Why to Study Finite Element Analysis!

That is, “Why to take 2.092/3”

Klaus-Jürgen Bathe

Why You Need to Study Finite Element Analysis!

Klaus-Jürgen Bathe

Analysis is the key to effective design

We perform analysis for:

- deformations and internal forces/stresses
- temperatures and heat transfer in solids
- fluid flows (with or without heat transfer)
- conjugate heat transfer (between solids and fluids)
- etc...

An **effective design** is one that:

- **performs the required task efficiently**
- **is inexpensive in materials used**
- **is safe under extreme operating conditions**
- **can be manufactured inexpensively**
- **is pleasing/attractive to the eye**
- **etc...**

Analysis means probing into, modeling, **simulating nature**

Therefore, analysis gives us insight into the world we live in, and this

Enriches Our life

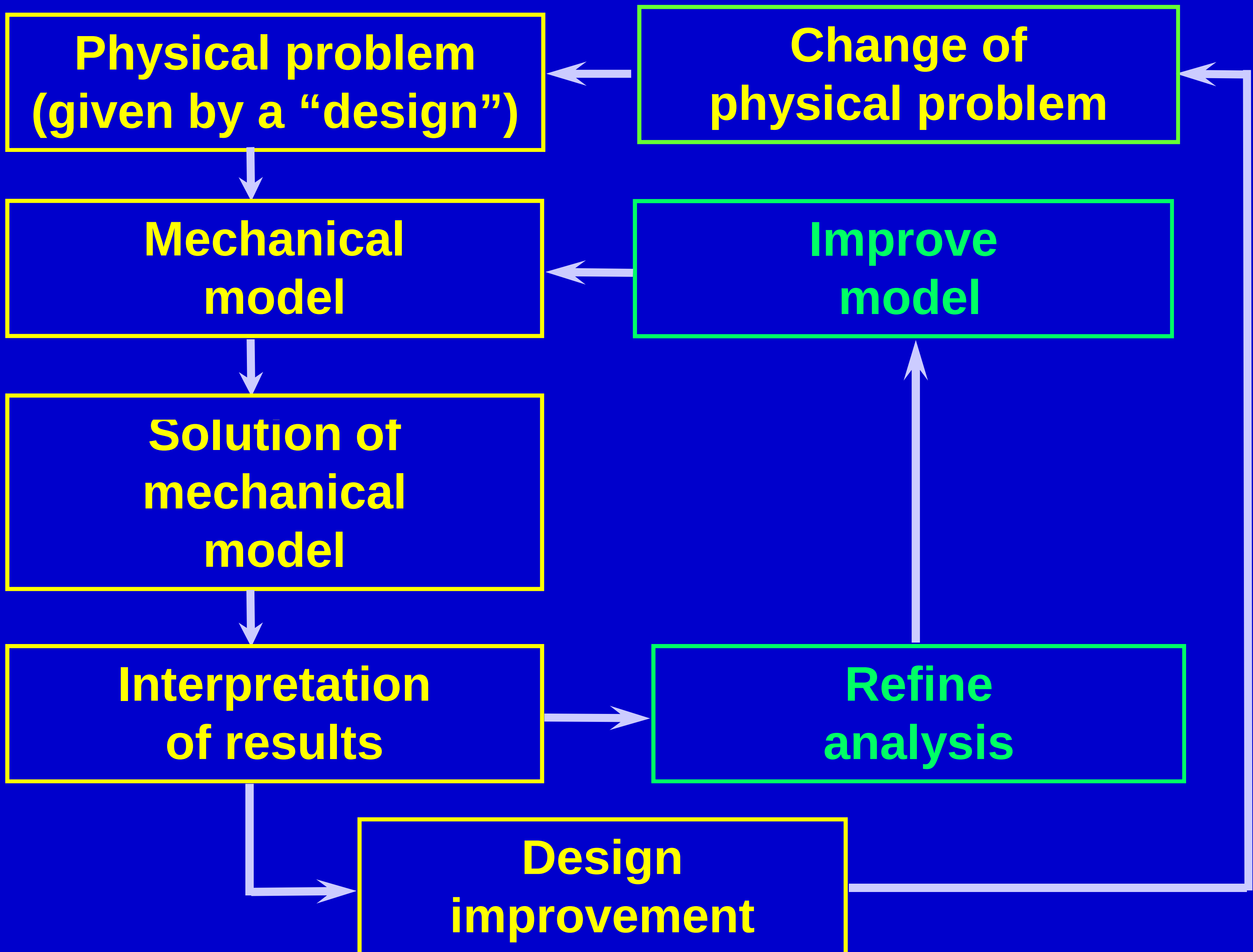
Many great philosophers were analysts and engineers …

Analysis is performed based upon the laws of **mechanics**

Mechanics

- Solid/structural mechanics (Solid/structural dynamics)
- Fluid mechanics (Fluid dynamics)
- Thermo-mechanics (Thermo-dynamics)

The process of analysis



Analysis of helmet subjected to impact

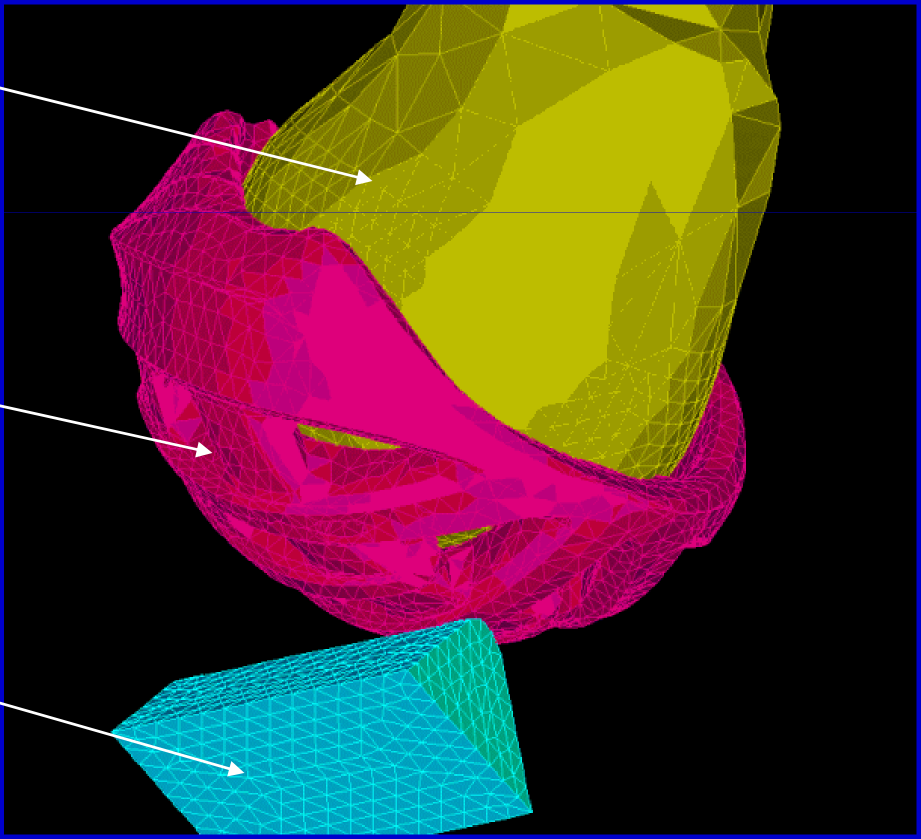
CAD models of MET bicycle helments removed due to copyright restrictions.

New Helmet Designs

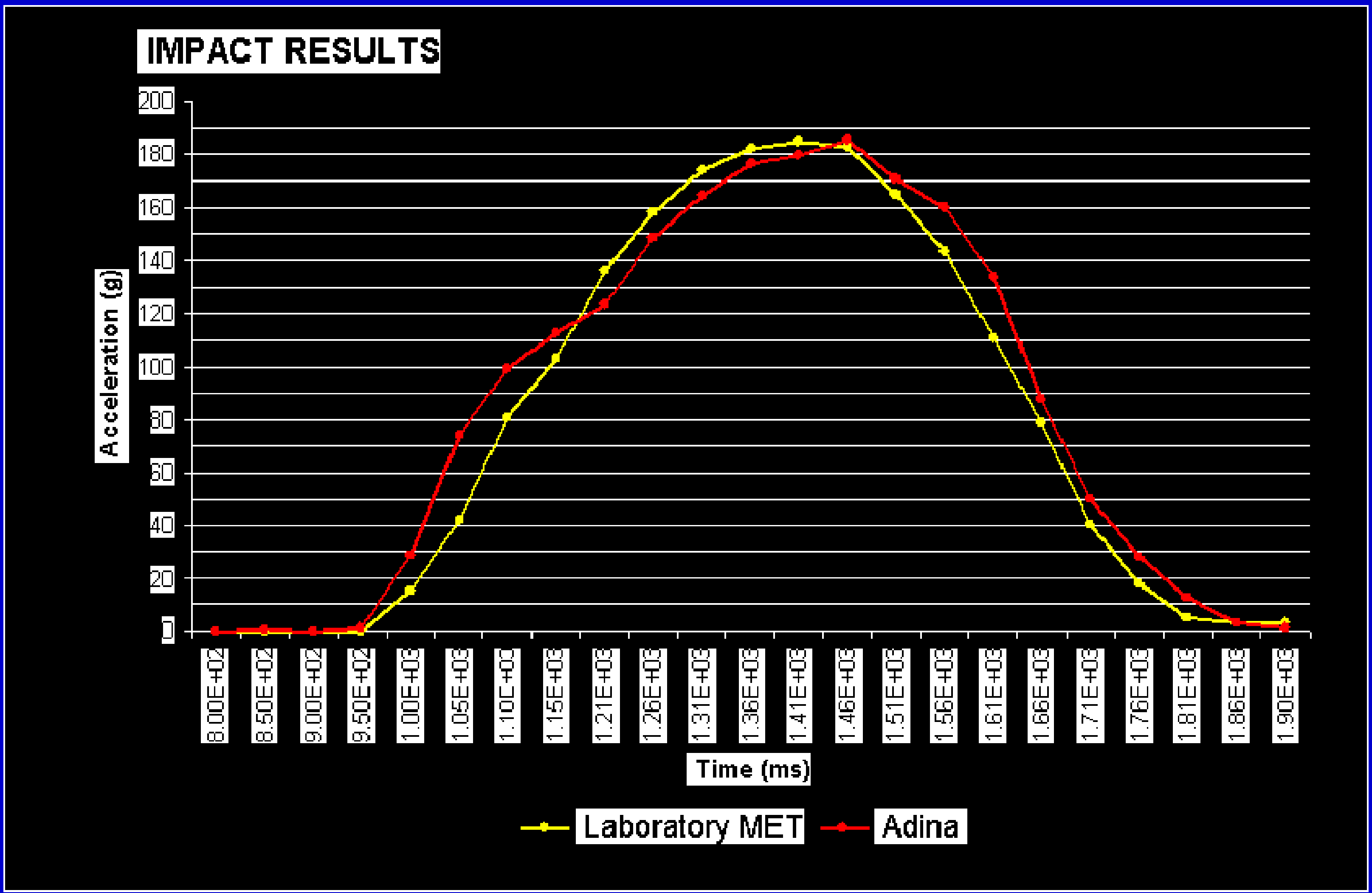
Analysis of helmet impact

Laboratory Test

ADINA Simulation Model



Analysis of helmet subjected to impact

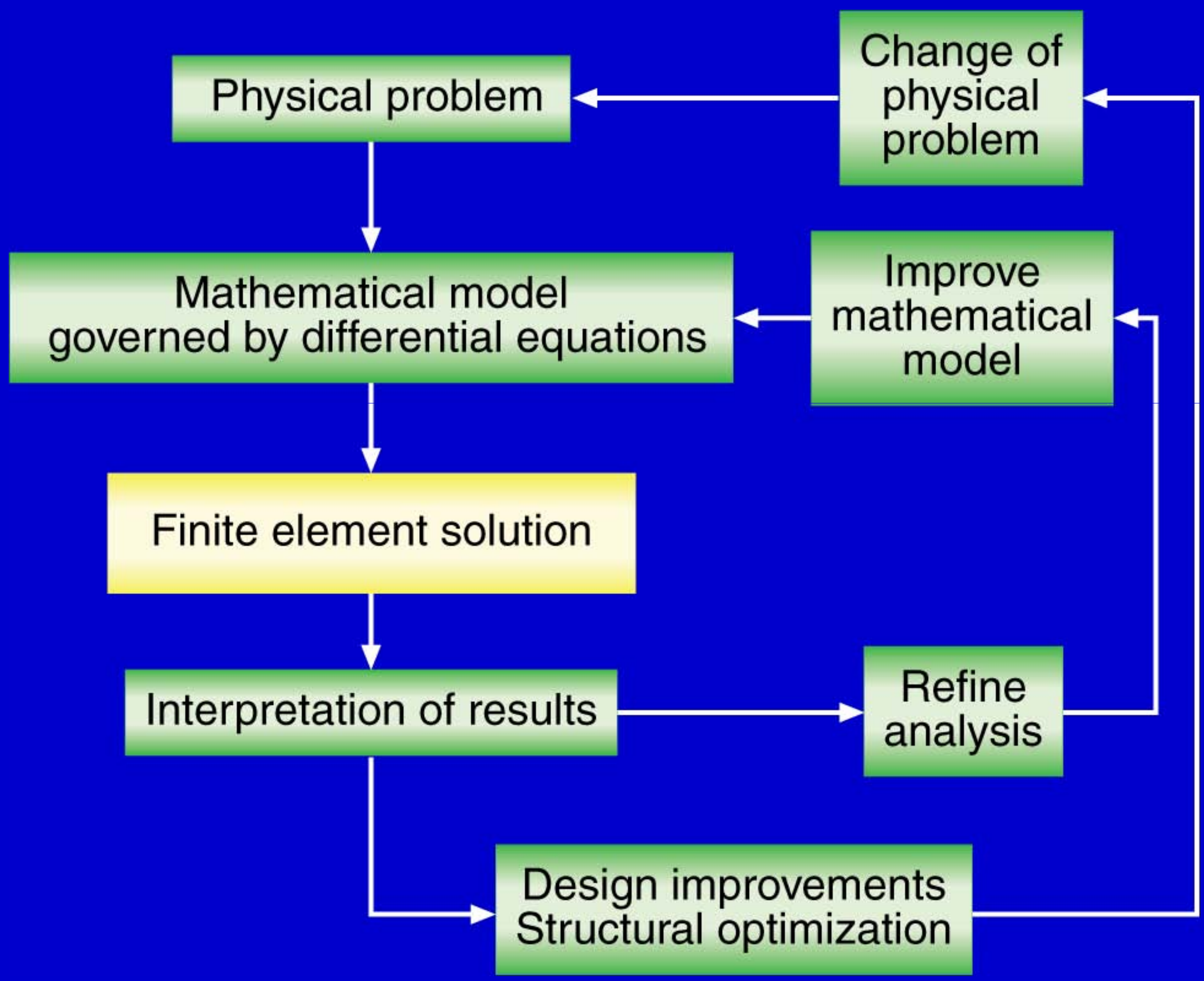


Comparison of computation with laboratory test results

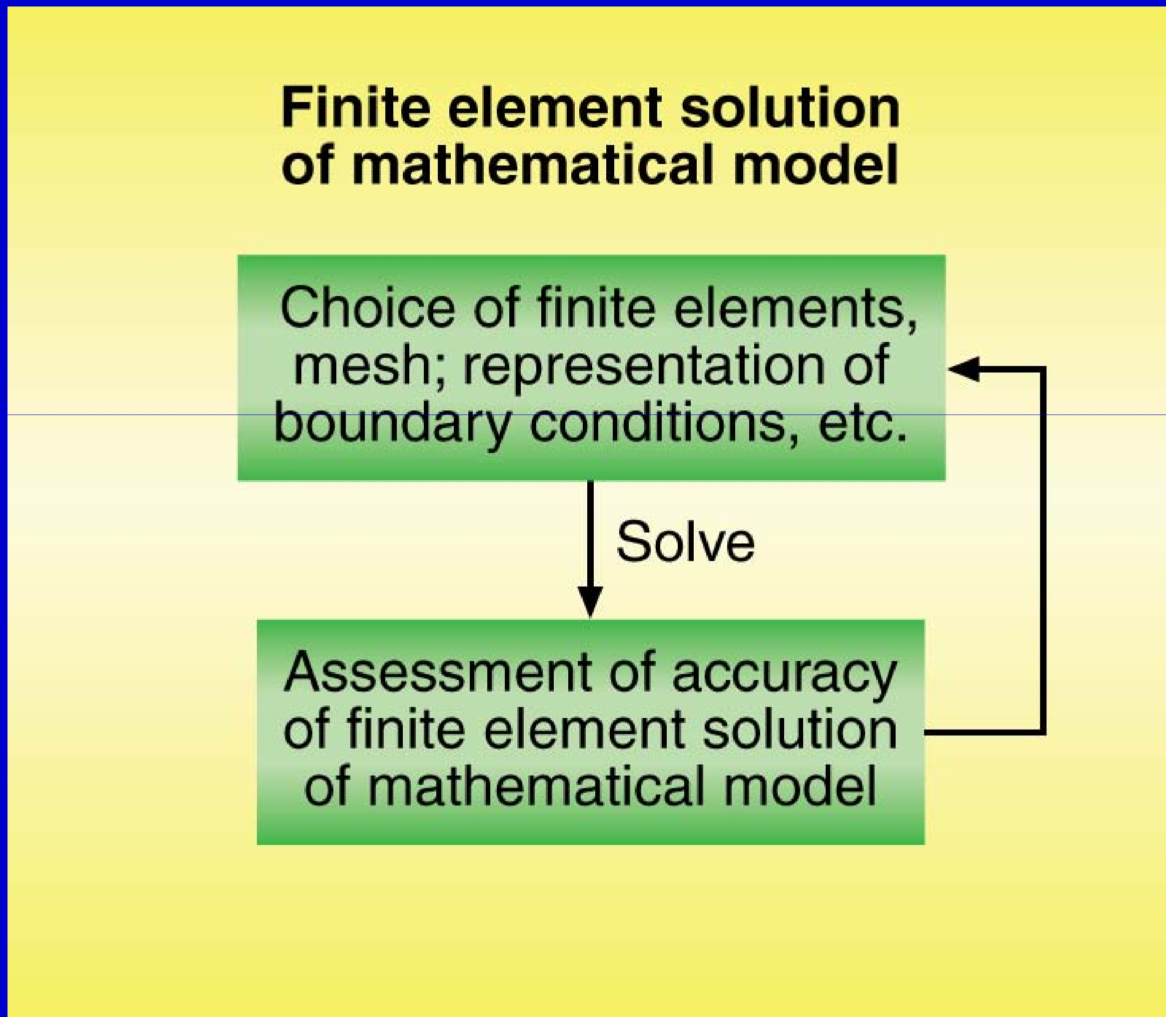
In engineering practice, analysis is largely performed with the use of finite element computer programs (such as NASTRAN, ANSYS, ADINA, SIMULIA, etc…)

These analysis programs are interfaced with computer-aided design (CAD) programs Catia, SolidWorks, Pro/Engineer, NX, etc.

The process of modeling for analysis



The process of modeling for analysis
(continued)



Hierarchical modeling

Means taking increasingly more complex models to simulate nature with increasing accuracy

Increasingly
more
complex
models

Assumptions:
spring, rod, truss
beam, shaft
2-D solid
plate
shell
fully three-dimensional
dynamic effects
nonlinear effects

nature

CAD and Analysis

In CAD System

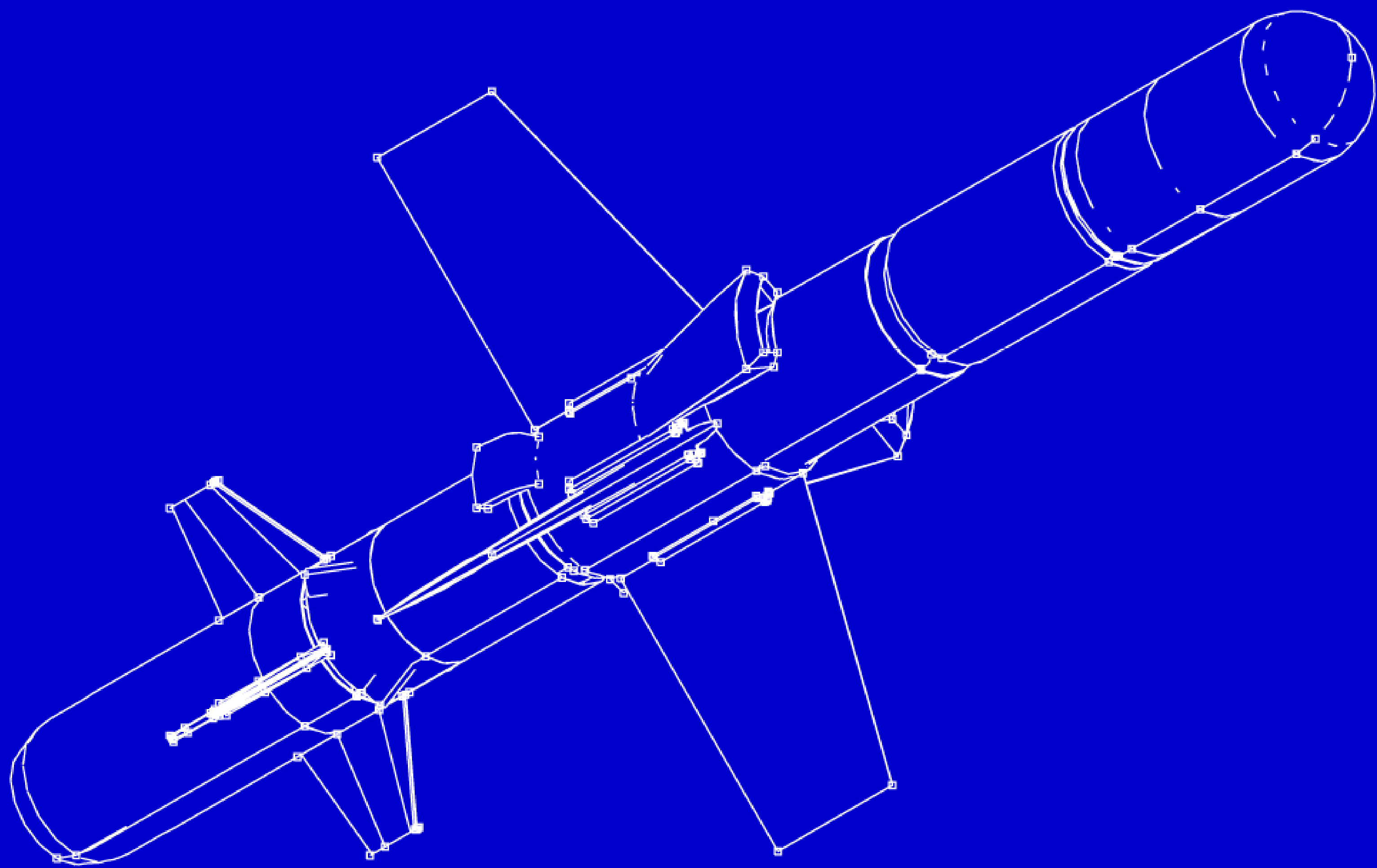
CAD solid model is established

In Analysis System

- Preparation of the mathematical model
- Meshing and Solution
- Presentation of results

