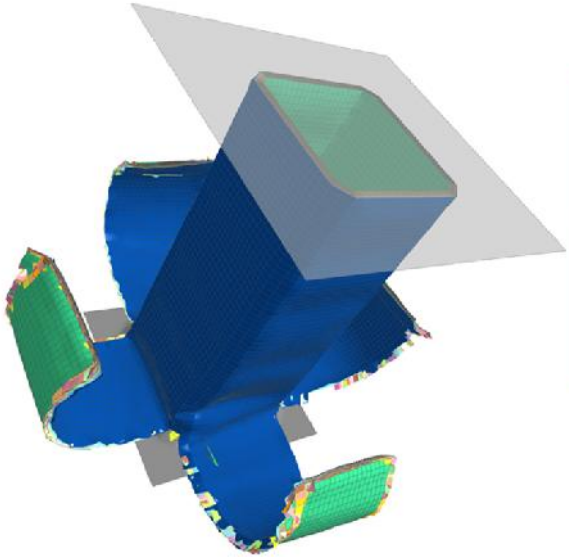


LS-DYNA® – development status

RECENT ENHANCEMENTS IN LS-DYNA® FOR COMPOSITE MODELING

C. Liebold

03/2018 – STUTTGART - GER

OVERVIEW

- MATERIAL MODELS
  - CFRP
  - SFRP
- PRE- AND POSTPROCESSING
  - LAMINATE DEFINITION
  - HISTORY - VISUALIZATION

MATERIAL MODELS

- Overview on available material models in LS-DYNA for CFRP

	Element	Failure criteria	New features
***MAT_054/055:** ENHANCED_COMPOSITE_DAMAGE	Shell, Tshell, Solid	54: Chang 55: fiber: Chang matrix: Tsai-Wu	**TI flag: for transversal isotropy for solid modeling** **2WAY – flag for 2-way fiber behavior (DFAILT, DFAILC, YC, YT, SLIMT2, SLIMC2 are altered if this flag is set**
***MAT_261:** LAMINATED_FRACTURE_DAIMLER_PINHO	Shell, Tshell, Solid	Pinho	**strain rate dependent strengths and fracture toughnesses via *DEFINE_CURVE and _TABLE**
***MAT_262:** LAMINATED_FRACTURE_DAIMLER_CAMANHO	Shell, Tshell, Solid	Camanho	**strain rate dependent strengths and fracture toughnesses via *DEFINE_CURVE and _TABLE**

MATERIAL MODELS

- *MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)

		1	2	3	4	5	6	7	8
plasticity parameters	Card 1	MID	RO	SIGY	LCSS	QR1	CR1	QR2	CR2
elastic, anisotropic parameters	Card 2	C11	C12	C13	C14	C15	C16	C22	C23
	Card 3	C24	C25	C26	C33	C34	C35	C36	C44
	Card 4	C45	C46	C55	C56	C66	R00 or F	R45 or G	R90 or H
plasticity parameters	Card 5	S11 or L	S22 or M	S33 or N	S12	AOPT	VP		MACF
material coordinate definition	Card 6	XP	YP	ZP	A1	A2	A3		EXTRA
	Card 7	V1	V2	V3	D1	D2	D3	BETA	IHIS
failure parameters	Card 8	XT	XC	YT	YC	SXY	FF12		NCFAIL
	Card 9	ZT	ZC	SYZ	SZX	FF23	FF31		

- All these parameters can be initialized on the integration point, using the **IHIS** flag.
- The value **IHIS** defines, which information is written in the initial card.
- The input in the *INITIAL_STRESS_SHELL/_SOLID card overwrites the input in the „original“ material card.

