Application of FSI/ALE on Mower Grass Cutting Simulation

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Abstract

A mower's grass mowing quality and energy consumption are two very important factors for battery powered mower development. The challenges include developing a highly efficient cutting blade that matches with the deck for creating the ideal air flow for bagging, mulching and side discharging and consumes as little energy as possible, which, improves the battery running time. It is critical for the development engineers to understand the mower's air flow inside the deck, the blade's energy consumption for air flow and clippings transportation during mowing. In this paper, the LS-DYNA® *FSI/ALE was used to simulate the mower mowing process. The simulation model was validated, and the result was used for improving the mower's deck and blade design.*

Introduction

In order to reduce the pollution, weight and noise, more and more for traditionally engine powered equipment (such as car, mower, compressor and so on), there is an ongoing transition to battery powered electric motors. Mowers are one of these products where the battery has a huge advantage in replacing gas engine. They are clean, quiet and almost maintenance free for the driven system. But the main challenge for doing so is the battery running time. For the average size lot (¼ acre), the mower should be able to finish the mowing with one battery charge. This requires the product development engineers to understand the grass cutting mechanism, grass clippings transportation (&air flow) for the optimal cutting quality and energy consumption. Simulation is the ideal tool for developing the virtual product and conducting the optimization before the real prototype mower is made. The LS-DYNA FSI/ALE Multiphysics technology [1] was used for simulating and evaluating the performance of the grass cutting, clippings transportation and bagging/discharging efficiency. Current products and new concepts were simulated to help the design engineers improve the product design.

Tradition Mower CFD Simulation

More and more mower companies adapt Computational Fluid Dynamics (CFD) technology on developing their products [2,3]. The tradition CFD simulation technology can help the engineers predict the air flow trajectory, pressure, velocity, vorticity distribution and blade energy consumption (for air flow only). Based on this technology, engineers can relate the mower's performance with the simulation results. For example, how do the grass cutting, clippings bagging, mulching and discharging relate to the air flow velocity, pressure and vorticity? What type of air flow pattern is good for the performance of the mower? Fig 1 & 2 are the air pressure contours of two different types of mowers (the simulation doesn't include grass cutting).