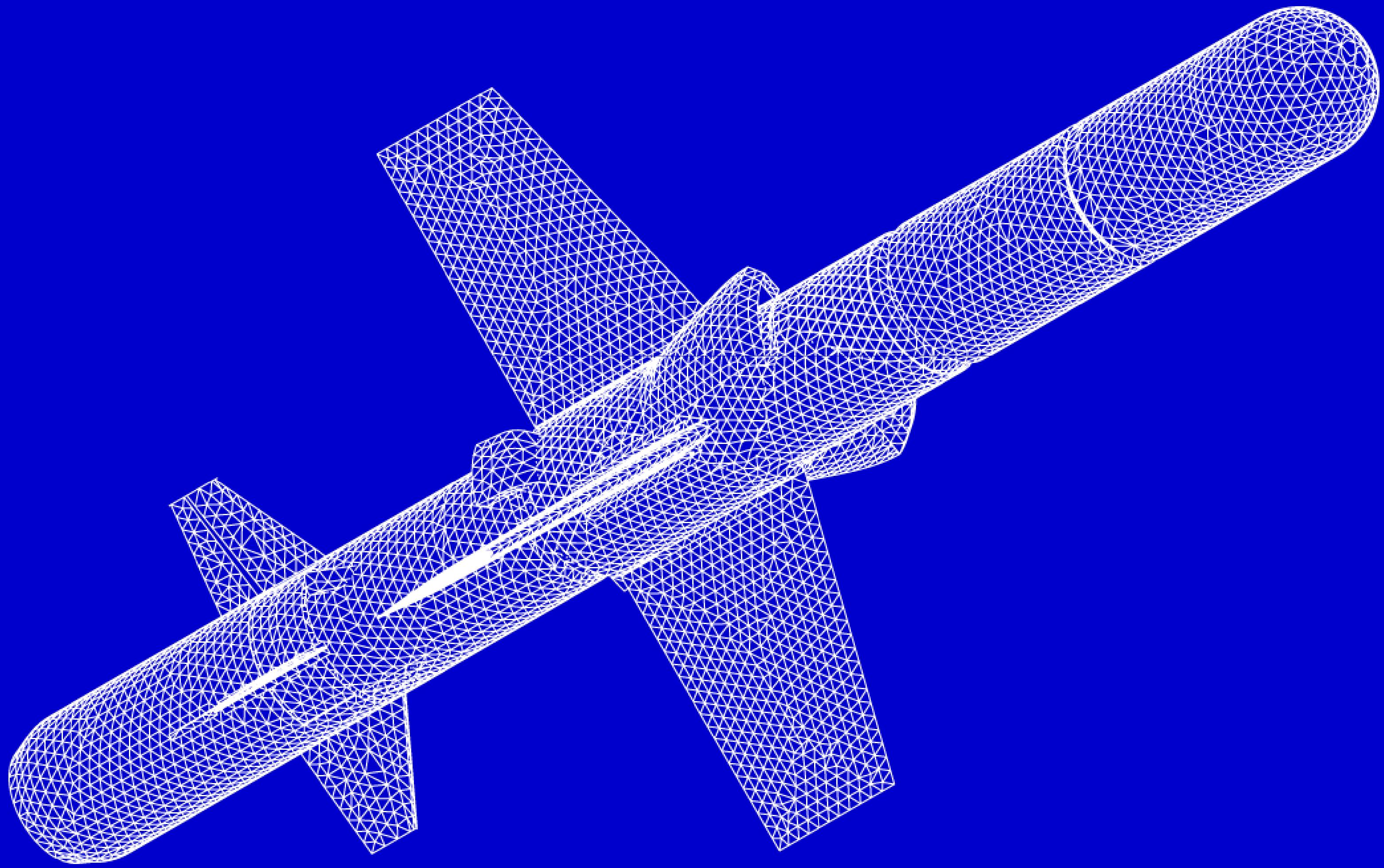
CAD model of missile

ADINA

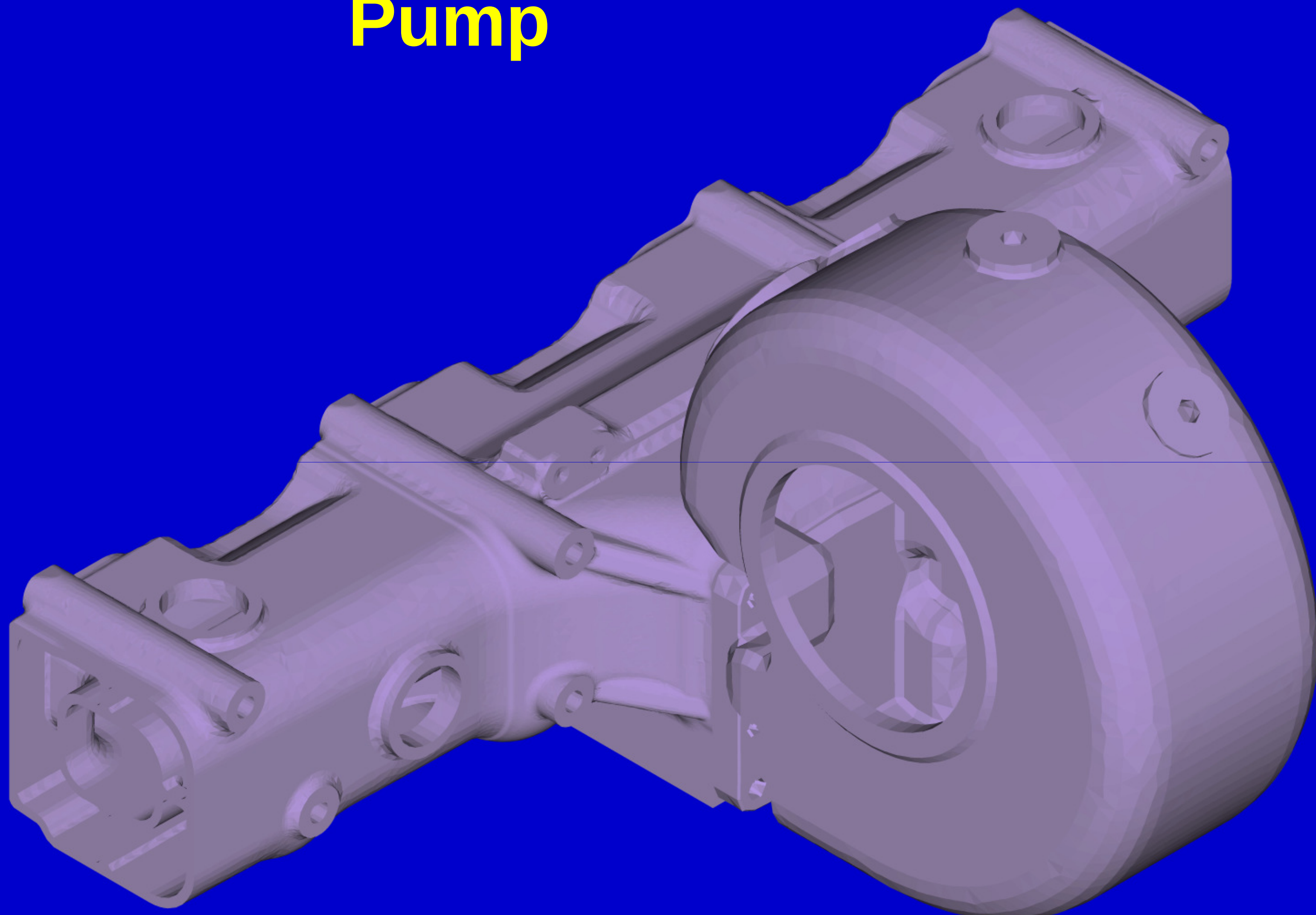


Finite Element Representation

ADINA

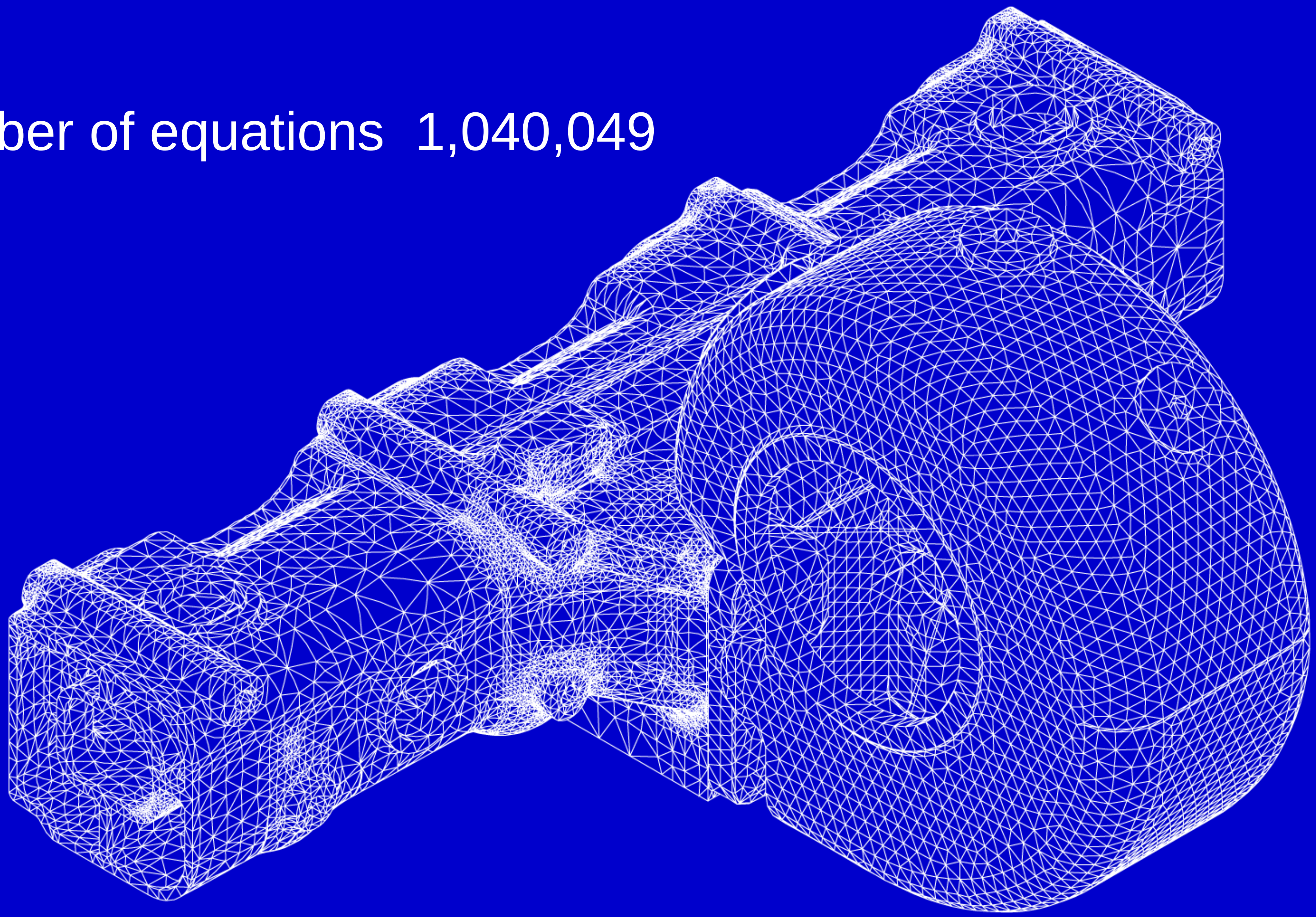


Pump



Finite Element Representation

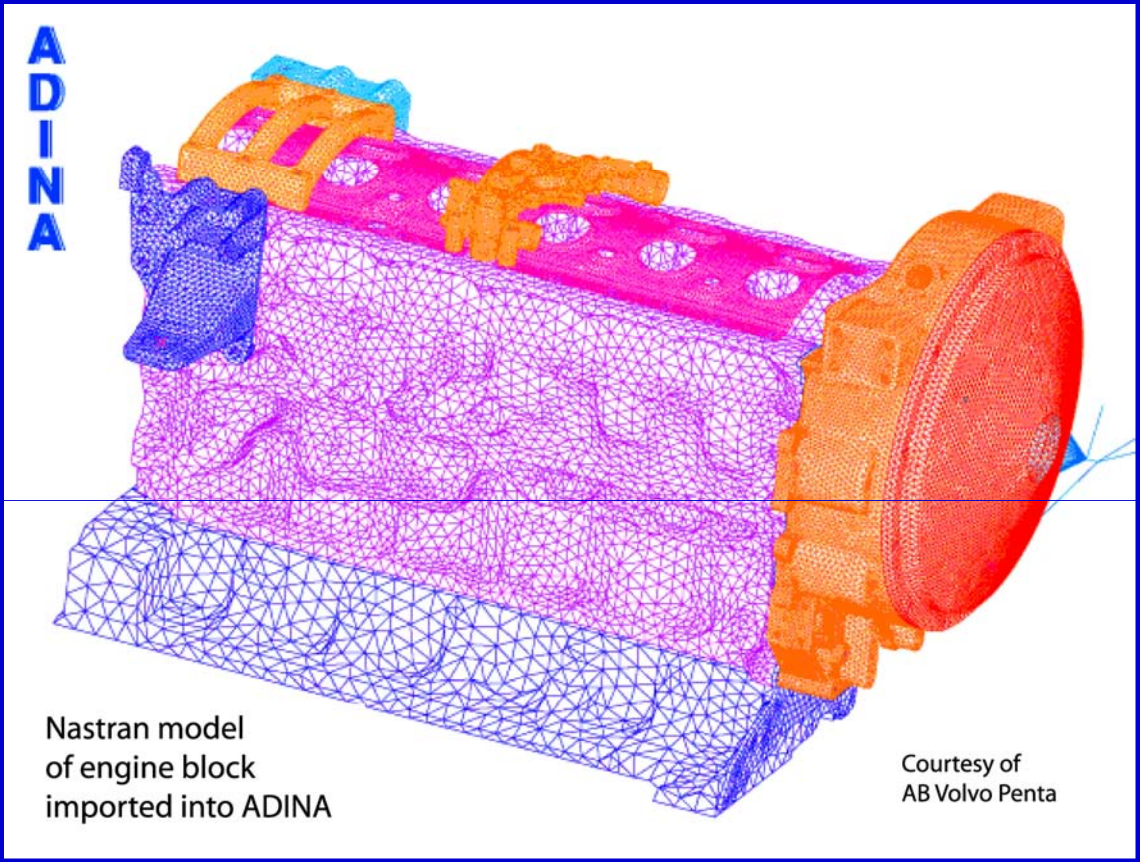
Number of equations 1,040,049



Pump

Engine block - photo

Courtesy of AB Volvo Penta. Used with permission



Engine block - mesh

Courtesy of AB Volvo Penta. Used with permission

A **reliable** and efficient finite element discretization scheme should

- for a well-posed mathematical model

- **always** give,
  for a reasonable finite element mesh,
  a reasonable solution, and

- if the mesh is fine enough, an accurate solution should be obtained

Element Selection

We want elements that are reliable for any

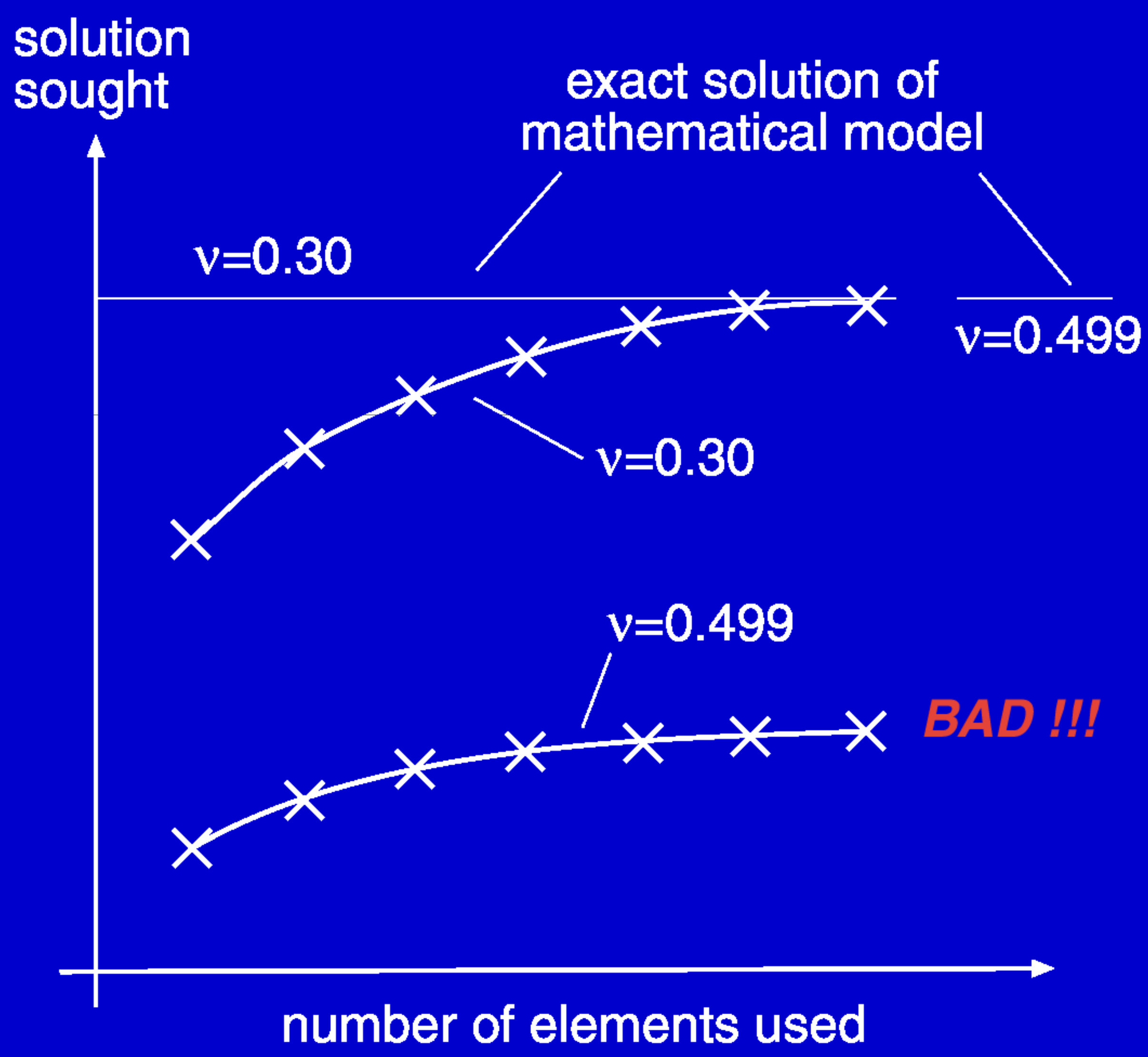
- geometry
- boundary conditions
- and meshing used

The displacement method is not

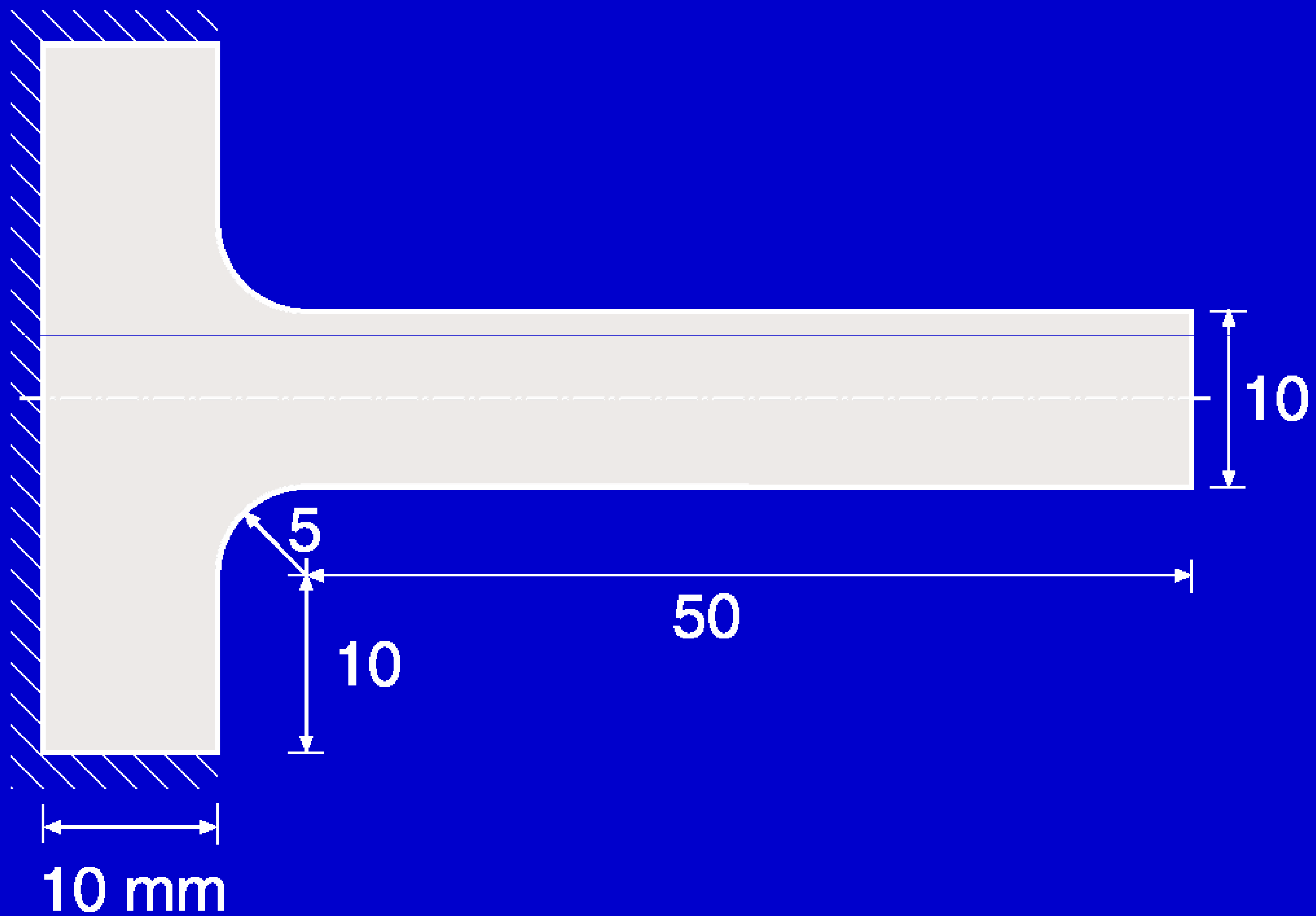
reliable for

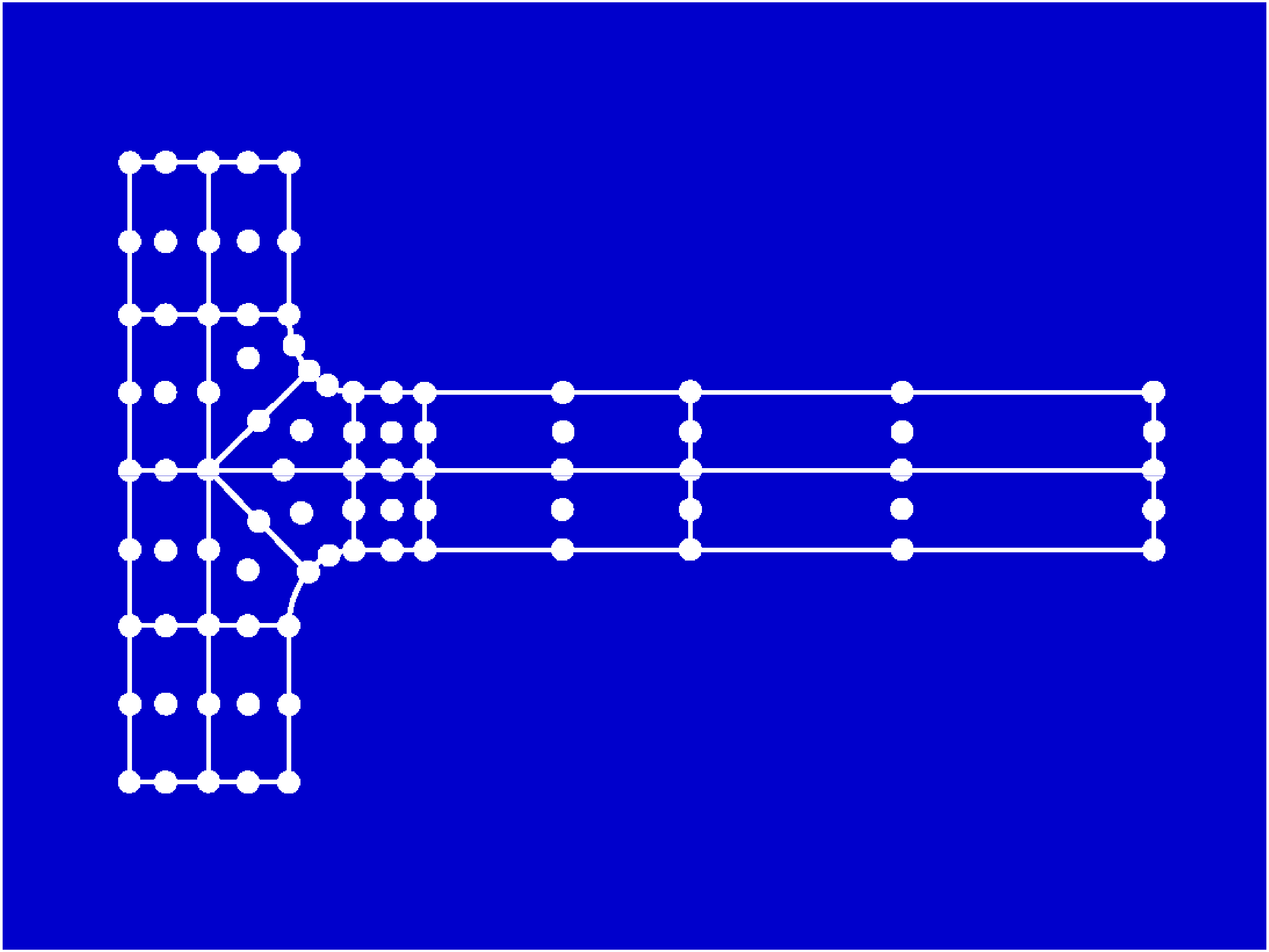
- plates and shells
- almost incompressible analysis

