Stretching boundaries of membrane and film

Some Recent Projects

Peter Lim

David Wakefield

TENSYS

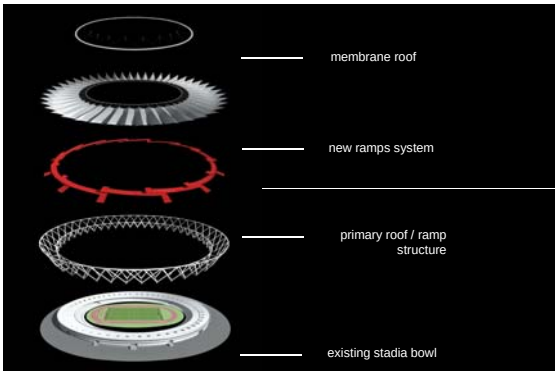
www.tensys.com

2

Jawarhalal Nehru Stadium CG Games 2010

www.tensys.com

Jawarhalal Nehru Stadium CG Games 2010

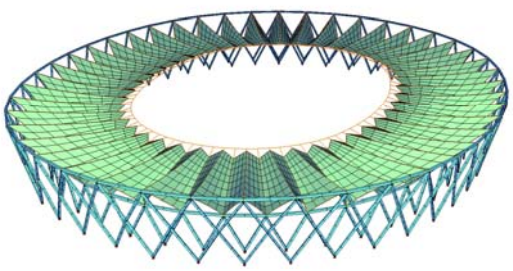


www.tensys.com

Jawarhalal Nehru Stadium CG Games 2010

www.tensys.com

Jawarhalal Nehru Stadium CG Games 2010



www.tensys.com

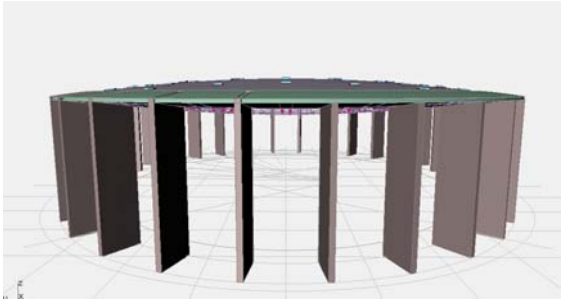
Jawarhalal Nehru Stadium CG Games 2010

www.tensys.com

Dr S P Murkerjee Stadium CG Games 2010

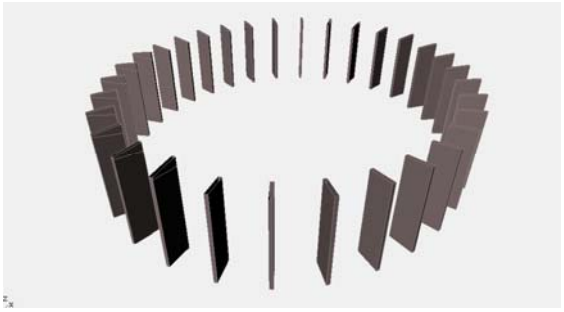
www.tensys.com

Dr S P Murkerjee Stadium CG Games 2010



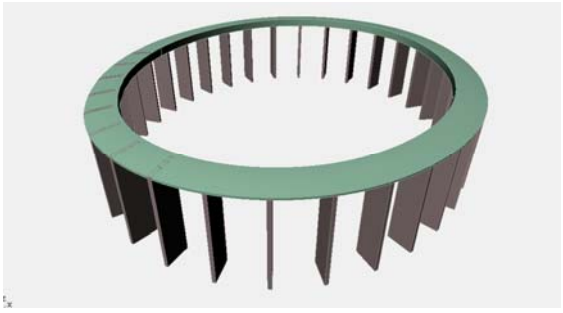
www.tensys.com

Dr S P Murkerjee Stadium CG Games 2010



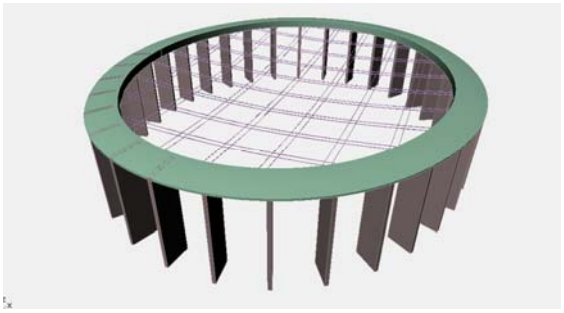
