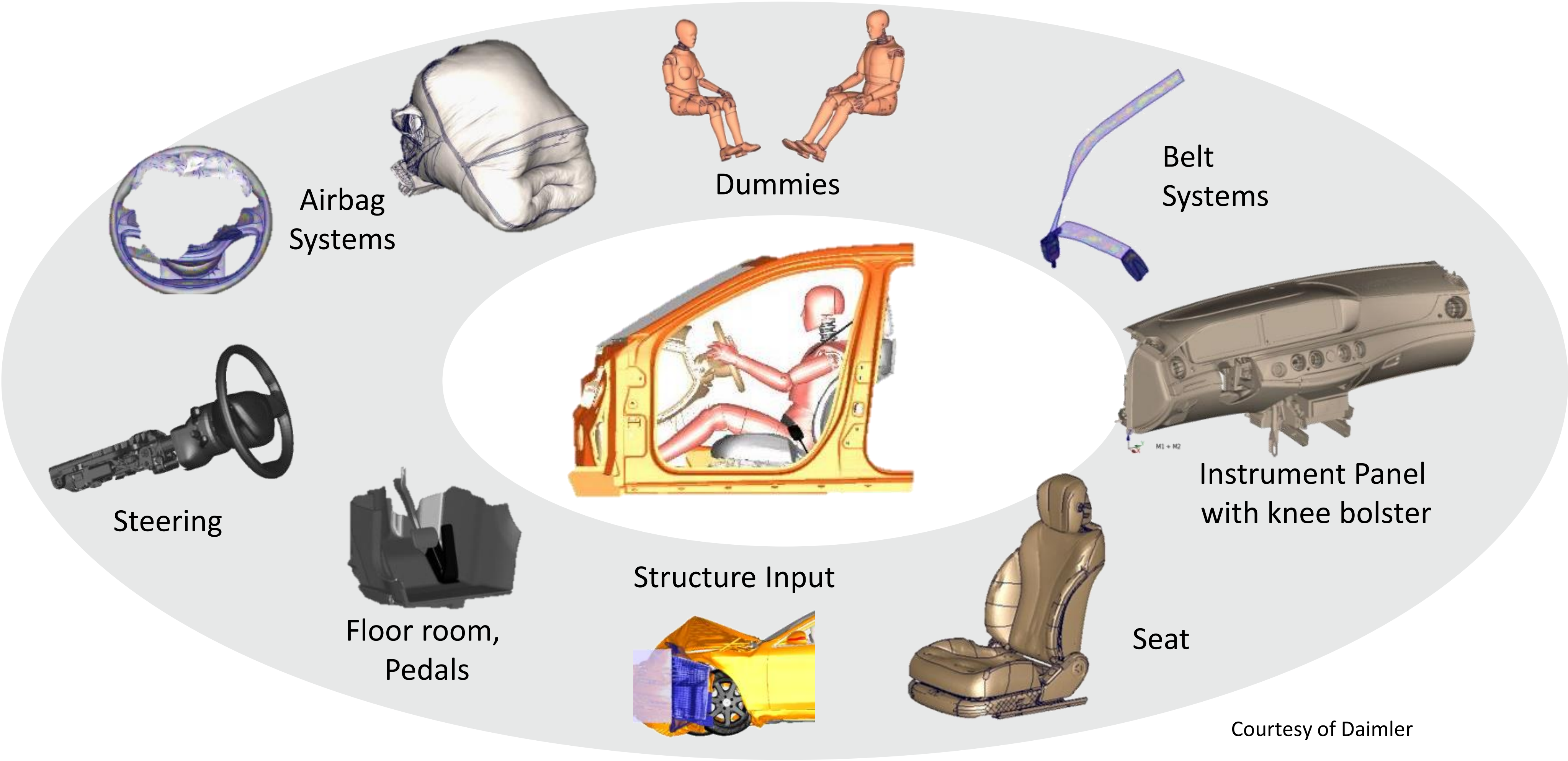
Powering Innovation That Drives Human Advancement

Modeling of Restraint Systems in LS-DYNA
LS-DYNA中车辆约束系统建模

Sheng Dong, Sebastian Stahlschmidt, Ercan Usta, Steffen Mattern

Components in Frontal Occupant Safety Simulations



Courtesy of Daimler

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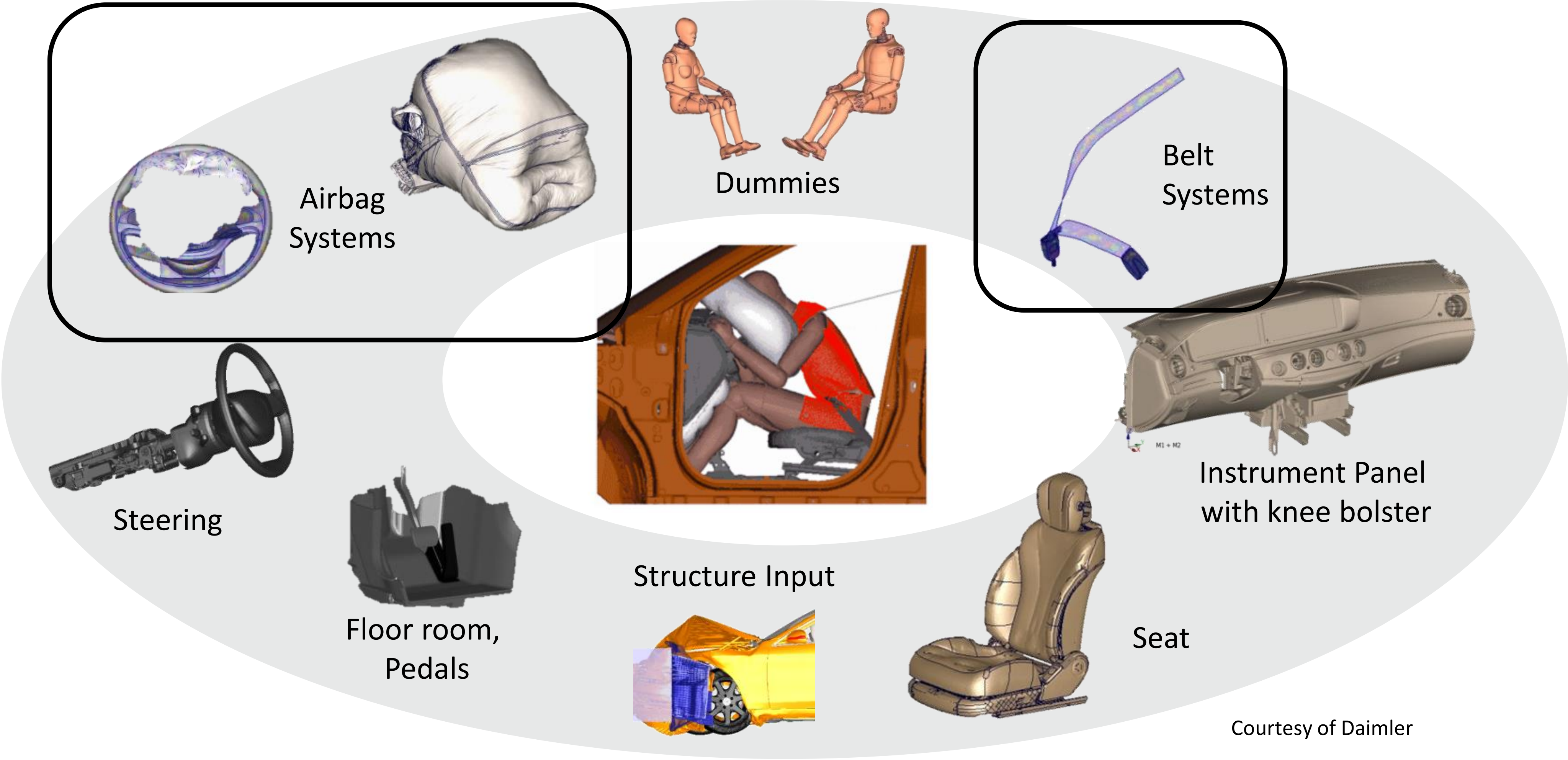
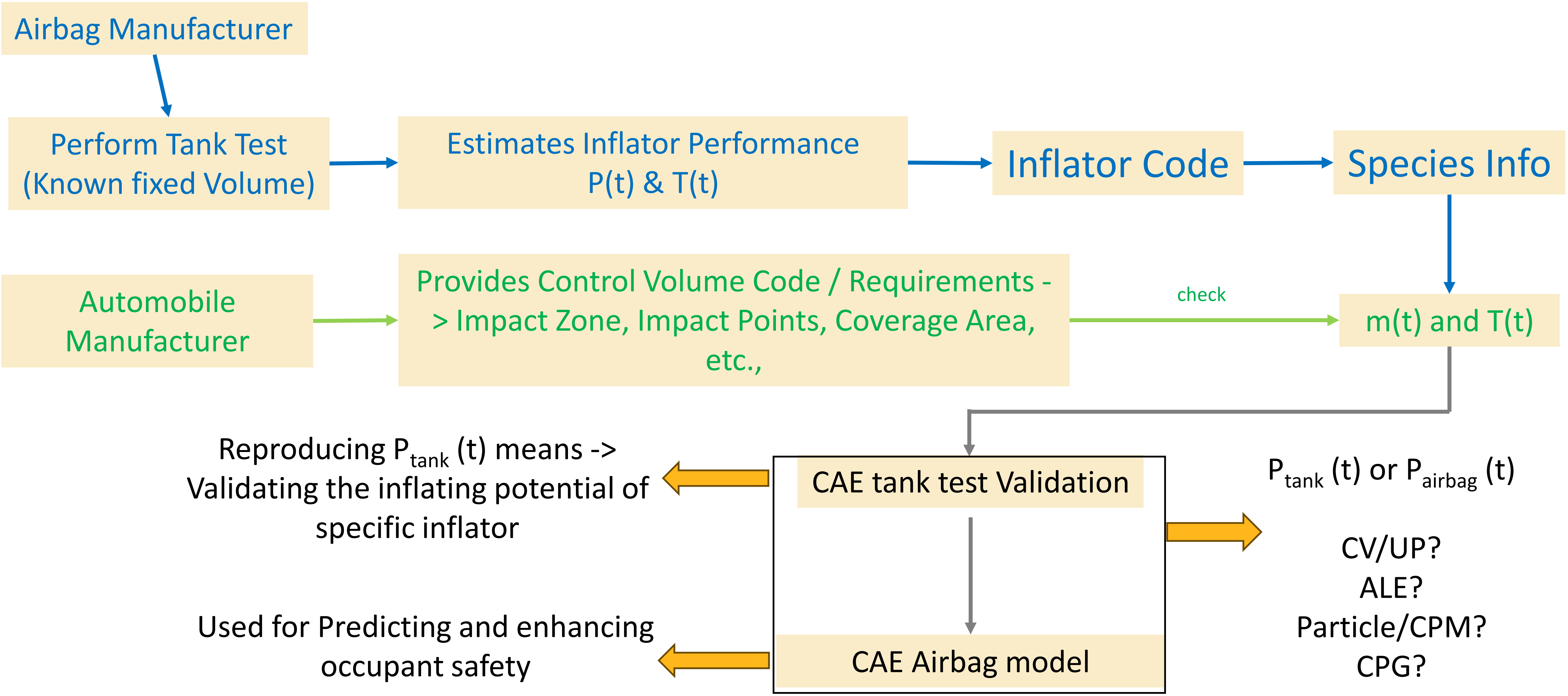


