5. Fachkongress Composite Simulation

ALTAIR – HyperWorks Solver **RADIOSS+MDS**

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Innovation Intelligence®

Agenda

- Company Introduction – Our Vision
- HyperWorks Solvers: RADIOSS
- Modelling of Composites
  - MDS
- Examples from the field

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- **Company Introduction – Our Vision**
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Who is Altair?

Engineering Technology Provider

Enabling Companies
to develop Superior, Innovative Products

Engineering Company

Deep Knowledge
in Virtual Product Development

Altair

Software Tools

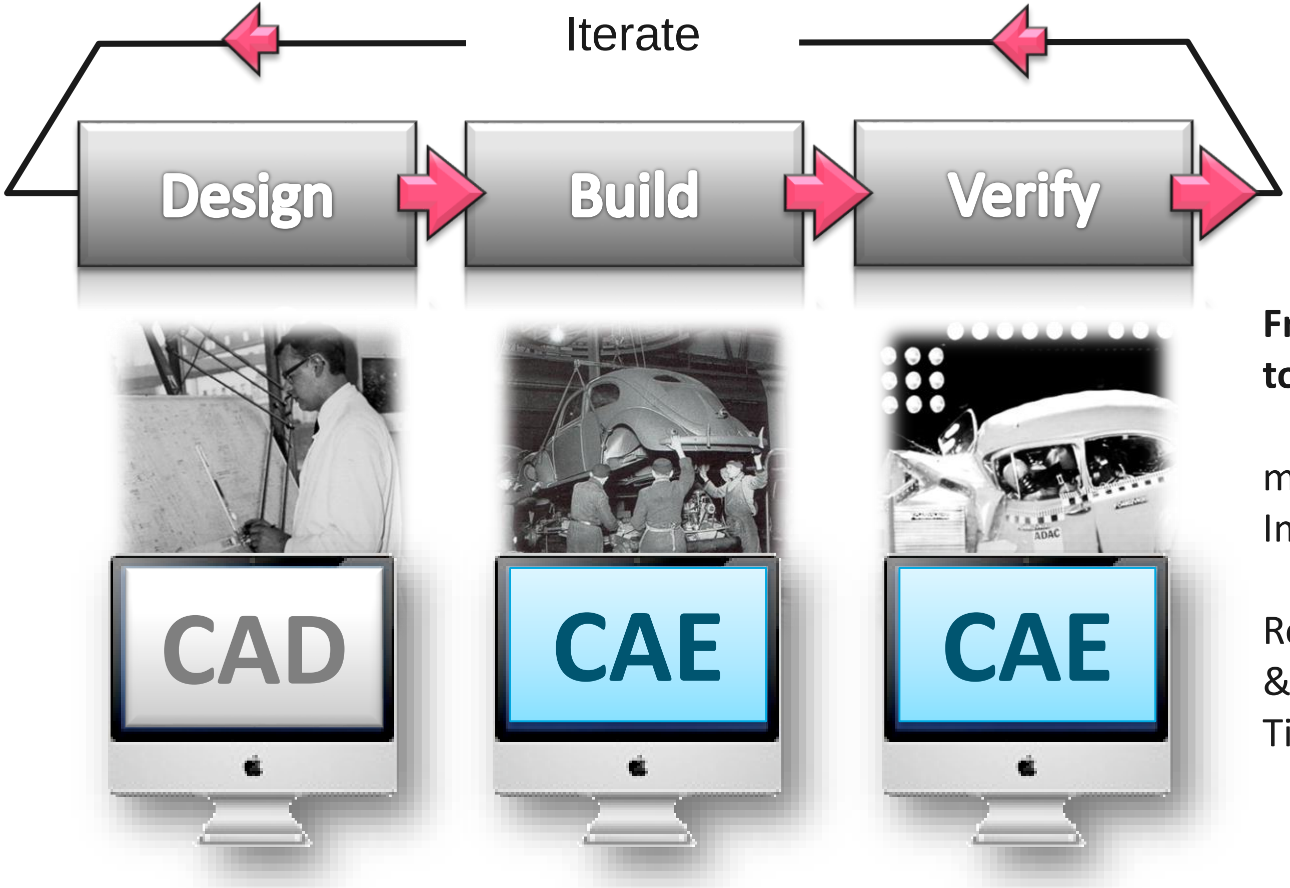
Knowledge & Processes

Resources

"Our vision is to radically change the way organizations design products and make decisions."

– James R. Scapa, Chairman & CEO, Altair

Who is Altair?



From “Real” to “Virtual”:

massive Improvements in

Resource Savings
&
Time-to-Market

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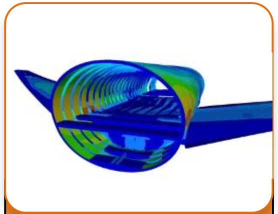
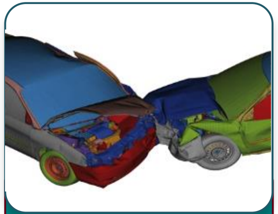
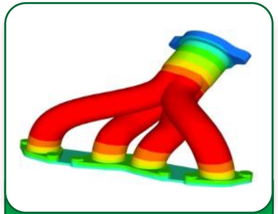
HyperWorks Solver Technology



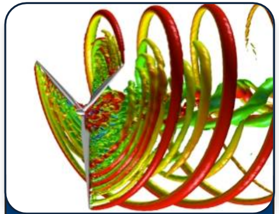
Structural Analysis



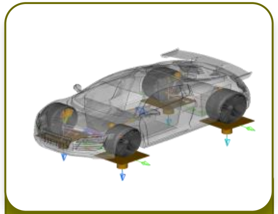
Crash, Safety, Impact & Blast



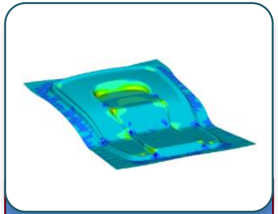
Thermal Analysis



Fluid Dynamics



Systems Simulation



Manufacturing Simulation

Multiphysics Analysis and Optimization

Basic Equation :

- **Simplified discrete form (with damping)**

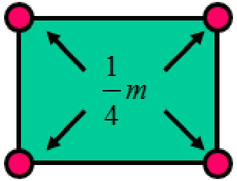
$$[M]\{\ddot{X}_n\}+[C]\{\dot{X}_n\}+[K]\{X_n\}=\{F_{ext}(t_n)\}$$

Time Integration :

- **Newmark scheme : General form**

$$X_n = X_{n-1} + dt\,\dot{X}_{n-1} + dt^2\left(\tfrac{1}{2}\ddot{X}_{n-1} + \beta\left(\ddot{X}_n - \ddot{X}_{n-1}\right)\right)$$
$$\dot{X}_n = \dot{X}_{n-1} + dt\left((1-\gamma)\ddot{X}_{n-1} + \gamma\,\ddot{X}_n\right)$$

- **Only [M] has to be inverted → [M] is diagonal with lumped mass approach. Easy !**



HyperWorks Solver Technology: RADIOSS

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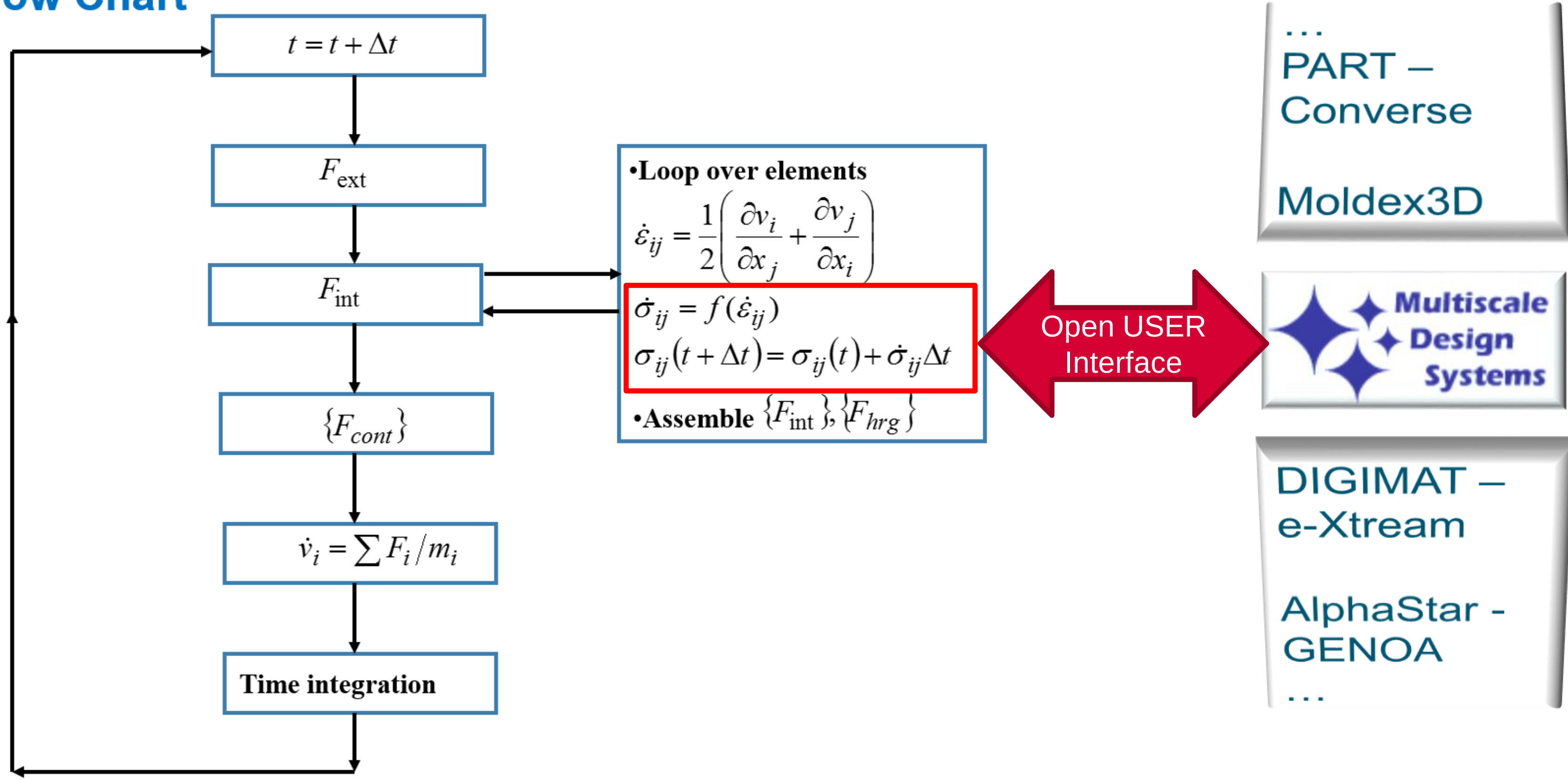
Explicit Flow Chart



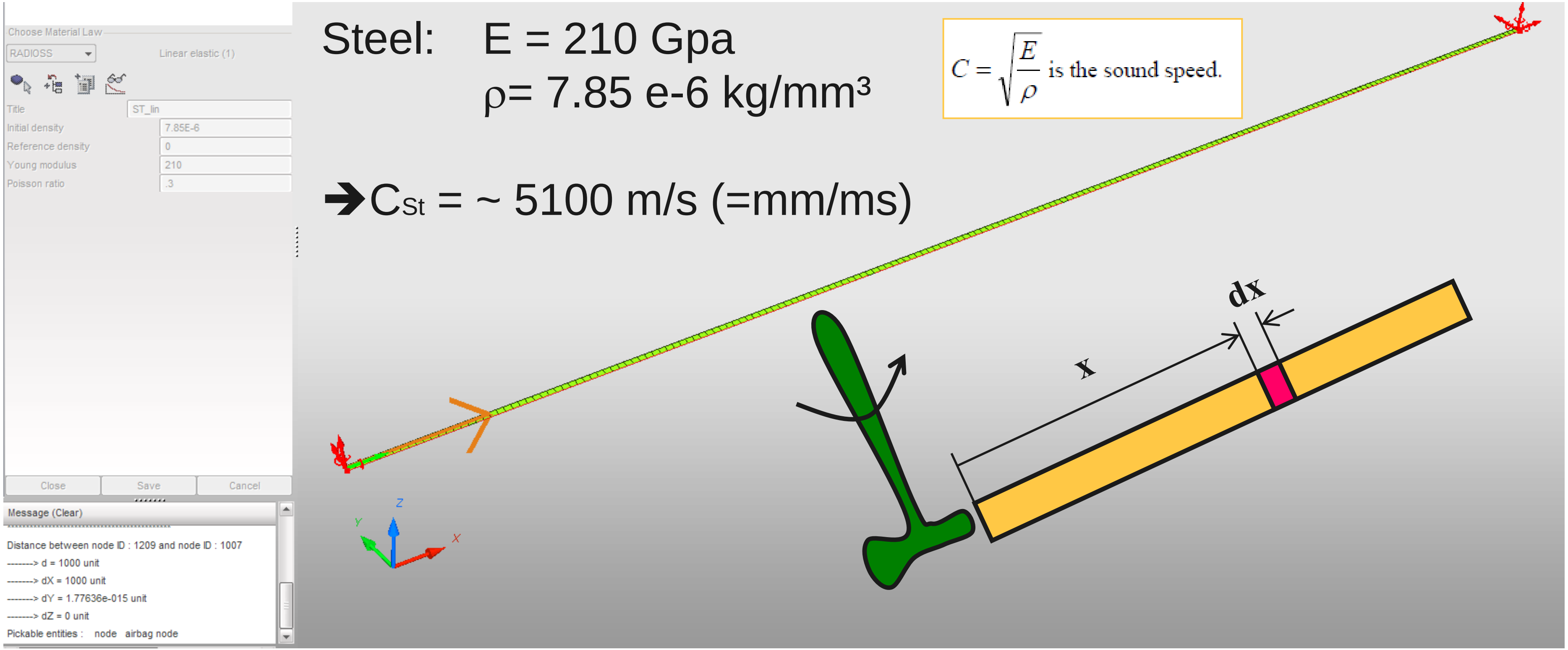
Small example: Stress-Wave propagation in Steel

Steel: E = 210 Gpa

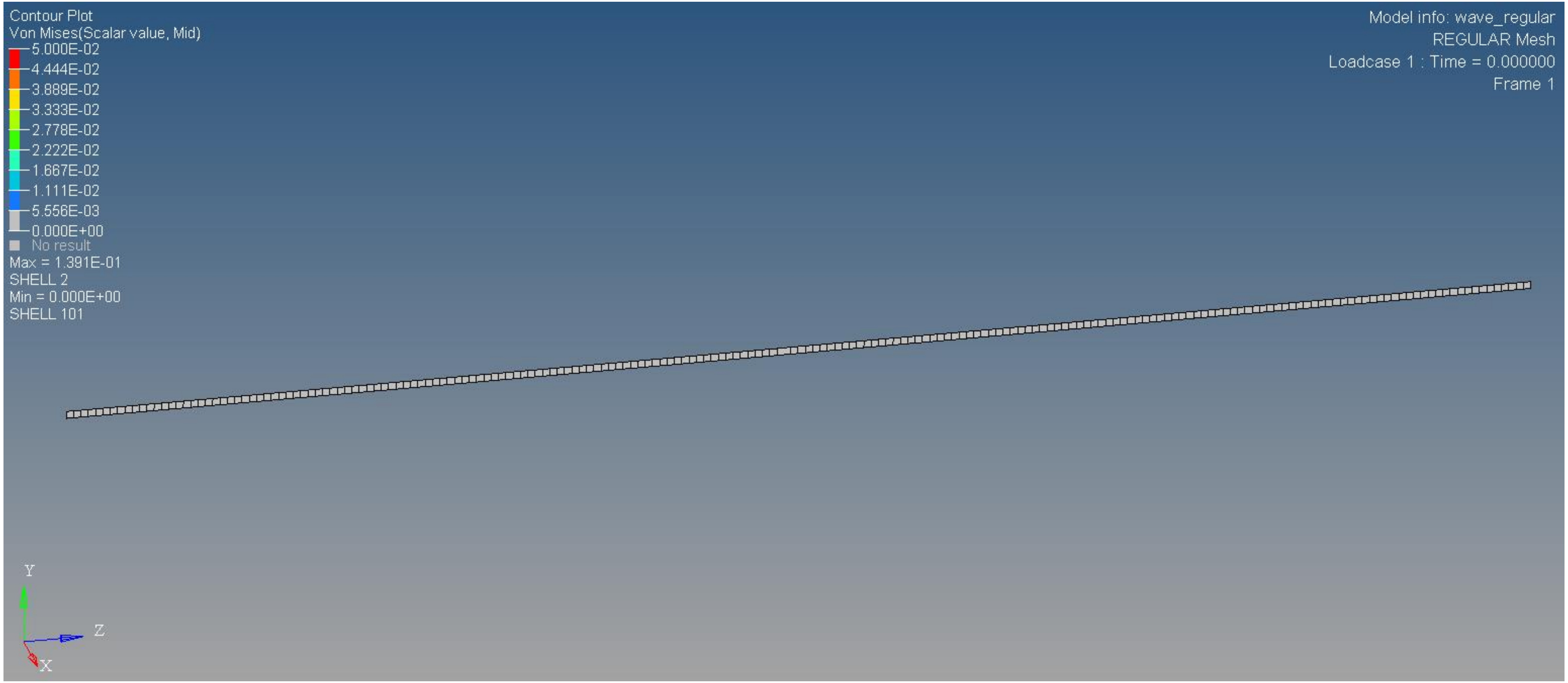
ρ= 7.85 e-6 kg/mm³

$$C = \sqrt{\frac{E}{\rho}} \text{ is the sound speed.}$$

➔ C_{St} = ~ 5100 m/s (=mm/ms)



Small example: Stress-Wave propagation in Steel



HyperWorks Solver Technology: RADIOSS

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RADIOSS

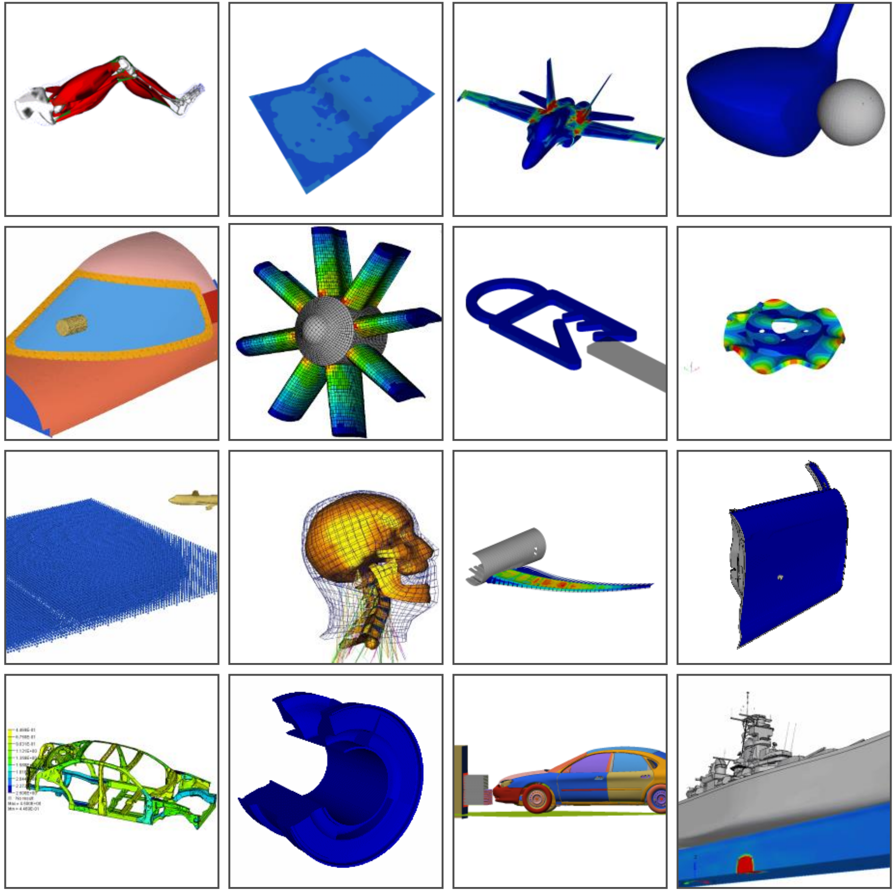
Linear
Statics, Dynamics, Buckling,
Thermal, Plasticity, Quasi-static, Contact