Schematic solution results



Example problem: to show what can go wrong





Smallest six frequencies (in Hz) of 16 element mesh

Consistent mass matrix is used

Mode number	16 el. model Use of 3x3 Gauss integration	16 el. model Use of 2x2 Gauss integration	16x64 element model use of 3x3 Gauss integration
1	112.4	110.5	110.6
2	634.5	617.8	606.4
3	906.9	905.5	905.2
4	**1548**	**958.4 ***	**1441**
5	2654	1528	2345
6	2691	2602	2664

***Spurious mode (phantom or ghost mode)**

Ref: Finite Element Procedures (by K. J. Bathe), Prentice Hall, 1996

Some analysis experiences

Tremendous advances have taken place –

- **mixed optimal elements** have greatly increased the efficiency and reliability of analyses
- **sparse direct solvers** and **algebraic multigrid iterative solvers** have lifted the analysis possibilities to completely new levels

In Industry:
Two categories of analyses

- Analysis of problems for which test results are scarce or non-existent
  – large civil engineering structures
- Analysis of problems for which test results can relatively easily be obtained
  – mechanical / electrical engineering structures

Examples of category 1 problems

- Analysis of offshore structures
- Seismic analysis of major bridges
  - only "relatively small" components can be tested

Reliable analysis procedures are crucial

Sleipner platform

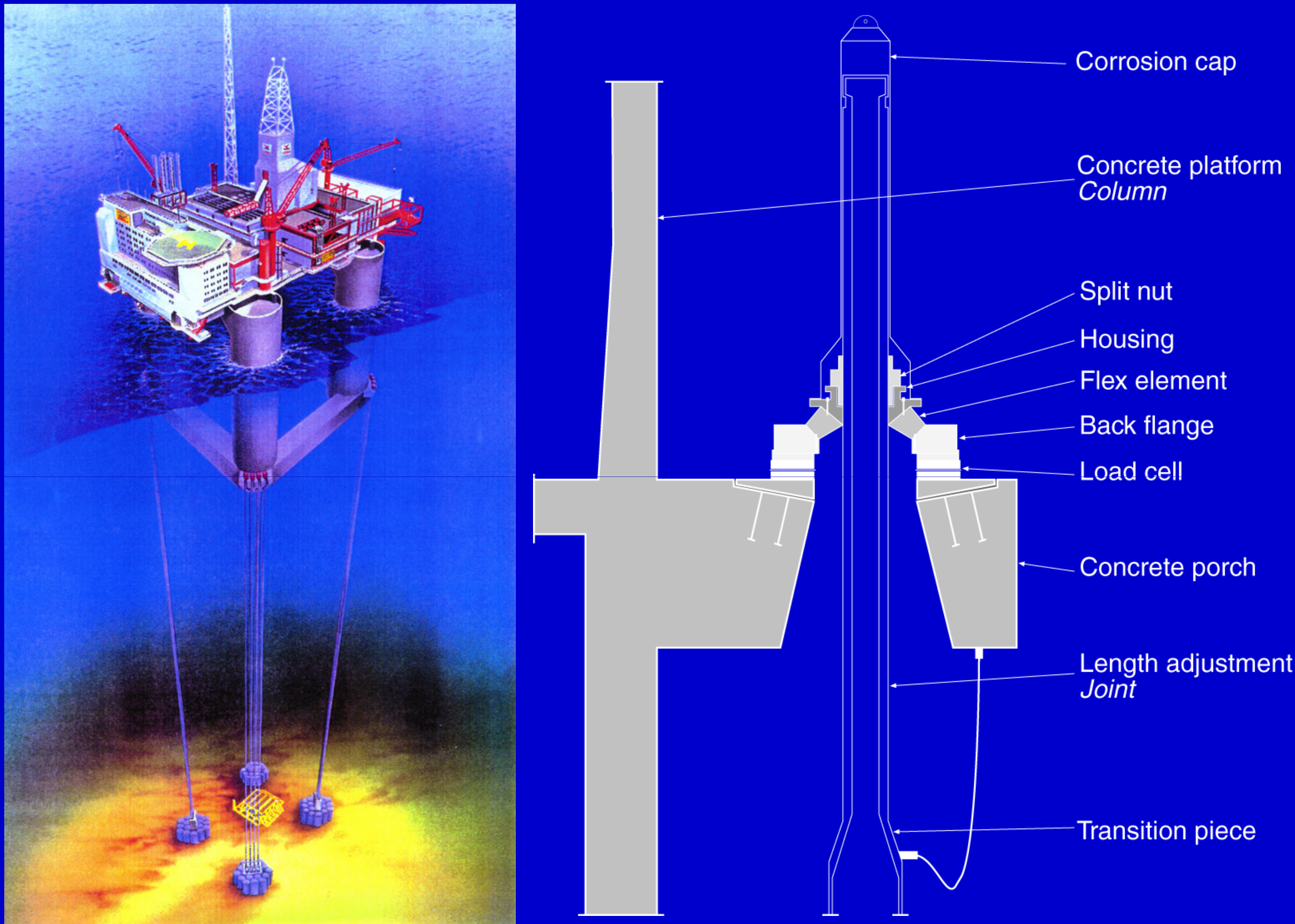
Recall the catastrophic failure in 1991 of the Sleipner platform in the North Sea

- Ref. I. Holand, "Lessons to be learned from the Sleipner accident"

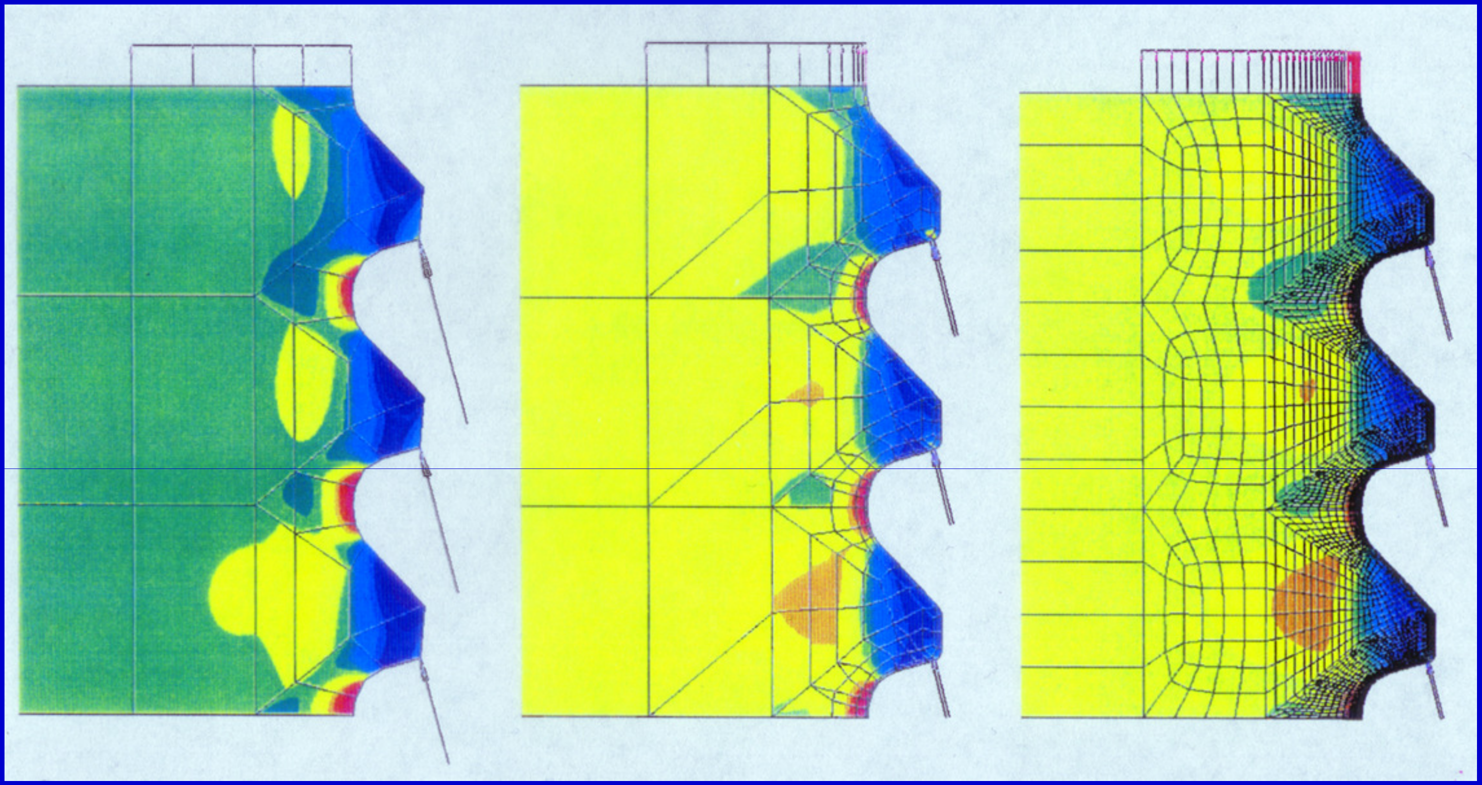
  Proceedings, NAFEMS World Congress '97, Stuttgart, Germany, April 1997.

Heidrun platform

- The world's largest of its kind (in 1997)
- Probably due to the Sleipner accident, increased analysis attention was given to critical components
  - designers and analysts worked closely together


Corrosion cap
Concrete platform
Column
Split nut
Housing
Flex element
Back flange
Load cell
Concrete porch
Length adjustment
Joint
Transition piece

Accuracy - part of reality



Coarse Mesh Converged Mesh Reference Mesh

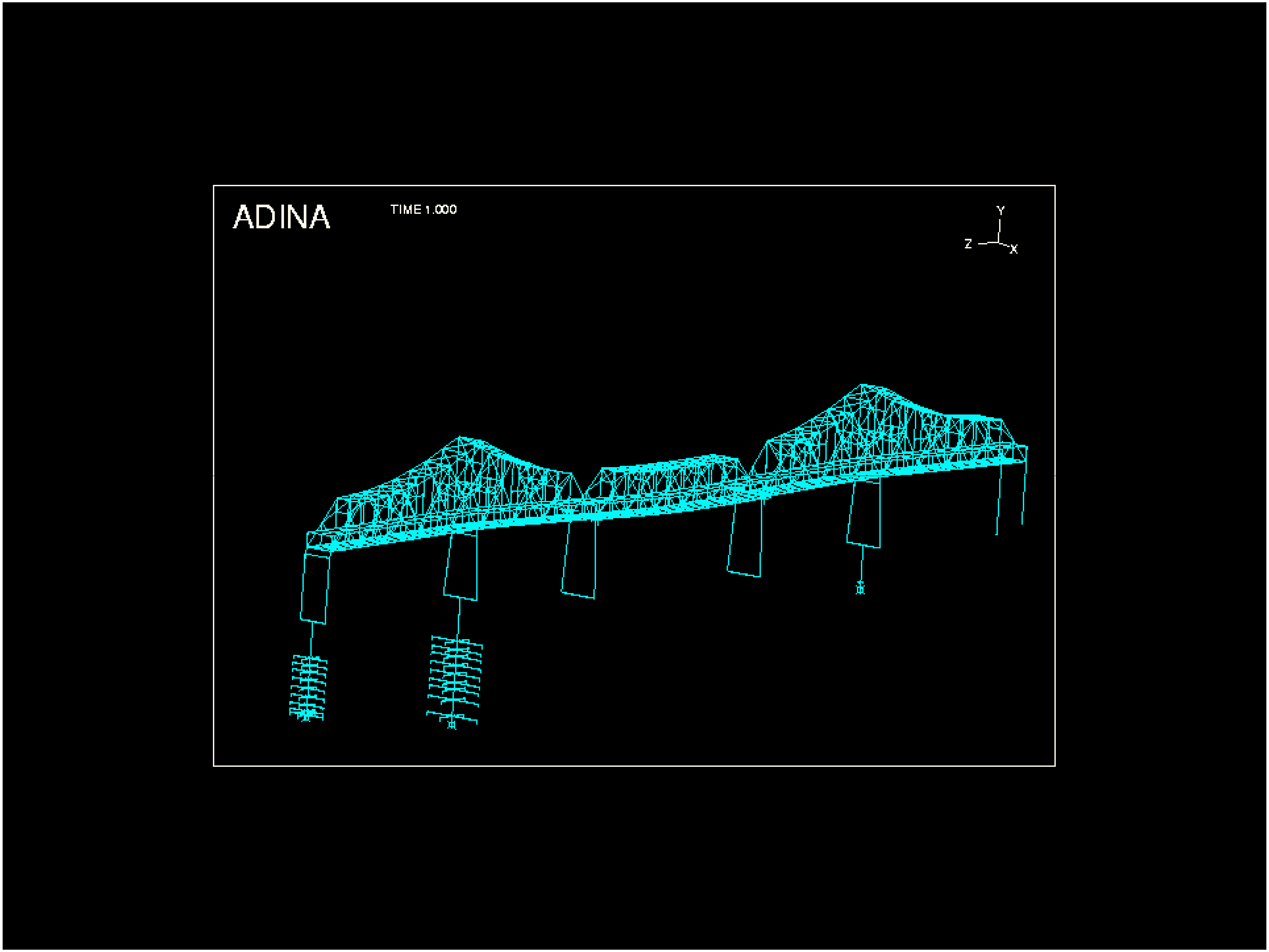
Correct surface stress prediction at critical locations is of vital importance for fatigue life determination

Seismic analysis of major California bridges

- Damage from the 1989 and 1994 earthquakes
- Objective is to retrofit / strengthen the bridges (including the famous San Francisco-Oakland Bay Bridge)

Photo by Luis Alberto Higgins.

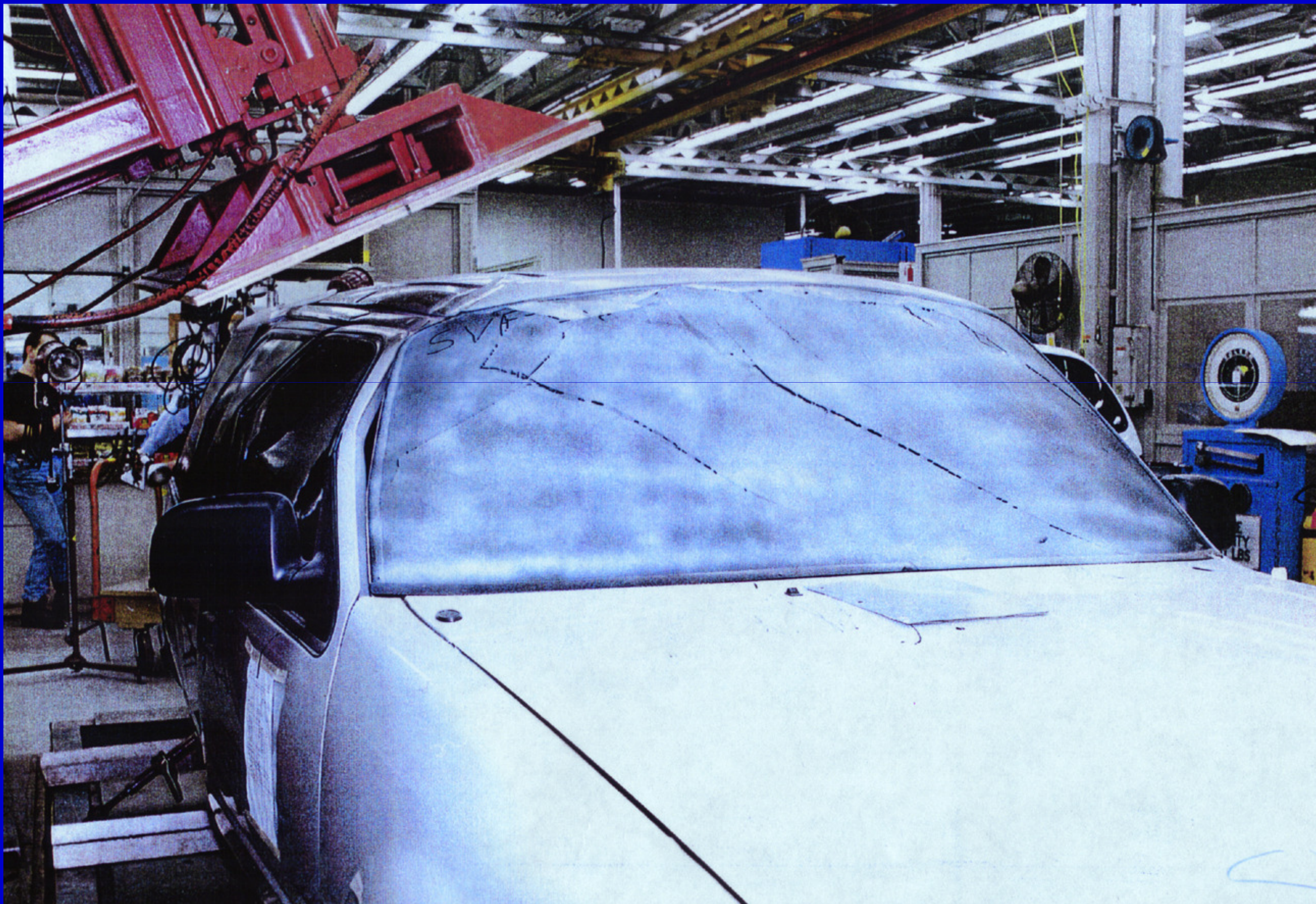
Photo by USGS.


ADINA
TIME 1.000
Y
Z
X

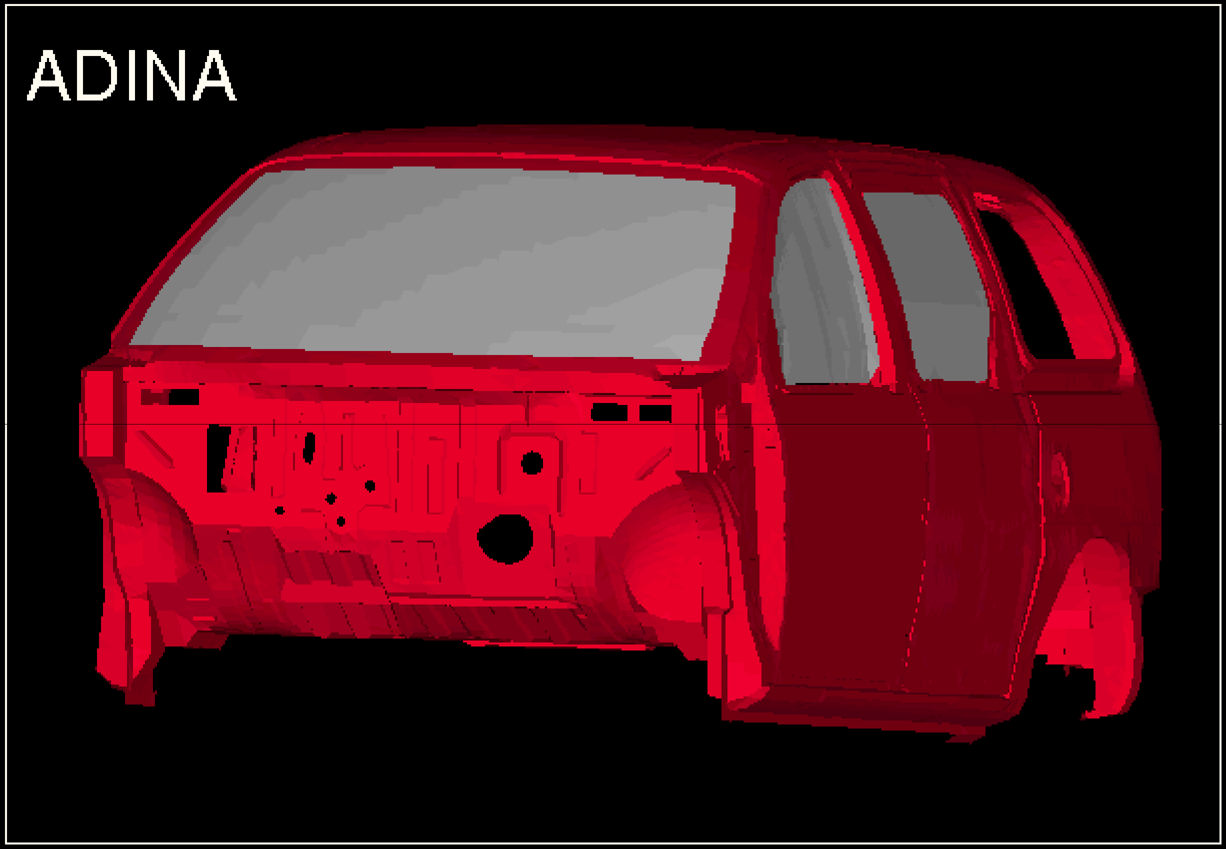
Examples of category 2 problems

- Metal forming, crash and crush analyses in the automobile industries
- These types of problems can now be solved much more reliably and efficiently than just a few years ago