Courtesy of Daimler

Motivation – Modeling airbags in LS-DYNA

- Airbag deployment has been a difficult problem to simulate from the start.
- In the last 20 years, airbags have evolved and complexified dramatically
  - Driver, side, passenger, knee, center, etc.
  - Important aspects to capture
    - Gas flow through narrow gaps
    - Interaction with internal structures (flow redirections)
    - Correct gas flow around vents
    - Flow across different chambers
- Computational resources have increased significantly

Airbag Modelling Process



Uniform Pressure (UP) Method

<u>Uniform Pressure method</u>: [Late 80s]

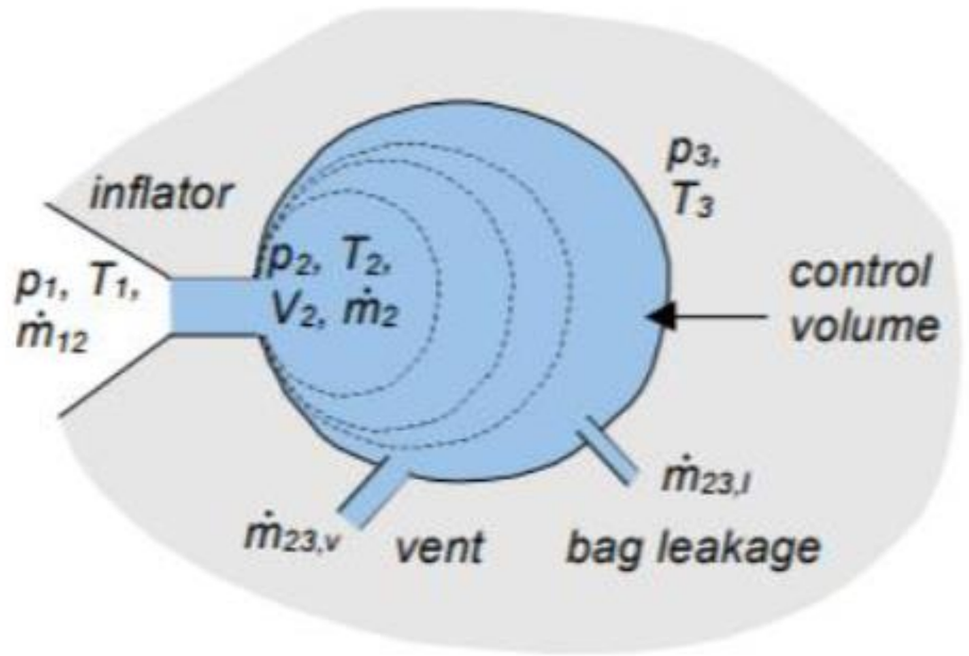
- Uniform pressure distribution is assumed
- Application of forces perpendicular to the defined airbag surfaces
- There is no discretization of the fluid flow
- Concept is based upon scalar thermodynamic equations
- Pressure is applied normal to the airbag fabric
- Widely used for side and front-crash simulations
- Opening of airbag can be tuned using airbag interaction keyword

Advantages:

- Numerically cheap and robust method
- Airbag definition is quite simple

Disadvantages:

- Flow simulation is not exact in the first few milliseconds
  → Not reliable in Out-of-position (OOP) situations
- Validation of the complete airbag model
  (Bag + Inflator) necessary



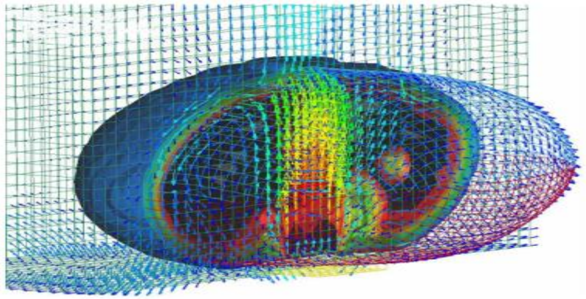
$$\dot{E}_{in} = \dot{m}_{in}\, c_p\, T_{in}$$

$\dot{E}_{in}$ → Energy into airbag by mass flow (inflator)

$\dot{E}_{out}$ → Energy out of airbag by mass flow (vents, leakage)

$$\dot{E} = \dot{E}_{in} - \dot{E}_{out} - p\,\dot{V}$$

Arbitrary Lagrangian-Eulerian (ALE) Method



<u>ALE method:</u> [Early 2000s]

- Fluid flow is discretized
- Exact simulation of flow through computational fluid dynamics approach thus additional Eulerian mesh is needed
- Pressure on the airbag fabric is built up by Fluid-Structure-Interaction

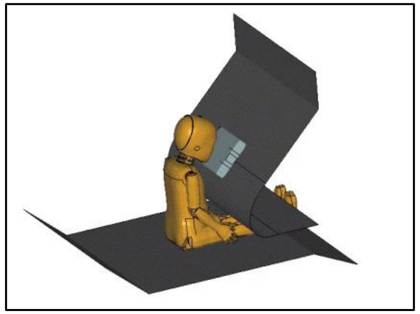
Advantages:

- Exact simulation of flow, thus realistic behavior also in the first ms
- Exact pressure distribution inside bag
- Produces good results for out-of-position situations
- Enhanced post-processing capabilities

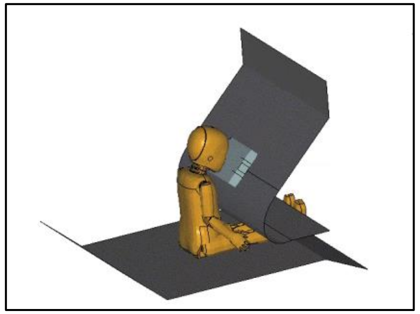
Disadvantages:

- Relatively complex method
- Airbag definition is cumbersome
- Computationally expensive
- Difficulties faced at airbag folds and fabric-fabric contact and leakages

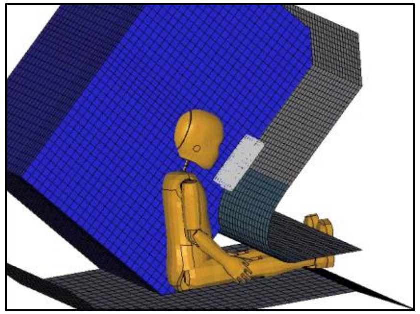
Out-of-position simulation -> 3 years old child



