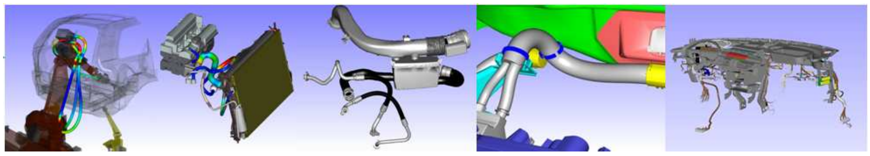
Simulation for assembly-oriented design and digital validation of cables and hoses



Dr. Klaus Dreßler, Dr. Joachim Linn

Berlin, Mai 2014

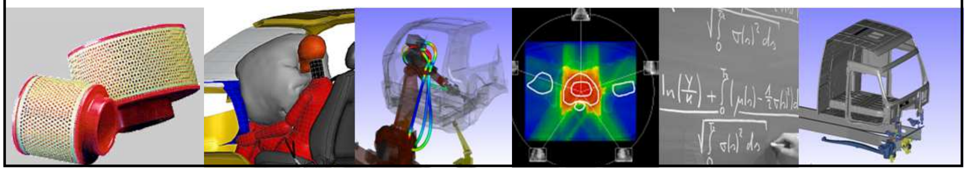
Simulation based design, assembly and validation of cables, hoses and wiring harness

- Introduction Fraunhofer ITWM
  - related activities
- Fast and accurate simulation of flexible structures
- IPS Cable Simulation
  - features & benefits
  - Application cases
- Summary
  - and outlook

Fraunhofer-Institute for Industrial Mathematics ITWM

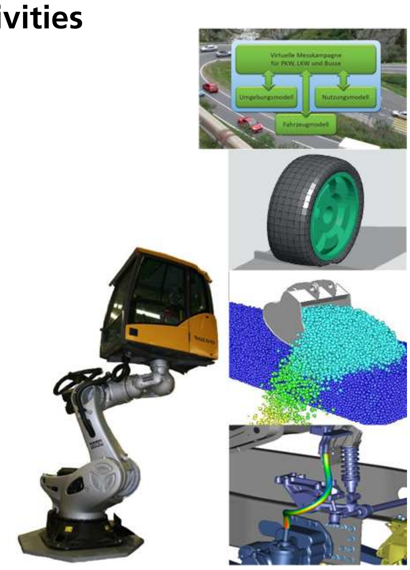
- Activities mainly in the context of engineering applications:
  - Dynamics and durability
  - Fluid dynamics, flow in complex structures
  - Image processing and quality assurance
  - Optimization, adaptive systems
  - High Performance Computing

- 260 employees
- budget 2013: 22,0 Mio Euro



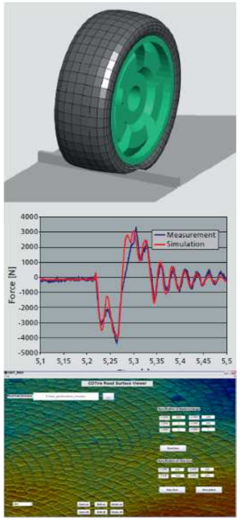
Simulation of cables, hoses and wiring harness - related Fraunhofer ITWM activities

- Simulation of flexible structures
  - **IPS Cable Simulation**
  - **CDTire**
- **Vehicle System Simulation**
  - MBS / co-simulation / FMI/FMU
  - realtime & hybrid simualtion
  - **RODOS** – Interactive driver and operator simulation
- **VMC – Virtual Measurement Campaign**
  - Geo-referenced model of the world for vehicle engineering
  - Simulation of usage variability



Fraunhofer ITWM activites
Tire simulation

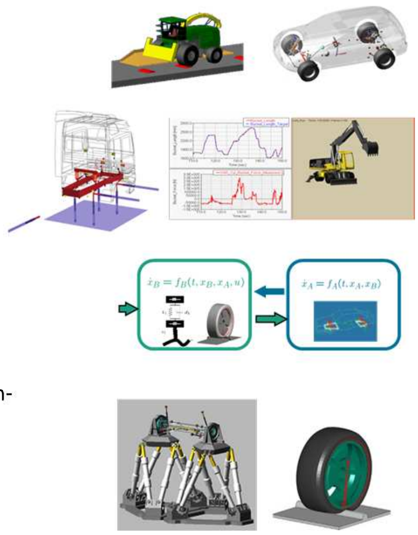
- **CDTire** – Tire model for comfort, durability, safety and NVH
  - Available with ADAMS, ALTAIR MotionSolve, LMS Virtual.lab, SIMPACK, Matlab/Simulink
  - flexible rim
  - **CDTire / Realtime**
    real time capable / up to 150 Hz
  - **CDTire / 3D** shell based detailed model of side-walls and belt



Fraunhofer
ITWM

Fraunhofer ITWM
Vehicle System Simulation / MBS

- System modelling and simulation for load path and energy flow
- Multibody System Simulation of full vehicles and subsystems at different complexity levels
- Invariant Loads
  - Identification of road-profiles based on measured wheel-loads, tire-models and optimal-control methods
  - ITWM-I6D-approach, derivation of geometrical road-profiles for / with CDTire
- On-board / realtime simulation and simulation-based monitoring



contact: Michael Burger & Manfred Bäcker

Fraunhofer
ITWM

Simulation based design, assembly and validation of cables, hoses and wiring harness

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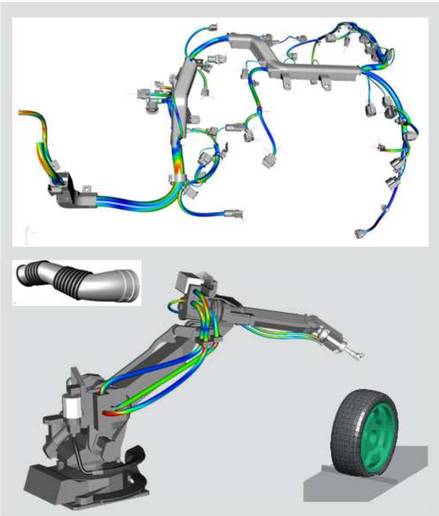
Simulation of "very" flexible structures

Challenges

- cables and wiring harnesses
- hoses
- ceiling / roof interior
- tires
- rubber mounts
- …



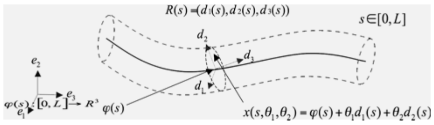
New Fraunhofer technology – available in **IPS Cable Simulation**

- Fast and physically correct simulation of large non-linear deformations
- Special focus on interactive virtual assembly of cables and hoses

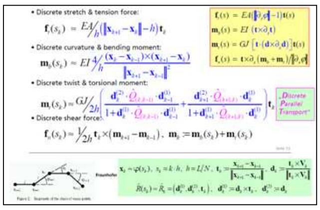
Simulation based design, assembly and validation of cables, hoses and wiring harness