www.tensys.com

Dr S P Murkerjee Stadium CG Games 2010



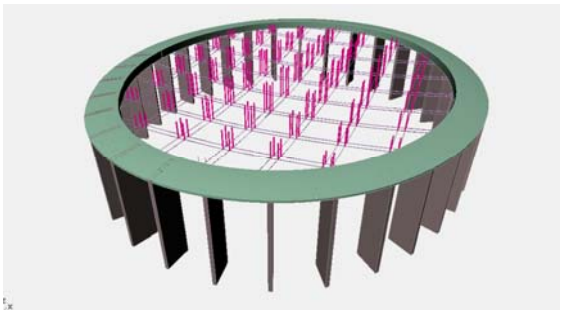
www.tensys.com

Dr S P Murkerjee Stadium CG Games 2010



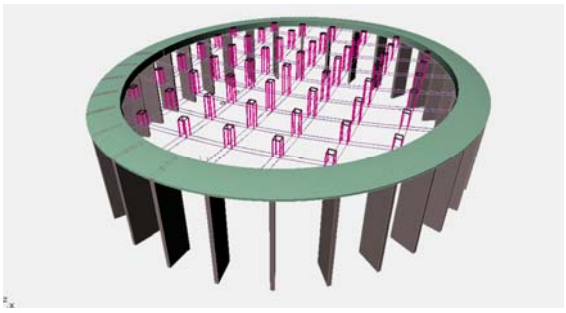
www.tensys.com

Dr S P Murkerjee Stadium CG Games 2010



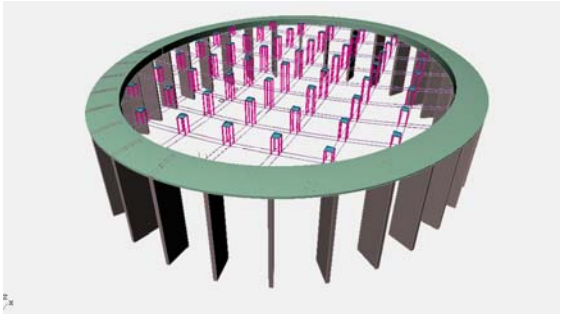
www.tensys.com

Dr S P Murkerjee Stadium CG Games 2010



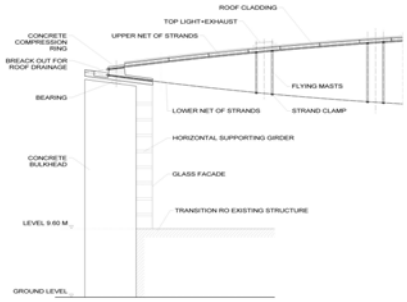
www.tensys.com

Dr S P Murkerjee Stadium CG Games 2010



www.tensys.com

Dr S P Murkerjee Stadium CG Games 2010

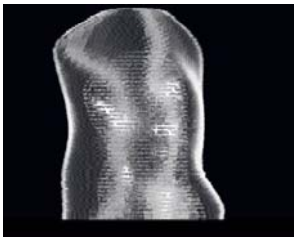


www.tensys.com

Dr S P Murkerjee Stadium CG Games 2010

www.tensys.com

Monumento M11 Madrid : FAM Architects



www.tensys.com

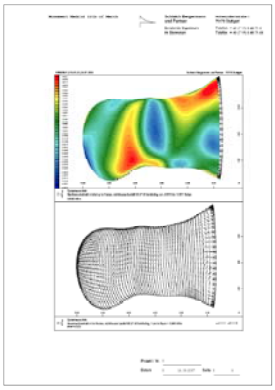
18

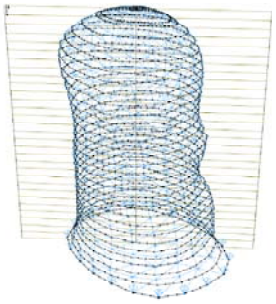
Monumento M11 Madrid : Architectural Concept

