

Elastomer Analysis Using MARC

**Prepared for: Elastomer - Fea Forum '99 3rd International Symposium on
Finite Element Analysis of Rubber and Rubber-like Materials**



**May 19th and 20th, 1999
The University of Akron
E. J. Thomas Hall
Akron, Ohio USA**

Organized by: Akron Rubber Development Laboratory, Inc. (ARDL)



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Vita for Dr. Daniel S. Wolf

Daniel S. Wolf received his Ph. D., M.S. and B.S. in Aeronautical Engineering from the School of Aeronautics and Astronautics at Purdue University. As a graduate instructor he taught many undergraduate mechanics and laboratory courses. He studied under Professor C.T. Sun and specialized in continuum mechanics. His thesis title was “Some Problems on Interfacial Cracks”. Upon graduation in 1976, he became an assistant professor, responsible for teaching, research, and expanding laboratory and computing facilities in the department of Ocean Engineering at Florida Atlantic University in Boca Raton Florida. In 1979 he became a project engineer responsible for an advanced finite element group to insure the proper utilization of all structural analysis simulation programs used by many engineers at Pratt & Whitney. He has significant experience with finite element application programs and computing systems including nonlinear thermal/structural analysis of hot section engine components such as combustors and turbine airfoils. He was awarded patent 4,477,222 titled “Mounting Construction for Turbine Vane Assembly”, in 1984. In 1989 he moved on to MARC Analysis Research Corporation and became responsible for customer service, where he remains today in the service of MARC’s valued customers.

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What Is New About Neo-Hookean?

Hookean (1660)

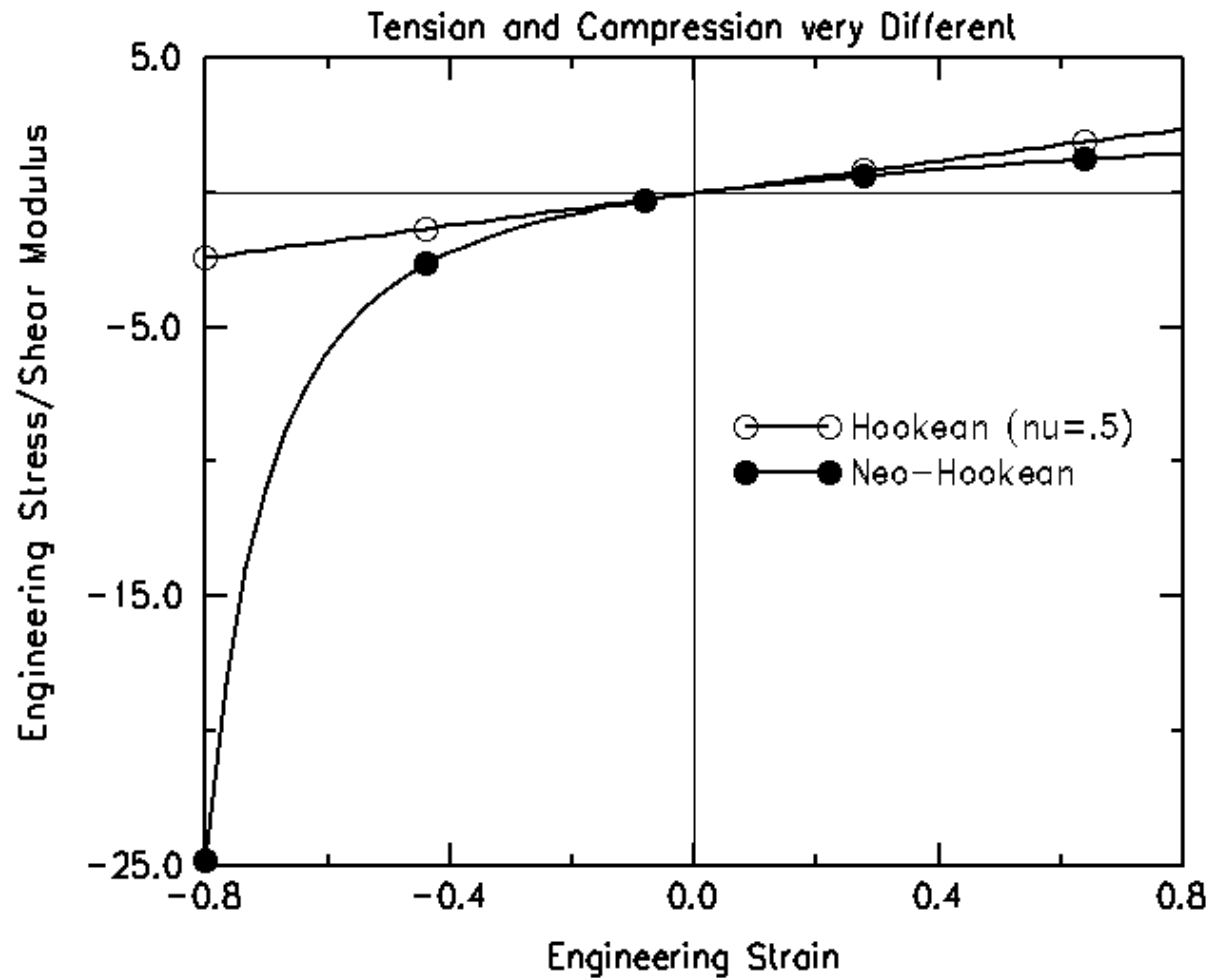
$$\sigma = 2(1 + \nu)G\varepsilon$$

$$\tau = G\gamma$$

Neo-Hookean (1940)

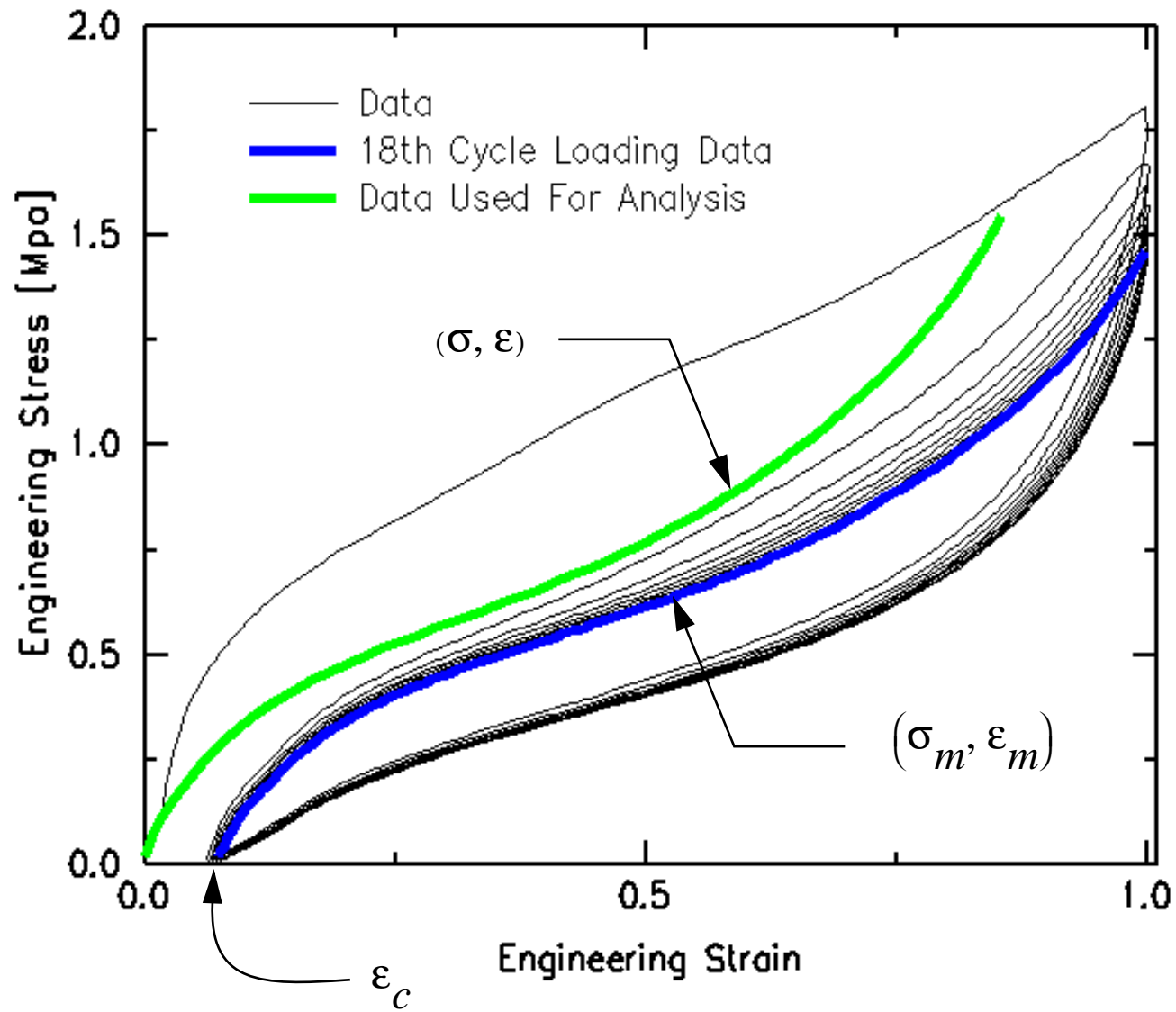
$$\sigma = G[(1 + \varepsilon) - (1 + \varepsilon)^{-2}]$$

$$\tau = G\gamma$$



Reduce Measured Data And Fit For Analysis

Equal Biaxial Test



Fit Uniaxial Compression Data To 2 Term Mooney

ELASTOMER/RUBBER DATA FIT

MATERIAL MODELS

PHENOMENOLOGICAL MODELS

MOONEY-RIVLIN

NEO-HOOKEAN

MOONEY(2)

MOONEY(3)

SIGNIORINI

SECOND ORDER INVARIANT

THIRD ORDER DEFORMATION

YEOH

OTHER

OGDEN

FOAM

DAMAGE MODELS

DAMAGE

VISCO-ELASTICITY

SHEAR RELAXATION

BULK RELAXATION

ENERGY RELAXATION

SCALE AXES

PLOT OPTIONS

ALL: SELECT VISIBLE OUTLINE

EXIST UNSEL INVIS SURFACE

SELECT END LIST (#)

RETURN MAIN

MOONEY(2) CONTROL PARAMETERS

☒ UNIAXIAL

☐ BIAXIAL

☐ PLANAR SHEAR

☐ SIMPLE SHEAR

☐ INVOLUTMETRIC

☐ USE ALL DATA

☐ POSITIVE COEFFICIENTS

EXTRAPOLATION

RELATIVE ERROR

COEFFICIENTS

C10 0.054073

C01 0.322352

BULK MODULUS 0

ERROR 1.91638

COMPUTE

APPLY

RESET

OK

EVALUATE

0

0

(x.1)

8

□-□-□ uniaxial/experiment

— biaxial/mooney2

— simple_shear/mooney2

— uniaxial/mooney2

— planar_shear/mooney2

Too Stiff

Fit Biaxial Data To 2 Term Mooney

ELASTOMER/RUBBER DATA FIT

MATERIAL MODELS

PHENOMENOLOGICAL MODELS

MOONEY-RIVLIN

NEO-HOOKEAN

MOONEY(2)

MOONEY(3)

SIGNIORINI

SECOND ORDER INVARIANT

THIRD ORDER DEFORMATION

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DAMAGE MODELS

DAMAGE

VISCO-ELASTICITY

SHEAR RELAXATION

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SCALE AXES

PLOT OPTIONS

ALL: SELECT VISIBLE OUTLINE
EXIST: UNSEL INVIS SURFACE
SELECT END LIST (#)
RETURN MAIN

MOONEY(2) CONTROL PARAMETERS

☐ UNIAXIAL
☐ BIAXIAL
☐ PLANAR SHEAR
☐ SIMPLE SHEAR
☐ INVOLUMETRIC
☒ USE ALL DATA
☐ POSITIVE COEFFICIENTS
EXTRAPOLATION
RELATIVE ERROR