Technology development by dedicated groups of experts at ITWM and FCC since 2005

- **based on geometricly nonlinear beam theory**
- **variational discretization**
- **special numerical methods: »geometric finite differences«**
  - discrete differential geometry: discretization of differential invariants



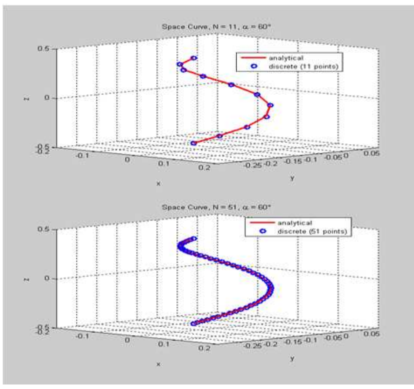
$$w_{el} = \frac{1}{2}(\Gamma-\Gamma_0)^T \cdot \begin{pmatrix} GA_1 & 0 & 0 \\ 0 & GA_2 & 0 \\ 0 & 0 & EA \end{pmatrix} \cdot (\Gamma-\Gamma_0) + \frac{1}{2}(\Omega-\Omega_0)^T \cdot \begin{pmatrix} EI_1 & 0 & 0 \\ 0 & EI_2 & 0 \\ 0 & 0 & GJ \end{pmatrix} \cdot (\Omega-\Omega_0)$$



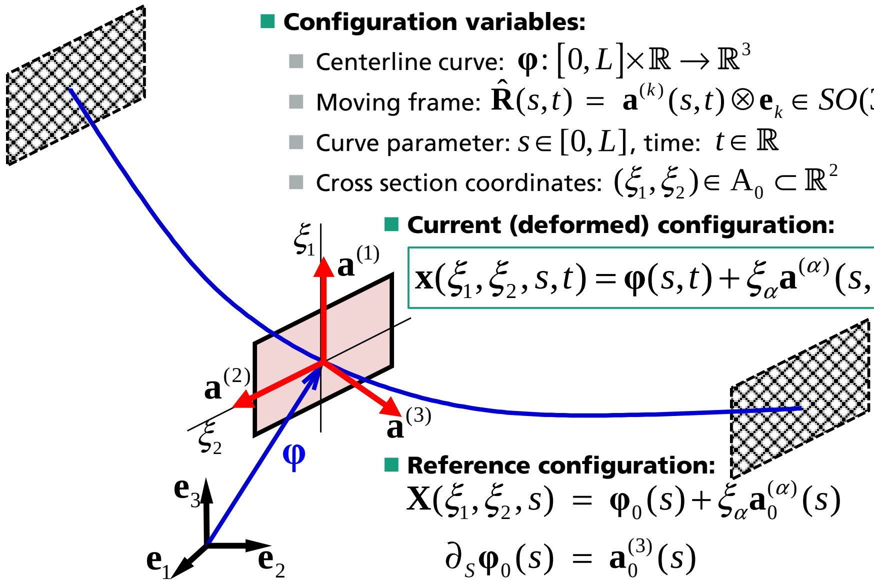
Simulation based design, assembly and validation of cables, hoses and wiring harness

Technology development by dedicated groups of experts at ITWM and FCC since 2005

- **based on geometricly nonlinear beam theory**
- **variational discretization**
- **special numerical methods: »geometric finite differences«**
  - discrete differential geometry: discretization of differential invariants
  - such that even for relatively coarse discretization the bending and torsion energy will be determined physically correct



Basic Cosserat rod kinematics: Configurations



- **Configuration variables:**
  - Centerline curve: $\boldsymbol{\varphi}: [0, L] \times \mathbb{R} \to \mathbb{R}^3$
  - Moving frame: $\hat{\mathbf{R}}(s,t) = \mathbf{a}^{(k)}(s,t) \otimes \mathbf{e}_k \in SO(3)$
  - Curve parameter: $s \in [0, L]$, time: $t \in \mathbb{R}$
  - Cross section coordinates: $(\xi_1, \xi_2) \in \mathrm{A}_0 \subset \mathbb{R}^2$
- **Current (deformed) configuration:**

$$\boxed{\mathbf{x}(\xi_1, \xi_2, s, t) = \boldsymbol{\varphi}(s,t) + \xi_\alpha \mathbf{a}^{(\alpha)}(s,t)}$$

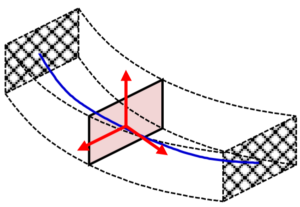
- **Reference configuration:**

$$\mathbf{X}(\xi_1, \xi_2, s) = \boldsymbol{\varphi}_0(s) + \xi_\alpha \mathbf{a}_0^{(\alpha)}(s)$$

$$\partial_S \boldsymbol{\varphi}_0(s) = \mathbf{a}_0^{(3)}(s)$$

Ref.: Simo (1985), Antman (2005)

Differential geometry of *Cosserat* curves in space



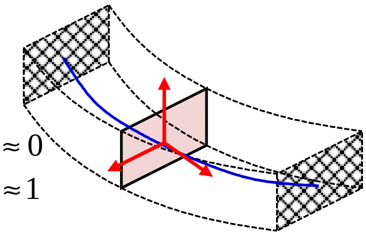
- **Framed space curve:** $\boxed{(\boldsymbol{\varphi}, \hat{\mathbf{R}}) : [0, L] \to \mathbb{R}^3 \times SO(3)}$
  - regular curve (arc length parametrization)
  - general frame field: $\hat{\mathbf{R}}(s) = (\mathbf{d}_1, \mathbf{d}_2, \mathbf{d}_3) \in SO(3)$
- Generalized **Frenet equations:** $\boxed{\mathbf{d}_k' = \mathbf{u} \times \mathbf{d}_k}$
  - *Darboux* vector $\mathbf{u}(s) = \sum_{k=1}^{3} U_k(s) \mathbf{d}_k(s)$
  - **Curvatures** $U_k(s)$ *given w.r.t. the frame directors* $\boldsymbol{d}_k(s)$
- Curve tangent components $V_k(s)$ *w.r.t. the frame directors* $\boldsymbol{d}_k(s)$:

$$\boxed{\begin{aligned} &\boldsymbol{\varphi}'(s) = \sum_{k=1}^{3} V_k(s) \mathbf{d}_k(s) \\ \Leftrightarrow\ &V_k(s) = \mathbf{d}_k(s) \cdot \boldsymbol{\varphi}'(s) \end{aligned}}$$

- **Natural equations / principal theorem:**
  »If the curvatures $U_k(s)$ and tangent components $V_k(s)$ are given as functions of the reference arc length, the curve and its frame are determined up to a rigid body motion!«

Ref.: Antman (1974, 2005)

Basic Cosserat rod kinematics: invariant strain measures



- **Transverse shear & extension / dilation:**

$$\boxed{\partial_S \boldsymbol{\varphi}(s,t) \;=\; V_k(s,t)\,\mathbf{a}^{(k)}(s,t)}$$

