Module SimBeam with Element of Linear Variable Cross Sections

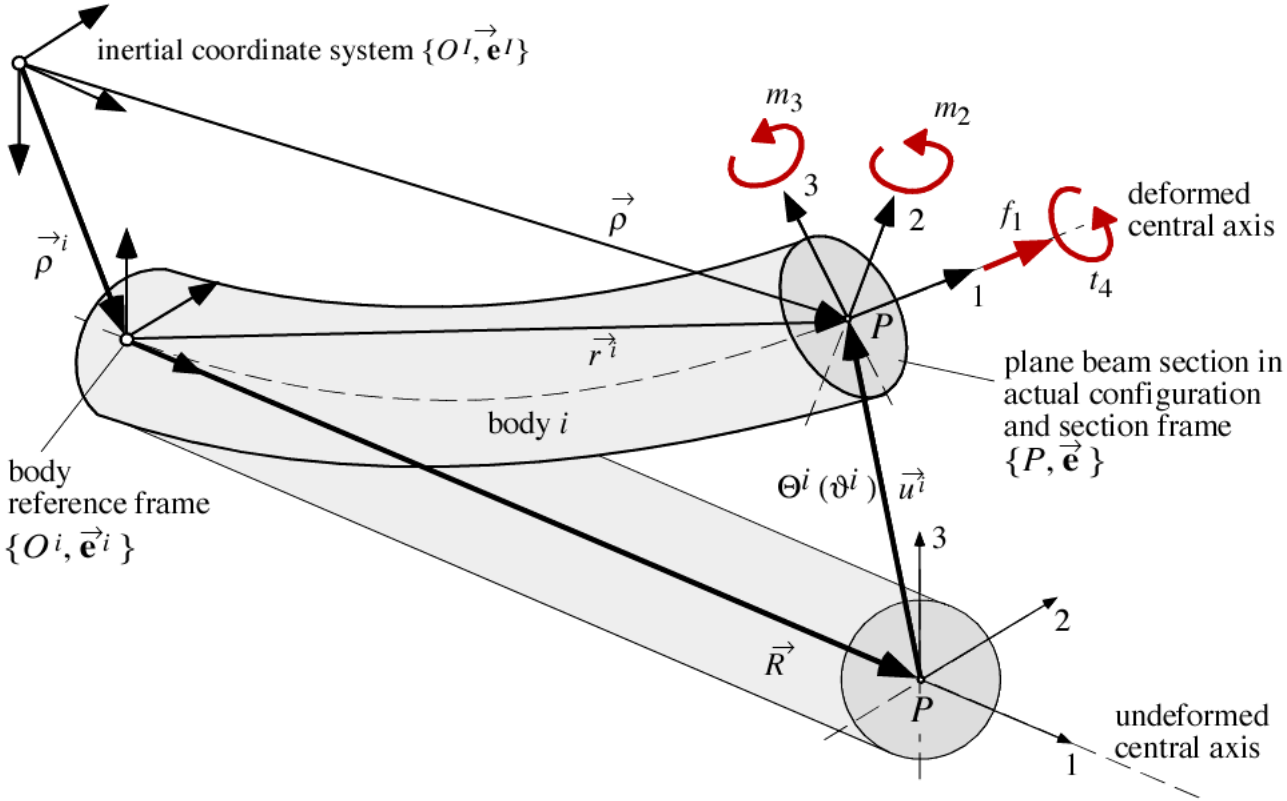
by
Prof. Dr. Oskar Wallrapp,
Wessling, Germany