Non-Linear (Implicit)
Quasi-static, Dynamics,
Post-buckling, Materials, Contact

Non-Linear (Explicit)
Impact, Thermal, Materials, Contact

Thermal and CFD
Fluid Structure Interaction (FSI),
Thermal Stress, Multibody

Multi-Body Dynamics
(Rigid & Flexible Bodies)
Kinematics, Static and Dynamic, Quasi-static



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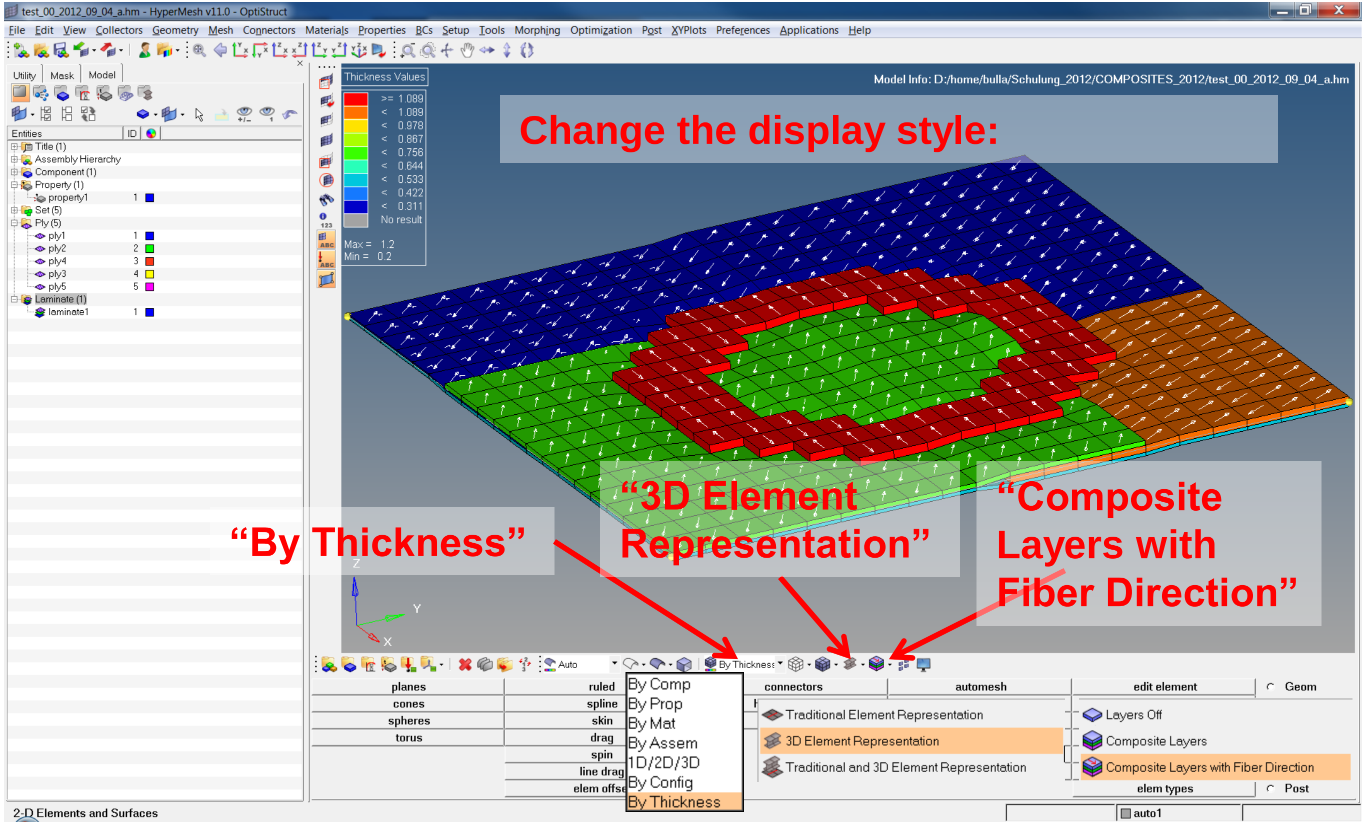
  - MDS
- Examples from the field

Composite modeling

Modelling of Composites

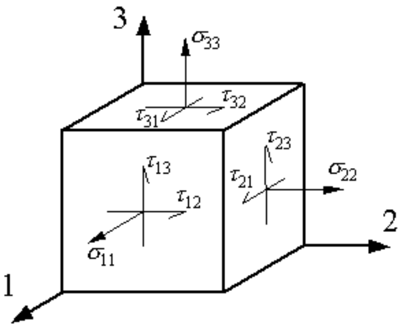
Ply Set-Up:



Modelling of Composites

General stress tensor:

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{21} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & a_{46} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & a_{56} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{21} \end{bmatrix}$$



Stress Tensor for Materials with Isotropic behavior (only E and ν needed):

$$C^{-1} = \begin{bmatrix} \frac{1}{E} & -\frac{\nu}{E} & -\frac{\nu}{E} & 0 & 0 & 0 \\ -\frac{\nu}{E} & \frac{1}{E} & -\frac{\nu}{E} & 0 & 0 & 0 \\ -\frac{\nu}{E} & -\frac{\nu}{E} & \frac{1}{E} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{2(1+\nu)}{E} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{2(1+\nu)}{E} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{2(1+\nu)}{E} \end{bmatrix}$$

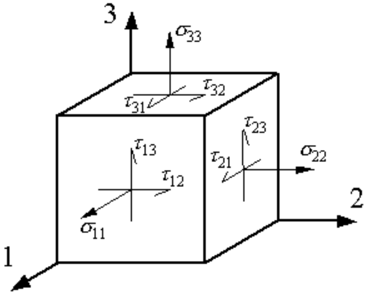
```
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
/UNIT/LENGTH/mm
/UNIT/MASS/Mg
/UNIT/TIME/s
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
#-  2. MATERIALS:
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
/MAT/ELAST/1
Steel
#        Init. dens.          Ref. dens.
              7.8E-9                   0
#                  E                  Nu
              210000                  .3
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
```

2 independent values needed

Modelling of Composites

General stress tensor:

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \tau_{23}\\ \tau_{31}\\ \tau_{21}\end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16}\\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26}\\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36}\\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & a_{46}\\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & a_{56}\\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66}\end{bmatrix} \begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \gamma_{23}\\ \gamma_{31}\\ \gamma_{21}\end{bmatrix}$$



Stress Tensor for Materials with Orthotropic behavior (**9 independent values needed**):

$$\begin{Bmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{33}\\ \gamma_{12}\\ \gamma_{23}\\ \gamma_{31}\end{Bmatrix} = \begin{bmatrix} \frac{1}{E_{11}} & -\frac{\nu_{21}}{E_{22}} & -\frac{\nu_{31}}{E_{33}} & 0 & 0 & 0\\ & \frac{1}{E_{22}} & -\frac{\nu_{32}}{E_{33}} & 0 & 0 & 0\\ & & \frac{1}{E_{33}} & 0 & 0 & 0\\ & & & \frac{1}{G_{12}} & 0 & 0\\ & Symm. & & & \frac{1}{G_{23}} & 0\\ & & & & & \frac{1}{G_{31}}\end{bmatrix} \begin{Bmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{33}\\ \sigma_{12}\\ \sigma_{23}\\ \sigma_{31}\end{Bmatrix}$$

where E_{ij} are the Young's modulus, G_{ij} shear modulus and ν_{ij} Poisson's ratios. γ_{ij} are the strain components due to the distortion.

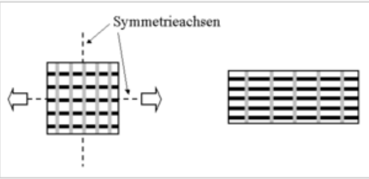


Bild 1:
Belastung eines orthotropen Werkstoffs (Gewebe) in den Symmetrieachsen. Keine Dehnungs-Schiebungs-Kopplung

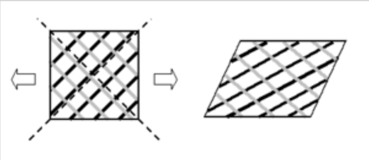


Bild 2:
Belastung eines orthotropen Werkstoffs (Gewebe) außerhalb der Symmetrieachsen. Dehnungs-Schiebungs-Kopplung tritt auf

Modelling of Composites

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Understanding the material property

- Strain-Stress relationship for **orthotropic Plane Stress** problems: 4 independent material values needed

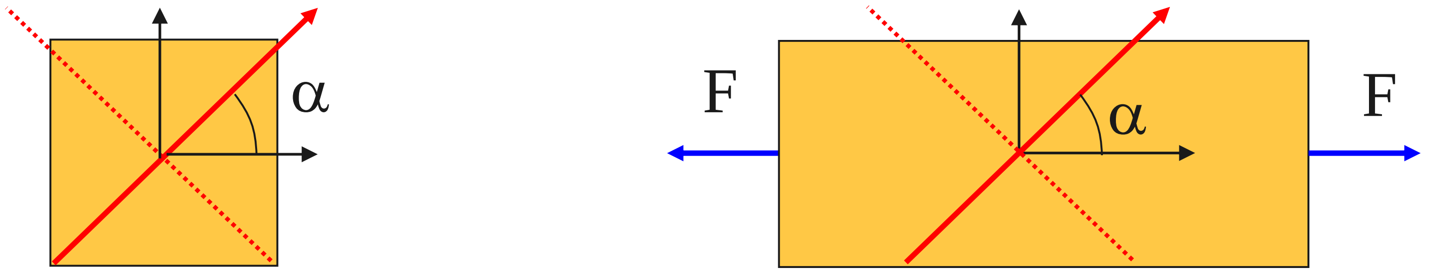
$$\sigma_3 = \tau_{13} = \tau_{23} = 0 \qquad \frac{\upsilon_{ij}}{E_j} = \frac{\upsilon_{ji}}{E_j} \qquad i,j = 1,2,3. \qquad i \neq j$$

$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E_1} & \frac{-\upsilon_{12}}{E_1} & 0 \\ \frac{-\upsilon_{12}}{E_1} & \frac{1}{E_2} & 0 \\ 0 & 0 & \frac{1}{G_{12}} \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix}$$

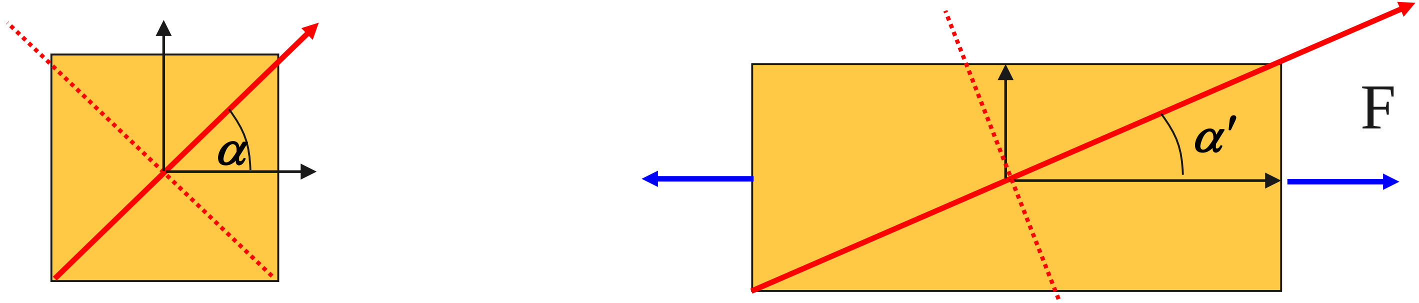
with: $$\varepsilon_3 = -\left(\frac{\upsilon_{12}}{E_1}\sigma_1 + \frac{\upsilon_{23}}{E_2}\sigma_2 \right)$$

Modelling of Composites

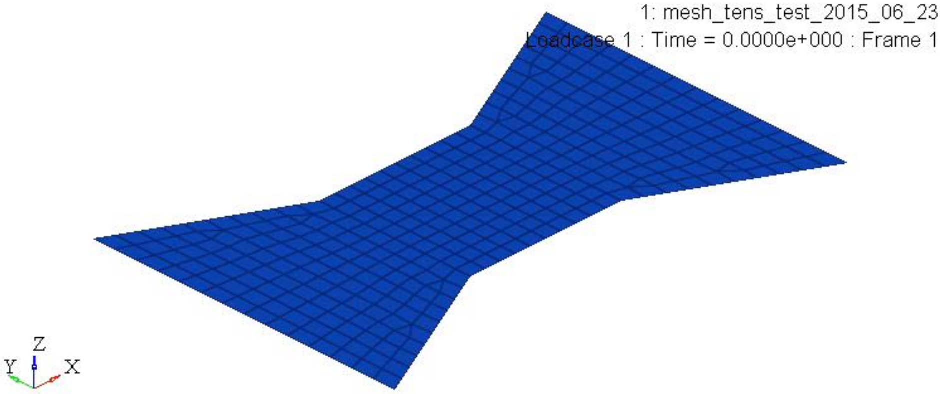
- The orthotropy direction follows the co-rotational local reference (default)

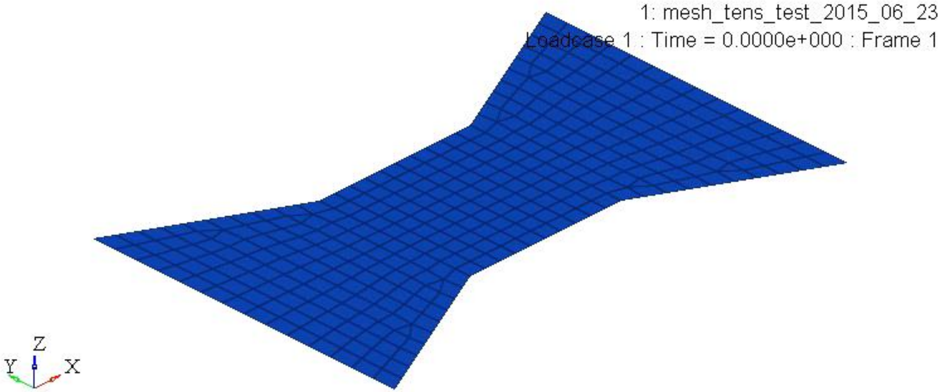


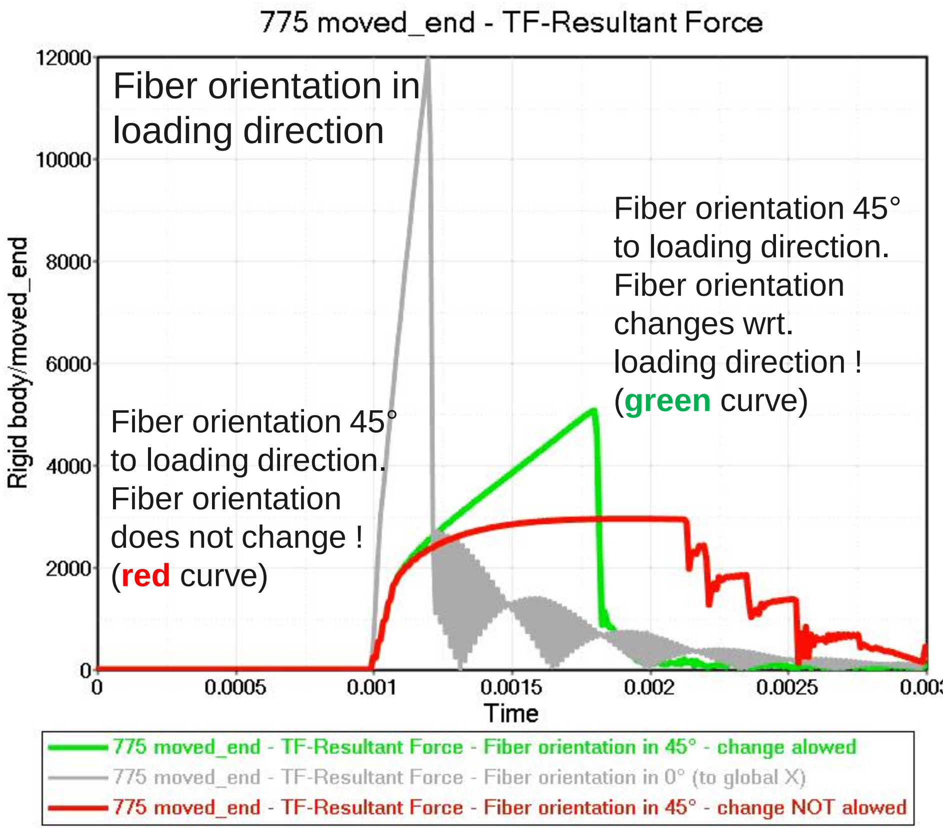
- The orthotropy direction is attached to the local isoparametric frame



Modelling of Composites







Modelling of Composites

Altair

Metallic alloys
- Law 1 : elastic material
- Law 2 : elasto-plastic material
- Law 27 : elasto-plastic brittle material
- Law 36 : tabulated elasto-plastic material
- Law 60: ~ 36 + quadratic strain rate interpolation

Austenitic & stainless steels
- Law 63: Hansel material
- Law 64: Ugine & ALZ material

Crushable foams *(Honeycomb)*
- Law 28: Honeycomb
- Law 50: Crushable foam
- Law 68: Cosserat medium

Foams
- Law 33: Closed Cell visco-elasto-plastic
- Law 35: Generalized Kelvin-Voigt open/closed cells
- Law 38: Tabulated visco-elastic material
- Law 70: Tabulated hyper visco elastic material

Rubber
- Law 42: Ogden-Mooney-Rivlin
- Law 62: Hyper Visco Elastic material

Plastic
- Law 36: tabulated elasto-plastic material
- Law 65: Elastomer material

Glass
- Law 27:elasto-plastic brittle material
- Law 36: tabulated elasto-plastic material

Composite
- Law 27:elasto-plastic brittle
- Law 36: tabulated elasto-plastic material
- Law 15:Tsai-Wu plasticity + Chang & Chang failure
- Law 25: Tsai-Wu plasticity model
- NEW: Law12: Composite Solid Material