Roof crush analysis

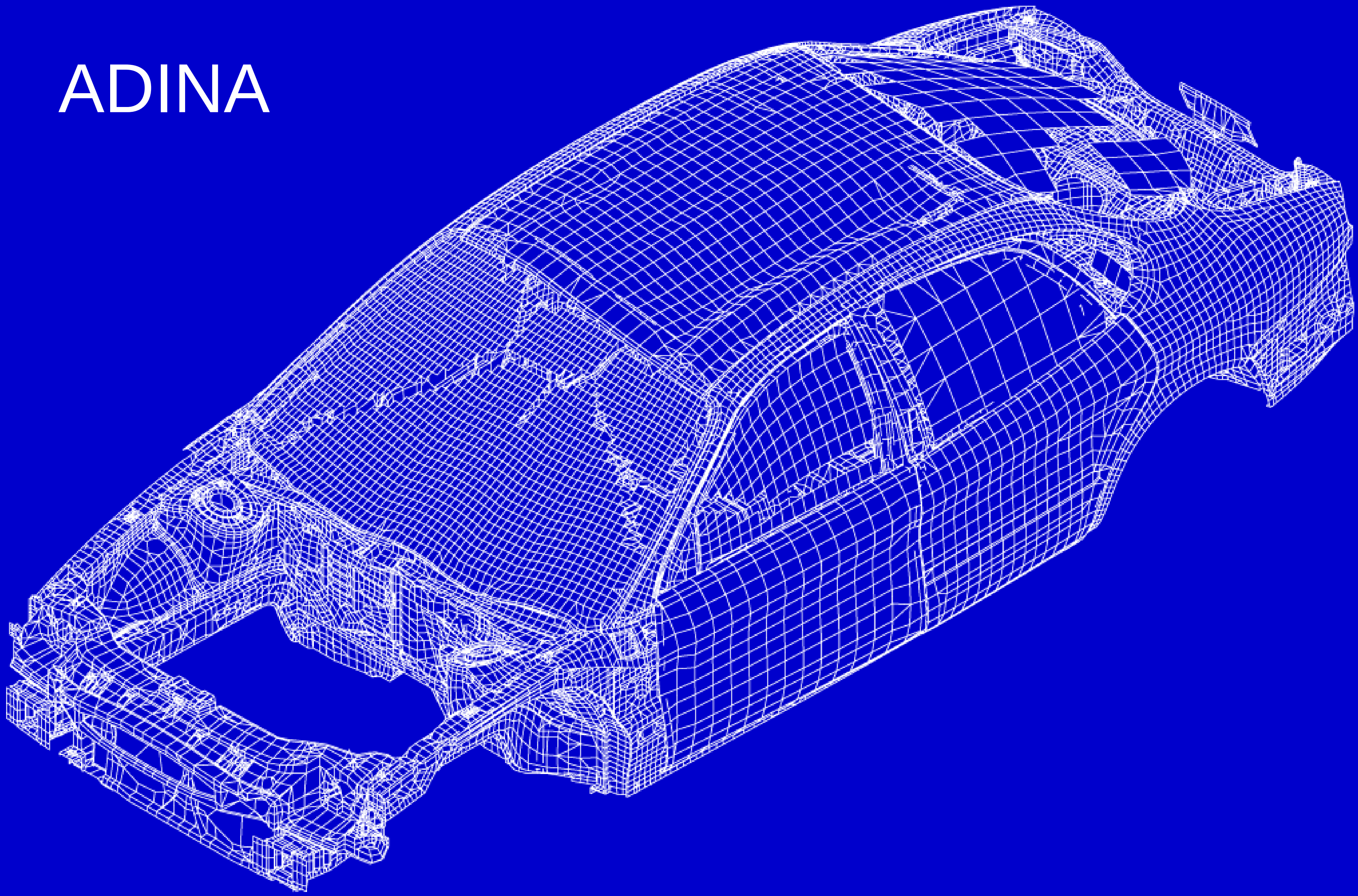


Roof crush analysis

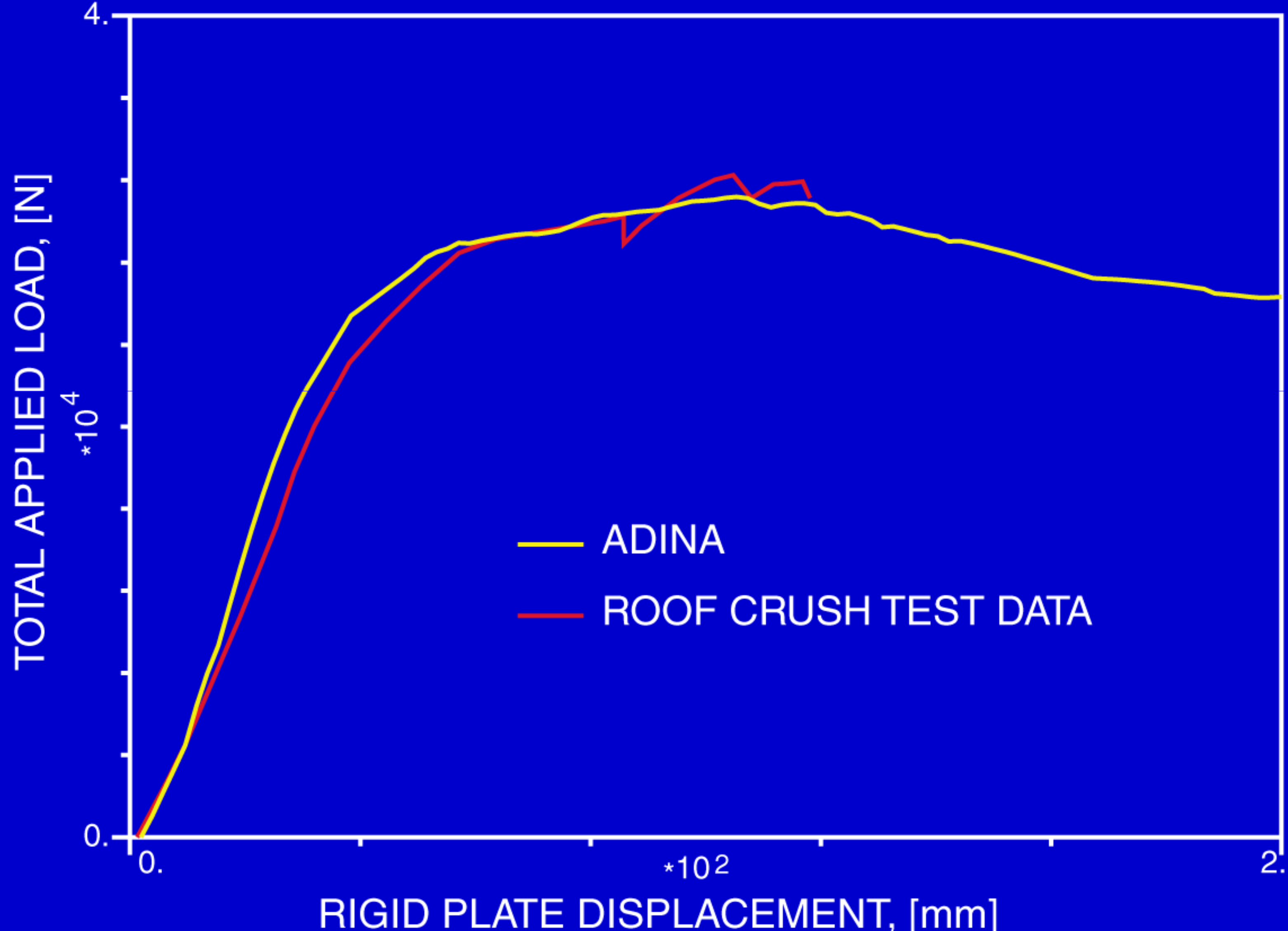


Roof crush analysis

ADINA



Roof crush analysis



Rolling

Multi-pass rolling

Material model:

slab – aluminum, elastic-plastic material

roll – rigid

ADINA:

static, implicit analysis

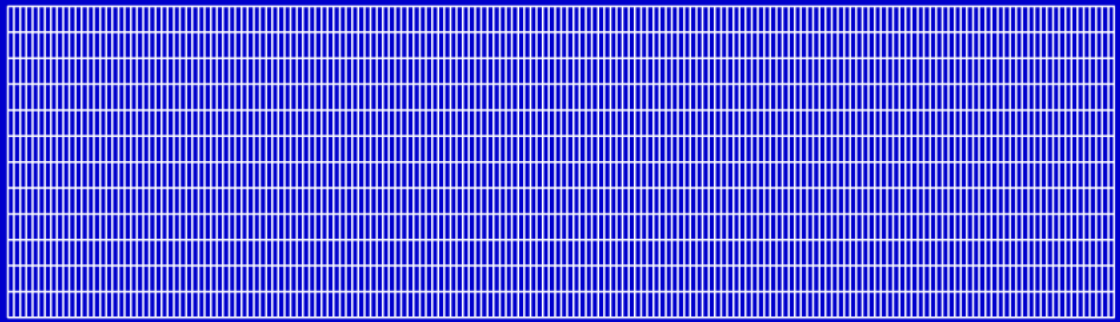
slab – 2160 u/p (4-node) elements, plastic-multilinear material model

roll – 360 rigid contact segments

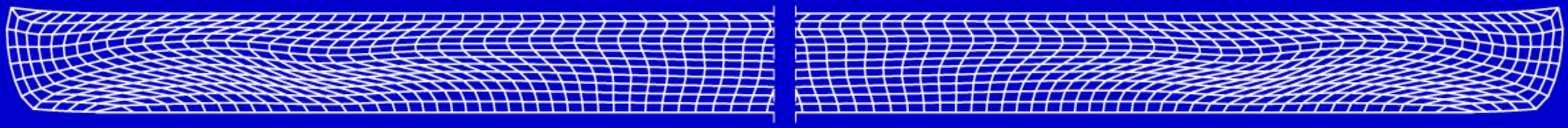
contact algorithms – constraint-function

Rolling

multi pass rolling

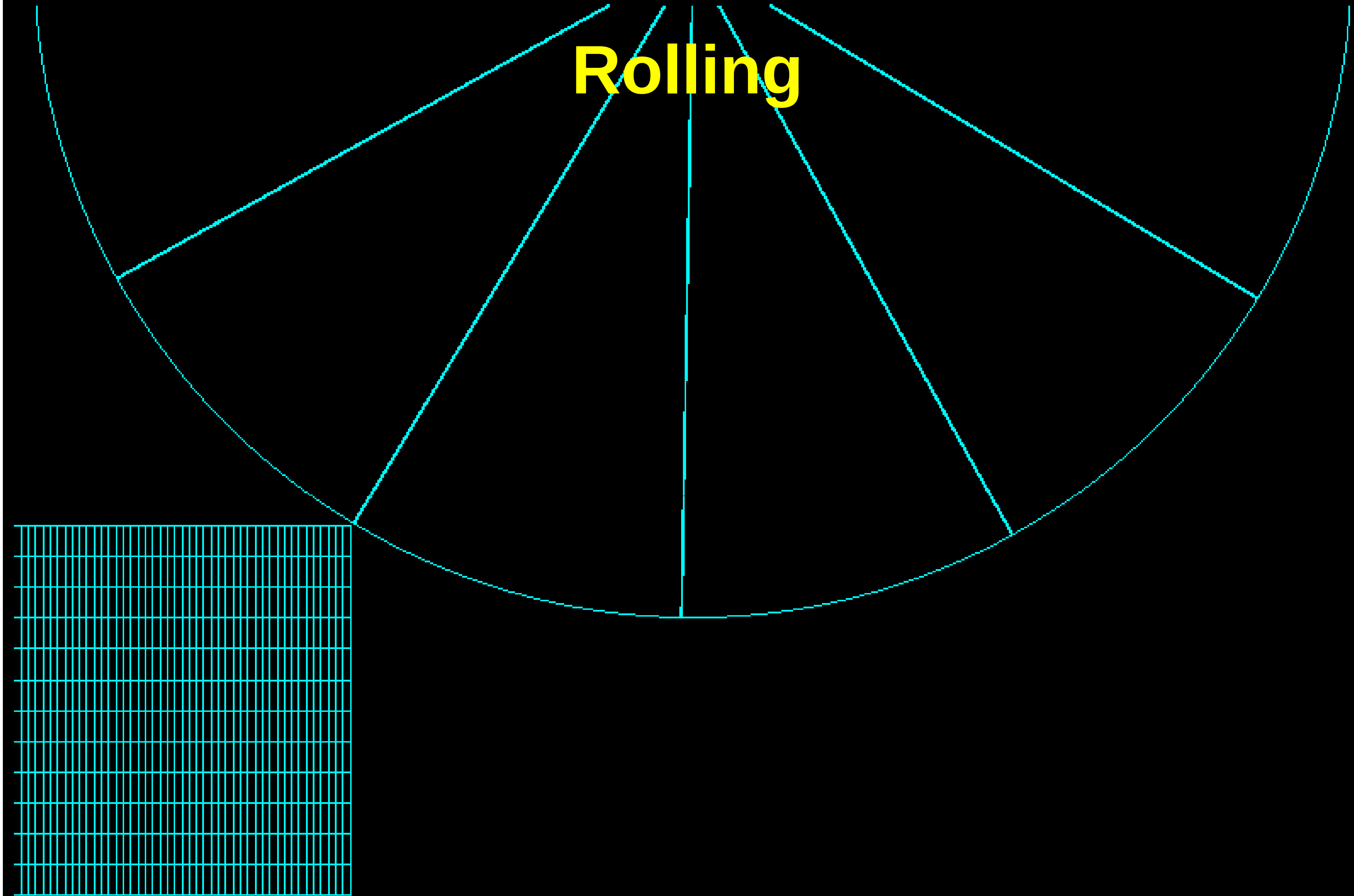


Initial mesh



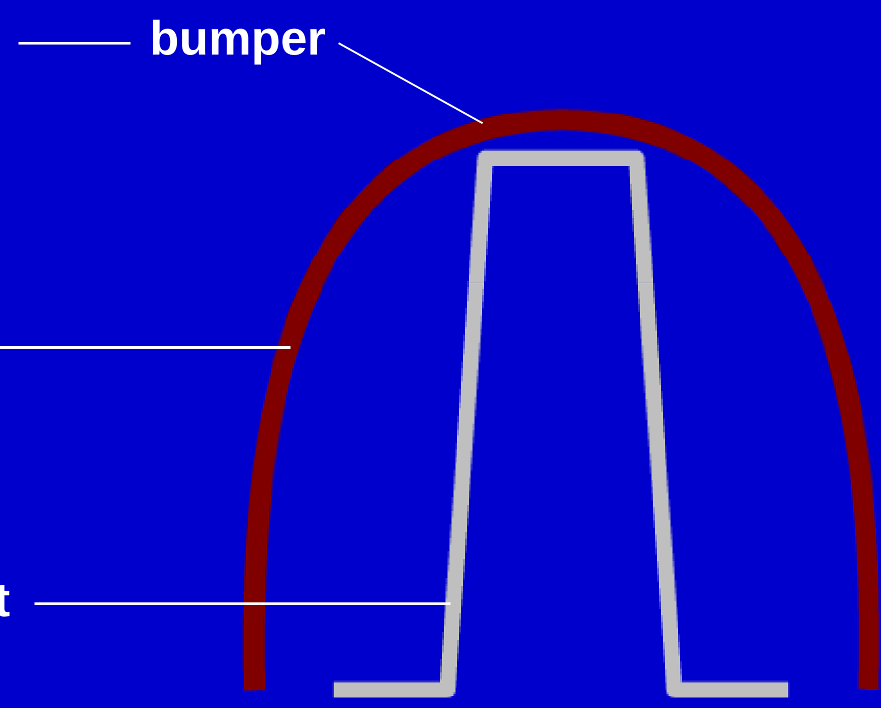
Final mesh

Rolling



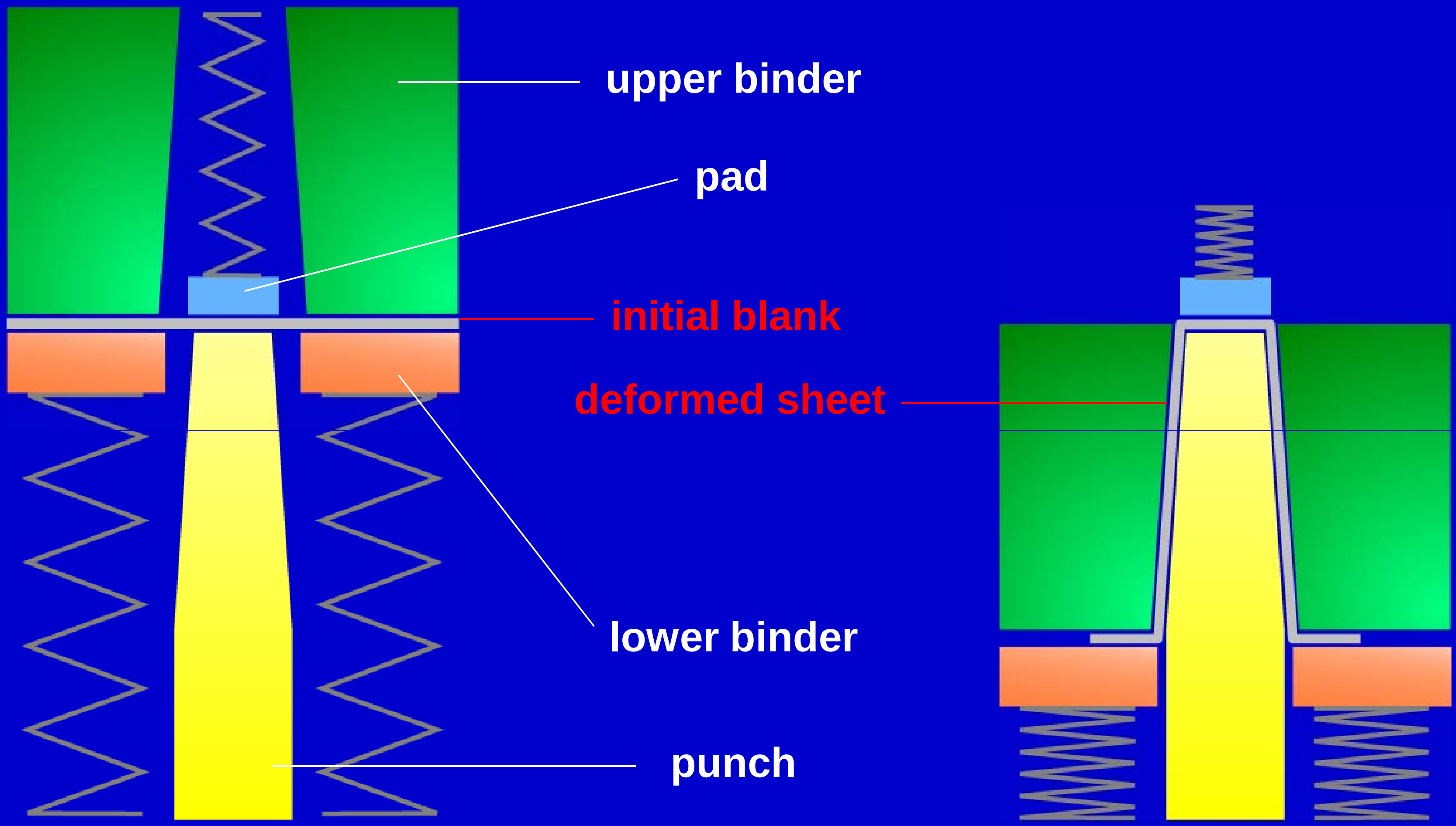
Bumper reinforcement

Image from the Open Clip Art Library.



Bumper cross-section

Bumper reinforcement



Stamping on a single action press,

“springs” provide constant holding force

Bumper reinforcement

Material data:

steel, 1.8 mm

friction coefficient, = 0.125

ADINA

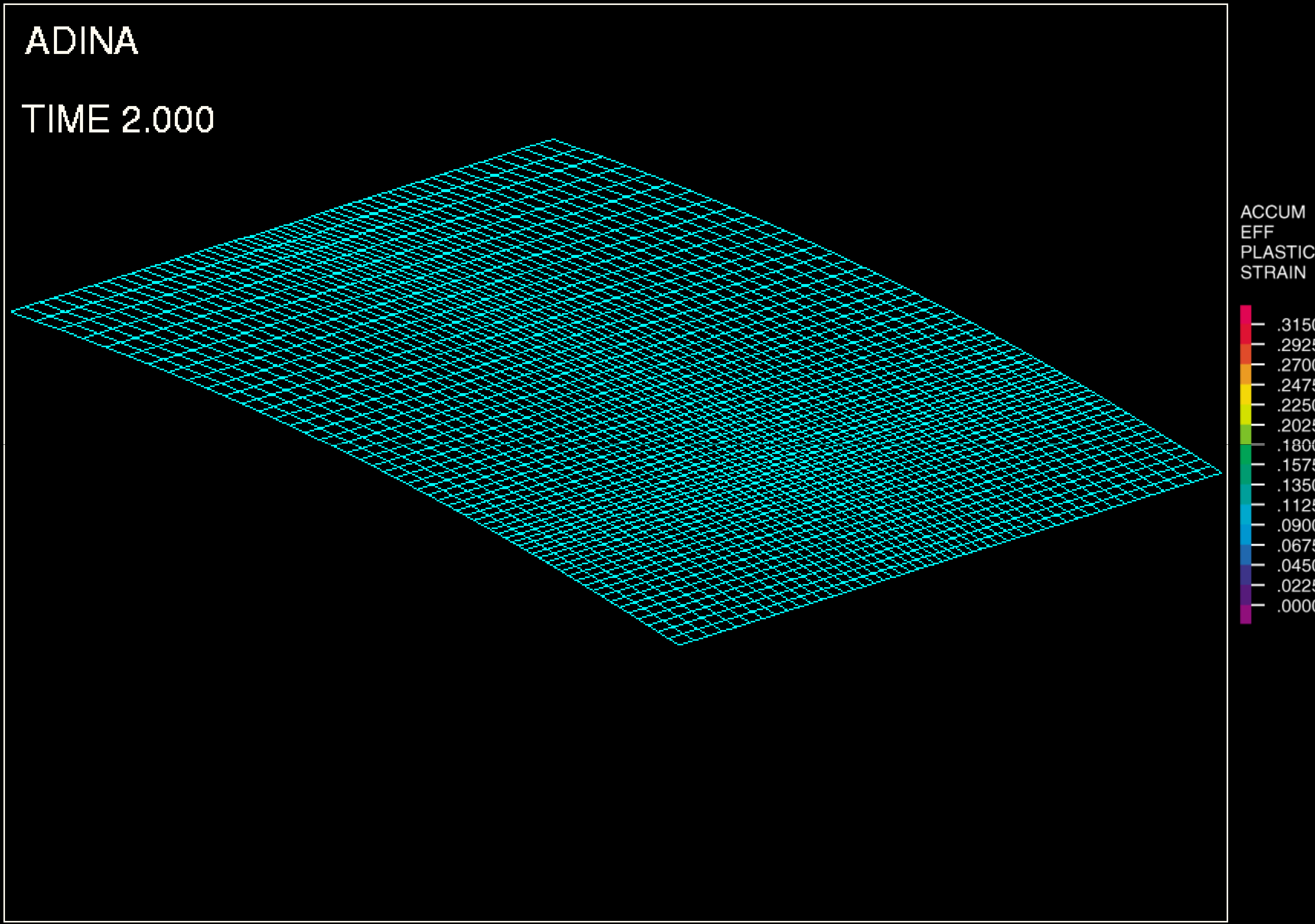
static, implicit analysis

2750 MITC elements, 4-nodes

plastic-multilinear material model

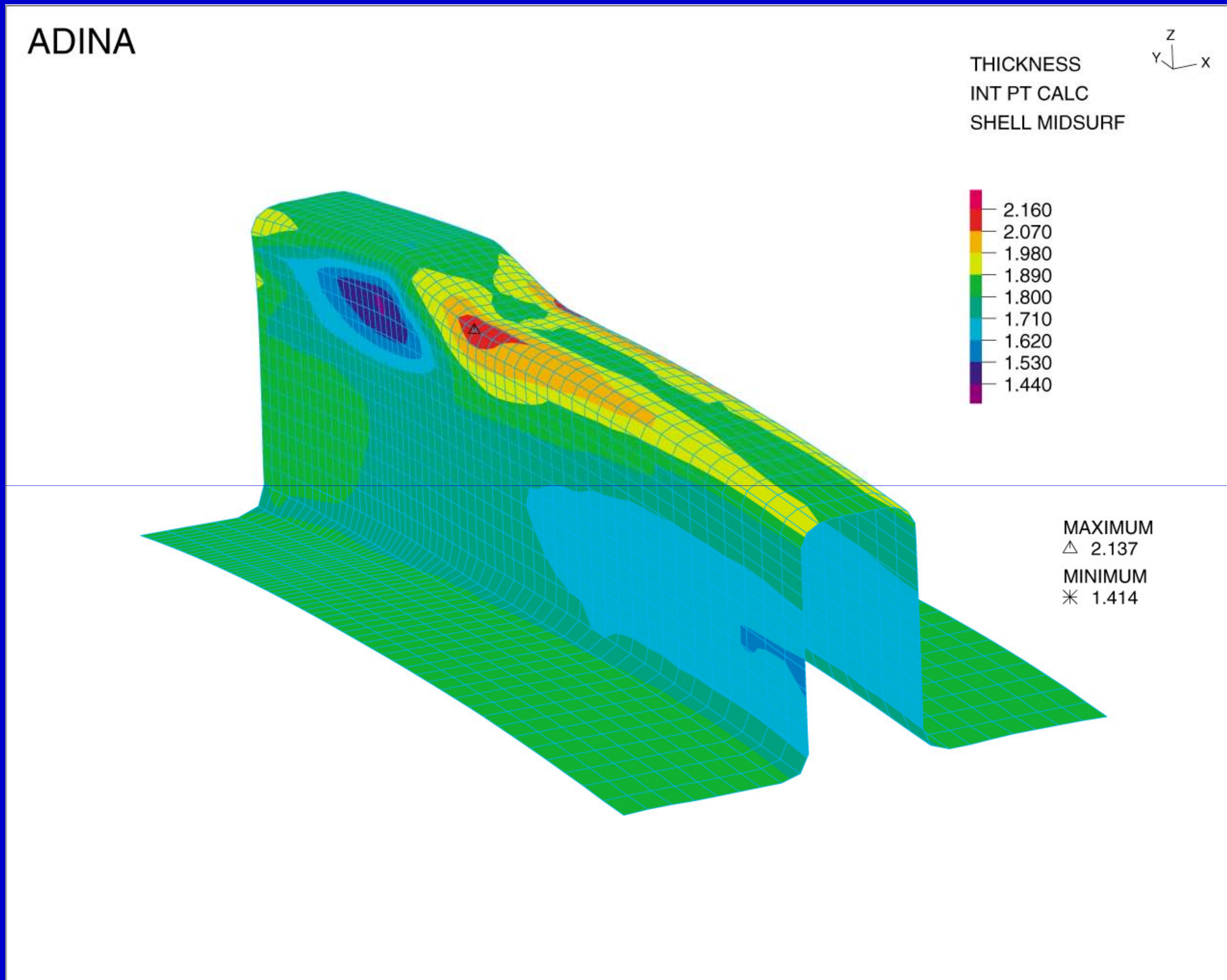
rigid-target contact

Bumper reinforcement



Effective plastic strain distribution

Bumper reinforcement



Final thickness distribution

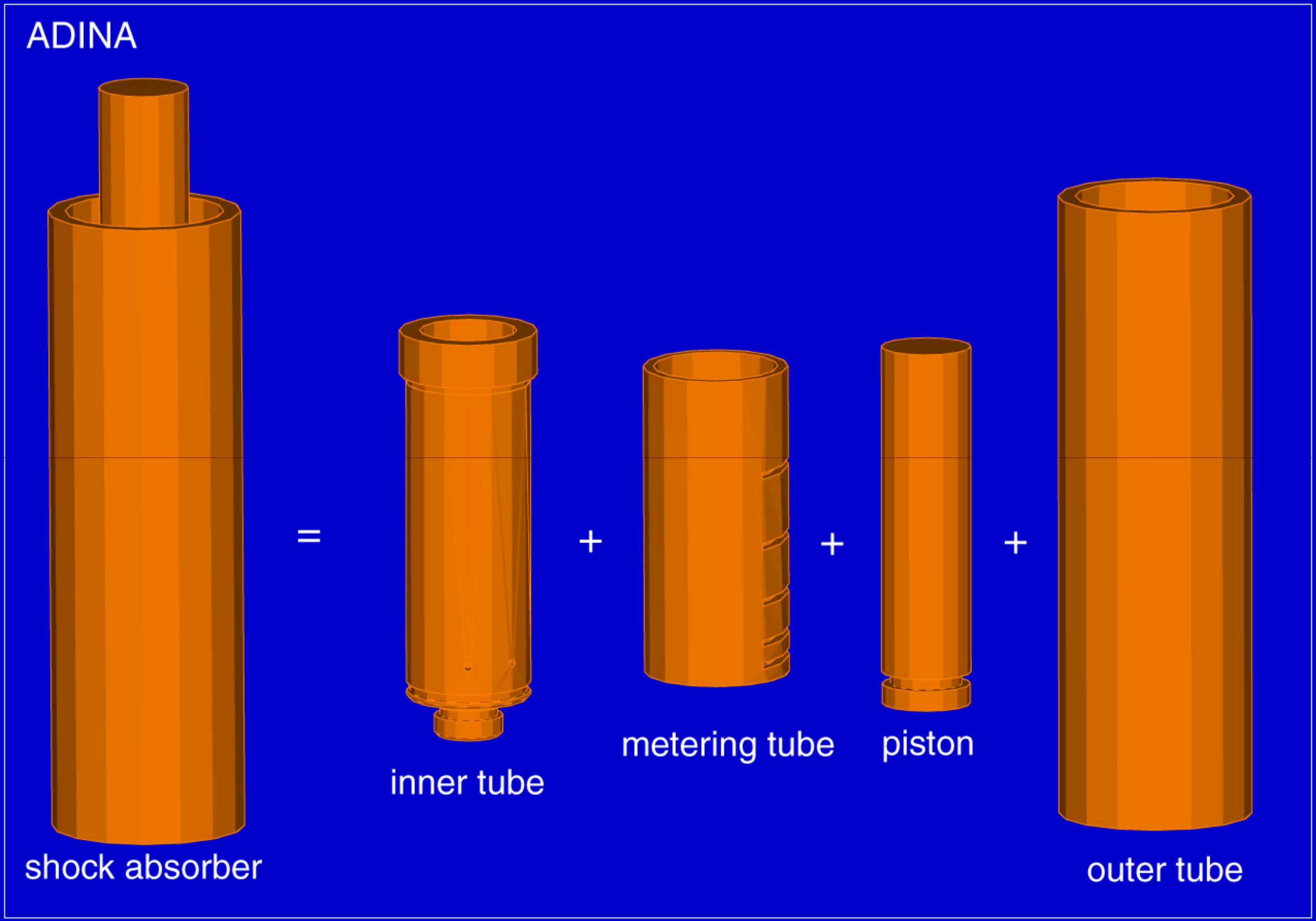
Fluid-flows fully-coupled with structural interactions –

an increasingly important analysis area

- **Full Navier-Stokes equations for incompressible or fully compressible flows**
- **Arbitrary Lagrangian-Eulerian formulation for the fluid**

