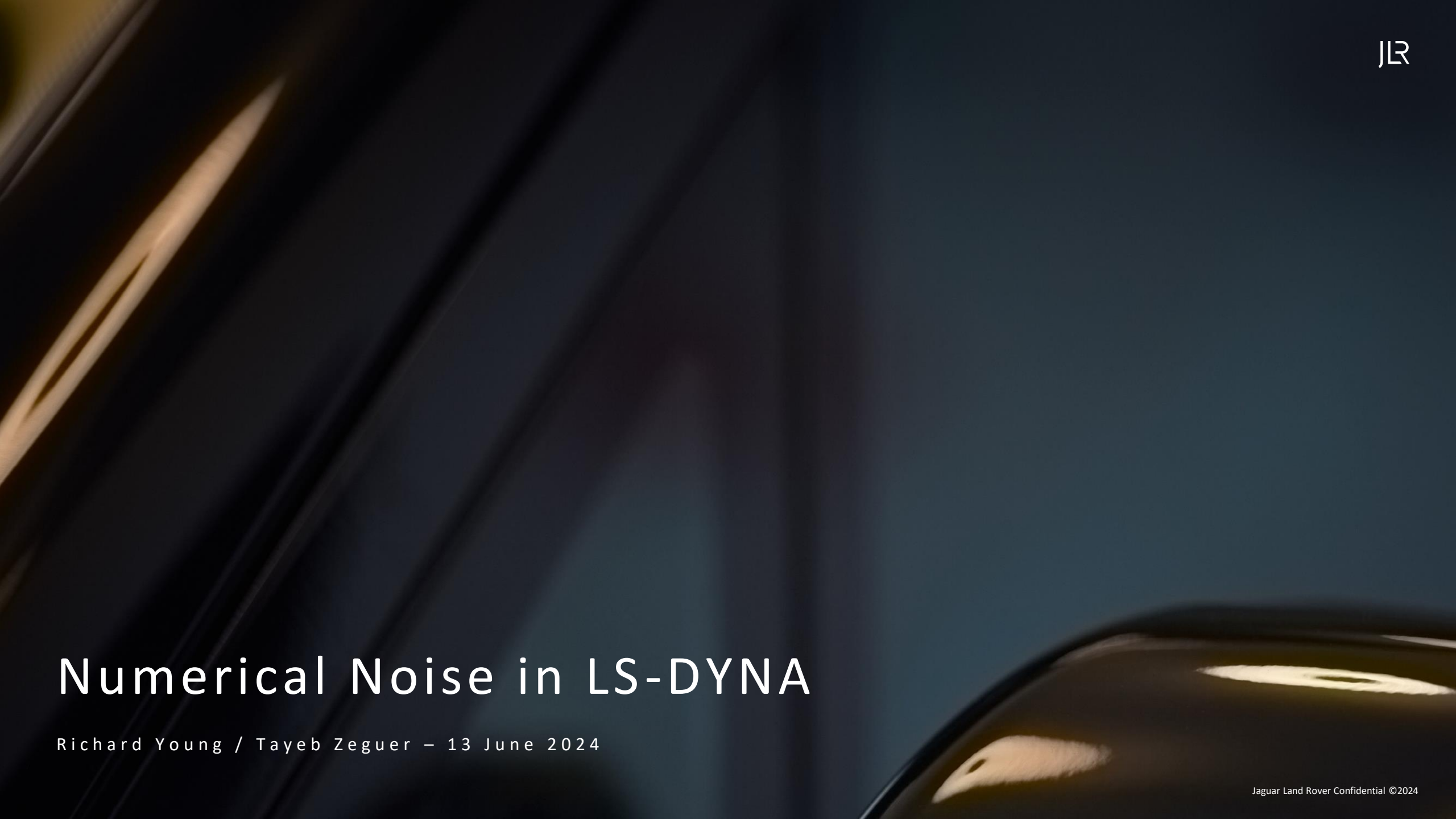
Customer Talk: Numerical Noise in LS-DYNA

Richard Young

MDO Lead Engineer

JLR

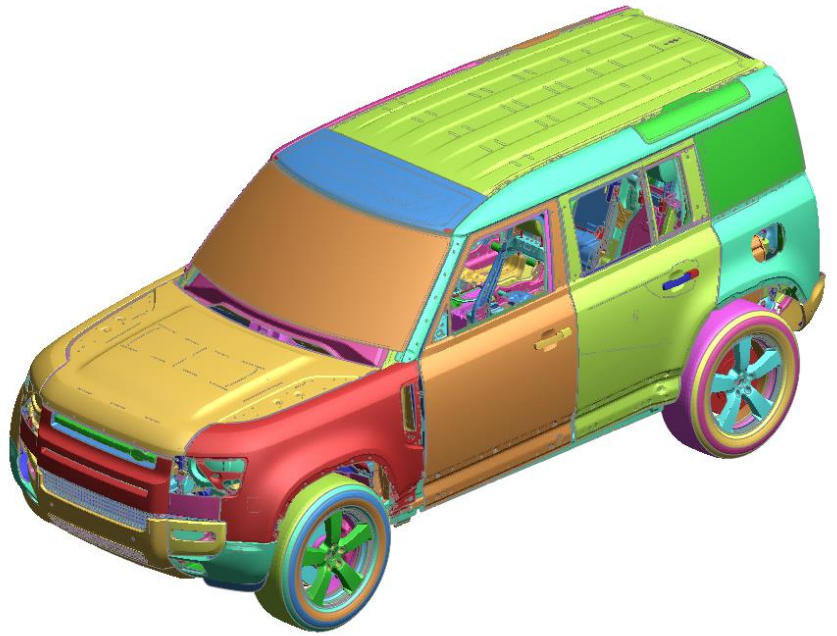


Numerical Noise in LS-DYNA

Richard Young / Tayeb Zeguer – 13 June 2024

01 Contents

- Introduction
- Decomposition Noise
- Natural Noise
- Conclusion



Decomposition Noise

Numerical Noise in LS-DYNA

02 **Previous Studies – Runtime Focus**

11th European LS-DYNA Conference 2017, Salzburg, Austria

Processor Count Independent Results: Challenges and Progress

15th International LS-DYNA® Users Conference — Modeling

Decomposition methods: For seat belt pull analysis, large models with fine meshes are generally used. The increase of computational time by the large models has been improved by domain decomposition in LS-DYNA.

13th International LS-DYNA Users Conference — Computing Technology

Decomp "Default" | Decomp "4x2x2"

none | "decomp {sz 8.5 sx 2 }"

Decomp "Angular" | Decomp "Concentric"

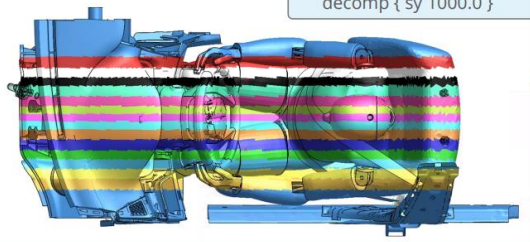
MPP Domains – Special Decompositions

- 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

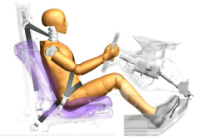
- In this example, the following line scales the Y axis of a by a factor of 1000.

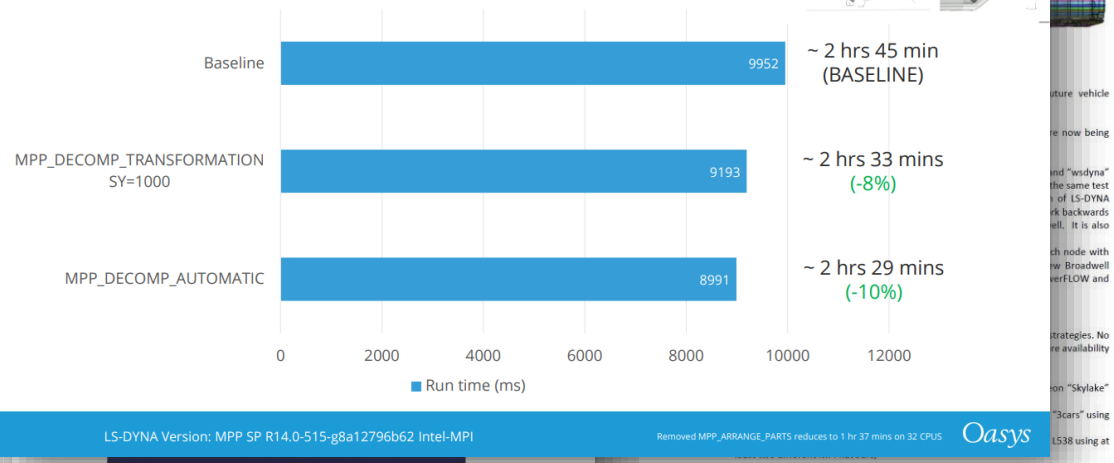
Command in partition file (pf
decomp { sy 1000.0 }



Run Time Comparison – Domain Decomposition

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





LS-DYNA Version: MPP SP R14.0-515-g8a12796b62 Intel-MPI

Removed MPP_ARRANGE_PARTS reduces to 1 hr 37 mins on 32 CPUS

Oasys

Fig.2: The total performance of R6.

June 10-12, 2018

R6 element

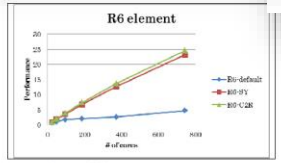


Fig.3: The element performance of R6.

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Figure 11. 3Cars Model

1-6

03 History – Consistency Flag and Deck Shuffle

Running same model on the same computer multiple times produced different results each time.

LS-DYNA developers add consistency flag to control order of calculation at a small runtime cost.

Changing the order of referenced includes changed the order of operation during the solution.

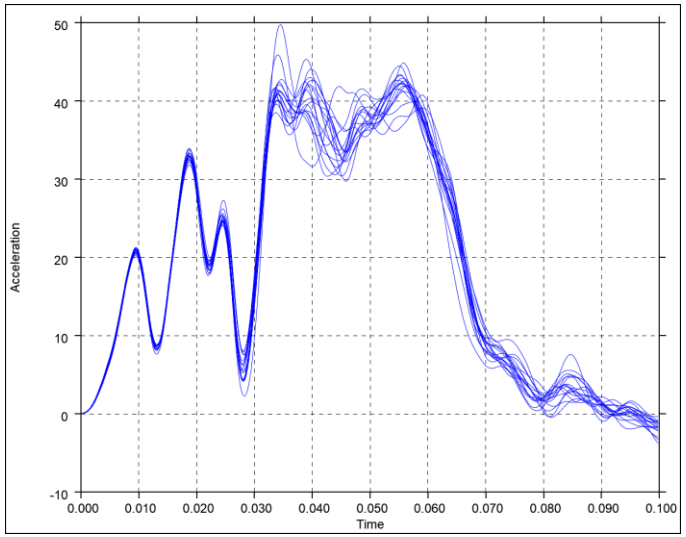
Current LS-DYNA sorts the model during initialisation for consistency.