Fabric
- Law 19: linear elastic orthotropic material
- Law 58: nonlinear elastic material

Modelling of Composites

RADIOSS : Composite material for crash

```
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
#-  2. MATERIALS:
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
/MAT/COMPSH/1
T300
#        Init. dens.          Ref. dens.
               .0015                   0
#                E11                 E22                NU12   IFLAG              E33
               75000               75000                  .1       1                0
#                G12                 G23                 G31               EPSF1               EPSF2
                2300                2300                2300                   0                   0
#              ESPT1               EPSM1               EPST2               EPSM2                Dmax
                 .01                 .02                 .01                 .02                  .9
#              Wpmax               Wpref      Ioff
                  15                   0         6
#                  C                 EPS               ALPHA                                     Icc
               1E-30                   1                   1                                       3
#         sig_trac_1                B_1T                N_1T         SIGMA_1MAXT                C_1T
                 650                   0                   1                 650                   0
#            EPS_1T1             EPS_2T1          SIGMA_RST1        Wpmax_trac_1
                   0                   0                   0                   0
#         sig_trac_2                B_2T                N_2T         SIGMA_2MAXT                C_2T
                 650                   0                   1                  65                   0
#            EPS_1T2             EPS_2T2          SIGMA_RST2        Wpmax_trac_2
                   0                   0                   0                   0
#         sig_comp_1                B_1C                N_1C         SIGMA_1MAXC                C_1C
                 650                   0                   1                 650                   0
#            EPS_1C1             EPS_2C1          SIGMA_RSC1        Wpmax_comp_1
                 .01                   0                   0                   0
#         sig_comp_2                B_2C                N_2C         SIGMA_2MAXC                C_2C
                 650                   0                   1                 650                   0
#            EPS_1C2             EPS_2C2          SIGMA_RSC2        Wpmax_comp_2
                 .01                   0                   0                   0
#             sig_12               B_12T               N_12T        SIGMA_12MAXT               C_12T
                  25                   0                   1                1E30                   0
#           EPS_1T12            EPS_2T12         SIGMA_RST12       Wpmax_trac_12
                  25                   0               1E-30                  14
#          GAMMA_INI           GAMMA_MAX                Dmax
                   0                   0                   0
#   Fsmooth                Fcut
          0                   0
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
```

Linear behavior

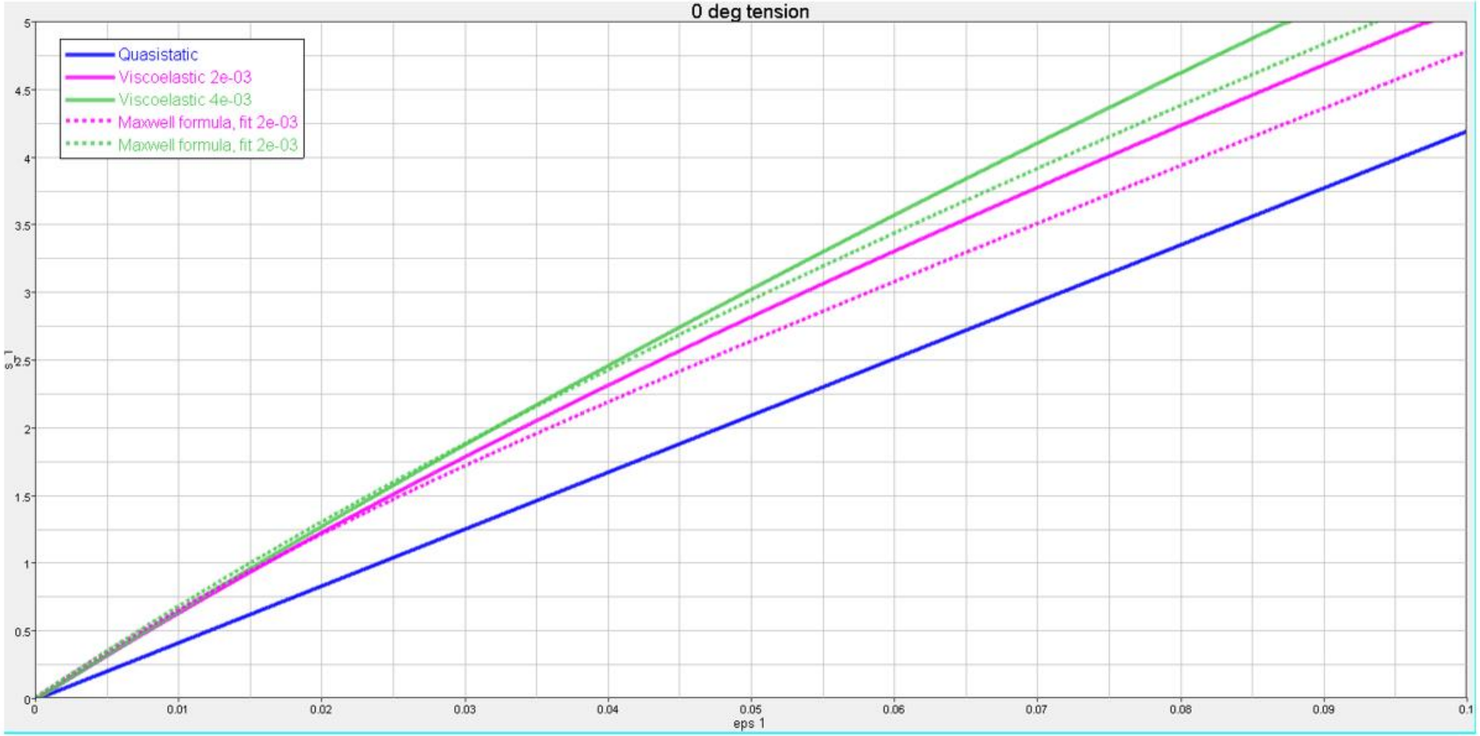
0 = Tsai-Wu
1 = Crasurv

Individual strain rate behavior

Nonlinear behavior

(simple) Delamination

Visco-elastic material

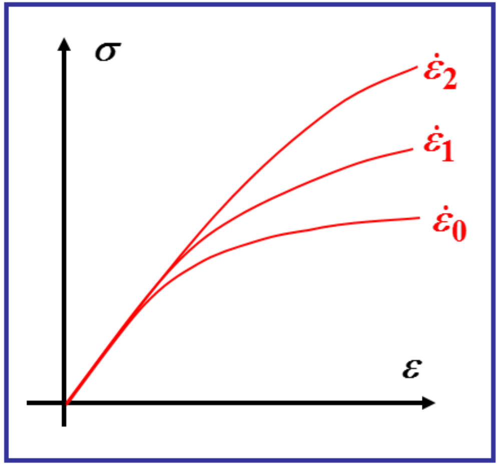


Modelling of Composites

Strain Rate Effect on plasticity

- Influence of strain rate on the yield stress and hardening

$$\sigma_y^i(W_P,\dot{\varepsilon}) = \sigma_{0y}^i\left(1 + bW_P^n\right)\left(1 + c\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)$$



  - « i » stands for orthotropy directions 1, 2 and shear direction 12
  - The general formula is applied for compression, tension and shear stresses
  - The new yield stresses σ_{yi} update the Tsai-Wu criterion parameters F_{ij}

Modelling of Composites

Non- linear properties for orthotropic material are determined through 6 sets of data

- Traction on 0 degrees
- Compression in 0 degrees
- Traction in 90 degrees
- Compression in 90 degrees
- Traction/Compression in 45 degrees

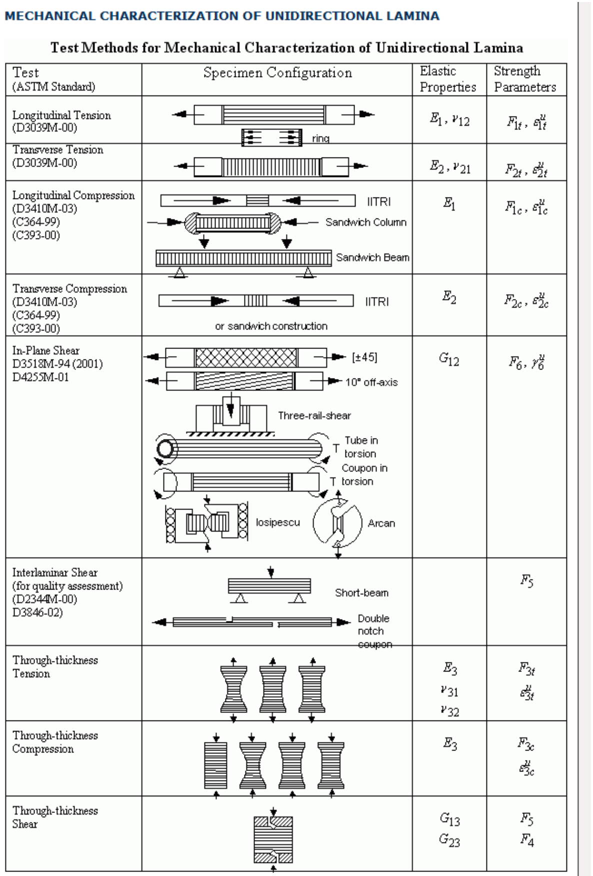
= 5 Tests

Environmentally Controlled Material Testing

Some of Available Tests

- Composite Tensile Properties (ASTM D3039)
- Composite Compression Properties (ASTM D3410)
- Composite Shear Properties (ASTM D5379)
- Poisson's Ratio (ASTM E132)
- Density (ASTM D792)
- Composite Fiber Volume Fraction (ASTM D3171)
- Adhesive Shear Strength (ASTM D3165)
- Flexural Properties (ASTM D790)

Modelling of Composites



MECHANICAL CHARACTERIZATION OF UNIDIRECTIONAL LAMINA

Test Methods for Mechanical Characterization of Unidirectional Lamina

Test (ASTM Standard)	Specimen Configuration	Elastic Properties	Strength Parameters
Longitudinal Tension (D3039M-00)	ring	E_1, ν_{12}	F_{1t}, ε_{1t}^u
Transverse Tension (D3039M-00)		E_2, ν_{21}	F_{2t}, ε_{2t}^u
Longitudinal Compression (D3410M-03) (C364-99) (C393-00)	IITRI Sandwich Column Sandwich Beam	E_1	F_{1c}, ε_{1c}^u
Transverse Compression (D3410M-03) (C364-99) (C393-00)	IITRI or sandwich construction	E_2	F_{2c}, ε_{2c}^u
In-Plane Shear D3518M-94 (2001) D4255M-01	[±45] 10° off-axis Three-rail-shear T Tube in torsion T Coupon in torsion Iosipescu Arcan	G_{12}	F_6, γ_6^u
Interlaminar Shear (for quality assessment) (D2344M-00) D3846-02)	Short-beam Double notch coupon		F_5
Through-thickness Tension		E_3 ν_{31} ν_{32}	F_{3t} ε_{3t}^u
Through-thickness Compression		E_3	F_{3c} ε_{3c}^u
Through-thickness Shear		G_{13} G_{23}	F_5 F_4

http://www.composites.northwestern.edu/research/characterization/mechchar.htm

Modelling of Composites

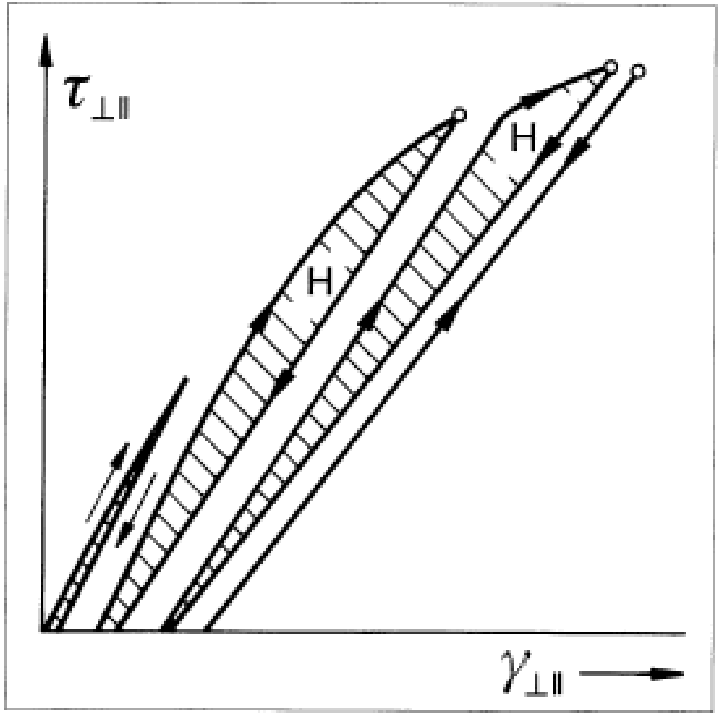


Bild 1.3: Schubspannungs, Schiebungs-Diagramm bei Quer/Längs-Schubbeanspruchung $\tau_{\perp\parallel}$ für Be- und Entlastungsvorgänge mit stufenweise gesteigerter Höchstlast. H = Hysterese infolge Mikroschädigungen

Source: Alfred Puck: Festigkeitsanalyse von Faser-Matrix-Laminaten: Modelle für die Praxis. Hanser Verlag 1996. ISBN: 3-446-18194-6

Modelling of Composites

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Failure Model Description

Failure Model	Type	Description
CHANG	Chang-Chang model	Failure criteria for composites
CONNECT	Failure	Normal and Tangential failure model
ENERGY	Energy isotrop	Specific energy
FLD	Forming limit diagram	Fld
HASHIN	Composite model	Hashin model
JOHNSON	Ductile failure model	Johnson-Cook
LAD_DAMA	Composite delamination	Ladeveze delamination model
PUCK	Composite model	Puck model
SPALLING	Ductile + Spalling	Spalling + Johnson-Cook
TAB	Strain failure model	Strain failure
TBUTCHER	Tuler-Butcher model	Failure due to fatigue
TENSSTRAIN	Traction	Strain failure
WIERZBICKI	Ductile material	Bao-Xue-Wierzbicki model
WILKINS	Ductile failure model	Wilkins model
XFEM_FLD	Forming limit diagram	Fld
XFEM_JOHNS	Ductile failure model	Johnson-Cook
XFEM_TBUTC	Ductile (brittle) failure model	Modified Tuler-Butcher model

Modelling of Composites

HASHIN

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Imodel	Ishell	Isolid							
σ_{t1}		σ_{t2}		σ_{t3}		σ_{c1}		σ_{c2}	
pmax		F σ_{12}		M σ_{12}		M σ_{23}		M σ_{13}	
ϕ		S_{delam}		T_{max}					

Material/Failure validation workshop

- Multidirectional failure criterion (two one fiber direction + matrix)
- 7 failure modes (crush mode for matrix is added)
- Tension/compression is interconnected with shear
- Deals with stresses not with strains
- 8 unknown constants
- We have 6 test: 0 deg (fiber) tension/compression

  90 deg (matrix) tension/compression

  45 deg (fiber+matrix) tension/compression

  → combined test are necessary

Material data

Modelling of Composites

Puck

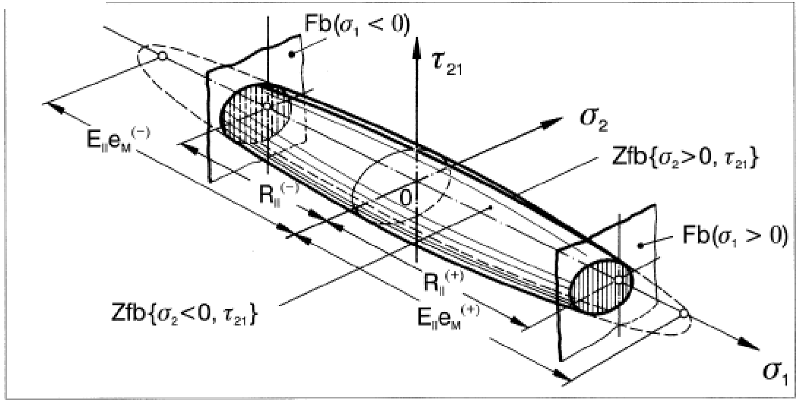


Bild 5.3: Als "Bruch-Zigarre" bezeichneter Bruchkörper für ebene $(\sigma_1, \sigma_2, \tau_{21})$-Spannungszustände

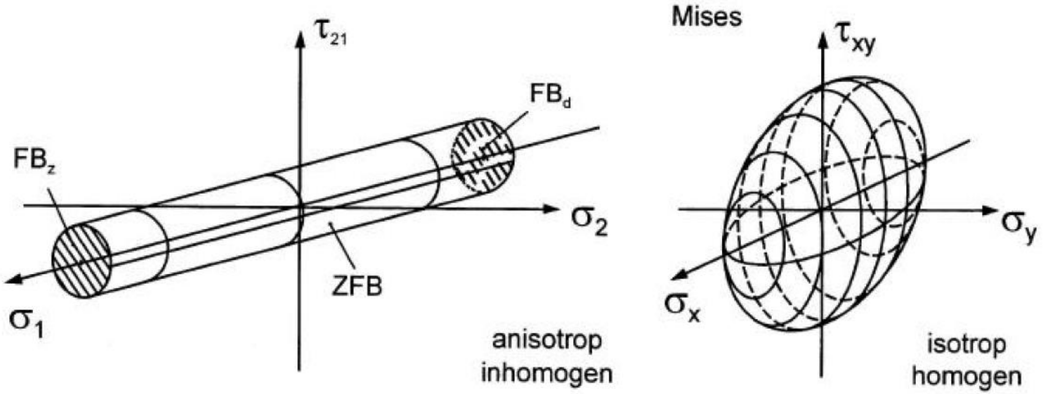


Bild 8: Qualitative Darstellung eines ES-Bruchkörpers und eines Fließkörpers duktiler Werkstoffe, [Mic 94]

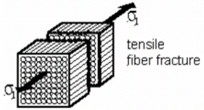
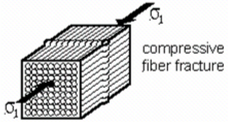
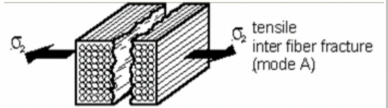
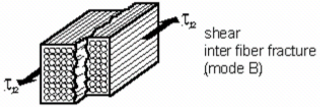
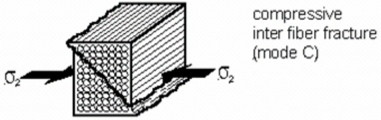
Source:

[Mic 94] MICHAELI, W., HUYBRECHTS, D., WEGENER, M.: Dimensionieren mit Faserverbundkunststoffen, Einführung und praktische Hilfen, Carl Hanser Verlag, München, Wien 1994, ISBN 3-446-17659-4

[Puck 96] PUCK, A.: Festigkeitsanalyse von Faser-Matrix-Laminaten, Modelle für die Praxis, Carl Hanser Verlag, München, Wien 1996, ISBN 3-446-18194-6