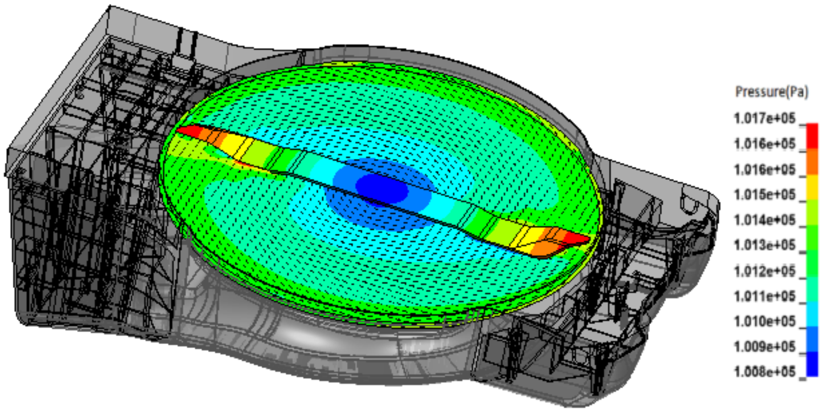


Fig 1: Single-blade Mower Air Pressure & Velocity Distribution

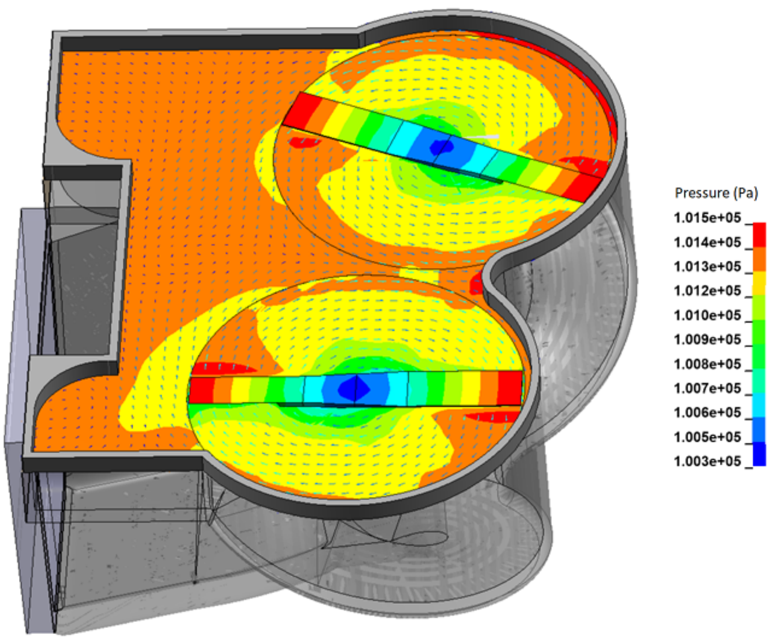
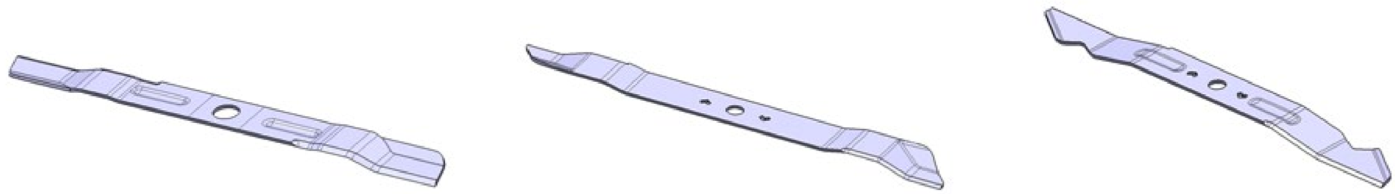


Fig 2: Twin-blade Mower Air Pressure & Velocity Distribution

From Fig 1 & 2, engineers can compare the real performance with the air pressure and velocity simulation results. Engineers can also extract the blade(s) air flow energy consumption data from these simulation results. Table 1 shows the energy consumption difference among 3 mower blades (shown in Fig 3). This information can help engineers design the shape of the lift on blade which has the least energy consumption with the best performance for bagging, mulching and discharging.

Table 1: Blade's Air Flow Energy Consumption CFD Simulation Results

Blade Design	Blade Air Flow Energy Consumption (Watts)
#1	116.0
#2	117.8
#3	80.7



Blade Design #1 Blade Design #2 Blade Design #3

Fig 3: Blade Design Comparison

Table 1 shows the blade design # 3 is the best one for improving the battery's running time (has least energy consumption for air flow), but it doesn't show if the mowing performance of this blade is sacrificed due to the different air flow pattern with the blade design #1 or 2. Currently, most of the mower companies don't have the simulation tools/experience to evaluate it virtually. What they do is to build these blades and put them in the mower and test them. How to evaluate and improve the performance of the mower, this question can't be answered by just tradition CFD simulation only.

Mower Grass Cutting FSI/ALE Simulation

Understanding the air flow pattern (trajectory, pressure, velocity and vorticity) only is not enough for optimizing the performance of the mower. Grass clippings' transportation during mowing can't be accurately predicted by using the tradition CFD technology. Grass clippings' size, weight and shape after the separation from their roots are all different. Most of the CFD simulation methods have two steps for predicting the particle trajectory. First, air flow simulation is run without the participation of the particles (grass clippings). Second, the particle's trajectory is evaluated based on the result of the air flow simulation. In this approach, there is only one-way interaction, the air flow decides the trajectory of particles. But the particles have no influence on the air flow. For small, light particles, this method may be good enough for predicting the particles' trajectories, but for the particles like grass clippings, the shape and the weight are quite different among clippings. They have strong coupling between the clippings and the air flow. The air flow affects the clippings' flow trajectories and vice versa. Another challenge for tradition CFD technology is that it can't include the glass cutting which is very important to simulate the mowing process accurately.

