LS-DYNA implicit Workshop

nonlinear Solver

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Outline

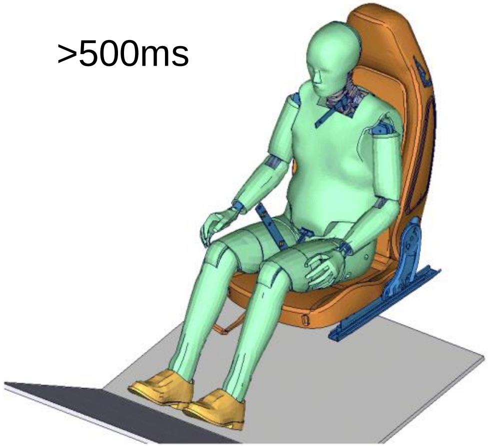
- Intro
- R9 Solver
- Walkthrough: NCAC Toyota Yaris model conversion to implicit
- LS-DYNA implicit with AVX2
- Convergence behavior monitoring
- Summary

Motivation: Why implicit?

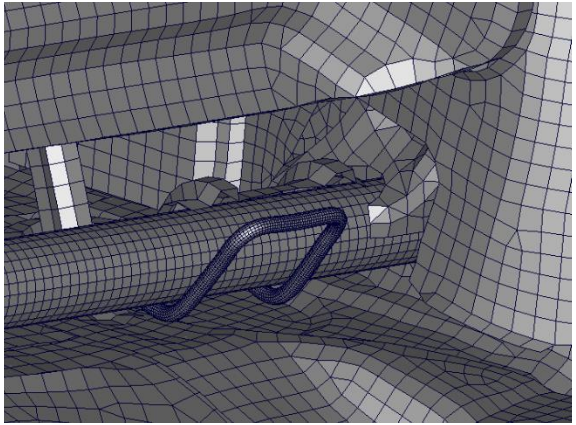
pre-stressed, quasi statically loaded structures

long duration analysis

>500ms



different scales in discretization



different time scales in process

e.g. static loading followed by transient loading or

transient loading followed by static loading

LS-DYNA provides explicit and implicit solution schemes

one code – one license - one data structure - one input / output

LS-DYNA implicit features

Basic equipment

- Newton, Quasi-Newton, arclength methods
- direct and iterative solvers
- automatic step size adjustment
- Newmark methods with consistent mass matrix
- …

LS-DYNA implicit features

Outstanding features

- one code – one license – one input – one output
- switching between implicit and explicit in one run
- high scalability through MPP
- mortar contact
- post-processing of residual (out-of-balance) forces

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Latest official release: R9.0.1 NEW

- Release R9.0.1 from August 2016
- Contains several new features in the areas of solid mechanics, multiphysics, and implicit
- Details: http://www.dynasupport.com/news/ls-dyna-r9.0.1-r9.109912-released
- **Highly recommended for implicit analyses**

General philosophy of LS-DYNA implicit

Increased accuracy implies better convergence

New feature: IACC

NEW

*CONTROL_ACCURACY

Card 1	1	2	3	4	5	6	7	8
Variable	OSU	INN	PIDOSU	IACC				
Type	I	I	I	I				
Default	1	2	0	0				

Implicit accuracy option IACC=1

- Higher accuracy in selected material models (24, 123)
  - Fully iterative plasticity, tightened tolerances, smooth failure
- Strong objectivity and consistency in selected tied contacts
  - Physical (only ties to degrees of freedoms that are ”real”)
  - Finite rotation
- Strong objectivity in selected element types
  - Finite rotation support for hypoelasticity

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CCSA (former NCAC) Toyota Yaris model

~ 1.2 mio nodes

~ 1.2 mio elements

1 global contact

1 global tied contact (spotweld)

Preparing the Yaris model for LS-DYNA implicit

- The model has a typical car crash model setup
- Idea: Do as less modifications as necessary to make the model „implicit ready“ and keep the explicit model structure/philosophy

- 3 step approach:

(1) Eigenvalue analysis
(2) “No load run”
(3) Small test load (e.g. gravity load)

Conversion to implicit

General model modifications:

- Changed control cards (for explicit analysis) to crash model recommendation
- Added *PART_CONTACT with appropriate OPTT to all parts in contact definition
  - OPTT = 0.9 * true shell thickness (secant errors)
  - Some volume parts are only represented by shell surfaces. In order to match the part masses the shells have high thickness values.
- Depenetration of the model
- Removed the seat foam parts (not needed for the following studies)

Implicit subset of control cards

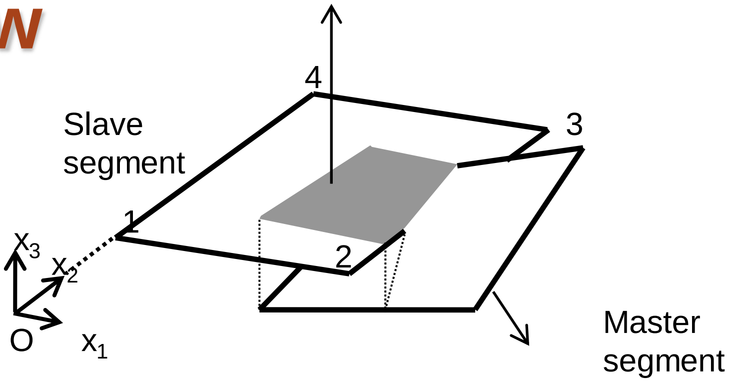
```
*CONTROL_ACCURACY
$       osu         inn     pidosu        iacc
          1           4                      1
*CONTROL_IMPLICIT_GENERAL
$    imflag         dt0
          1        0.01
*CONTROL_IMPLICIT_SOLUTION
$    nsolvr     ilimit     maxref      dctol      ectol      rctol    lstol   abstol
         12          6         15    2.5e-3                                  1.e-13
$     dnorm     diverg     istif    nlprint     nlnorm    d3itctl
          1                              2                      1
*CONTROL_IMPLICIT_AUTO
$     iauto     iteopt     itewin
          1         25          5
*CONTROL_IMPLICIT_DYNAMICS
$     imass      gamma       beta
          1       0.55       0.28
```

Conversion to implicit

Contact definition

```
*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR
$#     ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
   1000002         0         2
$#       fs        fd        dc        vc       vdc    penchk        bt        dt
  0.200000
$#      sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf

$#     soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq

$#   penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf

$#     igap    ignore    dprfac    dtstif   unused    unused    flangl
                     2
$
```

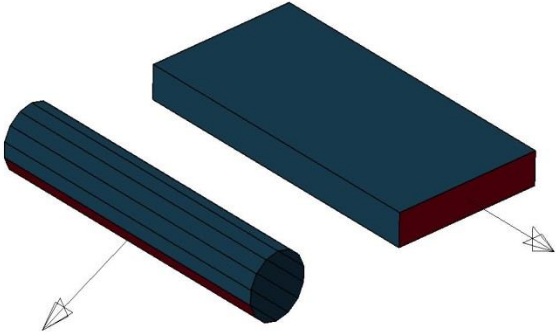
Mortar Contact: brief overview

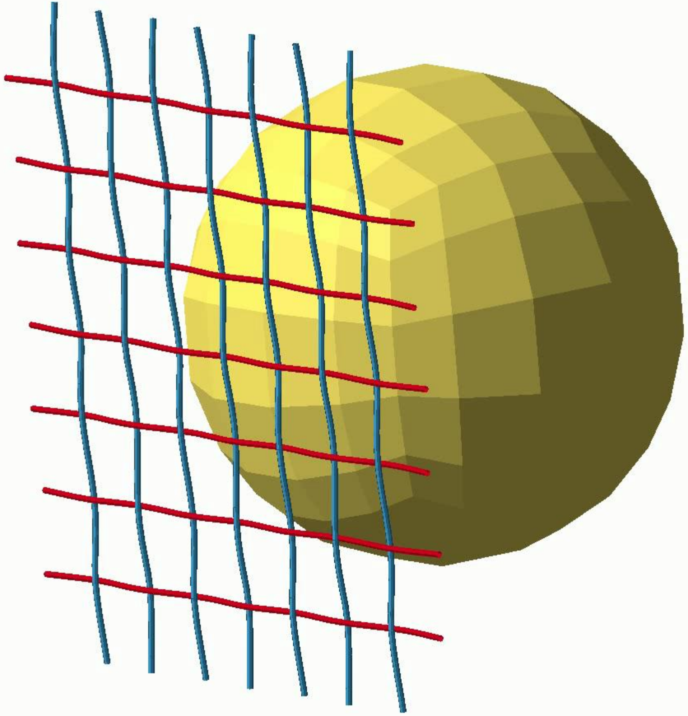


- Penalty based segment to segment contact
  - Finite element consistent force
  - Continuous force displacement relation
- Parabolic constitutive law
  - Continuous stiffness displacement relation
- Relatively expensive
  - Intended for implicit analysis, slow in explicit analysis (at this time)
  - **To the best of our knowledge best total implicit contact algorithm**

Mortar Contact: beams and shell edges

- Flat edge contact always apply in automatic contact
- Beam lateral surfaces are discretized into segments with mortar contact applied to each segment
- From R9: Support ”rolling beams”





Mortar Contact: stiffness and release

$$\sigma_c = \alpha \varepsilon K_s f\left(\frac{d}{\varepsilon d_c}\right)$$

$$f(x) = \begin{cases} \frac{1}{4}x^2 & x < \frac{1}{4\varepsilon} \\ \text{cubic function that depends on IGAP} & \frac{1}{4\varepsilon} \le x \end{cases}$$