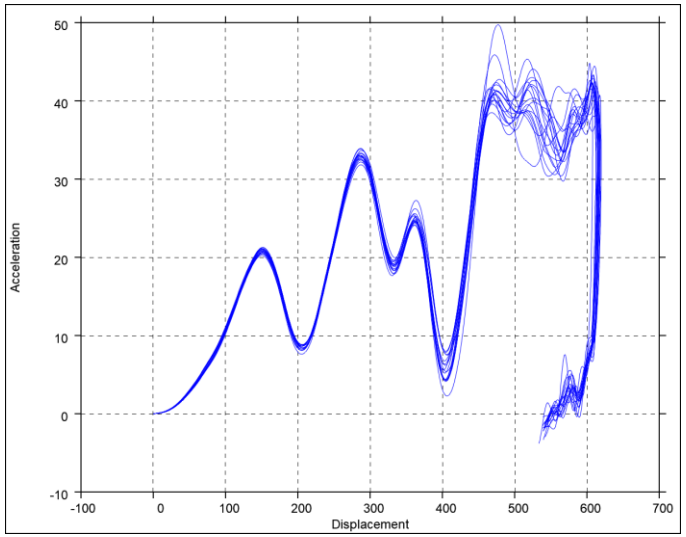
```
*KEYWORD
*INCLUDE
inc1.k
inc2.k
inc3.k
inc4.k
inc5.k
inc6.k
*END
```

```
*KEYWORD
*INCLUDE
inc4.k
inc2.k
inc6.k
inc1.k
inc3.k
inc5.k
*END
```

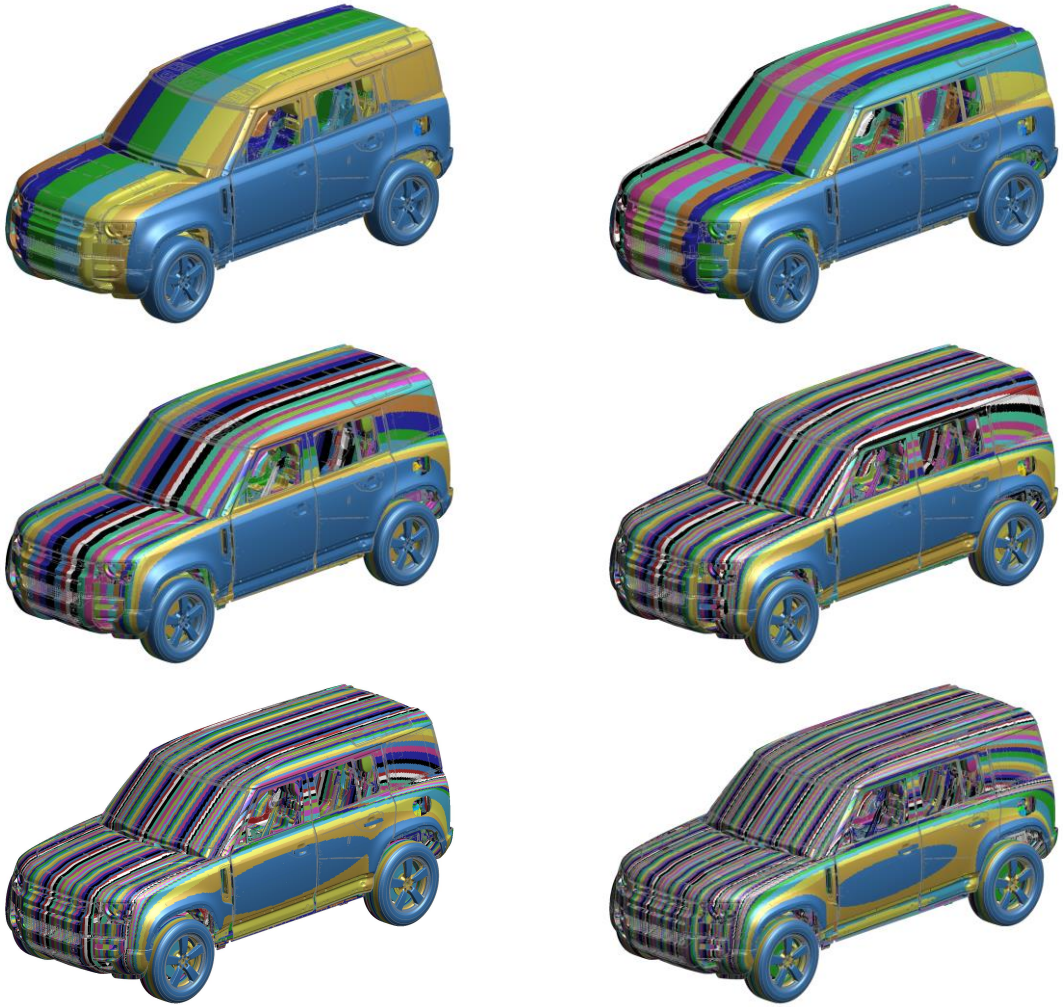
```
*KEYWORD
*INCLUDE
inc5.k
inc1.k
inc2.k
inc6.k
inc4.k
inc3.k
*END
```

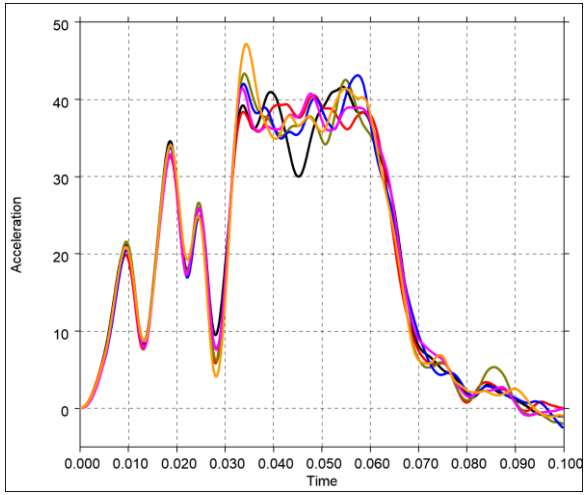
Run	Dash Int (mm)	TDD (mm)	Max Pulse (g)	VPI (g)
Nominal	143.8	616.5	41.4	70.1
Maximum	143.8	619.7	49.8	71.2
Minimum	132.0	607.8	39.6	69.4
Average	137.0	615.6	43.3	70.1
St Dev	2.8	2.7	2.2	0.4
RANGE	**11.8**	**11.9**	**10.2**	**1.8**

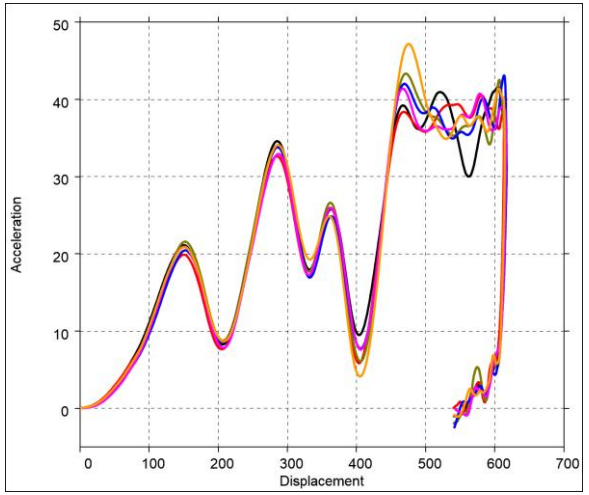




04 **Decomposition – Number of CPUs**



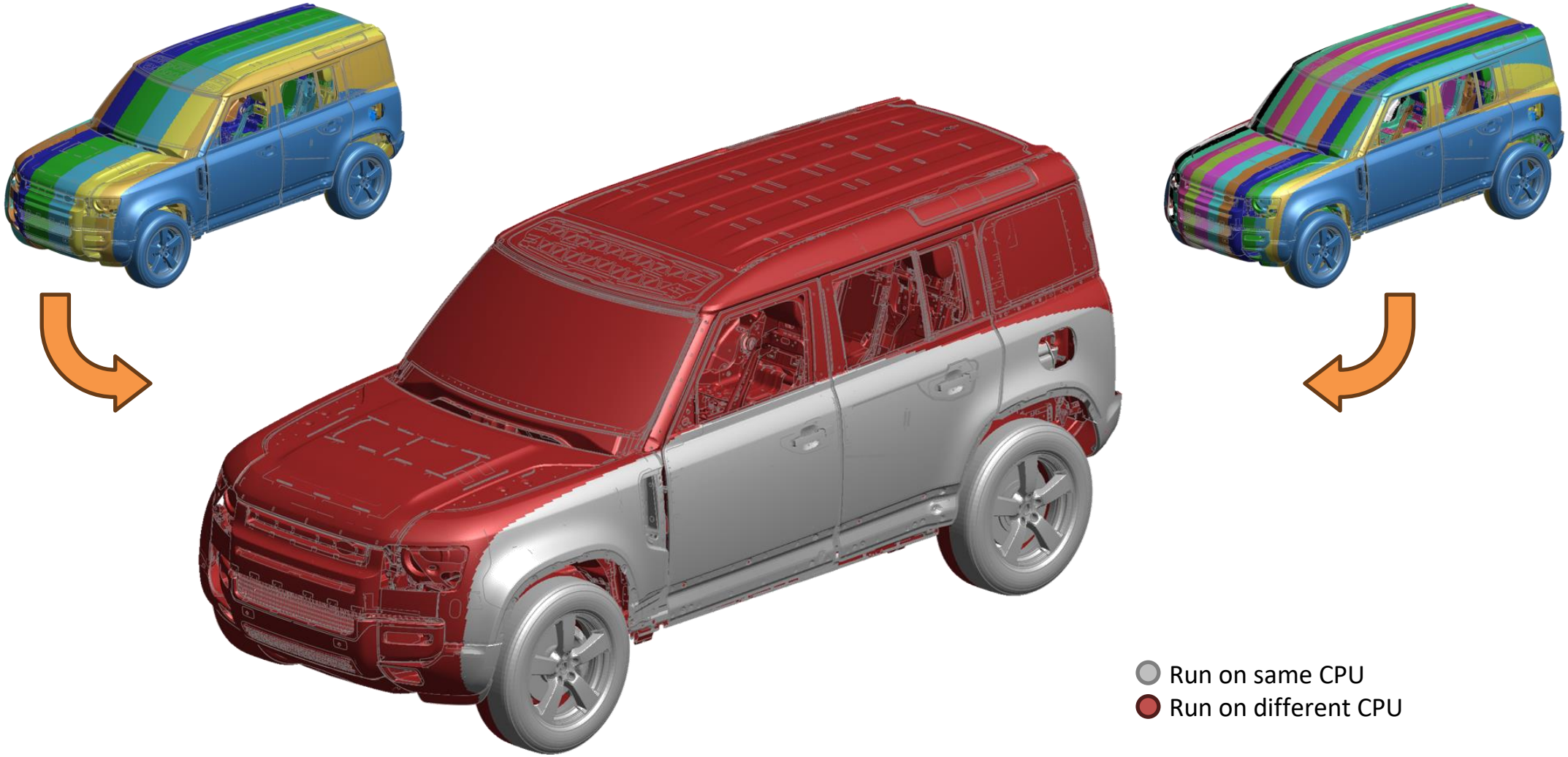




Run	Dash Int (mm)	TDD (mm)	Max Pulse (g)	VPI (g)	Runtime (s)	CPU Hours
8 CPU	139.6	615.4	41.6	**69.9**	134665	299.3
16 CPU	**137.6**	**613.4**	**40.5**	**70.5**	78140	347.3
32 CPU	138.8	615.1	43.3	70.2	45271	402.4
64 CPU	141.1	**617.3**	43.1	70.0	29425	523.1
96 CPU	**143.8**	616.5	41.4	70.1	23631	630.2
128 CPU	140.7	614.5	**47.2**	70.3	20202	718.3
RANGE	**6.2**	**3.9**	**6.7**	**0.4**		

