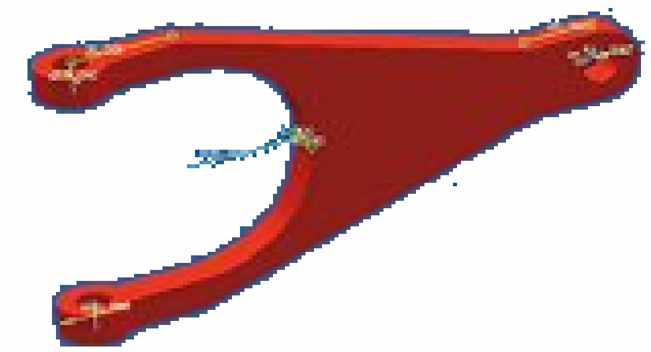


Optimisation

- **Optimisation Techniques**
  - Numerical
  - Design of Experiments (DOE)
- **Numerical**
  - Exact
  - Slow
- **DOE**
  - Approximate
  - Fast



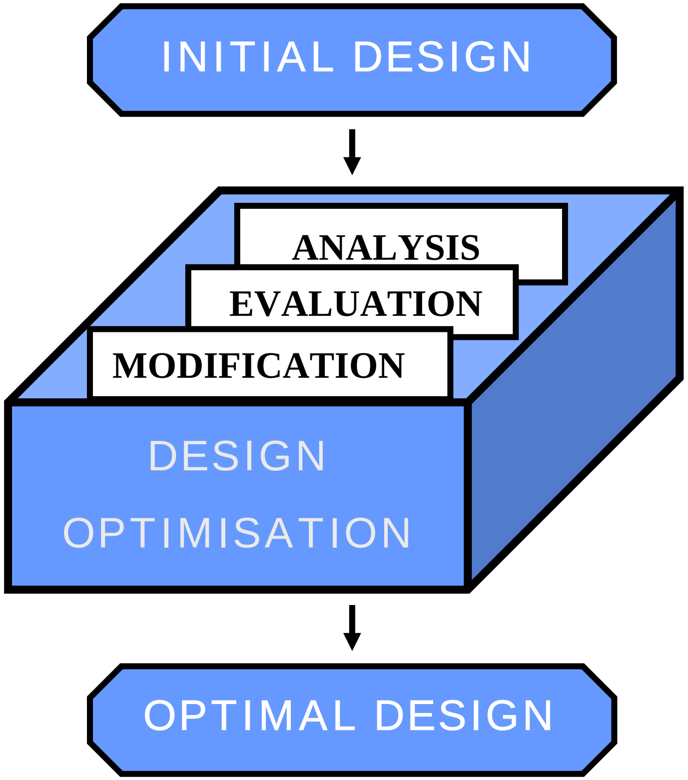
Initial design



Final design

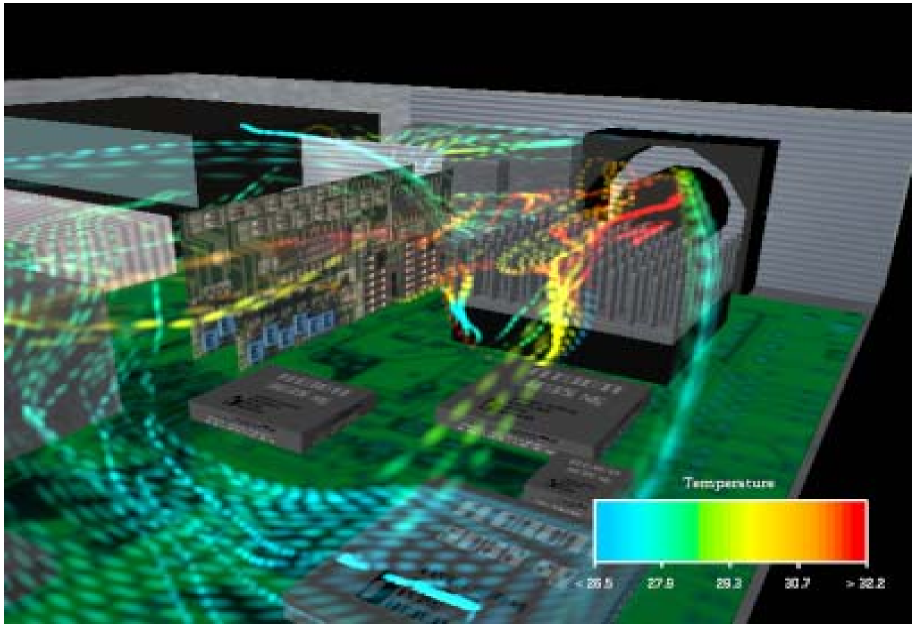
Optimisation Tools

- **http://optimal.hypermart.net/OPTM00.htm**
- **Optimisation Tool (DOT)**
  - VanderPlatts
  - VisualDoc (Graphical version)
  - Flexible software
  - Links to Analysis codes
  - http://www.vrand.com/
- **OptiStruct**
  - Altair Engineering
  - http://www.altair.com/
  - Structural Optimisation
- **Most major CAE tools have their own optimisation modules (e.g. ANSYS)**



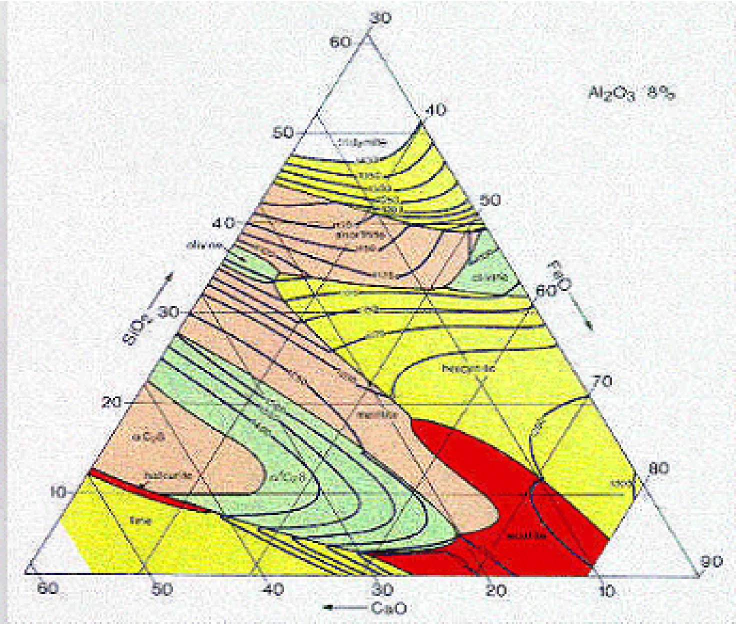
Visualisation Software

- Resource http://www.roe.ac.uk/~acd/vissys/
- Note that all analysis codes will have some visualisation capabilities.
- Leading-edge visualisation codes:
  - Wavefront
    - http://www.aliaswavefront.com/
  - AVS
    - http://www.avs.com/
  - Ensight
    - http://www.ceintl.com/



Thermodynamics Software

- **Computational Thermodynamics + Databases**
- **Chemical and Phase equilibrium**
- **Function of composition and process conditions**
- **Can link to Macro-Models**
  - i.e solidification



Software

- **MTDATA**
  - http://www.npl.co.uk/npl/cmmt/mtdata/mtdata.html
- **Thermo-Calc**
  - http://www.thermocalc.se