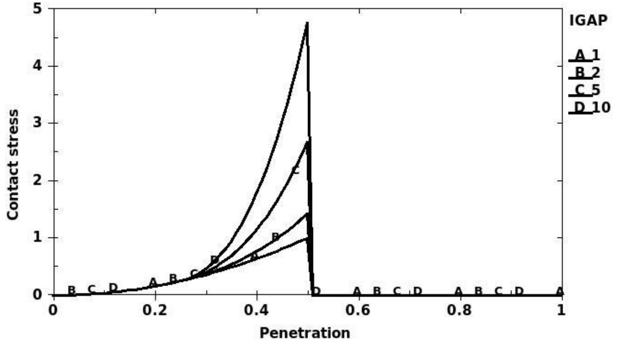
α = stiffness scaling factor (SFS * SLSFAC)

K_s = stiffness modulus of slave segment

d = penetration distance

$\varepsilon = 0.03$

d_c = characteristic length



- Contact is released if penetration is larger than half characteristic length *after* equilibrium
- Information of penetration may be requested

Conversion to implicit

(1) Eigenvalue check

- Basically a check of the stiffness matrix
- only a linearized version of the model is considered
- Eigenvalues must be ≥ 0 (if we want to run a static analysis EVs > 0)

```
$
*CONTROL_IMPLICIT_EIGENVALUE
$      neig
         20
$
```

→ eigout (ASCII)

→ d3eigv

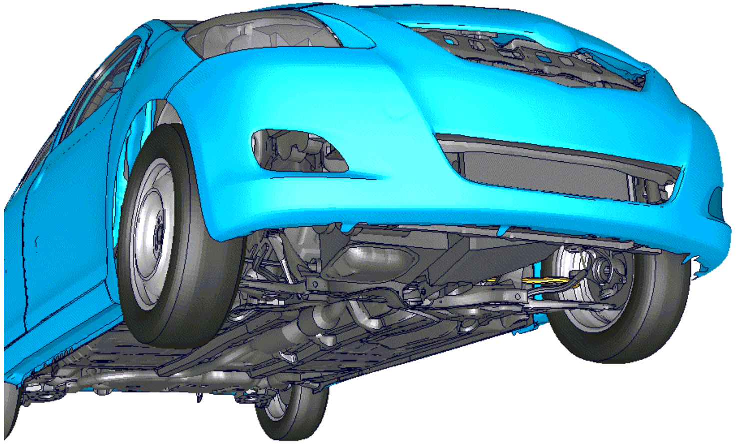
```
 ground
ls-dyna mpp.109095 d           date 07/06/2016

 r e s u l t s   o f   e i g e n v a l u e   a n a l y s i s:

 problem time =  1.00000E-02

 (all frequencies de-shifted)

                              |------ frequency -----|
       MODE    EIGENVALUE       RADIANS        CYCLES         PERIOD
          1  -2.439537E-03  4.939167E-02  7.860929E-03  1.272114E+02
          2  -8.982204E-04  2.997032E-02  4.769925E-03  2.096469E+02
          3  -7.700314E-06  2.774944E-03  4.416460E-04  2.264257E+03
          4   6.172319E-03  7.856411E-02  1.250387E-02  7.997527E+01
          5   1.321770E+02  1.149683E+01  1.829777E+00  5.465148E-01
          6   1.509247E+02  1.228514E+01  1.955241E+00  5.114460E-01
          7   2.477678E+02  1.574064E+01  2.505201E+00  3.991696E-01
          8   4.077650E+02  2.019319E+01  3.213846E+00  3.111536E-01
```

Conversion to implicit

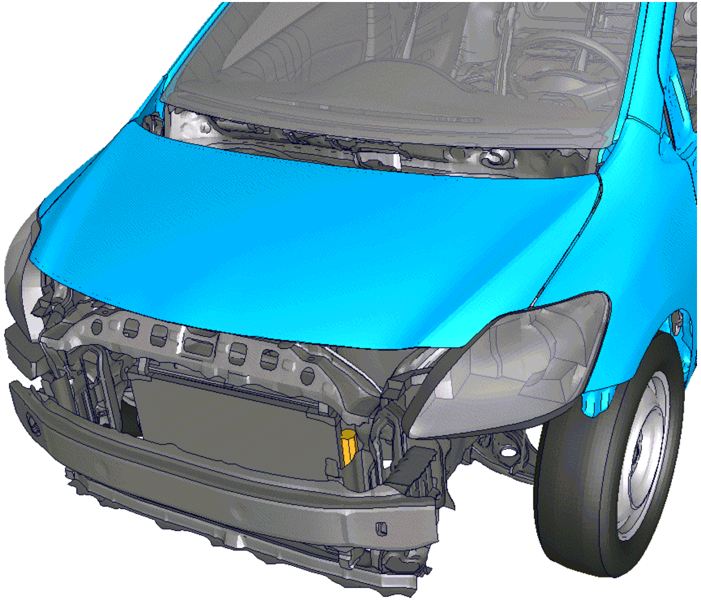
(1) Eigenvalue check

- Example of first eigen modes

≈0Hz eigen mode



≈ 0Hz eigen mode



Conversion to implicit

(1) Model modifications:

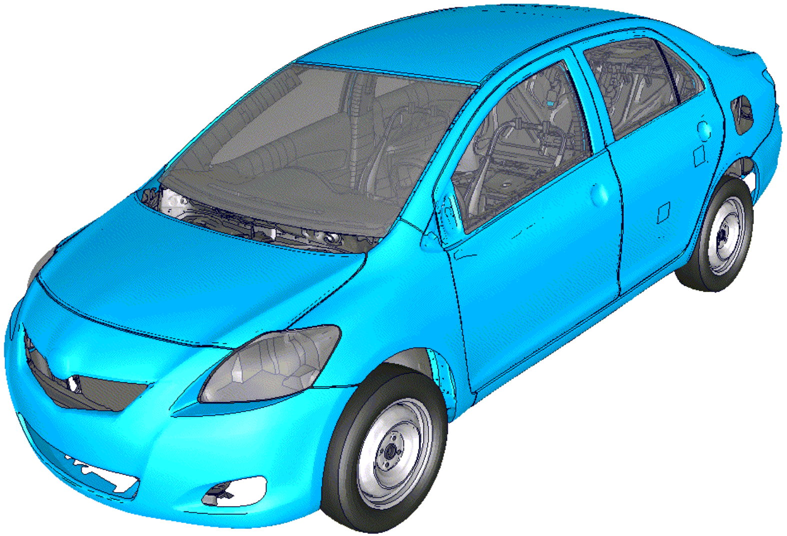
- Removed unsupported rotation d-o-f of wheels by adding small frictional moment to the wheel bearings with *CONSTRAINT_JOINT_STIFFNESS
- Removed unsupported rotation d-o-f steering linkage by adding small frictional moment to the wheel bearings with *CONSTRAINT_JOINT_STIFFNESS
- Fixed some of the engine parts properly

Conversion to implicit

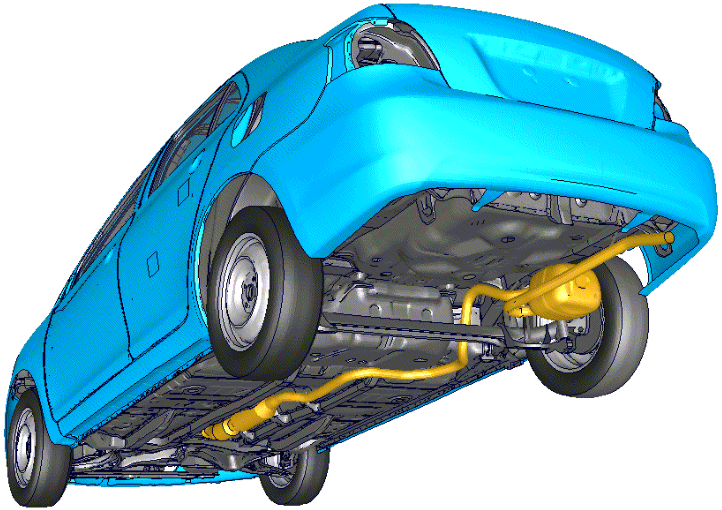
(1) Eigenvalue final check

- Lowest eigen modes after optimization

1.3Hz eigen mode



2.3Hz eigen mode



Conversion to implicit

(2) No-load run

- All definitions in the model are considered
- For a well defined model model this means:

No load → Equilibrium! → Instant convergence!

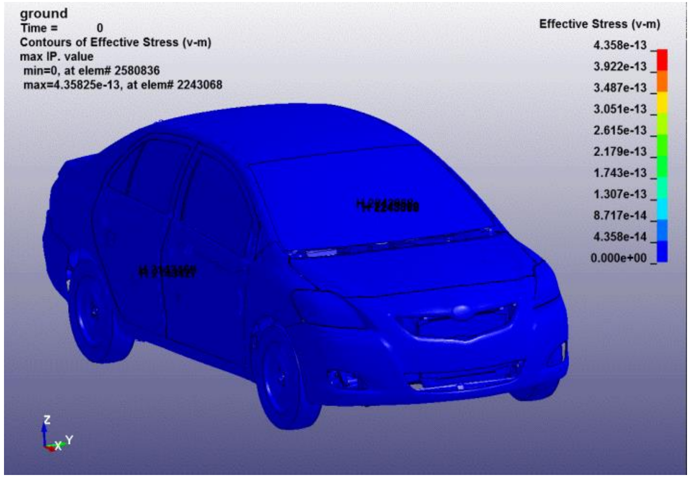
- In case of slow convergence there might be
  - Still penetrations
  - Bad defined materials
  - …

