

# **Module SimBeam with Element of Linear Variable Cross Sections**

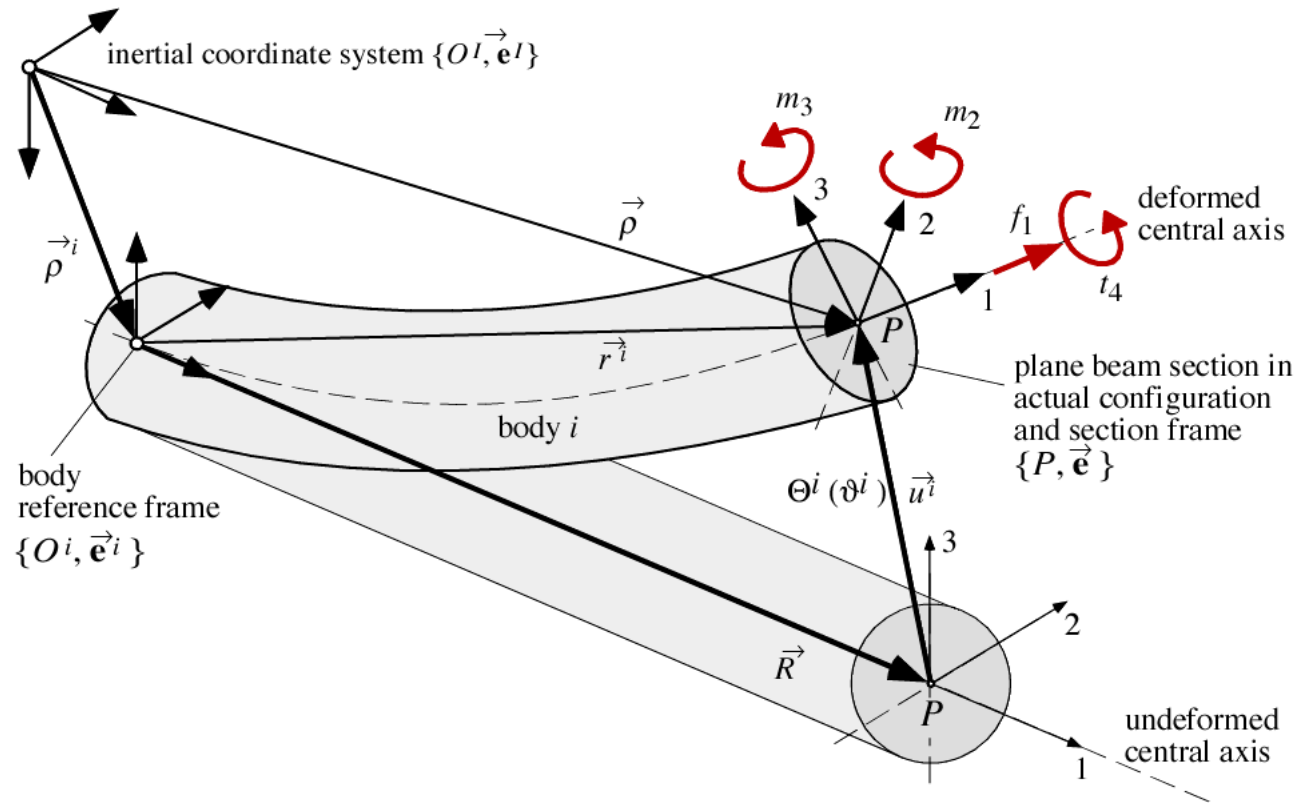
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**SIMPACK USER Meeting 2011**