Dr. Stefan Dietz,
SIMPACK AG

Byunghoon Song (Trainee Student)
SIMPACK AG

SIMPACK USER Meeting 2011

SIMPACK – Modeling of Flexible Body Motions



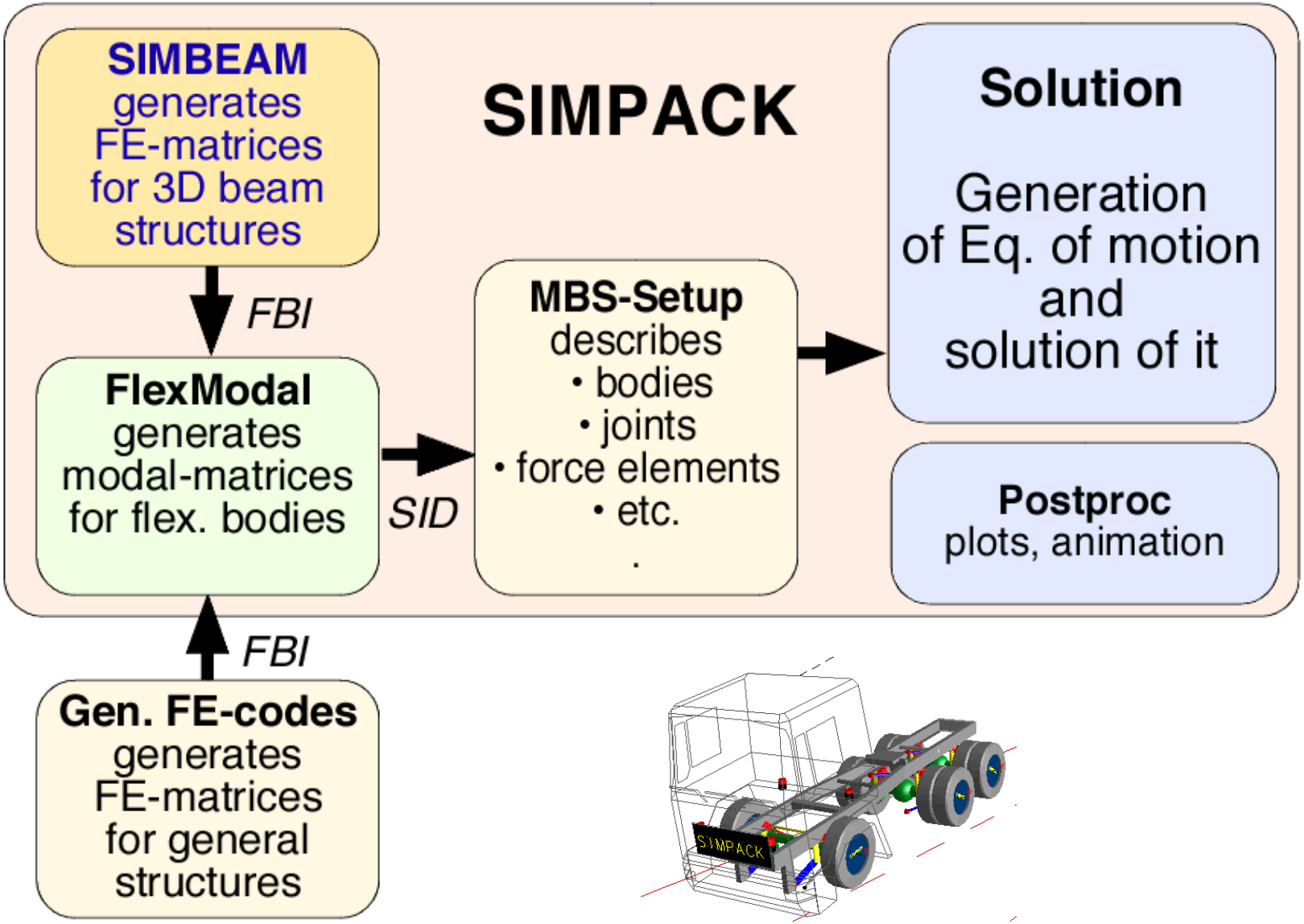
Absolute Body motion is a sum of

- **nonlinear body reference motion** +
- **small deformations** (up to order 2 terms in modal coordinates **q**)

