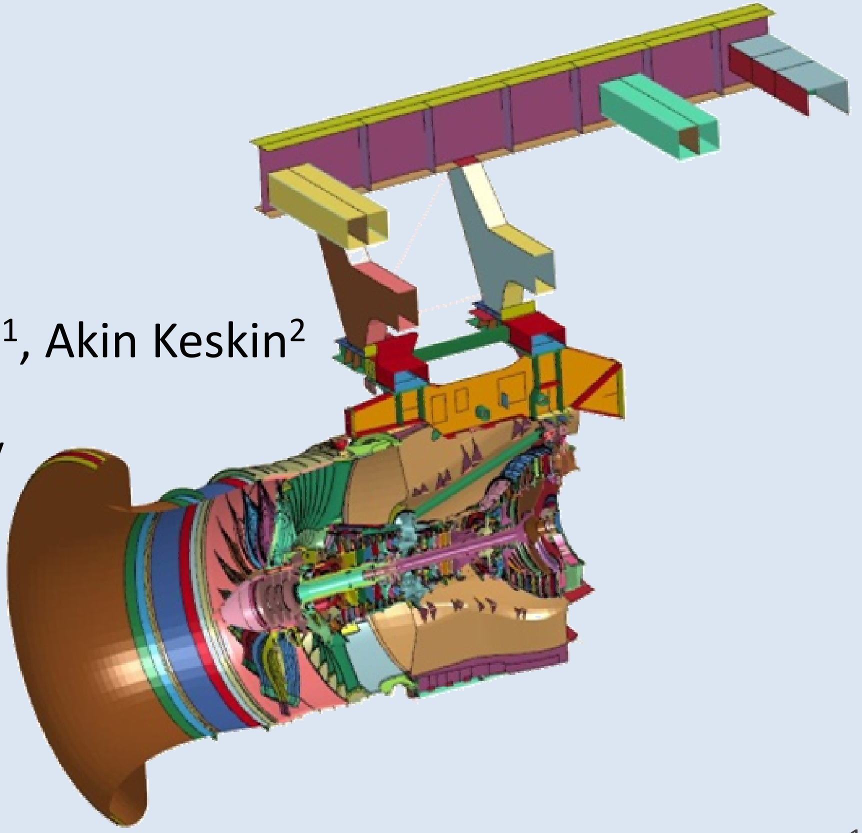
Identification of Stiffness Parameters of a Simplified Aero-Engine Mount System by Using a Higher Fidelity Model of the Mount System



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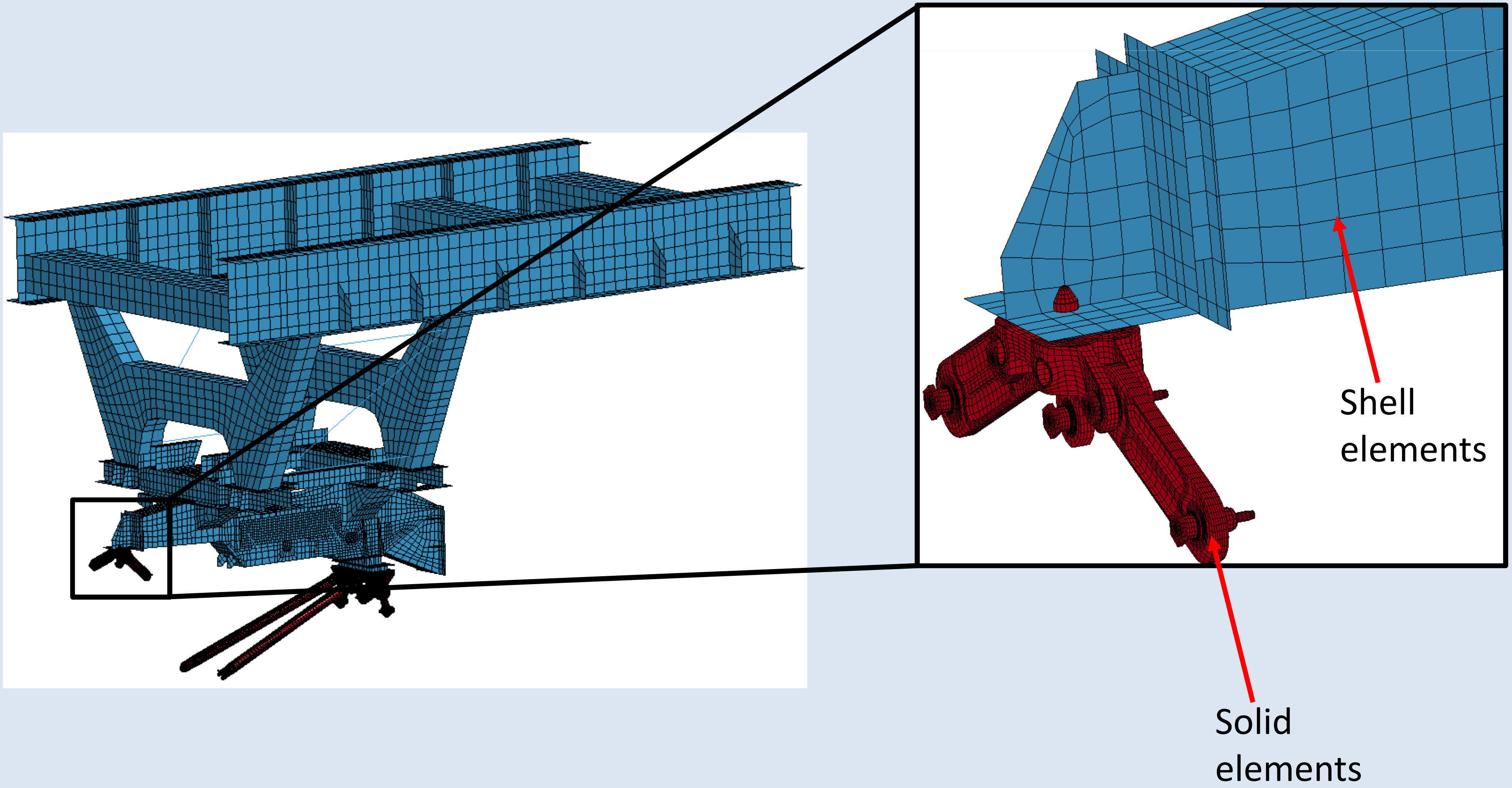
Outline

1. Coupling of pylon and engine (**classical approach**)
2. Coupling of pylon and engine (**new approach**)
3. Investigation of shell-to-solid coupling methods
4. Considerations before optimisation
5. Results of optimisation/parameter identification
6. Comparison of structural behaviour of optimised simple model (classical approach) and model with new approach

Summary

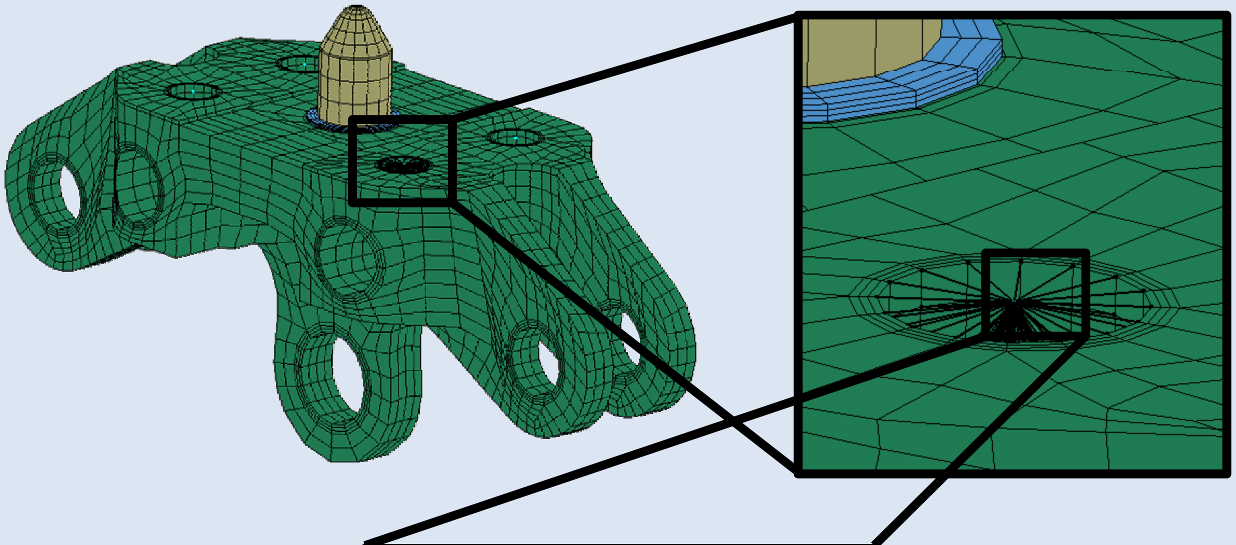
1. Coupling of pylon and engine (classical approach)