# SIMPACK – Modeling of Flexible Body Motions



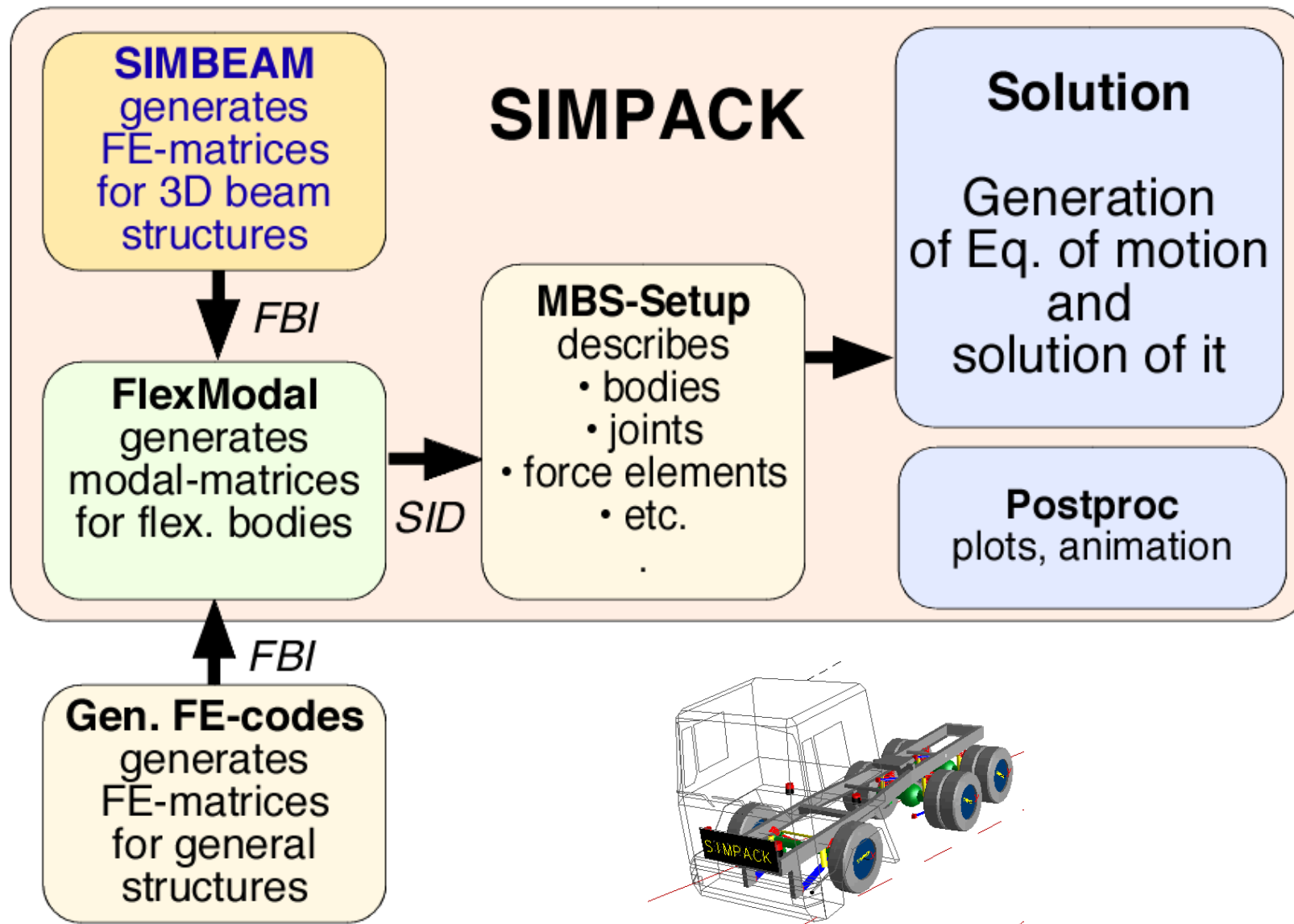
Absolute Body motion is a sum of

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

