A Study in Mass Scaling for Sheet Metal Forming with LS-DYNA®

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Abstract

Metal Forming simulation requires the deformed sheet metal to catch the tooling shapes precisely. With the limitation of lower order elements, mesh refinement is required to represent the key features of the geometry. In reality, the tooling travel speed is very low. Consequently, the physics of sheet metal forming involves a long termination time induced by the low Tool travel speed and a small timestep induced by the fine mesh. Many techniques are available to reduce the computation time for this important class of simulations. This presentation will study the effect of mass scaling, adaptive meshing and the related factor of tool travel speed and attempt to determine the acceptable range of settings for sheet metal forming simulation analysis. We will also identify what are the key criteria to identify the reliability of the simulation results.

Introduction

Sheet Metal forming simulation's uniqueness' is to catch the tooling geometry precisely. In order to achieve this we need to have a fine mesh towards the end of the simulation so that we can smoothly represent the deformed geometry of the blank. As the problem is largely displacement driven (i.e. the final deformed geometry is a given) the mesh usually does not need to be fine and uniform from the beginning leading to the approach of adaptive mesh refinement. This technique has been widely adopted and is the standard way of working in industry. Some features of the manufactured part such as the flanges may however not have their final position imposed by the tools and consequently bifurcations may occur during the deformation history. The arsenal of numerical tools that we have available in LS-DYNA to optimize the efficiency of forming simulations does not necessarily take this into account. In the current paper we will investigate the limits of numerical techniques such as adaptivity and mass scaling with respect to specific issues such as flange geometry.

Example description

The problem setup is shown in Figures 1 and Figure 2. the tooling setup is such that the Pad comes down and the Die travel's down until it closes with the Punch. The process is only partly displacement driven as the motion of the flanges is not fully constrained. The real life Die speed is around 100 mm/s and duration of the operation is around 2 seconds. The thickness of the blank was 3 mm.

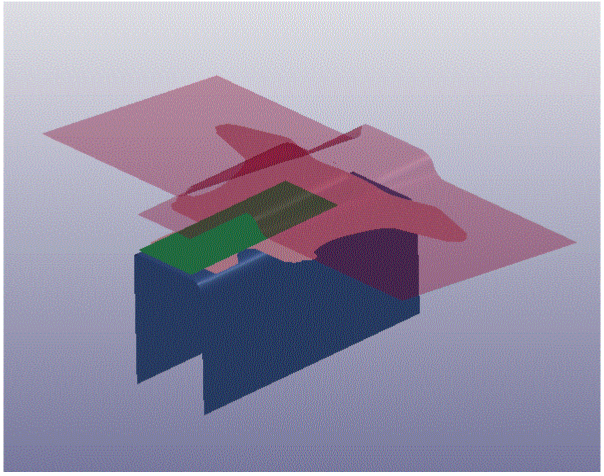


Figure 1

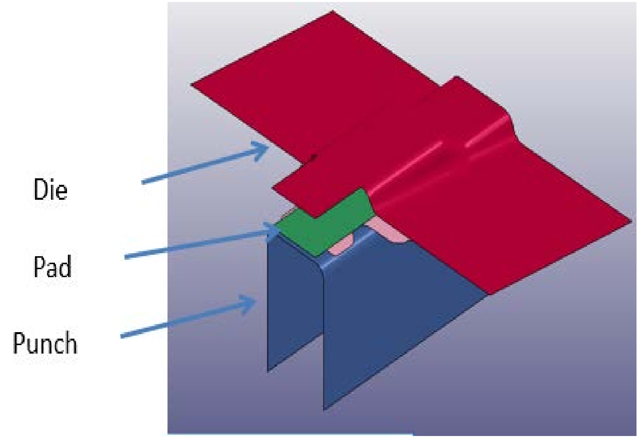


Figure 2

A scanned picture of the experimental result is given in Figure 3 and in Figure 4 we show a comparison of the final deformed shape resulting from a simulation with the scanned picture. It can be seen that the predicted deformed shape converges nicely to the physical solution. The numerical solution here is the result of a simulation performed at rather slow loading speed (5 times higher than real life) and using a moderate amount of mass scaling. In Figure 5 it can be seen how the final deformed shape, in particular the shape of the flanges, is negatively affected by an increased use of mass scaling.