- Coupling of pylon (shell elements) with mount system (solid elements) was classically done with beam elements



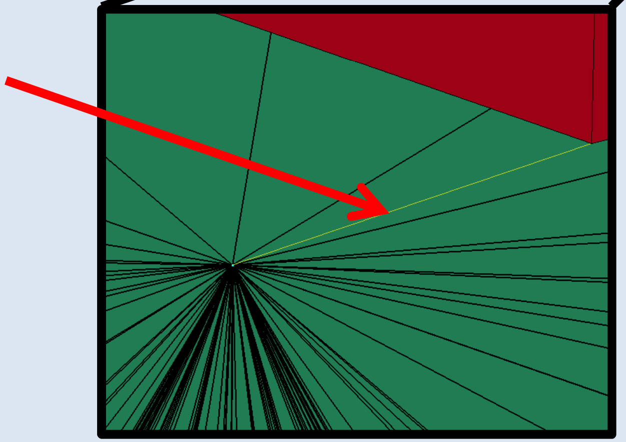
1. Coupling of pylon and engine (classical approach)

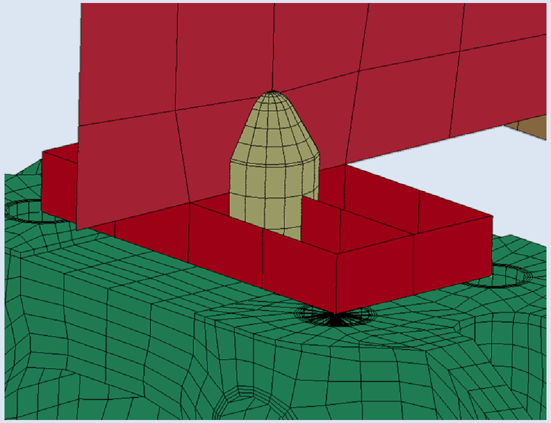
- Coupling by “constrained interpolations” and “discrete beams”:



Constrained interpolations
(special rigid beam formulation)

Discrete beam
(nearly zero
length, six
stiffness
parameters)