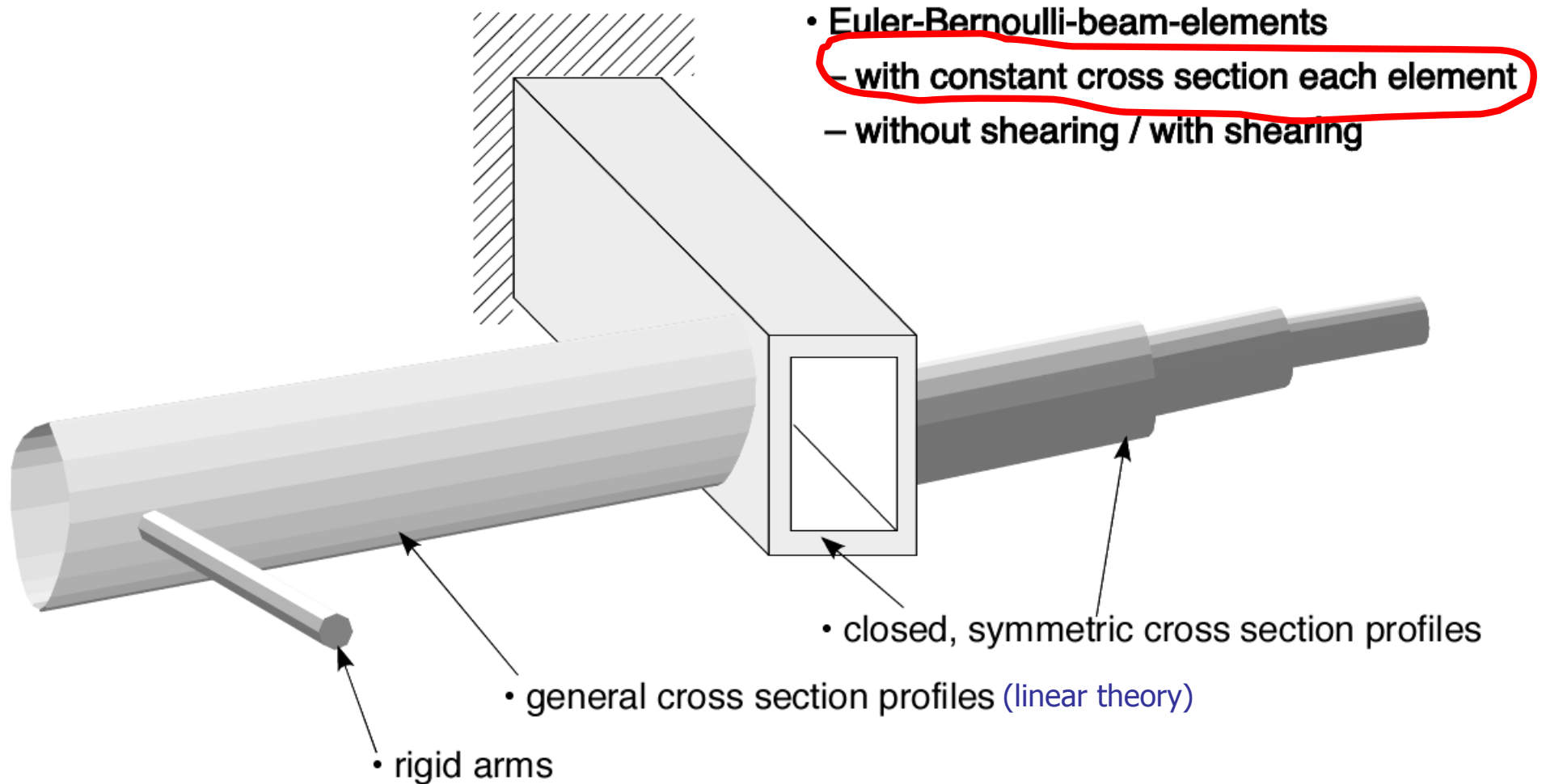
$$\boldsymbol{\rho}(t) = \boldsymbol{\rho}^i(t) + \mathbf{R} + \mathbf{u}(\mathbf{R}, t)$$