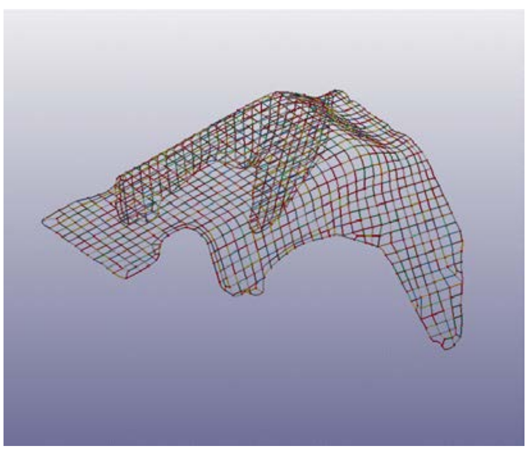


Figure 3

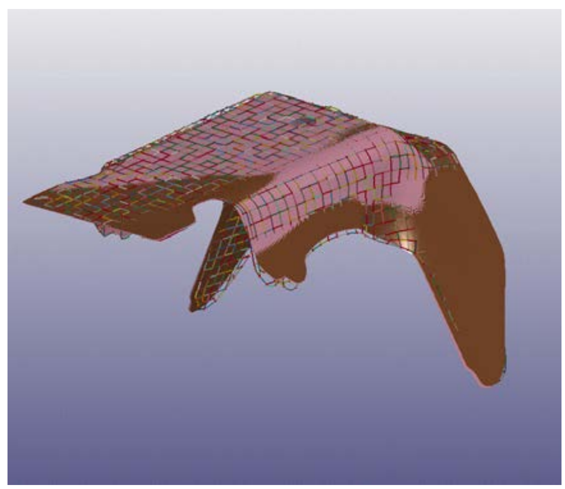


Figure 4

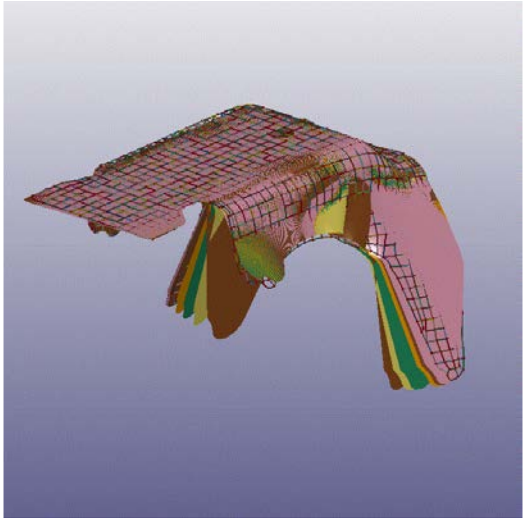


Figure 5

Parametric study

A parametric study was performed for blanks with 2 mm and 3 mm thickness. (experimental results were available for the 3 mm blank). A total of 4 different simulation strategies were investigated. We will first consider the parametric study performed on a model using a 2 mm thick blank.

In a first series of simulations we adhered as close as possible to common industrial simulation practice. Adaptive remeshing was used in combination with a highly increased loading speed (5 m/s or 50 times real life) . The mesh started off at 3 mm and was refined to 1.5 mm. LS-DYNA was used in MPP mode on a 31 CPU cluster. The simulation time was then reduced by increasing the time step from 0.3 microseconds to 6 microseconds using CMS (conventional mass scaling). The results of this study are summarized in table 1 and the deformed shapes are shown in Figures 6 till Figure 12.

