Comparison of different numerical methods for braiding process simulation

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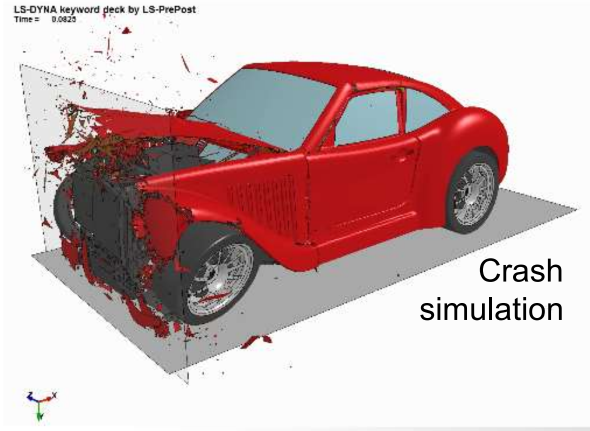
Outline of the presentation

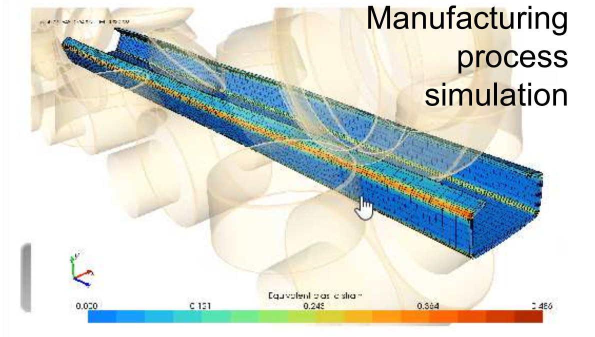
- Context – ViBra project
- Analytical and kinematic approaches
- Finite element approach
- Comparison on an industrial application
- Application to the ViBra use case
- Conclusions

About GDTech

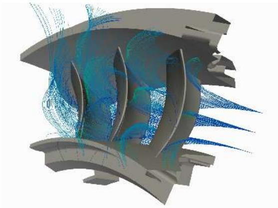
- Engineering Service company
  - Specialized in numerical modelling and simulation
- Founded in 1991
- Locations
  - Belgium: Liège area
  - France: Pau, Valenciennes, Nantes
- More than 200 employees
  - Bachelors, engineers, PhDs
  - R&T team for industrial partners (e.g. SAFRAN)
  - CAD team (Computer Aided Design)
  - CAE team (Computer Aided Engineering)
  - 3D multiphysics modelling
  - MBSE (System modelling)

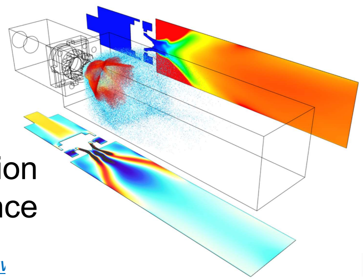


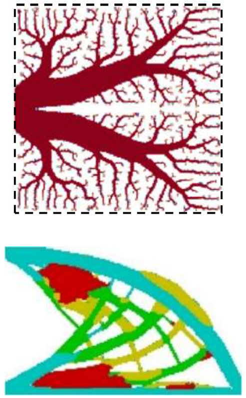
Crash simulation


Manufacturing process simulation

CFD




Combustion Turbulence


Topology optimization

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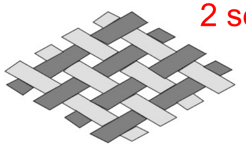
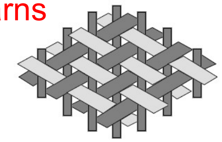
Context

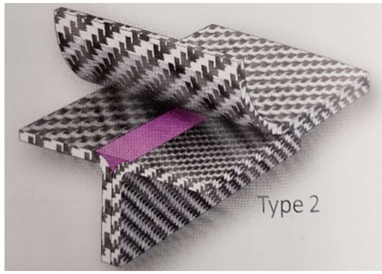
- Composite materials, made of plies with continuous fibers
- Braided composite materials are more and more attractive
  - Interlacement of yarns => limitation of delamination
  - Automated production of dry braids
  - Out-of-autocalve consolidation (=> RTM)



2 sets of yarns
Biaxial braid



3 sets of yarns
Triaxial braid



- A braiding machine is available at Centexbel, in Wallonia
  - Good opportunity for research in the topic

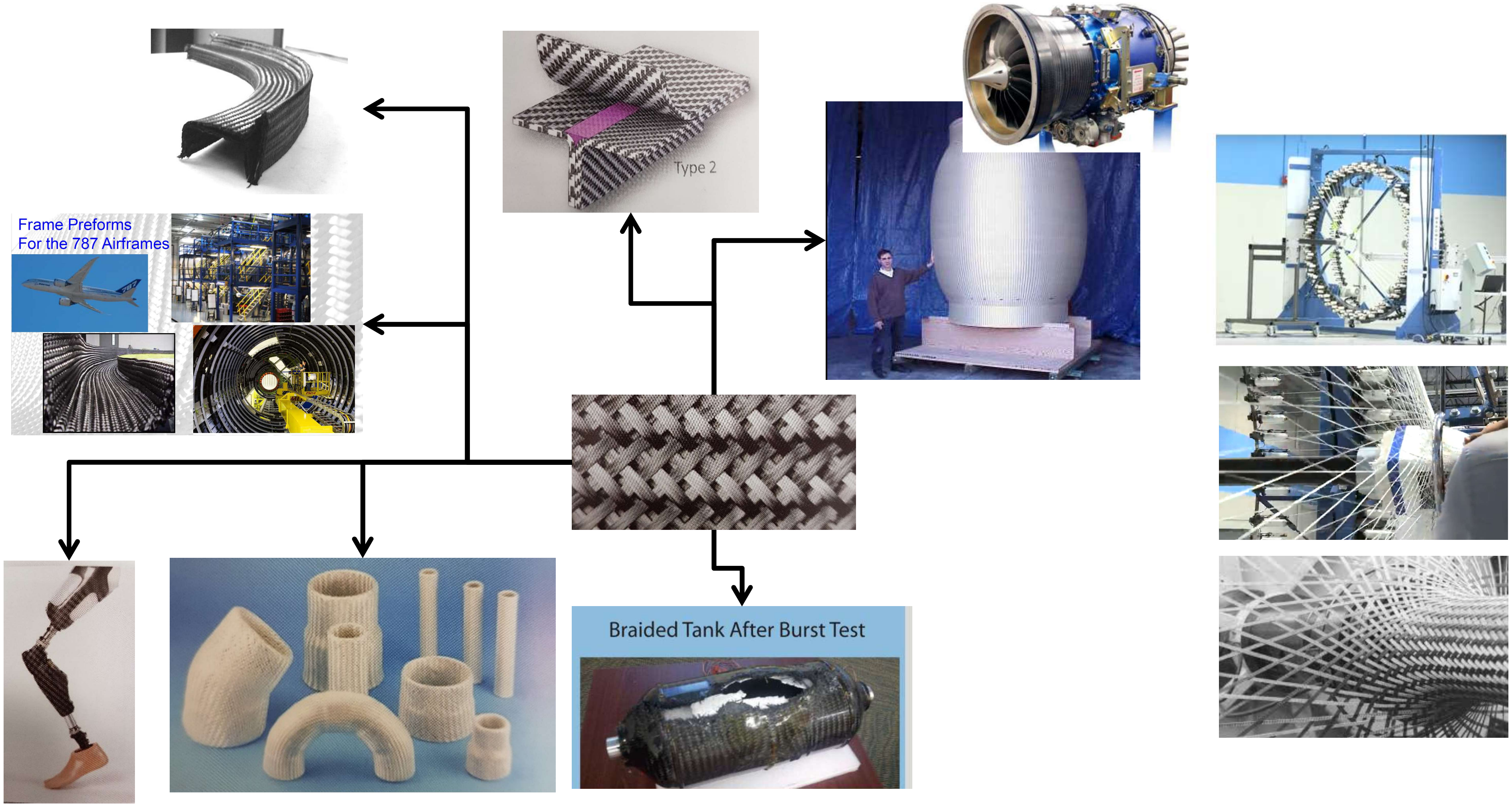
ViBra => Virtual Braiding

- Research project funded by the Walloon Region of Belgium, and supported by Skywin (Walloon Cluster for Aerospace)
- Started on September 2020; will end on September 2023
- Partners:
  - Companies: GDTech (coordinator), Open Engineering, ISOMATEX, SABCA
  - University & Research Center: University of Liège, CENTEXBEL