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

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

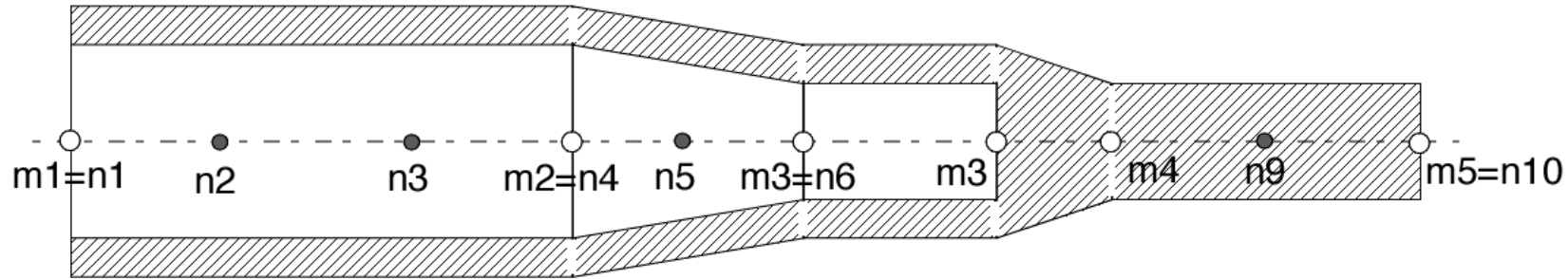


## SimBeam – Current Options of Modeling

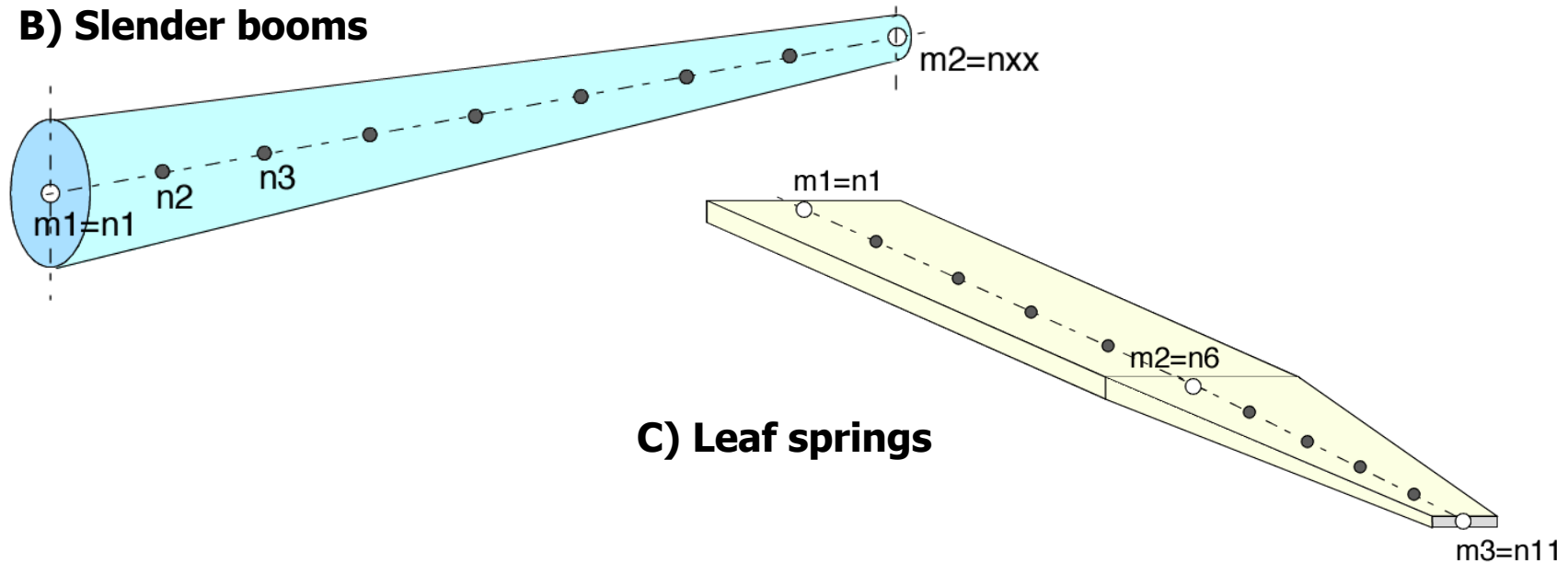


# SimBeam – Dilemma (1) of Modeling

## A) Shaft with conical sections



## B) Slender