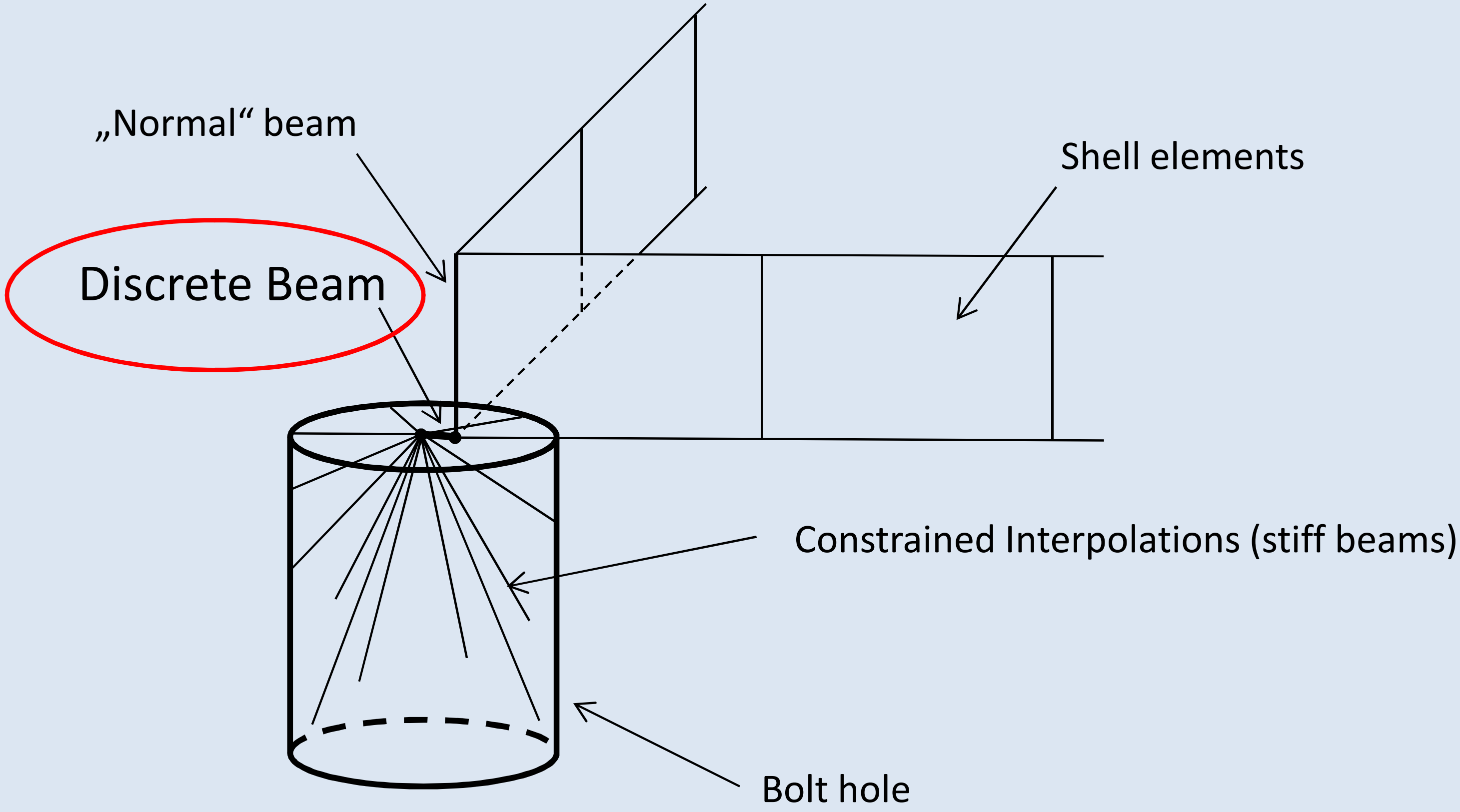




Discrete beam
connects shell
structure of
pylon to
constrained
interpolations

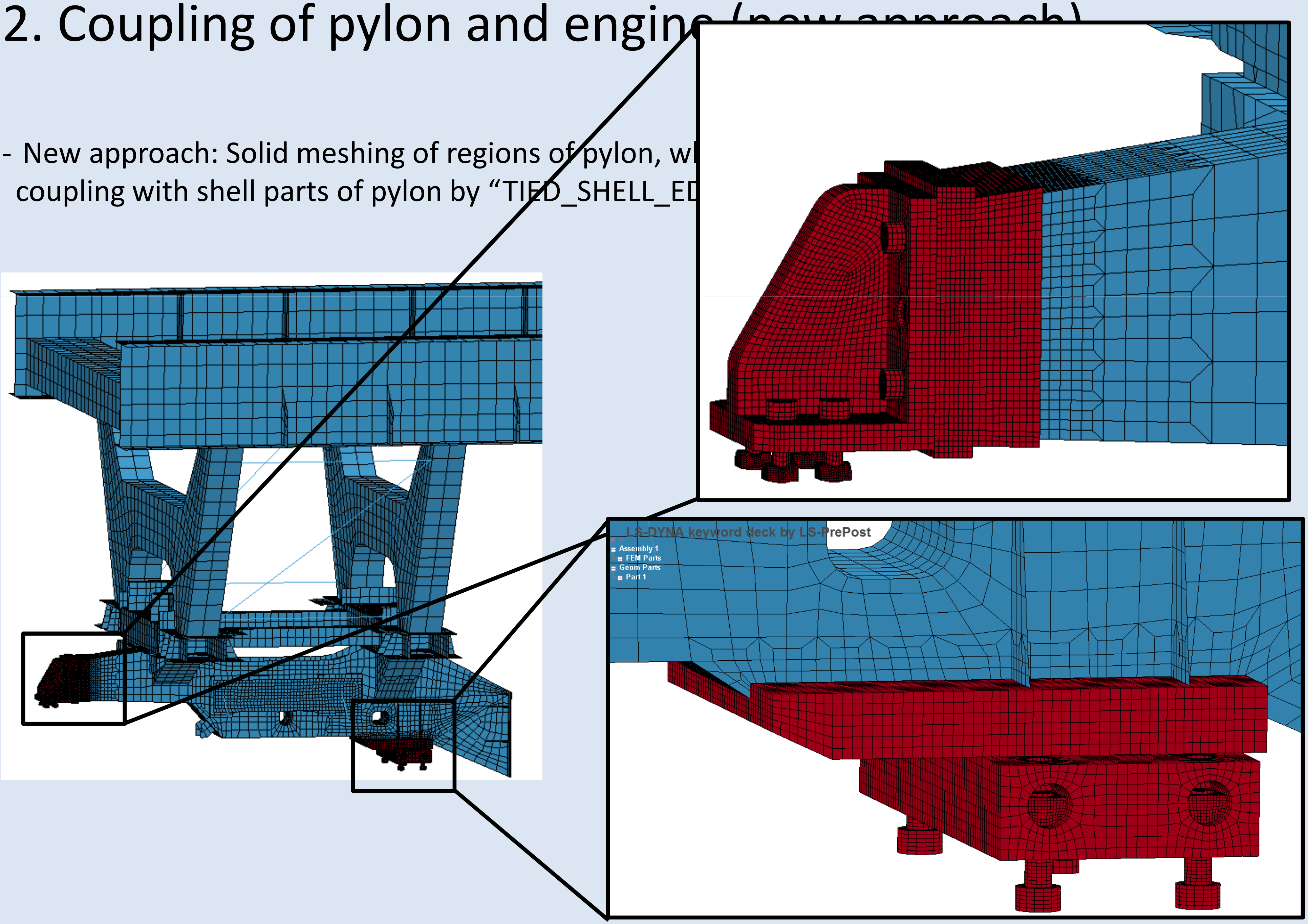
1. Coupling of pylon and engine (classical approach)

- Scheme of coupling:



2. Coupling of pylon and engine

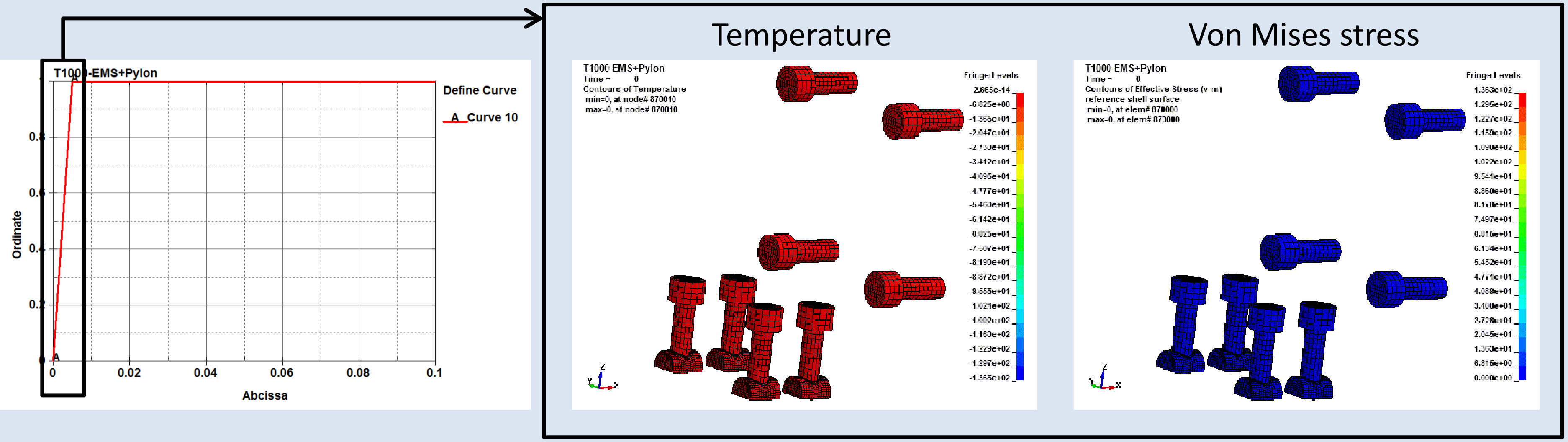
- New approach: Solid meshing of regions of pylon, wh
  coupling with shell parts of pylon by “TIED_SHELL_ED



2. Coupling of pylon and engine (new approach)

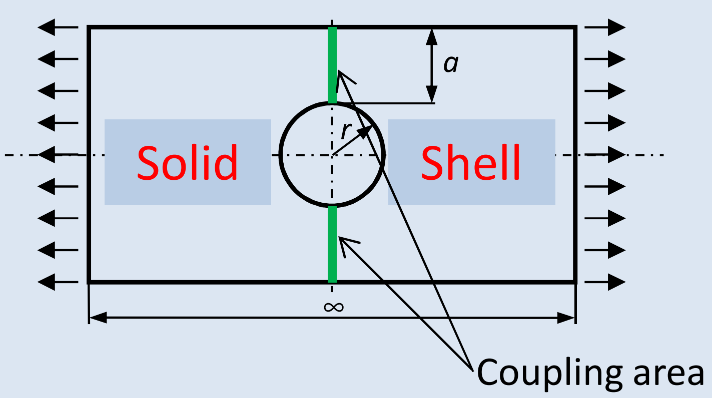
- Contact between bolds and surrounding structure as well as contact between pylon and engine mount system is modeled as surface-to-surface contact

- Tightening torque of bolts is applied via temperature load (bolts are cooled down)



3. Investigation of different shell-to-solid coupling methods

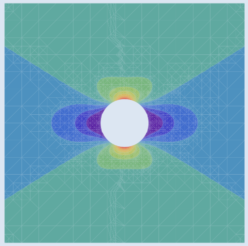
Example problem:



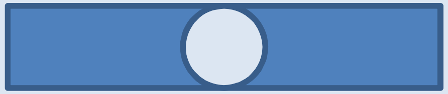
Analytical solutions exist for:

$a \to \infty$

Max. stress exaggeration factor for tension stress = **3**



$a \to 0$



Max. stress exaggeration factor for tension stress = **2**

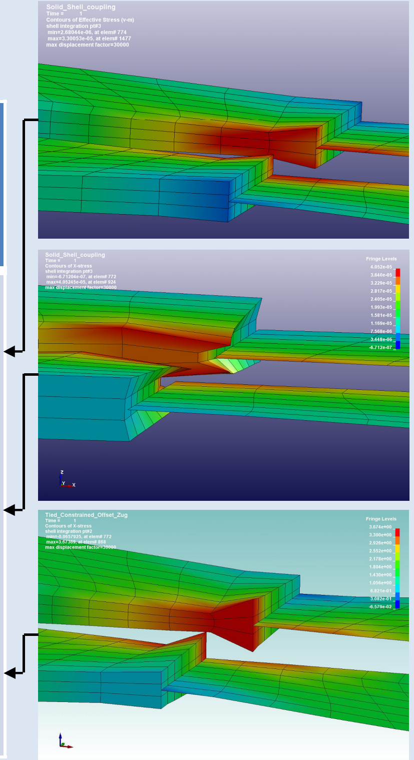
Analytical solutions give hints for correct FE solution