www.tensys.com

19

Monumento M11 Madrid : SBP Initial Shape Studies

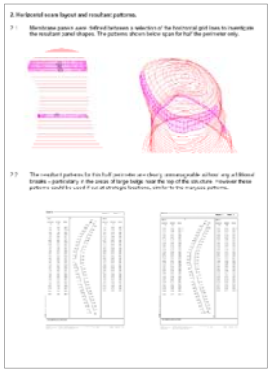


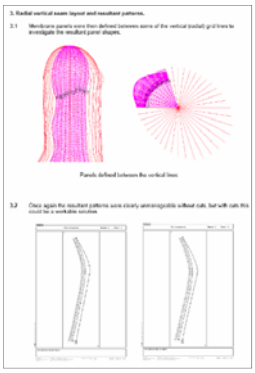


www.tensys.com

20

Monumento M11 Madrid : Patterning Possibilities

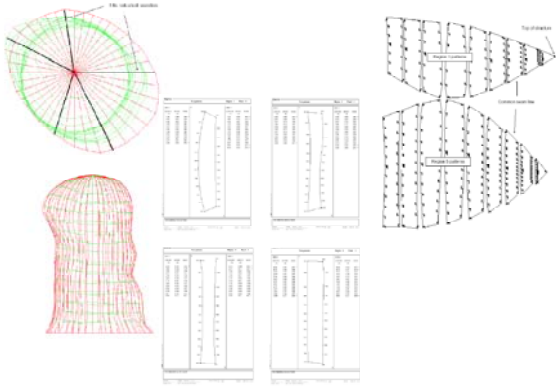




www.tensys.com

21

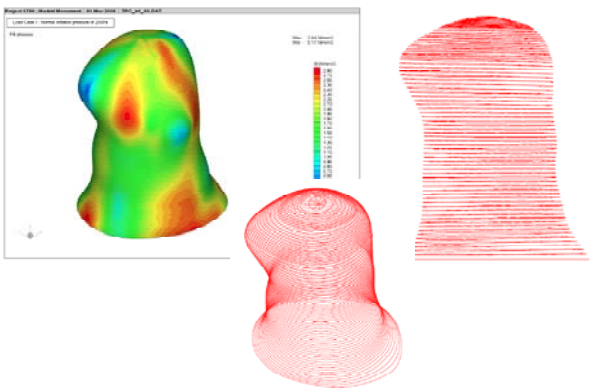
Monumento M11 Madrid : Patterning Possibilities



www.tensys.com

22

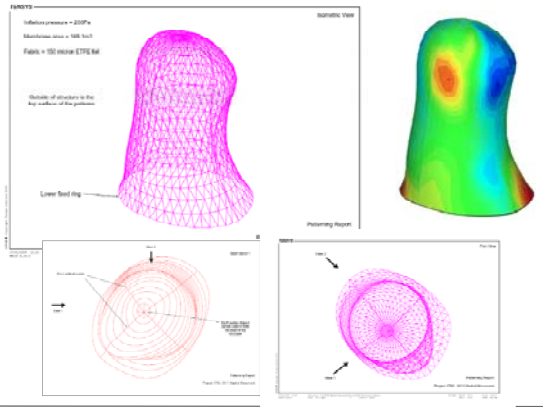
Monumento M11 Madrid : Fine Mesh Model



www.tensys.com

23

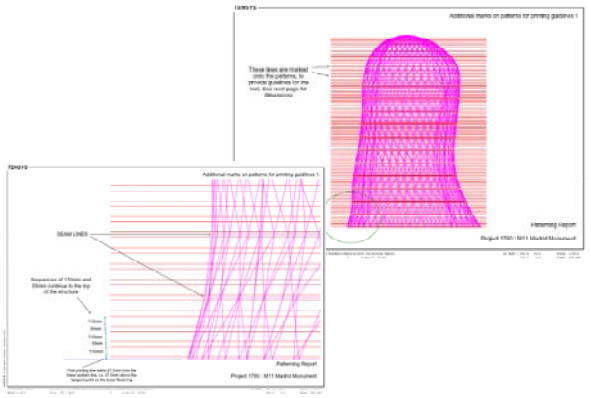
Monumento M11 Madrid : Final Pattern Layout