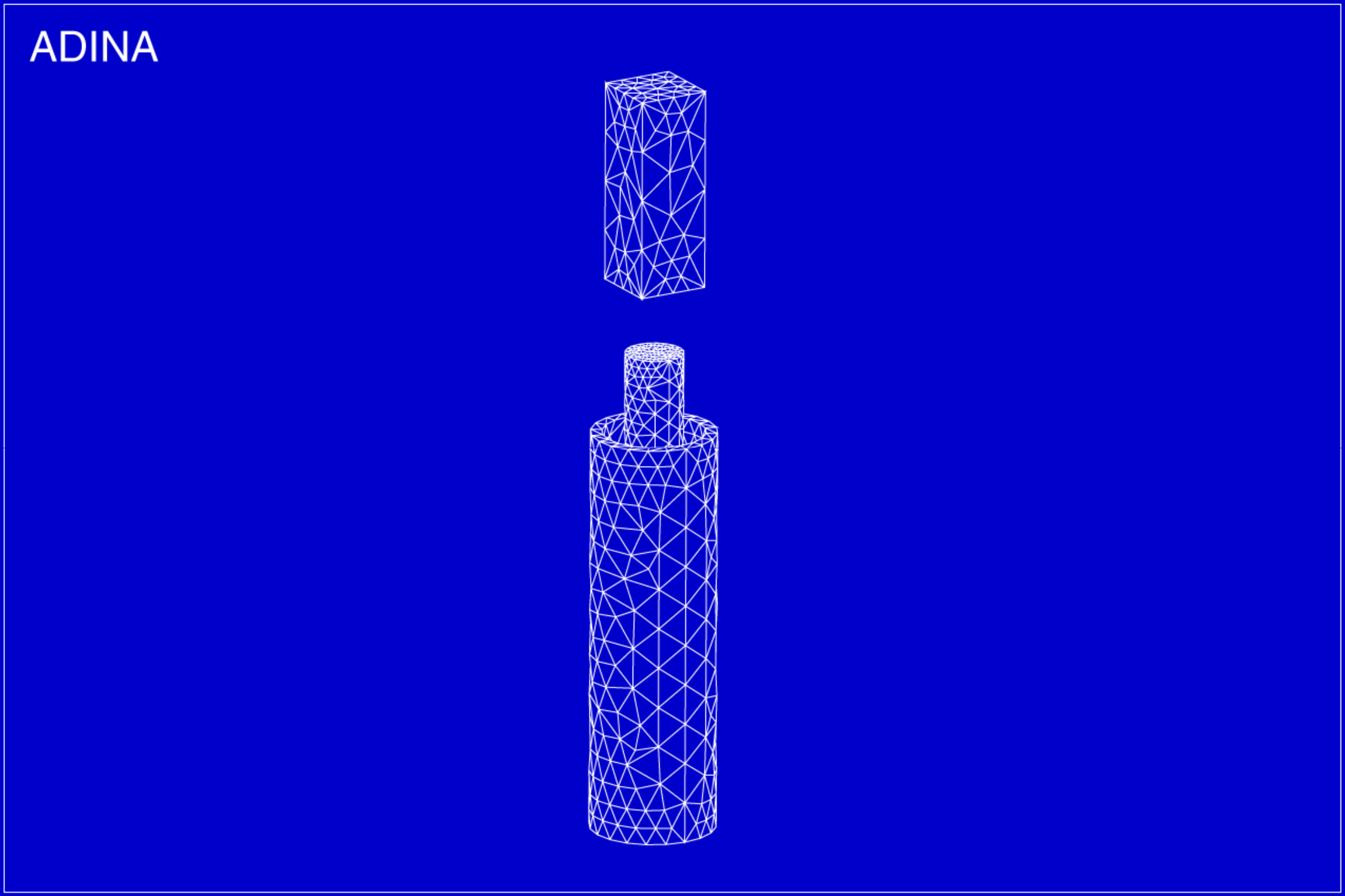
Shock absorber

Shock absorber



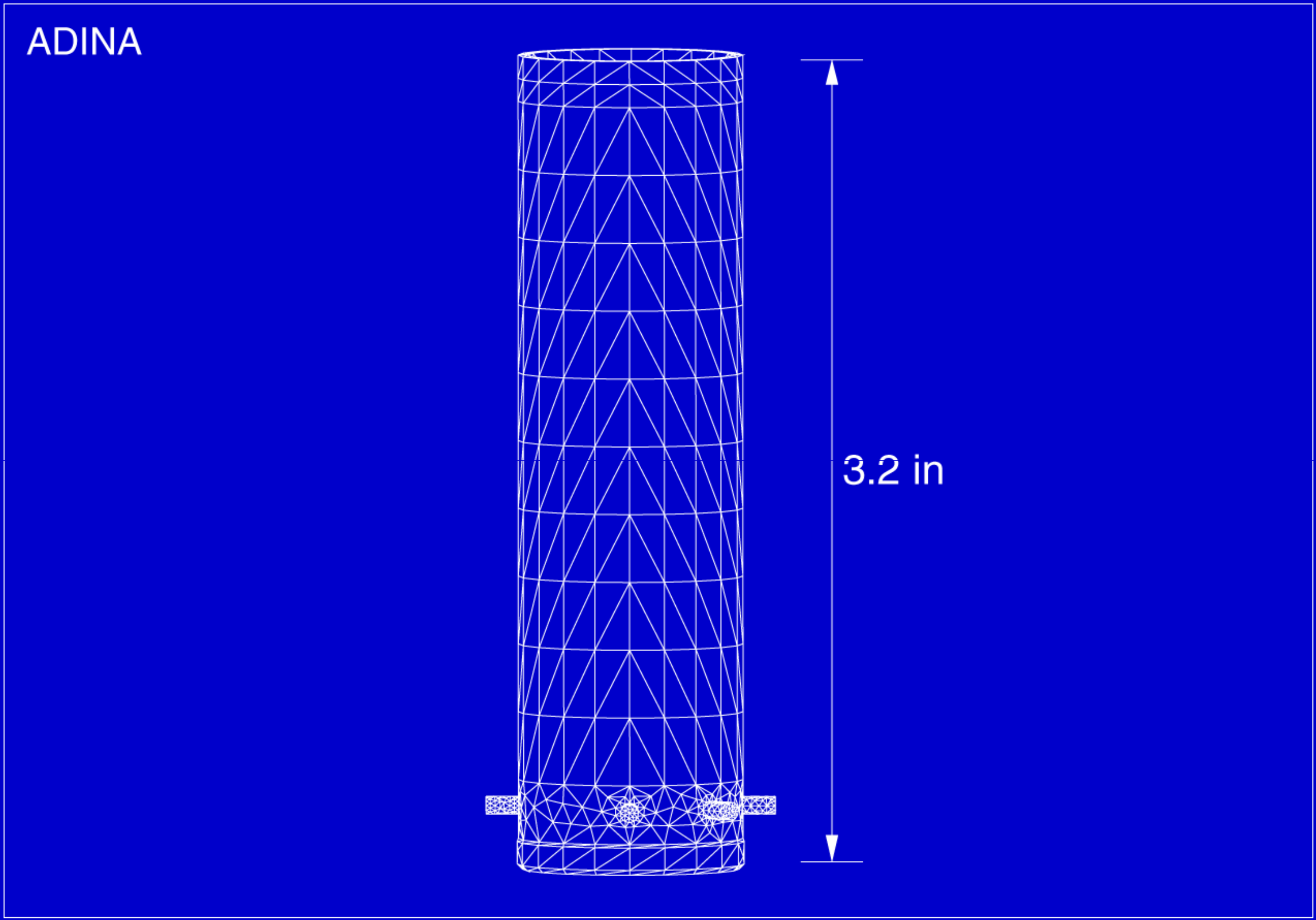
Assembly parts

Shock absorber



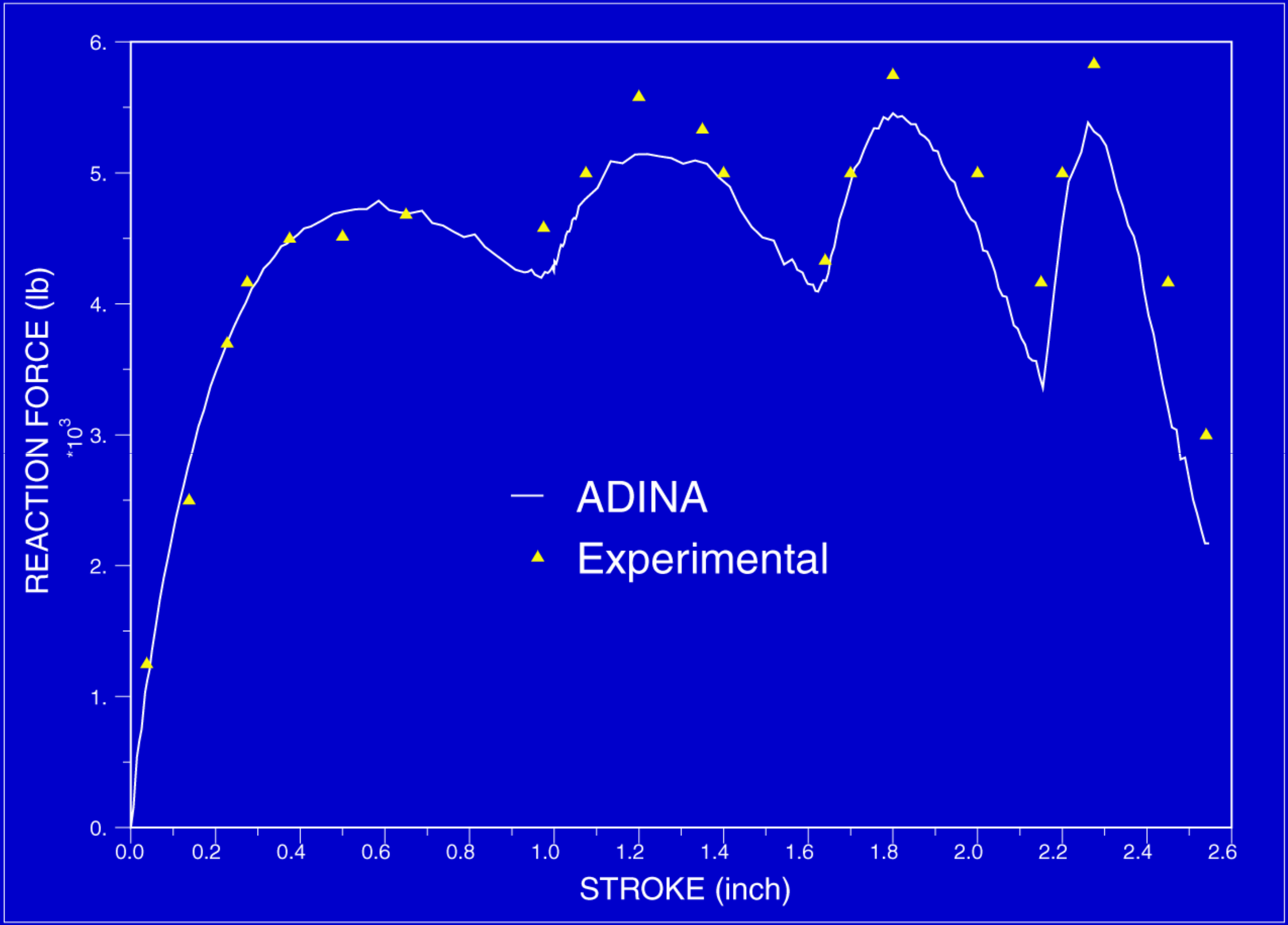
Structural model

Shock absorber

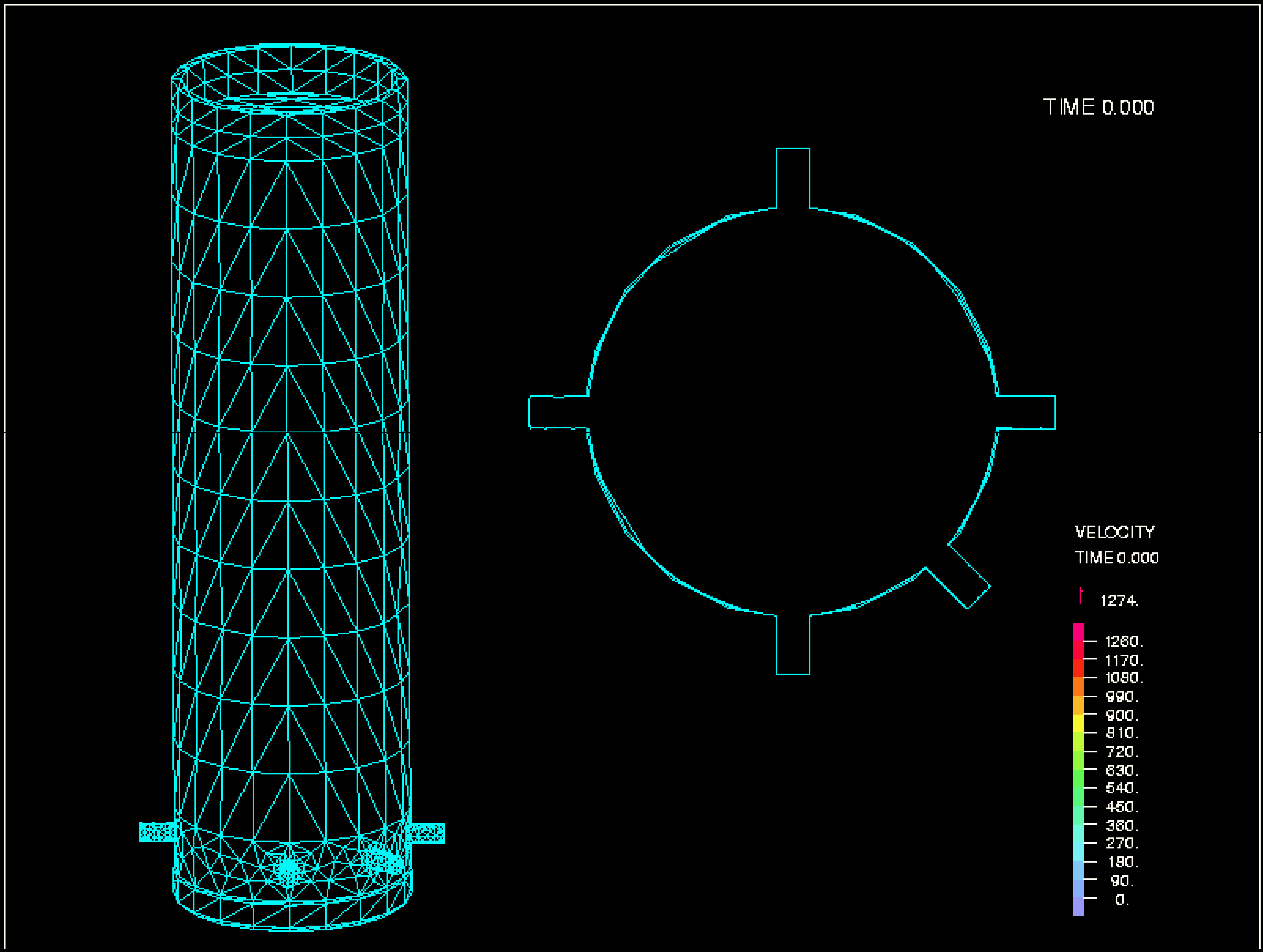


Fluid mesh

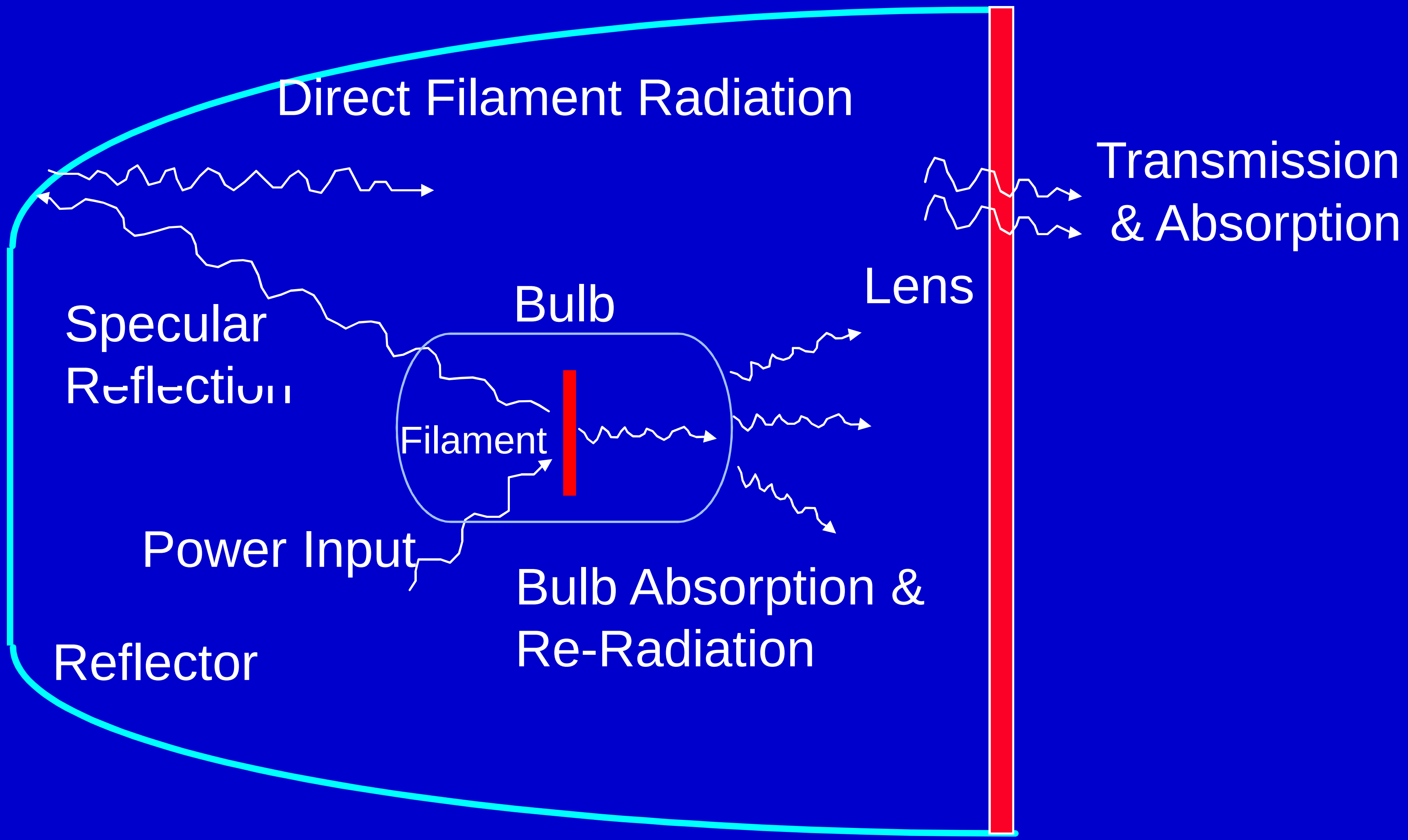
Shock absorber



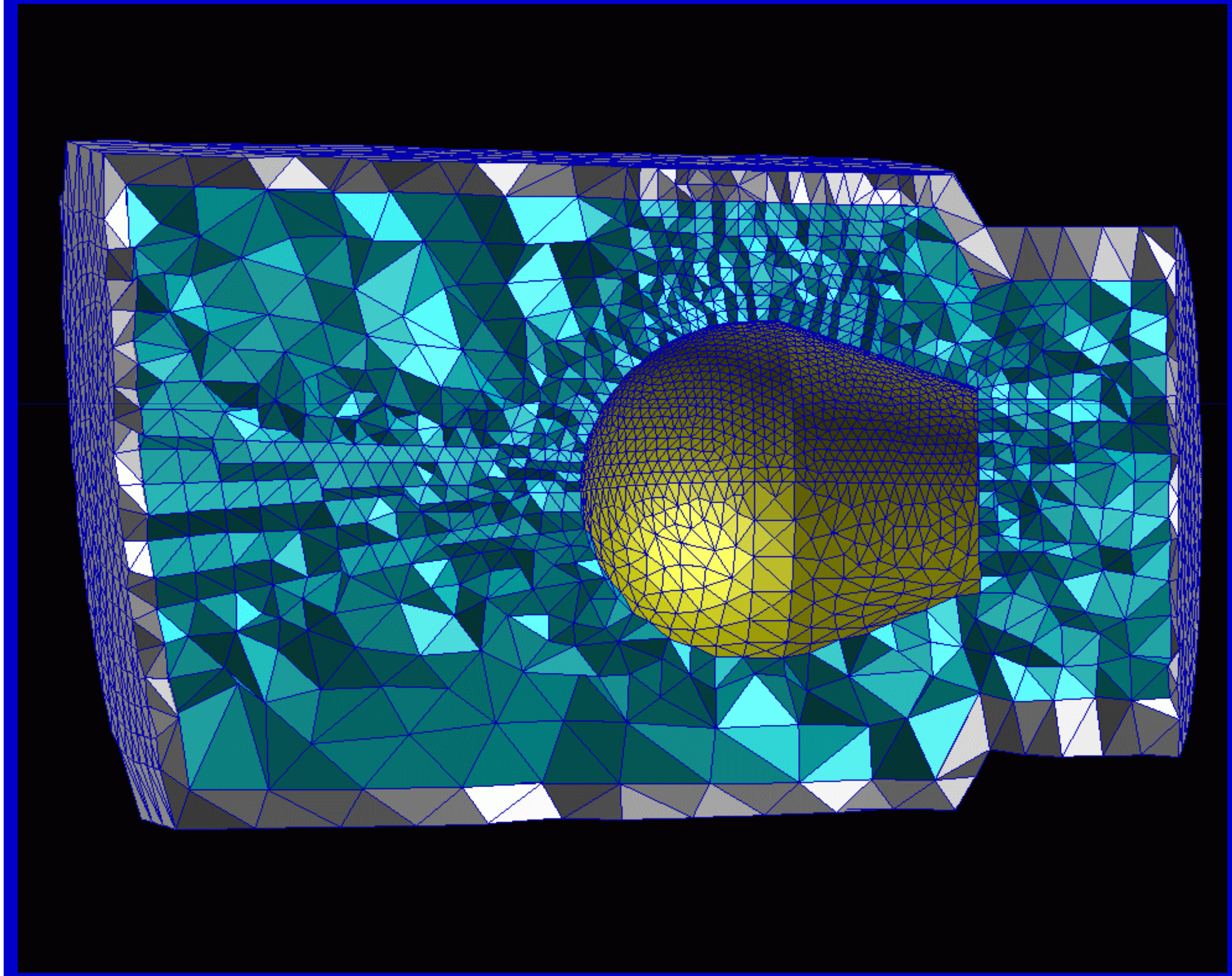
Shock absorber



Specular Radiation Model



Lamp Internal Air Volume Mesh

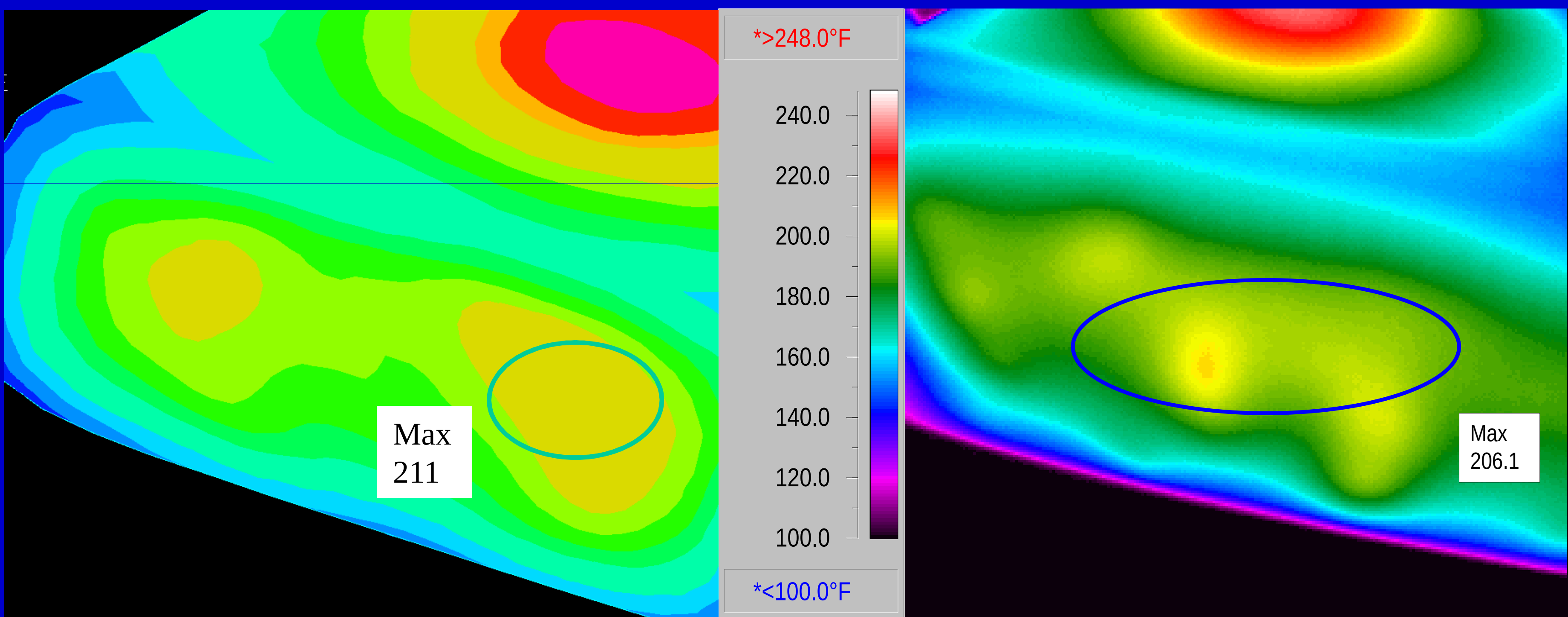


- 200,000 Tet Elements
- Smooth Transitioning
- Localized Mesh Refinement

Lens Temperature

Predicted

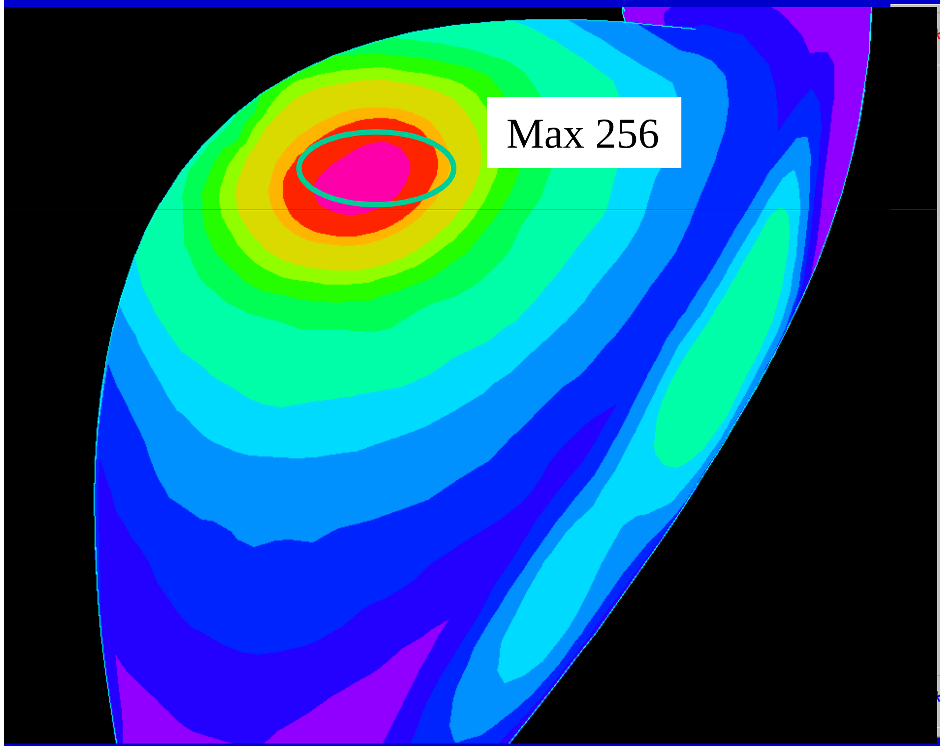
Measured

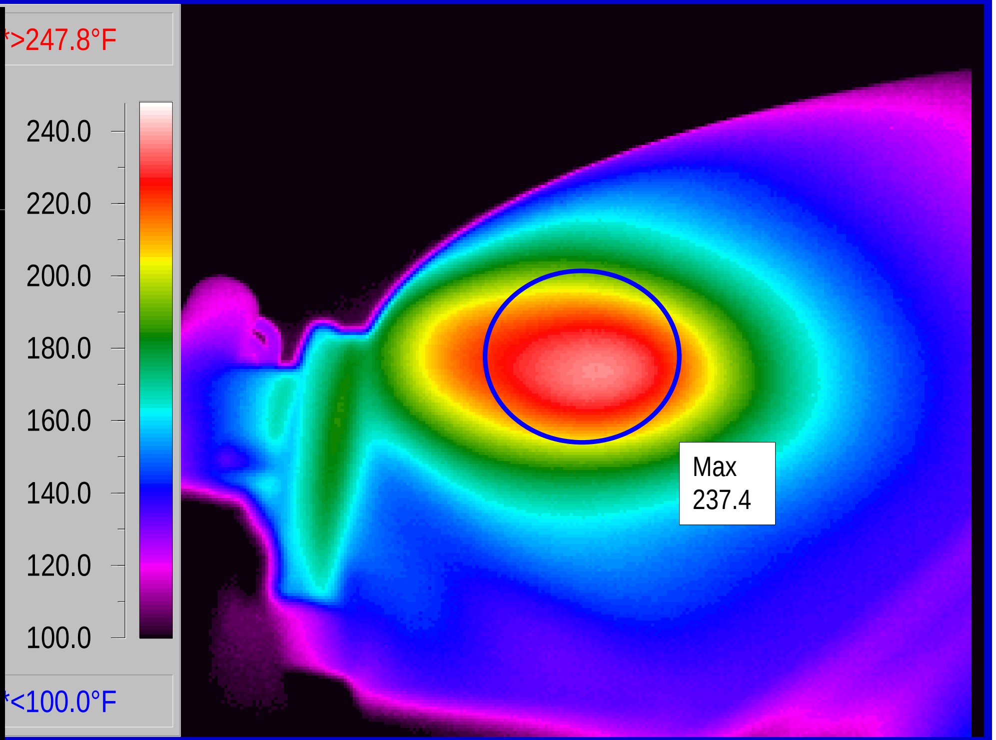


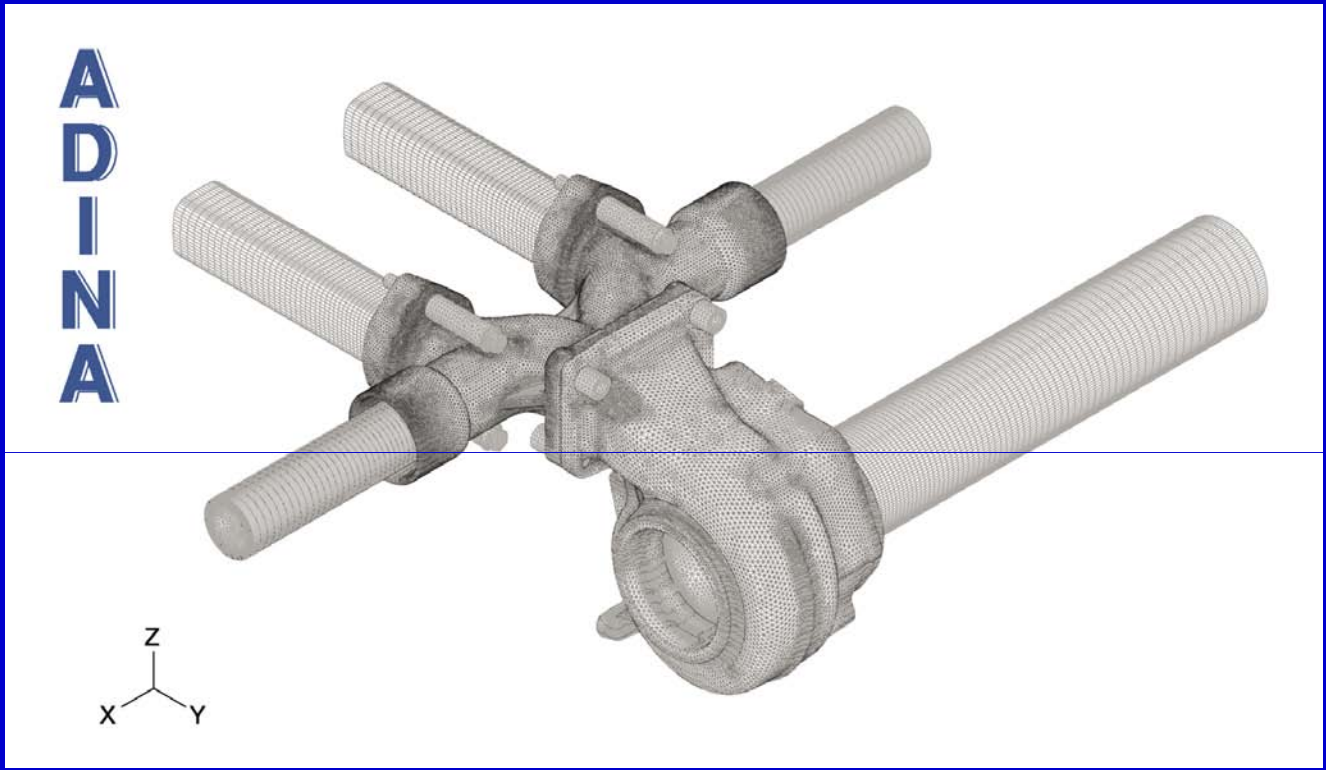
Signal Housing Temperature

Predicted

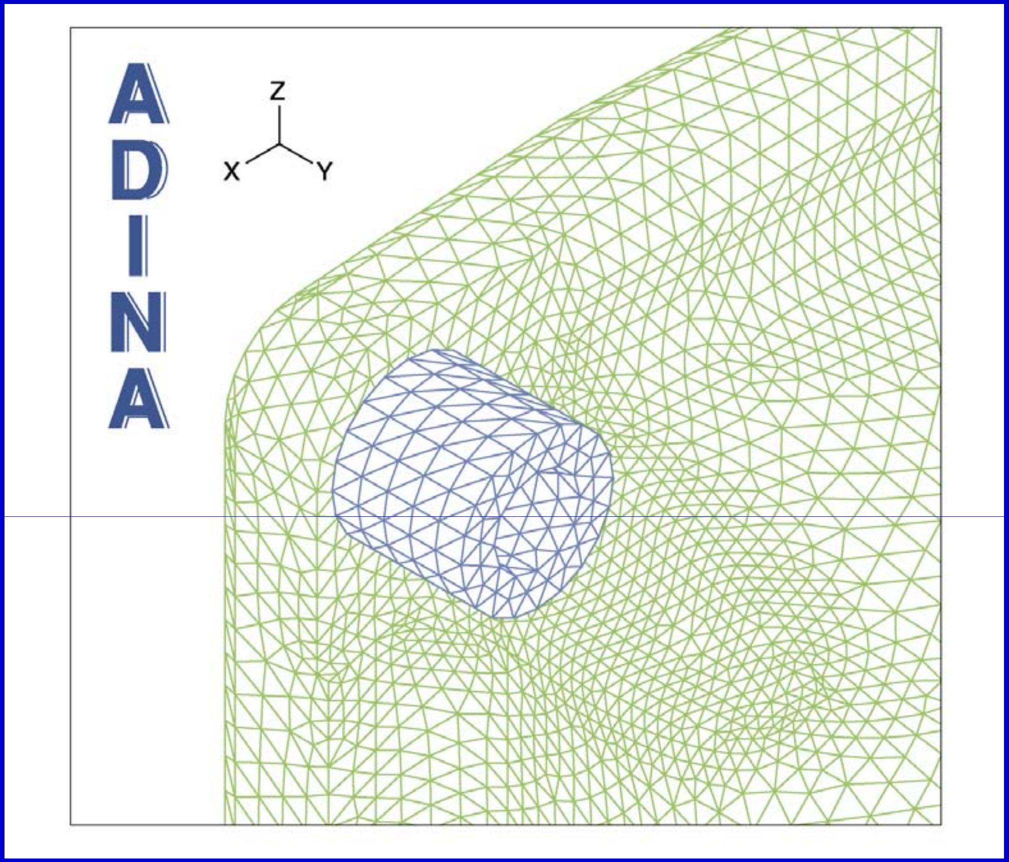
Measured



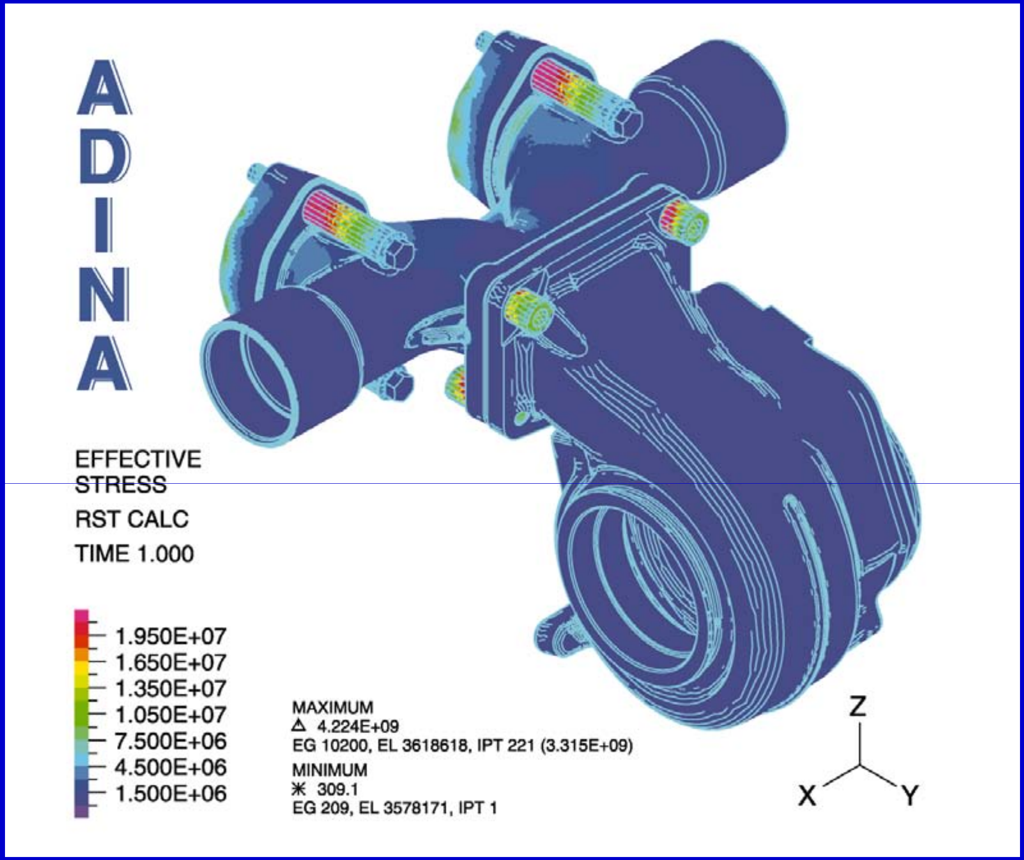




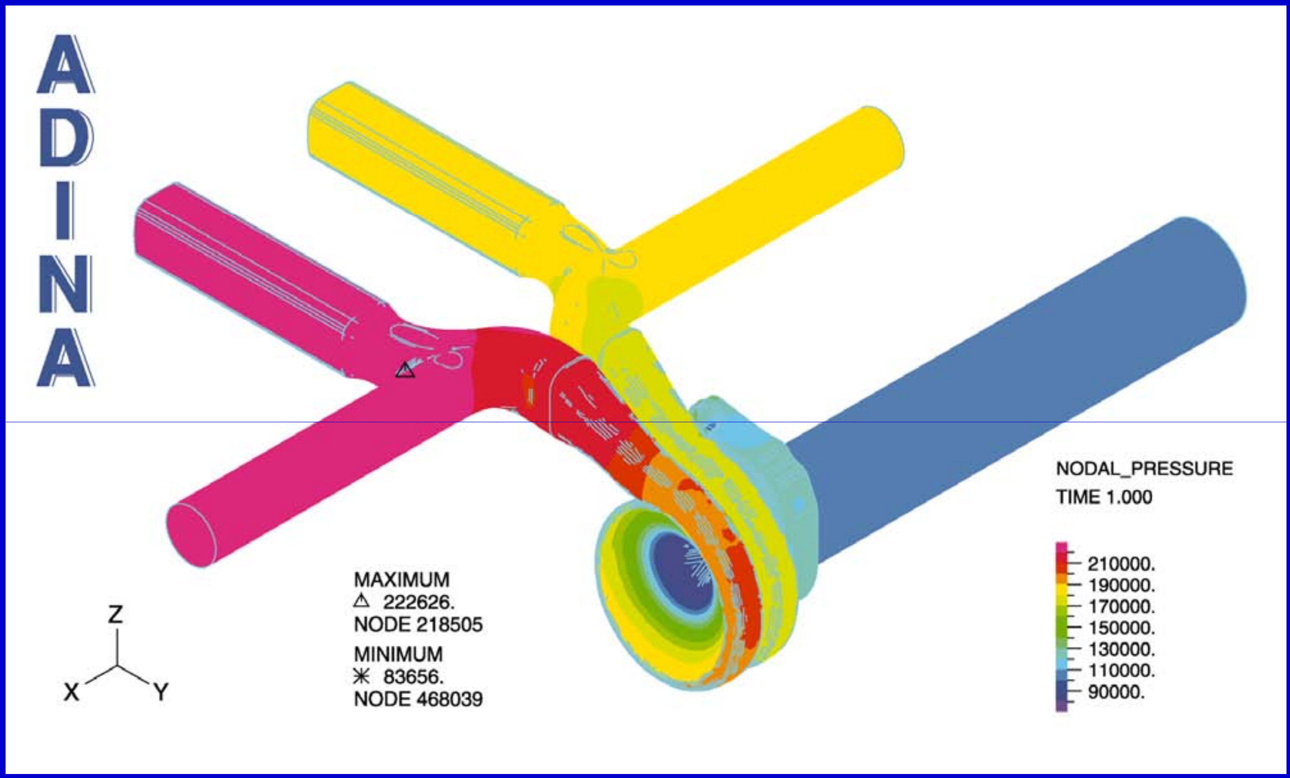
Exhaust Manifold Mesh



Detail showing mesh mismatch