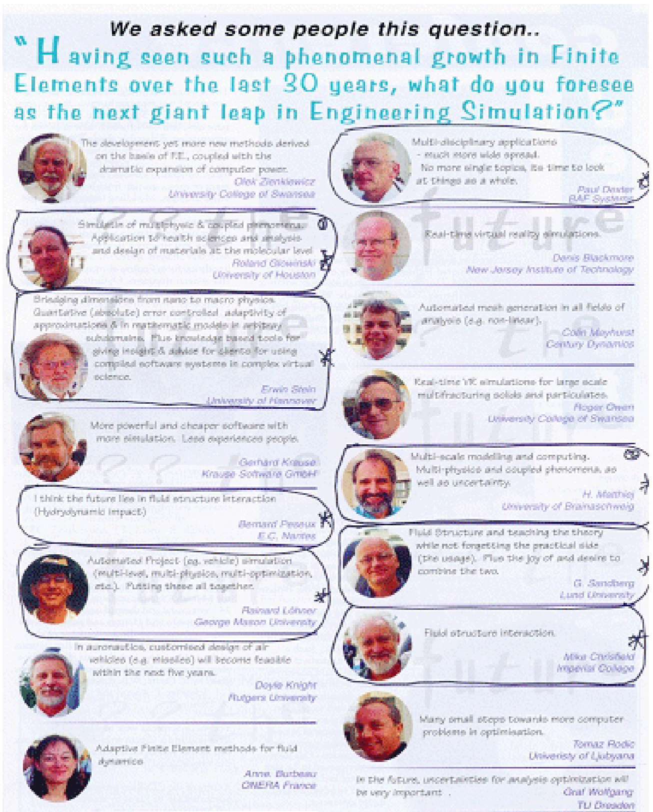
Multi-Physics and Multi-scale Modelling

Story So Far

- **Computational Fluid Dynamics (CFD)**
- **Finite Elements – Computational Solid Mechanics (CSM)**
- **Electro-Magnetics + Magneto-Hydro-Dynamics**
- **Each subject solves its own set of equations for the quantities of interest (e.g. velocity, stress, current).**
- **Some cross over in the quantities solved for (e.g. temperature)**

We asked some people this question..

"Having seen such a phenomenal growth in Finite Elements over the last 30 years, what do you foresee as the next giant leap in Engineering Simulation?"


We asked some people this question..

"Having seen such a phenomenal growth in Finite Elements over the last 30 years, what do you foresee as the next giant leap in Engineering Simulation?"

The development yet more new methods derived on the basis of F.E., coupled with the dramatic expansion of computer power.
Olek Zienkiewicz, University College of Swansea

Simulatin of multiphysic & coupled phenomena. Application to health sciences and analysis and design of materials at the molecular level
Roland Glowinski, University of Houston

Bridging dimensions from nano to macro physics. Quantative (absolute) error controlled adaptivity of approximations & in mathematic models in arbitrary subdomains. Plus knowledge based tools for giving insight & advice for clients for using compiled software systems in complex virtual science.
Erwin Stein, University of Hannover

More powerful and cheaper software with more simulation. Less experienced people.
Gerhard Krause, Krause Software GmbH

I think the future lies in fluid structure interaction (Hydrydynamic impact)
Bernard Peseux, E.C. Nantes

Automated Project (eg. vehicle) simulation (multi-level, multi-physics, multi-optimization, etc.). Putting these all together.
Rainard Löhner, George Mason University

In auronautics, customised design of air vehicles (e.g. missiles) will become feasible within the next five years.
Doyle Knight, Rutgers University

Adaptive Finite Element methods for fluid dynamics
Anne. Burbeau, ONERA France

Multi-disciplinary applications - much more wide spread. No more single topics, its time to look at things as a whole.
Paul Dexter, BAE Systems

Real-time virtual reality simulations.
Denis Blackmore, New Jersey Institute of Technology

Automated mesh generation in all fields of analysis (e.g. non-linear).
Colin Mayhurst, Century Dynamics

Real-time VR simulations for large scale multifracturing solids and particulates.
Roger Owen, University College of Swansea

Multi-scale modelling and computing. Multi-physics and coupled phenomena, as well as uncertainty.
H. Matthiej, University of Brainaschweig

Fluid Structure and teaching the theory while not forgetting the practical side (the usage). Plus the joy of and desire to combine the two.
G. Sandberg, Lund University

Fluid structure interaction.
Mike Chrisfield, Imperial College

Many small steps towards more computer problems in optimisation.
Tomaz Rodic, University of Ljubyana

In the future, uncertainties for analysis optimization will be very important .
Graf Wolfgang, TU Dresden

Simulatin of multiphysic & coupled phenomena.
Application to health sciences and analysis and design of materials at the molecular level
Roland Glowinski
University of Houston

Multi-scale modelling and computing.
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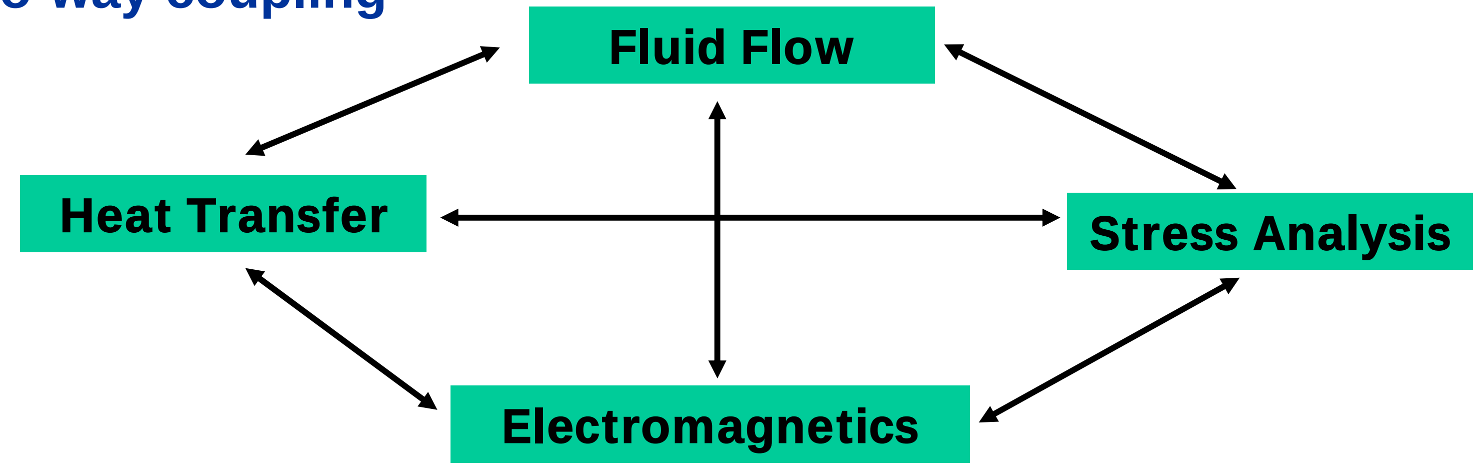
Mike Chrisfield
Imperial College

Multi-disciplinary applications - much more wide spread.
No more single topics, its time to look at things as a whole.
Paul Dext
BAF Systen

Why Multi-physics Modelling ?

- Large number of real world problems require multiphysics simulation tools.
- Examples
  - Solidification problems – Solder Joints
  - Fluid-Structure interaction – Flutter in aircraft wings
- Need to solve for integrated physics
- Ensure two-way coupling



Multi-physics Modelling

Current modelling technology mainly focused on distinct physics

- CFD (Fluid Flow)
- CSM (Stress)
- CEM (Electromagnetics)

Multi-physics modelling

- Interface codes together: CFX - ANSYS.
- Single modelling frameworks evolving.

Discretisation + Solution Procedure ?