Investigated coupling methods and results:

(solid ELFORM 18, shell ELFORM 16, absolute values for test load case)

Coupling Method	Stresses in coupled model (solid/shell area)	Max. tension stresses in pure solid/shell model	Max. displ. in coupled model	Max. displ. in pure solid/shell model
*CONSTRAINED_ SHELL_TO_SOLID	3.64/3.60	3.62/3.61	6.58	6.58/6.60
*CONSTRAINED_ INTERPOLAT	4.05/3.59		6.60	
*CONTACT_ _SHELL_EDG O_SURFACE			6.56	

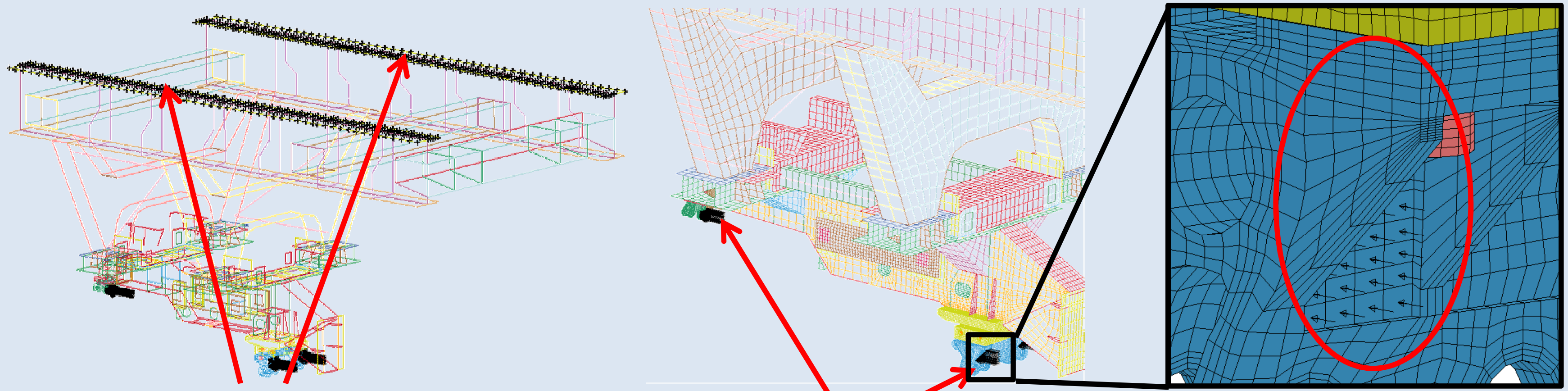
Nearly identical results in terms of displacements (also for additionally investigated bending load case)



4. Considerations before optimisation

4.1 Results of **explicit** calculation for test load case

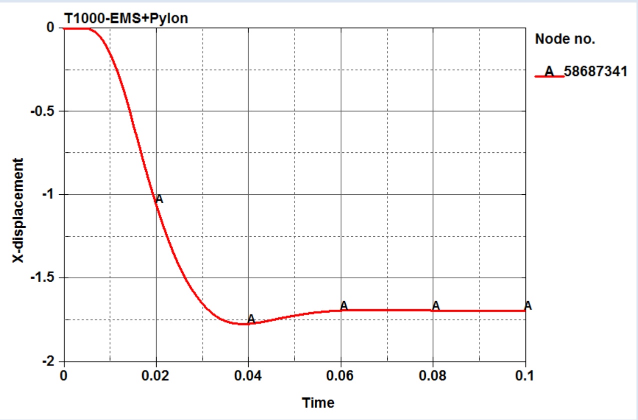
Load case:



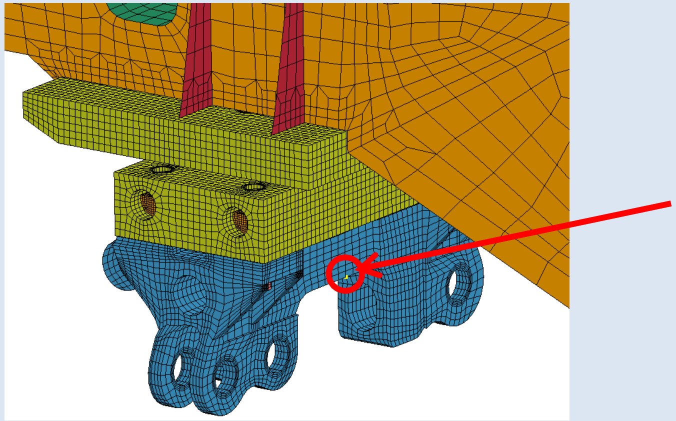
Fixed at upper side of
pylon support

Segment loads at mount system

Results (displacements in load-direction):



History of displacement
(global damping = 200)



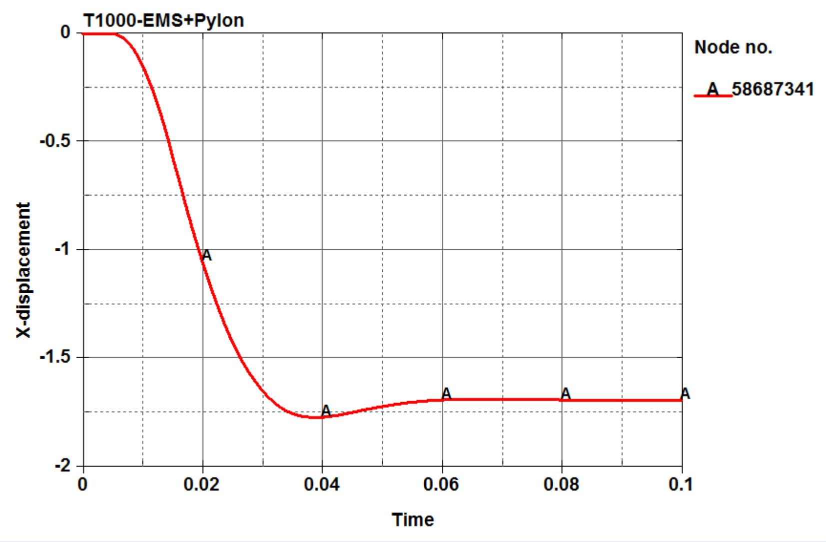
Node of
displacement
evaluation

4.2 Results of **implicit** calculation for test load case

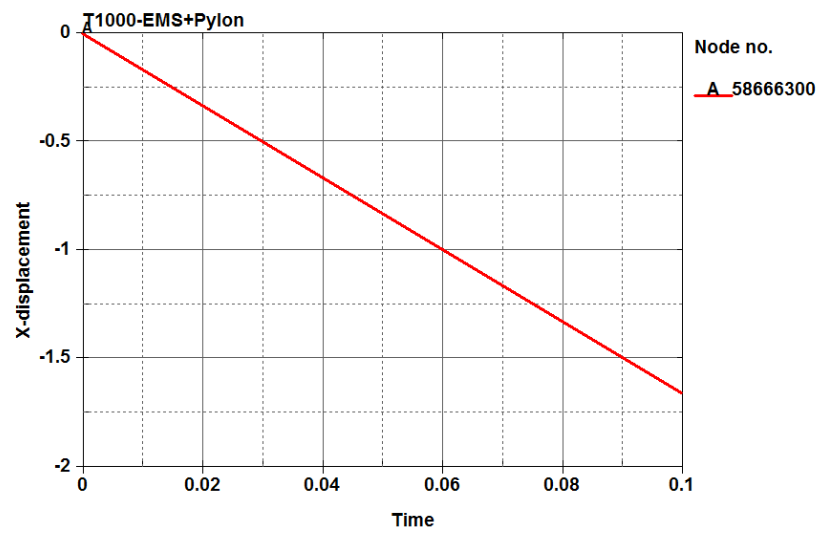
- Same boundary conditions and loads like in explicit calculation