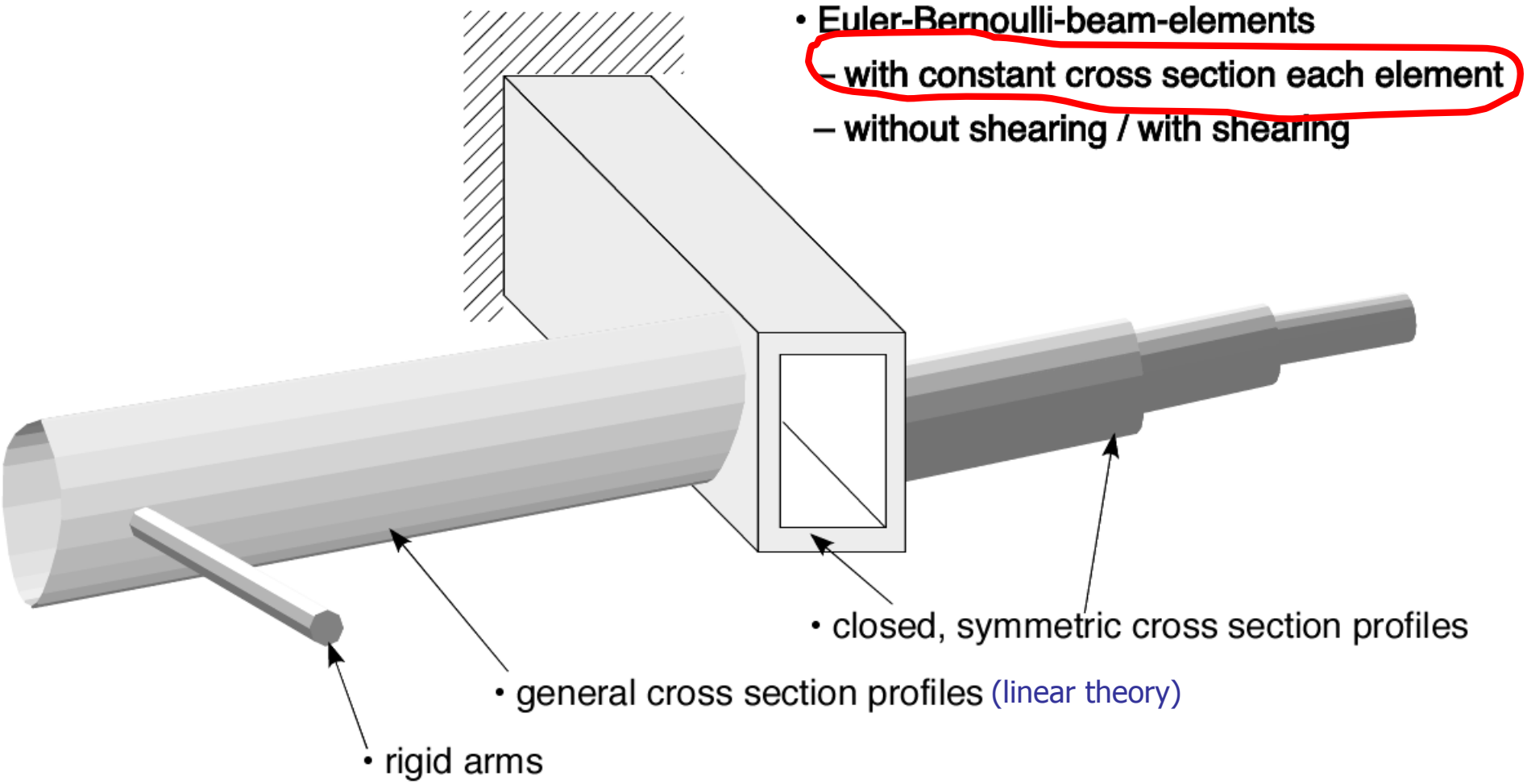
$$\boldsymbol{\rho}(t) = \boldsymbol{\rho}^i(t) + \mathbf{R} + \mathbf{u}(\mathbf{R},t)$$

$$\mathbf{u}(\mathbf{R},t) = \boldsymbol{\Phi}_L(\mathbf{R})\,\mathbf{q}(t) + \frac{1}{2}\,\mathbf{q}^T\,\boldsymbol{\Phi}_Q\,\mathbf{q}(t)$$