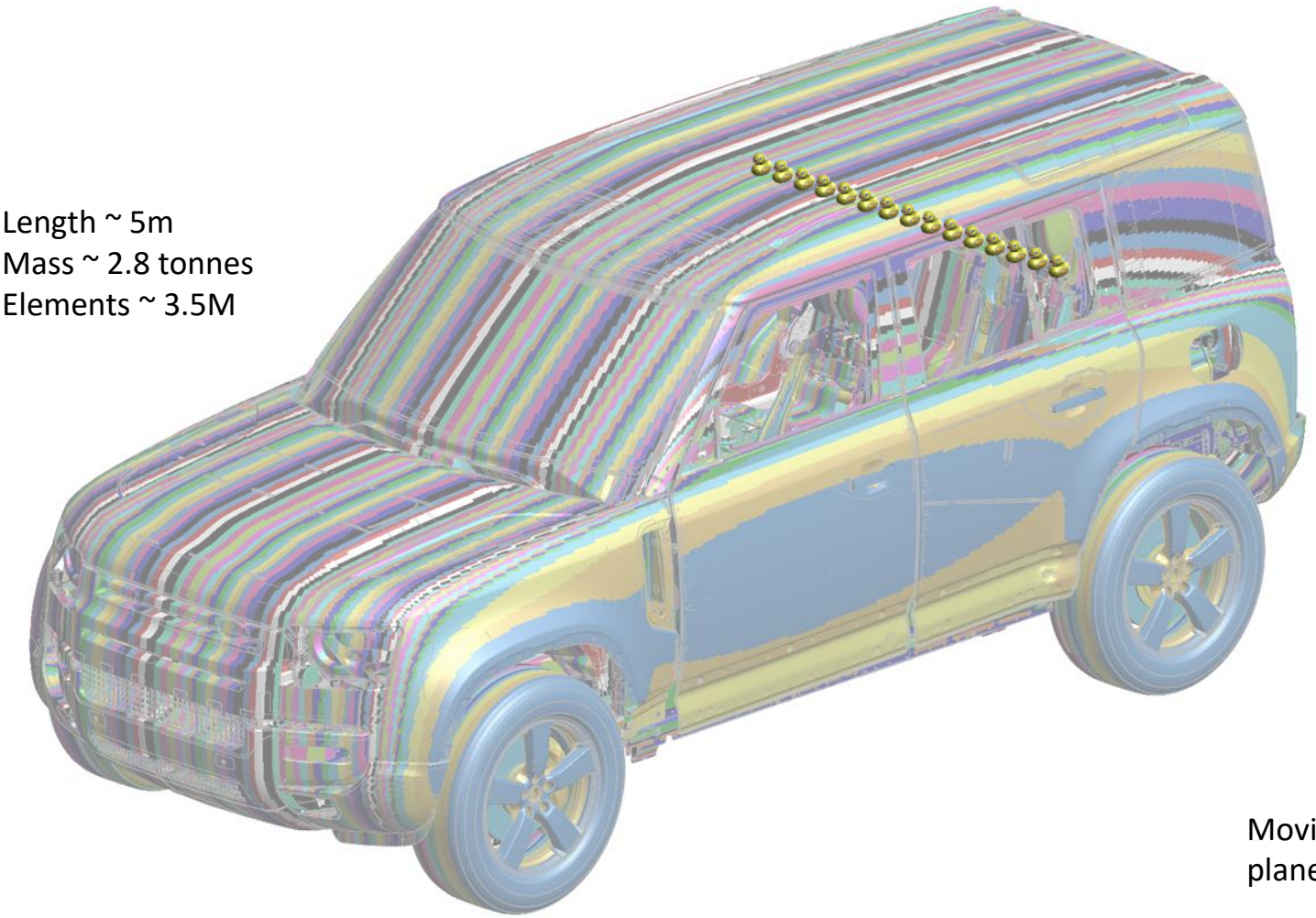
Variability in results with no physical change

04 **Decomposition – Number of CPUs**

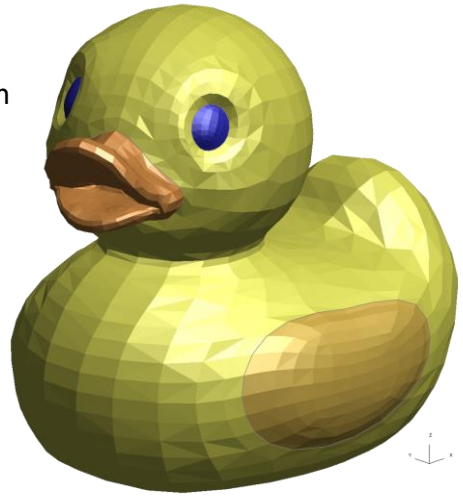


05 **Element Distribution Uniformity Change Kit**

Length ~ 5m
Mass ~ 2.8 tonnes
Elements ~ 3.5M



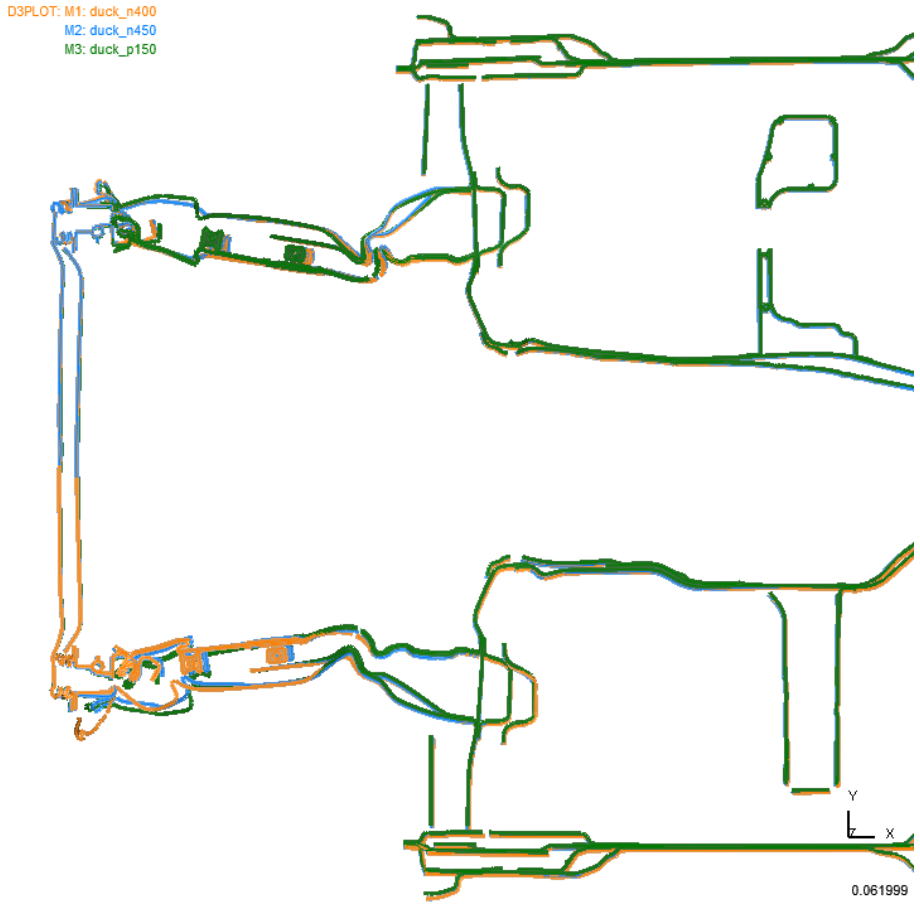
element
Distribution
Uniformity
Change
Kit

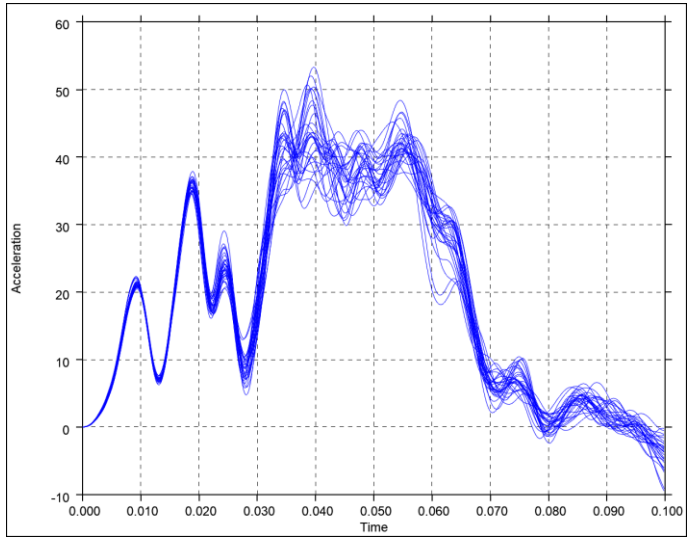


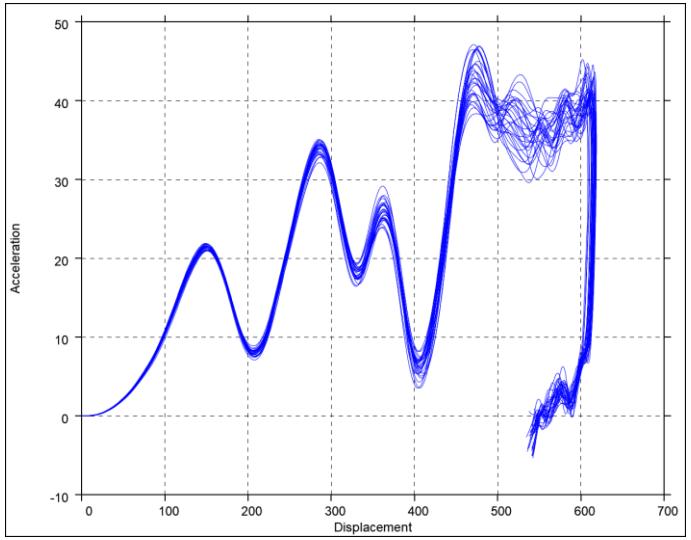
Length – 80mm
Mass – 60g
Elements – 2000

Moving duck perpendicular to cut planes affects position of cut planes.

05 Element Distribution Uniformity Change Kit



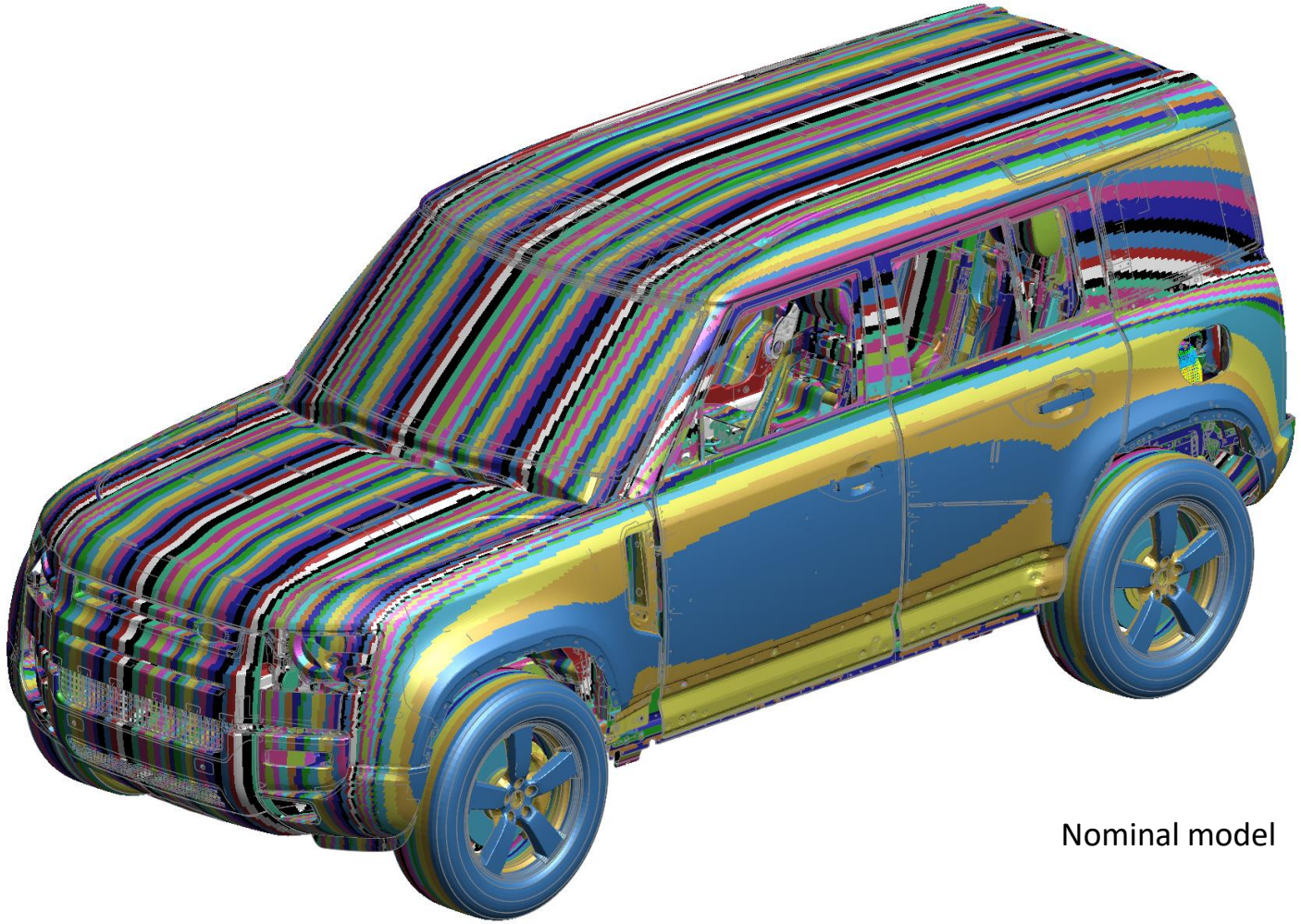




Run	Dash Int (mm)	TDD (mm)	Max Pulse (g)	VPI (g)
Nominal	143.8	616.5	41.4	70.1
Maximum	143.8	618.7	47.1	71.0
Minimum	134.6	608.3	39.9	69.6
Average	138.4	615.2	43.9	70.2
St Dev	2.2	2.7	2.0	0.4
RANGE	**9.2**	**10.4**	**7.2**	**1.4**