LS-DYNA FSI/ALE Multiphysics technology has several advantages and becomes an ideal method to model and simulate this mower cutting process:

1) Grass cutting process can be modeled with the interaction between the blade and grass with the contact and element eroding method. Fig 4 shows that the spinning blade hits the grass, when the leaf element(s) interacting with the blade reaches to its material breaking point, the element(s) is eroded, and the leaf is separated from its root and flows along with the air flow. The clippings' flowing pattern is determined by the clippings' weight, shape, speed when spearing from the grass roots and air flow surrounding them. This cutting process can't be simulated with tradition CFD method.

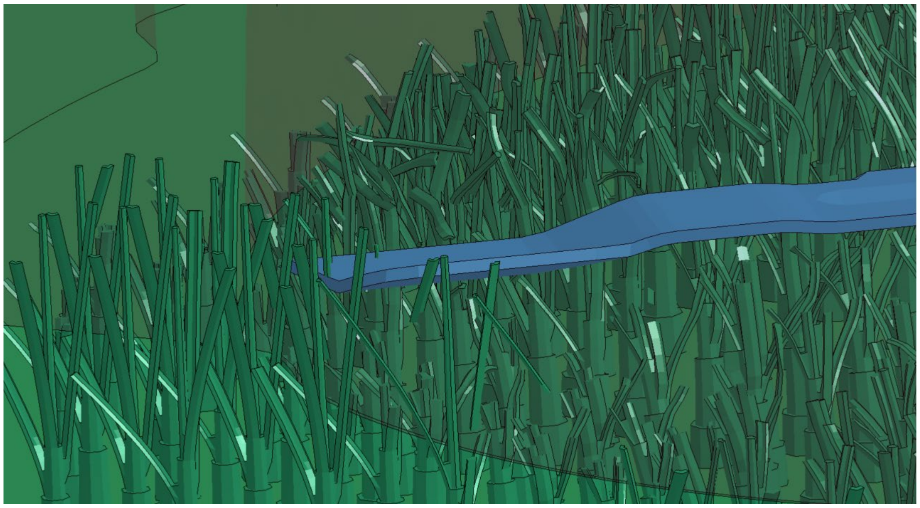


Fig 4: Separation of Grass Leaves from the Roots during the Cutting

2) Air flow and its interaction with the blade, deck, grass and clippings can be modeled by using the Arbitrary Lagrangian Eulerian (ALE) method. Fig 5 shows how the clippings flow when separating from their roots. Some clippings flow into the collecting bag, some circulate inside the deck, some are cut again by the spinning blade into smaller pieces (mulching) and some drop onto ground due to the air flow and gravity.