Modelling of Composites

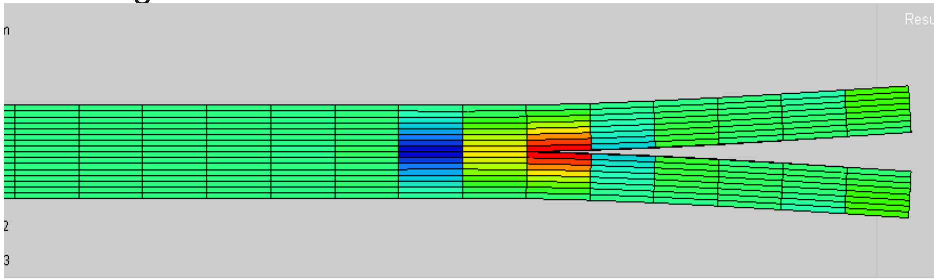
Puck

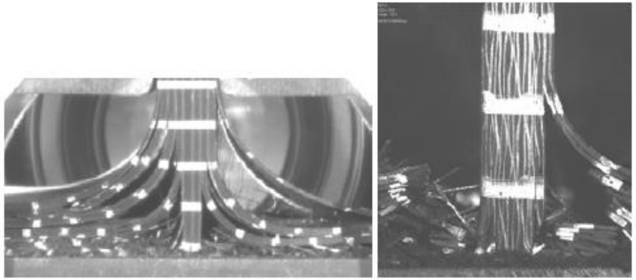
failure mode	condition
tensile FF	$\frac{\sigma_1}{X_t} = 1$ 
compressive FF	$\frac{\lvert\sigma_1\rvert}{X_c} = 1$ 
IFF mode A	$\sqrt{\left(\frac{\tau_{12}}{S}\right)^2 - \left(1 - p_{12}^{+}\frac{Y_t}{S}\right)^2\left(\frac{\sigma_2}{Y_t}\right)^2} + p_{12}^{+}\frac{\sigma_2}{S} = 1$ 
IFF mode B	$\frac{1}{S}\left(\sqrt{\tau_{12}^2 + \left(p_{12}^{-}\sigma_2\right)^2} + p_{12}^{-}\sigma_2\right) = 1$ 
IFF mode C	$\left[\left(\frac{\tau_{12}}{2\left(1 + p_{22}^{-}\right)S}\right)^2 + \left(\frac{\sigma_2}{Y_c}\right)^2\right]\frac{Y_c}{(-\sigma_2)} = 1$ 

Modelling of Composites

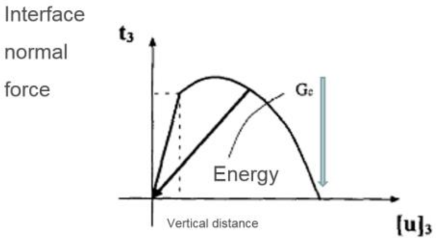
Delamination:

- Any material law with any solid elements
  - AMS if pressure wave propagation in transverse direction is neglected

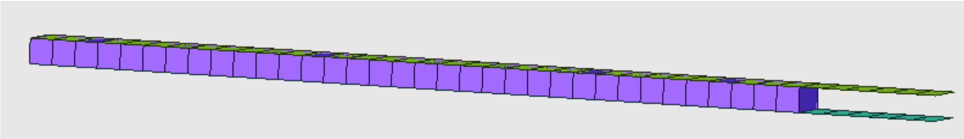




- **Cohesive** elements (LAW59) :
  - User defined plastic deformation in normal and shear directions
  - Rupture criteria
  - Definition and time step independent from the element height (which can be zero)

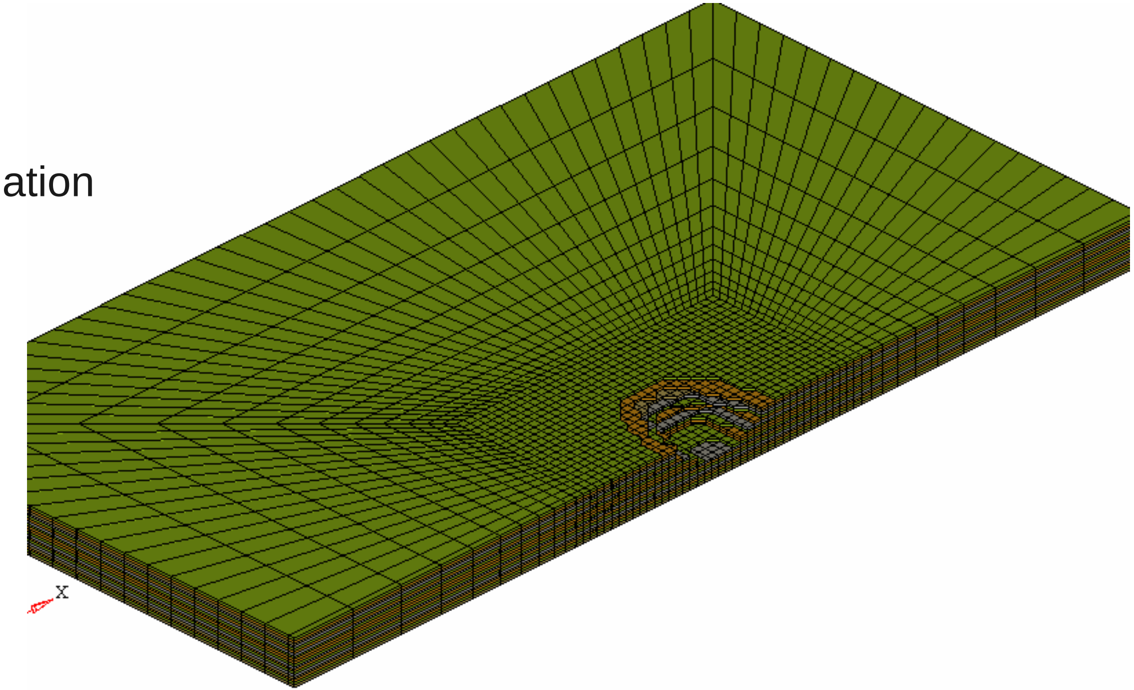


Failure occurs when energy absorbed by the bonding interface becomes greater than a certain limit.



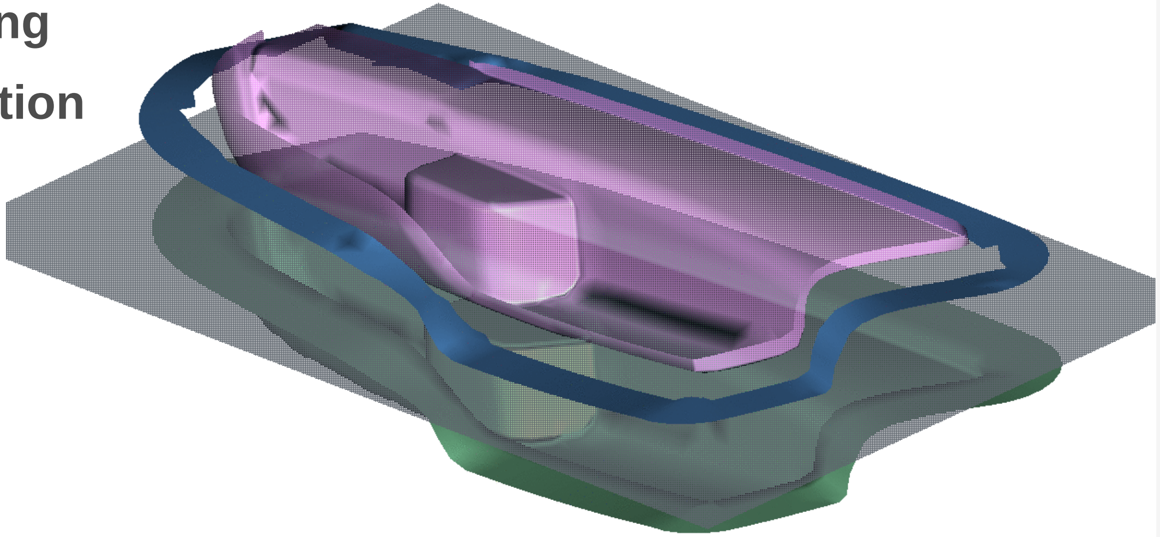
Modelling of Composites

- Possibility to apply several failure criteria for one material law :
  - Example :
    - Hashin for fiber
    - Puck for Matrix
    - Ladeveze for delamination

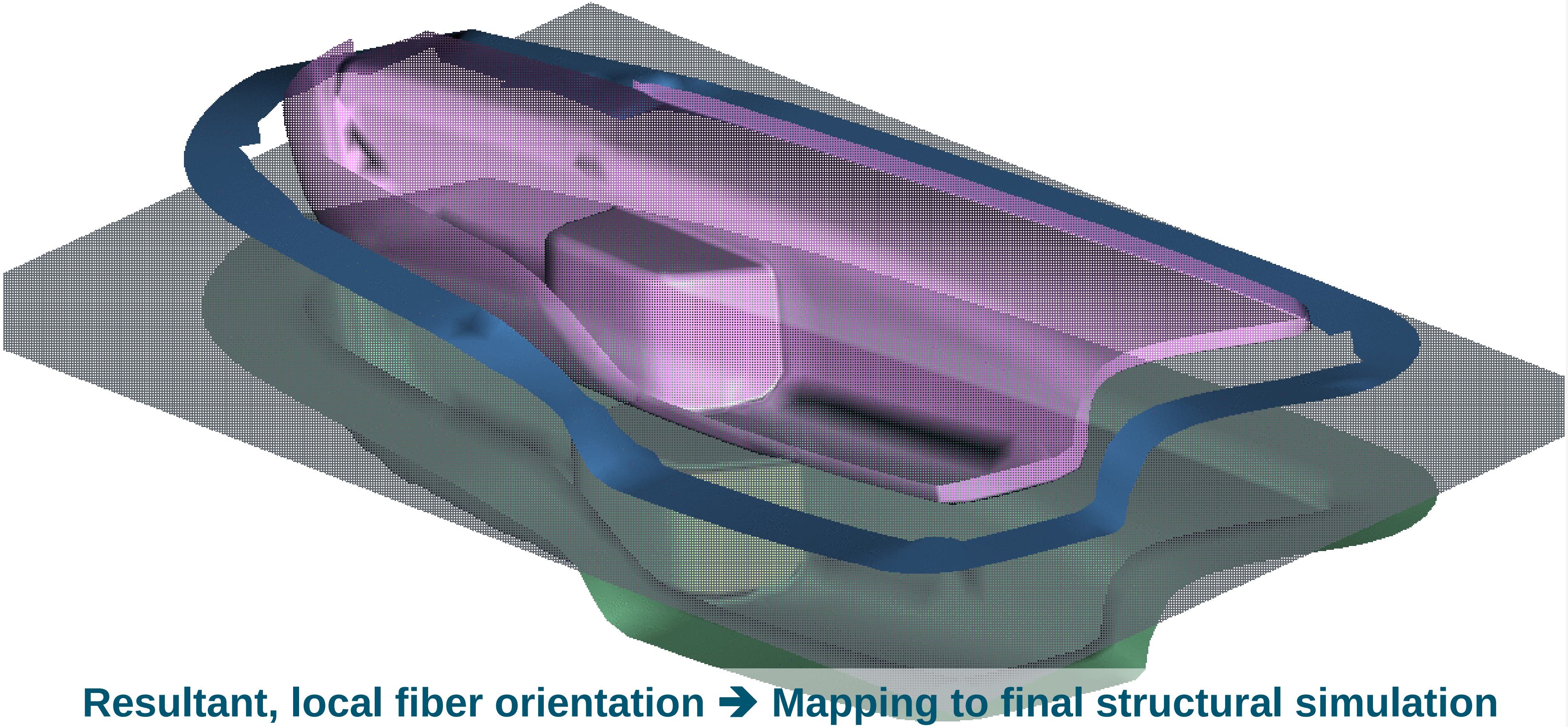


Modelling of Composites

- Model: Composite fairing
- Objective: Fibre orientation change & potential damage during forming
- Loading: Quasi-static forming
- Material flow & fibre orientation changes

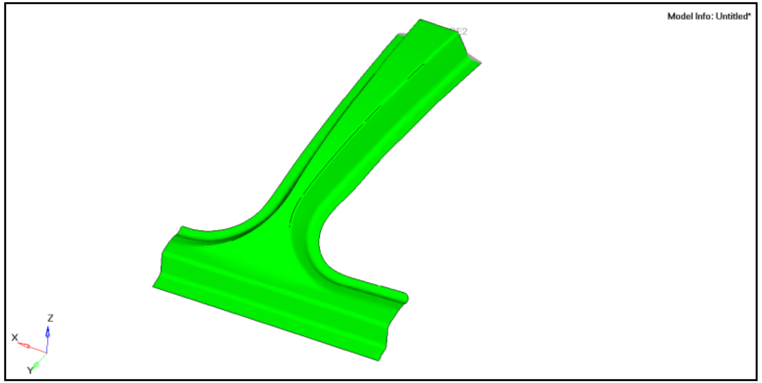


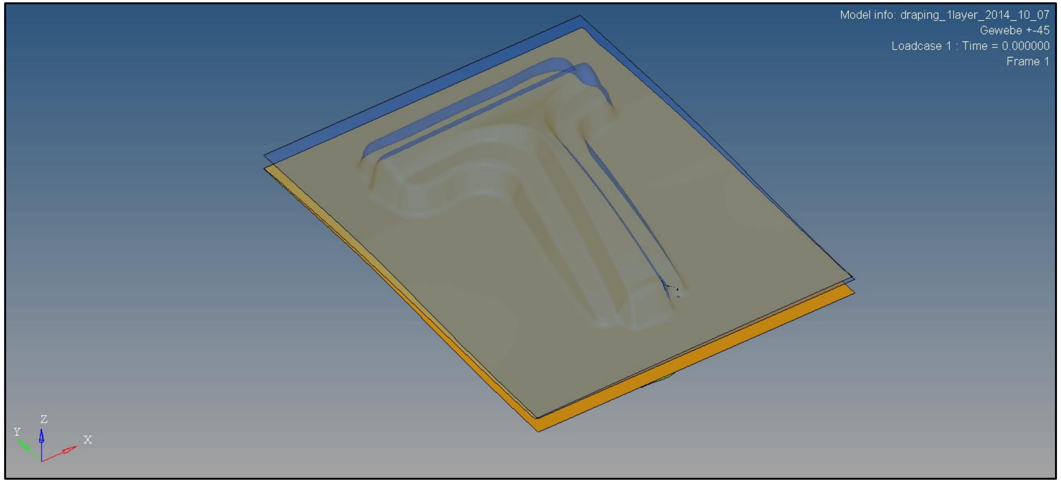
Modelling of Composites (Draping Simulation)



Resultant, local fiber orientation ➔ Mapping to final structural simulation

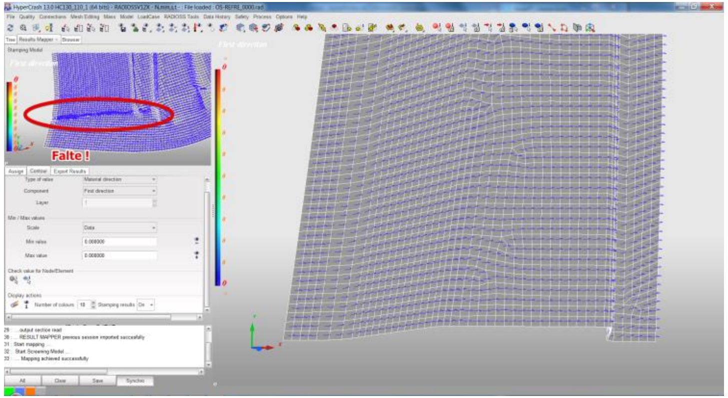
Modelling of Composites (Draping Simulation)



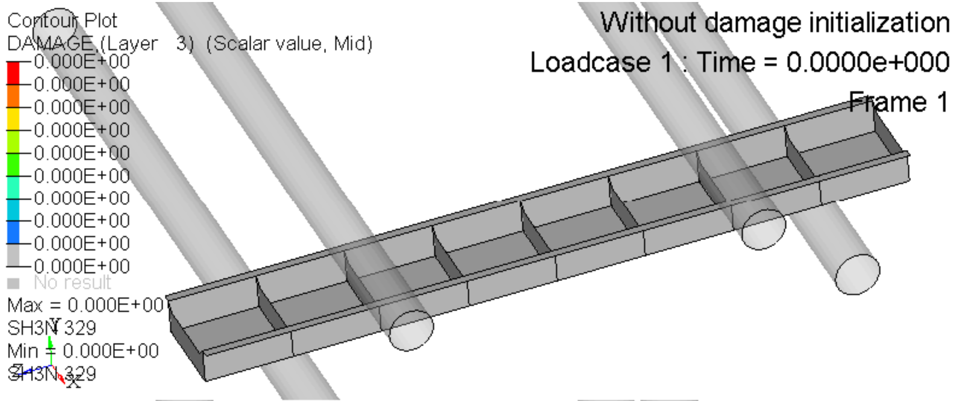


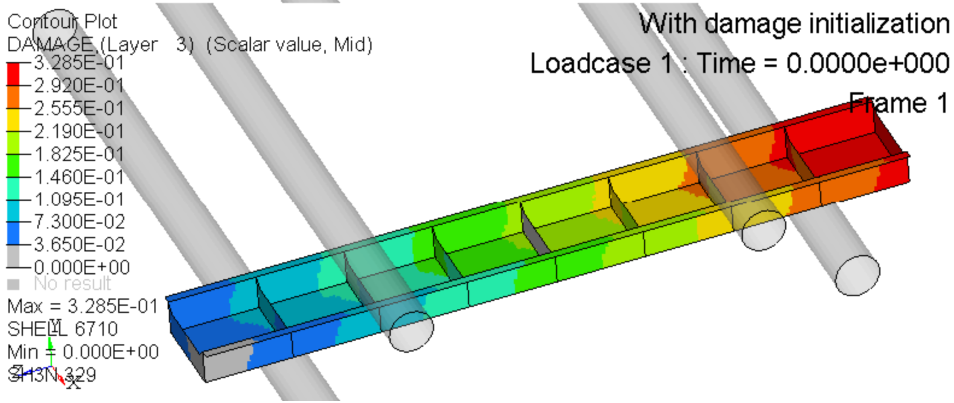
Forming Simulations were done for:
UD-Layers (0, 90, 45, minus 45)
Woven Fabric (0 and 45 orientation)