www.tensys.com

24

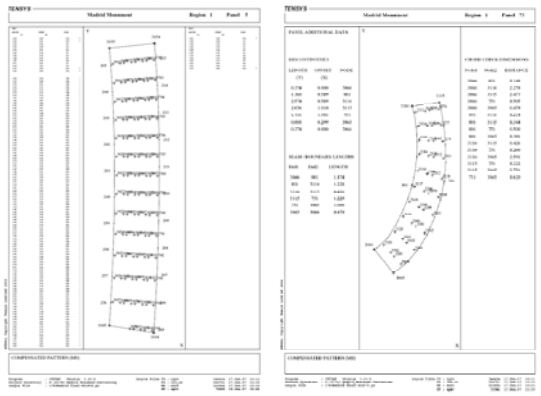
Monumento M11 Madrid : Horizontal Seams & Print Lines



www.tensys.com

25

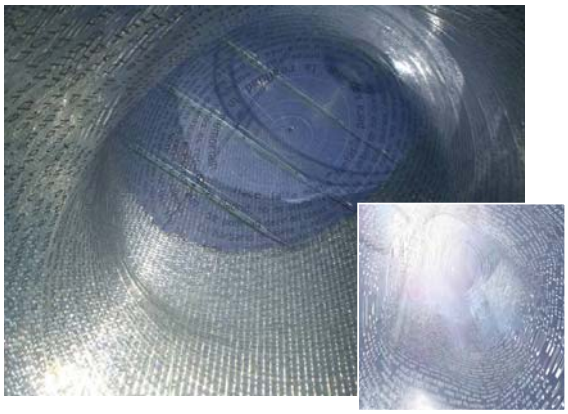
Monumento M11 Madrid : Sample Patterns



www.tensys.com

26

Monumento M11 Madrid



www.tensys.com

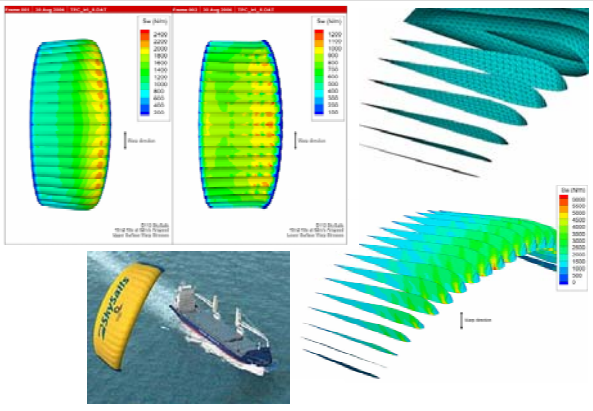
27

Monumento M11 Madrid

www.tensys.com

28

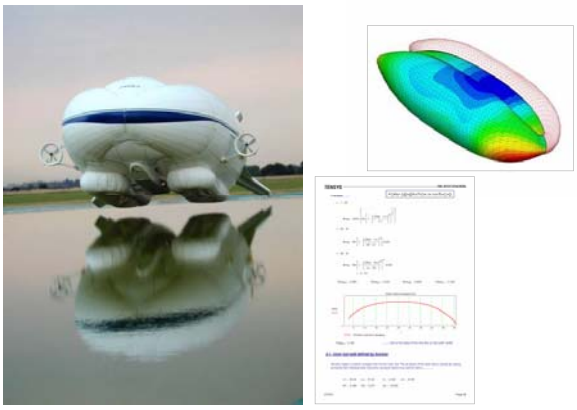
SkySails : Kite Analysis



www.tensys.com

29

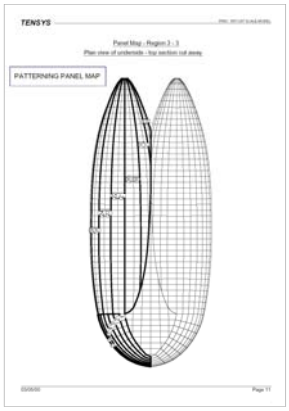
Airship Envelope Engineering



www.tensys.com

30

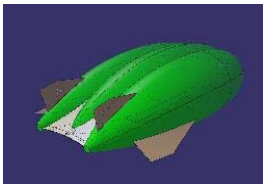
SkyKitten Pattern Layout



www.tensys.com

31

Hybrid Air Vehicles



www.tensys.com

32

Lockheed Martin P791

www.tensys.com

33

Lockheed Martin Skunk Works : P791 HAV : First Flight 31/01/06

www.tensys.com

34

Lockheed Martin P791

www.tensys.com

35

NASA ULDB – Ultra Long Duration Balloon

www.tensys.com

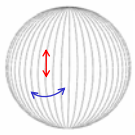
36

NASA ULDB Deployment Anomaly

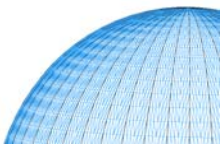
NASA Ultra Long Duration Balloon Program

www.tensys.com

Pumpkin Balloon Generation 1



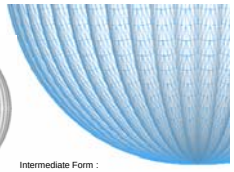
Initial Spherical Topology



Material Orientation
Warp (longitudinal)
Fill (circumferential)