SimBeam – the SIMPACK-Module to Setup Flexible Bodies via FE-Beam-Structures

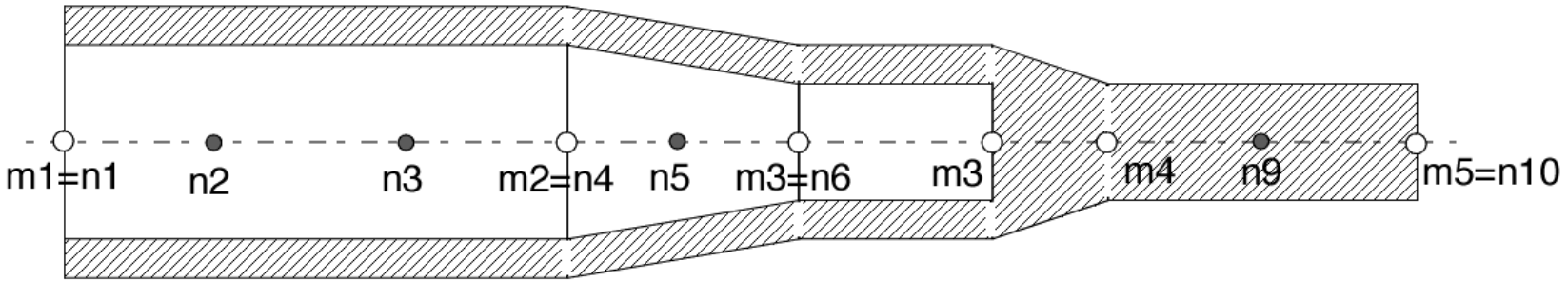


SimBeam – Current Options of Modeling

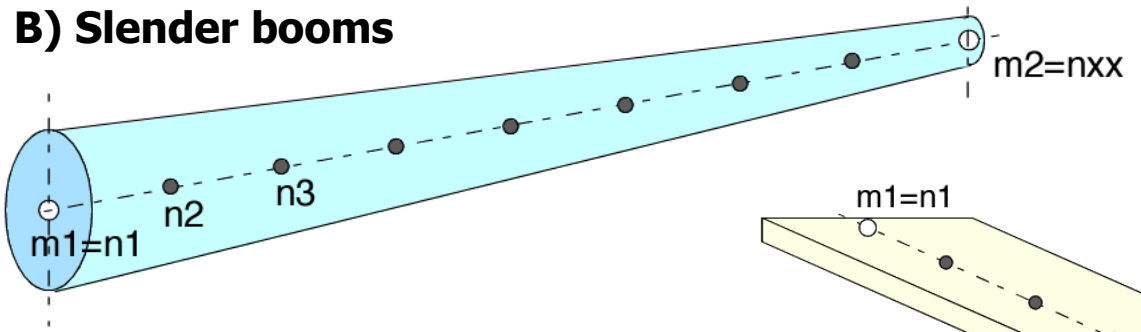


SimBeam – Dilemma (1) of Modeling

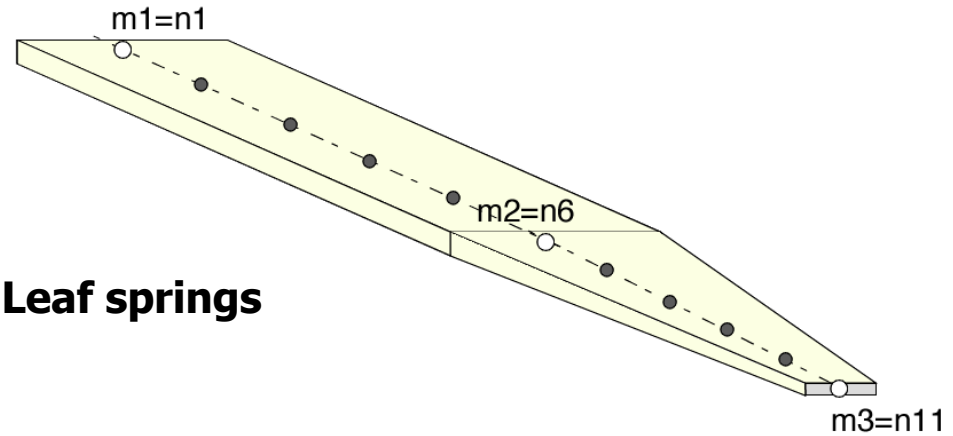
A) Shaft with conical sections



B) Slender booms

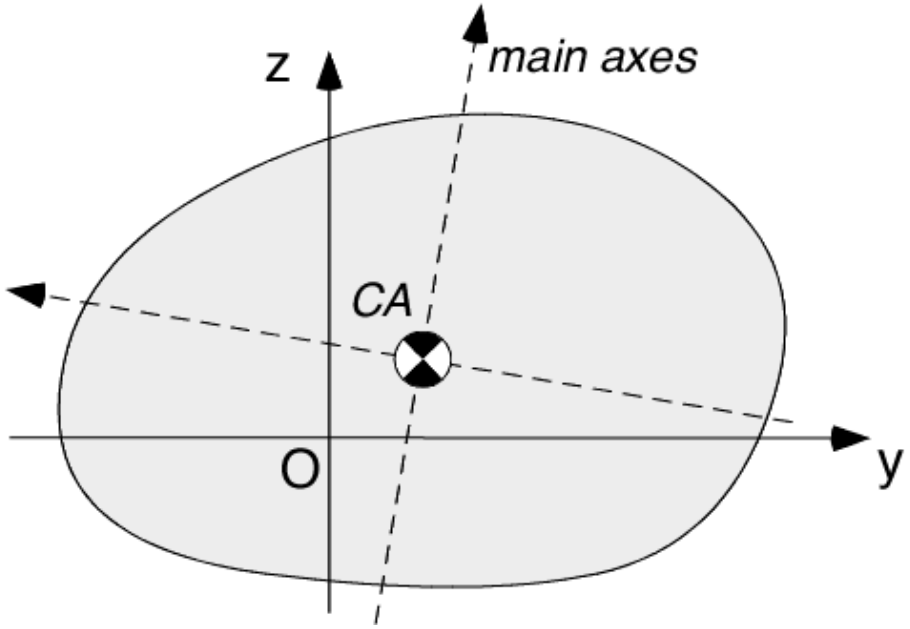


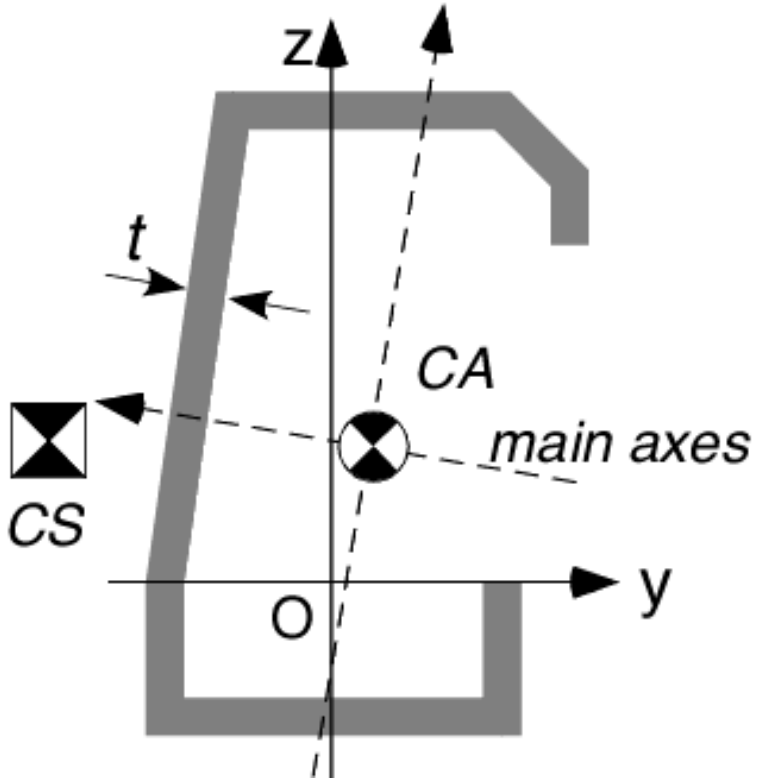
C) Leaf springs



=> These parts have to be divided into elements of constant cross section !