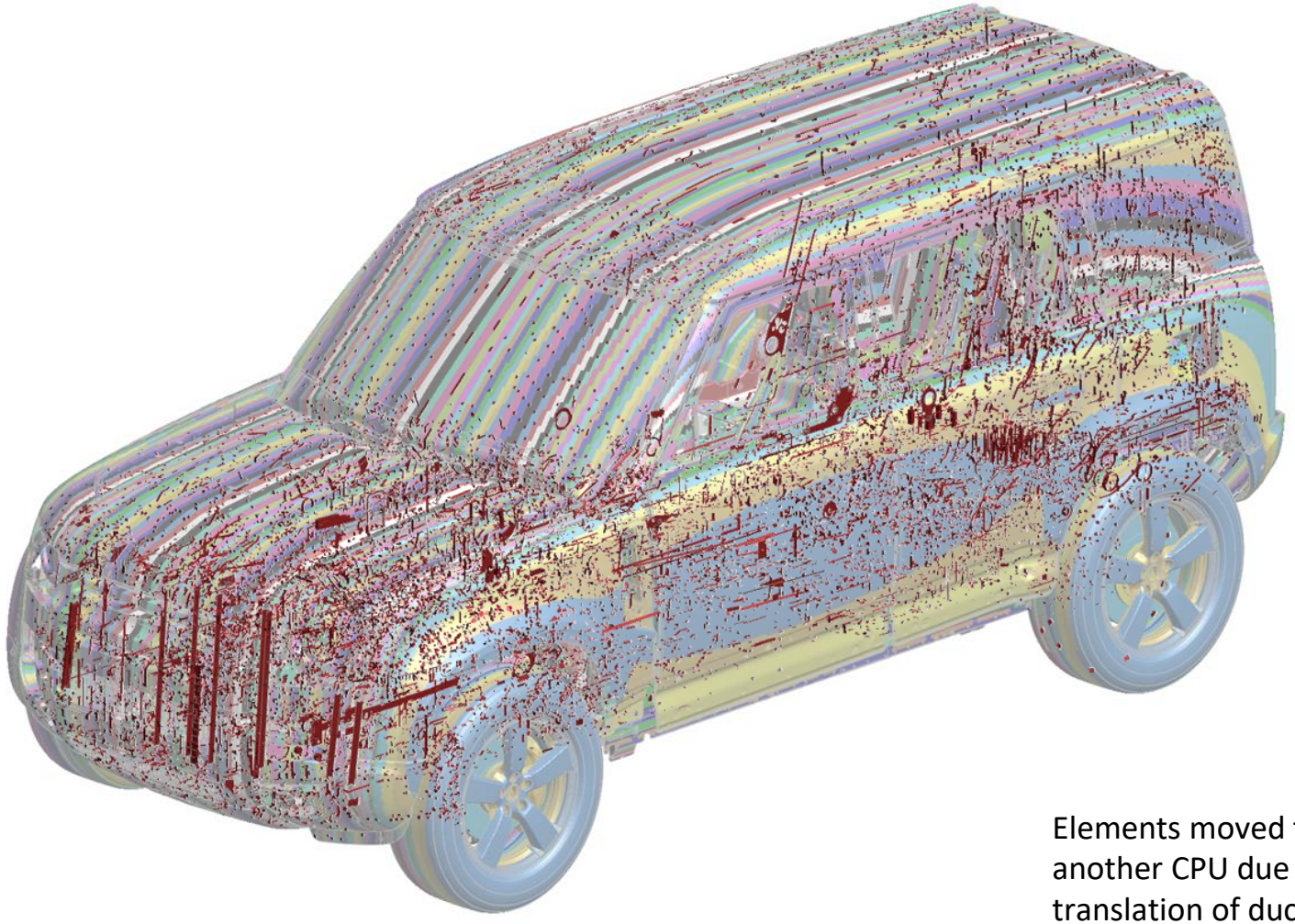
Variability in results with no physical change

06 **Decomposition Differential – Reference**



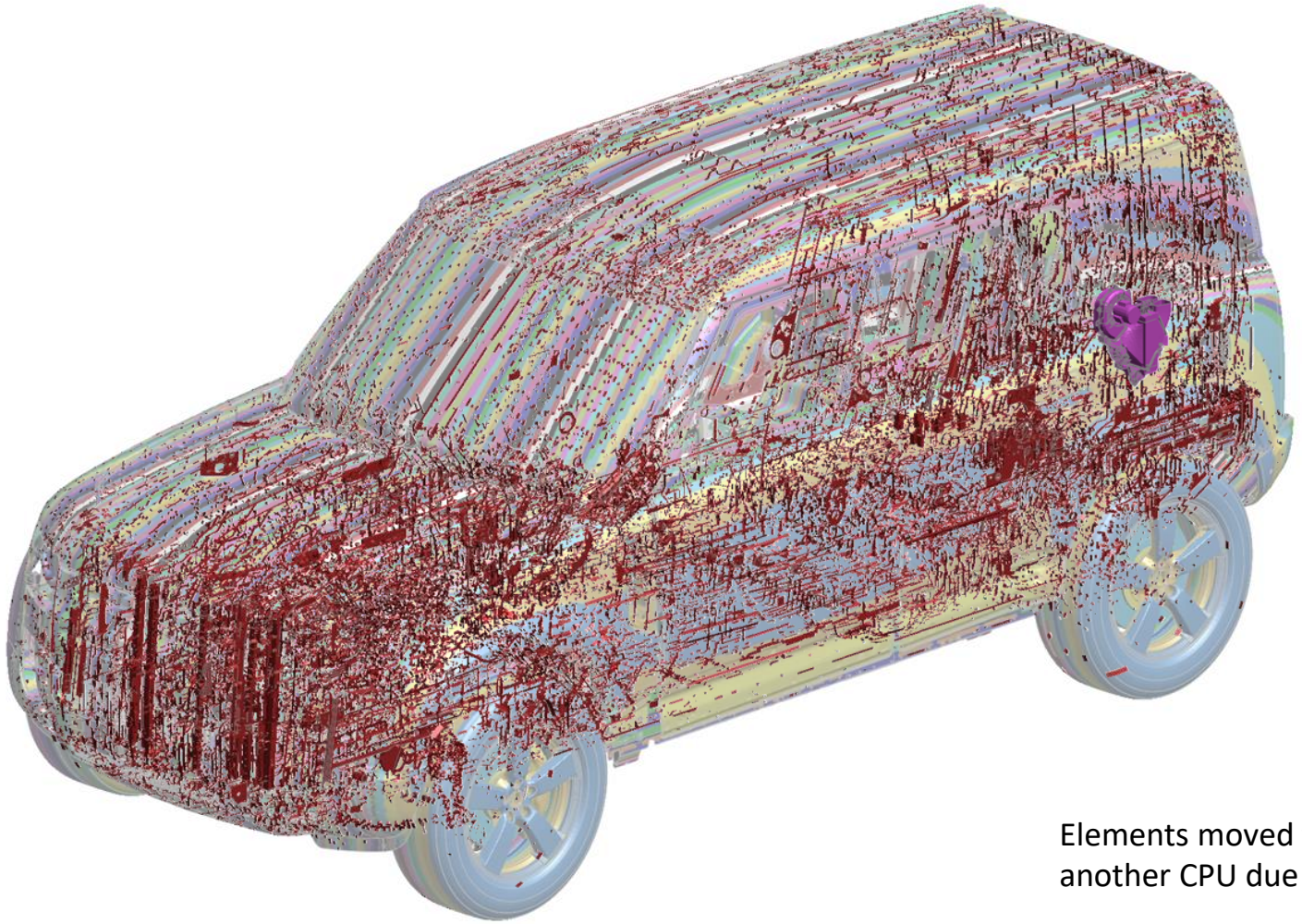
Nominal model

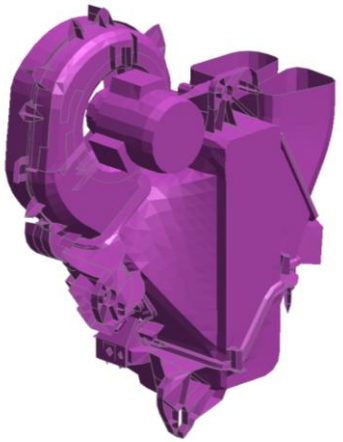
06 **Decomposition Differential – Duck Translations**



Elements moved from one CPU to another CPU due to addition and translation of duck.