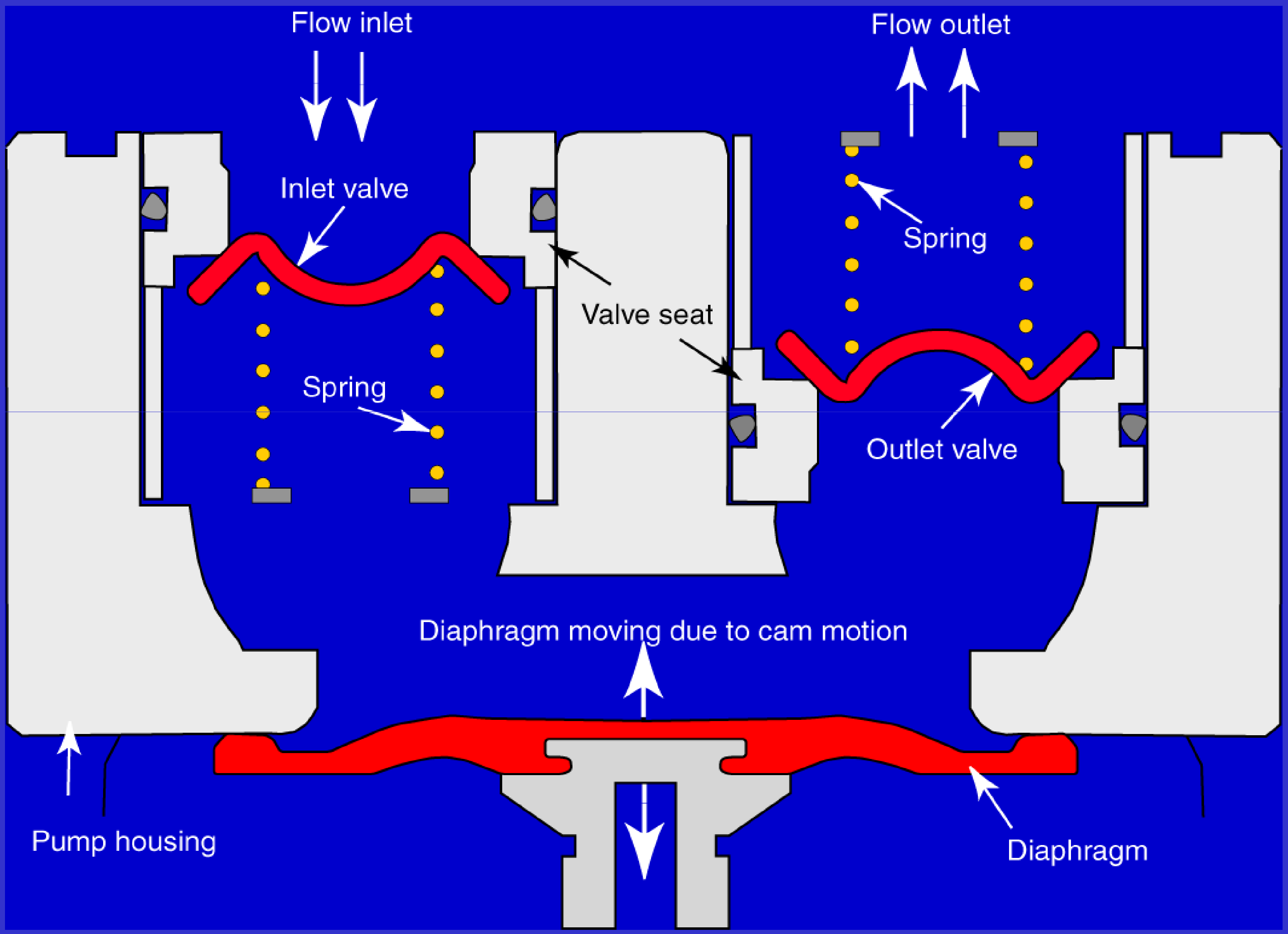


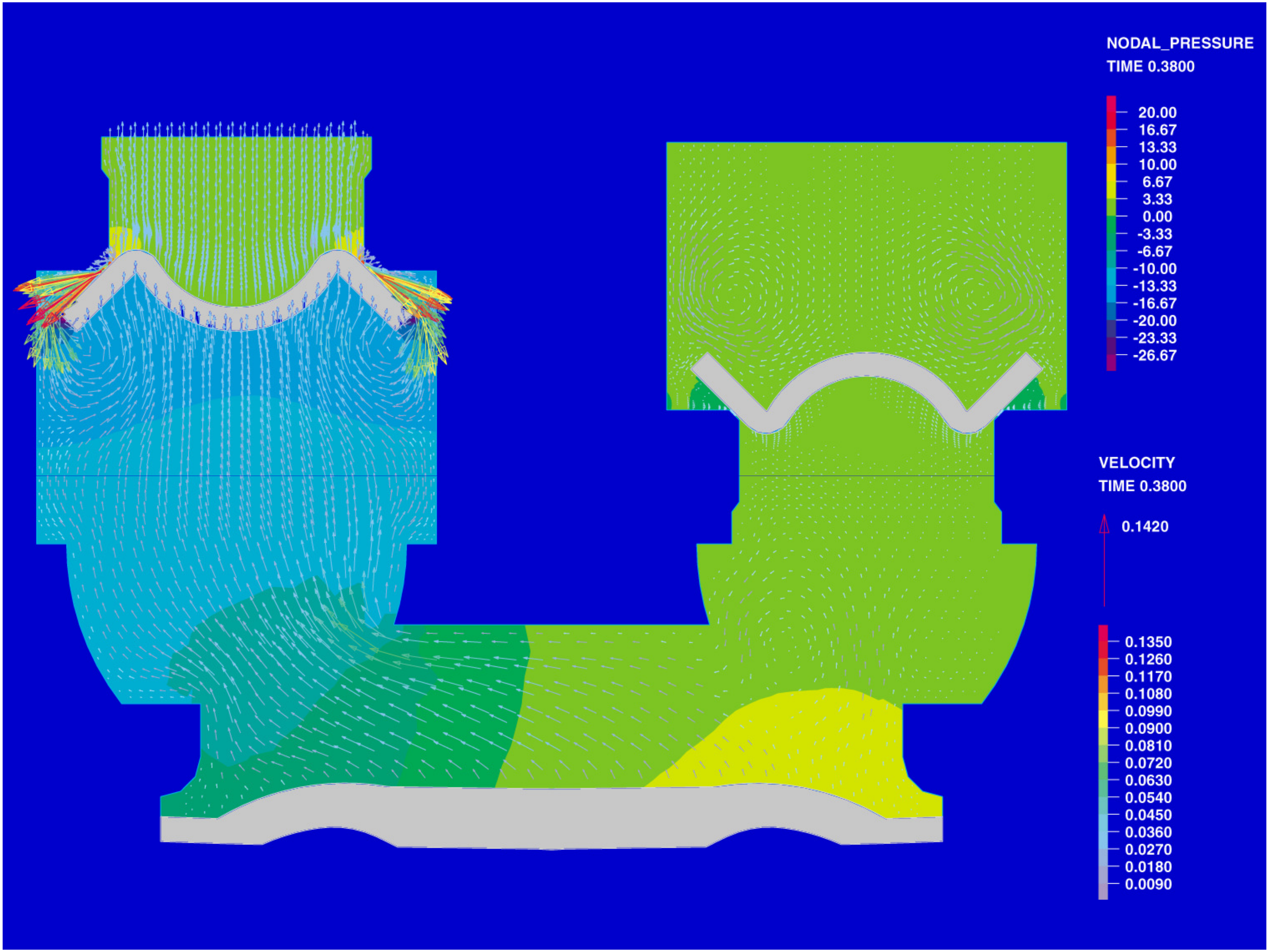
Plot of effective stress in the solid



Plot of pressure in the fluid

Fuel pump

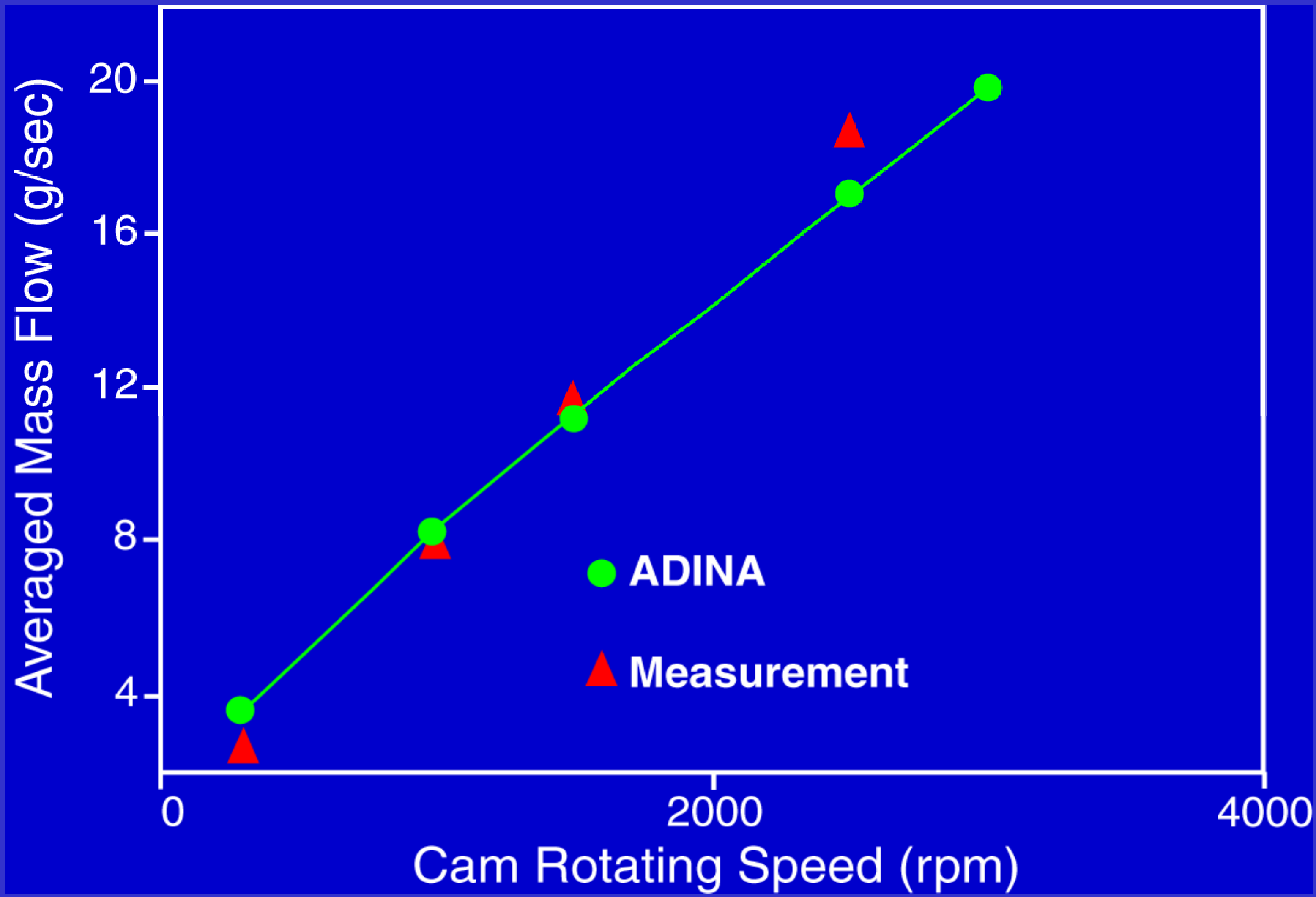

Flow inlet
Flow outlet
Inlet valve
Spring
Valve seat
Spring
Outlet valve
Diaphragm moving due to cam motion
Pump housing
Diaphragm



NODAL_PRESSURE
TIME 0.3800
20.00
16.67
13.33
10.00
6.67
3.33
0.00
-3.33
-6.67
-10.00
-13.33
-16.67
-20.00
-23.33
-26.67
VELOCITY
TIME 0.3800
0.1420
0.1350
0.1260
0.1170
0.1080
0.0990
0.0900
0.0810
0.0720
0.0630
0.0540
0.0450
0.0360
0.0270
0.0180
0.0090


NODAL_PRESSURE
TIME 0.2500
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
VELOCITY
TIME 0.2500
0.2165
0.2100
0.1950
0.1800
0.1650
0.1500
0.1350
0.1200
0.1050
0.0900
0.0750
0.0600
0.0450
0.0300
0.0150
0.0000

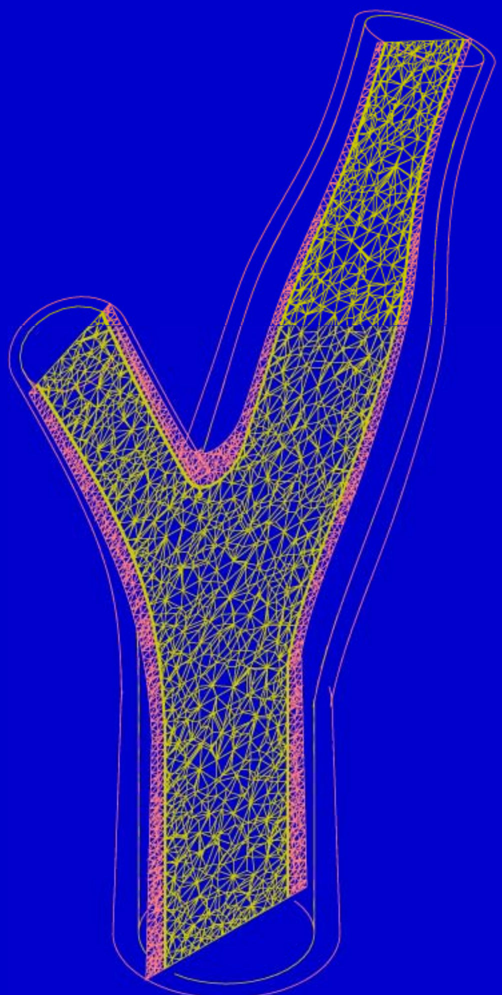
Fuel pump



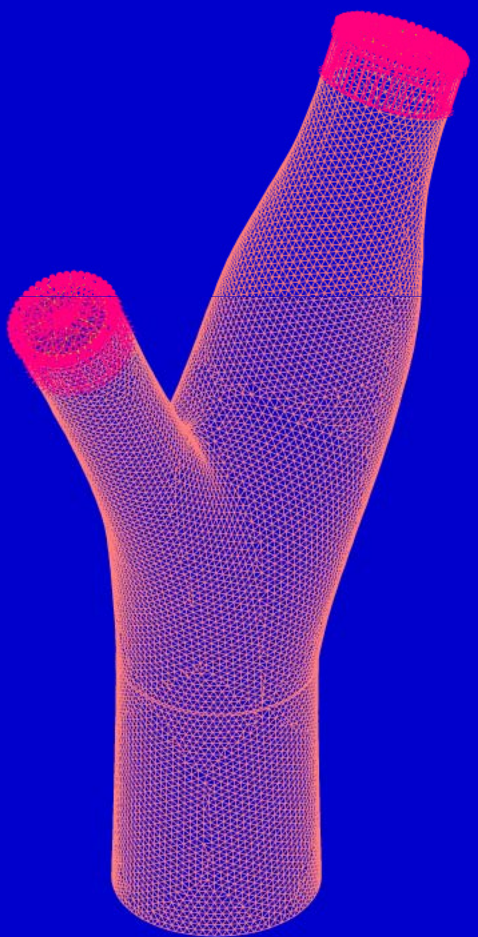
Averaged Mass Flow (g/sec)
20
16
12
8
4
0
2000
4000
Cam Rotating Speed (rpm)
ADINA
Measurement

