Optimise Your Simulation Run Times

UK Oasys LS-DYNA Users' Conference 2023

Contents

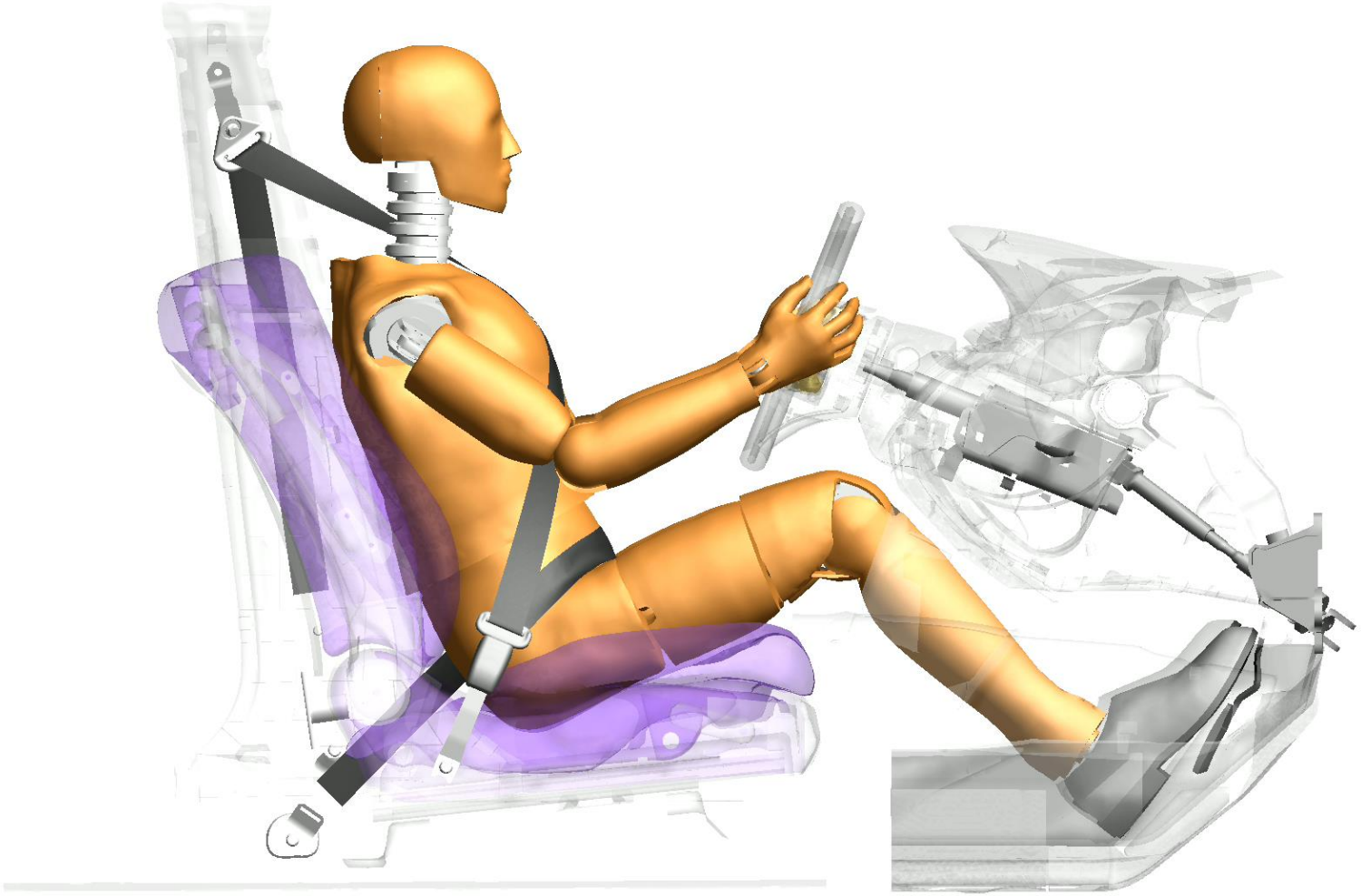
- Influencing factors on run time
- How to check ‘Timing Information’ and ‘Load balance’ across the processors – demo using PRIMER to visualise the data
- How to optimise and/or deal with unevenly loaded MPP analyses using *CONTROL_MPP keywords
- Determining termination time using *SENSORs

Influencing Factors on Run Time

- No. of elements
- Element formulations
- Material definitions
- Contact definitions
- Output - *DATABASE: ASCII, BINARY, HISTORY_* etc
- MPP decomposition methods and control options
- Termination time

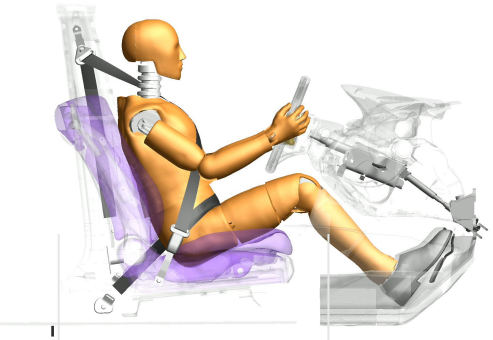
Session focus

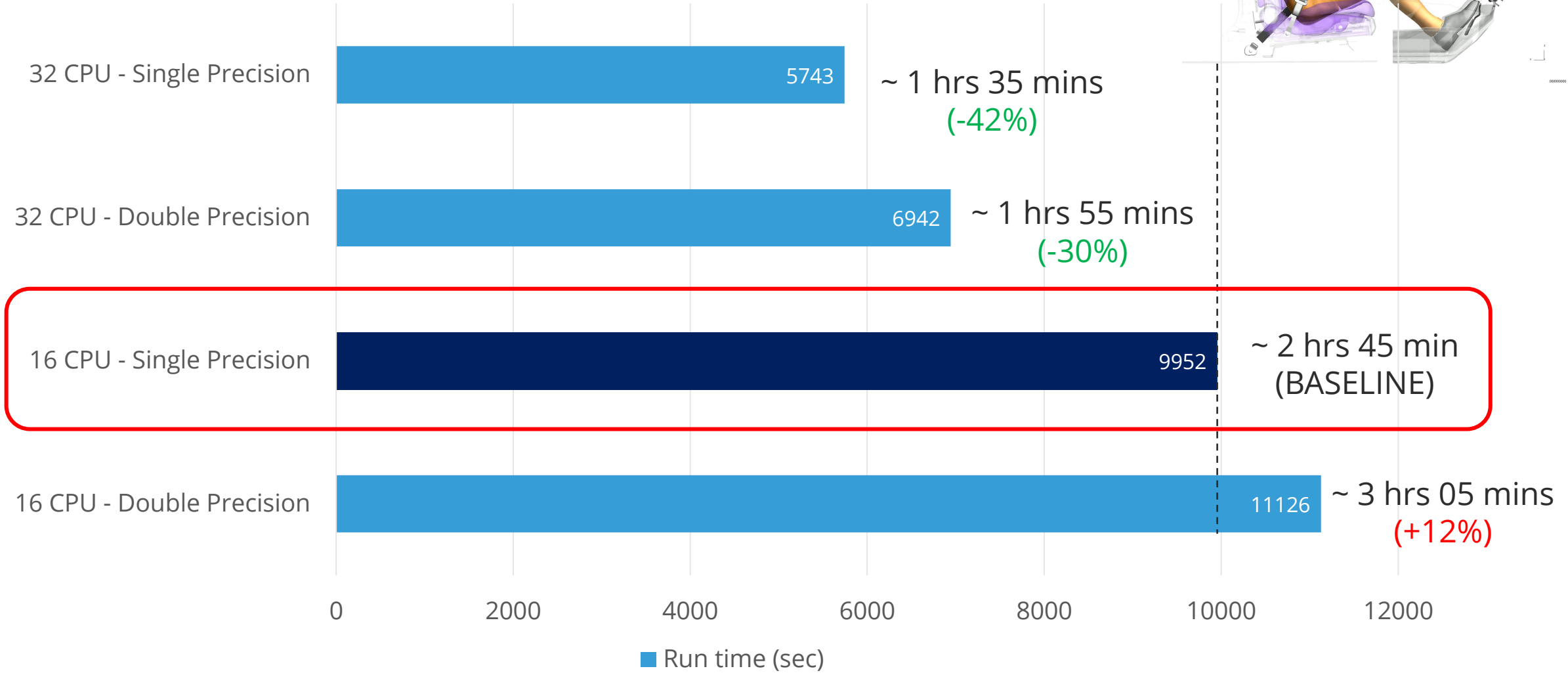
Example Analysis – Sled Test



- 64.8 kph pulse
- ~1e6 elements including an airbag and seat belt
- 100 ms analysis time
- MPP; LS-DYNA version R14.0

Run Time Comparison – CPUs & Precision





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Timing Information – d3hsp/*otf file

```
T i m i n g   i n f o r m a t i o n
                      CPU(seconds)    %CPU  Clock(seconds) %Clock
 ------------------------------------------------------------------
 Keyword Processing ... 1.6072E+01    0.16     1.6291E+01    0.16
   KW Reading ......... 7.7439E-01    0.01     7.9696E-01    0.01
 MPP Decomposition .... 6.9908E+00    0.07     7.2256E+00    0.07
   Init Proc .......... 5.2793E+00    0.05     5.3727E+00    0.05
   Decomposition ...... 9.4677E-01    0.01     9.5707E-01    0.01
   Translation ........ 7.6468E-01    0.01     8.9585E-01    0.01
 Initialization ....... 1.8993E+00    0.02     2.3755E+00    0.02
   Init Proc Phase 1 .. 8.3584E-01    0.01     8.9012E-01    0.01
   Init Proc Phase 2 .. 9.6432E-01    0.01     1.1830E+00    0.01
 Element processing ... 2.7998E+03   28.23     2.8091E+03   28.23
   Solids ............. 1.4946E+03   15.07     1.4996E+03   15.07
   Shells ............. 7.0014E+02    7.06     7.0250E+02    7.06
   Beams .............. 4.4541E+00    0.04     4.5721E+00    0.05
   E Other ............ 5.1675E+02    5.21     5.1830E+02    5.21
 Binary databases ..... 4.5420E+01    0.46     4.5680E+01    0.46
 ASCII database ....... 2.7400E+01    0.28     3.0556E+01    0.31
 Contact algorithm .... 4.7413E+03   47.80     4.7541E+03   47.77
   Interf. ID   1000001 2.3987E+02    2.42     2.4050E+02    2.42
   Interf. ID  46000001 8.6475E+00    0.09     8.6859E+00    0.09
   Interf. ID         1 8.0974E+02    8.16     8.1193E+02    8.16
                        …
 Rigid Bodies ......... 8.1610E+02    8.23     8.1814E+02    8.22
 Restraint system ..... 3.9424E-01    0.00     4.0280E-01    0.00
 Time step size ....... 1.9217E+02    1.94     1.9271E+02    1.94
 Nodal constraints .... 1.8616E-01    0.00     1.8595E-01    0.00
 Bnd prescribed opt ... 1.9355E+00    0.02     1.9236E+00    0.02
 Group force file ..... 3.0912E-01    0.00     3.7209E-01    0.00
 Others ............... 6.6461E+02    6.70     6.6631E+02    6.70
   Force Sharing ...... 6.6197E+02    6.67     6.6361E+02    6.67
 Misc. 1 .............. 3.8086E+02    3.84     3.8212E+02    3.84
   Scale Masses ....... 5.6450E+01    0.57     5.6594E+01    0.57
   Force Constraints .. 1.8644E-01    0.00     2.1403E-01    0.00
   Force to Accel ..... 1.4185E+01    0.14     1.4199E+01    0.14
   Constraint Sharing . 1.2857E+01    0.13     1.2891E+01    0.13
   Update RB nodes .... 9.8028E+00    0.10     9.8161E+00    0.10
 Misc. 2 .............. 5.8716E+01    0.59     5.8867E+01    0.59
 Misc. 3 .............. 9.7918E+01    0.99     9.8584E+01    0.99
 Misc. 4 .............. 6.6845E+01    0.67     6.7111E+01    0.67
                        …
 ------------------------------------------------------------------
 T o t a l s           9.9189E+03  100.00     9.9521E+03  100.00
```