Initial Topology generated between gores on spherical surface. Membrane interpolated linearly between gores

Number of gores, mesh density and tendon length defined in the data generator for automatic generation of topology data files



Intermediate Form :

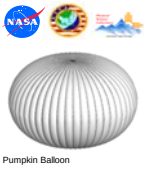
Tendons fixed and stress controlled lobes

Intermediate Form : Specify inflation pressure and membrane warp and fill prestress for required lobe geometry

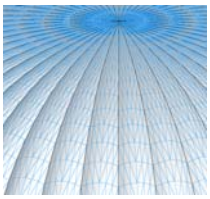
Restrain tendons on spherical geometry and generate equilibrium lobe geometry (this form finding stage is necessary to put tension into the tendons. Otherwise the whole membrane envelope will collapse inwards towards a cylinder with the radii of a single lobe)

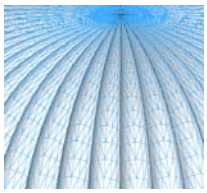
www.tensys.com

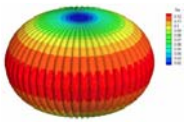
Pumpkin Balloon Generation 2



Pumpkin Balloon
Constant Radius Lobes
(Alpha = 120deg at equator)







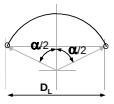
Constant Lobe Angle
Alpha = 170deg.

Release elastically controlled tendons for final form find. Pumpkin fully restrained at North Pole node, and restrained against horizontal movement only at South Pole.

For **constant radius lobes**, the warp (circumferential) prestress was held constant and the fill prestress set to zero.