Braiding machine available at Centexbel

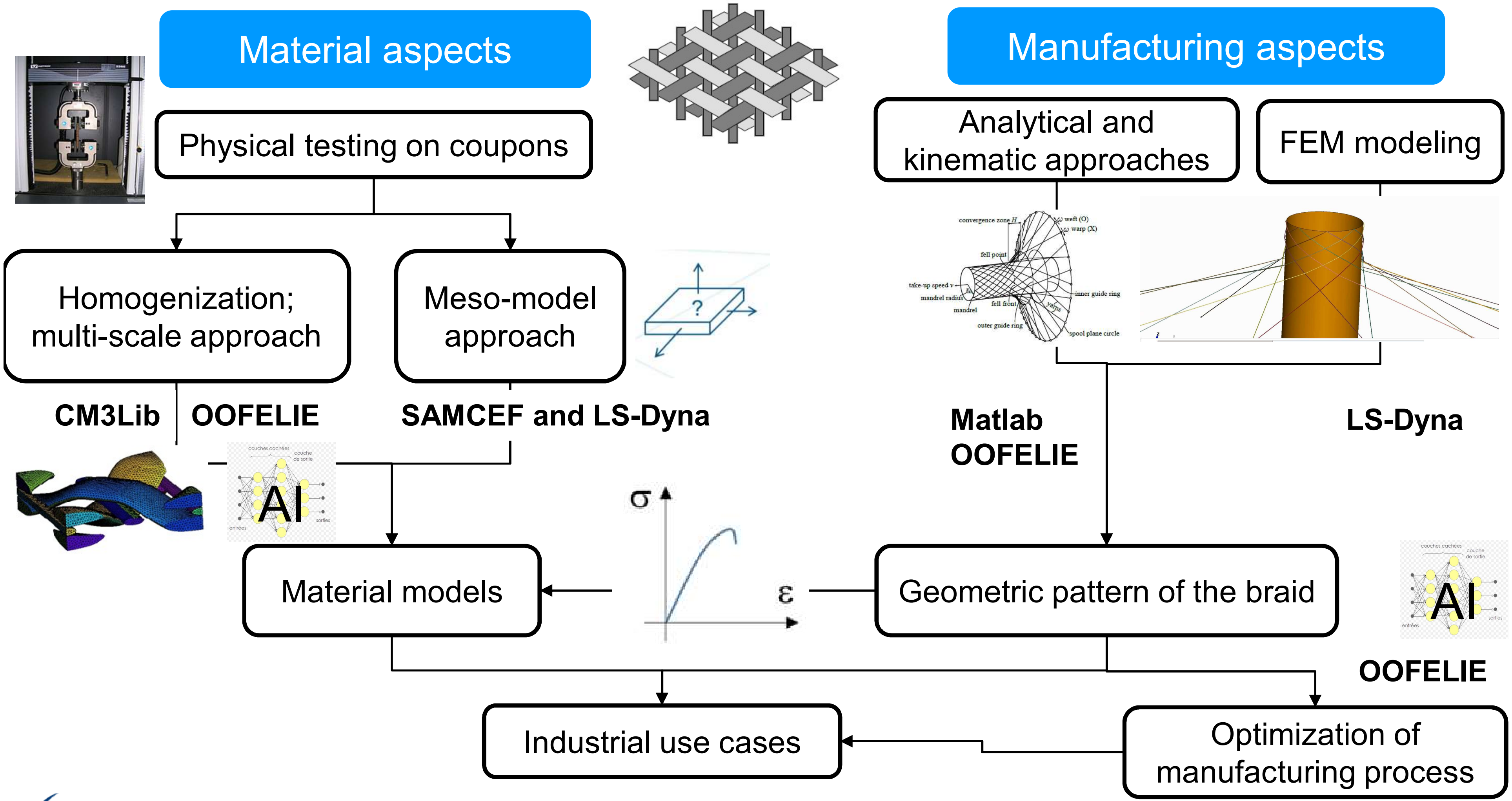
Context – ViBra project

Applications of braiding (pictures from A&P Technology and Eurocarbon)



Context – ViBra project

Research activities in ViBra



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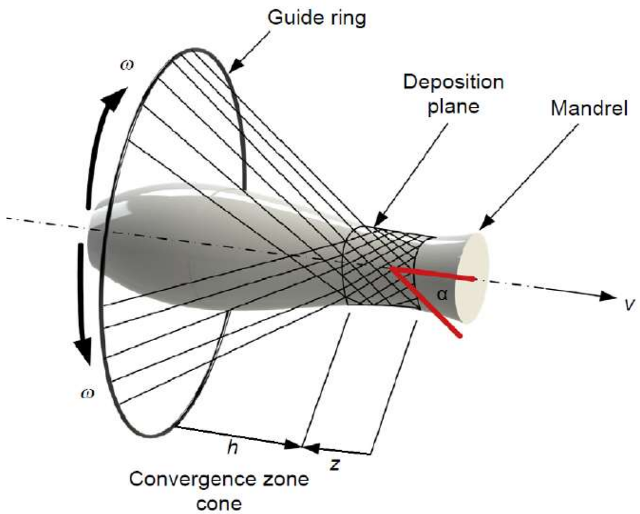
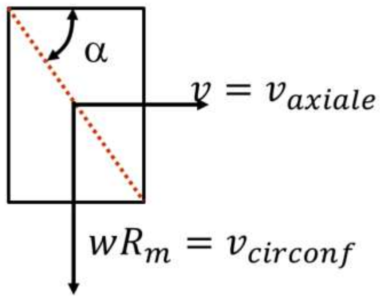
Ko et al., 1987

- Mandrel, guide ring
- ω = rotational speed of the bobines carriers
- v = take-up speed = mandrel translational speed
- α = braid angle



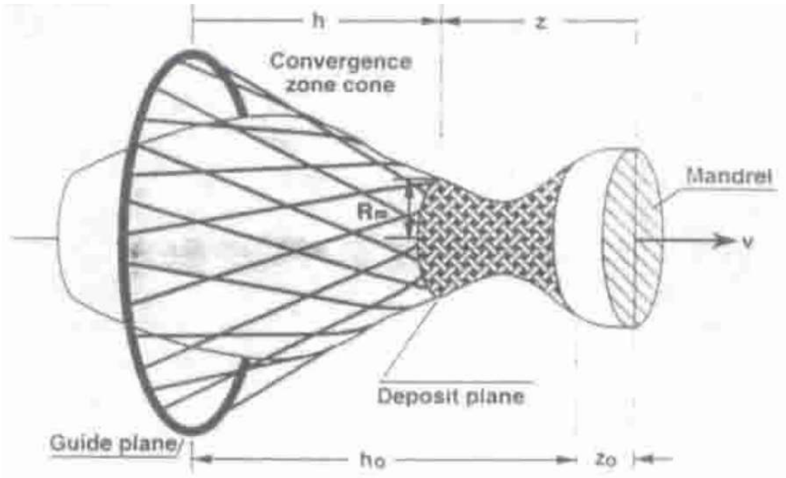


$$\tan(\alpha) = \frac{wR_m}{v}$$

⇒ No interactions between yarns and yarns/mandrel
⇒ No transient effects
⇒ Only valid for cylindrical mandrels

Du and Popper, 1994

- Mandrel = axisymmetric surface of revolution (cylindrical and conical parts)
- No interaction between the yarns
- No slipage of the yarns relative to the mandrel



$$\frac{\mathrm{d}h(t)}{\mathrm{d}t} + \frac{R_m(z)\omega(t)h(t)}{R_g\sqrt{1-\left[\frac{R_m(z)}{R_g}+\frac{h(t)}{R_g}\tan\gamma(z)\right]^2}} = v(t), \quad (1)$$

$$z(t) = z_0 + \int_0^t \left[v(t) - \frac{\mathrm{d}h(t)}{\mathrm{d}t}\right]\mathrm{d}t. \quad (2)$$