CAE analysis tools market history

FEA started mid 60's with

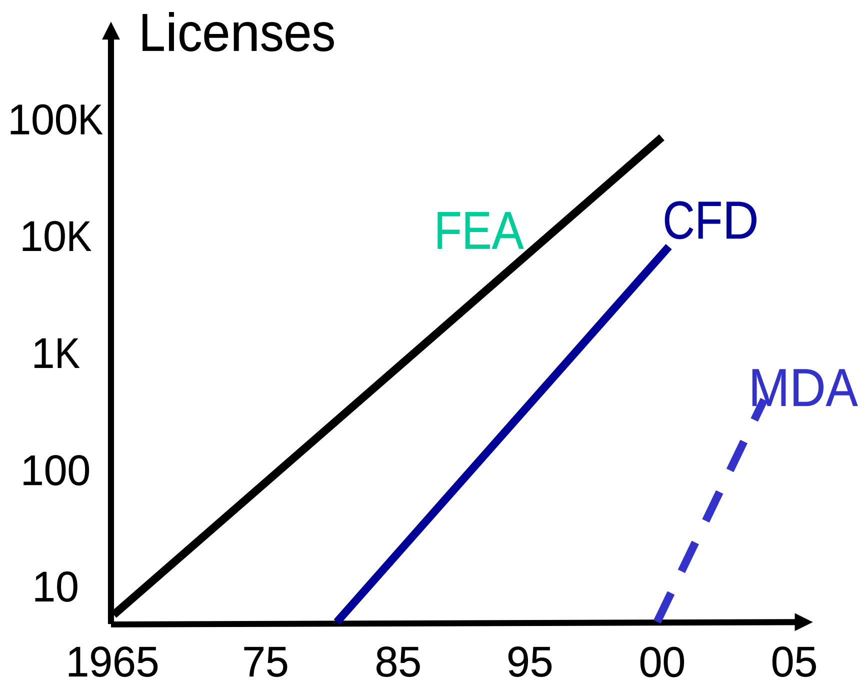
- NASTRAN, Abaqus, ANSYS, etc as major players

CFD started 1980 with

- FLUENT,CFX, PHOENICS & STAR-CD major players

MDA started mid 1990's

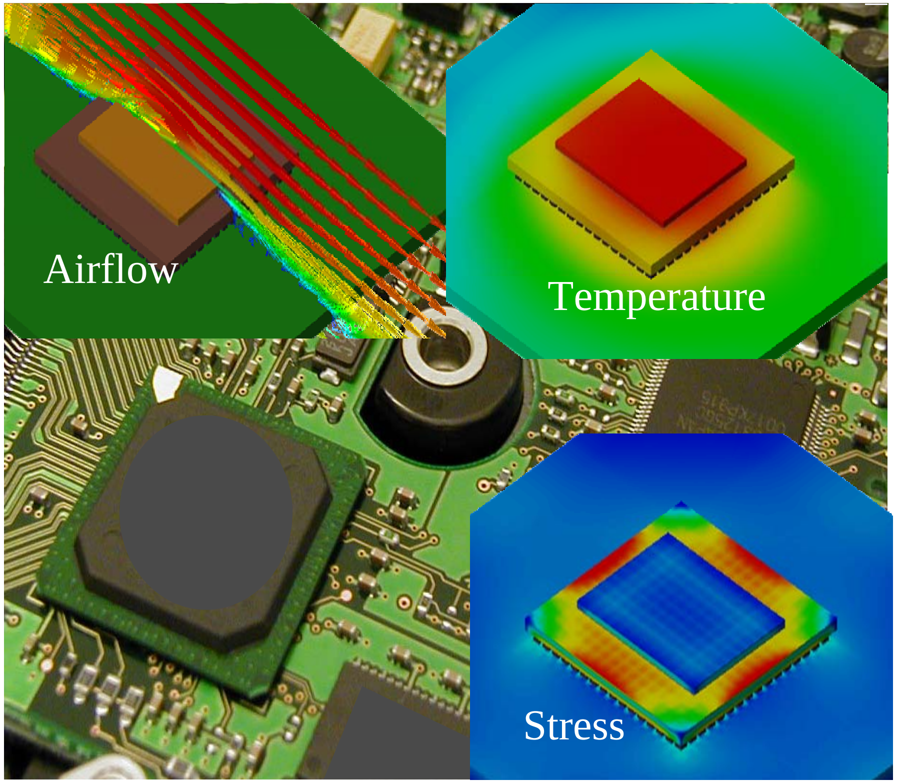
- Coupling codes
- MDICE, mpCCI, Spectrum, PHYSICA



Commercial Software – Multi-physics

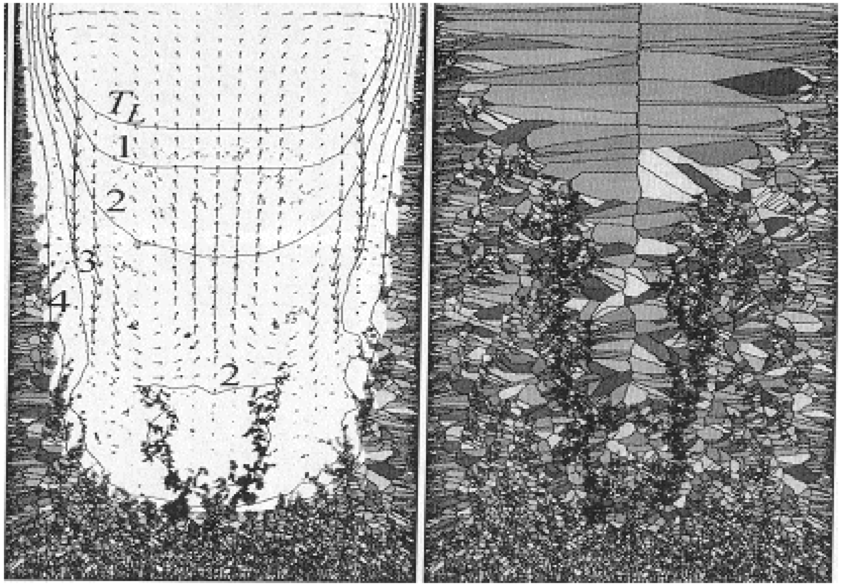
Number of products claiming to be multi-physics:

- **ANSYS/Multi-physics**
  - http://www.ansys.com/
- **PHYSICA**
  - http://www.multi-physics.com/
- **FEMLAB**
  - http://www.femlab.com/
- **ADINA**
  - http://www.adina.com/
- **AUTODYN, etc**
  - http://www.centdyn.com/
- **RADIOSS**
  - http://www.radioss.com/
- **DYTRAN**
  - http://www.mscsoftware.com/
- **Algor**
  - http://www.algor.com/



Why Multi-scale Modelling?

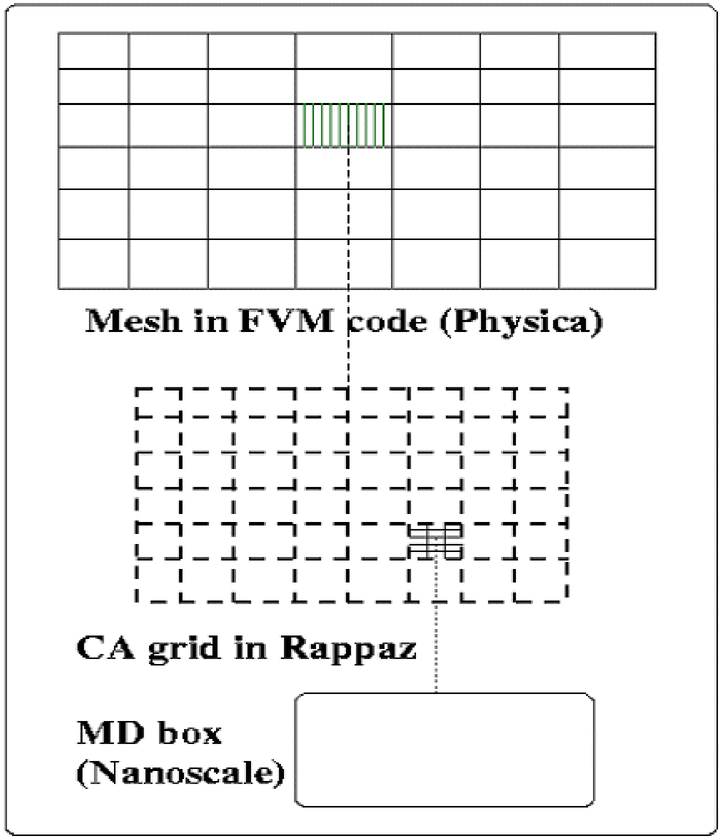
- **Material performance will be governed by its microstructure**
- **Nucleation and grain growth dependent on process conditions (Temperature, etc)**
- **Need to couple Macro – Micro codes**