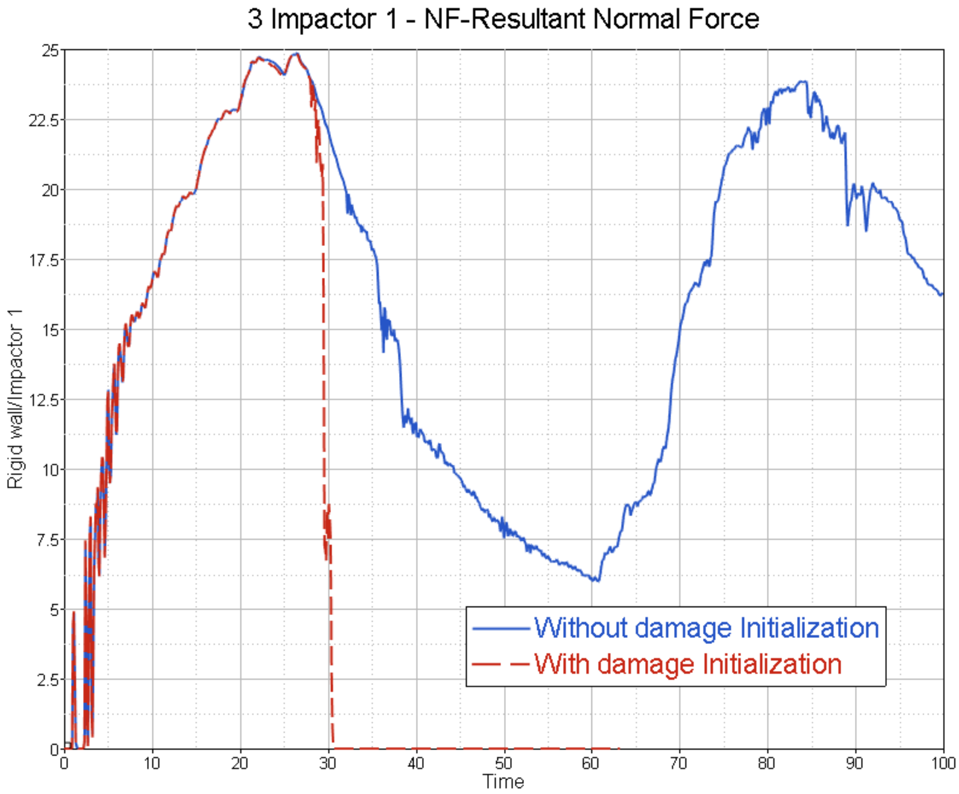
=> Leading to 6 different Drape tables as addional Inpiut for the freesize optimisation



Modelling of Composites

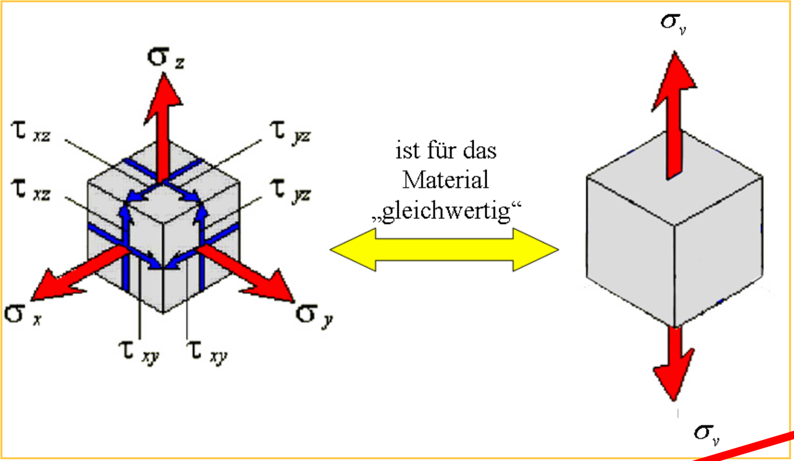


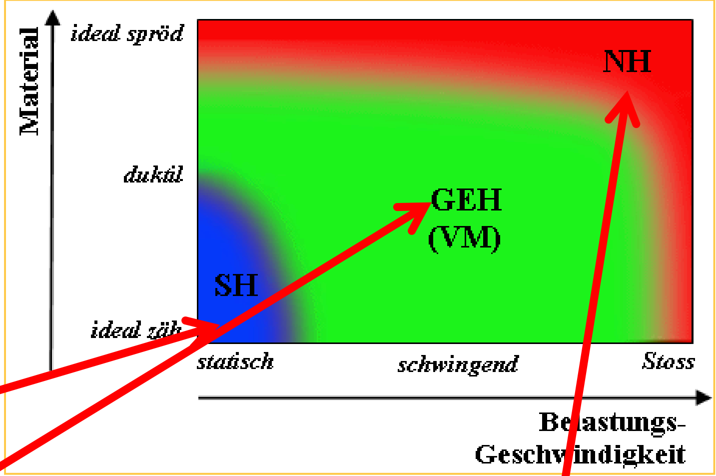




Modelling of Composites

Equivalent Stress:





Shear Stress Hypothesis (Tresca)

$$\sigma_v = 2\tau_{max}$$

Räumlicher Spannungszustand:

$$\sigma_v = \max(|\sigma_I - \sigma_{II}|;|\sigma_{II} - \sigma_{III}|;|\sigma_{III} - \sigma_I|)$$

σ_I, σ_{II} und σ_{III} sind die Hauptspannungen.

Ebener Spannungszustand:

$$\sigma_v = \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}$$

Gestalltänderungshypothese (von Mises)

Beschreibung im allgemeinen Spannungszustand:

$$\sigma_v = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - \sigma_x\sigma_y - \sigma_x\sigma_z - \sigma_y\sigma_z + 3(\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2)}$$

Beschreibung im Hauptspannungszustand:

$$\sigma_v = \sqrt{\frac{1}{2}[(\sigma_I - \sigma_{II})^2 + (\sigma_{II} - \sigma_{III})^2 + (\sigma_{III} - \sigma_I)^2]}$$

σ_I, σ_{II} und σ_{III} sind die Hauptspannungen.

Beschreibung im ebenen Spannungszustand:

$$\sigma_v = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\tau_{xy}^2}$$

Beschreibung im ebenen Verzerrungszustand mit:

$$\sigma_z = \nu(\sigma_x + \sigma_y)$$

$$\sigma_v = \sqrt{(\sigma_x^2 + \sigma_y^2)(\nu^2 - \nu + 1) + \sigma_x\sigma_y(2\nu^2 - 2\nu - 1) + 3\tau_{xy}^2}$$

Normal Stress Hypothesis (Rankine)

Räumlicher Spannungszustand:

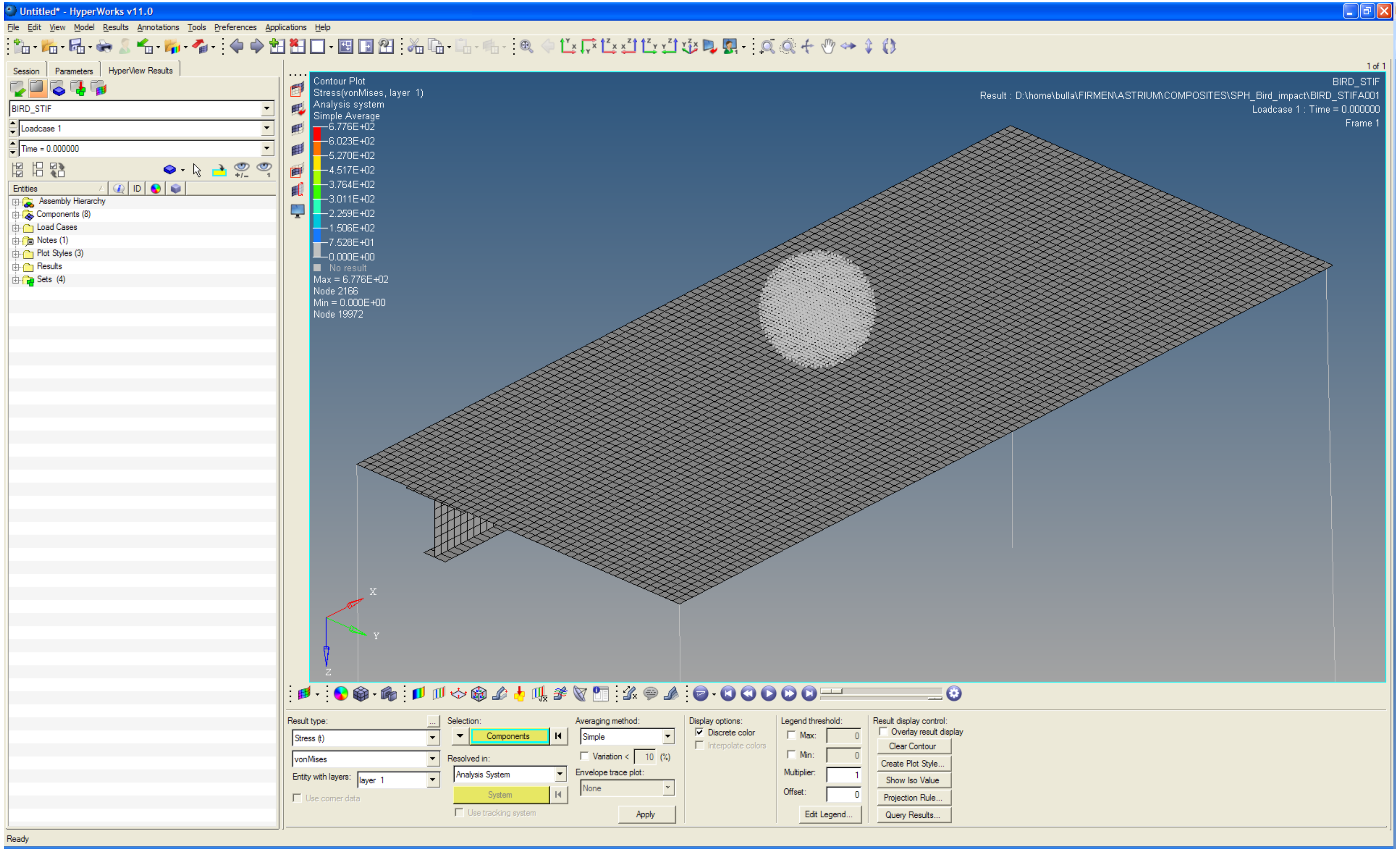
$$\sigma_v = \max(\sigma_I, \sigma_{II}, \sigma_{III})$$

Ebener Spannungszustand:

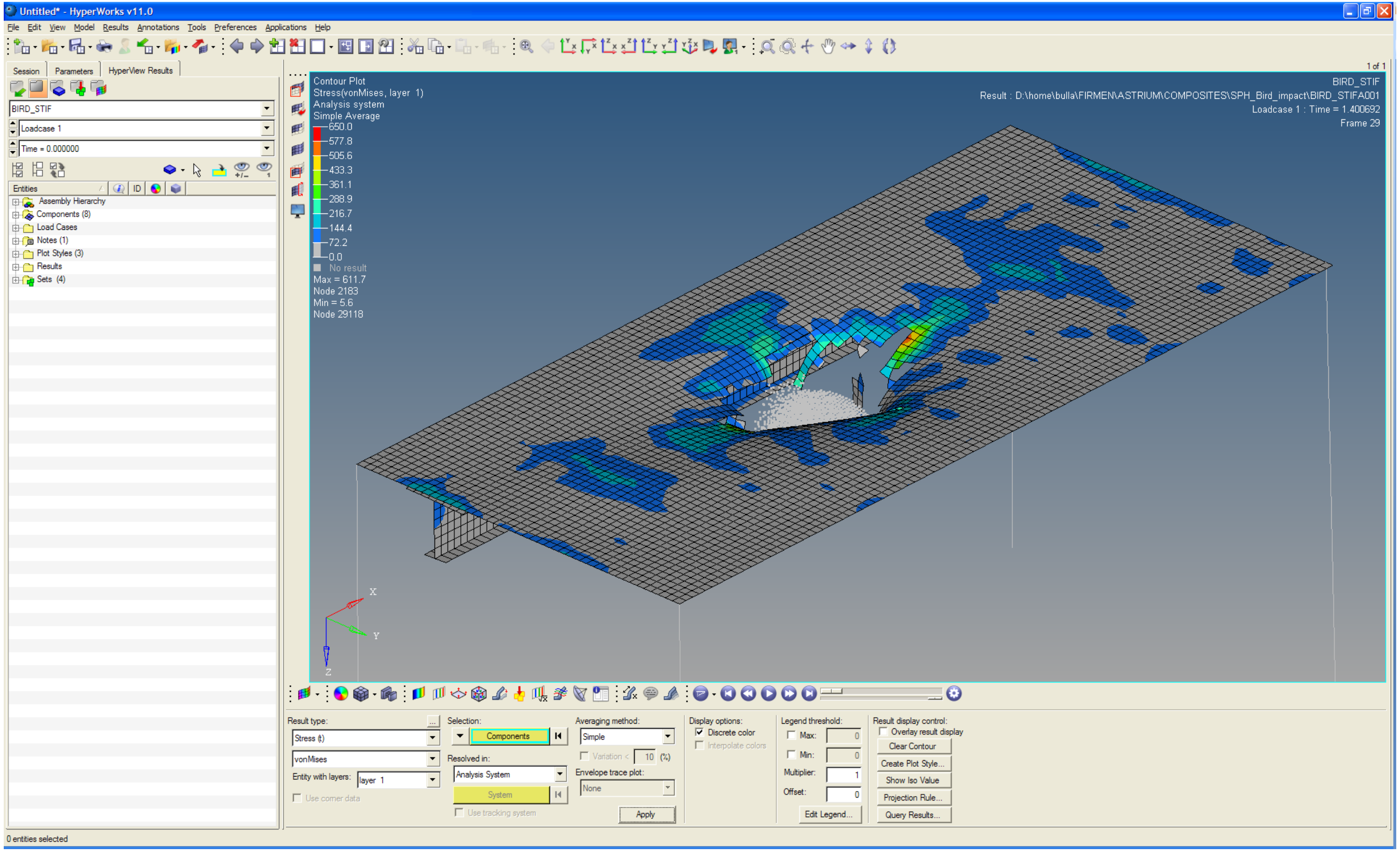
$$\sigma_v = \frac{1}{2}\left[(\sigma_x + \sigma_y) + \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}\right]$$

Quelle: Wikipedia

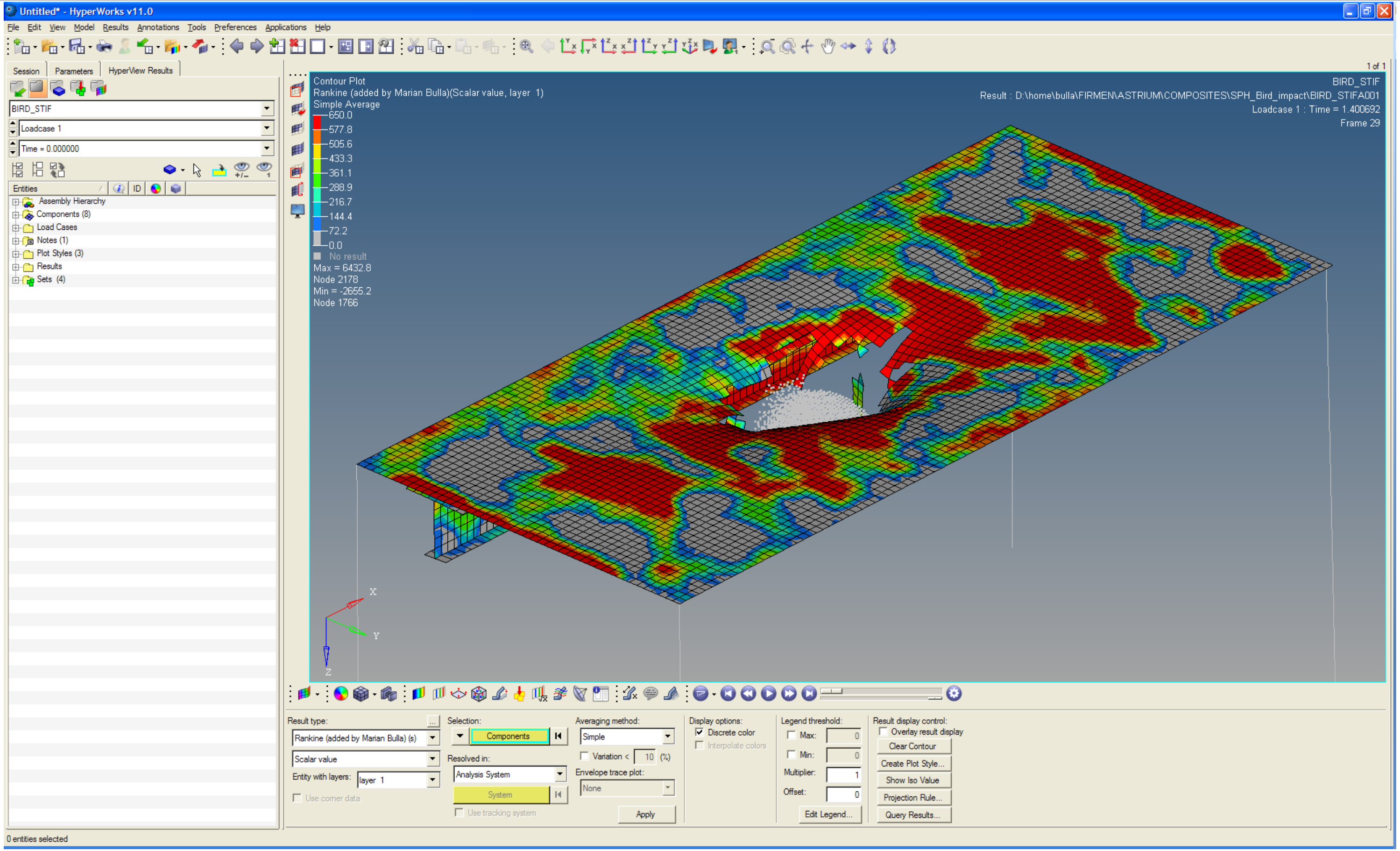
Modelling of Composites



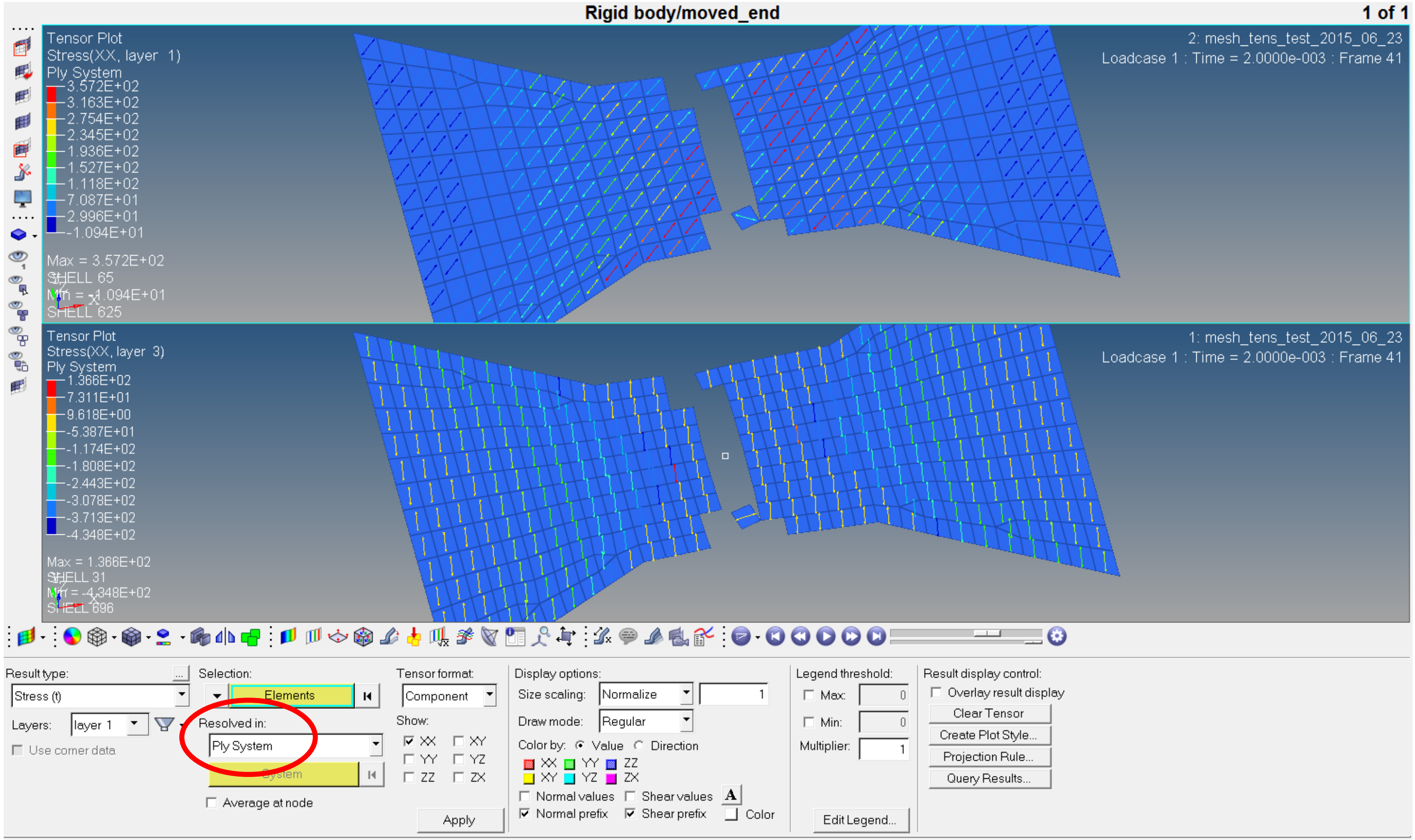
Modelling of Composites



Modelling of Composites



Modelling of Composites

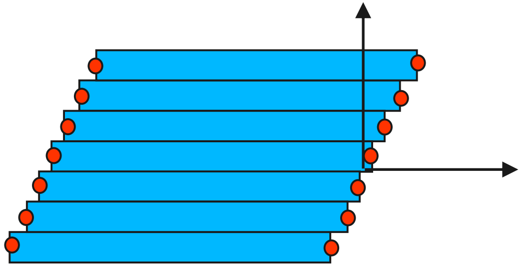


Modelling of Composites

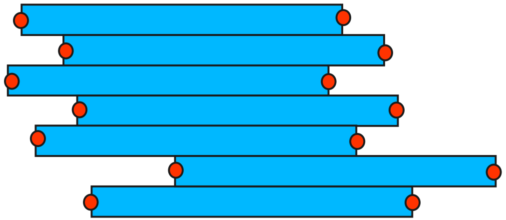
Ply-Xfem Approach

New shell formulation

- Based on standard Batoz shell element fully integrated
- Stack / ply input
- Additional variables on node/ply.
- Cohesive element between ply to control the sliding between ply
- Meshed with standard Batoz shell element