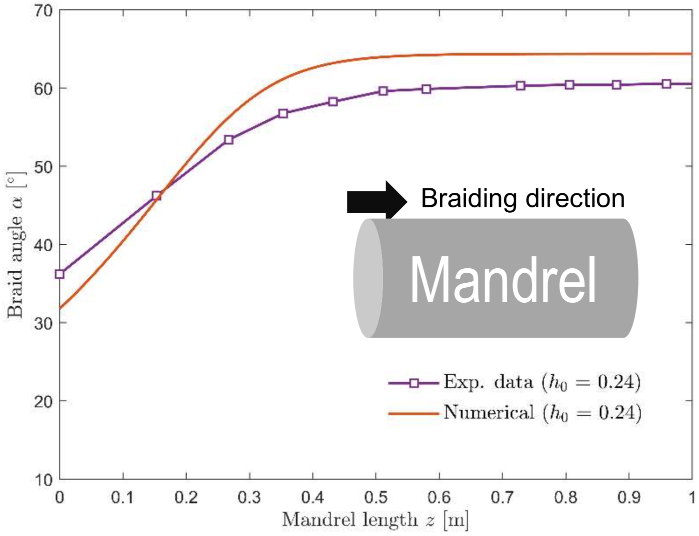
$$\tan\alpha(z) = \frac{R_g}{h(t)}\cos\gamma(z)\sqrt{1-\left[\frac{R_m(z)}{R_g}+\frac{h(t)}{R_g}\tan\gamma(z)\right]^2}. \quad (3)$$

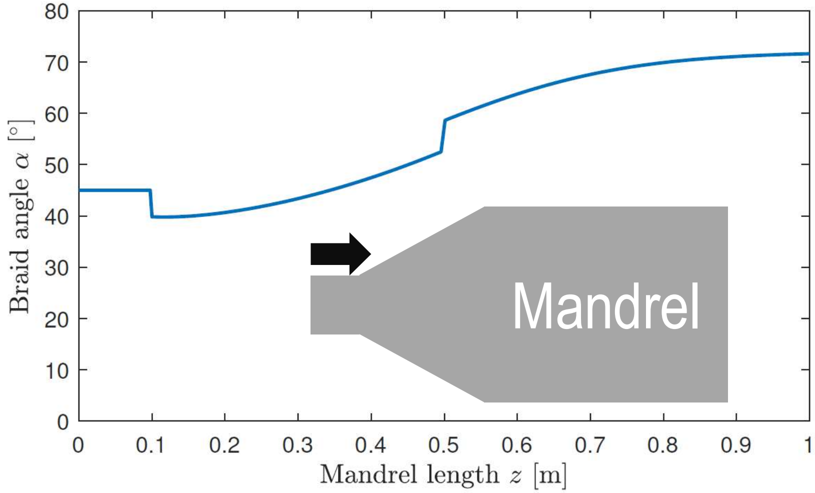
z = braiding length
Rg = guide ring radius
γ = ½ cone angle

2 possibilities:
- Direct solution: v and w given => look for α
- Inverse solution: α and w given => look for v

Du and Popper, 1994

- Implementation in Matlab
- Comparison to experimental data and Du's results
- CPU time ≈ second

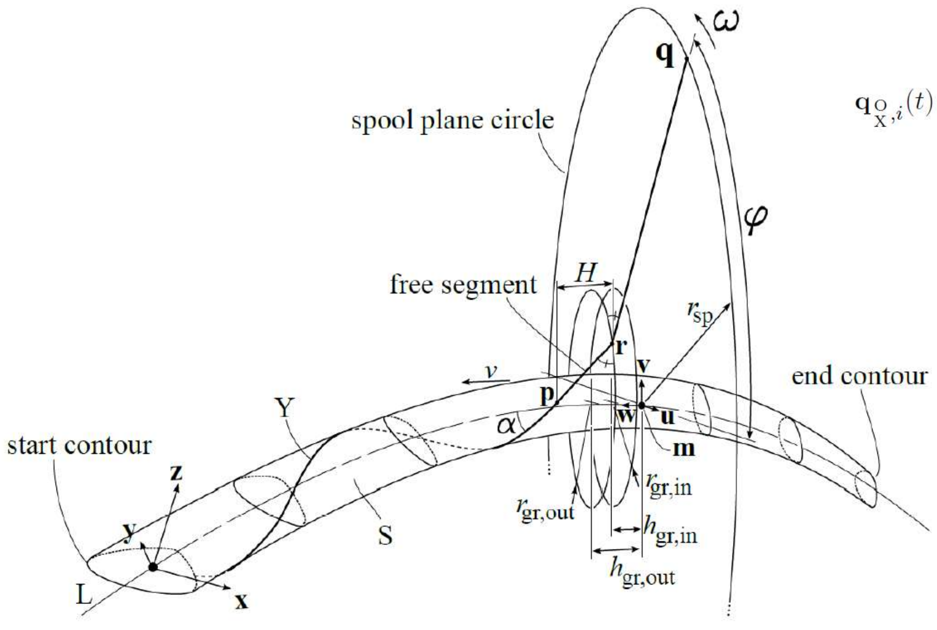




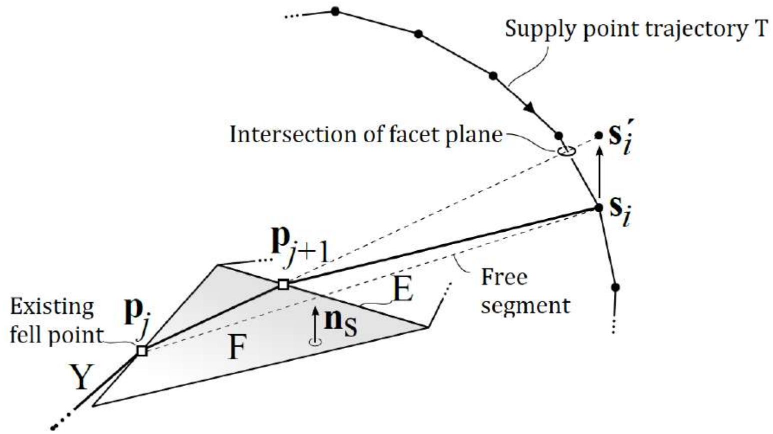
Analytical and kinematic approaches

Van Ravenhorst, 2018

- Mandrel = arbitrary cross section (circular, square, rectangular, …)
- Mesh of the mandrel
- Projections of the yarns onto the meshed mandrel