  - Transverse shearing: $V_\alpha = \mathbf{a}^{(\alpha)} \cdot \partial_S \boldsymbol{\varphi},\ |V_\alpha| \approx 0$
  - Extension / dilatation: $V_3 = \mathbf{a}^{(3)} \cdot \partial_S \boldsymbol{\varphi},\ V_3 \approx 1$

- **Curvature & twist:**

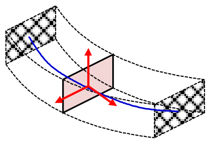
$$\boxed{\partial_S \mathbf{a}^{(k)}(s,t) \;=\; \mathbf{u}(s,t) \times \mathbf{a}^{(k)}(s,t)}$$

  - Darboux vector: $\mathbf{u}(s,t) = U_k(s,t)\,\mathbf{a}^{(k)}(s,t) = \hat{\mathbf{R}}(s,t)\cdot\mathbf{U}(s,t)$
  - Bending curvatures: $U_\alpha = \mathbf{a}^{(\alpha)} \cdot \mathbf{u} = \mathbf{a}^{(\alpha)} \cdot \left(\mathbf{a}^{(3)} \times \partial_S \mathbf{a}^{(3)}\right)$
  - Twisting curvature: $U_3 = \mathbf{a}^{(3)} \cdot \mathbf{u} = \mathbf{a}^{(2)} \cdot \partial_S \mathbf{a}^{(1)} = -\mathbf{a}^{(1)} \cdot \partial_S \mathbf{a}^{(2)}$

- **Reference strain measures:** $\boxed{\mathbf{V}_0(s) = (0,0,1)^T,\ \mathbf{U}_0(s) = \hat{\mathbf{R}}_0^T(s)\cdot\mathbf{u}_0(s)}$

Ref.: Simo (1985)
Antman (2005)

Cosserat rod: Mechanical energy



- **Kinetic energy:**

$$\boxed{W_{kin}^{(CR)} = \int_0^L ds\,\tfrac{1}{2}\rho_0\left[A(\partial_t\varphi)^2 + I_k\Omega_k^2\right]}$$

$$\partial_t \mathbf{a}^{(k)}(s,t) = \boldsymbol{\omega}(s,t) \times \mathbf{a}^{(k)}(s,t)$$
$$\boldsymbol{\omega}(s,t) = \Omega_k(s,t)\,\mathbf{a}^{(k)}(s,t)$$
$$\Omega_k(s,t) = \boldsymbol{\omega}(s,t) \bullet \mathbf{a}^{(k)}(s,t)$$

- **Elastic energy:**

$$\boxed{W_{el}^{(CR)} = \int_0^L ds\,\tfrac{1}{2}\left[\Delta\mathbf{V}\cdot\hat{\mathbb{C}}_F\cdot\Delta\mathbf{V} + \Delta\mathbf{U}\cdot\hat{\mathbb{C}}_M\cdot\Delta\mathbf{U}\right]}$$

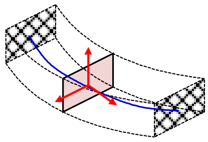
  - Change in the vectorial strain measures:

$$\Delta\mathbf{U}(s,t) := \mathbf{U}(s,t) - \mathbf{U}_0(s)\ ,\quad \Delta\mathbf{V}(s,t) := \mathbf{V}(s,t) - (0,0,1)^T$$

  - Effective stiffness matrices (← homogeneous, isotropic material):

$$\hat{\mathbb{C}}_F = \mathrm{diag}(GA_1, GA_2, EA),\ \hat{\mathbb{C}}_M = \mathrm{diag}(EI_1, EI_2, GJ_T)$$

Cosserat rod: Viscous stress power



- **Dissipation function for Kelvin-Voigt damping:**

$$\boxed{D_{KV}^{(CR)} = \int_0^L ds\ \tfrac{1}{2}\left[\partial_t \mathbf{V}\cdot\hat{\mathbb{V}}_F\cdot\partial_t\mathbf{V} + \partial_t\mathbf{U}\cdot\hat{\mathbb{V}}_F\cdot\partial_t\mathbf{U}\right] = \tfrac{1}{2}P_{visc}^{(CR)}}$$

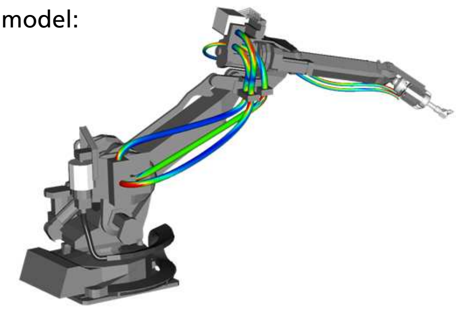
  - Effective viscosity matrices / damping parameters:

$$\hat{\mathbb{V}}_F = \mathrm{diag}\,(\eta A_1, \eta A_2, \eta_E A) \ = \hat{\mathbb{C}}_F \cdot \mathrm{diag}\,(\tau_S, \tau_S, \tau_E)$$
$$\hat{\mathbb{V}}_M = \mathrm{diag}\,(\eta_E I_1, \eta_E I_2, \eta J_T) = \hat{\mathbb{C}}_M \cdot \mathrm{diag}\,(\tau_E, \tau_E, \tau_S)$$

  - Shear & bulk retardation times: $\tau_S = \eta \,/\, G,\ \tau_B = \zeta \,/\, K$
  - Extensional viscosity: $\eta_E = \zeta(1-2\nu)^2 + \tfrac{4}{3}\eta(1+\nu)^2$
  - Extensional retardation time: $\tau_E = \eta_E \,/\, E = \tfrac{1}{3}[(1-2\nu)\tau_B + 2(1+\nu)\tau_S]$

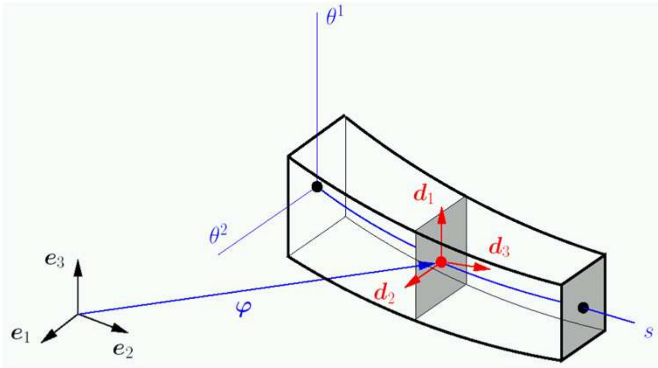
- **Balance of mechanical energy:** $\boxed{\dfrac{d}{dt}\left[W_{kin}^{(CR)} + W_{el}^{(CR)}\right] \ = \ -P_{visc}^{(CR)}}$