D) Generation general cross section profiles of full and tube profiles



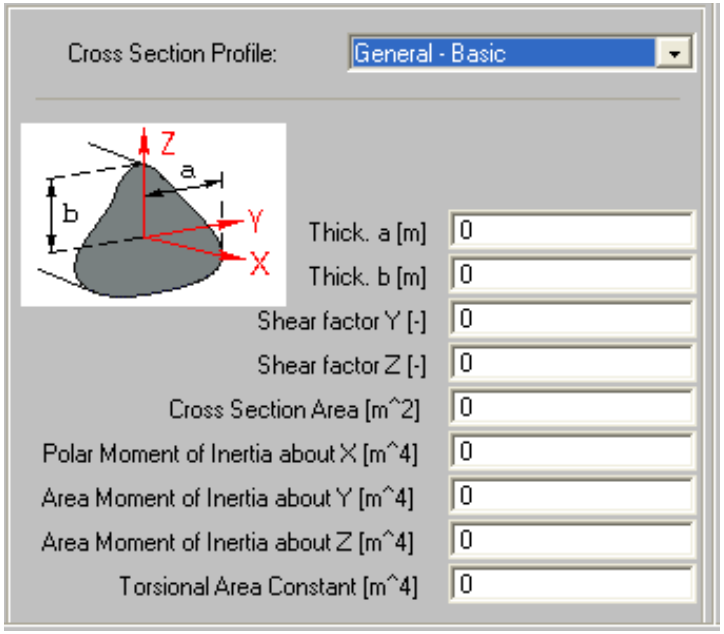


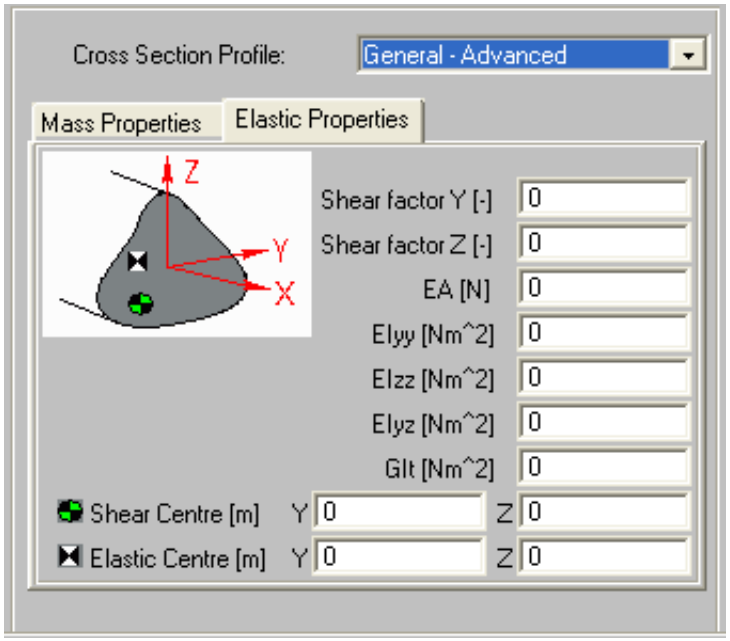
open/closed tubes with const. thickness

=> All geometrical data must be given by the user

SimBeam – Dilemma (3) of Modeling

E) Second order theory of elements with nonsymmetrical CS is not complete



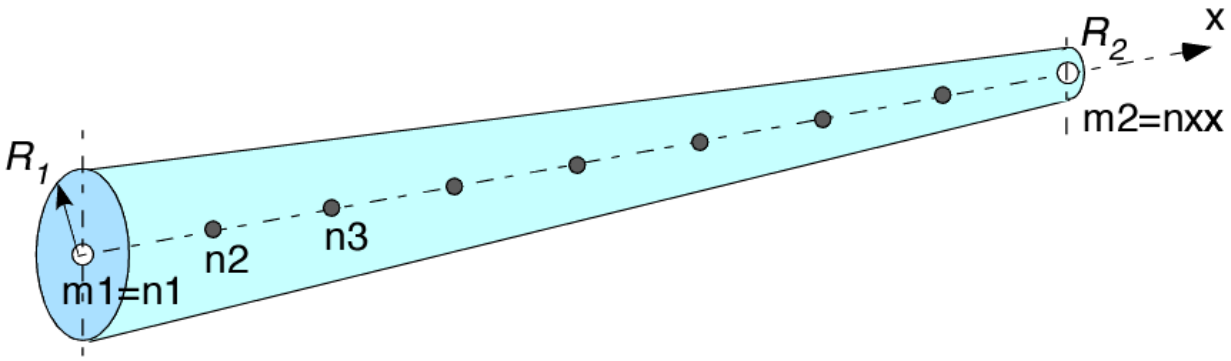


=> A first representation of second order matrices is used

SimBeam – New Beam Elements -> LVSCS

I) **Element with a linear variable cross section of standard symmetric profiles**

- as circle, rectangle, ellipse, tubes of them
- between 2 markers parameters are changed linearly (e.g. $R(x) = R_1 + (R_2 - R_1)\, x/l$)