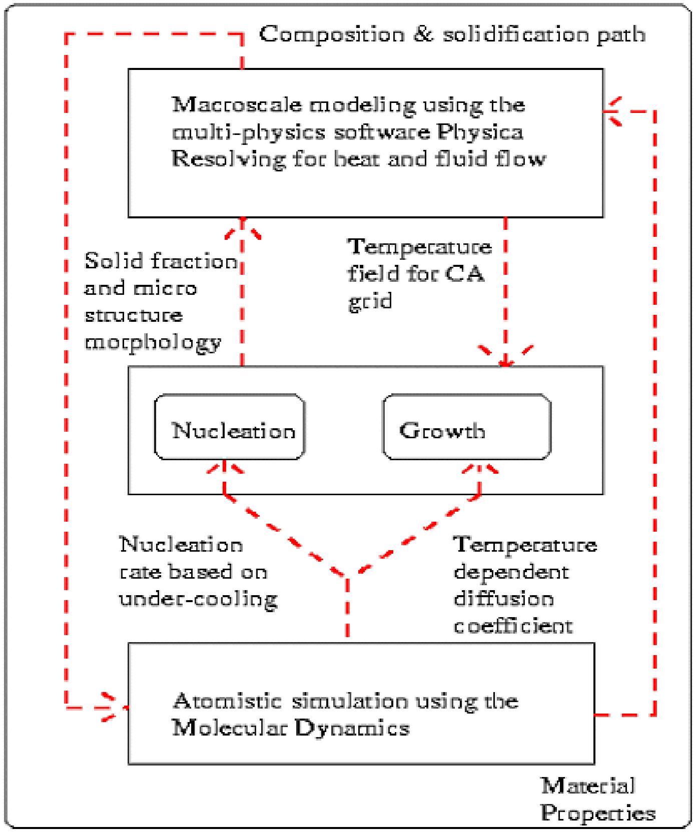


Micro-Macro Simulation

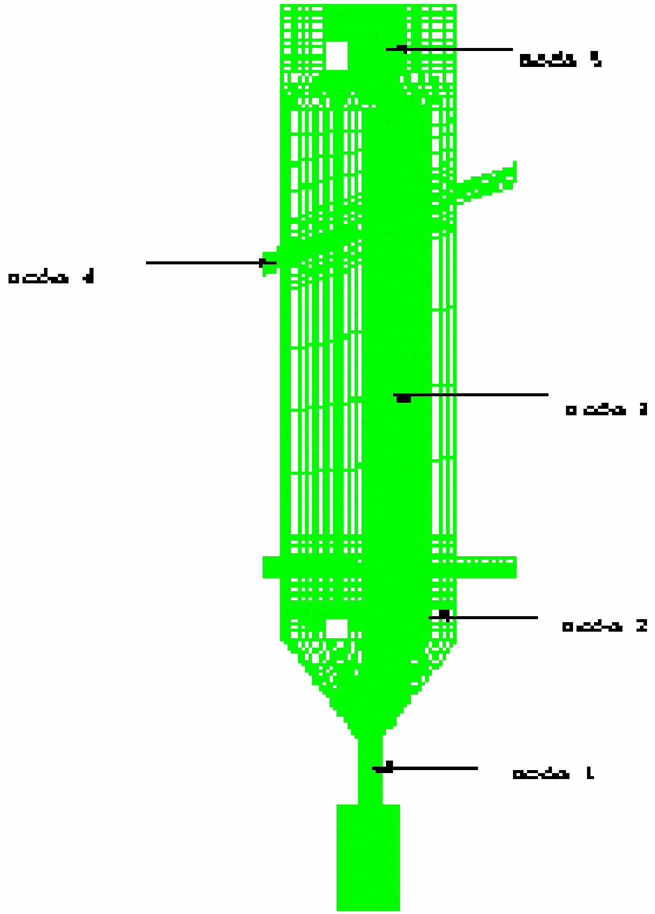
(From Ch.-A Gandin et-al, MCWASP VIII, Pub TMS (1998)

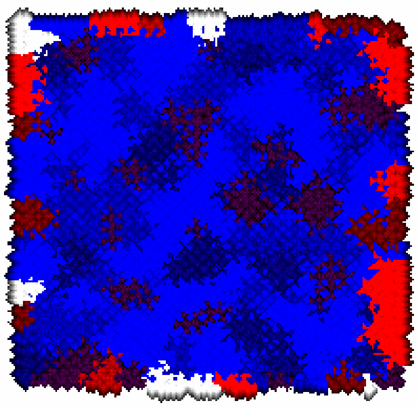
Macro – Structure including Nano Modelling

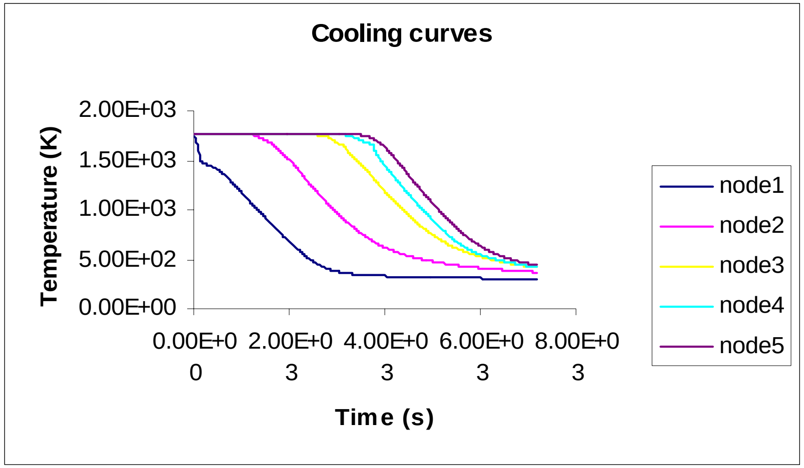




Macro – Structure including Nano Modelling







Definition of Multi-physics Modelling

- **Ask any software vendor to define what a multi-physics code is able to do:**
- **Ask any software vendor to define what a multi-physics code is able to do:**

And most will describe their code

Multi-physics modelling – a definition

- **Definition of a multi phenomena problem:**
  - ***A problem that requires the solution of two or more variables whose evolution is described by different classes of equations.***
- **For the problem to require** *multi-physics* **modelling there must be two way coupling between the constituent physics.**
- **If there is only one way coupling then the problem is** *multi-disciplinary***.**

Solution of Multi-physics Problems

- **Two alternative approaches for a coupled problem, e.g. fluids and structures:**
- **Two codes**
  - e.g. Ansys (CSM) and CFX (CFD)
  - linked through mpCCI