Conversion to implicit

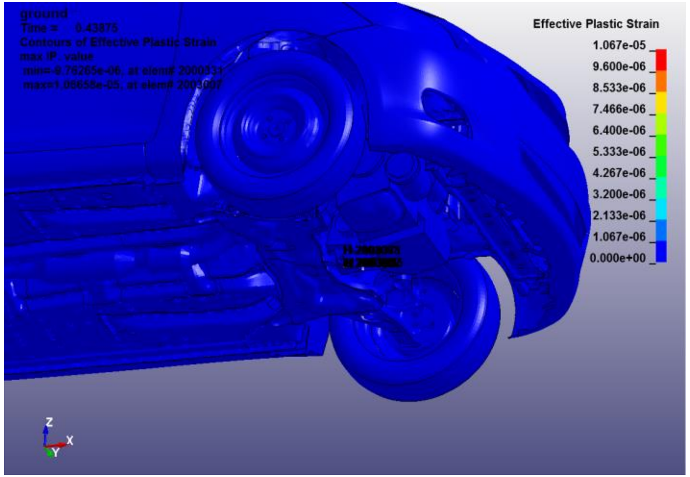
(2) No-load run

- Visualize stresses, plastic strains , residual forces, …

V-M-stress



plastic strains



- Here: LS-DYNA struggles with rubber bearing material definition (Blatz/Ko rubber) → replaced by *MAT_ELASTIC with corresponding parameters

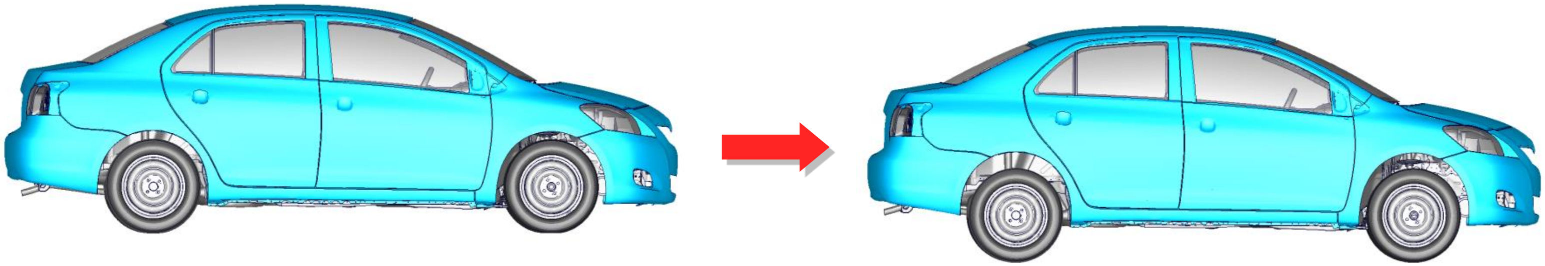
Conversion to implicit

(3) Small test load

- Final quality check for the model
- Expect plausible results
- Expect "Normal Termination"

Shock absorber loading setup

- Generated the geometry of an unloaded under-carriage



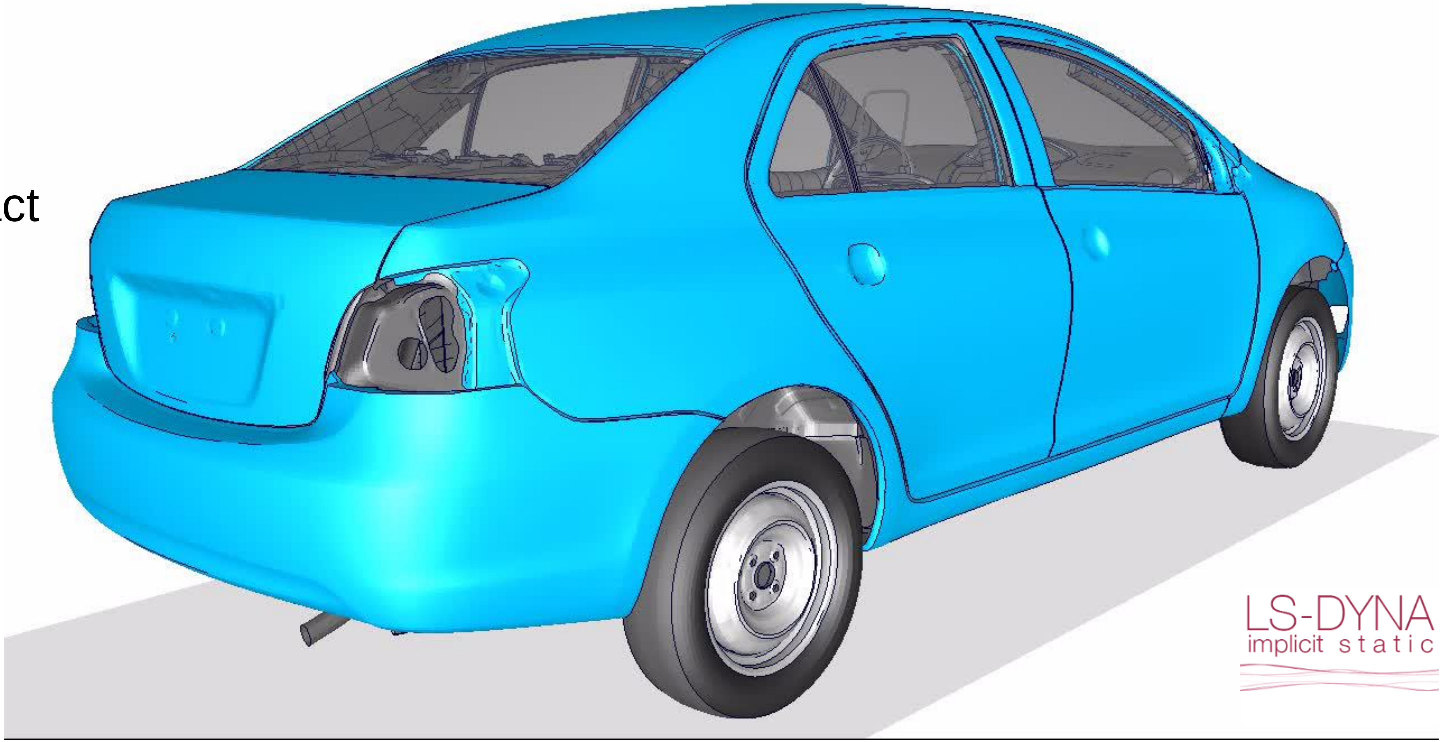
- Added a rigid ground model with

```
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_ID
       100tires2ground
$#      ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
   2000008  10000001         2         3
$#        fs        fd        dc        vc       vdc    penchk        bt        dt
  0.100000
$#       sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
```

Static shock absorber loading

three load steps

1) inflate tires
2) Initiating contact
3) gravity load



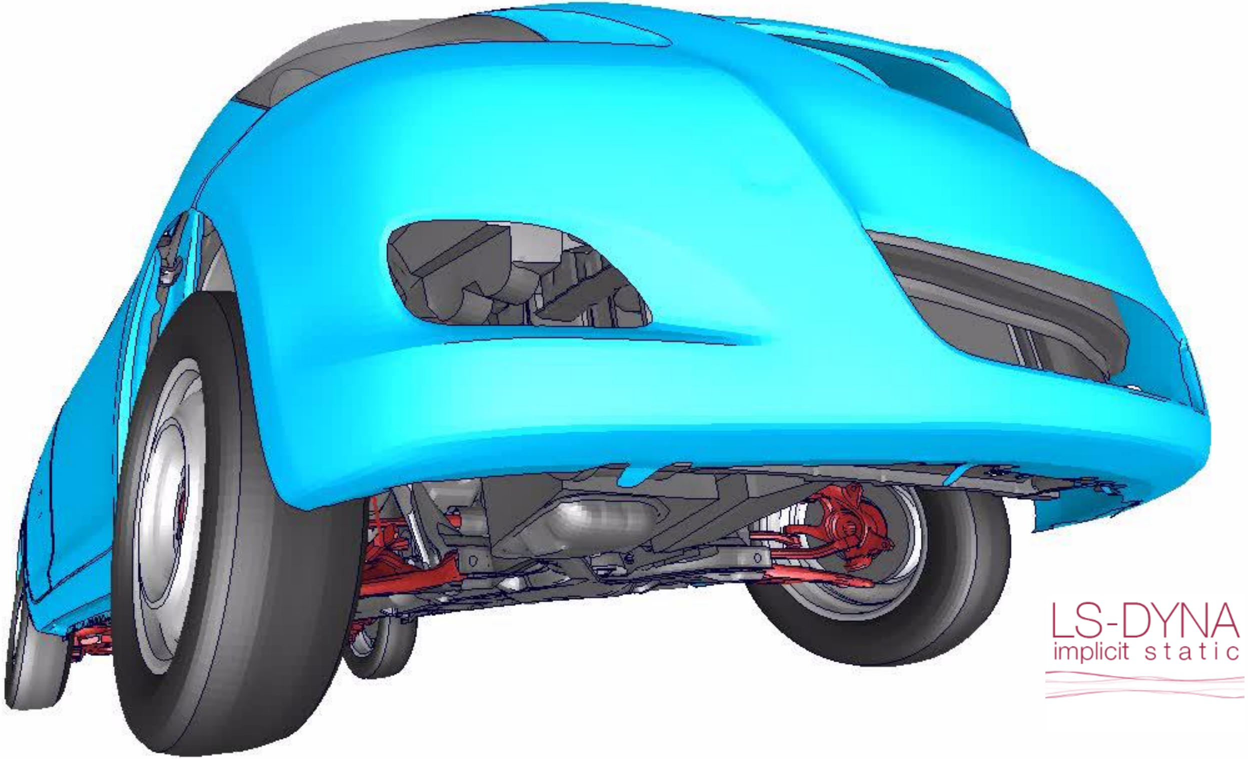
LS-DYNA implicit static

Conversion to implicit

Static shock absorber loading

Solution in 73 steps

5.5 hours on 16cores



Dynamic shock absorber loading setup

- Added ground with

```
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_ID
       100tires2ground
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
   2000008  10000001         2         3
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
  0.100000
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
```