- element data of elements between the markers are generated automatically



- all cross section data are expressed in terms of the marker area parameters (e.g. R_1, R_2)
- stiffness and mass matrices are calculated analytically

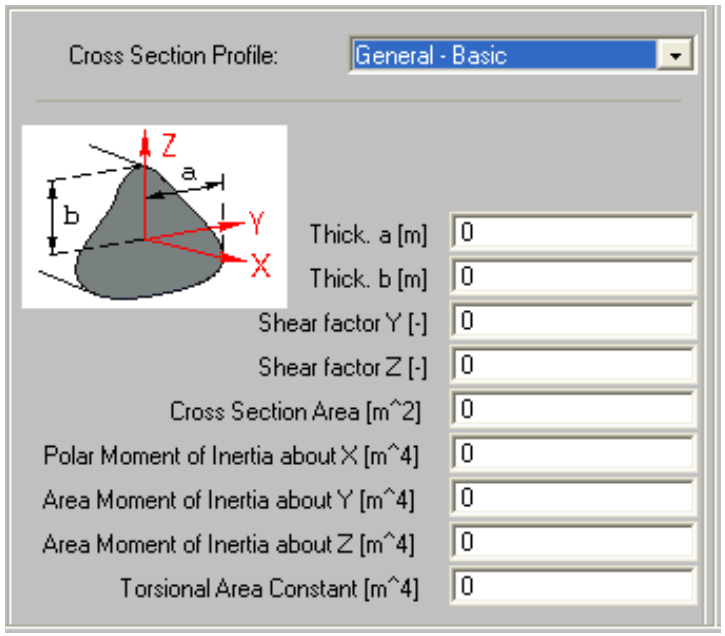
for one element with nodes A and B: $\xi = x/l^e$: $\quad R(\xi) = R_A + (R_B - R_A)\,\xi$

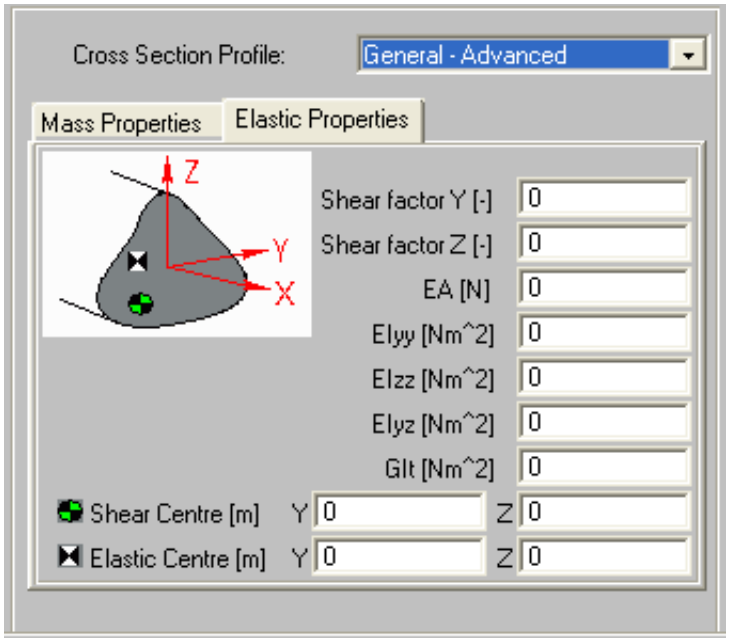
$$\Rightarrow \quad A(\xi) = A_0 + A_1\,\xi + A_2\,\xi^2; \qquad I(\xi) = I_0 + I_1\,\xi + I_2\,\xi^2 + I_3\,\xi^3 + I_4\,\xi^4;$$

$$\Rightarrow \quad K_{11}^e = \frac{E^e}{l^e}\left(A_0 + A_1/2 + A_2/3\right) \quad \text{etc.}$$

