A Comparison of the Computational Speed of 3DSIM versus ANSYS Finite Element Analyses for Simulation of Thermal History in Metal Laser Sintering

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Abstract

A new simulation infrastructure for predicting the effects of changes in process parameters on mechanical properties, residual stress/strain, crystal structure, and other micro & macro features of components made using metal-based AM techniques has been developed at the University of Louisville (UofL) and is being commercialized by 3DSIM, LLC. Based upon its MatLab and Fortran code, UofL personnel predicted their multi-scale, multi-physics finite element solvers should solve for thermal history and residual stress evolution many orders of magnitude faster than competing tools while achieving better solution accuracy. In order to test this contention, a series of computational experiments were designed to benchmark the performance of the code being commercialized by 3DSIM against a well-respected simulation tool, ANSYS. The results of these initial studies indicate the 3DSIM architecture is significantly faster than ANSYS for simulating metal-based AM processes.

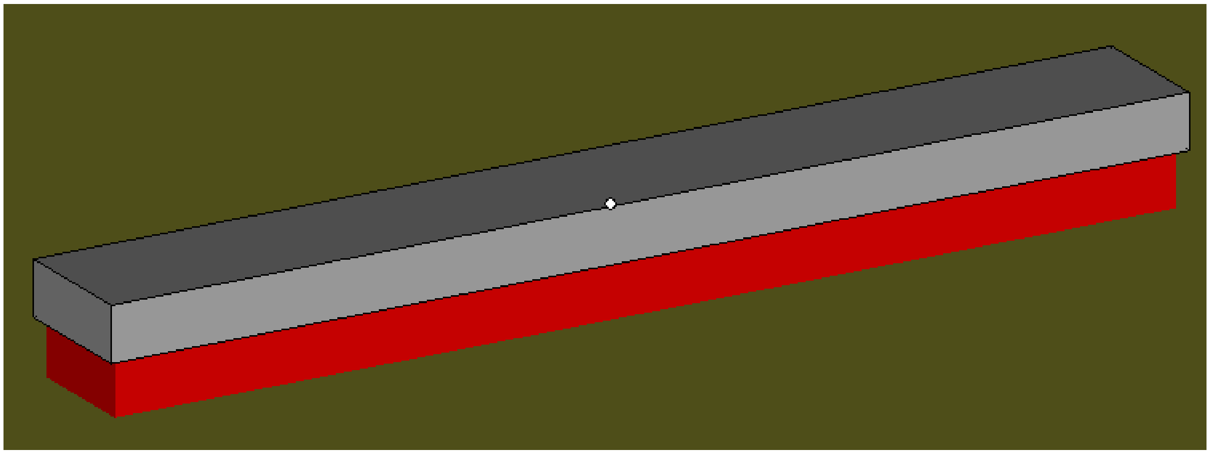
Introduction

A new simulation infrastructure developed at the University of Louisville [1-4] has resulted in the formation of a new start-up company, 3DSIM, LLC. 3DSIM is creating a commercial implementation of these algorithms in C++ which will be highly optimized in the future to run efficiently in Graphical Processing Unit (GPU) based high performance computing environments. This paper presents an initial test of the speed of the 3DSIM code, prior to final optimization and release. As such it represents a first indication of the computational benefits which should be achievable with this code once fully implemented and optimized.