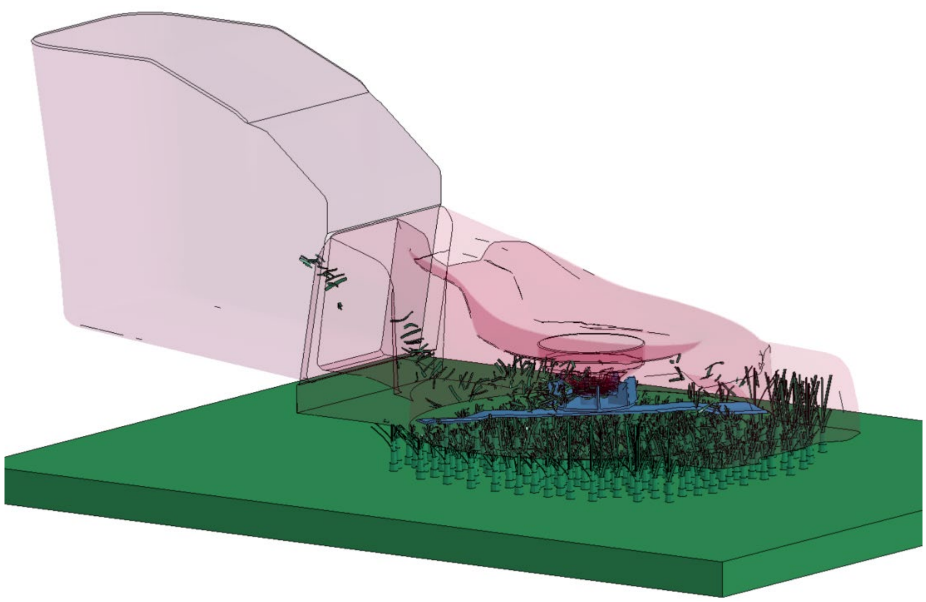


Fig 5: Interaction between Clippings and the Air Flow after the Cutting

3) Tracking the clippings' movement is fundamental to understanding how the trajectories relate to the mower performance of the bagging, mulching and discharging. Fig 6 shows how each clipping move after they are cut and separate from the root of grass. The engineers can calculate the weight of the clippings flow into the bag and compare the weight of the clippings which circulate or fall onto ground in certain time period. Thus, they can calculate the bagging efficiency which is one of the important factors for evaluating the mower's bagging performance.

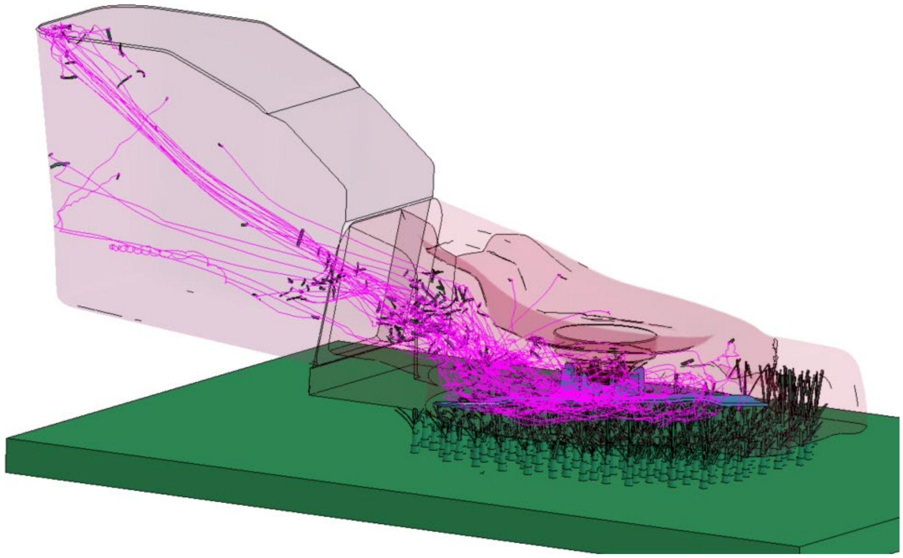


Fig 6: Tracking the Clipping's Trajectory (Magenta Streamlines) to Monitor the Flowing Path during Mowing

4) Validating the fidelity of the simulation model by correlating the simulation results with the high-speed video. Fig 7 is the side-by-side comparison between the high-speed video and the simulation results. The speed and trajectory of the clipping flowing inside the deck is close to the result recorded in the video. This gives us the confidence for using the simulation model to evaluate and compare the performances of the different decks and blades concepts.