MATERIAL MODELS

*MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)

- EXTRA = 1 (Tsai-Wu failure model) – 3D (Solids):

$$\left(\frac{1}{XT}-\frac{1}{XC}\right)\sigma_{aa}+\left(\frac{1}{YT}-\frac{1}{YC}\right)\sigma_{bb}+\left(\frac{1}{ZT}-\frac{1}{ZC}\right)\sigma_{cc}$$
$$+\frac{1}{XT\cdot XC}\sigma^2{}_{aa}+\frac{1}{YT\cdot YC}\sigma^2{}_{bb}+\frac{1}{ZT\cdot ZC}\sigma^2{}_{cc}+\frac{1}{SXY^2}\sigma^2{}_{ab}+\frac{1}{SYZ^2}\sigma^2{}_{bc}+\frac{1}{SZX^2}\sigma^2{}_{ca}$$
$$+2\cdot F_{12}\sigma_{aa}\sigma_{bb}+2\cdot F_{23}\sigma_{bb}\sigma_{cc}+2\cdot F_{31}\sigma_{cc}\sigma_{aa}<1$$

- with:

$$F_{12}=F12\sqrt{\frac{1}{XT\cdot XC\cdot YT\cdot YC}},\quad F_{23}=F23\sqrt{\frac{1}{YT\cdot YC\cdot ZT\cdot YC}},\quad F_{31}=F31\sqrt{\frac{1}{ZT\cdot ZC\cdot XT\cdot XC}}$$

- for plain stress elements, this reduces to:

$$\left(\frac{1}{XT}-\frac{1}{XC}\right)\sigma_{aa}+\left(\frac{1}{YT}-\frac{1}{YC}\right)\sigma_{bb}+\frac{1}{XT\cdot XC}\sigma^2{}_{aa}+\frac{1}{YT\cdot YC}\sigma^2{}_{bb}$$
$$+\frac{1}{SXY^2}\sigma^2{}_{ab}+2\cdot F_{12}\sigma_{aa}\sigma_{bb}<1$$

MATERIAL MODELS

*MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)

- EXTRA = 2 (Tsai-Hill failure model) – 3D (Solids):

$$(G+H)\sigma^2_{aa}+(F+H)\sigma^2_{bb}+(F+G)\sigma^2_{cc}-2H\sigma_{aa}\sigma_{bb}-2F\sigma_{bb}\sigma_{cc}-2G\sigma_{cc}\sigma_{aa}$$
$$+2\cdot N\sigma^2_{ab}+2\cdot L\sigma^2_{bc}+2\cdot M\sigma^2_{ca}<1$$

- H,F,G,N,L,M are expressed in terms of the stress limits, where the stress state defines whether the compressive- or the tensile strength limit enter the equation:

$$(G+H)=\frac{1}{X^2_i};\ (F+H)=\frac{1}{Y^2_i};\ (F+G)=\frac{1}{Z^2_i};$$

$$2\mathrm{N}=\frac{1}{SXY^2};\ \ 2\mathrm{L}=\frac{1}{SYZ^2};\ \ 2\mathrm{M}=\frac{1}{SZX^2};$$

$$H=0.5\cdot\left(\frac{1}{X^2_i}+\frac{1}{Y^2_i}-\frac{1}{Z^2_i}\right);\ F=0.5\cdot\left(\frac{1}{Y^2_i}+\frac{1}{Z^2_i}-\frac{1}{X^2_i}\right);\ G=0.5\cdot\left(\frac{1}{X^2_i}+\frac{1}{Z^2_i}-\frac{1}{Y^2_i}\right)$$

MATERIAL MODELS

*MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)

- EXTRA = 2 (Tsai-Hill failure model) – Shells:

$$(G+H)\sigma^2{}_{aa} + (F+H)\sigma^2{}_{bb} - 2H\sigma_{aa}\sigma_{bb} + 2\cdot N\sigma^2{}_{ab} < 1$$

- with:

$$(G+H) = \frac{1}{X^2{}_i};\ (F+H) = \frac{1}{Y^2{}_i};$$

$$2\mathrm{N} = \frac{1}{SXY^2};\ H = 0.5\cdot\left(\frac{1}{X^2{}_i}\right)$$

- If these conditions are violated, the stress tensor will be reduced to zero over NCFAIL time steps. Default is 10.