Standard Kinematic shell



Modified Kinematic shell

<u>Additional</u> variable are added on each node/ply

$$\delta_1, \delta_2 \text{ and } \delta_3$$

Modelling of Composites

Shell Generalized strain

- Additionnal variable are added on each node/ply $\delta_1, \delta_2 \text{ and } \delta_3$

So the Generalized Strain are modified for each ply j as

$$\varepsilon_{xx}^{j} = u_{,x} + z_j \theta_{1,x} + \delta_{1,x}^{j}$$

$$\varepsilon_{yy}^{j} = v_{,y} + z_j \theta_{2,y} + \delta_{2,y}^{j}$$

$$\gamma_{xy}^{j} = u_{,y} + z_j \theta_{1,y} + \delta_{1,y}^{j} + v_{,x} + z_j \theta_{2,x} + \delta_{2,x}^{j}$$

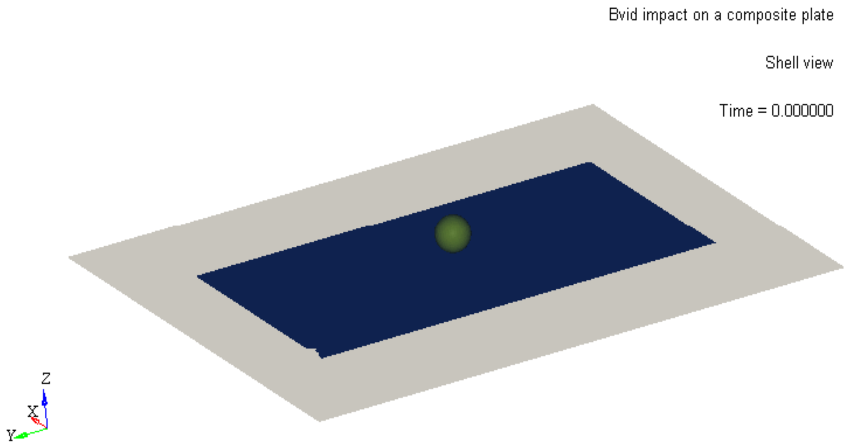
$$\gamma_{xz}^{j} = \theta_{1,z} + \boxed{\delta_{1,z}^{j}} + w_{,x}$$

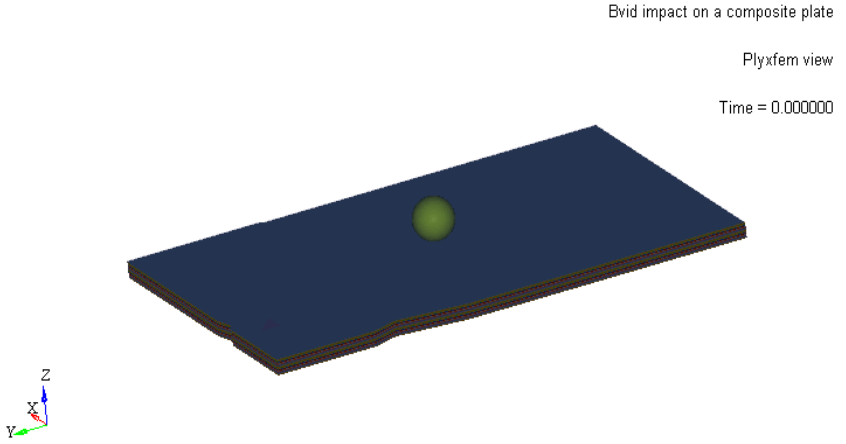
$$\gamma_{yz}^{j} = \theta_{2,z} + \boxed{\delta_{2,z}^{j}} + w_{,y}$$

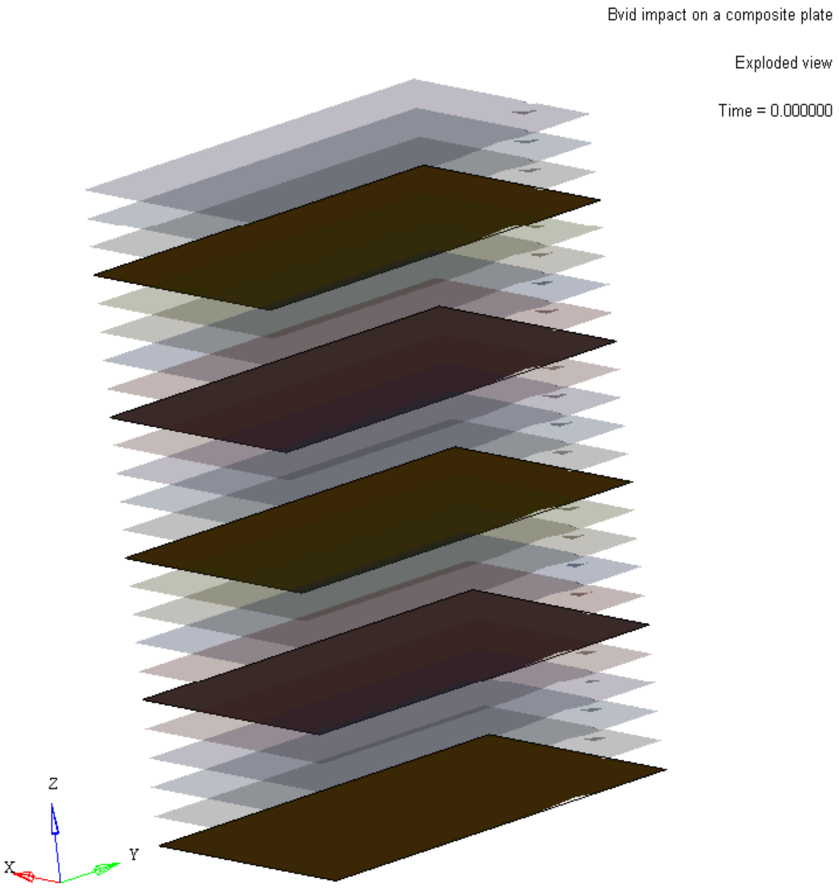
$$\varepsilon_{zz} = \boxed{\delta_{3,z}^{j}}$$

Taken into account in the interply

Modelling of Composites







Modelling of Composites

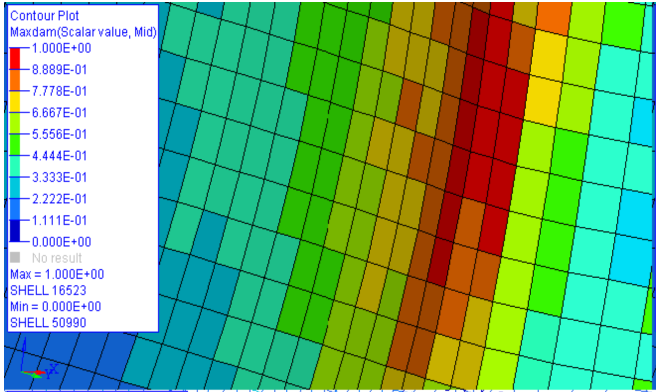
Altair

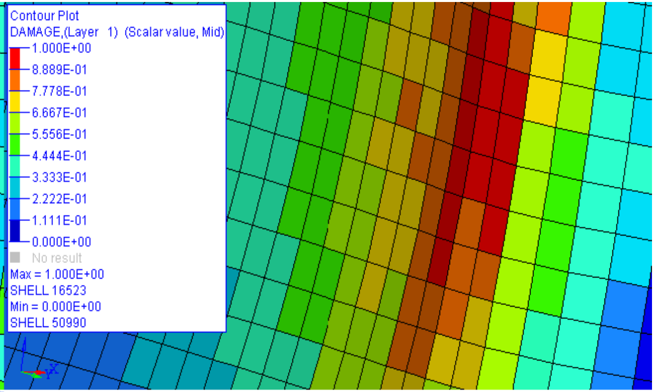
/ANIM/SHELL/DAMA : Understanding Failure Process

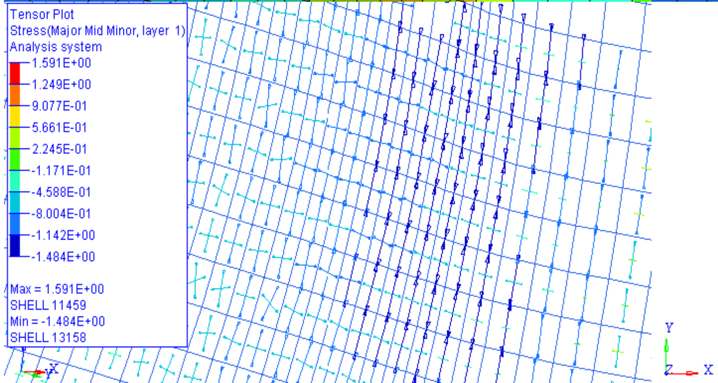
Composite:

Max damage over layers

Damage, layer 1







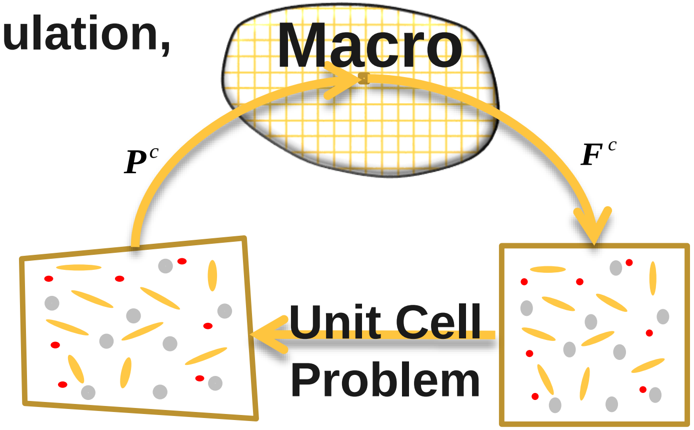
« Vertical compression » is critical

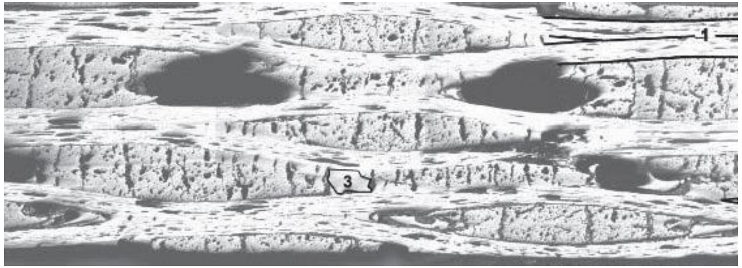
Agenda

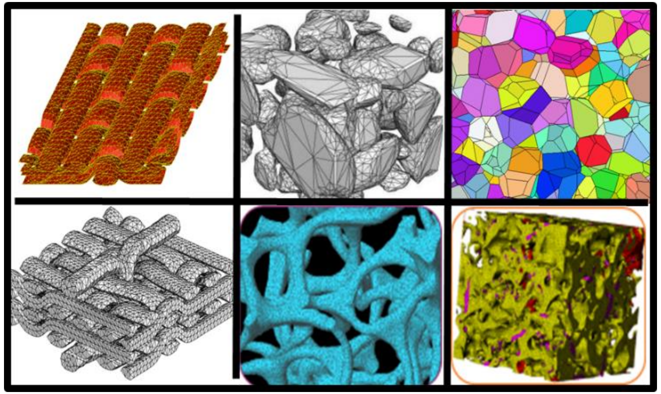
- Company Introduction – Our Vision
- HyperWorks Solvers: RADIOSS
- Modelling of Composites
  - **MDS**
- Examples from the field

Anything missing ? MDS

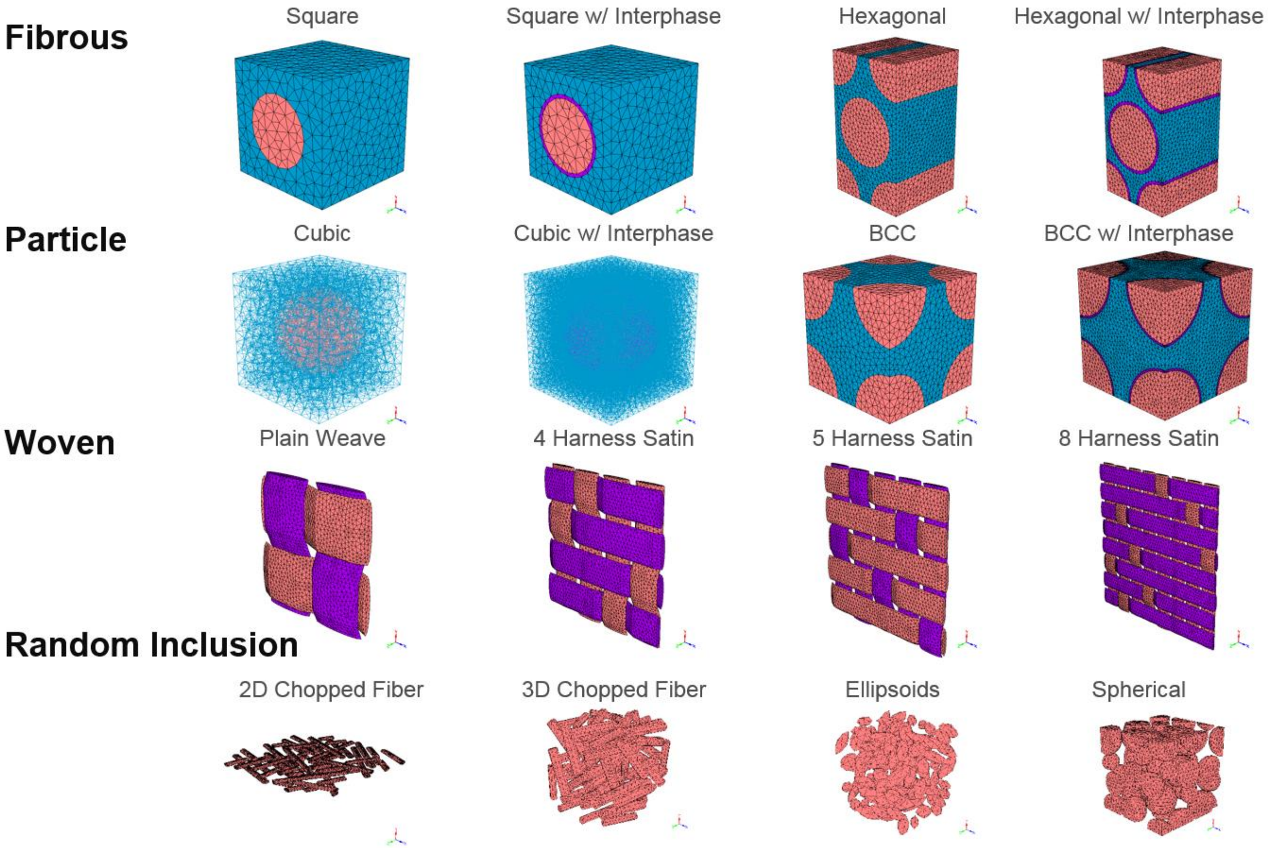
- Solution: Computational modeling, Simulation, and Analysis
- Computational Complexity
- Size Effect & Uncertainty





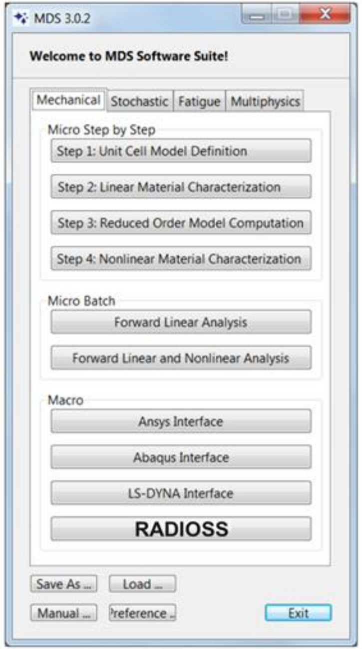


Anything missing ? MDS



Anything missing ? MDS

Need to determine $[E]^{ply}$ $\{\sigma\}^{ply}$ $[E]^{matrix}$ $[E]^{fiber}$ for a given unit cell to obtain $\{\sigma\}^{fiber}$ and $\{\sigma\}^{matrix}$ and ultimately predict material behavior.