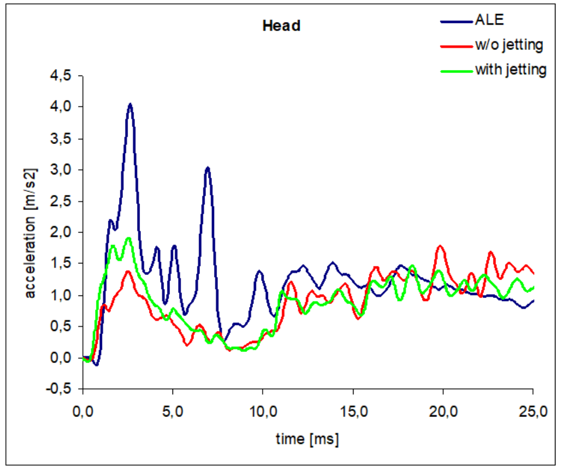
Uniform Pressure

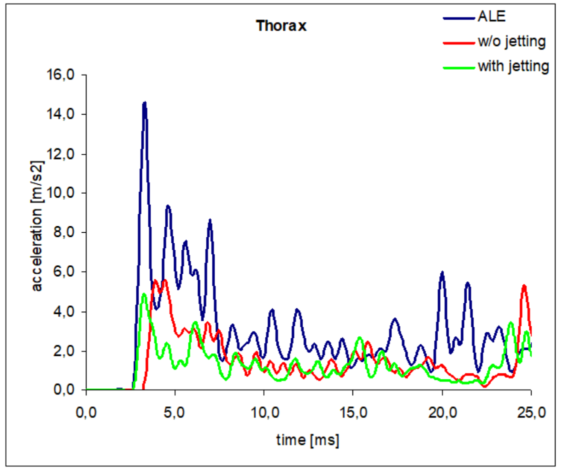


Uniform Pressure with jetting

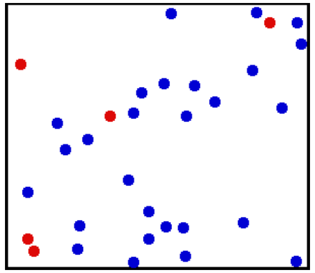


ALE





Corpuscular Particle (CPM) Method

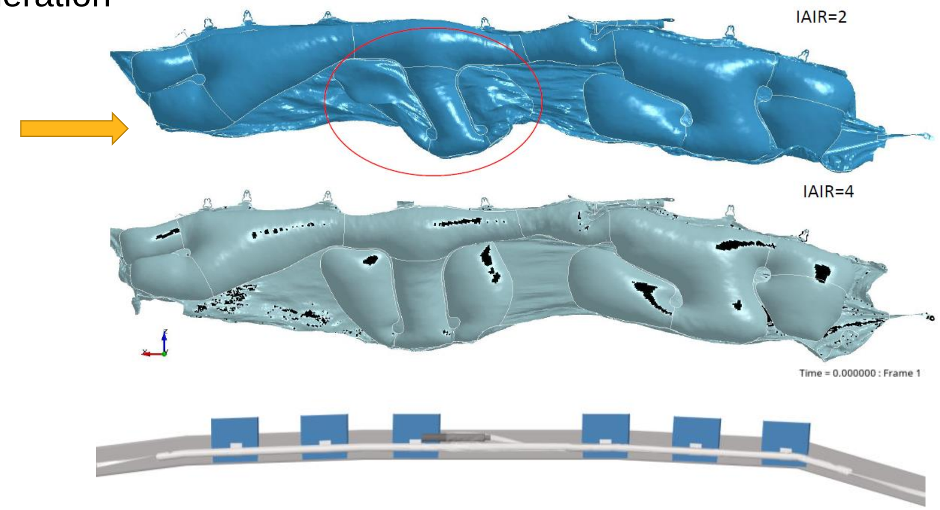


CPM method: [2003]

- The corpuscular method in LS-DYNA is based on the kinetic molecular theory.
- System is reduced, many molecules to few particles each particle represents many molecules.
- The particles are spherical in shape for efficient treatment of contact.
- For each particle, a balance exists between the translational kinetic energy and the vibration/ spin energy. This balance can be determined from the heat capacities.
- Since many molecules are represented by a single particle, it leads to dispersion and the generation of noise in the pressure signal. Internal algorithm to smoothen the pressure.
- Multiple approach to model initial air trapped in airbag -> influences the opening of airbag
- Option to create chambers in CPM for complex airbag designs

Assumptions

- The average distance between molecules is large compared to their size
- Molecule-molecule and molecule-structure collisions are perfectly elastic
- Molecules obey Newton's laws of motion
- Molecules are in random motion



Advantages:

- Simple and numerically robust
- Relatively easy to convert from *AIRBAG_HYBRID cards. Options to switch to UP
- Widely used and preferred over other airbag formulations in crash simulations

Drawbacks:

- The method cannot describe the actual flow field accurately. Efforts to incorporate more options in progress …… Hits accuracy limits for complex gas flows as observed in curtain airbags, for instance

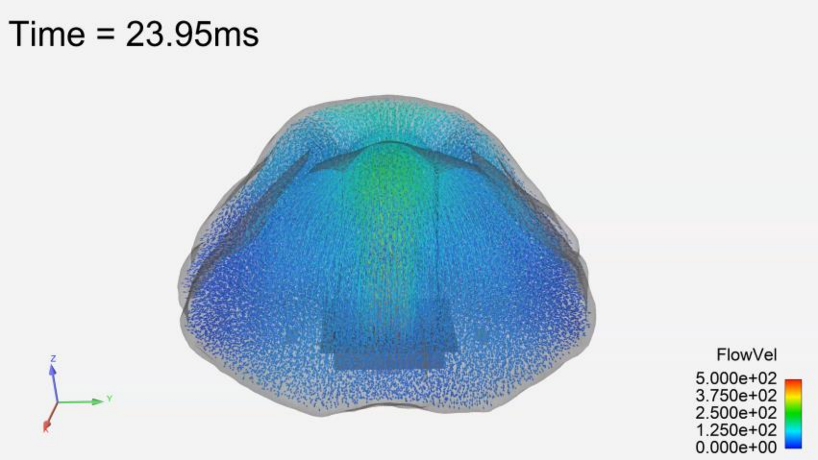
Need for a more sophisticated approach

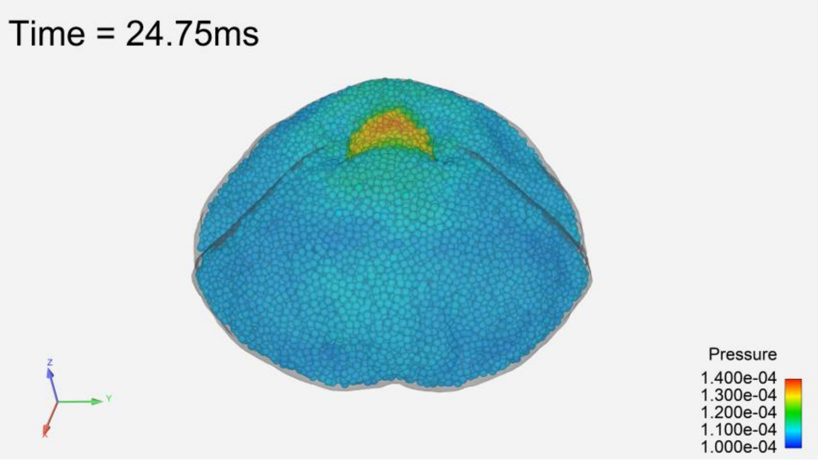
Continuum-based Particle Gas (CPG) -> A New CFD Approach

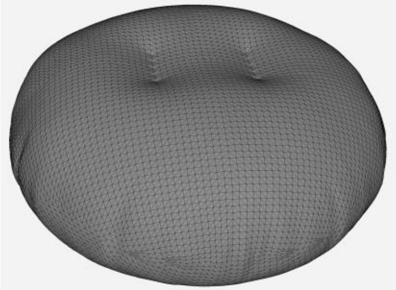
CPG method:

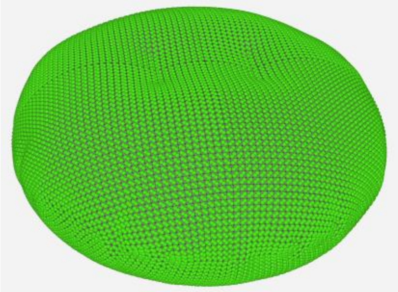
- Particle method solving Navier-Stokes equations
- Innovative CFD method particularly well-suited for airbag deployment simulations
- Superior accuracy for complex gas flows
- Validation studies with multiple partners
- Requires tank validation for tuning the Inflator orifice
- Brand new solver - First release R16
- New keyword *AIRBAG_CPG

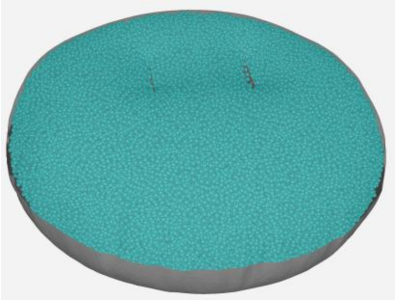
Continuum-based Particle Gas (CPG): A New Approach for Airbag Deployment Simulations — Dynalook






Airbag mesh


Gas boundary particles


Gas volume particles

- Gas boundary particles are initialized and fixed on the segments
- Gas volume particles are created/deleted by volume change