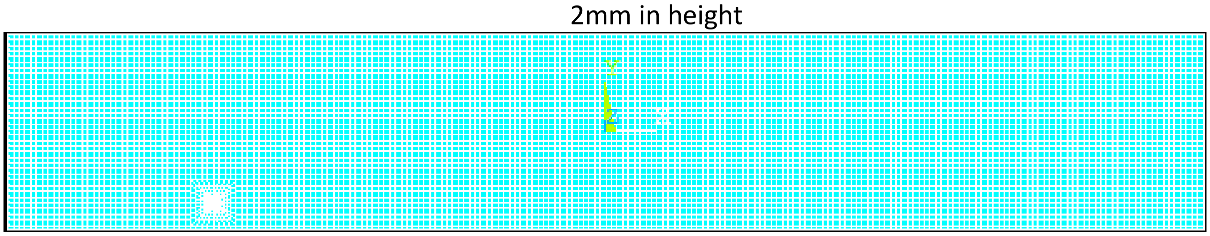
In this work, the metal laser sintering processes is simulated using a moving mesh strategy to capture dynamic thermal fields during traverse of a Gaussian laser energy source across the top of a powder bed. In the 3DSIM approach, a preprocessing architecture enables intelligent stiffness assembly to predict the thermal fields in space and time. By adopting a similar meshing strategy, a moving mesh model has been developed in parallel using the commercially available software tool ANSYS [5, 6] with user defined mesh and boundary conditions. Both models consider various heat transfer phenomena such as heat conduction, convection and phase changes that occur in metal laser sintering processes. The 3DSIM model also considers residual stress/strain.

Model

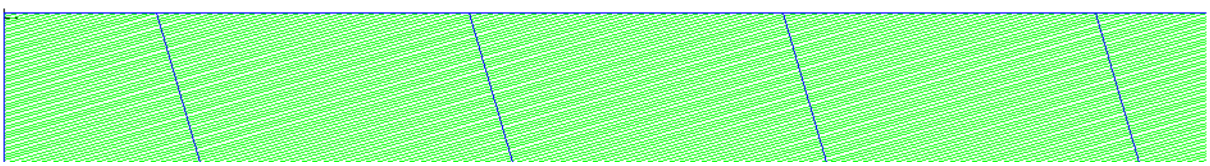
In this study, the time to simulate the small part shown in figure 1(a) has been estimated based upon results for ANSYS and 3DSIM simulations of sub-portions of the part. The part was simulated based upon standard process parameters for Ti6/4 used in an EOS M270 machine and the use of a block support structure with a 2 mm height. The simulations were set up to calculate an addition 1 mm of unmelted powder on each side of the part and 1mm of the baseplate, resulting in an FEM model size of 42 mm x7 mm in the XY plane and an initial 3 mm Z height, which increases as new layers are added in the Z direction. The mesh used for this problem, showing a uniform coarse mesh throughout and a fine discretization near the energy source, is shown in figure 1(b). The laser beam diameter has been assumed to be 100 μm and is sub-divided into 8 elements. The coarse mesh discretization encapsulating the remaining geometry has a 200 μm spatial grid size in the XY-plane. The layer thickness and the Z direction element size were assumed to be 30 μm. The Z-direction element size for the support structure and the build plate were set at 125 μm and the existence of the support structure was assumed to be already present at time t=0 with properties representative of a block support structure. The initial strip angle for scanning was observed to be 106.15° w.r.t. +X axis for an EOS M 270 machine, and this assumption has been replicated in figure 1(c). All coordinates follow ASTM standard terminology [7].



(a) A plate with dimensions of 40x5x2mm, built on top of a block support structure (in red) of 2mm in height