booms

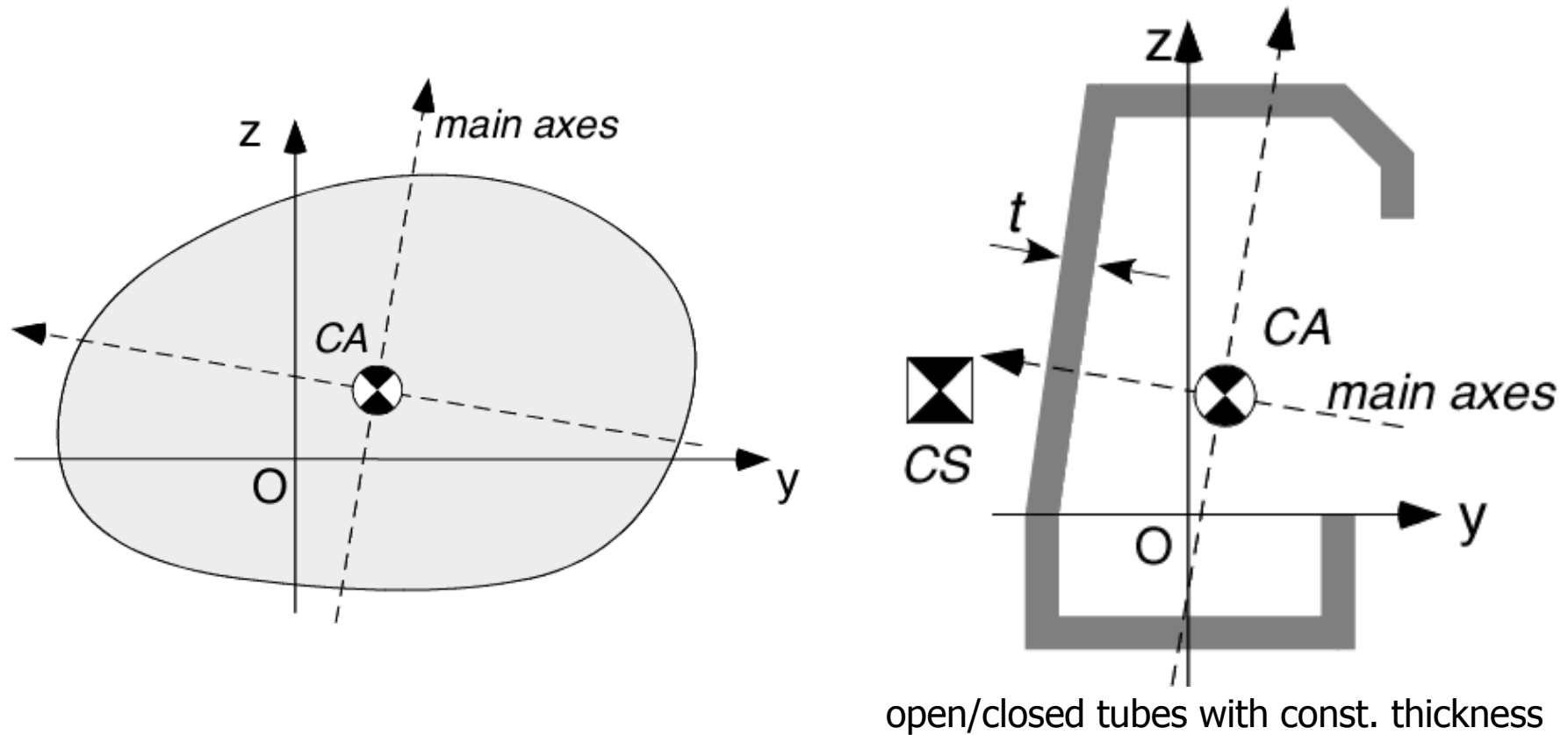


## C) Leaf springs

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

## SimBeam – Dilemma (2) of Modeling

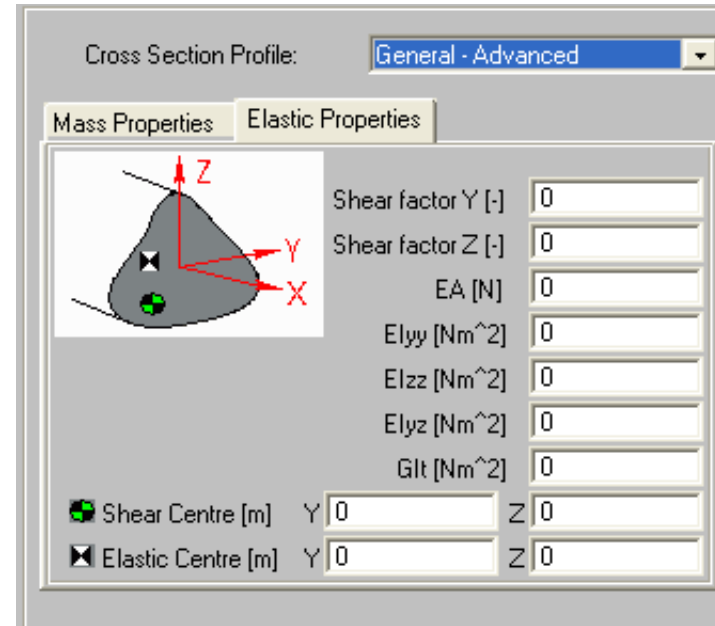
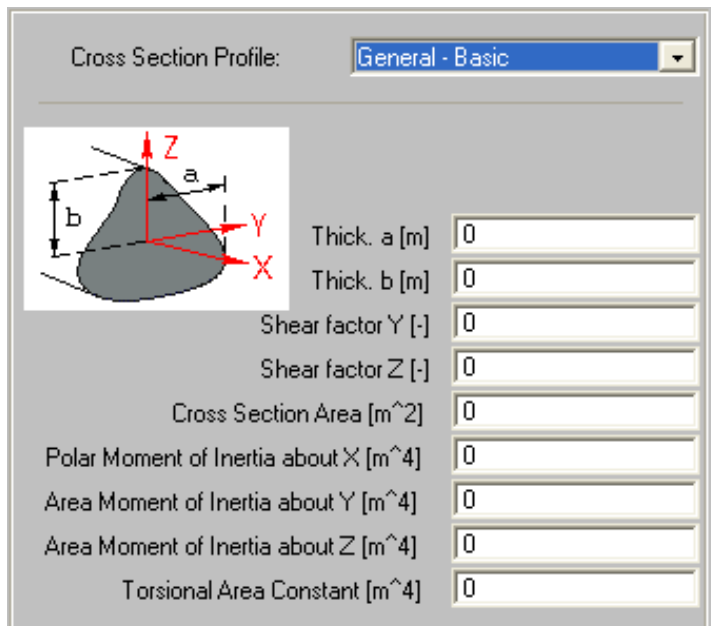
### D) Generation general cross section profiles of full and tube profiles