For both failure options: all failure parameter can be defined as load curves to consider strain rate dependency. If the first strain rate value is negative, a ln – scale is considered for the strain rate.

MATERIAL MODELS

- *MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)

$a_i \in 0,1$ for IHIS - calculation

*INITIAL_STRESS_SOLID:	*INITIAL_STRESS_SHELL:
IHISV $= a_4 \cdot 16 + a_3 \cdot 8 + a_2 \cdot 4 + a_1 \cdot 2 + a_0$	IHISV $= a_4 \cdot 16 + a_3 \cdot 8 + a_2 \cdot 4 + a_1 \cdot 2 + a_0$
NHISV $= 6a_0 + 21a_1 + 6a_2 + a_3 + 9a_4$	NHISV $= 2a_0 + 21a_1 + 3a_2 + a_3 + 5\,a_4$

flag	description	variables	number
a_0	material directions	q_{1i}, q_{3i}	6
a_1	anisotropic elastic stiffness	C_{ij}	21
a_2	anisotropic plasticity	F,G,H,L,M,N	6
a_3	hardening curve	LCSS	1
a_4	strength limits	XT,XC,…	9

flag	description	variables	number
a_0	material directions	q_1,q_2	2
a_1	anisotropic elastic stiffness	C_{ij}	21
a_2	anisotropic plasticity	r_{00},r_{45},r_{90}	3
a_3	hardening curve	LCSS	1
a_4	strength limits	XT,XC,…	5

PRE- AND POSTPROCESSING

since R10.0
LSPP 4.5

LAMINATE DEFINITION

- Proper laminate definition for non-continuous physical plies across a single part and post-processing for multi-layered, patched materials can be achieved using either `*ELEMENT_SHELL_COMPOSITE_LONG` with non-zero Ply-IDs or `*ELEMENT_SHELL_COMPOSITE`, when using MID=-1.

- This allows for the definition of zero-thickness integration points with a constant number of integration points in each element.

PRE- AND POSTPROCESSING

LAMINATE DEFINITION

since R10.0
LSPP 4.5

```
*ELEMENT_SHELL_OFFSET_COMPOSITE
$#   eid     pid      n1      n2      n3      n4      n5      n6      n7      n8
       1       1       2       3      11       9       0       0       0       0
$#        offset
            0.15
$#    mid1    thick1        b1    unused      mid2    thick2        b2
         1       0.1       0.0                  -1       0.0       0.0
         1       0.1       0.0                   1       0.1       0.0
        -1       0.0       0.0
```