- Added implicit dynamics control card

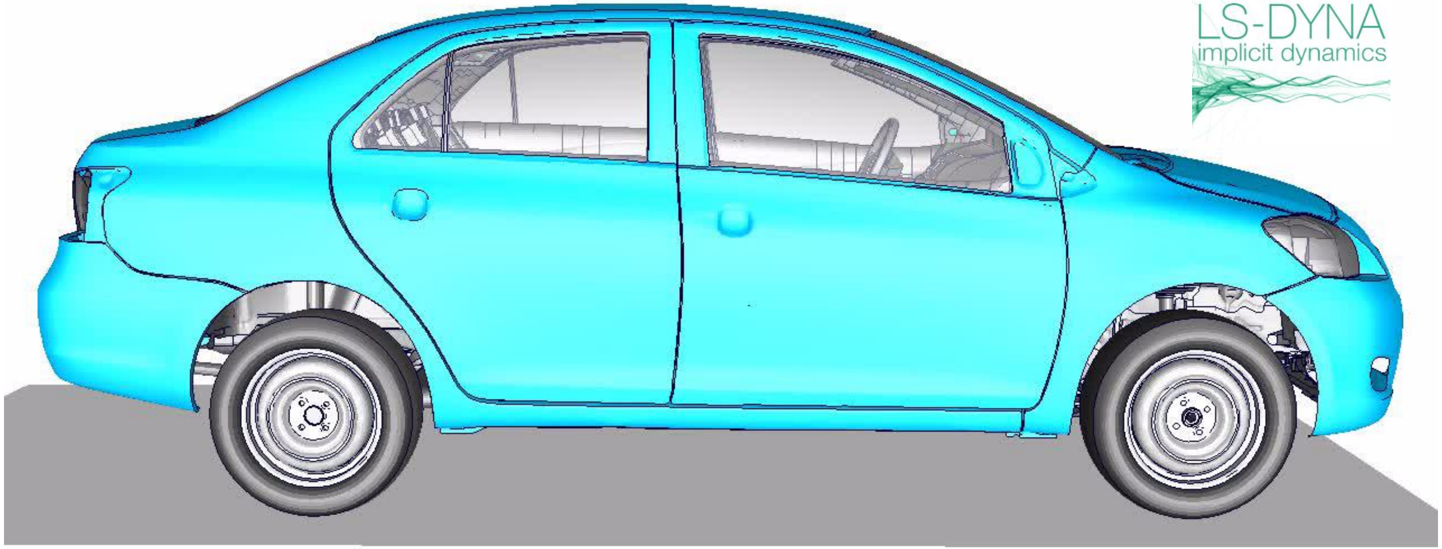
```
*CONTROL_IMPLICIT_DYNAMICS
$    imass     gamma      beta
         1      0.55      0.28
```