Comparison of results (displacements in load-direction at same node):

Explicit (comp. time 2 days):



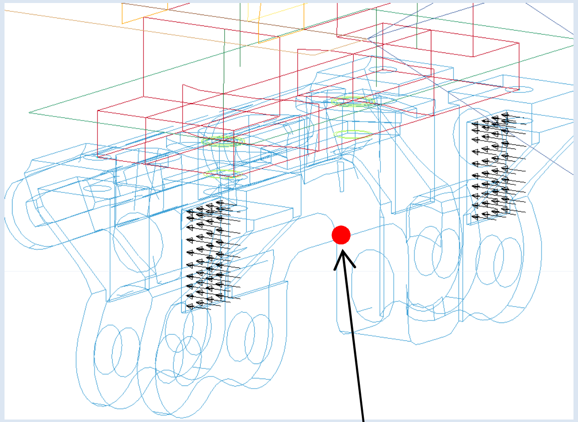
Implicit (comp. time 2 minutes):



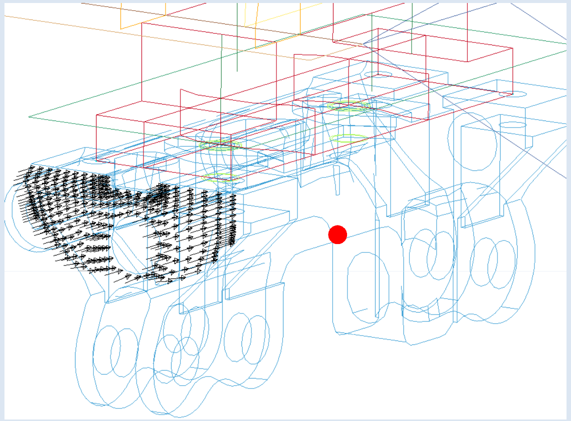
⇒**Results of implicit calculation coincide with results of explicit calculation**

⇒**Implicit calculation is much faster and therefore better suited for an optimization process**

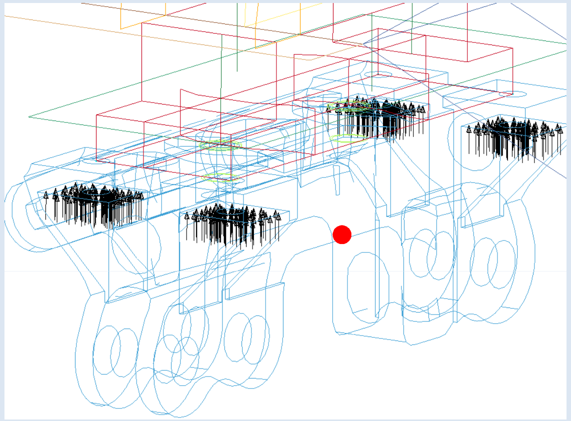
4.3 Definition of load cases for parameter identification



x-load rear

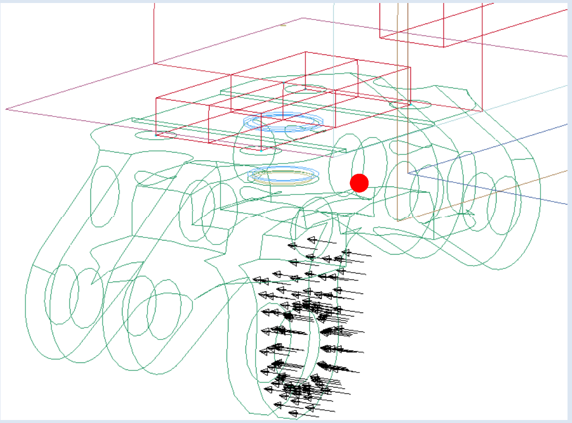


y-load rear

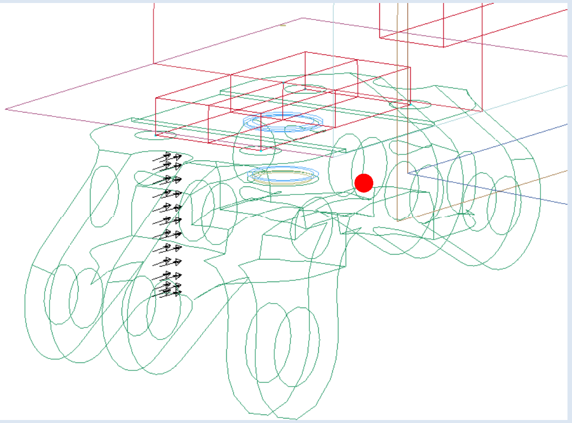


z-load rear (negative SF)

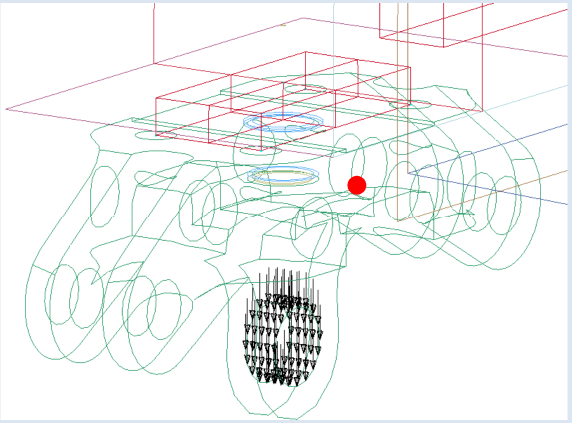
Node of displacement evaluation



x-load front



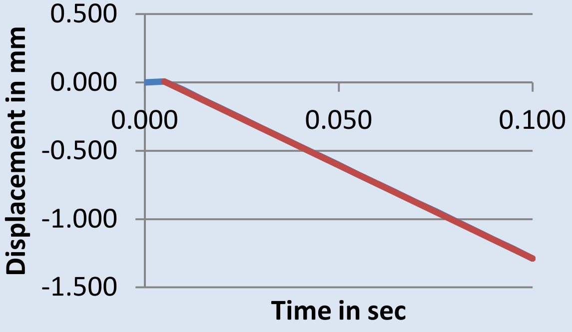
y-load front



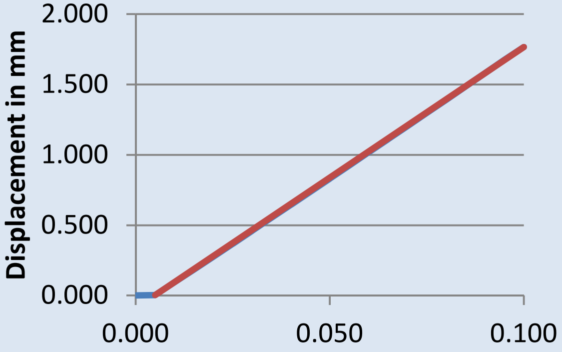
z-load front

4.4 Results of **implicit** calculation for load cases

- To discover possible non-linear effects in implicit calculations, now 20 time-steps are enforced