COEFFICIENTS

C10 0.25308

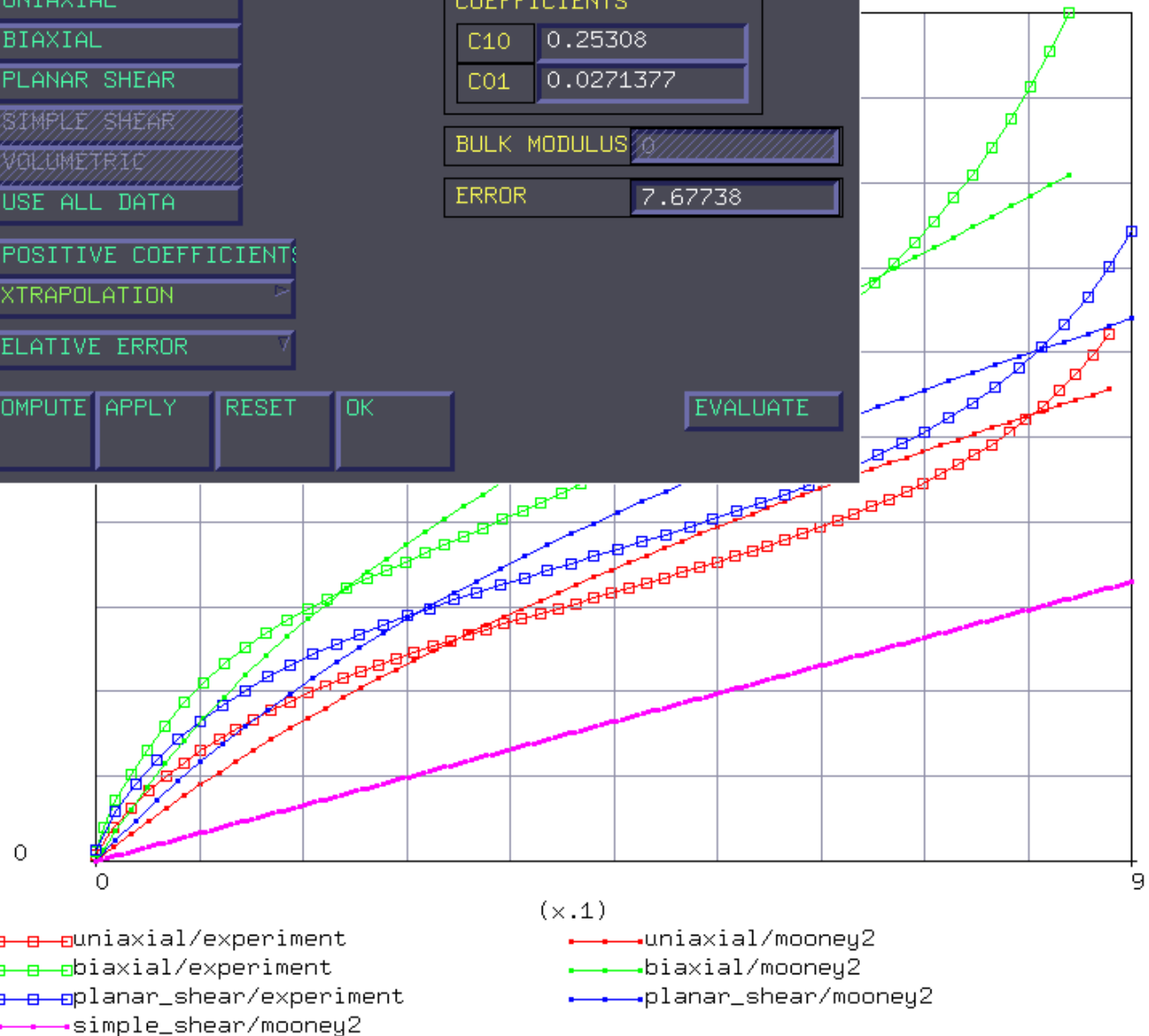
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BULK MODULUS 0

ERROR 7.67738

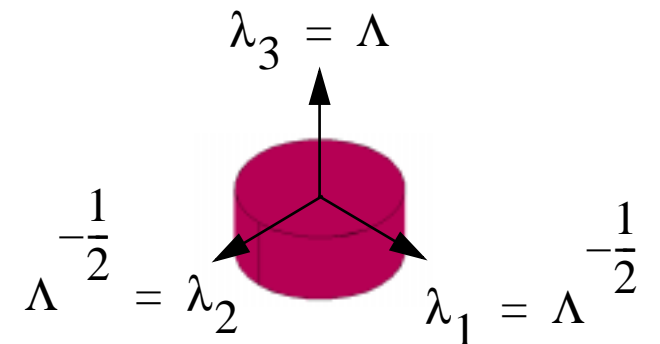
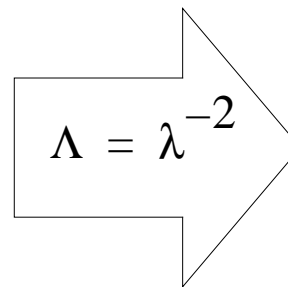
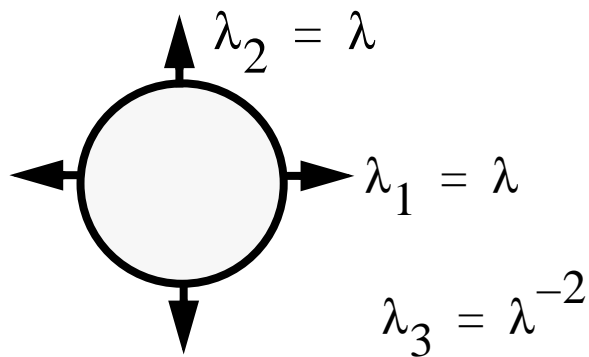
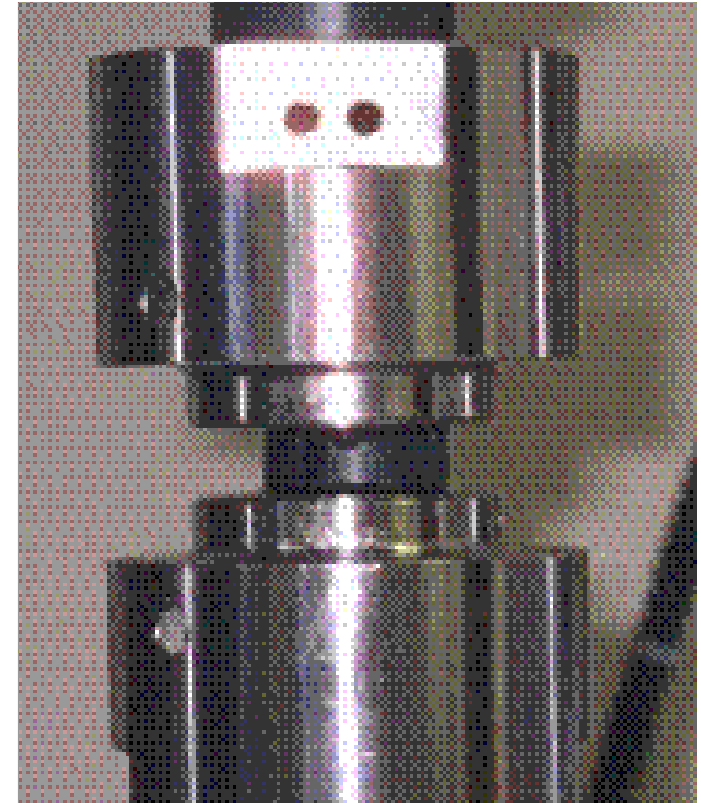
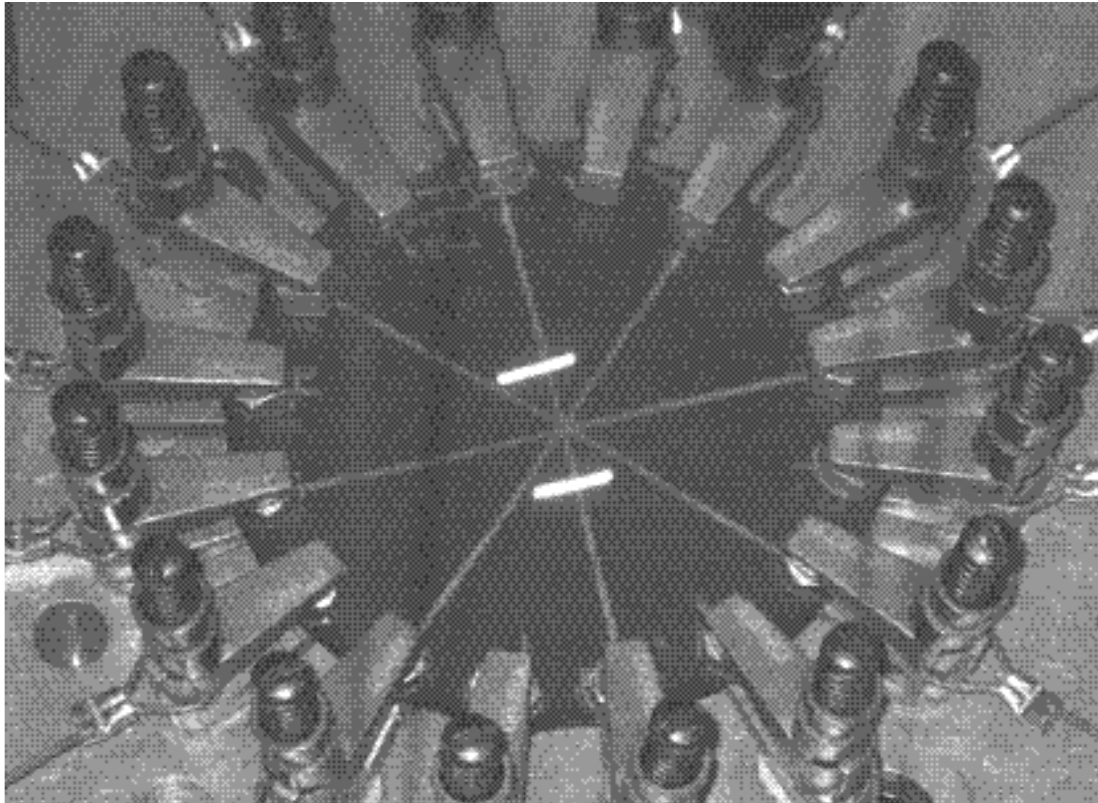
COMPUTE APPLY RESET OK