Versus

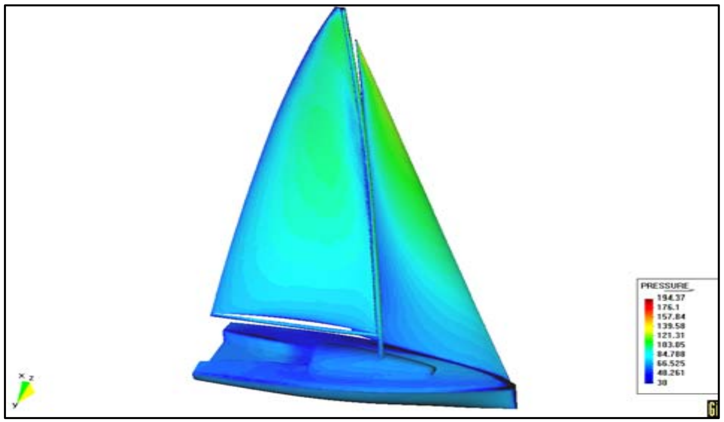
- **Single code**
  - e.g. PHYSICA

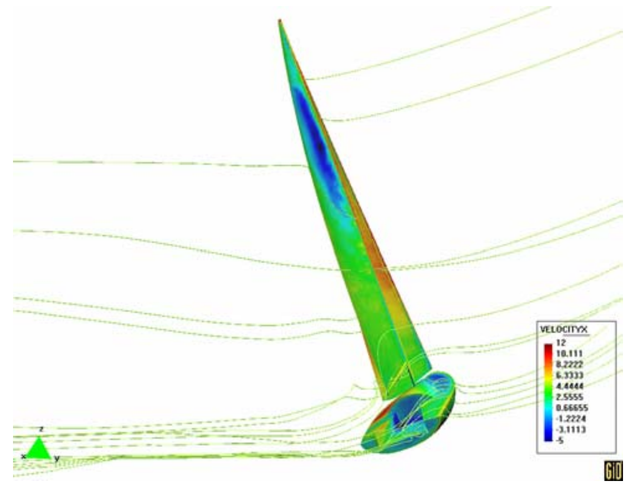
Issues in Multi-physics Modelling

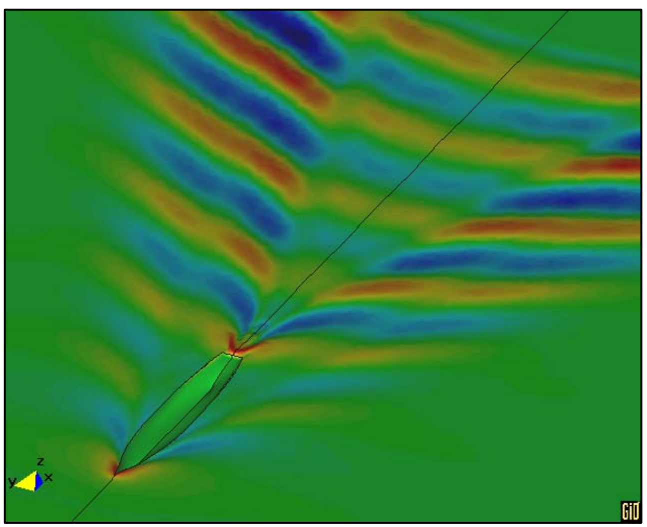
- **Levels of coupling between constituent physics**
  - How do variables influence each other.
  - How often do variables have to be updated
- **Interpolation of values between solvers**
  - Accuracy
  - Consistency

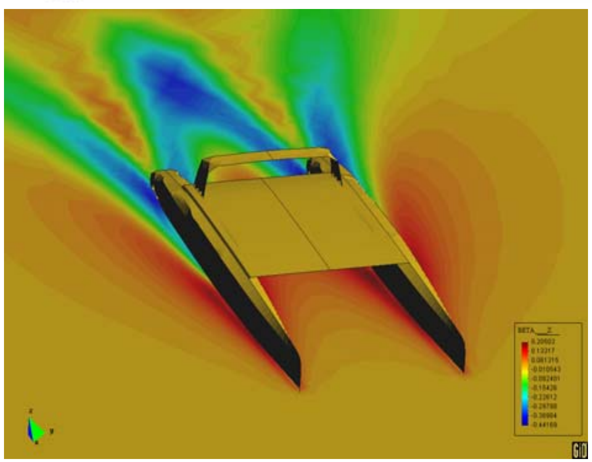
Tacoma Narrows Bridge
- serious dynamic fluid structure interaction

Sail Boat – more DFSI

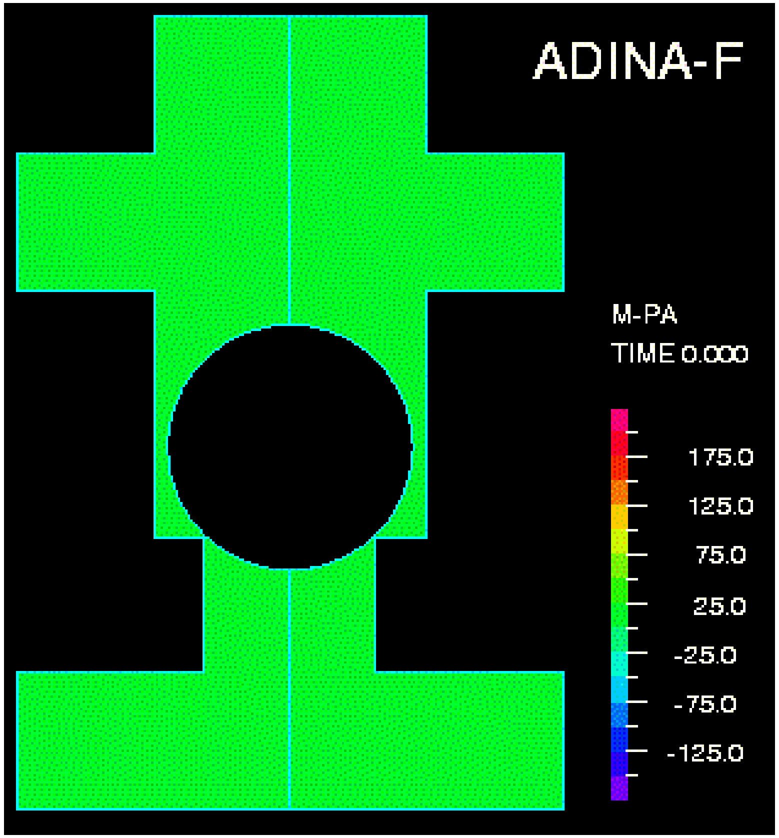




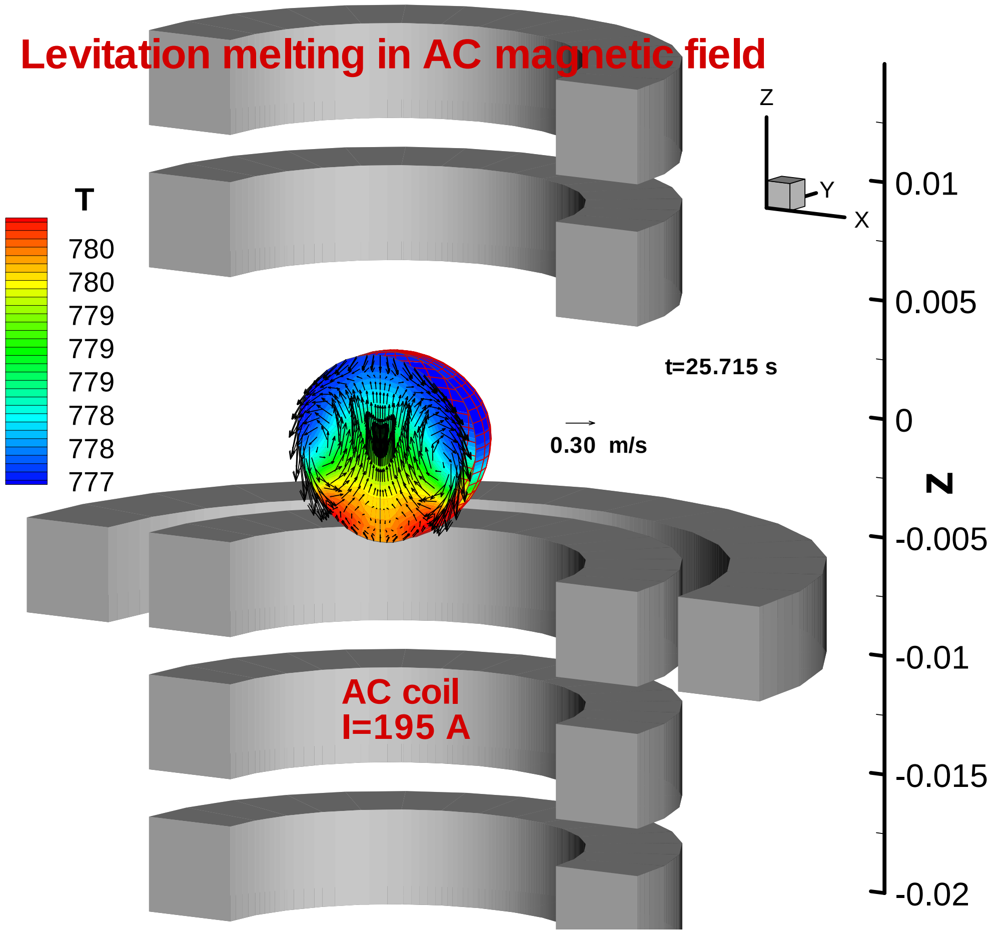




Anti-Locking Brakes



Magnetic Levitation



Parallel Multi-Physics Modelling

Multi-physics simulations : compute issues

- Genuine multi-physics has many key interactions
- Macro-defects predicted as a function of these interactions
- Simulation time on Compaq Alpha can be horrendous- measured in weeks, for a problem with only 75K nodes - not practical!!!
- Conclusion - can do multi-physics casting, etc simulation, but compute demand is extensive