Run time data taken from the d3hsp/*otf file as shown:

Element processing – material/element calculation

Contact algorithm – all contacts in the model breakdown by contact ID

T o t a l s – total analysis run time (clock time) corresponds to time in the first CPU [mes0000]

```
Problem time       =    1.0000E-01
Problem cycle      =    158731
Total CPU time     =      9919 seconds (   2 hours 45 minutes 19 seconds)
CPU time per zone cycle  =          63.774 nanoseconds
Clock time per zone cycle=          63.955 nanoseconds

Parallel execution with     16 MPP proc
NLQ used/max                96/    96
```

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MPP - Load Balancing Information

mes* - timing information for each processor

'Averages' at the end of mes* files is a copy of the d3hsp/*otf 'Timing information'.

cont_profile.csv/.xy – Contact calculation time breakdown for each contact and processor

CSV for contact profile - excluded tie and transducer
Clock (seconds)

Contact ID

Processor	1000001	1	2	3	4	5	70000010	50100003	50100004	50100005	50100006	50100007	50100008	50100009	50100010
1	0.00E+00	6.70E+02	0.00E+00	0.00E+00	9.69E+01	2.19E+03	0.00E+00	2.73E+02	1.18E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	6.74E+02	0.00E+00	0.00E+00	1.32E+02	1.87E+03	0.00E+00	5.43E+02	1.17E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	0.00E+00	6.72E+02	0.00E+00	0.00E+00	1.85E+02	1.81E+03	0.00E+00	4.87E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
...	0.00E+00	6.72E+02	0.00E+00	1.80E+03	1.89E+02	9.03E+00	0.00E+00	4.87E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	9.87E+02	6.95E+02	0.00E+00	1.71E+03	1.23E+02	9.69E+00	1.32E+02	6.43E+02	1.72E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	9.98E+02	6.96E+02	0.00E+00	1.72E+03	1.31E+02	7.41E+00	1.27E+02	6.20E+02	1.08E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7.16E+02	6.70E+02	0.00E+00	3.42E+02	1.91E+02	0.00E+00	1.22E+02	2.27E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7.15E+02	6.70E+02	0.00E+00	3.33E+02	1.93E+02	0.00E+00	1.27E+02	2.26E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	0.00E+00	6.71E+02	4.15E+02	1.15E+03	1.91E+02	0.00E+00	0.00E+00	1.21E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	0.00E+00	6.70E+02	4.67E+02	1.15E+03	1.90E+02	0.00E+00	0.00E+00	1.21E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

load_profile.csv/.xy – General load breakdown for each processor

CSV for general cost profile
Clock (seconds)

Type

Processor	Solids	Shells	Tshells	Beams	SPH	Time-Step	Contact	Rigid-Bdy	Others	Misc1	Misc2	Misc3	Misc4
1	1.59E+03	2.13E+02	0.00E+00	2.80E-01	0.00E+00	7.41E+02	4.46E+03	8.74E+02	9.07E+00	3.51E+02	9.86E+00	1.12E+02	1.55E+01
2	1.48E+03	2.95E+02	0.00E+00	5.45E-01	0.00E+00	2.56E+02	4.53E+03	8.74E+02	1.30E+01	4.13E+02	1.66E+01	1.06E+02	2.20E+01
3	1.50E+03	1.11E+02	0.00E+00	3.70E-01	0.00E+00	3.89E+02	3.21E+03	8.75E+02	1.26E+03	4.77E+02	7.43E+00	1.15E+02	1.34E+01
...	1.49E+03	1.19E+02	0.00E+00	0.00E+00	0.00E+00	3.91E+02	3.21E+03	8.78E+02	1.26E+03	4.81E+02	7.79E+00	1.15E+02	1.35E+01
	6.21E+02	1.11E+03	0.00E+00	5.63E-01	0.00E+00	3.90E+02	4.32E+03	8.89E+02	1.23E+02	4.92E+02	4.79E+01	7.43E+01	1.10E+02
	6.17E+02	1.12E+03	0.00E+00	6.18E-01	0.00E+00	3.90E+02	4.32E+03	8.88E+02	1.22E+02	4.91E+02	4.71E+01	7.53E+01	1.10E+02
	9.14E+02	1.01E+03	0.00E+00	4.91E-01	0.00E+00	2.45E+02	4.40E+03	1.34E+02	8.75E+02	4.14E+02	2.68E+01	9.54E+01	1.07E+02
	8.89E+02	9.80E+02	0.00E+00	4.77E-01	0.00E+00	2.53E+02	4.40E+03	1.33E+02	8.80E+02	4.15E+02	2.46E+01	9.78E+01	1.05E+02
	1.28E+03	4.51E+02	0.00E+00	5.78E+00	0.00E+00	2.55E+02	3.75E+03	9.72E+02	6.99E+02	4.07E+02	7.77E+00	1.14E+02	1.32E+01
	1.31E+03	4.48E+02	0.00E+00	4.30E+00	0.00E+00	2.63E+02	3.81E+03	9.77E+02	6.40E+02	4.07E+02	7.06E+00	1.15E+02	1.23E+01
	1.41E+03	4.49E+02	0.00E+00	7.73E+00	0.00E+00	2.53E+02	3.81E+03	1.59E+03	2.06E+01	4.08E+02	2.13E+01	1.01E+02	2.46E+01

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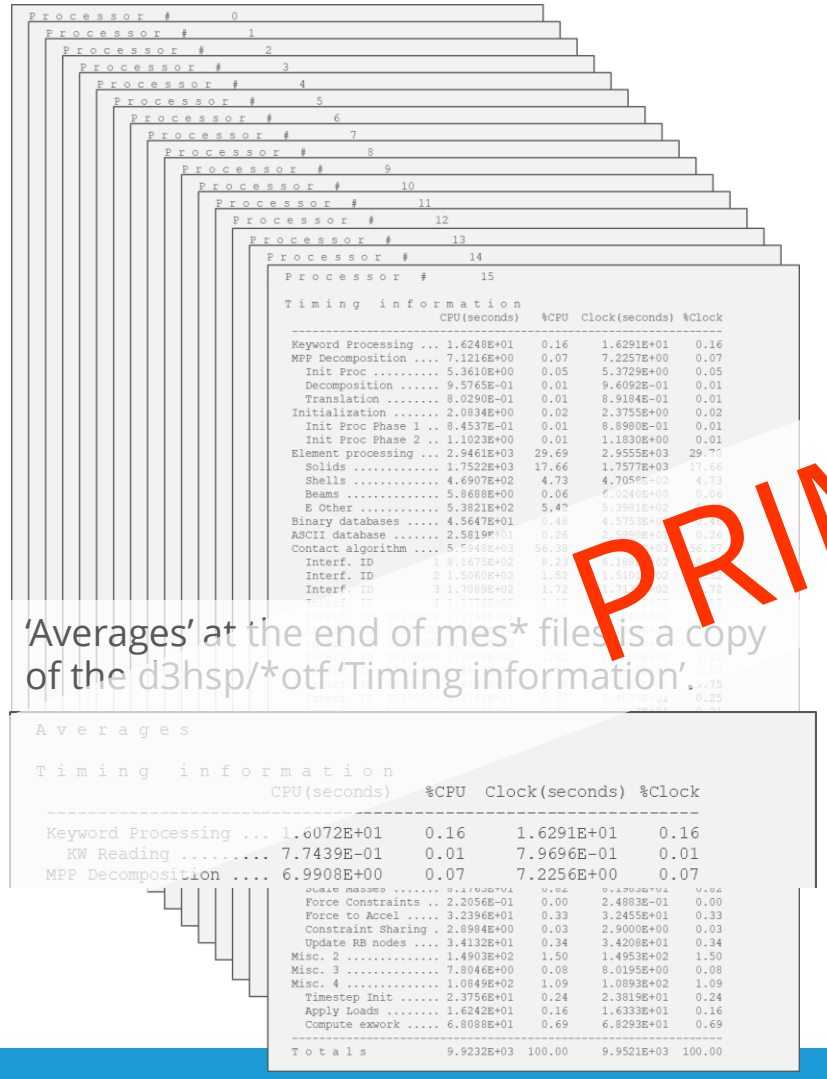
Load Balancing Information

mes* - timing information for each processor



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Clock (seconds)

Contact ID

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1	0.00E+00	6.70E+02	0.00E+00	0.00E+00	9.69E+01	2.19E+03	0.00E+00	2.73E+02	1.18E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	6.74E+02	0.00E+00	0.00E+00	1.32E+02	1.87E+03	0.00E+00	5.43E+02	1.17E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	0.00E+00	6.72E+02	0.00E+00	0.00E+00	1.85E+02	1.81E+03	0.00E+00	4.87E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
...	0.00E+00	6.72E+02	0.00E+00	1.80E+03	1.89E+02	9.[illegible]	0.00E+00	4.87E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	9.87E+02	6.95E+02	0.00E+00	1.71E+03	1.21E+02	1.69E+02	1.32E+02	6.43E+02	1.72E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	9.98E+02	6.96E+02	0.00E+00	1.72E+03	1.31E+02	1.81E+02	1.27E+02	6.20E+02	1.08E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7.16E+02	6.70E+02	0.00E+00	3.42E+02	1.91E+02	0.00E+00	1.22E+02	2.27E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7.15E+02	6.[illegible]E+02	0.00E+00	3.[illegible]E+02	1.[illegible]E+02	0.00E+00	1.27E+02	2.26E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	0.00E+00	6.[illegible]E+02	0.00E+00	1.15E+03	1.91E+02	0.00E+00	0.00E+00	1.21E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	0.00E+00	6.[illegible]E+02	0.00E+00	1.15E+03	1.90E+02	0.00E+00	0.00E+00	1.21E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

load_profile.csv/.xy – General load breakdown for each processor

CSV for general cost profile
Clock (seconds)