(b) Mesh for the structure

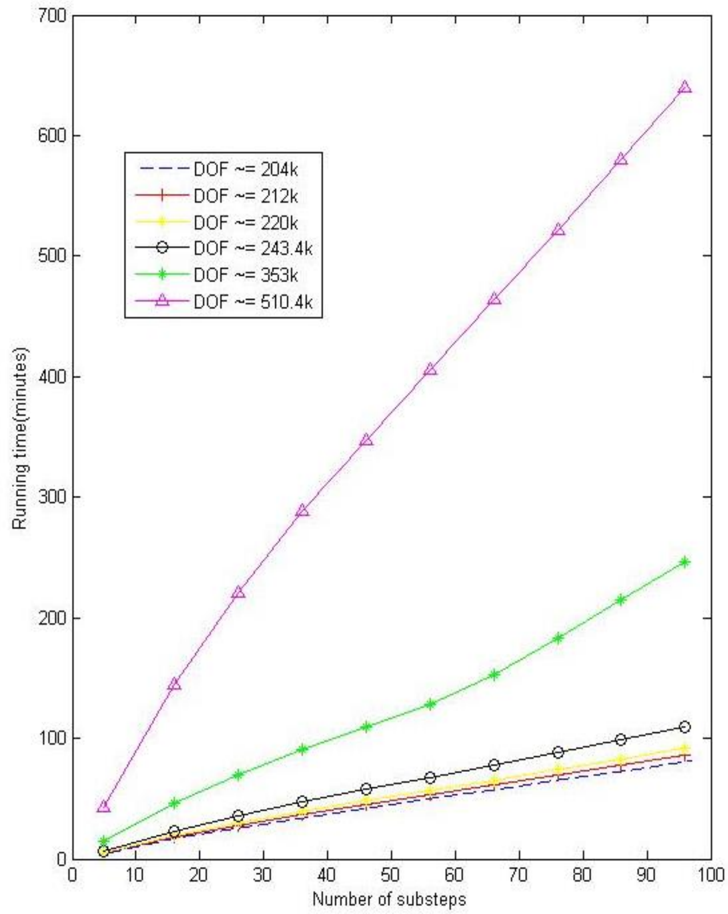


(c) Scan strategy for the first layer

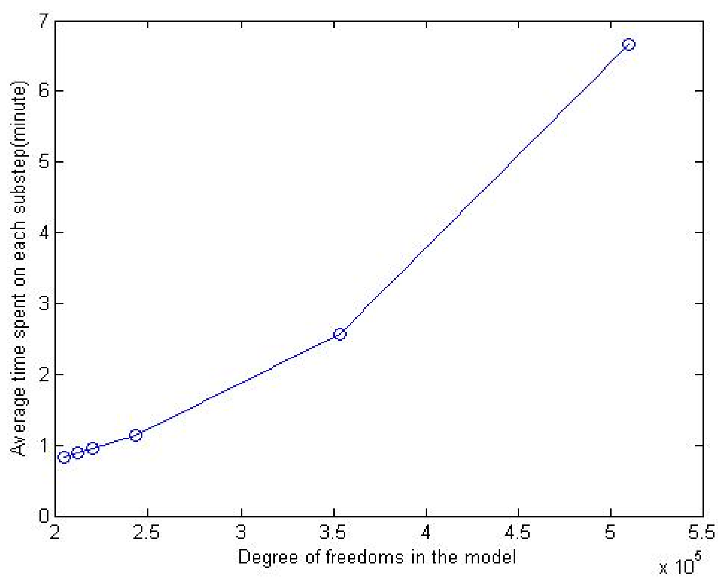
Figure 1. Problem definition showing the part, mesh and scan strategy employed in the simulation

Results and discussion

A 3 dimensional model built in ANSYS using the above-mentioned discretization and overall dimensions ranges from 204k to 714k degrees of freedom (DOFs). The number of DOFs linearly increase as the number of layers increase. Figure 2 shows the time to simulate various sub-portions of the model for different layers on a Dell Precision T1650 desktop computer with a processor speed of 3.2GHz and 8GB of RAM. Each model ran for the first ten laser offsets for each layer of simulation (it was not possible to finish running even one layer in an acceptable amount of time).



(a) Running time versus number of substeps



(b) Average time per substep versus DOFs (x10^5)

Figure 2 ANSYS sub-model run time on an ordinary desktop computer

The way laser offsets are modeled are different in ANSYS versus 3DSIM. The dynamic mesh developed for this problem has a fine mesh region that is stationary with respect to the coarse mesh for several time substeps as the laser energy traverses the fine mesh. Once the laser has crossed a pre-determined location in the fine mesh, the fine mesh moves in the direction of laser motion so that the melt pool remains within the fine mesh region. In the ANSYS model, this is approximated by causing the point of laser exposure to remain virtually stationary at the center of the fine mesh between time substeps until the laser position should have reached the fine mesh boundary (Figure 1b) leading to an advancement of the fine mesh by one coarse mesh distance in the direction of laser travel. In the 3DSIM model, the laser exposure changes location within the fine mesh region every time substep. The result of this difference is that 3DSIM more accurately captures temperature variations. Since this experiment was designed to test the speed difference of 3DSIM versus ANSYS, no detailed analysis of accuracy was done.