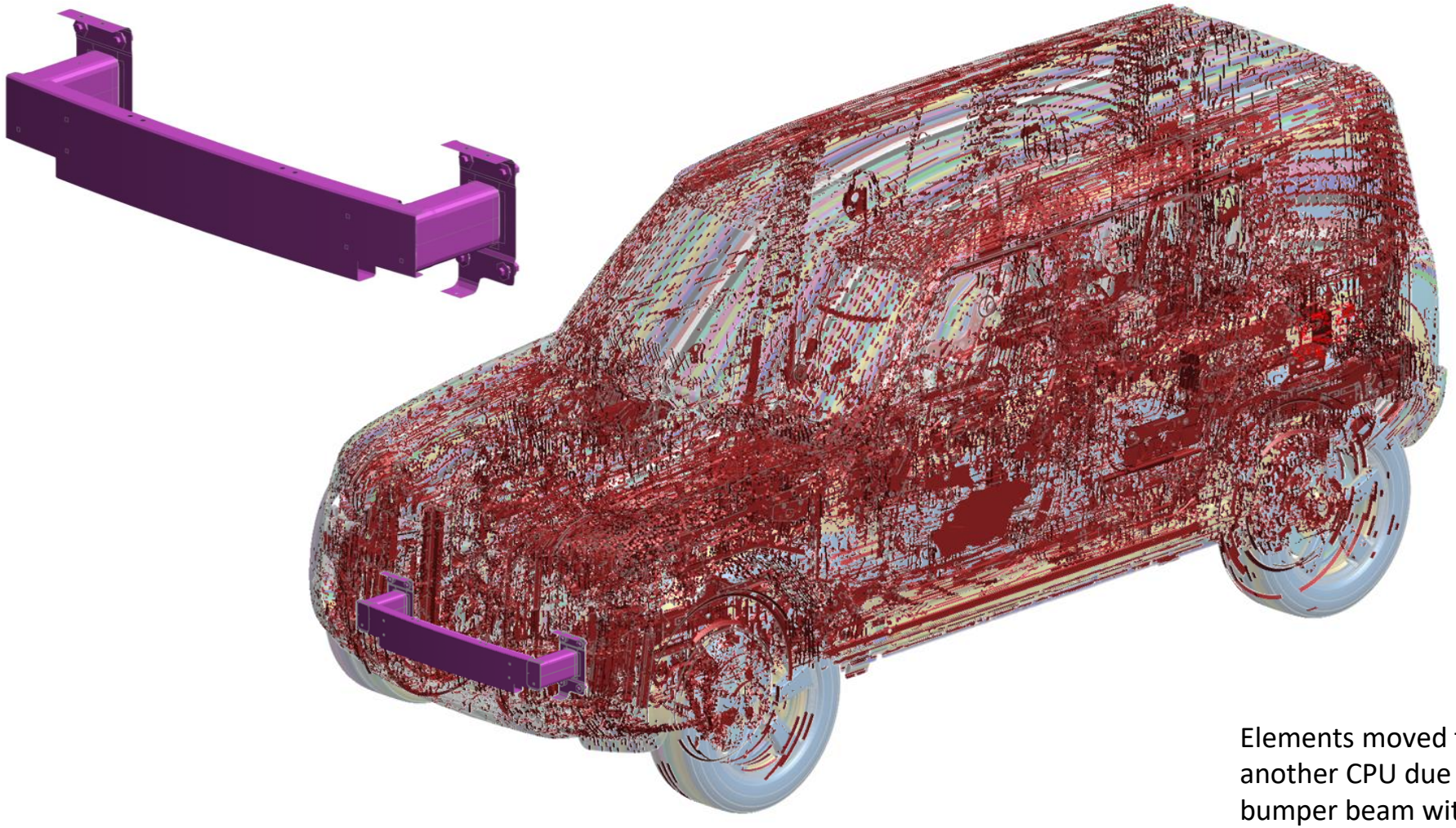
06 **Decomposition Differential – Secondary AC Removal**





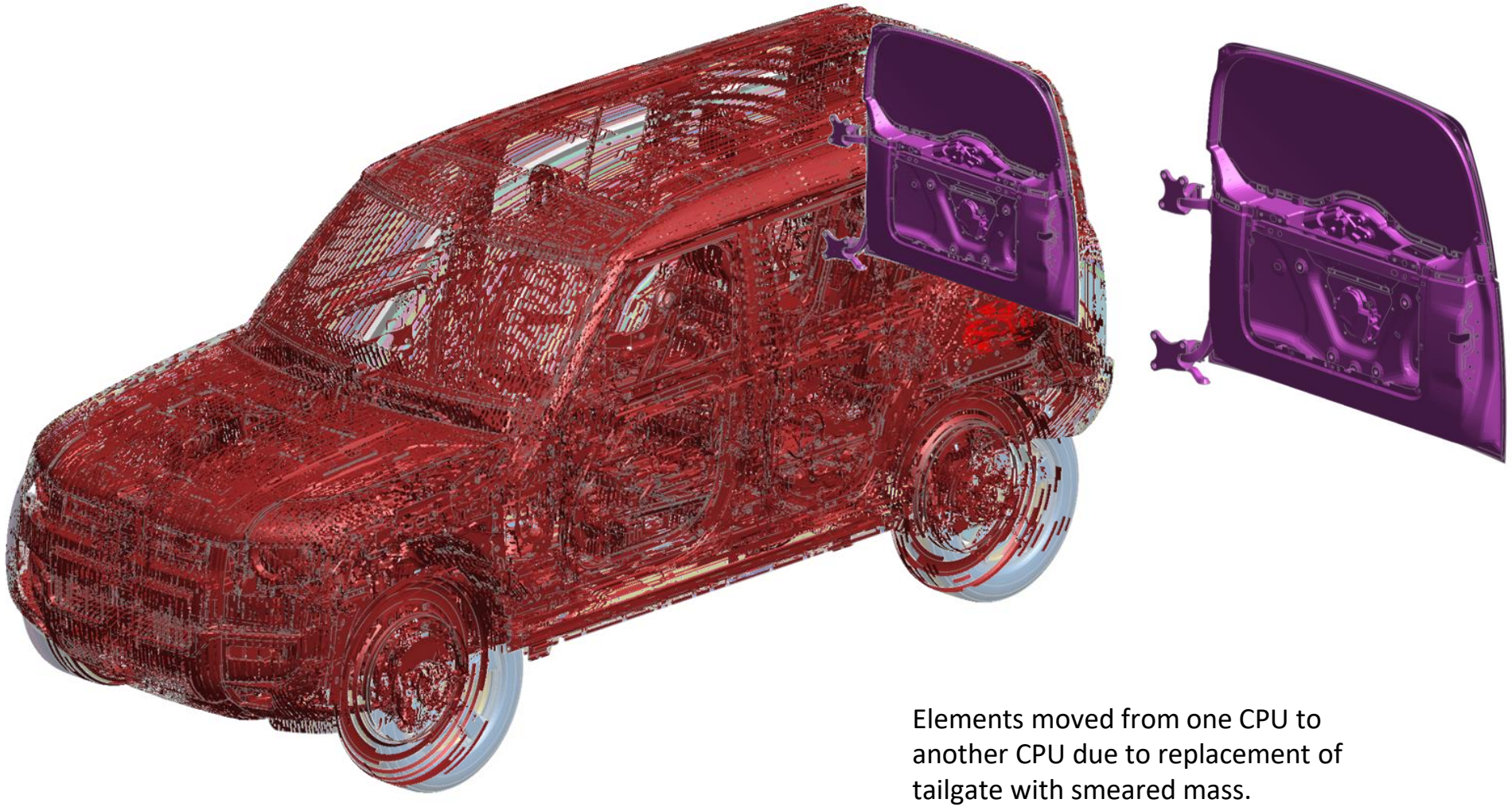
Elements moved from one CPU to another CPU due to removal of AC unit.

06 **Decomposition Differential – Bumper Development**



Elements moved from one CPU to another CPU due to replacement of bumper beam with refined mesh.

06 **Decomposition Differential – Tailgate Removal**



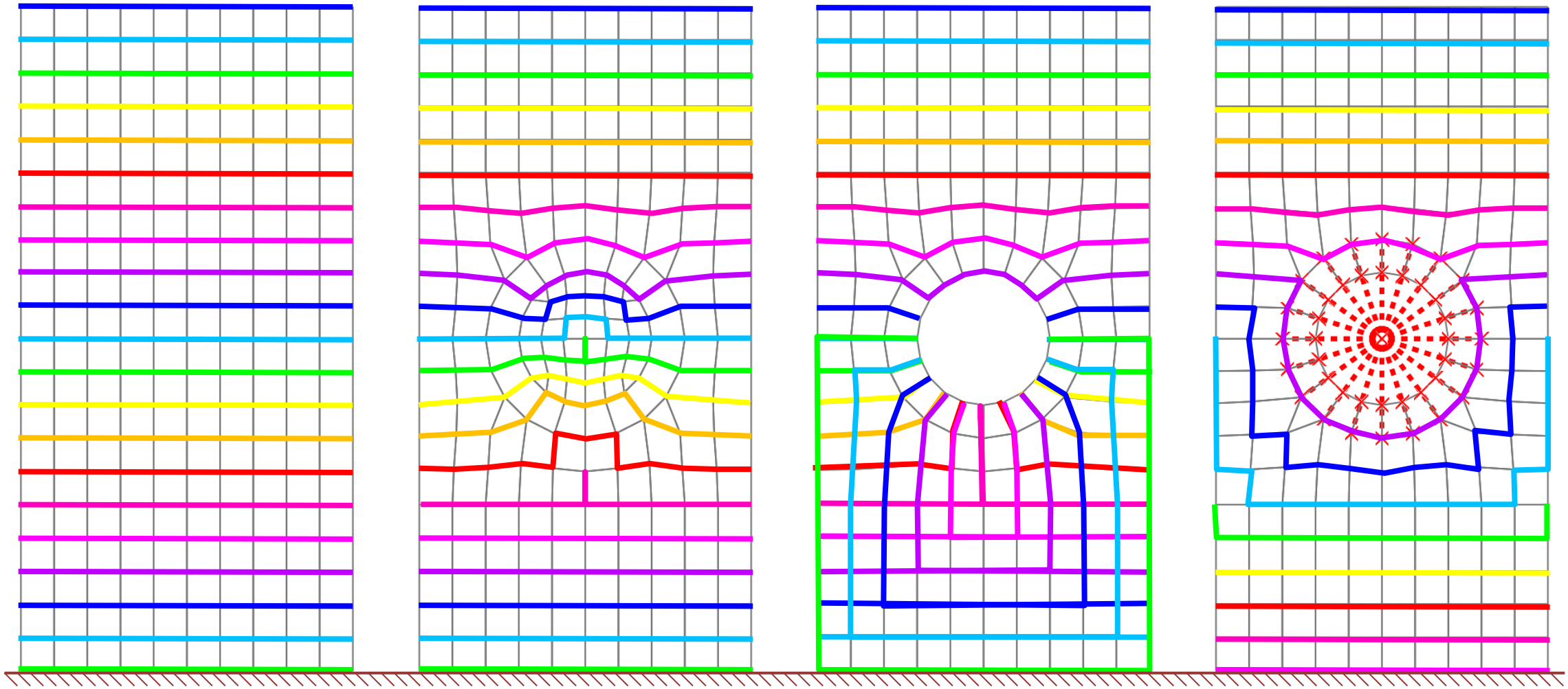
Elements moved from one CPU to another CPU due to replacement of tailgate with smeared mass.

Natural Noise

Numerical Noise in LS-DYNA

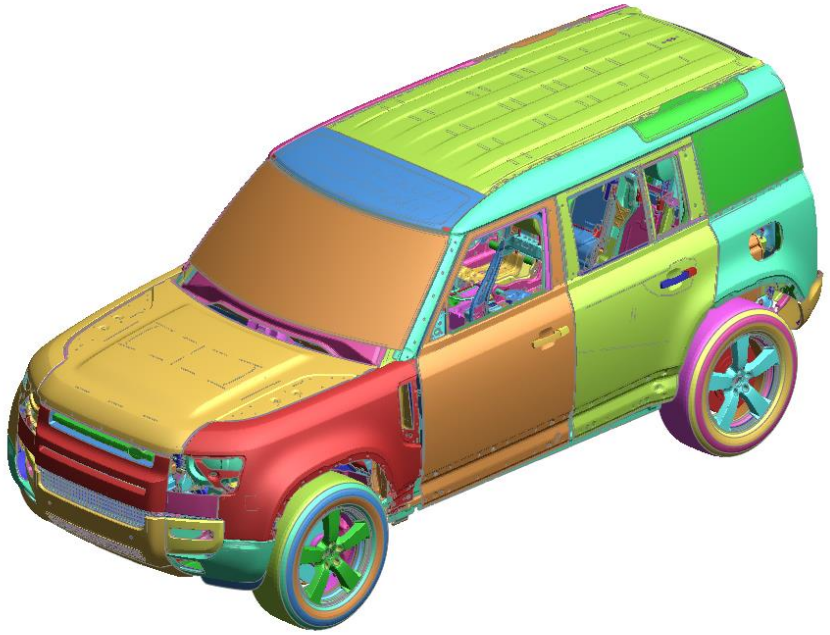
07 **Wave Propagation Through Mesh**

Mesh density and features change how waves propagate, reflect, refract and interact.