Type

Processor	Solids	Shells	Tshells	Beams	SPH	Time-Step	Contact	Rigid-Bdy	Others	Misc1	Misc2	Misc3	Misc4
1	1.59E+03	2.13E+02	0.00E+00	2.80E-01	0.00E+00	7.41E+02	4.46E+03	8.74E+02	9.07E+00	3.51E+02	9.86E+00	1.12E+02	1.55E+01
2	1.48E+03	2.95E+02	0.00E+00	5.45E-01	0.00E+00	2.56E+02	4.53E+03	8.74E+02	1.30E+01	4.13E+02	1.66E+01	1.06E+02	2.20E+01
3	1.50E+03	1.11E+02	0.00E+00	3.70E-01	0.00E+00	3.89E+02	3.21E+03	8.75E+02	1.26E+03	4.77E+02	7.43E+00	1.15E+02	1.34E+01
...	1.49E+03	1.19E+02	0.00E+00	0.00E+00	0.00E+00	3.91E+02	3.21E+03	8.78E+02	1.26E+03	4.81E+02	7.79E+00	1.15E+02	1.35E+01
	6.21E+02	1.11E+03	0.00E+00	5.63E-01	0.00E+00	3.90E+02	4.32E+03	8.89E+02	1.23E+02	4.92E+02	4.79E+01	7.43E+01	1.10E+02
	6.17E+02	1.12E+03	0.00E+00	6.18E-01	0.00E+00	3.90E+02	4.32E+03	8.88E+02	1.22E+02	4.91E+02	4.71E+01	7.53E+01	1.10E+02
	9.14E+02	1.01E+03	0.00E+00	4.91E-01	0.00E+00	2.45E+02	4.40E+03	1.34E+02	8.75E+02	4.14E+02	2.68E+01	9.54E+01	1.07E+02
	8.89E+02	9.80E+02	0.00E+00	4.77E-01	0.00E+00	2.53E+02	4.40E+03	1.33E+02	8.80E+02	4.15E+02	2.46E+01	9.78E+01	1.05E+02
	1.28E+03	4.51E+02	0.00E+00	5.78E+00	0.00E+00	2.55E+02	3.75E+03	9.72E+02	6.99E+02	4.07E+02	7.77E+00	1.14E+02	1.32E+01
	1.31E+03	4.48E+02	0.00E+00	4.30E+00	0.00E+00	2.63E+02	3.81E+03	9.77E+02	6.40E+02	4.07E+02	7.06E+00	1.15E+02	1.23E+01
	1.41E+03	4.49E+02	0.00E+00	7.73E+00	0.00E+00	2.53E+02	3.81E+03	1.59E+03	2.06E+01	4.08E+02	2.13E+01	1.01E+02	2.46E+01

MPP Control Options

***CONTROL_MPP_DECOMPOSITION_TRANSFORMATION**

***CONTROL_MPP_DECOMPOSITION_AUTOMATIC**

Decompose by domain

***CONTROL_MPP_REBALANCE**

Load rebalancing

***CONTROL_MPP_DECOMPOSITION_CONTACT_DISTRIBUTE**

***CONTROL_MPP_DECOMPOSITION_ARRANGE_PARTS**

Decompose by element

Visualising Domain Decomposition

- 2 options to visualise the decomposition of the element domains:

*CONTROL_MPP_DECOMPOSITION_SHOW

- Outputs one plot state in **d3plot** file then terminates the analysis.
- Each part correspond to the group of solids, shells, beams, thick shells, or SPH particles assigned to a particular processor

*CONTROL_MPP_DECOMPOSITION_OUTDECOMP

- Does not terminate the analysis early. Instructs LS-DYNA to output a settings file that contours elements according to processor ID.
  - ITYPE EQ.1: database in LS-PrePost format:
    decomp_parts.lsprepost (binary)
  - ITYPE EQ.2: database in animator format:
    decomp_parts.ses (ASCII)

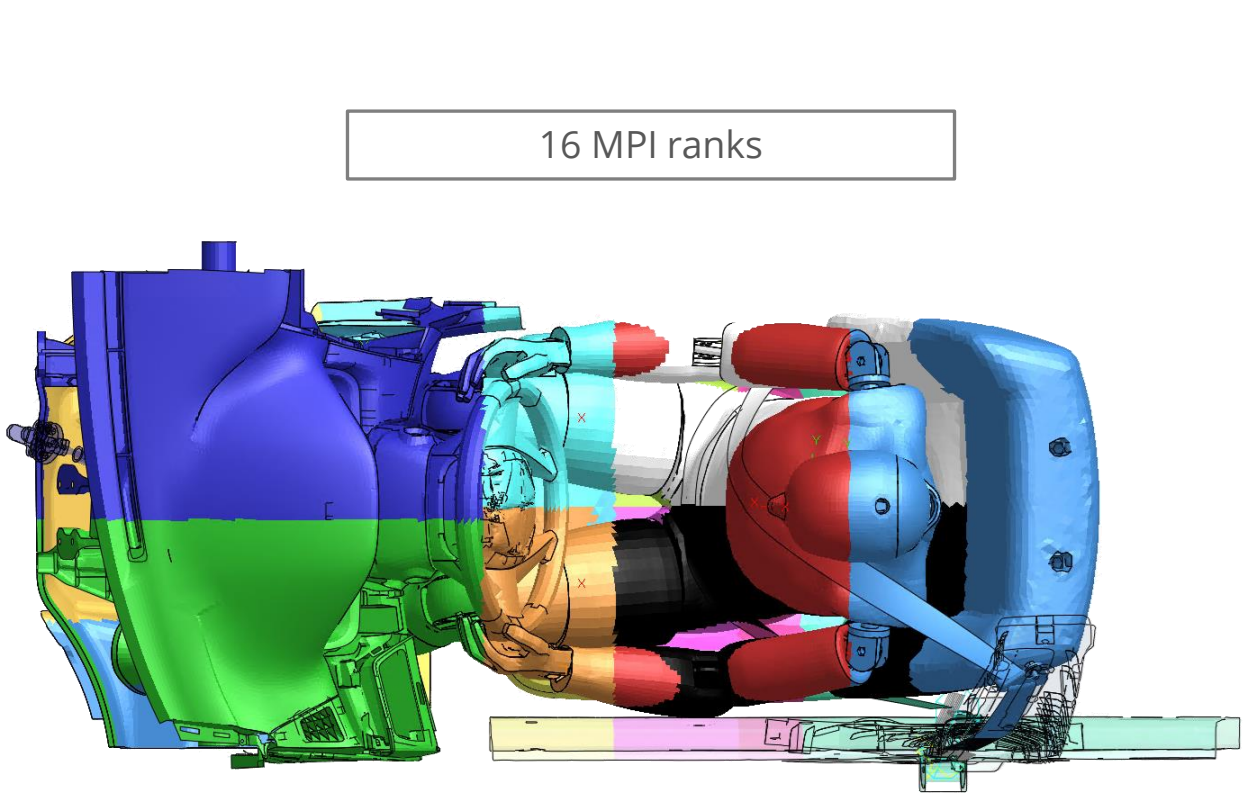
Command in partition file (pfile):
decomp { OUTDECOMP “ITYPE” }

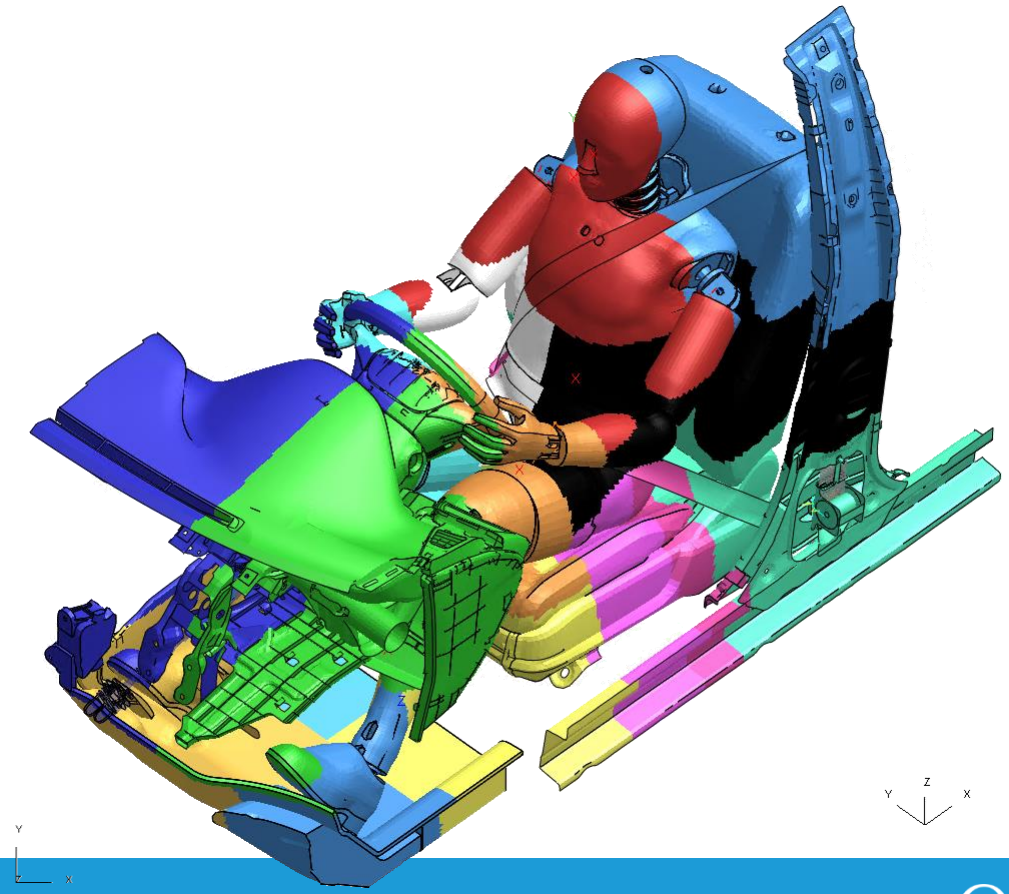
- *When ITYPE EQ. 1, the elements assigned to any particular core can be viewed and animate by LS-PrePost by (1) reading the d3plot data, and then (2) selecting Models > Views > MPP > Load > decomp_parts.lsprepost*

MPP Domain Decomposition – RCB

- Recursive Coordinate Bisection (RCB) is the default method.
- Recursively bisects the model about a plane perpendicular to the longest dimension.
- Default algorithm tends to generate cuboidal domains aligned along the coordinates axes.

16 MPI ranks

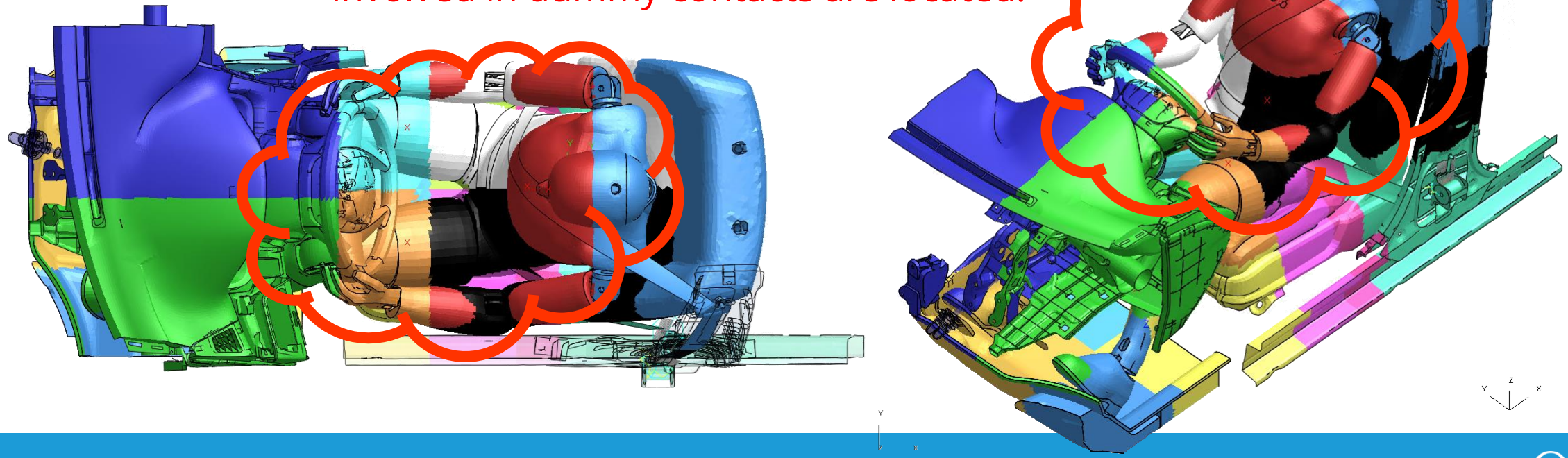




MPP Domain Decomposition – RCB

- Recursive Coordinate Bisection (RCB) is the default method.
- Recursively bisects the model about a plane perpendicular to the longest dimension.
- Default algorithm tends to generate cuboidal domains aligned along the coordinates axes.