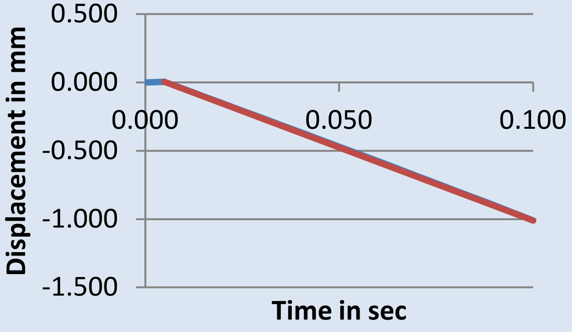


x-load rear



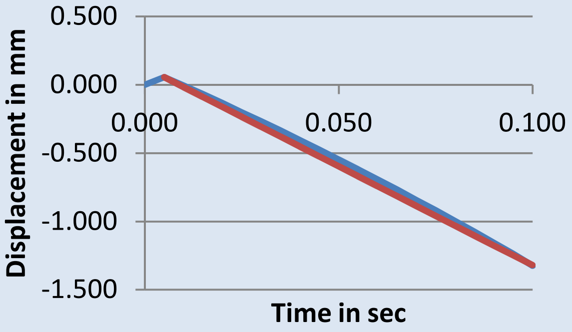
y-load rear

Time in sec

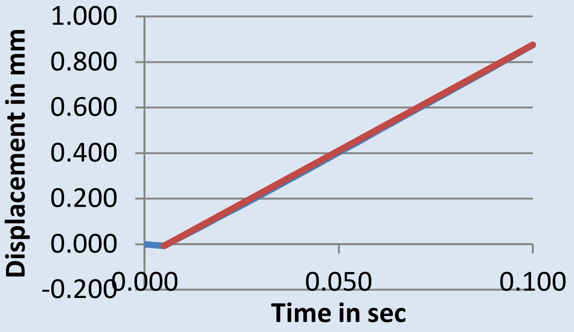


z-load rear

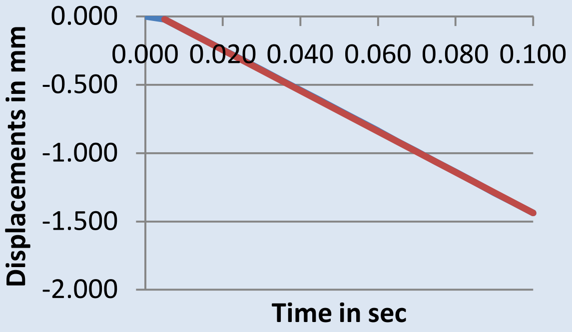
▬ Computed displacement history (20 time-steps) ▬ Linear function



x-load front



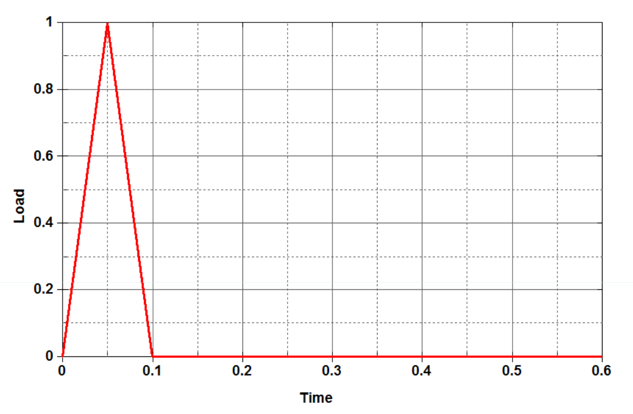
y-load front



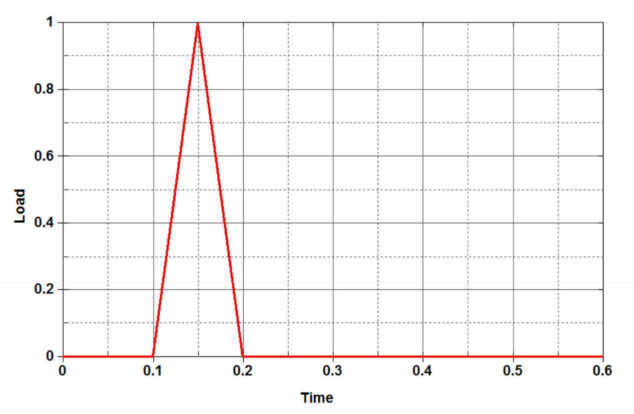
z-load front

=> Structure behaves approx. linear, therefore an optimization-based parameter identification is useful

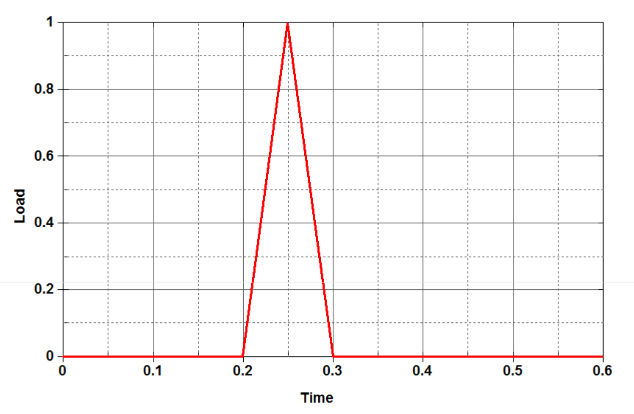
4.5 Load curves for load cases in simplified model