Dynamic shock absorber loading

3 seconds simulation time

Slight numerical damping

1) inflate tires
2) gravity load

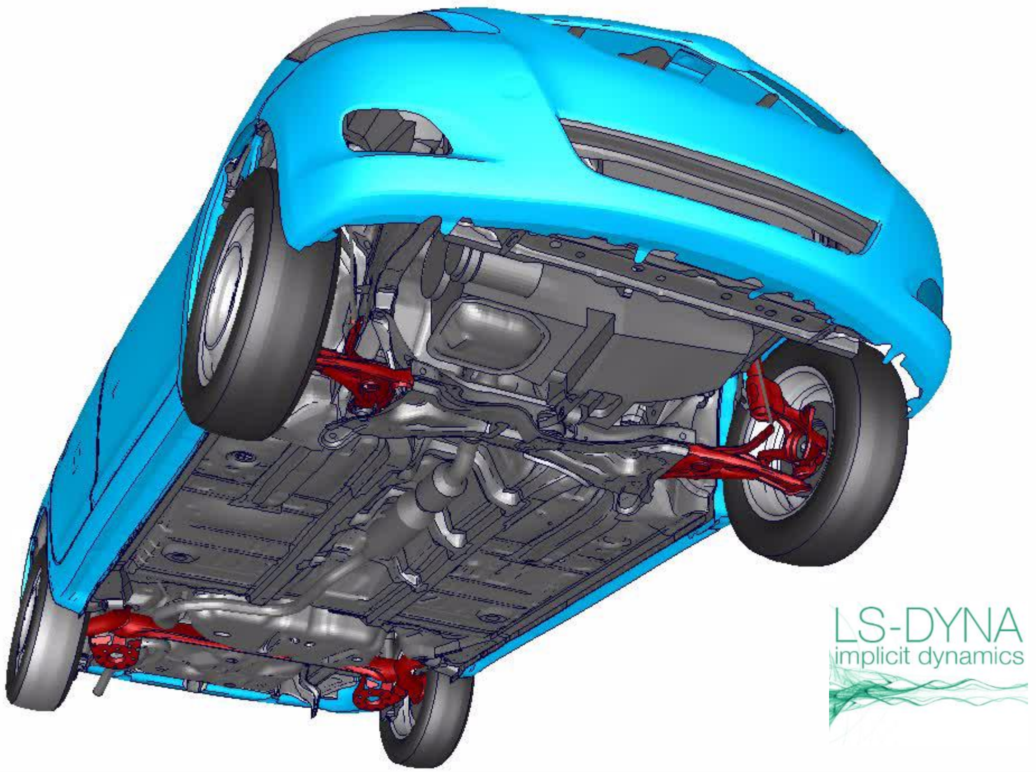


Conversion to implicit

Dynamic shock absorber loading

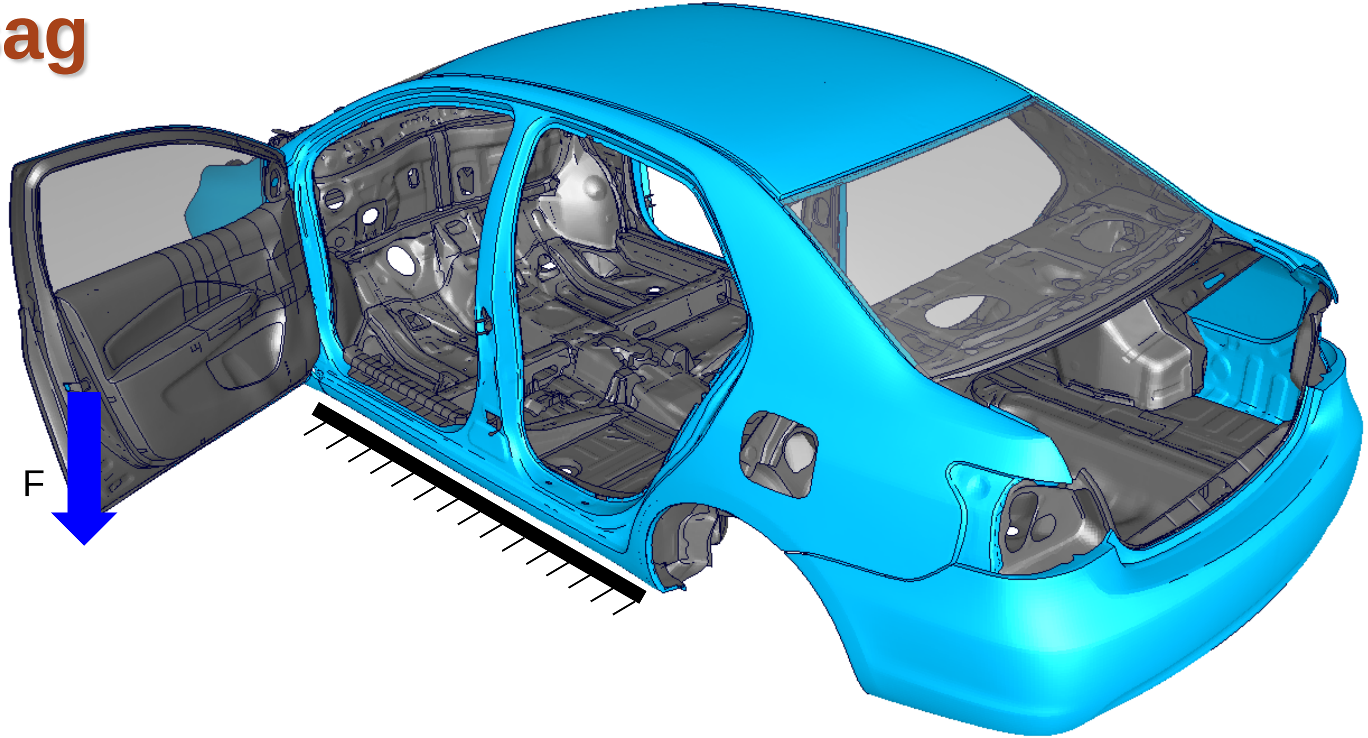
Solution in 103 steps

7.5 hours on 16cores



Conversion to implicit

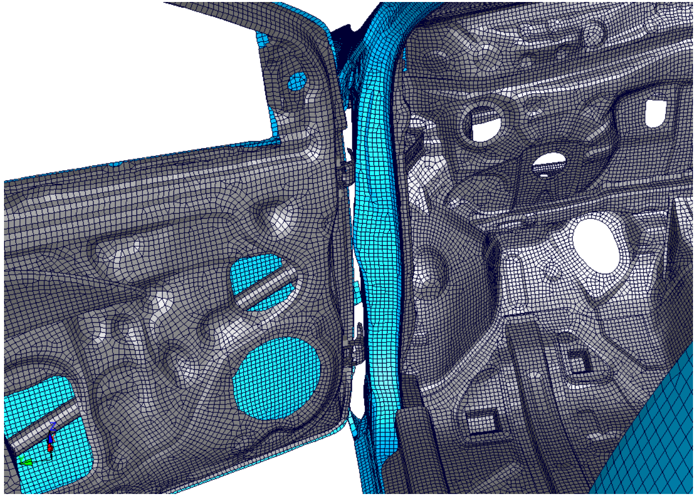
Static door sag

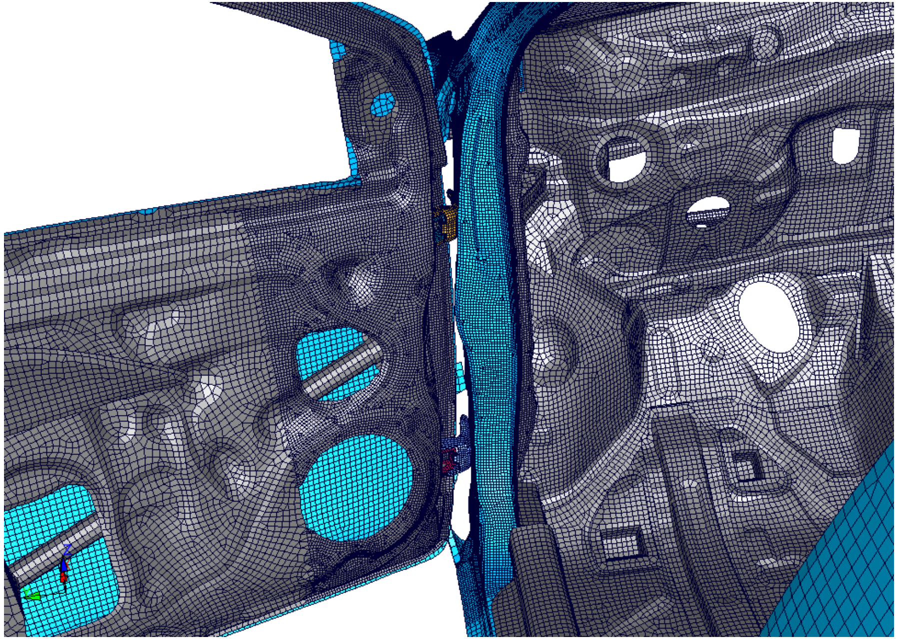


- two load steps
  - (1) gravity load
  - (2) Door load

Static door sag: modifications

- Removed non-necessary parts of the model
- Loadcase definitions
- Local mesh refinement
- Hinge brackets with solid elements



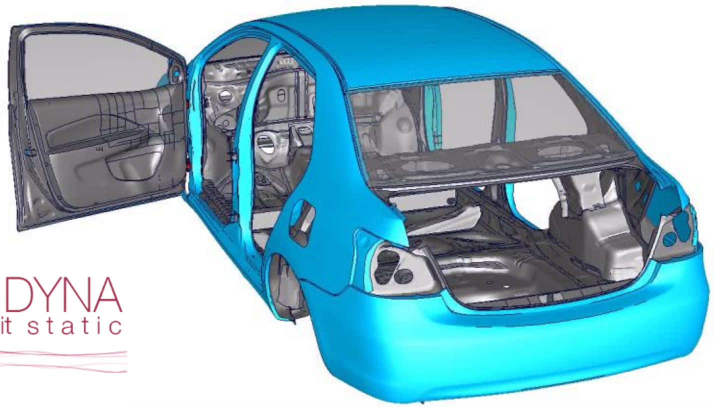


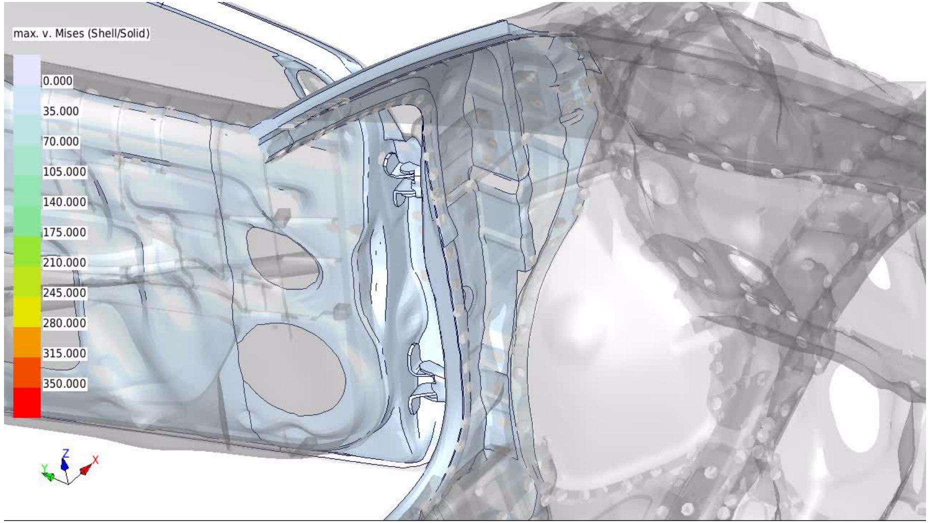
Conversion to implicit

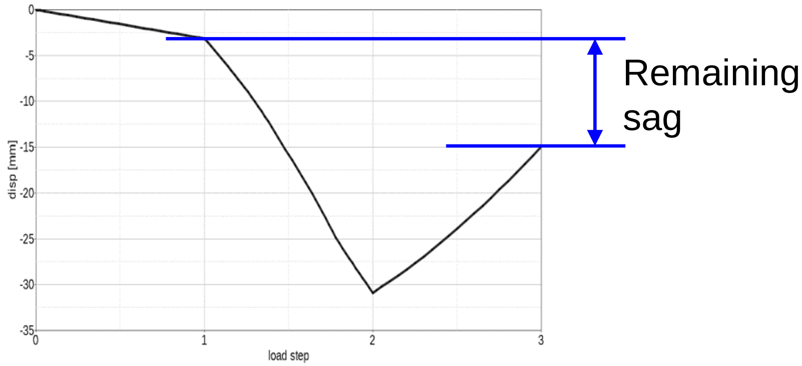
Static door sag

Solution in 94 steps (conservative)