08 **The Quiescent Model**

D3PLOT: l663_20my_110_upv3_p6h_mhev_twin_lhd_fixed_fl13_n400q



Magnification: 1.001 x

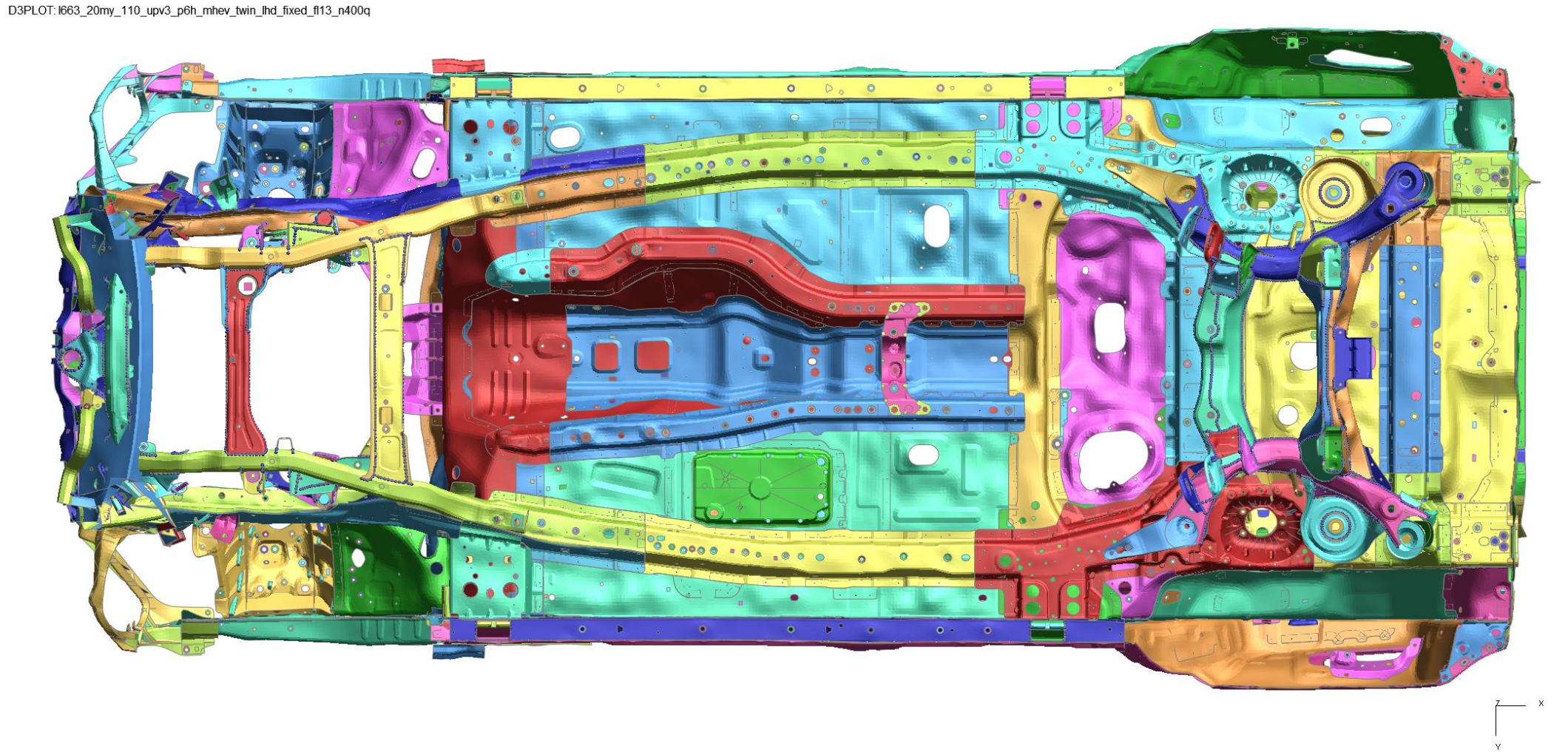
0.005000

D3PLOT: l663_20my_110_upv3_p6h_mhev_twin_lhd_fixed_fl13_n400q

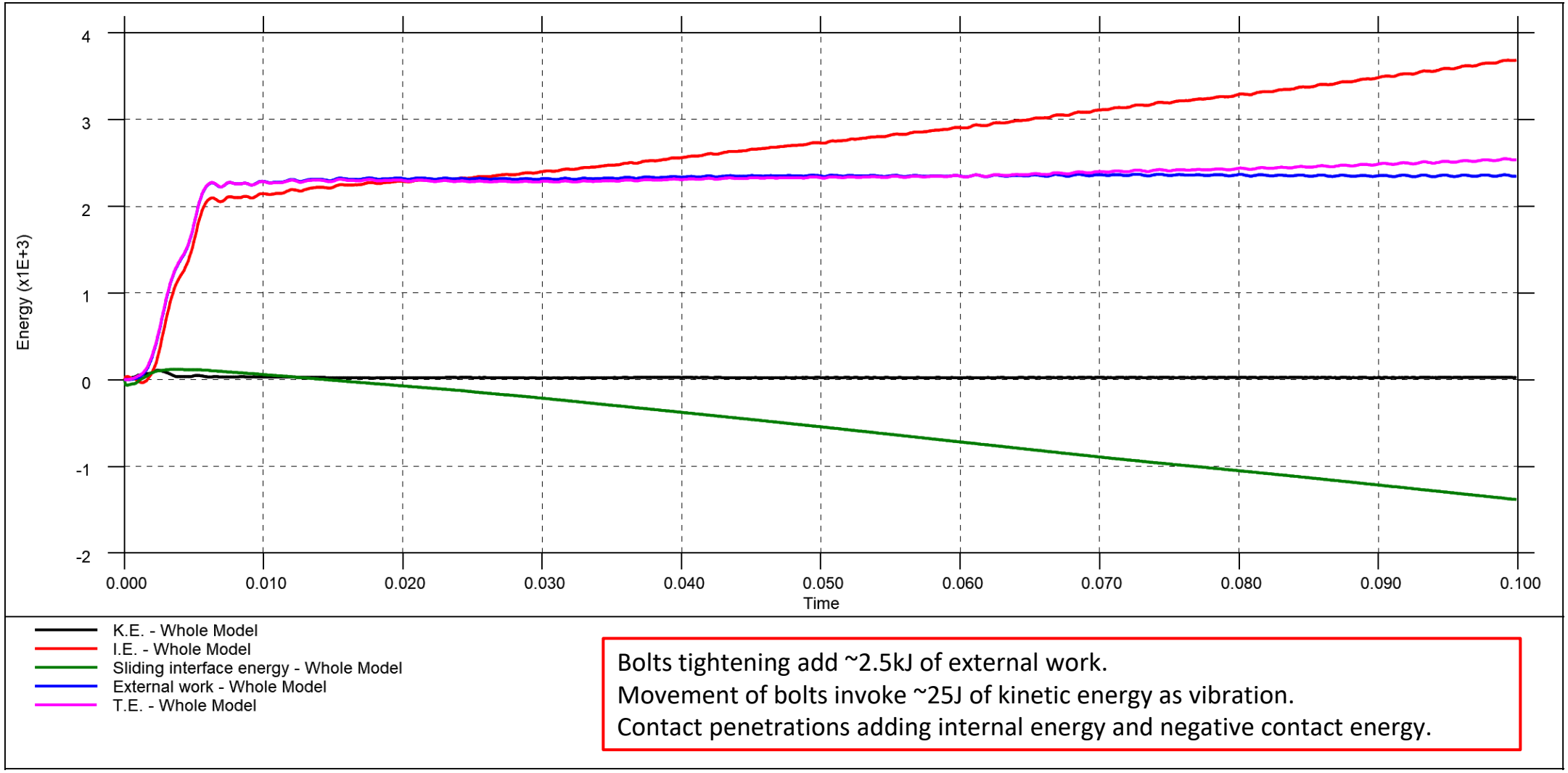
Magnification: 100.00 x

0.005000

08 **The Quiescent Model**

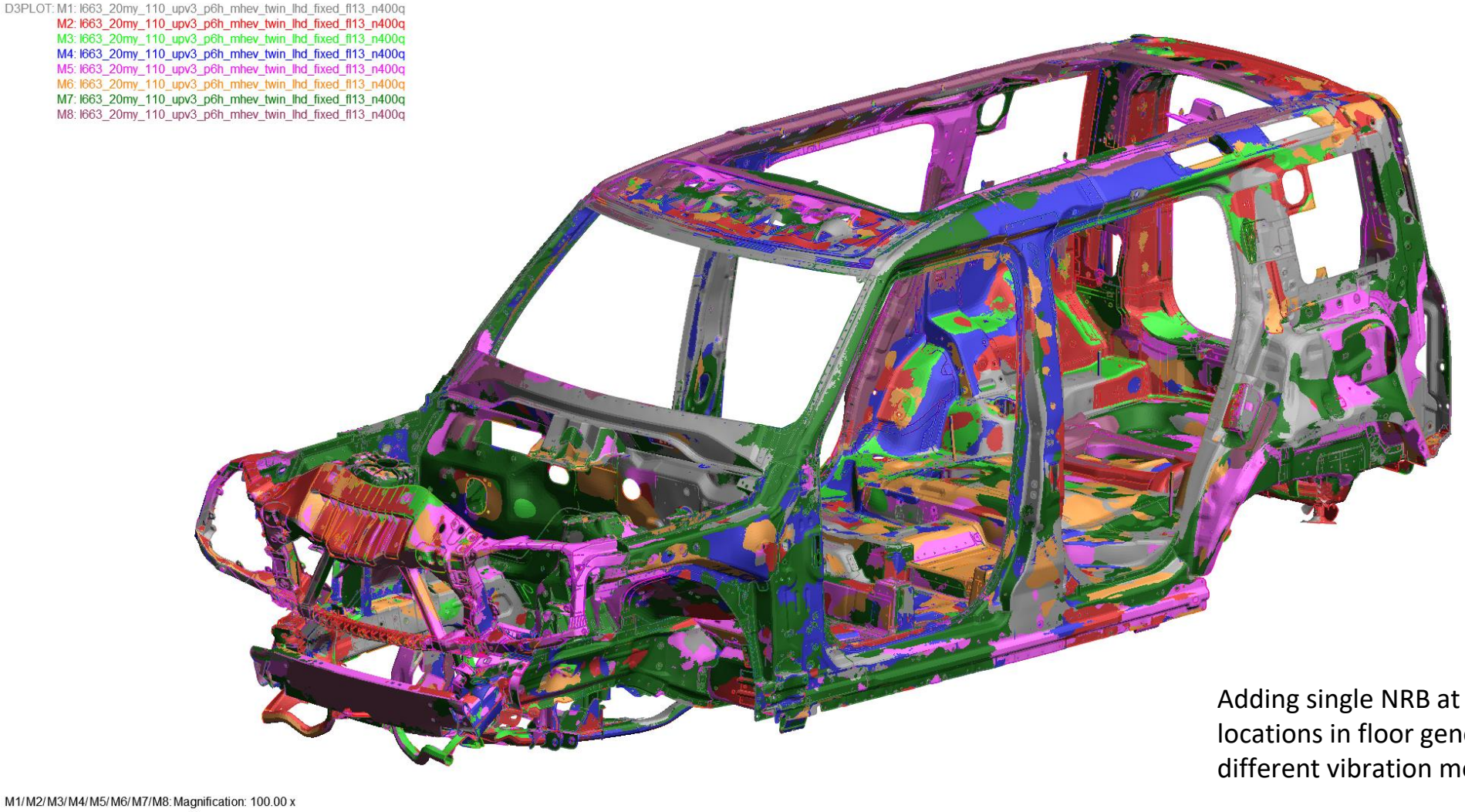


08 The Quiescent Model



Bolts tightening add ~2.5kJ of external work.
Movement of bolts invoke ~25J of kinetic energy as vibration.
Contact penetrations adding internal energy and negative contact energy.