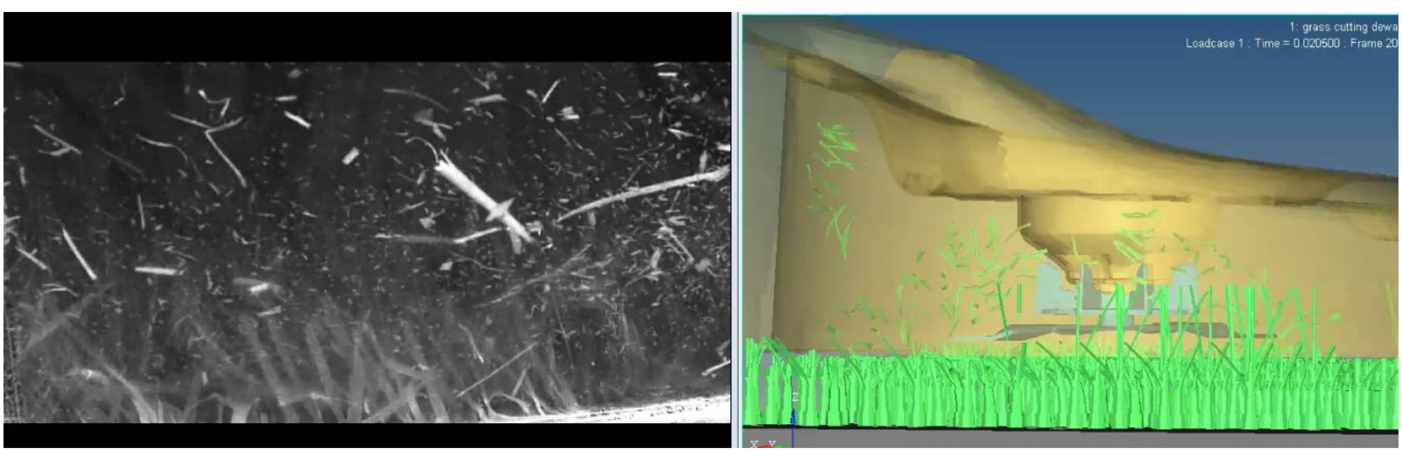


Fig 7: Correlating the Mower Mulching Simulation Results with the High-speed Video

Simulation/Test Results

Based on this FSI/ALE mower simulation model, several design concepts were evaluated, and the new deck design improvement recommendation (Comparison of the original deck design and the final recommended new deck design is shown in Fig 8) which has more than 40% higher bagging efficiency than the original desk design was provided to the design team for building the prototype. Fig 9 and 10 are the simulation results of two different deck designs. The percentage of the weight of the clippings flow though the bagging opening over the total weight of the clippings in the same time period was calculated and test results show that the recommendation based on the simulation results has significant improvement on bagging efficiency and capacity. Fig 11 shows the weight of the clippings in the new deck design is more than double of the weight of the original mower design in the test.

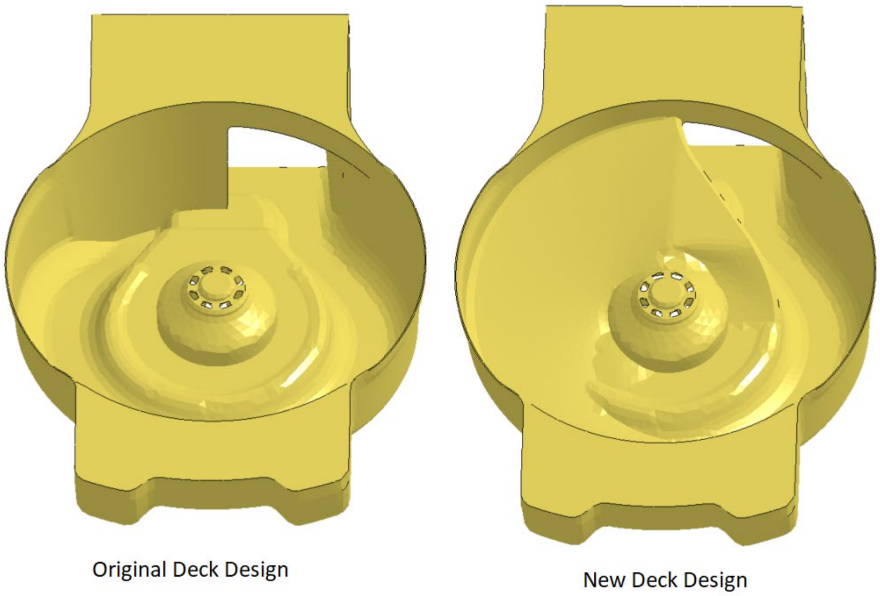


Fig 8: Comparison of the Original Deck Design and the Recommended New Deck Design