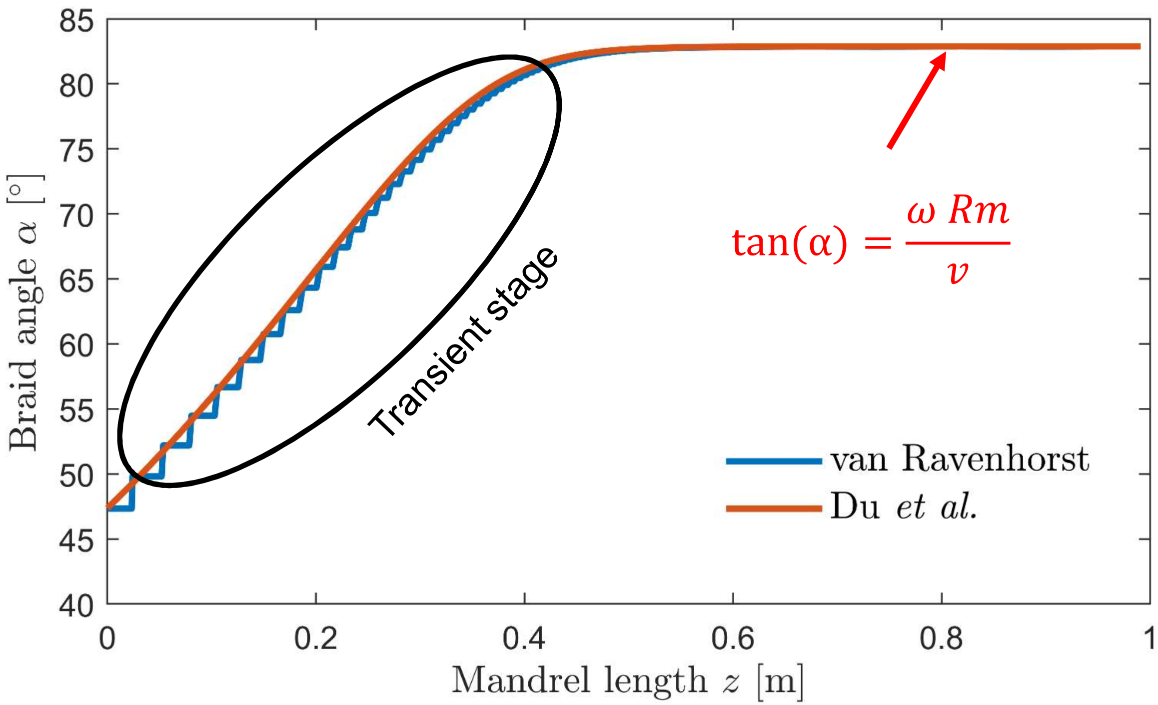


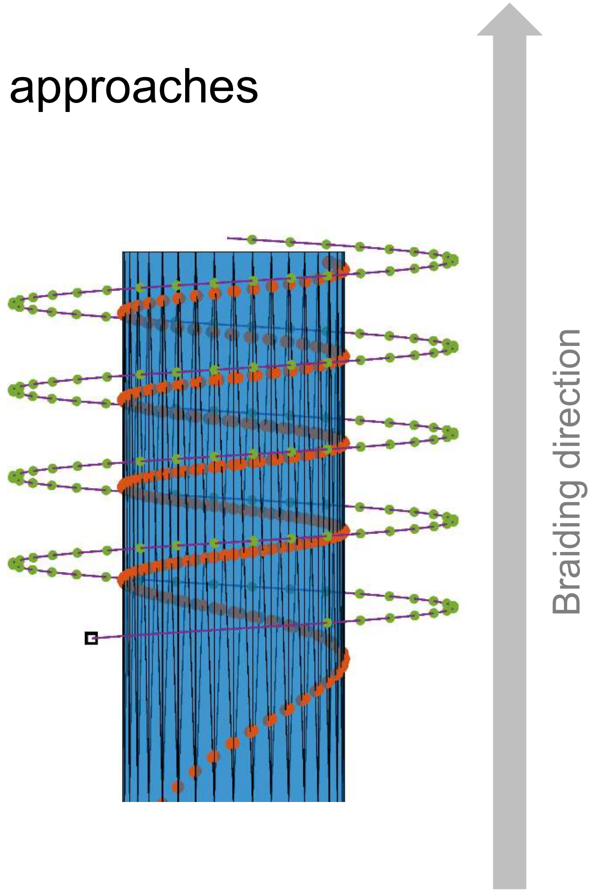
$$\mathbf{q}_{\overset{\circ}{X},i}(t) = \mathbf{m}_0 + r_{sp}\begin{bmatrix}\cos(\varphi_{0,i})\\ \pm\sin(\varphi_{0,i})\\ 0\end{bmatrix}^{T}\begin{bmatrix}\mathbf{u}(t)\\ \mathbf{v}(t)\\ \mathbf{w}(t)\end{bmatrix} + \int_{t=t_0}^{t=t_e}\begin{bmatrix}-\omega r_{sp}\sin(\varphi_{0,i}+\omega t)\\ \pm\omega r_{sp}\cos(\varphi_{0,i}+\omega t)\\ v(t)\end{bmatrix}^{T}\begin{bmatrix}\mathbf{u}(t)\\ \mathbf{v}(t)\\ \mathbf{w}(t)\end{bmatrix}\mathrm{d}t$$



Van Ravenhorst, 2018

- Implementation in Matlab
- CPU time ≈ minutes to hour
- Comparison between Du's and Van Ravenhorst's approaches





- **Van Ravenhorst, 2018**
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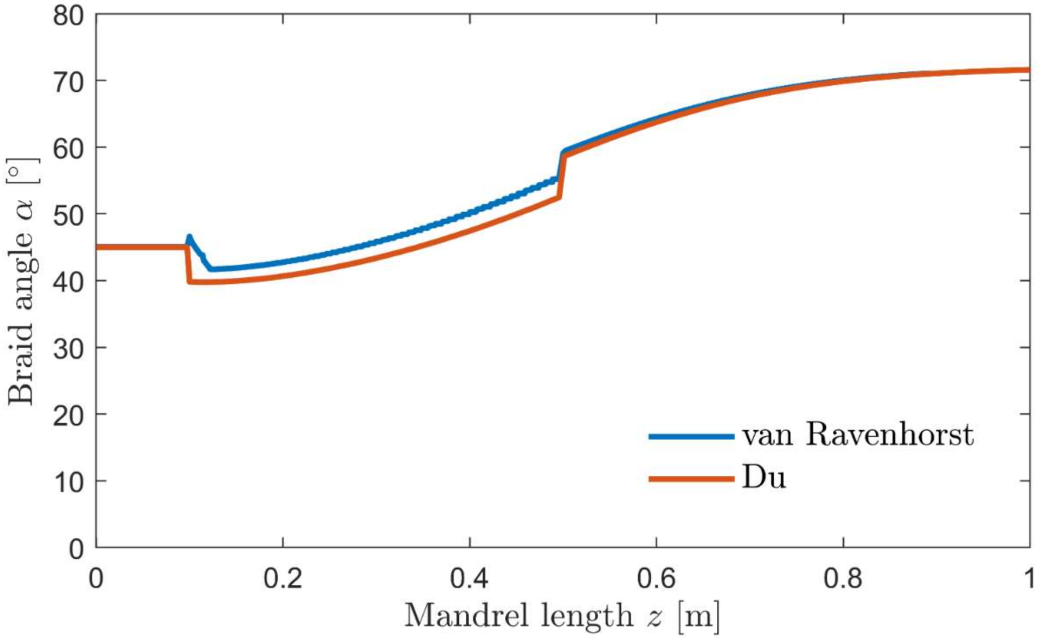