Timestep (s)	Added Mass (kg)	Added Mass (%)	EPS	Vonmises (MPa)	Max Thickness (mm)	Min Thickness (mm)	Final shape	CASE	CPU time
baserun	0	0	0.54	1328	2.31	1.60	good	1	6 min 8 s
0.3e-6	0.102	26%	0.53	1324	2.31	1.60	good	2	3 min 38 s
0.8e-6	3.93	1007%	0.58	1142	2.29	1.66	ok	3	2 min 13 s
1.2e-6	9.89	2536%	0.56	1166	2.28	1.62	Not good	4	1 min 57 s
1.6e-6	27.26	4714%	0.85	1345	2.35	1.60	Not good	5	1 min 46 s
2.0e-6	29	7436%	0.87	1302	2.41	1.59	bad	6	1 min 41 s
0.6E-5	27.2	69744%	2.59	4160	4.48	1.14	bad	7	1 min 20 s

Table 1

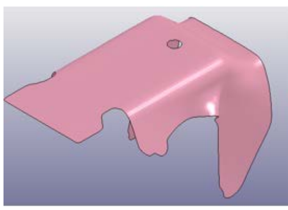


Figure 6

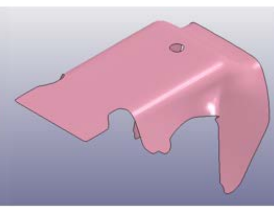


Figure 7

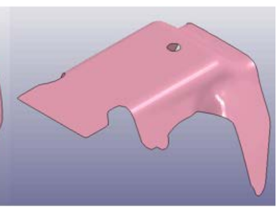


Figure 8

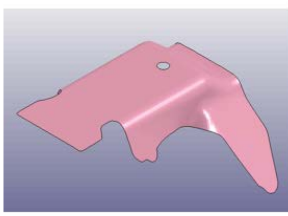


Figure 9

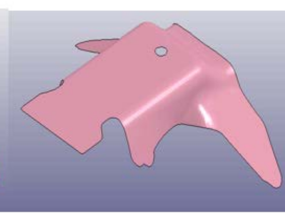


Figure 10

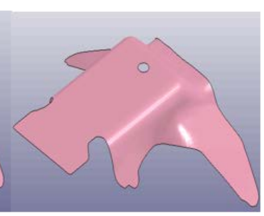


Figure 11

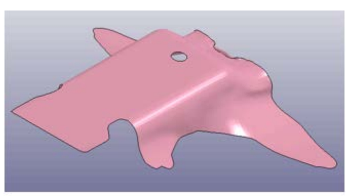


Figure 12

The second series of simulations differed from the first series only in the loading speed which was 10 times smaller (0.5 m/s or 5 times real life). The results of this study are summarized in table 2 and the deformed shapes are shown in Figures 13 till Figure 19.

Timestep (s)	Added Mass (kg)	Added Mass (%)	EPS	Vonmises (MPa)	Max Thickness (mm)	Min Thickness (mm)	Final shape	CASE	CPU time
baserun	0	0	0.54	1328	2.31	1.60	good	1	6 min 8 s
0.3e-6	0.102	26%	0.53	1324	2.31	1.60	good	2	3 min 38 s
0.8e-6	3.93	1007%	0.58	1142	2.29	1.66	ok	3	2 min 13 s
1.2e-6	9.89	2536%	0.56	1166	2.28	1.62	Not good	4	1 min 57 s
1.6e-6	27.26	4714%	0.85	1345	2.35	1.60	Not good	5	1 min 46 s
2.0e-6	29	7436%	0.87	1302	2.41	1.59	bad	6	1 min 41 s
0.6E-5	27.2	69744%	2.59	4160	4.48	1.14	bad	7	1 min 20 s