2 h 50min on 16cores



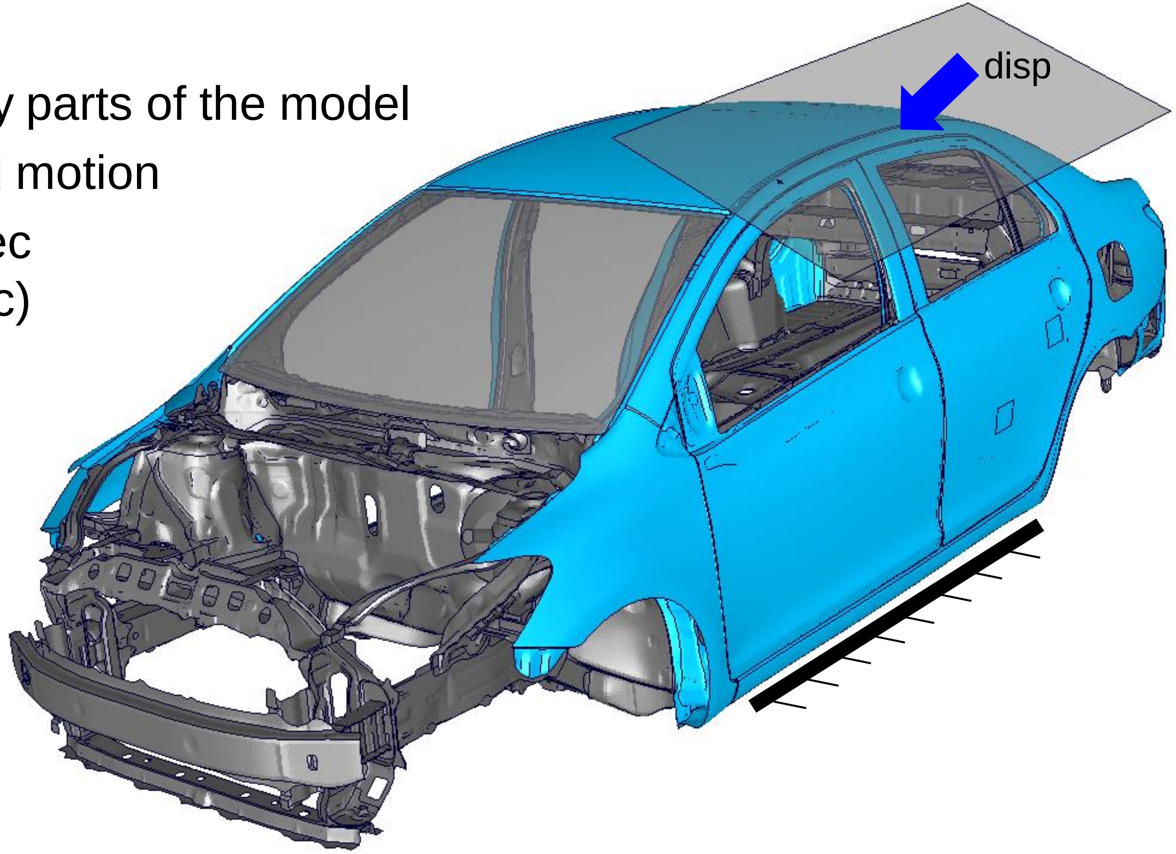




Conversion to implicit

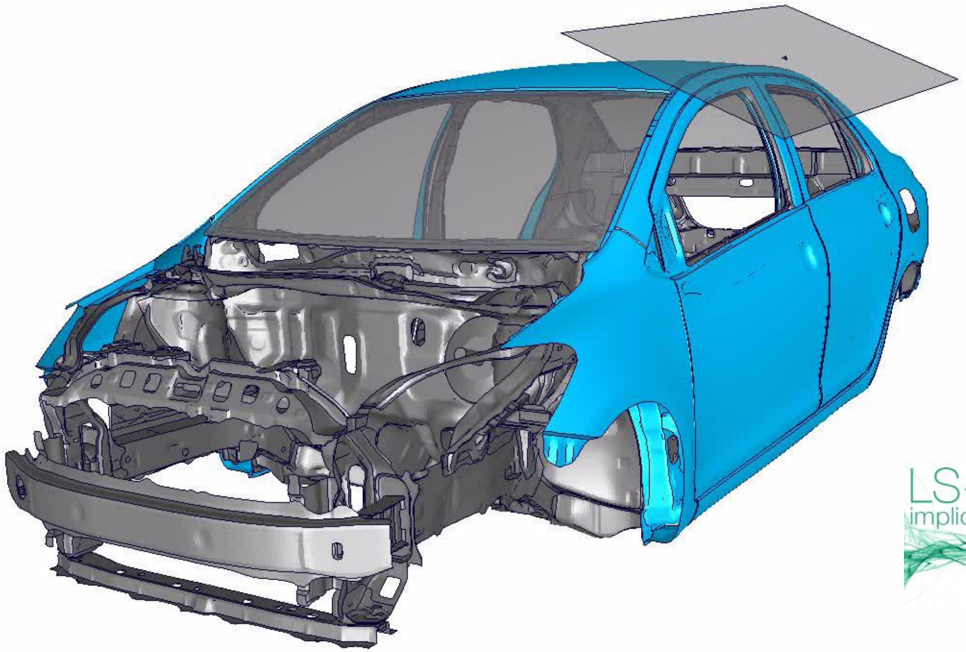
Roof crush

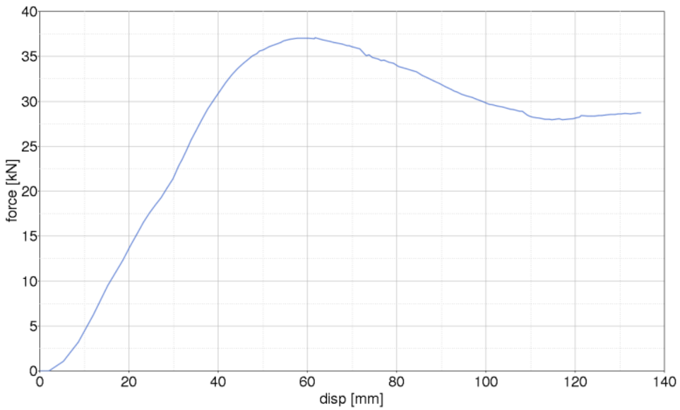
- Removed non-necessary parts of the model
- Impactor with prescribed motion
- Applying load within 2 sec
  (Termination time 2.2 sec)



Roof crush

- Takes about 20h on 10cores





Remarks

- Material definitions and connection modelling is not on most OEMs state-of-the-art level. However, it has on a quite detailed level of modeling. For the investigations of this project all required parts and model functionality was present in the baseline model.
- Model size is adequate but not as large as OEMs current models (up to 7mio elements)
- Conversion process may look straight forward but in deed it is not.

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Implicit with AVX2

Advanced Vector eXtensions

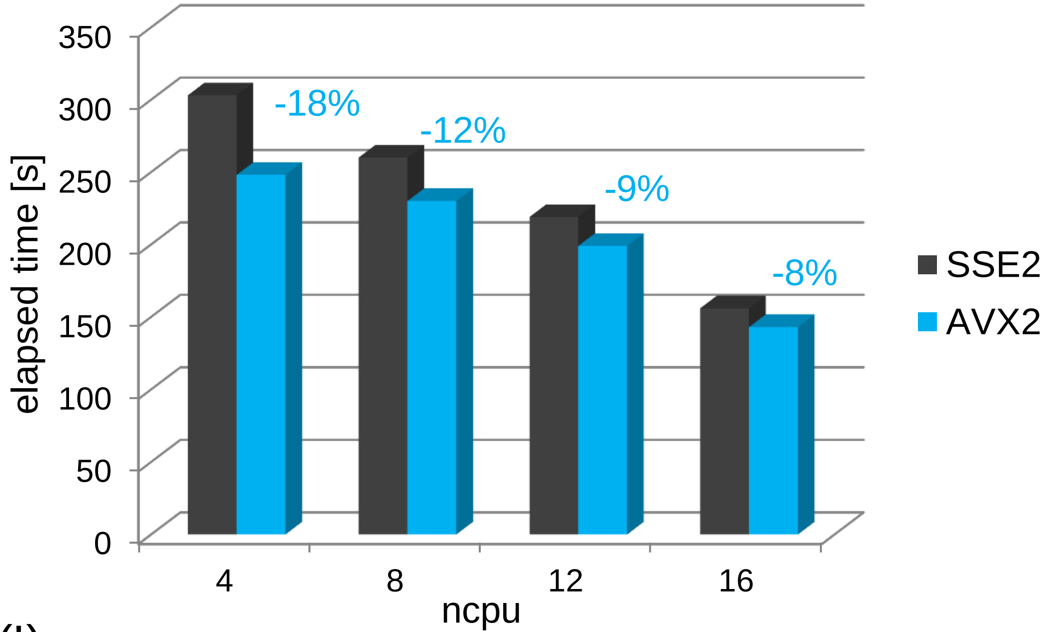
- Extensions to the x86 instruction set architecture
- Introduced 2013 with the Haswell processor generation
- Includes for example FMA3: solves

  (A*B)+C=D

  in a single CPU-cycle
- AMD‘s counterpart: Carrizo with Excavator microarchitecutre (Released end of 2015)

ls-dyna_mpp_d_R9_107411_x64_redhat54_ifort131_sse2_platformmpi
ls-dyna_mpp_d_R9_107411_x64_redhat54_ifort131_avx2_platformmpi

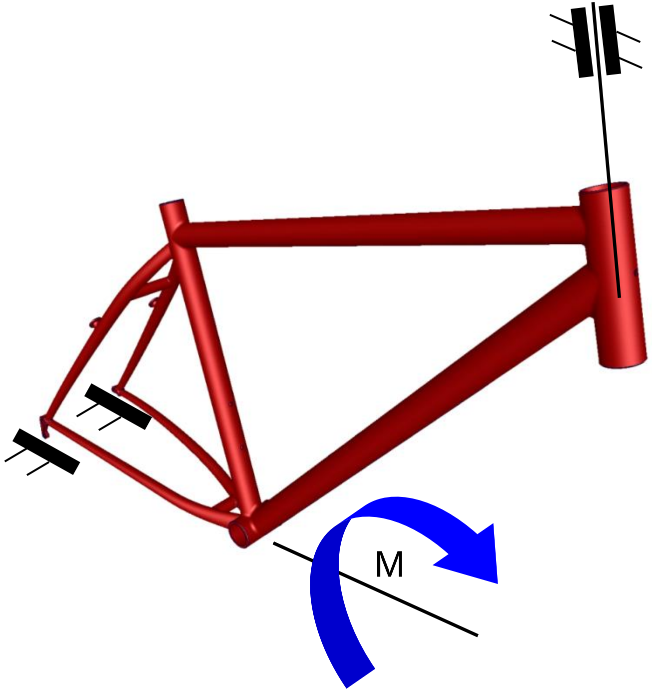
SSE2 vs AVX2: Eigenvalue analysis simple model

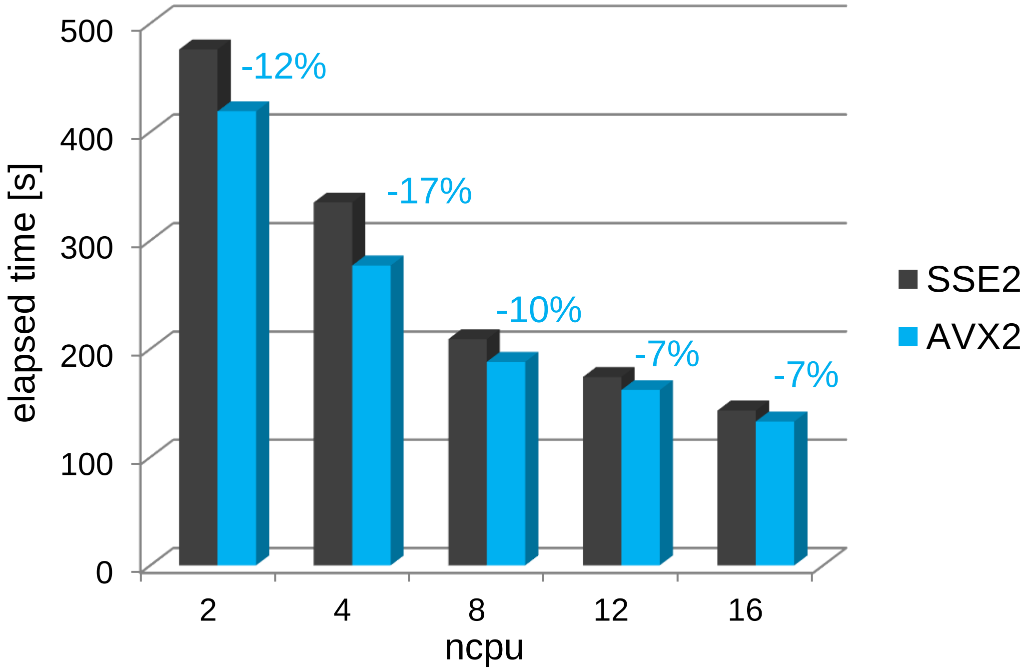


- Results are totally identical(!)