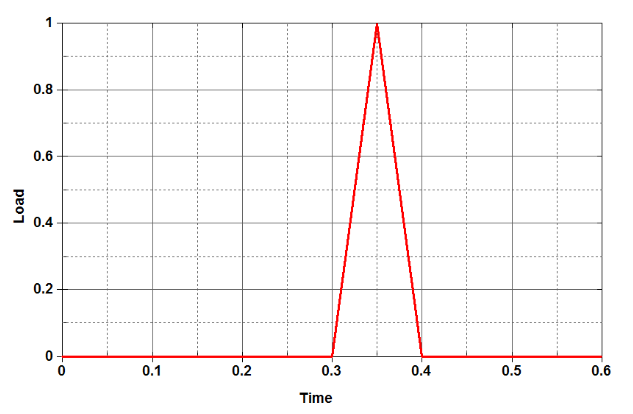
x-load rear



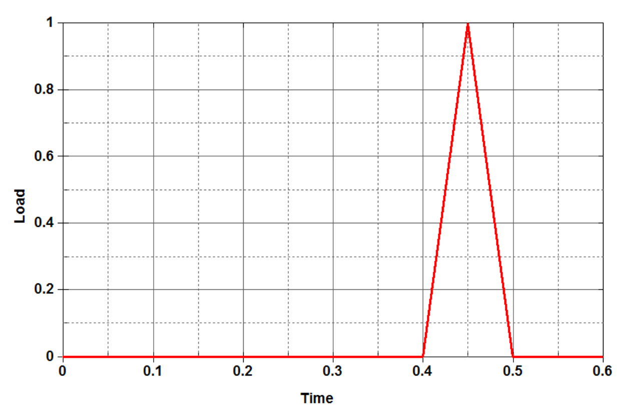
y-load rear



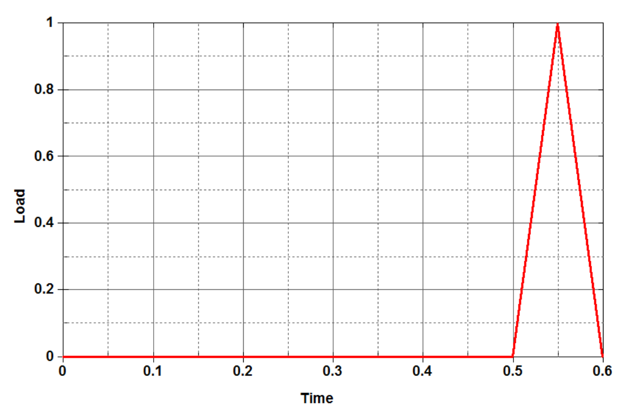
z-load rear



x-load front



y-load front



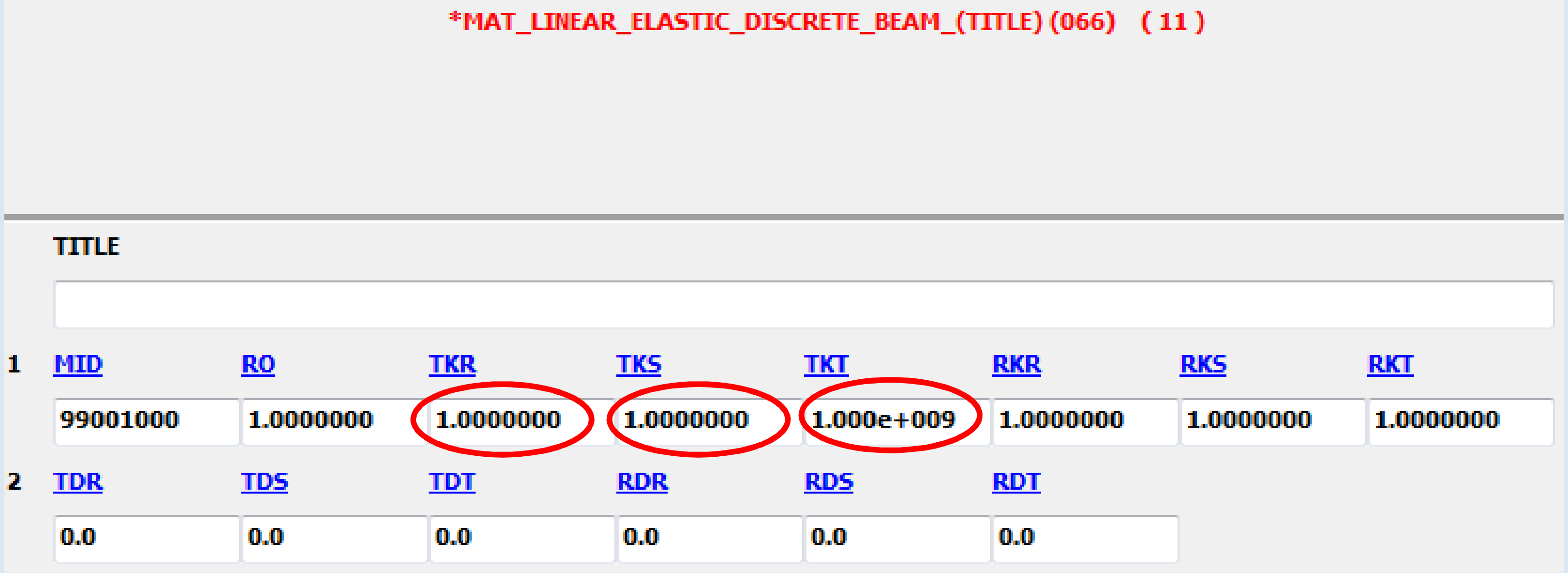
z-load front

- Displacements are evaluated at time 0.05, 0.15, 0.25 … for respective load case

4.6 Design variables and objective

- Design variables are stiffness parameters of discrete beams in x-, y- and z-direction for front and rear pins and bolts

- 4 front bolts (all equal) + 1 front pin + 4 rear bolts (all equal) + 1 rear pin lead to 12 design variables



*MAT_LINEAR_ELASTIC_DISCRETE_BEAM_(TITLE) (066)   (11)

TITLE

1	MID	RO	TKR	TKS	TKT	RKR	RKS	RKT
	99001000	1.0000000	1.0000000	1.0000000	1.000e+009	1.0000000	1.0000000	1.0000000
2	TDR	TDS	TDT	RDR	RDS	RDT		
	0.0	0.0	0.0	0.0	0.0	0.0		

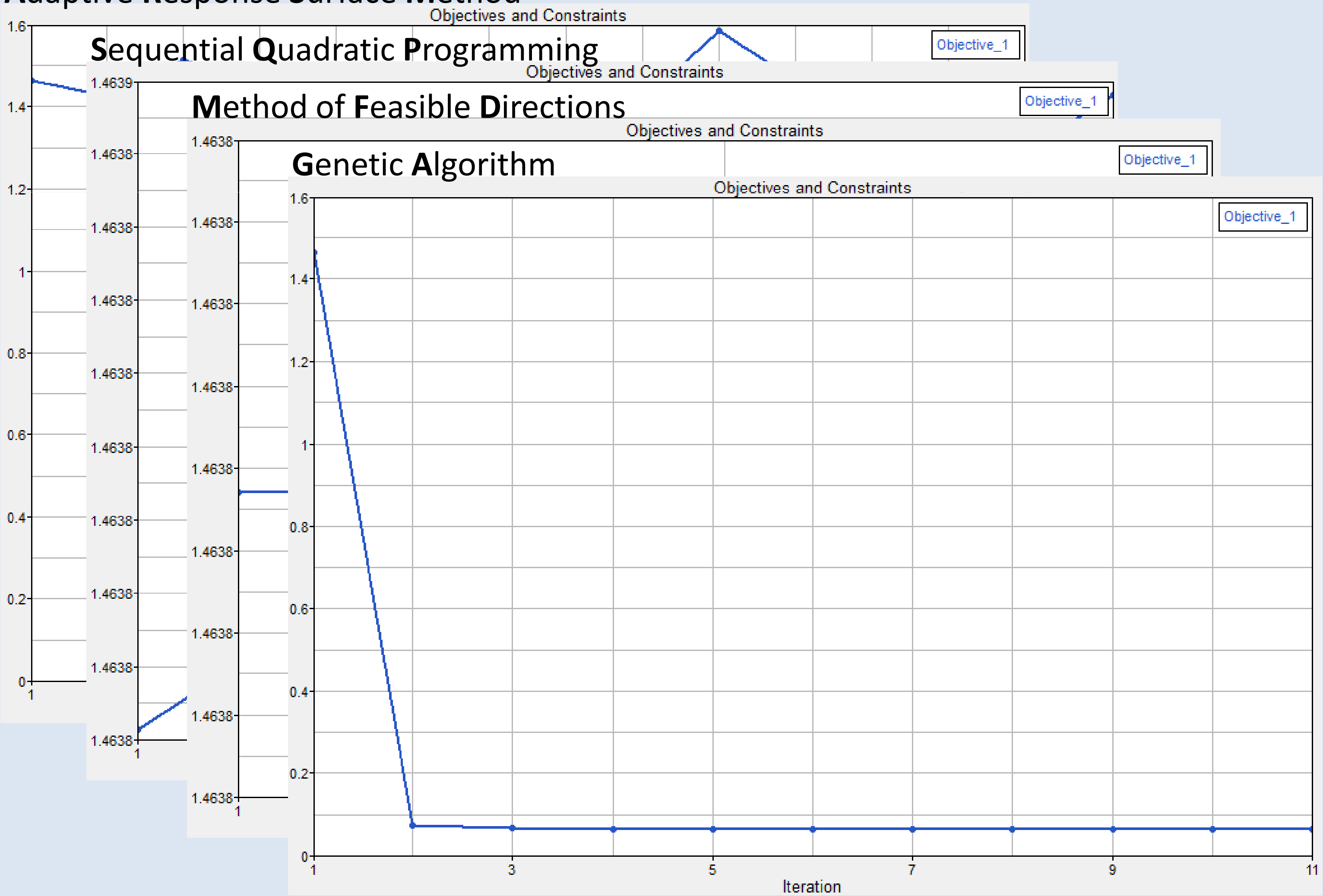
- Variation of stiffness parameters between 1.0 and 1.0e10

- Objective = sum of squared displacement differences between detailed and simplified model

5. Results of optimization/parameter identification

(**HyperStudy**)

Adaptive **R**esponse **S**urface **M**ethod



Sequential **Q**uadratic **P**rogramming

Method of **F**easible **D**irections

Genetic **A**lgorithm

=> Only genetic algorithm leads to satisfactory results

5. Results of optimization/parameter identification

(**HyperStudy**)

	Stiffness parameters					
	Old values			Optimised values		
	TKR	TKS	TKT	TKR	TKS	TKT
Front pin	1e9	1e9	1.0	1e10	5.5e9	1e10
Front bolts	1.0	1.0	1e9	5.8e9	2.9e5	1e10
Rear pin	1e9	1e9	1.0	9.9e10	4.3e9	1e10
Rear bolts	1.0	1.0	1e9	1e10	81.2	4.11e9

- Value of objective: Reduction from 1.46 to **0.064**

=> Classical approach uses to low stiffness values for some of the bolts

5. Results of optimization/parameter identification

(**LS-Opt**)

- Possible problem when using LS-Opt with keyword *PARAMETER
  - LS-Opt reads automatically all variables defined under *PARAMETER as design variables
  - In case of the pylon model this leads to hundreds of parameters which cannot be handled by LS-Opt