Blood flow through an artery

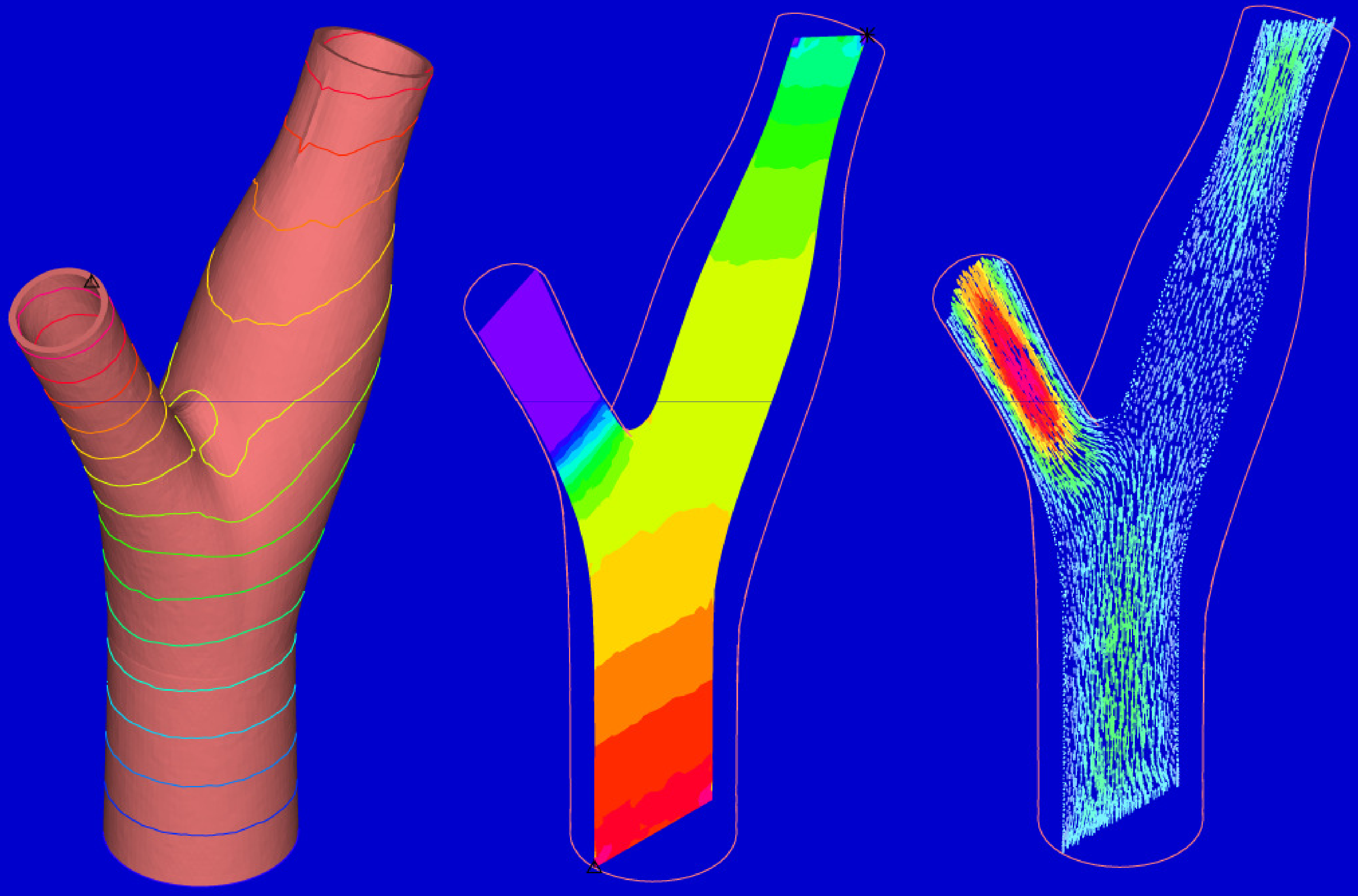
Fluid mesh



Solid mesh



Blood flow through an artery



Blood flow through a stenotic artery

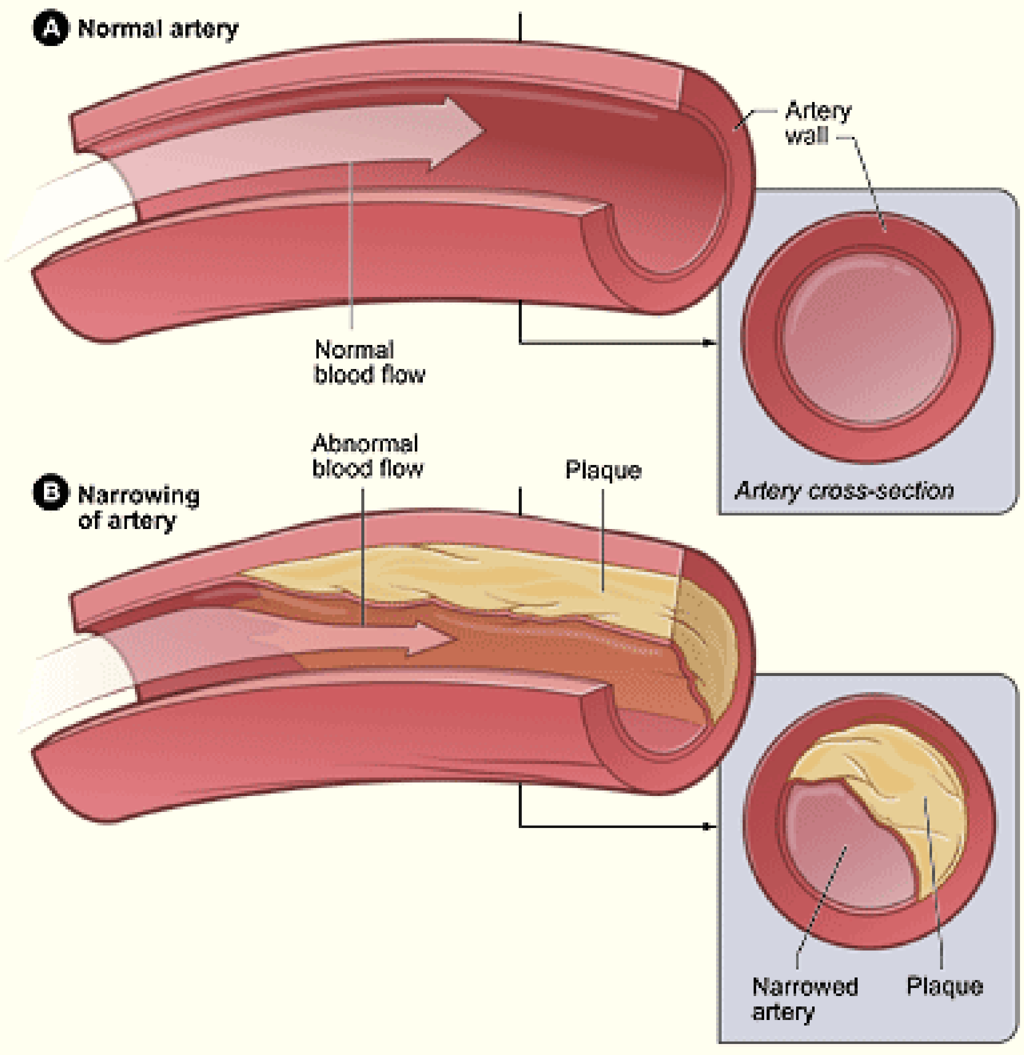
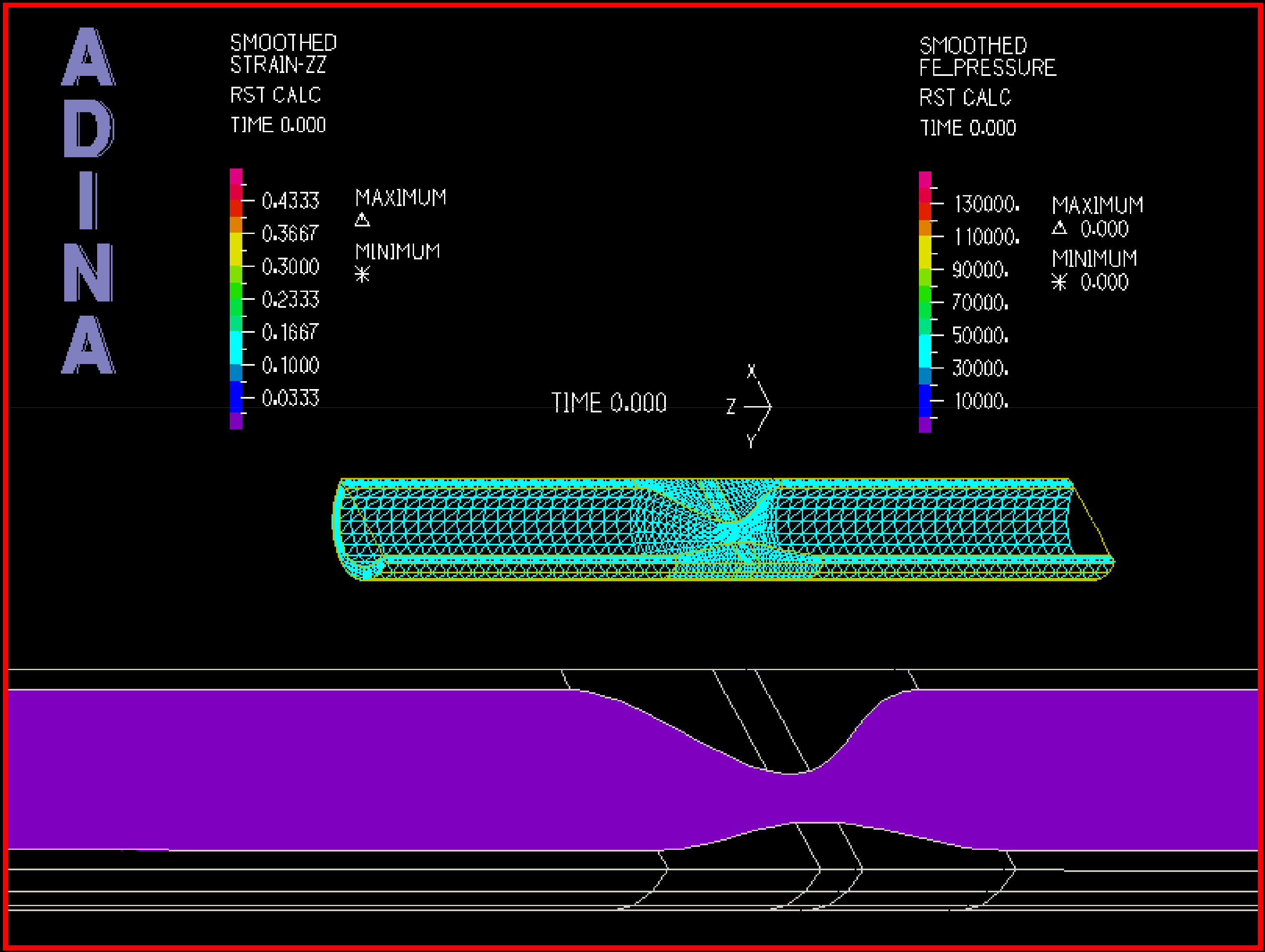


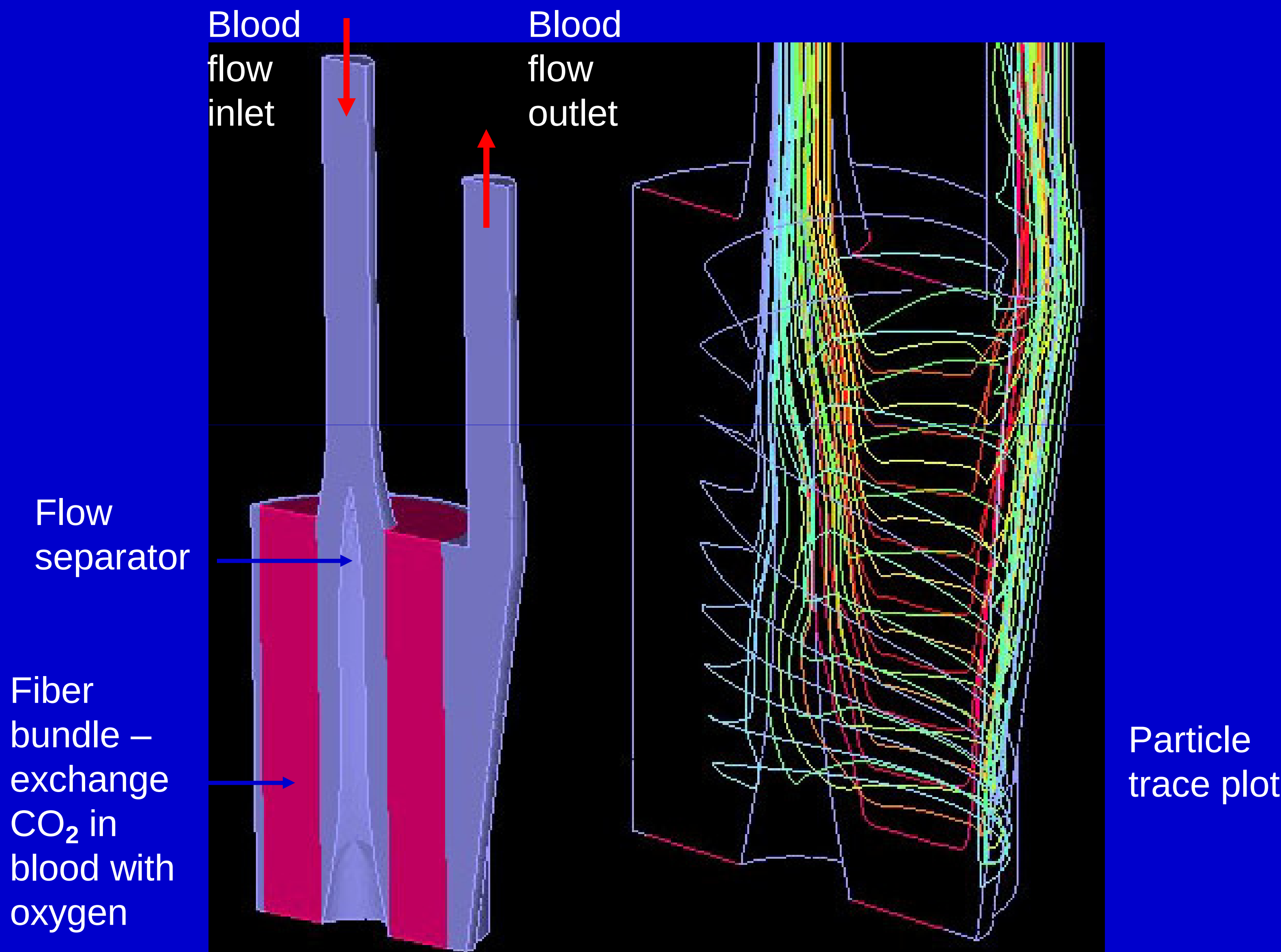
Image by the National Heart, Lung, and Blood Institute.

Blood flow through a stenotic artery



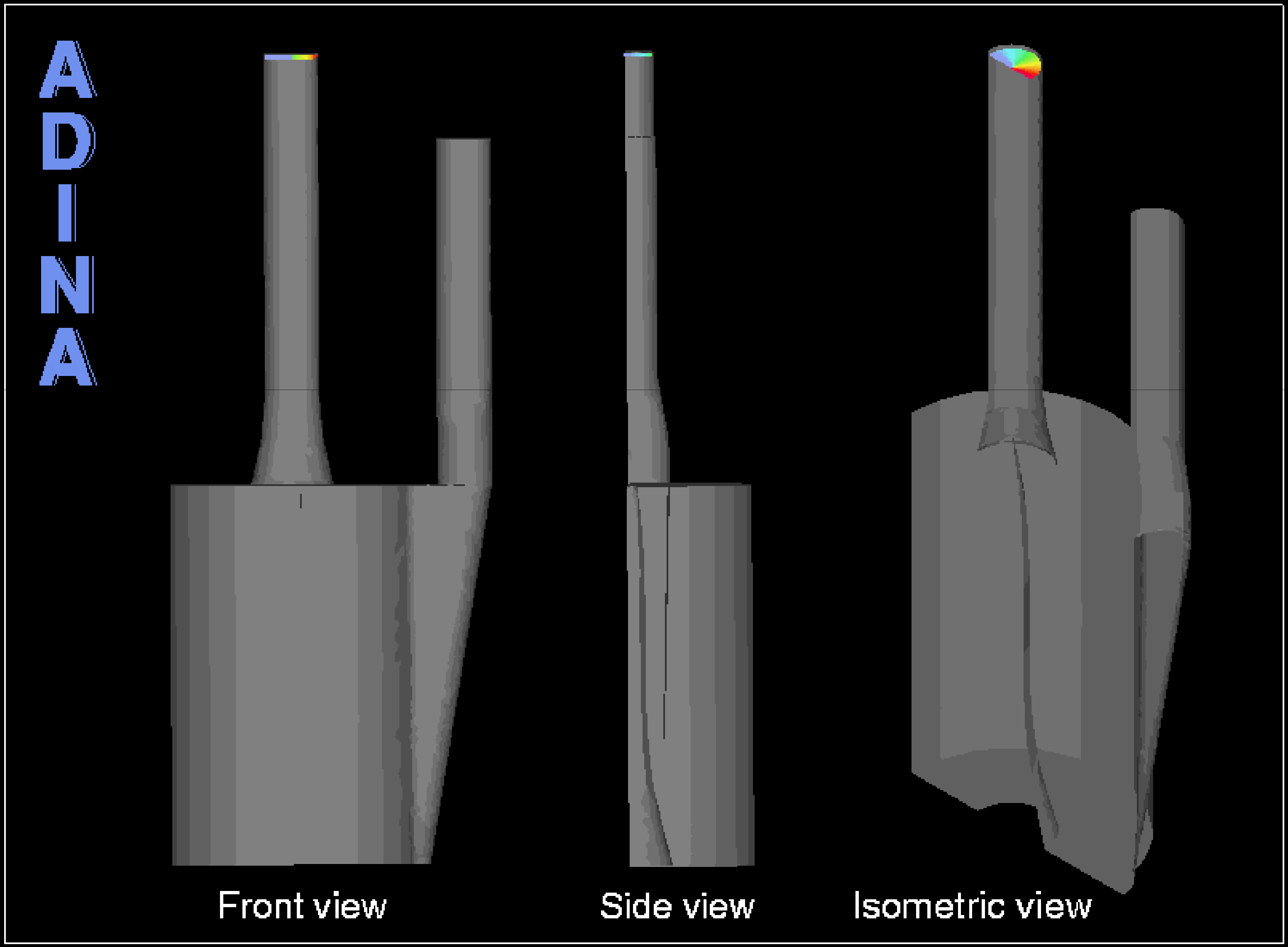
Analysis of an artificial lung

Artificial Lung


Blood
flow
inlet
Blood
flow
outlet
Flow
separator
Fiber
bundle –
exchange
CO_2 in
blood with
oxygen
Particle
trace plot

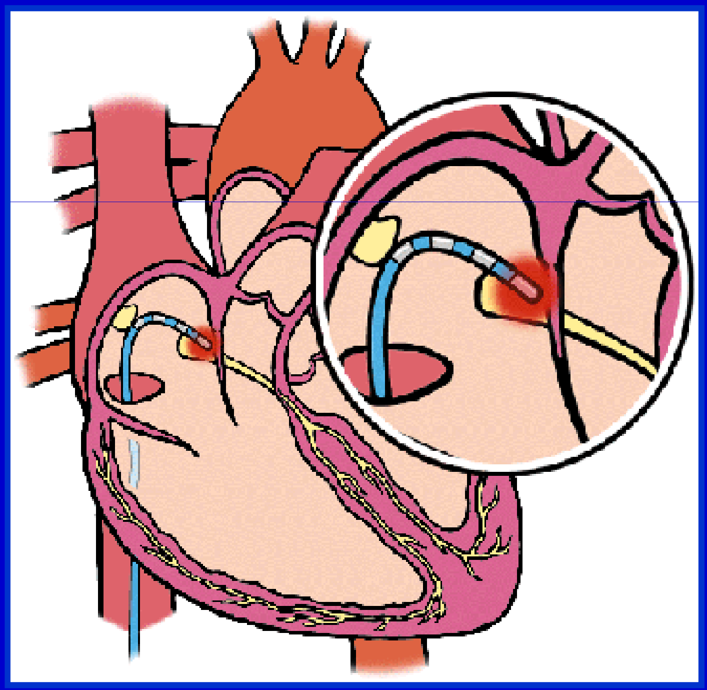
Analysis of an artificial lung

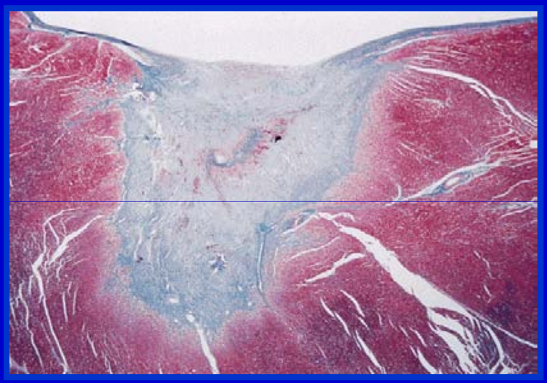
Particle trace



Radio-frequency tissue ablation

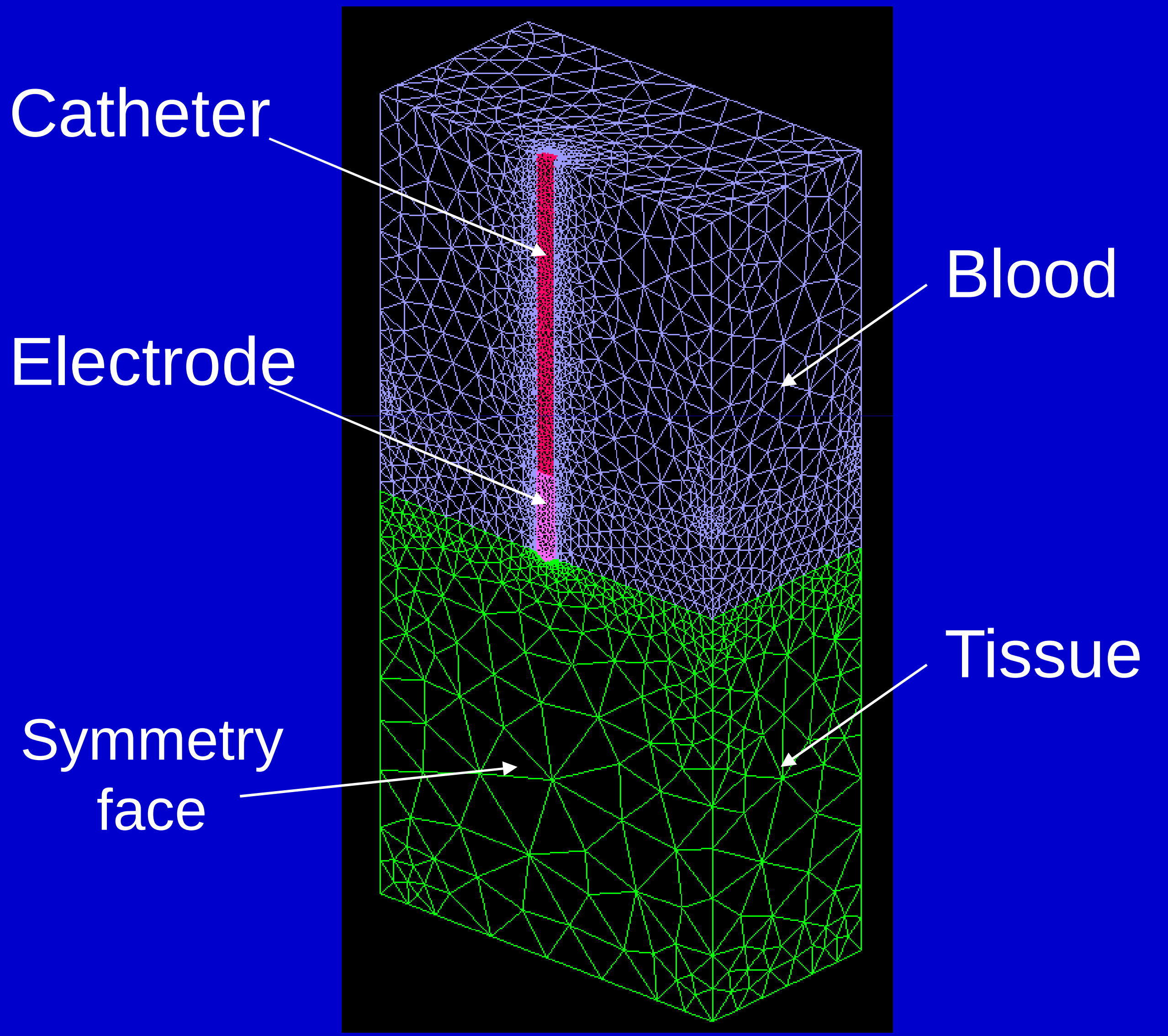
Electrode



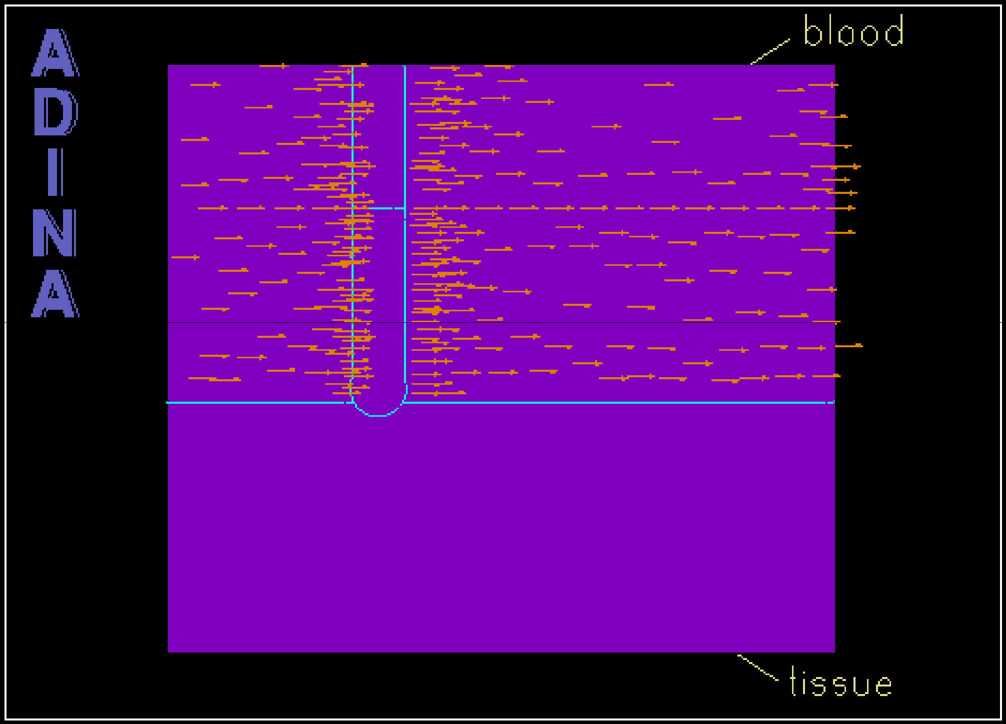


Lesion

Radio-frequency tissue ablation



Radio-frequency tissue ablation



Temperature variation during ablation cycle

So, why study finite element analysis?
because --

You learn modern analysis techniques used widely in engineering practice and the sciences

You learn how to establish computational models of problems of solids and fluids, solve them on a laptop, and assess the accuracy of the results

You capitalize on your knowledge of mechanics, reinforce your knowledge, and solve problems that can only be tackled numerically on the computer

Great knowledge in your "toolbox" whatever your goals!

2.092 / 2.093 Finite Element Analysis of Solids and Fluids I
Fall 2009