For a **constant lobe angle a** under inflation pressure P_{infl}, the specified warp prestress **Sw** is related to the local span D_L between tendons :

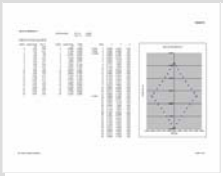
$$Sw = P_{infl} \times D_L / (2 \sin(\alpha/2))$$

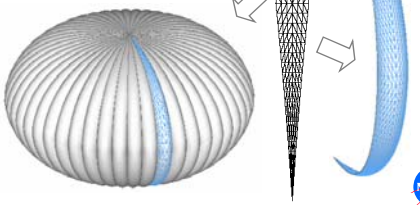


Once required form has been achieved, introduce membrane elastic properties for elastic control, rather than specified stress control as used for form generation. Individual element unstressed geometry is calculated such that current form and stress distribution is maintained.

www.tensys.com

Cutting Pattern Geometry into inTENS

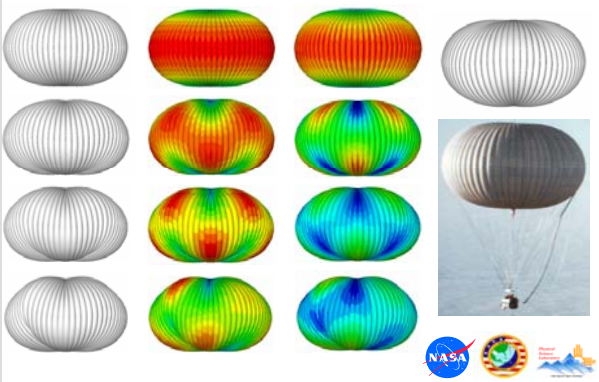




- Software extended for input of pre-defined cutting pattern geometry
- Unstressed flat panel geometry from cutting patterns
- Flat panel boundary obtained by spline data fit through original pattern geometry
- Unstressed film geometry then mapped onto single-gore or full pumpkin balloon models
- Unstressed tendon lengths taken as fully compatible with cutting patterns
- Mesh refinement may be adjusted as required

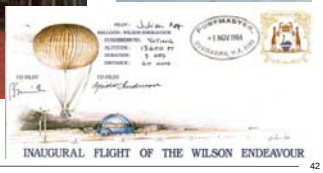
www.tensys.com

Development of Overall Geometric Instability with Increasing Pressure



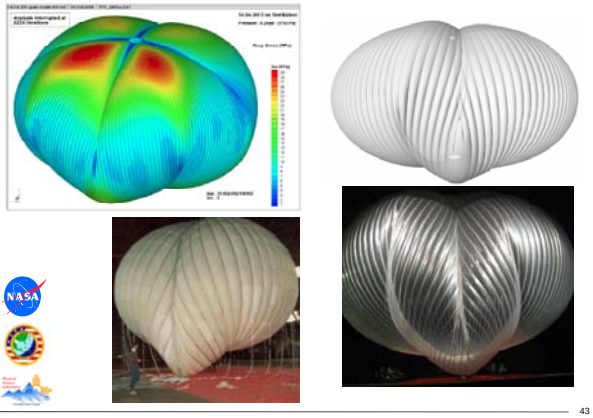
www.tensys.com

64 Gore Pumpkin Instability : Julian Nott's Endeavour



www.tensys.com

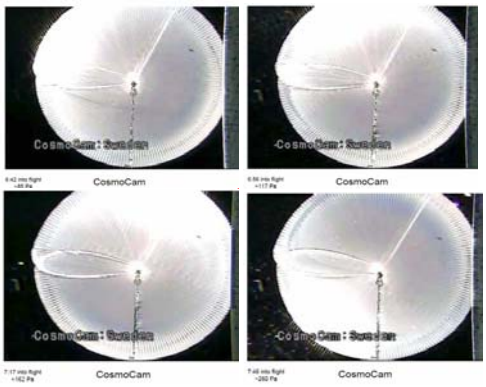
10m Diameter 145 Gore Deployment Test Balloon



www.tensys.com

43

ULDB Flight 555NT Sweden 2006 : S-Cleft Maintained under Increasing Pressure



www.tensys.com

44

S-Cleft Investigation : 27m Hangar Test : March '07

www.tensys.com

45

Deployment Investigation : 27m Hangar Test : July '07

www.tensys.com

46

Deployment Investigation : 27m Hangar Test : July '07

www.tensys.com

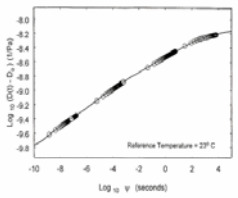
47

Deployment Investigation : 27m Hangar Test : July '07

www.tensys.com

48

Transient Viscoelastic Creep Compliance : The Master Curve



For linear viscoelastic response at low stresses the Master Curve is a representation of creep compliance as a factor of time.