Table 2

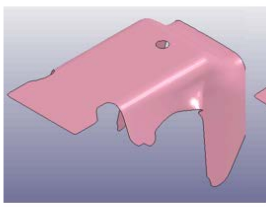
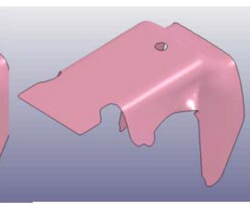


Figure 13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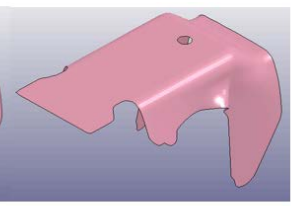
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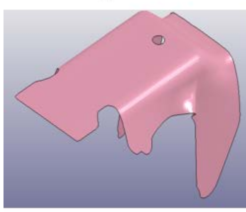
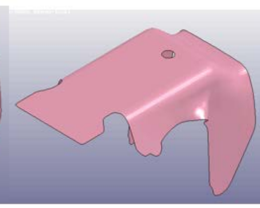


Figure 16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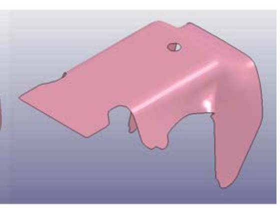
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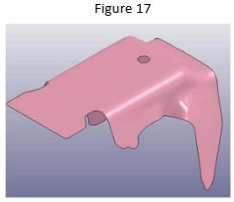
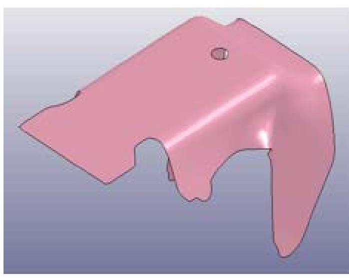


Figure 19

In the third series of simulations the loading speed was set back to 5m/s but no adaptive remeshing was used and a fine uniform mesh (with characteristic mesh length of 1.5 mm) was used from the start of the calculation. The results of this study are summarized in table 3 and the deformed shapes are shown in Figure 20 till Figure 26.

Timestep	Added Mass (kg)	Added Mass (%)	EPS	Vonmises (MPa)	Max Thickness (mm)	Min Thickness (mm)	Final shape	CASE	CPU time
baserun	0	0	0.55	1430	2.33	1.60	Good	1	10 min 43 s
0.3e-6	0.17	43.6%	0.51	1542	2.32	1.59	Good	2	5 min 11s
0.8e-6	5.97	1531%	0.70	1289	2.33	1.64	bad	3	2 min 53s
1.2e-6	14.4	3692%	0.96	1878	2.42	1.62	**bad**	4	2 mn 29 s
1.6e-6	26.3	6744%	1.04	1124	2.45	1.60	**bad**	5	2 min 11 s
2.0e-6	41.5	10641%	1.19	1282	2.52	1.59	bad	6	2min 8s
0.6E-5	392.81	100721%	3.44	11530	8.11	1.07	bad	7	1 min 47 s

Table 3



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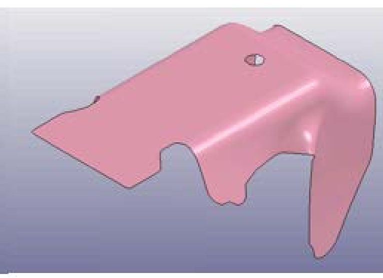

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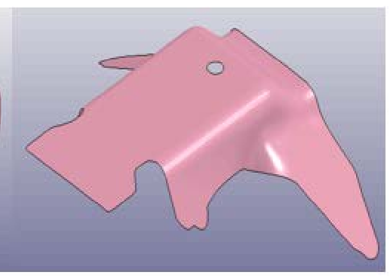

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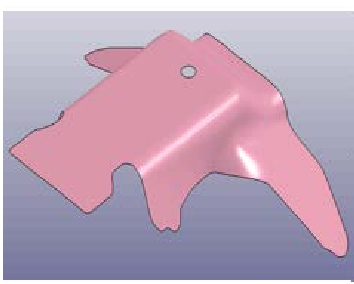