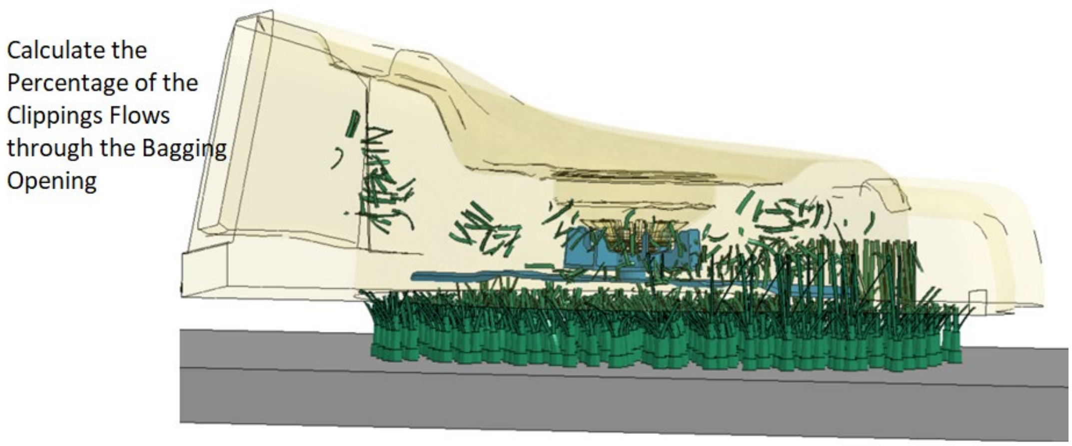


Fig 9: Simulation Result of Mower with the Original Deck Design

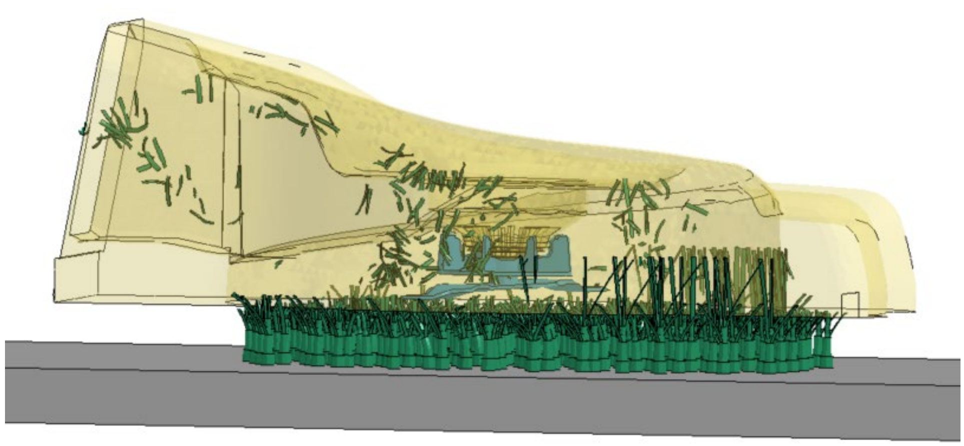


Fig 10: Simulation Result of Mower with the New Deck Design

Bagging Test Result with Original Deck

Maxium Weight of Clipings Collected:
5.20 lbs

Bagging Test Result with New Deck

Maxium Weight of Clippings Collected:
10.78 lbs

Fig 11: Bagging Test Results of Mower with the Different Deck Designs

Conclusion

The Multiphysics FSI/ALE technology in LS-DYNA makes it possible to simulate the mower grass cutting, clipping's transportation which is critical to guide the engineers to improve the whole mower system design. The high-speed video and the prototype test result show the good correlation between the simulation and test. The mowing FSI/ALE simulation can not only provide the air flow velocity and pressure contour but also the clippings' flowing trajectory inside/outside the deck. It is an ideal tool for improving the current mower's performance and guiding the engineers for developing a new mower with longer battery running time and better performance.

Acknowledgement

The Author would like to thank the members of the Mower Development Team, Motor Technology Group, Test Lab and Innovation Team of Stanley Black & Decker for providing the test unit and high-speed video for simulation correlation studies.

References

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[2] W. Chon, R.S. Amano, Investigation of Flow Behavior around Corotating Blades in a Double-Spindle Lawn Mower Deck, International Journal of Rotating Machinery, 2005: 1, 77-89.
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