Application demands on the *discrete* rod model



- Requirements for the discrete cable model:
  - (sufficiently) *correct mechanics* …
  - … **as fast as possible !!!**
  - … suitable for fast simulations *»at interactive rates«*
  - Compute cable deformations within a few *milliseconds* !
  - ⇒ The discrete model has to work with **as few d.o.f. as possible!**
- The **»Geometric Finite Differences«** approach to the discretization of Cosserat rod models:
  - **D**iscrete **D**ifferential **G**eometry (DDG) of framed curves
  - *Discretization* of the differential invariants that are *qualitatively correct for arbitrarily coarse meshes!*

Quaternionic Cosserat rods: Euler parametrization of SO(3)



Euler parametrisation:

$$\left(d_1(p) \mid d_2(p) \right) = \left(\begin{array}{c|c} p_0^2+p_1^2-p_2^2-p_3^2 & -2p_0p_3+2p_1p_2 \\ 2p_0p_3+2p_1p_2 & p_0^2-p_1^2+p_2^2-p_3^2 \\ -2p_0p_2+2p_1p_3 & 2p_0p_1+2p_2p_3 \end{array} \right) \quad p=(p_0,p_1,p_2,p_3)\in\mathbb{H},\ |p|=1$$

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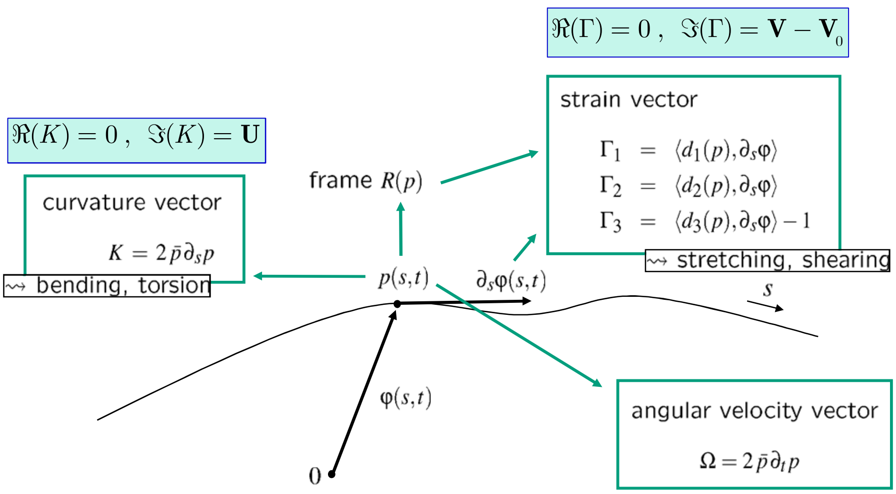
Quaternionic Cosserat rods: strain measures



Ref.: *Lang / Linn* (2008),
Zupan / Saje / Zupan (2008)

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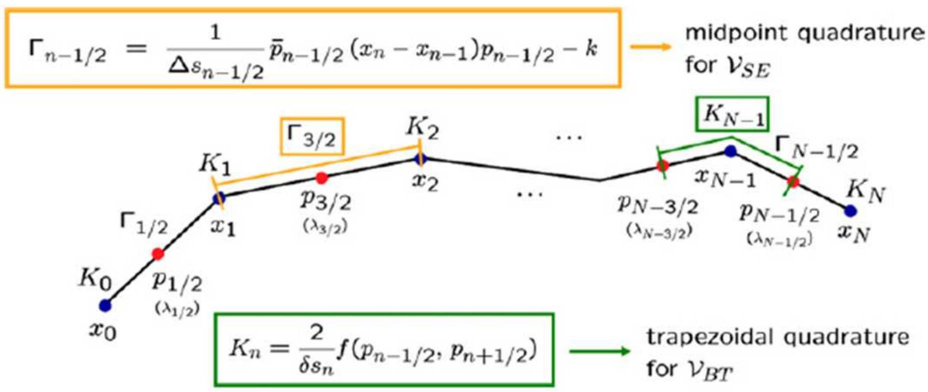
Discrete quaternionic Cosserat rods

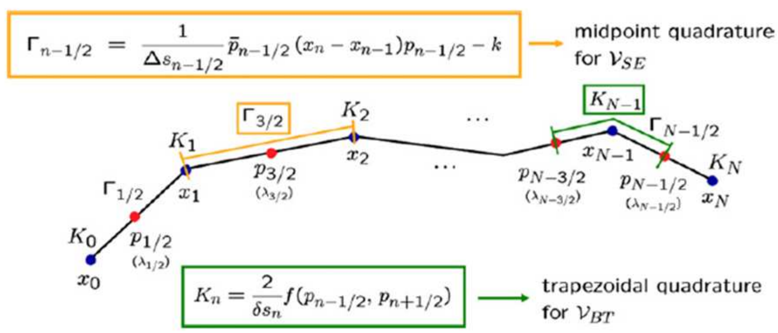
H. Lang, M. Arnold / Applied Numerical Mathematics 62 (2012) 1411–1427



Ref.: *Lang/Linn/Arnold* (2009, 2011), Lang/Arnold (2009, 2011)

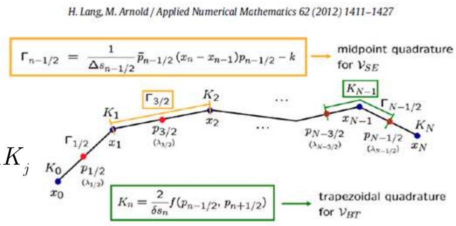
Discrete differential geometry of Cosserat curves

H. Lang, M. Arnold / Applied Numerical Mathematics 62 (2012) 1411–1427



Principal theorem of the DDG of framed curves:
»If the discrete curvatures K_n and discrete shear strains $\Gamma_{n-½}$ are given, the discrete curve and its quaternionic frame are determined up to a rigid body motion!«

Discrete Cosserat rod model: Energy & dissipation function



- **Discrete elastic energy:**

$$W_{el}^{(CR)} \approx \tfrac{1}{2}\sum_{j=1}^{N} \Delta s_j \, \Gamma_{j-1/2} \cdot \hat{\mathbb{C}}_F \cdot \Gamma_{j-1/2}$$
$$+ \tfrac{1}{2}\sum_{j=0}^{N} \tfrac{1}{2}(\Delta s_j + \Delta s_{j+1}) \Delta K_j \cdot \hat{\mathbb{C}}_M \cdot \Delta K_j$$

- **Discrete kinetic energy:**

$$W_{kin}^{(CR)} \approx \tfrac{1}{2}\sum_{j=0}^{N} \tfrac{1}{2}(\Delta s_j + \Delta s_{j+1}) \rho_j A_j \left\|\dot{\mathbf{x}}_j\right\|^2 + \tfrac{1}{2}\sum_{j=1}^{N} \Delta s_j \, \Omega_{j-1/2} \cdot \rho_j \hat{\mathbb{I}}_j \cdot \Omega_{j-1/2}$$