**=> 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

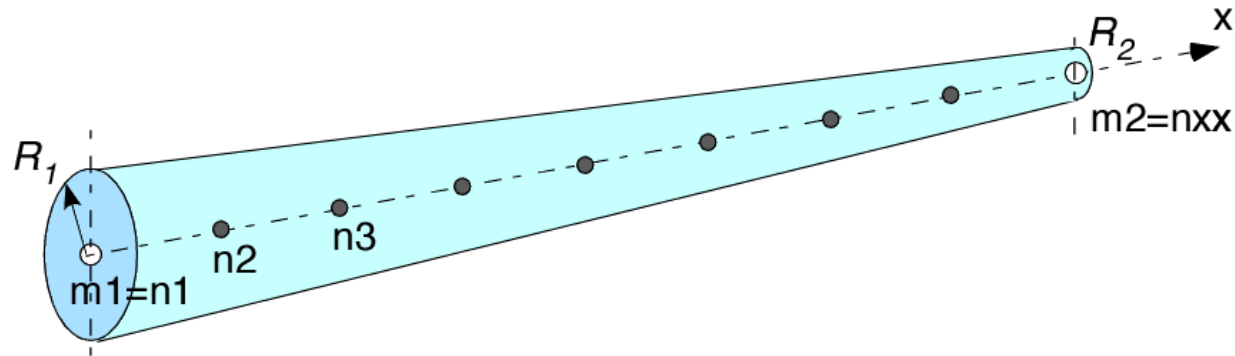


=> A first representation of second order matrices is used

## 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:  $\xi = x/l^e$ :  $R(\xi) = R_A + (R_B - R_A) \xi$

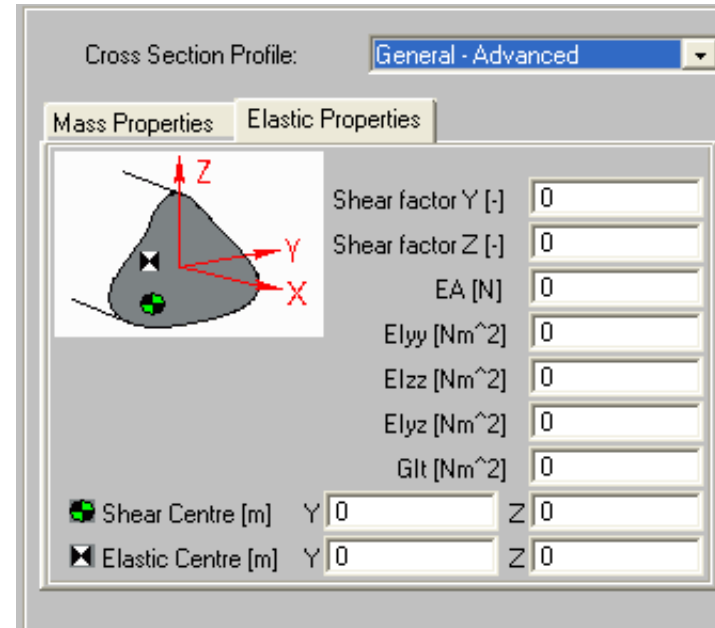
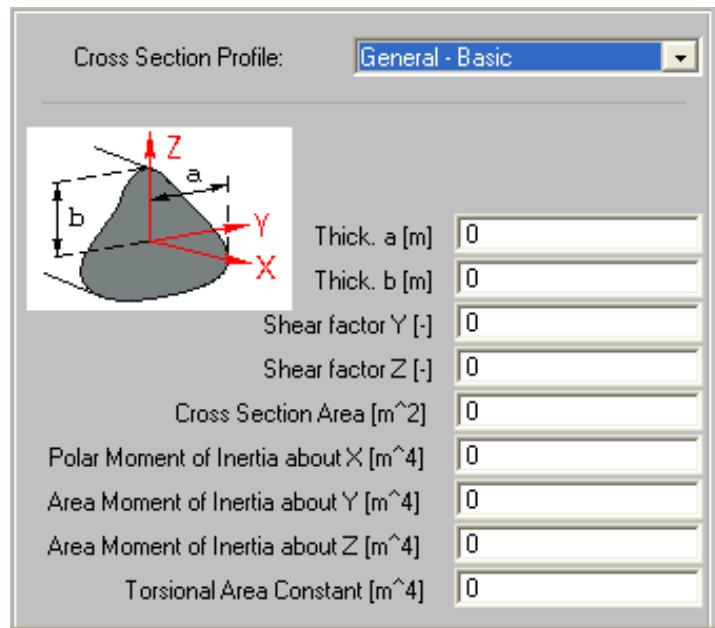
$\Rightarrow A(\xi) = A_0 + A_1 \xi + A_2 \xi^2$ ;  $I(\xi) = I_0 + I_1 \xi + I_2 \xi^2 + I_3 \xi^3 + I_4 \xi^4$ ;