EVALUATE



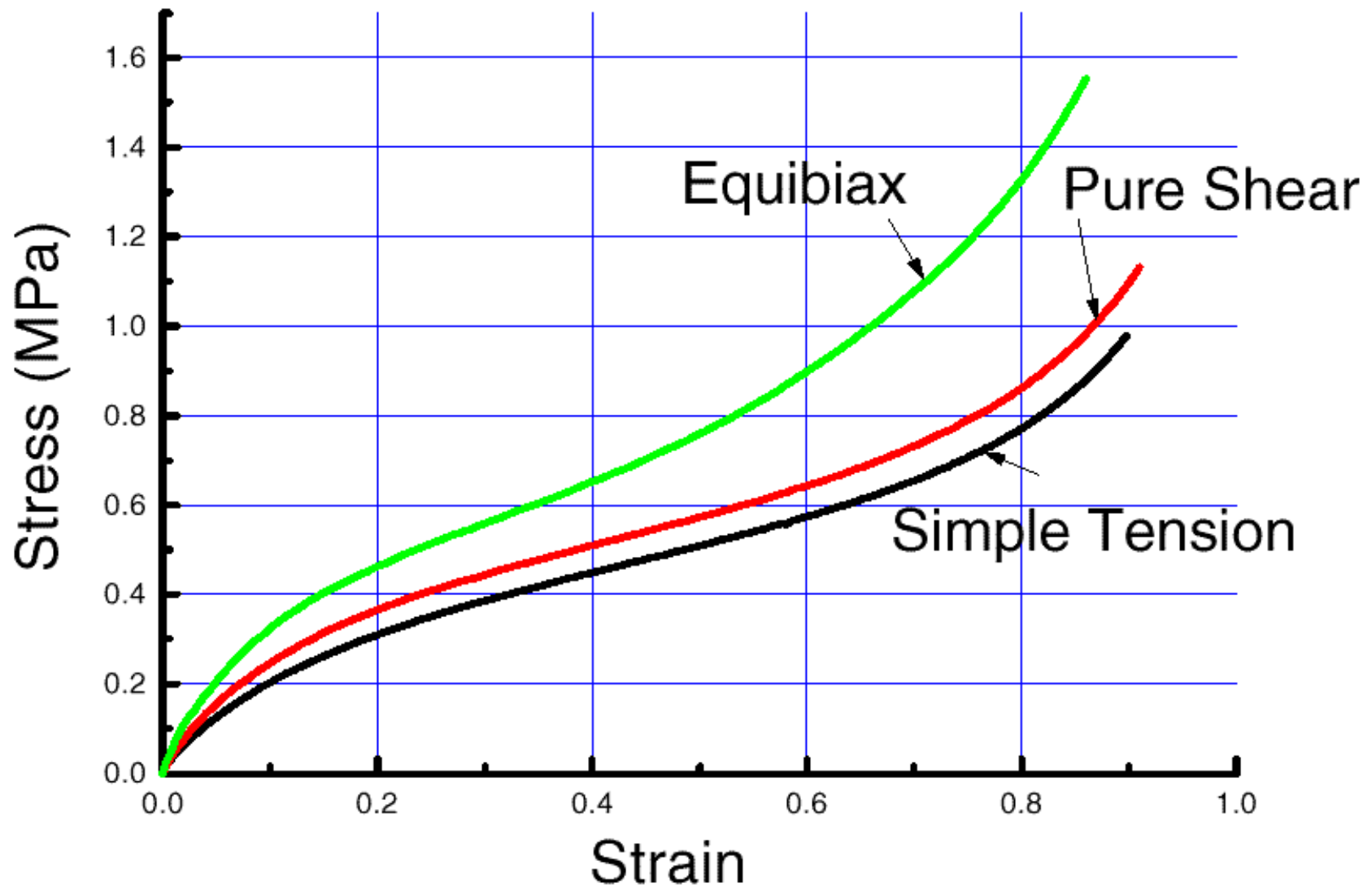
Biaxial Tension = Compression Strain State

Biaxial Tension is the same strain state as compression and is more reliable.