- **Discrete dissipation potential:**

$$\Omega_{j-1/2} = 2\overline{p}_{j-1/2}\dot{p}_{j-1/2}$$

$$D_{KV}^{(CR)} \approx \tfrac{1}{2}\sum_{j=1}^{N} \Delta s_j \, \dot{\Gamma}_{j-1/2} \cdot \hat{\mathbb{V}}_F \cdot \dot{\Gamma}_{j-1/2}$$
$$+ \tfrac{1}{2}\sum_{j=0}^{N} \tfrac{1}{2}(\Delta s_j + \Delta s_{j+1}) \Delta \dot{K}_j \cdot \hat{\mathbb{V}}_F \cdot \Delta \dot{K}_j$$

- … with boundary terms (*j=0, j=N*) adapted to the discrete approx. b.c.
- … and additional terms accounting for external forces & moments

flex structures

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Discrete Cosserat rod model: dynamic equilibrium equations

DYNAMICS

Lagrange function $L = T - V - g^T\lambda$
Potential energy V
Kinetic energy T
Dissipative energy D
Constraints $g = \|p\|^2 - 1$
Exterior forces $\hat{f}$ & moments $\hat{m}$

$q = (x, p)$

Euler-Lagrange equations

DAE-system
order one
index three

$$\begin{cases} \dot{q} &= v \\ M(q)\dot{v} &= \psi(q,v,t) - G(q)^T\lambda \\ 0 &= g(q) \end{cases}$$

Quasistatic equilibrium:
→ solve discrete eqns. for

$$\dot{q} = 0 = \ddot{q}$$

$$\psi(q,v,t) = \begin{pmatrix} \hat{f} \\ \hat{m} \end{pmatrix} - \frac{\partial V}{\partial q} - \frac{\partial D}{\partial v} + \frac{\partial T}{\partial q} - \frac{\partial}{\partial q}(Mv)v$$

$$G(q) = \nabla g(q)$$

Discrete Kirchhoff constraints (→ Lang&Arnold, 2009-2011):
→ zero transverse shear (and / or extensional) strains

flex structures

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11

Simulation based design, assembly and validation of cables, hoses and wiring harness

Technology development by dedicated groups of experts at ITWM and FCC since 2005

- **based on geometricly nonlinear beam theory**
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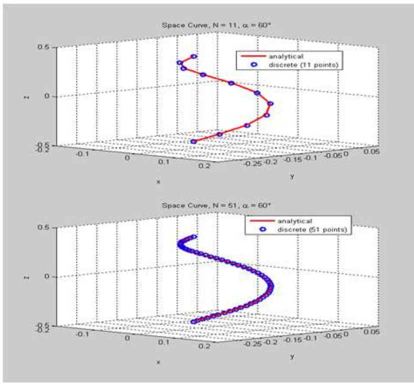

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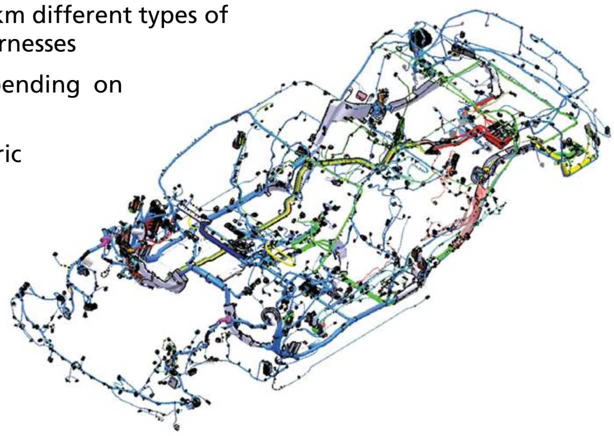
Simulation based design, assembly and validation of cables, hoses and wiring harness

Flexible parts in cars / Electrical System

- between 1 and 3.5 km different types of wires and wiring harnesses
- 60 kg and more depending on configuration
- even more for electric drivelines and hybrid cars



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Design, assembly and validation with IPS Cable Simulation

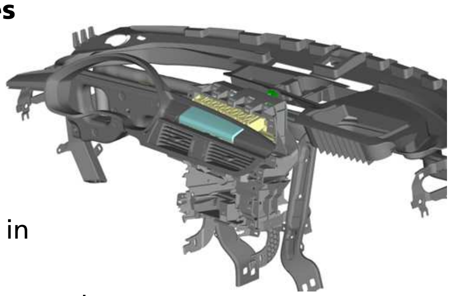
application focus: CAD, digital assembly and digital validation

modeling options, features and benefits

- interactive simulation
- cables and hoses, including non-circular cross sections
- junctions and branches
- car wire harness including various types of clips
- free hanging cable ends with plugs and connectors
- fixtures and clips (also handling the geometric shape)
- collision handling (cable to rigid and cable to cable)
- automatic flexibilization of CAD-defined cables
- huge variety of analysis and post-processing options

Example (AUDI): Assembly of retractable display in cockpit

3 project steps involving wires



- Assembly simulation of display in cockpit
- Assembly sequence of connectors and variation of clip types
- Functional reliability test and redesign of mount

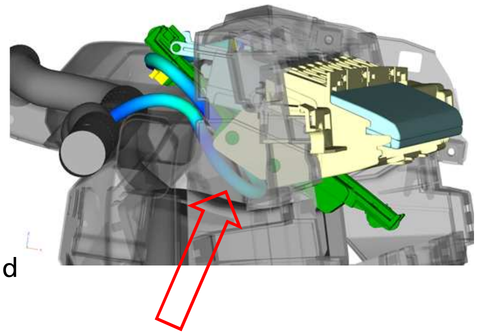
Assembly simulation of display in cockpit

Situation

- Assembly may cause buckling and clamping

Objectives

- Optimize length for robust and fast assembly
- Minimize length to save cost and reduce weight



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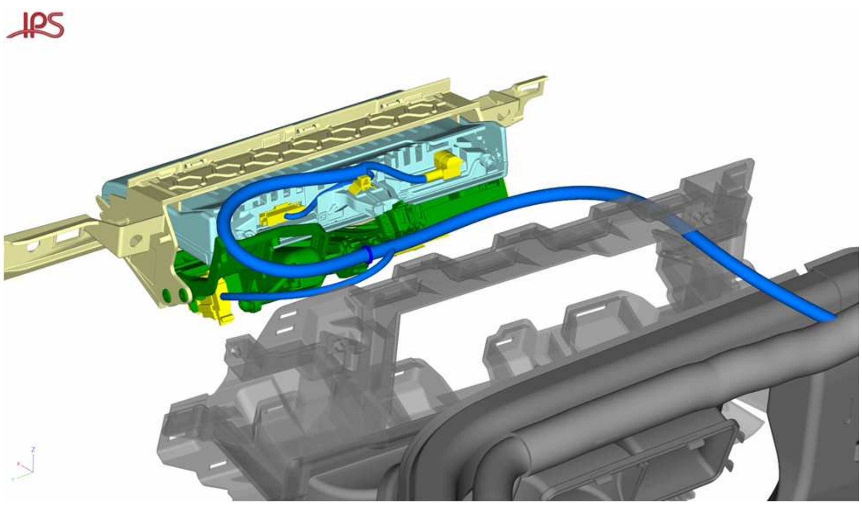
Real-time simulation of Cable with overlength