II) **General Element with a better quadratic derivation**

- for shear-stiff (Bernoulli) and shear-soft (Timoshenko) beam elements
- validated by experiments

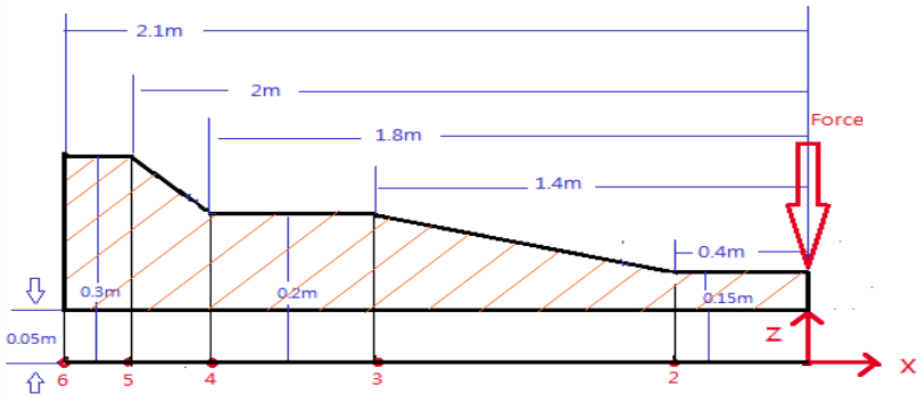




- Master thesis in non-linear beam theory

SimBeam – First Solutions using the LVSCS element

A) Conical transmission wheel (steel)



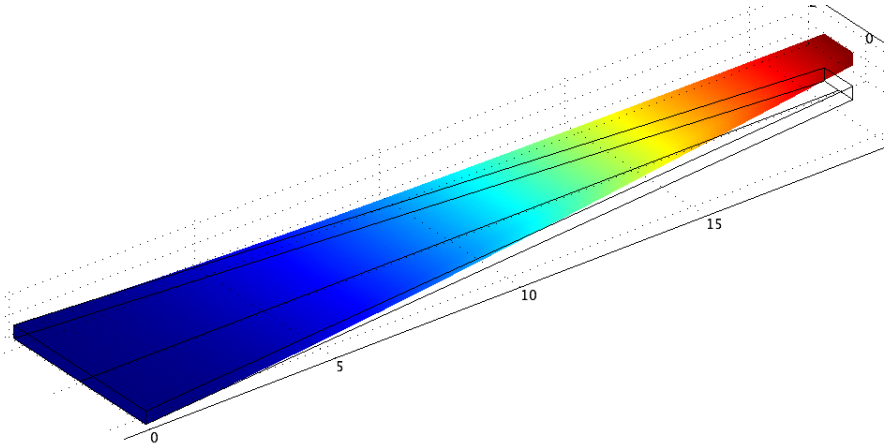
SimBeam model
6 markers at each break,
6 nodes, constrained at node 6,
force 1.e6 N at node 1,
36 DOF
Femlab volume model
68124 DOF

	Femlab	SimBeam LVSCS	
Tip displ. in z:	-11.28 mm	-10.96 mm	=> +2.7 % error

Straightforward model set-up with LVSCS Elements

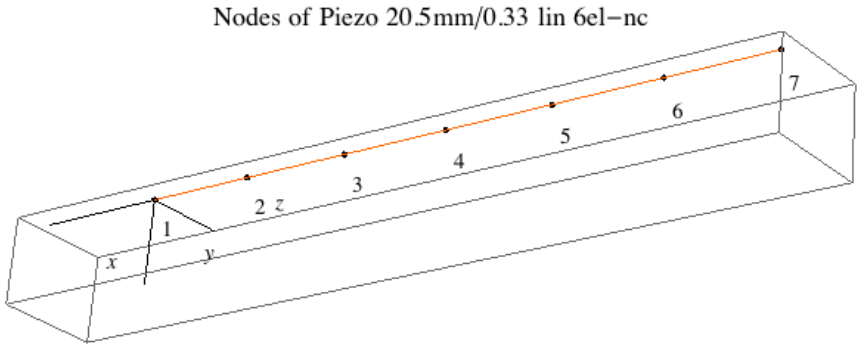
SimBeam – First Solutions using the LVSCS element

B) Piezo element (0.33 mm thickness rectangle profile), constrained at left, loaded at right side



Reference solution **Femlab**,
19482 DOF of solid elements
EV bending x: 706.95 Hz
EV bending y: 7729.2 Hz
EV torsion: 9998.4 Hz
tip displ.: 3.744 mm for F
tip torsion: 0.0288 rad for T

Simbeam 6 LVSCS elements, 7 nodes, 42 DOF, constrained at node 1, loads at node 7



EV bending x: 700.08 Hz =>-1.0 %
EV bending y: 7861.8 Hz =>+1.7 %
EV torsion: 9146.4 Hz =>-8.5 %
tip displ.: 3.789 mm for F =>+1.2 %
tip torsion: 0.0292 rad for T =>+1.4 %

=> leads to good results by a convenient description of the conical piezo !