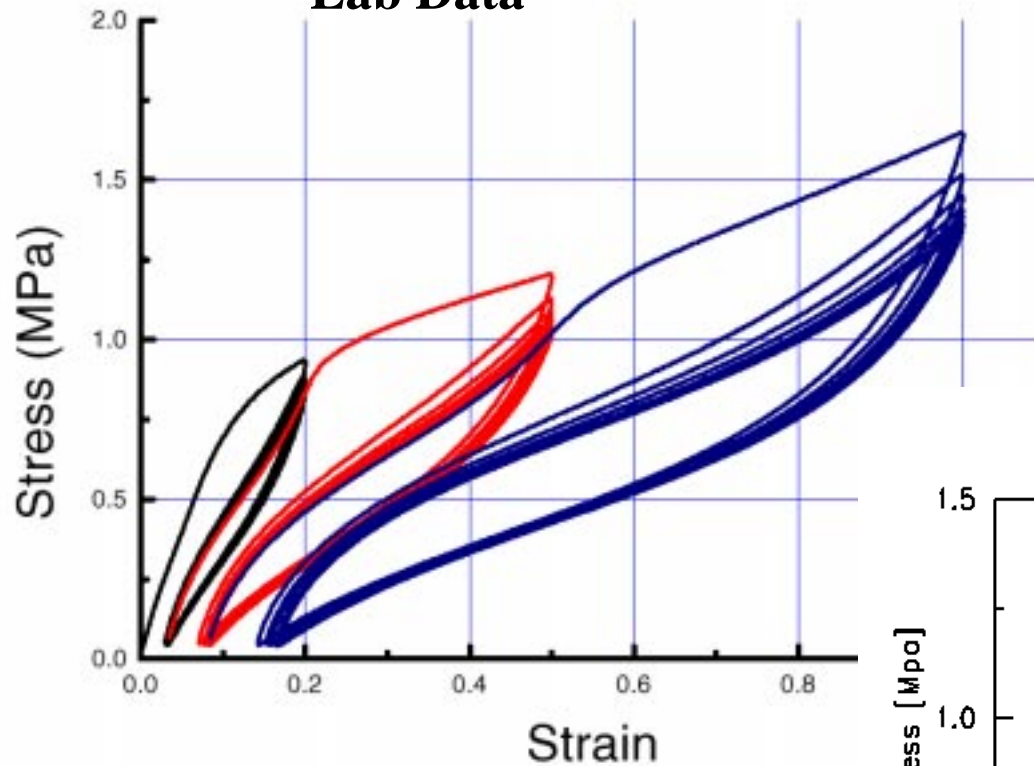
This Is A Reasonable Fit

Three Basic Strain States



Mullins Effect

Lab Data



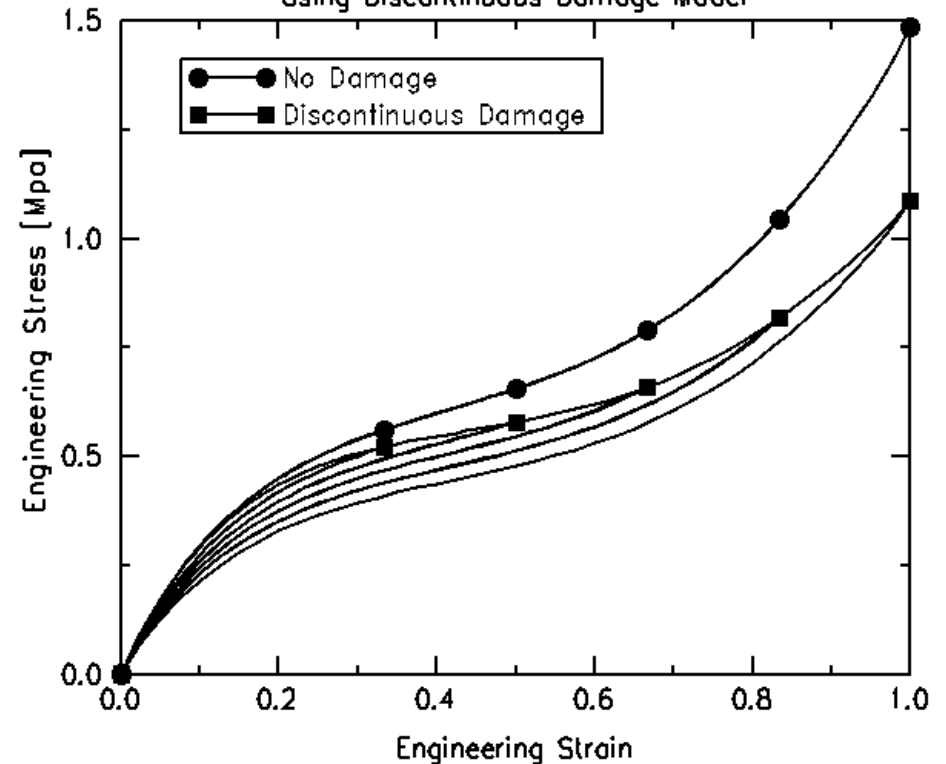
$$W = K(\alpha, \beta) W^0$$

The Kachanov factor, $K(\alpha, \beta)$, is implemented in MARC

Model Predictions

Modeling Mullins Effect

Using Discontinuous Damage Model

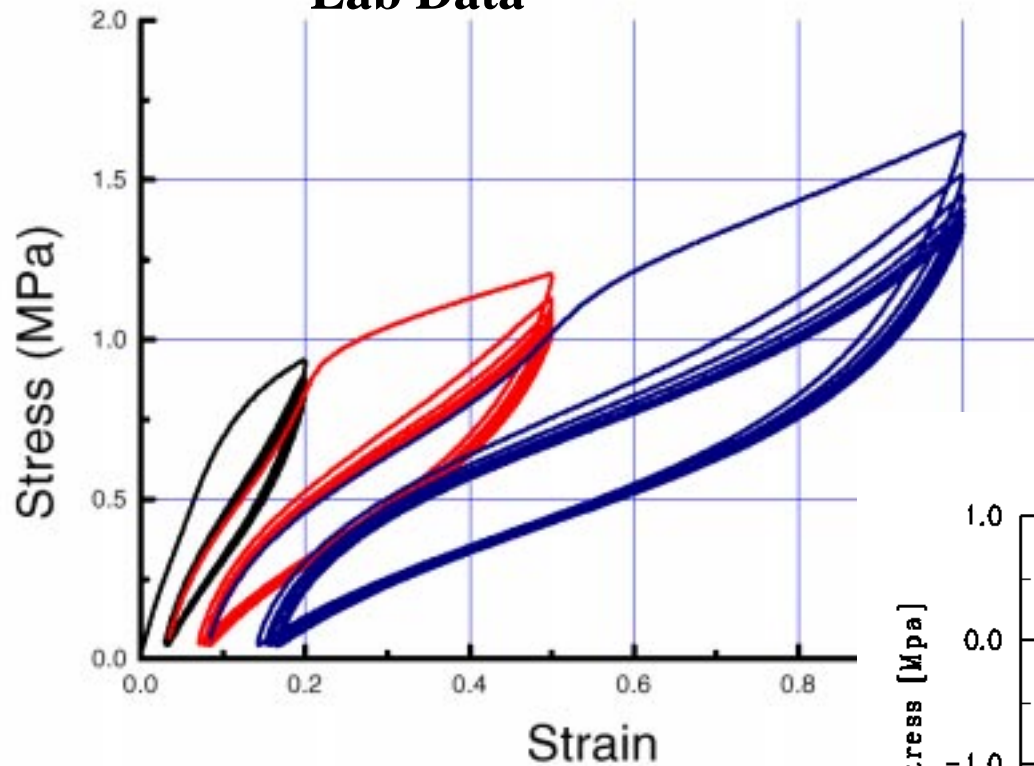


These factors can be entered directly or by fitting data in Mentat

DISCONTINUOUS (MULLINS) PARAMETERS			
SCALAR FACTORS		RELAXATION PARAMETERS	
1	0.9	1	3
2	0.1	2	10

Miehe Effect

Lab Data



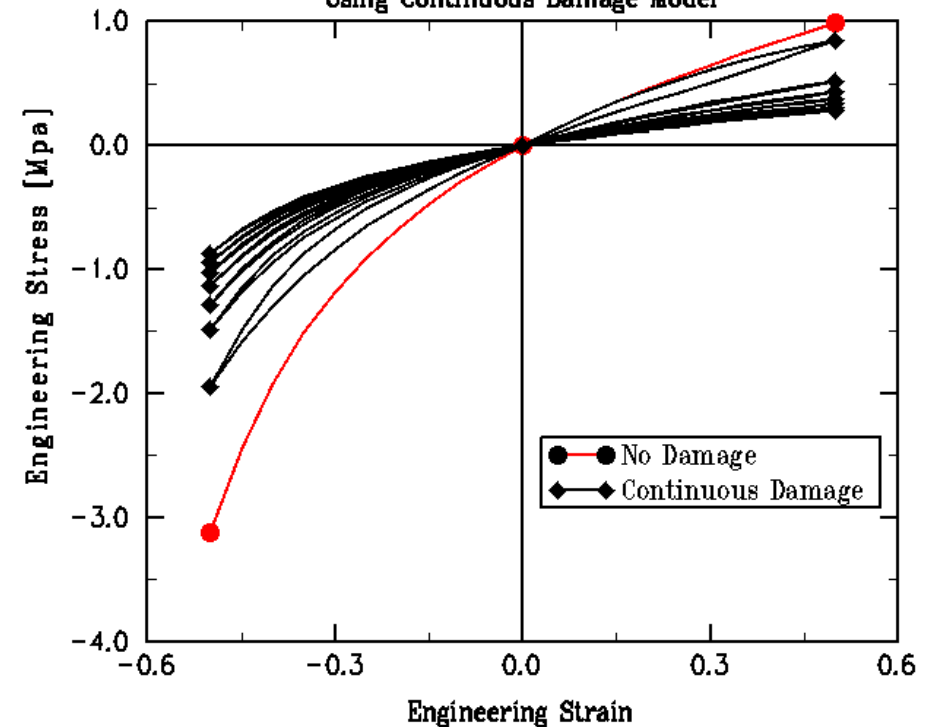
$$W = K(\alpha, \beta) W^0$$

The Kachanov factor, $K(\alpha, \beta)$, is implemented in MARC

Model Predictions

Modeling Miehe Effect

Using Continuous Damage Model

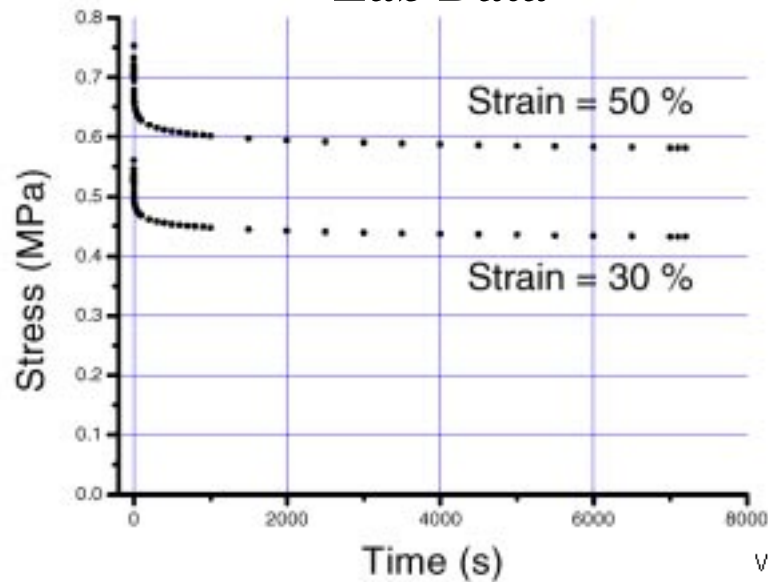


These factors can be entered directly or by fitting data in Mentat

CONTINUOUS (MIEHE) PARAMETERS			
SCALAR FACTORS		RELAXATION PARAMETERS	
1	0	1	1
2	0	2	1

Viscoelastic Effects

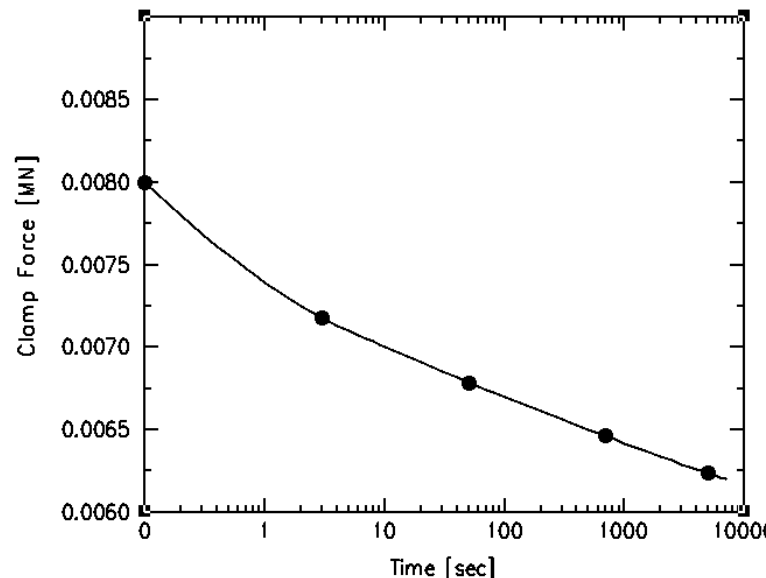
Lab Data



$$W = W^{\infty} + \sum_{n=1}^N W^n \exp(-t/\lambda^n)$$

**Prony series coefficients
generated by Mentat**

Clamp Force Decay

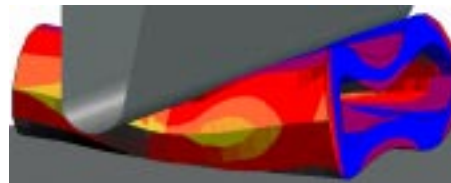


VISCO-ELASTICITY SHEAR RELAXATION CONTROL PARAMETERS

☒ RELAXATION

NUMBER OF TERMS

3



COEFFICIENTS

	LINEAR	RELAXATION TIME
1	0.111552	0.748714
2	0.0727897	41.4902
3	0.0638807	1441.73
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
LONG	0.908593	
SHOR	1.15682	