Most costly area is in the centre, where the airbag deploys, and elements involved in dummy contacts are located.



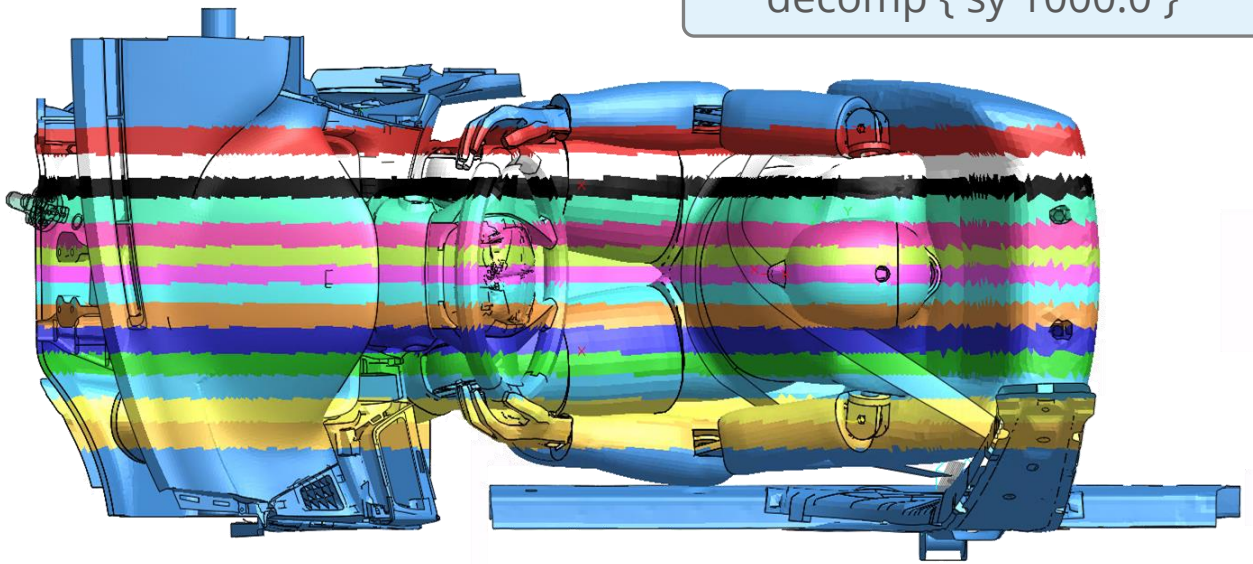
MPP Domains – Special Decompositions

- User defined options to prescribe a set of coordinate transformation functions, which are applied before the model is decomposed (see Appendix O: LS-DYNA MPP User Guide).

***CONTROL_MPP_DECOMPOSITION_TRANSFORMATION**

- In this example, the following line scales the Y axis of a model by a factor of 1000.

Command in partition file (pfile):
decomp { sy 1000.0 }

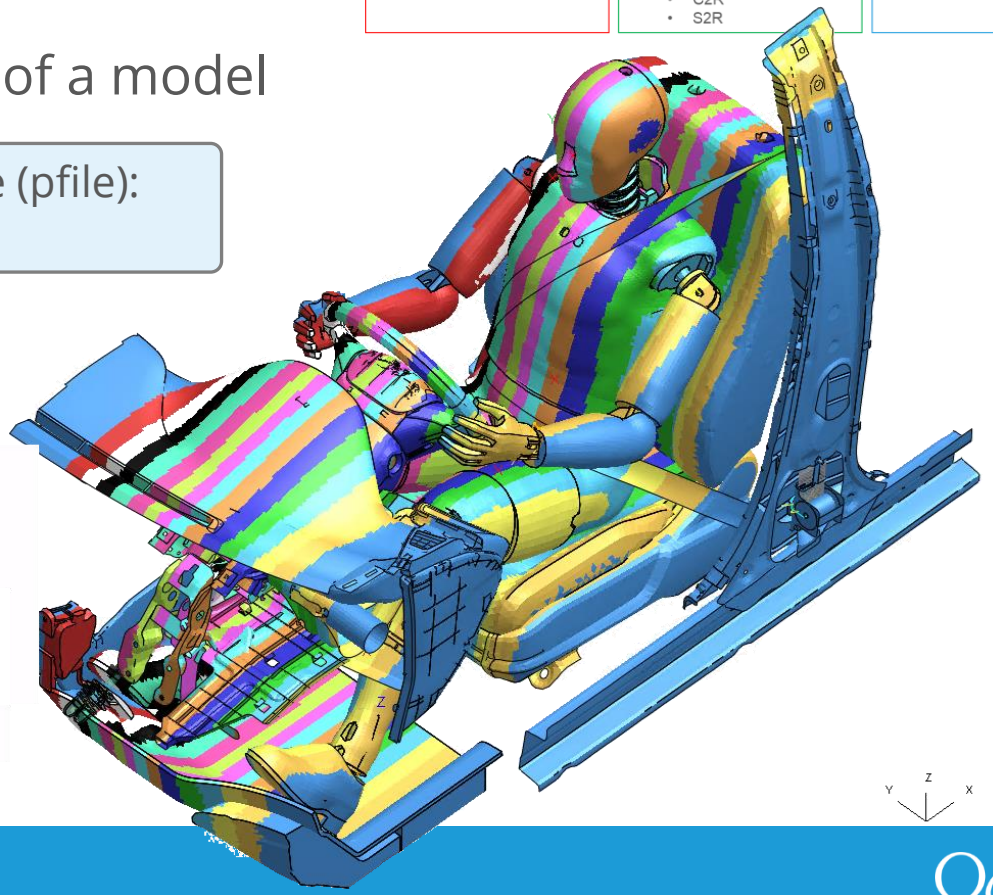


```
decomposition {
region { <region specifiers> <transformation> <grouping> }
region { <region specifiers> <transformation> <grouping> }
<transformation>
}
```

<region specifiers> are:
- box
- sphere
- cylinder
- parts
- partsets
- silist

<transformation specifiers> are:
- local
- sx t, sy t, sz t
- rx t, ry t, rz t
- txyz x y z
- mat
- 3vec
- C2R
- S2R

<grouping specifiers> are:
- lumped
- together (R11.0)
- nproc *n frstp* (R11.0)



MPP Domains – Special Decompositions

- User defined options to prescribe a set of coordinate transformation functions, which are applied before the model is decomposed (see Appendix O: LS-DYNA MPP User Guide).

***CONTROL_MPP_DECOMPOSITION_TRANSFORMATION**

- In this example, the following line scales the Y axis of a model by a factor of 1000.

```
decomposition {
region { <region specifiers> <transformation> <grouping> }
region { <region specifiers> <transformation> <grouping> }
<transformation>
}
```

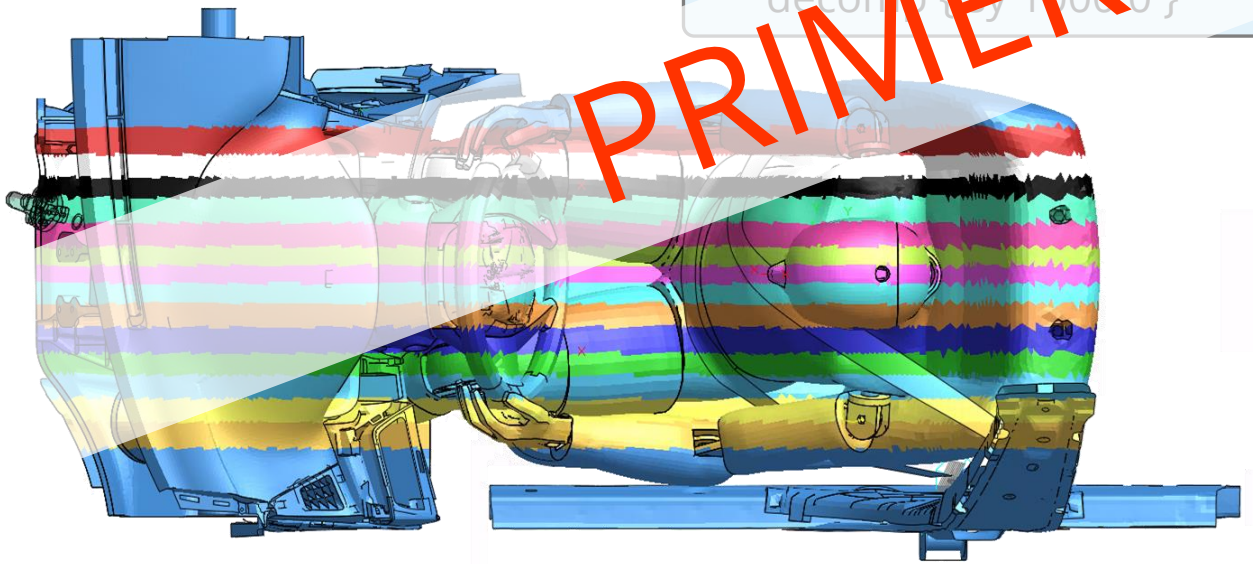
<region specifiers> are:
- box
- sphere
- cylinder
- parts
- partsets
- silist

<transformation specifiers> are:
- local
- sx t, sy t, sz t
- rx t, ry t, rz t
- txyz x y z
- mat
- 3vec
- C2R
- S2R

<grouping specifiers> are:
- lumped
- together (R11.0)
- nproc *n frstp* (R11.0)

Command in partition file (prile):
decomp { sy 1000.0 }

PRIMER Demo



MPP Decomposition Automatic

***CONTROL_MPP_DECOMPOSITION_AUTOMATIC**

- There are no input parameters.
- The existence of this keyword triggers the automated decomposition.
- This option should not be used if there is more than one occurrence of any of the following options in the model:

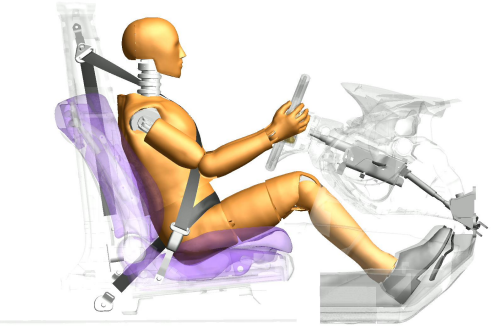
  *INITIAL_VELOCITY

  *CHANGE_VELOCITY

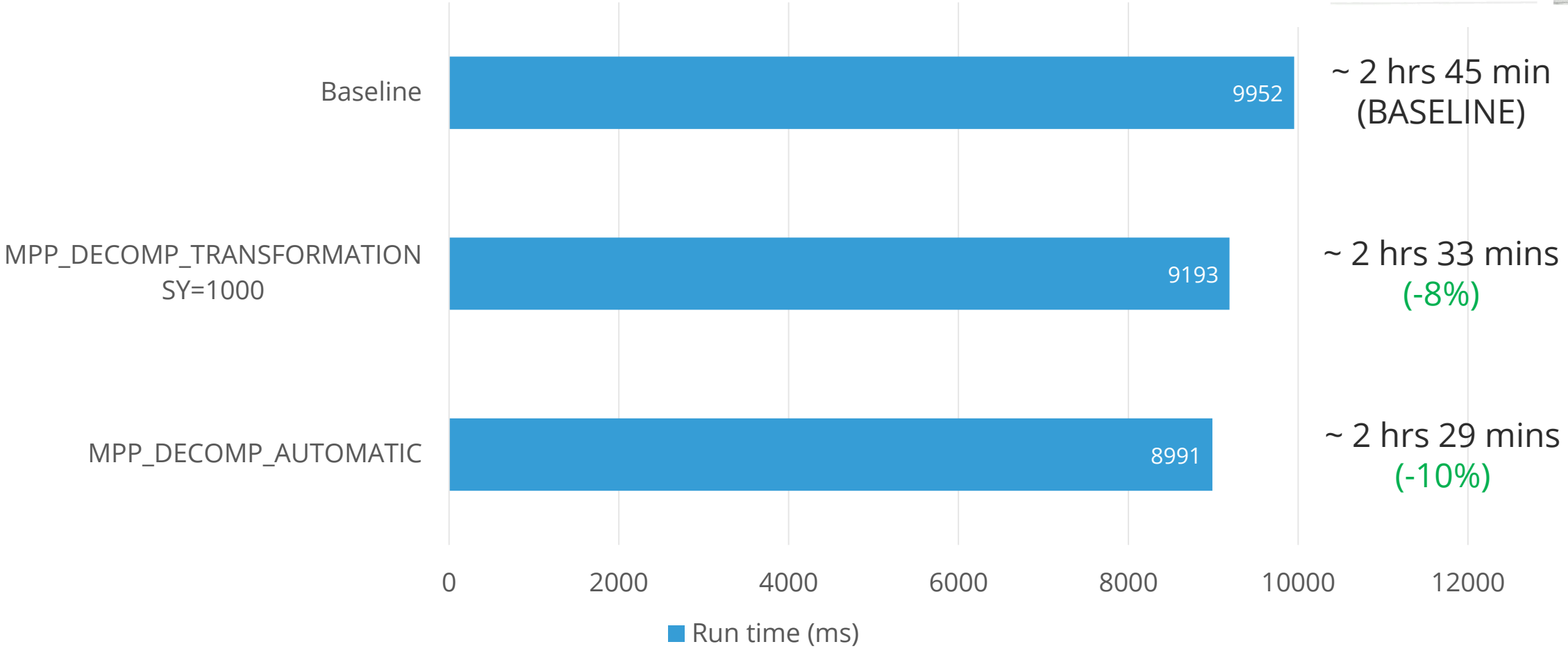
  *BOUNDARY_PRESCRIBED_MOTION
- And the following control card must not be used:

  *CONTROL_MPP_DECOMPOSITION_TRANSFORMATION

Run Time Comparison – Domain Decomposition



16 CPU; Single Precision; R14.0; 100 ms



Load Rebalancing

- Initial decomposition based on different types of elements and material models, and the domains are persevered throughout the analysis.
- Inaccuracy in elements costs during decomposition, and changes in material computational costs as elements distort can lead to computational imbalance.
- Dynamic load balancing with specific defined parameters can be achieved with the keyword:

***CONTROL_MPP_REBALANCE**

- NCYCLE: Number of cycles between rebalance steps (optional);
- THRES: Percent threshold for rebalancing when performing in-core adaptivity.

THRES = 80.0 was used.

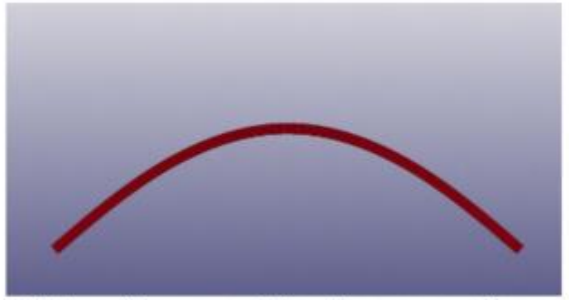


Fig.3: Initial, mid run, and final beam configurations

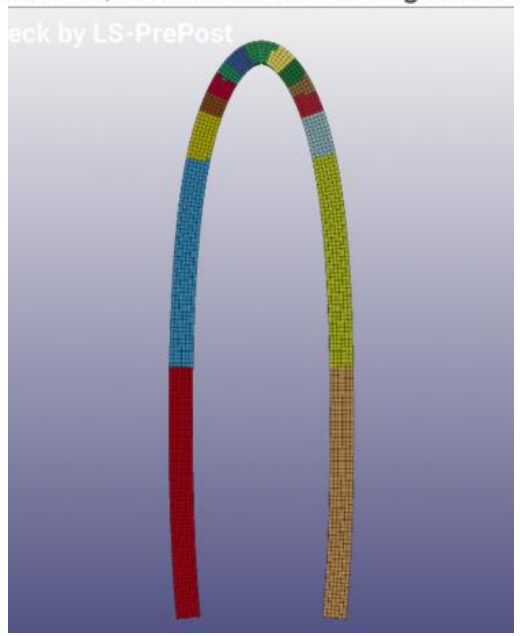
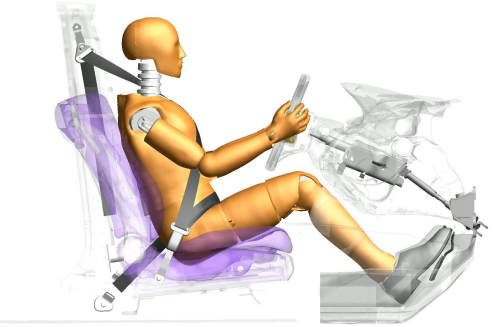
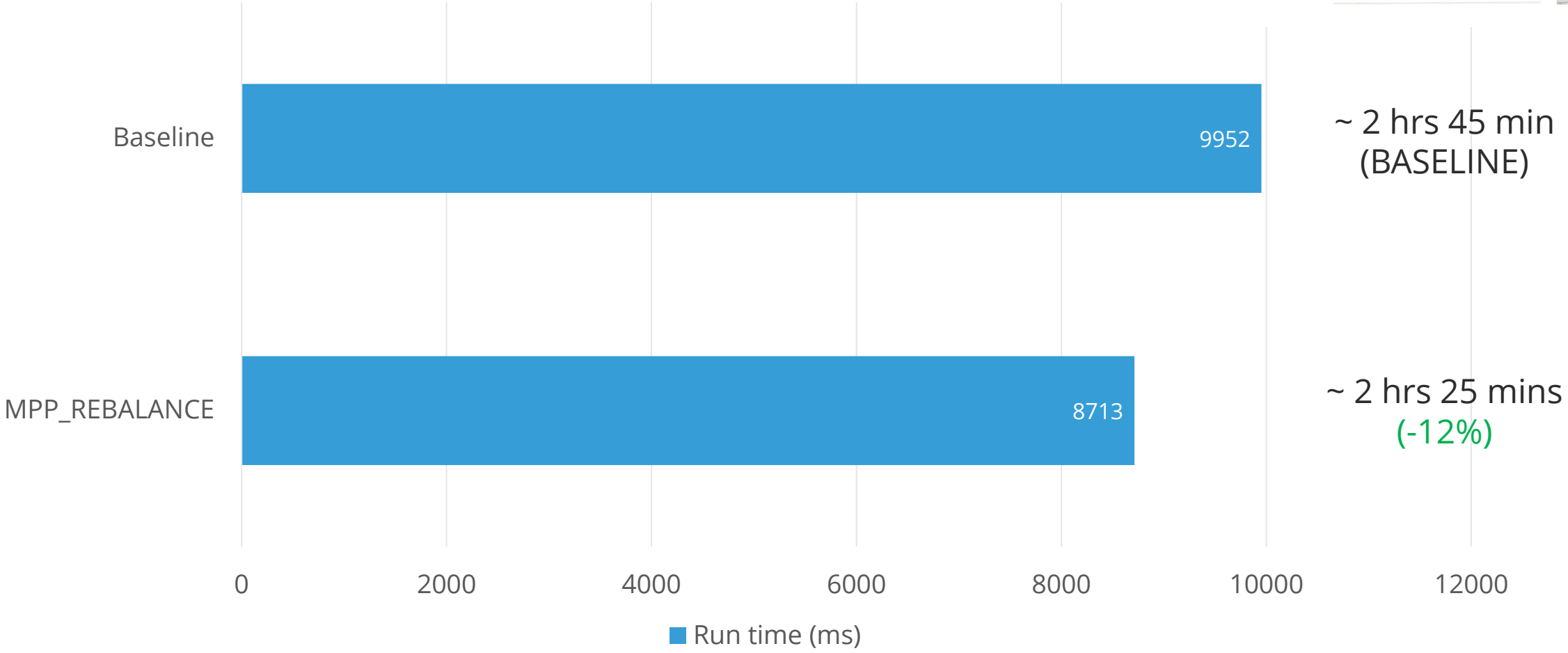