In figure 2a, the ANSYS execution time is plotted against the number of substeps for different DOF scenarios. In figure 2b, the average ANSYS time per substep is plotted against the number of DOFs. In order to predict the time needed for larger problems, the execution speed of the model using different computational configurations was tested and is shown in figure 3 for two cases of approximately 204k and 510k DOFs respectively. It was observed from these test results that the model runs fastest using the combination of 1 GPU and 2 CPU cores. The corresponding results for average time spent per substep w.r.t. DOFs is shown in figure 4.

In order to estimate the time for the execution of entire part model in ANSYS, the results shown in figure 4 have been for extrapolation. From figure 4, the time to solve increasing number of DOFs was assumed to be a linear function for DOFs exceeding 220k, and the data was fitted using a linear function. Using this linear estimation methodology, the execution time for ANSYS to fully simulating the small test peg model using 321,160 substeps (representing a solution of the laser for every 12.5µm of laser travel) would be about 61.5 years.

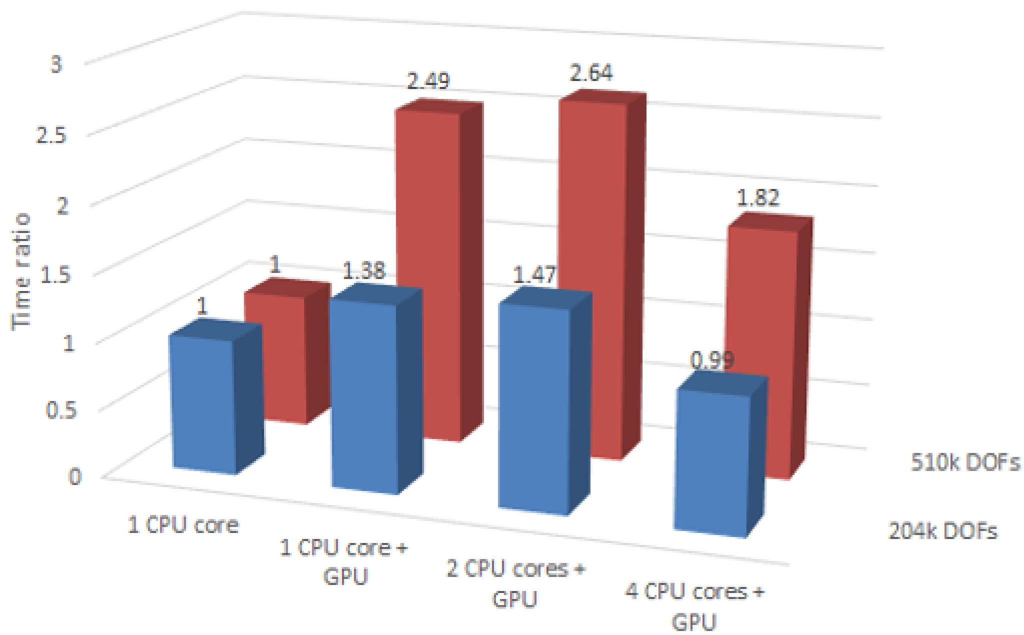


Figure 3 Different computational configurations comparison

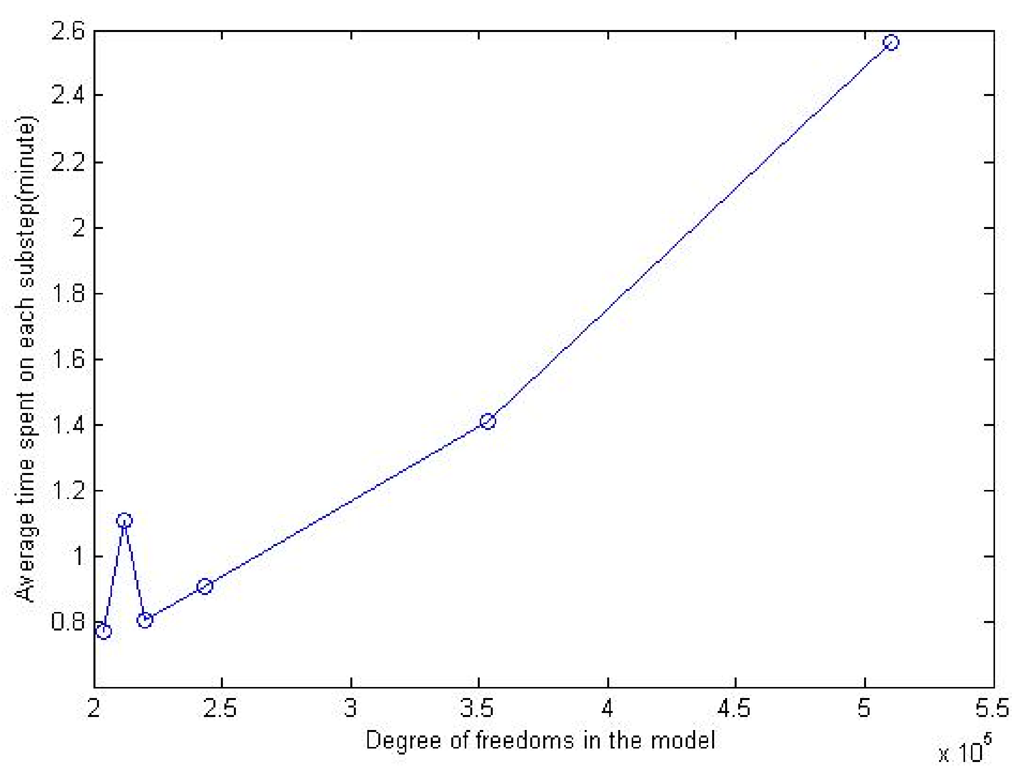


Figure 4 ANSYS model running time for multiple GPU processors

In order to compare the computational speed of the ANSYS model with its 3DSIM counterpart, a model with three elements in the Z direction was executed using 3DSIM. The execution time for finishing one layer with about 200K time steps are shown in table 1 for both 3DSIM and ANSYS. A previous case study reported in SFF 2013 showed that the Matlab version of 3DSIM's algorithms was about 66 times faster than ANSYS [6]. From the results in Table 1, the initial (non-optimized) C++ 3DSIM model used for this study is about 294 times faster.