COMPUTE

APPLY

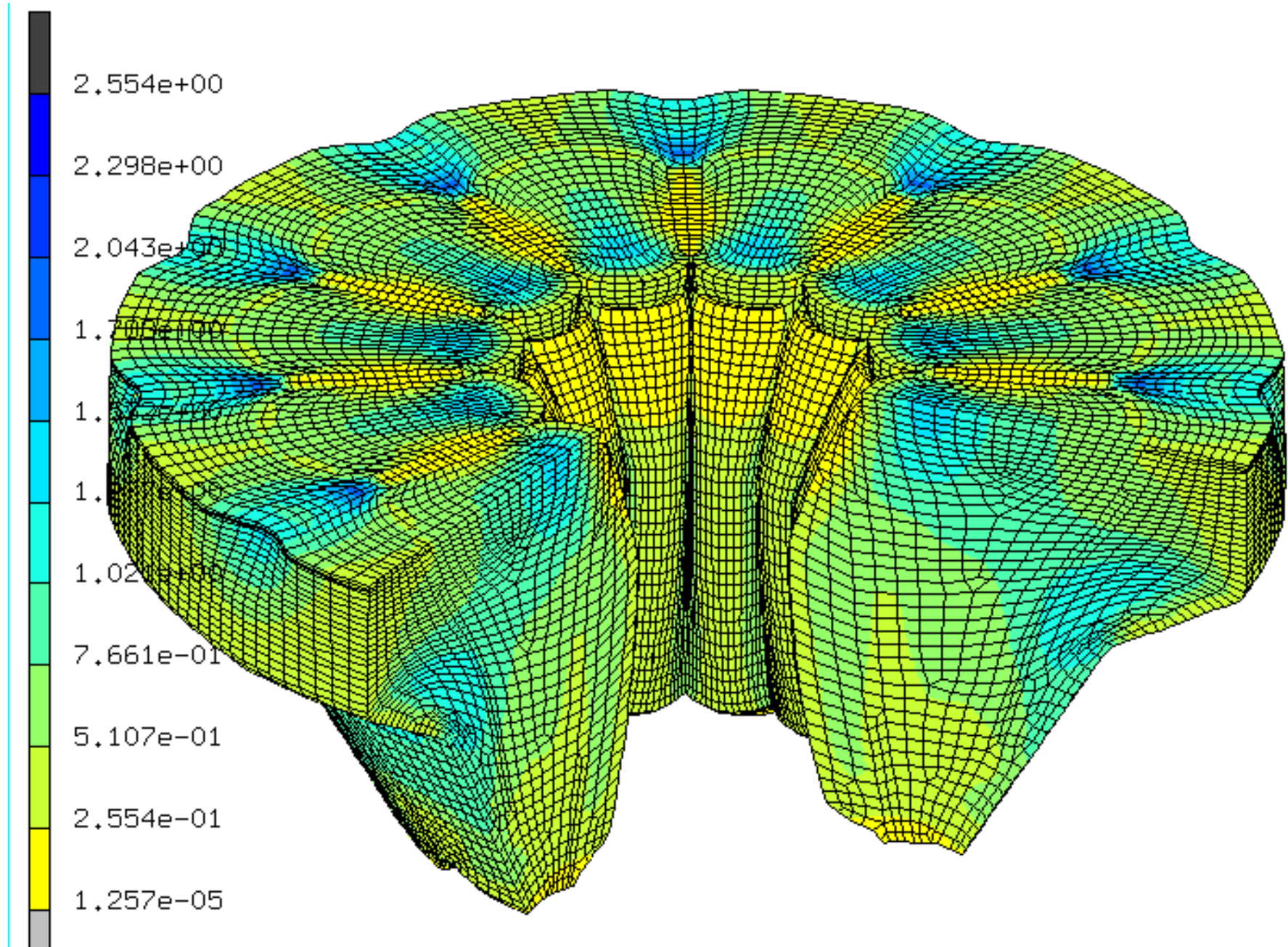
RESET

OK

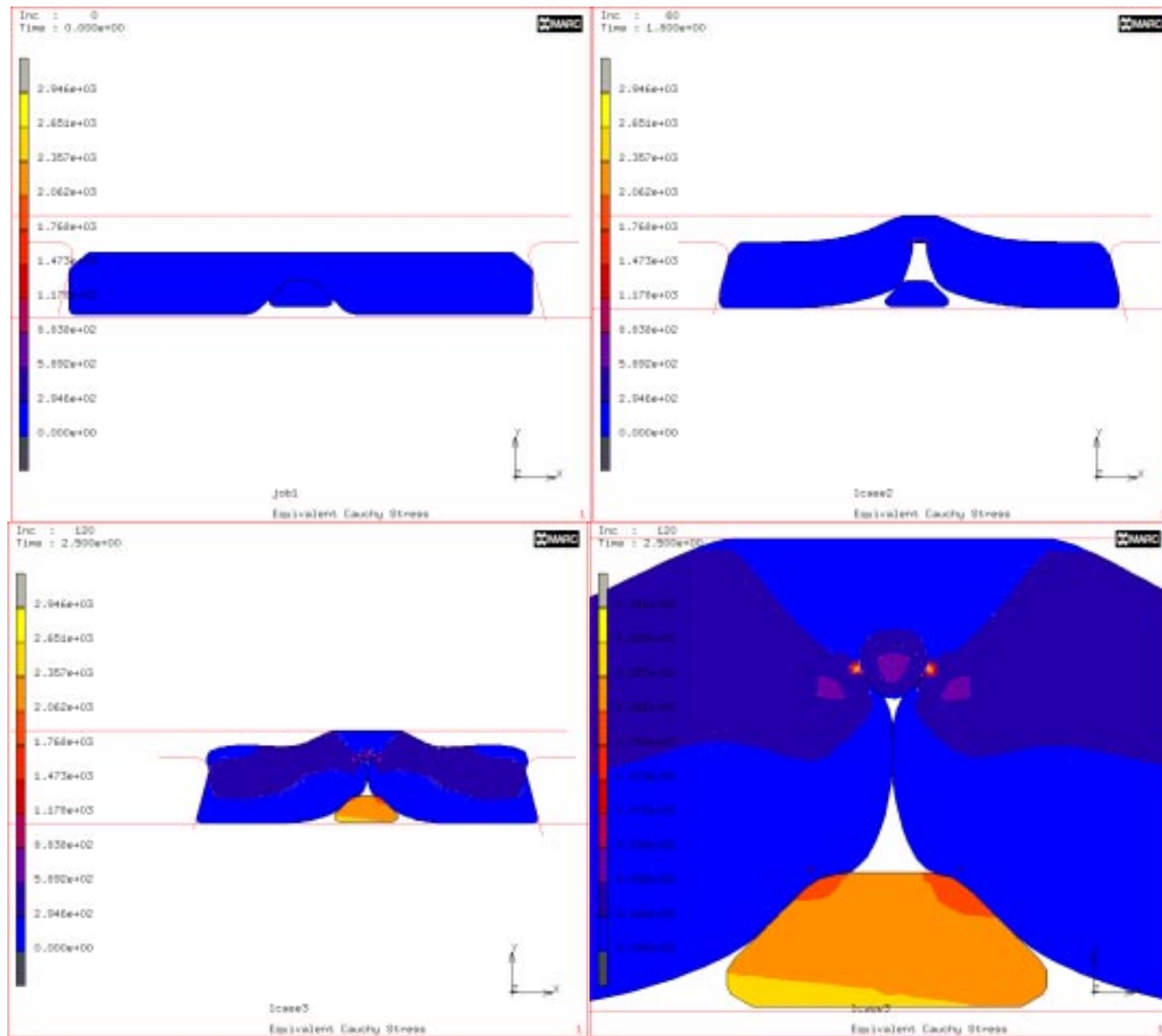
ERROR

0.000715663

3D Packer Seal



Axisymmetric Packer Seal



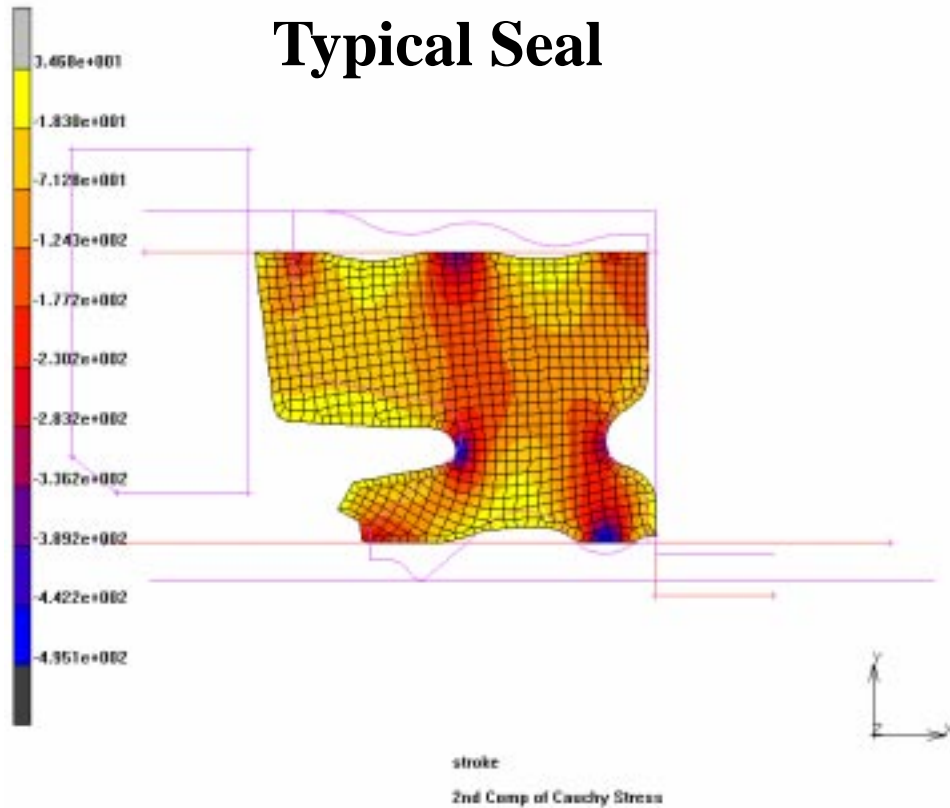
Zero Leak ABS Piston Seal



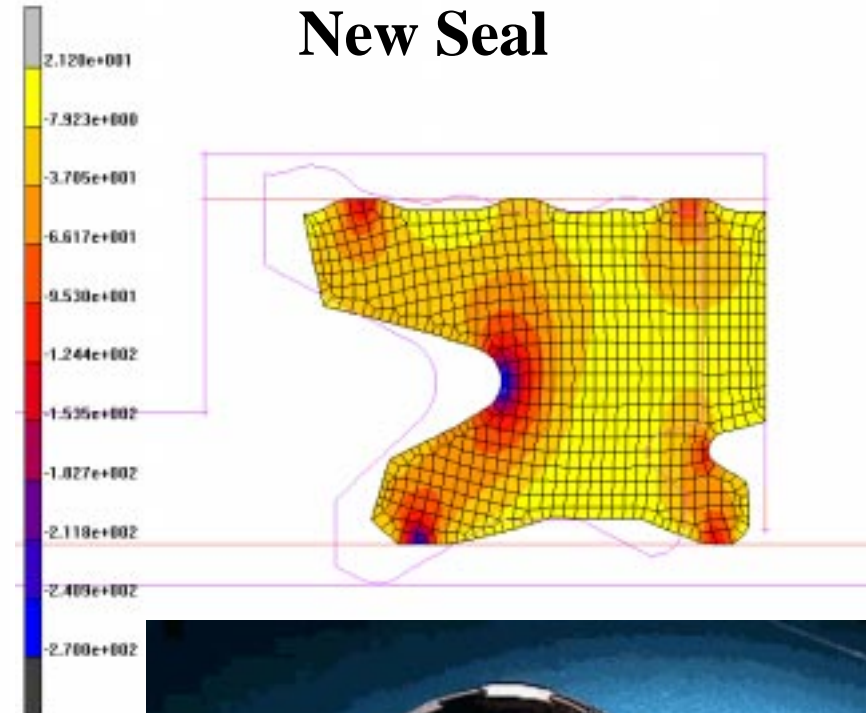
**Acushnet Rubber
Company, Inc.**

Prototypes for testing were required in 6 weeks

Typical Seal



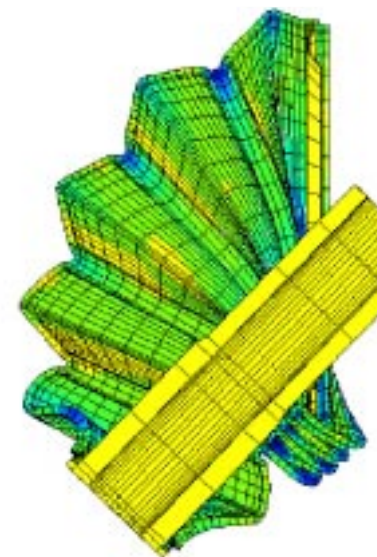
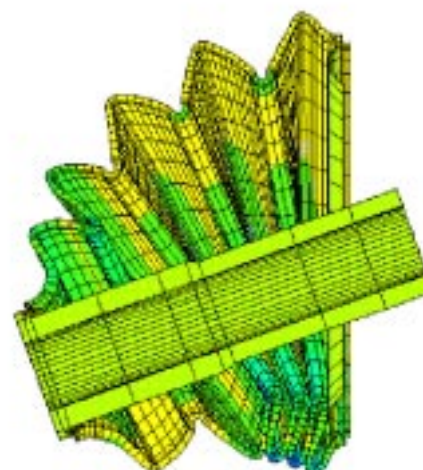
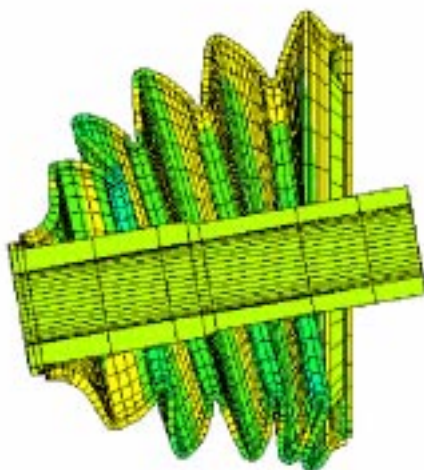
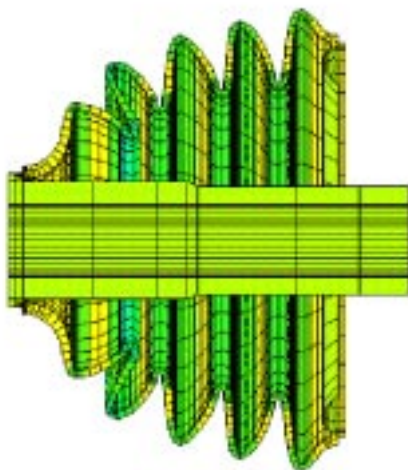
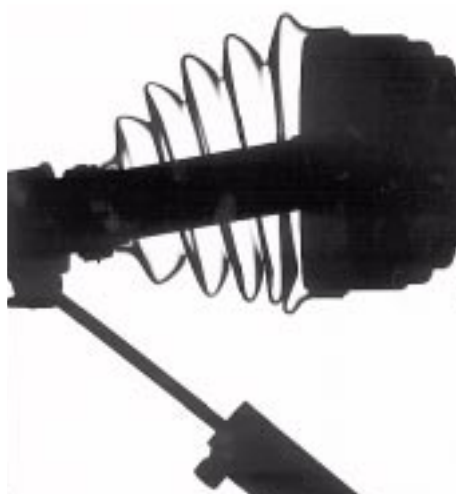
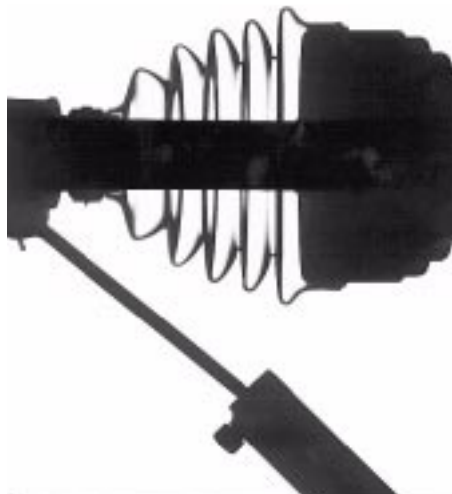
New Seal