SimBeam – Conclusion and Outlook

Conclusion

1) The new beam elements - linear variable cross section (LVSCS) allow a straightforward description of a beam structure in SIMPACK

2) A fully quadratic FE-Formulation allows a more correct calculation of

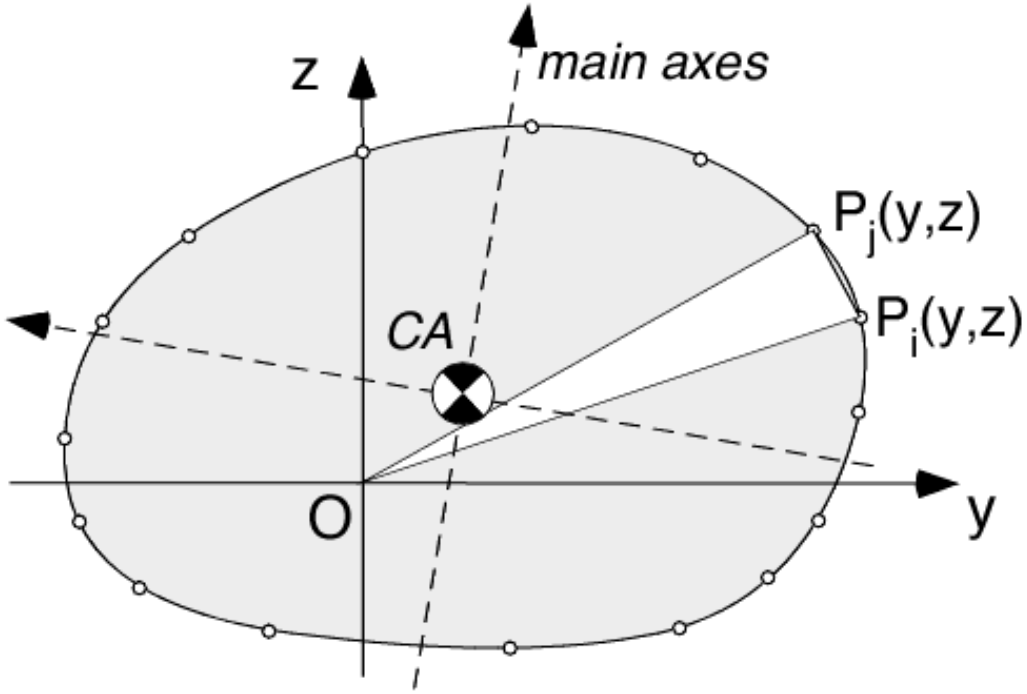
   - Eigenfrequencies and Eigenmodes (in case of pre-loads)
   - deformation of the flexible body in SIMPACK model

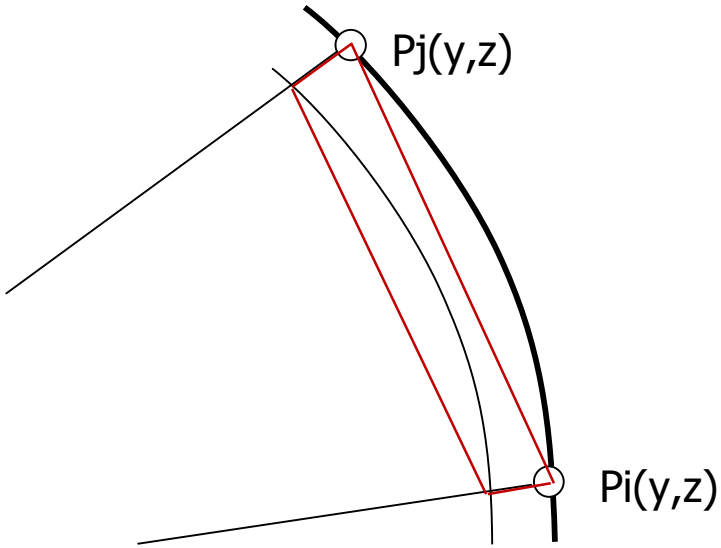
Outlook

- Complete implementation of the new beam elements LVSCS + PTCS
- Complete formulation of non-linear beam theory for the general beam element
- Polygon cross section description (PTCS)

Element with a polygon cross section full area or tube area

- approximated by triangles / trapezes described by corner points P(y,z)
- closed cross sections with const. thickness





- all cross section data are calculated from corner points P1,…,Pi,…,Pn
- stiffness and mass matrices calculated analytically