The effects of temperature and higher stresses may be accommodated by shifts in the time scale of the master curve.

Current compliance at any time comprises an elastic portion D_0, independent of time and temperature, and a transient component $\Delta D(\psi)$ where ψ is the reduced time that incorporated the effects of temperature and stress :

$$D(\psi) = D_0 + \Delta D(\psi)$$

The transient component may be expressed as a series of exponentials in the reduced time :

$$\Delta D(\psi) \equiv \sum_{r=1}^{N} A_r \left(1 - e^{\lambda_r \psi}\right) \qquad \lambda_r = 10^{16-r}$$

The three strains due to constant biaxial stress may then be expressed :

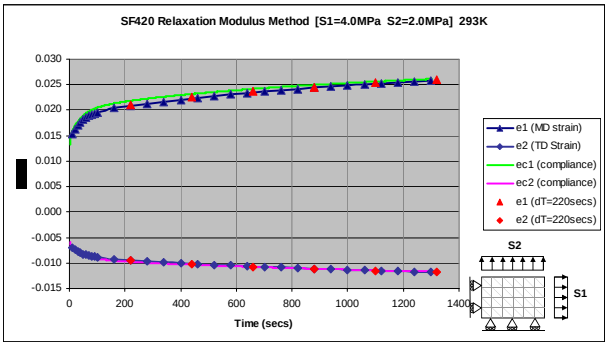
$$\varepsilon_1 = D_0(\sigma_1 + S_{12}^0\sigma_2) + g_2\Delta D(\psi)(\sigma_1 + S_{12}\sigma_2)$$

$$\varepsilon_2 = D_0(S_{12}^0\sigma_1 + S_{22}^0\sigma_2) + g_2\Delta D(\psi)(S_{12}\sigma_1 + S_{12}\sigma_2)$$

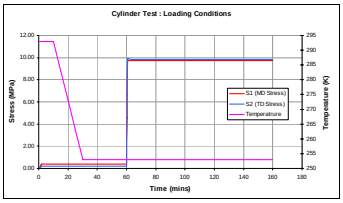
$$\varepsilon_6 = D_0 S_{66}^0\sigma_6 + g_2\Delta D(\psi)S_{66}\sigma_6$$

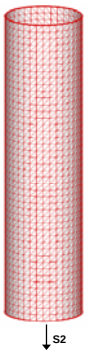
Where S_{ij} relates the transient compliance in any direction to that in the machine direction $\Delta D_{ij} = S_{ij}\,\Delta D$ and g_2 is a function of stress

Incremental Relaxation Model : Specified Stress

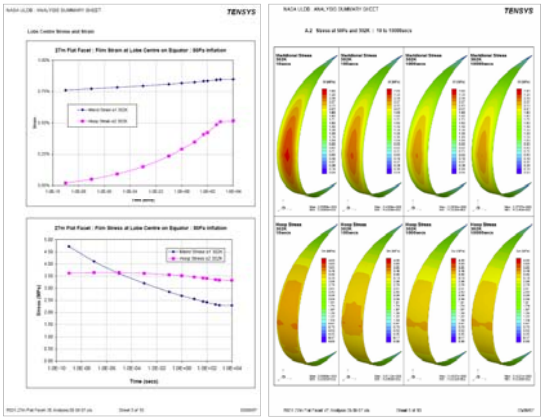


Simulation of Cylinder Biaxial Test

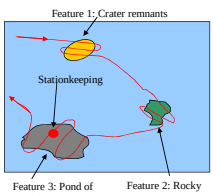




27m Test Balloon : Single Gore Viscoelastic Analysis



Titan Aerobot



Titan Aerobot


Tailpiece
www.tensys.com
19294
55


Engineering + Analysis
www.tensys.com