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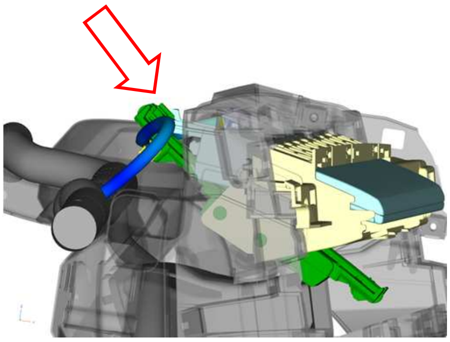
Assembly simulation of display in cockpit

Conflicting objectives:

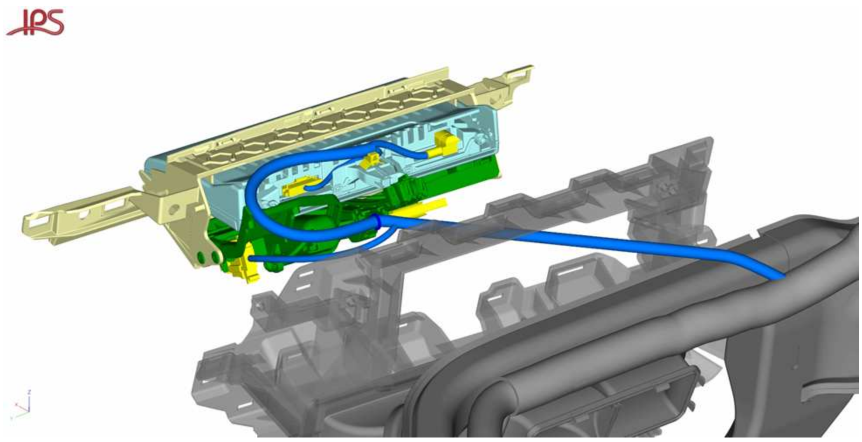
- Ease of installation
  -> longer cable
- Reduction of buckling risk
  -> shorter cable



Result

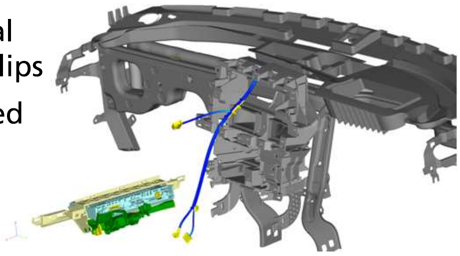
- Cable length reduced by 80 mm
- No clamping and
  sufficient clearance for manual assembly

Assembly optimized cable length (80mm shorter)



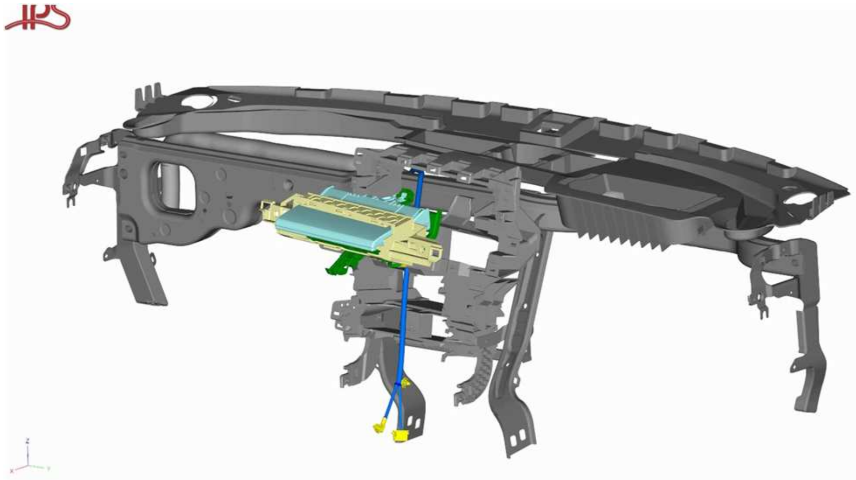
Assembly of connectors and variation of clip

Situation
- Reduced clearance for manual assembly of connectors and clips
- Last clip could not be mounted correctly

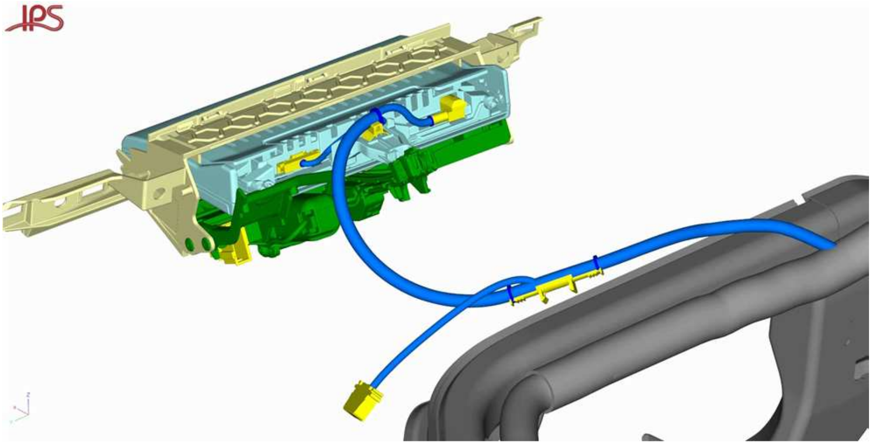


Objectives
- Keep length and change clip to reduce load and bending radius
- Check assembly sequence

Assembly simulation of connectors and clips



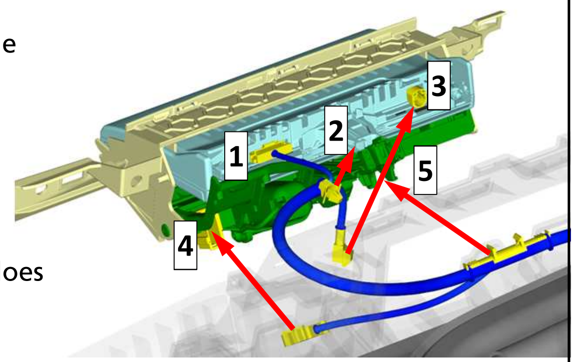
Assembly simulation of connectors and clips



Assembly of connectors and clip

Result

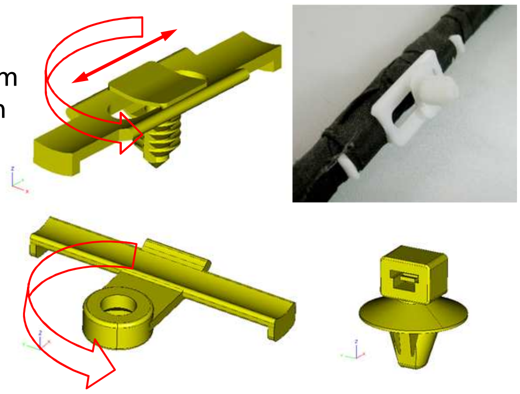
- Bending radius and tensile stress OK
- Clearance OK for manual installation
- Wires must be installed without crossing
- 180° rotation of display does not cause damage