Multi-physics compute demands:

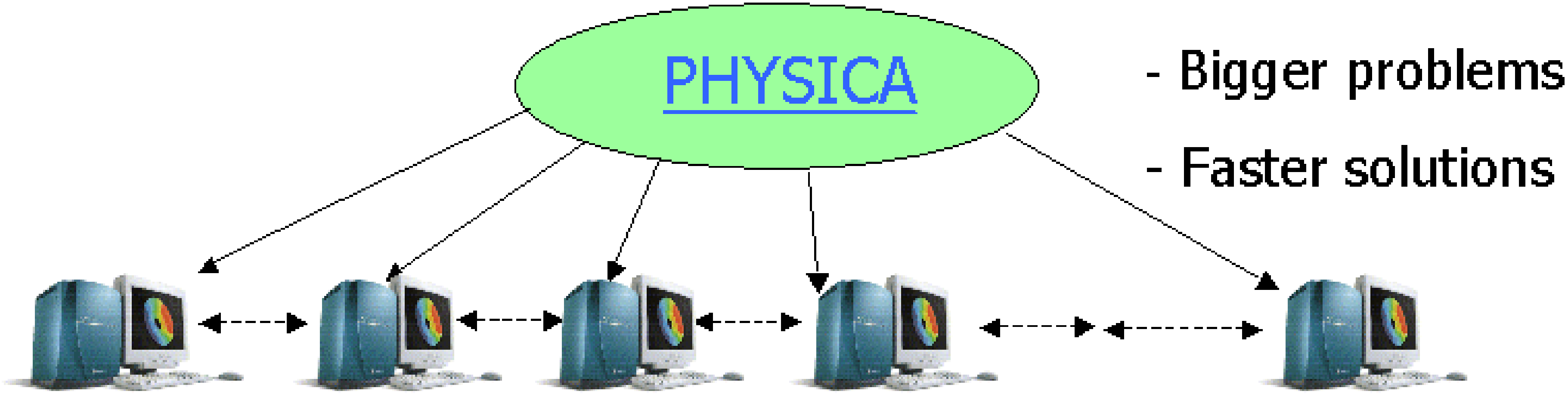
- **Unstructured Mesh analysis = 3* Structured mesh analysis**

- **Performance on a Compaq alpha 466Mhz**
  - Seconds per node or element per time step per problem class
    - Heat Transfer (HT) + Solidification (Sol) = 2. 10-3
    - Fluid Flow (FF) + HT + Sol = 6.10-3
    - HT + Sol + Stress = .09/ .55
    - FF + HT + Sol + Stress = .14
- **Casting simulation with 100K nodes, and 100 time steps is in excess of 300hours!**
- **Need simulation times that are 10-20x faster**

- **PARALLEL – WITH CHANGING PHYSICS**

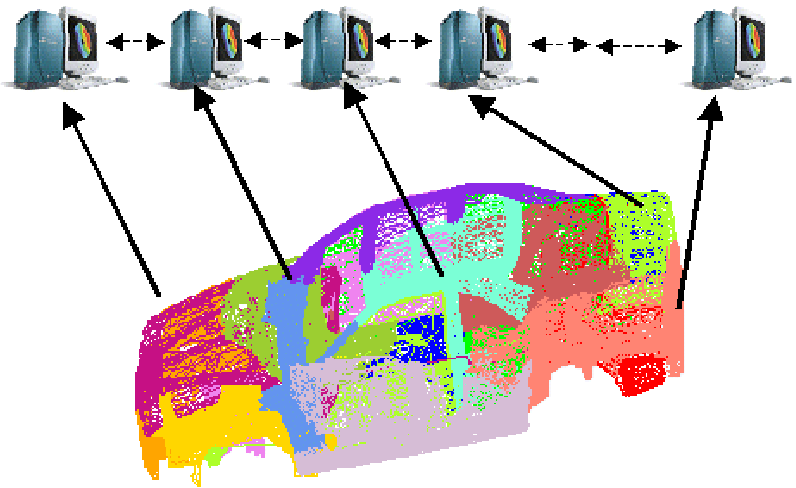
Parallel Strategy

- Single Program Multiple Data (SPMD)
- Program resident on each processor
- Mesh Partitioned across processors.
- Minimise communication times.



Mesh Partitioning - JOSTLE

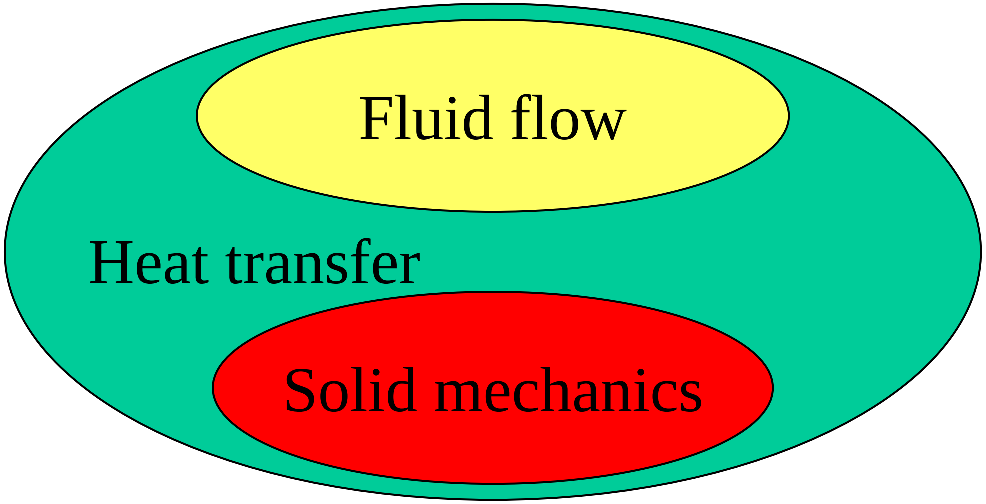
- **Partition of 3D unstructured mesh by JOSTLE assuming a non- homogeneous load balance across the mesh:**
- **SPMD Strategy**
  - load balanced (even distribution per processor)
  - attempts to minimises sub-domain interface elements
  - sub-domain connectivity matches processor topology of the parallel system



http://www.gre.ac.uk/~jostle/

Multi-physics Simulation parallel issues

- **Sub-domains have specific physics so partition must reflect this:**
  - non-uniform load/node
- **Distinct physics uses distinct discretisation procedures:**
  - secondary partitions
- **Also, sub-domains may change as problem develops:**
  - dynamic load balance



- **Strategy needs to address all the above issues**

Multi-physics Modelling

Physics Requirements

- Fluid Flow
- Solidification
- Stress
- Electromagnetics

→ MULTI-PHYSICS

Geometry

- Complex

→ UNSTRUCTURED MESHING

Large simulations

→ PARALLEL

Single Software Framework

- **Key route to closely coupled multi-disciplinary (multi-physics) simulation**
- **Basic requirements of a SSF:**
  - consistency of mesh for all phenomena
  - compatibility in the solution approaches to each of the phenomena
  - single database & memory map so that no data transfer & efficient memory use between programs
  - facility to enable accurate exchange of boundary or volume sources (e.g. body force)

PHYSICA – Multi-physics Framework

- **Begun in 1988 at University of Greenwich**
- **Used FV methods on unstructured mesh (FV-UM) using either cell centred or vertex based discretisation approaches**
- **Phenomena addressed:**
  - Fluid Flow – turbulent, free surface, multi-component
  - Electro-magnetics
  - Heat transfer with phase change & chemical reactions
  - Solid mechanics, linear, non-linear and dynamic (also in FE!)
- **Prototypes moved from 2D to 3D and from scalar to parallel**
- **Key issue was to ensure FLOW worked well in all contexts**
- **Solidification processes was originally a key target**