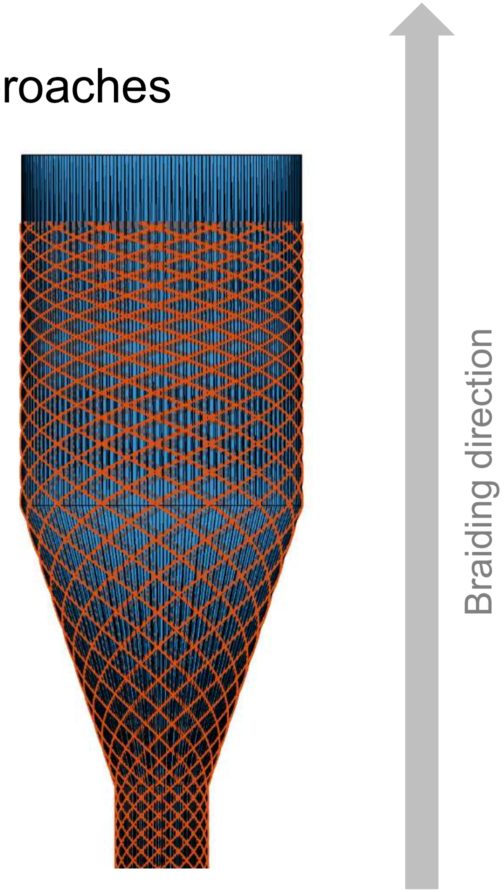

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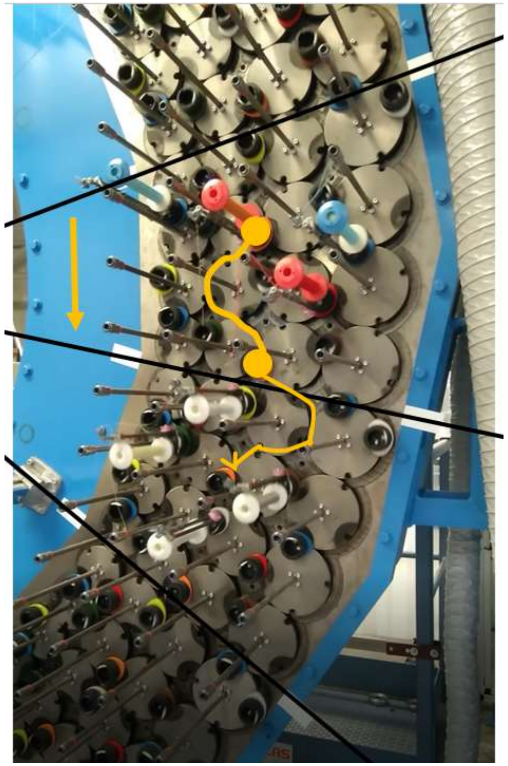
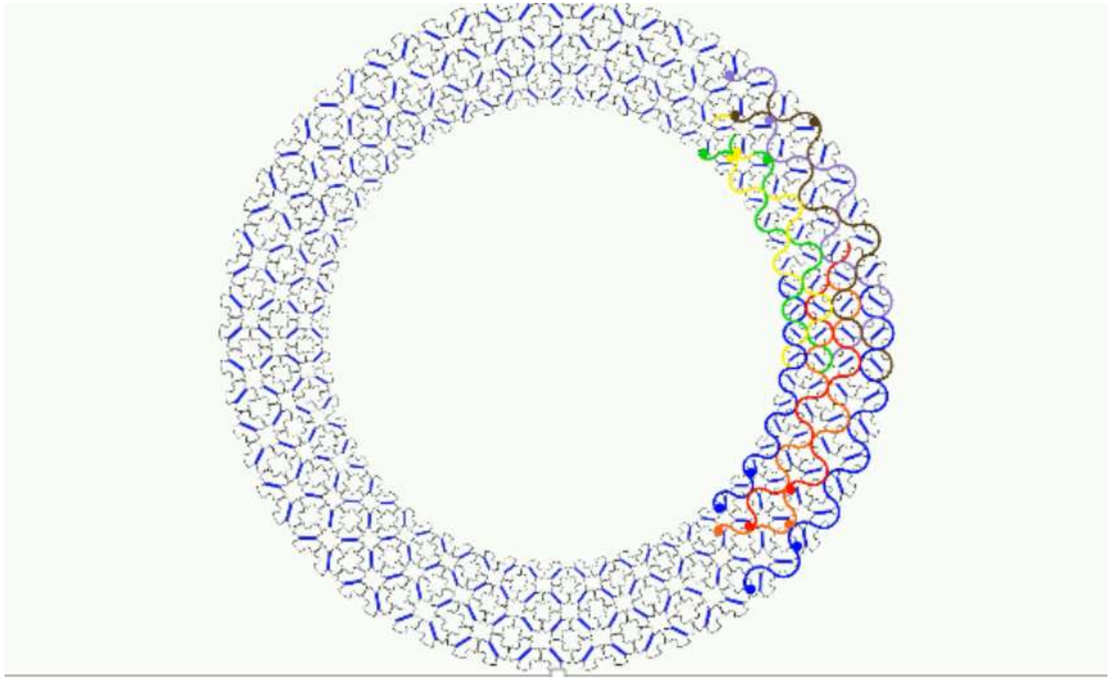
- **Ls-Dyna is used**

- **First sep:**
  - Reproduce the serpentine movement of the bobines

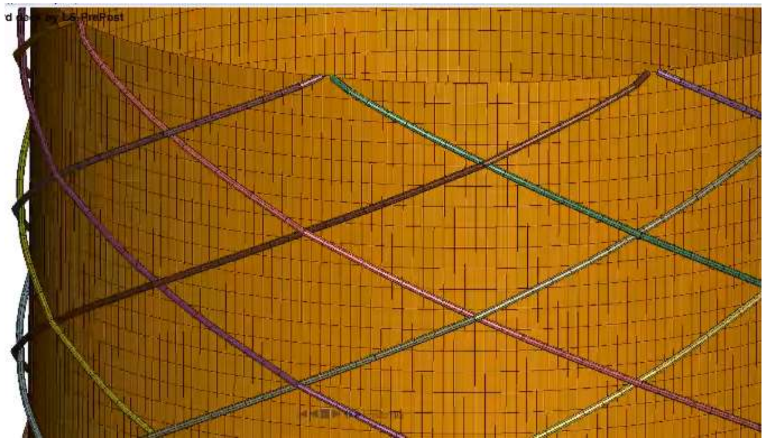


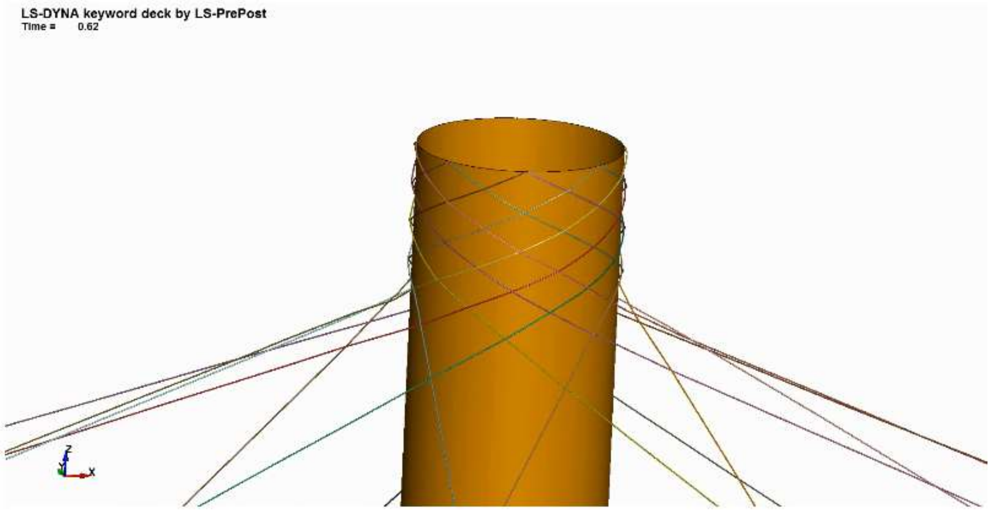


Step 2: develop the FEM strategy

- Explicit FEM solver
- Mandrel is meshed with shell elements; yarns are meshed with beam elements
- Beam source elements are used
- Contact and friction between yarns and yarns/mandrel are taken into account
- CPU time ≈ hours to days