Implicit with AVX2

SSE2 vs AVX2: transient analysis simple model



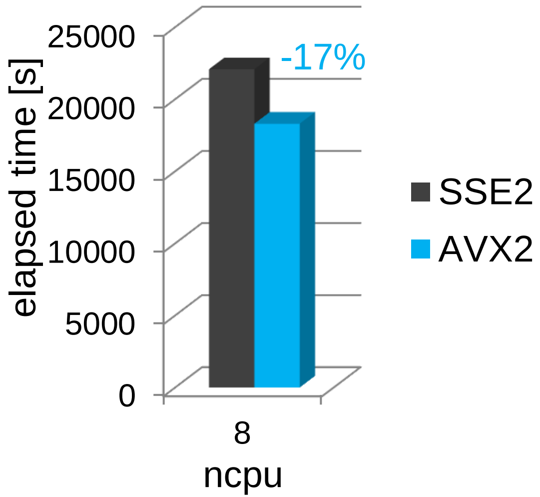


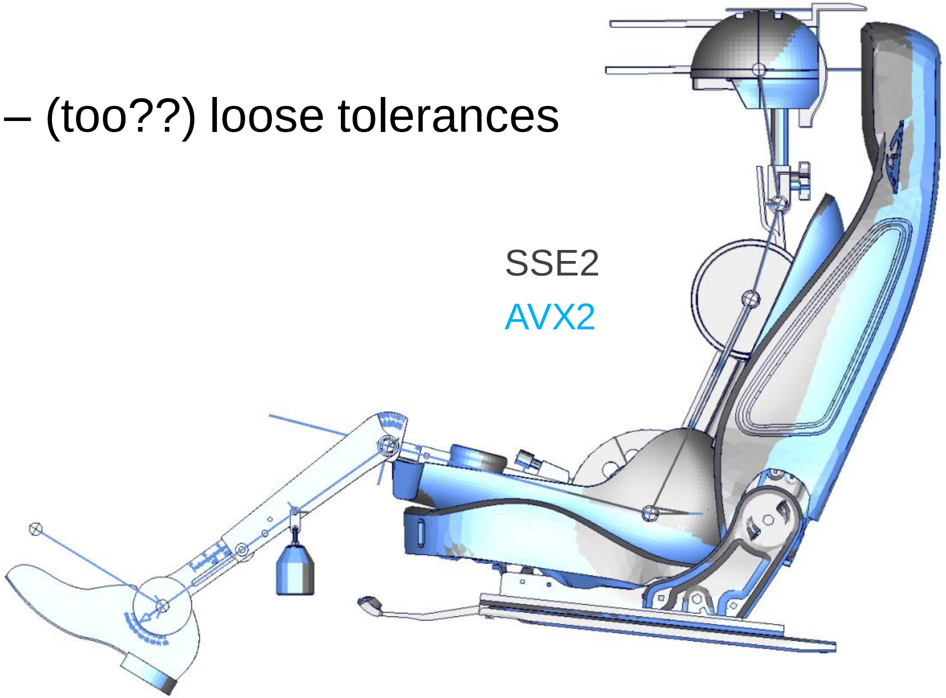
- Results are totally identical(!)

Implicit with AVX2

SSE2 vs AVX2: transient analysis HPM settling

- Benchmark on 8 cores
- Results have slight differences – (too??) loose tolerances
- Different steps during solution

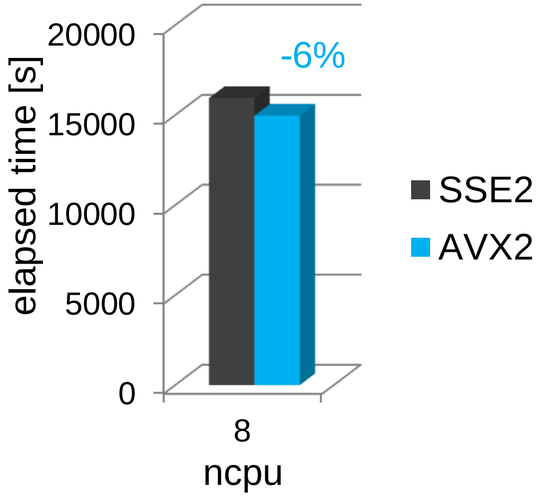


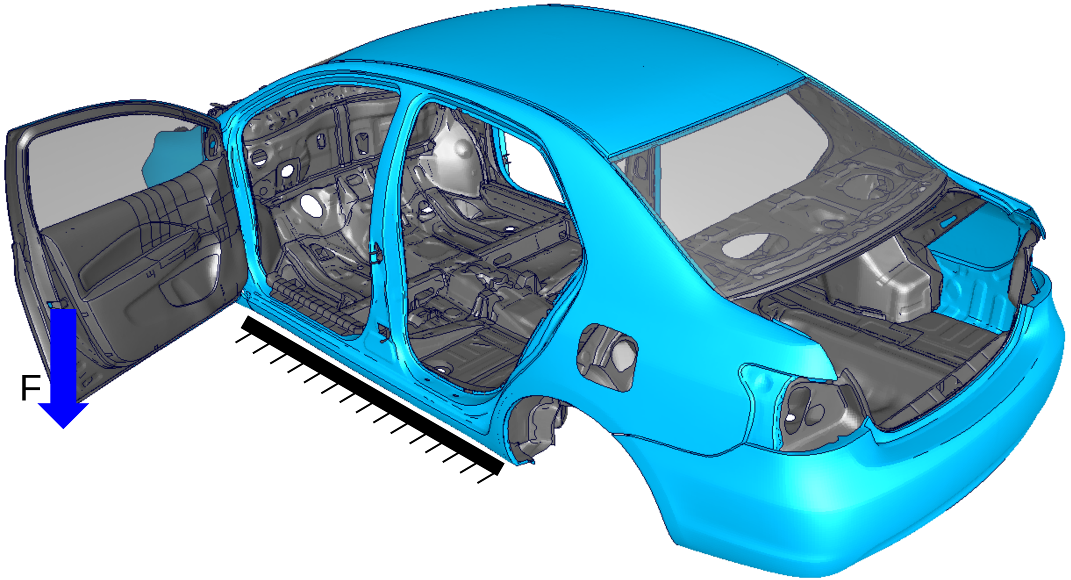


Implicit with AVX2

SSE2 vs AVX2: door sag

- Benchmark on 8 cores
- Results are totally identical(!)





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DYNAtool: check-convergence

Providing convergence related information

- Included in the DYNA-tools package
- Greps information about convergence behavior form d3hsp
- Prints out table view of information like interations, retry, …
- Generates csv-file for post-processing with EXCEL, HG, …

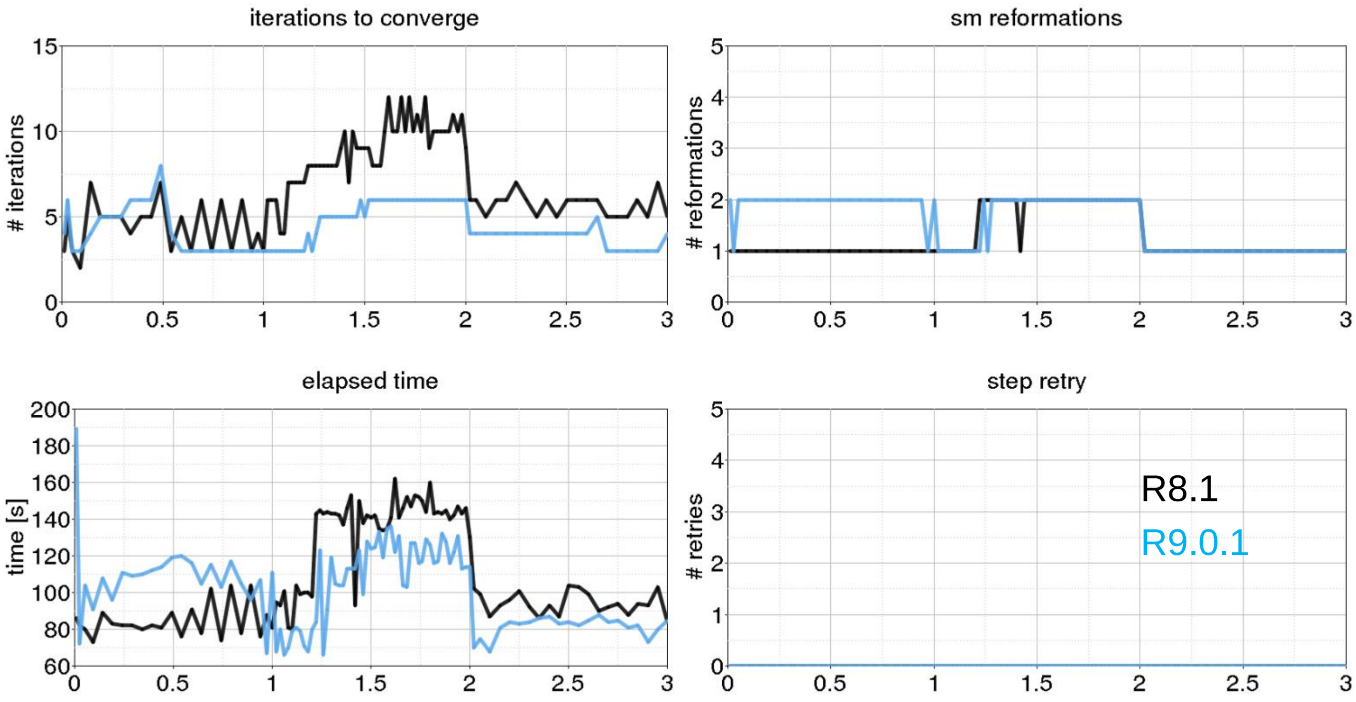
```
scanning d3hsp
------------------------------------------------------------------------------------------------
|     STEP     |      TIME      |  step size |   #iter    | #SM Reform |   #RETRY   | elaTime[s] |
------------------------------------------------------------------------------------------------
|          1   |  1.0000E+00    |    1.0000  |         2  |         0  |         0  |        18  |
|          2   |  2.5849E+00    |    1.5849  |         2  |         0  |         0  |        12  |
|          3   |  5.0968E+00    |    2.5119  |         2  |         0  |         0  |        13  |
|          4   |  9.0779E+00    |    3.9811  |        12  |         1  |         0  |       100  |
|          5   |  1.5387E+01    |    6.3091  |         7  |         0  |         0  |        41  |
 …..
|         39   |  1.5516E+03    |  271.8000  |        16  |         3  |         0  |       112  |
|         40   |  1.9825E+03    |  430.9000  |        37  |         5  |         0  |       247  |
|         41   |  2.0000E+03    |   17.5000  |        23  |         2  |         0  |       144  |
|         42   |  2.0928E+03    |   92.8000  |        14  |         1  |         2  |       209  |
|         43   |  2.2400E+03    |  147.2000  |        24  |         2  |         0  |       763  |
|         44   |  2.3482E+03    |  108.2000  |        26  |         2  |         1  |       588  |
|         45   |  2.4278E+03    |   79.6000  |        30  |         2  |         1  |       506  |
|         46   |  2.5540E+03    |  126.2000  |        39  |         3  |         0  |       917  |
|         47   |  2.6802E+03    |  126.2000  |        26  |         2  |         0  |       671  |
|         48   |  2.7233E+03    |   43.1000  |        30  |         2  |         2  |       246  |
|         49   |  2.7550E+03    |   31.7000  |        59  |         5  |         1  |       428  |
|         50   |  2.7709E+03    |   15.9000  |        84  |         8  |         0  |       536  |
…
|         63   |  3.7730E+03    |  316.9000  |         2  |         0  |         0  |        17  |
|         64   |  4.0000E+03    |  227.0000  |         2  |         0  |         0  |        16  |
|         65   |  4.5024E+03    |  502.4000  |        28  |         5  |         0  |       189  |
|         66   |  5.0000E+03    |  497.6000  |        15  |         4  |         0  |       131  |
------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------
|                                            |      1579  |       202  |        11  |     14633  |  TOTAL  |
---------------------------------------------------------------------------------------------------------
|                               |   75.7576  |      23.9  |       3.1  |       0.2  |       221  | AVERAGE |
---------------------------------------------------------------------------------------------------------
```