Step 1
- **Unit Cell Model Definition**

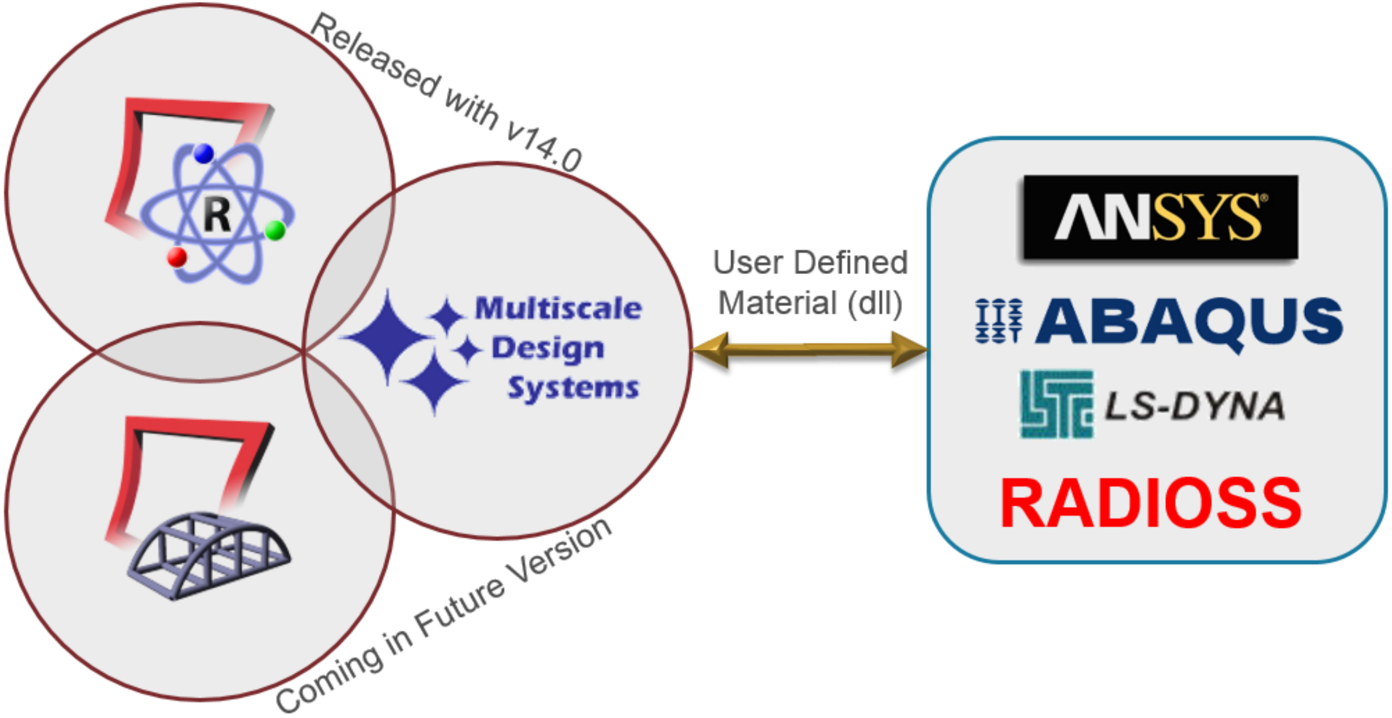
Step 2
- **Linear Material Characterization**
  - Forward $[E]^{fiber}$ $[E]^{matrix}$ → $[E]^{ply}$
  - Inverse $[E]^{ply}$ → $[E]^{Fiber}$ $[E]^{matrix}$

Step 3
- **Reduced Order Model Computation**
  - Provides Computational Efficiency to the Macro Solver

Step 4
- **Nonlinear Material Characterization**
  - Forward $[E]^{fiber}$ $[E]^{matrix}$ nonlinear law → $[E]^{ply\ nonlinear}$
  - Inverse $[E]^{ply\ nonlinear}$ nonlinear law → $[E]^{fiber}$ $[E]^{matrix}$

Step 5
- **Macro Solver Interface**
  - Develop a macro solver model
  - Uses the Reduced Order Model and the Nonlienar Material Characterization to transform $\{s\}^{ply}$ → $\{s\}^{fiber}$ $\{s\}^{matrix}$

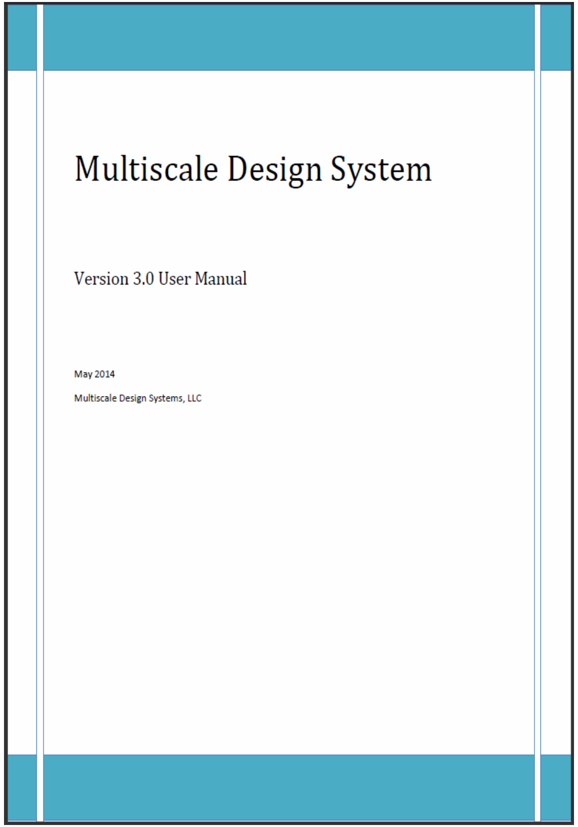
Anything missing ? MDS

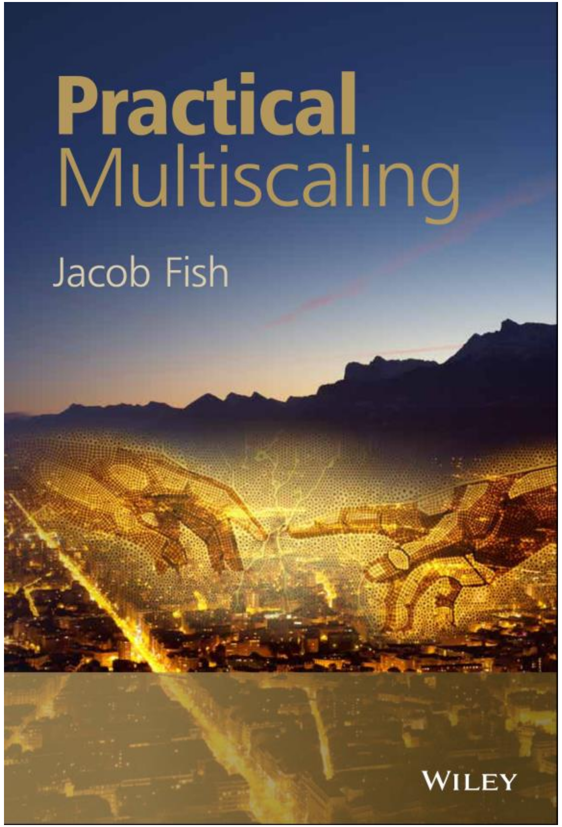


Anything missing ? MDS

Altair

Additional Information





Anything missing ? → Limited by your fantasy

User law Development

Workflow with dynamic libraries

linux64

libraduser_linux64.so

linux64
linux64_impi
linux64_plmpi

userlib_sdk
INTEL Compiler

win64

libraduser_win64.dll

win64
win64_impi
win64_msmpi
win64_plmpi

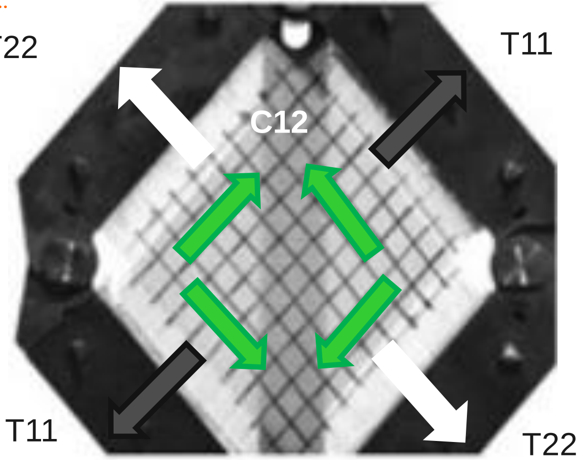
- There are two most used Operating Systems for calculating:
  - Windows64
  - Linux64
- There are two available Fortran compiler provider:
  - Intel
  - GNU (Freeware gcc - gfortran)

Production

Anything missing ?

Constitutive model for pre-impregnated thermoplastics composites

In collaboration with LAMCOS (INSA Lyon)



- Continuum approach:
  - Hyper elastic model (woven reinforcement)

$$\underline{\underline{S}} = 2\frac{\partial w}{\partial \underline{\underline{C}}}$$

$\underline{\underline{S}}$: 2nd Piola–Kirchhoff stress tensor

w : Strain energy

We can associate a strain energy function for each deformation mode :

$$w = \underbrace{w_1(I^1_{elong}) + w_2(I^2_{elong})}_{\text{Biaxial tension}} \underbrace{+ w_{cp}(I_{cp})}_{\text{In plane shear}}$$

« Physics invariants »

$$I^i_{elong} = \frac{1}{2}\ln\left(\sqrt{\underline{\underline{C}} : \underline{\underline{M}}_{ii}}\right) \qquad I_{cp} = \frac{1}{I_{41} I_{42}}\left(\underline{\underline{C}} : \underline{\underline{M}}_{12}\right)$$

[AIM10]

[AIM10] Aimène Y., Vidal–Sallé E., Hagège B., Sidoroff F., Boisse P. *A hyperelastic approach for composite reinforcement large deformation analysis*. Journal of Composite Materials, 2010, vol. 44, n°1, 5–26.

LaMCoS Unité Mixte de Recherche 5259

Agenda

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- **Examples from the field**

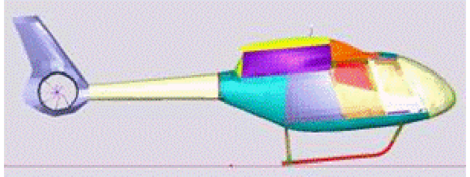
Example 1 - Helicopter Survivability

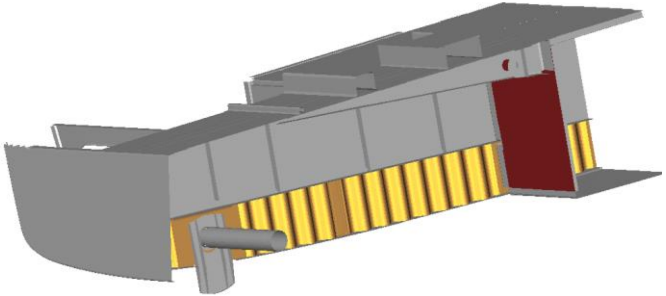
Altair

Model: Helicopter floor structure

Objective: Improve survivability of cabin crew under crash landing

Loading: Crash landing Vi= 3-10 m/s

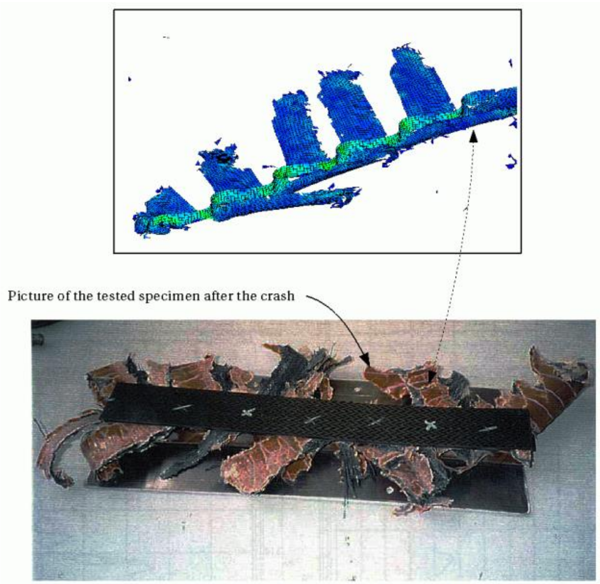


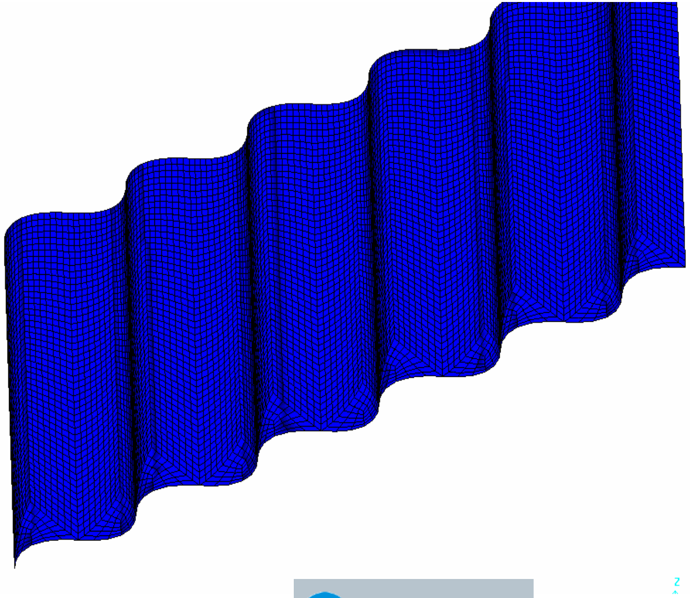


eurocopter
an EADS Company

Example 1 - Helicopter Survivability

Altair

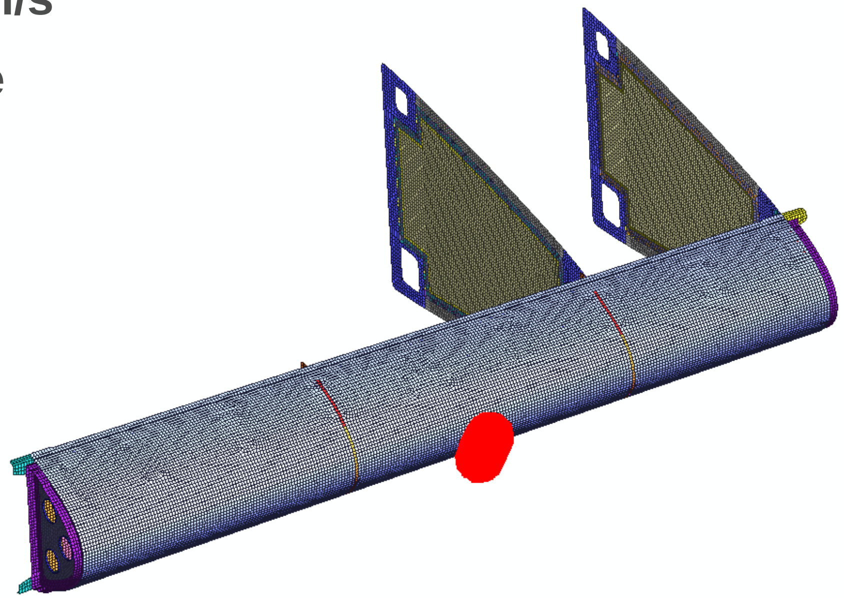




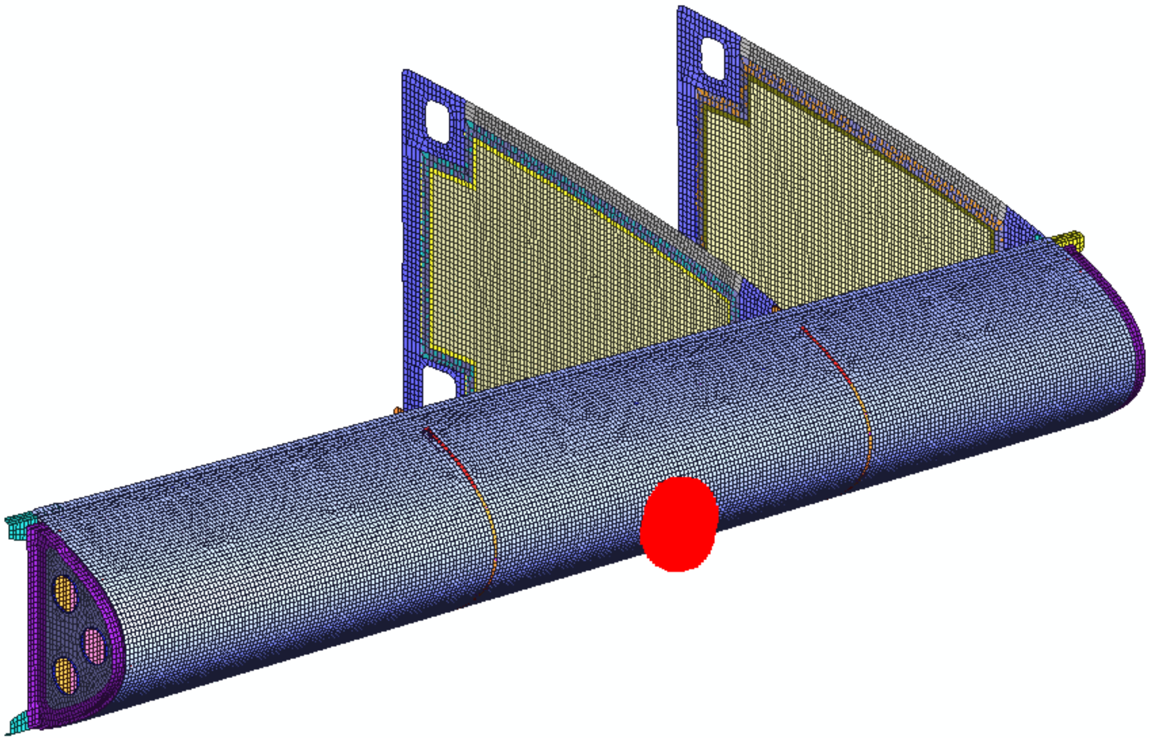
eurocopter
an EADS Company

Example 2: Aero Simulation

- **Model: Wing Leading Edge**
- **Objective: Aircraft vulnerability**
- **Loading: 4lbs bird strike Vi = 150 m/s**
- **Rupture of several panels, multiple penetration**