PRE- AND POSTPROCESSING

LAMINATE DEFINITION

since R10.0
LSPP 4.5

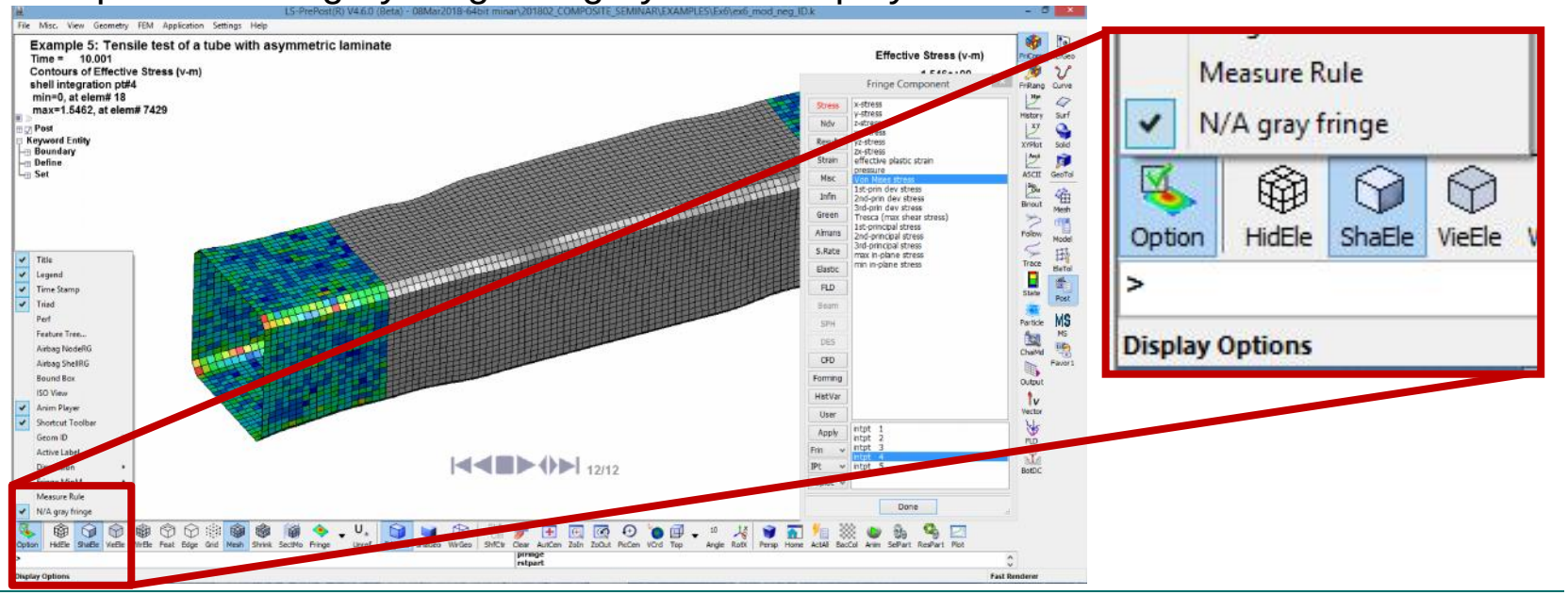
```
*ELEMENT_SHELL_OFFSET_COMPOSITE_LONG
$#   eid     pid      n1       n2       n3       n4       n5       n6       n7       n8
       1       1       2        3       11        9        0        0        0        0
$#        offset
            0.15
$#    mid1    thick1        b1    unused    plyid1
          1       0.1       0.0                 1
          0       0.0       0.0                 2
          1       0.1       0.0                 3
          1       0.1       0.0                 4
          0       0.0       0.0                 5
```

PRE- AND POSTPROCESSING

- LAMINATE DEFINITION – REMARKS:

since R10.0
LSPP 4.5

  - For post-processing read both, keyword – input and d3plot
  - Select Option -> N/A gray fringe for grayed out display of zero-thickness IPs