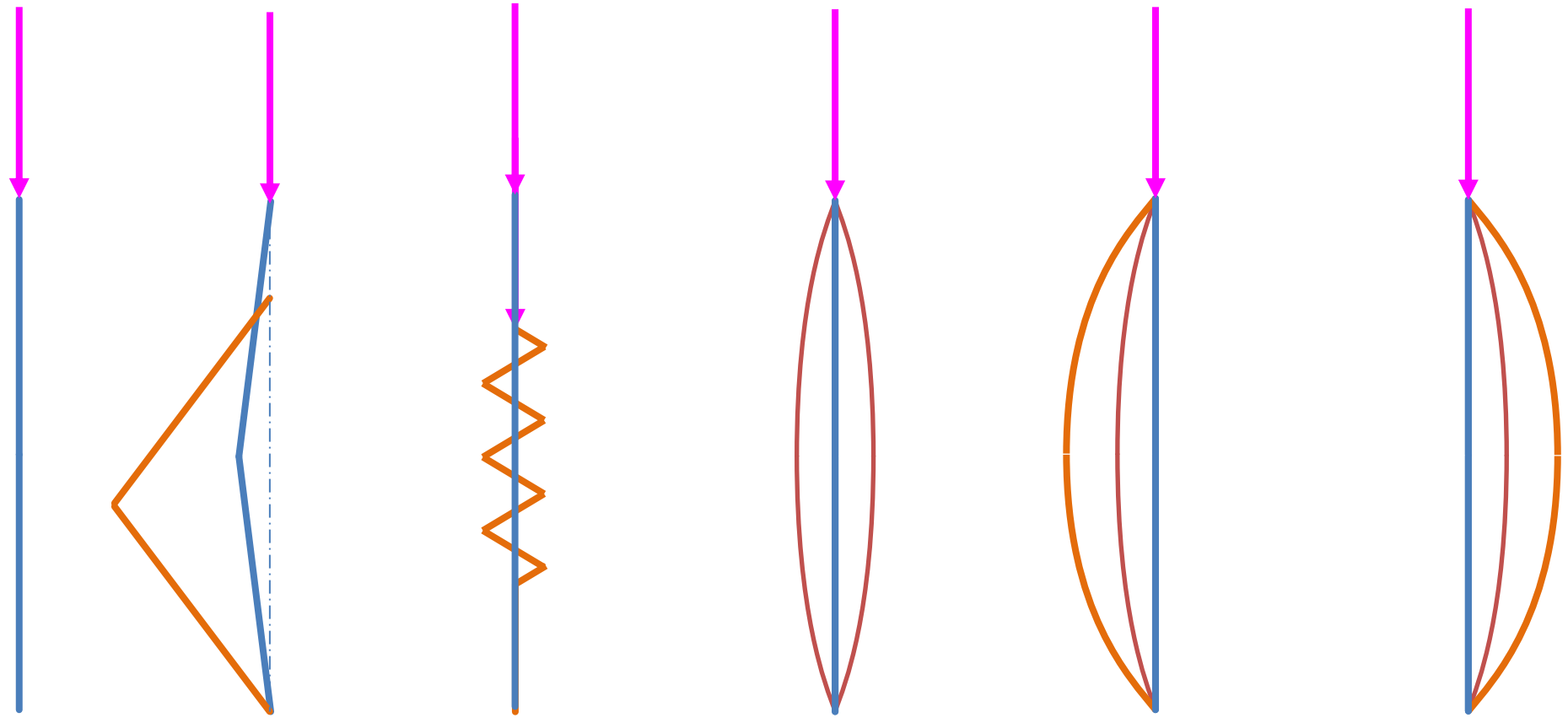
09 **Single Change Effect – Additional NRB**



Adding single NRB at different locations in floor generated different vibration modes.

10 **Mode Influence From Vibrations**

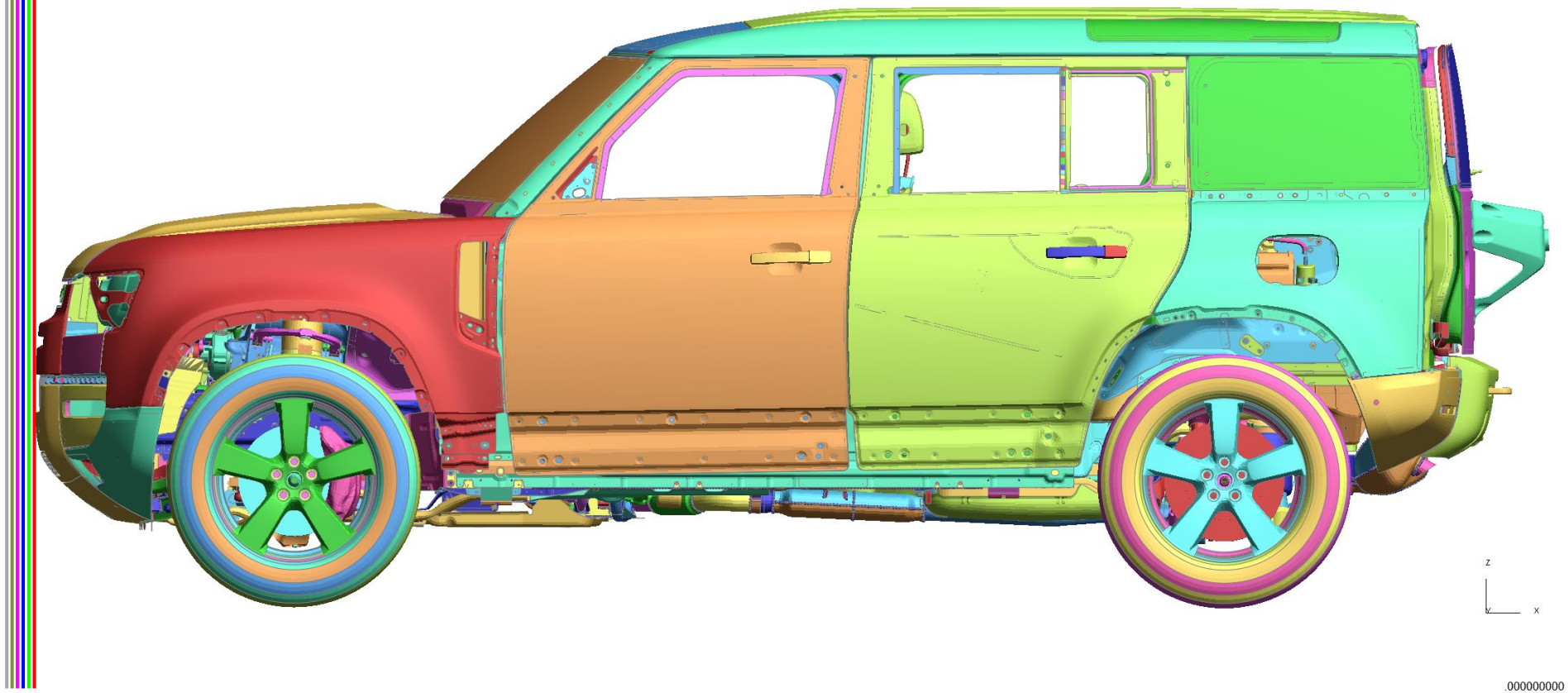
Vibration mode at first contact may influence rest of crash event.