- Solution: Keyword *PARAMETER_EXPRESSION should be used instead of *PARAMETER
  - Keyword *PARAMETER_EXPRESSION actually defines parameters like *PARAMETER but allows for general algebraic expressions but also definition of constants like done by *PARAMETER is possible
  - LS-Opt does not read the parameters defined under *PARAMETER_EXPRESSION as design variables

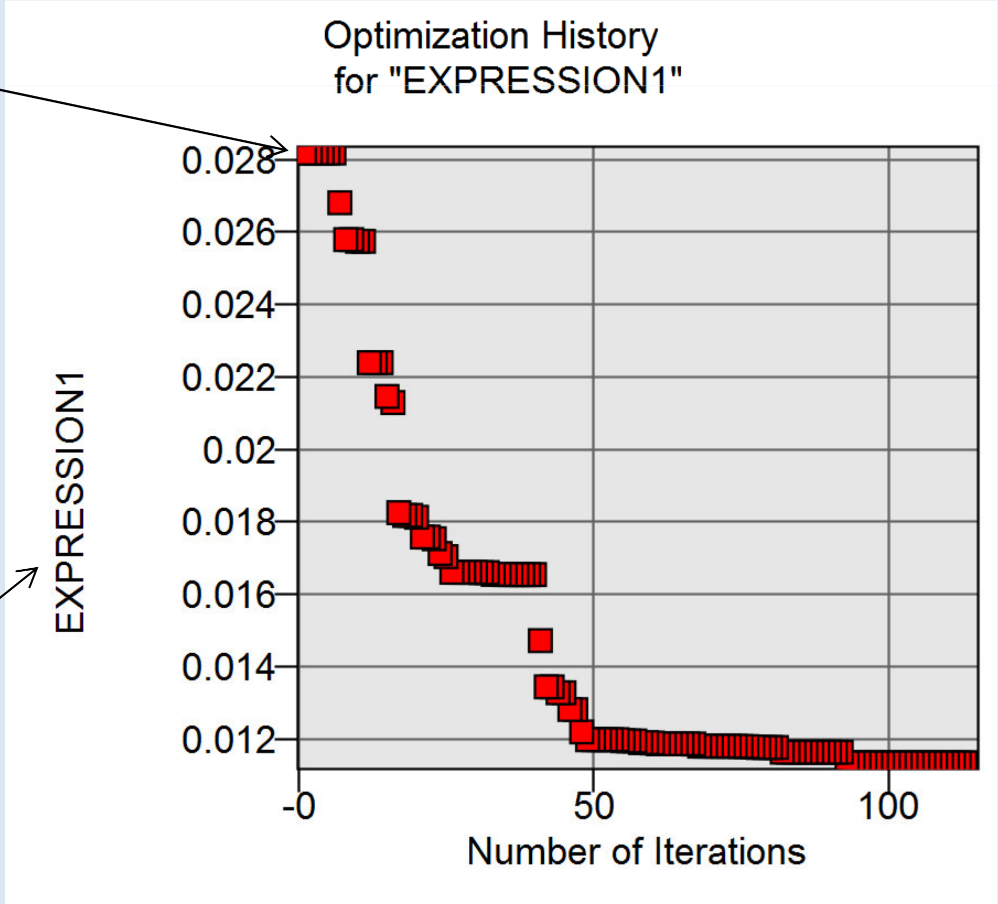
5. Results of optimization/parameter identification

(**LS-Opt**)

- LS-Opt offers only a genetic algorithm for optimization problems (30 individuals per generation were used)

LS-Opt does not plot the objective value for the start parameters (in contrast to HyperStudy -> reason for different objective values in diagrams)

“Expression1“ = Objective



Optimisation history of **first** LS-Opt optimization

5. Results of optimization/parameter identification

(LS-Opt)

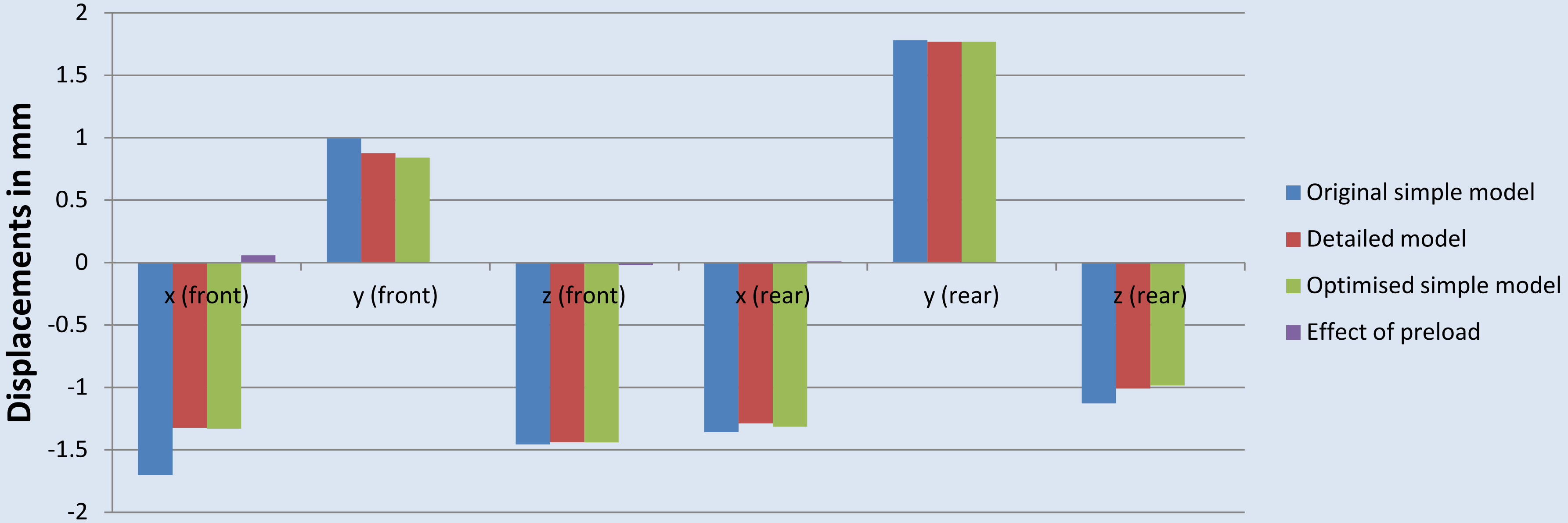
	Stiffness parameters					
	Old values			Optimized values		
	TKR	TKS	TKT	TKR	TKS	TKT
Front pin	1e9	1e9	1.0	9.09e9	9.02e9	1.06e6
Front bolts	1.0	1.0	1e9	3.25e8	9.78e9	9.37e9
Rear pin	1e9	1e9	1.0	8.09e9	6.95e3	1.8e9
Rear bolts	1.0	1.0	1e9	5.62e8	9.08e9	3.51e9

- Value of objective: Reduction from 1.46 to **0.011**

=> Most stiffness parameters of discrete beams are increased by optimisation algorithm

6. Comparison of absolute displ. at evaluated nodes for best optimisation result (first optimisation with LS-Opt)

		Original simple model	Detailed model	Optimised simple model
Front	x	-1.702	-1.324	-1.331
	y	0.9922	0.8759	0.8395
	z	-1.458	-1.438	-1.441
Rear	x	-1.358	-1.288	-1.315
	y	1.779	1.768	1.769
	z	-1.129	-1.009	-0.986



Summary

- With the help of a genetic optimisation algorithm the stiffness parameters of the simple pylon model were adjusted such that a much better correlation to the displacement results of the detailed approach is reached.

- Sensitivity-based optimisation algorithms were not successful in this case.

- It should be noted that even in the detailed model exist some uncertainties (e.g. the correct preload of the bolts, the correct shape of bolts, ...) which effect the computed displacements. Nevertheless, the approach works in general.

Thank you for your attention!

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