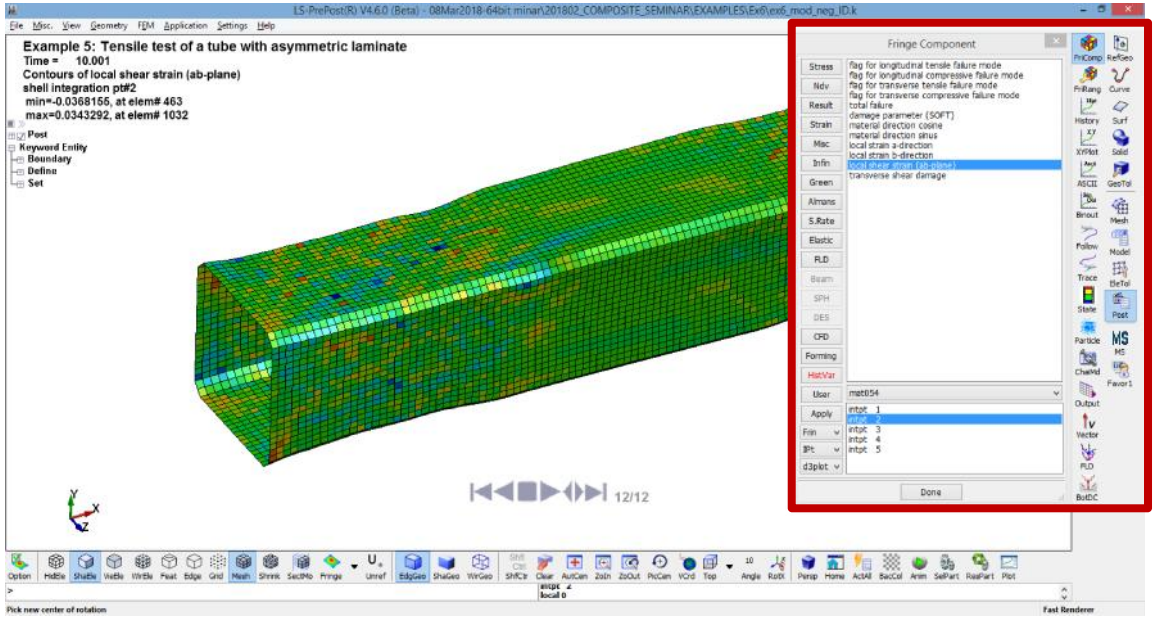


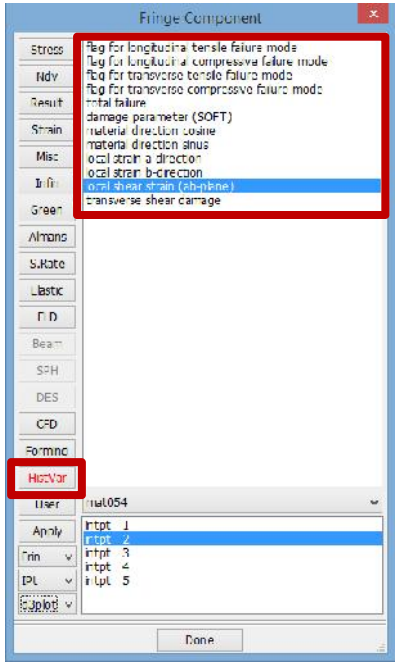
PRE- AND POSTPROCESSING

- LAMINATE DEFINITION – REMARKS:

since R10.0
LSPP 4.5

  - Meaning of history variables can be displayed using FriCopm->HistVAR, for specific material models (*MAT_54/55)