Fig.4: Final decomposition

Run Time Comparison – Contact & Rebalance



16 CPU; Single Precision; R14.0; 100 ms

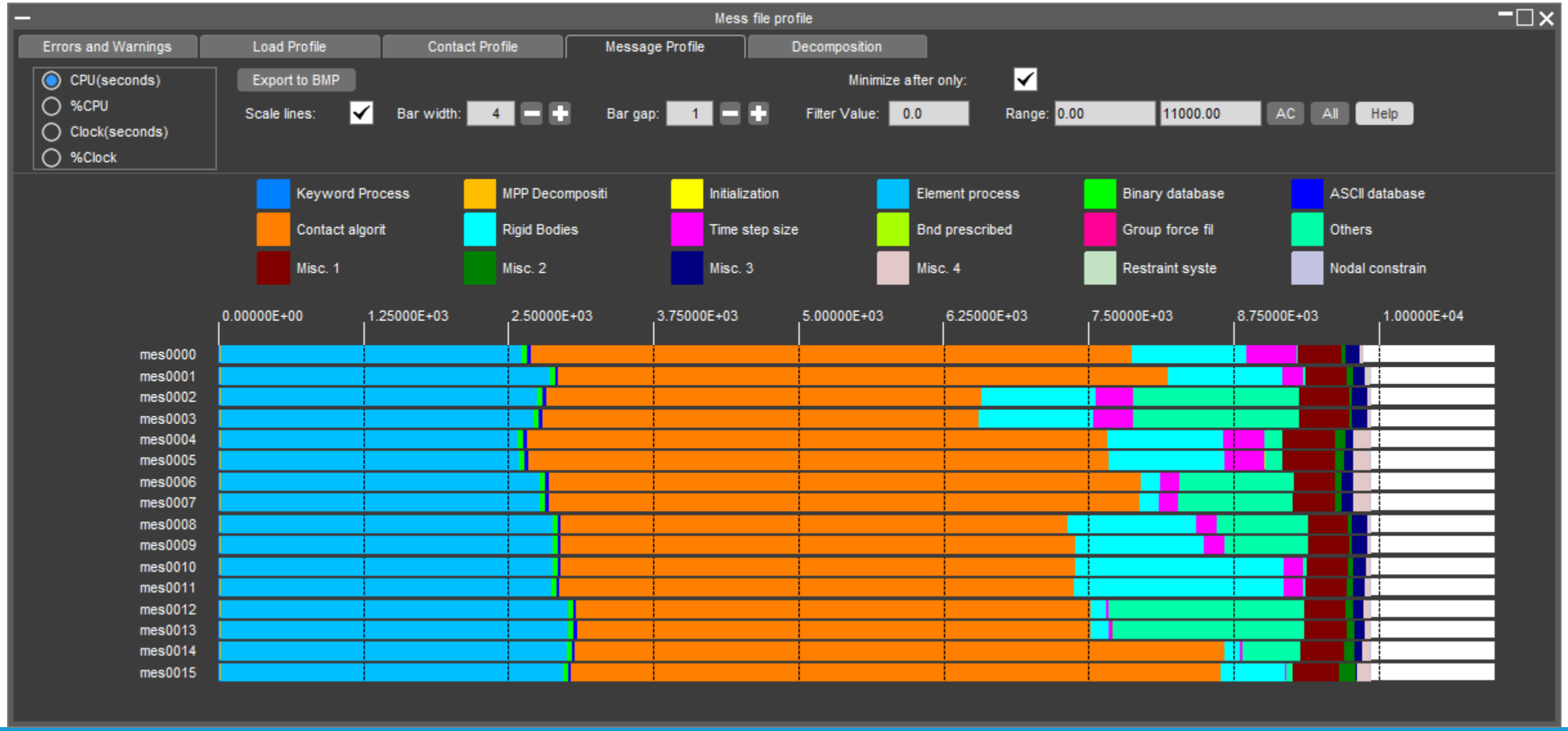


~ 2 hrs 45 min
(BASELINE)

~ 2 hrs 25 mins
(-12%)