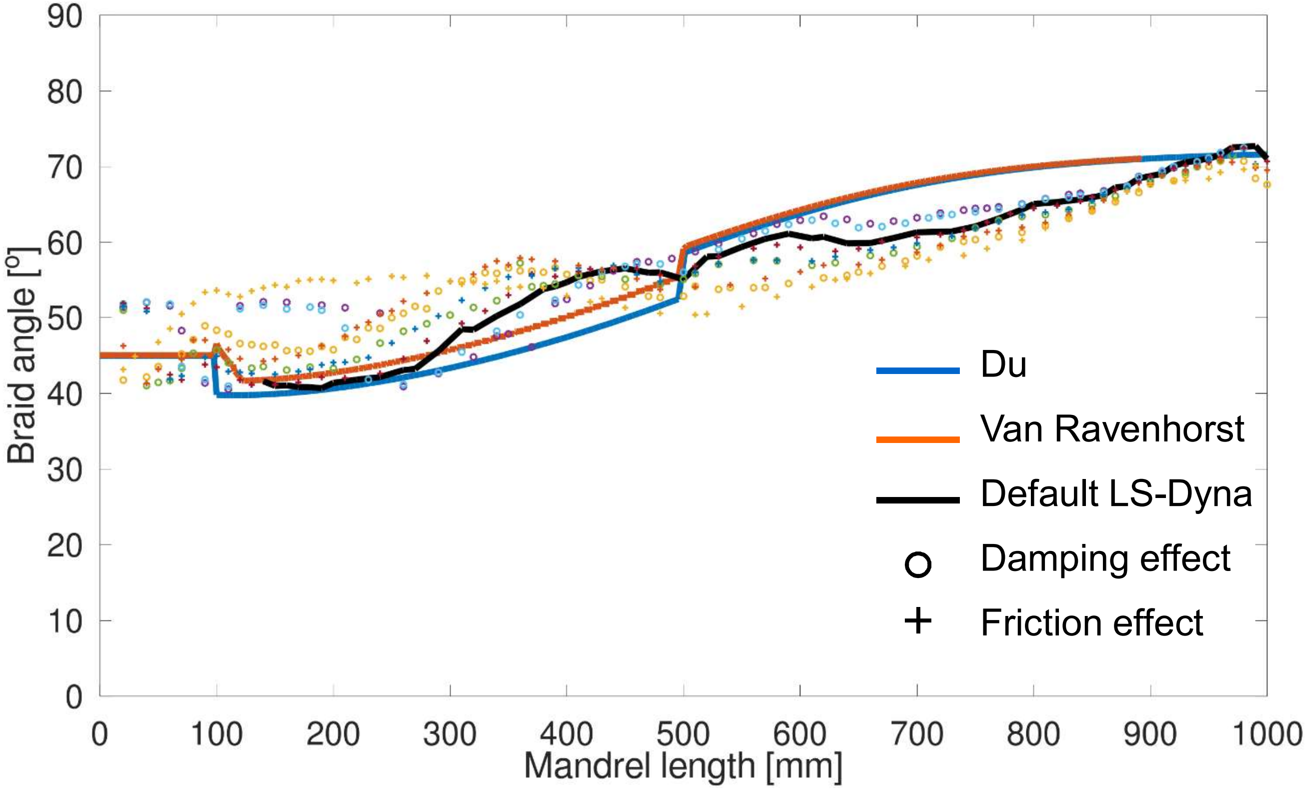
Obser
interac
yarns

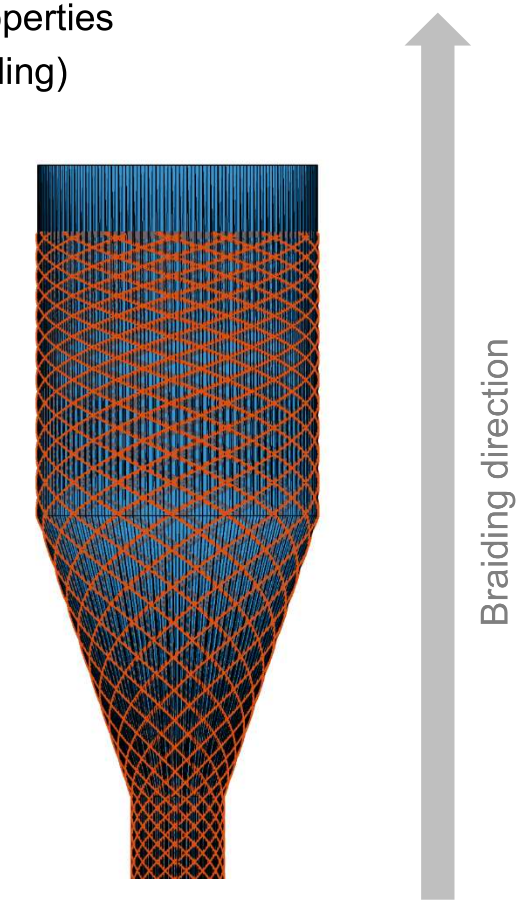




Comparison Du/Van Ravenhorst/Ls-Dyna

- Lots of numerical parameters for the LS-Dyna approach
  - Friction coefficients, damping, mass scaling, yarns material properties
  - Below: final values of the angles (interactions exist during braiding)





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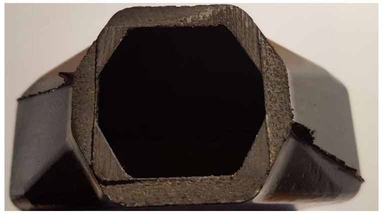
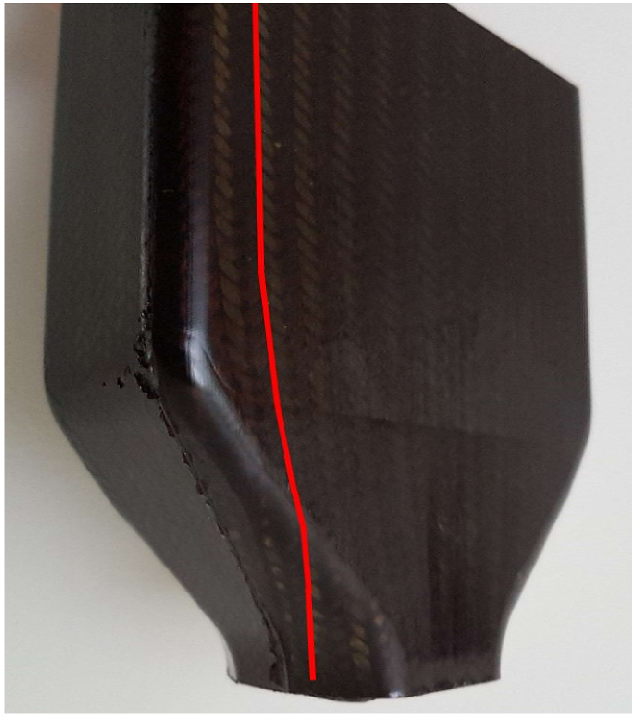
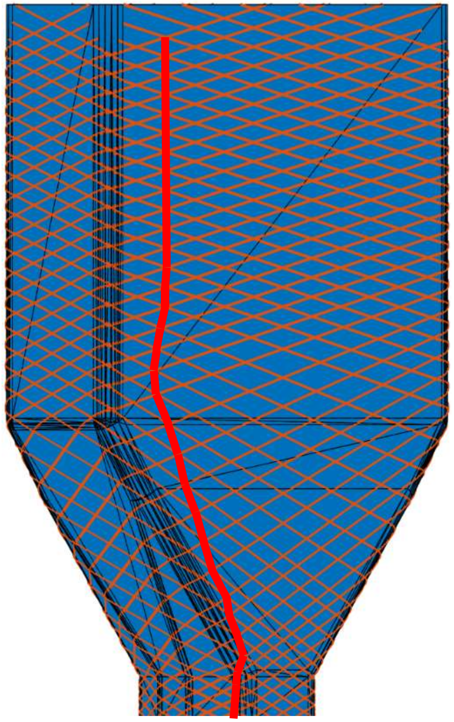
Comparison on an industrial benchmark



Complex mandrel

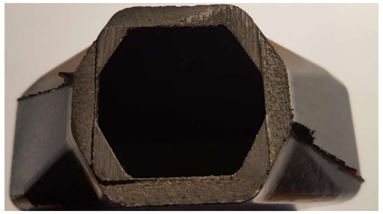
- Variable rectangular/octogonal cross sections
- Braiding angle depends on the width of the faces
- Comparison between Van Ravenhorst and FEM approach
  - FEM is carried out with and without friction





Kinematic approach

- No friction
- Ability to predict accurate braiding angles
- Ability to predict the fact that axial yarns don't stay on « the same face » during braiding