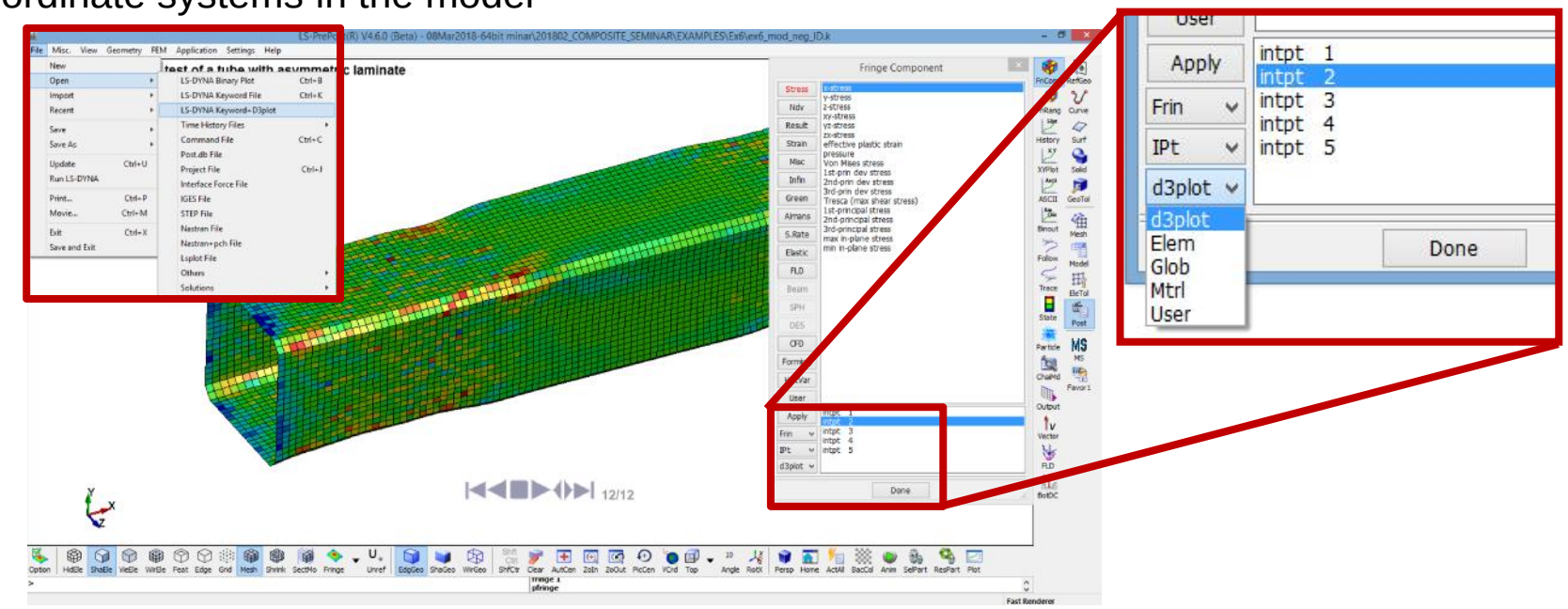


PRE- AND POSTPROCESSING

- LAMINATE DEFINITION – REMARKS:

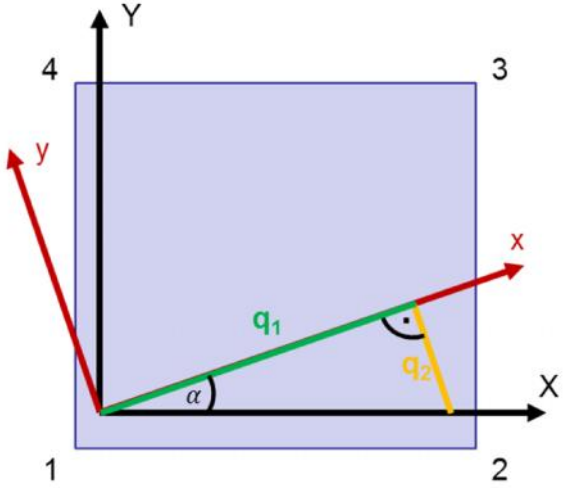
since R10.0
LSPP 4.5

  - When loading keyword and d3plot, the user can switch between the different coordinate systems in the model