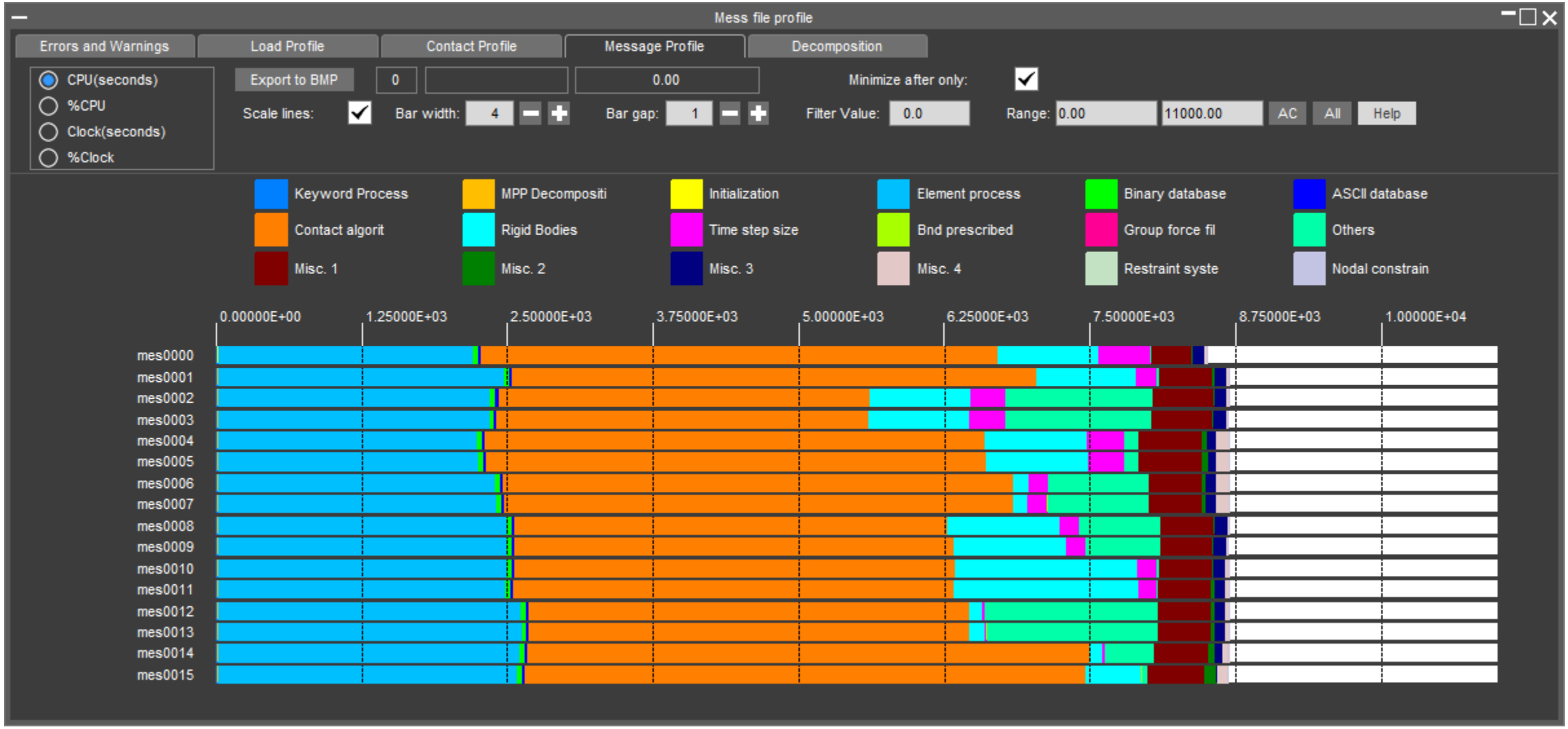
Baseline – Message Profile

Run time: 9952 s

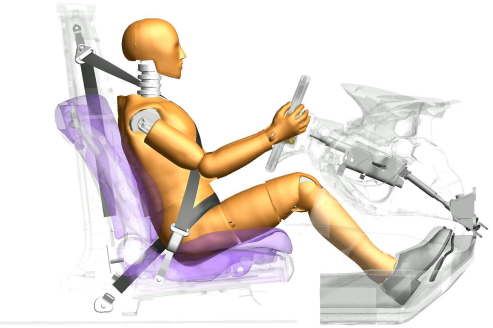


Rebalance – Message Profile

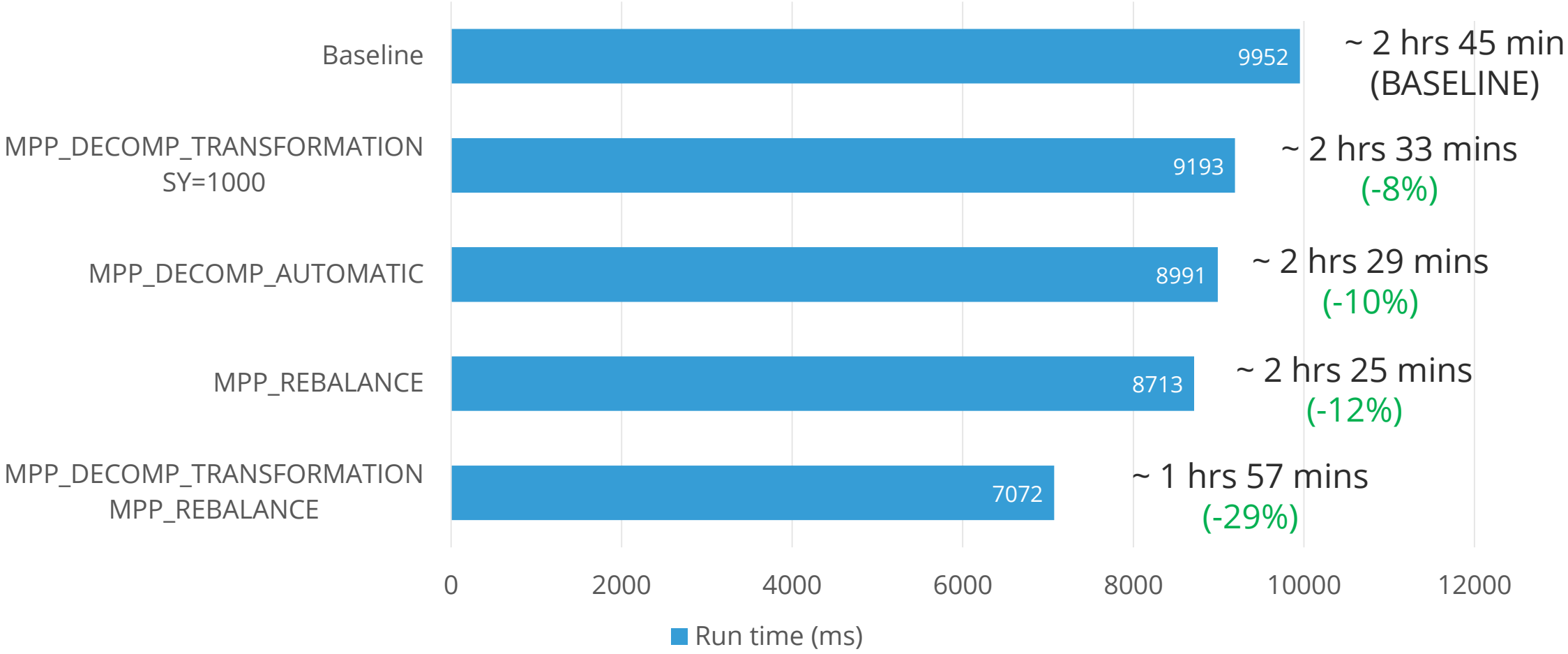
Run time: 8713 s



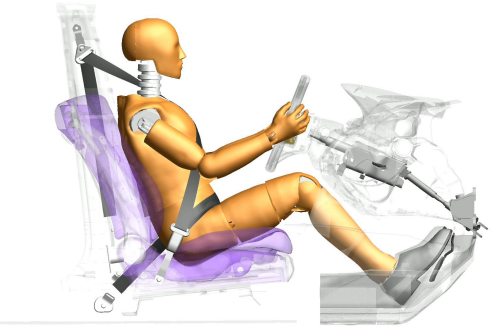
Run Time Comparison – Studies Summary



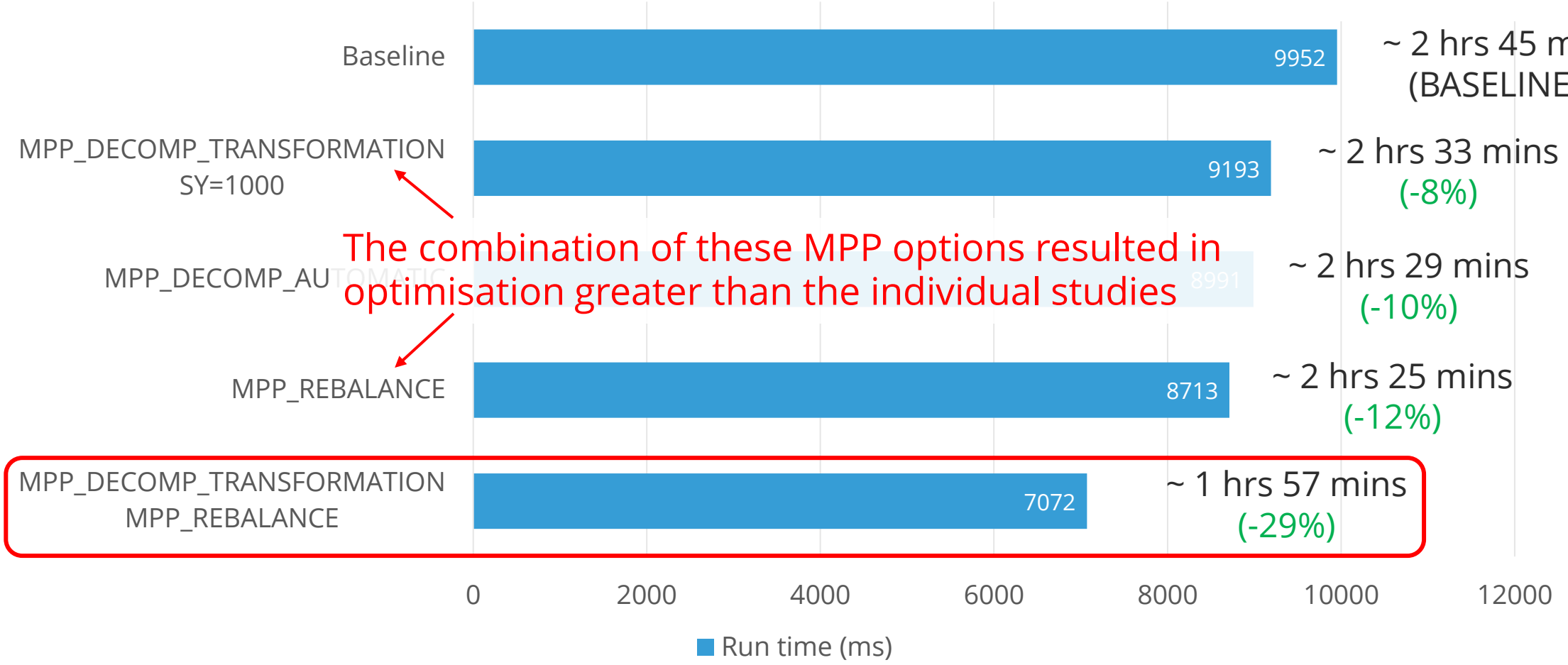
16 CPU; Single Precision; R14.0; 100 ms



Run Time Comparison – Studies Summary



16 CPU; Single Precision; R14.0; 100 ms



The combination of these MPP options resulted in optimisation greater than the individual studies

MPP Decomposition Arrange Parts

*CONTROL_MPP_DECOMPOSITION_ARRANGE_PARTS

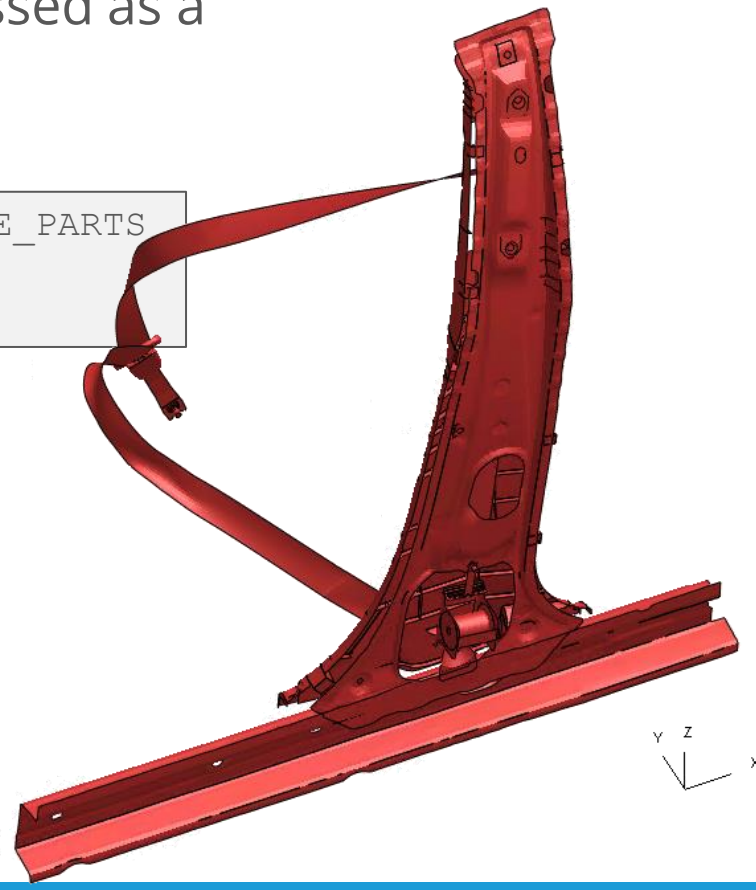
- Distribute certain part(s)/part set(s) to all processors, or to a single processor.
- This keyword supports multiple entries. Each entry is be processed as a separate region for decomposition.

TYPE	PFILE EQUIVALENT
0	region { parts PID nproc NPROC FRSTP }
1	region { partsets PSID nproc NPROC FRSTP }
10	region { parts PID lumped }
11	region { partsets PSID lumped }
20	region { parts PID together }
21	region { partsets PSID together }

```
*CONTROL_MPP_DECOMPOSITION_ARRANGE_PARTS
$:      id      type
  70000003        11
```

In the next example, a part set consisting the B-pillar and the seat belt was lumped into a single processor.

The load balance became less even, and run time increased.



Decomposition Contact Distribute

- Distribute contact interface(s) across all processors, which may lead to better load balance for large contact interfaces.
- The **elements involved** in the specified contacts are decomposed across the processors.
- Each processor is assigned several disjointed portions of the input, which will **increase communications** somewhat. However, this can be offset by **improved load balance** for the contact.

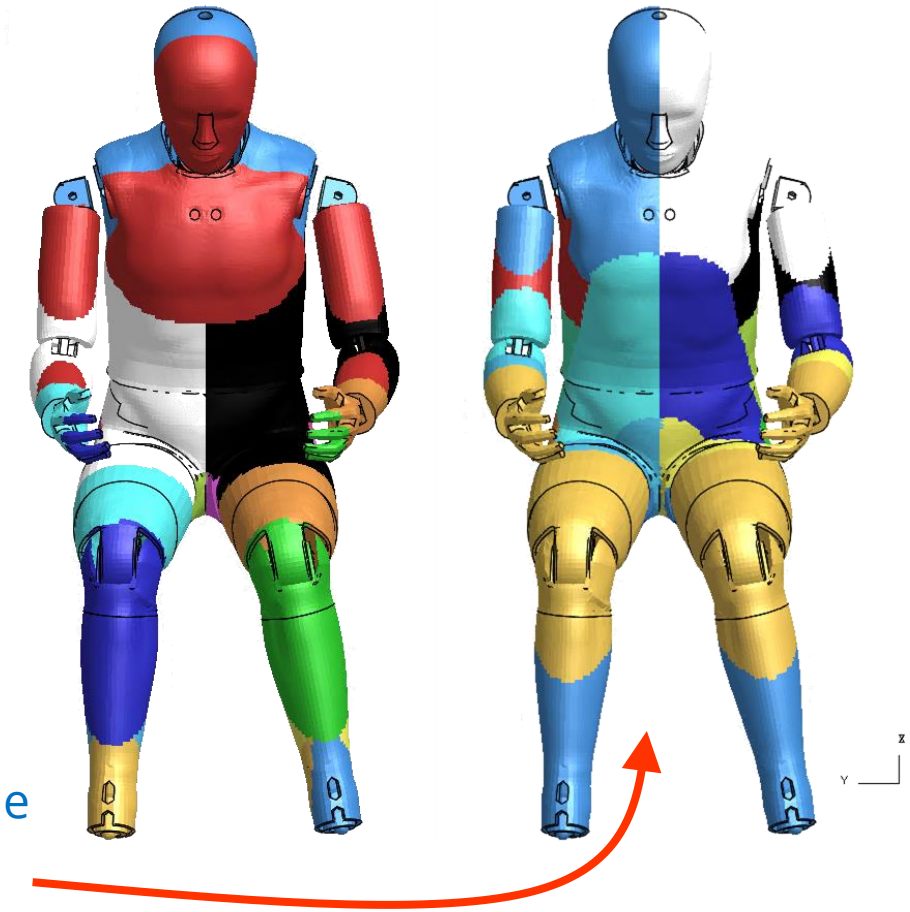
***CONTROL_MPP_DECOMPOSITION_CONTACT_DISTRIBUTE**

- ID[1 – 5]: Contact interface ID to distribute, up to 5.

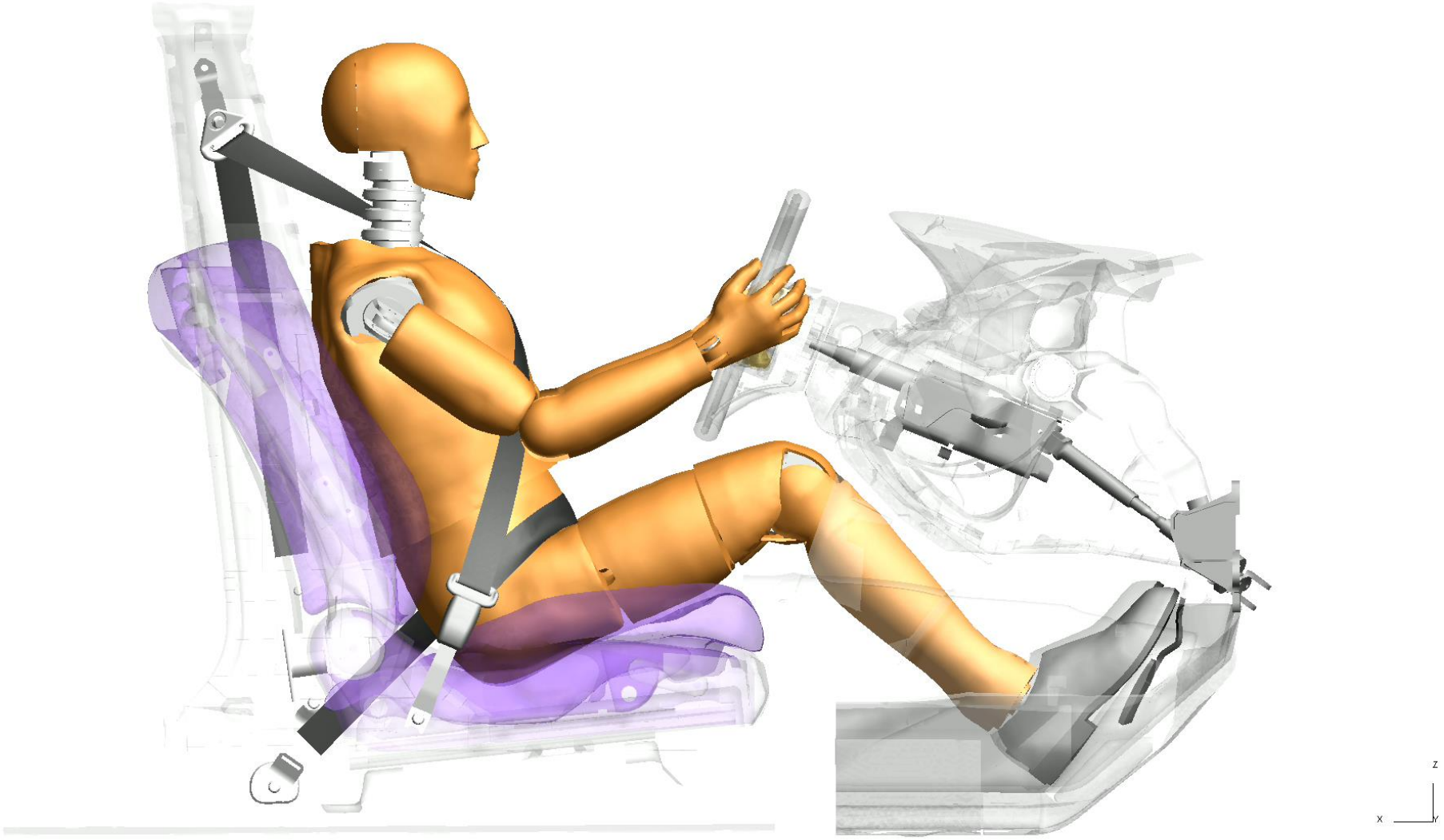
Distributing the most expensive contact – dummy automatic single surface, had negligible effect on run time (2% decrease).