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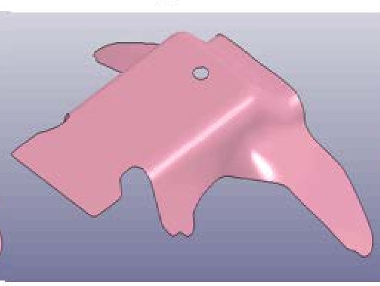

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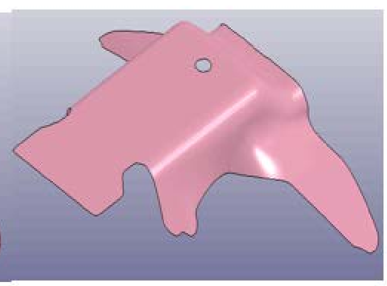

Figure 25

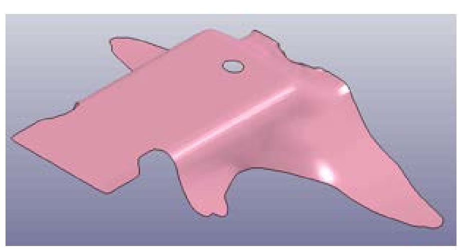

Figure 26

In the fourth and final series of simulations the loading speed which was kept at 5m/s and a uniform mesh (with characteristic mesh length of 1.5 mm) was used from the start of the calculation. However, this time the timestep was increased using SMS (Selective Mass Scaling) rather than CMS. The results of this study are summarized in table 4 and the deformed shapes are shown in Figure 27 till Figure 33.

Timestep	Added Mass (kg)	Added mass (%)	EPS	Vonmises (mpa)	Max Thickness (mm)	Min Thickness (mm)	Final shape	CASE	CPU time
baserun	0	0	0.55	1430	2.33	1.60		1	
0.3e-6	0.167	42.8%	0.55	1558	2.34	1.61	Good	2	12m58s
0.8e-6	5.97	1531%	0.6	1326	2.33	1.61	Good	3	9m3s
1.2e-6	14.41	3695%	0.55	1304	2.33	1.61	**Good**	4	8m24s
1.6e-6	26.23	6726%	0.51	1268	2.32	1.60	**Good**	5	7m46s
2.0e-6	41.44	10625	0.55	1268	2.32	1.61	Good	6	2m29s
4.0e-6	168.54	43215%	0.51	1211	2.3	1.58	Good	8	55s
0.6E-5							error	7	