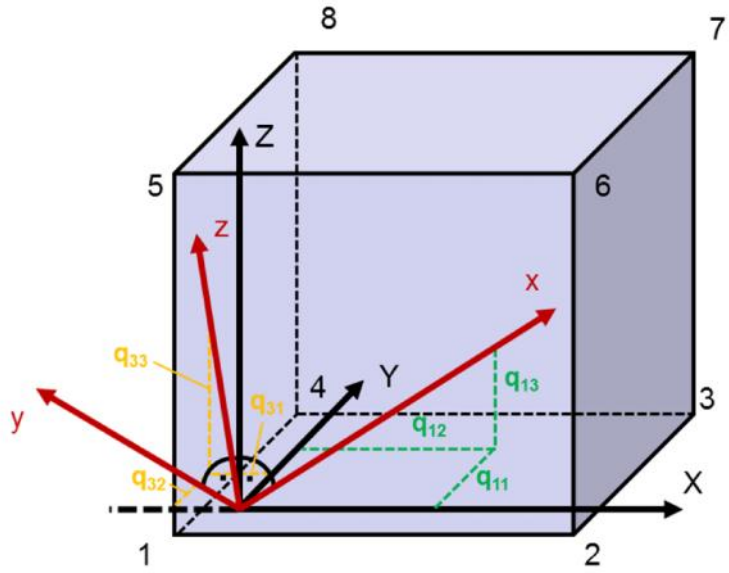


PRE- AND POSTPROCESSING

- For composite materials (SFRP/CFRP), orientations are often stored and initialized as history variables