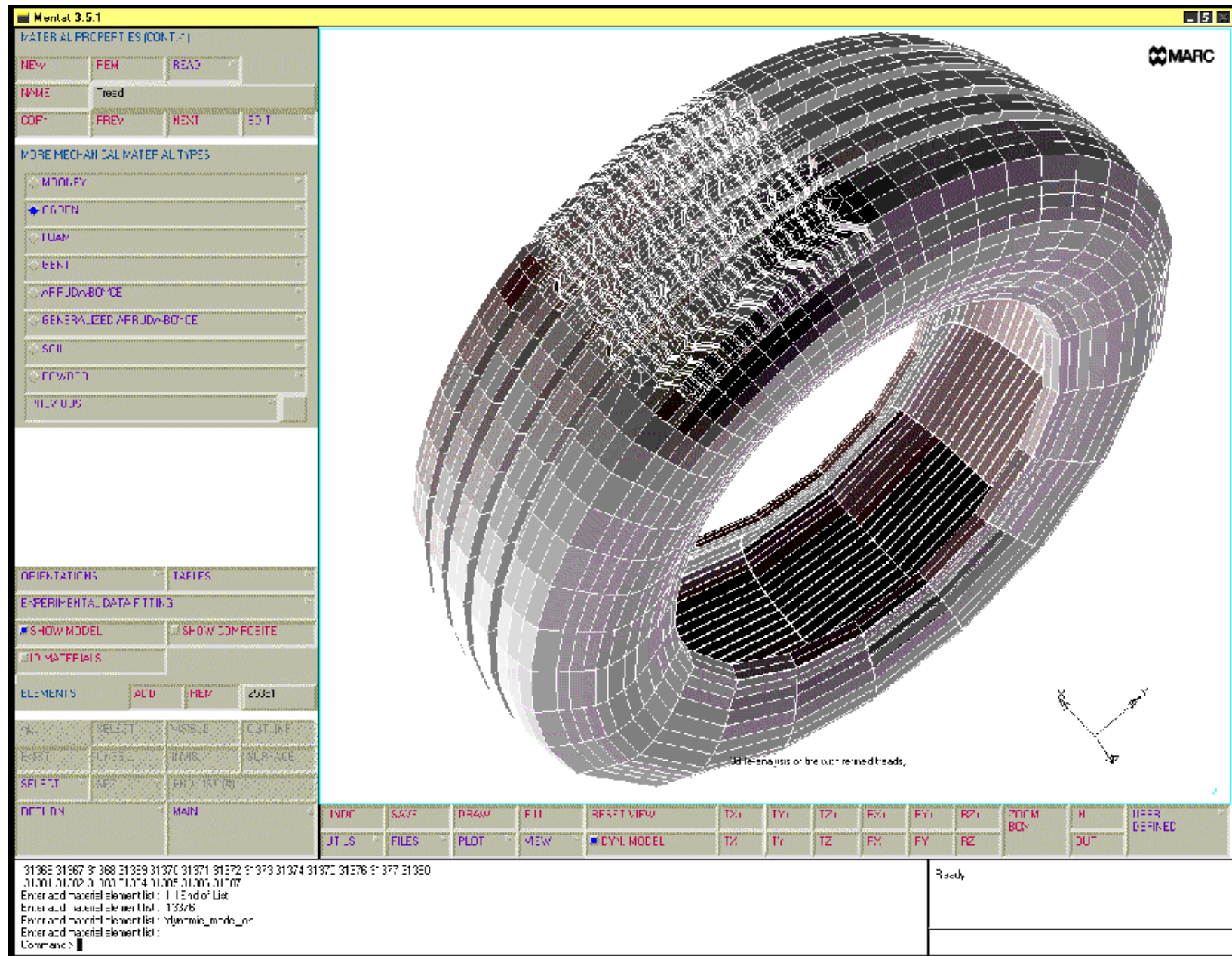
**See Customer Profile: Acushnet Rubber Company,
On The MARC Newsletter, Spring 1999 (PDF, 591
KB) at www.marc.com**



Constant Velocity Boot



Tires

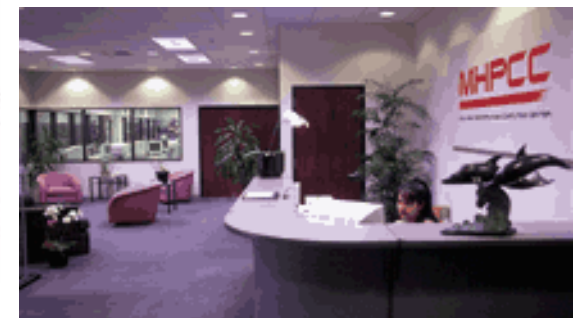
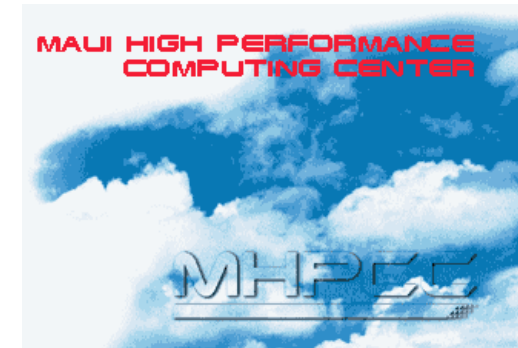
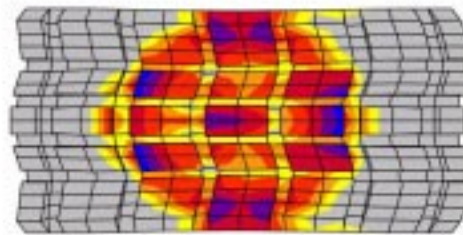
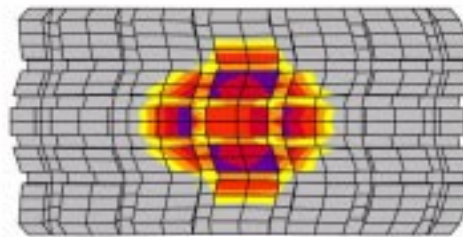
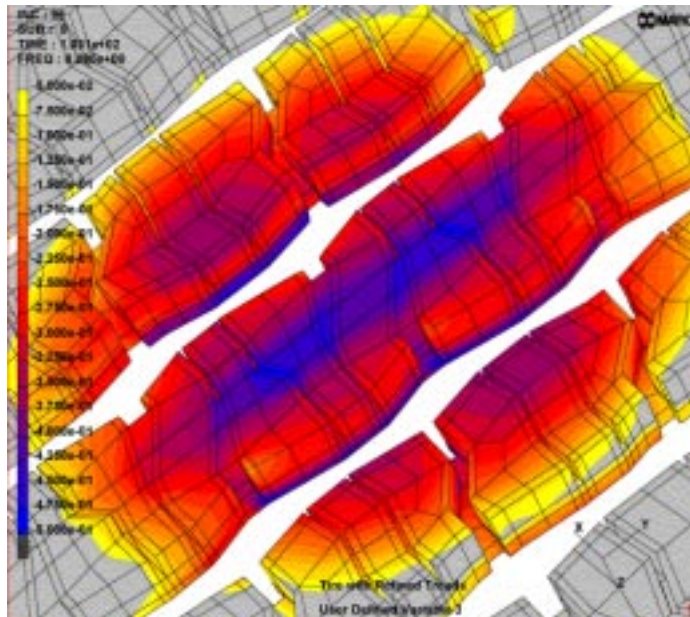
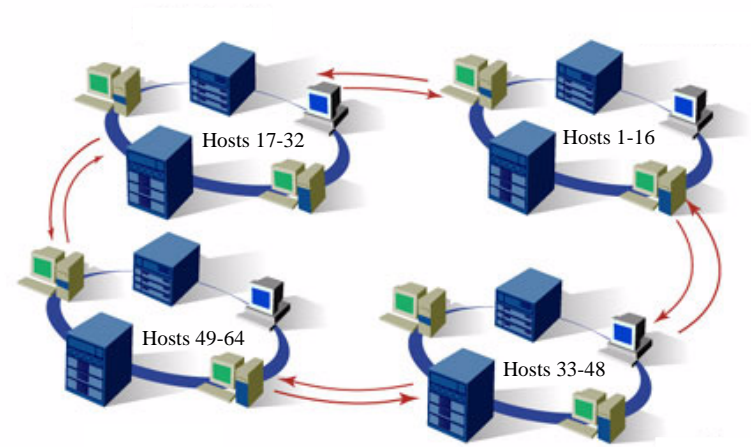
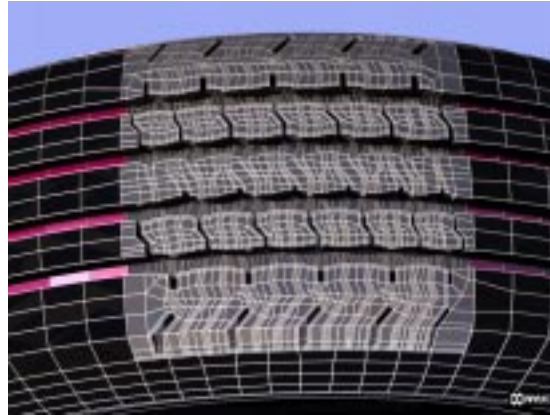


Tire Model Running MARC K73 Parallel

Shared: 64 400-MHz CPUs; 1 GBytes RAM/CPU

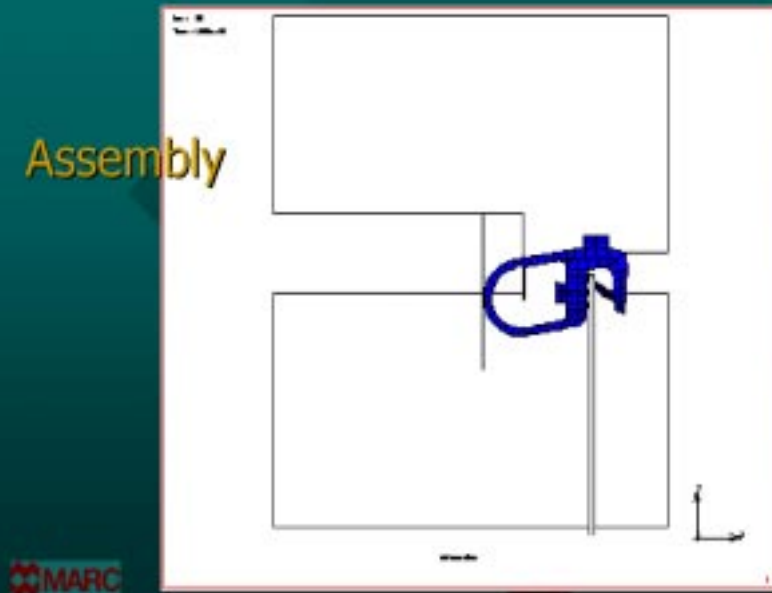
Distributed: 64 Hosts; 1 GBytes RAM/Host