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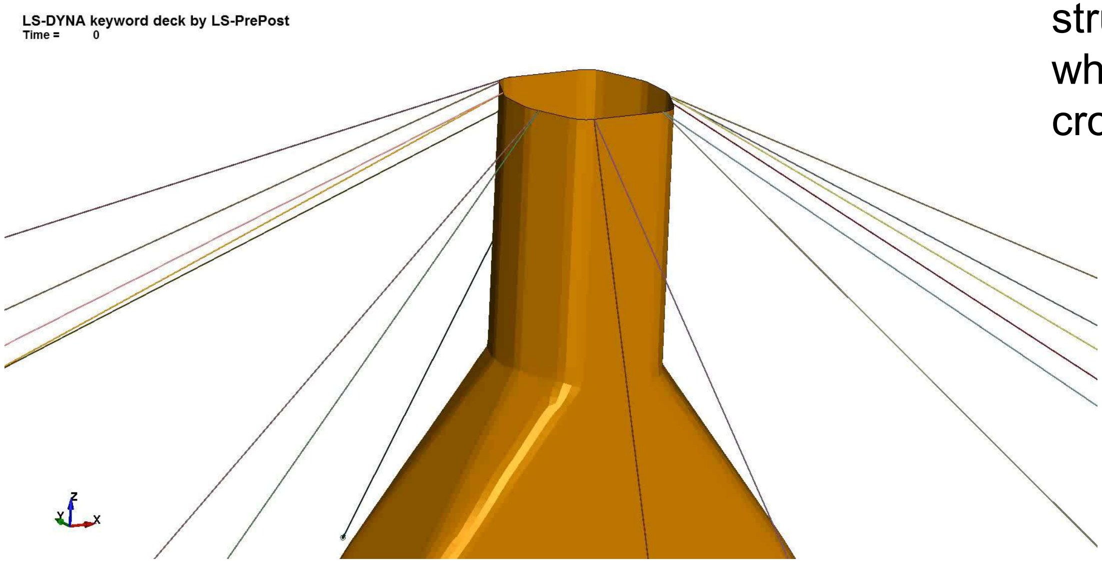
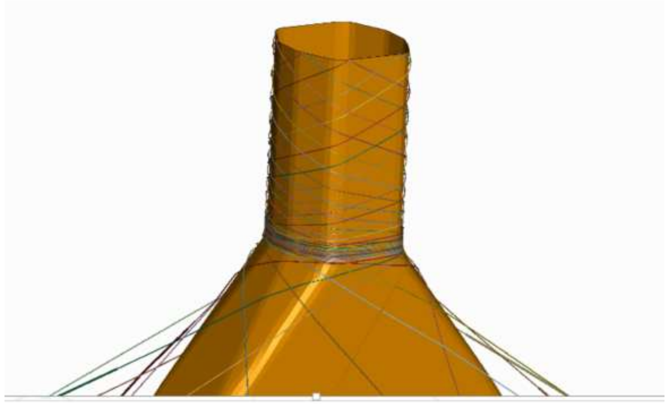
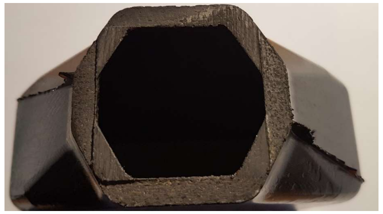


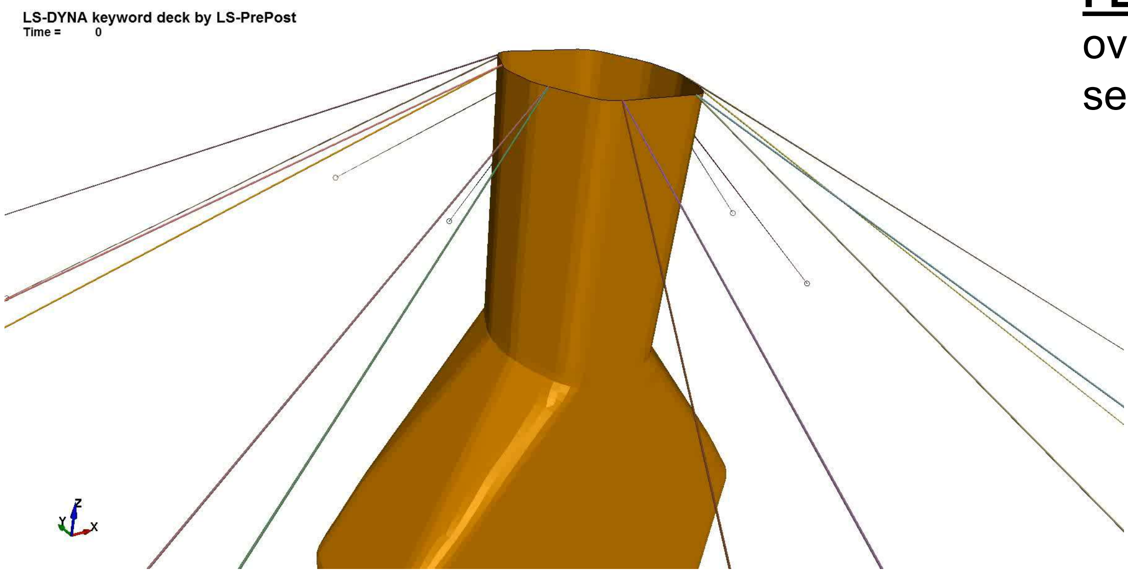
FEM without friction: the yarns are struggled and blocked at the area where we observe a change in the cross section geometry



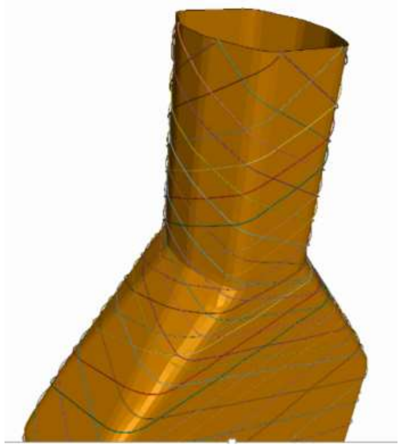
Comparison on an industrial benchmark



- **Complex mandrel**
  - Variable rectangular/octogonal cross sections
  - Braiding angle depends on the width of the faces
  - Comparison between Van Ravenhorst and FEM approach
    - FEM is carried out with and without friction



FEM with friction: the yarns can overcome the change in the cross section geometry



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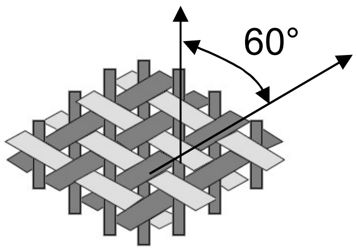
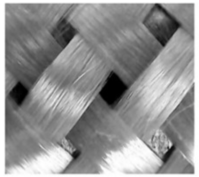
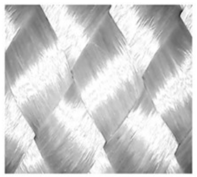
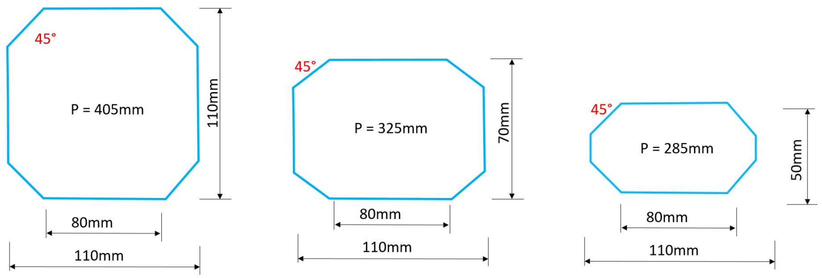
Composite box

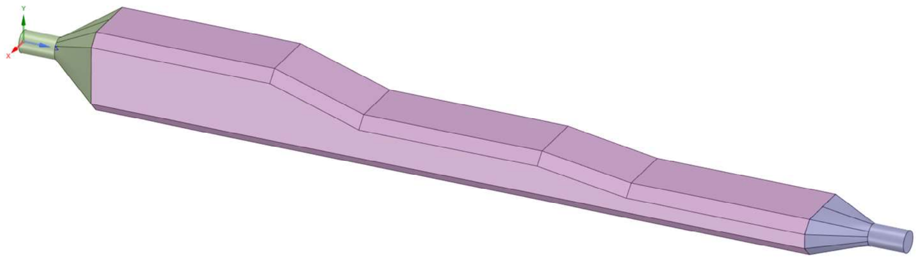
- Variable cross section
- Simulation is used to:
  - Set up braiding strategies (e.g. determine braiding speeds to have as much as possible 60° orientations for the bias yarns)
    - Avoid expensive and time consumming trials and errors on the physical machine
    - Information is then provided to the braid manufacturer
  - Predict the local angle, cover factor and thickness of the braid