q_1: material direction cosine
q_2: material direction -sine

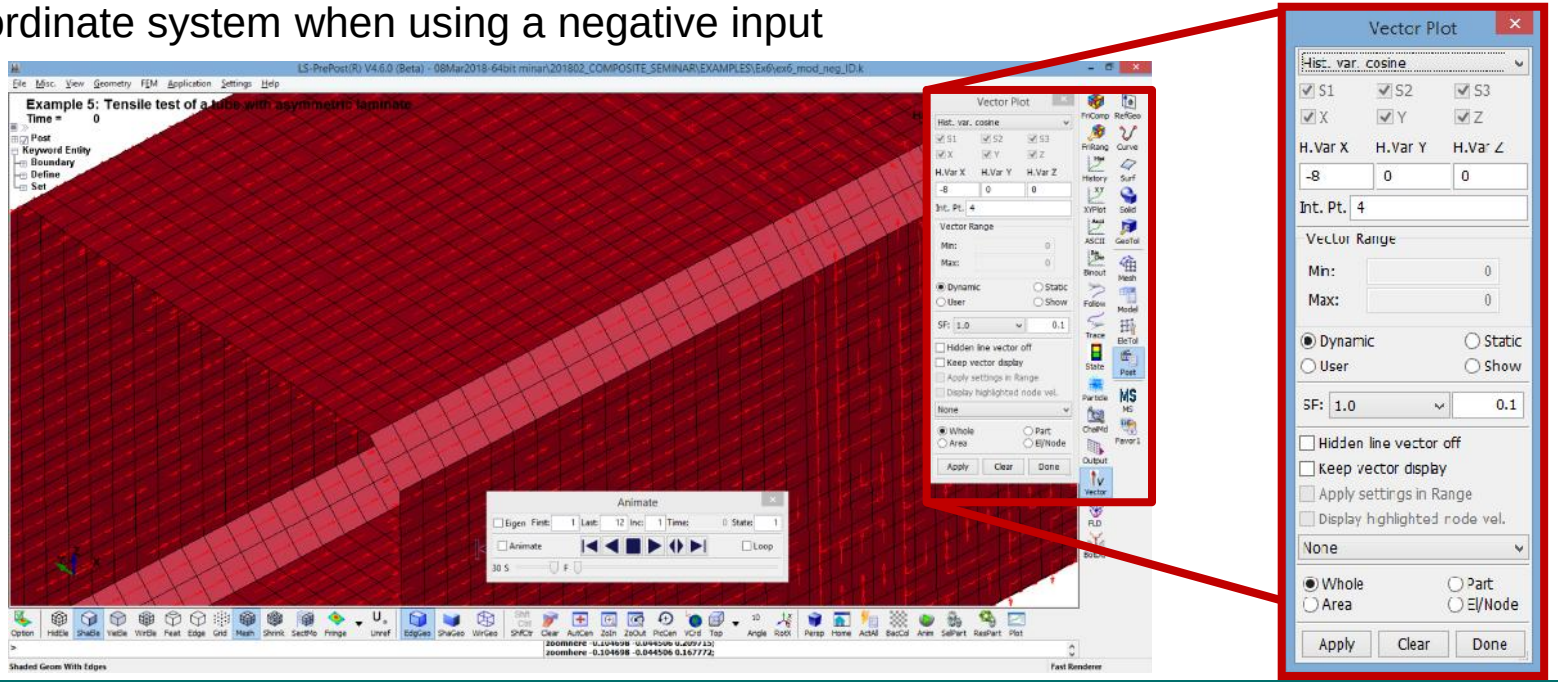


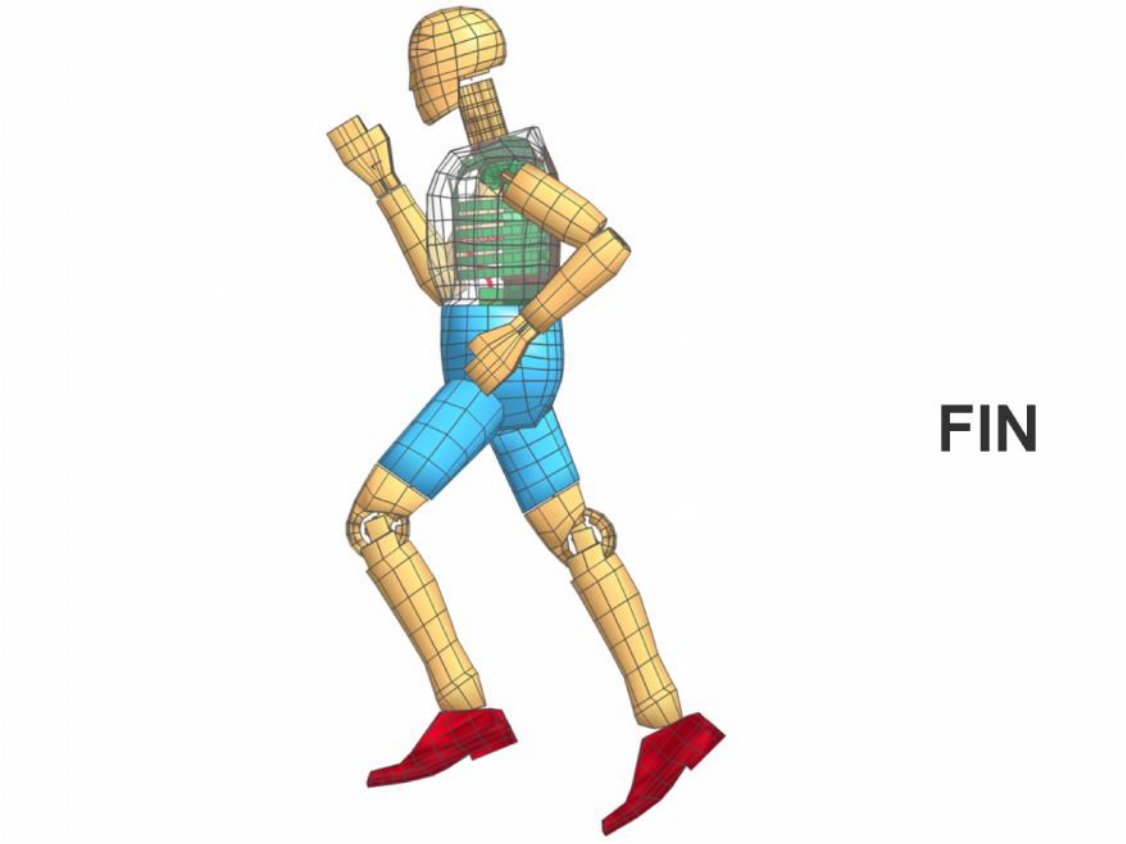
q_{1i}: first vector to define mat. coor. system
q_{3i}: second vector to define mat. coor. system

PRE- AND POSTPROCESSING

since R10.0
LSPP 4.5

- HISTORY VISUALIZATION:
  - The user can visualize history variables as vector plot, referring to the element coordinate system when using a negative input





FIN

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