Continuum-based Particle Gas (CPG) -> A New CFD Approach

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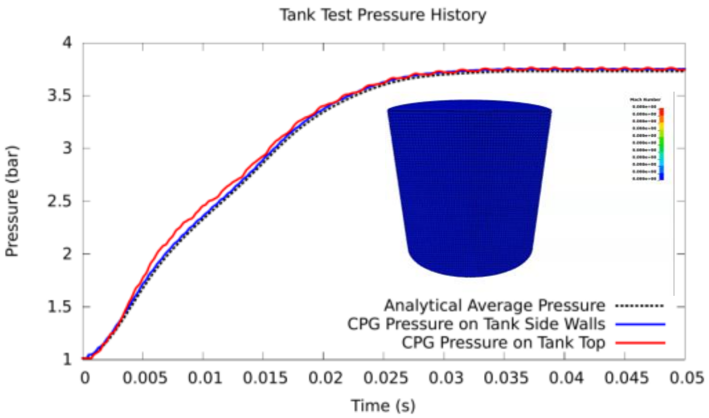
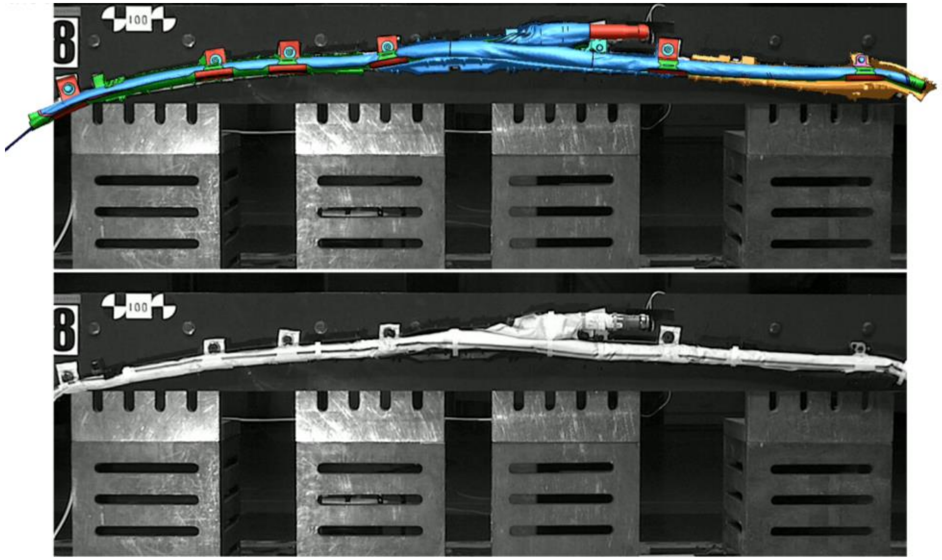
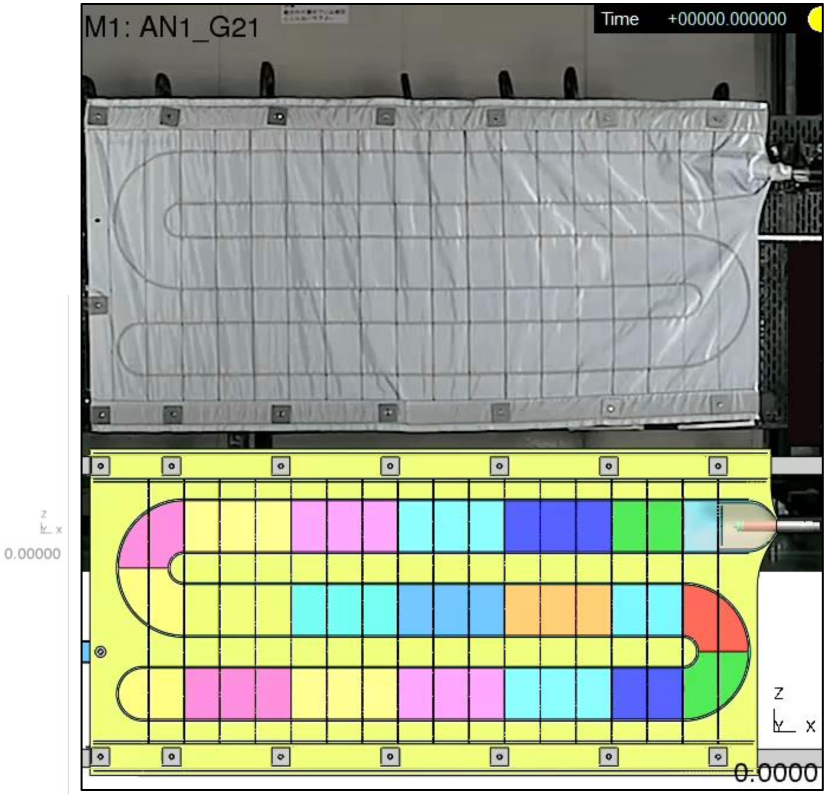






Experimental data courtesy of Toyoda Gosei Co., Ltd.
Numerical model courtesy of JSOL Corporation.

*AIRBAG_CPG keyword

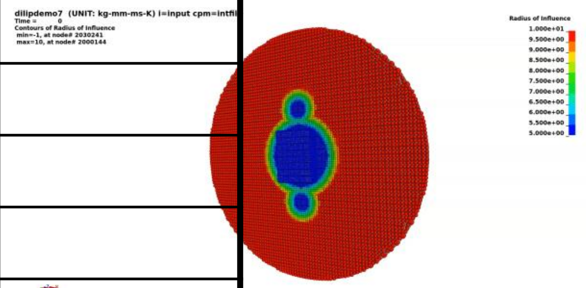
List of all airbag parts

List of internal parts

Particle size which can be locally changed with *MESH_SIZE_SHAPE

- It is recommended to keep this value at around the airbag's surface mesh size
- -ve sign in HLEN can be used for tank simulation. Solver avoids few routines required for airbags and will save simulation run time

BAGID	HEADING							
Card 1	SID1	STYPE1	SID2	STYPE2		NPDATA		
Card 2	HLEN	UNIT		TATM	PATM	NVENT		
Card 3		NGAS	NORIF	NID1	NID2	NID3		
Card 4	SIDH	STYPEH	HCONV	PFRIC				
Card 5	SID3	STYPE3		LCTC	LCPC			
Card 6	PAIR	TAIR	XMAIR	AAIR	BAIR	CAIR		
Card 7	LCMi	LCTi	XMi	Ai	Bi	Ci	INFGi	
Card 8	SSIDi				INFOi			



- Orifices are defined as shells (+ID) or shell sets (-ID) of which total area is calculated for initial boundary conditions of mass flow
- Orifice part must be defined only in SID1 even it is located within the closed volume

- Automatic HLEN-Refinement at inflator & vent regions
- Currently available only in **DEV version**
- *MESH_SIZE_SHAPE with a sphere shape defined automatically.
- Size of the sphere is computed based on the size of vent/inflator.
- Refined regions move accordingly.
- For inflator moving coordinate system through NID1-3 needed

*AIRBAG_CPG related keywords and Output

- *CONTROL_CPG
  - NPCP – number of cycles between point cloud check
  - VERB – CPG verbosity check
  - NSLIP – slip condition flag
  - ICORR – correction of density and total energy
- *DEFINE_CPG_GAS_PROPERTIES
- *INITIAL_CPG in conjunction with *DEFINE_CPG_REGION to initialize different gas properties in different regions of the domain.
- *MESH_SIZE_SHAPE to affect HLEN particle size distribution over a *DEFINE_FUNCTION for smooth transition.

Output Options

Airbag	Part
Area	Part areas
Average density	Part forces x
Average energy	Part forces y
Average pressure	Part forces z
Exact density	Part leakage
Exact energy	Part Pstat
Exact pressure	Part Ptot
Nparticles	Part Tstat
Volume	Part Ttot
Volume ratio	Part vfrate

CPG Development

Currently implemented

- Inviscid flow solver.
- CPG keyword similar to *AIRBAG_PARTICLE.
- Automatically placing particles on surfaces, refined sampling on orifice geometries, and initial volume filling.
- Inflators and associated mass flow rate and total temperature curves.
- Up to fourth-order Cp(T) curve through DEFINE_CPM_GAS_PROPERTIES.
- Good LSPP support through new flexible format.
- Validated through simple CFD benchmark tests (Adiabatic compression, Shock Tube, Flow through channel).

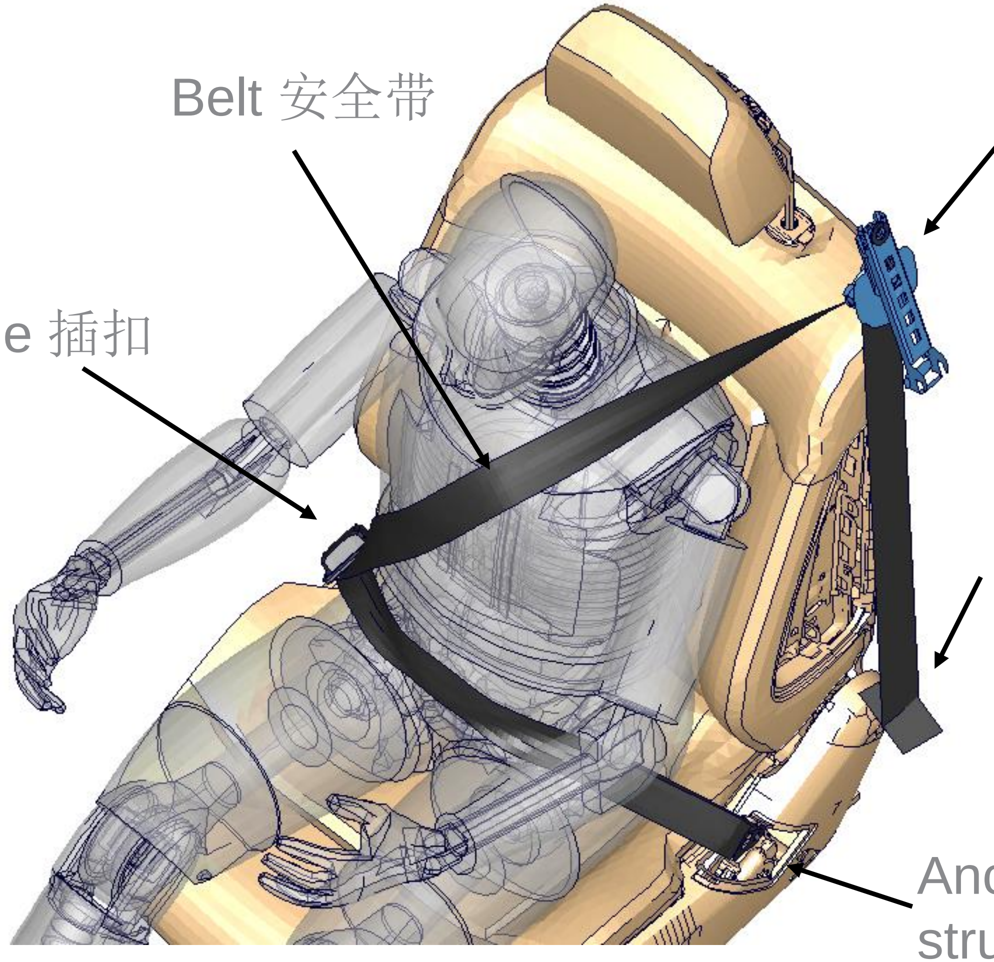
On-going and future work

- Dynamic particle sampling as domain deforms
- Multiple gas species
- Stability issues
- Vents
- Fabric and seam porosity
- Sensors and other post-processing capabilities
- Thermal coupling
- PERFORMANCE

…

All Feeback are welcome!