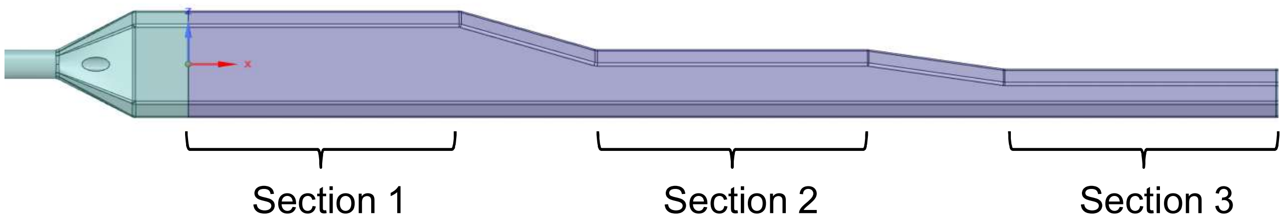








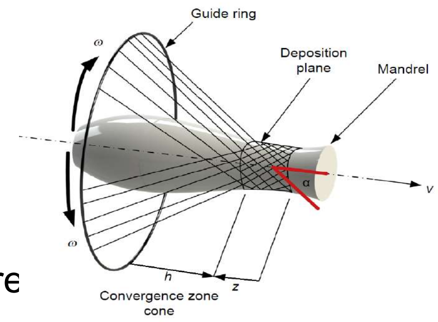


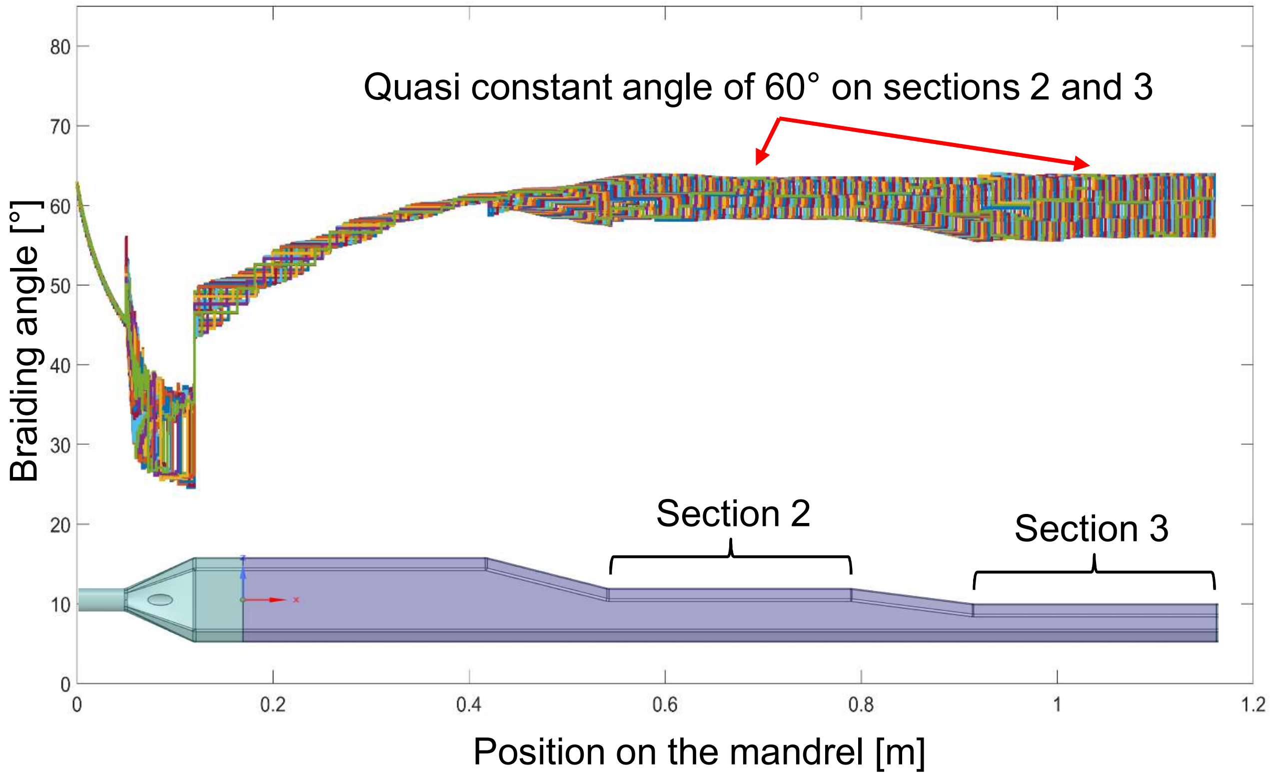


Application to ViBra use case

Composite box

- Illustration of results from process simulation
  - Rotational speed is constant
  - Take-up speed is adapted to obtain 60° bias angle almost everywhere





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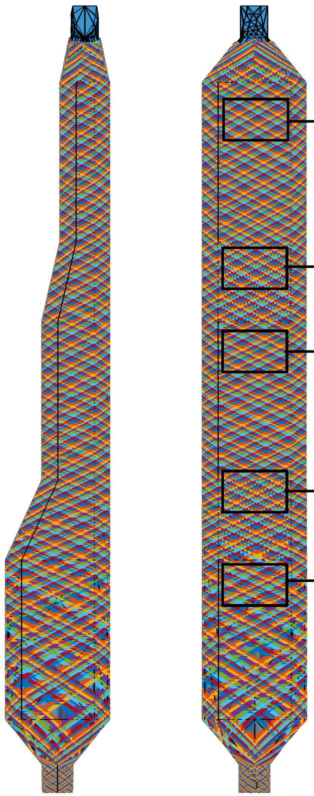

CF = 0.92 CF3 = 0.95	H = 0.3797mm
CF = 0.94 CF3 = 0.96	H = 0.3944mm
CF = 0.91 CF3 = 0.94	H = 0.3693mm
CF = 0.92 CF3 = 0.95	H = 0.3787mm
CF = 0.85 CF3 = 0.88	H = 0.3225mm

The cover factor and the thickness increase when the mandrel cross section decreases

CF = cover factor for 2D-biax

CF3 = cover factor for 2D-triax

H = braid thickness

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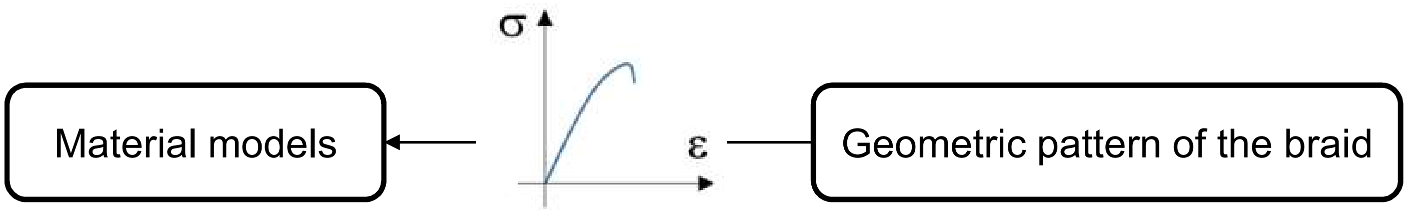
Conclusions

- The braiding manufacturing process for dry preforms of composite materials was presented
- Analytical, kinematic and FEM approaches
  - Were briefly presented
  - Were compared in terms of CPU and accuracy
  - Should be compared to physical braiding for additional validation
- Simulation of braiding manufacturing process is used to:
  - Avoid expensive and time consuming trials and errors on the physical machine
  - Predict the relevant braid characteristics, like local angle, cover factor and thickness
  - Determine the process parameters to obtain required braid angles
- Main next step is to make the link with the material model



- The results presented here were obtained during the research project **ViBra (Virtual Braiding)**, under the convention n°8422

- Contacts
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