Example: Yaris door sag R8.1 vs R9.0.1

R8.1 94 steps in 3h 7min

R9.0.1 with IACC=1

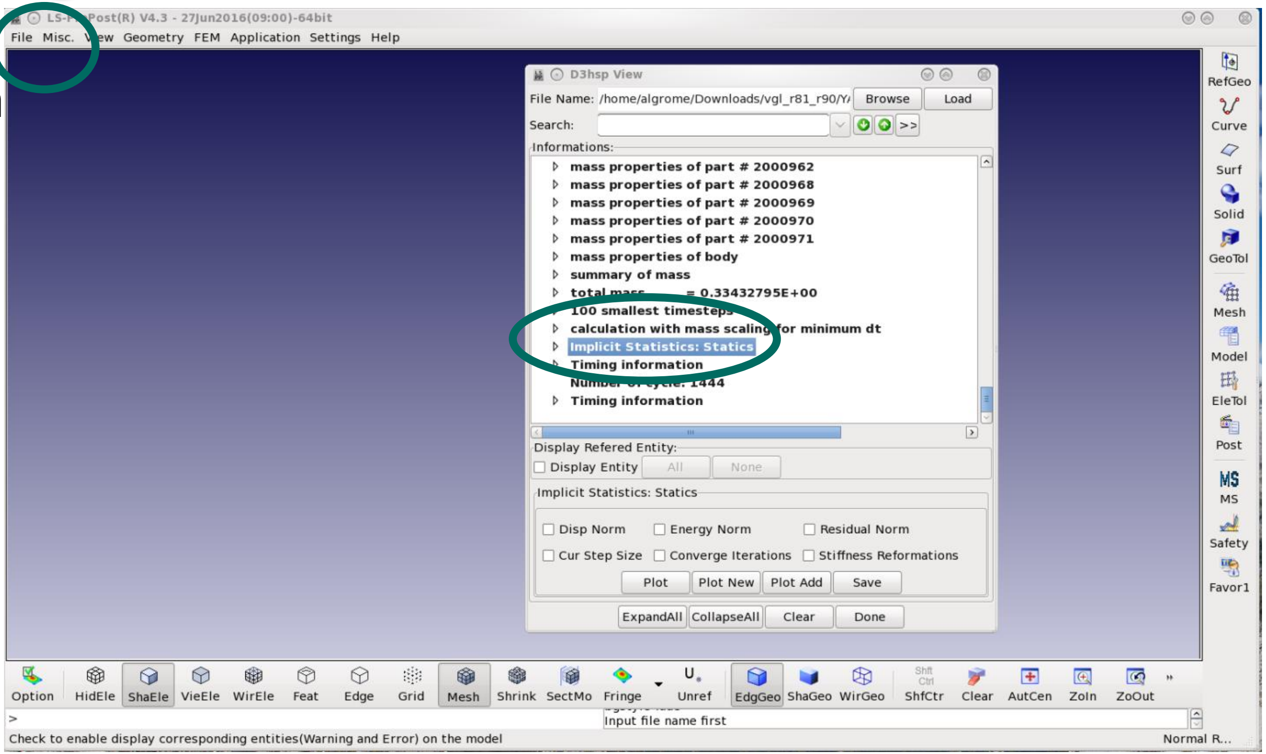
94 steps in 2h 49min



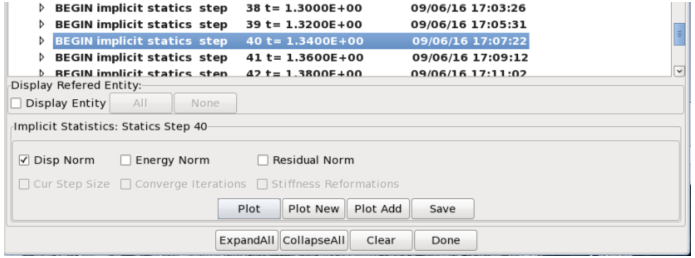
LSPP d3hsp view

Providing convergence related information

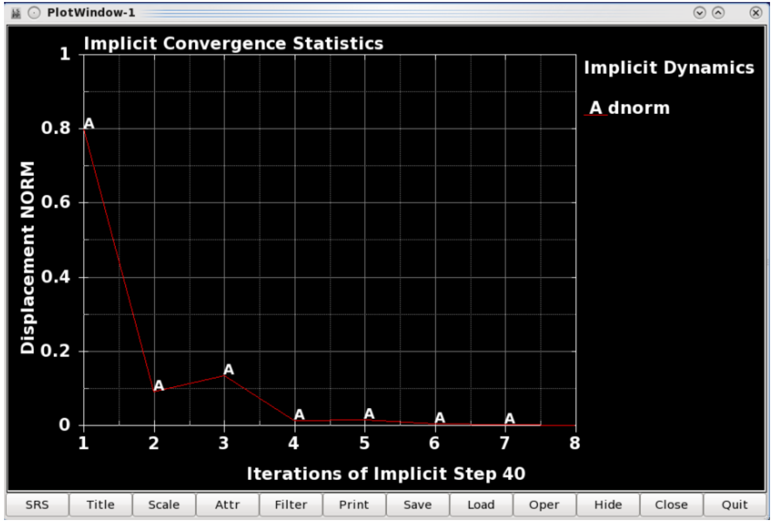
- Organized presentation of d3hsp's content
- For implicit runs: Display of each step's norms
- MISC – d3hsp view



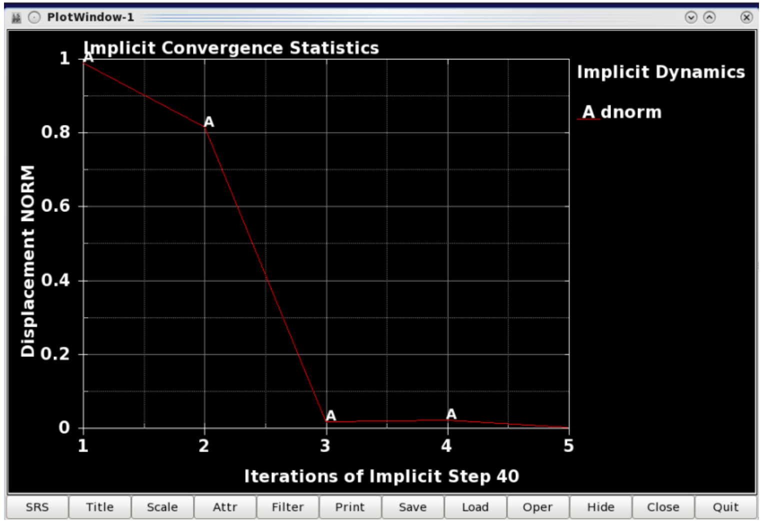
Example: Viewing the development of a disp norm



R8.1



R9.0.1



Outline

- Intro
- R9 Solver
- Walkthrough: NCAC Toyota Yaris model conversion to implicit
- LS-DYNA implicit with AVX2
- Convergence behavior monitoring
- **Summary**

Interesting sites to go

When you need information, help, inspiration, …

- https://www.dynamore.se/en/resources/tips-and-tricks
  - Implicit starter kit including guideline
- Appendix P: LS-DYNA DRAFT Manual
  - A lot of information about LS-DYNA implicit NEW
- www.dynasupport.com
  - Further guidelines, checklists
- www.dynaexamples.com/implicit
  - Application examples (free download)
  - Includes the Yaris models NEW
- support@dynamore.de

Summary

- LS-DYNA R9 solver is a successive enhancement. For running nonlinear implicit problems the R9 solver should be definitely the user first choice. Within the last years the LS-DYNA solver has grown to a powerful tool and it has reached a competitive grade.
- The successful conversion of the CCSA Yaris model demonstrates the capability of the implicit solver. The total effort of bringing the model to a "implicit ready" grade was manageable.
- On current hardware architectures implicit jobs turn around time can be reduced about 10% by using the avx2 executables of LS-DYNA. Considering robust models there is no effect on the results.
- With LSPPs d3hsp and the DYNATool check-convergence powerful tools can help user to learn more about the convergence behavior. A comparison between different versions of a model can be easily made.

THAT YOU

for listening