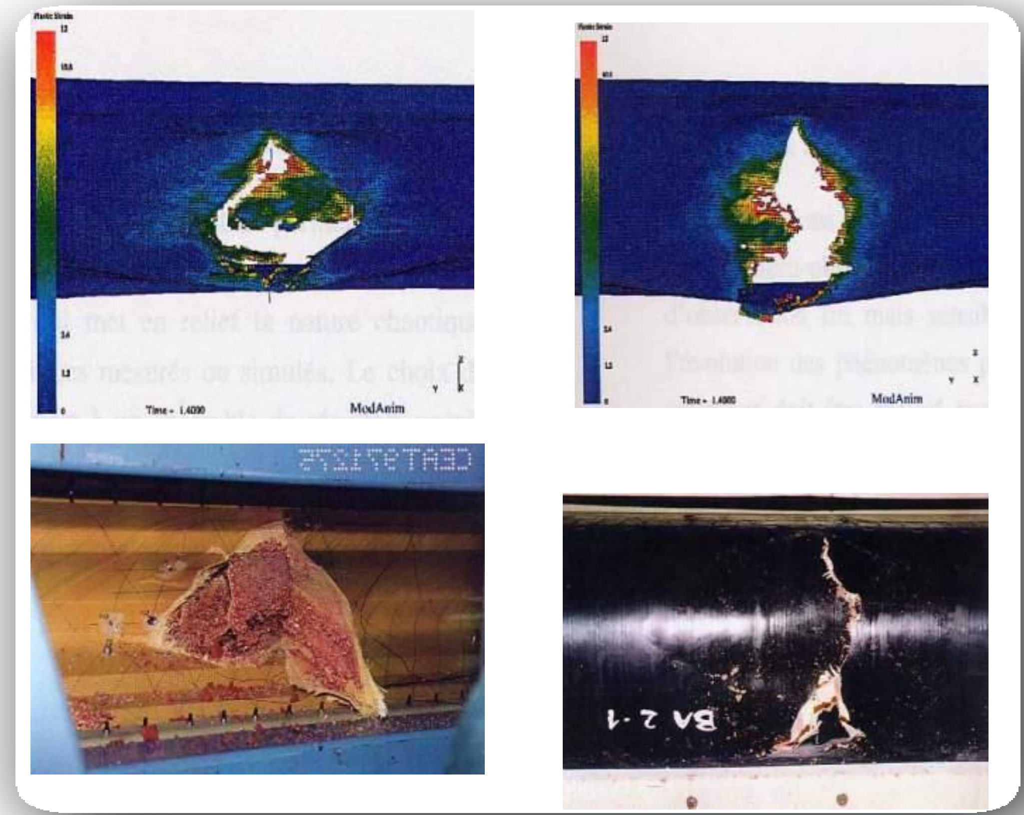
Example 2: Aero Simulation



Example 2: Aero Simulation

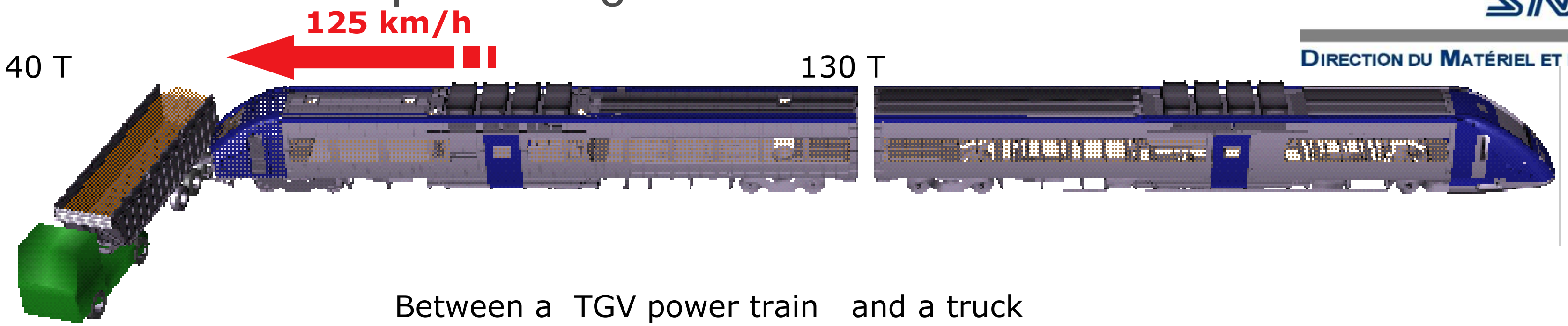
RADIOSS : Customer Composite Application

- Bird strike



Example 3: Transportation Simulation

- Model: Composite Engine cabin



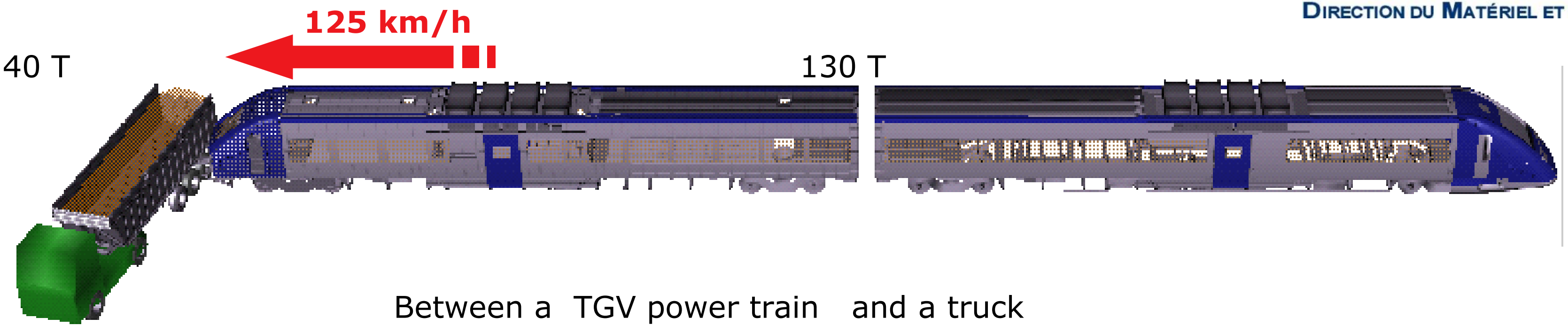
Between a TGV power train and a truck

- Objective: Accident reproduction, validation of the accident scenario and rupture sequence
- Loading: impact with truck, the truck rolls over and hits the cabin composite fairing
- General collapse of the fairing

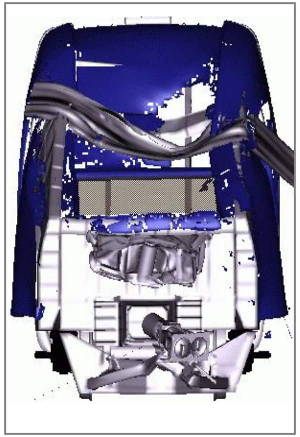
Example 3: Transportation Industries Railway Simulation

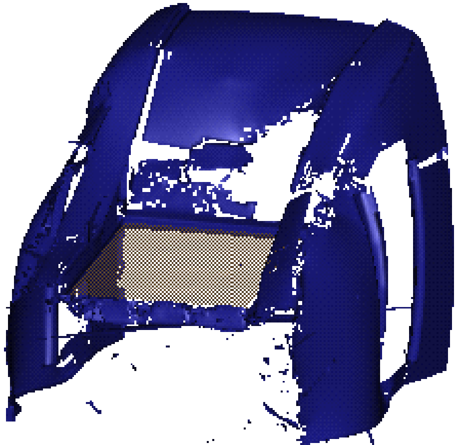
- **Accident Analysis**

DIRECTION DU MATÉRIEL ET DE LA TRACTION



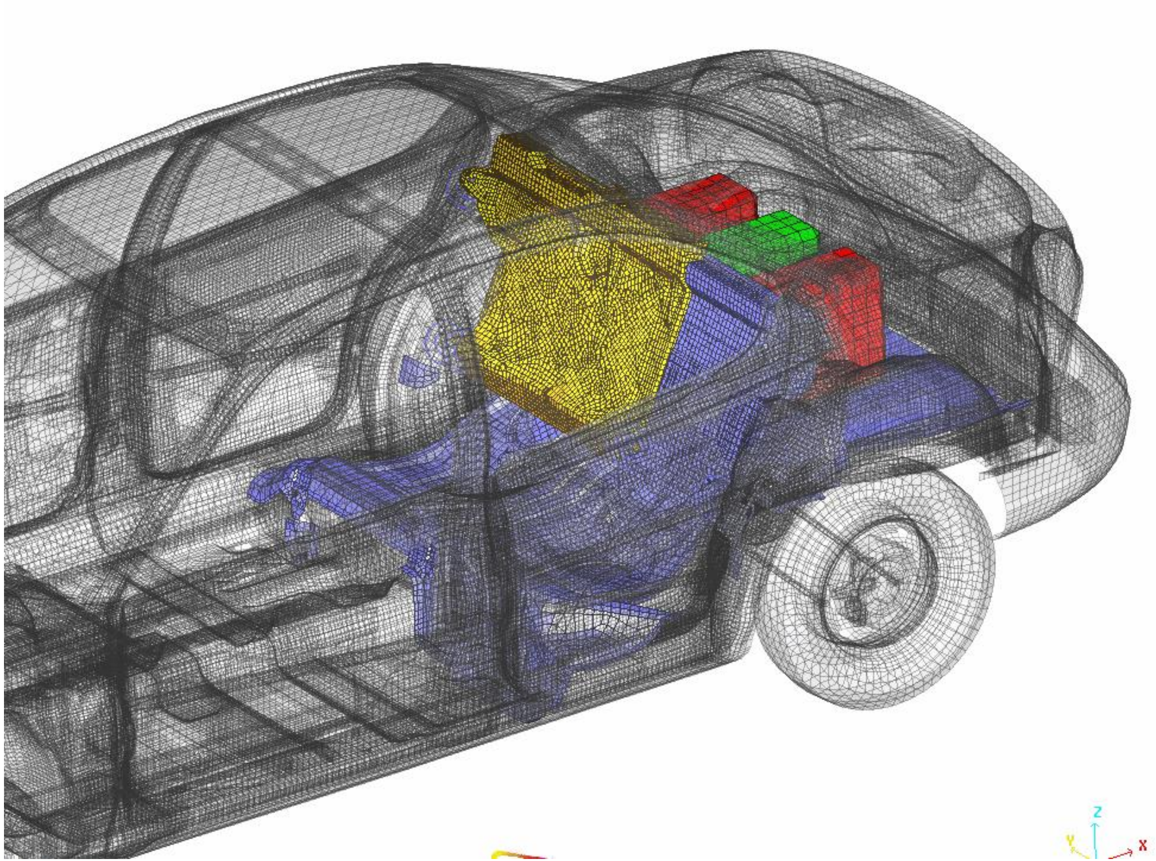
Between a TGV power train and a truck



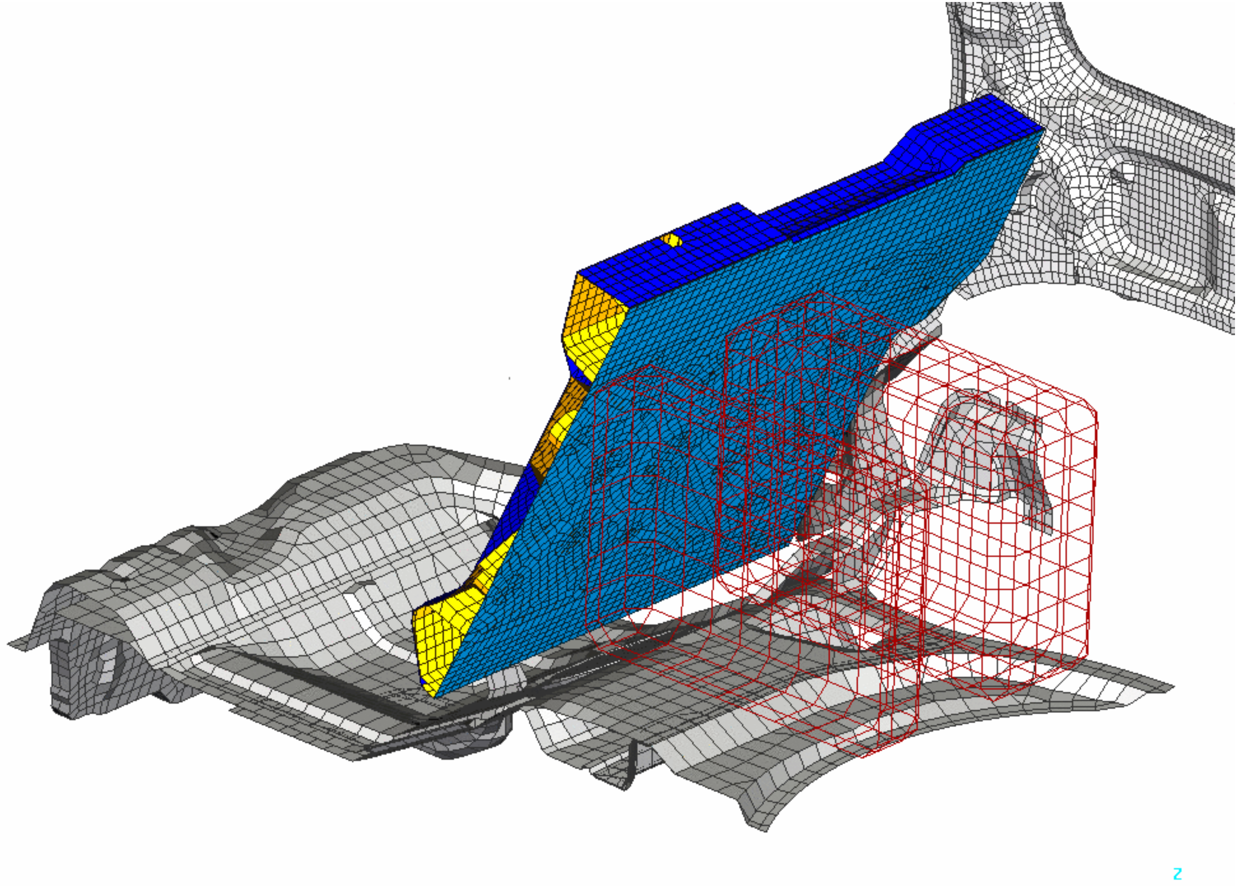


Example 4: Automotive Simulation

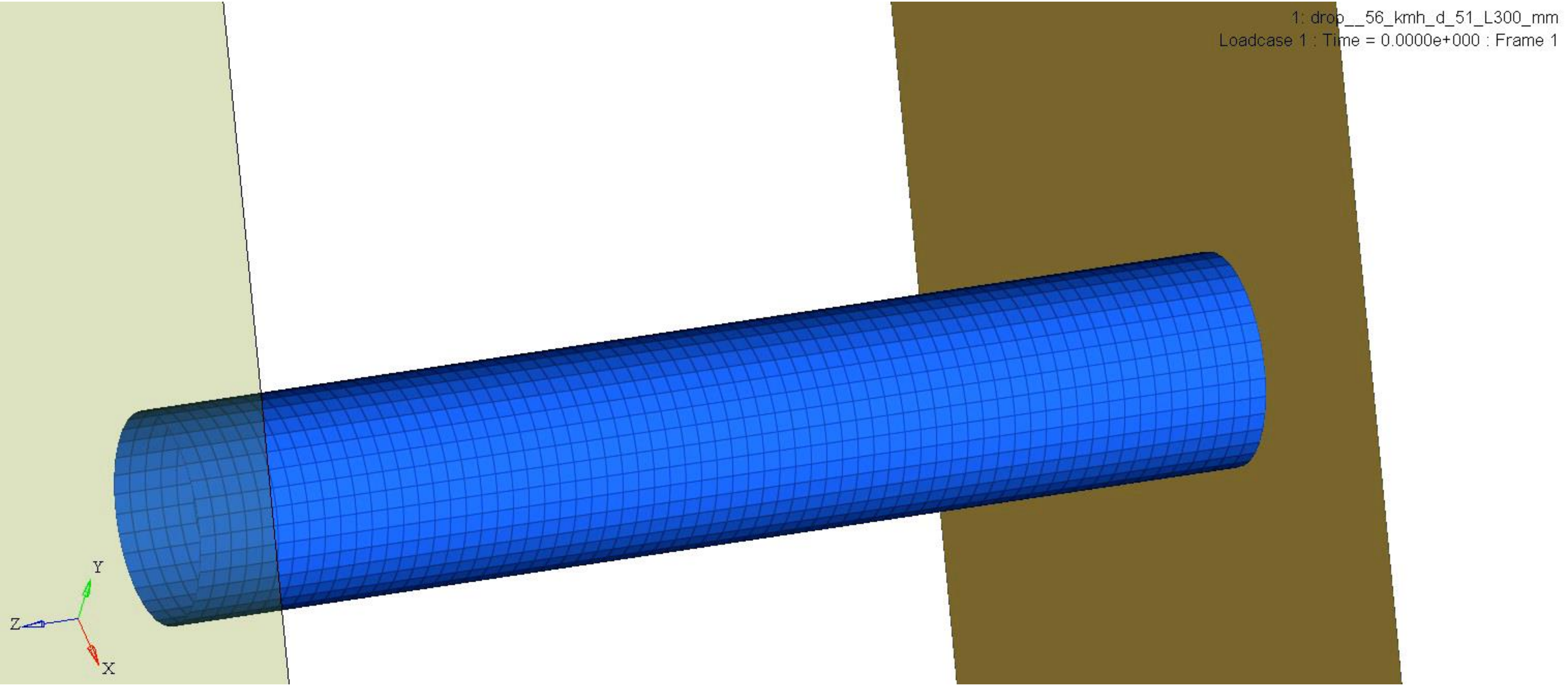
- **Model: Composite seat back**
- **Objective: Weight saving**
- **Loading: Luggage blocks from frontal crash at 35mph**
- **Local ruptures**



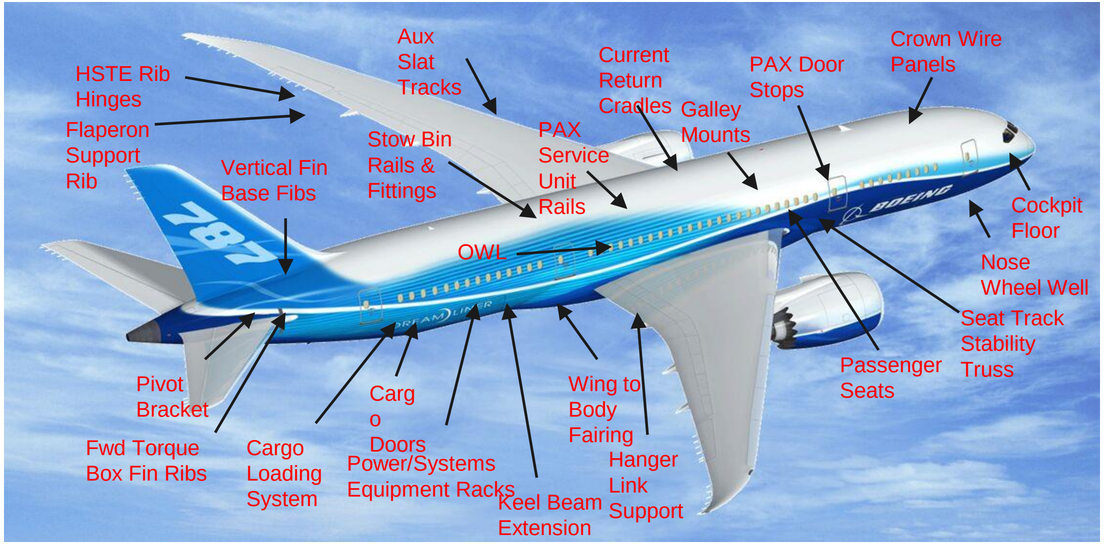
Example 4: Automotive Simulation



Example 5: Automotive Simulation



Technology Delivery Model Example: Boeing 787 Optimization Centre



- All Airframe Components screened for Optimisation – 1,500
- Around 150 Components Light Weighted using OptiStruct
- At the Projects Peak over 35 Altair Engineers
- Strong Local Focus,
- Global Centres of Competency

Thank you for your attention !

Open for questions…

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