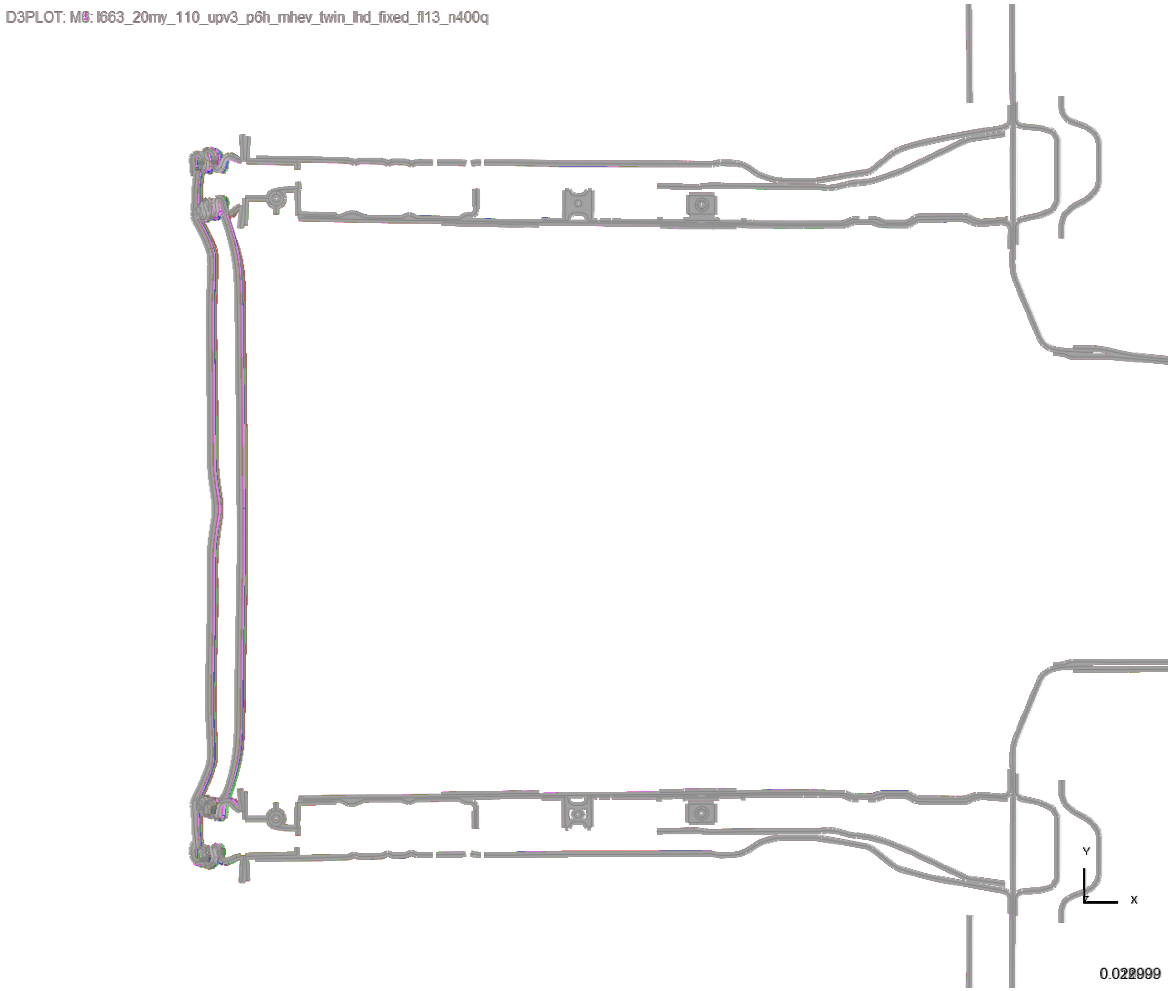
11 **Noise Accumulation**

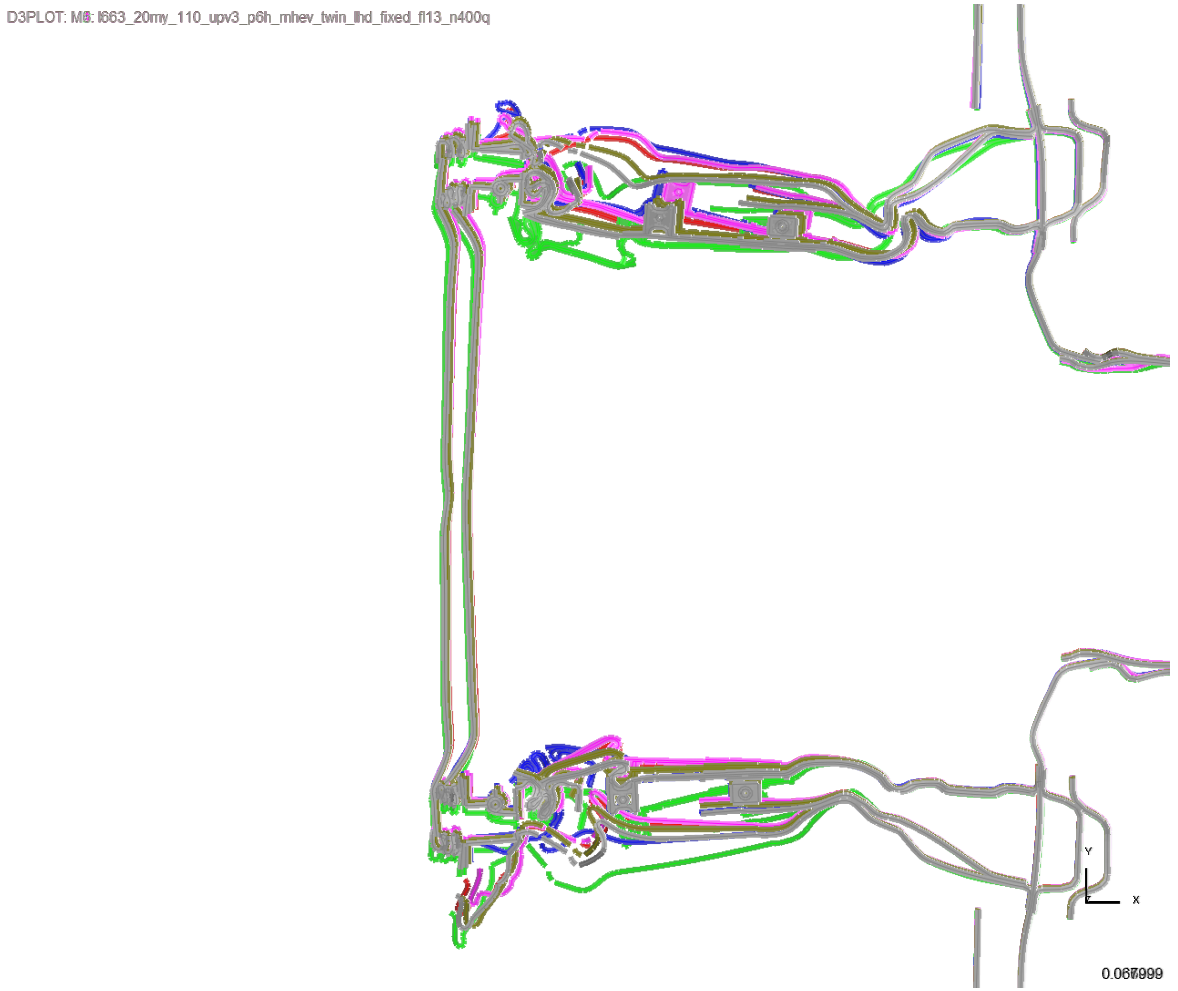
D3PLOT: M1: l663_20my_110_upv3_p6h_mhev_twin_lhd_fixed_fl13_n400q
M2: l663_20my_110_upv3_p6h_mhev_twin_lhd_fixed_fl13_n400q
M3: l663_20my_110_upv3_p6h_mhev_twin_lhd_fixed_fl13_n400q
M4: l663_20my_110_upv3_p6h_mhev_twin_lhd_fixed_fl13_n400q
M5: l663_20my_110_upv3_p6h_mhev_twin_lhd_fixed_fl13_n400q
M6: l663_20my_110_upv3_p6h_mhev_twin_lhd_fixed_fl13_n400q

Moving barrier away from vehicle to allow different vibration mode at first contact.

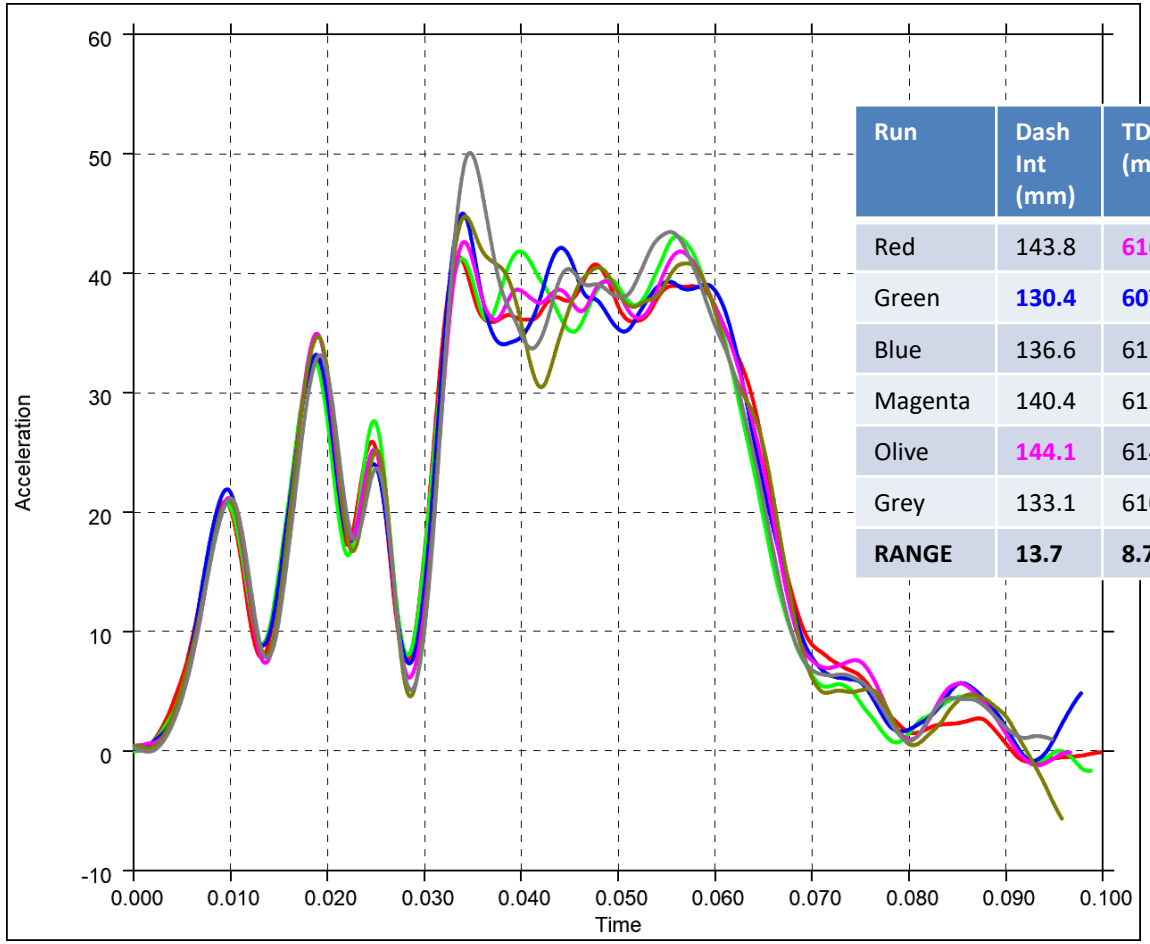


11 **Noise Accumulation**

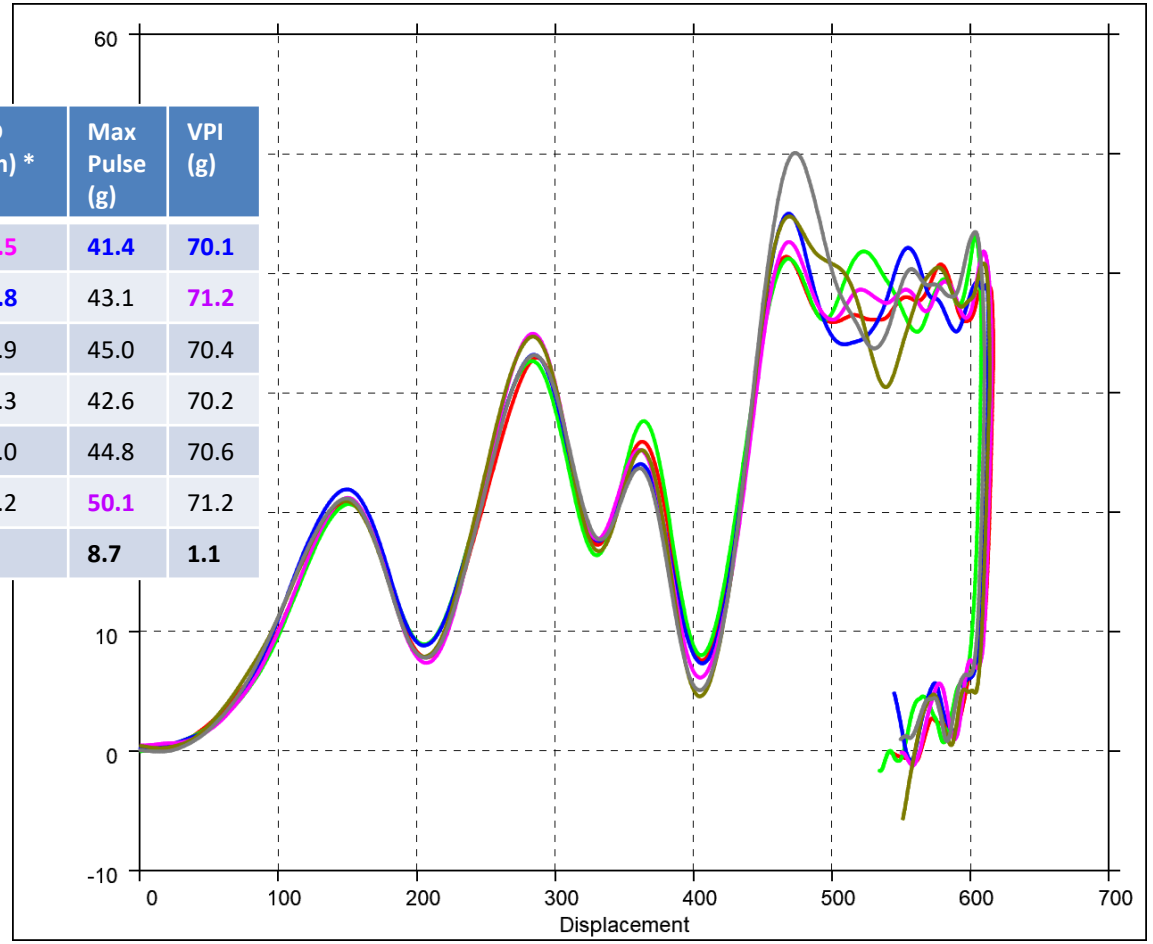




11 Noise Accumulation



Run	Dash Int (mm)	TDD (mm) *	Max Pulse (g)	VPI (g)
Red	143.8	616.5	41.4	70.1
Green	130.4	607.8	43.1	71.2
Blue	136.6	612.9	45.0	70.4
Magenta	140.4	615.3	42.6	70.2
Olive	144.1	614.0	44.8	70.6
Grey	133.1	610.2	50.1	71.2
RANGE	**13.7**	**8.7**	**8.7**	**1.1**



Noise Summary

Numerical Noise in LS-DYNA

12 **Conclusions and Open Questions**

- The change in results from running on a different number of CPUs is a well-known phenomenon. Changing local element density by adding, removing or exchanging a component invokes the same noise potential as changing the number of CPUs.

- Modelling dynamic features invoke vibrations which reduces clarity in what the initial condition is. Much like a NVH model, changing components, stiffnesses and masses changes further perturbates the initial condition.

- If an output is shown to be sensitive to noise, differential A-B comparison of two runs may require a statistical approach as one deliberate change is causing other uncontrolled changes and neither run may represent an average condition.

- If initial condition vibrations and procedural perturbations generate output noise, what is the cause?
    - The LS-DYNA solver?
    - The modelling practice used to represent the physical design?
    - An inherent property of the physical design itself?

Richard Young

MDO Lead Engineer

13 **Note**

The model in this presentation and the results generated are to demonstrate variance only and is not an indicator of real performance. The model is not set to a true mass or velocity used in any internal, consumer or regulatory standards.