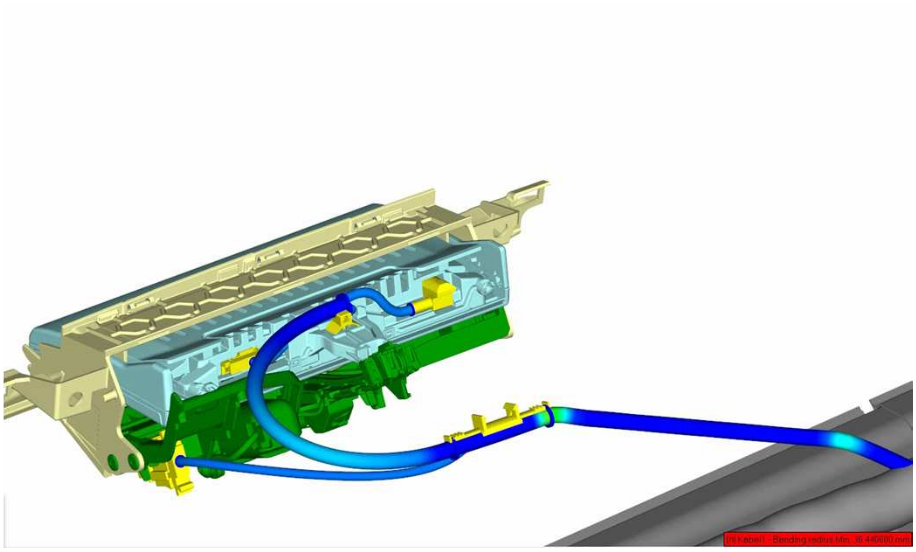
Variation of clip type

Custom clips from database

- Various clip types with different degrees of freedom are applicable with cables in real-time
- Plug and play
- Realistic look
- Insert from database



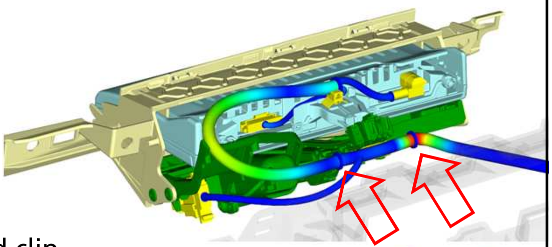
Variation of clip type

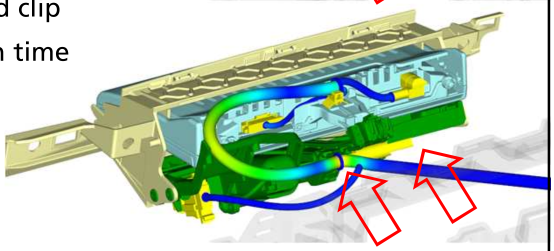


Variation of clip type

Result

- Best result achieved by opening one connection
- Bending radius OK
- Lower tension on wires and clip
- Shorter manual installation time
- No risk of damage





flеX structures Fraunhofer ITWM

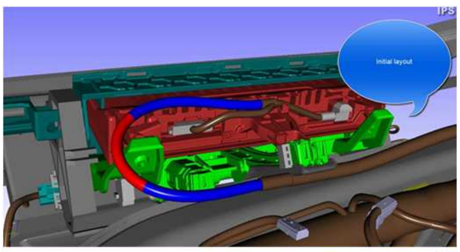
Functional reliability and redesign of mount part

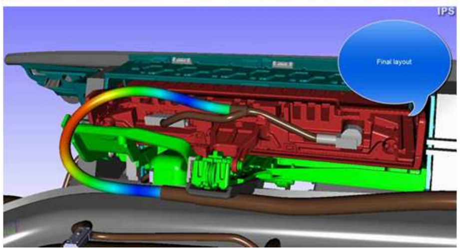
Situation

- Signal cable damaged during test
- Bending radius, acting forces and stresses could not be determined easily

Objectives

- Find root cause & redesign





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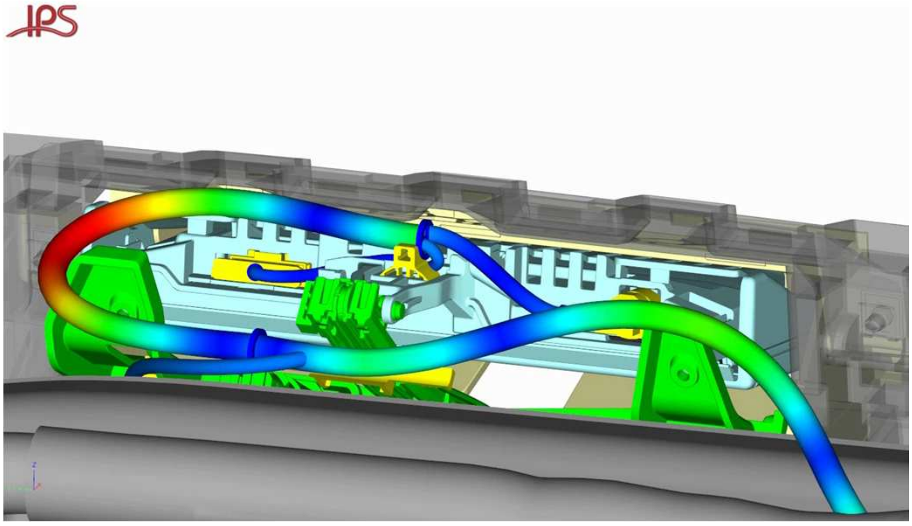
Functional reliability and redesign of mount part



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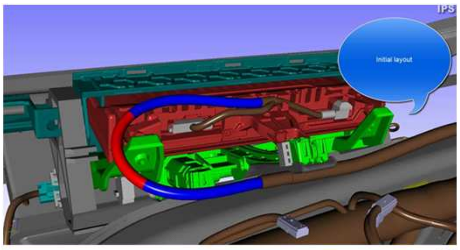
Functional reliability and redesign of mount part

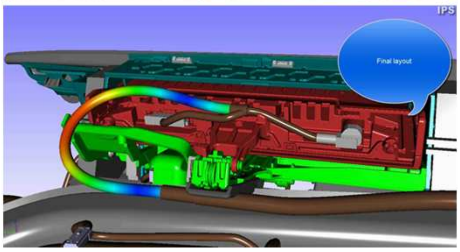
Result

- Root cause detected and shape of mount part redesigned
- Bending radius OK -> no damage

Advantage

- Product quality assured with efficient time saving process
- Cost reduction by saving prototypes





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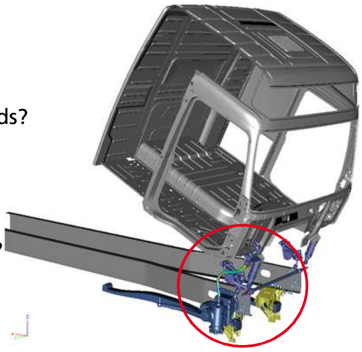
Application case (Volvo):
Design of hydraulic hoses at a driving cab of a truck

Cab moves relative to the chassis at tilting.