Table 4

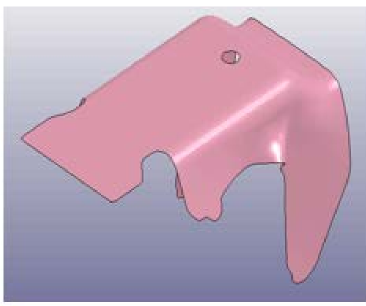

Figure 27

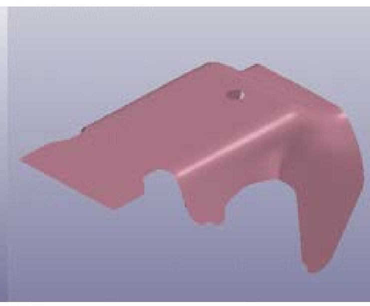

Figure 28

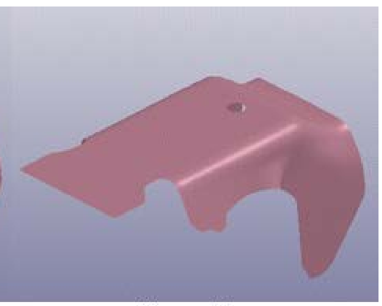

Figure 29

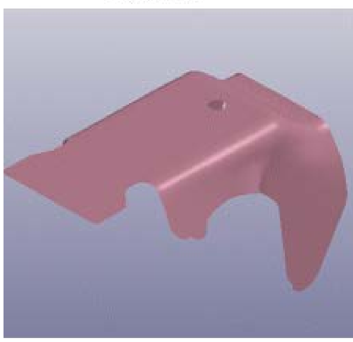

Figure 30

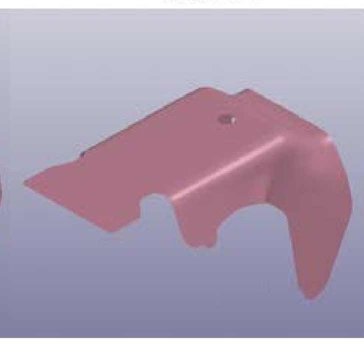

Figure 31

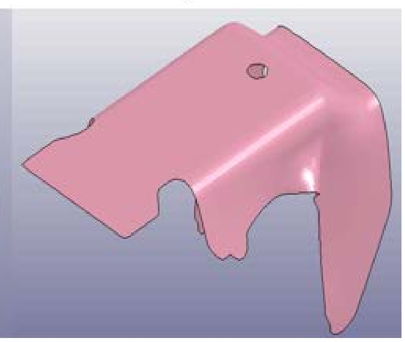

Figure 32

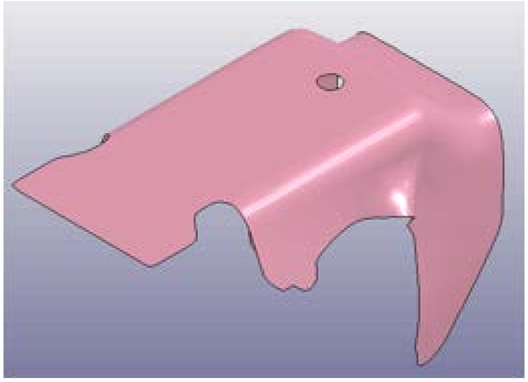

Figure 33

The runtime required to obtain a converged solution for all the different approaches was then compared. In Figure 34 we show the runtime for all simulations as a function of the timestep that was imposed. it is clear from looking at curves A and C that in the current study adaptive remeshing was beneficial only, using a uniform fine mesh during the entire analysis showed no advantage over the adaptive strategy

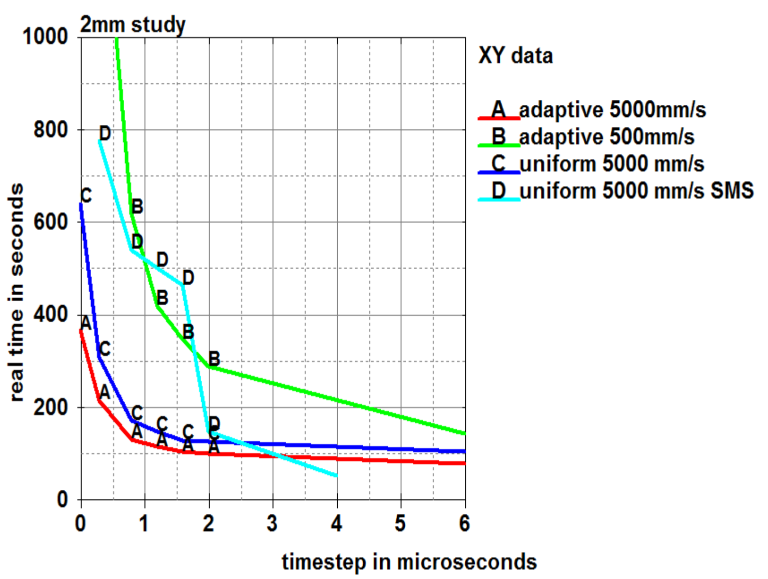

Figure 34

In Figures 35 and 36 we have kept only the runtime information for those simulations that gave satisfactory results with respect to final sheet thicknesses and with respect to final flange shape respectively. Clearly convergence is achieved much faster with respect to final thickness than with respect to final deformed shape, bifurcation is very unforgiving and requires much stricter modeling than displacement driven problems.