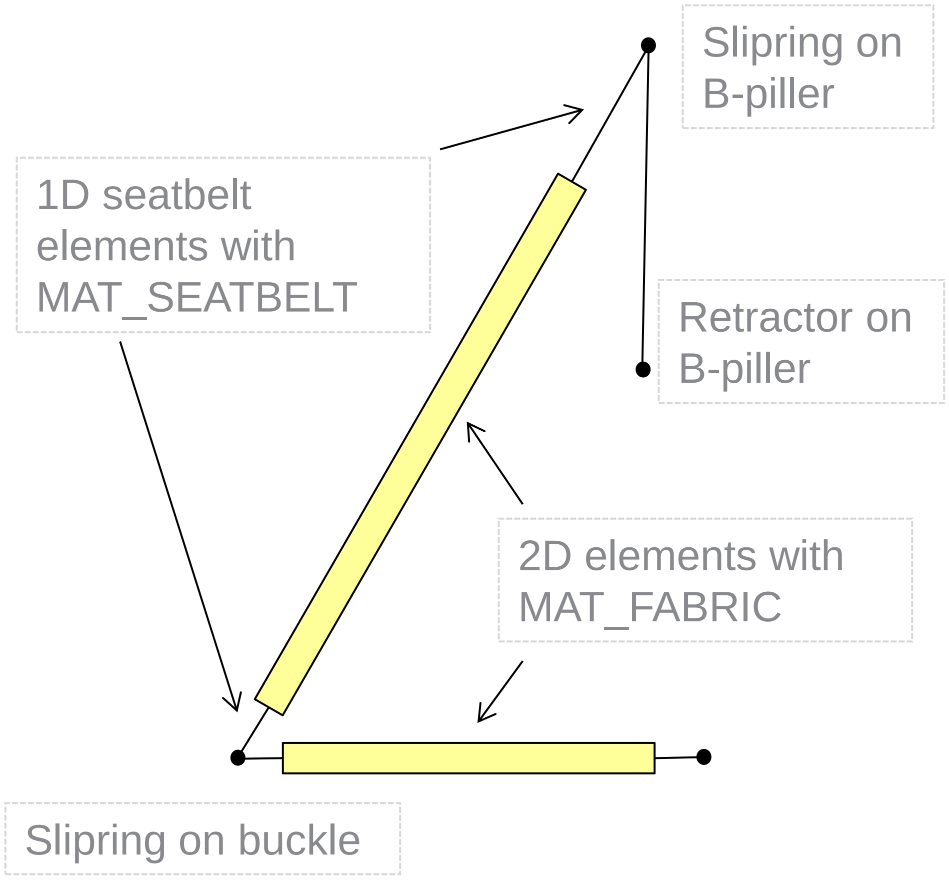
Components of a seatbelt system

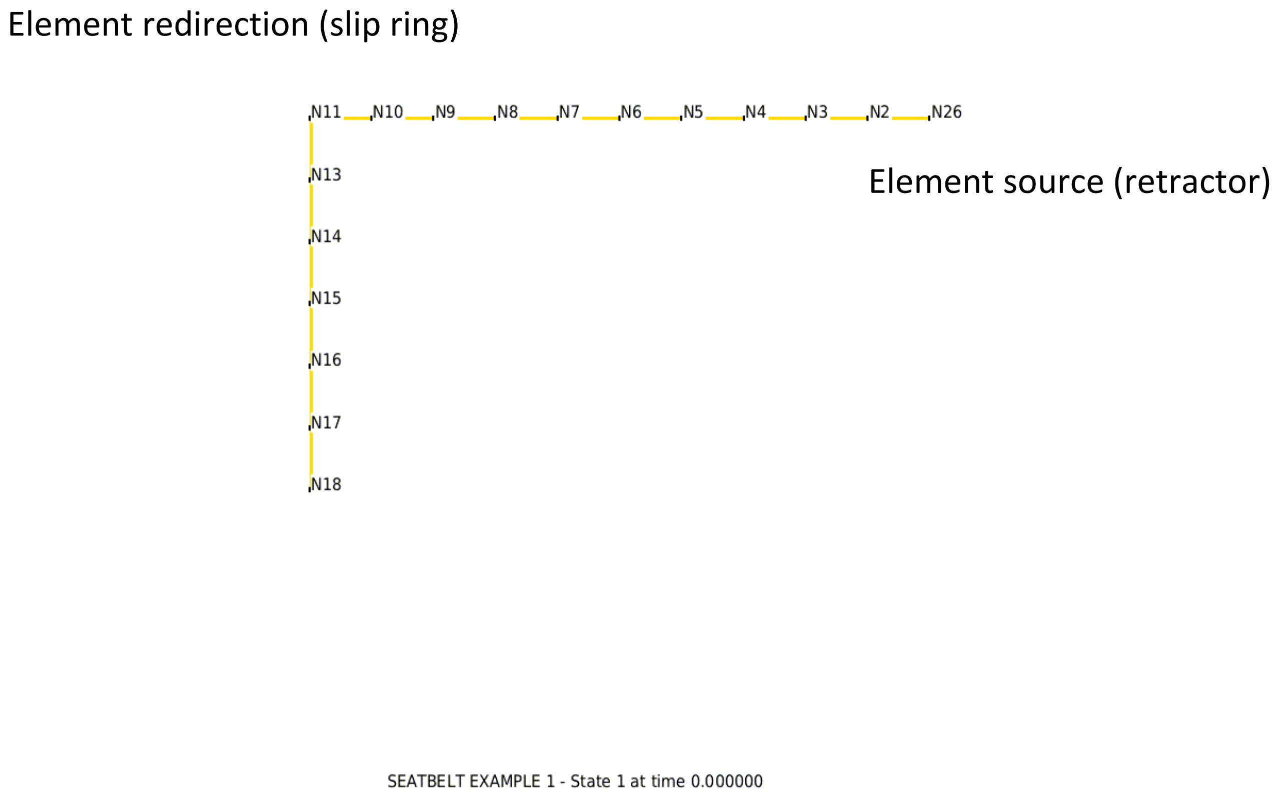


Courtesy of Daimler

Approaches in LS-DYNA for seatbelt modeling

obsolete modeling method





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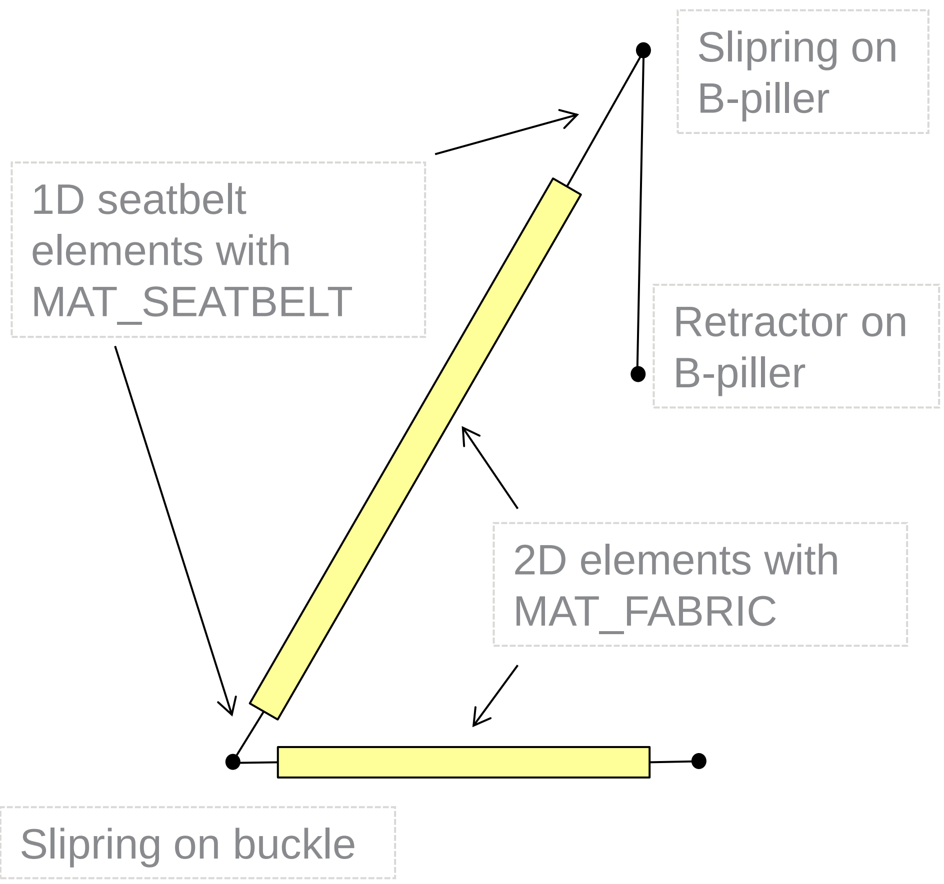
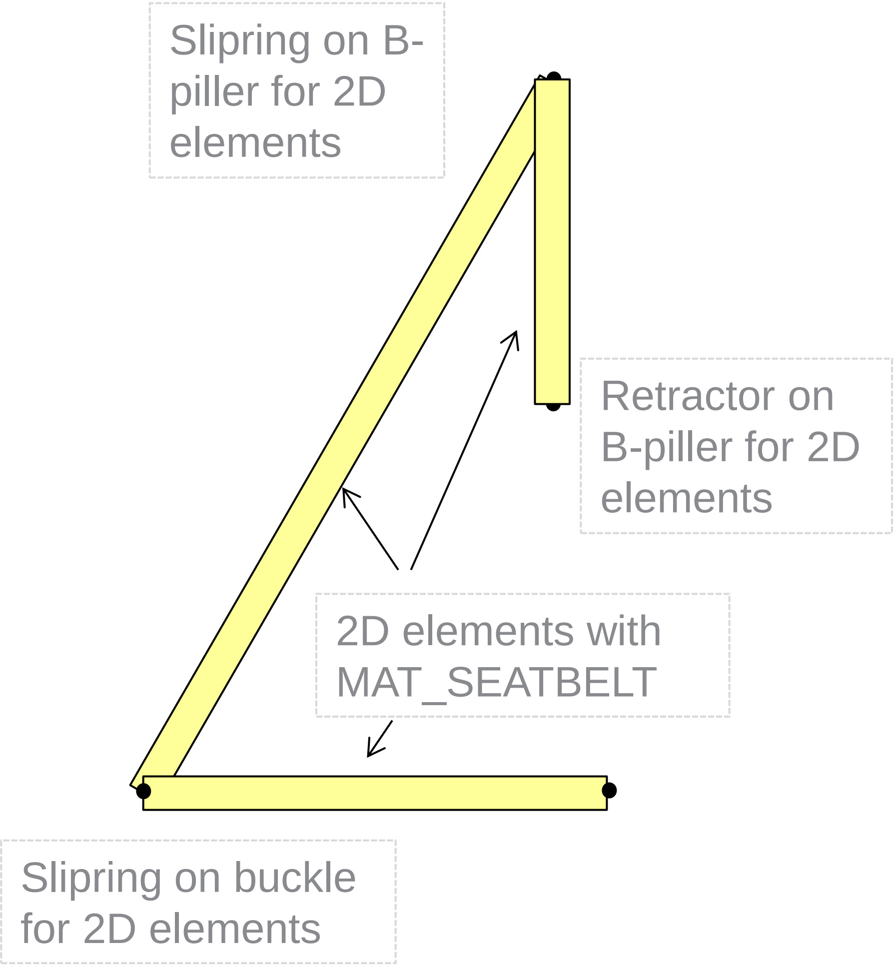
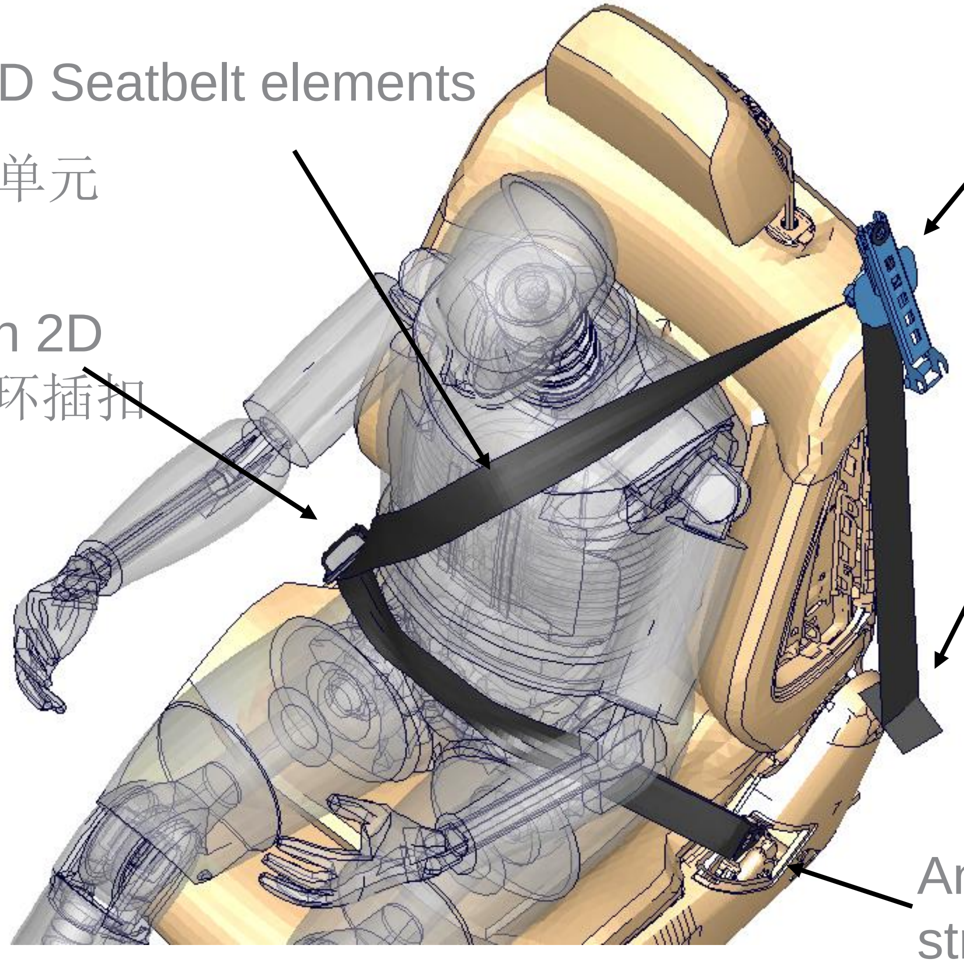


state-of-the-art in frontal crash



Best practice



Belt should have contact to seat

Courtesy of Daimler

Seatbelt Elements 安全带单元

*ELEMENT_SEATBELT

- Discrete element, only plotted if BEAM=0 (DATABASE_BINARY_D3PLOT). Results in ASCII file sbtout
- Defined with two nodes / four nodes, a part ID a retractor ID and an initial slack length.
- For <u>1D seatbelt elements</u>: *MAT_SEATBELT+ *SECTION_SEATBELT

For <u>2D seatbelt elements</u>:

*SECTION_SHELL, ELFORM=5 or 9

(Belytschko Tsay or fully integrated Belytschko Tsay)

- Regular mesh (no trias, only quads).