	Time steps	Offsets	s/time step	s/offset	Total(hours)
3DSIM	200244	11779	0.2	0.5	12.8
ANSYS	200584	N/A	67.54	0	3763.2

Table 1 – 3DSIM Processing Time for the model with 3 elements in Z direction

Conclusion and future work

ANSYS is arguably the best existing commercial tool for solving SLM thermal problems. Using ANSYS, however, to simulate even a relatively small SLM thermal problem requires many years of computational time. The set of algorithms and software tools being developed by 3DSIM show an initial advantage for speed, and thus capability, for simulating AM problems. Given meshing and other differences in algorithms between ANSYS and 3DSIM, results are difficult to compare; but this discussion illustrates how a solver built for AM simulations using highly optimized algorithms and novel numerical solutions shows promise for significantly reducing computational time.

The 3DSIM solver used for this study, was an early version of the software. Subsequent to this study several enhancements have been implemented which significantly increase the speed of the tool. In addition, unique algorithms developed by the co-authors and demonstrated on other problems, including intelligent Cholesky, Eigensolvers, DOF reduction, and periodic and higher order boundary condition solvers [8], have not yet been implemented into the 3DSIM C++ code. As these further enhancements are implemented, 3DSIM will be able to solve much larger problems even more quickly. As such, future work to fully document the computational speed of 3DSIM's core solver in conjunction with these additional algorithms is needed.

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