Tasks:

- Finding the ideal length of the hose.
- Is the designed space sufficient and can an assembly be performed?
- Where and how have the hoses to be fixed and/or bundled by setting clips of various kinds?
- Will the minimal bending radius be violated?
- Is there collision to other parts?
- What is the load on hoses that are assembled between relative to each other moving parts?
- What is the impact of an incorrect assembly (e. g. rotation of the connections)?



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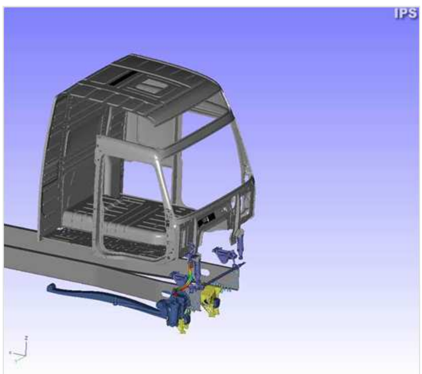
Application case:
Design of hydraulic hoses at a driving cab of a truck (@ Volvo)

- **Simulative approach:**
  - Interactive tilting of the cab includ-ing the assembled flexible hose.
  - Determination of the point in time where the highest load occurs.
  - For this point in time vary the length of the hose either manually or automatically.
  - Determination of the optimal length of the hose by using several analyze features.
  - Analysis by stresses, deformations, designed space, position(s) and type(s) of clip(s), bending radius, rotation of connections, …



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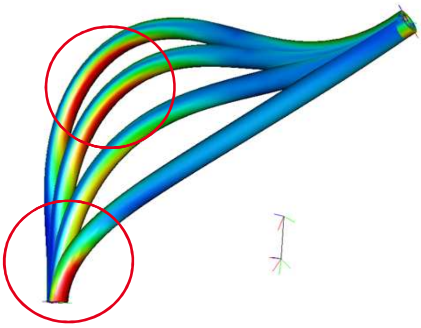
Application case:
Design of hydraulic hoses at a driving cab of a truck (@ Volvo)

- **Analyzed variants without clips:**
  - Shortest hose 630 mm
  - Longest hose 900 mm
  - All variants between 630 and 900 mm (by an increment of 1 mm) in worst-case position
- **Analysis of von Mises stresses:**
  - Maximum values differ over different lengths.
  - Area, where max. load occurs, changes
  - Optimal length of hose (without clips) is at approx. 700 mm



Exemplary plotted variants of length 630 mm, 700 mm, 800 mm, 900 mm

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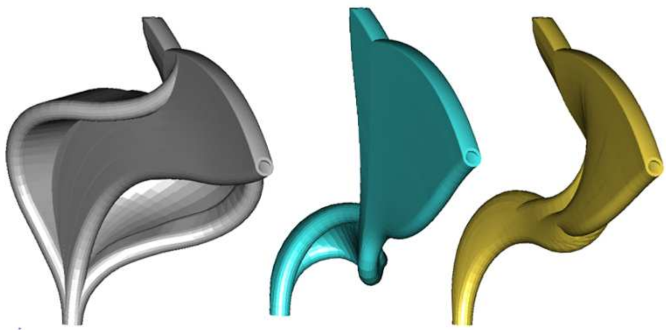
Application case:
Design of hydraulic hoses at a driving cab of a truck (@ Volvo)

Comparison of the designed space for different clamping and identical hose length of 700 mm:



grey: hose without clamping — *blue: fixed clamping* — *yellow: guided clamping, sliding and rotation allowed*

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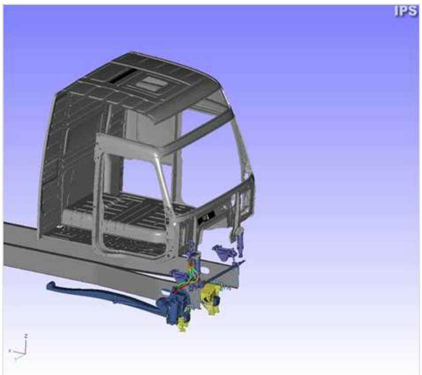
Application case:
Design of hydraulic hoses at a driving cab of a truck (@ Volvo)

- **Results:**
  - Optimal length of hoses for the actual loads during operation.
  - Original hose design could be optimized by 85 cm.
  - Ideal assembly position and type of clamping were determined.
  - Material loads and the necessary designed space could be reduced.



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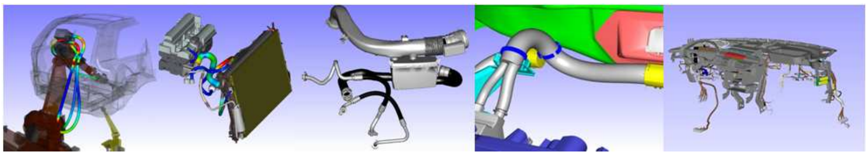
IPS Cable Simulation - Workflow



- Import geometry
- Define and create the cable
- Connect the cable(s) / hose(s)
- Analyze motion and loads
- Export geometry and results

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IPS Cable Simulation

Customers / references:

- AUDI
- Bosch
- BMW
- Daimler
- Delphi
- EADS / Cassidian
- FORD
- Fujikura
- GM
- Liebherr
- OPEL
- Saab
- SCANIA
- SEAT
- Stihl
- Volkswagen
- Volvo AB (Truck & CE)
- Volvo Car

IPS Cable Simulation

Technology development: Beyond own funding out of licence income our development is supported by public funding and specific method development projects financed by industry partners.

Public funding partners include

- VINNOVA (Sweden)
- BMBF
- EU and Rheinland-Pfalz (Fraunhofer Innovation Cluster)
- Fraunhofer Vorlaufforschung

Industry partners involved in method development projects

- Main partners since phase 1 – since 2005:
  Volvo, GM, Ford, Delphi, Scania, Saab,…
- Main partners since phase 2 / since 2010:
  AUDI, VW, **Daimler,** Bosch, BMW, Toyota, Stihl, Liebherr,…

Simulation based design, assembly and validation of cables, hoses and wiring harness

Summary

- IPS Cable Simulation provides leading technology for design, digital assembly and digital validation of cables, hoses and wiring harness, incl.:
  - interactive simulation of cables and hoses, incl. non-circular cross sections
  - car wire harness, incl. junctions, branches and various types of fixtures and clips
  - free hanging cable ends with plugs and connectors
  - collision handling (cable to rigid and cable to cable)
  - huge variety of analysis and post-processing options
  - Simulation of shell based structures (under development)