- Don’t forget **EDGESET** in section shell
- Compatible with 2d sliprings
- Since R8.0: bending stiffness is included

*MAT_SEATBELT

- Will be used with ELEMENT SEATBELT or shell elements.
- Weight defined by **mass per unit length**.
- Minimum length determines when element passes slipring (1/10 of initial length).
- Force strain behavior is described with two load curves (loading, unloading).
- Compression is neglected.

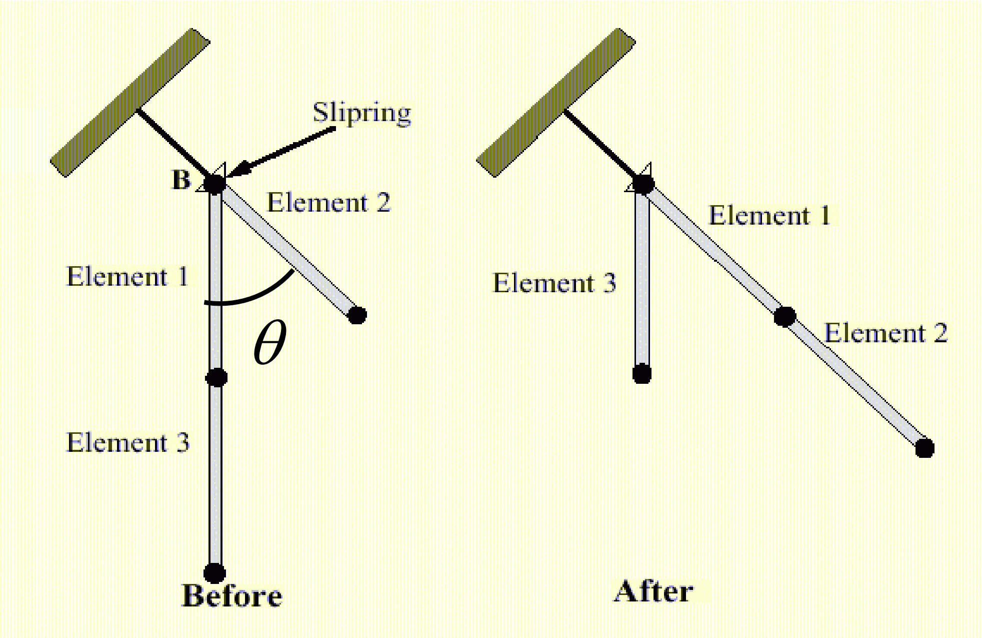
Slipring 滑环

*ELEMENT_SEATBELT_SLIPRING

- Allow continuous sliding of a belt through a sharp change of angle.
- Two belt elements meet at a slip ring.
- The slipring node has to be connected with the structure.
- For initialization one belt node has to be coincident with the slip ring node.
- One node remains attached to the slipring node at anytime.
- Locally remeshing if element length less than minimum length.
- No slip occurs if both elements are slack and if T1 close to T2.