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

# SimBeam – New Beam Elements

## II) General Element with a better quadratic derivation

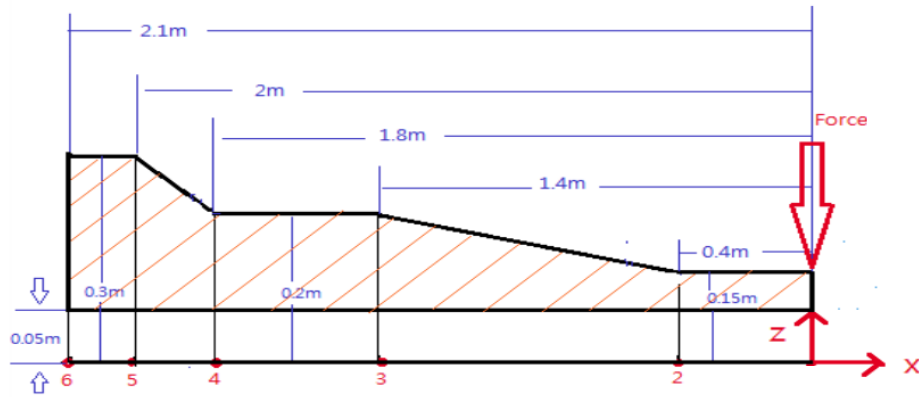
- for shear-stiff (Bernoulli) and shear-soft (Timoshenko) beam elements
- validated by experiments



- Master thesis in non-linear beam theory

# SimBeam – First Solutions using the LVSCS element

A) Conical transmission wheel (steel)



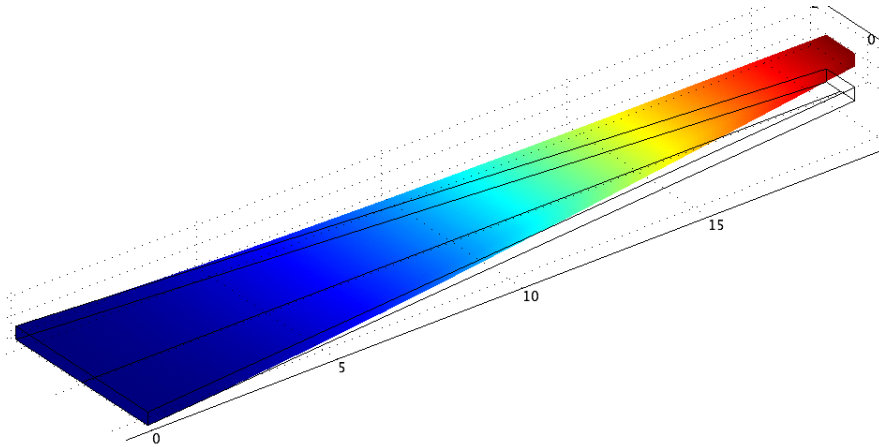
**SimBeam** model  
 6 markers at each break,  
 6 nodes, constrained at node 6,  
 force 1.e6 N at node 1,  
 36 DOF  
**Femlab** volume model  
 68124 DOF