Baseline

Distributed Dummy single surface contact



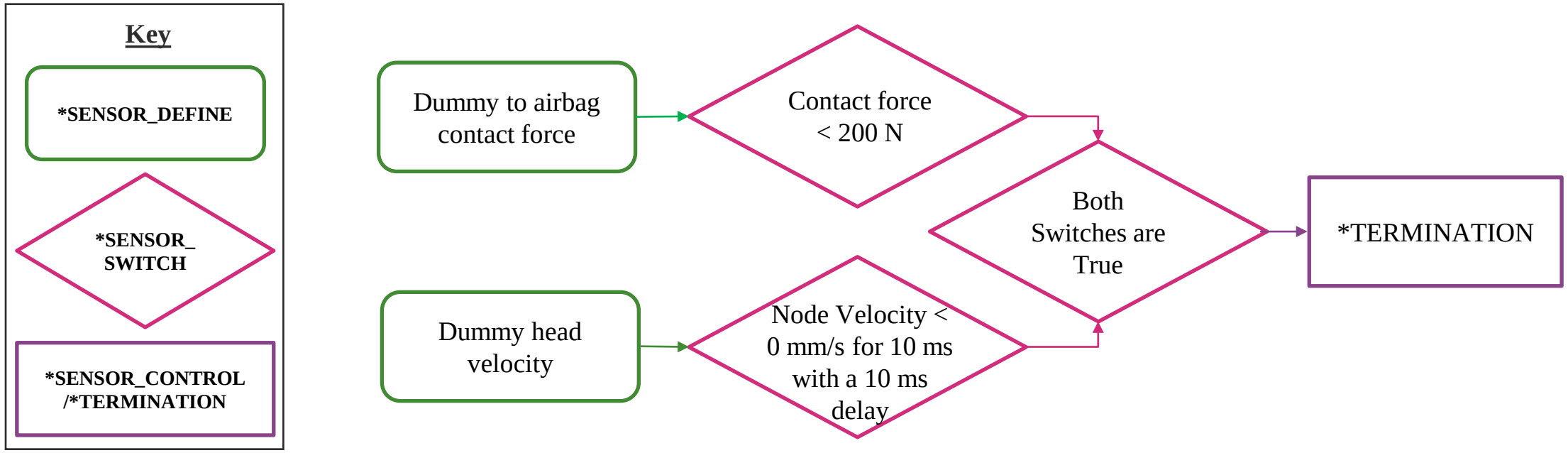
Termination Time: 100 ms



.000000000

Determining Termination Time – Using *SENSORs

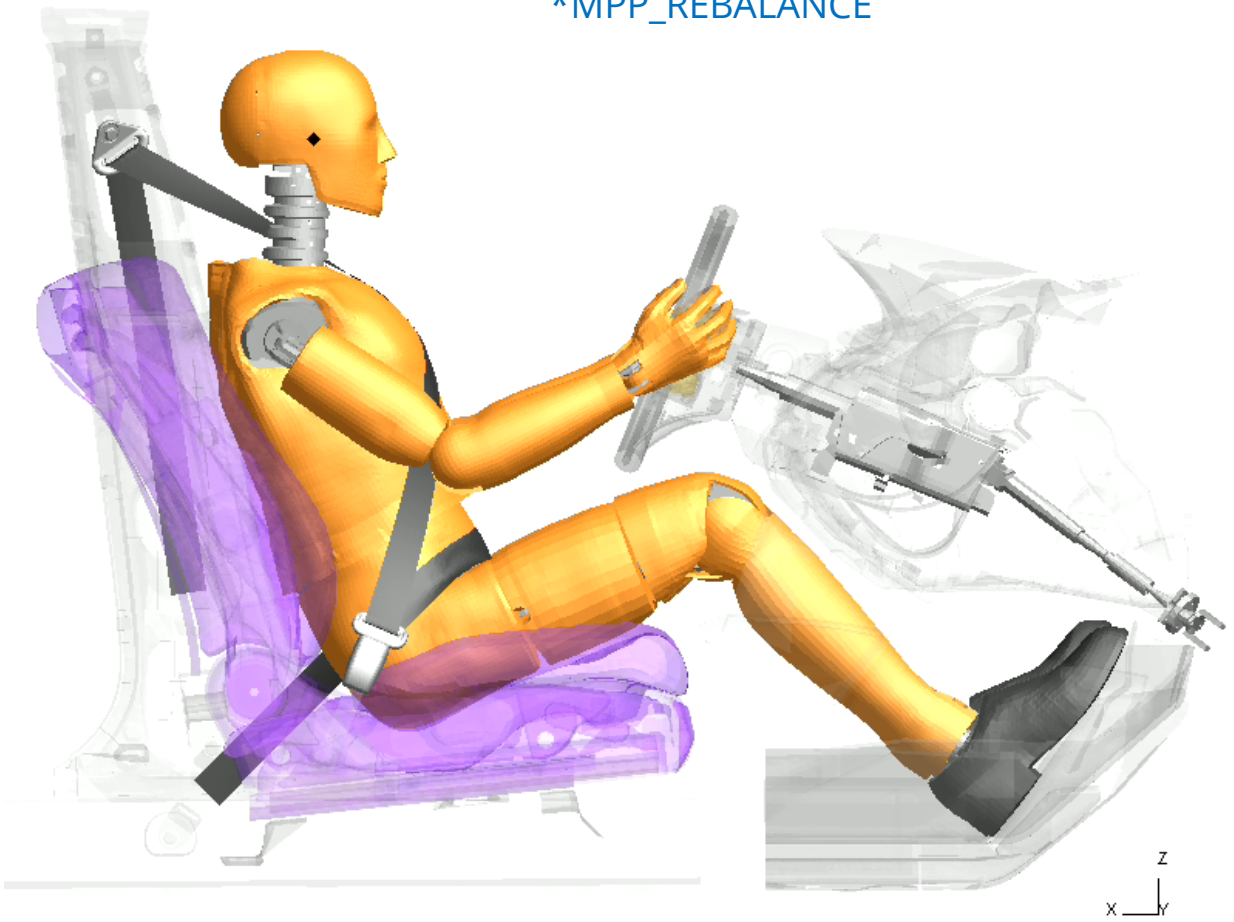
- *SENSOR can be used to activate/deactivate certain keywords, or terminate the analysis, when a condition or a set of conditions are met.
- In this worked example, the run will terminate when the following conditions are met:
  - Dummy to airbag contact force is less than 200 N.
  - Relative head node velocity < 0 for a period of 10 ms.

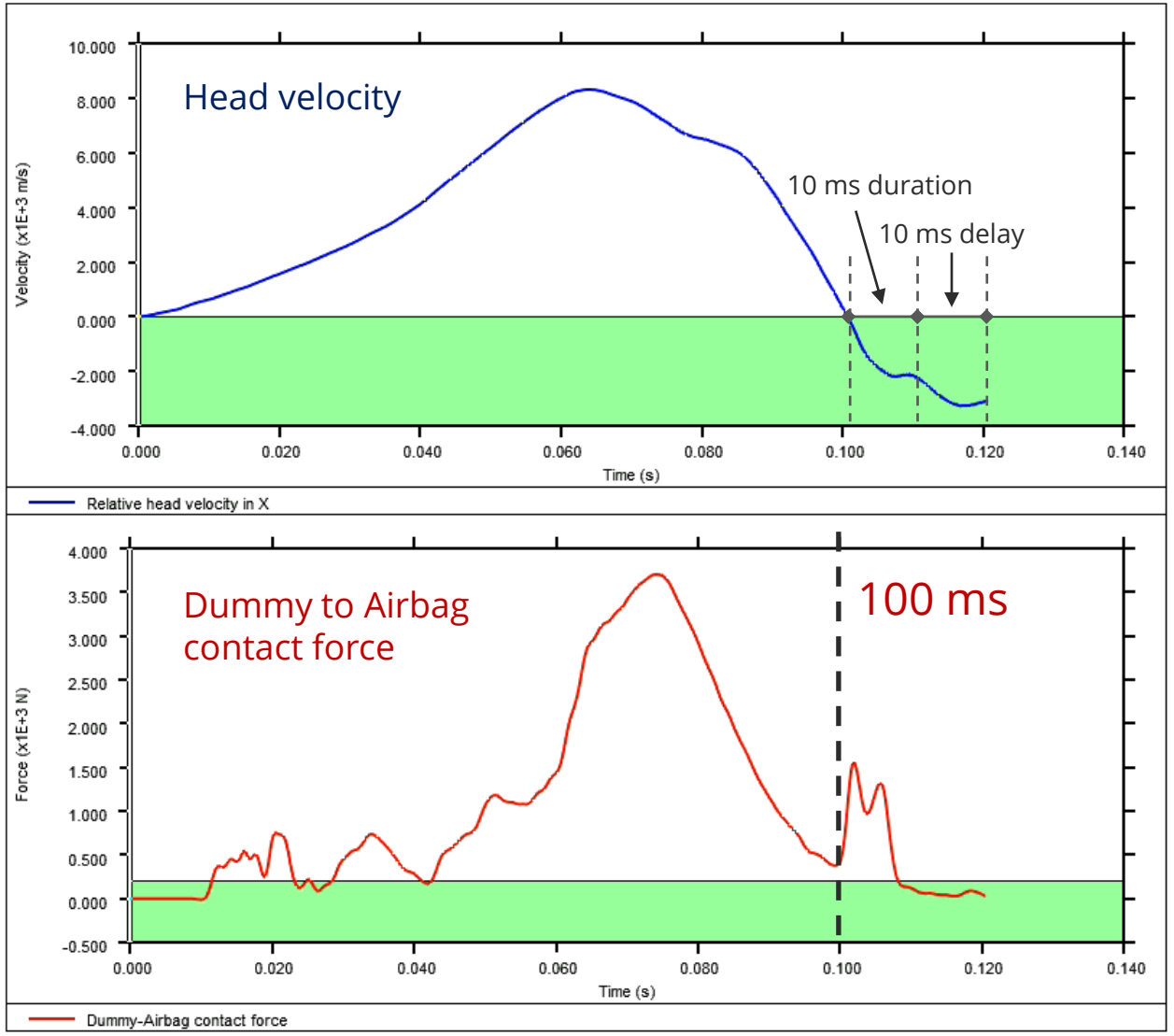


Determining Termination Time - *SENSOR

D3PLOT: DRIVER SLED

*MPP_DECOMP_TRANSFORMATION
*MPP_REBALANCE





Determining Termination Time - TTF +30 ms