$$T_2 = T_1 * e^{\mu\theta}$$

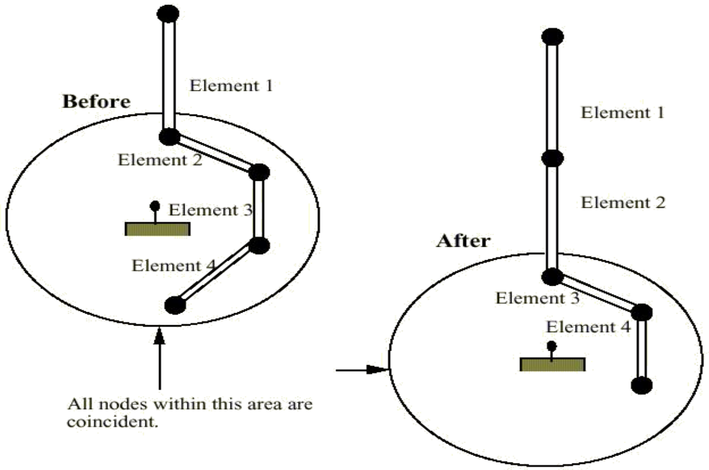
- $T_2 > T_1$, forces in connected belts
- μ Friction coefficient
- θ Angle between connected elements



Retractor 卷收器

*ELEMENT_SEATBELT_RETRACTOR

- Allows belt material to be paid out in a belt element.
- Operate in one of two regimes.
  - **Unlocked** (intimal state): belt material is paid out or reeled in, with a constant tension (first point of the loading curve) applied to the belt for initial tightening and ridding any slack.
  - **Locked** (triggered by sensor): a user defined force pullout relationship applies.
- The retractor pays belt material into Element 1.
  - If the amount of Lcrit is reached, Element 2 emerges with a unstretched length of 1.1*minimum length (LMIN).
  - Lcrit = fed length – 1.1*LMIN
- Sequence of events for the retractor to become locked:
  - Any one of up to four sensors must be triggered.
  - Then a user defined time delay occurs.
  - Then a user defined length of belt must be pay out.
  - Then the retractor locks and once locked it remains locked.

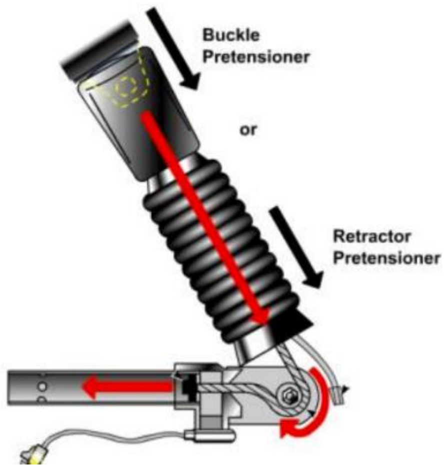


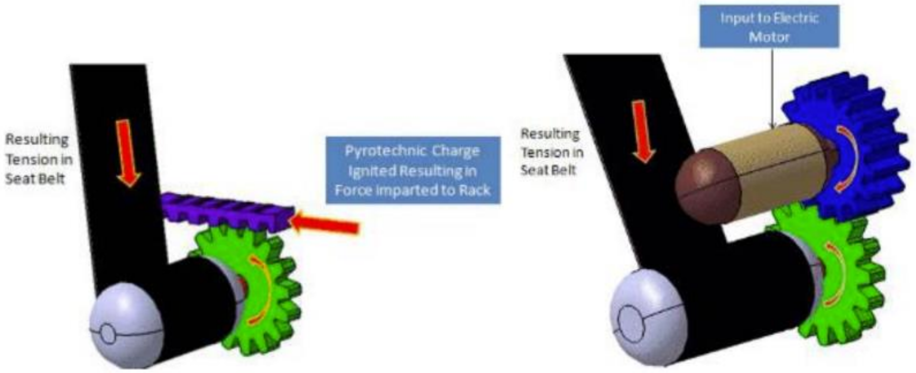
- Retractor node should not be on any belt elements but coincide with seatbelt nodes.

Pretensioner 预紧器

*ELEMENT_SEATBELT_PRETENSIONER

- 9 types are available which tighten the belt during the initial stages of crash.





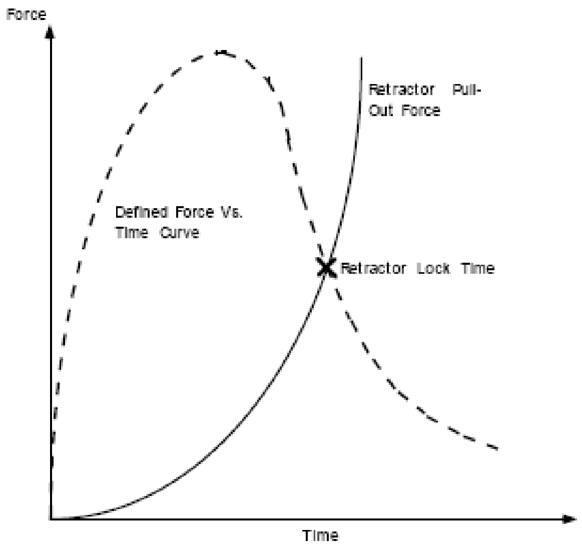


Figure 14.3. Force versus time pretensioner. At the intersection, the retractor locks.

- TYPE=2 & 3 & 9
- Connected with the buckle
- Pre-loaded spring becomes active (2)
- Lock spring removed (3)
- Energy vs time (9)

- TYPE=1 & 5 & 8
- Pyrotechnic retractor
- Pull-in length vs Time,
- With (1) or without (5) load limiter
- Energy vs time (8)
-

- TYPE=4 & 6 & 7: force vs time
- Compare force from retractor and pretensioner at each cycle until X
- TYPE4 Locks the retractor
- TYPE6 disable the pretensioner
- TYPE7 allow both the continue function and add the force together

Sensor 传感器

*ELEMENT_SEATBELT_SENSOR

- Used to trigger locking of retractors and pretensioners
- 4 types available:
  - Type 1
    - Triggers when the magnitude of x, y, or z – acceleration of a given node has remained above a given level continuously for a given time.
    - Does not work with nodes on rigid bodies.
  - Type 2
    - The rate of belt payout from a given retractor has remained above a given level continuously for a given time .
  - Type 3
    - The sensor triggers at a given time.
  - Type 4
    - Distance between two nodes exceeds a given maximum or become less then a given minimum.

Summary

*ELEMENT_SEATBELT_XXXX

- LS-DYNA features a lot of possibilities to model seatbelts for occupant models
- However, for high predictive state-of-the-art models the options of the standard elements for pretensioners and retractors are not sufficient in many cases.
- To cover all the physical effects of a retractor pretensioner systems the OEMs use the proprietary models delivered by the belt system suppliers. Since these models are usually accurately validated on component level the correlation effort on restraint system level (occupant model) is decreased.