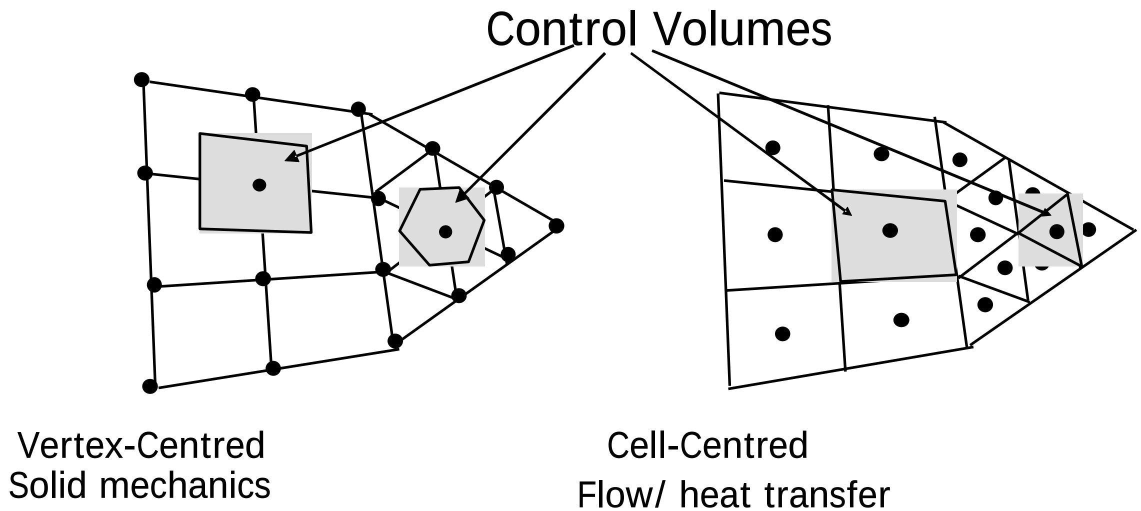
PHYSICA :

Design of a FV-UM multi-physics modelling software tool

- **Framework for the solution of any coupled set of PDEs up to second order**
- **Design concept - object oriented with reusable software modules in FORTRAN77**
- **Multi-level toolkit :**
  - focus at high level for model implementation
  - maximise control over numerical issues
  - essentially **open source**
- **Conceived and implemented in parallel**

PHYSICA – a SSF for multi-physics simulation

•Uses finite volume or element procedures on unstructured mesh



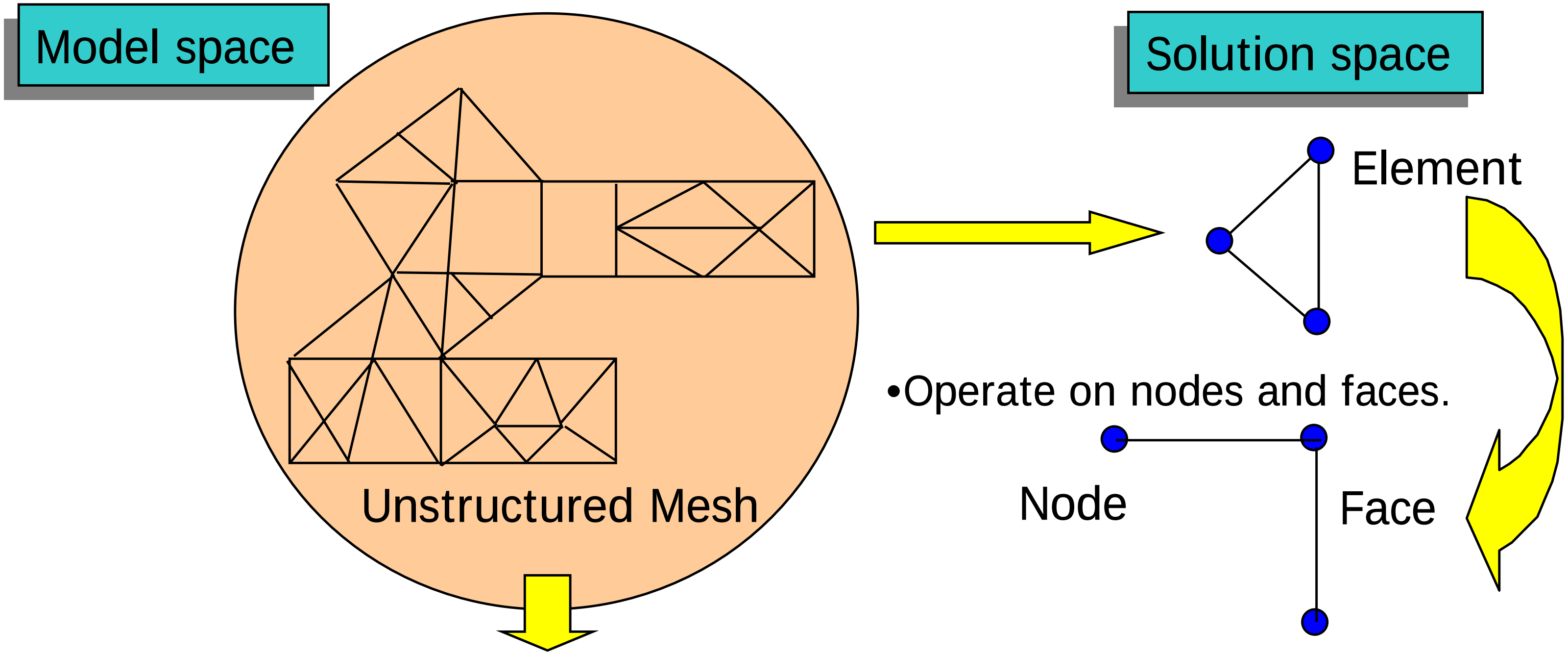
Implemented in 3D in PHYSICA

PhD's on FV-UM techniques and tools in PHYSICA

- Chow (93) FV-UM CFD procedures in 2D
- Fryer (93) FV-UM CSM procedures in 2D
- Chan (94) FV SEA procedure in 3D - free surfaces
- Hughes (94) FV-UM for MHD in 2/3D using PHOENICS
- Taylor (96) FV-UM material nonlinear CSM procedures in 3D
- McManus (96) Parallel multi-physics algorithms in 2D & 3D
- Croft (98) FV-UM CFD procedures in 3D turbulence/particle tracking/reactions
- Wheeler (00) FV-UM 3D free surfaces with surface tension and using level set
- Slone(00) FV-UM dynamic fluid-structure interaction in 3D
- Chirazi (00) FV-UM multi-scale ala Rappaz
- Fallah (01) FV-UM CSM - large strain elasticity & cell centred approximations
- Edussriya (03) FV-UM non-Newtonian free surface 3D fluids
- McBride (03) FV-UM Vertex based and hybrid CFD procedures in 3D
- Stoyanov (04) FV-UM multi-physics with optimisation