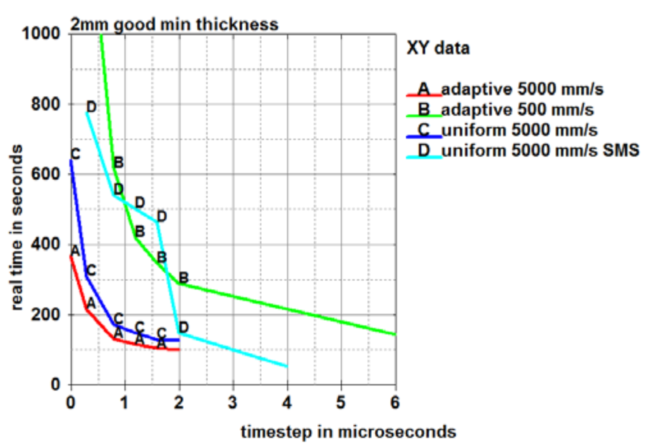

Figure 36

Comparing the end points of curves, A and B in both figures (35 and 36) we notice that in the current study high speedup combined with high scaling was more effective than low speedup combined with low scaling, the optimal combination may be hard to find in general. It should be noted though that low simulation speeds always yielded the better final flange shape. From curve D it is clear that selective mass scaling (SMS) is a very powerful tool allowing to get good final deformed shapes at high scaling, however some numerical problems occurred for very high timestep values.

In a second phase we now repeat the entire parametric study using a model based on 3 mm blank thickness. It should be noted that the tooling paths in this model were slightly different from the previous model.

The exact same series of 4 parametric studies were performed and the results are summarized in Tables 5 till 8.

In Figure 37 we show the runtime for all simulations as a function of the timestep that was imposed. A comparison of curves A and C shows that in the current study adaptive remeshing was beneficial only for small timestep values, at larger timesteps the uniform mesh models were more efficient.

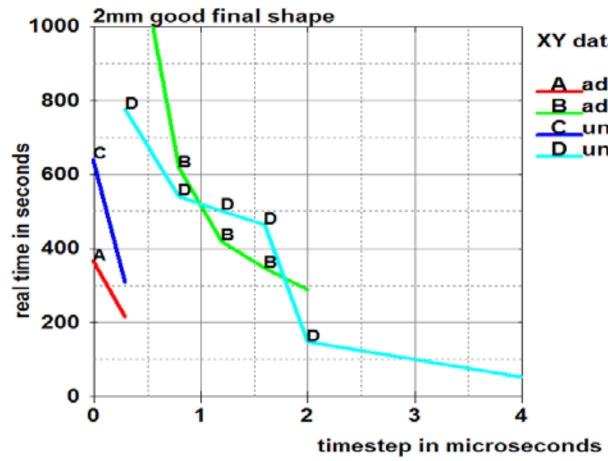

Figure 37

In Figures 38 and 39 we have kept only the runtime information for those simulations that gave satisfactory results with respect to final sheet thicknesses and with respect to final flange shape respectively. Again we see that convergence is achieved much faster wrt final thickness than wrt final deformed shape, bifurcation is very unforgiving and requires much stricter modeling than displacement driven problems.