	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

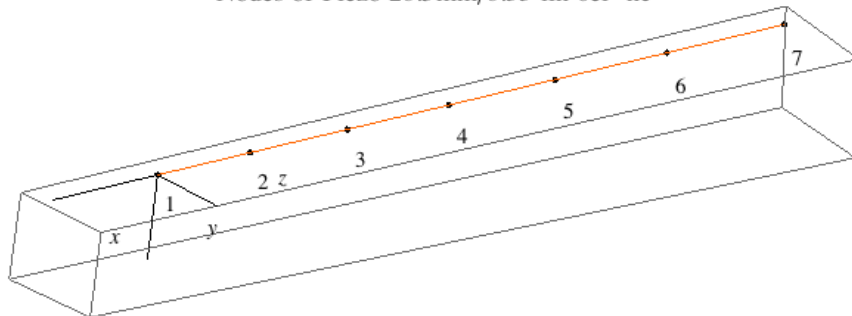
EV torsion: 9998.4 Hz

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

Nodes of Piezo 20.5mm/0.33 lin 6el-nc



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

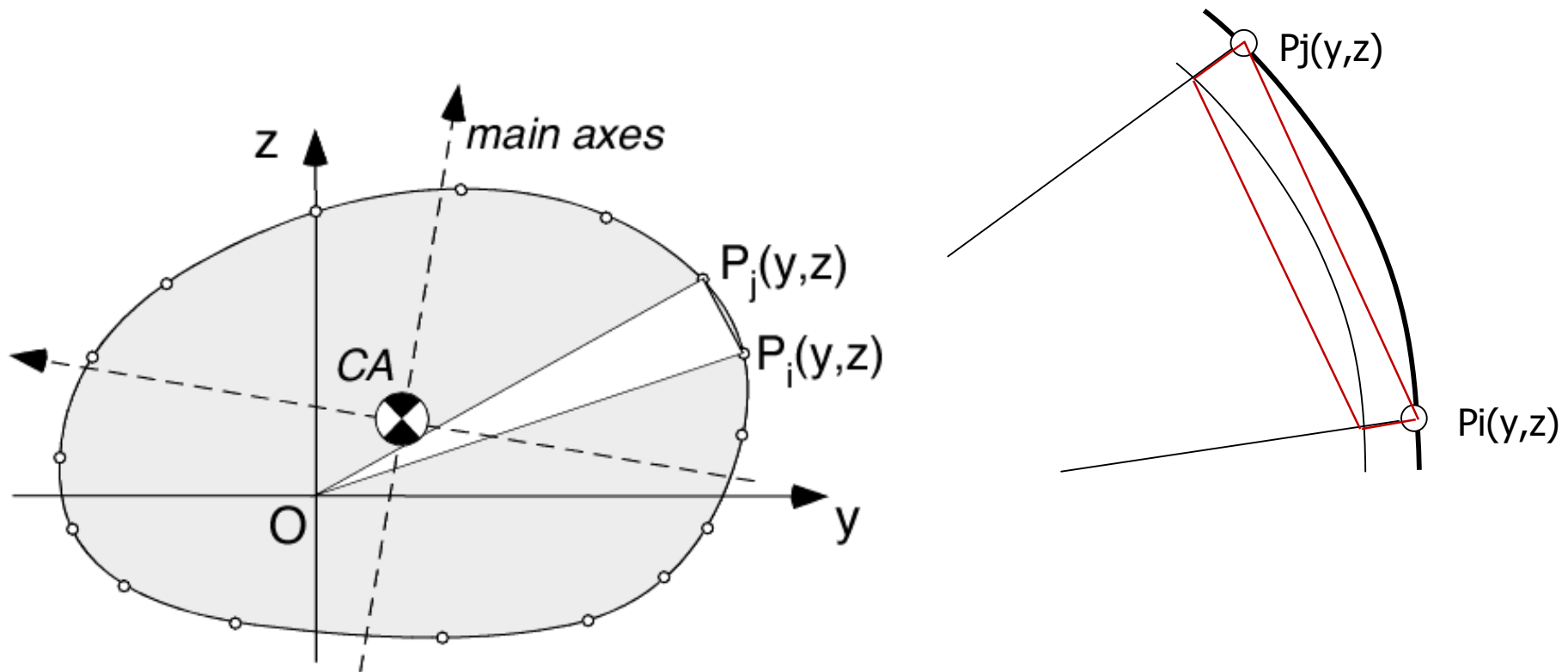
## Outlook

- 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)

## SimBeam – Outlook -> 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  $P_1, \dots, P_i, \dots, P_n$
- stiffness and mass matrices calculated analytically