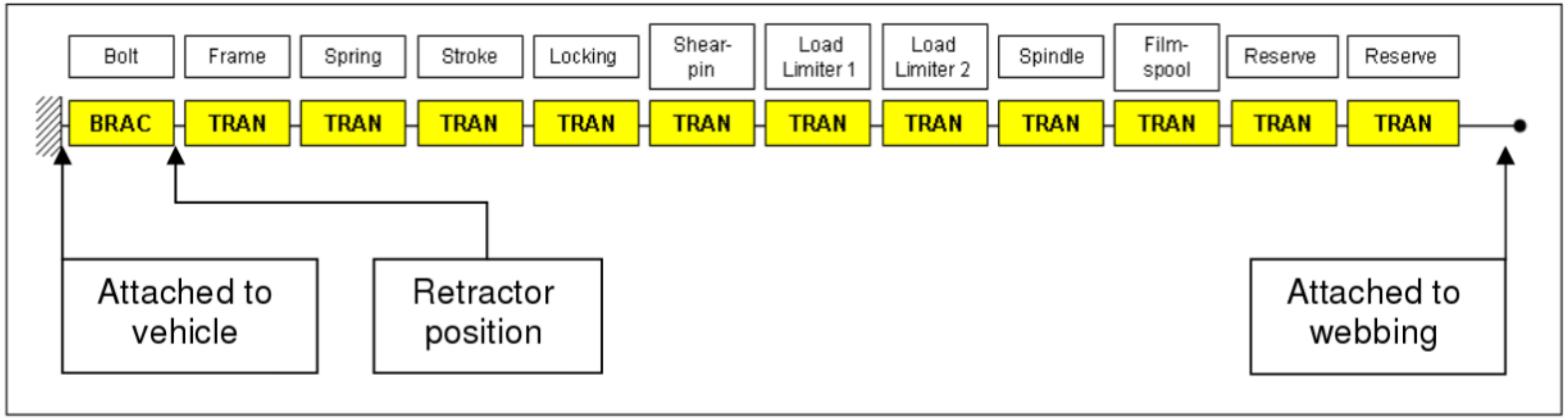


Figure 2.1.2 – Joint structure and nomenclature

Courtesy by Autoliv

Ansys

Seatbelt Material Card

*MAT_SEATBELT

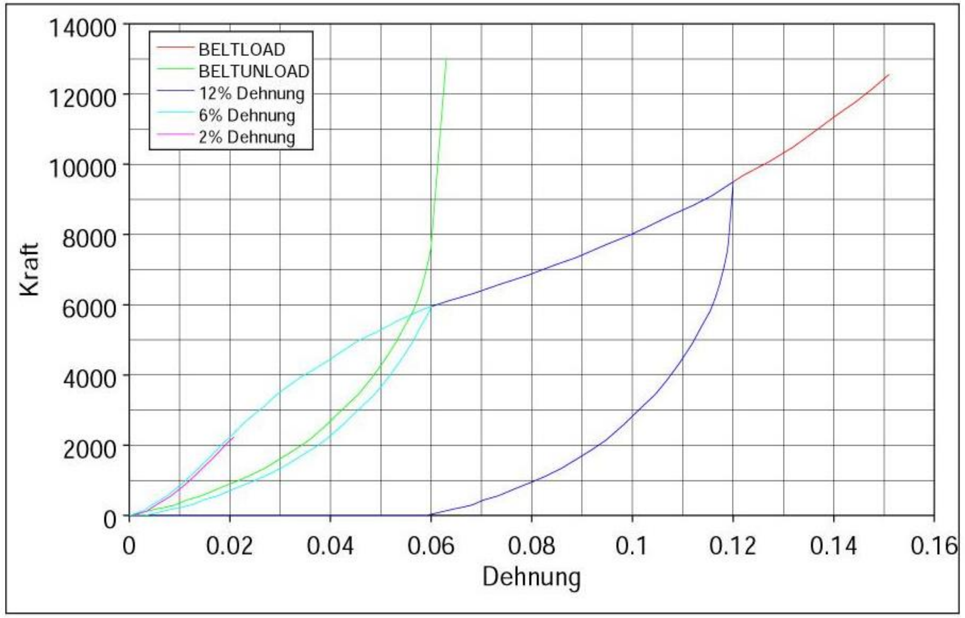
- Will be used with ELEMENT SEATBELT or shell elements.
- Weight defined by **mass per unit length**.
- Minimum length determines when element passes slipring (1/10 of initial length).
- Force strain behavior is described with two load curves (loading, unloading).
- Compression is neglected.

Strain is defined as engineering strain:

$$Strain = \frac{l_{cur}}{l_{init}} - 1$$

Damping force is evaluated by:

$$D = \frac{0.1 * m * v_{rel}}{\Delta t}$$



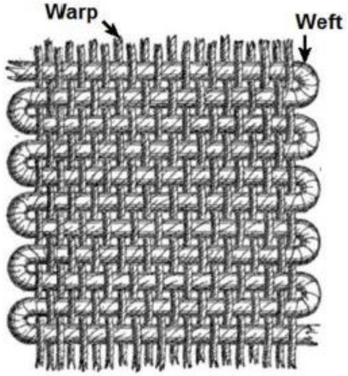
Airbag Modelling LSDYNA -> General Requirements

Element Type:

- Modelled with 2D shell elements (Mixed) -> Average 5mm or 2.5 mm

Material:

- Mat_34 -> Fabric -> Orthotropic material. Highly sophisticated material model to define material characteristics and leakage functions



Section:

- Element formulation -> 5 or 9 (fully integrated) -> membrane

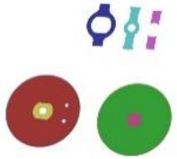
Contacts:

- Airbag Single Surface Contact (for airbag self)

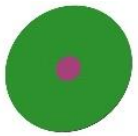
Reference Geometry:

- Node or Shell based -> Define a reference geometry to store an un-deformed state of the fabric elements. Elements receive an initial stress to restore their reference state.
- Use the RDT option -> time step size will be based on the reference geometry

Folded geometry



Shell reference geometry



Nodal reference geometry

```
*MAT_FABRIC_TITLE
Fabric Material
$:     mid        ro        ea        eb                prba      prab

$:     gab                            cse       el      prl     lratio      damp

$:    aopt       flc       fac       ela      lnrc      form     fvopt    tsrfac

$:            rgbrth     a0ref        a1        a2        a3        x0        x1

$:      v1        v2        v3        d1        d2        d3      beta

$:     lca       lcb      lcab      lcua      lcub     lcuab        rl

$:    lcaa      lcbb         h        dt               ecoat     scoat     tcoat

$
```

```
*SECTION_SHELL_TITLE
Fabric
$:   label    elform      shrf       nip     propt        qr     icomp     setyp
                   9       1.0         1       1.0       0.0         1         0
$:      t1        t2        t3        t4      nloc     marea      idof    edgset

$:      b1        b2
       0.0      90.0
$
```

```
*CONTACT_AIRBAG_SINGLE_SURFACE_ID
$:   label          title
         1Airbag_Self_Contact
$:   surfa     surfb  surfatyp  surfbtyp   saboxid   sbboxid      sapr      sbpr

$:      fs        fd        dc        vc       vdc    penchk        bt        dt
                                          20.0
$:    sfsa      sfsb      sast      sbst     sfsat     sfsbt       fsf       vsf

$:    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq
         2       0.0         0       0.0       3.0        45         0         0
$:  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf

$:    igap    ignore    dprfac    dtstif                         flangl   cid_rcf
         1         2       0.0   3.0E-4                             0.0         0
$:   q2tri    dtpchk     sfnbr    fnlscl    dnlscl      tcso    tiedid    shledg
         0       0.5      -1.0       0.0       0.0         0         0         0
$
```

Orthotropic friction in LS-DYNA

- Definition via *CONTACT_..._ORTHO_FRICTION
  - Only available for
    - AUTOMATIC_SURFACE_TO_SURFACE
    - AUTOMATIC_ONE_WAY_SURFACE_TO_SURFACE
    - SMP/MPP (Parameters 7 and 8 on extra cards 1 and 3 only valid in MPP)
  - No single surface contacts and SOFT=2 is also not supported!
  - The direction of friction can be influenced (next slide)

```
*** Warning 21392 (STR+1392)
    contact interface # 2 was switched from SOFT=2 to SOFT=1.
    The segment based contact option cannot be used with the
    ORTHO_FRICTION option.
      contact interface ID .........................        2
      contact order within input deck .............        1
```

```
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_ORTHO_FRICTION
$     ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
$       fs        fd        dc        vc       vdc    penchk        bt        dt
$      sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
$    FS1_S     FD1_S     DC1_S     VC1_S     LC1_S    OACS_S      LCFS      LCPS
       0.5       0.0       0.0       0.0         0         0
$    FS2_S     FD2_S     DC2_S     VC2_S     LC2_S
       0.2       0.0       0.0       0.0         0
$    FS1_M     FD1_M     DC1_M     VC1_M     LC1_M    OACS_M      LCFM      LCPM
       0.5       0.0       0.0       0.0         0         0
$    FS2_M     FD2_M     DC2_M     VC2_M     LC2_M
       0.2       0.0       0.0       0.0         0
$     soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq
```

MPP ONLY (LCFS, LCPS, LCFM, LCPM)

additional cards in “4th row”

- How to control directions of friction on segments
  - Manually define *SET_SEGMENT
    - First direction of each segment is defined by an offset angle in degrees from N1→N2 of the segment
    - Second direction is automatically computed perpendicular in the segment plane
      - Offset angle is the first attribute of the segment in *SET_SEGMENT
        - (D)Ai – (default) segment attribute for all segments [degrees]
        - A1 offset direction for each segment [degrees]
      - Offset angle is zero when part (set) IDs are used in the contact definition

Position	1	2	3	4	5	6	7	8
Variable	SID	DA1	DA2	DA3	DA4	SOLVER		
Variable	N1	N2	N3	N4	A1	A2	A3	A4

Extra cards 4 – 8 for *CONTACT_..._ORTHO_FRICTION

	Position	1	2	3	4	5	6	7	8
Slave side	Variable	FS1_S	FD1_S	DC1_S	VC1_S	LC1_S	OACS_S	LCFS	LCPS
	Variable	FS2_S	FD2_S	DC2_S	VC2_S	LC2_S			
Master side	Variable	FS1_M	FD1_M	DC1_M	VC1_M	LC1_M	OACS_M	LCFM	LCPM
	Variable	FS2_M	FD2_M	DC2_M	VC2_M	LC2_M			

MPP ONLY

- FSn_{S|M}:Static coefficient of friction in the local n orthotropic direction for surface slave and master
- FDn_{S|M}:Dynamic coefficient of friction in the local n orthotropic direction
- DCn_{S|M}:Exponential decay coefficient for the local n orthotropic direction
- VCn_{S|M}:Coefficient for viscous friction in the local n orthotropic direction
- LCn_{S|M}:Table ID of a 2-d table giving the friction coeff. in the local n direction
  as a function of the relative velocity and interface pressure
- OACS_{S|M}
  - .eq.0: comp. of frict. forces are based on the local segment directions
  - .eq.1: comp. of frict. forces are based on the local sliding nodes direct
- LCF{S|M}:Load curve giving the coef. of frict. as function of the direction of rel. motion (measured in degrees from the first ortho. direction (overrides FS, FD, DC, VC, LC)
- LCP{S|M}:Optional load curve giving a scale factor for the friction coefficient as function of interface pressure

- Example – small plate sliding on a bigger plate
  - Pressure load on small plate
  - Prescribed motion on small plate in either
    - X direction (0.1)
    - Y direction (0.3)
    - Combined X and Y direction
  - Evaluate friction force via bndout