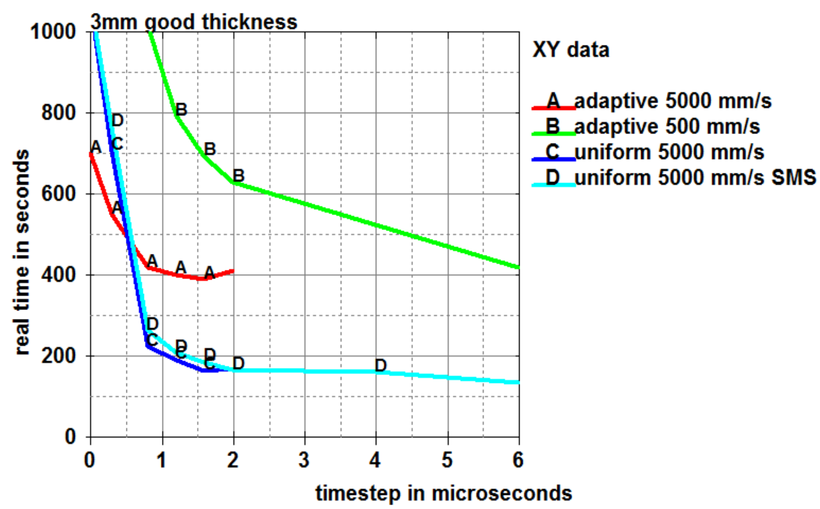

Figure 38

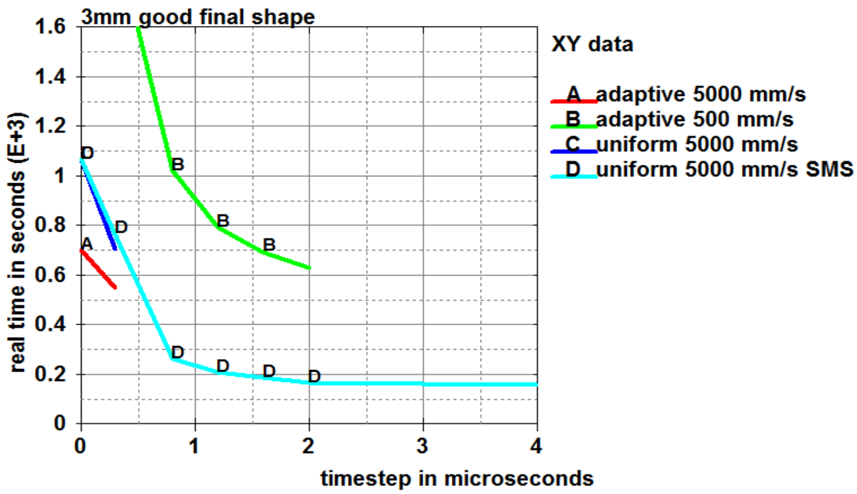

Figure 39

Comparison of curves A and B shows that high speedup combined with high scaling was equivalent to low speedup combined with low scaling, the optimal combination may be hard to find in general. Low speed did however give the best final shape. Again, from curve D we can see that selective mass scaling is a very powerful tool allowing to get good final deformed shapes at high scaling. No numerical problems occurred for very high timestep values with this model.

Conclusions

The study presented in this paper leads to somewhat different conclusions for the 2mm blank and the 3 mm blank models. This just shows that no 'guidelines' can achieve full generality. The differences in performance between the 2 models are due how the mpp-code handles the 2 slightly different models and in fact runtimes are much more consistent between both models when running on a single CPU. We do however believe that the comparisons presented are valid for simulations performed on the same model.

The main conclusions is that although a speedup of the load and mass scaling seem theoretically completely equivalent as they lead to the same amount of spurious kinetic energy, reality is more subtle and more complicated.

Our study has shown clearly that in order to obtain a correct flange shape from the stamping simulation the best strategy is to use a low loading speed, as close to real life as possible. Selective mass scaling turns out to be a viable alternative. On the other hand, if only displacement driven results such as final sheet thickness or plastic deformation are considered important, many alternative strategies can be considered to optimize the efficiency of the simulation.

References

1. *LS-DYNA* user manual, Version 971, Livermore, CA, 2017
2. Lars Olovsson et.al., **Selective Mass Scaling** for. Explicit Finite Element Analyses, Int. J. Num. Methods. Eng. (2005).