$$S_{64} = 58.3$$

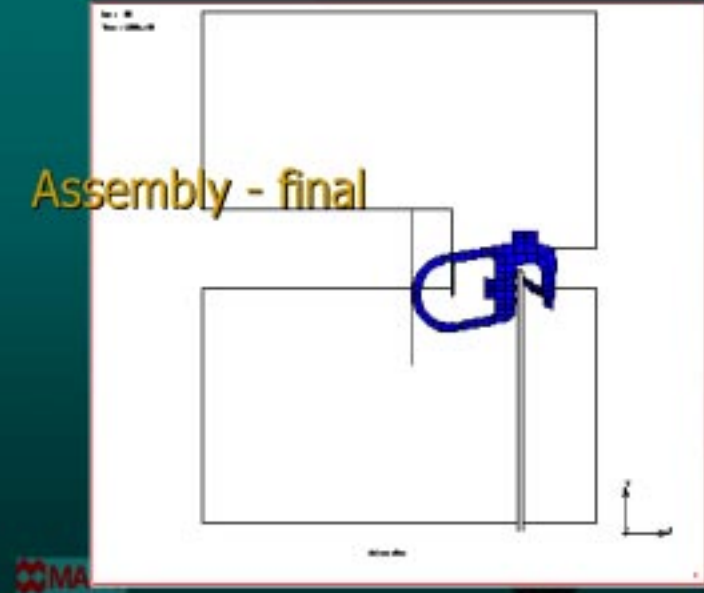


Coupled Acoustic-Structural Modal

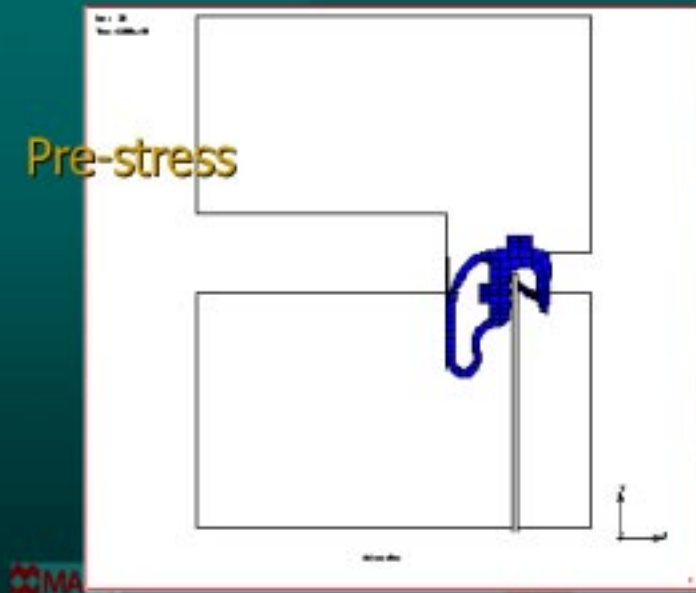
Assembly



Assembly - final



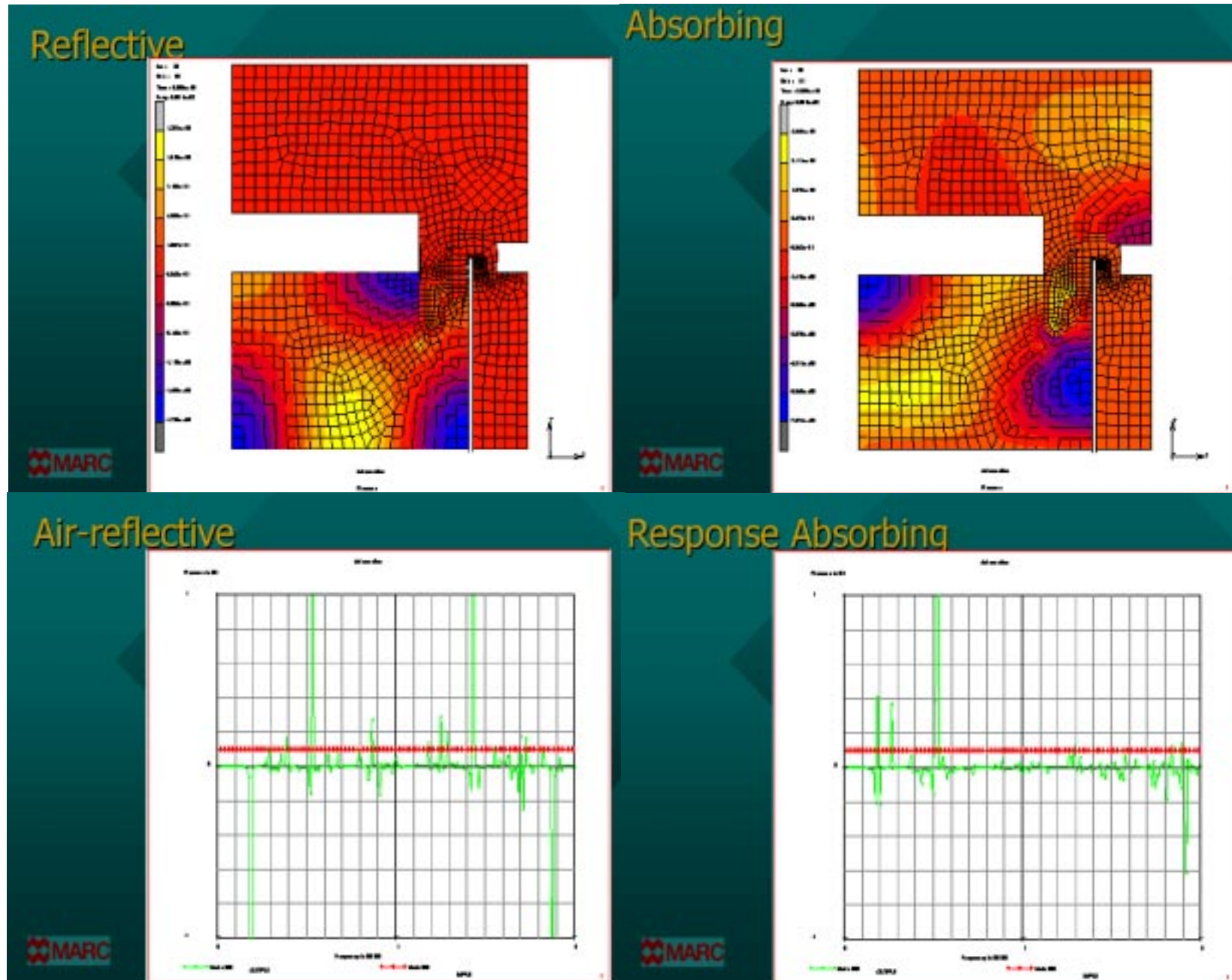
Pre-stress



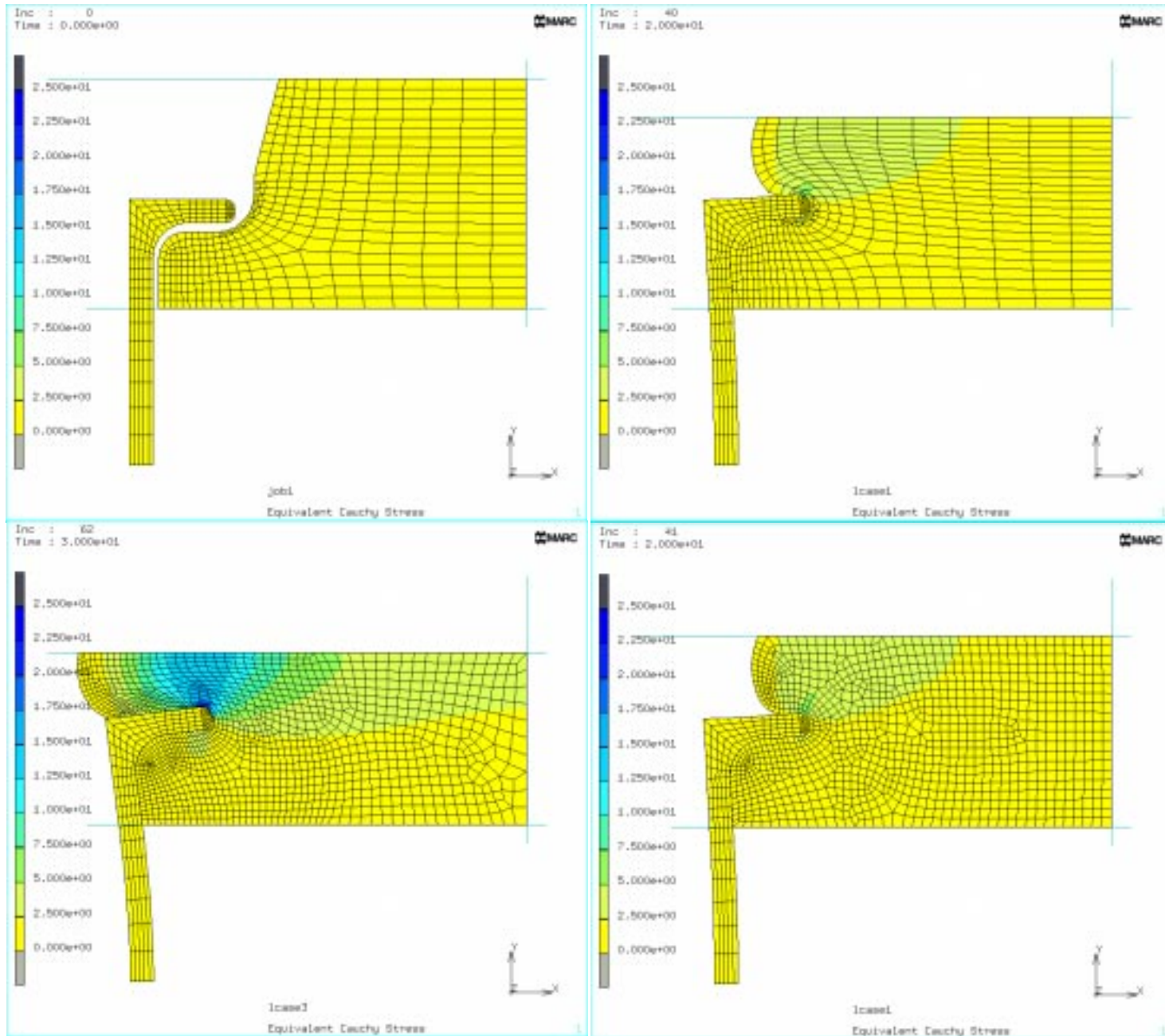
Air



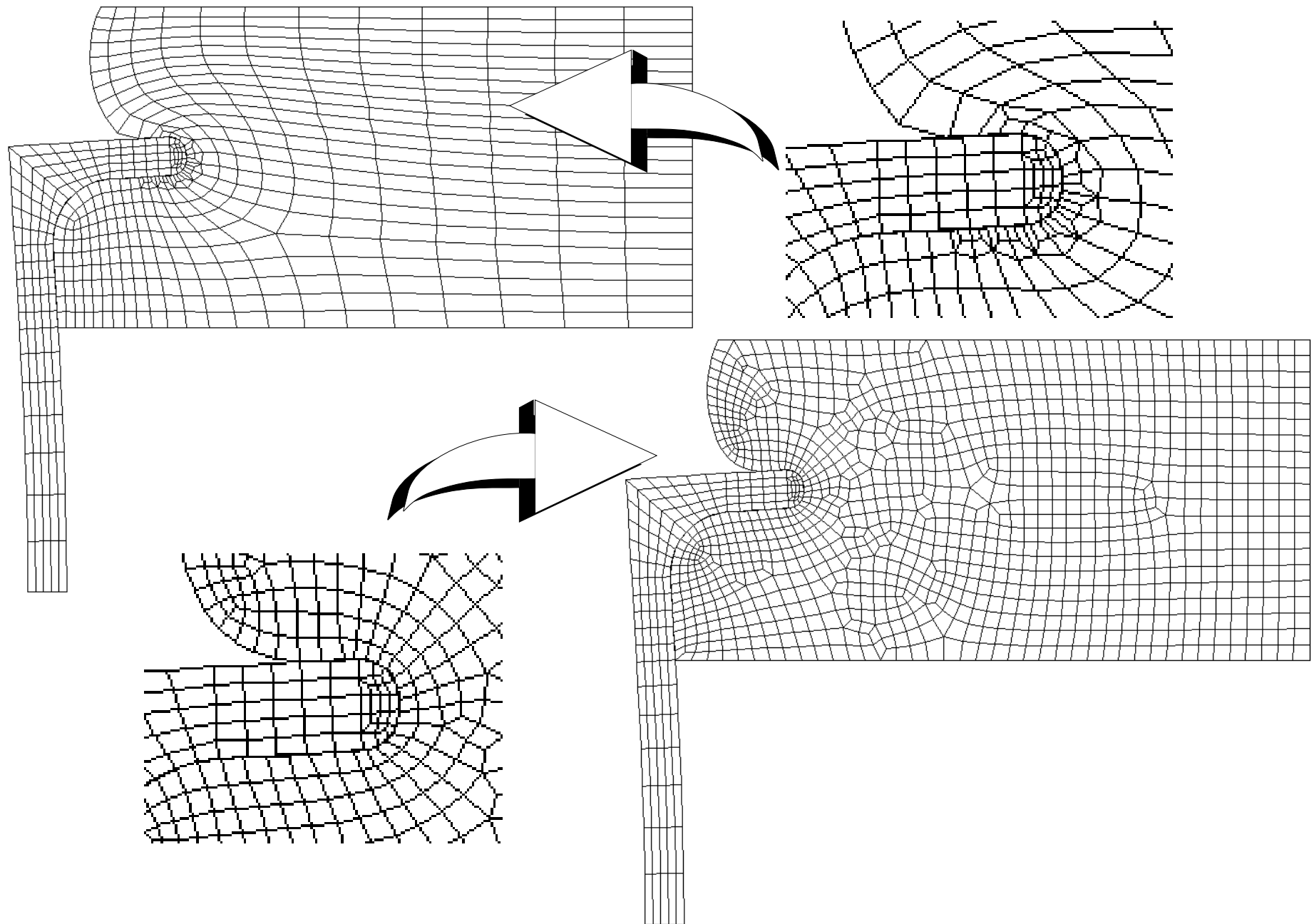
Coupled Acoustic-Structural Modal



Automatic Rubber Remeshing

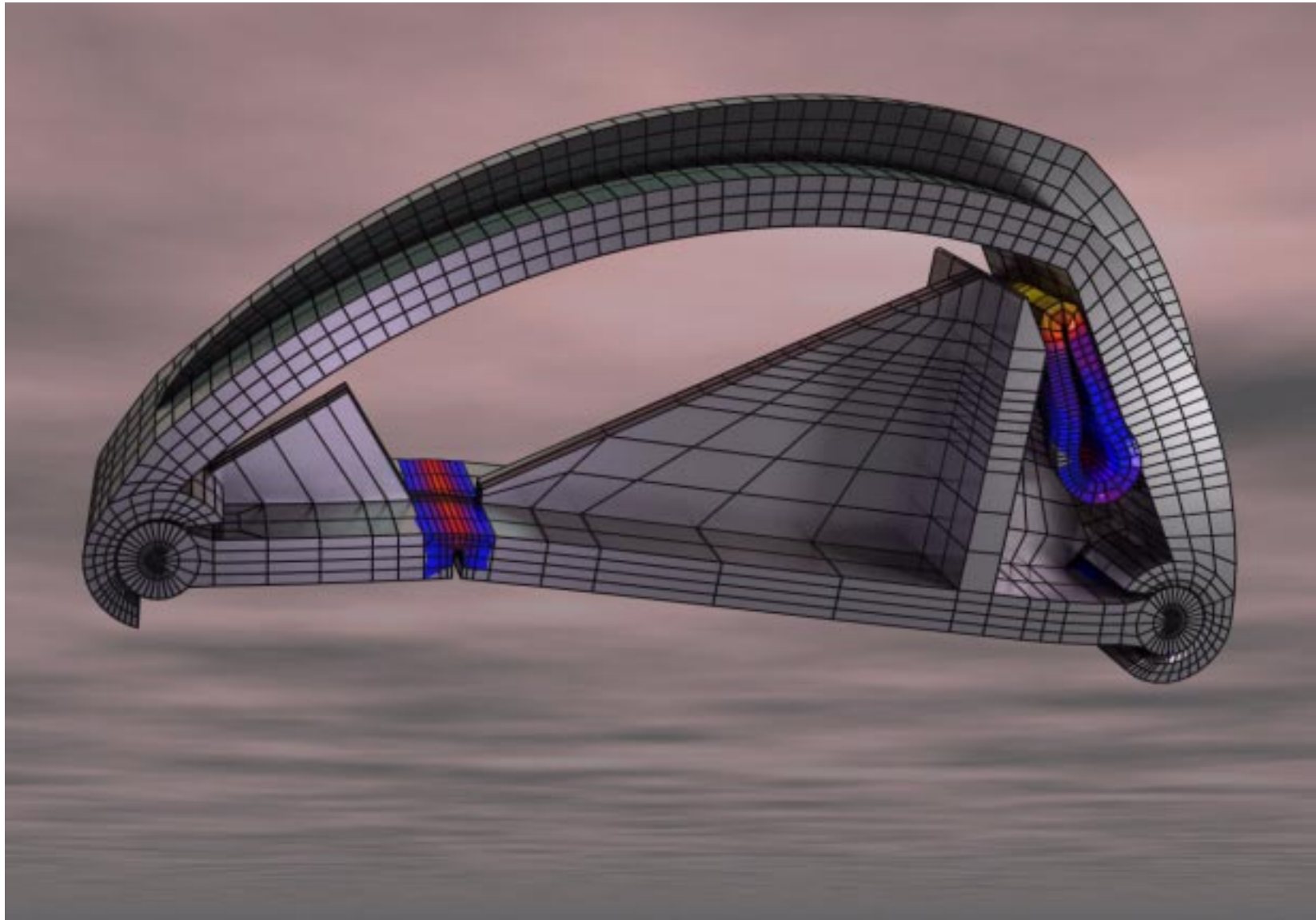


Automatic Rubber Remeshing



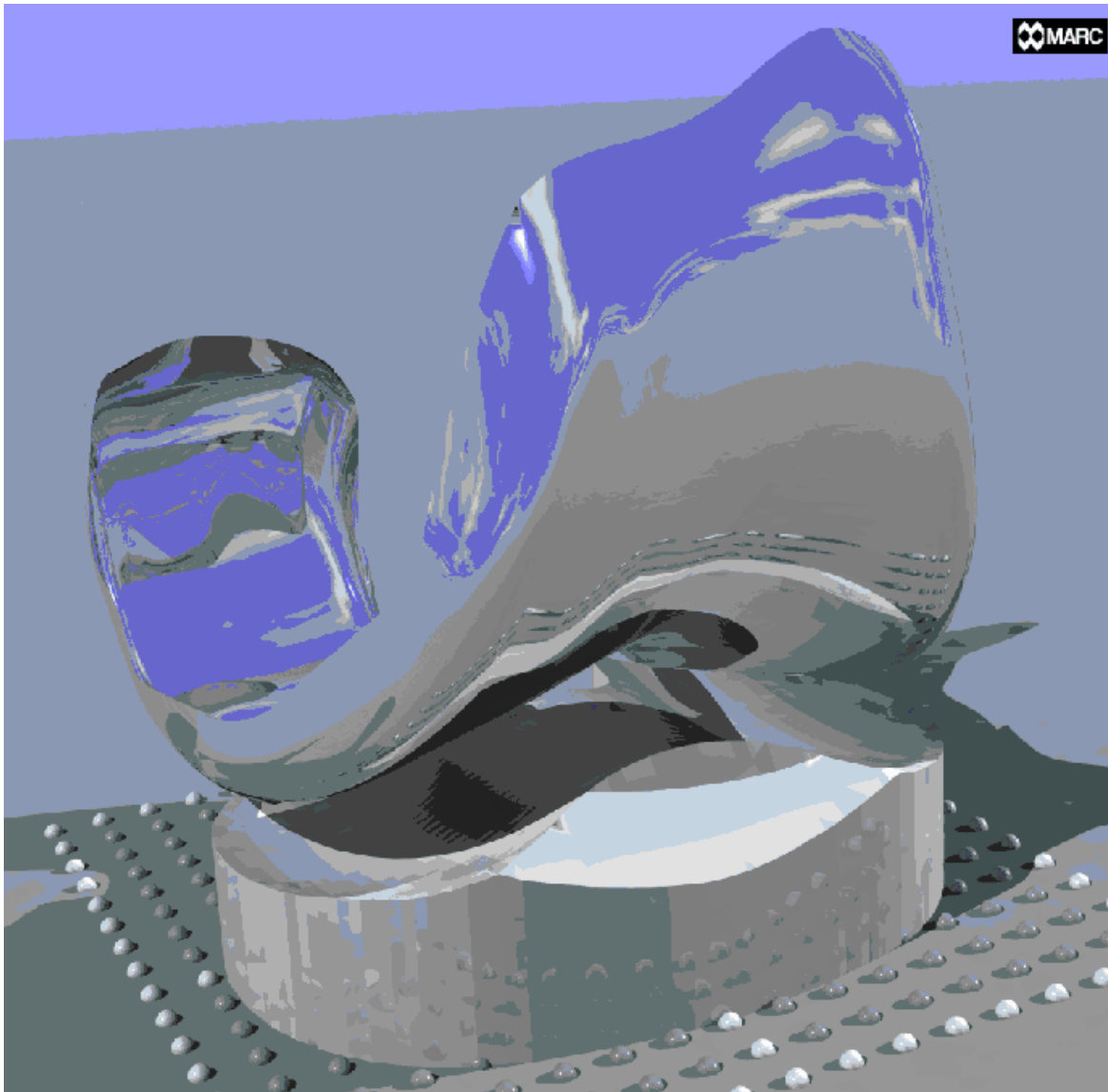
Intravenous Medical Tube Clamp

See www.marc.com/Theater/movies/ivclamp.htm

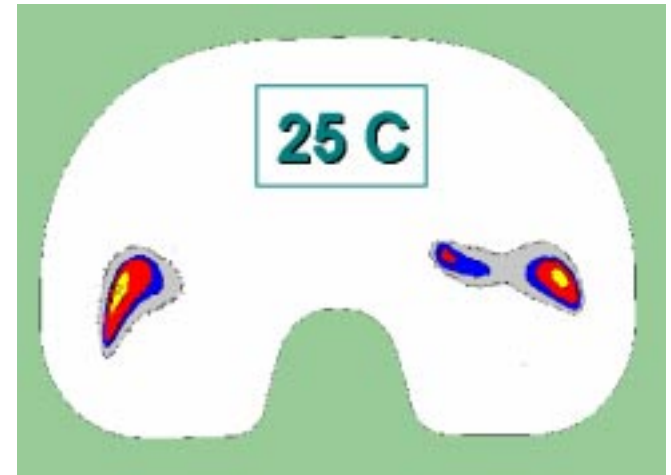


Knee Implant

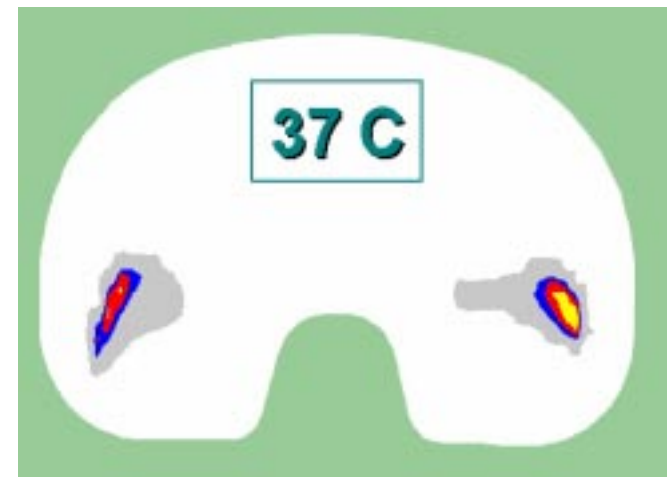
Orthopedic Research Laboratory, Cleveland, Ohio



Experimental: Fuji Film



Predictions: MARC FEA



Experimental Elastomer Analysis Training Class

“The experience of obtaining the experimental data in one room then walking to the next room and using it in FEA was invaluable”, **Greg Rea, Standard Products;**

“Excellent. My understanding of experimental testing and data reduction, elastomer material modeling, and material model confirmation using FEA increased tremendously. This workshop should be required for anyone involved with the FEA of elastomers”, **Ken Ogilvie, BTR;**

“The EEA workshop provides valuable guidance as to what one can expect and cannot expect elastomer FEA models to predict, and when correctly approached, how powerful FEA of elastomers is in a field traditionally viewed as art”, **Larry Castleman, Busak & Shamban.**