Object based design

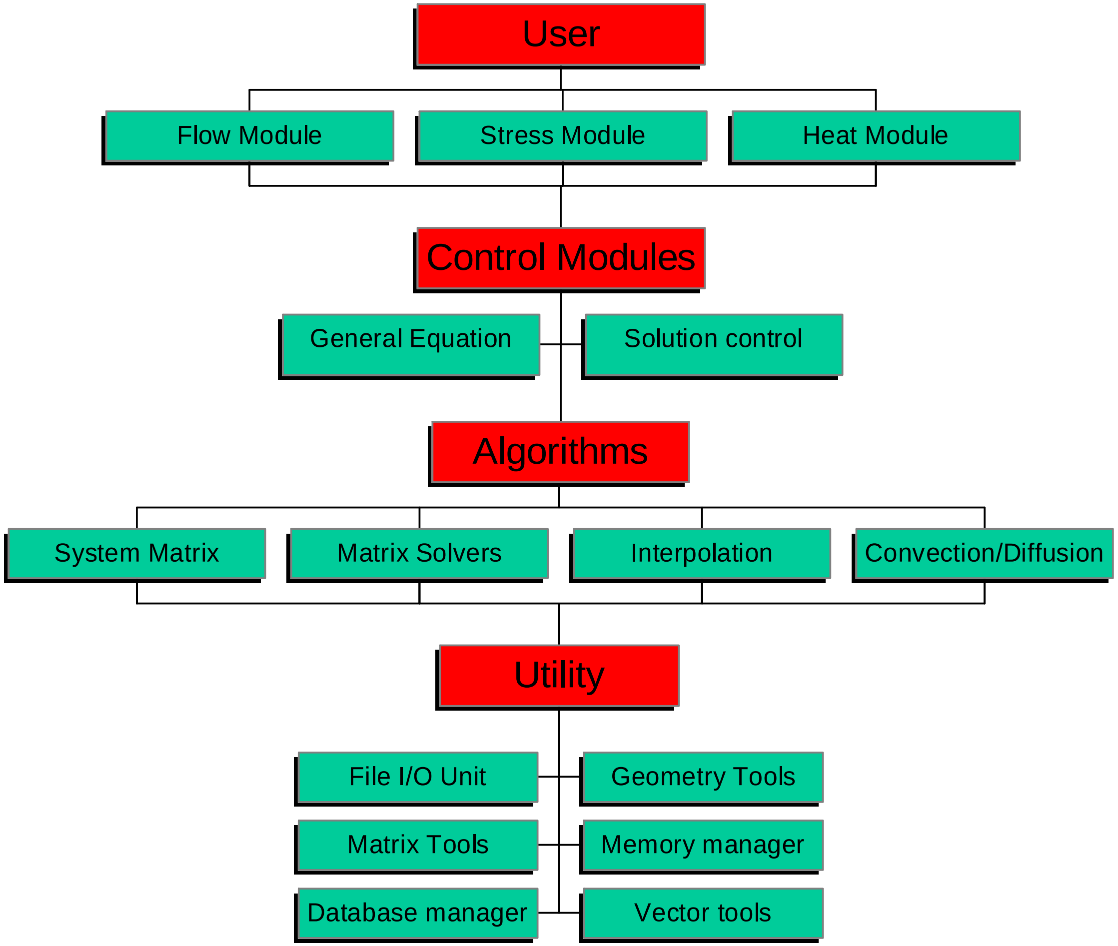
- Algorithms are built on methods for “Objects”.



•Operate on nodes and faces.

•Traditional approach is to use routines that perform a large number of operations on an element.

Levels of code abstraction



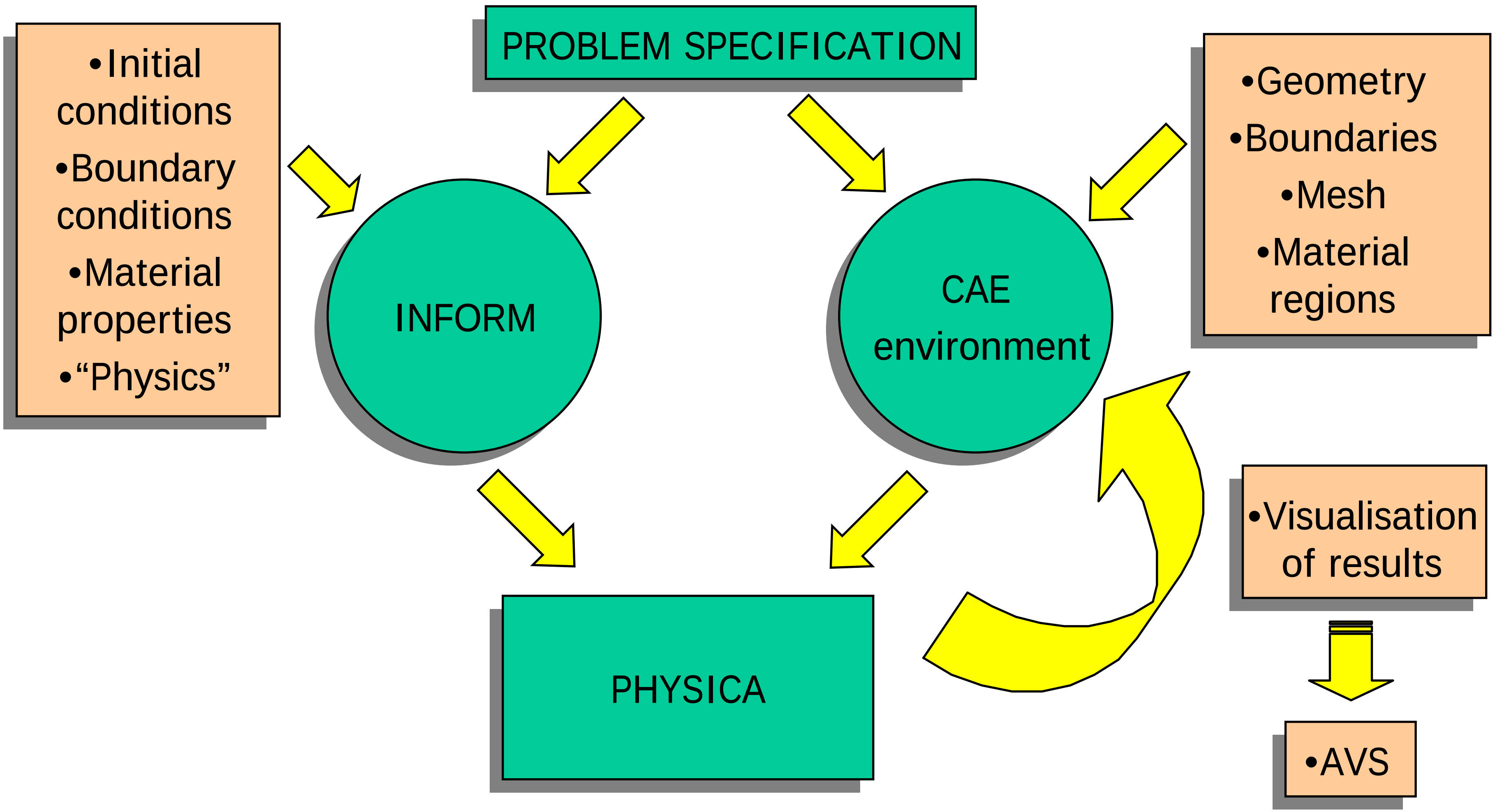
User can access user, control and algorithmic levels.

Governing Equations

- The governing equations can be expressed in a standard form:

$$\frac{\partial}{\partial t}(\rho A \phi) + \nabla . Q = \nabla . (\Gamma \nabla \phi) + S$$

	ϕ	A	Γ_ϕ	S	Q
Continuity	1	1	0	S_{mass}	$\rho \underline{v}$
Momentum	$\underline{v}$	1	Γ_v	$(S + \underline{J} x \underline{B} - \nabla P)$	$\rho \underline{v.v}$
Heat transfer	h	1	k/c	S_h	$\rho \underline{v} h$
Electromagnetism	$\underline{B}$	1	η	$(\underline{B}\nabla)\underline{v}$	$\underline{u.B}$
Solid Mechanics	$\underline{u}$	$\partial / \partial t$	μ	$\rho \underline{f}_b$	$\mu(grad\ \underline{u})^T + \lambda(div\,\underline{u} - (2\mu + 3\lambda)\alpha T)\underline{I}$



PROBLEM SPECIFICATION
•Initial conditions
•Boundary conditions
•Material properties
•“Physics”
INFORM
CAE environment
•Geometry
•Boundaries
•Mesh
•Material regions
PHYSICA
•Visualisation of results
•AVS

PHYSICA+

- PHYSICA+ = PHYSICA + Femgv
- Femgv is a pre and post processor
- PHYSICA is a modelling framework that can solve CFD, CSM and coupled problems.
- PHYSICA developed at Greenwich specifically to solve classes of multi-physics problems.

Course Presenters

Dr Avril Slone

- BSc (Maths) PhD (Multi-Physics)
- Senior Research Fellow, University of Greenwich
- Core development team for PHYSICA
- In another life mother of two grown up children & a Chartered Statistician.

Prof Mark Cross

- BSc (Maths) PhD (Math Physics) DSc (Comp Engg)
- Professor and Director of Centre for Numerical Modelling and Process Analysis, University of Greenwich
- Worked on Multi-Physics since inception of subject
- In another life father of 3 grown up kids and Pro Vice Chancellor for Research at Greenwich